4 ENVIRONMENTAL CONSEQUENCES

This chapter presents the comparative analysis of the environmental effects of the Long-Term Experimental and Management Plan (LTEMP) alternatives described in Chapter 2. Environmental effects are analyzed for resources that could be affected by the proposed action, to adopt and implement an LTEMP for Glen Canyon Dam over the next 20 years. The affected resources are described in Chapter 3. Affected natural resources include water, sediment, aquatic ecology, vegetation, wildlife, special status species, and air quality. Affected socioeconomic resources include cultural resources, visual resources, recreational resources, wilderness, park management and operations, hydropower, regional socioeconomics, resources of importance to Indian Tribes, and environmental justice.

The effects of alternatives result primarily from the patterns of water release from Glen Canyon Dam that are characteristic of each alternative. Monthly, daily, and hourly release rates directly affect flows and sediment distribution in the river channel and corridor, as well as water levels in Lake Powell and Lake Mead. These primary effects drive secondary effects on aquatic and terrestrial resources, historic properties, Tribal resources and values, and recreational resources. Hydropower generation and capacity are additional primary effects of release patterns, particularly the ability to adjust releases in response to changes in the demand for electric power. Alternatives also include non-flow actions such as mechanical trout removal and vegetation restoration activities, which would be undertaken as part of the alternative.

In the following sections, the effects of the alternatives are presented for each resource. Discussions begin with an identification of the resource issues being analyzed and a description of the indicators that are evaluated to assess the related issues. The analysis methodology is presented next, describing both the quantitative and qualitative methods used to assess effects. A summary of effects follows, focusing on the general effects of various flow conditions on resource indicators. An alternative-specific analysis is then presented wherein the effects of the various alternatives are presented individually and compared. Finally, in Section 4.17, an analysis is presented of the cumulative impacts of the alternatives on resources in combination with other past, present, and reasonably foreseeable future actions.

4.1 OVERALL ANALYSIS AND ASSESSMENT APPROACH

The quantitative analyses in this chapter employ a series of linked models that explicitly account for flow effects and the linkages among resources. The discussion of effects by resource acknowledges these linkages under a common conceptual model. This conceptual model is central to the construction of the LTEMP alternatives described in Chapter 2. The modeling approach used for this Draft Environmental Impact Statement (DEIS) is presented in technical appendices provided at the end of this document.

Six action alternatives are compared to the No Action Alternative (Alternative A), which describes how the dam is currently operated. Operations under Alternative A employ a release pattern established in the 1996 Record of Decision (ROD) (Reclamation 1996) associated with the 1995 EIS on operations of Glen Canyon Dam (Reclamation 1995). This operational release pattern, referred to as Modified Low Fluctuating Flows (MLFF), moderated the releases relative to operations practiced in the 1960s through 1980s. As described in Chapter 2, Alternative A also includes various practices and operational decisions that have been established since the 1996 ROD.

Operational characteristics and experimental actions of each alternative target particular resource effects. Environmental effects caused by actions included in different alternatives were modeled using historically observed resource responses to flow conditions and relationships derived from experimental results obtained since dam operations were last reviewed in 1995.

Responses of resources to operations and non-flow actions were predicted using linked models (e.g., reservoir operations model, hydropower operations models, sand budget model, and others, as depicted in Figure 4-1). The magnitude of effects was estimated using quantifiable metrics for indicators of the condition of a resource. The environmental effects of alternatives are compared quantitatively whenever possible, on the basis of the estimated effect on resource condition as measured by a set of resource metrics (see Appendix B for details); these quantitative predictions are supported when possible by published observations and findings.

We used a Structured Decision Analysis approach as the basis for our modeling framework (see Appendix C for a full description). Because several of the alternatives use a condition or information-dependent approach to experimentation that would adapt to new information gathered as the alternative is implemented (e.g., Alternatives B, C, D, and E), we developed a set of "long-term strategies" that represented possible ways the alternative might be implemented if uncertainties were resolved. With this approach, we established versions of these alternatives (the long-term strategies) that implemented subsets of the proposed experiments being considered in the alternative. Because there are many possible combinations of experiments possible within any alternative, we chose sets that would be representative of certain conditions related to uncertainties; there were 19 of these (Table 4.1-1). For example, if under Alternative D the effect of trout on humpback chub was determined to be more important than temperature, and trout management flows (TMFs) proved to be effective at controlling trout numbers, a long-term strategy that included spring and fall high-flow experiments (HFEs) and TMFs would be implemented. Under this scenario, there would be no need for low summer flows to warm water for chub. Long-term strategy D4 represents this scenario.

To facilitate comparisons of alternatives in the text, we chose a single-long-term strategy for each alternative—A, B1, C1, D4, E1, F, and G. Long-term strategies C1, D4, and E1 were chosen because they included a comparable set of experimental elements (spring and fall HFEs and TMFs). Long-term strategy B1 was chosen because it did not include hydropower improvement flows, and was thus comparable to other long-term strategies. The analytical results for the full suite of long-term strategies enabled a determination of the effects of experiments, and these effects are described in the individual resource sections of this chapter. The quantitative results for all 19 long-term strategies are presented in Appendix C and the resource-specific Appendices E, F, G, H, I, and J.

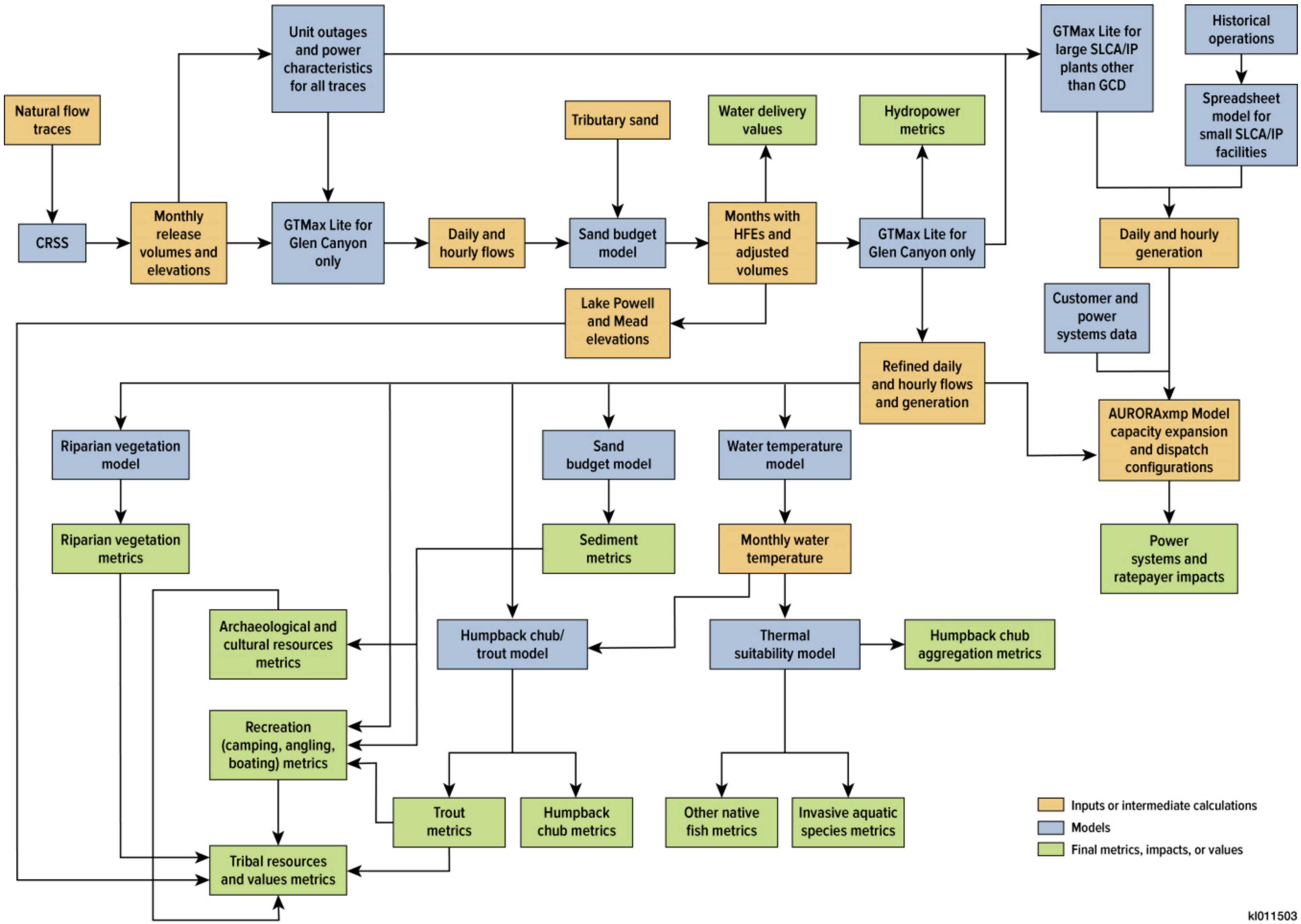

FIGURE 4-1 Model Flow Diagram for Analyses Showing Inputs, Intermediate Calculations, and Output

TABLE 4.1-1 Experimental Elements Included in Long-Term Strategies Associated with Each LTEMP Alternative (Letters depict alternative, numbers depict long-term strategy.)

	Alternative and Associated Long-Term Strategy[a]																		
Experimental Element	A	B1	B2	C1	C2	C3	C4	D1	D2	D3	D4	E1	E2	E3	E4	E5	E6	F	G
Spring HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	N	Y[d]	Y[d]	Y[d]	Y[d]	Y[e]	Y[e]	N	N	N	N	Y	Y
Fall HFE	Y[b]	Y[c]	Y[c]	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N	Y	Y
Spring proactive HFE	N	N	N	Y[f]	Y[f]	N	N	Y[f]	Y[f]	Y[f]	Y[f]	N	N	N	N	N	N	N	Y[f]
Extended- duration HFE	N	N	N	Y[g]	Y[g]	N	Y[g]	Y[h]	Y[h]	Y[h]	Y[h]	N	N	N	N	N	N	N	Y[i]
Load-following curtailment (steady flows)	N	N	N	Y[j]	Y[j]	N	Y[j]	Y[k]	Y[k]	Y[k]	Y[k]	Y[l]	Y[l]	N	Y[l]	N	N	N	N
Low summer flows	N	N	N	N	Y[m]	N	N	Y[n]	Y[n]	Y[n]	N	N	Y	N	N	Y	N	N	N
Steady weekend flows for macroinvertebrate production	N	N	N	N	N	N	N	N	Y	N	N	N	N	N	N	N	N	N	N
Mechanical trout removal	Y[b]	Y	Y	N	N	Y	Y	Y	Y	Y	Y	N	N	Y	Y	N	N	N	Y
TMFs	N	Y	Y	Y	N	N	N	Y	Y	N	Y	Y	N	N	N	N	Y	N	Y
Hydropower improvement flows	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N

[a] Y = element included; N = element not included. Long-term strategies that include the element are shaded gray.

[b] Activity ends after 2020.

[c] Not to exceed one HFE (spring and fall) every other year.

[d] Not to occur in first 2 years of LTEMP.

[e] Not to occur in first 10 years of LTEMP.

[f] Triggered in years with annual release volume ≥10 maf. Not implemented in the same water year as an extended-duration fall HFE.

[g] Volume limited to that of a 96-hr, 45,000-cfs release.

[h] Fall only, limited to four HFEs up to 250 hr if sediment will support, first implementation limited to 192 hr.

[i] Spring and fall HFEs, no limit in number, up to 336 hr long if sediment will support.

[j] Before and after spring and fall HFEs.

[k] After fall HFEs only.

[l] Before fall HFEs only.

[m] Target 13°C.

[n] Target 14°C, second 10 years only.

For those resource metrics that could be modeled quantitatively, a range of potential hydrologic conditions and sediment conditions were modeled for a 20-year period that represented the 20 years of the LTEMP. Twenty-one potential Lake Powell in-flow scenarios (known as hydrology traces) for the 20-year LTEMP were sampled from the 105-year historic record (water years 1906 to 2010) using the Index Sequential Method and selecting every fifth sequence of 20 years. Using this approach, the first 20-year period considered was 1906–1925, the second was 1911–1930, and so forth. As the start of traces reach the end of the historic record, the years needed to complete a 20-year period are obtained by wrapping back to the beginning of the historical record. For instance, the trace beginning in 1996 consists of the years 1996–2010 and 1906–1910, in that order. This method produced 21 hydrology traces for analysis that represented a range of possible traces from dry to wet. Although these hydrology traces represent the range of hydrologic conditions that occurred during the period of record, they may not fully capture the driest years that could occur with climate change (see Section 4.17).

In addition to these 21 hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record (water years 1964 to 2013) were analyzed that represented low (water years 1982 to 2001), medium (water year 1996 to 1965), and high (water years 2012 to 1981). In combination, the 21 hydrology traces and three sediment traces resulted in an analysis that considered 63 possible hydrology-sediment conditions.

Models depicted in Figure 4-1 were used to generate resource metric values for each of the alternatives under the 63 hydrology-sediment combinations. The values generated represent a range of possible outcomes that in many cases were graphed using box-and-whisker plots (Figure 4-2), which show the full distribution of values obtained as characterized by the minimum, maximum, mean (average of all values), median (50% of the values are less than this value), 25th percentile (25% of the values are less than this value), and 75th percentile (75% of the values are less than this value).

Some resources or environmental attributes do not lend themselves to quantification because there are insufficient data or understanding to support development of a model. In these cases, the assessment presented in this chapter includes qualitative assessments of the likely impacts on these resources and attributes. Qualitative analysis was particularly important for effects related to personal and cultural values, as well as for an assessment of impacts on resources not directly affected by river flow. In all cases, multiple lines of evidence were used to assess impacts on resources.

The analytical results presented in this chapter represent in part the results of modeling conducted in early 2015. After this modeling was completed, several adjustments were made to specific operational and experimental characteristics of Alternative D (the preferred alternative) based on discussions with Cooperating Agencies and stakeholders. These adjustments included (1) a change in August volume in an 8.23-maf year from 750 to 800 kaf; (2) elimination of load-following curtailment prior to sediment-triggered HFEs; (3) an adjustment of the duration of load-following curtailment after a fall HFE; and (4) a ban on sediment-triggered spring HFEs in the same water year as an extended-duration fall HFE. The description of Alternative D provided in Section 2.2.4 represents the final version of the alternative that resulted from these changes.

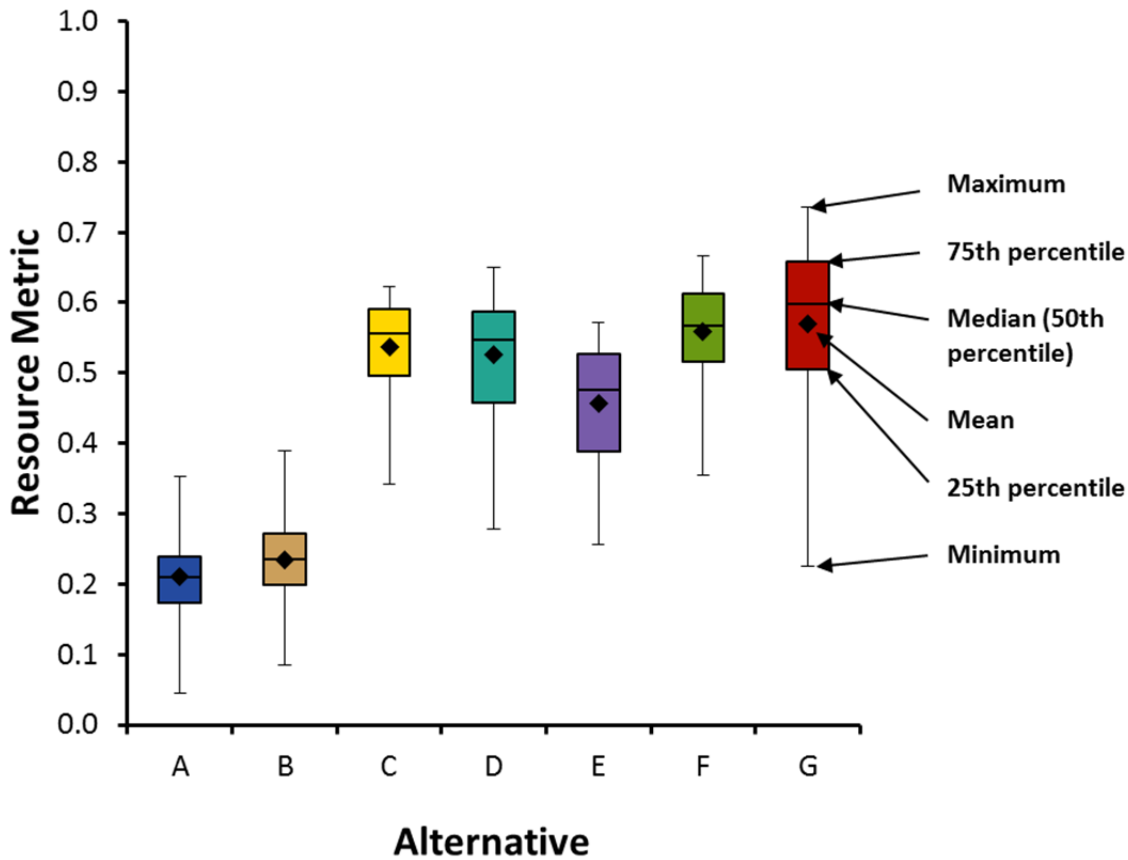

FIGURE 4-2 Example Box-and-Whisker Plot for Alternatives and Their Resource Metric Values

For most resources, these changes are expected to result in little if any change in impact relative to those predicted for the earlier modeled version of Alternative D. Any expected noticeable differences are identified in the individual resource sections of this chapter.

Information sources used for this analysis included a large quantity of observational and research data collected since the start of dam operations and resulting from research programs originating under the Glen Canyon Adaptive Management Program (GCDAMP) established under the 1996 ROD and carried out by the Grand Canyon Monitoring and Research Center (GCMRC) and other researchers. The geographic region of interest and the topics and issues analyzed as determined from project scoping are described in Section 1.5.

4.2 WATER RESOURCES

> **Issue:** How do the alternatives affect water resources in the project area?
>
> **Impact Indicators:**
>
> - Lake Powell releases (annual, monthly, daily, and hourly)
> - Lake Powell and Lake Mead reservoir elevations
> - Lake Powell annual Operating Tier and Lake Mead operating conditions
> - Monthly, hourly, and daily patterns in Colorado River flows downstream of Glen Canyon Dam

This section presents an analysis of impacts on water resources of the Colorado River between Glen Canyon Dam and Lake Mead, and in Lake Powell and Lake Mead. This section is organized into two broad topics—hydrology and water quality. Hydrology encompasses those topics related to the pattern and volume of monthly, daily, and hourly releases from Lake Powell that are a function of characteristics of the LTEMP alternatives and how these release patterns affect flows in the Colorado River and the water surface elevations of Lake Powell and Lake Mead. Water quality relates to non-flow characteristics of the water, including temperature, salinity, dissolved oxygen (DO), turbidity, nutrients, metals, organics, and bacteria and other pathogens. Analysis methods, a summary of impacts, and alternative-specific impacts are presented in Sections 4.2.1, 4.2.2, and 4.2.3, respectively.

The water resources goal is to ensure water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the Long-Range Operating Criteria (LROC) for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead.

Quantitative analysis of the effects of reservoir operations was performed using Reclamation's official basin-wide long-term planning model, Colorado River Simulation System (CRSS). Model results provide a range of potential future system conditions such as reservoir releases and storage, as well as operating tiers for Lake Powell and Lake Mead.

Direct impacts on water resources include those that may affect the annual operation of Lake Powell and Lake Mead. While all the alternatives are consistent with the 2007 Interim Guidelines (Reclamation 2007a), effects may include changes in the Lake Powell annual operating tier, Lake Mead operating condition, and changes in annual release volume. The primary aspect of reservoir operations that affects water resources is related to the monthly distribution of the Lake Powell annual release volume and its resulting impact on reservoir elevations, operating tiers, and annual release volumes. The impact analysis for water resources reflects the 20-year LTEMP period, which, for modeling purposes, was from October 1, 2013, to September 30, 2033.

4.2.1 Analysis Methods

4.2.1.1 Hydrology

Annual and Monthly Operations

Modeling of the Colorado River system was conducted to determine the potential effects of LTEMP alternatives on annual and monthly operations that could affect Colorado River system conditions (e.g., reservoir elevations, reservoir releases, and river flows) as compared to Alternative A (the No Action Alternative). Due to uncertainties associated with future inflows into the system, multiple simulations were performed for each alternative in order to quantify the uncertainties in future conditions, and the modeling results are expressed in probabilistic terms.

Future Colorado River system conditions under the LTEMP alternatives were simulated using CRSS. The model framework used for this process is the commercial software RiverWare™ (Zagona et al. 2001), a generalized river basin modeling software package developed by the University of Colorado through a cooperative arrangement with Reclamation, the Tennessee Valley Authority, and the U.S. Army Corps of Engineers. CRSS was originally developed by Reclamation in the early 1970s, was converted to RiverWare™ in 1996, and has been used as Reclamation's primary Colorado River Basin–wide planning model since that time. Previous studies that used CRSS include the 1996 Glen Canyon Operations EIS (Reclamation 1995), the 2007 Interim Guidelines Environmental Impact Statement (EIS) (Reclamation 2007a), and the Colorado River Basin Water Supply and Demand Study, referred to as the Basin Study (Reclamation 2012a).

CRSS simulates the operation of 12 major reservoirs on the Colorado River and provides information regarding the projected future state of the system on a monthly basis; the model simulates the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and diversions to and return flows from water users throughout the system. The basis of the simulation is a mass balance (or water budget) calculation that accounts for water entering the system, water leaving the system (e.g., from consumptive use of water, trans-basin diversions, and evaporation), and water moving through the system (e.g., either stored in reservoirs or flowing in river reaches). Further explanation of the model is provided in Appendix D. CRSS was used to project the future conditions of the Colorado River system for the 20-year LTEMP period, which for modeling purposes, was water years 2013 through 2033.[1]

The input data for the model includes monthly natural inflows; various physical process parameters such as the evaporation rates for each reservoir; initial reservoir conditions on January 1, 2013; and the future projected diversion and depletion schedules for entities in the seven Basin States (Appendix D) and for Mexico. These future schedules are based on demand and depletion projections prepared and submitted by the Basin States for the Basin Study, and

[1] The water year is defined as October 1 through September 30 of the following calendar year.

assume the Current Projected demand scenario (Schedule A) from the Basin Study. For purposes of this DEIS, depletions (or water consumptive uses) are defined as diversions from the river less return flow credits, where applicable.

For each alternative, the rules of operation of the Colorado River mainstem reservoirs, including Lake Powell and Lake Mead, were developed as input to the model. These sets of operating rules describe how water would be released and delivered under various hydrologic conditions. In the modeling of all alternatives, the operations of Lake Powell and Lake Mead are assumed to revert back in 2027 to the assumptions used to represent the No Action Alternative in the 2007 Interim Guidelines. Because CRSS is a monthly model, reservoir operations at sub-monthly intervals (e.g., daily release fluctuations, ramp rates, HFEs, and TMFs) were not explicitly modeled in CRSS, but they were modeled using other modeling software. Further explanation of the operating rules for each alternative is provided in Section 2.2.

Long-term planning models, such as CRSS, are typically used to project future river and reservoir conditions over a period of years or decades into the future. There are numerous inputs to, and assumptions made by, these models. As the period of analysis increases (for this DEIS the analysis period is 20 years), the uncertainty in those inputs and assumptions also increases. Consequently, these models are not used to predict future river and reservoir conditions, but rather to project the range of possible effects. When analyzing the potential hydrologic impacts from operational alternatives, most inputs, as well as other key modeling assumptions, are held constant for each alternative to isolate the differences due to each alternative. In this manner, the analyses for each alternative may be compared, and thus a relative comparison of the impacts of alternatives can be made.

Uncertainties in CRSS output are due to assumptions in input, including parameterization of physical processes such as reservoir evaporation and bank storage, the future diversion and depletion schedules for the entities throughout the Colorado River Basin, and the future inflows into the system. In addition, much of the input data are derived from actual measurements that have uncertainties associated with them. For example, natural flows (i.e., those flows that would occur in the absence of dams, reservoirs, diversions, and withdrawals) are partially based on data acquired from streamflow gages, which, when calibrated properly, have uncertainties of about 5 to 10%. Although these data are generally the best available, all of these uncertainties limit the absolute accuracy of the model. However, by holding most inputs constant, the relative comparisons among modeled conditions are still valid.

Despite the differences in some of the modeling assumptions under the LTEMP alternatives, the future conditions of the Colorado River system (e.g., future Lake Mead and Lake Powell elevations) are most sensitive to future inflows. Observations over the period of historical record (1906 through 2010) show that inflow into the system has been highly variable from year to year and over decades. Because it is impossible to predict the actual future inflows for the next 20 years, a range of possible future inflows are analyzed and used to quantify the probability of occurrences of particular events (e.g., higher or lower reservoir elevations). This technique, performed for the hydrologic analysis presented here, involves multiple simulations for each alternative, one for each future hydrologic sequence.

The future hydrology used as input to the model consisted of samples taken from the historical record of natural flow in the river system over the 105-year period from 1906 through 2010 from 29 individual inflow points (or nodes) on the system. The locations of the inflow nodes are described in Appendix D.

Typically, CRSS is run with the full suite of available natural flow traces created using a resampling technique known as the Indexed Sequential Method (ISM) (Ouarda et al. 1997). Using the ISM on a 105-year record (1906–2010) results in 105 inflow traces (i.e., plausible inflow sequences). For this DEIS, every fifth trace from the 105 natural flow traces was selected, resulting in 21 traces that are considered representative of the full period of record (Appendix D). For the climate change analysis described in Section 4.26, CRSS was run with 112 natural flow traces developed from downscaled general circulation model projected hydrologic traces (Reclamation 2011f).

As shown in Figure 4-1, a full set of resource models was used to analyze resource impacts, and CRSS output served as input for most of these models. Reservoir operations under each alternative were explicitly modeled in CRSS. Each alternative was modeled in CRSS with 21 different potential hydrology scenarios to account for uncertainty in future hydrologic conditions. Comparisons between alternatives are made on these 21 simulations per alternative. The interquartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

Daily and Hourly Operations

Monthly volumes under each alternative, as predicted by CRSS and described in the previous section, were used as input to determine daily and hourly patterns of releases using GTMax-Lite, a program developed by Argonne National Laboratory. Within each month, this program determines the pattern of daily and hourly releases that would maximize hydropower value based on CRSS-predicted monthly volume, reservoir elevation, hourly electricity market prices, and the operational constraints of each alternative, including maximum and minimum flows, ramping rates, and allowable daily range.

Hourly flows were generated using the GTmax-Lite model for the 20-year LTEMP period under each of the 21 hydrology scenarios and three sediment scenarios that were analyzed for each alternative. This resulted in 63 unique 20-year simulations for each alternative. Daily and hourly flow data were statistically analyzed to generate values of mean daily flow, mean daily change (maximum flow minus the minimum flow for each day), and monthly volume for each alternative, and to show the variation in these variables over the range of scenarios analyzed.

4.2.1.2 Water Quality

This section describes the methods used to determine the potential effects on water quality associated with the LTEMP alternatives. Details of the methodologies used are presented in Appendix F of this DEIS.

Using the hydrologic output from the CRSS RiverWare™ model (see Section 4.2.1.1), the CE-QUAL-W2 model (Cole and Wells 2003) was used to simulate water temperatures of Lake Powell (including dam releases).

Temperature exerts a major influence on biological and chemical processes. Aquatic organisms have preferred temperature ranges that influence their abundance and distribution. DO concentrations are generally lower, while salinity levels, nutrient, and pathogen concentrations are higher in warmer water. Temperature modeling for the Colorado River below Glen Canyon Dam was performed using the method described in Wright, Anderson et al. (2008). This model computes gains and losses of heat as water moves down the river. In general, predicted downstream temperatures are driven by the release temperature from Glen Canyon Dam, equilibrium water temperature (i.e., the temperature the water would eventually reach if it did not flow; dependent on air temperature, direct insolation, wind patterns, and evaporation), temperature and volumes of tributary inflows, and a heat exchange coefficient, which are all complex functions of environmental conditions (Walters et al. 2000).

The salinity module of the CRSS RiverWare™ model was used to analyze changes in salinity concentration for Colorado River reaches from Lake Powell to Imperial Dam, which is located downstream of Hoover Dam and Lake Mead. Monthly salinity estimates were aggregated to annual values because the salinity criteria/standards set for Colorado are based on flow-weighted average annual salinity (mg/L). Other water quality parameters (e.g., DO, turbidity, nutrients, metals, organics, and bacteria/pathogens) were not modeled quantitatively. Qualitative assessments of these parameters in the Colorado River between Lake Powell and Lake Mead were based on previous scientific studies and historical data, including published research, related EISs, and Environmental Assessments (EAs).

Detailed modeling for Lake Mead was conducted by the Southern Nevada Water Authority because of concerns related to the potential effects of LTEMP alternatives on the quality of municipal water supplies. The temperature modeling was performed using the model described in Flow Science (2011). The Lake Mead Model (LMM) uses the ELCOM (Estuary, Lake and Coastal Ocean Model) code to simulate hydrology and conservative constituents, and CAEDYM (Computational Aquatic Ecosystem Dynamics Model) code for simulating biogeochemical processes.

Ten 2-year model scenarios were chosen to represent a subset of LTEMP alternatives that could result in important water quality impacts (Tietjen 2015). The goal of modeling was to indicate the possibility of effects that could occur. The 10 selected scenarios were separated into three general elevation-based scenarios. The first scenario covers water years 2014–2015, which have higher relative lake surface elevations (1,080–1,110 ft AMSL), and models hydrology trace 8, sediment trace 1, and Alternatives A, E (represented by two long-term strategies, 1 and 5), and F. The second scenario looks at water years 2018–2019, with lower relative lake surface elevations (1,040–1,060 ft AMSL), and models hydrology trace 11, sediment trace 1, and Alternatives A, E (long-term strategy 1), and F. The third scenario covers water years 2019–2020, which displays a high starting lake surface elevation that decreases significantly (1,125–1,070 ft AMSL), and hydrology trace 18, sediment trace 1, and models Alternatives A, E (long-term strategy 6), and F.

4.2.2 Summary of Impacts

The overall impacts of the seven LTEMP alternatives on the hydrology and water quality of Lake Powell, the Colorado River below Glen Canyon Dam, and Lake Mead are presented in this section and summarized in Table 4.2-1. A discussion of alternative-specific impacts is provided in Section 4.2.3.

4.2.2.1 Hydrology

Impacts on annual, monthly, daily, and hourly reservoir releases, elevations, and annual operating tiers, as well as water delivery performance metrics, are discussed in the subsections below.

Lake Powell Operating Tier and Annual Release Volume

The Lake Powell annual operating tier and annual release volume are primarily driven by hydrological conditions in a given year. The modeled Lake Powell annual release volumes range from 7.0 maf to 19.2 maf, with a median value of 8.23 maf, across all years, traces, and alternatives.

The Lake Powell annual release volume is driven by the annual operating tier, which is set based on projections of, as appropriate, end-of-calendar year and end-of-water year, elevations in Lake Powell and Lake Mead. Under the 2007 Interim Guidelines, Lake Powell operates under four operating tiers. Each operating tier has a specific logic for determining the required annual release within that tier. Depending on the operating tier, the annual release is either a set volume determined at the beginning of the water year, or a variable volume based on projected and actual inflows and resulting Lake Powell and Lake Mead elevations and storages.

The selection of the annual operating tier at Lake Powell and Lake Mead and the annual release volumes can, in some instances, be affected by the differing monthly release patterns of the LTEMP alternatives. While all of the alternatives, including Alternative A (no action alternative), were designed to be implemented to comply with the 2007 Interim Guidelines (Reclamation 2007a) during their effective period, nevertheless there can still be differences regarding operating tier selections and annual volumes among alternatives that are small and minimal in the long term (i.e., the multi-decade analysis performed in this DEIS). It is important to emphasize that all alternatives implement the rules of the 2007 Interim Guidelines through

TABLE 4.2-1 Summary of the Impacts of LTEMP Alternatives on Hydrology and Water Quality

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology							
Overall summary of impacts	No change from current condition	Compared to Alternative A, no change from current condition related to lake elevations, annual operating tiers, monthly release volumes, or mean daily flows, but higher mean daily changes in flow in all months. Hydropower improvement flows would cause even greater mean daily flow changes.	Compared to Alternative A, some change from current condition related to lake elevations, annual operating tiers, monthly release volumes, and mean daily flows; lower mean daily changes in flow in all months.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; similar mean daily changes in flow in most months.	Compared to Alternative A, negligible change from current condition related to lake elevations; no change in annual operating tiers; more even monthly release volumes and mean daily flows; higher mean daily changes in flow in all but Sept. and Oct.	Compared to Alternative A, some change from current condition related to lake elevations and annual operating tiers; large changes in monthly release volumes and mean daily flows; steady flows throughout the year.	Compared to Alternative A, negligible change from current condition related to lake elevations and annual operating tiers; even monthly release volumes and mean daily flows; steady flows throughout the year.
Lake Powell and Lake Mead Reservoir elevations	No change from current condition; reservoir elevations vary significantly with inflow hydrology; Lake Powell and Lake Mead operate at times within the full range of operating elevations.	Same as Alternative A for end-of-December elevations for Lake Powell and Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 1.5 ft higher at Lake Powell and 0.6 ft lower at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 0.2 ft higher at Lake Powell but the same at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 0.3 ft higher at Lake Powell and 0.1 ft lower at Lake Mead.	Compared to Alternative A, end-of-December elevations would be on average 3.2 ft higher at Lake Powell and 2.9 ft lower at Lake Mead, the largest difference of all alternatives.	Compared to Alternative A, end-of-December elevations would be on average 0.4 ft lower at Lake Powell and 1.4 ft higher at Lake Mead.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Lake Powell annual operating tier	No change from current condition; Alternative A would operate at times within each of the four operating tiers during the period 2013–2026 and at times within both operating tiers during the period 2027–2033.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Same as Alternative A.	Same as Alternative A.	Compared to Alternative A, would operate in a different tier an average of 2.1% of years; for the modeled period 2014–2026, there would be fewer occurrences of Mid-Elevation Release Tier and more occurrences of Upper Elevation Balancing and Equalization Tiers; for the modeled period 2027–2033, there would be more releases of >8.23 maf.	Compared to Alternative A, would operate in a different tier an average of 0.7% of years; there would be the same frequency of operating tiers, but different timing during the analysis period.

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Monthly release volume	No change from current condition; monthly volumes would be highest in Dec., Jan., Jun., Jul., Aug., and Sept. (670,000 ac-ft to 1,500,000 ac-ft; 570,000 to 1,200,000 ac-ft in other months).	Same as Alternative A.	Compared to Alternative A, higher volumes in Feb. through May (by 82,000 to 157,000 ac-ft); lower in Aug., Sept., and Oct. (by 111,000 to 200,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 43,000 to 98,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 60,000 to 127,000 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Feb., Mar., and Apr. (by 45,000 to 128,000 ac-ft); lower in Dec., Jan., Jul., Aug., and Sept. (by 30,000 to 242,000 ac-ft).	Compared to Alternative A, much higher volume in Apr., May, and Jun. (by 439,000 to 651,000 ac-ft); much lower in Dec., Jan., Jul., Aug, and Sept. (by 214,000 to 433,00 ac-ft).	Compared to Alternative A, higher volume in Oct., Nov., Mar., and Apr. (by 71,000 to 286,000 ac-ft); lower in Dec., Jan., Jul., and Aug. (by 139,000 to 196,000 ac-ft).
Mean daily flow	No change from current condition; mean daily flows are highest in Dec., Jan., Jun., Jul., Aug., and Sept. (11,200 to 24,600 cfs; 9,400 to 14,400 cfs in other months).	Same as Alternative A.	Compared to Alternative A, higher mean daily flow in Feb. through May (by 1,300 to 2,500 cfs); lower in Aug., Sept., and Oct. (by 1,800 to 3,300 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 3,000 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 1,000 to 2,100 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Feb., Mar., and Apr. (by 700 to 2,100 cfs); lower in Dec., Jan., Jul., Aug., and Sept. (by 500 to 4,000 cfs).	Compared to Alternative A, much higher mean daily flow in Apr. through Jun. (by 7,400 to 10,600 cfs); much lower in Dec. and Jan. and Jul. through Sept. (by 3,600 to 7,000 cfs).	Compared to Alternative A, higher mean daily flow in Oct., Nov., Mar., Apr. (by 1,200 cfs to 4,800 cfs); lower in Dec., Jan., Jul., and Aug. (by 2,300 to 3,200 cfs).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Hydrology (Cont.)							
Mean daily change in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs in Dec., Jan., Jun., Jul., Aug., and Sept.; 2,600 to 6,400 cfs in other months.	Compared to Alternative A, mean daily change higher in all months (range about 2,500 to 12,000 cfs).	Compared to Alternative A, mean daily change lower in all months (about 1,300 cfs to 6,200 cfs).	Compared to Alternative A, mean daily change slightly higher in Oct. through Jun., same or less in Jul. through Aug. (range about 2,700 to 7,600 cfs).	Compared to Alternative A, mean daily change higher in all months but Sep. and Oct. (range about 1,100 to 9,600 cfs).	Mean daily change is zero except for ramping up and down from spring and fall HFEs.	Mean daily change is zero except for ramping up and down from spring and fall HFEs.
Water Quality							
Overall summary of impacts	No change in temperature or other water quality indicators from current conditions.	Negligible differences in temperature or other water quality indicators.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.	Compared to Alternative A and the other alternatives, greatest summer warming and potential for bacteria and pathogens.	Compared to Alternative A, greater summer warming and increased potential for bacteria and pathogens.
Water temperature (change from Lees Ferry to Diamond Creek)	No change from current conditions; summer warming would be lowest among alternatives (average 5.6°C).	Same as Alternative A.	Summer warming would be higher than under Alternative A (average 5.8°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be higher than under Alternative A (average 6.0°C).	Summer warming would be highest among alternatives (average 6.8°C).	Summer warming would be higher than under Alternative A (average 6.2°C).

TABLE 4.2-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Water Quality (Cont.)							
Salinity	Negligible change from current condition. Negligible alternative-specific differences (<2.5%) expected because, regardless of operating conditions, salinity would not increase over time or exceed control criteria.						
Turbidity	Negligible change from current condition. No alternative-specific differences expected because potential turbidity increases due to scouring during HFEs are expected to be temporary and any observed fluctuations recover quickly when lower flows return. Effects of operational changes related to tributaries are currently unknown.						
Bacteria and pathogens	No change from current condition.	Slightly lower probability of the occurrence of bacteria and pathogens compared to Alternative A because of higher within-day fluctuations.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Occasional low summer flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Annual low steady flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.	Year-round steady flows and relatively frequent HFEs could increase the probability of occurrence of bacteria and pathogens compared to Alternative A.
Nutrients	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, waters are expected to remain relatively low in nutrients.						
Dissolved oxygen	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, DO concentrations are expected to remain within the accepted healthy range for fish.						
Metals/ radionuclides	Negligible change from current condition. No alternative-specific differences expected because operational changes will not affect metal/radionuclide concentrations. There are no concerns related to these substances because levels do not exceed any enforceable human-health-based standards or guidance values.						
Organic/other contaminants	Negligible change from current condition. No alternative-specific differences expected because, regardless of operational changes, organic and other contaminant concentrations are expected to remain below those considered toxic.						

2026 regarding annual release volumes from Glen Canyon Dam. Three causes contribute to the identified model results showing differences in operating tier or different annual release volumes:

- October to December release ratio,
- Differences in evaporation and bank storage,[2] and
- Differences in equalization releases when maximum release is a constraining factor.

These topics are described next.

October to December Release Ratio. Alternatives that release proportionally less volume during October through December, relative to the rest of the water year, result in a slightly lower end-of-year Lake Powell elevation (and slightly higher end-of-year Lake Mead elevation), and can, accordingly in those circumstances, when Lake Powell elevation is projected to be close to an operating tier threshold, result in a different operating tier selection, potentially impacting the implementation of a different operating tier at Lake Powell and Lake Mead, as well as different annual volumes. This effect (a changed operating tier) is projected to occur very infrequently (0 to 2.1 % of years, depending on the alternative) and constituted all occurrences of operating tier differences from Alternative A in this modeling. Alternatives with the same October through December volume as Alternative A (2,000 kaf in an 8.23-maf year) did not result in a different operating tier. Alternatives B, D, and E also have October–December volumes of 2,000 kaf, but Alternatives C, F, and G have October–December volumes of 1,790 kaf, 1,466 kaf, and 2,075 kaf, respectively.

Effects Due to Differences in Evaporation and Bank Storage. Changes in the monthly pattern of releases result in differences in evaporation and losses or gains caused by bank storage, which in turn can affect the end-of-year pool elevation, and in some cases could affect the operating tier or annual release volume in equalization or balancing years. Alternatives that release proportionally less volume early in the water year typically result in a higher Lake Powell elevation and larger surface area in the summer. This can result in slightly higher losses from evaporation and bank storage during such periods. In certain operating tiers (those with a set volume release or those dependent on Lake Mead's elevation), this can result in a slightly different end-of-year elevation at Lake Powell. If Lake Powell is close to an operating tier threshold the following water year, a different operating tier could be triggered in the following water year due to differences in evaporation and bank storage. This effect did not show up in this modeling, but in theory it could occur.

[2] Water absorbed and stored in the banks of a reservoir and returned in whole or in part as the level of the reservoir surface falls.

Effects Due to Differences in Equalization Releases when Maximum Release Is a Constraining Factor. Equalization release volumes can be affected by the annual pattern of monthly volumes. Alternatives that have higher releases earlier in the water year are able to release more water in years when the maximum release through the powerplant becomes a limiting factor to equalizing within the water year. As hydrologic conditions change throughout the water year, the annual release volume also shifts. In years when the annual release volume increases throughout the year, it may not be possible to release it all in the remaining months of the water year through the powerplant turbines; thus, some must be released the following water year. Generally, the action alternatives pass more water earlier in the water year (through July) and thus have less potential for annual releases extending beyond the water year than Alternative A (0 to 200 kaf less, depending on the alternative). This can result in different annual volumes, but that difference is made up in the following water year. This effect does not result in different operating tiers.

Monthly Releases

Although annual release volumes would be nearly the same under each of the LTEMP alternatives, the monthly patterning of that annual volume varies significantly among the alternatives. Monthly release patterns for each of the alternatives in years with different annual release volumes are shown in Figure 4.2-1. Monthly releases were shaped for each alternative in an 8.23-maf year and then generally scaled proportionally to the 8.23-maf pattern relative to the annual volume.[3] For example, 763 kaf in January for Alternative D in an 8.23-maf year scaled to 1,104 kaf in January for an 11-maf year. For years when the annual volume was large enough that monthly releases were limited by the maximum release capacity of Glen Canyon Dam, the monthly distribution of releases became more similar across alternatives (Figure 4.2-1). Monthly release volumes for different annual releases are included in Appendix D.

Monthly releases sometimes would be limited by the minimum or maximum release constraints at Glen Canyon Dam. In low annual volume release years, monthly volumes sometimes would be increased to ensure that the minimum hourly release objective of each alternative could be maintained throughout the month. In high annual release years, monthly volumes sometimes would be decreased because they were capped at the maximum release capacity (45,000 cfs), and the remaining volume was released in the following month(s). See Appendix D for further detail.

Operationally, annual releases and the associated monthly releases are affected by hydrologic uncertainty. In some operating tiers, Lake Powell's annual release is determined by end-of-water year target elevations or storages of Lake Powell and Lake Mead. Because the actual inflow volume is not known until the end of the water year, reservoir operators utilize inflow forecasts throughout the year to project the expected annual release volume and allocate the monthly releases accordingly. As hydrologic conditions change throughout the water year,

[3] Note that adjustments to Alternative D made after modeling was completed resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

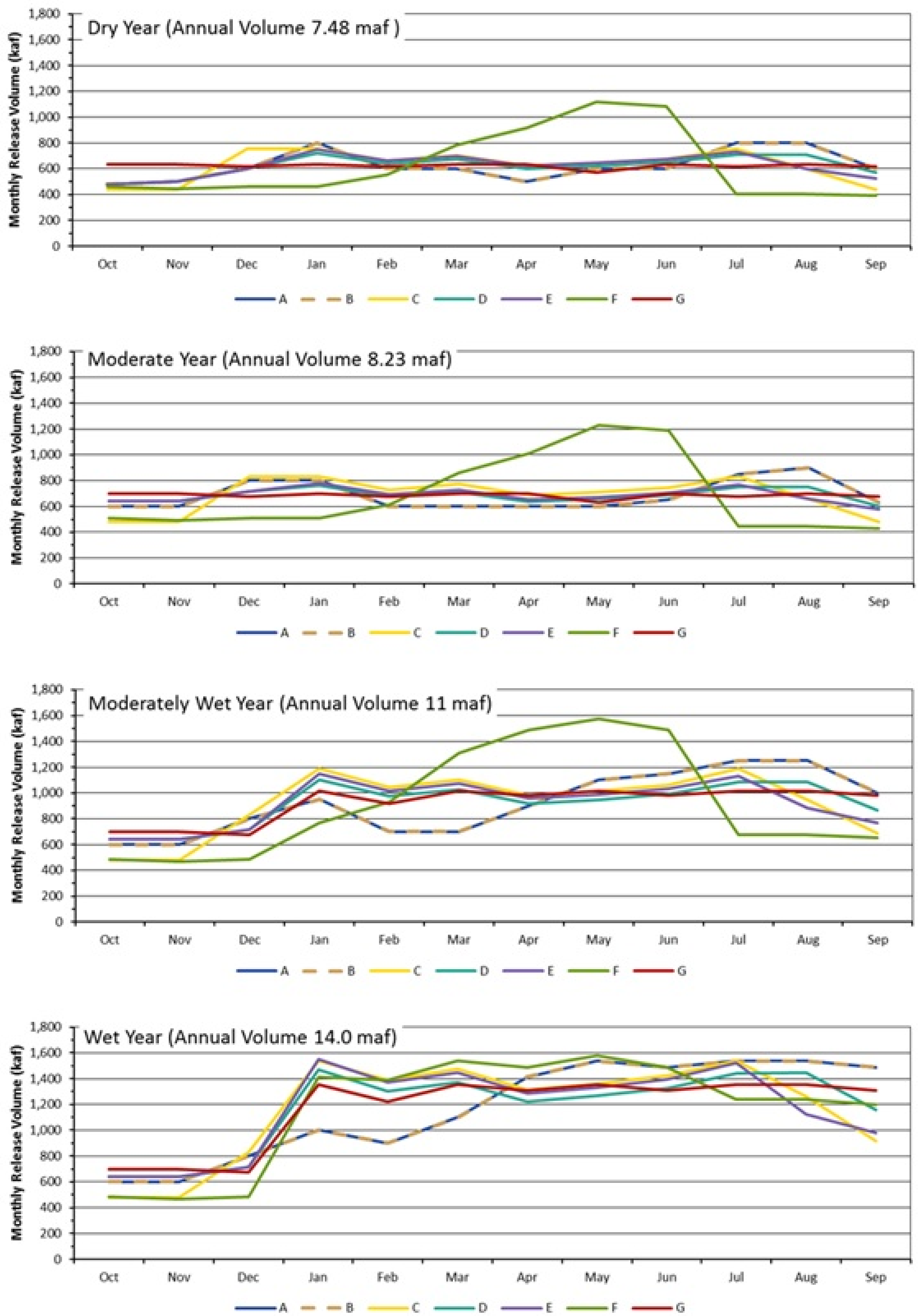

FIGURE 4.2-1 Monthly Releases under Each Alternative in Years with Different Annual Release Volumes

the annual release volume also shifts. This effect of hydrologic uncertainty is captured in CRSS through a forecasting algorithm. Resulting monthly releases, therefore, may not scale exactly proportionally with the final total annual release volume.

Monthly release volume can also be affected by HFEs. For HFEs that require more water than was already allocated for the given month of the HFE, water is reallocated from later months to ensure the water year release volume remains the same. The monthly reallocation of releases to support a HFE does not affect the Lake Powell operating tier. See Appendix D for further detail.

Monthly releases can also be affected by low summer flows. Low summer flows would be implemented as an experimental component under Alternatives C, D, and E. During years with low summer flows, releases would be lower than typical in July, August, and September and proportionally higher in May and June, in order to maintain the same annual release volume. Subject to the decision-making process outlined in Section 2.2.4.2, low summer flows may be implemented if three conditions are met: (1) the projected annual release was less than 10 maf; (2) the projected temperature at the confluence with the Little Colorado River in July, August, or September was < 13ºC (Alternatives C and E) or 14ºC (Alternative D); and (3) switching to the low summer flow pattern resulted in temperatures of 13ºC (Alternatives C and E) or 14ºC (Alternative D) in those months. For those alternatives with low summer flows, the number of those flows in the 20-year period was estimated to range from zero to four occurrences. Depending on the alternative, the average ranges from 0.7 to 1.8 low summer flows per 20-year run. See Appendix D for further detail.

Mean monthly release volumes averaged over all years within each run are shown in Figure 4.2-2. The variability in these values reflects the effect on operations of natural variability in inflows observed in the historical record. The differences among alternatives in mean monthly release volumes are a function of the monthly volume patterns established in the definition of each alternative (see Chapter 2 for a description of these operational constraints).

Within alternatives, mean monthly volumes would vary the most among the scenarios in the months of June through September (Figure 4.2-2). This pattern of variability is a result of adjustments in operations in the latter half of the water year in response to forecasts that become more certain after June 1. During the first half of the water year, operations tend to be more conservative (less variable) to ensure sufficient water remains for the remainder of the year to meet minimum flows.

Mean monthly volumes under Alternative F are consistently the most different from other alternatives, with volume being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

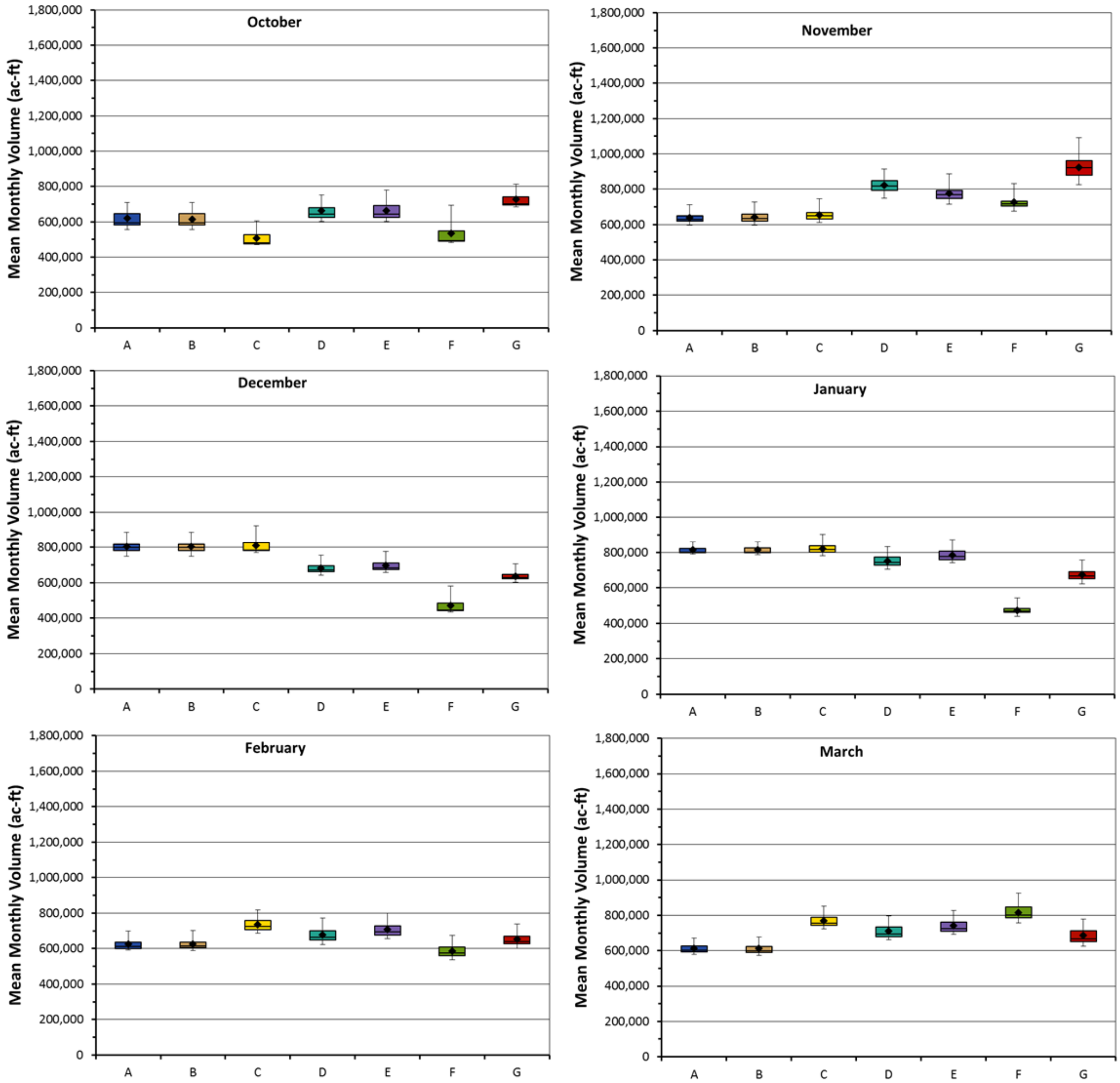

FIGURE 4.2-2 Mean Monthly Volume under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

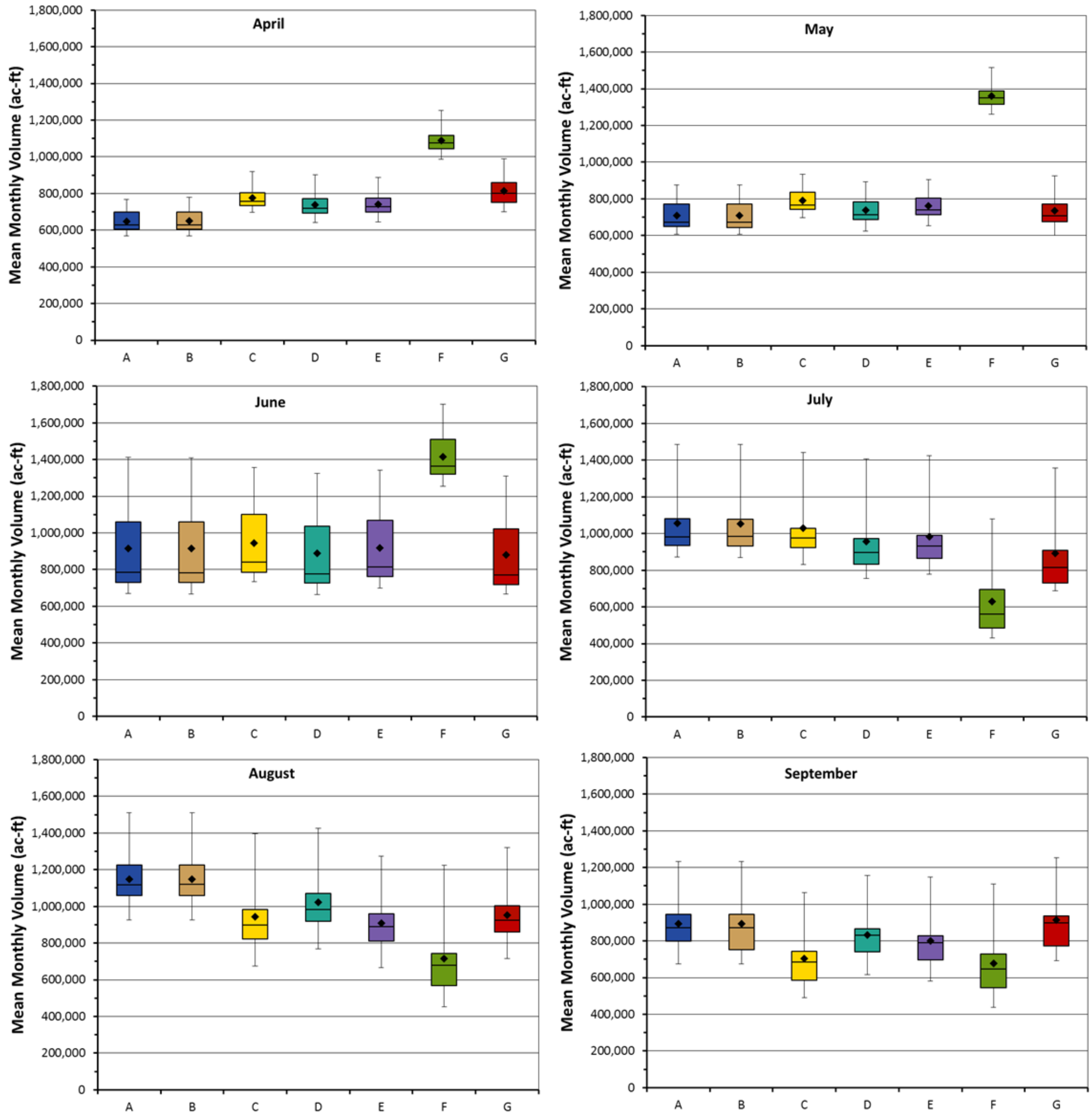

FIGURE 4.2-2 (Cont.)

Daily and Hourly Releases and Ramp Rates

For most alternatives, releases from Glen Canyon Dam fluctuate throughout the day in response to hydropower demand. Releases are generally higher during the day when there is a higher demand for hydropower, and lower during the night when the demand is lower. The fluctuation within a day (i.e., from nighttime low to daytime high) varies by alternative and is typically relative to the monthly release volume. For example, months with a higher release volume typically have a larger daily range of releases. Two alternatives, Alternatives F and G, do not have daily and hourly release fluctuations.

The range of daily releases is further defined by a required minimum release and is alternative specific. The scheduled hourly release rate must be equal to or greater than the prescribed minimum release. The minimum release during the daytime is typically higher than the minimum release during the nighttime.

The peak release in a day is determined by the maximum allowable daily fluctuation, and the daily and monthly release volume. In cases when the required monthly release is very large, the peak daily release could be limited by reservoir outlet works capacity, which is a function of reservoir head. Generally speaking, the maximum possible release without using the spillway was computed as 45,000 cfs. The actual maximum release may be lower, depending on reservoir elevation and the number of available hydropower units.

Ramp rates, the change in release from one hour to the next, are also specific to each alternative (Chapter 2). Ramp rates down vary by alternative; ramp rates up are the same for all alternatives (Chapter 2, Table 2-1). For all alternatives, the ramp rate up is faster than the ramp rate down.

Daily release volumes vary throughout the week relative to hydropower demand. Release volumes are typically larger during weekdays when the demand for hydropower is higher and release volumes are lower during the weekends and holidays.

Mean daily flow and mean daily change vary among alternatives, in part due to differences in the monthly volume patterns established for each alternative, but also as a result of operational constraints characteristic of each alternative (see Chapter 2 for a description of these operational constraints) (Figures 4.2-3 and 4.2-4).

Within alternatives, mean daily flows would vary the most among the scenarios in the months of June through September (Figure 4.2-3). This pattern can be attributed to increased variability in monthly volume, as described in the previous section.

Mean daily flows under Alternative F are consistently the most different from other alternatives, with mean daily flows being lower in December, January, July, August, and September, but higher in April, May, and June (Figure 4.2-3). These differences are a result of the monthly release pattern of this alternative, as described in the previous section. Other variations among alternatives are less apparent, although Alternatives C and E both target lower August and September volumes to conserve sediment prior to fall HFEs.

Similar to the pattern discussed above for mean daily flows, mean daily change would vary the most among the scenarios in the months of June through September (Figure 4.2-4). This pattern reflects the variability in monthly volume, which determines the level of amount of daily change allowed under each alternative.

Mean daily change varies among the alternatives, ranging from 0 cfs (in all but the months with HFEs) in the two steady flow alternatives (Alternatives F and G), to up to 12,000 cfs in Alternative B. Of the fluctuating flow alternatives (A–E), Alternative C has the lowest mean daily change. Relative to Alternative A, mean daily change under Alternative D is

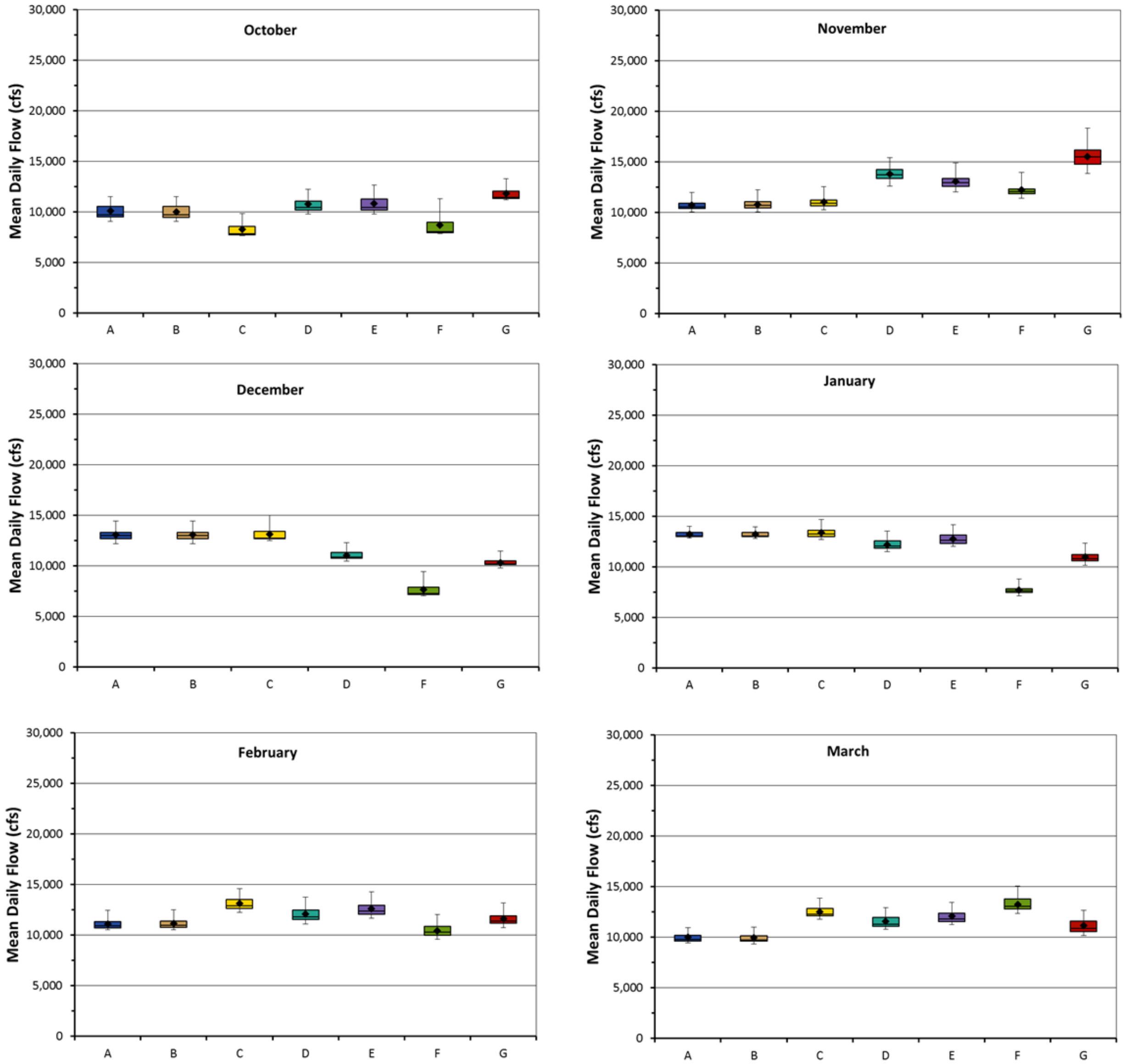

FIGURE 4.2-3 Mean Daily Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

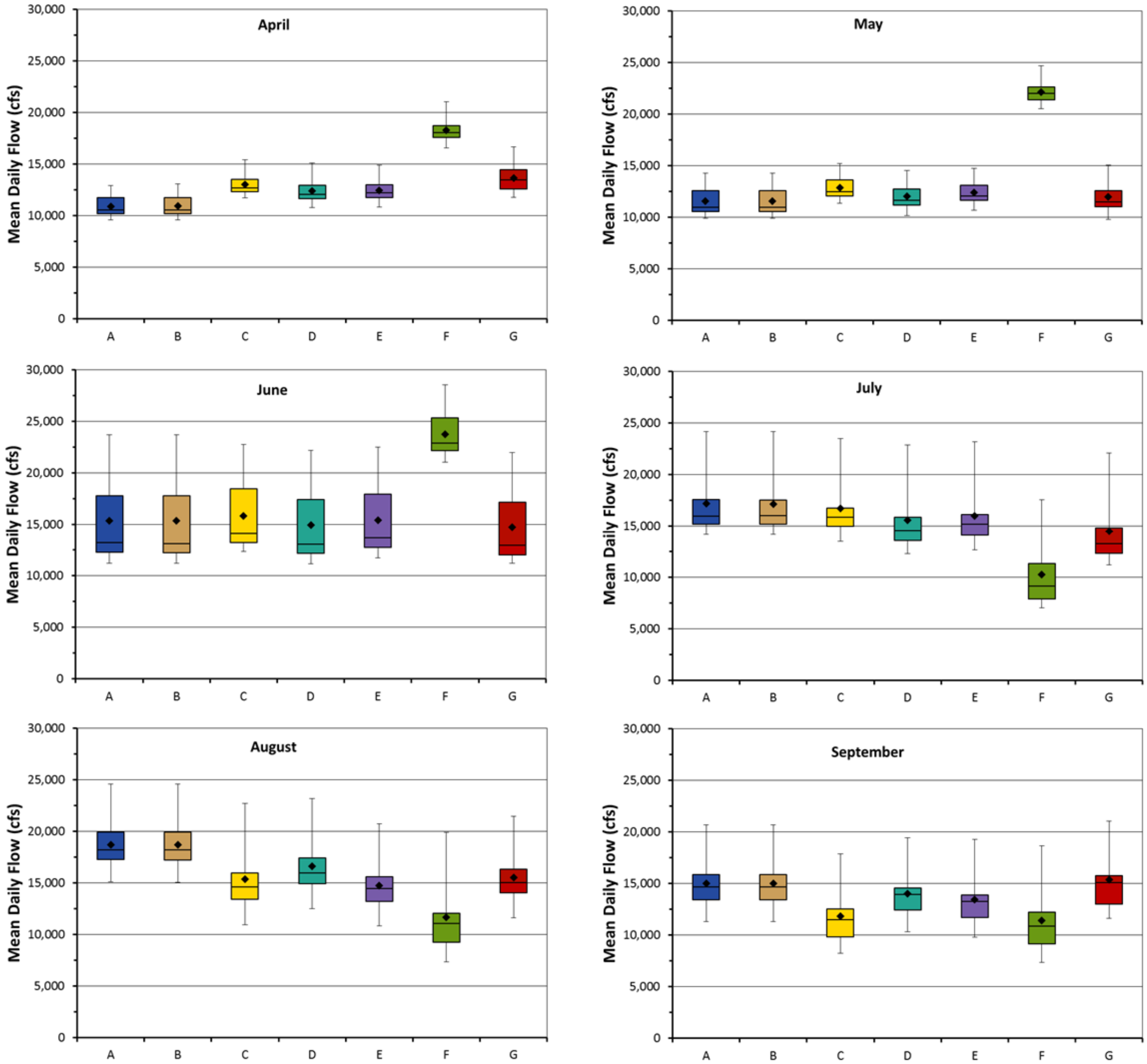

FIGURE 4.2-3 (Cont.)

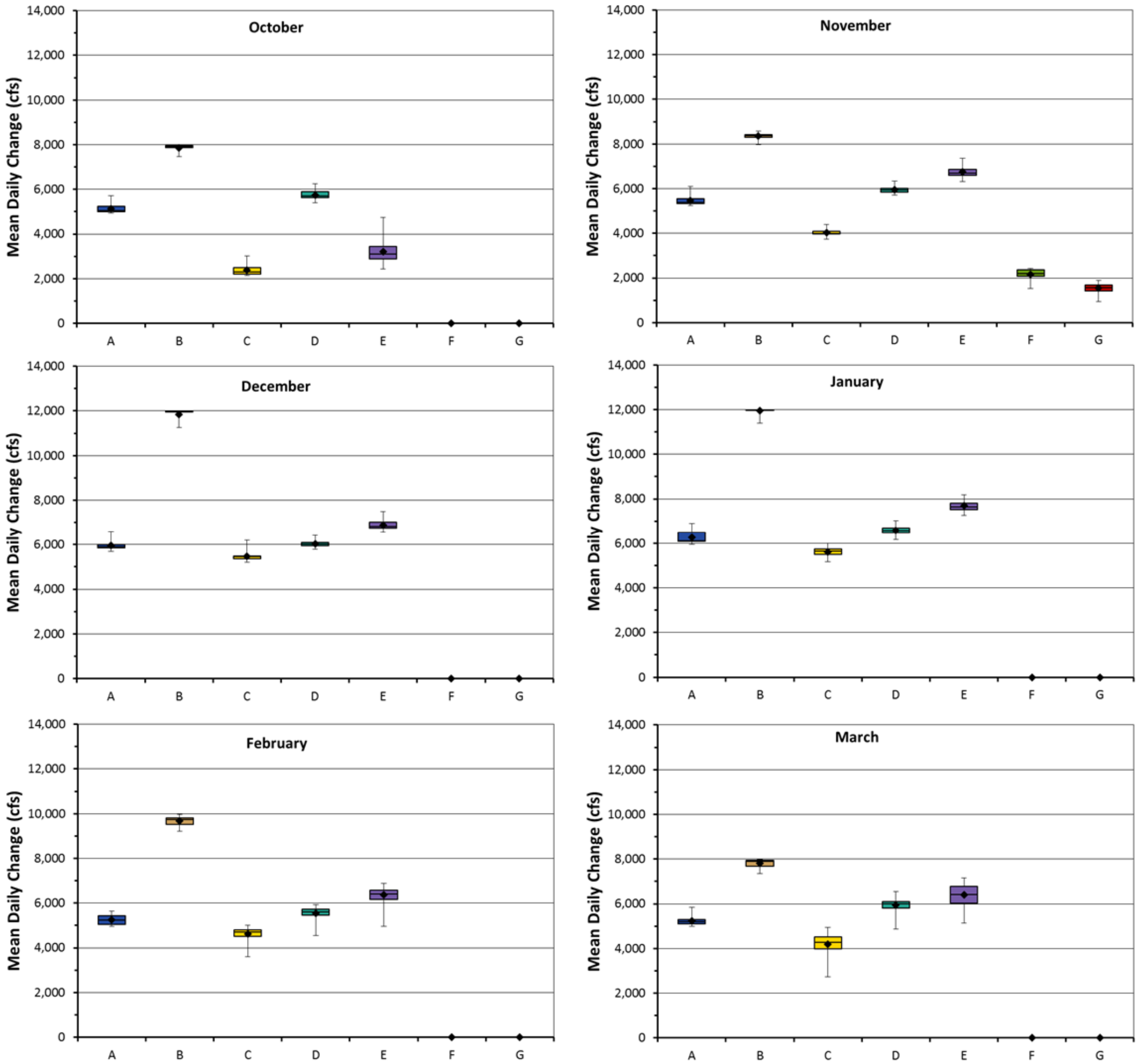

FIGURE 4.2-4 Mean Daily Change in Flows by Month under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios and Three Sediment Scenarios (Means were calculated as the average for all years within each of the 21 hydrology runs. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

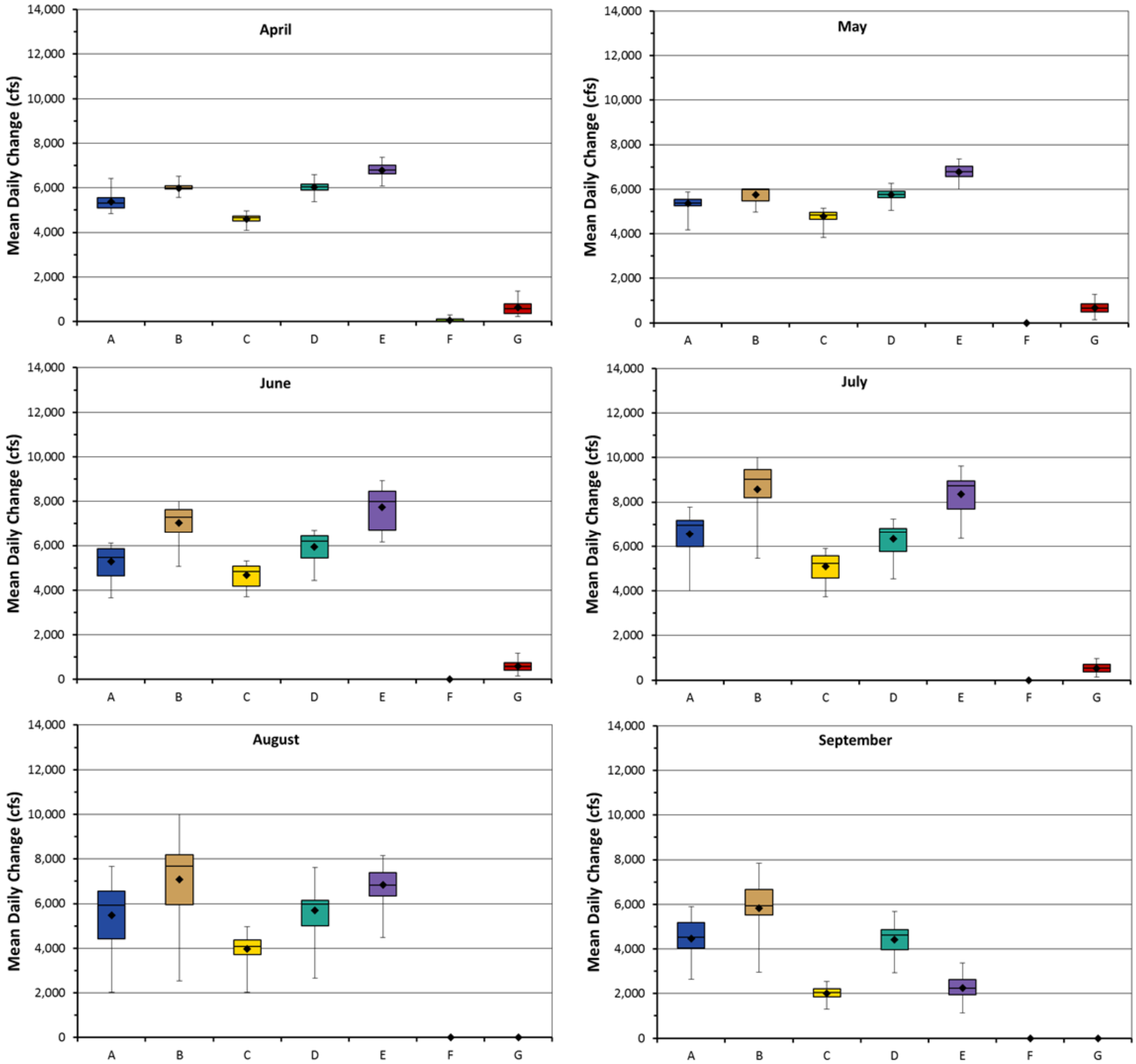

FIGURE 4.2-4 (Cont.)

most similar; Alternatives C, F, and G are consistently lower; Alternative B is consistently higher; and Alternative E is higher in all months but September and October when load-following curtailment prior to HFEs would occur.

Reservoir Elevations

Lake Powell elevations are affected by potential future hydrology and Glen Canyon Dam operations. Lake Mead elevations are similarly affected by Glen Canyon Dam releases and Hoover Dam operations (including those related to meeting downstream water delivery obligations).

The elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. Figure 4.2-5 presents end-of-calendar year elevations for Lake Powell and Lake Mead at the 10th, 50th, and 90th percentiles for 21 different hydrology traces and the seven different alternatives. The plots show that uncertainty associated with annual variation in inflow (variation among years) creates a larger range of pool elevations than do the differences within years among alternatives. In addition, differences among alternatives are greater at the 10th and 50th percentiles, corresponding to lower lake elevations and drier hydrology. Differences at the 90th percentile, which corresponds to higher lake elevations and wetter hydrology, are minimal across all alternatives.

The percentage of traces with Lake Powell falling below 3,490 ft (modeled minimum power pool) and the percentage of traces with Lower Basin shortages are shown in Figure 4.2-6. The probability of these conditions occurring is more affected by annual variation in inflow than by alternative. For Lake Powell elevations, all alternatives show very similar percentages for elevations that are ≤3,490 ft. The percentage of traces ranges between 0 and 5 and remains relatively constant throughout the 20-year period. Typically, alternatives that show differences from Alternative A are due to an alternative releasing more or less water from October through March (the typical low elevation months). Alternatives that release less water in this period will have a lower probability of falling below 3,490 ft (e.g., Alternative F reduces the probability in 2017 and 2032).

For Lower Basin shortages pursuant to the applicable provisions of the 2007 Interim Guidelines (i.e., when Lake Mead's elevation is projected to be at or below 1,075 ft on January 1), the percentages are also similar across alternatives, though with slightly more variability than with the Lake Powell minimum power pool. The percentage of traces with Lower Basin shortages generally increases over the 20-year period, ranging from zero in the first years of the period to nearly 62% of traces near the end of the period. The greatest difference across all alternatives is 19% in any given year. The October through December release from Lake Powell is the largest contributing factor in differences between Alternative A and the other alternatives.

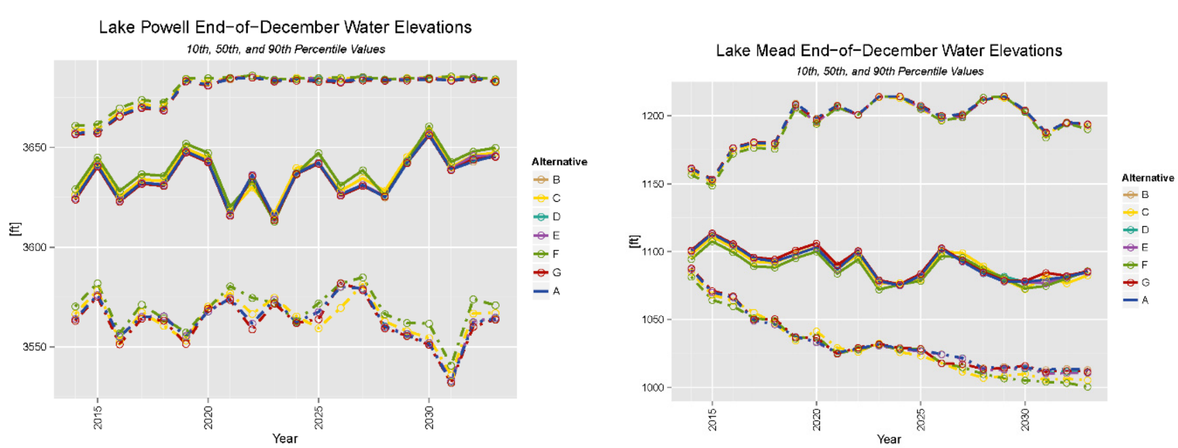

FIGURE 4.2-5 Lake Powell (left) and Lake Mead (right) End of Calendar Year Pool Elevation for 21 Hydrology Traces and Seven Alternatives

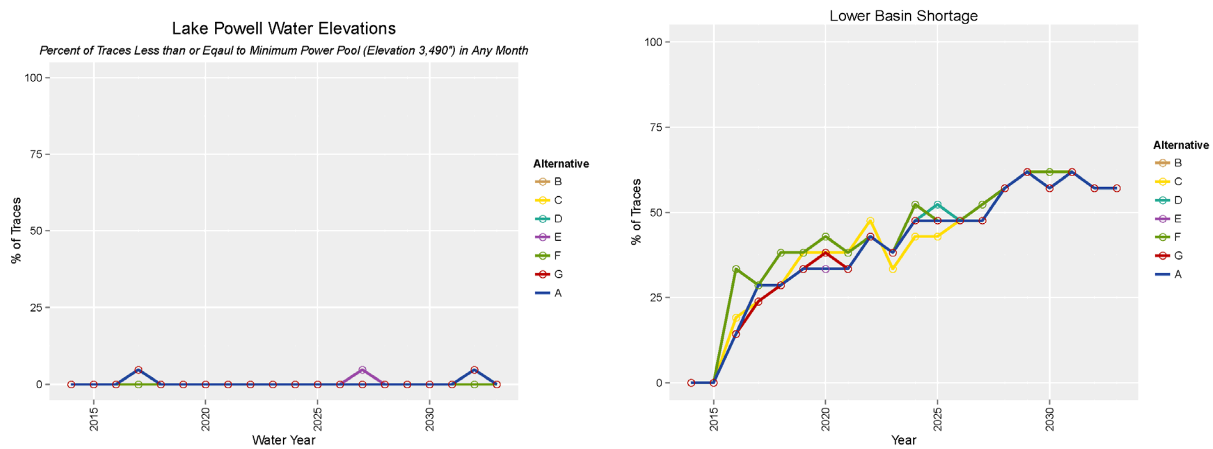

FIGURE 4.2-6 Percentage of Traces below Lake Powell's Minimum Power Pool (elevation 3,490 ft) (left) and Percentage of Traces with a Lower Basin Shortage (any tier) (right) for 21 Hydrology Traces and Seven Alternatives

Alternatives that release less water in October through December show higher chances of shortages in the Lower Basin (e.g., Alternative F).

Water Delivery

The water delivery resource goal is to ensure water delivery to the communities and agriculture that depend on Colorado River water consistent with applicable determinations of annual water release volumes from Glen Canyon Dam made pursuant to the LROC for Colorado River Basin Reservoirs, which are currently implemented through the 2007 Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead. Note that all alternatives must meet these legal requirements.

To evaluate potential differences among alternatives related to water delivery, the following metrics were calculated:

- Frequency of deviation from Alternative A with regard to Lake Powell annual operating tier as specified by the 2007 Interim Guidelines,

- Probability over time of Lake Powell being in each operating tier as specified in the 2007 Interim Guidelines, and

- Frequency and volume of exceptions to meeting the annual release target volumes specified by the 2007 Interim Guidelines.

Frequency of Deviation from Alternative A with Regard to Lake Powell Annual Operating Tier as Specified by the 2007 Interim Guidelines. The frequency of deviation from

Alternative A with regard to Lake Powell annual operating tier pursuant to the 2007 Interim Guidelines is shown in Figure 4.2-7. This frequency was calculated as the number of years in which an alternative was modeled to be in an operating tier that is different from the modeled operating tier of Alternative A for the same year and trace combination divided by the total number of years (420 years for the 20-year period). For 2014–2026, the operating tiers pursuant to the 2007 Interim Guidelines were used; for 2027–2033, the operating tiers were defined as either an 8.23-maf release or a release greater than 8.23 maf.[4] Operations under most of the alternatives do not result in a different operating tier from that under Alternative A. Of those alternatives that do show differences, the percentage of time in a different tier ranged from 0 to 15.4%. Alternatives with an October through December release volume other than 2,000 kaf occasionally result in a different operating tier from Alternative A. Of the alternatives,

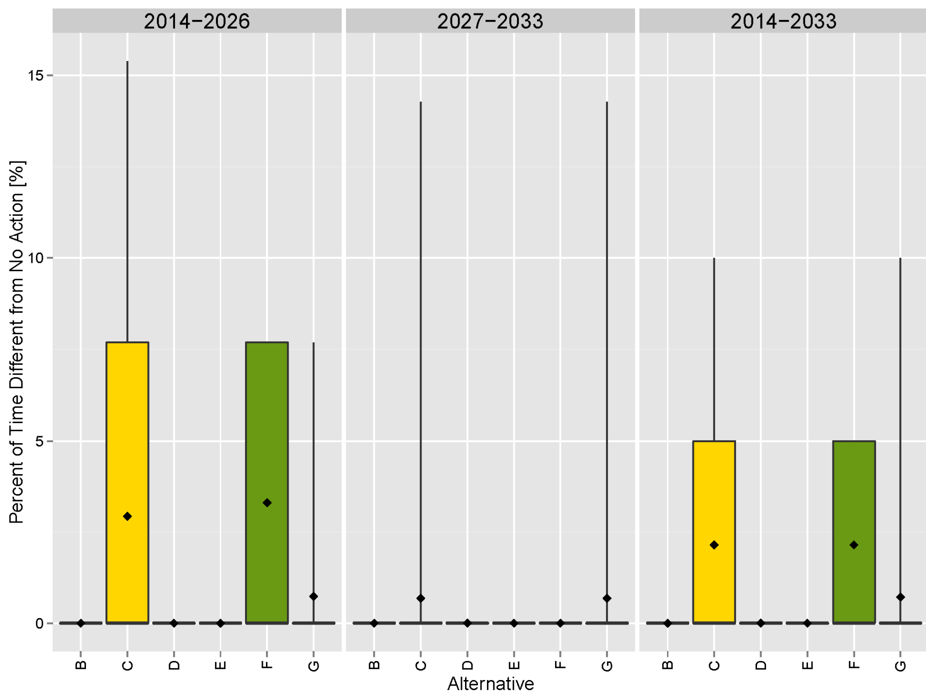

FIGURE 4.2-7 Percentage of Time in Different Operating Tier than Alternative A (The percentage of time in a different operating tier than the No Action Alternative is calculated for each trace and time period. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4 Under the 2007 Interim Guidelines, Lake Powell operates in four possible operating tiers through a full range of reservoir elevations and releases. The Interim Guidelines are in place through 2026 and include a provision that beginning no later than December 31, 2020, the Secretary of Interior shall initiate a formal review for purposes of evaluating these Guidelines. It is unknown what the outcome of the review will be, including whether or how new guidelines will be implemented. Unless new guidelines are implemented, after 2026, Lake Powell will revert back to the Interim Guidelines No Action Alternative with tiers defined as either an 8.23-maf release or a release greater than 8.23 maf.

Alternative C is in a different operating tier most frequently, an average of 2.1% of the time during the 20-year LTEMP period. If an alternative is in a different operating tier one year, it is more likely to be in a different operating tier than Alternative A in a following year, and the difference in a year-by-year comparison can cascade through the end of the period. It should be noted that in all instances, all alternatives implement the operating rules of the 2007 Interim Guidelines through 2026, but still show potential differences in operating tier.

Probability over Time of Lake Powell Being in Each Operating Tier as Specified in the 2007 Interim Guidelines. Figures 4.2-8 and 4.2-9 show the frequency of occurrence for Lake Powell operating tiers for each alternative during (Figure 4.2-8) and after (Figure 4.2-9) the interim period. The plots indicate that the frequency of each of the tiers is very similar across all alternatives, evidenced by the interquartile, minimum, and maximum values as well as the median and mean values. For all alternatives, the Upper Elevation Balancing Tier is the most common, followed by the Equalization Tier, then the Mid-Elevation Release Tier, and, lastly, the Lower Elevation Balancing Tier. Similar consistency across alternatives is evident in the period 2027–2033.

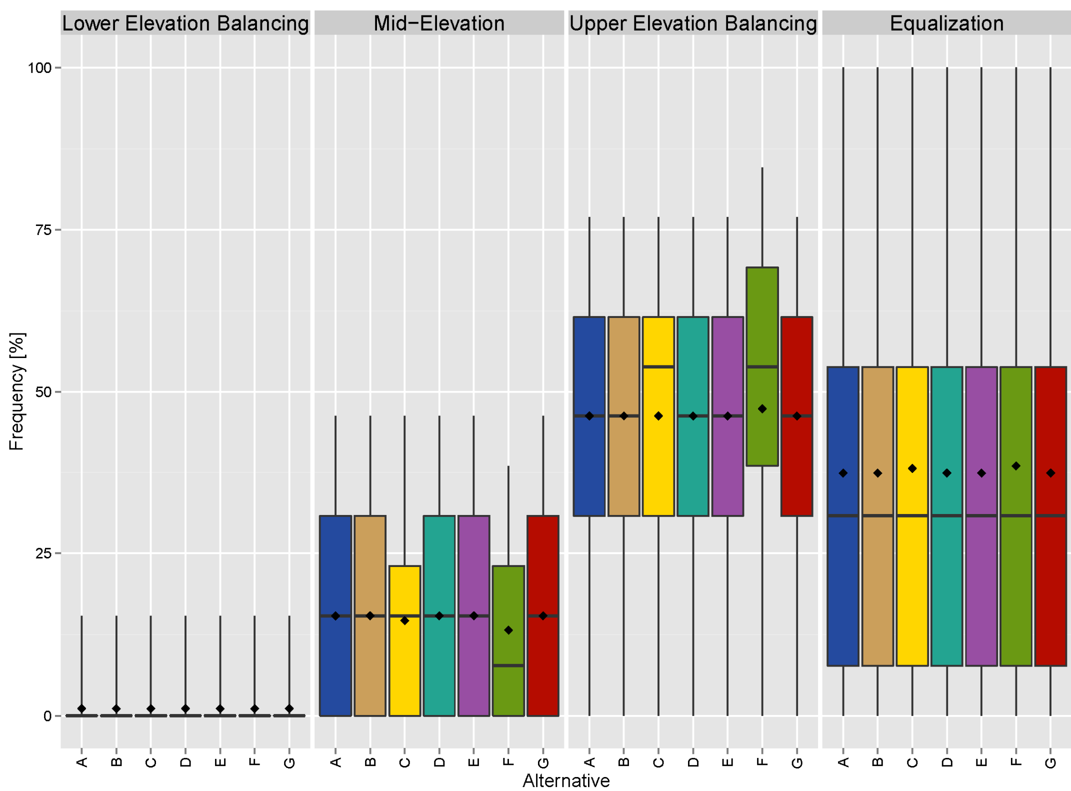

FIGURE 4.2-8 Frequency of Lake Powell Operating Tiers from 2014 to 2026 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

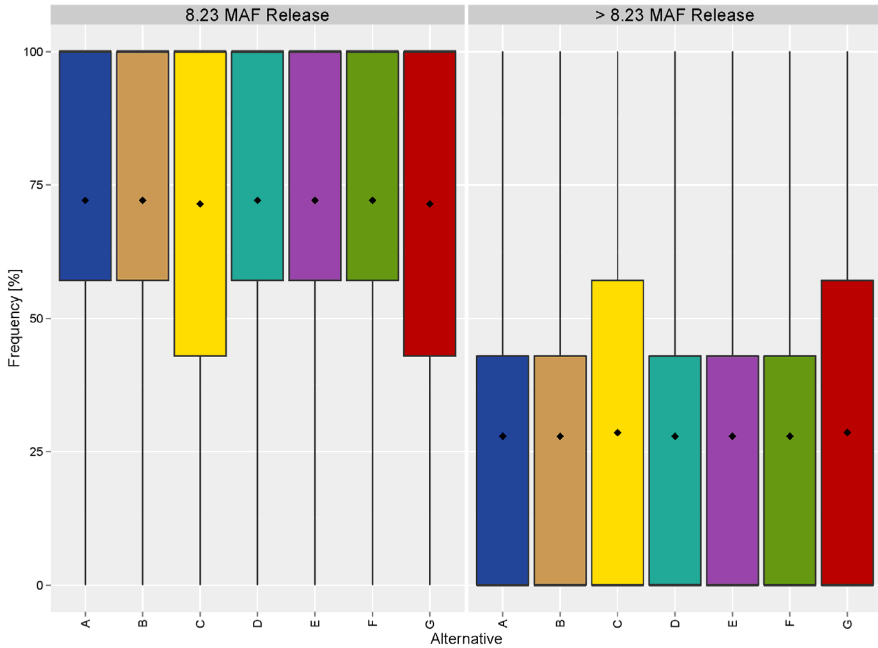

FIGURE 4.2-9 Frequency of Lake Powell Operating Tiers from 2027 to 2033 under Each of the Alternatives for 21 Hydrologic Traces (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Frequency and Volume of Exceptions to Meeting the Annual Release Target Volumes Specified by the 2007 Interim Guidelines. The frequency (Figure 4.2-10) and volume of exceptions to meeting the annual release target volumes specified by the Interim Guidelines are shown below. The 2007 Interim Guidelines were developed with an operational goal of meeting the annual release target volume specified by the Interim Guidelines fully within a water year – that is, projected releases are to be achieved as nearly as is practicable by the end of each water year. Any instances of not meeting the specific release volume under the Interim Guidelines by the end of the relevant water year are due to physical constraints of being able to pass the full equalization volume through the powerplant turbines by the end of the water year, potentially resulting in annual releases extending beyond the water year. For modeling purposes, if it is not possible to fully equalize by the end of the water year, the remaining volume necessary to fully equalize is computed at the end of September; this volume is added to be immediately released as the initial portion of the next water year's release. Again, for modeling purposes, this metric identifies the frequency and volume of annual releases extending beyond the water year. In these instances, the remaining volume was released as soon as physically possible (i.e., starting in October). Water would be released from Lake Powell up to full powerplant capacity until the annual release extending beyond the water year has been released in addition to the normal releases. In the modeling performed for this DEIS, all instances of annual releases extending beyond the water year were able to fully equalize within 3 months after the end of the water year and did not affect the operating tier for the next water year. The average number of years with annual releases extending beyond the water year in any 20-year trace is less than 1 for

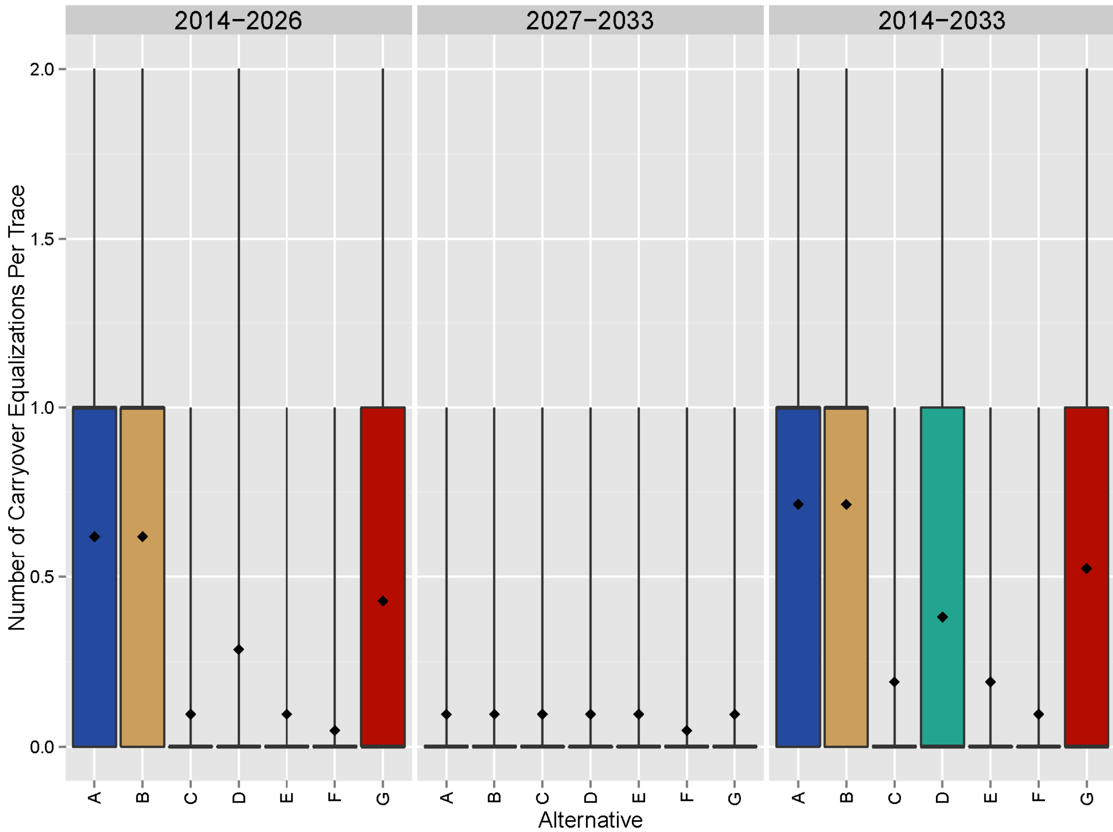

FIGURE 4.2-10 Frequency of Occurrence of Annual Releases Extending Beyond the Water Year per 20-Year Trace for Each of the Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

all alternatives, but ranges from 0 to 2. For most action alternatives (except for Alternative B), the average number of years with annual releases extending beyond the water year is less than under Alternative A. In addition, Alternatives C, E, and F reduce the maximum number of annual releases extending beyond the water year per trace from 2 to 1.

The volume of annual releases extending beyond the water year is also similar across alternatives. Across all alternatives, most of the volumes are 0 kaf, with the majority of the remaining volumes less than 500 kaf, and a handful of occurrences ranging up to 2,000 kaf of in 1 year. For the action alternatives, the volumes of annual releases extending beyond the water year are generally less than, though sometimes equal to, those under Alternative A. (See Appendix D for detail.)

4.2.2.2 Water Quality

This section discusses the general results of the water quality analyses and focuses on impacts on water temperature and salinity. Overall, there is little difference expected in water quality among the different alternatives because annual volumes are the same for all alternatives and the monthly and daily flow characteristics of alternatives do not vary drastically; any small changes are expected to be comparable across all alternatives.

Water Temperature

This section presents a quantitative description of the modeled temperatures and overall trends (e.g., seasonal changes) within and among the alternatives. More detailed analysis, as it relates to specific resources, is provided within the applicable resource sections.

In general, Glen Canyon Dam operations under the various alternatives are not expected to significantly affect Lake Powell reservoir water quality parameters; however, the dam outlet temperature and thermocline location may be a factor in determining effects on water quality downstream.

Lake Powell

As described in Section 3.3.3.2, Glen Canyon Dam release temperatures are highly dependent on the position of the penstocks (i.e., elevation 3,470 ft) relative to the surface of Lake Powell. In general, when lake surface elevations are high, releases tend to be cooler because they originate deeper in the lake relative to the surface of the reservoir (e.g., from within the hypolimnion). On the other hand, when lake surface elevations are low, withdrawals tend to be warmer because they originate closer to the surface (i.e., from the metalimnion or upper hypolimnion). Regardless of the alternative analyzed, temperature and elevation are highly correlated.

Examination of the modeling results for effects of alternative operations on release temperatures indicated that annual inflow volume to Lake Powell had a greater influence on the release temperature than the operational differences in monthly and daily flows. Under drought conditions, such as those seen recently (e.g., 2005–2010), release temperatures tend to be consistently higher because reservoir elevations are generally low and releases originate closer to the lake surface. However, during extreme drought, the elevation of Lake Powell may drop below the minimum power pool elevation of 3,490 ft AMSL. If this occurs, releases cannot be made from the powerplant penstocks and are instead routed through the river outlet tubes located 3,374 ft AMSL. Because water at the level of the river outlet tubes is generally colder due to its depth, release temperatures could drop to less than 10°C. If the reservoir elevations were to drop farther, closer to the elevation of the river outlet tubes, the releases would again gradually warm (Reclamation 2007a).

Figure 4.2-11 compares the mean temperatures of water released from Glen Canyon Dam for wet, medium, and dry hydrology traces. These figures illustrate how little temperature variation there is among the seven LTEMP alternatives (within any given trace) compared to the much larger variation across the traces. For example, the minimum, maximum, and mean values for modeled temperature at Glen Canyon Dam vary less than 0.3°C, 0.7°C, and 0.2°C,

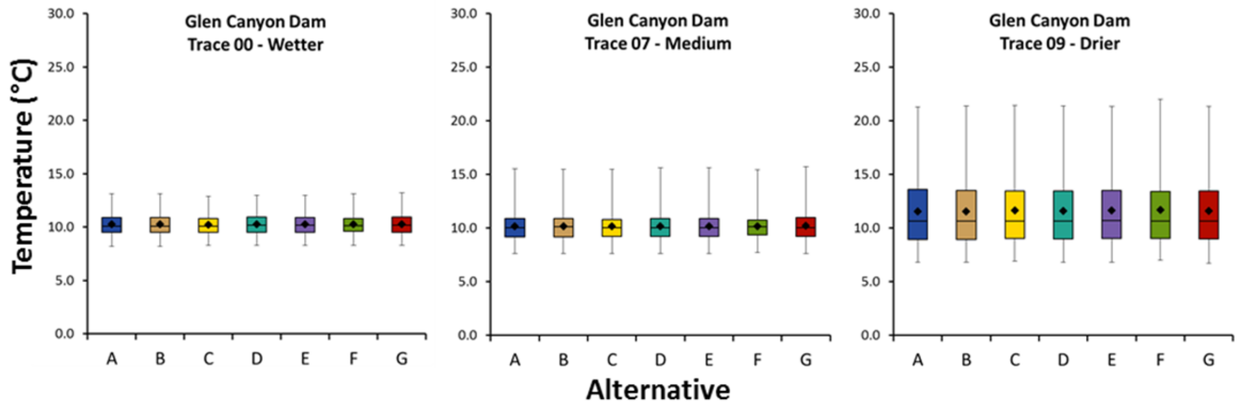

FIGURE 4.2-11 Comparison of Mean Water Temperatures for Representative Wetter, Moderate, and Drier Hydrology Traces for Glen Canyon Dam Releases (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

respectively, among the alternatives for any given trace. However, across hydrology traces the minimum, maximum, and mean values vary over a range of approximately 1.5°C, 8.8°C, and 1.5°C, respectively.

Drier hydrology traces exhibit greater variation in temperature values and more pronounced differences among alternatives, although the actual differences in means are still quite small (i.e., less than 0.2°C). This is because drier traces have lower overall inflow volumes and consequently lower reservoir levels in most years. The released water associated with lower lake elevations is drawn from closer to the surface, where it is more sensitive to atmospheric conditions (e.g., air temperature and solar radiation). However, the release water associated with higher lake elevations (resulting from higher cumulative inflow volumes) tends to be drawn from deeper in the hypolimnion, which exhibits a more stable temperature profile. Therefore, operational differences that have nearly negligible perceived impacts on temperature at larger water volumes (i.e., wetter traces) can become more pronounced during drier traces.

Figure 4.2-12 illustrates mean seasonal[5] release temperatures at Glen Canyon Dam, aggregated across the 21 hydrology traces for the modeled 20-year time period. Overall, the seasonal temperature ranges are similar across alternatives.

The minimum mean release temperatures occur in the spring, with aggregated mean values ranging from 9.0 to 9.3°C, depending on alternative. The lower end of this range is characteristic of Alternatives A and B. The top end of this range is associated with Alternative F, possibly because the reservoir elevation is lower by May after sustained higher releases in March and April. Considering all traces across the entire modeled time period, the full range of mean

[5] For the purposes of this discussion, seasonal temperatures are represented by 3-month periods representing the standard meteorological seasons: December–February for winter; March–May for spring; June–August for summer; and September–November for fall.

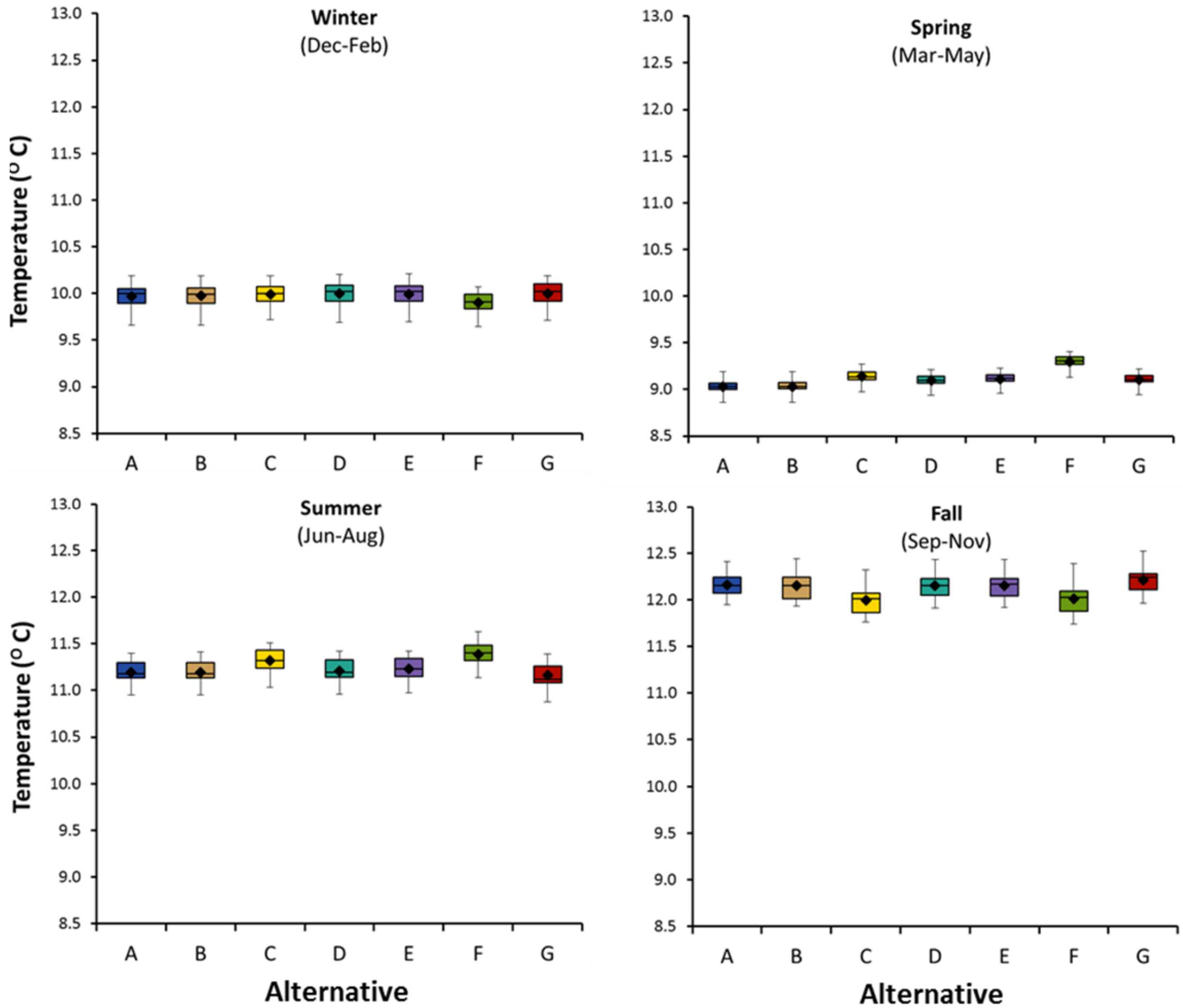

FIGURE 4.2-12 Seasonal Glen Canyon Dam Release Temperatures for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

spring release temperatures varied from around 8.8 to 9.5°C depending on alternative. The bottom of this range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

The peak mean release temperature occurs during the fall, with aggregated means ranging from 12.0 to 12.2°C, depending on alternative; however, there are no significant differences among alternatives in mean release temperature even in the fall. Considering all traces, the full range of mean fall release temperatures varied from around 10.7 to 14.3°C, depending on alternative. As with spring temperatures, the bottom of the fall range is generally representative of wetter traces (i.e., higher reservoir elevations), and the top of this range is generally represented by drier traces (i.e., lower reservoir elevations).

Glen Canyon Dam release temperatures (for all alternatives) are lower in spring than in winter, and lower in summer than in fall. This difference is a result of the lag time associated with warming and cooling of Lake Powell (refer to Section 3.3.3.1 for further information on Lake Powell hydrology).

Colorado River between Glen Canyon Dam and Lake Mead

Once released from the dam, typically warmer air temperatures regulate river temperature. Consequently, the warmer spring and summer months see significant downstream warming while colder winter and fall months have much less downstream warming, and perhaps even downstream cooling (Voichick and Wright 2007). Tributaries, such as the Little Colorado River (river mile [RM] 61), provide warmer inflows in the summer and cooler inflows in the winter (refer to Section 3.3.4.2 for additional details related to Colorado River water temperatures between Glen Canyon Dam and Lake Mead.)

Comparisons of the seasonal trends in river temperatures among the seven LTEMP alternatives are illustrated in Figure 4.2-13 at locations between Glen Canyon Dam (RM 0) and Diamond Creek (RM 225). Temperatures presented in these figures represent modeled values aggregated across the 21 hydrology traces. In general, projected temperatures vary due to three factors: release volume, release temperature, and downstream meteorology and hydrology. The rate at which the water released from a reservoir approaches ambient air temperature as it travels downstream depends on these factors as well (Reclamation 2007a).

Overall, mean seasonal temperatures increase as water moves downstream. Winter river temperatures are the coldest of any season. Mean winter temperatures ranged from 9.7 to 10.2°C at RM 0 (Lees Ferry), 9.9 to 10.4°C at RM 61 (Little Colorado River), 10.2 to 10.6°C at RM 157 (Havasu Creek), and 10.4 to 10.8°C at RM 225 (Diamond Creek). These data also indicate that within any given alternative, there is a very small longitudinal gradient (i.e., at most a 0.5–0.7°C difference for mean; 1.0–1.1°C difference across the full range of values) between the mean temperatures at the Glen Canyon Dam outlet and Diamond Creek during the winter.

For all alternatives, significant downstream warming (i.e., between 6.0 and 7.2°C difference for mean; 6.8–8.1°C difference across full range of values) is expected in the summer. Average summer temperatures are the warmest of any season, ranging from 11.3 to 12.1°C at RM 0, 12.9 to 14.0°C at RM 61, 15.3 to 17.0°C at RM 157, and 16.9 to 19.2°C at RM 225. More details related to temperature values and ranges for each of the seven LTEMP alternatives are presented in Section 4.2.3.

A number of experimental actions (described in detail in Section 2.3) would be incorporated into many of the LTEMP alternatives. Operational actions such as HFEs, TMFs, low summer flows, and sustained low flows for benthic invertebrate production may have noticeable impacts on water temperature at the Glen Canyon Dam outlet and downstream. Past experimental events and water temperature models have provided the following insights into water temperature response to these experimental actions.

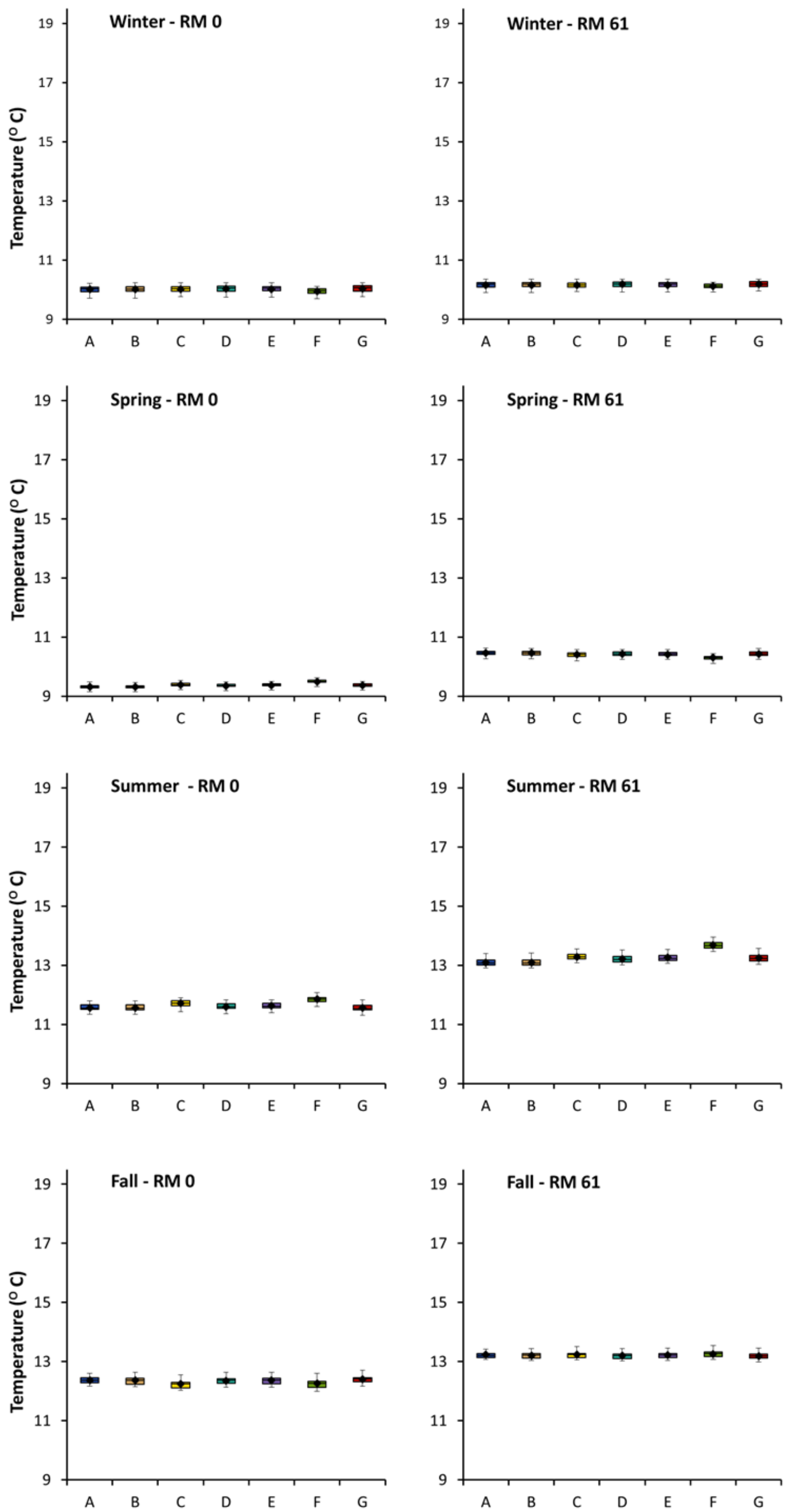

FIGURE 4.2-13 Seasonal Temperature Trends under the Seven LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

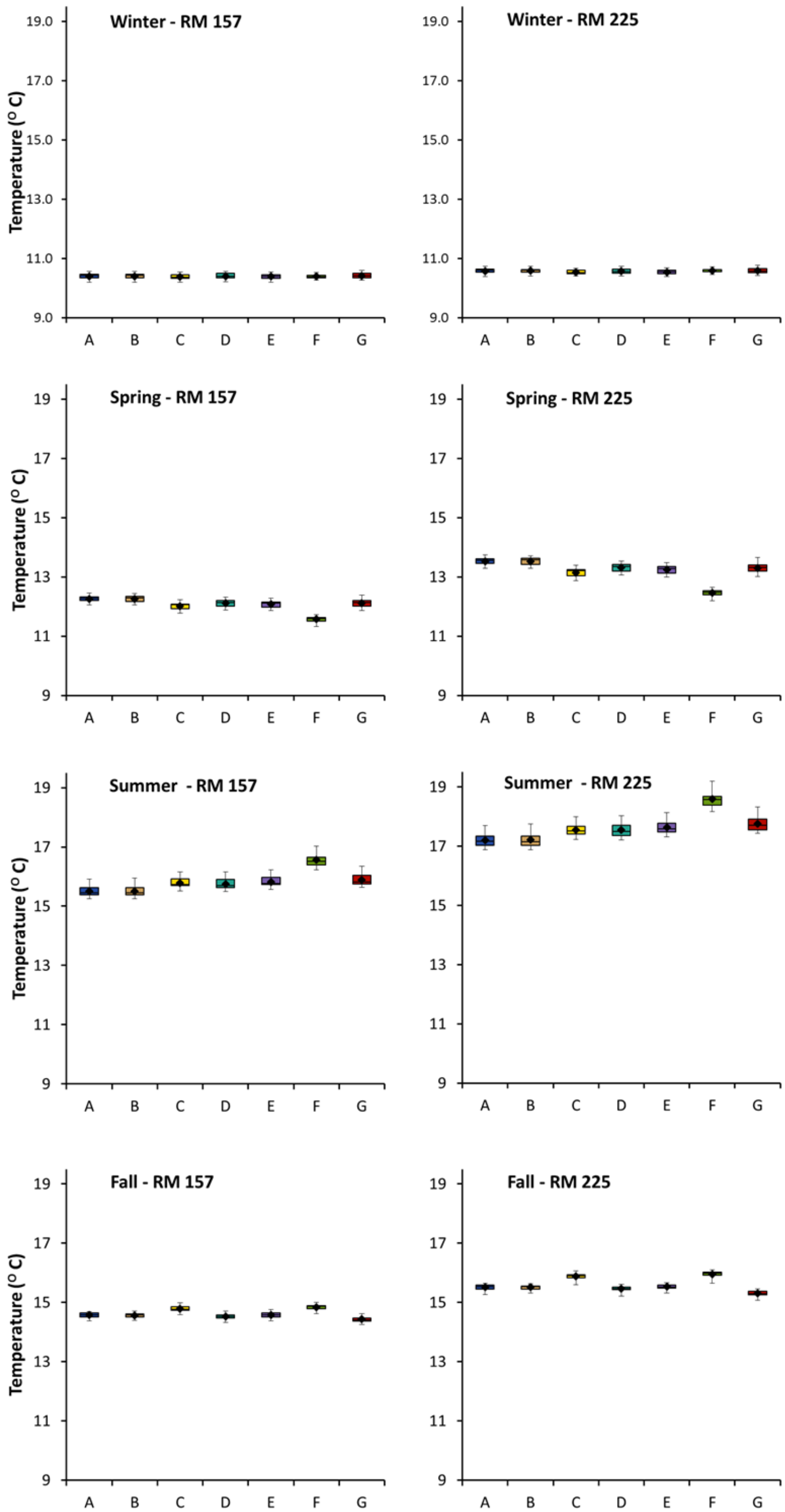

FIGURE 4.2-13 (Cont.)

The magnitude, duration, and seasonal timing of an HFE vary according to sediment input from the Paria River and other resource conditions. In the limited number of HFEs run and analyzed from 1996 to 2011 (i.e., fall of 1996, 2004, and 2008; spring of 2008), effects on water temperature have been observed to be minor and short-term, and to result in slight reductions in downstream water temperature (Vernieu et al. 2005; Reclamation 2011b). Modeling conducted for this DEIS reflects these observations. In general, fall end-of-month temperatures are approximately 1°C higher at Diamond Creek (RM 225) in years without an HFE event than in comparable fall seasons with HFEs. Downstream temperature cooling is similarly expected for spring HFEs, although temperature decreases are expected to be smaller (end-of-month temperatures 0.1–0.5°C cooler). Considering that the November 2012 HFE (releasing approximately 42,000 cfs for 24 hr) and the November 2013 HFE (releasing nearly 35,000 cfs for 96 hr) took only 55 and 54 hr, respectively, to reach Pearce Ferry (i.e., RM 279) (NPS 2012e, 2013j), any warming would be expected to be small and of short duration.

If very large amounts of sediment are input by the Paria River, HFEs may have durations of up to 336 hr under Alternative G and 250 hr under Alternative D. Modeling indicates that, when considering HFEs of similar magnitude (occurring in the fall), downstream warming increases slightly and gradually as the duration of the HFE increases. For example, the difference between the downstream warming of a 48-hr and 336-hr HFE (both at 45,000 cfs) was less than 1°C.

TMFs have not been tested in the Colorado River; therefore, water temperature effects of these flows are uncertain. Overall, the magnitude of flow changes for TMFs are smaller compared to HFEs. As a result, perceptible temperature changes at the dam or downstream are not expected. For example, a TMF modeled to run for 72 hours at a steady flow of 20,000 cfs does not exhibit noticeable effects on modeled water temperatures.

Experimental low summer flows could occur under Alternatives C, D, and E. Low summer flows are run at approximately 8,000 cfs for the months of July, August, and September. Modeled low summer flows show similar water temperatures just downstream of the dam, with slightly higher downstream warming, when compared to similar conditions without low summer flows. This is because lower velocity flows have a higher surface-area-to-volume ratio (compared to high flows) and greater exposure time with the ambient air, which facilitates water warming through solar radiation and atmospheric heat exchange (Vernieu et al. 2005). When considering individual model traces, variations in downstream temperatures were generally greatest in July (nearly 3°C warmer for low summer flows) and least in September (about 1°C warmer for low summer flows), with August falling in the middle (approximately 2°C warmer for low summer flows).

Sustained low flows for benthic invertebrate[6] production are one of the experimental modifications to base operations for Alternative D that could be tested during the LTEMP period. For this experiment, flow on Saturdays and Sundays of May through August would be held steady at the minimum monthly flow. These stable weekend flows would be tested to

[6] Animal without a backbone or spinal column, usually replaced by a hard exoskeleton or shell. Examples include insects, worms, crustaceans, snails, or clams.

determine whether they improved invertebrate production. This operational action increases the mean daily flows during the weekdays. Water temperature modeling indicates that release temperature would change little (e.g., ±0.01°C), and warming at downstream locations during the summer, as indicated by maximum temperature, would be less than 1°C (0.03°C at the confluence with the Little Colorado River [RM 61] and 0.12°C at Diamond Creek [RM 225]).

Lake Mead

Potential water quality issues in Lake Mead were evaluated based on a concern expressed by Southern Nevada Water Authority that water quality could be affected by significant shifts in the temperature of Colorado River water reaching Lake Mead. The temperature of the water determines its density and its position within the water column of Lake Mead. Warmer Colorado River inflows would enter and flow through Lake Mead in the middle of the water column (Tietjen 2014), and this could then have adverse impacts on bottom water oxygen concentrations, effectively trapping below the inflow area low-DO water that does not mix completely and could slowly expand down the lake.

Modeling was conducted by the Southern Nevada Water Authority on a selected set of LTEMP alternatives (Alternatives A, E, and F) and years (2-year runs) that were considered to represent the range of potential outcomes. Because Alternative F would produce the warmest water temperatures of all alternatives in the summer, it was chosen as the potential worst case. Modeling indicated there would be negligible differences in the distribution of areas of low DO among modeled alternatives (Tietjen 2015).

HFEs were not shown to have measurable impacts on Lake Mead water quality. They are expected to mix a portion of the low-DO water near the sediment-water interface up into the water column near the inflow area to Lake Mead, and this should act to reduce (or possibly eliminate) any observed low-oxygen problems (Tietjen 2014).

Salinity

The projected salinity concentrations presented in Figure 4.2-14 are the flow-weighted annual means over the 20-year LTEMP period at Lees Ferry (no criteria established for this location). The results assume continuation of existing and implementation of planned salinity control programs and projects.

Under all alternatives, salinity would increase as water moves downstream. Mean concentrations at Lees Ferry are 490 mg/L, with a full range from 468 to 508 mg/L considering the entire modeled period across all seven LTEMP alternatives (Figure 4.2-14). Considering all years individually, the differences in salinity concentrations among the different alternatives is less than 2.5%.

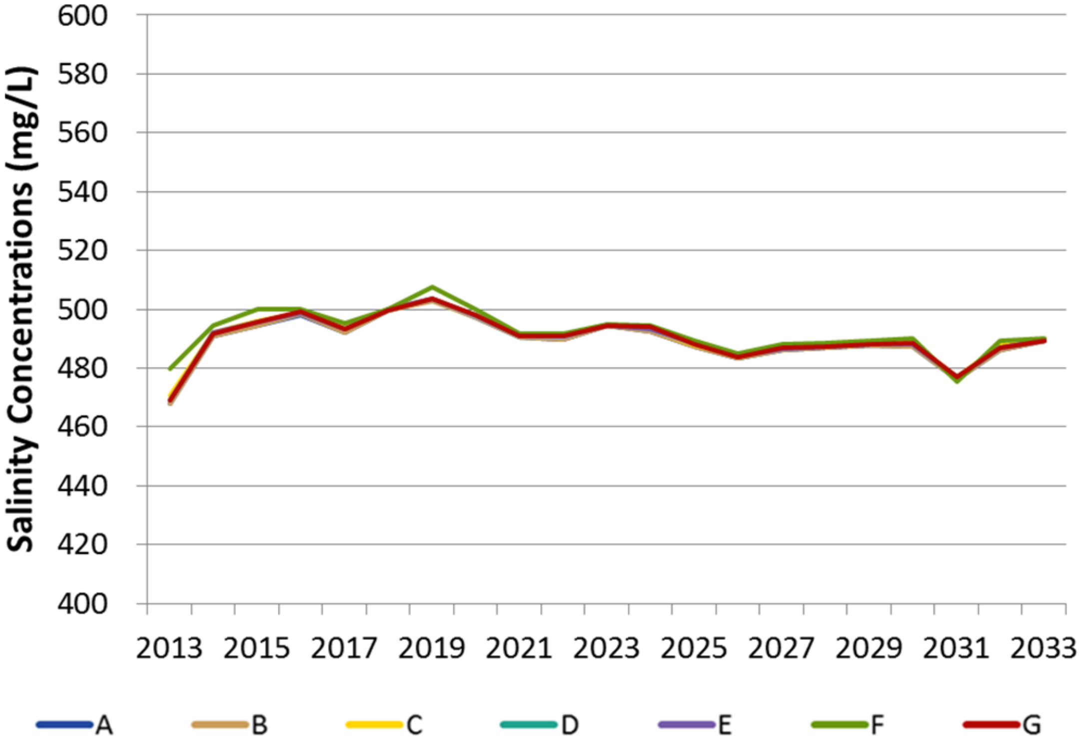

FIGURE 4.2-14 Projected Mean Salinity Concentrations under the LTEMP Alternatives at Lees Ferry

Other Water Quality Parameters

No significant impacts on other water quality parameters (e.g., DO, nutrients, metals, and organics) are expected under any LTEMP alternative. In addition, research (Reclamation 2011b) has indicated that the potential effects of HFEs on other water quality parameters (e.g., turbidity and DO) below the dam would only be temporary, and any observed effects would recover quickly when lower flows returned (refer to Section 3.3.4.2 for more details on the effects of HFEs on water quality of the Colorado River below the Glen Canyon Dam).

With respect to turbidity, a positive correlation with tributary sediment input is also expected (refer to Section 3.3.4.2 for more information on the relationship between turbidity and suspended sediment). However, no impacts are expected because operations will not affect tributary sediment input, and, therefore, will not result in differences among the alternatives.

Although an increase in visitor use could result in an increase in the occurrence of pathogens, current National Park Service (NPS) regulations restrict the number of river boating trips that can be taken; a long waiting list exists for private boating permits and a large number of commercial passengers cannot be accommodated due to these restrictions. As a consequence, the numbers of angling and boating trips are not expected to change as a result of any of the alternatives, and no difference in pathogenic or disease-causing organisms is expected as a result of variation in the number of visitors. However, certain types of flow have been associated with local occurrences of high pathogenic bacterial counts. For example, low steady flows, particularly during periods of high recreational use, can result in local areas of exceedances due to the buildup of bacteria along the shoreline. Higher velocity or flood flows can act to mobilize these bacteria harbored in streamside sediments from past recreational use, in effect, flushing out areas of concern, but also temporarily increasing downstream bacteria counts. As a result, alternatives with either low flows and/or high flows may lead to a higher potential for contamination from bacteria and other pathogens and, thus, could increase the possibility of health hazards associated with contaminated water. Years with low release volumes (<8.23 maf) would have a higher probability of occurrence. The probability of this contamination occurring is expected to be very low, and the effects would be localized for all alternatives. However, there are potential differences among alternatives related to the occurrence of low flows and HFEs. Alternatives C, D, E, and F all have low flows and frequent HFEs and could have a higher potential for bacteria and pathogen contamination than Alternatives A and B. Alternatives F and G have the highest potential (though still low), given the annual occurrence of steady flows and frequent HFEs.

4.2.3 Alternative-Specific Impacts

The following sections describe the range of alternative-specific impacts on hydrology, (i.e., reservoir releases and elevations, river flows) and water quality. Both water delivery metrics and other system relevant conditions (e.g., reservoir elevations) are discussed for each alternative. Each alternative was modeled using 21 different potential scenarios that accounted for uncertainty in future hydrologic conditions. Figures 4.2-1 through 4.2-14 show the results for all alternatives; plots comparing each action alternative to Alternative A can be found in Appendix D.

The modeling predicted that inflow hydrology has the most effect on operating tier, release volume, and resulting reservoir elevations, whereas the alternatives show smaller effects. Differences among the LTEMP alternatives are expected to be negligible with regard to salinity, turbidity, nutrients, DO, metals/radionuclides, or organic/other contaminants. As a result, temperature and bacteria and pathogens are the only water quality parameters discussed in this section. When analyzing the temperature differences between the LTEMP alternatives, differences of less than 0.5°C are not regarded as significant because of the inherent temperature variability observed in the natural environment, combined with the reported standard error (i.e., less than 0.5°C) for the temperature model applied (Wright, Anderson et al. 2008). Thus, only temperature differences greater than 0.5°C are explained in further detail.

4.2.3.1 Alternative A (No Action Alternative)

During the interim period (through 2026), Alternative A would operate at times within each of the four operating tiers, at the following mean annual frequencies: Upper Elevation Balancing Tier—46.2%; Equalization Tier—37.4%; Mid-Elevation Release Tier—15.4%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative A has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. For Alterative A, the mean number of occurrences of annual release extending beyond the water year per 20-year trace is 0.7, with a range of 0 to 2 occurrences per 20-year period. The mean volume of annual release extending beyond the water year is 248 kaf with a range from 0 to 2,021 kaf.

Under Alternative A, monthly reservoir releases are generally higher in December, January, July, and August and lower in the other months. In the years 2014–2020, when HFEs would be implemented under Alternative A, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell elevations would vary significantly with hydrology but would vary little by alternative. Depending on hydrology, Lake Powell elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Powell at the end of December was about 3,630 ft throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative A, this modeling showed two instances out of 420 (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool.

Lake Mead elevations would also vary significantly with basin hydrology and the resulting Lake Powell release, but would vary little by alternative. Depending on hydrology, Lake Mead elevations can be anywhere in the full range of operating elevations. Under Alternative A, the median elevation for Lake Mead at the end of December ranged from about 1,100 ft near the beginning of the period to about 1,080 ft near the end of the 20-year LTEMP period. End-of-December elevations at the beginning of the period ranged from about 1,080 ft to about 1,160 ft at the 10th and 90th percentiles, respectively, and from about 1,020 ft to about 1,210 ft near the end of 20-year LTEMP period. Under Alternative A, the percentage of traces with Lower Basin Shortages is 0 for the first 2 years of the period, and then increases to 62% of traces near the end of the 20-year period.

Mean monthly volume under Alternative A would be similar to current conditions and would be highest during months with relatively high hydropower demand (December, January, June, July, and August) when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

Mean daily flows under Alternative A also would represent no change from current conditions, and would be highest in the higher volume months of December, January, June, July, August, as well as September, when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative A, the allowable daily range is dependent on monthly volume and ranges from 5,000 to 8,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,000 to 7,800 cfs (Figure 4.2-4). In other months, mean daily change would range from 2,600 to 6,400 cfs.

Seasonal temperature data and trends are provided in Table 4.2-2 for the seven LTEMP alternatives as a function of distance downstream from RM 0 (i.e., Lees Ferry) through RM 225 (i.e., Diamond Creek). The minimum, maximum, and mean temperature data presented in these figures represent values aggregated across the 21 hydrology traces over the 20-year LTEMP period.

For Alternative A, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.6°C (11.6–17.2°F) difference. Spring temperatures warm around 4.2°C (9.3–13.5°C); fall temperatures warm about 3.1°C (12.4–15.5°C).

Under Alternative A, there would be no change from current conditions in the occurrence of bacteria or pathogen contamination along shorelines. The expected probability of this contamination occurring is very low, and would be localized and temporary.

In summary, Alternative A would result in no changes in current conditions related to hydrology or water quality.

4.2.3.2 Alternative B

Alternative B would show little or no difference from Alternative A with regard to operating tier, in almost every one of the 21 hydrology traces modeled. This is the smallest difference among all of the action alternatives. Compared to Alternative A, Alternative B would result in the same frequency of operating tiers, the same average number of occurrences of annual releases extending beyond the water year, and the same volume of annual release extending beyond the water year. In addition, the end-of-December elevations under Alternative B for Lake Powell and Lake Mead would be identical to those under Alternative A.

Under Alternative B, monthly reservoir releases would be identical to those of Alternative A. Releases from Lake Powell can vary from Alternative A by up to 4 kaf in 3% of months due to different ramp-down constraints. In years when HFEs would be implemented under Alternative B, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Mean monthly volumes under Alternative B would be identical to those under Alternative A and similar to current conditions. Volume would be highest during months with relatively high hydropower demand (December, January, June, July, and August) when volume would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would be approximately 570,000 to 1,200,000 ac-ft in other months.

TABLE 4.2-2 Summary of Seasonal Temperature Data for LTEMP Alternatives from Lees Ferry to Diamond Creek

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Winter (December–February)												
Alternative A	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative B	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative C	9.8	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.5	10.4	10.5	10.7
Alternative D	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.6	10.7
Alternative E	9.7	10.0	10.2	9.9	10.2	10.4	10.2	10.4	10.6	10.4	10.5	10.7
Alternative F	9.7	9.9	10.1	9.9	10.1	10.3	10.3	10.4	10.5	10.5	10.6	10.7
Alternative G	9.8	10.0	10.2	10.0	10.2	10.4	10.3	10.4	10.6	10.4	10.6	10.8
Spring (March–May)												
Alternative A	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.5	13.3	13.5	13.7
Alternative B	9.1	9.3	9.5	10.3	10.5	10.6	12.1	12.3	12.4	13.3	13.5	13.7
Alternative C	9.2	9.4	9.5	10.2	10.4	10.6	11.8	12.0	12.2	12.9	13.2	13.4
Alternative D	9.2	9.4	9.5	10.3	10.4	10.6	11.9	12.1	12.3	13.1	13.3	13.5
Alternative E	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.3	13.0	13.3	13.5
Alternative F	9.3	9.5	9.6	10.1	10.3	10.4	11.3	11.6	11.7	12.2	12.5	12.6
Alternative G	9.2	9.4	9.5	10.2	10.4	10.6	11.9	12.1	12.4	13.0	13.3	13.7
Summer (June–August)												
Alternative A	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	15.9	16.9	17.2	17.7
Alternative B	11.3	11.6	11.8	12.9	13.1	13.4	15.3	15.5	16.0	16.9	17.2	17.8
Alternative C	11.4	11.7	11.9	13.1	13.3	13.6	15.5	15.8	16.2	17.2	17.6	18.0
Alternative D	11.4	11.6	11.8	13.0	13.2	13.5	15.5	15.8	16.2	17.2	17.5	18.0
Alternative E	11.4	11.6	11.8	13.1	13.3	13.5	15.6	15.8	16.2	17.3	17.6	18.1

TABLE 4.2-2 (Cont.)

	Temperature (°C)											
	Lees Ferry (RM 00)			Little Colorado River (RM 61)			Havasu Creek (RM 157)			Diamond Creek (RM 225)		
Season	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean	Max
Summer (June–August) (Cont.)												
Alternative F	11.6	11.9	12.1	13.5	13.7	14.0	16.2	16.6	17.0	18.2	18.6	19.2
Alternative G	11.3	11.6	11.8	13.0	13.3	13.6	15.6	15.9	16.4	17.4	17.8	18.3
Fall (September–November)												
Alternative A	12.2	12.4	12.6	13.1	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative B	12.2	12.4	12.6	13.0	13.2	13.4	14.4	14.6	14.7	15.3	15.5	15.6
Alternative C	12.0	12.3	12.6	13.1	13.2	13.5	14.6	14.8	15.0	15.6	15.9	16.1
Alternative D	12.1	12.4	12.6	13.0	13.2	13.4	14.3	14.5	14.7	15.2	15.5	15.6
Alternative E	12.1	12.4	12.6	13.0	13.2	13.5	14.4	14.6	14.8	15.3	15.5	15.7
Alternative F	12.0	12.3	12.6	13.1	13.3	13.5	14.6	14.8	15.0	15.7	16.0	16.1
Alternative G	12.2	12.4	12.7	13.0	13.2	13.5	14.3	14.4	14.6	15.1	15.3	15.5

Mean daily flows under Alternative B also would be similar to current conditions, and highest in the higher volume months of December, January, June, July, and August, as well as September when flows would range from approximately 11,200 to 24,600 cfs under the scenarios evaluated (Figure 4.2-3). Mean daily flows would be approximately 9,400 to 14,400 cfs in other months.

Under Alternative B, the allowable daily change is higher than under Alternative A and ranges from 6,000 to 12,000 cfs (Chapter 2). Among the scenarios evaluated, the highest daily change would occur in December, January, July, and August, when mean daily change would vary from about 2,500 to 12,000 cfs (Figure 4.2-4). In other months, mean daily change would range from 3,000 to 10,000 cfs.

Modeled water temperature ranges and means under Alternative B are nearly identical to those under Alternative A (Table 4.2-2) because the two alternatives have the same monthly release volumes. Daily fluctuation differences, which are greater for Alternative B relative to Alternative A, are thought to have a negligible impact on water temperature (Anderson and Wright 2007). Other operational differences between the two alternatives related to ramp rates and test flows (e.g., HFEs, hydropower improvement flows, and TMFs) would not affect seasonal temperature trends.

Under Alternative B, there is a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines. This lower probability would result from the slightly higher daily fluctuations under this alternative relative to Alternative A. Experimental hydropower improvement flows would have the lowest probability of occurrence. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative B would result in no change from current condition related to lake elevations, annual operating tiers, monthly release volumes, or mean daily flows, but would produce higher mean daily changes in flow. Hydropower improvement flows would cause even greater mean daily flow changes. Compared to Alternative A, there would be negligible differences in temperature or other water quality indicators, but Alternative B has a slightly lower probability of the occurrence of bacteria or pathogen contamination along shorelines.

4.2.3.3 Alternative C

Alternative C would show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative C is 210 kaf less than Alternative A in an 8.23-maf release year; this difference could result in a slightly higher end-of-December elevation and sometimes a different operating tier. Alternative C would result in a different operating tier from that under Alternative A in 2.1% of years.

The frequency of operating tiers under Alternative C would be very similar to that under Alternative A. During the interim period (through 2026), Alternative C would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation

Balancing Tier—46.2%; Equalization Tier—38.1%; Mid-Elevation Release Tier—14.7%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative C has 1 year less than Alternative A, with annual releases of 8.23 maf (average of 71.4% of years), and 1 year more than Alternative A, with annual releases greater than 8.23 maf in an average of 28.6% of years. Because of the lower October through December release volume, it is possible that the higher elevation would result in Lake Powell operating in a higher operating tier. This is depicted in Figure 4.2-8, which shows at least one trace that operates in the Upper Elevation Balancing Tier instead of the Mid-Elevation Release Tier as compared to Alternative A (shown as a decrease in the Mid-Elevation Release 75th percentile and a corresponding increase in the Upper Elevation Balancing median relative to Alternative A).

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. Under Alternative C, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor volumes that are as high. Under Alternative C, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual releases extending beyond the water year also would be less than under Alternative A, with an average volume of 107 kaf and a range from 0 to 1,210 kaf.

Under Alternative C, monthly release volumes in July through November would be lower than under Alternative A. Release volumes from December through August are higher than those under Alternative A. In years when HFEs would be implemented under Alternative C, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative C, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.8 times per 20-year trace, with a range from zero to four per trace.

The inclusion of low summer flows under Alternative C would not affect operating tiers; however, the volumes of annual releases extending beyond the water year would show some slight differences, as do the end-of-year elevations at Lakes Powell and Mead. The median difference in elevation when low summer flows would be implemented is 0.08 and 0.13 ft at Lake Powell and Lake Mead, respectively.

Lake Powell end-of-December elevations under Alternative C would tend to be slightly higher than those under Alternative A. Under Alternative C, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 1.5 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 3,560 ft to about 3,680 ft at the 10th and 90th percentiles, respectively. Under Alternative C, end-of-December elevations at the 10th percentile were on average 0.7 ft higher than those under Alternative A, and on average 1.0 ft higher than those at the 90th percentile under Alternative A. Under Alternative C, the percentage of traces below minimum power pool would be identical to those under Alternative A.

Lake Mead end-of-December elevations under Alternative C would tend to be slightly lower than those under Alternative A. Under Alternative C, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.6 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C, elevations at the 10th percentile were on average 2.9 ft lower than Alternative A, with a maximum difference of 10 ft. Elevations at the 90th percentile were on average 3.2 ft lower than those under Alternative A. Under Alternative C, the percentage of traces with Lower Basin Shortages are sometimes 5% higher and sometimes 5% lower than under Alternative A; however, the general trend and range of traces with shortages are similar to Alternative A, ranging from 0 for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year simulation.

Compared to Alternative A, mean monthly volume under Alternative C would be higher (by 82,000 to157,000 ac-ft) from February through May, and lower (by 111,000 to 200,000 ac-ft) in August through October; volume would be comparable to that under Alternative A in other months (Figure 4.2-2). The pattern of monthly volumes results from targeted lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 670,000 to 1,500,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 490,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative C would follow the same pattern as monthly volume and be higher (by 1,300 to 2,500 cfs) than Alternative A from February through May, and lower (by 1,800 to 3,300 cfs) in August through October; mean daily flow would be comparable to that under Alternative A in other months (Figure 4.2-3).

Under Alternative C, the allowable daily change is lower than under Alternative A, but is proportional to monthly volume (Chapter 2). Mean daily change would be lower than under Alternative A in all months and would range from 1,300 to 6,200 cfs (Figure 4.2-4).

Under Alternative C, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 5.8°C (11.7–17.6°C) difference. Spring temperatures would warm around 3.8°C (9.4–13.2°C), and fall temperatures would warm about 3.6°C (12.3–15.9°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative C vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative C, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low and would be localized and temporary.

In summary, compared to Alternative A, Alternative C would result in some change from current condition related to lake elevations, annual operating tiers, monthly release volumes, and mean daily flows, but would result in lower mean daily changes in flow throughout the year. Compared to Alternative A, there would greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.4 Alternative D (Preferred Alternative)

Alternative D would show little or no difference from Alternative A with regard to operating tier. Alternative D does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. Under Alterative D, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor volumes that are as high. Under Alternative D, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, with an average of 0.4 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 146 kaf and a range from 0 to 1,495 kaf.

In years without experimental low summer flows, the monthly release volumes under Alternative D would be fairly constant throughout the year, the most constant of all alternatives except Alternative G. In the years when HFEs would be implemented under Alternative D, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative D, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. Under Alternative D, experimental low summer flows would be implemented only during the second 10 years of the LTEMP period; on the basis of release temperatures and the ability to achieve target downstream temperatures, these would take place on average 0.7 times per 20-year trace, with a range of zero to three per trace.

Lake Powell end-of-December elevations under Alternative D would be nearly indistinguishable from those under Alternative A. Under Alternative D, the median elevation for Lake Powell at the end of December would be about 3,630 ft, on average 0.2 ft higher than under

Alternative A throughout the 20-year LTEMP period. Near the beginning of the period, end-of-December elevations ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative D, end-of-December elevations were on average 0.2 ft and 0.1 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative D, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490-ft minimum power pool. This is one more year than under Alternative A and is a result of Alternative D releasing 151 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative D would be very similar to those under Alternative A. Under Alternative D, the median elevation for Lake Mead at the end of December was on average the same as Alternative A: about 1,100 ft near the beginning of the period and about 1,080 ft near the end of the period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative C, elevations were on average 0.7 ft and 0.4 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative D, implementation of low summer flows would result in one additional trace in shortage in 2025 compared with Alternative A (1 year out of 420 years total). Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Implementation of experimental low summer flows and sustained low flows for benthic invertebrate production under Alternative D would not affect the operating tier, but slight differences could result in annual releases extending beyond the water year and end-of-year elevations at Lake Powell and Lake Mead.

Compared to Alternative A, mean monthly volume under Alternative D would be higher (by 43,000 to 98,000 ac-ft) in October, November, February, March, and April, and lower (by 60,000 to 127,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes approximates that of Western Area Power Administration's (Western's) contract rate of delivery. Volume in high-demand months would range from approximately 640,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 620,000 to 1,200,000 ac-ft in other months. Note that adjustments to Alternative D made after modeling was completed resulted in a 50-kaf increase in August (changed from 750 to 800 kaf) and a corresponding 25-kaf decrease in May and June (changed from 657 to 632 kaf and 688 to 663 kaf, respectively) in an 8.23-maf year.

Mean daily flows under Alternative D would follow the same pattern as monthly volume and be higher (by 700 to 3,000 cfs) than Alternative A in October, November, February, March, and April, and lower (by 1,000 to 2,100 cfs) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-3).

Under Alternative D, the allowable daily change would be proportional to monthly volume (Section 2.2.4). Mean daily change would be slightly higher than that under Alternative A in October through June, but the same or less in July through August. Mean daily change would range from about 2,700 to 7,600 cfs (Figure 4.2-4).

Under Alternative D, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.5°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative D vary less than ±0.3°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative D, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative D would result in negligible changes from current conditions related to lake elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and lower mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.5 Alternative E

Alternative E would show little or no difference from Alternative A with regard to operating tier. Alternative E does not result in different operating tiers than Alternative A in any year, in any trace, because the October through December release volumes would be identical to those under Alternative A.

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. Under Alterative E, more water would be released in the earlier months of water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor volumes that are as high. Under Alternative E, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than Alternative A with an average of 0.2 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 109 kaf and a range from 0 to 1,022 kaf.

In years without experimental low summer flows, the monthly releases volumes under Alternative E would be fairly constant throughout the year and comparable to Alternative D. In years when HFEs would be implemented under Alternative E, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements. In years when experimental low summer flows would be implemented under Alternative E, the monthly volumes in May and June would be increased to accommodate lower July through September volumes. On the basis of release temperatures and the ability to achieve target downstream temperatures, experimental low summer flows would be implemented on average 1.5 times per 20-year trace, with a range from zero to four per trace.

Lake Powell end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Powell at the end of December was about 3,630 ft, and on average 0.3 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative E, end-of-December elevations were on average 0.2 ft and 0.3 ft higher than those at the 10th and 90th, respectively, under Alternative A. For Alternative E, this modeling showed 3 years out of 420 years (20 years and 21 traces) when Lake Powell would drop temporarily below the 3,490 ft minimum power pool. This is one more year than under Alternative A. This is a result of Alternative E releasing 203 kaf more than Alternative A in the October through March (the typical low elevation month) period in an 8.23-maf release year.

Lake Mead end-of-December elevations under Alternative E would be very similar to those under Alternative A. Under Alternative E, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 0.1 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative E, throughout the period elevations averaged 0.9 ft and 0.7 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Under Alternative E, implementation of low summer flows would result in one additional trace in shortage in 2020 compared with Alternative A (1 year out of 420 years total) and one fewer trace in 2022. Otherwise, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the model period, then increasing to 62% of traces near the end of the 20-year period.

Implementation of experimental low summer flows and sustained low flows for benthic invertebrate production under Alternative E would not affect the operating tier, but slight differences could result for volumes of annual release extending beyond the water year and end-of-year elevations at Lake Powell and Lake Mead.

Compared to Alternative A, mean monthly volume under Alternative E would be higher (by 45,000 to 128,000) in October, November, February, March, and April, and lower (by 30,000 to 242,000 ac-ft) in December, January, July, August, and September; volume would be comparable to that under Alternative A in May and June (Figure 4.2-2). The pattern of monthly volumes follows that of Western's contract rate of delivery, but it is lower in August and September to target lower volumes in August through October to conserve sand input from the Paria River during the monsoon period. Volume in high-demand months would range from approximately 660,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 580,000 to 1,100,000 ac-ft in other months.

Mean daily flows under Alternative E would follow the same pattern as monthly volume and would be higher (by 700 to 2,100 cfs) than Alternative A in October, November, February, March, and April, and lower in (by 500 to 4,000 cfs) December, January, July, August, and September; volumes would be comparable to those under Alternative A in May and June (Figure 4.2-3).

Under Alternative E, the allowable daily change would be proportional to monthly volume (Chapter 2), and higher than under Alternative A, in all months but September and October (lower in these two months). Mean daily change would range from 1,100 to 9,600 cfs (Figure 4.2-4).

Under Alternative E, mean winter temperatures are expected to warm the least, with a difference of about 0.5°C (10.0–10.5°C) between the Lees Ferry and Diamond Creek locations. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.0°C (11.6–17.6°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 3.1°C (12.4–15.5°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative E vary less than ±0.4°C from Alternative A depending on season. Thus, they are not considered to be significantly different.

Under Alternative E, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from occasional low summer flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternative A. The expected probability of this contamination occurring is very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative E would result in negligible change from current condition related to lake elevations, no change in annual operating tiers, more even monthly release volumes and mean daily flows, and higher mean daily changes in flow. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.6 Alternative F

Alternative F would show the greatest differences from Alternative A of all the alternatives with regard to operating tier. The October-through-December release volume for

Alternative F is 534 kaf less than Alternative A in an 8.23-maf year; this difference could result in a slightly higher end-of-December Lake Powell elevation, and sometimes a different operating tier. Alternative F would result in a different operating tier from that under Alternative A in 2.1% of years.

Alternative F would result in fewer instances of the Mid-Elevation Release Tier (decrease of 2.2% of years on average) and more instances of the Upper Elevation Balancing and Equalization Tiers (increase of 1.1% of years on average for both tiers). During the interim period (through 2026), Alternative F would operate at times within each of the four operating tiers at the following mean annual frequencies: Upper Elevation Balancing Tier—47.3%; Equalization Tier—38.5%; Mid-Elevation Release Tier—13.2%; and Lower Elevation Balancing Tier—1.1%. After the interim period, Alternative F has annual releases of 8.23 maf in an average of 72.1% of years and annual releases greater than 8.23 maf in an average of 27.9% of years.

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. Under Alterative F, more water would be released in the earlier months of the water year than under Alternative A; therefore, it would not result in as many instances of annual releases extending beyond the water year, nor volumes that are as high. Under Alternative F, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A, and the lowest of all the alternatives with an average of 0.1 years per trace, and a range from zero to one occurrence per 20-year period. The volume of annual release extending beyond the water year is also less than under Alternative A, and the lowest of all alternatives with an average volume of 69 kaf and a range of 0 to 1,135 kaf.

Under Alternative F, monthly release volumes follow a more natural hydrograph pattern than other alternatives, with the highest flows in the spring months April through June and lower flows in the remaining months. Release volumes in December through August are significantly lower than those under Alternative A. When HFEs would be implemented under Alternative F, water would be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative F would be higher than those under Alternative A; this would be the largest difference of all the alternatives. Under Alternative F, the median elevation for Lake Powell at the end of December was about 3,630 ft, on average 3.2 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,565 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,565 ft to about 3,680 ft near the end of the period. Under Alternative E, end-of-December elevations were on average 5.1 ft and 1.8 ft higher than those at the 10th and 90th percentiles, respectively, under Alternative A. For Alternative F, this modeling showed there would be no occurrences of Lake Powell elevations dropping below the minimum power pool.

Lake Mead end-of-December elevations under Alternative F would be lower than those under Alternative A. Under Alternative F, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 2.9 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative F, elevations throughout the period were on average 4.0 ft and 2.3 ft lower than those under Alternative A at the 10th and 90th percentiles, respectively. Near the end of the period, however, elevations under Alternative F were up to 12.5 ft lower than those under Alternative A at the 10th percentile. Under Alternative F, the percentage of traces with Lower Basin Shortages would be higher than that under Alternative A in nearly all years, with differences ranging from 0 to 10% higher than under Alternative A. However, the general trend and range of traces with shortages are the same as under Alternative A, ranging from zero for the first 2 years of the period, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative F would be much higher (by 439,000 to 651,000 ac-ft) in April, May, and June, but much lower (by 214,000 to 433,00 ac-ft) in December, January, July, August, and September (Figure 4.2-2). This monthly pattern is intended to more closely match a natural hydrograph with high spring flows and low summer through winter flows. Volume in high-demand months would range from approximately 430,000 to 1,700,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 440,000 to 1,500,000 ac-ft in other months.

Mean daily flows under Alternative F would follow the same pattern as monthly volume and would be much higher (by 7,400 to 10,600 cfs) in April, May, and June, but much lower (by 3,600 to 7,000 cfs) in December, January, July, August, and September (Figure 4.2-3).

Under Alternative F, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative F, mean winter temperatures (Table 4.2-2) are expected to warm the least, with a difference of about 0.6°C (9.9–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.8°C (11.9–18.6°C) difference. Spring temperatures would warm around 3.0°C (9.5–12.5°C), and fall temperatures would warm about 3.7°C (12.3–16.0°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative F are different than those under Alternative A in the spring and summer seasons. In the spring, the downstream temperature difference at Diamond Creek would be approximately 1.1°C cooler than that for Alternative A. This is likely due to the fact that this alternative has much higher average spring releases, so larger volumes of seasonally cooler Lake Powell water are released downstream (Vernieu et al. 2005; Reclamation 2011b) than in any of the other LTEMP alternatives. In addition, Alternative F features a total of 22 high flows (both sediment-triggered HFEs and other high flow events) in the spring, which may add to the overall downstream cooling effect.

For the summer period, the downstream mean temperature at Diamond Creek would be approximately 1.4°C warmer than that under Alternative A. This warming is a result of much lower summer flows associated with Alternative F compared to all of the other LTEMP alternatives. These lower flows allow for a larger surface-area-to-volume ratio and greater exposure time with the warmer summer ambient air, which facilitates downstream warming (Vernieu et al. 2005).

Under Alternative F, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from annual low steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E but is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative F would result in some change from current conditions related to lake elevations and annual operating tiers, large changes in monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A and the other alternatives, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.2.3.7 Alternative G

Alternative G is expected to show little or no difference from Alternative A with regard to operating tier. The October through December release volume for Alternative G is 75 kaf more than Alternative A in an 8.23-maf year; this difference could result in a slightly lower end-of-December Lake Powell elevation and sometimes a different operating tier. Alternative G would result in a different operating tier from that under Alternative A in 0.7% of years.

The frequency of operating tiers under Alternative G would be identical to that under Alternative A during the interim period (through 2026) and nearly the same as Alternative A after the interim period. After the interim period, Alternative G would have at least one trace with fewer annual releases of 8.23 maf (average of 71.4% of years) than Alternative A and at least one trace with more annual releases greater than 8.23 maf (average of 28.6% of years) than Alternative A.

During wet years, Lake Powell may not always be able to fully equalize within the water year, resulting in annual releases extending beyond the water year. Under Alterative G, more water would be released than under Alternative A in the earlier months of the water year; therefore, Alternative G would not result in as many instances of annual releases extending beyond the water year, nor volumes that are as high. Under Alternative G, the average number of occurrences of annual releases extending beyond the water year per 20-year trace is less than under Alternative A with an average of 0.5 years per trace, and a range from zero to two occurrences per 20-year period. The volume of annual release extending beyond the water year also would be less than under Alternative A, with an average volume of 151 kaf and a range from 0 to 1,440 kaf.

Under Alternative G, monthly release volumes are as constant as possible, given hydrologic uncertainty throughout the water year. Release volumes during December through August are slightly higher than those under Alternative A. In years when HFEs would be implemented under Alternative G, water may need to be reallocated from later months in the water year if the targeted monthly volume was insufficient to allow for an HFE and meet minimum release requirements.

Lake Powell end-of-December elevations under Alternative G would tend to be slightly lower than those under Alternative A. Under Alternative G, the median elevation for Lake Powell at the end of December would be nearly the same as under Alternative A (about 3,630 ft), and on average 0.4 ft lower than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations near the beginning of the period ranged from about 3,560 ft to about 3,660 ft at the 10th and 90th percentiles, respectively, and from about 3,560 ft to about 3,680 ft near the end of the period. Under Alternative G, end-of-December elevations were on average 1.2 ft and 0.3 ft lower than those at the 10th and 90th percentiles, respectively, under Alternative A. Under Alternative G, there are two occurrences of Lake Powell below the minimum power pool, the same as under Alternative A.

Lake Mead end-of-December elevations for Alternative G would tend to be slightly higher than those under Alternative A. Under Alternative G, the median elevation for Lake Mead at the end of December was about 1,100 ft near the beginning of the period, about 1,080 ft near the end of the period, and on average 1.4 ft higher than under Alternative A throughout the 20-year LTEMP period. End-of-December elevations ranged from about 1,080 ft to about 1,160 ft near the beginning of the period at the 10th and 90th percentiles, respectively, and about 1,010 ft to about 1,210 ft near the end of the period. Under Alternative G, elevations at the 10th percentile were sometimes higher and sometimes lower compared to Alternative A, with differences ranging from 6.8 ft lower to 4.0 ft higher throughout the 20-year period. Elevations at the 90th percentile were nearly identical to those under Alternative A (the maximum difference in any year was 1.0 ft). Under Alternative G, there was one fewer trace in shortage in 2020 compared to Alternative A (1 year out of 420 years total) and one more trace in 2020. Otherwise, the general trend and range of traces with shortage are the same as under Alternative A, ranging from zero for the first 2 years of the model run, then increasing to 62% of traces near the end of the 20-year period.

Compared to Alternative A, mean monthly volume under Alternative G would be higher (by 71,000 to 286,000 ac-ft) in October, November, March, and April, but lower (by 139,000 to 196,000 ac-ft) in December, January, July, and August (Figure 4.2-2). The monthly pattern for Alternative G is approximately equal to monthly volumes throughout the year, except for adjustments due to changes in forecast. Volume in high-demand months would range from approximately 60,000 to 1,400,000 ac-ft (Figure 4.2-2). Mean monthly volume would range from approximately 600,000 to 1,300,000 ac-ft in other months.

Mean daily flows under Alternative G would follow the same pattern as monthly volume and would be higher (by 1,200 cfs to 4,800 cfs) in October, November, March, and April, but lower (by 2,300 to 3,200 cfs) in December, January, July, and August (Figure 4.2-3).

Under Alternative G, flow typically would not change within days except to ramp up and down from HFEs or other high-flow releases (Chapter 2) (Figure 4.2-4).

Under Alternative G, mean winter temperatures are expected to warm the least, with a difference of about 0.6°C (10.0–10.6°C) between Lees Ferry and Diamond Creek. Summer temperatures are expected to warm the most as they move downstream, with an approximately 6.2°C (11.6–17.8°C) difference. Spring temperatures would warm around 3.9°C (9.4–13.3°C), and fall temperatures would warm about 2.9°C (12.4–15.3°C). The full range of minimum and maximum values is presented in Table 4.2-2.

Modeled seasonal water temperatures between Lees Ferry and Diamond Creek associated with Alternative G are slightly warmer than those under Alternative A in the summer season (temperature difference at Diamond Creek is approximately 0.6°C warmer than that under Alternative A). As under Alternative F, this summer warming is likely a result of the lower summer flows compared to those of Alternative A, which would facilitate downstream warming (Vernieu et al. 2005). The degree of warming is less than that observed under Alternative F, because summer flows associated with Alternative G are somewhat higher in comparison.

Under Alternative G, there is a slightly higher probability of the occurrence of bacteria or pathogen contamination along shorelines. This higher probability would result from year-round steady flows and relatively frequent HFEs, which could increase the occurrence of bacteria and pathogens compared to Alternatives A, B, C, D, and E, but is still considered very low, and it would be localized and temporary.

In summary, compared to Alternative A, Alternative G would result in negligible change from current conditions related to lake elevations and annual operating tiers, even monthly release volumes and mean daily flows, and steady flows throughout the year. Compared to Alternative A, there would be greater summer warming and slightly increased potential for bacteria and pathogens.

4.3 SEDIMENT RESOURCES

This section presents an analysis of impacts on sediment resources of the Colorado River corridor between Glen Canyon Dam and Lake Mead, and inflow deltas in Lake Mead. Sediment resources include sandbars, beaches, and lake deltas. Sediment is one of the fundamental components of the ecosystem along the river corridor in Glen and Grand Canyons. The dynamics considered are the building and erosion of sandbars and beaches as well as the sediment remaining in the river channel, in the river corridor below the dam. The sediment

Issue: How do alternatives affect sediment resources in the project area?

Impact Indicators:

- The amount of sand transported during high flows relative to total sand transport
- Sand mass balance in Marble Canyon
- The size and position of the Colorado River delta in Lake Mead

objective, as stated in Section 1.4, is to "increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes." This section evaluates alternatives against this objective.

Quantitative analysis using a set of numerical models was conducted for the Colorado River from Lees Ferry (RM 0) to Phantom Ranch (RM 87). Because a quantitative model is only available from Lees Ferry to RM 87, impact assessments for the Colorado River corridor upstream of Lees Ferry, downstream of RM 87, and for lake deltas are more qualitative in nature but were considered sufficient to assess these impacts.

There are two generally opposing processes related to sediment resources downstream of Glen Canyon Dam: (1) sediment deposition in sandbars at elevations above the range of normal flows and (2) retention of sediment within a reach of the river. Because of the limited sand supply, the flows needed to achieve the first objective (e.g., building high-elevation sandbars) reduce the amount of sand retained on the riverbed within a reach. Using dam operations, it is not possible to build high-elevation sandbars without transporting sand out of the reach.

Operations at Glen Canyon Dam directly affect sediment resources via changes in releases and corresponding downstream flows and changes in reservoir elevation in Lakes Powell and Mead. These changes can occur on hourly, daily, monthly, and annual timescales. Changes in river flow result in changes in sandbar sediment storage and riverbed sand storage. Aspects of operations and river flow that affect sediment resources are related to the monthly distribution of annual release volumes, daily fluctuations, and the frequency, magnitude, and duration of HFEs, TMFs, and proactive spring HFEs. This section analyzes the impacts of LTEMP alternatives on these resources for the 20-year LTEMP period.

4.3.1 Analysis Methods

Sediment resources, such as sandbars and riverbed sand, are linked to flow and to each other, just as most other resources discussed in this DEIS are linked to sediment.

Impacts were analyzed on the basis of the following categories of information, which are further explained below:

- Records of river stage, streamflow, and sediment discharge at USGS gaging stations along the river and on principal sediment-producing tributaries;

- Sandbar measurements made by Northern Arizona University;

- Published journal articles; and

- Results from the modified Sand Budget Model.

Sandbar deposits (and sandbar-dependent resources such as camping beaches and some archaeological sites) are affected by the amount of riverbed sand transported under a given alternative. A long-term net loss of riverbed sand would result in long-term loss in the number and size of sandbars, with corresponding changes in aquatic and riparian habitat (Reclamation 1995). Changes in sandbar and riverbed sand depend primarily on tributary sand supply; the magnitude, frequency, and duration of HFEs; and the magnitude of daily powerplant fluctuations.

Currently, there is no available model that can predict sandbar response to differing flow release volumes and patterns. It has been established, however, that “large eddy sandbars form when suspended-sediment loads are transported in high concentrations by the main flow. High sandbars are constructed by large magnitude floods that rise to relatively high elevations” (Schmidt and Grams 2011a). Thus, having high flows that are rich in suspended sediment provide the means for potential sandbar growth.

Because a model is not available to simulate reach-wide sandbar response to dam operations, an indicator of sandbar building was developed that represents the conditions necessary for sandbar deposition (high flows rich in suspended sediment). The potential for building sandbars was estimated using the Sand Load Index, which is a comparison of the mass of sand transported at river flows ≥31,500 cfs relative to the total mass of sand transported at all flows (Figure 4.3-1). The index varies from 0 (no sand transported at flows ≥31,500 cfs) to 1 (all sand transported at flows ≥31,500 cfs); the larger the Sand Load Index for an alternative, the more potential there is for bar growth (Appendix E). The Sand Load Index only estimates the potential for (and not actual) bar growth, because all sandbars have a maximum potential deposition volume; the closer any given bar is to full, the less deposition will occur (Wiele and Torizzo 2005). The Sand Load Index does not address fully the erosion of sandbars from intervening flows between HFEs.

The increase in potential sandbar growth necessarily increases the mass of sand that moves downstream, decreasing the sand budget. That is, having a high potential for bar growth (resulting from a high Sand Load Index) causes a decrease in the amount of sand on the riverbed, and having a low potential for bar growth (resulting from a low Sand Load Index) allows for more sand to be retained on the riverbed. The measure of sand budget used in this analysis is the Sand Mass Balance Index (Figure 4.3-2) calculated for Marble Canyon (RM 0 to RM 61); it is the estimated mass of sand remaining at the end of the 20-year LTEMP period relative to the sand mass at the start of the period. Data used to calculate the Sand Mass Balance Index and the Sand Load Index come from Sand Budget Model outputs.

The Sand Budget Model (Wright et al. 2010; Russell and Huang 2010) is a numerical model that tracks sand storage and transport from Lees Ferry (RM 0) to Phantom Ranch (RM 87). The Sand Budget Model was modified for the purpose of analyzing the impacts of LTEMP alternatives on the sand budget in Marble Canyon (Appendix E). The Sand Budget Model uses empirically based rating curves to compute the sand budget in three reaches; RM 0 to RM 30, RM 30 to RM 61, and RM 61 to RM 87. Modifications to the Sand Budget Model that were implemented for the purposes of the analysis in this DEIS include (1) determining when HFEs would be triggered, (2) reallocation of monthly water volumes (less water released in

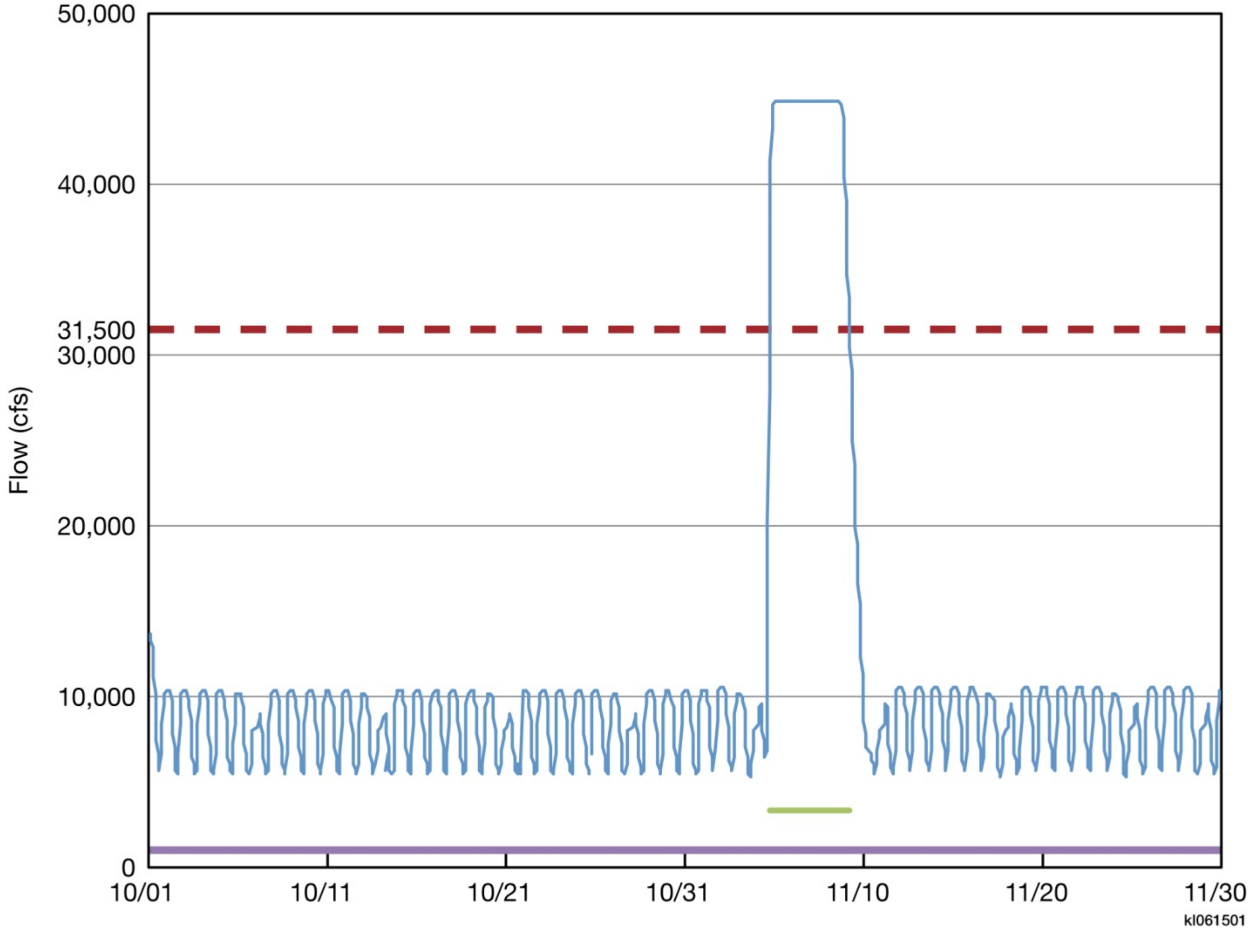

FIGURE 4.3-1 Conceptual Depiction of the Sand Load Index (The blue line is the time series of river flow, and the dashed red line is the threshold condition of 31,500 cfs. The green lines represent the amount of time during which river flow is ≥31,500 cfs. The purple line represents the entire time period of interest. The Sand Load Index is the amount of sand that is transported during the time represented by the green line, relative to the amount of sand transported during the time represented by the purple line.)

months without HFEs to accommodate HFE water release volume in months with HFEs), and (3) implementation of a trout recruitment model provided by fish subject matter experts to identify years when TMFs would be triggered (Section 4.5).

Potential future sediment delivery from the Paria River can affect results from the modified Sand Budget Model. The mean and median annual sand load from the Paria River for the approximately 50-year time period from October 1, 1963, to January 1, 2014, is approximately 761,000 metric tons and 756,000 metric tons, respectively (Topping 2014; GCMRC 2015b). Three different time series of sediment load for the Paria River were considered to account for uncertainty (Appendix E), with the mean annual input ranging from 648,000 metric tons to 918,000 metric tons. The three 20-year time series selected approximate the 10, 50, and 90% exceedance probabilities, as well as represent the entire historical sediment record explicitly.

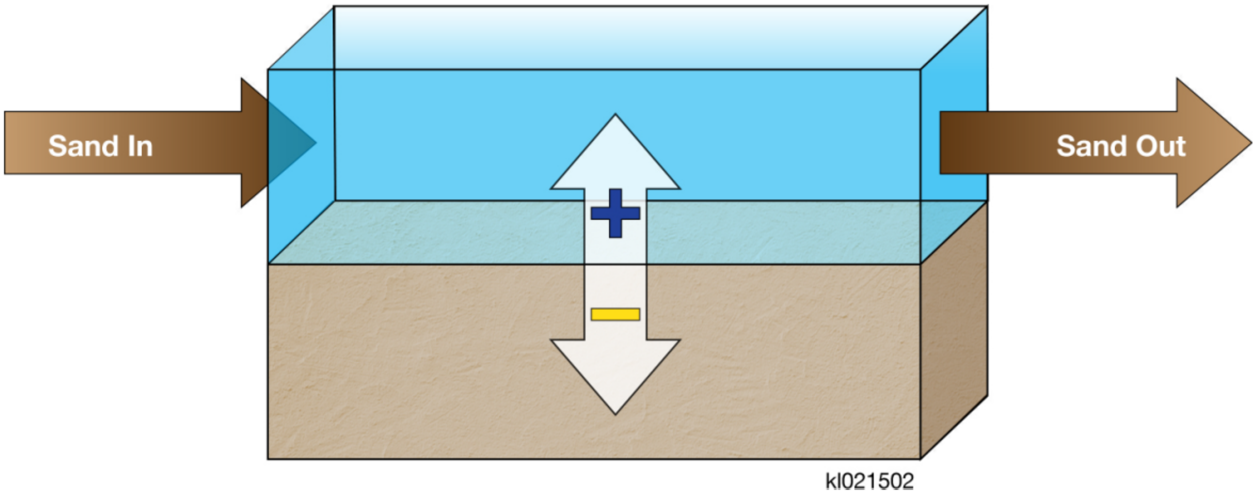

FIGURE 4.3-2 Conceptual Depiction of the Sand Mass Balance Model (The large rectangular solid is a control volume [lower half sand bed and upper half water]. Water and sand are flowing in from the left and out to the right. Purple plus symbol represents the case of a positive Sand Mass Balance where there is an increase in sand thickness due to the Sand In value being greater than the Sand Out value for a given time period. The yellow minus sign represents the case of a negative Sand Mass Balance, where there is a decrease in sand thickness due to the Sand Out value being greater than the Sand In value for a given time period.)

Each alternative was modeled in the modified Sand Budget Model with 21 different potential hydrology scenarios (Section 4.1) and three different potential Paria River sediment loads (Section 4.3.1, Appendix E) to account for uncertainty in future conditions. Comparisons between alternatives are made using the average of these 63 combinations of simulations per alternative, and confidence in the comparisons can be made by considering the inter-quartile range of the 63 simulations. The inter-quartile range indicates that 50% of the estimated values fall within this range, 25% of the values are below this range, and 25% are above this range.

The output of the Sand Budget Model includes the hourly time series of both the mass of sand transported at the downstream boundary of each reach and the sand budget (Sand In minus Sand Out) for each of the three reaches (Figure 4.3-2). Both of these time series are used in the assessment of impacts on sediment resources.

Impacts on sediment resources in the Grand Canyon upstream of RM 87, as analyzed here, are considered in general to be indicative of impacts further downstream, although the timing and magnitude of effects may be different. A quantitative assessment of the alternatives on the sediment resource downstream of RM 87 has not been made, but the literature suggests that the relative rankings of the alternatives would be maintained for downstream reaches (Hazel et al. 2010; Grams et al. 2015).

Lake deltas can be described by their size, which is directly affected by the amount of sand delivered to the delta, and by longitudinal position in a canyon, which is directly affected by lake elevation.

The position of the Lake Powell deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, is dictated by the water surface elevation of Lake Powell.

The size of any given delta on Lake Powell, whether it is the mainstem Colorado River or the tributaries, will not be affected by Glen Canyon Dam operations because operations cannot affect the amount of sediment being delivered to the upstream deltas.

The positions of the Lake Mead deltas, which occur at the inflows of both the mainstem Colorado River and its tributaries, are dictated by the elevation of Lake Mead. Lake Mead elevations are analyzed on a monthly timescale, and the change in elevation from one month to the next depends primarily on the amount of water released from Glen Canyon Dam during that month and the release schedule from Hoover Dam. A lower release volume from Hoover Dam and a higher release volume from Glen Canyon Dam would result in a higher water surface elevation in Lake Mead, causing deltas to form farther up the canyon. The size of Lake Mead's tributary deltas would not be affected by Glen Canyon Dam operations because these operations cannot affect the amount of sediment being delivered to the lake's tributary deltas. Glen Canyon dam operations can only affect the amount of sediment being delivered to the Colorado River delta in Lake Mead. The sand mass balance results from the modified Sand Budget Model are used to estimate the relative effects of the alternatives on the amounts of sediment that eventually would reach the Colorado River delta in Lake Mead under the alternatives.

4.3.2 Summary of Impacts

General impacts on sandbars, riverbed sand, and lake deltas are discussed below. Specific impacts on these resources are discussed under each alternative in Section 4.3.3. These impacts vary among the alternatives as a result of differences in dam operations, including monthly distribution of annual release volume, within-day fluctuations in releases, and the frequency, magnitude, and duration of high flows, such as sediment-triggered HFEs, TMFs, and proactive spring HFEs. Of these three types of high flows, sediment-triggered HFEs result in the largest impact on sediment resources.

Sandbars are built by high flows. According to Schmidt and Grams (2011a), "the HFE research program demonstrated that eddy sandbars are quickly constructed by high flows if those flows have high suspended-sand concentrations." They also state that "high flows similar in magnitude to those that occurred during the HFEs of 1996, 2004, and 2008 effectively mobilize accumulated fine sand delivered by tributaries downstream from Glen Canyon Dam and rebuild eddy sandbars in Marble and Grand Canyons" (Schmidt and Grams 2011a). This physical understanding of the process was verified in subsequent high flows experiments. In discussing the three high flows since the new HFE protocol (2012, 2013, and 2014), Grams et al. (2015) note that "time-lapse images showed that at least half the monitored sandbars increased in size following each controlled flood," and that resource managers "consider the 2012–2014 results encouraging." Sandbars cannot get bigger without high flows.

Sandbars erode between large flow events. Erosion rates tend to be highest immediately after a flood (when bars have the most sediment available for erosion), then decrease with time

(Grams et al. 2010). Furthermore, "monitoring data show that sandbars erode more quickly as release volumes and daily fluctuations increase, whereas the rate of erosion is reduced when tributary sand inputs continue to occur following sandbar building" (Melis et al. 2011). Steadier flows erode bars at a lower rate than fluctuating flows (Wright, Schmidt et al. 2008).

High flows necessarily export relatively large volumes of sand in order to transfer sand from the riverbed to high-elevation portions of sandbars (Wright, Schmidt et al. 2008). Within-day fluctuations resulting from powerplant operations also increase the amount of sediment that is transported downstream. As noted by Wright and Grams (2010), a steady flow will transport less sand than an equivalent-volume fluctuating flow and retain more sandbars and beaches. These dynamics are well understood, but the Sand Load Index does not fully address the potential erosion of sandbars from intervening flows.

In order to understand effects on sediment resources, it is necessary to evaluate both the indicators for sandbar growth potential (Sand Load Index) and the indicator for sand budget (Sand Mass Balance Index). Both are affected by the number of HFEs. During a 20-year period, there are a maximum of 40 possible HFEs (one in the fall, one in the spring each year) if there were sufficient water and sediment volume (see Figure 4.3-5 in Section 4.3.3). Some alternatives limit the maximum number of HFEs that can occur during the 20-year LTEMP period. Alternatives A and B would have the fewest HFEs, because HFEs would not be conducted after 2020 under Alternative A, and HFEs are limited to one every other year under Alternative B; consequently, these alternatives would have the lowest potential for building sandbars as indicated by their relatively low Sand Load Index values. Alternatives F and G would have the most HFEs, highest Sand Load Index values, and greatest potential to build bars. Alternatives C and D would have slightly fewer HFEs than Alternatives F and G, while Alternative E would be a bit lower because spring HFEs would not be implemented in the first 10 years of the LTEMP period. These four alternatives show relatively large improvements in the potential to build sandbars over Alternatives A and B. These differences among alternatives are discussed in greater detail for each alternative in Section 4.3.3.

Alternatives C, D, and E include steady flows associated with HFEs (these steady flows are also referred to as load-following curtailment). Alternative C would implement steady flows before and after a spring HFE and fall HFE. Alternative D would only implement steady flows after a fall HFE. Alternative E would only implement steady flows prior to a fall HFE. Although load-following curtailment does help conserve sediment prior to and after an HFE, the effect is relatively small because of the short duration of the curtailment, and the fact that two other factors reduce sand transport during this time period regardless of curtailment—HFEs reduce the average flow for the remainder of the month, and HFEs are applied in the lowest volume months out of the year.

In contrast to the 277 mi of Marble Canyon and Grand Canyon, the 15-mi Glen Canyon reach of the Colorado River receives very little sediment input. The Glen Canyon reach will continue to be affected by the river during equalization flows, HFEs, or other high flow events that continue to remove sediment within the reach. Sediment in the Glen Canyon reach is largely a non-renewable resource because the first major sediment-bearing tributary is the Paria River, 16 mi below the dam. As a result of this, HFEs and other high flows do not generally contribute to the replenishment or retention of beaches within the Glen Canyon reach, and pre-dam beach sediments may continue to be lost.

Annual releases from Glen Canyon Dam affect the transport of sand on the bed of the river as much as, if not more than, alternative-specific dam operations. For all alternatives, years or periods of years that have a relatively low average annual release volume tend to transport less sand, whereas those with higher average annual release volumes tend to transport more sand downstream.

The only delta in Lake Mead that can be affected by LTEMP alternatives in terms of both location and size is the Colorado River delta in Lake Mead; the tributary deltas in Lake Mead will be affected in terms of position by dam operations but not in terms of size. Using historical data on the GCMRC data portal (GCMRC 2015b), nearly half (approximately 46%) of the suspended sand load reaching the gage at Diamond Creek (RM 225) since October 2002 can be accounted for by suspended sand leaving Marble Canyon (RM 0 to 60). The other half of the suspended sand reaching Diamond Creek comes from tributaries downstream of Marble Canyon, most notably the Little Colorado River. The mass balance across alternatives varies by almost a factor of 3 (Table 4.3-1), but this magnitude of variability is insignificant when compared to both the average amount of sediment leaving Marble Canyon (10,000 kilotons per year) and the average amount of sediment reaching Diamond Creek (22,000 kilotons per year). Therefore the alternatives considered will have minimal impact on the size of the Colorado River delta in Lake Mead.

The position of deltas in Lake Mead is directly affected by reservoir elevation. The elevations of Lake Powell and Lake Mead are more sensitive to future hydrology and corresponding annual releases from Glen Canyon Dam (Section 4.1) than to any alternative. Figures 4.3-3 and 4.3-4 present the minimum, mean, and maximum monthly elevations relative to full pool for 21 different hydrology traces across the seven alternatives. Pool elevations and the effects on deltas are ultimately controlled by regional hydrologic conditions and will be minimally affected by the alternatives. Alternative-specific impacts on reservoir deltas were not further analyzed and are not discussed in Section 4.3.3.

4.3.3 Alternative-Specific Impacts

The impacts of LTEMP alternatives on sediment resources are summarized in Table 4.3-1. Indicators of riverbed sand are mainly derived from modeling, and sandbar indicators are the result of field surveys, modeling, and empirical data. Numerical values, based on sources of information listed in Section 4.3.1, were used as indicators of impacts for all sediment resources. Alternative-specific results for the number of HFEs, Sand Load Index values, and Sand Mass Balance Index values are presented in Figures 4.3-5, 4.3-6, and 4.3-7, respectively. Some uncertainty exists in the numerical values shown in these figures, in Table 4.3-1, and in the subsequent discussion of alternatives. In general, however, uncertainty would not affect relative differences among alternatives and would allow a comparison among the alternatives because the uncertainties apply across all alternatives. This uncertainty does mean that very small differences between alternatives may not be meaningful.

1 **TABLE 4.3-1 Summary of Impacts of LTEMP Alternatives on Sediment Resources**

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Least HFEs of any alternative would result in highest and mass balance, lowest potential for building sandbars.	The number of HFEs and bar building potential would be similar to those under Alternative A, but higher fluctuations would result in lower sand mass balance.	High number of HFEs would result in high bar-building potential, but lower sand mass balance than Alternative A.	High number of HFEs would result in high bar-building potential; sand mass balance comparable to Alternative A.	Number of HFEs would result in higher bar-building potential than Alternatives A but not other alternatives; lower sand mass balance than Alternative A.	Highest number of HFEs would result in highest bar-building potential, and lowest sand mass balance of all alternatives.	Second highest number of HFEs would result in second highest bar-building potential, and second lowest sand mass balance of all alternatives.
High Flow Events							
Average number of HFEs triggered in 20 years	5.5	7.2	21.3	19.3	17.1	19.3 (38.1)[a]	24.5
Maximum number of HFEs that could be implemented	14	10	40	38	30	40	40
Sandbars							
Sand Load Index value (20-year value)	0.21	0.23	0.54	0.53	0.46	0.56	0.58
Sand Load Index, relative to Alternative A (% change)	0%	10% increase	157% increase	152% increase	119% increase	167% increase	176% increase

TABLE 4.3-1 (Cont.)

Sediment Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Sediment Balance							
Sand Mass Balance Index (kilotons)[b]	-1,010	-1,810	-2,140	-1,480	-1,980	-3,320	-2,840
Sand Mass Balance Index, relative to No Action (% change)	0%	80% decrease	112% decrease	47% decrease	96% decrease	230% decrease	182% decrease
Mean relative to average annual Paria sand load	-1.3	-2.4	-2.8	-2.0	-2.6	-4.4	-3.7
Interquartile range relative to annual Paria sand load	-4.9 to 1.5	-5.2 to 0	-5.3 to -0.6	-3.9 to 0	-5.3 to -0.2	-5.5 to -3.4	-5.9 to -1.8
Lake Mead Delta	The size and the position of the Colorado River Delta in Lake Mead is influenced more by regional hydrology and less by the dam operation alternatives considered in this analysis						

[a] If alternative-defined annual spring flood (24 hr, 45,000 cfs flow if no sediment-triggered HFE) is counted, there would be a total of 38.1 HFEs.

[b] Sand mass at end of 20-year LTEMP period from RM 0 to 61 relative to start of LTEMP period; negative indicates net loss of sediment.

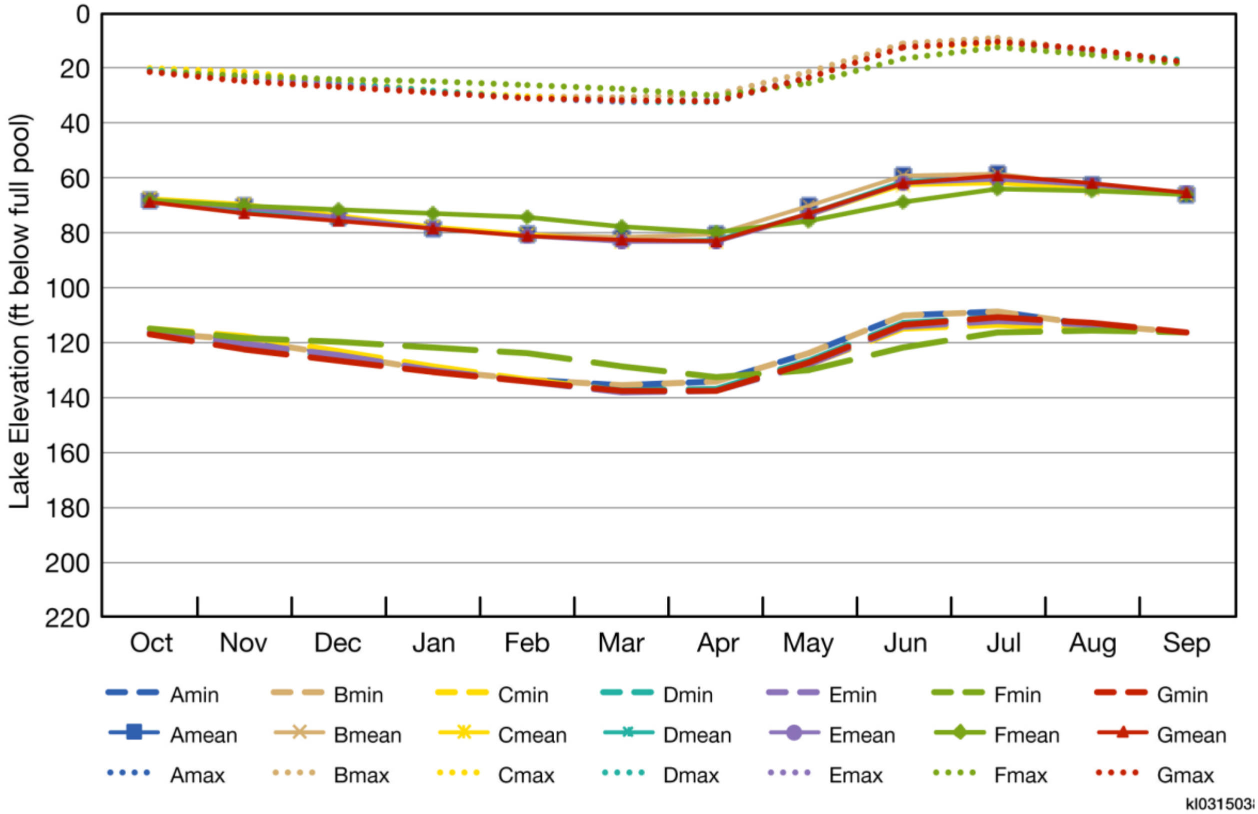

FIGURE 4.3-3 Variation in Lake Powell Pool Elevation Relative to Full (3,700 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

4.3.3.1 Alternative A (No Action Alternative)

Under Alternative A, HFEs would continue only for the period of the current HFE protocol, which will expire in 2020. In addition, spring HFEs would not occur until 2016 at the earliest. Therefore, Alternative A provides for a maximum of 14 HFEs during the 20-year period. On average, across 21 hydrology and 3 sediment time series (63 simulations total), there would be 5.5 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 39% of the maximum possible under Alternative A, and 14% of the overall maximum of 40 (one spring and one fall HFE every year).

The estimated 20-year average Sand Load Index for Alternative A is 0.21, with an inter-quartile range of 0.17–0.24 (Figure 4.3-6). This indicates that about 20% of the sediment transported over the 20-year LTEMP period is transported when discharge is >31,500 cfs, resulting in potential sandbar building. The Sand Load Index cannot currently be directly compared to sandbar response or size, but this value provides a baseline to which the other alternatives can be compared, and this alternative can be compared to dam operations that have been in place since 2012.

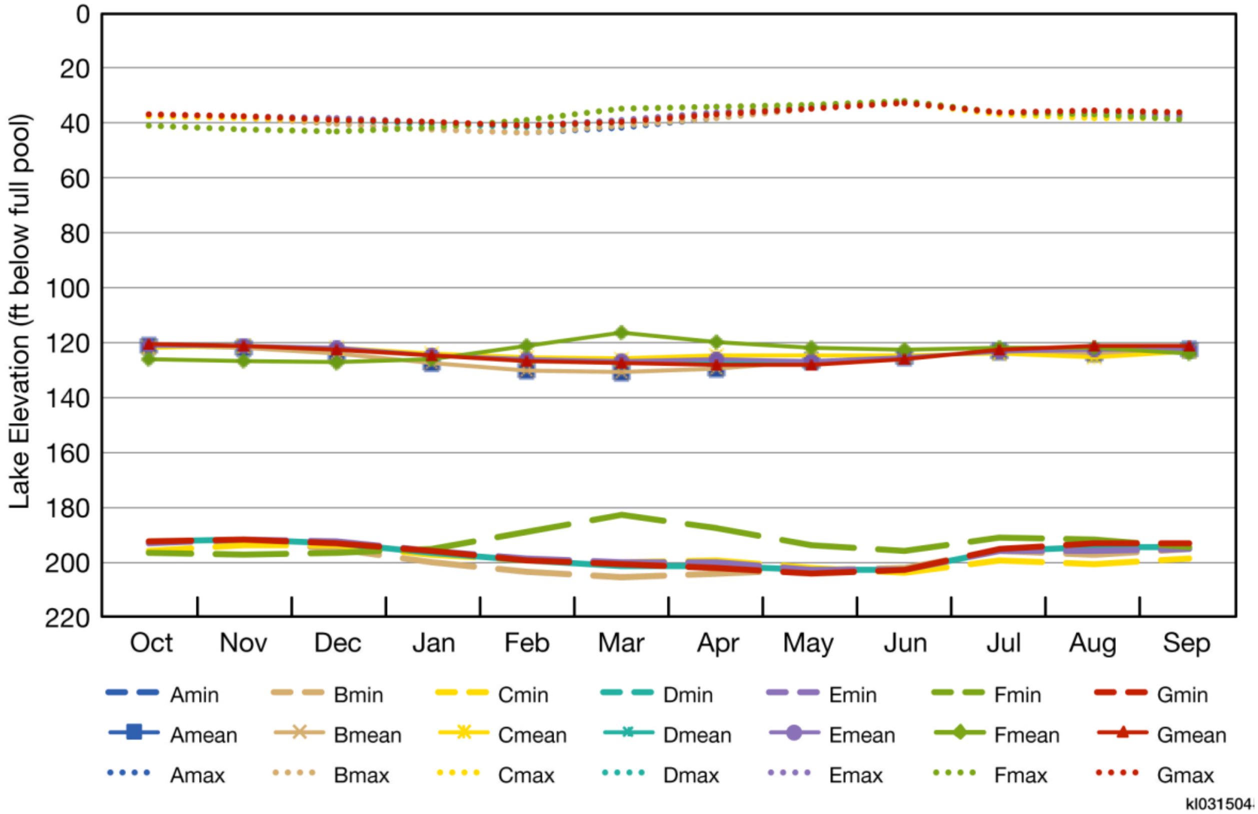

FIGURE 4.3-4 Variation in Lake Mead Pool Elevation Relative to Full (1,229 ft) for 21 Hydrology Traces and Seven Alternatives (The minimum, mean, and maximum values for each alternative are shown as dashed, solid, and dotted lines, respectively.)

Alternative A is a continuation of the current HFE protocol as defined in the 2011 EA (Reclamation 2011b). Three HFEs have been conducted under the HFE protocol; for these, sandbars increased in both volume and area as they did in response to the three preceding HFEs of 1996, 2004, and 2008 (Grams 2014). The Sand Load Index for Alternative A of 0.21 is the lowest of all alternatives (Table 4.3-1), indicating the lowest potential for building sandbars. This is due to the expiration of the HFE protocol in 2020, which in turn leads to the lowest number of HFEs for the simulation period of all alternatives. It is expected that bar building would continue through the HFE protocol window, and then bars would erode and decrease in size after 2020.

Under Alternative A, there would be an estimated average net loss of 1,010 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 1.3 times the annual average sand input from the Paria River. About 46% of the 63 conditions modeled resulted in a positive sand mass balance. This alternative retains, on average, the most sand in Marble Canyon of any alternative, but, as discussed above, the lowest potential for sandbar building after 2020.

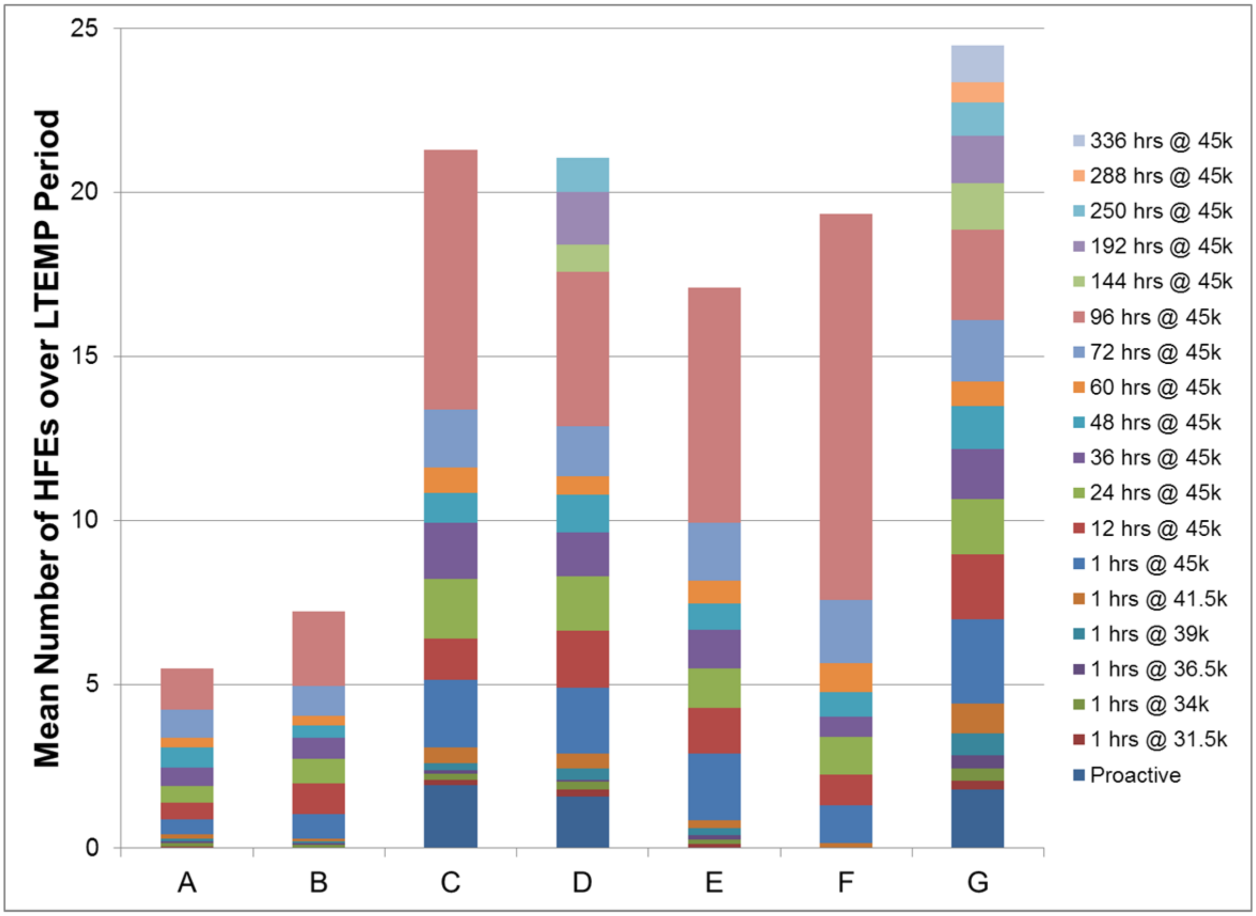

FIGURE 4.3-5 Number and Type of HFEs Expected to Occur during the 20-Year LTEMP Period under the Seven Alternatives

In summary, Alternative A has the least HFEs of any alternative and would result in the highest sand mass balance, but the lowest potential for building sandbars.

4.3.3.2 Alternative B

Under Alternative B, spring and fall HFEs could be implemented during the 20-year LTEMP period, but HFEs would not be implemented more often than once every 2 years. Therefore, Alternative B would allow a maximum of 10 sediment-triggered HFEs during the 20-year LTEMP period. On average, there would be 7.2 HFEs triggered and implemented in the 20-year period (Figure 4.3-5), which is 72% of the maximum possible under the alternative, and 18% of the maximum of 40 possible under other alternatives.

The estimated 20-year average Sand Load Index for Alternative B is 0.23, with an inter-quartile range of 0.20–0.27 (Figure 4.3-6). The estimated average Sand Load Index for Alternative B is 10% greater than the Sand Load Index for Alternative A, suggesting slightly higher bar-building potential under Alternative B. The number of HFEs and the Sand Load Index

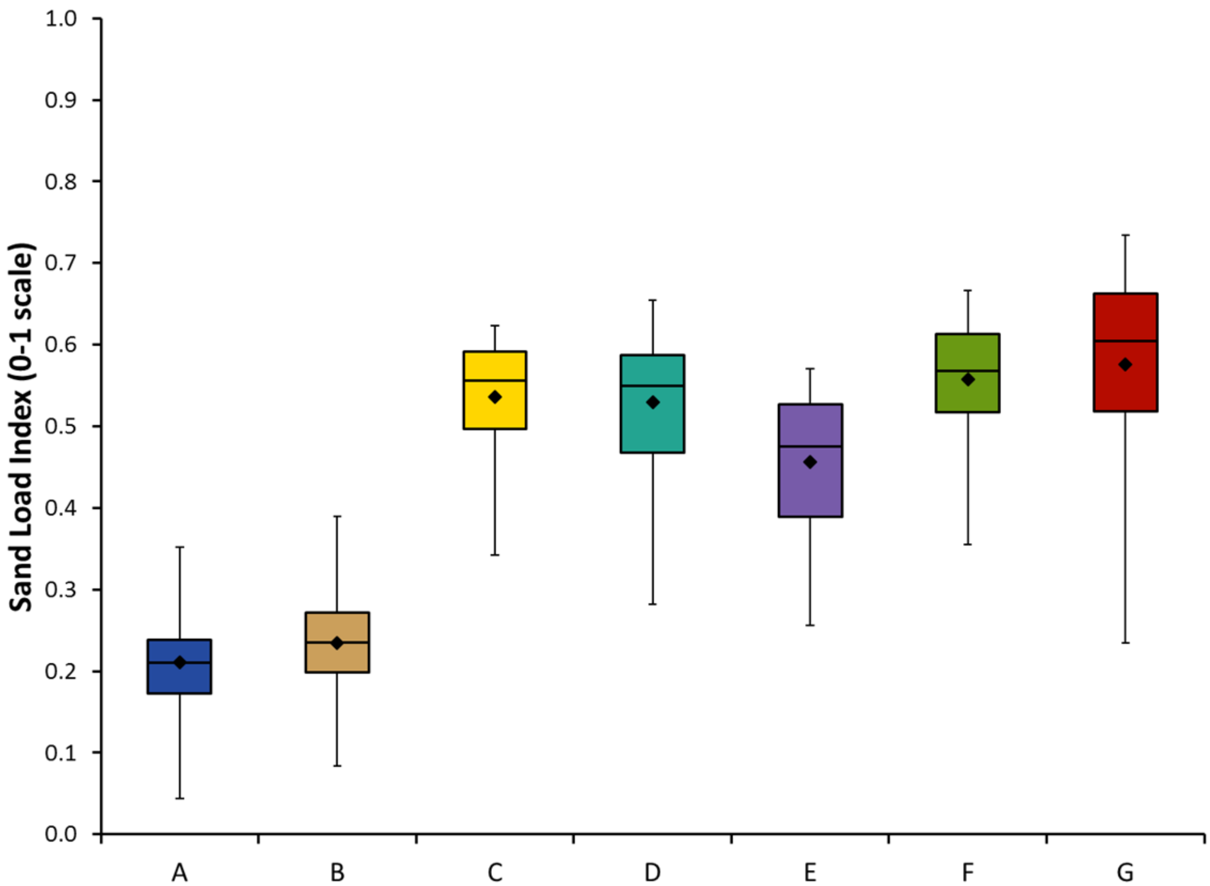

FIGURE 4.3-6 Sand Load Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values indicate a greater potential for building sandbars. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

for this alternative are comparable to those under Alternative A. The largest difference is with the timing of the HFEs. The limitation to one HFE every 2 years in Alternative B implies that sandbars should persist throughout the simulation period, although the bars may become smaller during the periods between HFEs.

Under Alternative B, there would be an estimated average net loss of 1,810 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.4 times the annual average Paria River sand input. About 27% of the 63 conditions modeled resulted in a positive sand mass balance. The estimated average net loss of sand under Alternative B is a larger depletion (about 80% higher) compared to Alternative A. This difference can be attributed to the higher within-day fluctuations under Alternative B. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

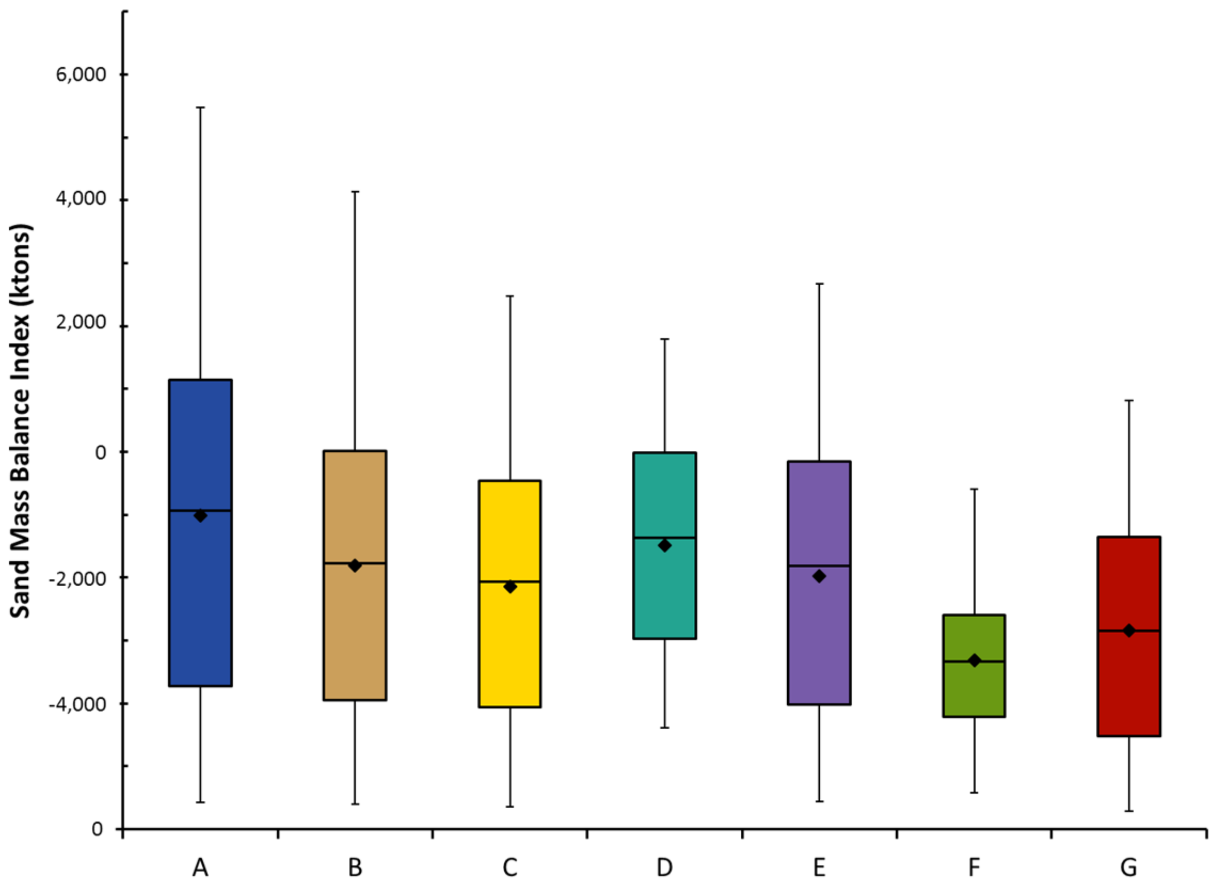

FIGURE 4.3-7 Sand Mass Balance Index Values for the 20-Year LTEMP Period under the Seven Alternatives (Higher values are considered better than lower values. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative B, including hydropower improvement flows, TMFs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. Hydropower improvement flows and TMFs were modeled for Alternative B, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

Hydropower improvement flows would feature increased daily fluctuation ranges and ramp rates that would resemble those of operations at Glen Canyon Dam prior to the early 1990s (Section 2.2.2). Under Alternative B, this experimental operation would be implemented a maximum of four times over the 20-year LTEMP period in years with annual volumes of 8.23 maf or less. This additional fluctuation range would reduce the mean Sand Load Index to 0.22, which is still slightly higher than Alternative A, and would result in a sediment depletion of 2,400 kilotons. This larger depletion of sediment is a direct result of the larger daily fluctuation range. This depletion would affect the channel bed sediments and the sandbars, reducing their size.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall there would be minimal adverse impact on sediment resources because TMFs would not change monthly volumes. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.4). The effect of HFEs on sediment would be much greater than the effects of TMFs on sediment.

In summary, Alternative B has a sandbar-building potential that would be similar to that under Alternative A, but higher fluctuations would result in lower sand mass balance.

4.3.3.3 Alternative C

Under Alternative C, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative C provides for a maximum of 40 sediment-triggered HFEs. On average, there would be 21.3 HFEs triggered and implemented (Figure 4.3-5), which is 53% of the maximum possible under the alternative, and 53% of the overall maximum of 40.

The estimated 20-year weighted average Sand Load Index for Alternative C is 0.54, with an inter-quartile range of 0.50–0.59 (Figure 4.3-6). The estimated average Sand Load Index under Alternative C is 2.6 times greater than the Sand Load Index under Alternative A. This does not imply that bars would be 2.6 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative C. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs as well as proactive spring HFEs. The reduced fluctuations of Alternative C also serve to conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative C, there would be an estimated average net loss of 2,140 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.8 times the annual average Paria River sand input. About 22% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative C is a larger depletion (about 112% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on mass balance than operational characteristics of the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative C, including TMFs, proactive spring HFEs, extended-duration HFEs (volume constrained), low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, long-duration HFEs, and low summer flows were modeled for Alternative C, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources (Appendix E). TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.4). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Proactive spring HFEs are intended to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. Proactive spring HFEs occur in high-volume release years (≥10 maf), unless a sediment-triggered HFE had occurred earlier in the spring. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these proactive HFEs would be effective at building and retaining sandbars, and field tests of this type of HFE are necessary to evaluate their potential effectiveness. Under Alternative C, proactive spring HFEs would only be continued if tests indicate a positive bar response.

Under Alternative C, extended-duration fall HFEs would be of equal release water volume to those triggered under the existing HFE protocol but would be of lower magnitude (e.g., 5-day 36,000 cfs HFE instead of a 4-day 45,000 cfs HFE). The difference in peak and duration for a given release volume will have a relatively minor effect on sediment transport but was not simulated for this analysis. Because of the nonlinear relationship between flow magnitude and sediment transport, a longer duration, same-volume HFE would transport less sand than a shorter duration, higher magnitude HFE. Such an HFE would also have a lower Sand Load Index, and thus have a lower potential to build sandbars.

Implementation of low summer flows would require higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

In summary, Alternative C would result in higher bar-building potential, but lower sand mass balance than Alternative A.

4.3.3.4 Alternative D (Preferred Alternative)

Under Alternative D, fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input, but spring HFEs would not be allowed in the first 2 years of the LTEMP period. Therefore, Alternative D provides for a maximum of

38 sediment-triggered HFEs. On average, there would be 21.1 HFEs triggered and implemented (Figure 4.3-5), which is 55% of the maximum possible under the alternative, and 53% of the overall maximum of 40.

The estimated 20-year average Sand Load Index for Alternative D is 0.53, with an inter-quartile range of 0.47–0.59 (Figure 4.3-6). The estimated average Sand Load Index under Alternative D is 2.5 times greater than the Sand Load Index under Alternative A. This does not imply that bars would be 2.5 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative D. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during much of the LTEMP period. The reduced fluctuations of Alternative D also serve to conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs. In addition, the more equal monthly volumes relative to those of Alternative A conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative D, there would be an estimated average net loss of 1,490 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.0 times the annual average Paria River sand input. About 25% of the 63 conditions modeled resulted in a positive sand mass balance for Marble Canyon over the 20-year LTEMP period. The estimated average net loss of sand under Alternative D is a larger depletion (about 46% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative D, including TMFs, proactive spring HFEs, extended-duration HFEs, low summer flows, benthic invertebrate flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, benthic invertebrate flows, and low summer flows were modeled as an integral part of Alternative D, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. By definition, proactive spring HFEs are HFEs that occur in 10-maf or greater annual release years when there is limited spring sediment input. They are 24-hour maximum magnitude-release HFEs (up to 45,000 cfs depending on unit outage at Glen Canyon Dam). Proactive spring HFEs are designed to utilize sediment on the riverbed to create bars in advance of the erosive flows associated with high annual release years. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative D, proactive spring HFEs would only be continued if tests indicate a positive bar response.

Under Alternative D, extended-duration fall HFEs (up to 250 hr) would be implemented during the 20-year LTEMP period, depending on sediment conditions. Modeling demonstrated that extended-duration HFEs would have substantial effects on both the Sand Load Index (increases index value) and the Sand Mass Balance Index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building. Extended-duration HFEs would result in higher Sand Load Index values, and consequently higher bar-building potential, than more typical 96-hour or shorter HFEs, but would also transport more sand out of the Marble Canyon reach. Extended-duration HFEs would be tested in up to 4 years during the LTEMP period and only when sufficient sand input from the Paria River would support the extended flow.

Implementation of low summer flows requires higher release volumes in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Due to the nonlinear relationship between sediment transport and flow, this increase in the amount of sand transported during the spring is more than the reduction in transport during low summer flows. The net effect for the year is an increase in overall downstream sand transport, resulting in less sediment being available for sandbar building during an HFE.

Sustained low flows for invertebrate production would consist of steady flows during the weekends of May through August. This flow action is expected to have a relatively minor effect on Sand Load Index and Sand Mass Balance Index values.

After modeling was completed for Alternative D, discussions with stakeholders resulted in some modifications to the alternative (see Section 2.2.4). Monthly volumes for August were simulated at 750 kaf, but the August volume was adjusted to 800 kaf, with this increase being offset by decreased volumes in May and June (25 kaf decrease in each month). Additional changes to the alternative made since the completion of modeling included a ban on sediment-triggered spring HFEs in the same water year as an extended-duration fall HFE, elimination of load-following curtailment prior to fall HFEs, and load-following curtailment until the end of the month in which fall HFEs occur (as opposed to December 1). On average, 3.5 extended-duration HFEs were triggered in 20 years (there is a maximum of 4 that are allowed during any given simulation). Of the 3.5 extended-duration HFEs, 1.3 were followed by sediment-triggered spring HFEs. These changes in the alternative are not expected to result in significant changes in the impacts of Alternative D on sediment resources and would not alter the relative ranking of alternatives.

In summary, Alternative D would result in higher sandbar-building potential than Alternative A, while preserving more sand than all alternatives except Alternative A.

4.3.3.5 Alternative E

Under Alternative E, fall HFEs could be implemented during the 20-year LTEMP period, but spring HFEs would not be implemented in the first 10 years of the program. Therefore, Alternative E provides for a maximum of 30 HFEs during the 20-year period. On average, 17.1 HFEs would be triggered and implemented (Figure 4.3-5), which is 57% of the maximum possible under the alternative, and 43% of the overall maximum of 40.

The estimated 20-year average Sand Load Index for Alternative E is 0.46, with an inter-quartile range of 0.39–0.53 (Figure 4.3-6). The estimated average Sand Load Index is 2.2 times greater than for Alternative A. This does not imply that bars would be 2.2 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative E. Higher bar-building potential is a consequence of the potential for sediment-triggered HFEs throughout the LTEMP period under this alternative. The more equal monthly volumes relative to those of Alternative A also conserve more sediment during normal operations, thus making more sediment available for sandbar building during HFEs.

Under Alternative E, there would be an estimated average net loss of 1,980 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 2.6 times the annual average Paria River sand input. The estimated average net loss of sand under Alternative E is a larger depletion (about 96% higher) than that of Alternative A. This difference can be attributed to the higher number of HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in a greater impact on the mass balance than the difference between the alternatives.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative E, including TMFs, low summer flows, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs and low summer flows were modeled for Alternative E, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would be minimal on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.4). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

Implementation of low summer flows would require higher releases of water in the spring to compensate for the lower releases from July through September. This increase in release volume during the spring increases downstream transport of sediment. Because sediment transport has a nonlinear relationship with flow, the increase in sand that is transported during the spring is of larger magnitude than the decrease in sediment transport during the summer. The net effect over the year is an increase in overall downstream sand transport, resulting in less sediment being available for transport during an HFE.

In summary, Alternative E would result in higher bar-building potential than Alternatives A and B, but not the other alternatives, and would have lower sand mass balance than Alternative A.

4.3.3.6 Alternative F

Under Alternative F, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative F provides for a maximum of 40 sediment-triggered HFEs. Under the alternative, in years when a spring HFE was not triggered, there would be a 24-hour 45,000 cfs release in the beginning of May, regardless of the availability of sediment. On average, 19.3 sediment-triggered HFEs would be called for in the 20-year LTEMP period (Figure 4.3-5), which is 48% of the maximum possible under the alternative, and 48% of the overall maximum of 40 (one spring and one fall HFE every year). If the alternative-prescribed annual May events in years without sediment-triggered HFEs are counted, there are on average 38.1 HFEs during the 20-year LTEMP period.

The estimated 20-year average Sand Load Index for Alternative F is 0.56, with an inter-quartile range of 0.52–0.61 (Figure 4.3-6). The estimated average Sand Load Index under Alternative F is 2.7 times greater than the Sand Load Index under Alternative A. This does not imply that bars would be 2.7 times larger under this alternative compared to Alternative A, but it does suggest that there would be substantially more bar-building potential under Alternative F. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, as well as a 24-hour 45,000 cfs release in May in years when a spring HFE is not triggered by sediment input.

Under Alternative F, there would be an estimated average net loss of 3,320 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 4.4 times the annual average Paria River sand input, about 230% higher than under Alternative A. This is the largest depletion associated with any of the alternatives, resulting from the high frequency of HFEs, including an alternative-prescribed flood every spring regardless of tributary sediment inflows, as well as extended elevated flow releases (approximately 20,000 cfs) for the duration of May and June. None of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that that future hydrology and sediment input results in a lesser impact on the mass balance than the alternative.

Other than sediment-triggered spring and fall HFEs, no experimental elements are identified under this alternative.

In summary, Alternative F has the highest number of HFEs and would result in the highest bar-building potential, but the lowest sand mass balance of all alternatives.

4.3.3.7 Alternative G

Under Alternative G, spring and fall HFEs could be implemented in every year of the 20-year LTEMP period when triggered by sediment input. Therefore, Alternative G provides for a maximum of 40 sediment-triggered HFEs. On average, 24.5 HFEs would be triggered and implemented (Figure 4.3-5), which is 61% of the maximum possible under the alternative, and 61% of the overall maximum of 40. This is the only alternative that would allow for HFE durations of up to 336 hr at the 45,000 cfs peak flow rate, and there would be no limit to the number of extended-duration HFEs as long as they could be supported by sediment inputs.

The estimated 20-year average Sand Load Index for Alternative G is 0.58, with an inter-quartile range of 0.52–0.66. This is the alternative with the highest average Sand Load Index. The estimated average Sand Load Index for Alternative G is 2.8 times greater than the Sand Load Index for Alternative A. This does not imply that bars will be 2.8 times larger under this alternative as compared to Alternative A, but it does suggest that there would be significantly more bar-building potential under Alternative G. Higher bar-building potential is a consequence of relatively frequent sediment-triggered HFEs, proactive spring HFEs, and extended-duration HFEs during the entire LTEMP period. The lack of daily fluctuations under Alternative G and equal monthly volumes also would conserve more sediment during normal operations, thus making more sediment available for transport during HFEs.

Under Alternative G, there would be an estimated average net loss of 2,840 kilotons of sand from the Marble Canyon reach over the 20-year LTEMP period (Figure 4.3-7). This amount is about 3.7 times the annual average Paria River sand input. About 6% of the 63 conditions modeled resulted in a positive mass balance at the end of the LTEMP period. The estimated average net loss of sand under Alternative G represents a depletion that is about 182% greater than that under Alternative A. This difference can be attributed to the higher number of HFEs and extended-duration HFEs that would be implemented under this alternative. Comparing the inter-quartile ranges for this alternative and for Alternative A (Figure 4.3-7) suggests that future hydrology and sediment input results in as much impact on the mass balance as the alternative definition.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements under Alternative G, including TMFs, proactive spring HFEs, extended-duration HFEs, and mechanical removal of rainbow and brown trout in the Little Colorado River reach. TMFs, proactive spring HFEs, and extended-duration HFEs were modeled for Alternative G, and their effects are described below (details are presented in Appendix E). Mechanical removal of trout would have no effect on sediment resources.

The estimated effect of TMFs varies with hydrology and sediment conditions, but overall would have a minimal effect on sediment resources. TMFs would be triggered by high levels of trout production, which are stimulated by spring HFEs and other high flows (Section 4.5). The effect of the HFEs on sediment would be much greater than the effect of a TMF.

All HFEs, including proactive spring HFEs, have the largest impact on sediment resources relative to other experimental elements. Proactive spring HFEs are expected to behave much the same as other HFEs by increasing the potential to build sandbars and increasing downstream sediment transport. The sediment models do not have the capability of determining whether these HFEs would be effective, and field tests of this type of HFE would be needed to evaluate their potential effectiveness. Under Alternative G, proactive spring HFEs would only be continued if tests indicate a positive bar response.

In this alternative, extended-duration HFEs may be up to 336 hr long and would be triggered by the appropriate sediment conditions. Modeling demonstrated that extended-duration HFEs would have important effects on both the Sand Load Index (increases index value) and the Sand Mass Balance Index (decreases index value). Extended-duration HFEs have never been performed in sediment-enriched conditions. The models and existing data suggest that these HFEs could result in substantially greater sandbar building.

In summary, Alternative G has the second-highest number of HFEs and would result in the second-highest bar-building potential and the second-lowest sand mass balance of all alternatives.

4.4 NATURAL PROCESSES

Issue: How do alternatives affect physical conditions which drive the natural processes that support native plants and animals, and their habitats, in Glen and Grand Canyons?

Impact Indicators:

- Flow characteristics, including monthly release patterns and within-day variability
- Seasonal water temperature patterns
- Sediment mass balance and sandbar building potential
- Water quality (nutrients and turbidity)

The Colorado River Ecosystem is defined as the Colorado River mainstem 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. An important objective of management of the Colorado River Ecosystem is the ability to sustain healthy populations of native plants and animals. As described in Chapter 3, management policies identified by the NPS (NPS 2006d) state that "whenever possible, natural processes will be relied upon to maintain native plants and animals and influence natural fluctuations in populations of these species."

Major physical drivers of natural processes in the Colorado River Ecosystem are flow, water temperature, sediment transport, and water quality (including nutrients and turbidity). The nature of these parameters directly and/or indirectly determines the abundance, condition, and status of habitats for native and nonnative plants and animals in the ecosystem below the dam.

The natural processes within the Colorado River Ecosystem reflect historic changes to the system (Chapter 3). The existing facilities and laws and regulations further constrain the options for fully restoring the original natural processes within the canyon. It is not possible to operate the dam in a manner that could restore to pre-dam conditions the physical parameters that drive natural processes. Nonetheless, physical and chemical parameters that influence natural processes and native and nonnative species communities may be affected differently by each of the LTEMP alternatives.

4.4.1 Analysis Methods

The range of variability of physical parameters in the Colorado River Ecosystem is constrained by the operational limits of the dam, but varies by alternative. It is assumed that the natural abundance, diversity, and genetic and ecological integrity of plant and animal species native to the river will be influenced by the physical riverine conditions that are produced under each alternative.

A conceptual model showing expected linkages among dam releases, physical conditions, habitats, and affected ecological resources is shown in Figure 4.4-1. As shown, the primary effects of any alternative on plant and animal species below the dam will be a direct function of the changes in the physical conditions (e.g., sediment transport, water temperature) that would occur under each alternative; how those alternative-specific changes affect habitat quality, quantity, and stability; and how aquatic and terrestrial biota will respond to those changes. Thus, the evaluation of how each alternative may affect natural processes below Glen Canyon Dam was based on the examination of how selected physical parameters would differ under each alternative. These differences in physical parameters were assessed as described in Sections 4.2.1 (for temperature-, flow-, and water-quality-related indicators) and 4.3.1 (for sediment-related indicators). These evaluations were then considered together to provide a qualitative determination of how natural processes in the river below Glen Canyon Dam would be affected under each alternative. Table 4.4-1 identifies the role of each of the physical parameters in influencing natural processes in the Colorado River Ecosystem.

4.4.2 Summary of Impacts

One of the most important factors affecting ecological resources (i.e., native plants and animals and their habitats) in the Colorado River Ecosystem is the interannual variability in the hydrology of the system as driven by weather patterns and climatic conditions. Under a natural hydrograph, physical conditions in the river would include a hydrograph with peak flows and volumes in later spring/early summer, daily flows ranging on average from 1,000 cfs in winter to >92,000 cfs in spring and summer, and daily fluctuations only in response to precipitation events and tributary inflows (Section 3.2.2.2). Water temperatures would range from near freezing in winter to 30°C (86°F) in the late summer, and turbidity would be high throughout the year (Section 3.2.3.2). It is under such conditions that natural processes would act to develop, support, and maintain the original native ecosystems of the river.

The nature, magnitude, pattern, and duration of flows, as well as water temperatures and water quality, in the Colorado River Ecosystem are so strongly constrained by the presence of the dam and by the existing laws and regulations that govern conveyance of water between the Upper and Lower Basins that it is not possible for any of the alternatives to restore natural

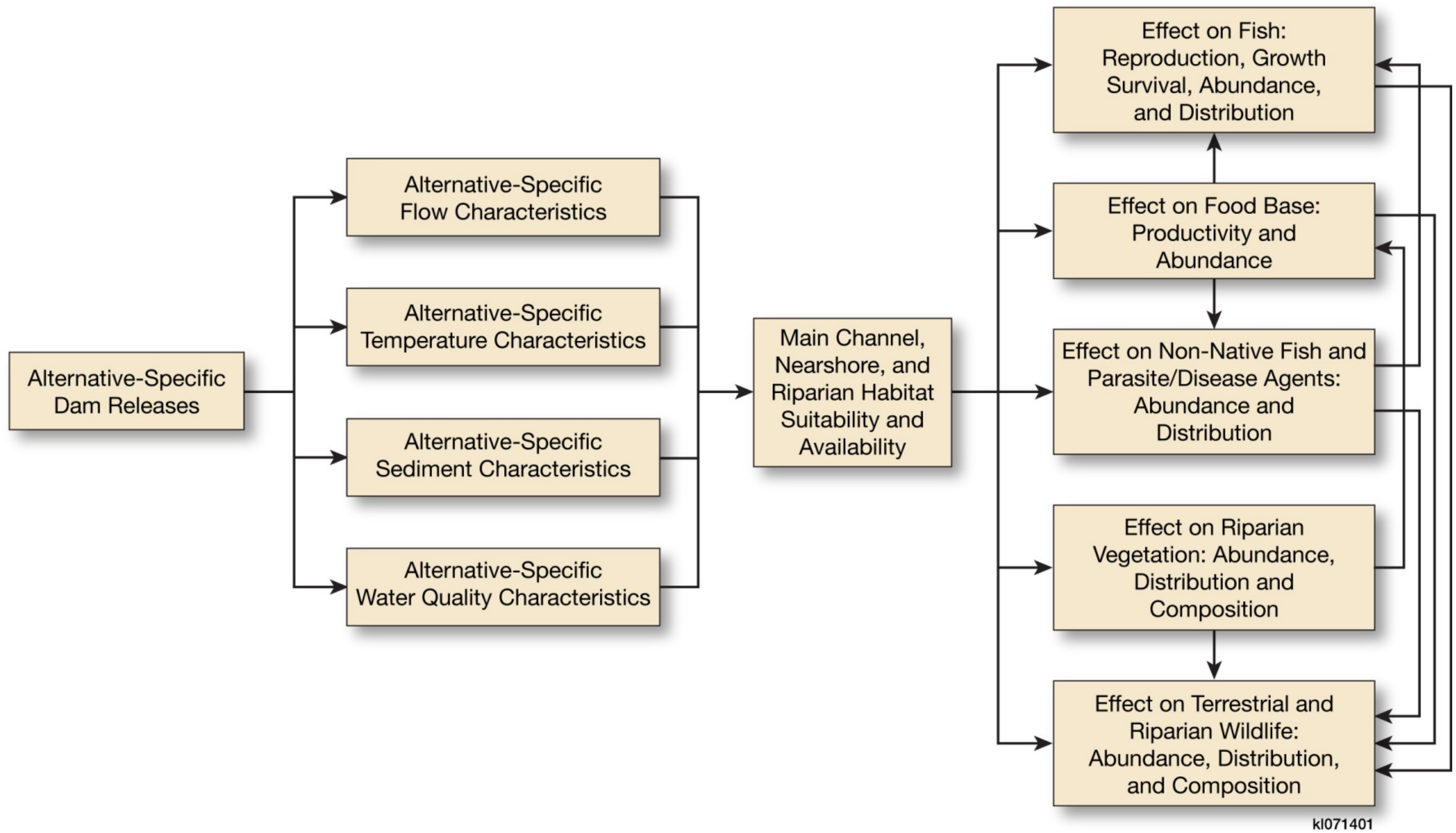

FIGURE 4.4-1 Anticipated Relationships among Dam Releases, Physical Conditions, Habitats, and Ecological Resources in the Colorado River Ecosystem

TABLE 4.4-1 Indicators Used To Examine Natural Processes under Each LTEMP Alternative

Indicator	Role in Affecting Natural Processes
Flow-Related Indicators	
Peak and base flows	The frequency, magnitude, duration, and timing of peak and base flows directly affect aquatic and riparian habitats and their biota, as well as other physical factors such as water temperature and sediment transport, deposition, and loss, which in turn affect aquatic and riparian habitats, native fish and aquatic invertebrates, the aquatic food base, and riparian vegetation and wildlife. There are also direct effects from peak and base flows on vegetation.
Monthly release volumes	The magnitude and pattern of monthly release volumes affect sediment transport and physical conditions that influence important life history parameters of aquatic biota, such as egg laying and hatching in fish, as well as the quality and quantity of mainstem and nearshore aquatic habitats and riparian habitats along the main channel.
Mean daily flows	The magnitude and pattern of daily flows (including ramp rates) affect main channel and nearshore aquatic habitats, riparian habitats, and the biota that rely on these habitats.
Mean daily flow fluctuations	Daily flow fluctuations (including ramp rates) affect sediment transport and directly affect daily changes in stage, which in turn affect mainstem riparian vegetation, main channel and nearshore aquatic habitat stability, and productivity and distribution of the aquatic food base.
Temperature-Related Indicators	
Mean main channel water temperatures	Water temperatures affect reproduction, growth, and survival of fish and aquatic invertebrates in main channel and nearshore habitats, as well as productivity of the aquatic food base.
Sediment-Related Indicators	
Sediment transport and deposition	These sediment parameters affect main channel and nearshore aquatic habitats as well as riparian habitats, the biota that rely on these habitats, and the aquatic food base.
Elevation of annual sediment deposition	Elevation of annual sediment deposits affects distribution, abundance, and composition of riparian vegetation and terrestrial wildlife habitat.
Water-Quality-Related Indicators	
Turbidity	Turbidity affects predator-prey relationships among aquatic biota, as well as primary productivity.
Nutrients	Nutrients affect aquatic habitat quality for fish, invertebrates, and the aquatic food base.

processes in the system to pre-dam conditions. In addition to their effects on flow, Glen Canyon Dam and Lake Powell trap most of the sediment from the Upper Basin that would normally be transported into and through the Colorado River in Glen and Grand Canyons. The dam also serves as a physical barrier to the movement of riverine organisms between the Upper and Lower Basins. In this context, the LTEMP alternatives have relatively similar effects and have the potential to produce only relatively small changes in current conditions that could improve natural processes.

Regardless of which alternative is implemented, there would be little change from current conditions with regard to peak or base flows (maximum daily flows up to 25,000 cfs, minimum daily flows 5,000 to 8,000 cfs), mean Glen Canyon Dam release water temperature, overall turbidity or nutrient concentrations, or the maximum height of annual sediment deposition (elevation of 45,000 cfs flows). Thus, natural processes dependent on these physical factors would not differ from current operations, and these are not discussed further in the analysis below.

Despite these limitations, LTEMP alternatives do vary to some extent in some physical parameters that directly affect natural processes and the native plants, animals, and habitats controlled by those processes. Differences among alternatives as related to natural processes were inferred on the basis of potential differences among the alternatives in physical indicators (Table 4.4-2).

Some changes in natural processes may be expected under all alternatives, as reflected by expected changes in one or more of the physical indicators, but these changes are expected to be relatively modest compared to current conditions, especially for the fluctuating flow alternatives (Alternatives B–E) (Table 4.4-2). By altering the monthly release patterns and eliminating within-day fluctuations, the two steady-flow Alternatives F and G would result in the greatest changes to natural processes relative to those under current conditions.

Alternatives with greater daily flow fluctuations (Alternatives B and E) could result in reductions in nearshore habitat stability compared to the other alternatives, and thus have more of an effect on aquatic and riparian biota in nearshore habitats (Sections 4.5, 4.6, and 4.7).

Compared to Alternative A, natural processes influenced by sediment dynamics could be affected under Alternatives B through G, as the potential for bar building (as inferred from Sand Load Index estimates) ranges from 11% to 173% greater than under Alternative A. In contrast, sediment depletion from Marble Canyon (as inferred from Sand Mass Balance Index estimates) ranges from 47% to 230% greater than under Alternative A. This sediment depletion, however, would be balanced by greater deposition of sediment in areas above the normal range of flows where that sediment could benefit terrestrial ecosystems. This redistribution of sediment would restore, albeit to a limited extent, the natural pattern of sediment distribution.

Alternative F may have the greatest effect of all alternatives on natural processes. Alternative F is the only alternative with a monthly release pattern that has been seasonally adjusted to more closely follow the seasonal pattern of inflow, and (along with Alternative G) has the least daily flow fluctuations, which would result in more stable and presumably higher

TABLE 4.4-2 Summary of Impacts of LTEMP Alternatives on Natural Processes Associated with Flow, Water Temperature, Water Quality, and Sediment Resources[a]

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Existing natural processes related to flow, water temperature, water quality and sediment resources would continue, but replenishment of sandbars would diminish after 2020 when HFEs would cease.	Compared to Alternative A, most natural processes would be unchanged, but there would be less nearshore habitat stability as a result of greater within-day fluctuations.	Compared to Alternative A, there would be more nearshore habitat stability as a result of lower within-day fluctuations, slightly higher summer and fall water temperatures due to lower flows, and more frequent sandbar building resulting from more frequent HFEs.	Similar to Alternative C.	Similar to Alternative B for flow-related processes, but more similar to C for water temperature and sediment-related processes.	Compared to Alternative A, flow-related processes, water temperature, and water quality would more closely match a natural seasonal pattern with little within seasonal variability; sediment-related processes similar to Alternative C.	Compared to other alternatives, there would be little variability in flow, water temperature, or water quality processes; Alternative G would have the highest potential of any alternative to build sandbars and retain sand in the system.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Flow-Related Indicators							
Daily maximum and minimum flows	No change from the current daily maximum of 25,000 cfs, and daily minimum of 5,000 to 8,000 cfs.	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Mean monthly release volume and mean daily flow	No change from current conditions, with highest mean monthly release volumes and mean daily flows in winter and summer.	Same as Alternative A	Higher mean monthly volumes and mean daily flows in winter, spring, and summer with lowest volumes in late summer and autumn favoring conservation of sediment inputs during the monsoon period.	Relatively even monthly volumes and mean daily flows favoring conservation of sediment year-round.	Relatively even monthly volumes and mean daily flows, but lower volumes in late summer favoring conservation of sediment inputs during the monsoon period.	Monthly volumes and daily flows seasonally adjusted to more closely match monthly pattern of inflows with high spring flows and low summer through winter flows.	Monthly volumes and daily flows are approximately equal, favoring conservation of sediment year-round.
Mean daily changes in flow	No change from current condition; mean daily change would range from about 2,000 to 7,800 cfs.	Mean daily change higher in all months (range about 2,500 to 12,000 cfs, and even higher with hydropower improvement flows), which could reduce stability of nearshore habitats.	Mean daily change lower in all months (about 1,300 to 6,200 cfs), which could increase stability of nearshore habitats.	Mean daily change slightly higher in Oct. through Jun., which could slightly reduce nearshore habitat stability. Mean daily change in other months comparable to Alternative A (range about 2,700 to 7,600 cfs).	Mean daily change higher in all months but Sept. and Oct. (range about 1,100 to 9,600 cfs), which could reduce stability of nearshore habitats.	Steady flows will increase stability of nearshore habitats.	Steady flows will increase stability of nearshore habitats.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Temperature-Related Indicators							
Mean Glen Canyon Dam release water temperature	Mean seasonal release temperatures are expected to be about 9.9°C in winter (about 9.7–10.2°C), 9.0°C in spring (8.8–9.2°C), 11.3°C (10.9–11.4°C) in summer, and 12.2°C (11.9–12.4°C) in fall.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A
Mean seasonal main channel water temperature and downstream warming	No change from current conditions. Mean seasonal water temperatures between Lees Ferry and Diamond Creek range 10.0–10.6°C in winter, 9.3–13.5°C in spring, 11.6–17.2°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.6°C.	Same as Alternative A	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.2°C in spring, 11.7–17.6°C in summer, and 12.3–15.9°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.5°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 5.9°C.	Similar to Alternative A. Mean seasonal water temperatures range 10.0–10.5°C in winter, 9.4–13.3°C in spring, 11.6–17.6°C in summer, and 12.4–15.5°C in fall. Mean summer warming by about 6.0°C.	Mean seasonal water temperatures range 9.9–10.6°C in winter, 9.5–12.5°C in spring, 11.9–18.6°C in summer, and 12.3–16.0°C in fall. Greatest amount of winter (0.9°C), summer (6.7°C), and fall (3.7°C) warming, and least amount of spring (3.0°C) warming of all alternatives.	Mean seasonal water temperatures range 10.0–10.6°C in winter, 9.4–13.3°C in spring, 11.6–17.8°C in summer, and 12.4–15.3°C in fall. Second highest summer warming (6.2°C) of all alternatives.

TABLE 4.4-2 (Cont.)

Natural Processes Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Sediment-Related Indicators							
Sediment transport and deposition	No change from current conditions with reduction of sandbar area and volume after HFE protocol expires in 2020. 20-yr average SLI of 0.21 and SMBI of −1,010.	Slight increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates. An 11% increase in the SLI, which could slightly increase sandbar building potential, and an 80% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; lower fluctuations would result in lower erosion and transport rates. A 154% increase in the SLI and a 112% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; fluctuations comparable to Alternative A. A 151% increase in the SLI and a 47% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A, but higher fluctuations would result in higher erosion and transport rates. A 116% increase in the SLI and a 96% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates. A 164% increase in the SLI and a 230% decrease in the SMBI compared to Alternative A.	Large increase compared to Alternative A; steady flows would result in lower erosion and transport rates. A 173% increase in the SLI and a 182% decrease in the SMBI compared to Alternative A.
Water Quality-Related Indicators							
Turbidity	No change from current conditions expected.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A
Nutrients	No change from current conditions expected.	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A	Similar to Alternative A

[a] SLI = Sand Load Index; SMBI = Sand Mass Balance Index.

quality nearshore and riparian habitats (Sections 4.5, 4.6, and 4.7). Under Alternative F, the timing of achieving suitable downstream main channel water temperatures could reduce overall temperature suitability for spawning and incubating humpback chub and other native fishes, but improve temperatures for growth of young-of-year (YOY) humpback chub (Section 4.5.2.1).

4.4.3 Alternative-Specific Impacts

Although alternatives did not differ with regard to peak and base flows, mean Glen Canyon Dam release water temperature, turbidity, or nutrient concentrations, alternatives do differ with regard to the magnitude and timing of HFEs, monthly flows, daily flows, within-day flow fluctuations, and sediment dynamics. These factors have the potential to produce only small changes in current conditions and thus are expected to have relatively small effects on natural processes, as discussed below. In 2026, the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a) that are currently in place will expire. Without knowing how dam operations may change at that time, it is not possible to postulate with any acceptable level of certainty how natural processes may be affected. Thus, the following assessments of alternative-specific impacts do not consider any changes in operations after 2026.

4.4.3.1 Alternative A (No Action Alternative)

Under Alternative A, there would be little change in physical parameters from current conditions; mean monthly release volumes, mean daily flows, and mean daily changes in flow would be the same as current conditions (Section 4.2). Because the current HFE protocol as defined in the 2011 EA (Reclamation 2011b) would continue under Alternative A, sediment deposition rates would not be expected to differ from current levels. Sandbar building would be expected to continue through the HFE protocol window, but bars would likely then erode and decrease in size after 2020 (Section 4.3). Vegetation and wildlife dependent on replenished sandbars would decline in abundance after the protocol expires in 2020 (Sections 4.6 and 4.7).

Under Alternative A, no changes from current conditions are expected in physical factors associated with monthly volumes, daily flows, and flow changes, water temperature, and water quality. As a consequence, natural processes in the Colorado River between Glen Canyon Dam and Lake Mead are not expected to differ from current conditions.

4.4.3.2 Alternative B

Under Alternative B, mean monthly volumes and mean daily flows would be the same as those under Alternative A (Sections 4.2 and 4.3), and thus natural processes influenced by these parameters are not expected to change from current conditions. However, Alternative B would have a greater mean daily change in flow in all months (Section 4.2), and thus may affect natural processes that govern aquatic ecology and vegetation, decreasing nearshore habitat stability affecting native fish, benthic productivity, and aquatic invertebrates that would otherwise inhabit these areas (Section 4.5). This increase in mean daily change in flow would also favor wetland processes along the river corridor below the dam and affect vegetation and wildlife species that inhabit wetland habitats (e.g., marsh vegetation, wetland invertebrates, and amphibians; Sections 4.6 and 4.7) along the corridor. In addition, this increase in within-day fluctuations is expected to inhibit trout production somewhat relative to Alternative A and all other alternatives, and could reduce competition with and predation by trout on, and result in slightly higher abundance of, humpback chub and other native fish (Section 4.5). Note that experimental hydropower improvement flows that would be implemented under Alternative B could result in a reduction in existing wetland area and would result in lower trout production than other alternatives.

While the average and maximum number of sediment-triggered HFEs would be similar to that under Alternative A, the SLI (an indicator of sandbar building potential) could be higher under Alternative B (Section 4.3). Thus, sediment-influenced natural processes that affect riparian vegetation, terrestrial wildlife, and nearshore aquatic habitats (such as backwaters) could be somewhat improved under Alternative B, but would be diminished relative to all other alternatives, which have more frequent HFEs. Within-day flow fluctuations would result in higher rates of sandbar erosion than under any other alternative.

In summary, in comparison to Alternative A, the higher mean daily changes in flow under Alternative B in all months may act to decrease sediment conservation and favor wetland processes (unless hydropower improvements are implemented), but reduce trout production and nearshore habitat stability (which would affect fish, aquatic invertebrates, and benthic productivity in those habitats).

4.4.3.3 Alternative C

Mean monthly volumes as well as mean daily flows under Alternative C would be higher in February through May, but lower in August through October when compared to Alternative A. While these differences are relatively small (Section 4.2), the reduced volume in August through November would favor sediment retention during the monsoon period and increase the frequency, magnitude, and duration of HFEs, the size and persistence of sandbars and associated backwaters, and the vegetation and wildlife species that depend on replenished sandbars (Sections 4.3, 4.6, and 4.7). The timing of spring HFEs would coincide more closely with the natural timing of the annual spring peak flow and could contribute to processes dependent on a spring peak flow. In addition, within-day changes in flow would be lower in all months under Alternative C than under Alternatives A, B, D, and E. The lower magnitude of daily changes in flows under Alternative C would reduce erosion rates of sandbars, and may improve the quality and stability of some nearshore aquatic habitats (including backwaters) and benefit fish and aquatic invertebrates in these areas, as well as some riparian habitats and biota (Sections 4.5, 4.6, and 4.7). This decrease in daily fluctuations would favor trout production (with possible negative effects on native fish that would be offset by implementation of trout management actions) and inhibit maintenance of wetlands and species dependent on them (Sections 4.5, 4.6, and 4.7).

In summary, compared to Alternative A, the higher monthly release volumes and daily flows in winter, spring, and summer, and the lower mean daily changes in all months under Alternative C may increase sediment conservation and increase the stability of nearshore habitats, and thus benefit biota that use those habitats, increase trout production, and reduce wetland area. The higher frequency of HFEs would increase sandbar building relative to Alternative A.

4.4.3.4 Alternative D (Preferred Alternative)

Compared to Alternative A, Alternative D would have slightly higher mean monthly volumes and daily flows in November and February through April, and lower volumes and flows in December, January, and July through September (Section 4.2), providing less seasonal variation in flow across the year than most alternatives. Mean daily changes in flow for Alternative D would be comparable to Alternative A. Thus natural processes influenced by daily changes in flow would differ little from current conditions. Therefore, the quality and stability of some nearshore aquatic habitats (including backwaters) could be comparable to those under current conditions and are expected to support similar fish and aquatic invertebrates in these areas. Within-day fluctuations in flow are expected to support current levels of wetland vegetation or provide some increase in wetlands (Section 4.6), as well as the invertebrate and wildlife species that inhabit wetlands (Section 4.7). Under Alternative D, there may be some slight downstream warming, which could improve downstream main channel temperature suitability for spawning and incubation of native fish.

The relatively even pattern of monthly volumes would serve to conserve sand, and, as a consequence, spring and fall HFEs would be triggered frequently under Alternative D. Thus, this alternative has a relatively high potential for bar building compared to other alternatives (Section 4.3). The higher number of HFEs could influence sediment-related natural processes that would build and maintain backwaters (Section 4.5) and support the vegetation and wildlife species that depend on replenished sandbars (Sections 4.6 and 4.7).

In summary, natural processes influenced by monthly volumes, daily flows, and within-day changes in flow would differ little between Alternatives A and D. However, the more even monthly release volumes and daily flows would favor sediment conservation and also provide some increase in downstream temperature suitability for spawning and incubation of native fish in spring, while nearshore aquatic habitat stability would be similar to that under Alternative A. The higher frequency of HFEs would increase sandbar building relative to Alternative A.

4.4.3.5 Alternative E

Compared to Alternative A, mean monthly volumes as well as mean daily flows would be higher in October, November, and February through March, but lower in December, January, July, August, and September. August and September volumes would be lower to conserve sediment during the monsoon period. Mean daily changes in flow under Alternative E would be higher than under Alternative A in all months but September and October, when daily changes would be lower. The greater daily changes in flow under this alternative could increase the erosion rates of sandbars and act to reduce the quality and stability of nearshore aquatic and riparian habitats (Sections 4.5, 4.6, and 4.7). This increase in within-day fluctuations also is expected to inhibit nonnative trout production somewhat relative to Alternative A and all other alternatives but Alternative B, and could result in reduced competition with and predation by trout on humpback chub and other native fish (Section 4.5).

Alternative E would have more sediment-triggered HFEs than Alternatives A and B, but slightly fewer than the other alternatives (Section 4.3), and, therefore, a greater potential for sediment conservation and deposition, and significantly more potential for bar building, than do Alternatives A or B. The lower August through October volumes are intended to conserve sand input during the monsoon period and would result in an increase in the frequency, magnitude, and duration of sediment-triggered HFEs, which would influence sediment-related natural processes that would build and maintain backwaters (Section 4.5) and support the vegetation and wildlife species that depend on replenished sandbars (Sections 4.6 and 4.7).

In summary, in comparison to Alternative A, the relatively even monthly release volumes and daily flows of Alternative E, together with lower summer volumes and flows, may favor sediment conservation during monsoon periods, while higher mean daily changes in flow in all months but October and November may reduce nearshore habitat stability, reduce trout production, and increase wetland area.

4.4.3.6 Alternative F

In contrast to all other alternatives, Alternative F has a pattern of monthly volumes and daily flows that are seasonally adjusted to more closely match the pattern of Lake Powell inflow, with high spring flows and low summer through winter flows. Under Alternative F, the highest mean monthly release volumes and mean daily flows occur in March through June, and lower volumes and daily flows occur in December, January, and July through August (Section 4.2). Under Alternative F, there would be no within-day flow changes except those needed for HFEs or other high-flow releases, or as a result of changes in the runoff forecast, equalization flows, or natural precipitation events and tributary inflows. Thus among all the alternatives, Alternative F is expected to result in flow-related natural processes that are most different from current conditions. Steady flows are expected to reduce the erosion of sandbars, provide for more stable main channel and nearshore aquatic habitats, and increase productivity in these habitats (Sections 4.5, 4.6, and 4.7), but would also result in decreases in wetland habitat and the species dependent on those habitats, as well as favor trout production with potential adverse effects on native fish. Unlike Alternatives B, C, D, E, and G, Alternative F would not include implementation of trout management actions.

Relative to other alternatives, Alternative F would have the least amount of downstream warming, and thus the coolest downstream main channel water temperatures in spring and the greatest amount of downstream warming and warmest downstream temperatures in summer (Section 4.2). This pattern and magnitude of downstream warming are due, in part, to the monthly patterns in release volumes and daily flows, as well as the relative absence of daily flow fluctuations, under Alternative F. As a result, temperature-linked natural processes could be affected more under Alternative F than under any of the other alternatives. For example, temperature suitability for trout may decrease at downstream locations but increase downstream for other nonnative fish (Section 4.5). Alternative F would have the greatest reduction in temperature suitability for spawning and incubating at humpback chub aggregation areas, while temperature suitability for humpback chub growth in the main channel would be greatest under this alternative.

Alternative F has a greater potential for sediment conservation and deposition, and significantly more potential for bar building, than for all alternatives but Alternative G, but the lowest SMBI. These HFEs would influence sediment-related natural processes that would build and maintain backwaters (Section 4.5) and support the vegetation and wildlife species that depend on replenished sandbars (Sections 4.6 and 4.7).

In summary, the monthly release volumes and daily flows under Alternative F would more closely match the pattern of inflows, with high spring and low summer through winter flows. In comparison with Alternative A, this pattern of monthly volumes and daily flows, together with steady within-day flows, would increase sediment conservation, increase nearshore habitat stability, increase trout production, and reduce wetland area. The greatest amount of winter, summer, and fall warming, and least amount of spring warming, of all alternatives may lower temperature suitability for spawning and incubation in the spring for native fish, but increase the suitability in summer and fall for growth.

4.4.3.7 Alternative G

Under Alternative G, mean monthly volumes as well as mean daily flows would be higher in October, November, and February through April, but lower in December, January, July, and August (Section 4.2). These steady flows would serve to conserve sediment relative to other alternatives but would provide no seasonal variability, and therefore could affect natural processes reliant on such variability. There would be no mean daily changes in flow except for ramping during HFEs or in response to changes in the runoff forecast, equalization flows, or precipitation events and tributary inflows. Steady flows are expected to reduce the erosion of sandbars, improve the quality and stability of nearshore and main channel aquatic habitats, and increase benthic productivity (Section 4.5). However, reduced fluctuations would also result in a decrease in wetland habitat and the species dependent on those habitats (Section 4.6), as well as favor trout production with potential adverse effects on native fish (Section 4.5). Increases in trout production would be offset by trout management actions.

Alternative G would have less downstream warming, and thus cooler downstream main channel water temperatures in spring and warmer downstream temperatures in summer, compared to Alternative A and all other alternatives but Alternative F (Section 4.2). As with Alternative F, this pattern of downstream warming is due, in part, to the pattern of monthly release volumes under Alternative G.

Alternative G has the highest average number of sediment-triggered HFEs of all the alternatives (Section 4.3). Alternative G is also the only alternative that would allow for durations of up to 336 hr at the 45,000-cfs peak flow, with no limit to the number of such flows. These HFEs would result in the most bar-building of any of the alternatives, and thus influence sediment-related natural processes that would build and maintain backwaters (Section 4.5) and support the vegetation and wildlife species that depend on replenished sandbars (Sections 4.6 and 4.7). The SMBI was the second lowest for this alternative.

In summary, the more even monthly release volumes and daily flows under Alternative G, together with steady within-day flows, may increase sediment conservation, increase nearshore habitat stability, increase trout production, and decrease wetland area. This alternative also has the second-highest summer warming of all alternatives, which may increase temperature suitability for growth of native fish in summer.

4.5 AQUATIC ECOLOGY

The assessment of impacts on aquatic ecology focused on four groups of aquatic resources: the food base (consisting of invertebrates, algae, and aquatic plants), native fish (including the endangered humpback chub [*Gila cypha*]), nonnative fish (including rainbow trout [*Oncorhynchus mykiss*]), and aquatic fish parasites. The specific attributes and conditions evaluated, the analysis methods, and the assessment results are presented in the following sections. Additional details are provided in Appendix F.

> **Issue:** How do alternatives affect aquatic resources (food base, native and nonnative fishes, and fish parasites) between Glen Canyon Dam and Lake Mead?
>
> **Impact Indicators:**
>
> - Abundance, distribution, and availability of the aquatic food base
> - Native and nonnative fish reproduction, survival, growth, and distribution
> - Availability and quality of aquatic habitats
> - Distribution and potential for spread of fish parasites

4.5.1 Analysis Methods

The evaluation of the potential impacts of LTEMP alternatives on aquatic resources below Glen Canyon Dam is based on alternative-specific differences in operations (including monthly and annual flow patterns and within-day flow fluctuations), and flow and non-flow actions. These characteristics of alternatives can affect aquatic organisms directly or through their effects on habitat availability and quality. The analysis methods for impacts on aquatic food base, native fish, nonnative fish, and aquatic parasites are presented next.

4.5.1.1 Aquatic Food Base

The aquatic food base assessment considers the effects of flow and temperature on the amount of food that is available to fish and other animals in Glen and Grand Canyon. The assessment focuses on changes at key locations in the Colorado River: RM 0 (Lees Ferry within the Glen Canyon reach), RM 61 (Little Colorado River within the Marble Canyon reach), and RM 225 (Diamond Creek within the Grand Canyon reach). As discussed in Section 3.2.1.2, within-day flow variation in releases continues downstream and decreases little as flows pass through Marble and Grand Canyons. Water, on the other hand, can warm considerably by the time it travels from the dam to western Grand Canyon (Section 3.2.2.2).

The effects of flow and temperature on the aquatic food base were evaluated by examining a number of important factors. The potential influence of flow on the aquatic food base includes changes in invertebrate drift (food organisms dislodged and moved by river current, e.g., algae, plankton, invertebrates, and larval fish); stranding of aquatic organisms in the varial zone (the portion of the river's edge affected by the daily range of flows); and effects to species abundance, composition, and diversity. Stranding of organisms in the varial zone may lead to their death, while growth of primary producers such as *Cladophora* is reduced in the varial zone. The potential influence of temperature includes changes in diatom composition; invertebrate egg development, fecundity, growth, maturation, number of yearly generations, and/or emergence of adults for aquatic insects with terrestrial adult stages; invertebrate composition, diversity, and production (e.g., biomass of benthic macroinvertebrates per unit of area per unit of time); and occurrence and distribution of invasive and parasitic species (Clarke et al. 2008; Poff et al. 1997; Power et al. 1988; Renöfält et al. 2010).

To assess potential flow effects on the aquatic food base, a qualitative comparison among alternatives was conducted because an appropriate quantitative model was not available. This qualitative analysis was based on potential impacts of elements of base operations (e.g., release volumes, maximum and minimum flows, daily flow range, and ramp rates) and other experimental flow actions (e.g., HFEs, low summer flows, TMFs, and hydropower improvement flows). To assess potential temperature effects on the aquatic food base, expected mean monthly temperatures at Lees Ferry, Little Colorado River, and Diamond Creek were compared to temperature requirements for select primary producers, zooplankton, and benthic macroinvertebrate species (Valdez and Speas 2007).

4.5.1.2 Nonnative Fish

The assessment of impacts on nonnative fish evaluated effects on reproduction, survival, growth, and abundance downstream of Glen Canyon Dam. The assessment considered results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of nonnative fish (e.g., see Makinster et al. 2010), as well as studies of the effects of experimental flows (such as HFEs and trout removal flows) on nonnative fish (e.g., Makinster et al. 2011; Korman et al. 2012). In addition, species-specific models that incorporated factors such as annual release volumes, water temperatures, and monthly and within-day changes in flows were used to examine effects at selected locations downstream of Glen Canyon Dam.

A coupled rainbow trout–humpback chub model was used to evaluate potential effects of alternatives on (1) the number and size of rainbow trout in the Glen Canyon reach, and (2) the number of age-0 rainbow trout expected to move (emigrate) into the Marble Canyon and Little

Colorado River reaches over the 20-year LTEMP period. The model estimates the number of rainbow trout that move downstream as a function of trout spawning and recruitment in the Glen Canyon reach. Historic observations and previous modeling suggest that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman, Persons et al. 2011; Korman et al. 2012; Section 3.5.4). The number of trout recruits in the Glen Canyon reach, and the numbers of trout and humpback chub in the Little Colorado River reach were used to determine when TMFs and mechanical removal in the Little Colorado River reach, respectively, would be triggered under certain alternatives.

Technical details about the coupled rainbow trout-humpback chub model are presented in Appendix F. The combined model uses an age-structured population dynamics model to predict the abundance and growth of rainbow trout in Glen Canyon, and the number of those fish that migrate into Marble Canyon. The model makes predictions on an annual time step for fish that are 1 to 6 years of age. Annual recruitment (i.e., the number of age-0 fish that enter the population in a given year) is predicted based on flow statistics, and annual growth is predicted as a decreasing function of overall rainbow trout abundance. Abundance, in combination with estimates of age-specific angling vulnerabilities, is used to make predictions of angling catch rates and predicted abundance and size distributions are used to compute the number of quality-sized fish (i.e., trout ≥16 in. total length) potentially available for capture in the fishery. The number of fish migrating into Marble Canyon each year (out-migrants) is predicted as a proportion of the previous year's recruitment, and is used as an input in a submodel that estimates the potential number of fish that eventually migrate down to the confluence of the Little Colorado River, where their effects on humpback chub are simulated in the humpback chub submodel. Basic parameters and those for key functional relationships in the trout submodel were derived or fitted to values from a stock synthesis model developed by Korman et al. (2012). That model used 21 years of electrofishing-based catch-per-effort data for Glen and Marble Canyons, in conjunction with length frequencies and considerable auxiliary information, to estimate annual recruitment, survival rate, growth parameters, and outmigration patterns for rainbow trout.

As with most models of biological systems, a number of simplifications and assumptions were made in the rainbow trout-humpback chub model. The model was tested by comparing predictions of key state variables such as recruitment, outmigration, and size at the terminal age generated using flow statistics from the historical record between 1990 and 2010 with observations and best estimates of those values for the same period. Predictions of angling catch rates were compared to annual estimates derived from creel surveys (Makinster et al. 2011). Predictions of rainbow trout abundance were compared to interannual trends from electrofishing surveys conducted by the AZGFD. Predictions of recruitment, asymptotic length, and outmigration were compared to best-fit estimates from a stock synthesis model developed by Korman et al. (2012). Overall, the predictions generated by the model resulted in a relatively good fit to historic observations and estimates.

Water temperature is a major factor affecting the distribution and abundance of fish through effects on reproduction, growth, and survival (Valdez and Speas 2007). A temperature model (Wright, Anderson et al. 2008) was used to estimate alternative-specific downstream temperatures and determine their suitability to support reproduction, growth, and survival of nonnative fish (specifically, rainbow and brown trout, smallmouth bass, green sunfish, channel catfish, and striped bass) at locations downstream of Glen Canyon Dam. The temperature suitability model assumed that the potential for self-sustaining populations of nonnative fish at specific locations is related to the combined suitability of temperatures for spawning, egg incubation, and growth of each species. Possible values for temperature suitability can theoretically range from 0 (completely unsuitable for one or more life history aspects) to 1 (magnitude and timing of temperatures would be optimal for all life history aspects). The temperature suitability modeling evaluates the potential for all life history needs to be met in the mainstem river, but some species are known to use tributaries for spawning, incubation, and growth. Thus, the model predicts relatively low temperature suitability even in some areas where species populations appear to be self-sustaining. In addition, modeled temperatures do not consider the potential for warming near tributary mouths or in shallow nearshore areas. Thus, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem Colorado River, rather than as an exact predictor of the potential for the presence or absence of nonnative fish species at particular locations.

The distribution and abundance of nonnative fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.3 Native Fish

The assessment of impacts on native fish considered the effects of alternative-specific differences in mainstem flow, water temperature, and sediment regimes on the following:

- The potential for the establishment of self-sustaining populations of native fish at selected mainstem locations;
- Changes in potential levels of competition and predation from nonnative fish;
- Potential increases in parasite infestations; and
- Main channel and nearshore habitat quality, quantity, and stability.

The evaluation of potential impacts of the alternatives on native fish included consideration of the results of previous investigations conducted below Glen Canyon Dam that examined the status and abundance of native fish (e.g., Coggins and Walters 2009; Albrecht et al. 2014; Gerig et al. 2014), as well as studies of the effects of experimental flows (such as HFEs and other flows) and water temperature on native fish (e.g., Makinster et al. 2011; Korman et al. 2010; Ward 2011; Ward and Morton-Starner 2015).

The coupled rainbow trout–humpback chub model described in Section 4.1.2.2 also was used to evaluate potential effects of alternatives on the humpback chub population in the Little Colorado River aggregation over the 20-year LTEMP period. The model estimated survival, growth, and abundance of adult humpback chub based on water temperatures and the estimated abundance of rainbow trout in the Little Colorado River reach, as well as previously reported rates (Yackulic et al. 2014). The effects of triggered mechanical removal and TMFs on trout abundance also were modeled. In order to evaluate the potential for operational scenarios to lead to extinction or improvement of the humpback chub population in the Grand Canyon, the modeled estimate of the minimum number of adult humpback chub that would occur during each 20-year simulation period was compared among alternatives.

Technical details about the humpback chub submodel are provided in Appendix F. The humpback chub submodel was based on the best available scientific information. As presented in Appendix F, the model provided a good fit between simulated adult humpback abundance and abundance estimates developed by Coggins and Walters (2009) for a period of time (1990–2008) that is separate from the period of time (2009–2013) over which most parameters were estimated. However, like all models, it is a simplified representation of the actual system it seeks to describe.

Water temperature is an important factor that affects the distribution and abundance of native fish through its effects on reproduction, growth, and survival (Valdez and Speas 2007). Species-specific models were used to estimate temperature suitability for native fish (including humpback chub) using the same methods and assumptions described in Section 4.5.1.2. As mentioned in that section, the results of temperature suitability modeling should be used to compare relative effects of alternatives on species-specific temperature needs in the mainstem Colorado River, rather than an exact predictor of the potential for the presence or absence of native fish species at particular locations.

The distribution and abundance of native fish also can be influenced by the effects of flow levels and fluctuations on the availability of low-velocity nearshore habitats, seasonal ponding of tributary mouths, sediment transport and deposition, turbidity (which may affect predation rates), and food base characteristics (Section 3.5.3). Alternative-specific flows were evaluated to assess their effects on these parameters.

4.5.1.4 Aquatic Parasites

The potential for fish parasites to expand their distribution within the river and result in infestations of native and nonnative species was examined for each alternative. Species-specific temperature suitability models, together with information on current distribution, life history, and ecological requirements (e.g., McKinney, Robinson et al. 2001; Choudhury et al. 2004; Hoffnagle et al. 2006) were used to predict the potential for each alternative to provide conditions in the mainstem river that could increase the occurrence and abundance of fish parasites at selected locations between Glen Canyon Dam and Lake Mead. The evaluations focused on four parasite species: Asian tapeworm (*Bothriocephalus acheilognathi*), anchor worm (*Lernaea cyprinacea*), trout nematode (*Truttaedacnitis truttae*), and whirling disease (*Myxobolus cerebralis*).

4.5.2 Summary of Impacts

The potential impacts of each alternative on the aquatic food base, trout, warmwater nonnative fish, native fish, and aquatic parasites are summarized in Table 4.5-1 and described in the following sections.

4.5.2.1 Aquatic Food Base

The impacts of LTEMP alternatives on the aquatic food base are expected to be negligible, beneficial, or adverse depending on the alternative. Some operational characteristics may cause both beneficial and adverse impacts (e.g., benthic productivity may increase while drift rates decrease with a reduction in daily fluctuations). The impacts are described in the following sections.

Flow Effects on the Aquatic Food Base

In general, flow effects on the aquatic food base depend on the magnitude of daily flows and the within-day and seasonal variability of those flows. The low-flow channel (permanently wetted area) supports most of the primary and secondary production in regulated rivers (Jones 2013b). Steady flows or reduced fluctuations may create conditions that allow a large standing crop of benthic algae and invertebrates to develop, particularly during spring and summer months (Leibfried and Blinn 1987; Pinney 1991; Shannon et al. 2001). Steady flows may also prevent the daily loss or reduction in size of backwaters. More stable backwaters potentially support increased planktonic and benthic communities (Reclamation 1995; Behn et al. 2010). Steady flows or reduced fluctuations may increase benthic productivity over the long term, and this will increase invertebrate drift (the preferred food of fish such as trout that feed in the water column) over the long term (Kennedy, Yackulic et al. 2014).

Flows up to 31,500 cfs do not have a large scouring effect on the aquatic food base downstream of Glen Canyon Dam, whereas flows of 41,000 to 45,000 cfs may scour a large portion of the aquatic food base (Reclamation 2011b). The highest mean daily flows for most alternatives would be <14,700 cfs (in an 8.23-maf year), except under Alternative F, which would have mean daily flows of 20,000 cfs in May and June. Thus, aquatic food base scouring would not be expected from base operations regardless of alternative. All alternatives would have HFEs of 45,000 cfs that would last up to 96 hr, while the lengthiest 45,000 cfs HFEs would be 250 hr for Alternative D and 336 hr for Alternative G. Scouring of the aquatic food base by HFEs would be expected for all alternatives. The potential extent of benthic scouring, and the subsequent length of time needed for recovery of the aquatic food base, would be higher with longer duration 45,000 cfs HFEs. Also, the number of HFEs would affect scouring and subsequent recovery of the aquatic food base. Table 4.5-2 summarizes the impact on the aquatic food base from HFEs from Glen Canyon Dam that occurred between 1996 and 2008.

The seasonal timing of HFEs (i.e., spring vs. fall) may influence the magnitude of ecological response and recovery rates of ecosystem processes. Recovery times are generally

TABLE 4.5-1 Summary of Impacts of LTEMP Alternatives on Aquatic Ecology

Aquatic Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions for the aquatic food base, nonnative fish, and native fish.	Slightly lower productivity of benthic aquatic food base, but short-term increases in drift associated with greater fluctuations in daily flows, compared to Alternative A, Habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced compared to Alternative A. Lower trout abundance and slightly higher humpback chub abundance than Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Habitat quality and stability for nonnative and native fish may be higher than under Alternative A. Higher trout abundance even with implementation of TMFs and mechanical removal, but no difference in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base and drift, compared to Alternative A. Experimental steady weekend flows may further increase productivity and diversity. Habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Negligible change in trout abundance with implementation of TMFs, and mechanical removal, and slight increase in humpback chub abundance compared to Alternative A.	Slightly higher productivity of benthic aquatic food base, and similar or increased drift, compared to Alternative A, Habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A. Lower trout abundance with implementation of TMFs and mechanical removal, and slightly higher humpback chub abundance than Alternative A	Increased productivity of aquatic food base and drift in spring and early summer, but lower rest of year compared to Alternative A. Positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Higher trout abundance and slightly lower humpback chub abundance than Alternative A.	Productivity of aquatic food base and long-term drift relatively high compared to Alternative A. Habitat stability for nonnative and native fish would be greater than under any of the other alternatives. Higher trout abundance even with implementation of TMFs and mechanical removal, and slightly lower humpback chub abundance than Alternative A.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base							
Mainstem benthic productivity	No change from current conditions and levels through 2020; no HFEs after 2020 may lower blackfly and midge production.	Slightly lower productivity compared to Alternative A due to higher daily flow fluctuations; infrequent HFEs may lower conditions favorable to blackfly and midge production.	Potential increase in productivity compared to Alternative A due to more uniform monthly flows from December through August, lower daily range in flows, and more frequent HFEs (which will favor blackfly and midge production).	Potential increase in productivity compared to Alternative A due to more uniform monthly flows and more frequent HFEs (which will favor blackfly and midge production); experimental steady weekend flows may also increase productivity and diversity.	Potential increase in productivity compared to Alternative A due to more uniform monthly flows and more frequent HFEs (which favor blackfly and midge production), but increase would be offset by higher within-day flow fluctuations.	Potential increase in productivity compared to Alternative A in spring and early summer from increased monthly flows with no daily flow fluctuations, but lower rest of year due to low steady flows; frequent HFEs will favor blackfly and midge production.	Productivity relatively high compared to Alternative A and consistent throughout the year due to relatively stable monthly flows with no daily flow fluctuations, but this may favor species that lack a terrestrial adult stage; frequent HFEs will favor blackfly and midge production.
Drift	No change from current conditions and levels, although infrequent HFEs will result in short-term drift increases.	Greater fluctuations in daily flows may increase drift compared to Alternative A. Infrequent HFEs will result in short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.; Higher weekday flows following experimental steady weekend flows may temporarily increase drift.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.	Increased drift compared to Alternative A due to increased benthic productivity. More frequent HFEs will also result in additional short-term drift increases.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Food Base (Cont.)							
Nearshore benthic productivity	No change from current conditions and levels, although no HFEs after 2020 may adversely affect backwater establishment.	Potentially lower nearshore productivity due to higher daily range in flow compared to Alternative A; infrequent HFEs throughout the LTEMP period may slightly improve backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from lower daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A based on more uniform monthly release volumes; more frequent HFEs may favor backwater establishment and maintenance.	Nearshore productivity slightly lower than Alternative A based on somewhat higher daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.	Potential increase in nearshore productivity compared to Alternative A from no daily flow fluctuations; more frequent HFEs may favor backwater establishment and maintenance.
Trout							
Spawning habitat	No change from current conditions.	Potential decrease in spawning habitat availability and stability compared to Alternative A due to higher within-day flow fluctuations during the spawning period.	Potential increase in spawning habitat availability and stability compared to Alternative A due to lower within-day flow fluctuations during the spawning period.	Slight potential decrease in spawning habitat availability and stability compared to Alternative A due to slightly greater within-day flow fluctuations during the spawning period.	Lowest spawning habitat availability and stability among all alternatives due to highest average within-day flow fluctuations during the spawning period.	Spawning habitat relatively available and stable within spring months due to absence of within-day flow fluctuations, but high flows in May and June affect availability and stability.	Greatest spawning habitat availability and stability among all alternatives due to absence of within-day flow fluctuations and even monthly distribution of flows.
Stranding	No change from current conditions and levels.	Greatest potential for increased stranding resulting from highest down-ramp rate of all alternatives	Potential increase compared to Alternative A due to higher down-ramp rate.	Similar to Alternative C.	Similar to Alternative C.	Relatively low potential for stranding compared to Alternative A due to absence of within-day flow fluctuations, but large drops in flow would occur after high flows in May and June.	Lowest potential for stranding due to absence of within-day flow fluctuations and even monthly distribution of flows.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Population size in Glen Canyon reach	No change from current conditions and levels. Estimated mean abundance 95,000 age-1 and older fish.	Small potential decrease compared to Alternative A. Estimated abundance 74,000 age-1 and older fish.	Small potential increase compared to Alternative A because of frequent HFEs and lower daily flow fluctuations. Estimated mean abundance 102,000 age-1 and older fish.	Negligible change from current condition. Estimated mean abundance 93,000 age-1 and older fish.	Small potential decrease compared to Alternative A because of higher flow fluctuations. Estimated mean abundance 88,000 age-1 and older fish.	Greatest potential increase compared to Alternative A among all alternatives because of frequent HFEs and steady flows. Estimated mean abundance 160,000 age-1 and older fish.	Similar to Alternative F. Estimated mean abundance 132,000 age-1 and older fish.
Number of fish >16 in. total length (TL) in Glen Canyon reach	No change from current condition. Estimated abundance 770 fish.	Potential increase compared to Alternative A because higher fluctuations and relatively few HFEs lower recruitment and reduces competition. Estimated mean abundance 870 fish.	Negligible change from current condition. Frequent HFEs and lower fluctuations increase recruitment but TMFs control trout numbers. Estimated mean abundance 750 fish.	Negligible change from current condition. Frequent HFEs increase recruitment but TMFs control trout numbers. Estimated mean abundance 810 fish.	Potential increase compared to Alternative A because of higher fluctuations, few spring HFEs, and implementation of TMFs lower recruitment and reduces competition. Estimated mean abundance 830 fish.	Greatest potential decrease of all alternatives because steady flows, annual spring HFEs, and no TMFs result in high recruitment and increased competition. Estimated mean abundance about 600 fish.	Potential decrease. compared to Alternative A. Steady flows and frequent HFEs result in high recruitment and increased competition, but TMFs offset increases. Estimated mean abundance about 700 fish.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Trout (Cont.)							
Emigration from Glen Canyon to Marble Canyon	No change from current conditions. Estimated mean emigration about 37,000 fish/yr.	Lowest potential emigration of all alternatives because higher fluctuations and relatively few HFEs lower recruitment. Estimated mean emigration about 30,000 fish/yr.	Potential increase in emigration compared to Alternative A. Frequent HFEs and lower fluctuations increase recruitment. Estimated mean emigration about 44,000 fish/yr.	Potential increase in emigration. Frequent HFEs increase recruitment, but offset by fluctuations and TMFs. Estimated mean emigration about 41,000 fish/yr.	Negligible change from current conditions; fewer spring HFEs, higher fluctuations, and TMFs result in low recruitment. Estimated mean emigration about 38,000 fish/yr.	Highest potential emigration of all alternatives. Annual spring HFEs, steady flows, and lack of TMFs result in high recruitment. Estimated mean emigration about 72,000 fish/yr.	Potential increase in emigration compared to Alternative A. Steady flows and frequent HFEs result in high recruitment, but TMFs offset increases. Estimated mean emigration about 59,000 fish/yr.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Some improvement in suitability at RM 61 but reduced suitability at RM 157 and RM 225.	Similar to Alternative A.
Warmwater Nonnative Fish							
Nearshore habitat quality, availability, and stability	No change from current levels and conditions.	Possible decrease compared to Alternative A due to highest ramp rates and within-day flow fluctuations of all alternatives.	Potential increase compared to Alternative A associated with lower within-day fluctuations.	Potential increase in habitat availability and stability compared to Alternative A based on more uniform monthly release volumes.	Possible decrease compared to Alternative A due to higher within-day fluctuations in most months.	Possible increase compared to Alternative A resulting from elimination of within-day flow fluctuations.	Similar to Alternative F.
Temperature suitability	No change from current levels and conditions.	Similar to Alternative A.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.	Compared to Alternative A, slight increase in average suitability at RM 157 and farther downstream.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Aquatic Parasites							
Potential for increased establishment and infestation	No change from current conditions and levels.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.
Native Fish							
Humpback chub population size	No change from current levels. Estimated average minimum number of adults about 5,000; estimated lowest minimum number of adults about 1,500.	Greatest potential increase compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,400; estimated lowest minimum number of adults about 1,900.	Negligible change from current levels. Estimated average minimum number of adults 5,000; estimated lowest minimum number of adults about 1,500.	Potential increase. compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,200; estimated lowest minimum number of adults about 1,800.	Potential increase. compared to Alternative A resulting from decreased trout recruitment. Estimated average minimum number of adults about 5,300; estimated lowest minimum number of adults about 1,600.	Greatest potential decrease of all alternatives resulting from highest increases in trout recruitment. Estimated average minimum number of adults about 4,400; estimated lowest minimum number of adults about 1,400.	Potential decrease. compared to Alternative A resulting from increased trout recruitment. Estimated average minimum number of adults about 4,700; estimated lowest minimum number of adults about 1,700.
Temperature suitability for humpback chub at aggregation locations	No change from current levels at all locations.	Similar to Alternative A.	Small potential reduction compared to Alternative A.	Similar to Alternative A.	Small potential reduction compared to Alternative A.	Greatest potential reduction compared to Alternative A.	Similar to Alternative A.
Humpback chub growth in main channel	Negligible change from current conditions. Estimated growth of YOY humpback chub in mainstem about 24 mm at RM 61 and about 50 mm at RM 213.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Greatest potential increase of all alternatives. Estimated growth of YOY humpback in mainstem about 26 mm at RM 61 and about 54 mm at RM 213.	Similar to Alternative A.

TABLE 4.5-1 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Native Fish (Cont.)							
Temperature suitability for other native fish	Negligible change from current levels at all locations.	Similar to Alternative A.	Similar to Alternative A.	Small potential increase at downstream locations compared to Alternative A.	Similar to Alternative A.	Small decrease at RM 225 compared to Alternative A.	Slight potential increase at downstream locations compared to Alternative A.
Interactions between native and nonnative fish	Negligible change from current levels for most species	Negligible change compared to Alternative A for most species. Possible decrease in humpback chub–rainbow trout interactions with reduced trout emigration to Marble Canyon reach.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative B.	Possible increase in interactions with warmwater nonnative fish at downstream locations compared to Alternative A, highest rainbow trout emigration to Marble Canyon among all alternatives may adversely affect humpback chub.	Similar to Alternative F.

TABLE 4.5-2 Impact of High-Flow Experiments from Glen Canyon Dam on the Aquatic Food Base

High Flow Event	Impact on Aquatic Food Base
45,000 cfs for 7 days, March 26–April 2, 1996	Scouring; 3 to 4 month reduction in abundance and biomass
31,000 cfs for 3 days, November 5–7, 1997	No effects detected
31,000 cfs for 3 days, May 2–4, 2000	No effects detected
31,000 cfs for 3 days, September 4–6, 2000	Some taxa and reaches affected; recovery period not determined
41,000 cfs for 2.5 days, November 21–23, 2004	Possible delayed recovery because HFE occurred in the fall after the growing season
41,500 cfs for 2.5 days, March 5–7, 2008	Reduced biomass of some taxa (e.g., New Zealand mudsnails and *Gammarus*) persisted for >1 year; enhanced drift biomass of some taxa such as midges and blackflies associated with their increased benthic production that lasted >1year

Source: Reclamation (2011b); Cross et al. (2011).

shorter for spring HFEs than for fall HFEs as a result of longer day lengths and warmer river temperatures in spring and summer. Fall HFEs precede winter months of minimal insolation, low temperatures, and reduced gross primary productivity (Cross et al. 2011). Controlled floods are expected to favor production of midges and blackflies within the Glen Canyon Dam tailwaters, apparently because the short-term adverse effects of scouring lead to an increase in future habitat quality for these organisms (Cross et al. 2011). In addition, although an HFE could reduce total invertebrate production, it may increase the amount of invertebrate prey available to rainbow trout by shifting the invertebrate assemblage toward species that are prone to drift (Cross et al. 2011). Fewer HFEs would occur under Alternatives A and B (Table 4.2-1). Therefore, these alternatives are not expected to cause long-term changes in invertebrate production due to HFEs, but neither would they favor the production of midges and blackflies in the short term after the HFE. The other five alternatives would have HFEs frequent enough to alter mainstem benthic productivity, which favors blackfly and midge production (Table 4.5-1).

Understanding the cumulative effects of multiple HFEs will be an important consideration of the experimental plan for all alternatives except Alternatives A and B (because these alternatives have relatively few HFEs during the 20-year LTEMP period). More frequent HFEs in the Grand Canyon could cause a shift to more scour-resistant taxa, resulting in an overall decrease in macroinvertebrate diversity, and possibly abundance, resulting in a reduction in the aquatic food base (Reclamation 2011a). Section F.2.2.1 (Appendix F) has a more thorough discussion of potential effects on the aquatic food base associated with more frequent HFEs.

During TMFs, drift rates should increase under the greater range of daily flow variations. No TMFs would occur under Alternative F, and TMFs would be tested under Alternative A (No

Action Alternative). TMFs would be tested and implemented, if tests are successful, for the other alternatives.

A more thorough discussion of potential flow effects on the aquatic food base is provided in Appendix F.

Temperature Effects on the Aquatic Food Base

The species composition, diversity, and production of the aquatic food base in the Colorado River could change in response to water temperature variations (Stevens, Shannon et al. 1997; Valdez et al. 2000). Blinn et al. (1989) observed that epiphytic diatom communities, which serve as an important food source for macroinvertebrates and some fish, change from upright (stalked) diatoms to closely adnate diatoms (those that grow flat on the substrate) with an increase in water temperature from 12 to 18°C (54 to 64°F). This is an important consideration because adnate forms of diatoms are generally more difficult for macroinvertebrates and fish to consume compared to stalked diatoms.

Temperature modeling results (Section 4.1.2.3) indicate that mean monthly temperatures over the 20-year LTEMP period for all alternatives will be ≤14.1°C (57.4°F) at Lees Ferry (RM 0) and the confluence with the Little Colorado River (RM 61). Thus, temperature differences among the alternatives are not expected to alter the diatom composition in the Glen Canyon or Marble Canyon reaches of the Colorado River. However, at Diamond Creek RM 225 (Grand Canyon reach), mean summer temperatures (July through September) for all alternatives would be high enough (e.g., ≥17°C [63°F]) to potentially favor adnate diatom species (see Table F-5, Appendix F). Mean monthly temperatures at Diamond Creek would be highest for Alternative F ranging from 18.5 to 20.5°C (65.3 to 68.9°F) and least for Alternatives A and B ranging from 17.2 to 17.5°C (63.0 to 63.5°F). However, increased algae production in the Grand Canyon reach, may not be realized because this reach is strongly light-limited due to higher turbidity levels.

Section 3.5.2 describes the improved aquatic food base conditions provided by *Cladophora* compared to *Oscillatoria* (types of algae). Light and flow conditions are the primary factors that affect the presence of these organisms in the Colorado River even though modeled monthly temperatures near Lees Ferry and the Little Colorado River otherwise favor the presence of *Cladophora*, which has a favorable temperature range of 13 to 17°C (55 to 63°F), compared to *Oscillatoria*, which has a favorable temperature range of 18 to 21°C (64 to 70°F) (Valdez and Speas 2007). This also applies to the Diamond Creek area, although modeled water temperature conditions in late spring and summer would favor *Oscillatoria* over *Cladophora* for all alternatives, particularly Alternative F where monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) (see Table F-5, Appendix F). Because conditions at Diamond Creek are already more suitable for *Oscillatoria* (which is more tolerant of turbidity) than *Cladophora*, it would remain more prevalent in the Grand Canyon reach.

The modeled mean monthly temperatures in the Colorado River downstream of Glen Canyon Dam are within the favorable temperature range for most macroinvertebrates (see

Table F-7, Appendix F). However, the modeled mean monthly temperatures for all alternatives for January through April range from 8.7 to 9.9°C (47.7 to 49.8°F) at Lees Ferry, which is below the lowered favorable temperature of 10°C (50°F) for blackflies (Valdez and Speas 2007). The modeled mean monthly temperatures would also be below favorable temperatures for blackflies near the Little Colorado River for February and March. Conversely, modeled monthly temperatures of 17.2 to 20.5°C (63.0 to 68.9°F) for July through August near Diamond Creek under all alternatives would be higher than the upper favorable temperature for planarians 16°C (61°F) (Valdez and Speas 2007).

Production rates of macroinvertebrates could increase by 3 to 30% for every 1°C (1.8°F) increase in annual temperatures (Valdez and Speas 2007). Temperature modeling results indicate that annual average temperatures would vary among alternatives by ≤0.2°C (0.4°F) at Lees Ferry, Little Colorado River, and Diamond Creek. This implies that temperature differences among alternatives are not likely to affect production of aquatic food base organisms. However, comparison of monthly average temperatures indicates a potential small difference among some of the alternatives during the summer at Diamond Creek. Most temperature differences among alternatives would be <0.5°C (0.9°F) and therefore not considered significant. However, Alternative F would be as much as1.5 to 3.0°C (2.7 to 5.4°F) higher than the other alternatives in the summer. Thus, summer macroinvertebrate productivity could be higher under Alternative F compared to the other alternatives.

A more thorough discussion of potential temperature effects on the aquatic food base is provided in Appendix F.

4.5.2.2 Nonnative Fish

The potential impacts of the alternatives on nonnative fish are described in this section and summarized in Table 4.5.2-1. Because of distinct differences in habitat needs and distributions, impacts on coldwater nonnative fish (trout) and warmwater nonnative fish are considered separately.

Impacts on Trout

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; McKinney, Robinson et al. 2001; Makinster et al. 2011; Wright and Kennedy 2011; Korman, Kaplinski et al. 2011; Korman et al. 2012). Increases in abundance have been attributed to the changes in flows beginning with interim flows in 1991 and later the implementation of MLFF in 1996. These changes both increased minimum flows and reduced fluctuations in daily flows, which created more stable and productive nursery habitats for rainbow trout in Glen Canyon (McKinney et al. 1999). Declines in abundance (such as observed from 2001 to 2007) have been attributed to the combined influence of warmer water releases from Glen Canyon Dam, high abundance and increased competition, and periodic DO deficiencies, along with possible limitations in the food base (Makinster et al. 2007). Increases in recruitment levels and 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 March 2008 HFE (Makinster et al. 2011).Recruitment of rainbow trout in Glen Canyon has been positively and strongly correlated with annual flow volume and reduced hourly flow variation; recruitment has also increased after two of three high-flow releases related to the implementation of equalization flows (Korman et al. 2012). 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. When abundance of rainbow trout is high, their condition typically deteriorates, so large numbers of fish generally also lead to fish of poorer quality to anglers in terms of size and condition (Makinster et al. 2011) and can also lead to declines in abundance.

Because rainbow trout spawning occurs mostly in the main channel of the Glen Canyon reach, the quality and availability of rainbow trout spawning habitat are expected to be affected by within-day flow fluctuations (McKinney, Speas et al. 2001; Korman, Kaplinski et al. 2011; Korman and Melis 2011), which vary among the alternatives. Within-day flow fluctuations in this reach may act to periodically dewater some spawning areas (redds) while down-ramping may strand larval or YOY rainbow trout (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011). Recent captures of young-of-the-year trout in the vicinity of the Little Colorado River confluence suggest that there may be some rainbow trout spawning in lower Marble Canyon; the degree to which spawning and recruitment of trout in this portion of the river might be affected by flow manipulations, including TMFs, is not clear. Mainstem spawning and recruitment of brown trout (*Salmo trutta*) in the Grand Canyon are thought to be limited because of unsuitable temperatures, competition from rainbow trout, and limited availability of suitable habitat for spawning and rearing of YOY trout (Makinster et al. 2010; Reclamation 2011a,b). Because brown trout reproduction primarily occurs in tributaries, especially in Bright Angel Creek (Reclamation 2011a, b), their spawning habitats generally would not be affected by the flows associated with any of the alternatives. The following discussion focuses on potential effects of the alternatives on rainbow trout.

Evaluation of the stability of rainbow trout spawning habitat for each of the alternatives considered the average allowable daily fluctuation and the evenness of the monthly volumes during the peak spawning months (March through May). Under Alternative A, no changes from current conditions are expected in spawning habitat availability or stability. Rainbow trout spawning habitat would be less stable under Alternatives B and E than under Alternative A because both would allow greater levels of within-day fluctuations during the peak spawning months. Alternative E is expected to have the lowest stability since daily fluctuations and variation in monthly volumes are slightly greater than under Alternative B during the peak spawning months, although the differences are small. Compared to Alternative A, Alternatives D and C would have lower allowable within-day fluctuations, similar or greater monthly volumes, and less variable monthly volumes during the spawning period; as a consequence, rainbow trout spawning habitat availability and stability under Alternatives D and C would be higher than under Alternative A. The two steady flow alternatives (Alternatives F and G) would provide the greatest level of spawning habitat stability.

Because of differences in down-ramp rates for base operations (i.e., not considering effects of HFEs and TMFs), the potential for stranding of YOY trout is expected to vary among the alternatives (Table 4.5-1). Potential for stranding under Alternative A is expected to be similar to that under current conditions. Stranding potential under Alternative G would be the lowest since there would be no within-day fluctuations for hydropower generation and relatively small down-ramping events between months. Although Alternative F would also exclude within-day fluctuations for hydropower operations, there would be large drops in flows after the annual 45,000 cfs spike releases that would occur in May and after the week-long 25,000 cfs high flow that precedes the drop to base flows at the end of June; as a consequence, stranding of YOY trout could be significant under this alternative. Compared to Alternative A, the greatest increase in stranding potential would occur under Alternative B, which has down-ramp rates 100% to 166% higher than any of the other alternatives. Alternatives C, D, and E may have a similar increased stranding potential, with down-ramp rates 66% higher than under Alternative A. As noted above, the degree to which spawning and recruitment of trout in lower Marble Canyon (i.e., in the vicinity of the Little Colorado River) might be affected by flow manipulations, including TMFs, is not clear.

As described in Section 4.5.1.2, a coupled rainbow trout–humpback chub model, which considers effects of flow variability, annual volumes, HFEs, and TMFs, and effects of annual trout numbers was used to evaluate potential effects of alternatives on the number and average size (length) of rainbow trout in the Glen Canyon reach, on the number of rainbow trout in the Glen Canyon reach exceeding 16 in. in total length, and on the number of age-0 rainbow trout expected to move into the Marble Canyon and Little Colorado River reaches over the 20-year LTEMP period. Among the alternatives, the model estimated average abundances of age-1 (i.e., individuals that are 1 year old) and older rainbow trout over the 20-year LTEMP period that ranged from about 65,000 to 196,000 individuals in the Glen Canyon reach (Figure 4.5-1). Although there is a considerable amount of overlap in the ranges of the estimates for some alternatives, the overall estimated average rainbow trout abundance in the Glen Canyon reach was greatest under Alternatives F and G and lowest under Alternative B, with intermediate abundance levels under Alternatives A, C, D, and E.

The model that predict that annual recruitment of rainbow trout will increase as a function of greater annual volumes, reduced daily variation in flow between May and August, and the occurrence of spring floods (see Appendix F). Modeling indicated that alternatives with more frequent HFEs (especially spring HFEs) would have higher recruitment rates. This increase could lead to increased mean abundance of rainbow trout, but could be offset by TMFs lowered recruitment rates and tended to decrease mean abundance; including both flow actions in an alternative would be expected to result in intermediate levels of trout abundance, with TMFs effectively controlling excess trout produced after HFEs. However, TMFs are considered an experimental action, and it is uncertain whether TMFs would be effective in controlling trout recruitment over the life of the plan. Appendix F presents differences in modeled trout abundance for some alternatives with HFEs and TMFs included or not included as management options. Because of the effects of trout density on growth rates due to competition for food and other resources, it is expected that the average size of rainbow trout would decrease as average population size increases (Korman, Kaplinski et al. 2011). Modeling results indicated that the average size

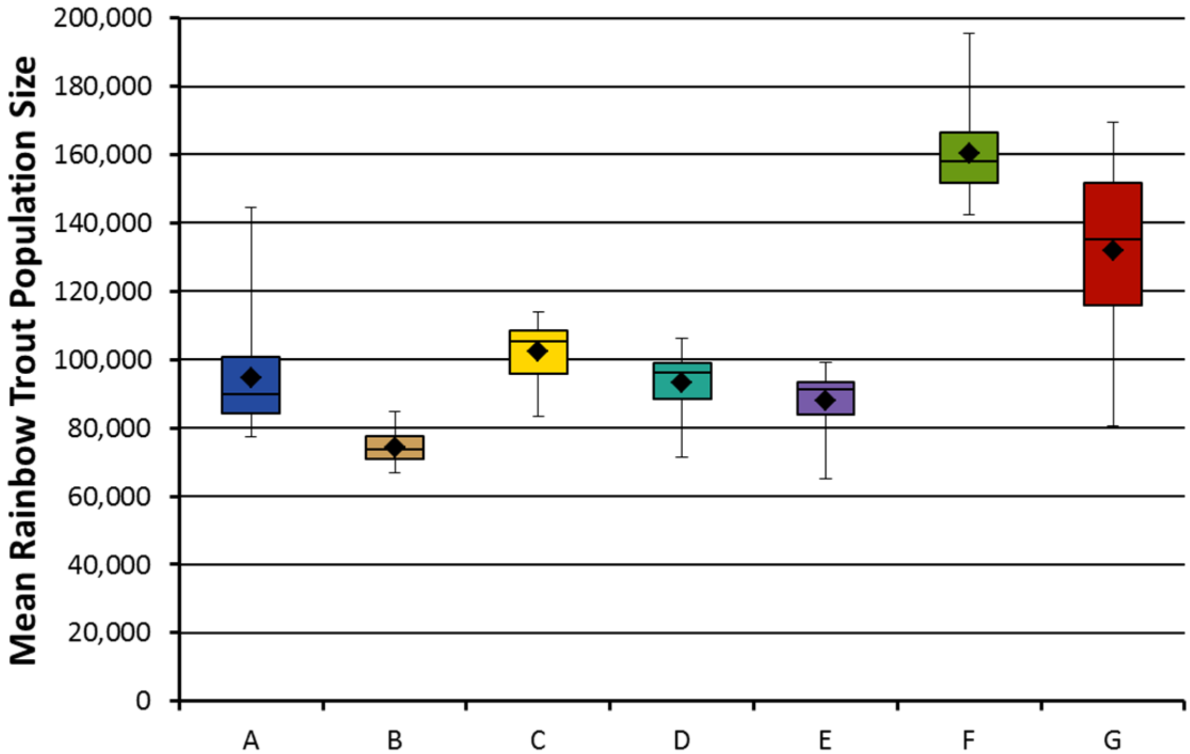

FIGURE 4.5-1 Modeled Average Population Size of Age-1 and Older Rainbow Trout in the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 21 Hydrology Scenarios (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum. Means were calculated as the average for all years within each of the 21 hydrology runs.)

of age-1 and older rainbow trout over the LTEMP period would be greatest under Alternative B, smallest under Alternatives F and G, and intermediate under Alternatives A, C, D, and E (see Appendix F).

The results of the trout modeling for LTEMP alternatives are consistent with historic observations and previous research, which suggests that recruitment of rainbow trout will be higher in years with higher annual release volumes from Glen Canyon Dam, in years with HFEs (especially spring HFEs), and in years with lower levels of within-day fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012; Section 3.5.4). Equalization flows, which would occur under all alternatives, are also expected to result in increased rainbow trout recruitment during years in which they occur. The high spring flows of Alternative F and spring HFEs would have similar effects on trout recruitment. Considering the frequency of HFEs alone (Table 4.2-1), average annual rainbow trout recruitment would be expected to be highest under Alternatives C, D, F, and G, and would be lowest under Alternatives A and B. It should be noted, however, that the effects of fall HFEs on trout recruitment are less certain and altering assumptions regarding the strength of the relationship between recruitment levels and fall HFEs could significantly affect the modeled results regarding relative effects of alternatives on average numbers of YOY trout, average numbers of trout emigrating to Marble Canyon, and average abundance of age-1 and older rainbow trout in the Glen Canyon reach during the LTEMP period.

Potential increases in rainbow trout recruitment levels due to equalization flows and HFEs could be offset in some years by the proposed testing and implementation of TMFs for all alternatives except Alternative A and F, which do not include TMFs. TMFs are highly variable flows intended to control the number of YOY trout in the Glen Canyon reach (and the associated emigration of trout into Marble Canyon) that would be implemented in years where production of YOY trout is expected to be high. YOY trout tend to occupy shallow habitats near the channel margin (Korman and Campana 2009; Korman and Melis 2011). Based on information from previous studies, raising the flow for a period of days and then suddenly dropping the flow is expected to strand and kill YOY trout, thus controlling numbers and emigration rates (Korman and Melis 2011). As currently envisioned, a typical TMF would consist of several days at a relatively high sustained flow (e.g., 20,000 cfs) followed by a rapid drop to a low flow (e.g., 5,000 cfs), which is held for a brief period (e.g., 6 hr) (Sections 2.2.3.2). This pattern would be repeated for a number of cycles in spring and summer months (May–July). Because of uncertainties about the effectiveness of TMFs, the timing, magnitude, duration, and number of cycles would be tested for efficacy in controlling trout numbers early in the LTEMP period. The number of TMFs that would be expected to occur under each alternative based on modeling are presented in Table 4.9-3 and in Appendix F (Table F-8).

The number of trout emigrating from the Glen Canyon reach into the Marble Canyon reach of the Colorado River was modeled as a function of recruitment levels, which is related to annual volumes, the occurrence of HFEs, the levels of within-day fluctuations during each water year, and whether TMFs are included as a management option for an alternative. The model estimated that average annual emigration of rainbow trout would be highest under the two steady flow alternatives (Alternatives F [about 72,000 fish/year] and G [about 59,000 fish/year]) and lowest under the alternative with the widest daily fluctuations (Alternative B [about 30,000 fish/year]); the model estimated that Alternatives A, C, D, and E would have intermediate levels of rainbow trout emigration (about 37,000 to 44,000 fish/year) (Figure 4.5-2).

As a measure of the quality of the rainbow trout fishery, the trout model was also used to estimate the average annual number of large rainbow trout (i.e., individuals with total lengths exceeding 16 in.) in the Glen Canyon reach. Among the alternatives, the estimated average number of large rainbow trout in the Glen Canyon reach would range from about 500 to 950 fish (Figure 4.5-3). The estimated average number of large trout present during the 20-year LTEMP period would be greatest under Alternative B (about 870 fish) and lowest under Alternatives F (about 590 fish) and G (about 700 fish), while Alternatives A, C, D, and E would produce intermediate numbers of large trout (about 770, 750, 810, and 830 fish, respectively). In general, growth rates and the number of large rainbow trout in the Glen Canyon reach are expected to be greater in years when overall population abundance is lower due to reduced competition for food and habitat. Because of their effect on recruitment levels and population size, alternatives that

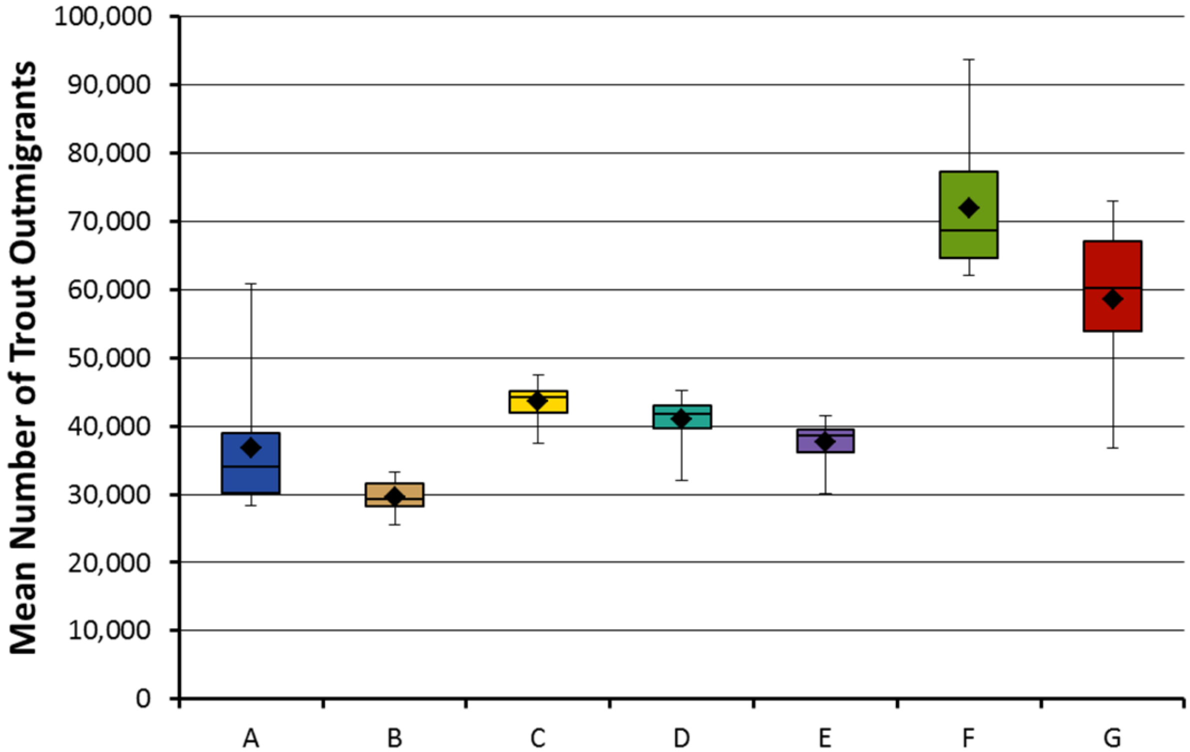

FIGURE 4.5-2 Modeled Annual Average Number of Rainbow Trout Emigrating into the Marble Canyon Reach from the Glen Canyon Reach during the 20-Year LTEMP Period under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

have fewer HFEs (especially spring HFEs), higher daily fluctuations, or implement TMFs are expected to have more large trout.

In general, temperature regimes under all of the alternatives would be suitable, although not optimal, for brown and rainbow trout. Temperature suitability for brown and rainbow trout would be similar among alternatives at most locations downstream of Glen Canyon Dam (Figure 4.5-4), and would be similar to current conditions. However, because of the timing of peak and base flow releases, temperature suitability would be slightly greater under Alternative F than other alternatives at the confluence with the Little Colorado River (RM 61) and lower than other alternatives for locations further downstream. Although main channel temperatures at and downstream of RM 61 would be more suitable for trout than at locations closer to the dam (Figure 4.5-4), the abundance of trout is lower at those locations because other habitat characteristics (e.g., substrate composition and water clarity) are less suitable at these downstream locations.

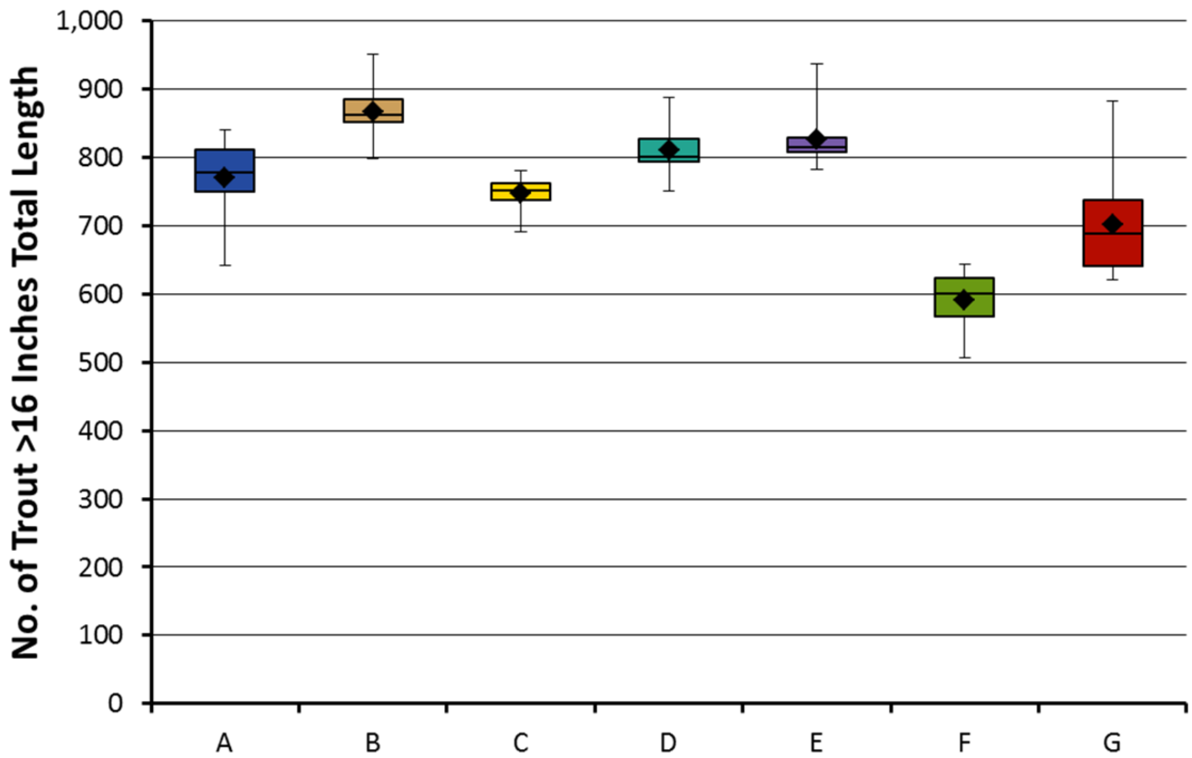

FIGURE 4.5-3 Modeled Mean Annual Number of Rainbow Trout in the Glen Canyon Reach Exceeding 16 in. Total Length during 20-Year Simulation Periods under the LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Impacts on Warmwater Nonnative Fish

As described in Section 3.5.4.2, 17 nonnative warmwater fish species have been documented between Glen Canyon Dam and the inflow to Lake Mead (Table 3.5-2). The distribution and abundance of warmwater nonnative fish could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. Of these factors, only the effects on temperature were considered to potentially be large enough to result in impacts on warmwater nonnative fish. To examine this effect, temperature suitability was modeled at various main channel locations for four nonnative warmwater species considered to be representative of the warmwater nonnative fish community (smallmouth bass [*Micropterus dolomieu*], green sunfish [*Lepomis cyanellus*], channel catfish [*Ictalurus punctatus*], and striped bass [*Morone saxatilis*]). In general, the estimated average main channel temperature suitability for these nonnative fish did not differ greatly among the alternatives, and was low under all alternatives; the suitability index was below 0.2 on a scale of 0 to 1 for all seven alternatives (Figure 4.5-5). The modeled temperature suitability indicated that temperature conditions would be most suitable for warmwater nonnative species at locations farther downstream from Glen Canyon Dam (e.g., RM 157 and RM 225) compared to upstream locations (e.g., RM 0 and RM 61); this agrees with past surveys that have found more warmwater nonnative fish species in

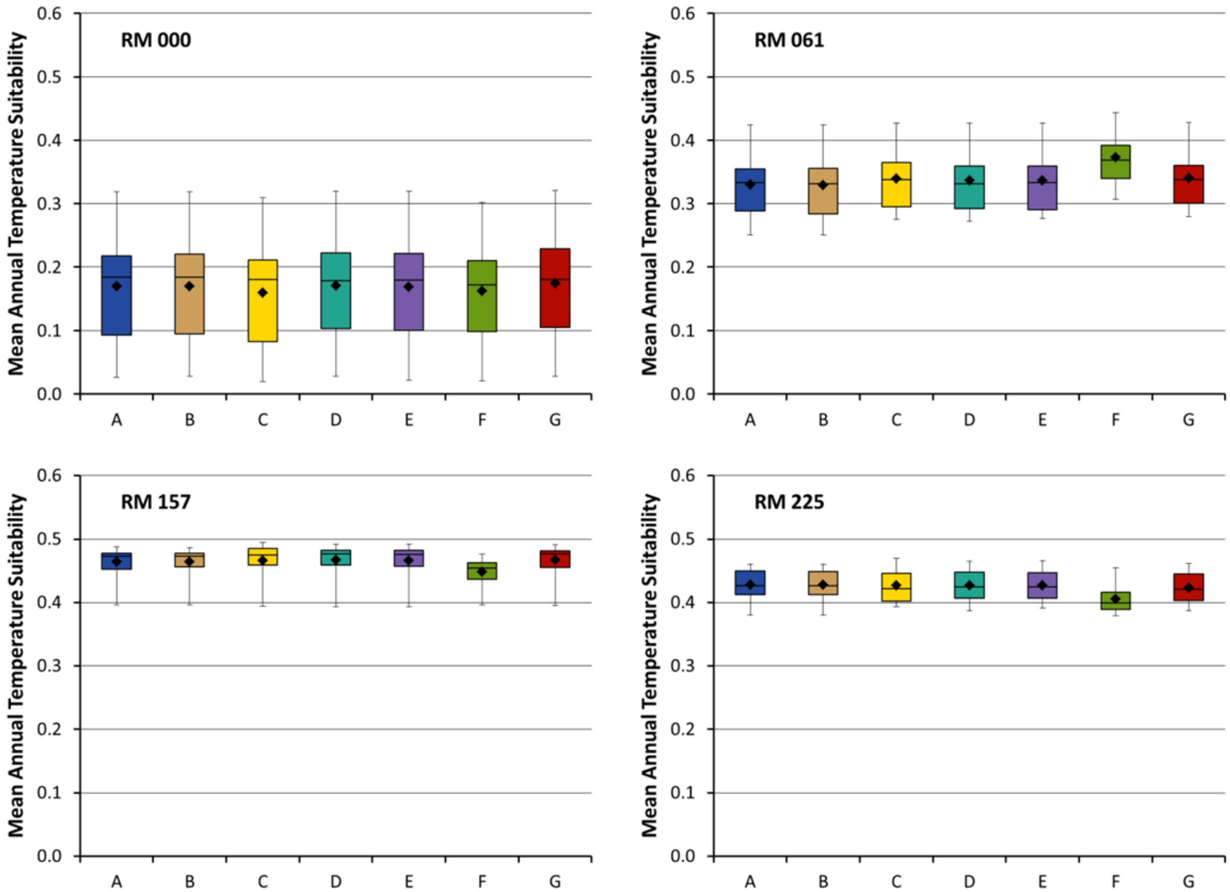

FIGURE 4.5-4 Modeled Mean Annual Temperature Suitability for Rainbow and Brown Trout under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

those areas. Relative to current conditions (as exemplified by Alternative A), the temperature suitability model indicated that Alternatives C and F have the greatest potential to improve conditions for warmwater nonnative fish at locations downstream of RM 157, which could result in increased numbers and a greater potential for upstream spread of warmwater nonnative fish species.

The Basin Study (Reclamation 2012a) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. Water elevations in Lake Powell could continue to decline, resulting in release of unprecedentedly warm epilimnetic and metalimnetic water through the penstocks. Summer water releases of up to 30°C water could facilitate establishment of detrimental warmwater fish with correspondingly detrimental impacts on native species, including humpback chub, and on the rainbow trout fishery. Although outside the scope of the LTEMP DEIS, effective management options to address warmwater species threats under this scenario may be limited to construction

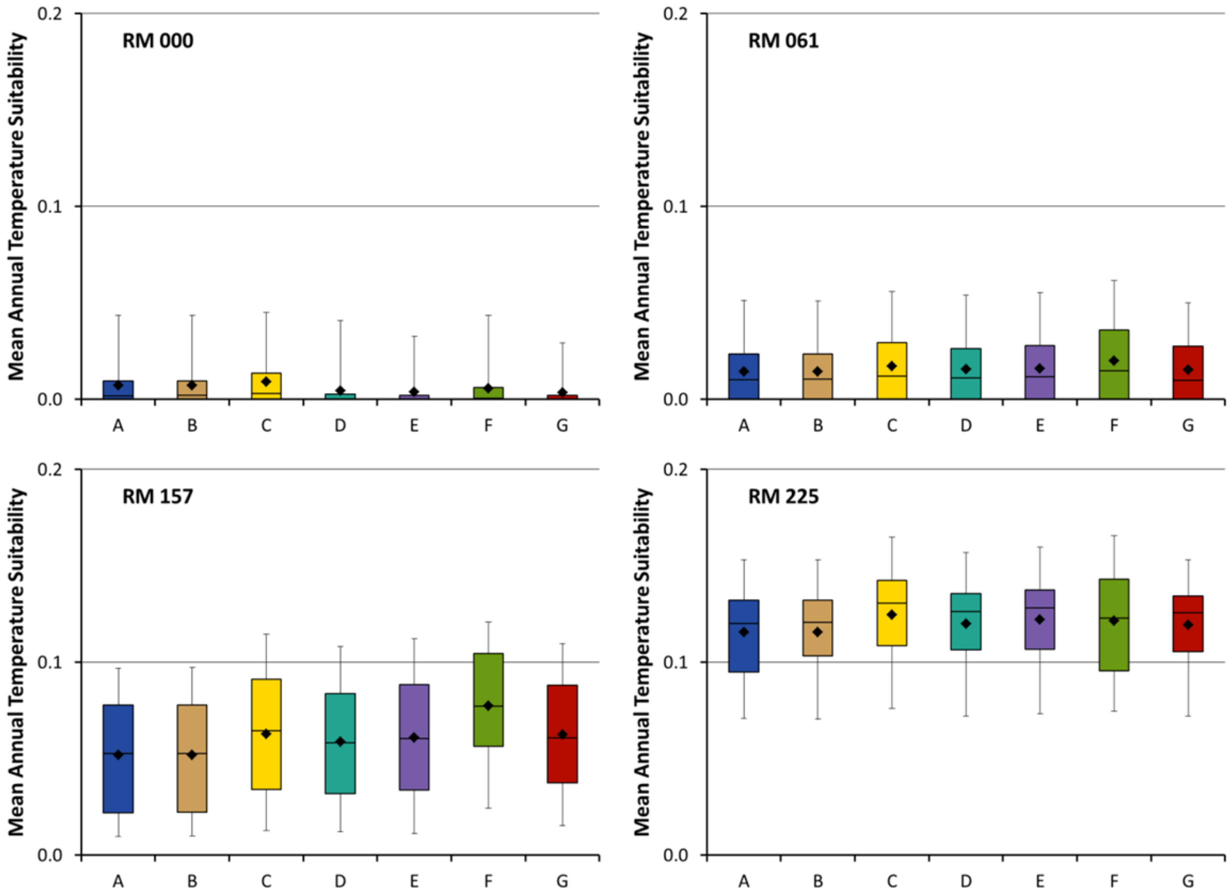

FIGURE 4.5-5 Modeled Mean Annual Temperature Suitability for Warmwater Nonnative Fish (smallmouth bass, green sunfish, channel catfish, and striped bass) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

of a hot and cold temperature control device for the hydropower intakes at Glen Canyon Dam or delivery of cooler water via bypass tubes.

4.5.2.3 Native Fish

Humpback Chub

Relatively little spawning and juvenile rearing of humpback chub occurs in the mainstem of the Colorado River, primarily because of relatively cold water (Andersen 2009). This species requires a minimum temperature of 16°C to reproduce, but mainstem water temperatures typically have ranged from 7 to 12°C during the spawning period (Andersen 2009). Drought-induced lower reservoir levels have resulted in warmer releases and mainstem water temperatures since 2003; temperatures have consistently exceeded 12°C in the summer and fall, and may have played a role in the recent observed increase in the humpback chub population (Andersen 2009; Coggins and Walters 2009; Yackulic et al. 2014).

Although survival of larval and juvenile humpback chub in the mainstem was very rare prior to 2000 (Clarkson and Childs 2000), mainstem conditions since the mid-2000s appear to have been suitable for juvenile growth, survival, and recruitment (Yackulic et al. 2014). Warmer water has been shown in the laboratory to increase hatching success, larval survival, and larval and juvenile growth; to improve swimming ability; and to reduce predation vulnerability from rainbow trout (Ward 2011; Ward and Morton-Starner 2015). Yackulic et al. (2014) speculated that when water temperatures are favorable, growth and survival of juveniles in the mainstem will be greater, resulting in increased mainstem recruitment and a larger adult population.

Under all alternatives, main channel water temperature at humpback chub aggregation areas was estimated to continue to be relatively low for spawning and egg incubation during spring and early summer at most locations downstream of Glen Canyon Dam (Figure 4.5-6). Modeled mean annual main channel temperature suitability for humpback chub at RM 61 (the Little Colorado River confluence) was slightly higher under Alternative F than under the other alternatives (Figure 4.5-6), because the low summer and fall flows of this alternative resulted in warmer water during these months. Because the water warms as it travels downstream from the dam, temperature suitability improves with increasing distance. At RM 213, mean annual temperature suitability was highest under Alternatives A, B, D, and G, and slightly lower under Alternatives C and E (Figure 4.5-6), although overall differences were small among these alternatives. Modeled temperature suitability at RM 213 was lowest under Alternative F (Figure 4.5-6), reflecting the higher, colder flows expected to occur under this alternative during spawning and egg incubation periods (April through June). Based on these results, the combined suitability of mainstem temperatures for spawning, egg incubation, and growth by humpback chub in the downstream-most aggregation sites is anticipated to be negatively affected under Alternative F; however, for the other alternatives, this would remain similar to the low historic levels, as represented by the suitability of Alternative A (the No Action Alternative). It should be noted that, historically, there have been years where the magnitude and timing of mainstem water temperatures have likely coincided to allow spawning and egg incubation to occur in some of the downstream aggregation areas; however, the overall average suitability, as measured by the models used in this analysis, has likely been low.

Based on temperature-dependent growth relationships developed by Robinson and Childs (2001), mean total lengths of YOY humpback chub at the end of their first growing season would differ little among the alternatives, although values under Alternative F could be slightly higher than under other alternatives (Figure 4.5-7). In addition, YOY humpback chub that rear in the main channel would be expected to reach a greater mean total length (approximately two times longer) by the end of the first calendar year at the Pumpkin Spring aggregation location (RM 213) than at the confluence with the Little Colorado River (RM 61) due to warming of the water as it travels downstream from Glen Canyon Dam (Figure 4.5-7).

HFEs, TMFs, and low summer flows would be included in many of the alternatives, but none of these flow actions would result in more than a 1 or 2°C change in

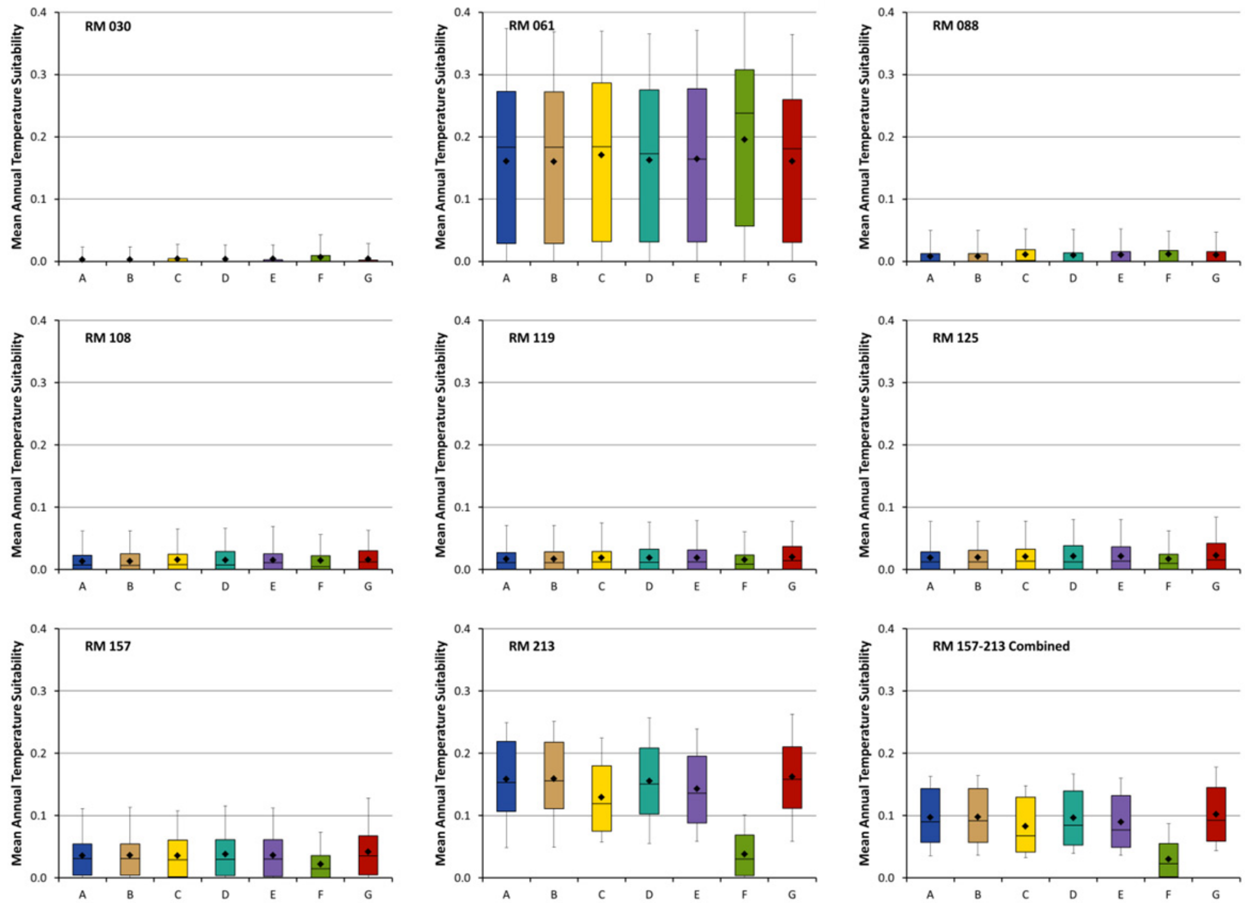

FIGURE 4.5-6 Mean Annual Mainstem Temperature Suitability for Humpback Chub under LTEMP Alternatives at Reported Aggregation Locations and Combined Temperature Suitability for RM 157 and RM 213 Locations (Temperature suitability is higher at RM 61 because spawning, incubation, and rearing values are based on temperatures in the relatively warm Little Colorado River where these life history elements occur. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

average monthly water release temperatures or downstream water temperatures during periods of the year considered most important for spawning and egg incubation (i.e., April through June) at any of the humpback chub aggregation locations.

Adult humpback chub numbers were modeled for each alternative under a range of hydrologic and sediment conditions. Overall, the minimum population sizes observed among the alternatives during the 20-year simulations ranged from 1,441 to 13,478 humpback chub (Figure 4.5-8). The lowest modeled minimum adult population size (1,441 fish) was observed under Alternative F, although the lowest minimum adult population values were relatively similar among all alternatives (1,441 to 1,912 adult fish). Similarly, the highest minimum numbers of adult humpback chub were similar among all the alternatives, with values exceeding 13,100 adult fish. The modeled average minimum population size ranged from 4,450 fish under

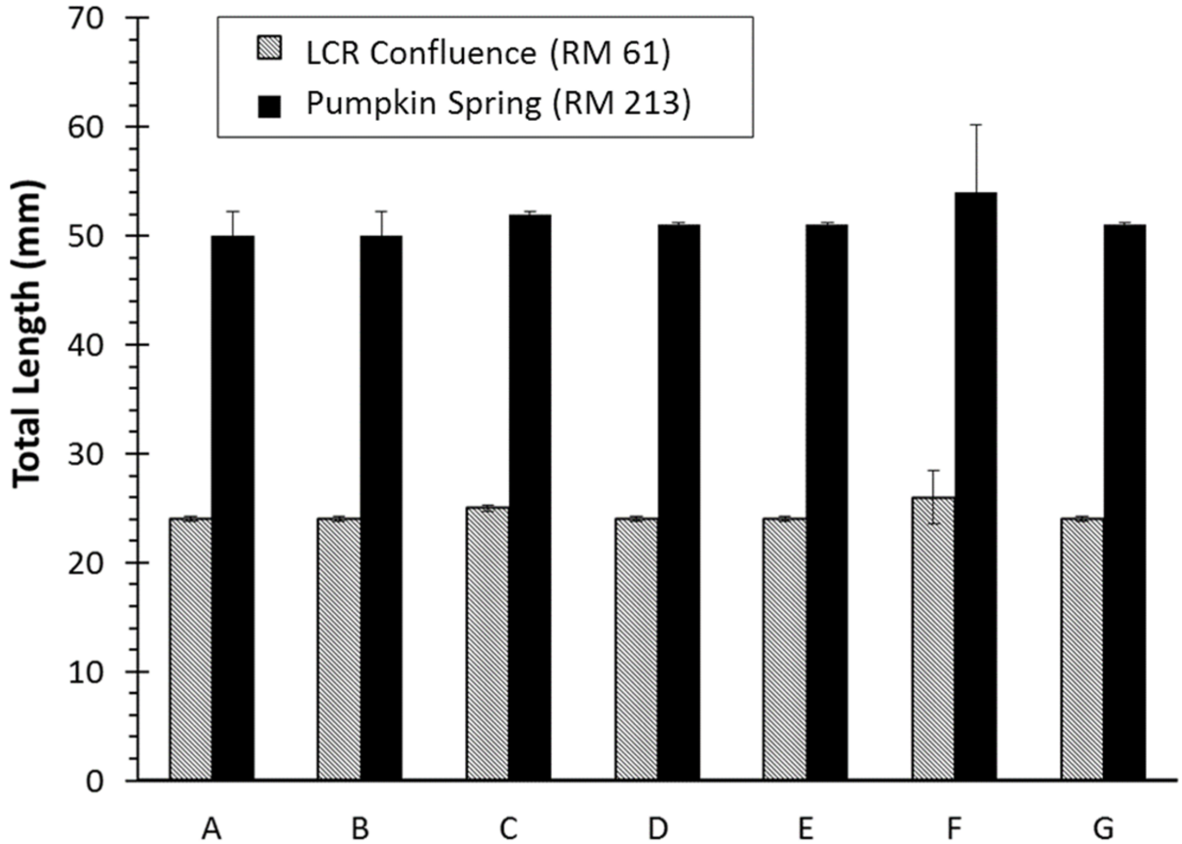

FIGURE 4.5-7 Mean (±1 standard error [SE]) Modeled Total Length Attained by December 31 for YOY Humpback Chub Based on Predicted Mainstem Water Temperatures at the Little Colorado River Confluence (RM 61) and at Pumpkin Spring (RM 213) under Each Alternative (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Alternative F to 5,392 fish under Alternative B (Figure 4.5-8). The average minimum number of adult humpback chub was highest for Alternatives B, D, and E, slightly lower under Alternatives A and C, and lowest under Alternatives F and G (Figure 4.5-8). These results indicate that although there are small differences among the alternatives with regard to the predicted minimum number of adult humpback chub in the Little Colorado River aggregation, all alternatives would maintain the population above at least 1,000 adults throughout the 20-year LTEMP period.

The differences in estimated minimum numbers of adult humpback chub among the alternatives were related, in part, to the estimated levels of recruitment of rainbow trout in the Glen Canyon reach, and to the resulting emigration of rainbow trout to the Little Colorado River reach where survival of YOY and juvenile humpback chub and subsequent recruitment of adult humpback chub could be affected by increased competition and predation from these trout (e.g., Yard et al. 2011). As previously discussed, observations indicate that both rainbow trout recruitment and emigration would increase with implementation of HFEs and with reduced

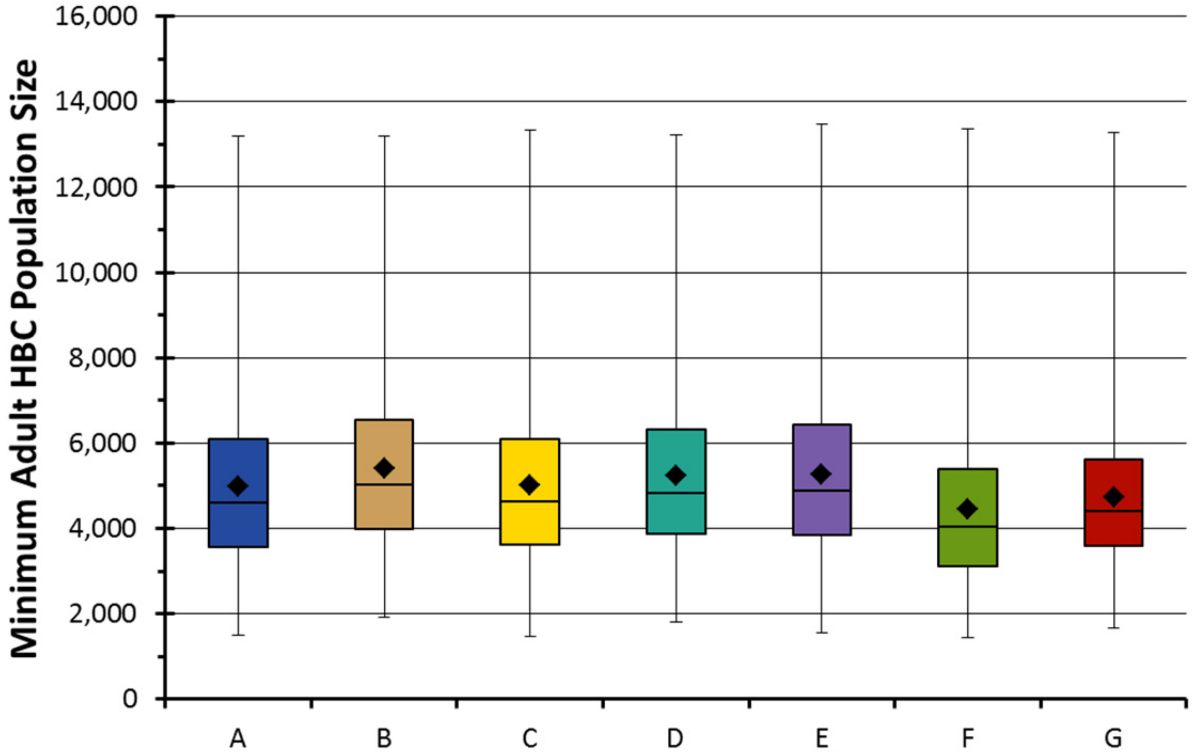

FIGURE 4.5-8 Modeled Minimum Population Size for Humpback Chub during the 20-Year LTEMP Period under LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

levels of daily fluctuations (Korman, Kaplinski et al. 2011; Korman et al. 2012). Alternatives with the most HFEs over a 20-year period are Alternatives C (mean of 21 HFEs), D (mean of 21 HFEs), F (mean of 19 sediment-triggered HFEs and an additional 19 non-triggered 45,000 cfs flow spikes in early May), and G (mean of 24 HFEs). Alternatives F and G additionally have no within-day fluctuations in flows and, consequently, are expected to have the lowest minimum population levels for adult humpback chub. Although water temperatures will alter the effect of trout on humpback chub survival and recruitment in some years (e.g., periods when lower reservoir elevations result in warmer releases), the overall differences in temperature regimes among the alternatives over the 20-year periods evaluated are expected to be relatively small. Based on results of laboratory studies on the effects of temperature on predation of humpback chub by trout (Ward and Morton-Starner 2015), the temperature-mediated differences in predation rates by trout among the various alternatives would be negligible.

TMFs are designed to cause mortality in YOY rainbow trout by inundating low-angle, near shore habitats for several days, and then quickly reducing dam discharge which would strand YOY fish. Although TMFs target the Glen Canyon area, where most rainbow trout production occurs, stage changes from the TMFs also will occur downstream in Marble and Grand Canyons (see discussion in Section 3.2.1.2). Thus, stranding of native fish further downstream could also occur, including the stranding of endangered humpback chub and razorback sucker.

Aquatic habitats along the river margin, including backwaters, and other slack water habitats may be important for juvenile native fish rearing because water temperatures may be warmer than in the main channel, and due to the presence of cover such as inundated roots, and overhanging and rooted vegetation. In monthly sampling of randomly selected larval fish habitats from Lava Falls (approx. RM 180) to Lake Mead between March and September, 2014, Albrecht et al. (2014) found that small-bodied YOY native fish catch rates in slack water and channel margins were highest in June through August. Endangered YOY humpback chub were first captured in May and were captured in all months until September, while larval razorback sucker were captured in the first four months of sampling (April–July; Albrecht et al. 2014). In Marble Canyon near the Little Colorado River inflow, Dodrill et al. (2015) showed that juvenile native fish, including humpback chub, can occur in high densities in backwaters and other channel margin habitats.

The extent of mortality due to stranding of native fish, including endangered species, in a given year in Marble and Grand Canyons as a result of TMFs is unknown, and may depend on the quantity of channel margin habitats and their sensitivity to flow changes, the distribution and abundance of juvenile fish in sensitive habitats, the timing and number of TMFs, and the degree of attenuation of flows downstream. TMFs could be implemented from May through August, and this would overlap with the presence of larval fish for many of the native fish species. Given that razorback sucker spawning was documented for the first time in in the study area in 2014 and studies are ongoing, potential impacts on the species are particularly difficult to predict. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected, an unknown number of native fish could also suffer mortality as a result of TMFs, downstream in GCNP. Risk to native fish would likely vary by location depending upon the level of stage changes that would be experienced and the steepness of shallow nearshore areas. Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Impacts on Other Native Fish

The distribution and abundance of native fish (other than humpback chub) could be affected by alternative-specific differences in temperature regimes, food production, sediment dynamics, and flow patterns. For the endangered razorback sucker (*Xyrauchen texanus*), suitable water temperatures for spawning, egg incubation, and growth range from 14 to 25°C (FWS 2002a), with estimated optimal temperatures of 18°C for spawning, 19°C for egg incubation, and 20°C for growth (Valdez and Speas 2007). Hatching success is temperature dependent, with complete mortality occurring at temperatures less than 10°C (AZGFD 2002a). Young razorback suckers 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). During May of 2014, razorback sucker larvae were found in the Colorado River as far upstream as RM 173 (upstream of Lava Falls), which is the farthest upstream razorback sucker spawning has been documented in the Grand Canyon (Albrecht et al. 2014). Additional larval sampling in the lower Grand Canyon found razorback sucker larvae to be distributed throughout most shoreline habitats from Lava Falls to Pearce Ferry from May to July and life stages from larvae through subadults are likely occur within these sections of the river. The highest density of larvae were found in isolated pools, which composed less than 2% of all habitat sampled.(As noted above, TMFs have the potential to strand razorback sucker and other native sucker larvae as well as rainbow trout).

Two additional species of native suckers—bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*C. latipinnis*)—occur in the Colorado River between Glen Canyon Dam and the headwaters of Lake Mead. Bluehead sucker spawning occurs at water temperatures >16°C (AZGFD 2003a; NPS and GCNP 2013); spawning is primarily limited to tributaries. In the Grand Canyon, flannelmouth suckers spawn at water temperatures ranging from 6 to 18°C in or near a limited number of tributaries, especially the Paria and Little Colorado Rivers (AZGFD 2001b; Weiss et al. 1998; Douglas and Douglas 2000), and Bright Angel Creek (Weiss et al. 1998). Flannelmouth sucker larvae, juveniles, and adults were encountered in the mainstem Colorado River of the lower Grand Canyon during surveys conducted in 2014 (Albrecht et al. 2014). Spawning 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). In the tailwaters below Glen Canyon Dam, mainstem water temperatures (8 to 12°C) are either at the lower end of or below those needed for spawning and recruitment of flannelmouth suckers. Even though some warming does occur downstream, the relatively cold water in summer is thought to limit survival of YOY fish, recruitment, and condition of this species in the main channel (Thieme et al. 2001; Rees et al. 2005; Walters et al. 2012). Past recruitment in the Colorado River below Glen Canyon Dam of both species was low in the 1990s and then increased after 2000; the largest recruitment estimates coincided with brood years 2003 and 2004, when there was an increase in mainstem water temperatures because of warmer releases from Glen Canyon Dam (Walters et al. 2012). From 2008 through 2014, the numbers of flannelmouth suckers captured in electrofishing surveys was greater in mainstem sample locations downstream of RM 109 (Albrecht et al. 2014), perhaps giving an indication of the point at which water temperatures became more suitable for recruitment. The speckled dace 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; it was captured most commonly in western Grand Canyon and the inflow to Lake Mead (Makinster et al. 2010). The speckled dace spawns during the spring to late summer periods (AZGFD 2002c) at temperatures >17°C (NRC 1991).

To examine the potential of each alternative to produce thermal conditions that could improve reproduction, recruitment, and growth of native fish in main channel habitats, temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four native fish species other than humpback chub that occur in the river between Glen Canyon Dam and Lake Mead (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace [*Rhinichthys osculus*]). In general, the estimated temperature suitability for these species did not differ greatly among the alternatives, was comparable to suitability under current operations (Alternative A), and was low for all four species at most locations (Figure 4.5-9). At RM 225 (Diamond Creek), the mean modeled temperature suitability for native fish was highest under Alternative D and lowest under Alternative F; the mean temperature suitability levels for Alternatives A, B, C, E, and G were similar to each other at RM 225 (Figure 4.5-9). Inclusion of flow actions such as HFEs, TMFs, and low summer flows had only minor influences on modeled monthly mainstem water temperatures during periods of the year considered most important for spawning and egg incubation by native fish. As a consequence, these flow actions would have minor effects on temperature suitability for native fish and would not alter the relative suitability among alternatives.

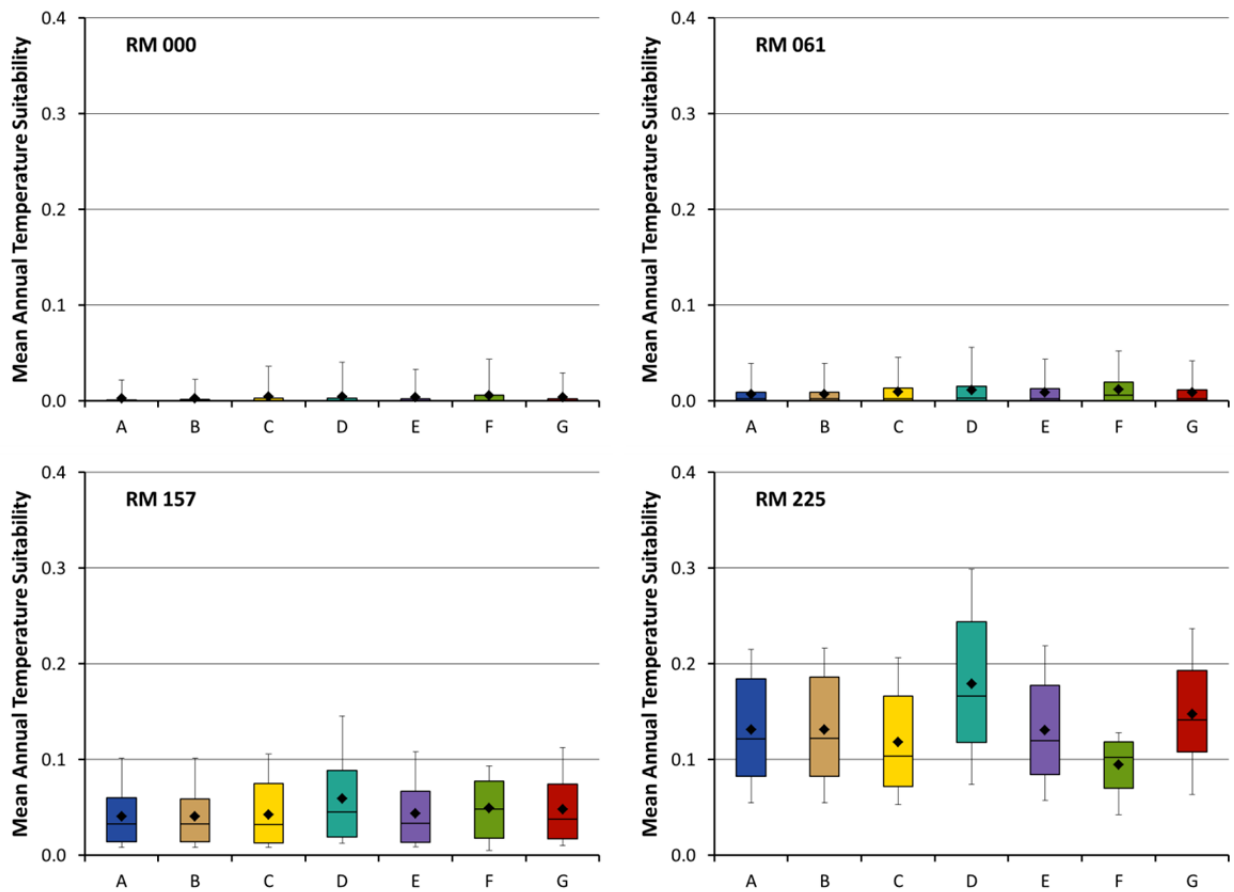

FIGURE 4.5-9 Modeled Mean Annual Temperature Suitability for Native Fish (bluehead sucker, flannelmouth sucker, razorback sucker, and speckled dace) under LTEMP Alternatives at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

4.5.2.4 Aquatic Parasites

The distribution and potential for infestation of aquatic parasites could be affected by alternative-specific differences in temperature regimes, sediment dynamics, and flow patterns. Of these factors, only the effects on temperature were considered to potentially be large enough to result in impacts on aquatic parasites. Temperature suitability was modeled at various locations downstream from Glen Canyon Dam for the four most important parasite species (Asian tapeworm, anchor worm, trout nematode, and whirling disease). Suitability under all alternatives and all species would generally be very low, would not differ at a biologically significant level among alternatives, and would be comparable to conditions under current operations as represented by Alternative A (No Action Alternative; Figure 4.5-10). As a consequence, the relative distributions of aquatic parasites or the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current

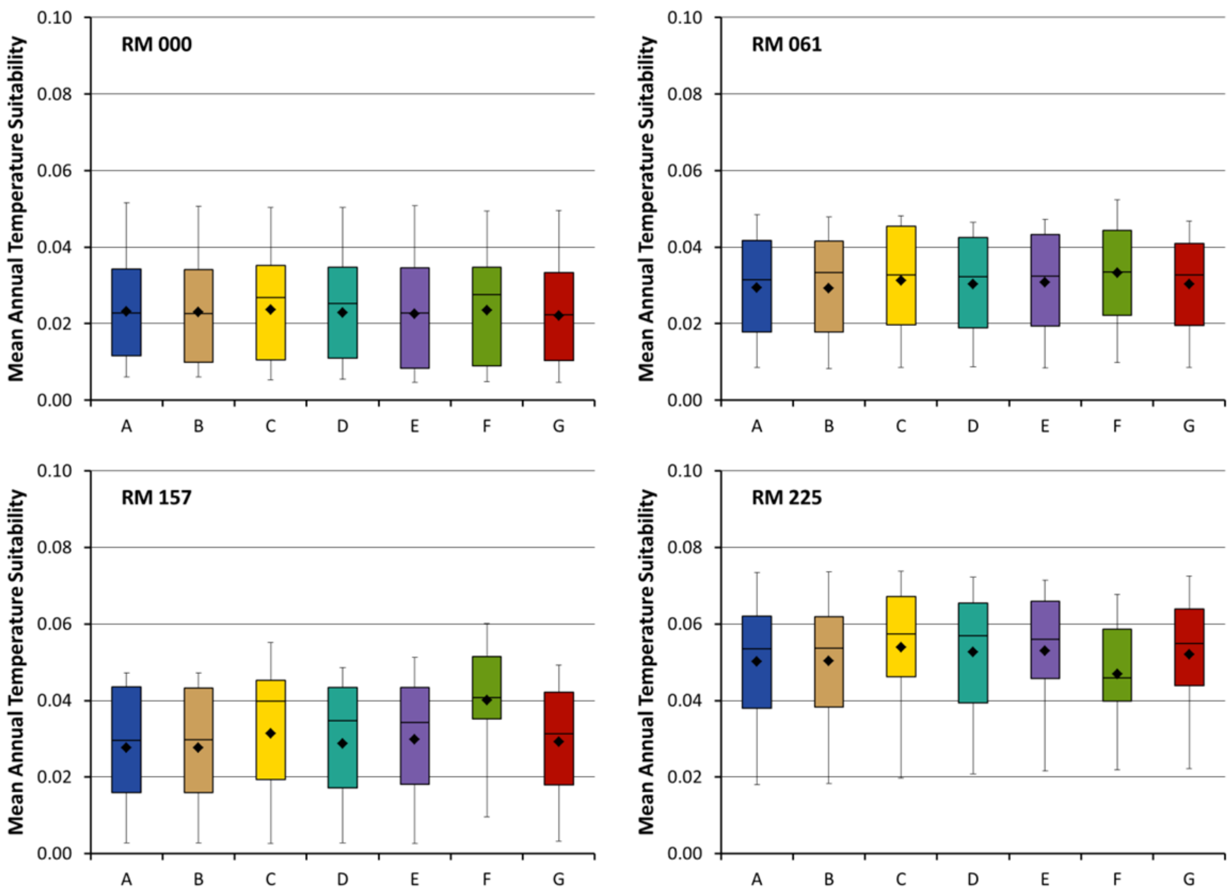

FIGURE 4.5-10 Overall Modeled Mean Annual Temperature Suitability under LTEMP Alternatives for Aquatic Fish Parasites (Asian tapeworm, anchor worm, trout nematode, and whirling disease) at Four Locations Downstream of Glen Canyon Dam (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

conditions under any of the alternatives. Under current conditions, population-level effects of parasites on survival and growth of native fish or trout have not been observed.

4.5.3 Alternative-Specific Impacts on Aquatic Resources

This section describes alternative-specific impacts on aquatic resources, and focuses on assessment results. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.5.2. As described above, none of the alternatives would be expected to noticeably alter temperature suitability for aquatic parasites, and the relative distributions of aquatic parasites and the effects of aquatic parasites on survival and growth of native fish or trout would not be expected to change relative to current conditions under any of the alternatives. For this reason, this topic is not discussed below.

4.5.3.1 Alternative A (No Action Alternative)

Impacts of Alternative A on Aquatic Food Base

Alternative A, the No Action Alternative, would continue the implementation of MLFF and other flow and non-flow actions currently in place and, as a consequence, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period. That being said, any significant hydrologic changes over the period or inadvertent introductions of nonnative species could result in unanticipated changes. The future impact of the recent introduction of quagga mussels on the aquatic food base is uncertain.

Dam operations under MLFF have led to increases in the standing mass of food base organisms (i.e., algae and invertebrates) due to steadier flows and greater minimum releases relative to operations prior to 1991. By restricting daily fluctuations in discharge to <8,000 cfs and limiting minimum discharge to 5,000 cfs, the MLFF regime has reduced the size of the varial zone and increased the amount of river bottom that is permanently submerged. Both of these conditions potentially increase the productivity and standing mass of important components of the aquatic food base. Fluctuating flows displace benthic macroinvertebrates into the drift, but they usually recover quickly from such disturbances. The effect of freezing during winter will reduce benthic productivity to the minimum stage level (Shannon et al. 1994; Blinn et al. 1995). The ramping rates for Alternative A would cause a minor increase in drift over the course of a fluctuation, particularly during up-ramping.

For Alternative A, an average of 5.5 HFEs would occur over the 20-year LTEMP period, with a maximum of 14 HFEs not extending past 2020; see Table 4.2-1). Impacts on the aquatic food base from a spring or fall HFE under Alternative A would be similar to those discussed in Section 4.5.2.1 (e.g., benthic scouring, particularly for HFEs of 41,000 cfs or more, and a shift to invertebrate species more prone to drift such as midges and blackflies). Drifting blackflies and midges are important contributors to the diet of trout. HFEs under Alternative A would only occur through 2020. Therefore, the number of HFEs would be less than for the other alternatives (Section 4.2). The cessation of HFEs after 2020 may result in a shift back to a food base community not dominated by midges and blackflies (Reclamation 2011a).

As mentioned in Section 4.5.1.2, trout removal, as would occur under Alternative A, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources.

Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base, under the base operations of Alternative A would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Impacts of Alternative A on Nonnative Fish

Under Alternative A, no change from current conditions is anticipated. Trout would continue to be supported in the Glen Canyon, Marble Canyon, and Little Colorado River reaches. Warmwater nonnative species would continue to be largely restricted to the lower portions of the river nearer to the headwaters of Lake Mead except in areas where warmer inflows from tributaries provide appropriate temperature regimes, or are sources of nonnative fish, from outside GCNP.

Within-day flow fluctuations (between 5,000 and 8,000 cfs) would continue to affect the stability of spawning habitats for rainbow trout and nearshore habitats for other nonnative fish (Reclamation 1995; Korman et al. 2005; Korman, Kaplinski et al. 2011; Korman and Melis 2011), and would result in trout redd exposure and stranding levels similar to those currently occurring. Implementation of spring and fall HFEs could result in increased recruitment of rainbow trout in the Glen Canyon reach, followed by increased emigration of trout to the Little Colorado River reach (Wright and Kennedy 2011; Korman et al. 2012). These HFEs would not be implemented after 2020 under Alternative A.

Because of the relatively small number of HFEs that would be implemented under this alternative, opportunities for any such increases in trout abundance under Alternative A would be the lowest among all alternatives. TMFs are not included as an explicit element of Alternative A, although some experimentation with TMFs could occur in some years. Mechanical removal of trout at the Little Colorado River confluence, as described in Reclamation (2011a), would be allowed only up through 2020. Modeling indicated that removal of trout might not be effective at limiting the abundance of trout in the Little Colorado River reach because of continued emigration from upstream areas in Marble Canyon. If trout removal is effective, limited benefits to the humpback chub populations in the vicinity of the Little Colorado River could be realized (see Appendix F); other alternatives would allow these management actions to be implemented throughout the entire LTEMP period if tests are deemed successful (e.g., Alternatives B, C, D, E, and G). The modeled average rainbow trout population size in the Glen Canyon reach during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A.

Impacts of Alternative A on Native Fish

Under Alternative A, within-day flow fluctuations (5,000 to 8,000 cfs), and ramp rates (4,000 cfs/hr up ramp and 1,500 cfs/hr down ramp), would continue to affect the stability and quality of nearshore habitats used by native fish, and would not result in a change in current conditions. Mainstem temperature suitability for humpback chub and other native fish would continue to be relatively low in most years.

Mainstem water temperatures are expected to continue restricting successful reproduction of humpback chub and other native fish to areas warmed by inflows from springs, to tributaries, or to nearshore locations that are far enough downstream for substantial warming to occur (e.g., RM 157 or farther downstream). Under Alternative A, successful spawning, larval survival and growth, and juvenile growth of humpback chub would continue to occur mostly in the Little Colorado River, with possible spawning occurring in Havasu Creek (NPS 2013g) and additional nursery and rearing habitats being used between RM 180 and RM 280 (Albrecht et al. 2014). Successful spawning of razorback sucker has recently been documented as far upstream as Lava Falls in the lower Grand Canyon under current operations (Albrecht et al. 2014) and would be expected to continue to occur under Alternative A, at least in years when temperature regimes are suitable.

The abundance, distribution, reproduction, and growth of native fishes, including humpback chub, are not expected to change appreciably from current conditions as a result of implementing Alternative A. The estimated average minimum number of adult humpback chub under Alternative A is about 5,000 adult fish over the 20-year LTEMP period, which is similar to the estimated minimum adult humpback chub numbers that have occurred during the period from 1989 through 2012 (see Section 3.5.3.1). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period is about 1,500. Under Alternative A, it is estimated that YOY humpback chub would achieve a total length of about 24 mm by the end of their first year at RM 61, and about 50 mm at RM 213 if rearing occurred in main channel habitats; fish of these sizes are unlikely to survive the winter in the mainstem. HFEs that could be implemented under this alternative (an average of 5.5 and a maximum of 14 over a 20-year period) would be similar to existing frequencies, so levels of recruitment of rainbow trout in the Glen Canyon reach of the river and numbers of rainbow trout emigrating to downstream reaches, where they may compete with and prey on humpback chub and other native species, would be expected to be unchanged.

Summary of Alternative A Impacts

Under Alternative A, existing conditions and trends in the composition, abundance, and distribution of the aquatic food base is expected to persist over the LTEMP period (e.g., increases in the standing mass of food base organisms). The cessation of HFEs after 2020 may shift to a food base community not dominated by midges and blackflies. Drifting midges and blackflies are important contributors to the diet of trout. Water temperatures, and their resultant influences on species composition, diversity, and production of the aquatic food base under the base operations of Alternative A, would be similar to current temperatures in the Colorado River downstream of Glen Canyon Dam.

Under Alternative A, there would be no change from current conditions for nonnative and native fish. HFEs could increase recruitment of rainbow trout in the Glen Canyon reach followed by increased emigration to the Little Colorado reach. However, HFEs would not be implemented after 2020. The modeled average rainbow trout population size during the 20-year LTEMP period was about 95,000 age-1 and older fish, with an average annual emigration from the Glen Canyon reach to the Marble Canyon reach of about 37,000 fish. The modeled number of large trout (>16 in. total length) averaged about 770 fish under Alternative A. Under Alternative A, the estimated average and absolute minimum number of adult humpback chub under Alternative A is about 5,000 and 1,500 adult fish over the 20-year LTEMP period.

4.5.3.2 Alternative B

Impacts of Alternative B on Aquatic Food Base

The total wetted area, and therefore the area of main benthic production, for Alternative B would be similar to that of Alternative A because these two alternatives have the same monthly water volumes. However, the greater allowable daily flow fluctuations and more rapid down ramp rates under Alternative B may result in greater instability and reduced quality of backwater and varial zone habitats. Thus, drift rates and stranding within the varial zone may be somewhat higher for Alternative B compared to Alternative A.

Fluctuating flows (>10,000 cfs/day) can fragment *Cladophora* from its basal attachment and increase its occurrence in the drift. Consuming drifting *Cladophora* (with its attached epiphytes and any invertebrates) allows rainbow trout to expend less energy in searching for food (Leibfried and Blinn 1987). Daily range in flows >10,000 cfs for base operations only occur during December and January (12,000 cfs) for Alternative B.

Slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively). Impacts on the aquatic food base from a spring or fall HFE under Alternative B would be similar to those discussed under Alternative A. However, there would not be more than one (spring or fall) HFE every other year. Less frequent HFEs (e.g., less often than annually) may lower the potential for establishing an aquatic food base that is more adaptable to flood conditions (e.g., an increased shift to blackflies and midges). Alternative B would have relatively few HFEs (Table 4.2-1); however, unlike Alternative A, HFEs would be implemented over the entire LTEMP period.

Hydropower improvement flows, tested experimentally under Alternative B up to four times in years with ≤8.23 maf, could decrease primary and secondary production because of scouring, although macroinvertebrate drift may increase in the short term. Rapid down-ramping may increase stranding of organisms in the varial zone, and this could reduce invertebrate productivity.

Mechanical removal of trout near the Little Colorado River could indirectly increase the availability of invertebrates to native fish because of reduced competition for food resources. Under Alternative B, TMFs would be tested and implemented, if tests are successful. TMFs could increase drift rates and slightly decrease primary production.

Water temperatures in the Colorado River under Alternative B would be similar to current temperature conditions because monthly volumes would be identical to those of Alternative A. Therefore, temperature impacts on the aquatic food base would be similar to those for Alternative A.

Impacts of Alternative B on Nonnative Fish

Under Alternative B, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Under Alternative B, habitat quality and stability may be slightly reduced compared to Alternative A. The higher within-day flow fluctuations (6,000–12,000 cfs), and down-ramp rates (3,000–4,000 cfs/hr) could adversely affect the stability of nearshore main channel habitats. The greater within-day flow fluctuations and faster down-ramp rates could also result in greater levels of exposure of trout redds and stranding of YOY rainbow trout. Stability of nearshore habitats under Alternative B could also be negatively affected by inclusion of testing of hydropower improvement flows, which would feature wide daily flow fluctuations (up to a 5,000 to 25,000 cfs range) and would allow increased up- and down-ramp rates. Temperature suitability under Alternative B would be similar to that under Alternative A for both coldwater and warmwater nonnative fish.

Although slightly more HFEs would occur during the 20-year LTEMP period under this alternative than under Alternative A (mean of 7.2 vs. 5.5, respectively), the estimated abundance and emigration of rainbow trout would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). These lower abundance and emigration numbers reflect the effect of greater within-day flow fluctuations and ramp rates. The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than under Alternative A. Inclusion of hydropower improvement flows would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (see Appendix F).

TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if the tests were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative B, it is anticipated that TMFs would be triggered in 3 out of 20 years, on average. Alternative B also would allow use of triggered mechanical trout removal at the Little Colorado River for the entire 20-year LTEMP period, whereas such removal would cease after 2020 under Alternative A. Modeling indicates that the inclusion of these actions may be able to reduce the abundance of trout in both the Glen Canyon and Little Colorado River reaches and could benefit the humpback chub population in the vicinity of the Little Colorado River throughout the LTEMP period (see Appendix F). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The modeled average trout population size in Glen Canyon under Alternative B was substantially lower than under Alternative A (Figure 4.5-2).

Impacts of Alternative B on Native Fish

Under Alternative B, higher within-day flow fluctuations and down-ramp rates could result in greater instability and reduced quality of nearshore habitats as compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9) in the mainstem river, as well as estimated growth of YOY humpback chub (Figure 4.5-7), would differ little from suitability and growth under Alternative A.

Higher within-day fluctuations during most periods of the year, limitations on the allowable frequency of HFEs, and implementation of TMFs would be expected to reduce recruitment of rainbow trout and the potential for rainbow trout emigration to the Little Colorado River reach (RM 61) compared to Alternative A, which is expected to reduce competition with and predation by rainbow trout on native fishes in that reach (Yard et al. 2011). Alternative B also includes mechanical trout removal near RM 61 for the entire 20-year period, whereas such removal would cease after 2020 under Alternative A.

Considering the lower trout recruitment that would result from higher within-day fluctuations, low number of HFEs, and implementation of triggered TMFs, the average modeled minimum number of adult humpback chub (about 5,400 adult fish) is higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative B is about 1,900. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Summary of Alternative B Impacts

Under Alternative B, the area of main benthic food base production would be similar to Alternative A. HFEs conducted less often than annually may lower the potential to establish a food base adaptable to flood conditions (i.e., one dominated by midges and blackflies). Hydropower improvement flows could decrease benthic primary and secondary food base production, although macroinvertebrate drift may increase in the short term. Temperature impacts on the aquatic food base under Alternative B would be similar to those under Alternative A.

Under Alternative B, habitat quality and stability and temperature suitability for both nonnative and native fish may be slightly reduced compared to Alternative A. The estimated abundance and emigration of rainbow trout under Alternative B would be less than under Alternative A (74,000 vs. 95,000 average abundance; 30,000 vs. 37,000 average number of emigrants). The number of large trout (>16 in. total length) was estimated to average about 870 fish, which is more than the 770 fish estimated under Alternative A. Estimated growth of YOY humpback chub under Alternative B would be similar to Alternative A. The average modeled minimum number of adult humpback chub over the LTEMP period (about 5,400 adult fish) is slightly higher under Alternative B than under Alternative A (about 5,000 adult fish). The estimated absolute minimum number of adult humpback chub under Alternative B is about 1,900 compared to 1,500 for Alternative A.

4.5.3.3 Alternative C

Impacts of Alternative C on Aquatic Food Base

Compared to Alternative A, Alternative C has higher monthly release volumes (and thus higher benthic biomass) from December through June, and lower volumes (and thus lower benthic biomass) from August through November. The daily range in flows would be lower under Alternative C compared to Alternative A. Therefore, benthic productivity may be somewhat increased particularly in the Glen Canyon reach because less of the benthic substrate would be exposed during fluctuation cycles. Increased benthic productivity would result in long-term increases in benthic drift (Kennedy, Yackulic et al. 2014).

Impacts on the aquatic food base from a spring or fall HFE under Alternative C would be similar to those discussed under Alternative A. Unlike Alternative A, HFEs would be implemented for the entire LTEMP period, with an average of 21.3 HFEs (maximum 40 HFEs) (Table 4.2-1). The more frequent HFEs are expected to favor blackfly and midge production. Proactive spring HFEs with maximum possible 24-hr release up to 45,000 cfs may be implemented under Alternative C in equalization years (years with annual volumes ≥10 maf) if no other spring HFE occurs in the same water year. Although a proactive spring HFE may scour the benthic community, particularly in the Glen Canyon reach, it would also increase the aquatic food base (e.g., blackflies and midges) available to drift-feeding fishes in the short term and may help control New Zealand mudsnail populations (Rosi-Marshall et al. 2010; Kennedy et al. 2013).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. Fall HFEs longer than 96 hr (i.e., maximum of 137 hr) could be implemented under Alternative C. The HFE volume would be limited to that of a 45,000 cfs, 96-hr flow. Thus, these extended-duration HFEs would be of lower magnitude and produce less benthic scouring, assuming less shoreline sediments would be affected by flows less than 45,000 cfs. Drift during an HFE longer than 96 hr may be elevated due to increased biomass of benthic invertebrates that may develop over the summer months. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance, although abundance in the 250-km stretch of river above Lake Mead tends to be more than an order of magnitude less than in the 110-km stretch below Glen Canyon Dam (Shannon, Benenati et al. 2003).

Steady flows would occur just prior to and after spring or fall HFEs under Alternative C. These flows could result in several months of maximized benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters. Benthic productivity in the mainstem should also increase under steady flows.

Tests and implementation of low summer flows would be conducted under Alternative C if conditions warrant it. Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative C, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative C, TMFs would be tested and implemented, if tests are successful. TMFs could temporarily increase drift rates and slightly decrease primary production.

The slightly warmer mean monthly water temperatures under Alternative C at RM 225 may slightly increase benthic production compared to Alternative A as modeled temperatures would be 18.1 and 18.2°C (64.6 and 64.8°F) for August and September, respectively, compared to 17.2 and 17.4°C (63 and 63.3°F). In addition to favoring adnate diatoms over stalked diatoms, these slightly warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. Overall, these changes would be considered detrimental to the aquatic food base (Section 4.5.2.1). Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative C on Nonnative Fish

Under Alternative C, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish may be higher because of smaller within-day flow fluctuations. However, stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative C was estimated to be similar that under Alternative A for trout at all locations

(Figure 4.5-4), but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream compared to Alternative A (Figure 4.5-5).

Alternative C has a much higher number of HFEs (average of 21.3 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. The greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, together with reduced fluctuations, could result in higher rainbow trout recruitment and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative C, it is anticipated that TMFs would be triggered in 6 out of 20 years, on average. This alternative has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives, even though implementation of TMFs is included as an element of the alternative.

Impacts of Alternative C on Native Fish

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative C than under Alternative A. Within-day flow fluctuations would be scaled according to monthly volumes (3,500 to 6,000 cfs during average hydrologic conditions) and would be less under this alternative than under Alternative A. However, improvements to habitat stability that may result from reduced fluctuations may be offset, in part, by the higher down-ramp rates (2,500 cfs/hr). Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The relatively high number of HFEs under Alternative C would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub could be offset by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish) and slightly less than under Alternatives B, D, and E. The estimated average minimum number of adult humpback chub under Alternative C would be greater than under Alternatives F and G. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative C is about 1,500, the same as Alternative A. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Summary of Alternative C Impacts

Under Alternative C, benthic food base productivity may be higher in December through June due to higher flows, but lower from August through November due to lower flows compared to Alternative A. The more frequent HFEs compared to Alternative A favor the production of midges and blackflies. Slightly warmer water temperatures for August and September at RM 225 under Alternative D may slightly increase food base production compared to Alternative A, although this could be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Under Alternative C, habitat quality and stability for nonnative and native fish may be higher than under Alternative A because of smaller within-day flow fluctuations. However, stranding of YOY rainbow trout may be slightly higher. Temperature suitability under Alternative C would be similar to Alternative A for trout, native fishes, and growth of YOY humpback chub; but could slightly improve conditions for warmwater nonnative fish at the locations farthest downstream from Glen Canyon Dam. The greater number of HFEs, coupled with reduced fluctuations, under Alternative C compared to Alternative A could result in higher rainbow trout recruitment and emigration rates. Alternative C has the highest estimated number of rainbow trout (about 102,000 age-1 and older fish) and emigrants (about 44,000 fish), and the fewest large rainbow trout (about 750 fish) relative to all of the other non-steady flow alternatives. The estimated average minimum number of adult humpback chub under Alternative C would be similar to that under Alternative A (about 5,000 adult fish); while the estimated absolute minimum number of adult humpback chub under Alternative C is about the same as Alternative A (1,500 fish).

4.5.3.4 Alternative D (Preferred Alternative)

Impacts of Alternative D on Aquatic Food Base

Under Alternative D, monthly release volumes would be relatively consistent throughout the year compared to Alternative A. This would produce a more consistent and stable aquatic food base. Daily range in flows would be similar to, but slightly lower under Alternative D compared to Alternative A. Therefore, benthic productivity may be somewhat increased, particularly in the Glen Canyon reach, because less of the benthic substrate would be exposed during fluctuation cycles. Stranding within the varial zone may be somewhat lower under Alternative D compared to Alternative A as a result. Increased benthic productivity would increase drift in the long term (Kennedy, Yackulic et al. 2014).

Under Alternative D, there would be an average of 19.3 HFEs (maximum of 38 HFEs) (Table 4.2-1). The more frequent HFEs are expected to favor blackfly and midge production. Spring HFEs may not be tested in years when there appear to be unacceptable risks to key resources including the aquatic food base. Impacts on the aquatic food base from a proactive spring HFE would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative D, up to four of the fall HFEs could be long-duration HFEs (lasting up to 250 hr). These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. Drift from an extended-duration fall HFE may be elevated due to increased biomass of benthic invertebrates that may develop over the summer months. HFEs longer than 96 hr could help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance. The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-duration HFE, could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. For this reason, implementation of a spring HFE in years that follow an extended duration fall HFE would be carefully considered.

Steady flows would occur after significant sediment input before fall HFEs, as well as for the remainder of the month in which the HFE occurred. Impacts on the aquatic food base would be similar to those under Alternative C (Section 4.5.3.3).

Tests of low summer flows would be conducted under Alternative D in the second 10 years of the LTEMP if conditions warrant it (as described in Section 2.2.4). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative D, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative D, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

An aquatic resource–related experiment unique to Alternative D would be to test the effects of sustained low weekend flows in May through August on benthic invertebrate production and diversity. It has been hypothesized that the large varial zone created by fluctuating flows limits recruitment of mayflies (order Ephemeroptera), stoneflies (order Plecoptera), and caddisflies (order Trichoptera), collectively referred to as EPT (Ephemeroptera-Plecoptera-Trichoptera), due to high egg mortality. For example, adult females of the mayfly genus *Baetis* land on rocks protruding from the water surface and then crawl underwater to lay their eggs on the underside of the rock. These rocks may become dry for up to 12 hr during a fluctuation cycle, causing mortality of the mayfly eggs (Kennedy 2013). If EPT deposit eggs principally along the shallower shoreline areas, then eggs laid during stable low flows over the weekend may not be subjected to drying prior to their hatching. Depending on the findings from the first test, this experiment could be repeated during the LTEMP period. In addition to potentially increasing EPT, sustained low weekend flows may benefit other aquatic food base organisms that have terrestrial adult life stages, such as dragonflies and true flies (including midges and blackflies). Some loss of benthic production is expected in the shoreline areas that remain dewatered over the weekend. If this results in an unacceptable risk to overall benthic production, the experiment might not be repeated.

Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative D on Nonnative Fish

Under Alternative D, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish is expected to be slightly higher because of slightly lower within-day flow fluctuations, especially during the winter. Stranding of YOY rainbow trout may be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability for trout under Alternative D was estimated to be similar to that under Alternative A at all locations (Figure 4.5-4), but could improve slightly compared to Alternative A for warmwater nonnative fish at the locations farthest downstream (Figure 4.5-5).

Alternative D has a much higher number of HFEs (average of 21 HFEs and a maximum of 38 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B. This greater number of HFEs, including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, could result in higher rainbow trout abundance and emigration rates (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). This alternative is expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A, suggesting that inclusion of TMFs would offset the increased recruitment that would be anticipated with a greater occurrence of HFEs (see Appendix F). However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish) (Figure 4.5.2). TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative D, it is anticipated that TMFs would be triggered in about 4 out of 20 years, on average.

Alternative D is the only alternative to include low benthic flows for invertebrate production which includes low benthic flows for invertebrate production (low stable flows every weekend, May-August). These flows could have both beneficial and adverse effects to the aquatic food base which could either increase or decrease nonnative fish abundance.

Impacts of Alternative D on Native Fish

The quantity, quality, and stability of nearshore habitats would be affected less under Alternative D than under Alternative A because within-day flow fluctuations would be slightly less under this alternative than under Alternative A, especially during winter. Mainstem temperature suitability for humpback chub (Figure 4.5-6) and growth of YOY humpback chub under predicted mainstem temperatures (Figure 4.5-7) are expected to differ little from suitability and growth predicted for Alternative A. Temperature suitability for other native fish could improve slightly compared to under Alternative A (Figure 4.5-9) because, under Alternative D, it is predicted that monthly volumes would result in more favorable mainstem temperatures at downstream locations (e.g., RM 225) during early summer months when spawning and egg incubation would benefit.

The relatively high number of HFEs under Alternative D would normally be expected to increase the recruitment levels for trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2). As discussed above, even though TMFs that would be implemented (when triggered by high predicted levels of recruitment) throughout the LTEMP period may result in smaller average trout population size in the Glen Canyon Reach, the model indicated that emigration of trout to the Marble Canyon reach under Alternative D would increase, on average, by about 11% compared to Alternative A. This increases the potential for trout to occur in the Little Colorado River reach where humpback chub survival and growth could be affected. The potential for competition with and predation on humpback chub by trout is expected to be partially offset by allowing mechanical removal of trout in the Little Colorado River reach when triggering conditions are met (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Based on modeling, the estimated average minimum number of adult humpback chub under Alternative D (about 5,200 adult fish) would be about 4% higher than under Alternative A; 1 and 3% lower than under Alternatives E and B, respectively; and 11 and 18% higher than under Alternatives G and F, respectively (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative D is about 1,800. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Alternative D is the only alternative to include low benthic flows for invertebrate production which includes low benthic flows for invertebrate production (low stable flows every weekend, May-August). As described above, these flows could have both beneficial and adverse effects to food base which could either increase or decrease native fish abundance.

Summary of Alternative D Impacts

The relatively similar month-to-month release volumes under Alternative D compared to Alternative A would produce a more consistent and stable aquatic food base. The more frequent HFEs under Alternative D are expected to favor midge and blackfly production compared to Alternative A. Sustained low weekend flows in May through August under Alternative D would be tested to determine if they increase benthic food base production and diversity including the recruitment of mayflies, stoneflies, and caddisflies (important food base organisms currently rare to absent throughout much of the mainstem below Glen Canyon Dam). Temperature impacts on the aquatic food base under Alternative D would be similar to those under Alternative C.

Under Alternative D, habitat quality and stability for nonnative and native fish are expected to be slightly higher than under Alternative A. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A. Temperature suitability for trout, humpback chub, and growth of YOY humpback chub under Alternative D would be similar to that under Alternative A, but could slightly improve suitability for warmwater nonnative fish and other native fish. The high number of HFEs could result in higher rainbow trout abundance and emigration rates. Alternative D is expected to result in average rainbow trout numbers of about 93,000 age-1 and older fish and 810 large rainbow trout, similar to those estimated for Alternative A. However, modeling results suggest that the number of trout emigrating into Marble Canyon under Alternative D (about 41,000 fish) would be about 11% higher, on average, than under Alternative A (about 37,000 fish). The estimated average minimum numbers of adult humpback chub under Alternative D (about 5,200 adult fish) would be higher than under Alternative A (5,000 adult fish). The estimated absolute minimum number of adult humpback chub over the LTEMP period under Alternative D is about 1,800 compared to 1,500 under Alternative A.

4.5.3.5 Alternative E

Impacts of Alternative E on Aquatic Food Base

More even monthly release volumes would improve aquatic food base productivity compared to Alternative A. However, this benefit could be offset by increased daily fluctuations, which would strand invertebrates within the varial zone. Higher daily fluctuations may also cause short-term increases in drift.

Under Alternative E, fall HFEs would be allowed throughout the 20-year LTEMP period, while spring HFEs would be allowed for the last 10 years of the LTEMP period with an average of 17.1 HFEs (maximum of 30 HFEs) (Table 4.2-1). The frequent HFEs will favor blackfly and midge production. The number of HFEs would be less than under Alternative C because there would be no spring HFEs in the first 10 years (see Section 2.3). Steady flows would occur after significant sediment inputs prior to fall HFEs under Alternative E. Consequently, there could be several months of improved benthic production in the mainstem and possible maintenance and development of planktonic and benthic production in shoreline areas, especially backwaters.

Tests of low summer flows would be conducted under Alternative E in the second 10 years of the LTEMP if conditions warrant (as described in Section 2.2.5). Since some fluctuation would still be allowed during these tests, overall food base production is expected to be less than that which would occur under higher flow conditions.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative E, TMFs would be tested and implemented, if tests are successful. TMFs could increase cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative E on Nonnative Fish

Under Alternative E, trout would continue to be supported primarily in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to be largely restricted to the lower portions of the river and to tributaries. Compared to Alternative A, habitat quality and stability for nonnative fish would be slightly lower due to increased levels of within-day fluctuations during most months. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A due to slightly greater down-ramp rates. Temperature suitability under Alternative E would be similar to suitability under Alternative A for trout at all locations, but would be slightly higher compared to Alternative A for warmwater nonnative fish at the locations farthest downstream. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative E, it is anticipated that TMFs would be triggered in about 3 out of 20 years, on average.

Alternative E has more HFEs (average of 17.1 HFEs and a maximum of 30 HFEs over the 20-year LTEMP period) than either Alternative A or Alternative B, but fewer than the other alternatives. This greater number of HFEs is expected to result in relatively high rainbow trout abundance and emigration rates (see discussion of effects of HFEs in Section 4.5.2.2), although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish (Figure 4.5-1), but slightly higher levels of emigration (about 38,000 fish/yr) compared to Alternative A (see discussion of effects of removal actions in Section 4.5.2.2). Slightly more large rainbow trout are expected (on average about 830 fish) than under Alternative A based on modeling results (Figure 4.5-3).

Impacts of Alternative E on Native Fish

Under Alternative E, habitat quality and stability for native fish would be slightly lower due to increased levels of within-day fluctuations during most months compared to Alternative A. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes

(Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), is expected to differ little from suitability and growth predicted for Alternative A.

Alternative E allows no spring HFEs for the first 10 years, but it has relatively similar numbers of fall HFEs compared to Alternatives C, D, F, and G. The relatively high number of HFEs under Alternative E would be expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach (see discussion of effects of HFEs on nonnative fish in Section 4.5.2.2) with potential adverse effects on humpback chub. The potential for competition with and predation on humpback chub is expected to be partially controlled by mechanical removal of trout in the Little Colorado River reach (see discussion of effects of removal actions on native fish in Section 4.5.2.3). However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) was about 6% higher than under Alternative A (about 5,000 fish) (Figure 4.5-8), reflecting the combined effects on growth and survival of humpback chub associated with slightly higher emigration rates for trout from the Glen Canyon reach, slightly warmer mainstem temperatures at the confluence with the Little Colorado River, and implementation of mechanical removal of trout in the Little Colorado River reach when triggering criteria are met. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources.

Summary of Alternative E Impacts

Under Alternative E, relatively even monthly release volumes would increase aquatic food base productivity, but this increase could be offset by increased daily fluctuations. The number of HFEs under Alternative E would favor midge and blackfly production, though the number of HFEs would be less than under Alternative C. Temperature impacts on the aquatic food base for Alternative E would be similar to those under Alternative C.

Under Alternative E, habitat quality and stability for nonnative and native fish would be slightly lower than under Alternative A due to increased levels of within-day fluctuations during most months. Stranding of YOY rainbow trout may also be slightly higher than under Alternative A. Temperature suitability for trout, native fish, and growth of YOY humpback chub under Alternative E would be similar to that under Alternative A; but would be slightly higher for other warmwater nonnative fish species at locations farthest downstream from Glen Canyon Dam. The high number of HFEs under Alternative E is expected to result in relatively high rainbow trout abundance and emigration rates compared to Alternative A; although the greater levels of within-day fluctuations and the implementation of TMFs are expected to result in an overall reduction in age-1 and older fish but slightly higher levels of emigration compared to

Alternative A. Slightly more large rainbow trout (830) are expected than under Alternative A (770). The modeled average minimum number of adult humpback chub under Alternative E (about 5,300 fish) is slightly higher than under Alternative A (about 5,000 fish). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative E is about 1,600 compared to 1,500 under Alternative A.

4.5.3.6 Alternative F

Impacts of Alternative F on Aquatic Food Base

Compared to all other alternatives, Alternative F would have lower flow volumes, and therefore potentially less benthic biomass, from July through the following March. Seasonally adjusted steady flows would minimize the adverse effects of desiccation and dewatering that occurs in a varial zone (Reclamation et al. 2002). Flow stabilization may allow for very high snail densities, especially for the New Zealand mudsnail (Reclamation et al. 2002). In addition, reduced drift rates occur under mildly fluctuating or steady flows (Shannon et al. 1996; Rogers et al. 2003). Lower benthic productivity may also cause decreased drift over the long term (Kennedy, Yackulic et al. 2014). Higher volumes in April through June may increase benthic biomass compared to Alternative A, and would somewhat mimic pre-dam conditions with increased flows during spring and early summer. Increased benthic productivity during this period may also increase drift (Kennedy, Yackulic et al. 2014).

Under Alternative F, the 24-hr, 45,000-cfs high flows in early May in years without sediment-triggered spring HFEs, together with the May and June period of sustained high flows and the week-long 25,000 cfs release at the end of June, would scour the benthos, particularly within the Glen Canyon reach. This could improve the aquatic food base by reworking sediments and removing fines that can limit production of benthic organisms. Alternative F would have an average of 38.1 HFEs (maximum of 40 HFEs) (Table 4.2-1). The frequent HFEs will favor blackfly and midge production. Sustained high flows and HFEs would also decrease the density of New Zealand mudsnails.

No trout management actions would occur under Alternative F, but the rapid drop from high flows in June to low flows in July could have similar effects to those of TMFs. If these flow changes did not mimic the effects of TMFs, there would be continued competition for aquatic food base resources between trout and other fish species.

The warmer mean monthly water temperatures under Alternative F at RM 225 may slightly increase benthic production compared to all other alternatives, as modeled monthly summer temperatures would range from 18.6 to 20.5°C (65.5 to 68.9°F) for July through August. In addition to favoring adnate diatoms over stalked diatoms, these warmer temperatures would tend to favor *Oscillatoria* over *Cladophora*. These changes would be considered detrimental to the aquatic food base (Section 4.5.2.1). Otherwise, temperature impacts on the aquatic food base would be similar to those described for Alternative A (Section 4.5.3.1).

Impacts of Alternative F on Nonnative Fish

Because there would be no within-day flow fluctuations, Alternative F is expected to have positive effects on nonnative fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Although the results of the temperature suitability modeling show only small differences among the alternatives in overall suitability for trout, temperature suitability under Alternative F would be slightly greater, compared to Alternative A, at RM 61 and slightly lower at RM 157 and RM 225 (Figure 4.5-4). For warmwater nonnative fish, mainstem temperature suitability is expected to improve slightly, compared to Alternative A, at RM 61and RM 157 (Figure 4.5-5). The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A.

Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach (Figure 4.5-1), and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. These numbers reflect the more stable habitat conditions and very high number of HFEs (an average of 39 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period) of this alternative that are expected to result in increased production and survival of YOY rainbow trout (see discussion of effects of HFEs in Section 4.5.2.2). Because this alternative does not include implementation of TMFs or mechanical removal, there is no offset to conditions that would be likely to increase recruitment, resulting in larger numbers but lower growth rates for trout in the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives (Figure 4.5-3). The modeled results for Alternative F are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011).

Impacts of Alternative F on Native Fish

Under Alternative F, there would be no within-day fluctuations in flow, resulting in a high degree of nearshore habitat stability. The 24-hr, 45,000-cfs peak flow in May, extended high flows of 20,000 cfs in May and June, and 7-day 25,000-cfs high flow at the end of June may improve forage for native fish by reworking sediments and removing fines that can limit production of benthic organisms. Compared to Alternative A, temperature suitability would be slightly higher at RM 61 and lower at RM 213. Temperature suitability for native fish would be lower at RM 225 (Diamond Creek) compared to other alternatives (Figure 4.5-9). Under Alternative F, modeling estimated that YOY humpback chub would achieve a total length of about 26 mm by the end of their first year at RM 61, and about 54 mm at RM 213 if rearing occurred in main channel habitats; this level of growth is slightly higher than that estimated for all other alternatives (Figure 4.5-7).

The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives (Figure 4.5-8). This lower estimated population size results from the high number of HFEs, low summer flows, and lack of within-day fluctuations that promote production of rainbow trout in the Glen Canyon reach and subsequent high emigration to the Marble Canyon reach (see Section 4.5.3.2), as well as the lack of TMFs or mechanical removal that could offset increases in trout. The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative F is about 1,400.

Historically, there have been few opportunities to study the effects of steady-flow operations on fish resources downstream of Glen Canyon Dam, especially the effects of long-term steady flow operations. During the spring and summer of 2000, a series of steady discharges of water from Glen Canyon Dam were used to evaluate effects of aquatic habitat stability and water temperatures on native fish growth and survival, with a particular focus on the humpback chub (Ralston 2011). The hydrograph implemented for the experiment achieved steady discharges at various levels that lasted for periods of 4 days to 8 weeks. The steady flows did not appear to result in increased growth rates by humpback chub or other native fish, although there was some evidence that nonnative fish species that could compete with or prey upon native fish species (fathead minnow, plains killifish, and rainbow trout) experienced population increases associated with reduced fluctuations and/or warmer water temperatures that occurred during the experimental period (Ralston 2011). However, the short-term nature of the experiment makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have.

Summary of Alternative F Impacts

Under Alternative F, food base biomass from July through the following March would be potentially less compared to all other alternatives due to comparatively lower flow volumes. Flow stabilization may allow for high benthic densities of New Zealand mudsnails, while reduced benthic productivity is expected to reduce drift. Higher flow volumes in April through June may increase benthic food base biomass and drift compared to Alternative A. The frequent HFEs will favor blackfly and midge production. The warmer water temperatures for August and September at RM 225 under Alternative F may slightly increase food base production even more than Alternative D, although this could similarly be offset by change in diatoms from stalked to adnate forms and favoring *Oscillatoria* over *Cladophora*.

Alternative F is expected to have positive effects on nonnative and native fish and their habitats by providing a greater level of habitat stability than would occur under any of the non-steady flow alternatives. Temperature suitability for nonnative and native fish under Alternative F would be slightly higher than Alternative A at RM 61 and slightly lower at sites further downstream. The warmer temperatures at the downstream locations during summer and fall months may slightly increase the potential for successful reproduction, survival, and growth of warmwater nonnative fish compared to Alternative A. Among all alternatives, Alternative F has the greatest average modeled population size of age-1 and older rainbow trout (about 160,000 fish) in the Glen Canyon reach, and the greatest average annual number of rainbow trout (about 72,000 fish/yr) emigrating from the Glen Canyon reach. There are expected to be, on average, fewer large rainbow trout (about 590 fish) under this alternative than under any of the other alternatives. The minimum number of adult humpback chub under Alternative F (about 4,400 adult fish) was estimated to be lower than under any of the other alternatives. The estimated absolute minimum number of adult humpback chub under Alternative F is about 1,400.

4.5.3.7 Alternative G

Impacts of Alternative G on Aquatic Food Base

Under Alternative G, changes in monthly release volumes would be limited only to those necessary to adjust to changes in runoff forecasts. The benthic community would benefit from these even monthly volumes and the steady within-day flows of this alternative. This would allow somewhat consistent and stable aquatic food base conditions to persist throughout the year. In addition, benthic community biomass would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher under Alternative G. However, the year-round stable conditions may favor dominance by less-desirable species such as the New Zealand mudsnail. Increased benthic production could result in long-term increases in drift (Kennedy, Yackulic et al. 2014).

Alternative G would have an average of 24.5 HFEs (maximum of 40 HFEs) (Table 4.2-1). The frequent HFEs are expected to favor blackfly and midge production. HFEs would also decrease the density of New Zealand mudsnails. Impacts on the aquatic food base from proactive spring HFEs would be similar to those under Alternative C (Section 4.5.3.3).

Under Alternative G, there could be fall HFEs of up to 45,000 cfs that could last as long as 336 hr. These extended-duration HFEs would be of higher magnitude and could produce more benthic scouring than the extended-duration HFEs for Alternative C. Drift from an extended fall HFE may be elevated due to increased biomass of benthic invertebrates that may develop over the summer months. HFEs longer than 96 hr may help to control the abundance of New Zealand mudsnails in the Glen Canyon reach, while possibly contributing to their downstream abundance.

The 4 to 5 months between a fall and spring HFE could preclude full recovery of most benthic invertebrate assemblages. A spring HFE following a fall HFE, particularly a long-duration HFE, could scour the remaining primary producers and susceptible invertebrates and further delay the recovery of the aquatic food base. For this reason, implementation of a spring HFE in years that follow an extended-duration fall HFE would be carefully considered.

Trout removal, as would occur under Alternative E, could indirectly increase the availability of invertebrates to native fish by reducing the number of trout near the confluence of the Little Colorado River (RM 61), thereby reducing competition for food resources. Under Alternative G, TMFs would be tested and implemented, if tests are successful. TMFs could cause short-term increases in drift rates and slightly decrease primary production.

Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C (Section 4.5.3.3).

Impacts of Alternative G on Nonnative Fish

Under Alternative G, there would be no within-day fluctuations, and monthly volumes would only vary as a result of changes in runoff forecasts. As a result, habitat stability would be greater under this alternative than under any of other alternatives. Under this alternative, trout would continue to be supported in the upper reaches of the river below Glen Canyon Dam, while warmwater nonnative species would continue to occur in the lower portions of the river and tributaries. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats. TMFs would be tested under this alternative and would be implemented for the entire LTEMP period if they were deemed successful at limiting rainbow trout recruitment in the Glen Canyon reach. Based on modeling for Alternative G, it is anticipated that TMFs would be triggered in about 11 out of 20 years, on average.

The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively). Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). The relatively high abundance and emigration rate reflect, in part, the high number of HFEs that could occur with this alternative (an average of 24.5 HFEs and a maximum of 40 HFEs over the 20-year LTEMP period), including sediment-triggered and proactive spring HFEs, which may strongly favor trout recruitment, and the absence of within-day fluctuations. However, TMFs and mechanical removal of trout, which are included as operational elements in this alternative, are expected to partially mitigate the increased trout production. Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length) (Figure 4.5-3). The modeled results for nonnative fish under Alternative G are consistent with results from an experiment conducted during the spring and summer of 2000 to examine effects of low summer steady flows (Ralston 2011). During that study, the abundance of some nonnative fish species (e.g., fathead minnow, plains killifish, and rainbow trout) increased following periods with reduced fluctuations and/or warmer water temperatures (Ralston 2011). However, the short-term nature of the experiment that was conducted makes it difficult to draw conclusions about what effects a multi-year steady flow operation would have.

Impacts of Alternative G on Native Fish

Under Alternative G, habitat stability for native fish would be greater than under any of the other alternatives. Temperature suitability for humpback chub (Figure 4.5-6) and other native fishes (Figure 4.5-9), as well as growth of YOY humpback chub (Figure 4.5-7), are expected to differ little from suitability and growth predicted for Alternative A.

The high number of HFEs under Alternative G is expected to increase the abundance of trout and the number of emigrants to the Little Colorado River reach, with potential adverse effects on humpback chub. The potential for competition with and predation of humpback chub are expected to be partially offset by mechanical removal (when triggering criteria are met) of trout in the Little Colorado River reach. However, the reduction in trout numbers at the Little Colorado River, and resulting benefits to humpback chub, might be short-lived due to ongoing emigration from areas upstream in Marble Canyon. Modeling indicated that the average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives and would be approximately 6% lower than under Alternative A (Figure 4.5-8). The estimated absolute minimum number of adult humpback chub over the 20-year LTEMP period under Alternative G is about 1,700. While indirect benefits of TMFs to native fish as a result of reduced competition and predation by rainbow trout are expected under this alternative, an unknown number of native fish would also suffer mortality as a result of TMFs, downstream in GCNP (see discussion of TMFs in Section 4.5.2.2). Monitoring of the impacts of TMFs throughout GCNP would be implemented to assess effectiveness of the action, as well as the detrimental impacts on native fish and other resources. For information regarding past studies of the effects of steady-flow operations on native fish downstream of Glen Canyon Dam, refer to Section 4.5.3.6.

Summary of Alternative G Impacts

Under Alternative G, somewhat consistent and stable aquatic food base conditions to persist throughout the year. Benthic food base biomass and drift would probably be greater under Alternative G compared to Alternative F, because flows from July through the following February would be higher. However, stable flows may favor dominance by the New Zealand mudsnail. Potentially higher drift rates from spring flows under Alternative F would not occur under Alternative G. The frequent HFEs are expected to favor blackfly and midge production. Temperature impacts on the aquatic food base for Alternative G would be similar to those under Alternative C.

Habitat stability for nonnative and native fish would be greater under Alternative G than under any of the other alternatives. Similar to Alternative F, improved temperature suitability in the lower reaches of the river could increase the potential for successful spawning of warmwater nonnative fishes in nearshore main channel habitats; whereas, temperature suitability for native fishes, as well as growth of YOY humpback chub, are expected to differ little from Alternative A. The annual population size of rainbow trout in the Glen Canyon reach is expected to be higher under Alternative G than under any of the non-steady flow alternatives, and only slightly less than under Alternative F (about 135,000 fish vs. 160,000 fish, respectively).

Similarly, the estimated annual number of rainbow trout emigrating from the Glen Canyon reach to the Marble Canyon reach is greater than under any of the non-steady flow alternatives, and second only to Alternative F (about 60,000 fish/yr vs. 72,000 fish/yr, respectively). Alternative G would have the second-lowest average number of large rainbow trout (about 690 fish >16 in. total length). The average minimum number of adult humpback chub (about 4,700 adult fish) under Alternative G would be the second lowest value of all alternatives. The estimated absolute minimum number of adult humpback chub under Alternative G is about 1,700.

4.6 VEGETATION

This section presents an evaluation of the impacts of the LTEMP on riparian vegetation of the Colorado River corridor between Glen Canyon Dam and Lake Mead. Glen Canyon Dam operations affect river flow and stage, which in turn affect the disturbance regime, soil moisture, and ultimately the distribution of vegetation species and communities in the river corridor. In addition to the effects of operations on vegetation communities, the effects on vegetation of non-flow actions were evaluated, including vegetation restoration activities. Analysis methods, a summary of anticipated impacts, and alternative specific impacts are presented.

4.6.1 Analysis Methods

Issue: How do alternatives affect riparian vegetation in the project area?

Impact Indicators:

- Change in the composition of plant communities in the Old High Water Zone
- Changes in habitat of special status plant species
- Changes in cover of wetland community types
- Changes in the composition of the New High Water Zone and wetland vegetation as indicated by four metrics: (1) change in cover of native community types; (2) change in diversity of native community types; (3) change in the ratio of native to nonnative community types; and (4) change in the arrowweed community type

Three sources of information were evaluated in order to analyze the impacts of the alternatives on plant communities. First, information found in studies on vegetation done to date was examined. Secondly, a model based on published studies and collected data was used to predict potential effects. Third, the combined information from the studies and model was evaluated to analyze the potential effects of the alternatives over the period of the LTEMP. The studies allowed an assessment of effects that go beyond the limitations of the model.

The model enabled an evaluation of effects by predicting four characteristics of vegetation. The metrics that reflect these characteristics were calculated using the results of an existing model for Colorado River riparian vegetation downstream of the Paria River (Ralston et al. 2014). Seven vegetation states were used in the model to represent plant community types found along the river on sandbars and channel margins in the New High

Water Zone and Fluctuation Zone (Section 3.6). Species associated with a particular state respond similarly to Colorado River hydrologic factors such as depth, timing, and duration of inundation. These states and the plant species associated with each are given in Table 4.6-1. The model and data used for the calculation of performance metrics are based on vegetation studies conducted within GCNP (see citations in Ralston et al. 2014) and was not used to assess changes to riparian vegetation communities within Glen Canyon. Although the model is a simplification of the complexities of the riparian ecosystem, it is a valuable tool for assessing potential changes in riparian vegetation under a variety of flow regimes. Model details are described in Ralston et al. (2014). The four metrics are:

1. Relative change in cover of native-dominated vegetation community types (other than arrowweed) on sandbars and channel margins using the total percentage increase in native states (change in native cover = $cover_{final}/cover_{initial}$; a result >1 is a beneficial change).

2. Relative change in diversity of native vegetation community types (other than arrowweed) on sandbars and channel margins using the Shannon Weiner index for richness/evenness (change in diversity = $diversity_{final}/diversity_{initial}$; a result >1 is a beneficial change).

3. Relative change in the ratio of native- (other than arrowweed) to nonnative-dominated vegetation community types on sandbars and channel margins (change in native/nonnative ratio = $ratio_{final}/ratio_{initial}$; a result >1 is a beneficial change).

4. Relative change in the arrowweed community type on sandbars and channel margins using the total percentage decrease in the arrowweed state (change in arrowweed = $arrowweed_{initial}/arrowweed_{final}$; a result >1 is a beneficial change). Because the desired change is a decrease in arrowweed, this metric is calculated as initial/final, unlike the other metrics.

These performance metrics were developed from the resource goal for riparian vegetation downstream of Glen Canyon Dam: *Maintain native vegetation and wildlife habitat in various stages of maturity that are diverse, healthy, productive, self-sustaining, and ecologically appropriate*.

The vegetation model has several limitations that should be noted when considering the modeling results. The model was designed as a conceptual as opposed to a predictive model; therefore, the results are used in this analysis carefully and in combination with the literature because the model is a simplification with limitations in the ability to assess on-the-ground changes. However, it is the best available tool for impact analysis, when used in conjunction with field studies and literature.

Several issues that could not be addressed by the model are discussed qualitatively or quantitatively based on literature from field studies in this section below. These include the dynamics of the tamarisk leaf beetle (*Diorhabda* spp.) on tamarisk distribution and abundance;

TABLE 4.6-1 Vegetation States, Plant Associations, and Corresponding Submodels

Vegetation States	Primary Plant Species	Additional Species	Submodel/Landform
Bare Sand	<1% vegetation cover		All submodels
Common Reed Temperate Herbaceous Vegetation (Marsh)	Common reed (*Phragmites australis*), cattail (*Typha domingensis, T. latifolia*)	Common tule (*Schoenoplectus acutus*), creeping bent grass (*Polypogon viridis*)	Lower Reattachment Bar
Coyote Willow-Emory Seep Willow Shrubland/ Horsetail Herbaceous Vegetation (Shrub Wetland)	Horsetail (*Equisetum laevigatum*), coyote willow (*Salix exigua*), *Baccharis emoryi*, *Schoenoplectus pungens*	*Eleocharis palustris, Muhlenbergia asperifolia*	Lower Channel Margin, Lower Reattachment Bar
Tamarisk Temporarily Flooded Shrubland	Tamarisk (*Tamarix* spp.)		All submodels
Cottonwood/Coyote Willow Forest[a] (Cottonwood-willow)	Coyote willow, cottonwood (*Populus fremontii*)	*Salix gooddingii, Baccharis salicifolia, Distichlis spicata, Muhlenbergia asperifolia, Phragmites australis*, *Equisetum spp., Juncus* spp., *Carex* spp., *Elaeagnus angustifolia, Tamarix* spp., *Agrostis stolonifera, Melilotus* spp.	Lower Channel Margin, Lower Separation Bar
Arrowweed Seasonally Flooded Shrubland (Arrowweed)	Arrowweed (*Pluchea sericea*)	*Baccharis* spp., mesquite (*Prosopis glandulosa*), coyote willow	Lower Reattachment Bar, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin
Mesquite Shrubland (Mesquite)	Mesquite (*Prosopis glandulosa* var. *torreyana*)	*Baccharis* spp., *Pluchea sericea*	Lower Channel Margin, Upper Separation Bar, Upper Reattachment Bar, Upper Channel Margin

[a] Although an element of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

Source: Ralston et al. (2014).

the overall decrease in area of the Old High Water Zone and the mortality of species within that zone; the increase or decrease of open sand that could not be captured in this model, as it could not be coupled with the sediment models; the effects from NPS's experimental vegetation restoration program (common to all alternatives); and the fact that the model considers hypothetical sandbars and was not spatially explicit in relation to current and potential future conditions.

The vegetation model was developed to compare the effects of various flow regimes on Colorado River riparian vegetation. The model consists of six geomorphic submodels based on landforms that are known to influence vegetation floristics and structure: Lower Separation Bar, Upper Separation Bar, Lower Reattachment Bar, Upper Reattachment Bar, Lower Channel Margin, and Upper Channel Margin. The upper and lower landform surfaces are separated at the 25,000-cfs stage elevation (see Section 3.3.1.1 for a description of these landforms).

The four vegetation states dominated by native plant species are marsh (Common Reed Temperate Herbaceous Vegetation), shrub wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation), cottonwood-willow (Cottonwood/Coyote Willow Forest), and mesquite (Mesquite Shrubland). Although arrowweed is a native species, prior to the dam's construction, it was strongly controlled by spring flooding and was not common, but with cessation of spring floods it has invaded many sandbars and formed monocultures. Because of this tendency to form monocultures under these conditions, arrowweed (Arrowweed Seasonally Flooded Shrubland) states are excluded from the desired native states in the metrics. One nonnative state, tamarisk (Tamarisk Temporarily Flooded Shrubland), is included in the model. Bare Sand is also included as one of the possible states in the model. As described in Section 3.6, a number of other plant community types also occur within the riparian area downstream of Glen Canyon Dam (see also Table H-3). These plant community types vary somewhat by river reach, in the Old High Water Zone, New High Water Zone, and Fluctuation Zone.

In the model, the magnitude and timing of various important hydrologic events were identified for each model run and evaluated for the potential effects on vegetation (see Table G-2 in Appendix G for a listing and description of these hydrologic events). The model uses the daily maximum flow for the evaluation of each alternative. Important hydrologic events included spill flows (>45,000 cfs), spring HFEs (>31,500 cfs to 45,000 cfs), fall HFEs (>31,500 cfs to 45,000 cfs), extended low flows (daily maximum ≤10,000 cfs for at least 30 consecutive days), extended high flows (daily maximum ≥20,000 cfs for at least 30 consecutive days), and flows that can fluctuate up to 25,000 cfs, (i.e., the absence of spill flows or extended high or extended low flows). Although periodic spill flows (>45,000 cfs) could occur based on historic hydrologic conditions within the 20-year period of this evaluation, these would likely be infrequent and would occur at equal frequency under all alternatives. These spill flows are non-discretionary emergency actions and are not part of the alternatives, but were part of the hydrologic modeling. The timing of these events relative to the growing season (May–September) or non-growing season (October–March) was also determined. Growing seasons vary depending on the reach, but were generalized to these months for the model.

Daily fluctuation patterns generally produce the extended high and extended low flows. For example, Alternative B, with relatively large fluctuations, has a higher frequency of daily maxima ≥20,000 cfs for at least 30 consecutive days, and therefore more extended high flows; Alternatives F and G, two alternatives with no fluctuations, have a higher frequency of extended low flows. Monthly release volumes also affect these events. Alternative C, for example, has relatively small fluctuations but also low release volumes August through November, resulting in a higher frequency of extended low flows than Alternative G.

The model predicts transitions from one state to another, based on a set of rules that considers the frequency and duration of hydrologic events. The transition rules for the upper portions of the bars and channel margin are the same because of the similarity of plant community types and responses to flow characteristics. These transition rules are based on the effects of scouring, drowning, desiccation, and sediment deposition on riparian plant species. HFEs result in sediment deposition, but scouring is minor and limited to low-elevation wetland species (Kearsley and Ayers 1999; Ralston 2010; Stevens et al. 2001). HFEs transport seeds of nonnative as well as native species (Kennedy and Ralston 2011; Ralston 2011; Spence 1996). Repeated extended high flows (i.e., flows with daily maximum ≥20,000 cfs for at least 30 consecutive days) result in removal of vegetation by drowning and scouring, primarily on lower elevation surfaces (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010). Increased soil moisture at upper elevations from extended high flows can increase vegetation growth and seedling establishment (Waring 1995; Sher et al. 2000; Mortenson et al. 2012). The germination of seeds transported by HFEs or extended high flows is promoted by extended low flows (e.g., elevated base flows) that reduce disturbance, expose lower elevation surfaces, and maintain soil moisture at lower elevations, all of which are conducive to seedling growth (Porter 2002; Ralston 2011). Extended low flows (i.e., flows with daily maximum ≤10,000 cfs for at least 30 consecutive days) also can result in the lowering of groundwater levels, thus increasing the depth to groundwater and the reduction of soil moisture, creating conditions that favor the growth of more drought-tolerant species (Porter 2002; Stevens et al. 1995).

Model results include the total number of years each state occurs for the 20-year period of the model run according to each potential starting state in each submodel. For example, the reattachment bar submodel uses five different starting states for each hydrologic trace: bare sand, marsh, shrub wetland, tamarisk, and arrowweed. Model results were used to calculate the metrics for each alternative using the sum of each of the states for all six models. This value was then compared to the number of years each state would have accumulated, if the current condition was maintained, i.e., if no transitions occurred and each of the seven states remained the same for the full 20 years of the model run. This proportion was multiplied by the acreage of mapped cover types from the NPS Vegetation Map of GCNP (Kearsley et al. 2015) corresponding to the seven model states in order to provide a sense of the relative spatial scale of potential changes under each Alternative (Table 4.6-2). Because, as noted above, the model considers hypothetical sandbars due to the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area, and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

TABLE 4.6-2 Vegetation States and Corresponding Mapped Vegetation Types

Vegetation States	Mapped Vegetation Classes[a]	Area (ac)
Bare Sand	Unvegetated Surfaces and Built Up Areas	112
Marsh (Common Reed Temperate Herbaceous Vegetation)	*Phragmites australis* Western North America Temperate Semi-Natural Herbaceous Vegetation	4.4
Shrub Wetland (Coyote Willow-Emory Seep Willow Shrubland/Horsetail Herbaceous Vegetation)	Arid West Emergent Marsh	0.2
Tamarisk (Tamarisk Temporarily Flooded Shrubland)	*Tamarix* spp. Temporarily Flooded Semi-Natural Shrubland	273.7
Cottonwood-Willow (Cottonwood/Coyote Willow Forest[b])	*Baccharis* spp.–*Salix exigua*–*Pluchea sericea* Shrubland Alliance	177.3
Arrowweed (Arrowweed Seasonally Flooded Shrubland)	*Baccharis* spp.–*Salix exigua*–*Pluchea sericea* Shrubland Alliance	177.3
Mesquite (Mesquite Shrubland)	*Prosopis glandulosa* var. *torreyana* Shrubland	137.1

[a] Kearsley et al. (2015), which mapped RM 0-278; vegetation classes and area are based on 2007 and 2010 aerial photography and do not necessarily reflect current conditions. This mapping was limited to GCNP and did not include Glen Canyon.

[b] Although a component of this vegetation community type, cottonwoods are scarce in the Colorado River corridor between Glen Canyon Dam and Lake Mead.

The results for the four metrics were then summed to derive a final score for each alternative. Alternatives with higher scores were considered to have come closer to achieving the resource goal. Several factors other than the operational characteristics considered by the models have a strong influence on the riparian vegetation below the dam, however, due to a lack of information on these potential effects and for the purposes of this analysis, it is assumed that these effects would apply equally across all alternatives. These include changes in precipitation, defoliation of tamarisk by the tamarisk leaf beetle and other insects, and experimental vegetation management activities implemented by the NPS to reduce invasive plant populations and increase local populations of desired native plants (Figure 4.6-1). The impacts of these factors were assessed in light of the potential vegetation changes shown by the state and transition model.

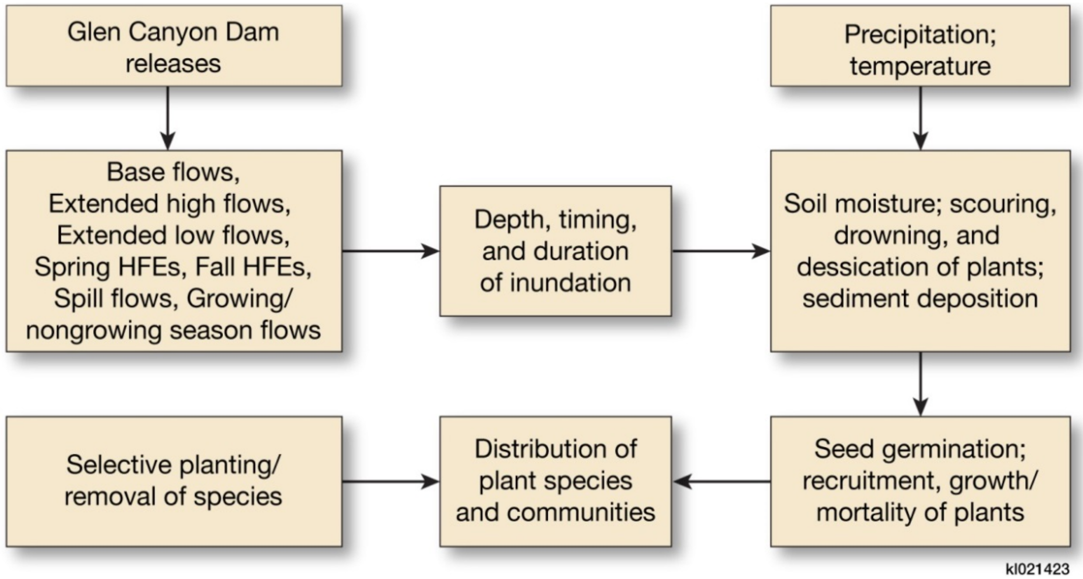

FIGURE 4.6-1 Dominant Factors Affecting Riparian Plant Communities below Glen Canyon Dam

4.6.2 Summary of Impacts

Impacts on plant communities of the Old High Water Zone, New High Water Zone, and wetlands for the 20-year LTEMP period are summarized below. Table 4.6-3 provides an overview of the anticipated impacts by alternative, as well as the important flow characteristics associated with the effects of each alternative. Figure 4.6-2 compares the predicted effects of each alternative on vegetation characteristics as measured using four metrics. A score of 1 indicates no change from initial conditions; values >1 indicate an improvement relative to current conditions (increase in native cover, native diversity, or native/nonnative diversity; decrease in arrowweed); values <1 indicate a decline relative to current conditions (decrease in native cover, native diversity, or native/nonnative ratio; increase in arrowweed), and Figure 4.6-3 presents the overall impacts under the LTEMP alternatives. In this case, a total score of 4.0 calculated by summing the scores for each of the 4 metrics under each alternative indicates no change from initial conditions; values >4 indicate an improvement relative to current conditions; and values <1 indicate a decline relative to current conditions. See Appendix G for additional details regarding the application of the vegetation model in the analysis of impacts.

4.6.2.1 Impacts on Old High Water Zone Vegetation

The riparian vegetation that became established along the Colorado River channel margin in response to annual peak flows prior to the construction of Glen Canyon Dam is located at high flow stage elevations (above 60,000 cfs, but primarily from about 100,000 to approximately 200,000 cfs), well above the level of current dam operations. The Old High Water Zone plant communities are described in Section 3.6. Mortality of riparian plants within this zone, along with a lack of seedling establishment for some species, such as mesquite and hackberry, have

TABLE 4.6-3 Summary of Impacts on Old High-Water Zone, New High-Water Zone, and Wetland Plant Community Types

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Adverse impact relative to current condition resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, increase in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Similar to Alternative A (decline under hydropower improvement flows). Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, increase in arrowweed, increase in native diversity (decrease under hydropower improvement flows), and increase in native/nonnative ratio (decrease under hydropower improvement flows); decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.	Improvement from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native/nonnative ratio, decrease in arrowweed and increase in native diversity; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio, increase in arrowweed; decrease in wetland community cover; impacts on special status species.	Decline from Alternative A. Some adverse impacts and some benefits resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio (the largest increase in tamarisk of any alternative); decrease in arrowweed; decrease in wetland community cover; impacts and potential benefit to special status species.	Decline from Alternative A. Adverse impact resulting from: narrowing of old high water zone; an expected decrease in new high water zone native plant community cover, decrease in native diversity, decrease in native/nonnative ratio; decrease in arrowweed; decrease in wetland community cover; impacts on special status species.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Old High Water Zone							
	Relative to current conditions, continued narrowing of zone due to lack of sufficiently high flows.	Same as Alternative A	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.	Same as Alternative A	Narrowing of zone as under Alternative A; annual spring HFEs may result in greater survival of lower elevation plants.	Narrowing of zone as under Alternative A; more spring HFEs may result in greater survival of lower elevation plants.
New High Water Zone and Wetlands[a]							
Relative change in cover of native vegetation community types	Relative to current conditions, 17% (55.2 ac[a]) overall decrease in native plant community cover over the LTEMP period, resulting from few spring HFEs, occasional fall HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows; 28% (1.3 ac) decrease in wetland community cover resulting from extended high flows.	Improvement from Alternative A; 15% (48.3 ac) overall decrease in native plant community cover, (47 % decrease under hydropower improvement flows) resulting from few spring HFEs, more fall HFEs, slightly more extended high flows; 20% (0.9 ac) decrease in wetland community cover (83% [3.8 ac] decrease under hydropower improvement flows) resulting from extended high flows.	Decline from Alternative A;37% (117.7 ac) overall decrease in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 75% (3.4 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.	Improvement from Alternative A;12% (39.5 ac) overall decrease in native plant community cover, resulting from more HFEs, more seasons without extended high or low flows, frequent extended high flows; 16% (0.8 ac) decrease in wetland community cover resulting from extended high flows.	Decline from Alternative A 20% (63.5 ac) overall decrease in native plant community cover, resulting from more fall HFEs, slightly more growing-season extended low flows; 38% (1.7 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Decline from Alternative A 30% (95.0 ac) overall decrease in native plant community cover, resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows; 86% (4.0 ac) decrease in wetland community cover resulting from extended high flows and extended low flows.	Decline from Alternative A 29% (93.7 ac) overall decrease in native plant community cover, resulting from more HFEs, more extended low flows, occasional extended high flows; 58% (2.6 ac) decrease in wetland community cover resulting from extended low flows and extended high flows.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in diversity of native vegetation community types	Relative to current conditions, 2% decrease in native diversity over the LTEMP period due to decrease in wetland communities resulting from occasional growing-season extended low flows.	Improvement from Alternative A; 3% increase in native diversity, distribution of community types similar to initial condition (9% decrease under hydropower improvement flows).	Decline from Alternative A; 8% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.	Improvement from Alternative A; 2% increase in native diversity, distribution of community types similar to initial condition.	Decline from Alternative A; 2% decrease in native diversity, decrease in wetland communities resulting from slightly more growing-season extended low flows.	Decline from Alternative A; 9% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.	Decline from Alternative A; 3% decrease in native diversity, decrease in wetland communities resulting from fewer seasons without extended high or low flows, more extended low flows.
Relative change in the ratio of native- to nonnative-dominated vegetation community types	Potential benefit relative to current conditions; 5% increase in ratio, 58.4 ac decrease in tamarisk over the LTEMP period resulting from frequent extended high flows, few extended low flows, and spring HFEs. Tamarisk leaf beetle and non-flow vegetation restoration activities may increase benefit.	Improvement from Alternative A; 15% increase in ratio (13% decrease under hydropower improvement flows), 71.4 ac decrease in tamarisk (107 ac decrease under hydropower improvement flows) resulting from few spring HFEs, slightly more extended high flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may increase benefit.	Decline from Alternative A; 54% decrease in ratio, 104 ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 5% decrease in ratio, 22.4 ac decrease in tamarisk resulting from extended high flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 4% decrease in ratio, 45.7 ac decrease in tamarisk resulting from more fall HFEs, slightly more growing-season extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 62% decrease in ratio, 231 ac increase in tamarisk resulting from more HFEs, fewer seasons without extended high or low flows, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.	Decline from Alternative A; 40% decrease in ratio, 46.4 ac increase in tamarisk resulting from more HFEs, more extended low flows. Tamarisk leaf beetle and non-flow vegetation restoration activities may decrease adverse impact.

TABLE 4.6-3 (Cont.)

	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
New High Water Zone and Wetlands[a] (Cont.)							
Relative change in the arrowweed community type	Adverse impact; 25% (44.5 ac) increase in arrowweed over the LTEMP period resulting from few spring HFEs, occasional growing-season extended low flows, frequent growing-season extended high flows. Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 19% (33.3 ac) increase in arrowweed resulting from more extended high flows (24% increase under hydropower improvement flows). Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 14% (25.1 ac) decrease in arrowweed resulting from repeated extended low flows and extended high flows. Non-flow vegetation restoration activities may increase benefit.	Improvement relative to Alternative A; 10% (17.1 ac) decrease in arrowweed resulting from repeated extended high flows, frequent fall HFEs, and few growing season extended low flows. Non-flow vegetation restoration activities may increase benefit.	Similar to Alternative A; 25% (44.0 ac) increase in arrowweed resulting from more HFEs, more growing-season extended low flows, frequent growing-season extended high flows. Non-flow vegetation restoration activities may decrease adverse impact.	Improvement relative to Alternative A; 13% (22.2 ac) decrease in arrowweed resulting from more HFEs, repeated extended high flows. Non-flow vegetation restoration activities may increase benefit.	Improvement relative to Alternative A; 11% (20.1 ac) decrease in arrowweed resulting from more HFEs, growing-season extended low flows, fewer growing-season extended high flows. Non-flow vegetation restoration activities may increase benefit.
Special status plant species[b]	Adverse impact on wetland species from loss of habitat.	Similar to Alternative A. Adverse impact on wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.	Similar to Alternative A. Adverse impact on wetland species from loss of habitat.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, Lake Mead shoreline species from high lake levels, wetland species from loss of habitat; potential benefit for inactive floodplain species from HFEs.	Decline relative to Alternative A. Potential impacts on active floodplain species from HFEs, wetland species from loss of habitat.

TABLE 4.6-3 (Cont.)

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[a] Changes in area are presented for each community type; however, because of the very dynamic nature of sand deposition and erosion in the canyon, the model cannot be used to accurately predict changes in total bare sand or riparian vegetation area and results should only be used to determine the relative contribution of vegetation states to total area. Changes in areas under different alternatives presented in Table 4.6-3 are provided to give a sense of the overall scale of vegetation changes, but do not represent actual predicted changes in area.

[b] Details regarding special status plant species are provided in Table 4.6-6.

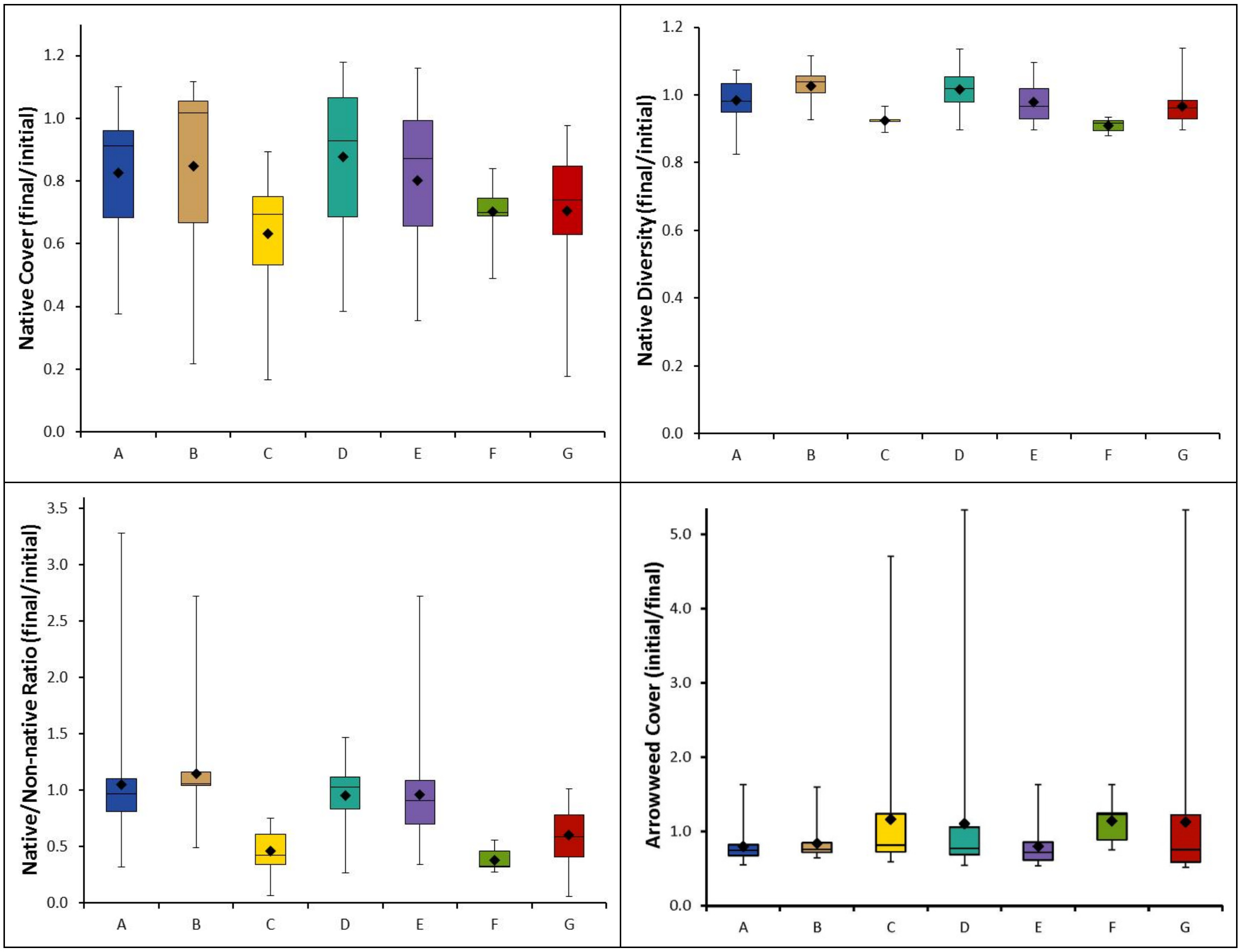

FIGURE 4.6-2 Comparison among Alternatives for Four Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an improvement relative to current conditions; values <1 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

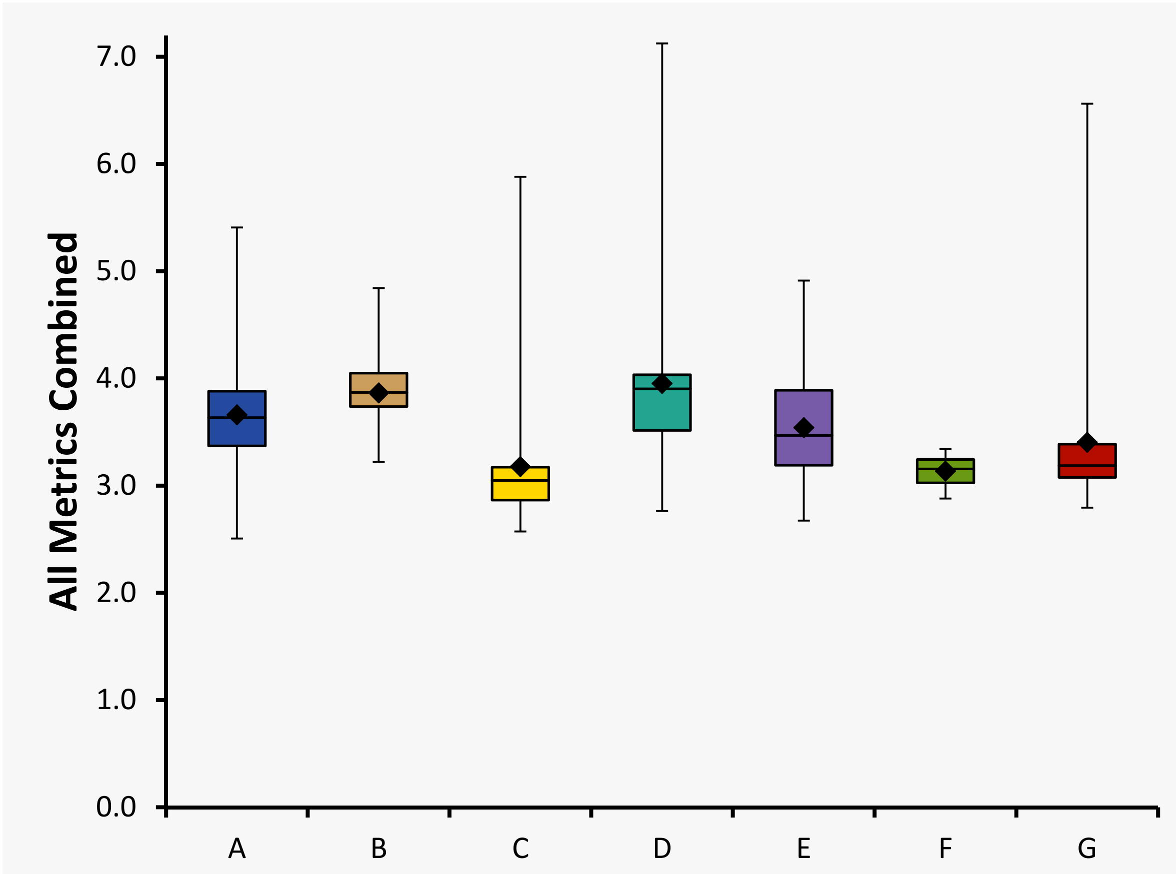

FIGURE 4.6-3 Comparison among Alternatives for Combined Riparian Vegetation Metrics as Predicted by a Vegetation Model (Metrics are based on the estimated amount of each vegetation type at the end of the LTEMP period relative to the amount at the beginning; values of 4 indicate no change over the LTEMP period; values >4 indicate an improvement relative to current conditions; values <4 indicate a decline relative to current conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

been occurring for decades, because of a lack of sufficiently high flows and nutrient-rich sediment (Kearsley et al. 2006; Anderson and Ruffner 1987; Webb et al. 2011).

Dam operations, other than HFEs, do not exceed 31,500 cfs flows (although all alternatives have a normal maximum operating flow of 25,000 cfs), and HFEs do not exceed 45,000 cfs. None of the alternatives considered would include flows sufficient to maintain these pre-dam plant communities. HFEs could provide soil moisture to the deep root systems of some Old High Water Zone plants, providing occasional soil moisture. Studies indicate that dam releases can affect water availability to plants at elevations up to approximately 15,000 cfs above flow levels (Melis et al. 2006; Ralston 2005). Alternatives with more frequent spring HFEs, such as Alternative F with annual spring HFEs, or Alternatives C, D, and G, all with considerably more spring HFEs than Alternative A (Section 4.2), may result in higher survival rates of plants at lower elevations of the Old High Water Zone than Alternative A. Several alternatives include extended-duration HFEs (longer than 96 hr; e.g., up to 250 hr under Alternative D); however, as these HFEs only occur during the fall (the non-growing season), their contribution to higher survival rates would likely be limited.

Because of generally continued low soil moisture and lack of recruitment opportunities under all alternatives, the upper margins of this zone would be expected to continue moving downslope, with a continued narrowing of the riparian zones. Desert species occurring on the pre-dam flood terraces and windblown sand deposits above the Old High Water Zone would increasingly establish within this zone, depending on climate and precipitation. Overall, all alternatives would result in a decline in upper margins Old High Water Zone plant communities, because none feature regular flows >45,000 cfs. The likelihood of these very high flows, which would occur only under emergency dam operations, is considered very low, and would be the same for all alternatives.

4.6.2.2 Impacts on New High Water Zone

Plant community types that have developed in the New High Water Zone in response to Glen Canyon Dam operations include cottonwood-willow and mesquite communities, both native species-dominated community types, as well as tamarisk (a nonnative species-dominated community type) and arrowweed (an invasive native species-dominated community type) (Ralston et al. 2014). Two native species-dominated wetland community types, marsh and shrub wetland, that occur in the Fluctuation Zone are discussed in Section 4.6.2.3. Transitions between plant community types, or to bare sand, are driven by specific flow events that vary among the alternatives. Spring HFEs, fall HFEs, spill flows, extended low flows, extended high flows, and seasons without extended high or low flows occurring during the growing or non-growing season result in changes in the distribution and cover of New High Water Zone plant communities. HFEs alone do not result in transitions but generally act in combination with other flow events. Colorado River flows affect the composition, structure, and distribution of riparian vegetation communities through the effects of drowning, scouring, sediment deposition, desiccation, and maintaining alluvial groundwater levels (Sankey, Ralston et al. 2015; Ralston et al. 2014; Ralston 2005, 2010, 2012; Kennedy and Ralston 2011; Kearsley et al. 2006; Porter 2002; Kearsley and Ayers 1999; Stevens et al. 1995). HFEs result in sediment deposition and increased water availability at higher stage elevations but little scouring, extended high flows drown and scour plants and maintain ground-water levels, while extended low flows can desiccate plants, especially seedlings, while providing a consistent water supply to plants at very low stage elevations. Transitions and initiating flows are presented in Table G-3, in Appendix G.

Flows that result in increases or decreases in cottonwood-willow and mesquite communities are given in Table 4.6-4. Alternatives with greater occurrence of transitions from bare sand to native plant communities and/or maintenance of those communities (i.e., a lack of transitions to bare sand) would result in greater native community cover. However, repeated seasons of extended high flows, extended high flows above 50,000 cfs, or spill flows transition native communities to bare sand through the processes of drowning, scouring, and burial (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). All of the alternatives

TABLE 4.6-4 Transitions between Riparian Community Types and the Flows That Initiate Transitions

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Increase New High Water Zone Natives			
Bare sand	Cottonwood-willow	Lower separation bar	Growing season and non-growing season without extended high or low flows the same year (7 yr; slowed by non-growing-season extended high flow with growing season without extended high or low flow the same year) (Waring 1995; Ralston et al. 2008).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow next growing season (Ralston 2010).
Tamarisk	Mesquite	Upper bars/channel margin; lower channel margin	Spring HFE with growing season without extended high or low flow or extended high flow the same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Decrease New High Water Zone Natives			
Cottonwood-willow	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high plus growing-season extended high same year; or growing-season extended high followed by non-growing-season extended high the next year.(Stevens and Waring 1986a)
Cottonwood-willow	Bare sand	Lower channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Mesquite	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a] or any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Transitions That Increase Wetland			
Bare sand	Marsh	Lower reattachment bar	Growing season without extended high or low flow (2 yr; slowed by growing season with extended high flow) (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010).
Bare sand	Shrub wetland	Lower channel margin	Non-growing season without extended high or low flow plus growing season without extended high or low flow (4 yr, can be slowed by growing season with extended low flow or HFE; extended high flow starts process over) (Stevens and Waring 1986a; Porter 2002).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Wetland			
Marsh, shrub wetland	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012).
Marsh, shrub wetland	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow next growing season; growing season with extended high flow followed by a non-growing season with extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Shrub wetland	Bare sand	Lower channel margin	Any season with extended high flow over 25,000 cfs (Stevens and Waring 1986a).
Shrub wetland	Cottonwood-willow	Lower channel margin	Any season with extended high flow followed by an extended low flow the next growing season (Ralston 2010).
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Transitions That Increase Tamarisk			
Marsh, shrub wetland, arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002).
Bare sand	Tamarisk	Lower separation bar; lower channel margin	Non-growing season with extended high flow, or spring HFE plus growing season with extended low flow the same year (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012; Sher et al. 2000).
Bare sand	Tamarisk	Lower reattachment bar	Growing season with extended low flow (Stevens and Waring 1986a; Porter 2002; Sher et al. 2000).
Bare sand	Tamarisk	Upper bar/channel margin	Spring HFE plus growing season with extended high flow the same year (Sher et al. 2000; Mortenson et al. 2012).
Transitions That Decrease Tamarisk			
Tamarisk	Bare sand	Lower separation bar	Spill flow[a]; non-growing-season extended high flow plus growing-season extended high flow same year; or growing-season extended high flow followed by non-growing-season extended high flow the next year (Stevens and Waring 1986a).

TABLE 4.6-4 (Cont.)

Initial Community Type	Final Community Type	Landform	Transition-Initiating Flows
Transitions That Decrease Tamarisk (Cont.)			
Tamarisk	Bare sand	Lower reattachment bar	Spill flow[a]; 4 consecutive seasons of non-growing-season extended high flow plus growing-season extended high flow; growing-season extended high flow (4 consecutive years) (Stevens and Waring 1986a; Kearsley and Ayers 1999).
Tamarisk	Bare sand	Lower channel margin; upper bar/channel margin	Spill flow[a]; any season extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Tamarisk	Mesquite	Lower channel margin; upper bar/channel margin	Spring HFE with growing season without extended high or low flow or extended high same year (13 yr; slowed by growing-season extended low flow) (Anderson and Ruffner 1987).
Transitions That Increase Arrowweed			
Marsh	Arrowweed	Lower reattachment bar	Growing season with extended low flow (Porter 2002).
Bare sand	Arrowweed	Upper bar/channel margin	Non-growing season with extended low flow, or seasons without extended high or low flow, or non-growing season with extended high flow, plus growing season with extended low flow, or seasons without extended high or low flow, or growing season with extended high flow; same year (3–6 yr, extended high flows increase the rate, slowed by fall HFE) (Waring 1995).
Transitions That Decrease Arrowweed			
Arrowweed	Bare sand	Lower reattachment bar	Spill flow[a]; any season with extended high flow followed by an extended high flow the next growing season; growing season with extended high flow followed by a non-growing season extended high flow (Kearsley and Ayers 1999; Ralston 2010).
Arrowweed	Bare sand	Upper bar/channel margin	Spill flow[a]; any season with extended high flow above 50,000 cfs (Stevens and Waring 1986a).
Arrowweed	Tamarisk	Lower reattachment bar	Any season with extended high flow followed by an extended low flow the next growing season (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002).

[a] Spill flows are releases through the spillway and are non-discretionary emergency actions that do not vary among alternatives.

Source: Ralston et al. (2014).

would result in a decrease in native plant community cover (see discussions below under individual alternatives). However, annual hydrology has a greater effect on the change in native community types than the operational characteristics of the alternatives.

Flows that result in increases or decreases in tamarisk are given in Table 4.6-4. The overall cover of tamarisk-dominated communities would be expected to increase under Alternatives C, F, and G, each of which are expected to produce frequent transitions to tamarisk communities, in large part because they frequently have extended high flows, extended low flows, and spring HFEs. This combination of flows encourages transitions to tamarisk because tamarisk increases when high flows coincide with seed release during spring and early summer, followed by lower flows, all of which results in establishment of seedlings above the elevation of subsequent floods (Mortenson et al. 2012; Stevens and Siemion 2012). Also, under these alternatives, various community types frequently shift to bare sand, which then shifts to tamarisk. Each of these alternatives has more extended low flows and more spring HFEs than the other alternatives. The overall cover of the tamarisk is expected to decrease under Alternatives A, B, D, and E. Each of these alternatives has frequent extended high flows, which result in consecutive seasons and consecutive years of extended high flows. Two or more years of extended high flows are required for tamarisk to be removed by drowning, leaving a bare sand lower reattachment bar, or two consecutive seasons (growing and non-growing) on a lower separation bar (Kearsley and Ayers 1999; Stevens and Waring 1986a).

The presence of the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.) along much of the Colorado River below Glen Canyon Dam has resulted in defoliation of tamarisk in many areas, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Considerable uncertainty still exists regarding the long-term effects of the beetle and weevil on the tamarisk population below the dam and subsequent effects on ecosystem dynamics within the New High Water Zone. The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics. Tamarisk may not establish as readily on bare sand substrates, or transition from other community types, as in the past (and described above) if seed sources are reduced. Additionally, tamarisk communities may become less stable and more easily removed by high flows than in the past. Therefore, increases in tamarisk that would be expected to result under Alternatives C, F, and G, may be less than expected, and decreases of tamarisk under Alternatives A, B, D, and E may be greater than expected.

Flows that would result in increases or decreases in arrowweed are given in Table 4.6-4. The overall cover of the arrowweed community type would be expected to increase under Alternatives A, B, and E; under these alternatives, bare sand would transition to arrowweed rather than tamarisk because there are few spring HFEs and/or few growing-season extended high flows, both of which promote the establishment of tamarisk on bare sand, and, except in Alternative B, arrowweed would transition from marsh because of growing-season extended low flows (Porter 2002). Once established, arrowweed would tend to remain for many years under these alternatives. HFEs alone are not effective at reducing arrowweed as burial typically results in resprouting from roots, buried stems, and rhizomes, and subsequent vegetative growth occurs (Ralston 2012). Arrowweed would decrease under Alternatives C, D, F, and G, usually by transitioning to bare sand with repeated extended high flows (Ralston 2010; Stevens and

Waring 1986a), but often by transitioning to tamarisk. The hydrology of the river (e.g., wet years vs. dry years), however, has a greater effect on the change in arrowweed than the characteristics of the alternatives. Drier years tend to have fewer extended high flows resulting in more arrowweed due to fewer transitions to bare sand or tamarisk.

Given that under all alternatives vegetation condition degrades to some degree, experimental riparian vegetation restoration activities are planned under all alternatives except for Alternative A. These activities are expected to modify the cover and distribution of plant communities along the Colorado River and improve the vegetation conditions. These restoration activities include removal of nonnative plants and prevention of new introductions, native plant restoration, clearing of undesirable plants from campsites, and removal of vegetation that blocks wind transport of sediment. Plantings of native species, such as Goodding's willow and cottonwood, would be conducted to increase and maintain populations of these species. Restoration of native species would include the collection of propagules (seeds, cuttings, poles, or whole plants) from riparian areas in both the river corridor and side canyons. Removal of nonnative plants would include mechanical means (e.g., cutting), smothering, spot burning, or use of herbicides. Monitoring of riparian areas subsequent to the implementation of any alternative would direct the specific locations and degree of implementation of non-flow actions. Nonnative species targeted for removal would be those considered the greatest threat to park resources and having a high potential for successful control (Table 4.6-5). Control and removal of the native arrowweed would be conducted where this species is encroaching on campsites. Full-scale restoration at selected sites or sub-reaches would include removal of tamarisk and replanting and seeding of natives. The acreage that would be targeted for priority treatment would vary by alternative, depending on expected changes in riparian community types. An estimate of the change in acreage of tamarisk or arrowweed under each of the alternatives is given in Section 4.6.3. Alternatives that result in greater increases in these species would be expected to also result in a greater extent of targeted restoration. Therefore, differences among alternatives in changes of tamarisk or arrowweed may be somewhat less than indicated by flow effects alone. Restoration actions would be expected to occur at limited locations, and these areas would likely only comprise a small proportion of the riparian area below Glen Canyon Dam.

4.6.2.3 Wetlands

Wet marsh communities of flood-tolerant herbaceous species that occur on low elevation areas of reattachment bars within the Fluctuation Zone (i.e., the range of normal operational fluctuations between the elevations of 5,000 and 25,000 cfs flows) have developed in response to frequent inundation (daily for at least part of the year) (Stevens et al. 1995; Ralston 2005, 2010). These marsh communities (with common reed and cattail the dominant species) occur on fine-grained silty loam soils in low-velocity environments on lower areas of eddy complex sandbars, which, although easily scoured by high flows, can redevelop quickly. Clonal wetland species such as cattail, common reed, and willow are adapted to burial and regrowth and recover following HFEs (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Native flood-adapted species increase in low-elevation areas following growing-season steady high flows, potentially by vegetative reproduction (Porter 2002; Ralston 2011). Shrub wetland communities (with coyote willow, seep willow, and horsetail the dominant species) occur on sandy soils of

TABLE 4.6-5 Priority Nonnative Species Identified for Control within the Colorado River Corridor

Scientific Name	Common Name
Rhaponticum repens	Russian knapweed
Alhagi maurorum	camelthorn
Brassica tournefortii	Sahara mustard
Convolvulus arvensis	black bindweed
Cortaderia selloana	Pampas grass
Echinochloa crus-galli	barnyardgrass
Eragrostis curvula	weeping love grass
Elaeagnus angustifolia	Russian olive
Lepidium latifolium	perennial pepperweed
Malcolmia africana	African mustard
Phoenix dactylifera	date palm
Saccharum ravennae	Ravenna grass
Salsola tragus	Russian thistle
Schedonorus arundinaceus	tall fescue
Sisymbrium altissimum	tumble mustard
Sisymbrium irio	London rocket
Solanum elaeagnifolium	silverleaf nightshade
Sonchus asper	spiny sowthistle
Sonchus oleraceus	common sowthistle
Tamarix aphylla	athel
Tamarix spp.	salt cedar
Tribulus terrestris	puncture vine
Ulmus pumila	Siberian elm

reattachment bars and channel margins, below the 25,000 cfs stage, that are less frequently inundated. Mortality of horsetail occurs at higher elevations above the water table during growing-season low steady flows (Porter 2002). Large daily fluctuations increase the area of saturated soil, and thus the sandbar area available for wetland species establishment (Stevens et al. 1995; Carothers and Aitchison 1976; Kearsley et al. 2006). The reduction of daily fluctuations may increase the establishment of wet marsh species at lower elevations and promote the transition of higher elevation marshes to woody phreatophyte species such as tamarisk or arrowweed (Stevens et al. 1995). Periodic flooding and drying tends to increase diversity and productivity in wetland communities (Reclamation 2011b; Stevens et al. 1995). Although low-elevation plants in marshes in Marble Canyon and Grand Canyon, such as cattail, common reed, and willow, may become buried with coarse sediment, recovery generally occurs within 6–8 months (Kearsley and Ayers 1999; Kennedy and Ralston 2011). Low steady flows can cause some wetland patches to dry out, resulting in considerable mortality (Porter 2002). Sustained high releases reduce wetland vegetation cover to less than 20% on lower reattachment bars, allowing tamarisk to occupy open space, if sustained low releases occur in the next growing season (Ralston et al. 2014; Sher et al. 2000). Extended high flows typically scour herbaceous vegetation; however, most woody plants often remain (Ralston et al. 2014). Thus, extended high flows followed by extended low flows in the following growing season result in a transition from shrub wetland to a cottonwood-willow community on channel margins because of an increase in overstory cover and a decrease in herbaceous understory plants (Ralston 2010).

Flows that result in increases or decreases in marsh or shrub wetland communities are given in Table 4.6-4. A transition from marsh to shrub wetland occurs on lower reattachment bars with 4 years of consecutive seasons of low fluctuating flows or non-growing-season sustained low flows (Ralston et al. 2014; Stevens et al. 1995). A fall or spring HFE delays the transition for 1 year; however, an extended high flow before the transition removes the established plants (Ralston et al. 2014).

Wetland communities generally transition only from bare sand or other wetlands (Ralston et al. 2014; Stevens et al 1995); they can transition back to bare sand or to arrowweed, tamarisk, or cottonwood-willow communities (Mortenson et al 2012; Ralston 2010; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a). A greater occurrence of transitions from bare sand to wetlands and/or maintenance of wetlands (lack of transitions to other community types) would result in greater wetland cover. Alternatives that include frequent extended low flows, such as annually for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases for Alternative F. The relative change in cover (final based on model results/initial) of wetland community types is presented in Figure 4.6-4.

4.6.2.4 Special Status Plant Species

Impacts on special status plant species that are known to occur along the Colorado River from Glen Canyon Dam to Lake Mead are summarized in Table 4.6-6. Scientific names, listing status, and habitat are presented in Section 3.6, Table 3.6-2. The analyses of impacts for special status plant species is similar to the analysis for other vegetation and relies on an evaluation of impacts on the habitat associated with each species.

Species of active floodplains occur above the elevation of daily releases (25,000 cfs) but within the stage elevation of HFEs (45,000 cfs). These include Grand Canyon evening primrose (*Camissonia specuicola* ssp. *hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), and may include giant helleborine (*Epipactis gigantea*). These species are generally not affected by HFEs because of their short duration, however, Alternatives C, D, and G include extended duration HFEs (up to 250 hr under Alternative D and 336 hr under Alternative G), while Alternative F has annual spring HFEs. A slightly increased potential for burial from these HFEs could result in an increased potential for impacts on special status species because of their small populations.

Species of the Lake Mead shoreline include sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), and Las Vegas bear poppy (*Arctomecon californica*). These species are generally not affected by fluctuations in the Lake Mead surface elevation, as under current operations. However, alternatives that raise the reservoir surface elevation, such as

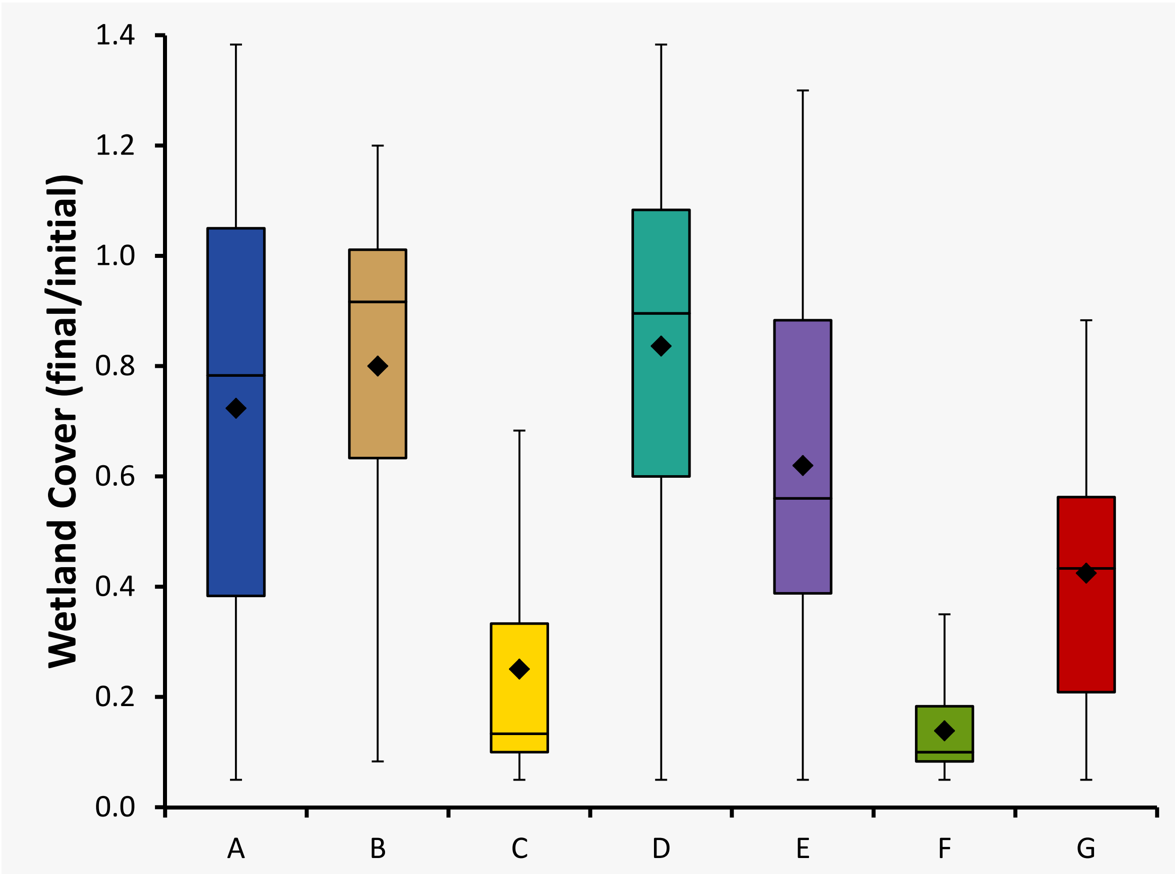

FIGURE 4.6-4 Comparison among Alternatives for Wetland Cover as Predicted by a Vegetation Model (Metric represents the proportion of the estimated amount of wetland vegetation types at the end of the LTEMP period relative to the amount at the beginning; values of 1 indicate no change over the LTEMP period; values >1 indicate an increase; values <1 indicate a decrease. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

the minor elevation increase in April-June under Alternative F (see Figure 4.2-4), inundate the shoreline habitat for these species, potentially resulting in drowning of individuals.

Species of inactive floodplains, Marble Canyon spurge (*Euphorbia aaron-rossii*) and hop-tree (*Ptelea trifoliata*), occur above the stage elevation of HFEs (45,000 cfs) but below the elevation of the desert scrub community. These species are not directly affected by dam operations. However, the annual spring HFEs that occur under Alternative F potentially provide a slight benefit to these species through frequent increases in soil moisture.

Species of the fluctuation zone are inundated by daily operations and are typically associated with wetland communities. These include satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), and American bugleweed (*Lycopus americanus*). The loss of wetland community cover under all alternatives would result in a loss of habitat for these species.

TABLE 4.6-6 Summary of Impacts on Special Status Plant Species under LTEMP Alternatives

Species	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Species of active floodplains (25,000–45,000 cfs) Grand Canyon evening primrose (*Camissonia specuicola* ssp. *Hesperia*), Mohave prickly pear (*Opuntia phaeacantha* var. *mohavensis*), lobed daisy (*Erigeron lobatus*), giant helleborine (*Epipactis gigantea*)	No impact from current operations; located above the level of daily operations.	Same as Alternative A.	Small potential for impacts from extended duration HFEs.	Small potential for impacts from extended duration HFEs.	Same as Alternative A.	Small potential for impacts from high frequency of HFEs.	Small potential for impacts from extended duration HFEs.
Species of the Lake Mead shoreline sticky buckwheat (*Eriogonum viscidulum*), Geyer's milkvetch (*Astragalus geyeri*), Las Vegas bear poppy (*Arctomecon californica*)	No impact on species from current operations.					Minor increase in April–June in Lake Mead shoreline elevation inundating habitat; adverse impact.	Similar to Alternative A.
Species of inactive floodplains (>45,000 cfs) Marble Canyon spurge (*Euphorbia aaron-rossii*), hop-tree (*Ptelea trifoliata*)	No impact from current operations; located above dam operational effects.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Same as Alternative A.	Small potential for benefit from high frequency of spring HFEs.	Same as Alternative A.
Species of fluctuation zones and wetlands satintail (*Imperata brevifolia*), rice cutgrass (*Leersia oryzoides*), American bugleweed (*Lycopus americanus*)	Adverse impact; wetland habitat decreases.						

4.6.3 Alternative-Specific Impacts

The resources addressed in this section include the riparian plant communities of the New High Water Zone and the Fluctuation Zone. The mechanisms underlying New High Water Zone vegetation changes associated with hydrologic events, and the associated research supporting those mechanisms, are described in Section 4.6.2. Details of the model and calculation of the performance metrics can be found in Appendix G. Although the model is not spatially explicit and, therefore, cannot predict changes to plant communities on individual sandbars and channel margin depositional features, acreage changes that are calculated from the currently mapped extent of each of the modeled community types are presented in this section, based on the modeled increase or decrease in each type.

As noted in Section 4.6.2.2, experimental vegetation restoration actions would also be implemented that would result in modifications to the riparian vegetation communities in the New High Water Zone. Although these areas may be a relatively small proportion of the riparian area below Glen Canyon Dam, implementation of non-flow actions would result in the reduction of nonnative species populations, including tamarisk, and increases in native species populations on sandbars and channel margin areas. Consequently, the native/nonnative ratios (as well as changes in tamarisk) identified for each alternative in this section would likely be higher with the implementation of non-flow actions under those alternatives. Similarly, the arrowweed metric presented for each alternative would likely be higher with the implementation of non-flow actions under those alternatives.

4.6.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), base operations (i.e., the intervening flows that occur between HFEs or other experimental flow manipulations) are MLFF, the flow regime that was put in place by the 1996 ROD (Reclamation 1996) for the 1995 Glen Canyon EIS (Reclamation 1995). This alternative includes sediment-triggered spring and fall HFEs through 2020 (no spring HFEs until 2016) that would be implemented according to the HFE protocol developed and evaluated in the HFE EA (Reclamation 2011b). Alternative A has higher monthly volumes in the high electricity demand months of December, January, July, and August than in other months. This alternative has fewer spring and fall HFEs than other alternatives, occasional extended low flows, and more frequent extended high flows than most other alternatives, the latter being particularly frequent in the growing season.

Frequent extended high flows would result in a decrease in the native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a). Repeated seasons of extended high flows have been observed to cause the transition of native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). This is supported by modeling results which indicate a 17% (55.2 ac) overall decrease in native plant community cover and 28% (1.3 ac) decrease in wetland community cover.

The frequent extended high flows and few extended low flows (along with few spring HFEs) would tend to remove tamarisk and would be accompanied by a reduced level of establishment of tamarisk (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000; Kearsley and Ayers 1999; Stevens and Waring 1986a), resulting in an overall decrease in tamarisk-dominated communities. Because the decrease in tamarisk modeled (58.4 ac) exceeds the decrease in native community types (55.2 ac), the ratio of native to nonnative community types would be expected to increase by about 5% under Alternative A.

Frequent extended high flows, few spring HFEs, and occasional fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of modeling, Alternative A is expected to result in a 25% (44.5 ac) increase in the arrowweed community type.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3.

In summary, Alternative A would result in beneficial changes associated with an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (5% increase in ratio, 58.4 ac decrease in tamarisk). These benefits could be greater than anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation restoration experiment. However, Alternative A is also expected to result in adverse effects associated with a decrease in native cover (17% overall decrease in native plant community cover; 28% decrease in wetland community cover) and native diversity (2% decrease in native diversity over the LTEMP period due to decrease in wetland communities), and an increase in arrowweed cover (25% increase in cover). Several special status species could be impacted as a result of the decrease in wetland community cover. The Old High Water Zone would continue narrowing. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative A would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.2 Alternative B

Alternative B includes spring and fall HFEs (the number of HFEs not to exceed one every other year), with few spring HFEs, similar to Alternative A, but slightly more fall HFEs compared to Alternative A. TMFs are also included in this alternative. This alternative has the same monthly pattern in release volume as the Alternative A; however, due to the large daily fluctuations, Alterative B has no extended low flows and has frequent extended high flows, at a slightly greater frequency compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types including wetlands (Ralston 2010; Ralston et al. 2008; Kearsley and Ayers 1999; Stevens and Waring 1986a); however, the decrease, including wetland decrease, is less (statistically significant) than under Alternative A. Repeated seasons of extended high flows transition native communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a).

This is supported by modeling results which indicate a 15% (48.3 ac) overall decrease in native plant community cover and 20% (0.9 ac) decrease in wetland community cover. Although the amount of native cover would be expected to decrease under this alternative, the diversity of native community types is expected to increase 3%. This alternative would result in a greater area of wet marsh than Alternative A primarily because of a lack of extended low flows that would contribute to a loss of marsh (Sher et al. 2000; Porter 2002).

The frequent extended high flows would result in a tendency to remove tamarisk through repeated effects (consecutive seasons or years) of drowning, limited growth, and depleted energy reserves (Kearsley and Ayers 1999; Stevens and Waring 1986a), and a lack of extended low flows (along with few spring HFEs) would result in a reduced level of tamarisk seedling establishment (Ralston 2011; Mortenson et al. 2012; Porter 2002; Sher et al. 2000), resulting in an overall decrease in tamarisk-dominated communities, with there being more of a decrease than under Alternative A. Because of the large decrease in tamarisk-dominated communities modeled (71.4 ac) and smaller decrease in native cover (48.3 ac), the ratio of native to nonnative community types under this alternative would increase 15% and is significantly higher (statistically significant) than that for Alternative A.

Frequent extended high flows, few spring HFEs, and more fall HFEs would also promote the establishment of arrowweed on upper elevation areas (Waring 1995). Based on results of modeling, Alternative B is expected to result in a 19% increase (33.3 ac) in arrowweed, although at a level less than under Alternative A (however, the difference is not statistically significant).

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. One experimental element, hydropower improvement flows, results in a considerable increase in the frequency of extended high flows, resulting in a greater decrease in native community types (150.1 ac) and tamarisk (107.0 ac) and a slightly greater increase in arrowweed (41.9 ac) (although not a statistically significant difference).

In summary, Alternative B would result in beneficial changes associated with an increase in native diversity (3% increase over the LTEMP period, a higher diversity than Alternative A), and an increase in the ratio of native to nonnative community types as a result of a decrease in tamarisk cover (a 15% increase in ratio, a higher ratio than under Alternative A; 71.4 ac decrease in tamarisk, a greater decrease than under Alternative A). These benefits could be greater than anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation restoration experiment. However, Alternative B is also expected to result in adverse effects associated with a decrease in native cover (15% overall decrease in native plant community cover, 20% decrease in wetland community cover; both less of a decrease than under Alternative A) and an increase in arrowweed cover (19% increase in cover, less than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover. The Old High Water Zone would continue narrowing. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative B would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk. Alternative B would result in higher fluctuation flows, although flows prior to the 1996 ROD (Reclamation 1996) had a much greater daily range than Alternative B

(28,500–30,500 cfs; Reclamation 1995). The shift from those flows to MLFF resulted in a general reduction of marsh habitat and an increase in tamarisk and arrowweed, particularly in the upper elevations of the former Fluctuation Zone (Ralston 2005). An increase in fluctuations would not necessarily reverse those trends but would be expected to result in greater marsh area (Stevens et al. 1995) and potentially less tamarisk and arrowweed than under MLFF of Alternative A. These increases would not be realized under experimental hydropower improvement flows.

4.6.3.3 Alternative C

Alternative C includes spring and fall HFEs that could be triggered by Paria River sediment inputs in all years during the LTEMP period and proactive spring HFEs (24 hr, 45,000 cfs HFE) that would be tested in April, May, or June in high-volume years. Lower fluctuation levels conserve more sediment, and therefore result in more triggered HFEs. As a result, this alternative has a far greater frequency of fall and spring HFEs compared to Alternatives A and B (see Section 4.2). TMFs are also included in this alternative. Alternative C has highest monthly release volumes in December, January, and July, and lower volumes from August through November; volumes in February through June would be proportional to power contract delivery rates. This alternative has a higher frequency of extended low flows compared to Alternative A and far fewer growing or non-growing seasons without extended high or low flows. Although Alternative C generally has fewer growing-season extended high flows than Alternative A, it has a slightly greater frequency of non-growing-season extended high flows.

Repeated high flows have been observed to shift vegetation communities to bare sand (Kearsley and Ayers 1999; Ralston 2010; Stevens and Waring 1986a). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in a lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than that under Alternative A. This alternative has the greatest decrease in native cover of all the alternatives and the second greatest decrease in wetlands (only Alternative F is greater). Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 37% (117.7 ac) overall decrease in native plant community cover and 75% (3.4 ac) decrease in wetland community cover. The diversity of native community types decreases 8% under this alternative is lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) and promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012;

Sher et al. 2000). Consequently, tamarisk-dominated communities would be expected to increase considerably under Alternative C (104.0 ac, only Alternative F has a greater increase). Because of the large decrease in native community types (117.7 ac), the ratio of native to nonnative community types under this alternative decreases 54% and is significantly lower (statistically significant) than under Alternative A, and is the largest difference between the two alternatives.

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010), while extended low flows contribute to tamarisk replacing arrowweed (Sher et al. 2000; Stevens and Waring 1986a; Porter 2002). Arrowweed would therefore decrease 14 % (25.1 ac) based on results of modeling, under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows and TMFs, which have little effect on the results, and proactive spring HFEs, which result in twice the tamarisk increase (more bare sand becoming tamarisk rather than arrowweed) and a decrease in arrowweed.

In summary, Alternative C would result in a beneficial change associated with a decrease in arrowweed cover (14% decrease in cover, less cover than the increase under Alternative A). This benefit could be greater than anticipated depending on the effects of the non-flow vegetation restoration experiment. However, Alternative C is also expected to result in adverse effects associated with a decrease in native cover (37% overall decrease in native plant community cover, 75% decrease in wetland community cover; both greater decreases than under Alternative A), decrease in native diversity (8% decrease, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (54% decrease in ratio, a lower ratio than under Alternative A; 104 ac increase in tamarisk, greater tamarisk cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than Alternative A could potentially result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative C would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.4 Alternative D (Preferred Alternative)

This alternative includes a variety of HFE types throughout the LTEMP period including: sediment-triggered spring (March–April) and fall (October–November) HFEs; proactive spring HFEs (24 hr, 45,000 cfs) would be tested (April, May, or June) in high-volume years; no spring HFEs in the first two years; and extended-duration fall HFEs (up to 250 hr duration, up to 45,000 cfs), up to four in 20-year period. More even monthly volumes conserve more sediment and therefore result in more triggered HFEs. As a result, Alternative D has a considerably greater frequency of fall and spring HFEs compared to Alternatives A and B (Section 4.2). TMFs are also included in this alternative. This alternative has very few growing-season extended low flows, as well as slightly fewer non-growing-season extended low or high flows, due to the monthly pattern of flows as well as the amount of daily fluctuations. Alternative D has frequent growing-season extended high flows but fewer than under Alternative A. Seasons without extended low or high flows are frequent, especially non-growing seasons.

Frequent extended high flows would result in a decrease in native community types, including wetlands, although less (statistically significant) of a decrease than under Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. A greater frequency of HFEs would tend to slow establishment of shrub wetland on bare sand; extended high flows prevent establishment of this community type (Stevens and Waring 1986a; Porter 2002) and establishment of wet marsh (Stevens et al. 1995; Kearsley and Ayers 1999; Ralston 2010). However, few extended low flows during the growing season would limit the occurrence of wetland communities shifting to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). This is supported by modeling results, which indicate a 12% (39.5 ac) overall decrease in native plant community cover and 16% (0.8 ac) decrease in wetland community cover. The diversity of native community types, a 2% increase, is significantly greater (statistically significant) under this alternative than under Alternative A because of a greater degree of evenness in native community types, as this alternative would result in a greater area of wet marsh than under Alternative A, which has more frequent extended high flows.

Repeated extended high flows, as occur under this alternative, can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. The low number of growing-season extended low flows would limit tamarisk establishment (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). However, spring HFEs and growing-season extended high flows can promote the establishment of tamarisk (Sher et al. 2000; Mortenson et al. 2012). Because the decrease in native community types is greater than the decrease in tamarisk (22.4 ac) based on results of modeling, the ratio of native to nonnative community types under this alternative decreases and is lower than under Alternative A (the difference is statistically significant).

Repeated extended high flows remove arrowweed (Kearsley and Ayers 1999; Ralston 2010). The establishment of arrowweed on upper elevation areas is slowed by fall HFEs (Waring 1995). In addition, the low number of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed (Porter 2002). Based on results of modeling arrowweed would therefore decrease 10% (17.1 ac) under this alternative, a statistically significant difference from the increase under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2, 4.6-3, and 4.6-8. Experimental elements of this alternative include low summer flows, TMFs, and low flows for benthic invertebrate production. Low summer flows result in a greater reduction in native community types and an increase in arrowweed due to more growing-season extended low flows. TMFs would result in a greater reduction in native cover and less of an increase in arrowweed due to a loss of marsh to arrowweed from occasional extended low flows. Benthic invertebrate production flows do not result in any statistically significant differences in performance metrics.

In summary, Alternative D would result in a beneficial change associated with an increase in native diversity (2% increase, greater diversity than under Alternative A) and decrease in arrowweed cover (10% decrease, lower cover than under Alternative A). These benefits could be greater than anticipated depending on the effects of the non-flow vegetation restoration experiment. However, Alternative D is also expected to result in adverse effects associated with a decrease in native cover (12% overall decrease in native plant community cover, 16% decrease in wetland community cover; both decreases less than under Alternative A) and a decrease in the ratio of native to nonnative community types (5% decrease in ratio, a lower ratio than under Alternative A; 22.4 ac decrease in tamarisk, less of a decrease than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than Alternative A could potentially result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative D would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.5 Alternative E

This alternative includes sediment-triggered spring and fall HFEs implemented according to the HFE protocol (Reclamation 1995) with the exception that no spring HFEs would be implemented in first the 10 years. As a result, Alternative E has a greater frequency of HFEs, particularly fall HFEs, than Alternative A (Section 4.2). TMFs are also included in this alternative. Lower monthly water volumes would occur in August, September, and October. This alternative has frequent growing-season extended high flows but fewer than under Alternative A, and slightly more growing-season extended low flows. The non-growing season frequently has no extended high or low flows.

Frequent extended high flows would result in a decrease in the native community types including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) including wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. These flows, in combination with extended low flows, can result in wetlands transitioning to tamarisk (Sher et al. 2000; Mortenson et al. 2012). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a,b; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 20% (63.5 ac) overall decrease in native plant community cover and 38% (1.7 ac) decrease in wetland community cover. The diversity of native community types under this alternative would decrease and is similar to that under Alternative A.

Repeated extended high flows can remove tamarisk (Stevens and Waring 1986a; Kearsley and Ayers 1999), resulting in a decrease in tamarisk-dominated communities, although less of a decrease than under Alternative A. Because the decrease in native community types modeled (63.5 ac) is greater than the decrease in tamarisk (45.7 ac), the native to nonnative ratio under this alternative decreases 4% and is lower than under Alternative A.

Growing-season extended low flows can result in wetlands becoming replaced by arrowweed (Porter 2002), and non-growing seasons without extended high or low flows combined with growing-season extended low or extended high flows allow arrowweed to become established on bare sand (Waring 1995). Based on results of modeling arrowweed-dominated communities would be expected to increase 25% (44.0 ac) under this alternative, similar to the increase under Alternative A.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements of this alternative include low summer flows (result in slightly more growing-season extended high flows), which result in a slightly greater decrease in native community types, and TMFs, which have little effect on results, and HFEs, which when absent result in a smaller decrease in native community types, a greater decrease in tamarisk, and a greater increase in arrowweed (arrowweed establishment on bare sand is slowed by fall HFEs; Waring 1995).

In summary, Alternative E would result in an adverse change associated with a decrease in native cover (20% overall decrease in native plant community cover, 38% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (2%, similar to Alternative A), decrease in the ratio of native to nonnative community types (4% decrease in ratio, a lower ratio than under Alternative A; 45.7 ac decrease in tamarisk, less of a decrease than under Alternative A), and an increase in arrowweed cover (25%, similar to Alternative A). These adverse effects could be less than anticipated depending on the effects of the tamarisk leaf beetle in the area and the non-flow vegetation restoration experiment. Several special status species could be impacted as a result of the decrease in wetland community cover. The old high water zone would continue narrowing. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative E would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to a greater decrease in tamarisk.

4.6.3.6 Alternative F

This alternative includes a much greater frequency of spring and fall HFEs than Alternative A and any other alternative (see Section 4.2). Alternative F also features higher volumes than Alternative A in April, May, and June, and lower volumes than Alternative A in other months, with low flows from July through January. This alternative has a far greater number of extended low flows than Alternative A, few seasons without extended high or low flows, and frequent growing-season extended high flows, with slightly fewer extended high flows compared to Alternative A.

Frequent extended high flows would result in a decrease in native community types, including wetlands, with there being more (statistically significant) of a decrease than Alternative A. Growing-season extended high flows can contribute to the loss of New High Water Zone native communities (Stevens and Waring 1986a) or wetlands (Stevens and Waring 1986a; Kearsley and Ayers 1999; Ralston 2010), resulting in bare sand. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002). A greater frequency of HFEs, very few seasons without extended high or low flows, and far more extended low flows would result in lack of establishment of native community types, including wetlands (Ralston et al. 2008; Waring 1995; Anderson and Ruffner 1987). The establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low or high flows or HFEs (Stevens and Waring 1986a; Porter 2002). Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). This is supported by modeling results which indicate a 30% (95.0 ac) overall decrease in native plant community cover and 86% (4.0 ac) decrease in wetland community cover. Alternative F results in a greater loss of wetlands than any other alternative due to the frequent extended high flows, the far greater number of extended low flows, and the small number of seasons without extended high or low flows. The diversity of native community types under this alternative is expected to decrease 9% and is lower (statistically significant) than that under Alternative A and lower than any other alternative, primarily due to the large decreases in wetland community types.

Growing-season extended low flows resulting from low steady flows from July through October can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002) as wetlands dry and arrowweed colonizes former wetland areas. Wetlands transition to tamarisk with growing-season extended high flows in combination with extended low flows (Sher et al. 2000; Mortenson et al. 2012). The frequent extended high flows often shift all states to bare sand, which then shifts to tamarisk. Spring HFEs and growing-season extended high and low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002; Mortenson et al. 2012). In addition, tamarisk communities are not expected to transition to other community types under this alternative, and as a result, this alternative would result in the greatest increase in tamarisk of any alternative (230.7 ac). Because of the large decrease in native community types (95.0 ac), the native to nonnative ratio under this alternative decreases 62% and is lower (statistically significant) than under Alternative A.

Extended low flows contribute to wetlands becoming replaced by arrowweed (Porter 2002). Extended low flows combined with extended high flows result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Based on results of modeling, Alternative F would result in a 13% (22.2 ac) decrease in the arrowweed community type, with arrowweed cover being lower (statistically significant) than under Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation goals for camping.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative F would result in a beneficial change associated with a decrease in arrowweed (13%, lower cover than under Alternative A). This benefit could be greater than anticipated depending on the effects of the non-flow vegetation restoration experiment. However, Alternative F is also expected to result in adverse effects associated with a decrease in native cover (30% overall decrease in native plant community cover, 86% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (9%, lower diversity than under Alternative A), and decrease in the ratio of native to nonnative community types (62% decrease in ratio, a lower ratio than under Alternative A; 230.7 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover. There is a small potential for impacts on active floodplain and Lake Mead shoreline special status species and benefit to inactive floodplain special status species. The Old High Water Zone would continue narrowing, although annual spring HFEs could result in higher survival rates than Alternative A of plants at lower elevations of the zone. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative F would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.6.3.7 Alternative G

This alternative includes sediment-triggered spring and fall HFEs, extended-duration fall HFEs (up to 336-hr, 45,000-cfs releases), and proactive spring HFEs in high volume years. Equal monthly volumes and steady flows conserve more sediment, and therefore result in more triggered HFEs. As a result, Alternative G has a far greater frequency of fall and spring HFEs compared to Alternative A and most other alternatives (Section 4.2). Because monthly volumes would be approximately equal, this alternative has a far greater number of extended low flows and fewer extended high flows compared to Alternative A.

Occasional extended high flows (although less frequent than under Alternative A) would result in a decrease in native community types through scouring and drowning, including wetlands, with there being more (statistically significant) of a decrease than under Alternative A. A greater frequency of HFEs and far more extended low flows would result in lack of establishment of native community types; consequently, native community types including wetlands decrease under this alternative (Ralston et al. 2008;Waring 1995; Anderson and Ruffner 1987), with the decrease being greater (statistically significant) than under Alternative A. Extended low flows during the growing season contribute to the shifting of wetland communities to tamarisk or arrowweed (Sher et al. 2000; Mortenson et al. 2012; Porter 2002), and the establishment of shrub wetland communities on bare sand can be slowed by growing-season extended low flows or HFEs (Stevens and Waring 1986a; Porter 2002). This is supported by modeling results which indicate a 29% (93.7 ac) overall decrease in native plant community cover and 58% (2.6 ac) decrease in wetland community cover. The diversity of native community types under this alternative would be expected to decrease 3%, and would be lower than that under Alternative A, primarily due to the large decreases in the wetland community types.

Growing-season extended low flows along with an extended high flow can contribute to the shifting of wetland and arrowweed communities to tamarisk (Sher et al. 2000; Mortenson et al. 2012; Stevens and Waring 1986a; Porter 2002). Growing-season extended low flows promote tamarisk establishment on bare sand (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002). Spring HFEs in combination with growing-season extended low flows can also contribute to tamarisk establishment on bare sand (Stevens and Waring 1986a; Porter 2002; Mortenson et al. 2012) or spring HFEs in combination with a growing-season extended high flow (Sher et al. 2000; Mortenson et al. 2012). Consequently, tamarisk-dominated communities would be expected to increase under Alternative G, a 46.4 ac increase based on results of modeling. Because of the large decrease in native community types (93.7 ac), the native to nonnative ratio under this alternative would decrease (40% decrease) a lower ratio (statistically significant) than under Alternative A.

Extended low flows can contribute to wetlands becoming replaced by arrowweed (Porter 2002), and extended low flows combined with extended high flows can result in the establishment of arrowweed on bare sand (Waring 1995). However, extended high flows followed by a growing-season extended low flow causes arrowweed to be replaced by tamarisk (Stevens and Waring 1986a; Sher et al. 2000; Porter 2002), and growing-season extended high flows contribute to the loss of arrowweed, resulting in bare sand (Kearsley and Ayers 1999; Ralston 2010). Based on the results of modeling, Alternative G would result in a 11% (20.1 ac) decrease in the arrowweed community type, with arrowweed cover being significantly lower (statistically significant) than for Alternative A. Note that this reduction is considered a benefit because of the invasive nature of this species and associated impacts on meeting sediment resource objectives and recreation camping goals.

The model results for each of the metrics are presented in Table 4.6-3 and shown in Figures 4.6-2 and 4.6-3. Experimental elements are not included in this alternative.

In summary, Alternative G would result in a beneficial change associated with a decrease in arrowweed (11%, lower cover than under Alternative A). This benefit could be greater than anticipated depending on the effects of the non-flow vegetation restoration experiment. However, Alternative G is also expected to result in adverse effects associated with a decrease in native cover (29% overall decrease in native plant community cover, 58% decrease in wetland community cover; both decreases greater than under Alternative A), decrease in native diversity (3% decrease in native diversity over the LTEMP period, lower than under Alternative A), and reduction in the ratio of native to nonnative community types (40% decrease in ratio, a lower ratio than under Alternative A; 46.4 ac increase in tamarisk, greater cover than under Alternative A). Several special status species could be impacted as a result of the decrease in wetland community cover. There is a small potential for impacts on active floodplain special status species. The Old High Water Zone would continue narrowing, although more spring HFEs than Alternative A could result in higher survival rates of plants at lower elevations of the zone. Although the non-flow vegetation restoration experiment may decrease these adverse effects to some extent, it is expected that Alternative G would result in a movement away from the riparian vegetation resource goal over the LTEMP period. The tamarisk leaf beetle may contribute to reducing the increase in tamarisk.

4.7 WILDLIFE

This section addresses the effects of the LTEMP alternatives on wildlife, including special status species.

> **Issue:** How do alternatives affect wildlife species in the project area?
>
> **Impact Indicators:**
>
> - Change in riparian and wetland wildlife habitats
> - Change in aquatic habitats and food base used by wildlife
> - Direct effects of HFEs and other flow and non-flow actions on wildlife

4.7.1 Analysis Methods

Models of the effects of alternatives on wildlife populations were not available for use in this analysis. This is, in part, a reflection of the relatively limited amount of quantitative data available on wildlife of Glen and Grand Canyons, which would serve as the basis of such models. Impact assessments are based on previous studies of wildlife in the project area and on the assessments conducted for aquatic ecology (Section 4.5) and vegetation (Section 4.6), because these assessments reflect impacts on terrestrial wildlife habitat and food production upon which wildlife species depend.

Impacts of LTEMP alternatives were evaluated for the following wildlife species groups (impacts on fish and other aquatic species are discussed in Section 4.5):

- Terrestrial invertebrates,
- Amphibians and reptiles,
- Birds,
- Mammals, and
- Special status species.

Impacts of each alternative on these species groups were evaluated based on the following impact indicators:

- Change in riparian and wetland wildlife habitats,
- Change in aquatic habitats and food base, and
- Direct effects of HFEs and other flow and non-flow actions on wildlife.

Other factors that could contribute to impacts on wildlife species and their habitats, such as climate change, defoliation of tamarisk by the tamarisk leaf beetle (*Diorhabda* spp.), noise, and uranium mining, are addressed as cumulative impacts (in Section 4.17.3.6).

4.7.2 Summary of Impacts

As described in Section 3.7, terrestrial wildlife populations in Glen and Grand Canyons are influenced by the availability of suitable habitat, food, and water resources. Of most importance for the analysis of the effects of LTEMP alternatives are those species dependent on riparian, wetland, and aquatic habitats, because these habitats could be directly and indirectly affected by LTEMP alternatives. Habitats above the riparian zone (mostly desert scrub) and the wildlife that inhabit those areas would be unaffected by LTEMP alternatives.

Water release patterns associated with both daily and monthly base operations, and experimental elements, particularly HFEs, are important factors that determine the coverage and characteristics of riparian vegetation and wetlands. Section 4.6 describes the anticipated changes in the characteristics of riparian vegetation communities over the LTEMP period; however, the anticipated impacts of the alternatives on vegetation relate to transitions among plant community types, not to increases or decreases in the amount of riparian and wetland vegetation coverage. None of the alternatives are expected to result in important structural changes in riparian habitat or overall riparian habitat coverage that could have population-level effects on terrestrial wildlife species. As noted in Section 4.5, there has been a net increase in vegetation since construction of the dam and none of the alternatives are expected to reverse these gains. In addition, many of the terrestrial wildlife species that occur in Glen and Grand canyons utilize a variety of terrestrial habitats and are not solely dependent on riparian habitat in general, or on the specific types of riparian vegetation that occur along the river. These factors reduce the potential for impacts of LTEMP alternatives on terrestrial wildlife.

Direct impacts of LTEMP alternatives on terrestrial wildlife species are possible, but these are likely to be short term. Although HFEs could displace less mobile species such as invertebrates, amphibians, and reptiles (Reclamation 2011b), these species can quickly recolonize disturbed areas from adjacent areas; most vertebrate animals that occupy riparian habitats are mobile enough to move in response to fluctuations in flow, and would return shortly after the HFE is over.

A summary of impacts of the LTEMP alternatives on various wildlife groups is presented in Table 4.7-1 and discussed below.

4.7.2.1 Terrestrial Invertebrates

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on terrestrial invertebrates. Invertebrates contribute to the diversity of the riparian corridor of the Colorado River and perform important ecological functions as decomposers, herbivores, predators, and pollinators. In addition, this diverse community of animals is an important component of the prey base of insectivorous vertebrates including fish, frogs, toads, lizards, snakes, songbirds, small mammals, and bats.

Most invertebrates in the riparian zone obtain their food from terrestrial sources, but the diets of some species (e.g., ground beetles, ants, and spiders) are also subsidized by emerging aquatic insects or by drifting aquatic organisms that become stranded in the varial zone (Paetzold et al. 2006). Some changes in the characteristics of vegetation communities (e.g., changes in diversity) and aquatic habitats may cause localized changes in terrestrial invertebrates (Anderson, B.W. 2012). Terrestrial invertebrates in the riparian zone recovered from the impacts of natural annual historic flood events, and are expected to recover quickly from HFEs (Reclamation 2011b). None of the LTEMP alternatives are expected to result in long-term population-level changes to terrestrial invertebrates.

Differences in the monthly and daily flow patterns of alternatives could affect the production of insects with aquatic and terrestrial life stages (e.g., blackflies, midges, and dragonflies) by affecting the stability of nearshore habitats and the amount of wetted area that supports these insects. Alternatives with more stable flows (Alternatives C, F, and G) and those with more even monthly release volumes (Alternatives C, D, E, and G) are expected to have higher production of these insects because of greater habitat stability; however, any differences among alternatives are expected to be relatively small (Section 4.5). The year-round steady flows of Alternative G are likely to result in the greatest production of these insects, and experimental steady weekend flows under Alternative D also target increased production and diversity. Although these experimental flows have not been tested, on a conceptual basis, providing steadier flows during important production months should produce more insects.

Experimental actions being considered under different alternatives also could adversely affect or benefit terrestrial invertebrates in the Colorado River corridor. Experimental vegetation restoration activities (common to all alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to terrestrial invertebrates. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic macroinvertebrate production on temporarily exposed substrates, and this could in turn affect the production of aquatic insects with terrestrial life stages. Low summer flows have the potential to have a greater impact than TMFs on these insects because the flows would last for a 3-month period during the growing season while the low flows of TMFs would be of

TABLE 4.7-1 Summary of Impacts of LTEMP Alternatives on Wildlife

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts on wildlife	No change from current conditions for most wildlife species, but ongoing wetland decline could affect wetland species.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Less nearshore habitat stability would result in decreased production of aquatic insects and would adversely impact species that eat insects or use nearshore areas, especially with the implementation of hydropower improvement flows. Less decline of wetland habitat compared to Alternative A, however hydropower improvement flows would cause a greater decline of wetland habitat.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas. Greater decline of wetland habitat compared to Alternative A.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas. Least decline of wetland habitat of any alternative.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Increased production of aquatic insects, but accompanying benefits may be offset by higher within-day flow fluctuations.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Greater nearshore habitat stability would result in increased production of aquatic insects and would benefit species that eat insects or use nearshore areas. Greatest decline of wetland habitat of any alternative.	Impacts on most terrestrial wildlife species would be similar to those under Alternative A. Greater nearshore habitat stability would result in increased production of aquatic insects (highest among alternatives) and would benefit species that eat insects or use nearshore areas. Greater decline of wetland habitat compared to Alternative A.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Terrestrial invertebrates	No change from current conditions.	Similar to Alternative A, but potentially lower production of insects with aquatic and terrestrial life stages due to higher daily flow fluctuations. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A due to more uniform monthly flows from December through August, lower daily range in flows. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A due to more uniform monthly flows; experimental steady weekend flows may also increase insect production and diversity. No effect on other terrestrial invertebrates.	Similar to Alternative A. Potential slight increase in production due to more uniform monthly flows, but any increase could be offset by higher within-day flow fluctuations. No effect on other terrestrial invertebrates.	Potential increase in production of insects with aquatic and terrestrial life stages compared to Alternative A resulting from steady flows and relatively high spring flows. No effect on other terrestrial invertebrates.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages of all alternatives. No effect on other terrestrial invertebrates.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians and reptiles	Negligible impact on amphibians and reptiles; some decrease in wetland habitat from current condition, but no change in the stability of nearshore habitats that support adult and early life stages of amphibians and serve as food production areas for amphibians and reptiles. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A, but potentially lower insect production due to higher daily flow fluctuations. Second lowest wetland loss of any alternative. Hydropower improvement flows would have larger adverse effects on wetlands (similar to Alternative C) and food production than Alternative A. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to reduced daily fluctuations. Second highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to relatively even monthly release volumes; experimental steady weekend flows may increase insect production and diversity. Lowest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Negligible impact, similar to Alternative A.	Benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to steady flows. Highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. Third highest wetland loss of any alternative. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

TABLE 4.7-1 (Cont.)

Wildlife Species Group	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect terrestrial birds over the long term. HFEs would occur outside of the breeding season of most birds.	Similar to Alternative A, but larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on insect-eating birds and waterfowl using nearshore areas. HFEs would occur outside of the breeding season of most birds.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to reduced daily fluctuations. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Similar to Alternative A.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to steady flows. Annual 45,000 cfs spike flow would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.	Benefit compared to Alternative A for insect-eating birds and waterfowl using nearshore areas due to steady flows and even monthly release volumes. Proactive spring HFEs would be implemented during the nesting season (May), and could affect nesting birds in elevations below 45,000 cfs.
Mammals	No change from current conditions. Anticipated changes in riparian habitats are not expected to result in important changes in habitat structure or food production that could affect mammals over the long term. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A, but larger daily fluctuations, especially with hydropower improvement flows, could have minor impacts on semi-aquatic mammals and other mammals using nearshore areas. HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to reduced daily fluctuations. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.	Similar to Alternative A.	Similar to Alternative C.	Benefit compared to Alternative A for semi-aquatic mammals and other mammals using nearshore areas due to steady flows and even monthly release volumes. Increased number of HFEs could kill or temporarily displace individuals in the flood zone, but no long-term population-level effects are expected.

short duration (less than 1 day). Mechanical removal of trout should have no effect on terrestrial invertebrates.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would result in noticeable or measurable changes in invertebrates with only terrestrial life stages. However, alternatives with reduced fluctuations (Alternatives C, D, F, and G) or more even monthly release volumes (Alternatives C, D, E, and G) would have greater nearshore habitat stability, and could result in an increase in the production of insects with both aquatic and terrestrial life stages. Section 4.7.3 addresses the potential impacts on invertebrates under each LTEMP alternative.

4.7.2.2 Amphibians and Reptiles

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on amphibians and reptiles. Glen Canyon Dam operations may affect amphibians (including their aquatic larval stages) and reptiles along the Colorado River corridor, primarily though alterations of riparian and wetland habitats and effects on aquatic insect production (Dettman 2005). The effects of alternatives on amphibians (frogs and toads) could result from potential changes to wetland habitat and nearshore habitat that supports both adult and early life stages and serves as production areas for aquatic invertebrate prey. The effects of alternatives on reptiles (snakes and lizards) could result from potential changes in riparian vegetation and terrestrial invertebrate prey production. In addition, raised water levels from HFEs may drown some amphibians and reptiles that are unable to escape the rising water (Dettman 2005), or flood habitats used by amphibians and reptiles.

Amphibian and reptile populations along the river have increased under the modified Colorado River flow regime created by operation of Glen Canyon Dam (Section 3.7.2). Operations since completion of the dam have reduced the magnitude of spring floods and subsequently allowed an increase in riparian vegetation colonizing areas previously scoured by annual floods, and allowing the formation of wetlands under variable daily flows, but more consistent monthly flows (Reclamation 1995). Effects of alternatives on these habitats and the amphibians and reptiles supported by them are expected to be relatively small compared to these larger changes from pre-dam conditions.

Amphibians could be affected by the predicted decreases in wetland habitat area over the 20-year LTEMP period. Wetland area along the river corridor downstream of Glen Canyon Dam is limited (approximately 5 ac), making any loss potentially important for species dependent on wetland areas. Based on vegetation modeling presented in Section 4.6, wetland habitat is expected to decline over the LTEMP period under all alternatives, but impacts would be greater under alternatives with steadier flows (Alternatives C, F, and G) than alternatives with higher fluctuations (Alternatives A, B [except with experimental implementation of hydropower improvement flows], D, and E), which provide daily watering of habitats in the varial zone.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect amphibians or reptiles over the long term. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (alternatives with lower within-day fluctuations, such as Alternatives C, F, and G, or more even monthly release volumes, such as Alternatives C, D, E, and G). Lower fluctuations would also result in potential benefits for the survival of amphibian eggs and tadpoles; however, as discussed in the previous paragraph, these alternatives also support less wetland habitat, which is important to amphibians. Lizard and snakes would benefit less from increases in aquatic-based food production because these reptiles are less dependent on these food sources than are amphibians.

In addition to these habitat and food-based impacts, HFEs can directly affect amphibians by disrupting breeding activities and by flushing egg masses and tadpoles from backwaters depending on the time of year in which they occur. Breeding and egg deposition occurs between April and July, with metamorphosis to adult occurring between June and August (Dettman 2005). Thus, any HFEs conducted between April and August (e.g., sediment-triggered spring HFEs or proactive spring HFEs) are likely to result in some disruption of reproduction and/or mortality (Reclamation et al. 2002). Rising waters have the potential to trap lizards and snakes that are resident below the elevation of HFE flows and drown them or their buried eggs (Warren and Schwalbe 1985). In addition, possible reductions in riparian vegetation (e.g., from scouring) and direct mortality of prey items could lead to a decrease in prey availability (Dettman 2005; Reclamation et al. 2002). These effects are expected to be temporary and not to result in long-term effects on amphibian and reptile populations, because the area affected by scour would be small (below the elevation of 45,000 cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and amphibian and reptile populations in adjacent unaffected areas is expected to occur. Prior to construction of the dam, flooding was an annual natural event in the Grand Canyon from which amphibians and reptiles recovered. Thus, they are expected to quickly recover from individual HFEs (Reclamation 2011b).

Other experiments being considered under different alternatives also could affect amphibians and reptiles in the Colorado River corridor. Experimental vegetation restoration activities (common to all alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to amphibians and reptiles. Activities associated with this restoration could disturb amphibians and reptiles in and adjacent to restoration areas, but this should be temporary unless individuals were inadvertently killed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates; this could in turn affect amphibians and reptiles that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on amphibians and reptiles because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on amphibians or reptiles.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect amphibian and reptile populations. However, alternatives could produce changes in nearshore aquatic and wetland habitats occupied by some amphibian and reptile species, and those that serve as important food production areas for them (Table 4.7-1). Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore habitat areas, but these alternatives would provide less support for wetlands than would alternatives with higher fluctuations (Alternatives A, B, and E). Direct impacts from HFEs on amphibians and reptiles are expected to be negligible and temporary. Periodic flooding is a natural phenomenon along rivers; amphibian and reptile species have adapted to flooding and, from an ecosystem maintenance perspective, they are dependent on it. Section 4.7.3 addresses the potential impacts on amphibians and reptiles under each LTEMP alternative.

4.7.2.3 Birds

Riparian birds, many of which are protected under the Migratory Bird Treaty Act, have increased along the river corridor downstream of Glen Canyon Dam in response to an increase in riparian vegetation under dam operations (Brown et al. 1983; LaRue et al. 2001). In general, birds that use the Grand Canyon corridor temporarily during migration are not affected by Glen Canyon Dam operations; however, birds that breed or overwinter in the riparian zone can be directly and indirectly affected by operations. Table 4.7-1 summarizes the potential effects of LTEMP alternatives on birds.

Changes in riparian and wetland plant coverage can alter foraging and nesting habitats. Even the loss of less desirable vegetation such as tamarisk may have potential negative effects on bird species unless replaced promptly by native woody vegetation (Yard et al. 2004; see also Section 4.17.3.6). The structural complexity of riparian vegetation (e.g., tree, shrub, and ground vegetation layers) and the ecological function they provide is particularly important for many nesting birds (Sogge et al. 1998). Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period, but none of the alternatives are expected to result in significant structural changes in riparian habitat or vegetation productivity that could affect bird populations over the long term.

Differences in the monthly and daily flow patterns of alternatives could affect nearshore foraging areas used by waterfowl and wading birds. As discussed in Section 4.7.2.1, insects with only terrestrial life stages are not expected to be affected differentially by alternatives, and those with both aquatic and terrestrial life stages are expected to benefit under certain alternatives (those with lower within-day fluctuations or more even monthly release volumes such as Alternatives C, D, F, and G). These changes in food production could result in very minor adverse impacts on birds, in part because most birds forage over broad areas that include habitats outside of the river corridor.

In general, the potential for direct impacts of flows on birds would be greatest during the nesting period when nests could be inundated. Impacts of normal operating flows (between 5,000 and 20,000 cfs) are expected to be negligible because few birds nest in these areas (Sogge et al. 1998), and Brown and Johnson (1985) reported that flows up to 31,000 cfs do not affect the nests of riparian birds. Only flows above the normal operating range, such as HFEs, could affect nesting birds, and only if they occurred during the peak nesting period (May through August) because active nests could be destroyed by these high flows. For shrub-nesting songbirds such as Bell's vireo (*Vireo bellii*) and common yellowthroat (*Geothlypis trichas*), inundation of the ground below nests begins to occur at flows of about 36,000 cfs, and nest losses of 50% or more begin to occur from 40,000 to 62,000 cfs. These species can renest as long as high waters do not persist (Brown and Johnson 1985). The nests of some ground-nesting waterfowl species such as mallards (*Anas platyrhynchos*), gadwalls (*A. strepera*), and American wigeon (*A. americana*) could be more susceptible to HFEs than those of songbirds that nest in riparian vegetation, in part because these species breed earlier in the year when spring HFEs would be implemented. Sediment-triggered spring and fall HFEs would occur outside of the main nesting period for most birds, although proactive spring HFEs considered for testing under Alternatives C, D, and G could occur during the nesting period (April through June). Alternative F features an annual 45,000 cfs spike flow that would occur in May. HFEs outside of the nesting period are expected to only temporarily displace birds within the flood zone, and they are expected to use flooded areas once the high flows recede. Overall, riparian bird populations were unaffected by prior floods, so no effects are expected from HFEs (Reclamation 2011b).

Waterfowl that winter in Glen and Grand Canyons would not be present during the months when spring and fall HFEs would most likely occur (March through June and October or November, respectively). Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl.

Other experiments being considered under different alternatives also could adversely affect or benefit birds in the Colorado River corridor. Experimental vegetation restoration activities (common to all alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to birds. Activities associated with this restoration could disturb birds in and adjacent to restoration areas, but this should be temporary unless nests were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, which could in turn affect birds that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on birds because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*) and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

In summary, none of the LTEMP alternatives are expected to produce changes in aquatic and riparian habitats that would result in long-term, population-level impacts on riparian bird populations. However, alternatives could produce changes in nearshore habitats that could affect waterfowl and wading birds; Alternatives C, D, F, and G would produce more stable nearshore habitat for these species. Direct impacts from HFEs on birds would be minimal, mostly because the timing of HFEs would occur outside of the peak breeding season. Under Alternatives C, D, and G, proactive spring HFEs would occur in high-volume release years (≥10 maf); these could occur during the peak nesting season (April through June) and result in the loss of some nests. Alternative F also could affect nesting birds, because it features an annual 45,000-cfs spike flow that would occur in May. Section 4.7.3 addresses the potential impacts on birds under each LTEMP alternative.

4.7.2.4 Mammals

Table 4.7-1 summarizes the potential effects of LTEMP alternatives on mammals. Section 4.6 describes changes in the riparian vegetation community types over the LTEMP period, but these are not expected to result in important structural changes in riparian habitat or vegetation productivity that could affect mammal populations over the long term. Differences in the monthly and daily flow patterns of alternatives could have differential effects on the habitat stability of nearshore areas used by semi-aquatic mammals and other mammals using nearshore areas. As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages are not expected to be affected differentially by alternatives and those with both aquatic and terrestrial life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in very minor effects on insect-eating mammals, such as shrews, mice, and bats. Riparian vegetation changes during the LTEMP period are not expected to have adverse impacts on habitat or food resources for herbivorous mammals that occupy riparian habitats.

HFEs may have direct impacts on some mammals. Less mobile species such as shrews, mice, and other small mammals may drown but some individuals would be able to move upslope away from flood waters. Recolonization of flooded areas would be expected to occur rapidly. Loss of young mammals in ground nests could be destroyed, but multiple litters per year may compensate for any losses from an individual HFE (Dettman 2005). No long-term population-level impacts on these mammals are anticipated.

Along the Colorado River, American beavers (*Castor canadensis*) inhabit and raise their young in bank dens, which they create near the water's edge; the lack of high flows allows them to build their dens lower down in the banks. HFEs may drown young or adults in their bank dens (Dettman 2005; Reclamation et al. 2002). HFEs affect muskrats (*Ondatra zibethicus*) similarly (Reclamation 2011b). Young born prior to a spring or proactive spring HFE may drown if they are located below the flood stage and are unable to leave the lodge. Fall HFEs are unlikely to impact the American beaver or muskrat because they would be able to leave their dens and swim to safety (Reclamation 2011b). These species regularly occur in riverine habitats subjected to regular flood flows, and are adapted to these conditions both in terms of their ability to respond to increases in flow and to recolonize areas affected by floods.

Large carnivores such as the cougar (*Puma concolor*) would experience minimal impacts from dam operations because they generally have large ranges and can obtain prey from both riparian and upland (desert) communities. Similarly, bighorn sheep (*Ovis canadensis*) and mule deer (*Odocoileus hemionus*) are highly mobile and use a variety of habitats within the Grand Canyon, including non-riparian habitats (Dettman 2005).

Other experiments being considered under different alternatives also could adversely affect or benefit mammals in the Colorado River corridor. Experimental vegetation restoration activities (common to all alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to mammals. Activities associated with this restoration could disturb mammals in and adjacent to restoration areas, but this should be temporary unless individuals or nests were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect mammals that consume terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on mammals because the flows would last for a 3-month period during the growing season, while the low flows of TMFs would be of short duration (less than 1 day). Mechanical removal of trout should have no effect on mammals.

In summary, none of the LTEMP alternatives are expected to produce changes in riparian habitats that would affect mammal populations. Direct impacts from HFEs on mammals would be negligible and temporary, and no long-term population-level impacts are expected. Section 4.7.3 addresses the potential impacts on mammals under each LTEMP alternative.

4.7.2.5 Special Status Species

Eleven special status wildlife species, listed under the Endangered Species Act, Bald and Golden Eagle Protection Act, or the State of Arizona, are known to occur or could occur along the Colorado River corridor between Glen Canyon Dam and Lake Mead (Section 3.7). Potential impacts on these species from LTEMP alternatives are summarized in Table 4.7-2 and discussed below.

The effects of dam operations and HFEs under the LTEMP alternatives are discussed for each special status species below. Other experiments being considered under different alternatives also could adversely affect or benefit these species in the Colorado River corridor. Experimental vegetation restoration activities (common to all alternatives) would remove low-value nonnative plant species and attempt to reestablish native species that could be of greater value to special status species. Activities associated with this restoration could disturb special status birds in and adjacent to restoration areas, but this should be temporary unless nests were inadvertently destroyed. Low summer flows under Alternatives C, D, E, and F and TMFs under Alternatives B, C, D, E, and G could adversely affect aquatic food base production on temporarily exposed substrates, and this could in turn affect special status species that consume aquatic invertebrates or terrestrial life stages of aquatic insects. Low summer flows have the potential to have a greater impact than TMFs on special status species because the flows would last for a 3-month period during the growing season while the low flows of TMFs would be of short duration (less than 1 day). TMFs

TABLE 4.7-2 Summary of Impacts of LTEMP Alternatives on Special Status Wildlife Species

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Losses of habitat and individuals of Kanab ambersnail. Decrease in potential wetland habitat for northern leopard frog and Yuma clapper rail. Sediment-triggered spring HFEs could adversely affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat, but this benefit would not persist past 2020 when HFEs are discontinued. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A. Compared to Alternative A, similar decrease in wetland habitat for northern leopard frog and Yuma clapper rail, but greater potential decrease under hydropower improvement flows. Sediment-triggered spring HFEs could adversely affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Least wetland loss of any alternative would benefit northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency could inhibit rebound of the population. Similar wetland loss to Alternative A. Spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration annual high flow in May could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Annual extended-duration high flow in May could affect nests of southwestern willow flycatcher. Spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.	Losses of habitat and individuals of Kanab ambersnail similar to Alternative A, but higher HFE frequency and extended-duration HFEs could inhibit rebound of the population. Adverse impact due to greater wetland loss on northern leopard frog and Yuma clapper rail. Proactive spring HFEs may affect nests of southwestern willow flycatcher; sediment-triggered and proactive spring HFEs may affect nests of Yuma clapper rails. HFEs may benefit California condor by increasing beach habitat. No impacts on other special status species.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Invertebrates							
Kanab ambersnail (*Oxyloma haydeni kanabensis*) ESA-E; AZ-SGCN	No change from current conditions. The average of 5.5 HFEs and maximum of 14 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise through the early portion of the LTEMP period (HFEs would expire in 2020); some rebound between HFEs and after 2020 would be expected; no impacts would occur on the Elves Chasm population.	The average of 7.2 HFEs and maximum of 10 HFEs could cause losses of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the low frequency of HFEs would allow some rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 21.3 HFEs and maximum 40 HFEs could cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 19.3 HFEs and maximum 38 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 17.1 HFEs and maximum 30 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 38.1 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and the annual extended-duration high flow in May would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.	The average 24.5 HFEs and maximum 40 HFEs would cause loss of habitat and individuals in <20% of occupied habitat at Vasey's Paradise; the high frequency of HFEs and extended-duration HFEs would inhibit rebound between HFEs; no impacts would occur on the Elves Chasm population.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Amphibians							
Northern leopard frog (*Lithobates pipiens*) AZ-SGCN	Species may already be extirpated downstream of Glen Canyon Dam. Negligible change from current condition. Some decrease in wetland habitat, but no change in the stability of nearshore habitats that support adult and early life stages and serve as food production areas.	Similar to Alternative A, but potentially lower insect production due to higher daily flow fluctuations; hydropower improvement flows would have larger adverse effects on wetlands and food production than Alternative A.	Potential benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations, but these benefits could be offset by greater wetland losses.	Potential benefit compared to Alternative A due to lowest wetland habitat loss and an increase in habitat stability and insect production in nearshore habitats from reduced daily fluctuations and relatively even monthly release volumes; experimental steady weekend flows may also increase insect production and diversity.	Negligible impact, similar to Alternative A.	Potential benefit compared to Alternative A due to an increase in habitat stability and insect production in nearshore habitats due to steady flows, but these benefits could be offset by greater wetland losses.	Similar to Alternative F, but year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest insect production of all alternatives. These benefits could be offset by greater wetland losses
Birds							
American peregrine falcon (*Falco peregrinus*) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.	No impact. None of the alternatives are expected to affect food or habitat availability for the American peregrine falcon.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Bald eagle (*Haliaeetus leucocephalus*) BGEPA; AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the bald eagle.
California condor (*Gymnogyps californianus*) ESA-EXPN; AZ-SGCN	HFEs may benefit the species by temporarily increasing the amount of beach habitat until 2020, when HFEs expire.	Similar to Alternative A, but HFEs would continue for the duration of the LTEMP period.	Increased number of HFEs compared to Alternative A may produce long-term benefits associated with beach habitats.	Similar to Alternative C.	Similar to Alternative C.	Similar to Alternative C.	Similar to Alternative C.
Golden eagle (*Aquila chrysaetos*) BGEPA; AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.	No impact. None of the alternatives are expected to affect food or habitat availability for the golden eagle.
Osprey (*Pandion haliaetus*) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.	No impact. None of the alternatives are expected to affect food or habitat availability for the osprey.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Southwestern willow flycatcher (*Empidonax traillii extimus*) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August).	Same as Alternative A.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Experimental low summer flows could result in adverse effects on nesting habitat.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Experimental low summer flows could result in adverse effects on nesting habitat.	Same as Alternative A. Experimental low summer flows could result in adverse effects on nesting habitat.	Annual 45,000-cfs high flow would be implemented during the nesting season (May), but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August). Low steady flows in summer could result in adverse effects on nesting habitat.	Proactive spring HFEs could occur in May or June and affect nests in riparian habitats, but sediment-triggered spring and fall HFEs would occur outside of the nesting period of the flycatcher (May through August).
Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) ESA-T(DPS); AZ-SGCN	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.	No impact. None of the alternatives are expected to affect the preferred habitat (cottonwood forest) of the western yellow-billed cuckoo.

TABLE 4.7-2 (Cont.)

Species and Status[a]	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Birds (Cont.)							
Yuma clapper rail (*Rallus longirostris yumanensis*) ESA-E; AZ-SGCN	No change from current conditions. Sediment-triggered spring HFEs could affect nests in wetland areas.	Similar to Alternative A.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Lower wetland loss compared to others could benefit this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Wetland loss comparable to Alternative A.	Annual 45,000-cfs high flow in May increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.	Increased number of HFEs increase potential to impact nests compared to Alternative A. Relatively high wetland loss could adversely affect this species.
Mammals							
Spotted bat (*Euderma maculatum*) AZ-SGCN	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.	No impact. None of the alternatives are expected to affect food or habitat availability for the spotted bat.

[a] AZ-SGCN = Arizona Wildlife Species of Greatest Conservation Need; BGEPA = Protected under the Bald and Golden Eagle Protection Act; ESA-E = Endangered Species Act-Endangered; ESA-EXPN = Endangered Species Act-Experimental Population, Non-Essential; ESA-T(DPS) = Endangered Species Act-Threatened (Distinct Population Segment).

and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species.

Section 4.7.3 addresses the potential impacts on the special status species under each LTEMP alternative, including potential impacts of condition-dependent and experimental elements of the alternatives.

Kanab Ambersnail (*Oxyloma haydeni kanabensis*)

Within the Grand Canyon, populations of the Kanab ambersnail occur at Vasey's Paradise and Elves Chasm. Because the Elves Chasm population is located above the 100,000 cfs stage (FWS 2008), this population would not be affected by any of the LTEMP alternatives. At Vasey's Paradise, very little Kanab ambersnail habitat and only a few individuals occur below the 25,000-cfs stage (Meretsky and Wegner 2000; Sorensen 2009). Most Kanab ambersnail habitat is located above the 33,000 cfs stage (Reclamation 2011b). HFEs may scour or inundate portions of Kanab ambersnail habitat (Kennedy and Ralston 2011). The November 1997 test flow of 31,000 cfs scoured 1% (7 m^2) of Kanab ambersnail habitat (FWS 2008). HFEs of 45,000 cfs cause a temporary loss of as much as 17% (119 m^2) of Kanab ambersnail habitat (FWS 2008). Surveys conducted after HFEs revealed no population-level declines in the Kanab ambersnail population (Kennedy and Ralston 2011). Kanab ambersnails can survive up to 32 hours underwater in cold, well-oxygenated water (FWS 2011c); so as long as they are not washed away, they could survive inundation from the short-term HFEs. The effects of extended-duration HFEs (up to 250 hr in length) proposed under Alternatives C, D, and G, and the extended-duration high flow in May under Alternative F are not known, but they could pose a greater threat to Kanab ambersnail habitat within the area affected by 45,000-cfs flows.

Recovery of ambersnail habitat scoured by HFEs can take 2.5 years (Sorensen 2009). Therefore, frequent HFEs or extended-duration HFEs may result in long-term loss of ambersnail habitat that occurs below the 45,000-cfs flow level (FWS 2011c). However, the snails survived and persisted through natural pre-dam floods and the 1983 flood (Reclamation 1995), which were much larger in magnitude and duration than HFEs proposed under the LTEMP, so HFEs may not represent a substantial threat to the persistence of the Kanab ambersnail (Kennedy and Ralston 2011).

Section 4.7.3 addresses the potential impacts on the Kanab ambersnail under each LTEMP alternative.

Northern Leopard Frog (*Lithobates pipiens*)

Only one population of northern leopard frogs, located within the Glen Canyon National Recreation Area (GCNRA), has been recorded along the Colorado River between Glen Canyon Dam and Lake Mead. However, individuals have not been observed at this location since 2004 (Drost 2005), and it is possible this population has been extirpated. If the species still occurs in Glen Canyon, operations and experiments under the LTEMP alternatives could affect it by affecting the extent of wetland habitat, production of terrestrial invertebrates, or the stability of nearshore habitats potentially used by adults and early life stages. As discussed in Section 4.6.2.2, alternatives could produce changes in nearshore aquatic and wetland habitats. Alternatives C, D, F, and G would produce more stable flows, which would favor food production in nearshore areas and provide higher quality habitats for adults and early life stages of the leopard frog, but Alternatives C, F, and G would provide less support for wetlands than would alternatives with higher fluctuations (Alternatives A, B, and E) or Alternative D, which would result in the least wetland loss of any alternatives. Section 4.7.3 addresses the potential impacts on the northern leopard frog under each LTEMP alternative.

American Peregrine Falcon (*Falco peregrinus*)

Any impacts on the American peregrine falcon from dam operations are likely to be indirect, possibly through influences on the distribution and abundance of aquatic and terrestrial macroinvertebrate populations, which in turn would influence the availability of prey such as swifts, other songbirds, bats, and—in winter—waterfowl (Holmes et al. 2005). However, based on the evaluations presented in Sections 4.7.2.1 (invertebrates) and 4.7.2.3 (birds), differences among alternatives are expected to be small and not affect the abundance of food available to peregrine falcons. No effects of alternatives on foraging habitats (riverine, riparian, and desert areas) or roosting and nesting habitats (cliffs) are anticipated. Section 4.7.3 addresses the potential impacts on the American peregrine falcon under each LTEMP alternative.

Bald Eagle (*Haliaeetus leucocephalus*)

Bald eagles migrate through and overwinter in Marble Canyon and the upper half of the Grand Canyon. There is no evidence that bald eagle abundance is directly affected by river flows (Holmes et al. 2005). During low river flows, bald eagles can capture and scavenge proportionally more prey from isolated pools and nearshore habitats. Inundation of these habitats during high flows reduces or eliminates prey availability (Brown et al. 1989). During the winters of 1990 and 1991, bald eagle foraging in the river, nearshore, and isolated pool habitats of the Colorado River decreased to 0% at flows >20,000 cfs; foraging in adjacent creek habitat increased to 100% (Brown et al. 1998). These observations demonstrate the ability of eagles to respond to changes in foraging conditions by moving to more favorable areas nearby. Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of eagles to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on the bald eagle (*Haliaeetus leucocephalus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. Alternatives would have no effect on habitats used for roosting (cliffs or trees). Wintering and migrant bald eagles are generally not present during the months in which spring and fall HFEs would occur (Sogge et al. 1995). Section 4.7.3 addresses the potential impacts on the bald eagle under each LTEMP alternative.

California Condor (*Gymnogyps californianus*)

California condors are opportunistic scavengers that consume carcasses of mammals, birds, and fishes. Along the Colorado River corridor in Glen and Grand Canyons, they utilize cliff locations for roosting, and beaches when drinking, resting, preening, and feeding (Section 3.7). Individual HFEs are expected to temporarily increase beach habitat. Therefore, Alternatives C, D, E, F, and G, which have the most HFEs, could provide a long-term benefit to the California condor. Section 4.7.3 addresses the potential impacts on the California condor under each LTEMP alternative.

Golden Eagle (*Aquila chrysaetos*)

Golden eagles are rare to uncommon residents and rare fall migrants throughout the region (Gatlin 2013). None of the alternatives are expected to impact golden eagles, because they nest on cliff edges and primarily feed on upland terrestrial wildlife. Indirect effects of LTEMP alternatives on the abundance of mammals and other prey items within the narrow riparian zone would be negligible, because the home range of the golden eagle can be over 300 km^2 (NatureServe 2014). Section 4.7.3 addresses the potential impacts on the golden eagle under each LTEMP alternative.

Osprey (*Pandion haliaetus*)

Ospreys typically occur along the Colorado River during their fall migration (August–September), although a nesting pair recently fledged young near the dam (Section 3.7). Alternatives differ in expected effects on trout recruitment (Section 4.5), but would have negligible effects on the ability of osprey to find and catch fish. TMFs and trout removal in the Little Colorado River reach could have a minor effect on osprey (*Pandion haliaetus*), because of the reduction in trout numbers. However, these experimental trout control measures are only intended to be used in cases when trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as special status species. There would be no effect of alternatives on habitats used for roosting (cliffs or trees) or nesting. Section 4.7.3 addresses the potential impacts on the osprey under each LTEMP alternative.

Southwestern Willow Flycatcher (*Empidonax traillii extimus*)

The southwestern willow flycatcher nests and forages in habitats ranging from dense, multi-storied riparian vegetation (such as cottonwood/willow stands with a mix of trees and shrubs) to dense tamarisk stands with little layering of vegetation. However, changes in the availability of suitable habitat may not necessarily translate into changes in the southwestern willow flycatcher populations. Despite the abundance of woody riparian vegetation (e.g., tamarisk) since construction of the Glen Canyon Dam, numbers of nesting southwestern willow flycatchers in the Grand Canyon have declined since the 1980s and no nests have been confirmed in the Grand Canyon since 2007 (Stroud-Settles et al. 2013).

The effect of HFEs on the southwestern willow flycatcher depends on whether the HFE enhances or substantially reduces riparian habitat at potential breeding sites (Holmes et al. 2005). High flows can scour and destroy riparian nesting habitat and foraging habitat. Alternatives C, D, and G feature proactive spring HFEs in May or June that coincide with the nesting period of the southwestern willow flycatcher. Alternative F features an annual 45,000-cfs spike flow and extended-duration high flow in May. However, southwestern willow flycatchers nests in Grand Canyon have typically been located above the elevation of 45,000-cfs flows (Gloss et al. 2005), and thus may not be affected by the HFEs that would be implemented under the LTEMP alternatives. In addition, sediment-triggered spring and fall HFEs would generally occur before and after, respectively, the nesting period for the southwestern willow flycatcher (Reclamation 2011b).

In addition to HFEs, lower flows during the May to August nesting period can have a negative effect on southwestern willow flycatchers by drying riparian habitat (Reclamation 2007d). Normal operations under most alternatives would have monthly average flows of 10,000 cfs or more during the nesting period, except for Alternative F, with low steady flows in summer through winter (July through February), and during the experimental implementation of low summer flows under Alternatives C, D, and E. Under these three alternatives, there is the potential for adverse effects on nesting habitat of this species. Only under Alternative F are these impacts expected to be long term, because low summer flows would occur annually under this alternative; low summer flow experiments under Alternatives C and D would occur relatively infrequently and are not expected to have long-term effects on nesting habitat.

Section 4.6 describes some changes in the characteristics of riparian vegetation communities over the LTEMP period (e.g., changes in diversity), but none of the alternatives are expected to result in important structural changes in riparian habitat or vegetation productivity that could affect the southwestern willow flycatcher.

As discussed in Section 4.7.2.1, invertebrates with only terrestrial life stages, are not expected to be affected differentially by alternatives, and those invertebrates with both aquatic and terrestrial life stages are expected to benefit from alternatives with more stable flows. These changes in food production are expected to result in very minor impacts on the southwestern willow flycatcher.

In summary, only Alternative F is expected to produce changes in riparian habitats (through regular low summer flows) that would affect the southwestern willow flycatcher. Direct impacts from HFEs on nesting flycatchers would be minimal, mostly because the timing of HFEs would be outside of the peak breeding season. Alternatives C, D, F, and G could have high flows that occur during the peak nesting season; proactive spring HFEs under these three alternatives would occur in high volume release years (≥10 maf); Alternative F features an annual 45,000-cfs spike flow that would occur in May. Section 4.7.3 addresses the potential impacts on the southwestern willow flycatcher under each LTEMP alternative.

Western Yellow-Billed Cuckoo (*Coccyzus americanus occidentalis*)

The western yellow-billed cuckoo occurs at a number of sites in the lower Grand Canyon, near the Lake Mead delta where mature cottonwood forests are located. It requires structurally complex riparian habitats with tall trees and a multi-storied vegetative understory; the large caterpillars on which it feeds depend on cottonwoods and willows (Section 3.7). It is a rare restricted transient in dense tamarisk thickets, with a few observations in the Lees Ferry reach (Spence et al. 2011). Cottonwood/willow habitats that support the western yellow-billed cuckoo are not expected to be affected by any of the LTEMP alternatives. Section 4.7.3 addresses the potential impacts on the western yellow-billed cuckoo under each LTEMP alternative.

Yuma Clapper Rail (*Rallus longirostris yumanensis*)

The Yuma clapper rail inhabits marshes dominated by emergent plants. Generally, it is associated with dense riparian and marsh vegetation dominated by cattails and bulrushes along margins of shallow ponds with stable water levels (FWS 2014c). It is only a casual visitor to marshy mainstem riparian habitats along the Colorado River downstream of Separation Canyon (e.g., RM 227 and 246 and near Burnt Springs). The only confirmed nesting was reported in 1996. Its occurrence along the Colorado River in the affected area only occurred once suitable habitat was created through dam construction (FWS 2014c). Other than predation, main threats to the Yuma clapper rail include habitat destruction, primarily due to stream channelization and drying and flooding of marshes resulting from water flow management (FWS 2014c). Spring HFEs associated with LTEMP alternatives could cause inundation of Yuma clapper rail nests, although nesting in the area may not occur or only rarely occur. All alternatives would have spring HFEs, but these are expected to be less frequent for Alternatives A, B, and E (i.e., no more than six for Alternative A and no more than 10 for Alternatives B and E). Spring HFEs could occur every year under Alternatives C, D, F, and G. Section 4.7.3 addresses the potential impacts on the Yuma clapper rail under each LTEMP alternative.

Spotted Bat (*Euderma maculatum*)

Most spotted bats occur in dry, rough desert shrublands or in pine forest communities. These habitats are all located well above the river corridor and the area potentially affected by Glen Canyon Dam operations. Their roost sites, including hibernacula, do not occur within the area along the Colorado River affected by daily operations and HFEs. Only negligible adverse effects on insects, the prey base for the spotted bat, would occur under any of the alternatives, and the spotted bat can feed within upland areas that would not be impacted by LTEMP operations. Thus, the spotted bat is not expected to be affected by any of the LTEMP alternatives.

4.7.3 Alternative-Specific Impacts on Wildlife

This section describes alternative-specific impacts on wildlife, including special status wildlife species. More detailed descriptions of the basis of impacts and supporting literature citations for these impacts are presented in Section 4.6.2. Tables 4.7-1 and 4.7-2 summarize the potential impacts of all alternatives on wildlife and special status wildlife species, respectively.

4.7.3.1 Alternative A (No Action Alternative)

Changes in riparian habitats under Alternative A would not result in noticeable or measurable changes in invertebrates with only terrestrial life stages (Table 4.7-1). Because aquatic food base productivity under Alternative A would be similar to current conditions (Table 4.5-1), the contribution of aquatic insects with a terrestrial adult stage to the prey base for wildlife that consume invertebrates will also remain unchanged.

Changes in riparian habitats under Alternative A would not affect amphibian, reptile, bird, or mammal populations, but some amphibians and other wetland-dependent species could be affected by wetland habitat decline expected under Alternative A (Section 4.7.2). The higher flow fluctuations under Alternative A, which provide daily watering of habitats in the varial zone, would limit wetland habitat loss. The effects of HFEs on reptiles and amphibians are expected to be temporary and not result in long-term population effects because the area affected would be small (below the elevation of 45,000-cfs flows) relative to total habitat availability, and recolonization of disturbed areas by vegetation and by amphibians and reptiles following HFEs are expected to occur rapidly from nearby unaffected areas.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect bird populations over the long term. HFEs under Alternative A would occur outside the main nesting period of birds and are expected to only temporarily displace birds within the flood zone. Fall HFEs may have a short-term effect on foraging habitat and food resources for early-arriving winter waterfowl. Potential effects of HFEs, although negligible, would not occur after 2020 under Alternative A.

No important structural changes in riparian habitat or vegetation productivity are expected under Alternative A that could affect mammal populations over the long term. HFEs could cause the direct loss of individuals belonging to less mobile species (e.g., small mammals). Recolonization of flooded areas would be expected to occur rapidly. High reproductive rates of most small mammals may compensate losses. HFEs, which would only occur through 2020, may also cause the loss of some individual American beavers and muskrats, but long-term population-level effects are not anticipated (Section 4.7.2.4). Minimal impacts are expected for bats and large mammals.

Impacts of Alternative A on special status wildlife species are summarized in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. HFEs could cause losses of habitat and individuals in <20% of occupied habitat of the Vasey's Paradise population of the Kanab ambersnail. Some rebound from the losses would occur between HFEs or after 2020, when HFEs would expire. No impacts are expected on the Elves Chasm population. A 28% decrease in wetland habitat may cause a change in potential habitat of the northern leopard frog (which may already be extirpated downstream of Glen Canyon Dam) and Yuma clapper rail (which has not been observed nesting in the area since 1996). Beach areas created by individual HFEs may temporarily provide habitat used by the California condor, but this would end after the HFE protocol expires in 2020. There would be no change from current conditions for the southwestern willow flycatcher, because HFEs would mainly occur outside its nesting period, and nesting is expected to occur above the elevation of HFEs.

In summary, under Alternative A, there would be little or no change from current conditions for most wildlife species, including special status species, with the exception of a potential adverse impact on amphibians and other species dependent on wetland habitats, including the northern leopard frog and Yuma clapper rail. Beach areas created by individual HFEs may temporarily provide habitat used by the California condor, but this would end after the HFE protocol expires in 2020. There would be no impacts on other special status species.

4.7.3.2 Alternative B

Impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1), but there would be less impact on wetland habitat (i.e., 20% decrease compared to 28% for Alternative A), except with the implementation of experimental hydropower improvement flows, which could cause an 83% decrease in wetland habitat. There would be slightly more HFEs under Alternative B (mean of 7.2 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by HFEs, but these impacts are not expected to result in long-term population-level effects. Higher daily flow fluctuations would reduce nearshore habitat stability, especially with experimental hydropower improvement flows, and could lower production of insects with aquatic and terrestrial life stages, and adversely impact amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or utilize nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative B on special status wildlife species are presented in Table 4.7-2. As under Alternative A, no impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts on the Kanab ambersnail would be similar to those under Alternative A. Larger negative wetland and food production losses from hydropower improvement flows under Alternative B may have greater effects on the northern leopard frog (which may be already be extirpated downstream of Glen Canyon Dam) and the Yuma clapper rail (which has not been observed nesting in the area since 1996). Beneficial impacts on the California condor from HFEs would be similar to those under Alternative A, but would extend through the entire LTEMP period. There would be no change from current conditions for the southwestern willow flycatcher, because HFEs would occur outside its nesting period.

In summary, impacts of Alternative B on most terrestrial wildlife species would be similar to those under Alternative A. Higher fluctuations under Alternative B would reduce nearshore habitat stability and result in lower production of aquatic insects, which would adversely impact species that eat insects or use nearshore areas. Experimental implementation of hydropower improvement flows would result in adverse impacts on wetland habitat. There would be some losses of habitat and individuals of Kanab ambersnail associated with HFEs comparable to those under Alternative A. Beneficial impacts on the California condor of HFEs would be similar to those under Alternative A, but would extend through the entire LTEMP period. There would be no impacts on other special status species.

4.7.3.3 Alternative C

Impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (75% decrease compared to a 28% decrease), which could adversely affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative C (mean of 21.3 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs; however, these impacts are not expected to result in long-term population-level effects. More uniform monthly flows from December through August under Alternative C compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. In addition, an increase in habitat stability of nearshore habitats compared to Alternative A may result from lower within-day fluctuations. Both increases in insect production and nearshore habitat stability may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*) and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative C on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and extended-duration HFEs could adversely affect Kanab ambersnail and Yuma clapper rail. Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard frog and Yuma clapper rail. Beach habitats created by more frequent HFEs could provide a long-term benefit to the California condor. Proactive spring HFEs could occur in May and June, affecting nests of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring and fall HFEs would occur outside its nesting period. Experimental low summer flows under Alternative C could have an adverse effect on the quality of nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on this habitat.

In summary, impacts of Alternative C on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes and lower fluctuations under Alternative C would provide more stable nearshore habitats and result in higher production of aquatic insects compared to Alternative A, potentially benefitting wildlife that eat insects and use nearshore areas. Compared to Alternative A, Alternative C is expected to result in a minor benefit to California condor (HFE effect on beaches), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on nests and nesting habitats). There would be no impacts on other special status species.

4.7.3.4 Alternative D (Preferred Alternative)

Impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a smaller loss of wetland habitat (16% decrease compared to a 28% decrease), which could benefit wetland-dependent amphibians, reptiles, and birds; Alternative D has the lowest expected wetland loss among all alternatives. There would be more HFEs (mean of 19.3 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5), which could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. More uniform monthly flows throughout the year under Alternative D compared to Alternative A would provide more stable aquatic habitats and may increase the production of insects with aquatic and terrestrial life stages. Experimental weekend low flows may also increase production and diversity of aquatic insects with terrestrial life stages. More stable nearshore habitat and insect production may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative D on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and extended-duration HFEs compared to those under Alternative A could adversely affect Kanab ambersnail and Yuma clapper rail. Lower wetland habitat losses under this alternative compared to all others could benefit northern leopard frog and Yuma clapper rail. Potential benefits on the California condor and adverse impacts on the southwestern willow flycatcher would be similar to those under Alternative C.

In summary, impacts of Alternative D on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly release volumes under Alternative D would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to Alternative A, potentially benefiting species that eat insects or use nearshore areas. Experimental low weekend flows could also increase insect production. Compared to Alternative A, Alternative D is expected to result in a minor benefit to California condor (HFE effect on beaches), northern leopard frog (less wetland loss), and Yuma clapper rail (less wetland loss), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat), Yuma clapper rail (HFE effects on nests), and southwestern willow flycatcher (HFE effects on nests and nesting habitats). There would be no impacts on other special status species.

4.7.3.5 Alternative E

Impacts of Alternative E on most terrestrial wildlife would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a slightly greater loss of wetland habitat under Alternative E (38% compared to a 28% decrease), which could adversely affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative E (mean of 17.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects. More uniform monthly flows may increase production of aquatic insects compared to Alternative A, but this may be offset by higher within-day flow fluctuations, which would reduce habitat stability. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative E on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: northern leopard frog, American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts on the Kanab ambersnail would be similar to Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. Potential beneficial impacts on the California condor would be similar to those und Alternative C. Although HFEs would occur outside its nesting period, experimental low summer flows under Alternative E could have an adverse effect on the quality of nesting habitat, but these experiments would occur relatively infrequently and are not expected to have long-term effects on this habitat.

In summary, impacts of Alternative E on most terrestrial wildlife species would be similar to those under Alternative A. More even monthly flows under Alternative E would provide greater nearshore habitat stability and result in higher production of aquatic insects, and potential benefits for species that eat insects, but these benefits may be offset by higher within-day fluctuations. Compared to Alternative A, Alternative E is expected to result in a minor benefit for California condor (HFE effect on beaches), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on nests and nesting habitats). There would be no impacts on other special status species.

4.7.3.6 Alternative F

Impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (86% decrease compared to a 28% decrease), which could adversely affect wetland-dependent amphibians, reptiles, and birds. Wetland habitat loss would be higher for Alternative F than for all other alternatives. There would be more HFEs under Alternative F (mean of 38.1 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term population-level effects; their frequency under this alternative would be comparable to the frequency of annual floods in the pre-dam river. Steady flows and relatively high spring flows under Alternative F compared to Alternative A may increase the production of insects with aquatic and terrestrial life stages. This, in addition to an increase in habitat stability of nearshore habitats compared to Alternative A, may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore areas.

Impacts of Alternative F on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. Impacts on the Kanab ambersnail would be similar to those under Alternative A; however, more frequent HFEs may prevent recolonization of impacted habitat over the long term. The relatively large decrease in wetland habitat compared to other alternatives may adversely affect the northern leopard frog and Yuma clapper rail. Potential benefits for the California condor would be similar to those under Alternative C. The annual 1-day 45,000-cfs flow in May could affect nests of the southwestern willow flycatcher, although it generally nests above the area that may be inundated by 45,000-cfs flows. Annual low summer flows under Alternative F could have a long-term adverse effect on the quality of nesting habitat of this species.

In summary, impacts of Alternative F on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative F would provide greater nearshore habitat stability and result in higher production of aquatic insects compared to

Alternative A, and would benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative F is expected to result in a minor benefit for California condor (HFE effect on beaches), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE and low summer flow effects on nests and nesting habitats). There would be no impacts on other special status species.

4.7.3.7 Alternative G

Impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A (Table 4.7-1). Compared to Alternative A, there would be a greater loss of wetland habitat (58% decrease compared to a 28% decrease), which could adversely affect wetland-dependent amphibians, reptiles, and birds. There would be more HFEs under Alternative G (mean of 24.5 over the 20-year LTEMP period) compared to Alternative A (mean of 5.5). This could increase the occurrence of short-term impacts on individuals of wildlife species that occur in areas inundated by the HFEs, but these impacts are not expected to result in long-term, population-level effects. Year-round steady flows with little monthly variation would produce the most stable nearshore habitats and greatest production of insects with aquatic and terrestrial life stages. These conditions may benefit amphibians, waterfowl, semi-aquatic mammals, and other species that eat insects or use nearshore habitats. TMFs and trout removal in the Little Colorado River reach could have a minor effect on piscivorous birds such as great blue heron (*Ardea herodias*), and belted kingfisher (*Ceryle alcyon*), because of the reduction in trout numbers. These experimental trout control measures are only intended to be used in cases where trout recruitment and population size is considered to be high, and annual implementation considerations include consideration of impacts on other resources such as wildlife.

Impacts of Alternative G on special status wildlife species are presented in Table 4.7-2. No impacts are anticipated on the following species: American peregrine falcon, bald eagle, golden eagle, osprey, western yellow-billed cuckoo, and spotted bat. More frequent HFEs and extended-duration HFEs could adversely affect Kanab ambersnail and Yuma clapper rail. Greater wetland habitat loss compared to Alternative A could adversely affect northern leopard frog and Yuma clapper rail. Beach habitats created by more frequent HFEs could provide a long-term benefit to the California condor. Proactive spring HFEs could occur in May and June, affecting nests of the southwestern willow flycatcher located in riparian habitats, although it generally nests above the area that may be inundated by 45,000-cfs flows. Sediment-triggered spring and fall HFEs would occur outside its nesting period.

In summary, impacts of Alternative G on most terrestrial wildlife species would be similar to those under Alternative A. Steady flows under Alternative G would provide greater nearshore habitat stability, result in higher production of aquatic insects, and benefit species that eat insects or use nearshore areas. Compared to Alternative A, Alternative G is expected to result in a minor benefit for California condor (HFE effect on beaches), but minor adverse impacts on Kanab ambersnail (HFE effects on habitat), northern leopard frog (wetland loss), Yuma clapper rail (wetland loss and HFE effects on nests), and southwestern willow flycatcher (HFE effects on nests and nesting habitats). There would be no impacts on other special status species.

4.8 CULTURAL RESOURCES

4.8.1 Compliance with Federal Regulations

> **Issue:** How do the alternatives affect the preservation of cultural resources in Glen Canyon and Grand Canyon?
>
> **Impact Indicators:**
> - Erosion of terraces in Glen Canyon that support cultural resources
> - Visitor effects on cultural resources
> - Wind transport of sediment to protect resource-bearing terraces
> - Flow effects on the Spencer Steamboat

The National Historic Preservation Act (NHPA) of 1966 (as amended) requires that federal agencies take into account the effects of their undertakings on cultural resources. Historic properties, a subset of cultural resources, include archeological resources, historic and prehistoric structures, cultural landscapes, traditional cultural properties (TCPs), ethnographic resources, and museum collections. Historic properties include any archaeological sites, structures, buildings, districts, cultural landscapes, or TCPs that are determined to be eligible for listing in the *National Register of Historic Places* (NRHP). They also include locations and objects that are important for American Indian Tribes for maintaining their culture. (Cultural resources and TCPs of importance to Tribes are addressed in Section 4.9.)

The process for considering the effects of an undertaking on historic properties is identified in Section 106 of the NHPA, and an overview of the process is provided in Section 3.8 of this DEIS. For the proposed action, the area of potential effect (APE) is described in Chapter 3. Approximately 200 historic properties could be affected by the LTEMP. Most of these sites are situated on or within terraces located in the river corridor that are above the modern inundation zone, but that could receive windblown sediment from lower elevation areas that are regularly inundated by river flows or could be exposed by bank retreat or sediment depletion.

4.8.2 Analysis Methods

The alternatives being evaluated in this DEIS differ in the way Glen Canyon Dam would be operated under each over the next 20 years. The resource goal for cultural resources is to maintain the integrity of *National Register*-eligible or listed cultural resources in place, where possible, with preservation methods employed on a site-specific basis. There is the potential for the alternatives to affect cultural resources along the river corridor downstream of Glen Canyon Dam via differing flow patterns or non-flow actions. This section focuses on two specific types of historic properties: archeological sites and historic districts; Section 4.9 focuses on other types of historic properties, including cultural landscapes and TCPs that are specifically important to Tribes. Section 4.9 also discusses other resources that are important to Tribes as contributing elements to their TCPs, but which may not qualify for listing on the *National Register* independently. The variables considered include direct flow effects (i.e., erosion of river margin sediments, deposition of sediments along the river margin, and inundation of sites), indirect effects (i.e., changes in the availability of sediment for redistribution by wind, erosion resulting from reduced sediment availability), and cumulative effects. The analysis relied on both quantitative and qualitative information to determine the potential effects of each of the alternatives. Three indicator metrics (1 in GCNRA and 2 in GCNP) were identified to describe the relative differences among the alternatives in order to evaluate the range of potential impacts on cultural resources.

For this analysis, cultural resources, as described in Section 3.8, that are potentially affected by Glen Canyon Dam operations are archeological resources (including historic and prehistoric structures), TCPs, and ethnographic resources. While museum objects are defined as cultural resources, there are no effects or differences in effects on these classes of resources from the alternatives and will therefore not be discussed in the text. Impacts on cultural landscapes are not discussed separately, but any impacts on other resources (e.g., vegetation, wildlife, and sediment) are considered to have an effect on the landscape.

The physical attributes of cultural resources are nonrenewable, with few exceptions, and the primary concern is to minimize the loss or degradation of culturally significant material. Cultural resources analyzed within the Colorado River corridor range from artifact scatters, dwellings (both prehistoric and historic), resource collection areas, food preparation (roasting and food processing) activity areas, horticultural areas, and petroglyph and pictograph panels, collectively representing more than 12,000 years of human history.

Direct flow effects from releases from Glen Canyon Dam are most noticeable in the river reach immediately below the dam. This is primarily because this reach has little sediment input to help buffer the river terraces, and to a lesser degree because the affected resources are found in closer proximity to the Colorado River in this reach. In GCNP, most affected resources are located on terraces that are primarily affected indirectly by dam operations. Over time, flows and climatic conditions could affect the terraces on which archeological sites are located.

An indicator of flow effects that was considered in the analysis is the erosion of elevated terraces in the Glen Canyon reach, which was evaluated using a flow effects metric for Ninemile Terrace. In general, repeated inundation of the toe of a terrace could produce slumping of the terrace face, which could destroy or destabilize the cultural resources within or on the terrace deposits. The toe of Ninemile Terrace is estimated to be inundated when flows reach 23,200 cfs. The flow effects metric considered the frequency of when flows under the various alternatives reach levels that could create conditions that could result in terrace edge slumping and, ultimately, how they could affect the archeological sites within or on the terraces. The results of the metric were expressed as the number of days per year that the maximum daily flow would be >23,200 cfs under each alternative. See Appendix H for additional information on the flow effects metric.

Another historic property in GCNRA that was considered when assessing direct flow effects under the alternatives is the Spencer Steamboat site, which lies within the Colorado River channel. Although the flow effects metric did not reveal any appreciable difference among alternatives in effect on the Spencer Steamboat, impacts are still possible under the 20-year duration of the LTEMP from repeated exposure to high flows and repeating cycles of inundation and exposure. The wet-dry cycling resulting from fluctuations in lower flow levels contributes to the deterioration of structural elements. Flow levels that expose the steamboat also increase the potential for impacts from visitation and the accumulation of debris resulting in damage to fragile remains.

Visitor effects are frequently noted at many of the archeological sites along the river; these include the moving or theft of artifacts on archeological sites and the defacing of inscriptions, pictographs, and petroglyphs. A metric, visitor time off river, was developed to characterize how the various alternatives could influence the frequency at which archeological sites could be visited by people on river trips. The metric considered flow rates under the various alternatives during the summer months, when the number of visitors on the river is at its highest. The metric reflects the degree to which, due to the flows under an alternative, visitors would be able to spend more time exploring off of the river, which could result in more cultural resources being visited and possibly affected. See Appendix H for additional information on the time off river metric.

Erosion poses a threat to maintaining the condition of many of the archeological sites in both GCNRA and in GCNP. Any actions that help retain sediment are considered to have a potentially positive effect on maintaining the condition of archeological sites in the canyons because they aid in maintaining the river corridor landscape and site stability. Most of the archeological sites along the Colorado River are located on terraces that represent the river terraces of the predam river system. Prior to construction of the dam, the terraces would have been directly affected by flooding on a 7–10 year return interval (Topping et al. 2003), and many contain flood deposits indicating they were flooded during or after occupation (see Schwartz et al. 1979; Bright Angel Site). The persistent removal of sediment from the system is a long-term effect on cultural resources resulting from the presence of the dam and will continue under all alternatives. While sites may experience sediment transport (both aggradation and degradation), the amount of possible sediment transport is unknown. Sediment availability in the system for transport by the wind is linked to alternatives that include more HFEs (which deposit sediment in locations that may allow for transport by the wind) and sediment retentive flows. As discussed in Section 3.8, research has shown (Draut and Rubin 2008) that sediment deposited by HFEs can be transported by the wind to terraces that contain historic properties where that sediment could help stabilize these properties. The actual extent to which current sediment levels can stabilize the archeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, factors that could lead to loss of integrity of an historic property.

A Wind Transport of Sediment Index addresses the potential for sediment to be transported by the wind to the terraces along the river which contain hundreds of archeological sites. The metric reflects when conditions exist for movement of sediment by wind, and therefore the potential exists for cultural resources to receive sand and potentially be protected, under each alternative. Optimal conditions for wind transport of sediment occur when (1) fine sediment is deposited by flows above the stage of normal operations, and (2) low flows occur during the windy season (March–June), which exposes dry sand for potential redistribution by the wind. The metric used the Sand Load Index and a flow factor which captures the frequency of low flows in the spring for each alternative. See Appendix H for additional information on the wind transport index. There would be a great deal of variability from site to site throughout the system with regard to the amount of sand deposited upwind by HFEs and the exposure of sediment at varying flows.

Another element incorporated into the alternatives is non-flow vegetation management efforts. All of the alternatives except for Alternative A incorporate non-flow vegetation management efforts (Section 4.6). Vegetation removal could increase erosion near an archeological site, or create more open sand, which could facilitate wind transport and deposition of sediment onto terraces. The effect of non-flow vegetation management is not considered in the alternative-specific discussions because any vegetation management efforts would be coordinated with the cultural resources managers and would therefore not be anticipated to affect known cultural resources.

Each of the alternatives has the potential to affect cultural resources. These effects can be beneficial, meaning the alternative results in increased stability or preservation of cultural resources in the APE, or they can be adverse when an alternative results in destabilization of these resources. It is also possible that the alternatives would have no additional effect beyond those already occurring. The effects of alternatives could differ due to varying frequency, timing, and magnitude of daily flows, HFEs, and of the intervening flows between HFEs.

4.8.3 Summary of Impacts

Although the alternatives vary significantly in how water is released from Glen Canyon Dam within a year, the range of effects alternatives would have on cultural resources is expected to be minimal (Table 4.8-1), in part because annual water release volumes among alternatives would be nearly identical and cultural resources are dependent upon landform stability, a consideration that is primarily controlled by the amount of sediment in the system. The majority of cultural resources within the APE would not be inundated under any alternative, but some sites could experience indirect effects. Appendix H provides the results for each of the quantitative metrics considered in this analysis.

It has been noted that the potential for degradation of terrace stability at Ninemile Terrace is currently estimated to begin at 23,200 cfs when flows can begin to erode the toe of the terrace (Baker 2013). Erosion of the toe of a terrace can undermine the stability of the terrace and lead to slumping, as was noted after the 1996 HFE (Baker 2013), a 168-hr 45,000-cfs flow. This single event demonstrated that terrace bank erosion may occur as flow elevations increase, during the period of peak high flow, and following the decrease of high flows to normal operational levels. Under most of the LTEMP alternatives, the greatest flows would be 45,000-cfs flows lasting for 96 hr (Section 4.3); these would be comparable to or less than flows that have occurred historically that resulted in slumping. The only alternatives in which this duration could be exceeded are Alternatives D and G. Alternatives D and G allow for longer duration HFEs (up to

TABLE 4.8-1 Summary of Impacts of LTEMP Alternatives on Cultural Resources in Glen and Grand Canyons

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions which may contribute to slumping of terraces in Glen Canyon. HFEs will deposit additional sediment which will be available for wind transport; however, it is expected that the additional sediment will not significantly improve the stability of archaeological sites in Grand Canyon. No change from current conditions related to the stability of Spencer Steamboat and visitor time off river.	Similar to Alternative A.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect to the stability of Spencer Steamboat and time off river.	Compared to Alternative A, extended-duration HFEs could result in additional destabilization of terraces in Glen Canyon but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.	Compared to Alternative A, operations could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.	Compared to Alternative A, operations could result in additional destabilization of terraces in Glen Canyon due to sustained high flows in the spring, but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Small increase in the visitor time off river in June. Negligible effect on the stability of Spencer Steamboat.	Compared to Alternative A, extended-duration HFEs could result in additional destabilization of terraces in Glen Canyon, but could increase the potential for windblown sediment to be deposited on terraces in Grand Canyon. Negligible effect on the stability of Spencer Steamboat and time off river.
Erosion of terraces in Glen Canyon that support cultural resources	No change from current conditions which may contribute to slumping of terraces in Glen Canyon.	Similar to Alternative A.	Similar to Alternative A.	May influence erosion of landforms containing cultural resources in GCNRA due to extended-duration HFE.s	Similar to Alternative A.	May influence erosion of landforms containing cultural resources in GCNRA due to high flows in May and June.	May influence erosion of landforms containing cultural resources in GCNRA due to extended-duration HFEs.

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Visitor effects on cultural resources	Negligible effect on time off river.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A.	Small increase in visitor time off river in June when flows are high, which could result in cultural resources being visited more frequently; effect could be offset by the effects of lower flows in July–September.	Similar to Alternative A.
Wind transport of sediment to high-elevation cultural resources	Negligible influence on windblown sediment (index 0.16 out of 1); some benefit from HFEs until 2020 when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020.	Negligible influence on windblown sediment (index 0.17); some benefit from HFEs over entire LTEMP period.	Some improvement in potential for windblown sediment (index 0.38) resulting from increase in frequency of HFEs.	Similar to Alternative C (index 0.38).	Similar to Alternative C (index 0.31).	Similar to Alternative C (index 0.30.)	Similar to Alternative C (index 0.46).

TABLE 4.8-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Spencer Steamboat	No change from current conditions. The cumulative effects of multiple HFEs on the Spencer Steamboat are not known but potentially increase the risk of degradation.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative A. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known but potentially increase the risk of degradation.	Similar to Alternative A.	Similar to Alternative A.	Similar to Alternative D.

250 and 336 hr, respectively) when there is adequate sediment. However, flows will reach the lower threshold of 23,200 cfs under all alternatives. Under most alternatives, HFEs would be limited in magnitude and duration, but the cumulative effect of more than one HFE in a year and in sequential years is not known, and could result in an even higher risk of slumping compared to the effects of individual HFEs.

The results from the Glen Canyon flow effects metric are shown in Figure 4.8-1. Alternative A most closely represents the current operational conditions. Under the metric, Alternative F would have the highest number of days per year; flows would be >23,200 cfs with an average of 14 days per year more than under Alternative A. Alternative F, therefore, has the highest potential for impacts on terraces that contain cultural resources in Glen Canyon. The higher number of days under Alternative F results from the relatively high spring flows between May and June (Section 2.3.6). The remaining alternatives have an average number of days per year where flows would be >23,200 cfs within 4 days of those under Alternative A.

Although there are differences among alternatives in the number of HFEs, these differences have little effect on the number of days per year flows would be >23,200 cfs. This occurs because HFEs are relatively brief, and the large volume released under the HFE must be compensated by releasing less water at other times of year. Since all alternatives must release the same annual volume of water, alternatives with HFEs may have lower releases at other times of

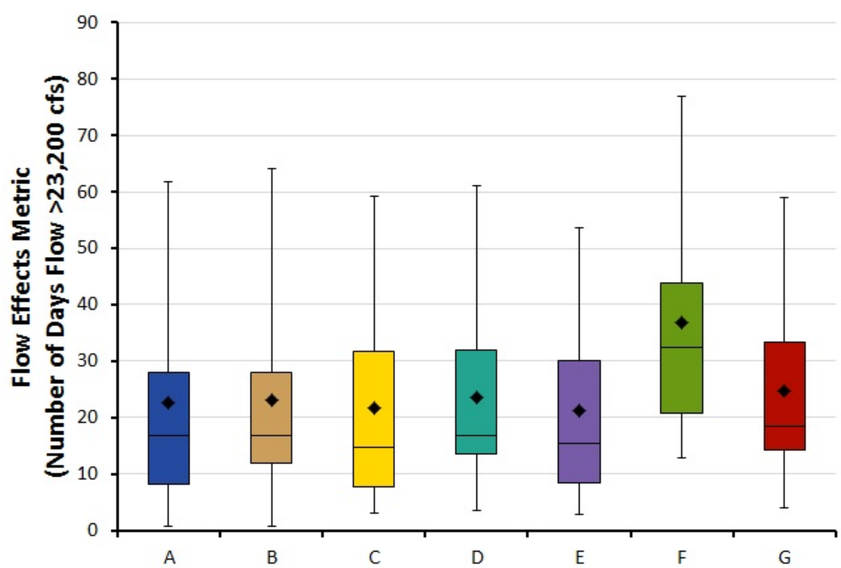

FIGURE 4.8-1 Number of Days per Year Flows Would Be >23,200 cfs under LTEMP Alternatives (letters). (Flows of this magnitude have the potential to affect cultural resources in Glen Canyon. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

years than those without. The effect on the metric would be greater in years of high volume (≥10 maf) when equalization flows would be implemented according to the Interim Guidelines (Reclamation 2007a).

A persistent source of impacts on cultural resources is visitors (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013). The effects being identified include the moving of artifacts on archaeological sites and the defacing of inscriptions, pictographs, and petroglyphs. The LTEMP does not incorporate any specific recommendations or policies concerning visitors under any alternatives. The Colorado River Management Plan (CRMP) is the primary document addressing visitor policies related to cultural resources in GCNP (NPS 2005a). Because LTEMP alternatives do not alter any policies concerning visitors, they do not differ with respect to any direct effect caused by visitors on cultural resources. Visitor effects are discussed under cumulative impacts.

An indirect effect related to visitor disturbances to cultural resources concerns the amount of time boaters have off river to explore and potentially interact with archaeological sites. More time would be available when flows are higher during the tourist season (June–September), and this factor could vary among alternatives. Analysis determined that the time off river did not vary among most alternatives. However, Alternative F has higher flows during May and June, so it could provide for more time off river during those months; these higher flows are offset by lower flows in July, August, and September when time off river would be less than for other alternatives.

The Spencer Steamboat, located in GCNRA, could be directly affected by flows. The steamboat lies in the river, is part of the Lees Ferry/Lonely Dell Ranch National Historic District, and has been subject to all past dam releases, including HFEs (2012, 2013, and 2014), extended-duration HFEs (1996), low flows (2002), fall steady flows (2011–2013), and higher fluctuation flows (pre-1992). Although the site appears to be receiving an ongoing accumulation of sediment, which is beneficial for site preservation, ongoing monitoring has demonstrated that the wet-dry cycling resulting from fluctuations at low flow levels has caused the most obvious and persistent impacts on the site, as predicted by Carrel (1987). The recent installation of submerged monitoring stations (Pershern et al. 2014) will allow the opportunity to systematically evaluate the nature and origin of sediment accumulating at the site, and determine how that mechanism of transport may be influenced or affected by dam operations. Because the proposed flows do not exceed or vary greatly from past flows, similar effects are anticipated under any of the alternatives. The cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The results from the Wind Transport of Sediment Index under the various alternatives are shown in Figure 4.8-2. Alternative G scores the highest of all the alternatives, with an average index value nearly three times greater than Alternative A. Alternative G has the highest number of HFEs and the lowest maximum daily flows during the windy months. Alternative G has parameters which are ideal for wind-transport of fluvial sediment to terraces that contain cultural resources. The second highest scoring alternative is Alternative D.

On the whole, the Wind Transport of Sediment Index is highly correlated to the number of HFEs and the corresponding Sand Load Index. The relationship between the Sand Load Index

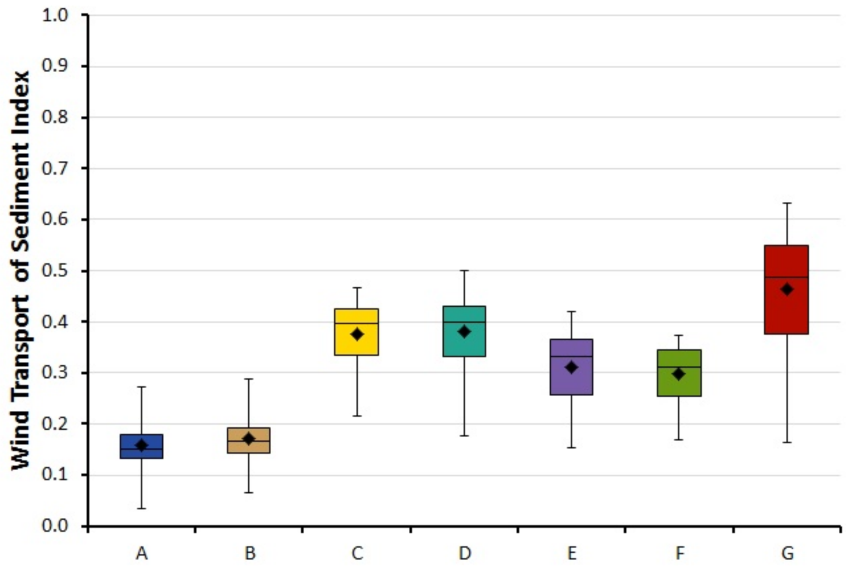

FIGURE 4.8-2 Wind Transport of Sediment Index Values for LTEMP Alternatives (letters) (Values of 1 are considered optimal. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

and HFEs is discussed in Appendix E. The Wind Transport of Sediment Index is highly correlated to the Sand Load Index because the average maximum discharge between March and June for each of the alternatives is within 5,000 cfs. With minimal difference in flow, the amount of sediment for distribution becomes the determining factor for the index. The exception to this is Alternative F. Although Alternative F was determined to have the second highest potential sand deposition (second highest Sand Load Index, only less than Alternative G), it ultimately has an average index value lower than Alternatives C, D, E, and G because larger discharges of water create less ideal conditions for wind transport.

4.8.4 Alternative-Specific Impacts

4.8.4.1 Alternative A (No Action Alternative)

Dam operations under Alternative A are expected to continue to contribute to conditions that could affect terraces that contain cultural resources in Glen Canyon. Observations in Glen Canyon noted that effects on the toe of the resource-bearing terrace at Ninemile Terrace begin with flows above 23,200 cfs (Baker 2013). Under Alternative A, flows could exceed 23,200 cfs and create conditions that could affect the stability of resource-bearing terraces. However, based on no significant deterioration of the Ninemile site since the 1996 flows, the effects of HFEs and interim operations on terraces in Glen Canyon under Alternative A would not be expected to change from current conditions. However, the cumulative effects of daily flows and the lack of sediment availability remain factors which could affect the stability of the terraces and continue to create the potential for effects as identified under the current MLFF operation. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In Grand Canyon, sandbar building that would result from HFEs under Alternative A could provide windblown sediment to high terraces; however, based on observations of existing conditions, this effect is expected to be small and would be reduced after HFEs were discontinued under this alternative in 2020. Alternative A is not expected to significantly improve the stability of archaeological sites.

In summary, operations under Alternative A could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under current conditions. Operations under Alternative A are not expected to significantly improve the stability of archaeological sites in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.2 Alternative B

Dam operations under Alternative B are not expected to have additional effects on terraces that contain cultural resources in Glen Canyon. Daily fluctuations under Alternative B would be higher than under Alternative A. In addition, experimental hydropower improvement flows under this alternative could result in daily flows of 25,000 cfs between December and February, as well as between June and August. However, these wider daily fluctuations are not expected to result in increased erosion rates because the alternative results in only a slight increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows >23,200 cfs) compared to Alternative A, which would result in a minor increase in the potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

It is anticipated that there will be some increase in the amount of sediment available for wind transport under Alternative B; both Alternatives A and B are expected to have approximately the same number of HFEs. Alternative B is expected to have a smaller beneficial effect from windblown sediment in Grand Canyon relative to other alternatives that have more frequent HFEs. With hydropower improvement flows, there is expected to be a minor decrease with respect to wind transport compared to Alternative A.

In summary, operations under Alternative B could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. Operations under Alternative B are not expected to significantly improve the stability of archaeological sites in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.3 Alternative C

Dam operations under Alternative C are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative C would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the 1996 HFE of 168 hr, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative C would not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs; thus, there is no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

The amount of sediment available for wind transport in Grand Canyon under Alternative C is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from lower daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and after HFEs.

In summary, operations under Alternative C could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be similar to those under Alternative A. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.4 Alternative D (Preferred Alternative)

Dam operations under Alternative D could result in some additional destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 250 hr) that would be implemented as an experimental treatment in years when large inputs of sediment from the Paria River occur. No more than four extended-duration HFEs would be implemented during the LTEMP period under Alternative D. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative D would result is a slight increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in a slightly increased potential for slumping. There would be no change from current conditions with respect to the stability of

Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In Grand Canyon, the amount of sediment available for wind transport under Alternative D is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention resulting from slightly lower daily fluctuations, proactive spring HFEs in wet years, and reduced fluctuations before and after fall HFEs.

In summary, operations under Alternative D could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.5 Alternative E

Dam operations under Alternative E are not expected to have any additional effects on terraces that contain cultural resources in Glen Canyon. Although HFEs under Alternative E would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the base of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative E do not result in a substantial increase in the number of days when the base of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs),), which would result in no measurable difference in the potential for increased slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In Grand Canyon, the amount of sediment available for wind transport under Alternative E is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period (although fewer than under Alternatives C, D, F, and G).

In summary, operations under Alternative E could result in conditions which may contribute to slumping of terraces in Glen Canyon, although these effects are expected to be negligible. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.8.4.6 Alternative F

Alternative F is expected to have additional effects on terraces that contain cultural resources in Glen Canyon because there would be an increase in the number of days when the bases of terraces in GCNRA would be inundated. Flows in May and June would be sustained at higher levels under this alternative, resulting in an increased number of days in wetter years when the bases of the terraces would be inundated, compared to Alternative A. Although HFEs would be limited to a maximum of 45,000 cfs for 96 hr, and erosion of the bases of terraces was only observed after the longer duration 1996 HFE (168 hr), the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative F would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,200 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

Dam operations under Alternative F would allow faster travel times for boaters in May and June; therefore, boaters would have additional time off river to visit cultural resources during those months. This increase would be offset by the effects of lower flows in July–September. Alternative F is the only LTEMP alternative that, based on the analysis, could have any influence on visitor effects.

In Grand Canyon, the amount of sediment available for wind transport under Alternative F is greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period and increased sediment retention from low steady flows throughout much of the year. However, the highest flows under Alternative F are in May, which reduces the potential for wind transport of sediment to terraces during this windy period.

In summary, operations under Alternative F could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat; there could be a small increase in the visitor time off river in May and June, which could result in increased visitation and potential damage to cultural resources.

4.8.4.7 Alternative G

Dam operations under Alternative G could result in some destabilization of terraces that contain cultural resources in Glen Canyon. This could result from the extended-duration HFEs (up to 336 hr) that would be implemented in years when large inputs of sediment from the Paria River occur. Some slumping was observed in Glen Canyon as a result of the 1996 HFE, which had a magnitude of 45,000 cfs and duration of 168 hr. In addition, the cumulative effect of multiple HFEs on the stability of terraces is not known. Compared to Alternative A, operations under Alternative G would result in an increase in the number of days when the bases of the terraces in GCNRA would be inundated (i.e., flows ≥23,300 cfs), which would result in an increased potential for slumping. There would be no change from current conditions with respect to the stability of Spencer Steamboat, but the cumulative effects of multiple HFEs and extended-duration HFEs on the Spencer Steamboat are not known and could increase the risk of degradation.

In Grand Canyon, the amount of sediment available for wind transport under Alternative G would be greater than under Alternative A because there would be more frequent HFEs through the entire 20-year LTEMP period, increased sediment retention from steady flows throughout the year, and proactive spring HFEs in wet years. Alternative G has the lowest spring operational flows when windy conditions are most typical. These factors create the best conditions under any of the alternatives for wind transport of sediment to the terraces.

In summary, operations under Alternative G could result in additional destabilization of terraces in Glen Canyon. There could be some improvement in the potential for windblown sediment to protect archaeological sites on terraces in Grand Canyon. There would be no change from current conditions with respect to the stability of Spencer Steamboat or visitor time off river and subsequent effects on cultural resources.

4.9 TRIBAL RESOURCES

Assessing the comparative impacts of the LTEMP alternatives on Tribal resources presents a challenge both because of the Tribes' holistic view of the Canyons, in which all things are interconnected, and because there is no single "Tribal view" held by all members of all Tribes. The holistic view encompasses most of the subject areas considered in this DEIS and Tribal perspectives on these resources are found throughout the document.

The values placed by the Tribes on the river and its Canyons are significant and real but may be intangible; thus, they are not easily quantifiable. In addition, many of the values and resources most important to the Tribes are not directly affected by the proposed action as defined by operational patterns of water releases from Glen Canyon Dam.

Issue: How do alternatives affect Tribal resources in Glen, Marble, and Grand Canyons?

Impact Indicators:

- Health of the ecosystem including vegetation, wildlife, fish, and wetlands
- Water rights
- Condition of traditional cultural places

Issue: How do alternatives affect the sacred integrity of and Tribal connections to the Canyons?

Impact Indicators:

- Stewardship and educational opportunities
- Independent access to Canyons
- Number of nonnative fish removed each year
- Economic opportunity
- Incorporating traditional knowledge into the LTEMP EIS

4.9.1 Tribal Resource Goals

As discussed in Section 3.9, the Tribes that have the closest ties to the Canyons and are most actively involved in the LTEMP DEIS process are the Havasupai, Hualapai, Hopi, Kaibab Band of Paiutes, Navajo Nation, Pueblo of Zuni, and Fort Mojave Indian Tribe. Eight important themes or values relative to the Colorado River and its Canyons emerged from meetings, workshops, and webinars held with individual Tribal representatives and from reviewing ethnographies and Canyon monitoring reports produced by or for the Tribes. These have been identified as Tribal resource goals for the LTEMP DEIS and grouped according to whether they can be represented quantitatively and whether they would be differentially affected by alternative management practices at or related to the operation of Glen Canyon Dam. An initial evaluation was made based on Tribal sources, and the Tribes were afforded the opportunity to review and provide input.

For this discussion, Tribal resources are divided into two categories: (1) traditional cultural places—those elements with fixed and defined locations, and (2) traditional cultural resources—resources that are either widely scattered or mobile, such as riparian vegetation, birds, mammals, and fishes. For many Tribes, resources in these two categories may be considered TCPs or contributing elements to a TCP and may be differently affected by flow and non-flow elements of the seven LTEMP alternatives.

4.9.1.1 Increase the Health of the Ecosystem in Glen, Marble, and Grand Canyons

Tribes such as the Hopi express their perception of the state of the Canyons in terms of the Canyons' health (Yeatts and Huisinga 2003, 2006, 2009, 2010, 2011, 2012, 2013). For the Hopi, natural elements and resources are significant for creating a culturally significant, harmonious landscape. Without them, the landscape would not be whole. These resources, because they are either widely scattered or mobile, rather than existing in a fixed location, may be considered traditional cultural resources.

Although the affected Tribes are concerned with the state of the Canyons as a whole, they tend to be especially focused on the riparian corridor because of its association with emergence narratives, and in some cases the Tribes give particular value to native plants. The determination of Canyon health from a Tribal point of view is to some extent subjective. For example, a recent survey of Hopi Canyon monitors showed that most respondents found the Canyons to be in good health, or at least better taken care of than in the past, in part because of Hopi participation in the adaptive management process by monitoring important sites such as the salt mine, and because of the offerings made in the Canyons by Tribal members (Yeatts and Huisinga 2013). Some aspects of Canyon health are quantifiable and parallel or reflect values that have been expressed by the Tribes or their representatives. These include riparian plant diversity, wetland abundance, and characteristics of native fish populations considered here. The interest of the Tribes extends beyond these measures to impacts on other aspects of Canyon health explored elsewhere in this chapter, including natural processes (Section 4.4), aquatic ecology (Section 4.5), vegetation (Section 4.6), wildlife (Section 4.7), hydropower (Section 4.13), and environmental justice (Section 4.14).

The Western concept of ecosystem has much in common with the Tribes' view of their place in an interconnected natural world. Plant communities form a fundamental aspect of any ecosystem, and vegetation health is an indicator of ecosystem health. Metrics for vegetation community diversity and wetland abundance in the riparian zone most directly affected by flow management at the Glen Canyon Dam have been developed based on the results of an existing state and transition model developed by GCMRC for Colorado River riparian vegetation downstream of Glen Canyon Dam; this is described by Ralston et al. (2014) and in Appendix G and discussed in Section 4.6.1. The metrics are on a scale relative to starting conditions where a higher value means greater vegetation community diversity or wetland abundance relative to starting conditions.

A healthy ecosystem from a Tribal perspective is characterized by a high degree of species diversity, represented here by diversity in vegetation community types. The model projects transitions over the 20-year LTEMP period for each alternative analyzed. During discussions with the Tribes, they often expressed their view that all forms of life have value, whether native or nonnative. To take this perspective into account, evaluation of diversity included nonnative (primarily tamarisk) as well as native vegetation, including the invasive arrowweed. The analysis indicated that all alternatives on average would result in a decrease in total vegetation diversity over the 20-year LTEMP period.

The loss in diversity would be greatest under Alternatives C, F, and G. Under these alternatives, the acreage occupied by the invasive tamarisk increases (Table 4.9-1). Alternatives under which tamarisk[9] would increase are characterized by spring high flows (HFEs or ≥30 days

TABLE 4.9-1 Vegetation Community Diversity and Change in Tamarisk Cover

Alternative	Mean Diversity Score[a]	Change in Tamarisk Cover (ac)
A	0.95	−58.4
B	0.97	−71.3
C	0.75	104.0
D	0.94	−22.4
E	0.93	−45.7
F	0.70	230.7
G	0.83	46.4

[a] Higher values of diversity indicate better condition relative to other alternatives. A value less than 1 indicates an expected reduction in diversity relative to current conditions over the 20-year LTEMP period. A value greater than 1 indicates an expected increase in diversity.

[9] The model takes into account the effects of scouring, drowning, desiccation, and sediment deposition, but does not account for the effects of the tamarisk leaf beetle or tamarisk weevil. These two insect species are expected to result in a reduction in the amount of live tamarisk in the river corridor.

with flows >20,000 cfs), which serve to distribute seed, followed by low flows in the growing season (May–September) which would allow seedlings to establish themselves. Alternative B results in the least loss of diversity, followed by Alternatives A, D, and E. Under these alternatives, the area covered by tamarisk decreases.

Another indicator of Canyon health is the abundance of wetlands in the riparian zone. Although they make up only a small part of the riparian area of the river corridor (4.6 acres, or 0.5% of total area of all vegetation types), wetlands include plants of medicinal and cultural significance to some Tribes (Jackson et al. 2001) that continue to be harvested with care (Yeatts and Huisinga 2006). The Hopi generally see the marshes as healthy and well taken care of, but there is some indication in the Tribal monitoring reports that cattail and reed marshes are decreasing in size and number and that cattails are decreasing in number (Yeatts and Huisinga 2013).

Based on the vegetation models discussed in Section 4.6, the change in abundance was determined for each of the wetland community types (common reed wet marsh and willow/baccharis/horsetail wetland). Wetlands would expand under hydrologic regimes that lack extended periods of high flows (≥30 days with maximum daily flows >20,000 cfs) and extended low flows (≥30 days with maximum daily flows <10,000 cfs), but are maintained with occasional extended high flows (in many cases) or HFEs and an absence of extended low flows during the growing season. Alternatives that include frequent extended low flows, such as the annual flows for Alternative F, or extended high flows followed by extended low flows tend to result in transitions of wetlands to other plant community types. All of the alternatives are expected to result in a decrease in wetland cover, with particularly large decreases under Alternative F.

The state of aquatic life in the Canyons is discussed in Section 4.5. Section 4.5.2 presents a summary of projected impacts on native and nonnative fishes and the aquatic food base. These projections correlate well with recent results from the Hopi monitoring program, which found the native fish populations in the Canyons, particularly the humpback chub, to be healthy (Yeatts and Huisinga 2013).

Impacts on riparian and terrestrial wildlife are discussed in Section 4.7.2. Impacts on indicators of wildlife and habitat health are expected to be limited, with no major differences among the alternatives. Alterations in riparian vegetation and the aquatic food base are not expected to be sufficient to adversely affect amphibians and reptiles over the long term; however, alternatives could produce changes in near-shore aquatic and wetland habitats that are important to amphibians and that serve as important food production areas for both amphibians and reptiles (Section 4.7.2.2). The distribution of woody riparian vegetation is not expected to vary enough under any alternative to disrupt the migration of riparian bird species or to have noticeable differences in impacts on species that nest in riparian vegetation; however, alternatives could produce changes in shoreline habitats that could affect waterfowl and wading birds (Section 4.7.2.3). Impacts on mammals such as muskrat and beaver would be negligible under all alternatives (Section 4.7.2.4). Larger mammals such as deer and bighorn sheep are mobile and able to adjust their use of different habitats along the corridor. Impacts on bighorn sheep under all alternatives are expected to be negligible (Section 4.7.2.4). A recent Hopi monitoring report found birds, mammals, insects, and snakes in the Canyons all to be healthy (Yeatts and Huisinga 2013).

4.9.1.2 Protect and Preserve Sites of Cultural Importance

Sites of cultural importance to the Tribes include archaeological sites, places associated with traditional narratives of Tribal identity, rock writing, sacred places, offering sites, springs, and traditional resource collection areas. As a group these may be referred to as traditional cultural places. Expected effects of the alternatives on archaeological sites and historic properties are discussed in Section 4.8. Other cultural resources associated with specific locations are likely to experience the same types of impacts as those on archaeological sites. Those Tribes that regularly monitor the condition of culturally important sites and resources in the Canyons most often list intentional and unintentional damage to sites from visitors to the Canyons as the prime threat to site integrity. Reported damage includes trailing, trampling, removal of vegetation, disturbance of artifacts, vandalism, and disruption of the sacred context through inappropriate behavior (Section 4.9.1.4). Bank erosion and inundation are mentioned less frequently in the monitoring reports. The majority of visitors to the river corridor arrive by boat. Higher flows have faster currents, so boaters travel more quickly between campsites, leaving more time to explore off-river, which could lead to more visitation of cultural sites and a greater potential for damage. Modeling of visitor time off the river indicates that there is almost no difference in expected amount of time off river among the LTEMP alternatives, with the exception of Alternative F. Under this alternative, boaters could spend slightly more time off the river in May and June when flows are relatively high and steady. Overall, impacts on these sites of importance are not expected to vary significantly as a result of visitation among the alternatives.

For the Tribes of the desert Southwest, all water is sacred and the places where it emerges from the ground as seeps and springs are particularly sacred. Tribal members travel to sacred springs in the Canyons to retrieve water for ritual use in their own communities (Dongoske 2011b; Jackson-Kelly et al. 2013). Warm mineral springs, such as Pumpkin Springs, are sacred and their waters are considered therapeutic (Austin et al. 2007). The Tribes are concerned with the purity of these sacred waters and exercise stewardship over them, which can include appropriate prayers and offerings at the springs and along sacred trails that lead to them. The Hopi largely consider the springs to be healthy, as a result of their having access to the springs and being able to perform appropriate stewardship activities (Yeatts and Huisinga 2009). Occasionally, spring sources, such as Pumpkin Springs, may take on a murky, polluted appearance and an HFE is welcome in order to flush out the muck and algae that have accumulated. This may disrupt access for a short amount of time, but water levels return to normal within a few weeks. During consultation, the Tribes that monitor Tribal resources in the Canyons—Hopi, Hualapai, Navajo, Southern Paiute, and Zuni—all have expressed more concern with damage to the springs and disrespect for the sanctity of the waters by non-Tribal visitors to the Canyons than with inundation resulting from flow management. Hopi monitoring reports suggest that the health of the springs is largely unaffected by the operation of Glen Canyon Dam. Overall, adverse impacts on springs and seeps from operation of Glen Canyon Dam are expected to be negligible, while the HFEs have some benefit.

Some adverse impacts can be mitigated through education and communication. All of the Tribes with ties to the Canyons are affiliates of Native Voices on the Colorado River (https://nativevoicesonthecolorado.wordpress.com) and many have their own outreach programs developed to educate visitors to the Canyons regarding Tribal histories and affiliations with the Canyons. This is discussed further in Section 4.9.1.4. Mitigation of potential effects on resources of Tribal concern will be subject to ongoing consultation.

4.9.1.3 Preserve and Enhance Respect for Canyon Life

For those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni TCP. The Zuni expressed their view on this subject in Section 3.9.6. In the past, the Zuni have expressed a willingness to consult with Reclamation in good faith in "seeking and reaching agreement with the Zuni to avoid, reduce, compensate for, or otherwise mitigate any adverse effects" (Zuni Tribal Council 2010). The Zuni along with the Hualapai, Navajo, Kaibab Band of Paiute, and Hopi continue to consult with Reclamation, the NPS, and other agencies regarding nonnative fish control. As noted in Chapter 2, since 2011, the presence of whirling disease prohibits live removal of trout due to the risk of spreading the disease to other waters. In the event that nonnative fish are removed, Reclamation commits to live removal of nonnative fish whenever practicable and then only if the best available science indicates that nonnative fish are posing a threat to endangered native fish species. Reclamation has also committed to consult with the Tribes whenever live removal is not feasible to determine acceptable mitigation for the adverse effect, such as beneficial use (Reclamation 2012b). In the past, Reclamation and NPS have worked with the Tribes to determine a beneficial use of the removed fish and will continue to do so during the 20-year LTEMP period. Note that what is considered beneficial use may not be the same for all Tribes.

The purpose of trout management activities is to enhance the survival of the endangered humpback chub by reducing the numbers of trout in the river. Reducing the trout population would reduce competition with and predation on young-of-the-year chub near the confluence with the Little Colorado River from trout moving downstream from reaches just below Glen Canyon Dam (Section 4.5). Two forms of trout management have been proposed: TMFs and mechanical removal. Each is being considered as a management action that may be triggered when trout and/or chub populations are at specified levels. Trout management is included in all alternatives except Alternative F, and mechanical removal is only possible under Alternative A until 2020 (see Appendix J).

A TMF is a highly variable flow pattern of water releases at Glen Canyon Dam intended to control the number of young-of-the-year trout in the Glen Canyon reach of the Colorado River and, subsequently, the migration of trout to downstream areas such as the confluence of the Little Colorado River (Chapter 2). A typical TMF would consist of several days at a relatively high sustained flow (e.g., 20,000 cfs) that would prompt young fish to move into the shallows along the channel margins and, depending on the time of year, would prompt spawning fish to construct redds and lay eggs in nearshore shallow areas. The high flows would be followed by a rapid drop to a low flow (e.g., 5,000 cfs), stranding young-of-the-year trout and, depending on the time of year, possibly exposing the eggs, thus preventing them from hatching. With the exception of Alternatives C and D, under which TMFs could be implemented early in the LTEMP period even if not triggered by predicted high trout recruitment, TMFs may be triggered during years in which trout recruitment in the Glen Canyon reach is anticipated to be high. Under each of the alternatives in which TMFs are included, they would initially be conducted as experiments; they would be implemented only if they prove to be successful in reducing the trout population in the Glen Canyon reach. In general, TMFs would most likely be triggered when spring HFEs, which can stimulate the food base and thus trout production, are followed by relatively high steady summer flows. Where the number of HFEs is limited, as in Alternative B, it is expected that TMFs would be triggered in fewer years. Modeling indicates TMFs would be triggered most often under Alternative G. If TMFs prove successful, they would reduce the number of times mechanical removal would be triggered.

Mechanical removal would employ electrofishing to stun and remove nonnative fish. Usually, the removed fish would then be euthanized and put to some beneficial use. For example, in one mechanical removal test, the trout were emulsified and used as fertilizer in the Hualapai Tribal gardens (Reclamation 2011a). In their Comprehensive Fisheries Management Plan, the NPS committed to put all removed nonnative fish (including trout) to beneficial use through human consumption (NPS 2013e). GCMRC has modeled the number of years in which mechanical removal would be triggered under various alternatives. In general, mechanical removal would be triggered in far fewer years than TMFs. In general, when TMFs are projected to be triggered in more years, mechanical removal of trout would be triggered in fewer years. Modeling indicates that under Alternative G (the alternative under which the most TMFs would be triggered), mechanical removal would never be triggered in more than 7 years out of 20.

With regard to fish management, the Tribes have expressed a preference for letting nature take its course rather than intervening to mitigate the consequences of past actions. For example, the Zuni have suggested that it could be that the emergence of whirling disease in trout is nature's way of tempering out-of-balance fish dynamics. The Zuni and Hopi have also expressed some doubt that the humpback chub population is endangered and have urged additional studies of the relationship of the rainbow and brown trout to the humpback chub before undertaking the large-scale removal of fish (Zuni Tribal Council 2010; Yeatts and Huisinga 2013). For them, TMFs and mechanical removal are equally offensive and would be considered an adverse effect on the Grand Canyon TCP. Likewise, the Hopi Tribe "recommends that efforts to understand what are the limiting factors for the humpback chub (both habitat issues in mainstem and Little Colorado River, and the life stage(s) where mortality rate is limiting) continue to be a focus of aquatic research. In addition, management actions such as the translocation should be continued as long as they are continuing to be successful" (Yeatts and Huisinga 2012). The Navajo also prefer live removal; however, according to a separate Navajo Nonnative Fish Control Agreement, if live removable is not feasible, Reclamation is to consult with the Navajo Nation to determine a course of action, and that fish shall not be euthanized within the area 0.5 mi upstream of the Little Colorado River to 0.5 mi downstream of the salt mine (Reclamation 2012b).

4.9.1.4 Preserve and Enhance the Sacred Integrity of Glen, Marble, and Grand Canyons

The preservation of the sacred integrity of the Canyons is vitally important to the Tribes. Under the provisions of Executive Order 13007, both Reclamation and the NPS have obligations to accommodate access to and ceremonial use of Indian sacred sites by Indian religious practitioners; to avoid adversely affecting the physical integrity of sacred sites; and to maintain the confidentiality of the location of sacred sites as requested by the Tribes. Inappropriate behaviors and activities within the Canyons can negatively affect the sanctity of the Canyons. Visitor impacts noted by Tribes include, but are not limited to, trampling of resources, lack of respect for sacred sites, trailing, illegal collection of artifacts, artifact movement, vandalism, and littering. Disruptive, boisterous behavior in the Canyons disturbs the spiritual ambiance that surrounds sacred trails and sites. Many Tribes have reported experiencing discomfort when performing ceremonies at certain sites within the river corridor because of the number and behavior of visitors present. In some cases, Tribal members have been approached by curious visitors during private ceremonies (Bulletts et al. 2008. 2012; Jackson-Kelly et al. 2013). During consultation meetings, Tribal representatives expressed concerns regarding integrity of the Canyons. For example, the Zuni expressed that from their perspective, any impact on the Canyons is an impact on the Zuni people, because the spirits that are disturbed can bring adverse consequences to the Zuni and their families; and the Navajo indicated that they have observed a reduction in the strength of plants gathered from sites along the river to be used for medicinal and ceremonial purposes, and have sought out other collection sites. In addition, visitor impacts could diminish the feeling, association, settings, and materials of important places, aspects used to evaluate the integrity of a traditional cultural place.

Non-Tribal visitors will continue to be present under all alternatives. As noted in Section 4.8, Alternative F is modeled to result in slightly more visitor time off-river, resulting in slightly more risk to sacred sites than the other alternatives. There is very little variation in the modeled time off river among the other alternatives

Possible adverse effects on sacred sites that result from tourists in the Canyons could be mitigated and in some cases prevented through communication and education. All of the Tribes with historical and cultural ties to the Canyons are affiliates of Native Voices on the Colorado River, an educational program that offers the Tribes a chance to share their historic and contemporary perspectives of the Colorado River and the Canyons with river guides, river outfitters, and the public. River guides and outfitters in turn share this information with their clients on river trips (NVCR undated). In addition, some Tribes have developed their own outreach programs. The Southern Paiute Consortium has developed outreach programs with Colorado River guides, local schools and universities, and civic organizations. When they are conducting monitoring trips or present in the corridor, the consortium also talks with Canyon visitors. The goal of the program is to educate non-Tribal members about the Southern Paiute history and broad cultural landscape of the Canyons (Bulletts et al. 2012). The Hualapai encourage public outreach and education as a means of teaching people about negative impacts on Hualapai resources (Jackson-Kelly et al. 2013). The Zuni have expressed interest in developing an educational program that would allow Zuni cultural advisors to inform river guides, boatmen, NPS, and Reclamation about the importance of Zuni history and traditional issues as they are related to the Canyons (Dongoske 2011a). Reclamation and NPS are committed to continue working with the Tribes to develop or continue development of education and outreach programs. It is important that visitors to the Canyons understand the magnitude of the consequences their presence has on Tribal resources and Tribal members.

4.9.1.5 Maintain and Enhance Healthy Stewardship Opportunities and Maintain and Enhance Tribal Connections to the Canyons

During the development of the LTEMP DEIS, the Tribes expressed concern with maintaining and improving their connection to the Canyons, including the stewardship responsibilities given to them at creation or emergence. Stewardship is partly expressed through their participation in the Glen Canyon AMWG and TWG, which encourage participation in an open discussion of issues related to the operation of Glen Canyon Dam as well as the design of monitoring and research conducted by the GCMRC.

The Tribes regard maintaining their connection to the Canyon through traditional activities and fulfilling their stewardship responsibilities as vital. Tribal stewardship takes place on many levels, including participation in the management of Canyon resources through monitoring programs, ceremonial activities, and recounting oral histories. These stewardship activities are important for all Tribal members, but they are particularly important for passing down traditions and oral histories to Tribal youth. As discussed above, insensitive behavior by Canyon visitors and researchers may disrupt the Tribes' ritual activities of stewardship and passing cultural values connected to the Canyons to the next generation (Bulletts et al. 2008, 2012; Jackson-Kelly et al. 2013).

Adverse effects can be avoided or mitigated through continued communication; this includes communicating about the timing and duration of HFEs. Many of the Tribes are members of both the AMWG and TWG. Many Tribes also have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Continued communication and collaboration between the Tribes and federal agencies will enhance stewardship opportunities for the Tribes, as will maintaining the Tribes' continued access to the Canyons to conduct important religious practices necessary for continued stewardship.

4.9.1.6 Economic Opportunity

As discussed in Section 4.14.2.1, economic ventures currently operated by the Tribes and Tribal members rely heavily on tourism both in and around the Canyons. These ventures include commercial rafting on the river, tourist facilities in or near the Canyons, and vendors of Native American crafts, such as jewelry, basketry, and ceramics, that rely heavily on trade with tourists. Within the Canyons, the Grand Canyon West Corporation, owned by the Hualapai Tribe, provides recreational facilities including river running below Diamond Creek. The Hualapai River Runners provide day and overnight whitewater rafting trips, and flat-water day trips. The Tribe (working with GCNP) also issues some permits for private whitewater boating below Diamond Creek. The one-day whitewater boating trips create the largest river recreation impacts within the Canyons (61 jobs and $1.4 million in annual regional income), while day-use flat-water trips also make a significant contribution (19 jobs and $0.4 million in annual regional income). The NPS CRMP (NPS 2006b), developed in consultation with the Hualapai Tribe, places limits on the number and size of trips below Diamond Creek. There are a fixed number of river trip launches allowed under the NPS plan and more demand than capacity. The number of trips would not change as a result of any of the alternatives, so the impacts on the river runners would be the same as Alternative A for all alternatives. The same annual economic impacts would be expected under each of the alternatives.

The Hualapai, Havasupai, and Navajo all operate land-based tourist facilities in or adjacent to the Canyons. The Havasupai operate a lodge, café, trading post, and campground on their reservation, and offer Canyon tours. The Navajo have Tribal parks overlooking the Little Colorado River and Grand Canyon, and along Lake Powell. Tourism is a major source of Tribal income for the Hualapai and Havasupai. No difference in tourist use of land-based facilities or Native American craft vendors is expected among the LTEMP alternatives. However, Tribes have expressed the desire for communication before and during HFEs to enable them to communicate information to tourists as necessary. The Navajo also operate the Antelope Point Marina on Lake Powell. Direct and indirect economic impacts of visitation to Lake Powell facilities are discussed in Section 4.14.2.1. There is very little difference among the alternatives regarding impacts on marinas on Lake Powell. Models indicate that all alternatives except Alternative F would result in negligible change in regional income, less than 0.6%. The largest potential decrease would be 1.1% under Alternative F because that alternative has higher releases in the spring and lower releases through the summer every year, and consequently slightly different reservoir levels in the summer months.

4.9.1.7 Maintain Tribal Water Rights and Supply

Reclamation is committed to operating Glen Canyon Dam so that all water obligations are met, including those to Tribes. Lake Powell supplies water to both the Navajo Chapter of LeChee and the City of Page, Arizona, which share a water intake system (NPS 2009b). Currently, two intakes provide water. There is an intake on the face of the dam at 3,480 ft above mean sea level and a second intake off the penstocks to Units 7 and 8 at 3,470 ft above mean sea level. In the current configuration, the minimum pool elevation necessary to supply LeChee and Page is 3,470 ft above mean sea level. The minimum power pool elevation is 3,490 ft above mean sea level, well above the water intakes (Grantz 2014). Plans now under consideration call for a new, lower intake at 3,373 ft above mean sea level. The modeling results for all of the alternatives show Lake Powell levels remaining above the existing and proposed intakes for the entire 20-year period (see Appendix J). The lowest pool level projected is 3,480.3 ft above mean sea level, about the level of the intake on the dam face and 10 ft above the penstock intake.

4.9.1.8 LTEMP Process

Tribes have been involved in the LTEMP development process and will continue to be involved in the implementation of LTEMP. Tribes have routinely expressed concern regarding how LTEMP decisions are made rather than what decision is made, the genuine incorporation of Tribal input, and the importance of learning to improve management over time. They have favored an experimental approach resulting in adaptive management.

Over the course of the development of the LTEMP DEIS, Reclamation and the NPS have sought to incorporate Tribal input into the LTEMP process. Cooperating and consulting Tribes were included in Cooperating Agency and stakeholder meetings. Reclamation and NPS have also held Tribal meetings, workshops, conference calls, and webinars. Various documents related to the development of the LTEMP DEIS have been provided to the Tribes for their review and input. When requested, there have been face-to-face meetings with the Tribes. Tribes were given the opportunity to contribute to the Tribal lands, affected environment, and environmental consequence sections of the DEIS, and Tribal views have been incorporated throughout this DEIS. A complete summary of Tribal consultation efforts is provided in Section 5 and Appendix N.

4.9.2 Analysis Methods

Two main issues emerged in analyzing how the proposed action would be likely to affect Tribal resources in the Canyons: (1) How would alternatives affect the continued existence of Tribal resources in the Canyons? and (2) How would alternatives affect the sacred integrity of and Tribal connections to the Canyons? Since the Tribes are the best judges of how the alternatives would affect them and because some Tribal resources are sacred and their locations confidential, the answers to these questions require input from the Tribes. The analysis presented here is based mainly on input from the Tribes, augmented with analysis of quantifiable impacts.

Input from the Tribes was sought and continues to be sought in a number of ways. Initially, NPS and Reclamation identified 43 federally recognized Tribes with potential historical and cultural ties to the Colorado River and its Canyons and invited them to participate in the LTEMP DEIS process, as either Cooperating Agencies or consulting parties. NPS and Reclamation conducted meetings with groups of cooperating and consulting Tribes; these meetings included workshops, teleconferences, webinars, and face-to-face meetings with Tribal authorities in efforts to fully identify Tribal concerns about impacts of alternatives on resources. The agencies also consulted with Tribes during Cooperating Agency meetings. Tribes that chose to become Cooperating Agencies also were given the opportunity to contribute to the writing of the DEIS. Chapter 5 and Appendix N provide descriptions and other information for the consultation process. Goals for resources of Tribal concern were developed from information obtained at these meetings, and Tribes had an opportunity to review, edit, and contribute additional information and concerns. Where possible, potential impacts on these resource goals were determined quantitatively, and modeling was used to quantify impacts. Modeling and analysis incorporated analyses from other resource areas such as aquatic resources, riparian vegetation, and economics. Tribes were invited to meetings where the results of the modeling were presented, and they were given a chance to ask questions and contribute comments.

Qualitative assessments of impacts were based on written information produced by or for the Tribes. Significant insight into Tribal priorities came from the Tribes that regularly monitor the state of resources in the Canyons that they consider significant. Tribal monitoring reports from the Hopi (Yeatts and Brod 1996; Dongoske 2001; Yeatts and Huisinga 2006, 2009, 2010, 2011, 2012, 2013), Hualapai (Jackson et al. 2001; Jackson-Kelly et al. 2009, 2010, 2011, 2013), Navajo (NNHPD 2012), Southern Paiute (Austin et al. 1999; Drye et al. 2000, 2001, 2002, 2006; Bulletts et al. 2003, 2004, 2008, 2010, 2011, 2012; Snow et al. 2007), and Zuni (Dongoske 2011a) were consulted for information on sites and resources of importance, as were ethnographies produced for the Tribes during previous related National Environmental Policy Act of 1969, as amended (NEPA) analyses (Ferguson and Lotenberg 1998; Lomaomvaya et al. 2001; Roberts et al. 1995; Yeatts and Huisinga 2003; Stoffle et al. 1994, 1995; Hart 1995).

4.9.3 Summary of Impacts

A summary of the impacts of the LTEMP alternatives on Tribal resources is presented in Table 4.9-2. In general, it is anticipated that there will be limited impacts on places and resources from the proposed action and the impacts that are anticipated do not vary greatly among the alternatives. Flow-related impacts on traditional cultural places include inundation by high flows (i.e., flows above the normal maximum operating flow of 25,000 cfs), resulting in erosion and temporary loss of access to such features as springs. Inundation impacts are temporary and can be mitigated through communication between Reclamation and the Tribes regarding scheduled high flows. The potential for the inundation of historic properties and erosion of terraces where historic properties are located is discussed above in Section 4.8. It is anticipated that traditional cultural resources most directly affected by flows would be riparian vegetation and fishes. Flow impacts on culturally important terrestrial wildlife would be minimal and do not vary among alternatives (see Section 4.7).

Non-flow actions include trout removal and vegetation management. Proposed experimental vegetation management activities include the removal of nonnative species, clearing vegetation to expose sand for camping and distribution by wind, removing encroaching vegetation from campsites, and replacing removed nonnative species with native species, many of which have cultural importance to the Tribes. Vegetation management has the potential for both beneficial and adverse impacts (see Section 4.9.4). Increasing campable area by clearing campsites may not be seen as positive by Tribes that consider the Canyons a sacred space and are concerned with visitors disrespecting and interfering with important ceremonial and other

TABLE 4.9-2 Summary of Impacts of LTEMP Alternatives on Tribal Resources

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	Operations would result in no change in the amount of sand available for wind transport to cultural resource sites; a negligible loss of riparian diversity; a small loss of wetlands and no impact to Tribal water and economic resources. No TMFs, but mechanical trout removal could be triggered. After 2020, potential adverse impact to culturally important archaeological sites.	Compared to Alternative A, operations would result in a slight increase in the amount of sand available for wind transport to cultural resource sites except during hydropower improvement flows when there would be a slight decrease. There would be a slight loss in riparian diversity and slightly more loss in wetlands. There would be no impact on Tribal water and economic resources. TMFs and mechanical trout removal could be triggered.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the second largest loss in wetlands and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; the least amount of wetlands loss across alternatives; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could occur with or without triggers.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites; an increase in wetlands loss; and similar riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered.	Compared to Alternative A, operations would result in an increase in the amount of sand available for wind transport to cultural resource sites but would result in an increase in the potential for river runners to explore and potentially damage places of cultural importance during May and June. The greatest loss of wetlands, largest increase in invasive species, and lowest riparian plan diversity occur under this alternative. Tribally operated marinas could experience a slight loss of income under this alternative. There would be no TMFs or mechanical trout removal.	Compared to Alternative A, operations would result in the greatest potential increase in the amount of sand available for wind transport to cultural resource sites; the third-largest wetlands loss across alternatives; and a decrease in riparian plant diversity. Tribally operated marinas could experience a negligible drop in income. TMFs and mechanical trout removal could be triggered.

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Places							
Visitation of culturally significant sites	No change in the potential for recreationists to visit culturally significant sites	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Slight increase in the potential for recreationists to visit culturally significant sites in May and June	Same as Alternative A
Availability of sand for wind transport to protect culturally important archaeological sites	Negligible change in wind transport of sand; some increase in sand from HFEs until 2020, when HFEs are discontinued; potential adverse impact due to reduction in sediment availability after 2020	Similar to Alternative A either with slight potential increase (+7%) from HFEs continuing over entire LTEMP period or slight decrease (−10%) from Alternative A due to hydropower improvement flow tests.	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+137%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to protect cultural resource sites (+139%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+96%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+88%), resulting from increase in frequency of HFEs	Increase compared to Alternative A in potential for wind transport of sand to cultural resource sites (+193%), resulting from increase in frequency of HFEs

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Traditional Cultural Resources							
Riparian plant diversity	Slight loss of riparian plant diversity (0.97 diversity index)	Similar to Alternative A (0.99 diversity index)	Decrease in riparian plant diversity compared to Alternative A (0.75 diversity index)	Similar to Alternative A (0.97 diversity index)	Similar to Alternative A (0.95 diversity index)	Lowest riparian plant diversity (0.68 diversity index) compared to Alternative A; largest acreage of invasive plants	Decrease in riparian plant diversity compared to Alternative A (0.83 diversity index)
Retention of wetlands (existing marsh is less than 5 ac total)	Approximately 3.6 ac retained; 28% loss.	Approximately 4 ac retained; 8% more than Alternative A. Under hydropower improvement, flows wetlands loss would be greater.	Approximately 1.25 ac retained; 47% less than Alternative A. Second-largest area of wetlands loss across alternatives.	Approximately 4.2 ac retained; 12% more than Alternative A. Least loss of wetlands across alternatives.	Approximately 3.1 ac retained; 10% less than Alternative A.	Approximately 0.7 ac retained; 58% less than Alternative A. Largest area of wetlands loss across alternatives.	Approximately 1.5 ac retained; 30% less than Alternative A. Third-largest area of wetlands loss.
Frequency of TMFs	No TMFs	TMFs expected in 3 of 20 years	TMFs expected in about 6 of 20 years	TMFs expected in 8 of 20 years	TMFs expected in 3 of 20 years	No TMFs	TMFs expected in 11 of 20 years
Frequency of mechanical removal of trout	Trout removal expected in <1 of 20 years	Trout removal expected in <1 of 20 years	Trout removal expected in about 1 to 3 of 20 years	Trout removal expected in about 2–3 of 20 years	Trout removal expected in about 1 or 2 of 20 years	No trout removal	Trout removal expected in 3 of 20 years
Impacts on culturally important wildlife	Negligible adverse impact effects on culturally important wildlife	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

TABLE 4.9-2 (Cont.)

Resource	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic and Water Resources							
Impact on Tribal flat-water or whitewater rafting services	No impact on flat-water or whitewater runs	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Impact on Tribal land-based vendors	No impact on land-based vendors	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Impact on Tribal Lake Powell marina	No change from current condition	No difference from Alternative A	Negligible difference from Alternative A (<0.6%)	Negligible difference from Alternative A (<0.6%)	Negligible difference from Alternative A (<0.6%)	Slight decrease in marina income (1.1%)	Negligible difference from Alternative A (<0.6%)
Water supply	Lake Powell elevation would remain above the level of the water intakes used by the Navajo Nation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

cultural activities. All LTEMP alternatives would have the same overall level of visitation, set by the number of permits, so effects would be negligible in terms of a difference from No Action. Also there are potential positive effects that could result from using plants as barriers, closing off trails to culturally sensitive sites, and increasing native plants in restoration areas that are important to Tribes. Removing vegetation to open up sandy beaches has the potential for allowing the wind transport of fine sediment to higher elevations and potentially shielding archaeological sites from erosion. These impacts would not vary among the alternatives. Lethal removal of trout has been identified by the Zuni with the support of other affiliated Tribes as having an adverse effect on the TCP of the Grand Canyon, particularly when it takes place in proximity to the confluence of the Colorado River and the Little Colorado River, an area of special significance to the Zuni (Dongoske 2011b), the Hopi (Yeatts and Huisinga 2013), and the Navajo (Roberts et al. 1995). The lethal mechanical removal of trout and/or TMFs would be considered a significant adverse impact by some Tribes; however, if done in conjunction with mandated consultation with the Tribes, the impact may be reduced through beneficial uses and other practices that have been used for the Bright Angel fish removal efforts. For a discussion of alternative specific impacts see Section 4.9.4.

As discussed in Section 3.9, many of the Tribes that have been involved with this DEIS consider portions of the Colorado River and its tributaries, the Canyons through which they flow, as well as elements within the river and Canyon corridors, as a TCP or part of a TCP. Any impact on any cultural place or cultural resource—be it an archaeological site, sacred place, traditional collection area, important plant or animal, or other element considered a TCP or contributing element to a TCP—is also considered an impact on the TCP, because these resources add to the overall traditional value of the TCP for these Tribes. As previously discussed, many Tribes have their own monitoring programs whereby resources and sites of importance are monitored, the health of the Canyon is examined, sacred sites are visited, and respects are paid to the Canyon and its resources. Any effect on the Canyons and their resources will likely be evaluated by each Tribe during the monitoring assessments. The Zuni in particular have stated that any action within the Grand Canyon will have to be assessed by the Zuni people for adverse effects that may be experienced in the Zuni Pueblo itself.

4.9.4 Alternative-Specific Impacts

This section presents the impacts of the LTEMP alternatives on the Tribal resource goals presented in Section 4.9.1. Impacts are based on both quantitative and qualitative indicators of the status of resources that Tribes have indicated are culturally important. Factors considered include the state of riparian plant communities, riparian and terrestrial wildlife, and aquatic resources. Also considered are the time Canyon visitors spend off the river, potentially impacting traditional cultural places and economic opportunities for commercial Tribal river runners.

4.9.4.1 Alternative A (No Action Alternative)

Under Alternative A, the No Action Alternative, the modified fluctuating flows as defined in the 1996 ROD for the operation of Glen Canyon Dam would continue. Existing operations and recent decisions would be maintained. The existing HFE protocol and nonnative fish control actions and experimentation would continue until 2020 as specified in existing EAs. The HFE protocol EA (Reclamation 2011b) projected that access to and use of certain cultural properties could possibly be altered due to inundation in the area directly affected by an HFE. Less sand would be moved from Marble Canyon downstream under this alternative than under any other and it has the lowest sand load index score, which suggests there would be less building of sandbars, resulting in less sand being available for windborne transport to culturally important sites.

Alternative A is likely to result in a relatively even proportional distribution of plant community types, but a slight loss in plant community diversity. Modeling results suggest that 3.6 ac of wetland habitat will remain at the end of the 20-year LTEMP period, a decrease of 28% from the current wetland acreage (Section 4.6). An estimated 4.6 ac of wetlands occurs downstream from the dam.

Testing of TMFs is allowed under Alternative A, but since there has not been a decision to implement these flows, they are not considered a regular action under this alternative. Modeling of trout numbers suggests that mechanical removal trips would only rarely be triggered, resulting in the fewest removal trips of any alternative where mechanical removal is allowed, in part because removal actions would expire in 2020. As indicated by lack of significant changes in the riparian plant communities and the mobility of larger animals, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and would not differ among the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Income from Hualapai river-running is not expected to diminish and would not be affected by the alternatives. The Canyons are expected to continue to draw tourists who would patronize land-based Tribal tourist facilities and Native American craft vendors. These would not be affected by the flow alternatives. There would be no effect to the Navajo marina under this alternative (Sections 4.2 and 4.14.2.1; Reclamation 2011a).

In summary, under Alternative A, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity and wetland acreage. Trout removal trips are expected to be triggered in 1 year out of 20, the lowest expected number of trips among alternatives, which represents no change from current conditions. The availability of sand for wind transport could provide some benefit to some places of traditional cultural importance due to HFEs until 2020 when the HFE protocol expires, at which point these areas could experience an adverse impact due to lack of available sediment for wind transport. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change from current conditions related to Tribal flat-water or whitewater rafting services, Tribal land-based vendors, marinas operated by Tribal enterprises, or Navajo Nation water supply. Any impact on a Tribally important cultural place or resource is also considered an impact on a Tribe's TCP.

4.9.4.2 Alternative B

Alternative B would follow the same monthly water release volumes as Alternative A, but there would be greater fluctuations in 10 months of the year and increased down-ramp rates. Under this alternative, HFEs would be implemented over the entire 20-year LTEMP period, but they are limited to no more than one every other year. There is greater daily flow fluctuation than in Alternative A for most months. Hydropower improvement flows—operations with wider fluctuations in high electrical demand months—would be tested in 4 years when the annual release volume is ≥8.23 maf. TMFs would be tested and implemented if successful.

This alternative is likely to result in the maintenance of current levels of evenness and diversity of plant community distribution; slightly higher plant diversity is expected than under Alternative A. Due to a lack of extended high or low flows that scour or desiccate wetlands, approximately 4 ac of wetlands would be retained under Alternative B, 8% more than under Alternative A (Section 4.6), except under the hydropower improvement flows, in which case there would be increased loss of wetlands. An estimated 4.6 ac of wetlands occurs downstream from the dam.

The wider daily fluctuations under Alternative B would reduce the potential for bar-building, making less sand available for windborne transport to culturally important places relative to normal operations under Alternative B. Under typical operations, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the Sand Load Index would be slightly greater (+7%) than under Alternative A, unless hydropower improvement flows are included, in which case the Sand Load Index would be slightly less than under Alternative A (−10%).

Under this alternative, TMFs are expected to occur in about three of the 20 LTEMP years. This alternative and Alternative E likely would have the fewest TMFs among the alternatives that allow TMFs (Alternatives A and F do not). Low numbers of TMFs result from lower numbers of trout recruits in the Glen Canyon reach. Low trout numbers result from higher daily fluctuations and fewer spring HFEs. When trout numbers are low, mechanical removal is triggered in fewer years.

Based on the lack of significant changes in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as big horn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience no loss in income when compared to Alternative A.

In summary, under Alternative B, current wetland acreage is expected to be retained and plant diversity would be slightly higher than under Alternative A, except under hydropower improvement flows, which would result in greater loss of wetlands. TMFs are expected to be triggered in 3 years out of 20; while trout removal trips are expected to potentially be triggered, if at all, in 1 year out of 20. The availability of sand for wind transport to potentially protect some places of traditional cultural importance would somewhat increase relative to Alternative A because HFEs would occur over the entire LTEMP period. However, the high fluctuations of hydropower improvement flow would potentially decrease the availability of sand. Places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. Economic effects on Tribal tourist enterprises would be the same as under Alternative A. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.3 Alternative C

Under Alternative C, the highest water release volumes would occur in the high electric demand months of December, January, and July, with lower volumes from August through November to conserve sediment inputs during the monsoon period. The HFE protocol would be followed for the entire 20-year period, and some additional HFEs would be allowed. Proactive spring HFEs would be tested in years with a high volume of flow (>10 maf). Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the Sand Load Index would be greater (+137%), making more sand available for windborne transport to cultural sites (Section 4.3).

Operations under this alternative are expected to result in relatively low plant community diversity and evenness. High flows followed by growing season lows are likely to result in more loss of diversity than under Alternative A (Section 4.6). This alternative is expected to retain approximately 1.25 ac of wetlands, 47% less than that retained under Alternative A. This alternative results in more wetland loss than any other alternative except Alternative F. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs are expected to be triggered in about 6 out of 20 years under this alternative because of the relatively higher number of trout expected to be produced (Section 4.5). Mechanical trout removal is expected to be triggered in few if any of the 20 years modeled.

As under other alternatives, because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds (an important group of birds for the Hopi Tribe)—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (see Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience a negligible loss in income when compared to Alternative A (<0.6%).

In summary, under Alternative C, the diversity of riparian plant communities is expected to decrease, and this alternative is expected to result in the second-largest area of wetland loss when compared to Alternative A. TMFs are expected to be triggered in 6 out of 20 years, and trout removal trips could potentially to be triggered in 3 out of 20. Under Alternative C, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. Economic effects on Tribal tourist enterprises would be the same as under Alternative A, except for Tribally operated marinas, which would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe’s TCP.

4.9.4.4 Alternative D (Preferred Alternative)

Alternative D adopts characteristics of Alternatives C and E to achieve sediment retention characteristics and other resource benefits while reducing impacts on the value of hydropower generation and capacity, when compared to Alternatives C and E. Like Alternatives C and E, Alternative D includes a number of condition-dependent flow and non-flow actions that may be triggered by resource conditions. Alternative D differs from the other two in the specific trigger conditions and the actions that would be taken. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the Sand Load Index would be greater (+139%), making more sand available for windborne transport to cultural sites (Section 4.3).

Under Alternative D, riparian plant community diversity and evenness would be virtually the same as under Alternative A and similar to Alternative E. These alternatives would result in only a slight loss of plant community diversity. There would be on average an overall loss of invasive species; both tamarisk and arrowweed would decrease under Alternative D. There would be somewhat less loss of tamarisk under Alternative D than under Alternatives A or E. Repeated extended high flows can remove tamarisk and arrowweed. The low number of growing season extended low flows would limit tamarisk establishment and the shifting of wetland communities to arrowweed (Section 4.6.3.4).

Approximately 4.2 ac of wetlands would be retained under Alternative D, 12% more than under Alternative A. This alternative would result in the least amount of wetland loss of all alternatives. Greater wetland acreage is associated with greater plant community diversity. Low numbers of extended low flows during the growing season would limit the occurrence of wetland communities shifting to arrowweed. An estimated 4.6 ac of wetlands occurs downstream from the dam.

Spring HFEs, which stimulate the food base, and steady summer flows are factors that tend to result in trout population growth. Spring HFEs would be more common under Alternative D than under Alternative A, and summer daily fluctuations would be slightly less under Alternative D than under Alternative A. Under Alternative D, TMFs are expected to be triggered in about 8 out of 20 years. This would be more often than under any alternative except Alternative G, partly because TMFs could be triggered during years in which the production of young-of-the-year rainbow trout in the Glen Canyon reach is anticipated to be high. Overall, because TMFs are expected to reduce the number of fish in the trigger reach, mechanical removal could be triggered in fewer years. Under Alternative D, modeling suggests that trout removal would occur in about 2 to 3 out of 20 years, more often than under any other alternative except Alternative G.

As under other alternatives, because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience a negligible loss in income when compared to Alternative A (<0.6%).

In summary, under Alternative D, there would be a relatively even distribution of plant community types, but a slight loss in plant diversity, similar to Alternative A. The least amount of wetland acreage loss would occur under this alternative. TMFs are expected to be triggered in 8 years out of 20, and trout removal trips could potentially be triggered 3 years out of 20. Under Alternative D, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be no change in the potential for recreationists to visit culturally significant sites. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. Economic effects on Tribal tourist enterprises would be the same as under Alternative A, except for Tribally operated marinas, which would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.5 Alternative E

Like Alternatives C and D, Alternative E includes a number of condition-dependent flow and non-flow actions that would be triggered by resource conditions. Alternative E differs from the other two in the specific trigger conditions and the actions that would be taken. Under Alternative E, the relatively high number of HFEs projected would result in a higher Sand Load Index (+96%) and significantly more sandbar building potential than under Alternative A, making more sand available for windborne dispersal to culturally important places.

This alternative would result in a slightly less diverse and even distribution of plant community types than under Alternatives A, B, and D, but more diversity and evenness than under Alternatives C, F, or G. This alternative is expected to retain approximately 3.1 ac of wetlands, 10% less relative to Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

TMFs would be triggered in about the same number of years as under Alternative B. Fewer TMFs are expected because the number of trout in the Glen Canyon reach is expected to be lower under this alternative as a result of higher summer fluctuation levels and fewer spring HFEs. Mechanical removal would be triggered in about 1 or 2 out of 20 years.

Because of the types of changes expected in riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience a negligible loss in income when compared to Alternative A (<0.6%).

In summary, under Alternative E, diversity and evenness of plant community types would be slightly less than under Alternatives A, B, and D, but slightly more than under Alternatives C, F, or G. This alternative would retain more wetland acreage than Alternatives F, G, and C. TMFs are expected to be triggered in 3 years out of 20, and trout removal trips could potentially to be triggered 2 years out of 20. Under Alternative E, there is a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change in the potential for recreationists to visit culturally significant sites. There would be no impact on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply. Marinas operated by Tribal enterprises would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.6 Alternative F

Alternative F is designed to re-create a more natural (pre-dam) flow pattern while limiting sediment transport and providing lower, stable base flows in summer, fall, and winter, and warmer temperatures in the summer. It allows both spring and fall HFEs, which should significantly increase the deposition and retention of sediment relative to Alternative A. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the Sand Load Index would be greater (+88%), making more sand available for windborne transport to cultural sites (Section 4.3).

This alternative would result in the lowest degree of evenness and diversity and the greatest spread of tamarisk-dominated communities. This alternative would have high flows that spread tamarisk seeds followed by growing season low flows, which would allow seedlings to establish themselves. Similarly, this alternative is expected to result in the greatest amount of wetland loss of any alternative, retaining only 0.7 ac of wetlands, 58% less than under Alternative A. An estimated 4.6 ac of wetlands occurs downstream from the dam.

This alternative includes neither mechanical removal nor TMFs and would thus allow nature to take its course regarding the interaction of humpback chub and nonnative trout. The steady flows and frequent spring HFEs of this alternative are expected to produce larger numbers of trout relative to most other alternatives.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Under this alternative, visitors to the Canyons would spend slightly more time off the river than under any of the other alternatives (Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience a 1.1% loss of income (Section 4.14.2.1).

In summary, under Alternative F, plant diversity would be at its lowest, wetland loss would be at its highest, and the largest acreage of invasive species would occur. There would be no TMFs or mechanical trout removal trips under this alternative.

Under Alternative F, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. There would be a slight increase in the potential for recreationists to visit and potentially damage culturally significant sites during May and June. Impacts to Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no impact on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply. Marinas operated by Tribal enterprises would experience a slight drop in income under this alternative. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.9.4.7 Alternative G

Alternative G targets the conservation of sediment through steady, equal monthly release volumes that would maximize retention of sediment, and the largest number of HFEs of any alternative, some with extended duration, which would distribute and retain sediment at higher elevations. Compared to Alternative A, more sediment would be deposited above the 31,500 cfs level and the potential for sandbar building as reflected in the Sand Load Index would be greater (+193%), making more sand available for windborne transport to cultural sites (Section 4.3).

With more high flows, it is likely that this alternative would result in somewhat less diversity and evenness of plant communities than under Alternative A, but more diversity and evenness than under Alternatives C and F. The alternative would retain approximately 1.5 ac of wetlands, 30% less than Alternative A. Mean wetland acreage would be lower that of

Alternatives A, B, D, and E, but above that of Alternatives C and F (see Appendix J). An estimated 4.6 ac of wetlands occurs downstream from the dam.

The steady summer flows and spring HFEs that characterized this alternative create favorable conditions for the growth of the trout population. As a consequence, TMFs are expected to occur more often under this alternative (11 out of 20 years) than under any other. Mechanical removal would also occur more often under this alternative than any other, on average about 3 out of 20 years.

Because of the types of changes expected in the riparian plant communities and the mobility of larger wildlife species, impacts on terrestrial wildlife—including species important to Tribes, such as bighorn sheep, deer, snakes, amphibians, and yellow-feathered nesting birds—are likely to be negligible and not to differ across the alternatives (Section 4.7).

Time off river under this alternative would be the same as all other alternatives except Alternative F (Section 4.8.3).

Effects on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, and Navajo Nation water supply would be the same as under Alternative A. Marinas operated by Tribal enterprises would experience a negligible loss in income when compared to Alternative A (<0.6%).

In summary, under Alternative G, there would be a decrease in riparian plant diversity, and the third-largest wetland acreage loss across alternatives would occur. TMFs are expected to be triggered in 11 out of 20 years, and trout removal trips could potentially to be triggered 3 out of 20 years.

Under Alternative G, there would be a slight increase in the potential for wind transport of sand to protect some places of traditional cultural importance when compared to Alternative A. However, places of traditional cultural importance are present throughout the Canyons and vary in nature. Wind-transported sand may not always be considered a benefit for these resources. As stated in Section 4.8.2, the actual extent to which current sediment levels can stabilize the archaeological sites on the terraces remains unknown. Sediment can also be removed from archaeological sites by wind and rain, a factor that could lead to loss of integrity of a traditionally important cultural place or resource. Impacts on Tribally important riparian plant communities and terrestrial wildlife are expected to be negligible. There would be no change in the potential for recreationists to visit culturally significant sites when compared to Alternative A. There would be no impact on Tribal flat-water or whitewater rafting services, Tribal land-based vendors, or Navajo Nation water supply. Marinas operated by Tribal enterprises would experience a negligible drop in income. Any impact on a Tribally important cultural place or resources is also considered an impact on a Tribe's TCP.

4.10 RECREATION, VISITOR USE, AND EXPERIENCE

Issue: How do the alternatives affect recreation, visitor use, and experience?

Impact Indicators:

- Fish size and catch rate
- Flow fluctuation levels
- Navigability and safety
- Lost visitor opportunities
- Camping and recreation facilities on old sediment terraces
- Campsite area
- Campsite crowding
- Encounters with other groups
- Lake recreation
- Sediment impacts on Tribal recreation program in lower Grand Canyon

This section presents the potential impacts of LTEMP alternatives on recreation, visitor use, and experience. Background information on the resources or resource attributes included in this analysis can be found in Section 3.10. There are also references to Sections 4.5 (Aquatic Ecology), Section 4.6 (Plant Communities), Section 4.14 (Socioeconomics and Environmental Justice), and the Recreation Economic Analysis in Appendix L, as they apply to visitor use and experience.

4.10.1 Analysis Methods

The analysis of impacts on recreation, visitor use, and experience downstream of Glen Canyon Dam was based on assessment of alternative-specific differences in 10 indicators that were based on six quantitative metrics developed using recreational findings in published papers and reports, and quantified based on alternative-specific flow characteristics. The metrics were developed through consultation with subject matter experts and with consideration of comments from Cooperating Agencies.

Four of the metrics address issues important to visitor use and experience in GCNP, while the other two metrics focus on the Glen Canyon reach between the dam and Lees Ferry. Some information used for the assessment is not from measures of specific factors but is qualitative in nature. Most metrics were created as indices with values ranging from 0 to 1, where 1 is the optimal condition for that resource, and 0 represents the lowest possible value. An index with a relative scale was used because it was often impossible to quantify the condition of the resource, but it was possible to generate a relative scale that reflected that condition. For example, there is no current methodology that defines how specific camping areas in GCNP might respond to HFEs, but there is a basis for making conclusions about which conditions are likely to favor a general increase in camping area in the park. The exception to the 0 to 1 scale is the Glen Canyon Rafting Metric, which measures the number of potential lost rafting trips. All of the metrics except the Glen Canyon Rafting Metric are seasonally weighted to reflect seasonal differences in recreational use, with more weight given to conditions in the peak recreation period than in periods with less use. More information including assumptions and limitations of these metrics is in Appendix J. The six recreation-specific metrics are as follows:

- *Camping Area Index*—Accounts for optimal campsite area building and maintenance flows and sediment load (also used as input to the assessment of campsite crowding).

- *Time Off-River Index*—Relates the level of flows to visitors being able to spend time ashore visiting attractions.

- *Fluctuation Index*—Based on combinations of flows and fluctuations identified as preferable by experienced boat operators.

- *Navigation Index*—Based on the percentage of time minimum daily flows are less than 8,000 cfs (also used as input to the assessment of campsite crowding and encounters with other groups).

- *Glen Canyon Rafting Metric*—Estimates the number of visitors unable to participate in day rafting in Glen Canyon due to high flows; the metric is the mean annual number of lost visitor opportunities.

- *Glen Canyon Inundation Index*—Accounts for flows that impact recreational sites and recreational uses within the Glen Canyon reach.

In the discussions below, the anticipated impacts of the alternatives are compared to the effects of Alternative A, the No Action Alternative. Impacts on recreation were developed using these metrics as well as published literature to evaluate how recreation would be affected by the alternatives. Information used includes the number and seasonality of HFEs, daily flow information, economic analysis, and fishery and vegetation management information that is documented in other portions of this DEIS. Metric values are based on 20-year simulations of Glen Canyon Dam releases under different hydrology and sediment conditions as determined for the various LTEMP alternatives.

The economic analysis conducted by Gaston et al. (2015) quantified the net economic use value (NEV) of recreation at Lakes Powell and Mead, and for three reaches of the Colorado River: Glen Canyon, the Upper Grand Canyon, and the Lower Grand Canyon under the LTEMP alternatives. The results of this analysis are presented in Section 4.14 and Appendix L.

4.10.2 Summary of Impacts

The impacts of LTEMP alternatives on visitor use and experience are summarized in Table 4.10-1. Graphs showing the performance of the alternatives for each of the metrics are shown in Figure 4.10-1. A more detailed analysis for each of the alternatives is presented in Section 4.10.3.

Differences in the alternatives' effects on recreation tend to be mostly related to differences in the frequency and characteristics of experimental flows, particularly HFEs and TMFs, but are also related to differences in operations such as fluctuating flow effects during

TABLE 4.10-1 Summary of Impacts of LTEMP Alternatives on Visitor Use and Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Fewest HFEs, moderate fluctuations, intermediate trout catch rates, few navigability concerns, declining camping area	Compared to Alternative A, comparable number of HFEs, higher fluctuations, and lowest catch rates; most navigability concerns; declining camping area similar to Alternative A	Compared to Alternative A, more HFEs, lower fluctuations, similar catch rates; fewer navigation concerns, increasing camping area	Similar to Alternative C, but with higher daily fluctuations	Similar to Alternative C, but with higher daily fluctuations	Compared to Alternative A and all other alternatives ,most HFEs, steady flows, higher catch rates, but least large trout; very few navigability concerns, most lost Glen Canyon rafting trips, increasing camping area	Similar to Alternative F; greatest potential increase in camping area
Glen Canyon—Fishing							
Fish size, catch rate, and angler satisfaction with flow levels and fluctuations	No change from current conditions; intermediate catch rates and estimated 770 large trout (≥16 in.); high angler satisfaction with flow levels and daily fluctuations	Lowest angler catch rates, 13% more large trout; slightly lower angler satisfaction than Alternative A	Slightly higher catch rates than Alternative A; 3% fewer large trout (750); slightly lower angler satisfaction than Alternative A	Similar catch rates as Alternative A; 5% more large trout (810); slightly lower angler satisfaction than Alternative A	Similar catch rate as Alternative A; 8% more large trout (830); slightly lower angler satisfaction than Alternative A	Highest catch rates; 22% fewer large trout (600) and lower angler satisfaction than Alternative A due to high flows in peak angling months	Second highest catch rates; 9% fewer large trout (700) and slightly lower angler satisfaction than Alternative A

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Glen Canyon—Fishing (Cont.)							
Navigability/ safety	No change from current conditions; intermediate number of days when flows below 8,000 cfs could affect navigability; minimal safety concerns from up-ramp rates	Lowest navigability due to occasional flows below 8,000 cfs; slightly increased wading risk during tests of hydropower improvement flows	Somewhat higher navigability than Alternative A; minimal safety concerns from up-ramp rates	Same as Alternative A; minimal safety concerns from up-ramp rates	Somewhat lower navigability than Alternative A; minimal safety concerns from up-ramp rates	Somewhat higher navigability than Alternative A; minimal safety concerns, steady flows	Highest navigability, with few if any flows below 8,000 cfs; minimal safety concerns, steady flows
Glen Canyon—Day Rafting/Recreation							
Lost rafting visitor opportunities	No change from current conditions; estimated loss of 49 visitors/year out of a total of 50,000 due to HFEs (0.1%)	71 out of 50,000 fewer visitors/year due to HFEs	315 out of 50,000 fewer visitors/year due to HFEs	348 out of 50,000 fewer visitors/year due to HFEs	177 out of 50,000 fewer visitors/year due to HFEs	919 out of 50,000 fewer visitors/year because of large number of HFEs in peak rafting season	51 out of 50,000 fewer visitors/year due to HFEs
Camping and recreation facilities on old sediment terraces	No change from current conditions; lowest potential adverse impact on terraces; estimated 5.5 HFEs and no TMFs over the LTEMP period	Intermediate potential impact on terraces; estimated 7 HFEs, 3 TMFs, and 4 years with hydropower improvement flows	Intermediate potential impact on terraces; estimated 21 HFEs and 6 TMFs	Intermediate potential impact on terraces; estimated 21 HFEs and 4 TMFs	Intermediate potential impact on terraces; estimated 17 HFEs and 3 TMFs	Highest potential impact on terraces; estimated 38 HFEs, but no TMFs	Intermediate potential impact on terraces; estimated 24 HFEs and 11 TMFs

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Grand Canyon—Whitewater Boating							
Campsite area	No change from current conditions; lowest improvement of campsite area; would continue long-term decline since there are no HFEs after 2020; camping area index (CAI) = 0.14 out of 1	About the same as Alternative A; effects of 2 more HFEs offset by larger fluctuating flows; overall campsite loss is expected to continue, CAI = 0.15, an increase of 5% over Alternative A	Possible increase in campsite area; more HFEs than Alternative A, moderate fluctuations, and reduced fluctuation pre- and post-HFEs; CAI = 0.38, an increase of 170% over Alternative A	Similar to Alternative C; CAI = 0.36, an increase of 158% over Alternative A	Similar to Alternative C, but reduced fluctuation pre-HFEs only; CAI = 0.30, an increase of 118% over Alternative A	Similar to alternative C; most HFEs and no daily fluctuations, high sustained spring flows; CAI = 0.41, an increase of 191% over Alternative A	Highest improvement of campsite area; second most HFEs; steady, moderate flow; CAI = 0.45, an increase of 224% over Alternative A
Lakes Powell and Mead—Recreation Access Issues Based on Lake Elevation							
Lake Powell[a]	No change from current conditions; 21.8% of lake elevation simulated seasons indicate access issues (percent of seasons with access issues occurring in any month)	2.5% increase in lake elevation simulated seasons indicating access issues (22.3%)	Negligible (0.4%) increase in lake elevation simulated seasons indicating access issues (21.8%)	5.1% increase in lake elevation simulated seasons indicating access issues (22.9%)	5.1% increase in lake elevation simulated seasons indicating access issues (22.9%)	4.7% increase in lake elevation simulated seasons indicating access issues (22.8%)	4.7% increase in lake elevation simulated seasons indicating access issues (22.8%)
Lake Mead[b]	No change from current conditions; 25.5% of lake elevation simulated seasons indicate access issues (percent of seasons with access issues occurring in any month)	10.6% decrease in lake elevation simulated seasons indicating access issues (22.8%)	Negligible (0.3%) decrease in lake elevation simulated seasons indicating access issues (25.4%)	2.5% decrease in lake elevation simulated seasons indicating access issues (24.8%)	1.2% decrease in lake elevation simulated seasons indicating access issues (25.2%)	2.5% decrease in lake elevation simulated seasons indicating access issues (24.8%)	1.9% decrease in lake elevation simulated seasons indicating access issues (25.0%)

TABLE 4.10-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Tribal Recreation Program							
Sediment impacts in lower Grand Canyon[c]	No change from current conditions; sand transported downstream at current rate until 2020, then reduced when HFEs cease	Slightly greater impacts than Alternative A due to slightly more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to most frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs
Impacts on park facilities at Pearce Ferry	No change from current conditions; facilities have been damaged in the past by HFEs; lowest of alternatives	Slightly greater impacts than Alternative A due to slightly more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs	Greater impacts than Alternative A due to most frequent HFEs	Greater impacts than Alternative A due to more frequent HFEs

[a] Percent of simulation seasons with at least 1 month with Lake Powell elevations equal to or below 3,580 ft AMSL, the level below which boat ramp access is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. See Appendix J.

[b] Percent of simulation seasons with at least one month with Lake Mead elevations equal to or below 1,050 ft AMSL, the level below which marinas and boat ramp function is assumed to be impeded; based on 21 traces over 20 years for 12 months per year. See Appendix J.

[c] Relative sand mass transported downstream from Marble Canyon, RM 0 to 61 over the 20-year LTEMP period (Table 4.2-10). Transported sand could potentially have adverse effects on Hualapai recreational facilities in lower Grand Canyon.

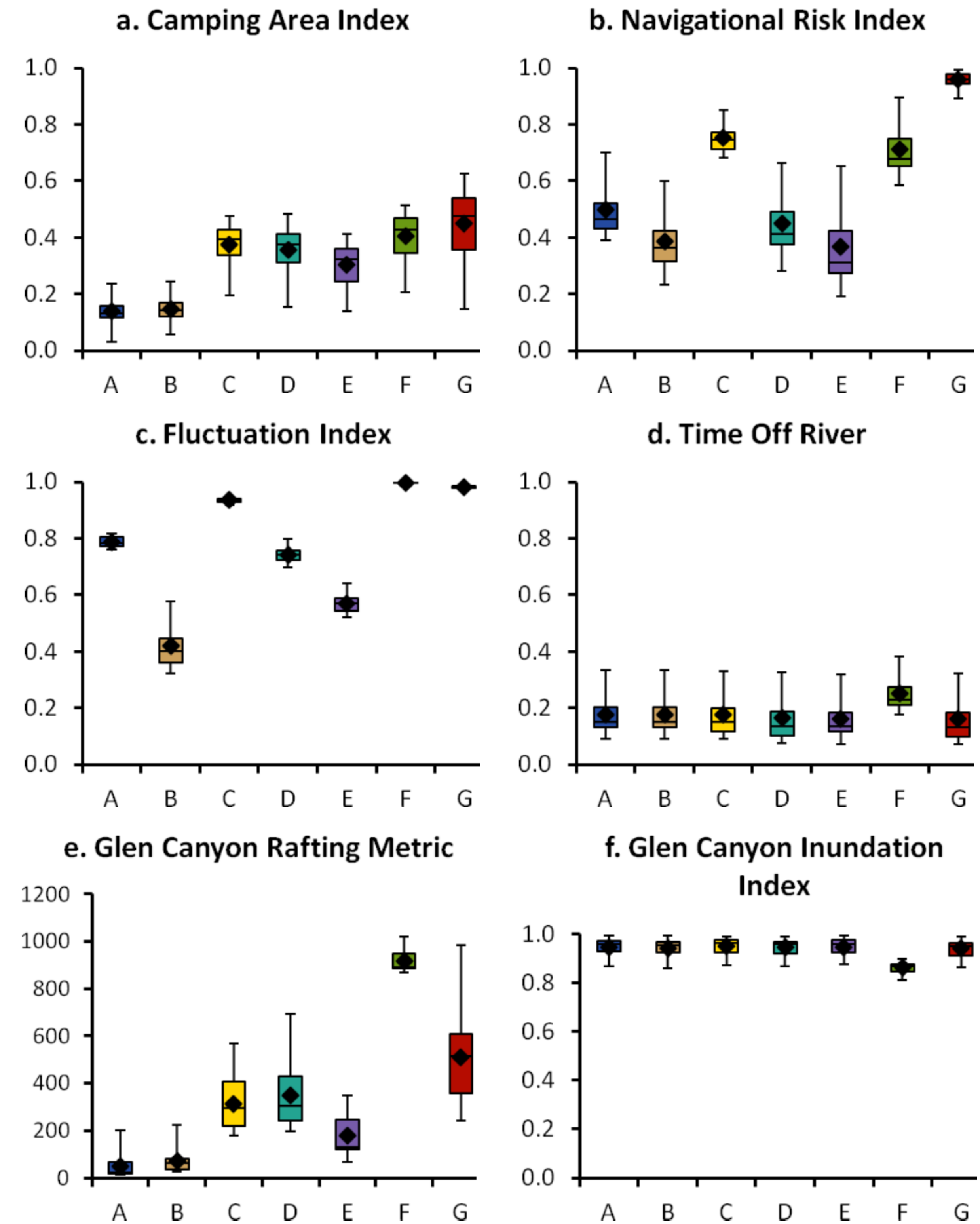

FIGURE 4.10-1 Recreation, Visitor Use, and Experience Metric Results for LTEMP Alternatives (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

high-demand seasons for hydropower. Effects are greater for actions that occur during peak recreational use months, for example certain spring HFEs that may occur during the peak rafting season. Some experimental flows and actions occur in only a few years; thus, for the majority of time, the LTEMP alternatives' experimental flows cause little difference for recreation effects. Differences in daily maximum and minimum flows under normal operations can, however, distinguish between alternatives with respect to potential effects on recreation. Daily maximum flows above 8,000 cfs increasingly reduce usable beach area, and would effectively submerge all beach area at flows above 31,500 cfs (Section J.2.1.1). In addition, daily fluctuations resulting in minimum flows below 8,000 cfs can affect river navigability and cause delays at rapids. Flow fluctuations can also affect shoreline angling, and rafters who camp may be forced to move to higher ground and to check boat moorings overnight. Such effects would not occur or would be less prominent under alternatives with reduced fluctuation or steady flows (e.g., Alternatives A, C, D, F, and G), while high steady flows under Alternative F in some spring and summer months would reduce usable camping area. Lastly, not all effects are experienced by all recreational users, and other effects are localized. For example, flow fluctuations may affect overnight boaters who camp more than day-only boaters, while vegetation management and mechanical trout removal are both localized actions that would affect recreation in only portions of the river at any given time.

4.10.2.1 Glen Canyon Fishing

Fluctuations and Water Levels

Anglers in the Glen Canyon reach identified a preference for steady flows and flows between 8,000 and 15,000 cfs (Bishop et al. 1987). Stewart et al.'s (2000) follow-up of the Bishop et al. (1987) study after the implementation of MLFF flows in 1996 did not identify river level fluctuations as an issue, and in 2011 an AZGFD creel study found that angler satisfaction in the Glen Canyon reach was high (Anderson, M. 2012), indicating that the existing flow regime was favorable for Glen Canyon anglers.

Steady flow Alternative F and Alternative G provide daily flows with no fluctuations; Alternative G might be considered better for anglers because flows would be at preferred levels throughout the year, whereas Alternative F has higher-than-preferred flows during some of the most popular fishing months, April through June. The highest fluctuations of fluctuating flow Alternatives C, A, D, E, and B (listed in order from lowest to highest within-day fluctuations) may not occur during peak fishing months. Furthermore, because the daily fluctuations analyzed in Bishop et al. (1987) were greater with respect to angling than those under the proposed alternatives, little difference is expected in effects on angling between alternatives due to fluctuations. Stewart et al. (2000) found that current fluctuations under MLFF were not identified by anglers as an issue. The effects of flow and fluctuation levels on angler satisfaction under the alternatives are quantified in economic terms in Section 4.14.2.1, which indicates that Alternative A would have the highest angler use value by a small margin over all alternatives; Alternative F would have the lowest due to high flows in peak fishing months.

The Glen Canyon Inundation metric was developed to identify the percentage of time river flows were above certain elevations that affect boating, fishing, and shoreline access. The metric is a measure of the suitability of flows between 3,000 and 31,500 cfs. Most alternatives perform similarly with regard to this metric, with Alternative F having a slightly lower metric value as illustrated in Figure 4.10-1. However, because all of the alternatives perform so consistently on this metric, it will not be discussed further.

Angling in the Glen Canyon Reach

Anglers in the Glen Canyon reach are almost evenly split in their preference for catching either large fish or for catching more fish (Anderson, M. 2012). Analysis described in more detail in Section 4.4.2.2 concludes there will likely be differences among the alternatives both in the percentages of larger fish (individuals exceeding 16 in. in length) in the population and in the angler catch rate. Among the alternatives, the estimated number of large trout was generally greatest under Alternative B and lowest under Alternatives F and G. Alternatives E, D, A, and C in descending order are expected to produce intermediate numbers of large trout. The modeled angler catch rates are greatest under Alternatives F and G because of their steadier flow regimes. Based on this analysis, it is anticipated that recreational angling use in the Glen Canyon Reach would be similar to the current situation under all alternatives and that angler satisfaction also would likely remain high, but satisfaction for some alternatives would be based on the size of fish, while that of others would be based on the number of fish.

Navigability and Wading Safety in the Glen Canyon Reach

The ability for boats to navigate freely within the Glen Canyon reach was an issue when low flows of 1,000–3,000 cfs occurred prior to 1996. All alternatives now include a minimum 5,000 cfs flow between 7 PM and 7 AM, and 8,000 cfs from 7 AM to 7 PM (with the exception of Alternative F, which has flows near or somewhat below 8,000 cfs all day during the summer, fall, and winter). The Navigation Index (Figure 4.10-1) is based on the amount of time flows are above 8,000 cfs. Alternatives B and E have lower Navigation Index values than Alternative A due to more frequent low flows. Alternatives C, F, and G are higher than Alternative A, and Alternative D is about the same as Alternative A.

Wading anglers are always at risk from swift water and from rapidly rising water levels, and anglers are urged to exercise caution. Specifically, rapidly increasing flow is a safety concern with respect to the ability of wading anglers to move toward shore. At least three drownings in 12 years preceding the 1995 EIS possibly were related to river stage or stage change (Reclamation 1995). Implementation of the MLFF protocol limiting up-ramp rates to 4,000 cfs/hr for all fluctuating-flow alternatives has reduced the potential safety concerns for wading anglers. An up-ramp rate of 5,000 cfs/hr proposed under Alternative B during tests of hydropower improvement flows could result in an adverse impact on safety of anglers due to rapidly rising water levels. With respect to HFEs, Reclamation and NPS would coordinate to ensure that safety measures are implemented during an HFE, including restricting access immediately below Glen Canyon Dam, and providing public notice about the timing of an HFE.

Each of the affected NPS units—GCNRA, GCNP, and Lake Mead National Recreation Area (LMNRA)—has clearly designated responsible parties, staffing needs, and actions that are required to occur prior to and during an HFE.

4.10.2.2 Glen Canyon Day Rafting

The 15-mi Glen Canyon reach hosts a large number of day rafters who use the pontoon-raft concession that departs from near Glen Canyon Dam and travels to Lees Ferry (Section 3.11.1.2). Bishop et al. (1987) established that day rafting participants express no preferences regarding either river flows or fluctuations. As a result, impacts on rafting use are related only to the occurrence of HFEs, which result in lost visitor recreation opportunities and lost revenue for the rafting concessioner. The variables influencing the level of impact are the number of HFEs and the time of year in which they occur. Spring HFEs have a greater impact than fall HFEs because visitor use is higher in the spring months. HFEs are scheduled only in October, November, March, and April, with the exception of proactive spring HFEs (under Alternatives C, D, and G), which can occur in April, May, or June.

Because of the high number of HFEs, Alternative F would have by far the greatest adverse impact on day-use rafting with an anticipated mean annual loss of about 919 visitor opportunities over the LTEMP period out of a typical annual total of 50,000 such trips expected over the LTEMP period. Alternatives G, D, C, and E would have the next largest adverse impacts with 512, 348, 315, and 177 mean annual lost visitor use opportunities, respectively. Alternatives A and B would be similar in their impact and would result in 49 and 71 mean annual lost visitor use opportunities, respectively (Figure 4.10-1).

4.10.2.3 Glen Canyon Recreational Facilities

Glen Canyon contains both high-elevation sediment terraces, which are remnants of larger terraces that existed prior to construction of Glen Canyon Dam, and lower elevation terraces, which are still affected by dam operations. Glen Canyon has six designated campsites with fire pits and bathrooms along its 15-mi stretch. These recreational facilities are generally located above the high-water level of normal dam operations; however, HFEs are the principal flow actions that could affect these campsites through erosion of terraces combined with an absence of sediment sources in the Glen Canyon reach for possible deposition and rebuilding of terraces. Alternative F would have the largest adverse impact on these facilities from the projected number of HFEs and annual spring floods (Table 4.2-1), followed by Alternatives G, C, D, E, B and A, in decreasing order. In addition, higher fluctuation levels, including during tests of hydropower improvement flows under Alternative B, could lead to increased campsite erosion relative to the other alternatives.

4.10.2.4 Whitewater Boating

The availability, size, and quality of campsites in Grand Canyon is an important resource for whitewater boaters. As discussed in Section 3.11-2, total campsite area has undergone a long-term downward trend due to sandbar erosion and vegetation growth, having decreased by 56% from 1998 to 2006 (Kaplinski et al. 2010). Generally, alternatives with more sediment-triggered HFEs are expected to result in greater campsite area, although flow and fluctuation levels as well as vegetation control will affect the maintenance of campsite area. Alternatives G and F show the highest potential to create and maintain campsite area based on Camping Area Index values (Figure 4.10-1). These are followed by Alternatives C, D, and E which have index values more than two times greater than those of Alternatives A and B.

River flow levels and fluctuations are important for whitewater boaters (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). The minimum daily flow levels of 5,000 cfs from 7 PM to 7 AM and 8,000 cfs from 7 AM to 7 PM provided by most alternatives are considered only minimally adequate for Grand Canyon boating. Transit times of morning flow increases to 8,000 cfs from 5,000 cfs overnight at the dam to downstream locations may delay the arrival of 8,000 cfs or higher desired at more challenging rapids. Such concerns would arise only in low-volume months, however, when minimum flow limits would be applied. Flows on most days under the fluctuating flow alternatives would exceed these limits. Steady flow Alternatives F and G could feature daily flows of 5,000 cfs for extended periods of time; however, only four occurrences of 5,000 cfs flows for a period of a month or more appeared in LTEMP 20-year hydrology simulations for Alternative F, and there were none for Alternative G. Extended low flows of 5,000 cfs would adversely affect navigability and trip management in GCNP because of a greater risk of boating incidents. Conversely, the normal steady flows of Alternatives F and G would offer benefits to river trip planning over the alternatives with fluctuating flows because river travel time and off-river time is more predictable. Commercial and private whitewater trip leaders reported (Bishop et. al. 1987) a preference for steady flows in the 20,000–26,000 cfs range. Alternative F approaches these levels in April through June, and thus would have higher perceived value to rafters than would Alternative G, which limits flows to near 12,000 cfs or less year round in 8.23-maf years.

The Navigation Index and the Fluctuation Index both address aspects of the impact of fluctuations on whitewater boating (Figure 4.10-1). Both indices are designed to produce values that increase in the direction of improved boating conditions. Thus, a higher Navigation Index value indicates that an alternative presents relatively lower navigation risks due to low flows (below 8,000 cfs), while higher Fluctuation Index values indicate that an alternative will have fluctuations more often within a preferred range for whitewater boating (Bishop et al. 1987). Alternatives G, F, and C have the highest values for both indices (indicating the best conditions), while Alternatives B and E had the lowest index values (indicating the worst conditions). Alternatives A and D have intermediate values for these two indices.

The Time Off-River Index values indicate there would not be much difference in time available for off-river activities between the alternatives, likely due to similar mean annual flows of between 10,000 and 15,000 cfs. Because the index does not provide a meaningful distinction among the alternatives, it will only be referenced in special circumstances in Section 4.10.3.

4.10.2.5 Lake Activities and Facilities

Recreation on Lakes Powell and Mead can be affected by water levels dropping below the level at which ramps and marinas can function. In the case of Lake Powell, the Castle Rock cut is also a critical feature. Although the lowest boat ramp elevations on Lake Powell are not all the same, 3,580 ft AMSL is representative of the level below which major access issues occur. The frequency at which lake elevations would be above 3,580 ft AMSL at the end of the month seasonally has been analyzed to determine whether there is any significant difference among the alternatives. The same has been done for Lake Mead using an elevation of 1,050 ft AMSL, the level to which the NPS has committed in order to keep marinas and launch ramps functional.

Simulations were performed of end of the month lake elevations by season (summer, winter, or spring/fall) for the 20-year lake level simulations using 21 hydrology traces for both lakes. For Lake Powell, with respect to the 3,580 ft AMSL reference level for boat access, approximately 22% of all simulated seasons showed at least one month with end of the month elevations at or below this level for all alternatives. There was very little difference among the alternatives; all alternative means fall between 21.75% for Alternative A and 22.86% for Alternative E. Such differences by alternative are likely due to small changes in elevation when lake elevation is near the 3,580-ft reference level.

The results for Lake Mead simulations were similar to those for Lake Powell, with a slightly greater range of results. Alternative B, with 22.78%, had the lowest percentage of seasons with at least 1 month at or below the reference elevation, and Alternative A, with 25.48%, had the highest. Differences by alternative are likely due to small changes in elevation when lake elevation is near the 1,050-ft reference level.

As discussed in Section 4.1.2.1, the elevations of Lake Powell and Lake Mead are more affected by annual variation in inflow than by alternative. The dominating effect of hydrology was also observed in the analysis of lake elevations with respect to lake access, with relatively small effects attributable to differences in alternatives.

4.10.2.6 Tribal Recreation Operations

The Hualapai Tribe operates recreational facilities in the Lower Gorge of Grand Canyon and their facilities and activities can be adversely affected by operation of the dam. The Hualapai have expressed concern over dam operations they believe are increasing the amount of sediment collecting in their operational area below Diamond Creek. Their primary operations are centered in and around the Quartermaster area (RM 260). They have reported adverse impacts on their commercial operations from river sediment, including turbidity effects on equipment, access to their docks, and navigation in the river. They are also concerned over the steep and unstable slopes previously inundated by Lake Mead that are now exposed due to lake levels retreating from the previous high-water line. The issues associated with the steep and unstable shorelines in the Lake Mead delta are related to the declining lake level, and will not be resolved until the level of Lake Mead either regains its previous high levels or until the banks naturally stabilize under new, lower lake levels. However, the number and duration of HFEs under the various alternatives could have an effect on boat docks and other facilities operated by the Hualapai Tribe.

It is expected that dam operations, HFEs, equalization flows, and other flow events will continue to deliver sediment to the Lower Gorge in Grand Canyon and Lake Mead. Nearly all sediment that enters the Grand Canyon below Lake Powell will eventually move downstream. Higher flows, in general, do transport more sediment, and sediment transport will continue in the free-flowing portions of the river below Diamond Creek.

Transport of sand downstream from sources in Marble Canyon (RM 0–RM 61) under various LTEMP alternatives is discussed in Section 4.2. The least amount of sand would be transported under Alternative A, primarily due to the cessation of the HFE protocol in 2020; HFEs are the major source of sand transport under the alternatives. Sand transport would be second lowest under Alternative D and greatest under Alternatives F and G. The estimated sand transport out of Marble Canyon is as much as 230% greater under the highest alternative (Alternative F) than under the lowest alternative (Alternative A). Although the percent difference between Alternative F and Alternative A is large, this difference is small in comparison to the overall system.

The amount of change in sand storage in Marble Canyon for Alternative A and Alternative F, when compared to the estimated annual sand load from the Paria River (approximately 830 ktons/yr), indicates that Alternative A will store 14% more sand from the Paria River annually compared to Alternative F. A similar comparison can be made to the annual sand flux that passes the USGS gage at RM 225, which is 35 river miles upstream of the Hualapai recreational facilities and 164 river miles downstream of Marble Canyon. The increase in sand that leaves Marble Canyon under Alternative F relative to Alternative A is 7% of the annual sediment flux at RM 225 (Appendix E). There is very little difference between alternatives in terms of sand transport to Hualapai recreational facilities and operations.

4.10.2.7 Pearce Ferry

As discussed in Section 4.9, park facilities at Pearce Ferry, managed by LMNRA, have been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects would vary among alternatives, and those with more frequent HFEs, particularly spring HFEs, may have more effects. There would be temporary impacts in the months following HFEs to both park operations and visitor access when there is damage until the takeout ramp is repaired. Damage in April–June (following a spring HFE) would have more effects on visitors than in November–January (following a fall HFE).

4.10.2.8 Park Operations and Management

As discussed in Section 3.10.4, potential effects on NPS staffing levels are related to recreation and resource concerns. For this analysis, staff levels were generally calculated as full-time equivalents, based upon known amounts of time currently dedicated to operational functions. To estimate the changes to staff levels that might be different among alternatives, an assumed relationship to a quantitative metric from modeling was used. For instance, if vegetation modeling indicated a 5% increase in nonnative invasive plants, it was assumed that there would be a 5% increase in the need for vegetation restoration work. Staff time for monitoring and maintenance of camping beaches and trails was estimated using the modeled Camping Area Index. Staff time related to special flows, such as HFEs or TMFs, was estimated based on the tracking of GCNRA and GCNP staff time for notification and coordination related to HFEs from 2011 to 2015. Flow patterns were looked at in terms of safety, and boating hazards and staff time for ranger patrols were analyzed, though this was looked at as trend information rather than quantitative contributions to the total as staff time for safety issues can vary greatly from year to year.

Another consideration that was evaluated was impacts on park facilities at Pearce Ferry, managed by LMNRA, as these facilities have been damaged in the past by HFEs and are likely to be damaged by HFEs in the future. Effects would vary between alternatives, as those with more frequent HFEs, particularly spring HFEs, may have more effects than those with fewer HFEs. There would be temporary impacts in the months following HFEs to both park operations and visitor access when there is damage, until the takeout ramp is repaired. Damage in April–June (following a spring HFE) would have more impact on visitors than damage in November–January (following a fall HFE).

Based on the analysis conducted, the maximum difference between action alternatives (B through G) and Alternative A was a 1.8 full-time equivalent decrease (Alternative D), and the maximum was an increase of 0.1 full-time equivalent (Alternative B). However, factors such as safety response and repairs at Pearce Ferry, which were considered but were not possible to quantify, did not vary in the same direction as the quantified effects. Therefore, the differences among alternatives may be less than indicated by the quantified effects. Based on this analysis, it was determined that the variation among alternatives for park staffing for recreation and resource concerns would be negligible.

4.10.3 Alternative-Specific Impacts

The following section provides descriptions of impacts that are expected to occur under each of the LTEMP alternatives.

4.10.3.1 Alternative A (No Action Alternative)

Under Alternative A, trout abundance, size, and catch rates are expected to vary within the ranges that have been observed under MLFF operations over the past 20 years. About

770 large trout (a number intermediate among the alternatives; large trout are defined as individuals exceeding 16 in. in length) would be expected under Alternative A, as well as intermediate levels of angler catch rates (Section 4.4.2.2). Therefore, under Alternative A overall angler satisfaction is anticipated to remain the same as at present, with a consistent trend in the fishery toward more, but smaller, fish. Alternative A is expected to result in the highest angler satisfaction of all alternatives, by a small margin (Section 4.14.2.1).

Alternative A would have fewer HFEs that might disrupt angling than other alternatives, and about 80% of the time daily fluctuations would remain in a range preferred by whitewater boaters (Figure 4.10-1). Navigational boating risks due to flows below 8,000 cfs under Alternative A, as reflected in the Navigation Index (Figure 4.10-1), would be about in the middle of those for all alternatives. The current MLFF maximum up-ramp rate of 4,000 cfs/hour under this alternative has been adopted for all DEIS alternatives and it is not anticipated that this ramp rate would create angler safety issues. The down-ramp rate of 1,500 cfs is the same as the current rate and also does not create issues for anglers.

Because this alternative only allows for HFEs until 2020 and has the fewest total number of HFEs, Alternative A scores the best among alternatives in the Glen Canyon Rafting Metric, with a projected mean annual loss of only 49 visitor rafting trips (Figure 4.10-1), compared to a total mean annual visitor use of 50,000 visitors. This is a 0.01% reduction. In addition, the lower number of HFEs would result in the lowest anticipated impact on the sediment terraces and the recreational resources they support.

Having the lowest mean number of HFEs over the LTEMP period, Alternative A has among the lowest potential for increasing campsite area of all alternatives (Figure 4.10-1). Based on observed effects under the current MLFF operating regime, this alternative is expected to lead to a continued loss of campsite area due to erosion and increased campsite crowding.

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative A, including mechanical removal of trout in the Little Colorado River reach and testing TMFs. Mechanical trout removal activities are intensive activities that can last many days and over a period of several months (Reclamation 2011a). Mechanical trout removal activities would have a short-term impact to visitor experience from motorized use. Based on modeling of trout numbers, there is a low probability that this activity will occur under Alternative A during the LTEMP period. TMFs are intended to decrease trout abundance, which might reduce angler catch rate, but could also result increasing the number of larger fish in the fishery in the Glen Canyon reach. Under this alternative, TMFs would be tested but not implemented.

In summary, there would be little change from current conditions under Alternative A. Alternative A would have the fewest HFEs (ending in 2020), and moderate flow fluctuations. Anglers would expect to see intermediate numbers of large trout and intermediate catch rates. Few navigability concerns from low flows would occur. Concerns for angler safety from high up-ramp rates would be low. Alternative A would have the fewest lost rafting trips resulting from HFEs. Ongoing loss of camping area would continue, leading to increased crowding. There would be very little interference with recreation from testing and implementing experimental elements under the alternative.

4.10.3.2 Alternative B

Of all the alternatives, Alternative B has the lowest estimated number of rainbow trout and trout emigrants in the trout fishery below Glen Canyon Dam, but it has the greatest estimated number of large rainbow trout (>16 in.), about 870 fish. Hydropower improvement flows would be expected to result in even lower trout abundance and emigration and an increase in the numbers of large trout (Section 4.4.3.2). Angler catch rates would be the lowest of all alternatives because of the relatively low number of trout under this alternative. Alternative B is expected to have angler satisfaction similar to that under Alternative A and all other alternatives, except Alternative F, which would have somewhat reduced satisfaction due to high flows in peak fishing months (Section 4.14.2.1).

High daily fluctuations and sharp down-ramp rates as high as 4,000 cfs/hour, compared to a maximum of 1,500 cfs/hour under Alternative A, result in relatively low navigability due to more frequent flows below 8,000 cfs (Figure 4.10-1).

Alternative B is expected to have slightly more HFEs than Alternative A; there would be a mean of 7.5 versus 5.5 during the 20-year LTEMP period (Table 4.2-1), resulting in an anticipated mean loss of 71 annual Glen Canyon day-rafting opportunities for this alternative (Figure 4.10-1). This represents a negligible impact in terms of fewer visitors/year in comparison to Alternative A. The estimated annual visitor use total is about 50,000.

Under Alternative B, due to the slightly higher number of HFEs during the LTEMP period, there is a slightly increased likelihood of additional impacts on sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

Alternative B is expected to result in slightly more camping area than Alternative A (Figure 4.10-1) due to a higher number of HFEs, but there would be a continued declining trend in campsite area due to high flow fluctuations. Total number of campsites and campsite area would continue to decrease under Alternative B, potentially increasing competition and crowding at campsites. Usable campsite area would be further restricted by high daily fluctuations, which limit campsites to areas above the highest water level.

As stated above, daily fluctuations under Alternative B would be greater than under any other alternative. In addition, the down ramp rate is 2 to 2.6 times higher than under Alternative A, which could lead to boats being stranded in both GCNRA and GCNP resulting in a minor adverse impact on boating associated with the level of river fluctuations.

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative B, including mechanical removal of trout in the Little Colorado River reach, testing and implementing TMFs, and testing hydropower improvement flows in 4 years during the LTEMP period when annual volume is ≤8.23 maf (Section 2.3.2).

The impacts of mechanical trout removal activities would be similar to those described under Alternative A; however, based on modeling of trout numbers there is a low probability that this activity will be triggered under Alternative B during the LTEMP period.

TMFs are expected to be triggered relatively infrequently under this alternative (mean of three TMFs triggered over the 20-year LTEMP period); therefore the overall impact of TMFs on recreation is expected to be minimal. TMFs are intended to decrease trout abundance in the fishery in the Glen Canyon reach, which could result in a reduced angler catch rate but could also increase the number of larger fish.

Tests of hydropower improvement flows in 4 years when annual volume is ≤8.23 maf would more closely resemble the operations at Glen Canyon Dam prior to the early 1990s, and would produce daily fluctuations up 20,000 cfs (5,000 cfs nighttime to 25,000 cfs daytime). The daily minimum flow would be 5,000 cfs and the up- and down-ramp rates would each be 5,000 cfs/hr. High ramp rates, when combined with the overall level of fluctuations under Alternative B, would create additional difficulties in navigating rapids and managing boats tied to shore. In the 1995 EIS (Reclamation 1995), rapidly increasing flow was identified as a safety concern for wading fishermen with respect to their ability to move toward shore. This pattern of river fluctuations and high daytime flows would also adversely affect fishing and usable campsite area.

In summary, Alternative B would have the second fewest HFEs and the greatest flow fluctuations; the former would result in relatively few days that would disrupt angling and boating from river closings, similar to Alternative A, and the latter would result in reduced whitewater boater satisfaction due to high daily fluctuations compared to Alternative A. The number of large trout would be highest of all alternatives, but catch rates lowest. Navigability and boat stranding concerns would be the greatest of all alternatives due to high fluctuations and high down-ramp rates, but relatively low overall. Few lost rafting trips due to HFEs would occur, similar in number to Alternative A. Camping area is expected to continue to decrease due to erosion, similar to Alternative A. Interference with recreation from testing and implementing experimental elements would be low and similar to that under Alternative A, with the exception of hydropower improvement flows, which would produce greater impacts than under Alternative A.

4.10.3.3 Alternative C

Under Alternative C, about 750 large trout are predicted to be present below Glen Canyon Dam, similar to the number under Alternative A (770); angler catch rates would be similar to those under Alternatives A, D, and E, more than under Alternative B and less than under Alternatives F and G. Angler satisfaction under this alternative is estimated to be slightly lower than those under Alternative A and similar to those under all other alternatives except Alternative F, which would have the lowest expected satisfaction due to high flows during peak fishing season (Section 4.14.2.1).

Within the 20-year LTEMP period, Alternative C is expected to have more HFEs (21) than Alternative A that would disrupt angling and boating. Conversely, a low frequency of flows below 8,000 cfs results in good navigation (Figure 4.10-1), exceeded only by Alternative G. The down-ramp rate is 1.7 times that under Alternative A, but it is not expected to create an issue for anglers.

The more frequent HFEs under this alternative would result in an estimated 315 lost day-rafting visitor opportunities (Figure 4.10-1) as compared to a loss of 49 such opportunities under Alternative A. In addition, under Alternative C, the larger mean number of HFEs is expected to result in erosion of sediment terraces from wetting and undercutting in the Glen Canyon reach that support recreation facilities and campsites.

Because of the relatively high number of HFEs and moderate fluctuations under Alternative C, it has a relatively high probability of producing an increase in campsite area relative to Alternatives A, B, and E (Figure 4.10-1) resulting in a beneficial effect to the visitor experience. HFEs could adversely affect Hualapai recreational facilities in the western Grand Canyon.

In addition to sediment-triggered spring and fall HFEs, there are several experimental elements featured in Alternative C, including proactive spring HFEs, extended duration HFEs, mechanical removal of trout in the Little Colorado River reach, testing and implementing TMFs, and testing and implementing low summer flows.

Implementing proactive spring HFEs and longer duration HFEs would disrupt day-rafting operations and cause a small increase in lost visitor opportunities and loss of concessioner revenue, as well as disruption of visitor trip schedules. Proactive spring HFEs have potential to conserve sediment and might slightly increase or help maintain camping area over the long term. Mechanical trout removal activities would be triggered infrequently and would limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate, but could also result in an increased number of larger fish in the Glen Canyon reach. TMFs are expected to be triggered six times during the 20-year LTEMP period under Alternative C, compared to no TMFs under Alternative A (Table 4.8-2).

The impacts of testing low summer flows would vary depending on the level of flows and the number of years they are employed. Flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, and potentially more difficult navigation.

In summary, Alternative C would have almost 4 times the number of HFEs as Alternative A, but lower daily fluctuation levels. The number of larger trout and trout catch rates would be similar to Alternative A. Few navigation concerns would exist, similar to Alternative A. However, the number of lost rafting trips due to HFEs would be about 6 times that of Alternative A, but still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, while continued reduction is expected under

Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.4 Alternative D (Preferred Alternative)

Under Alternative D, an estimated 810 large trout are predicted to be present in the trout fishery below Glen Canyon Dam, with angler catch rates similar to those under Alternatives A, C, and E; this would be more than under Alternative B, and less than under Alternatives F and G. Angler satisfaction under Alternative D would be similar to that under Alternative A and all other alternatives except Alternative F, which would have somewhat reduced angler satisfaction due to high flows during peak fishing season.

With an estimated 21 HFEs within the 20-year LTEMP period (Table 4.2-1), Alternative D would disrupt angling and boating more often than would Alternative A, with a mean of 5.5 HFEs. Daily flow fluctuations and daily minimum flows that may affect navigability under Alternative D are similar to those under Alternative A (Figure 4.10-1).

Restricted boating during HFEs under this alternative would result in an estimated 348 lost day-rafting visitor opportunities (Figure 4.10-1). This is an increase of about 290 over that under Alternative A. In addition, more frequent HFEs under Alternative D compared to Alternative A are expected to result in relatively greater erosion of sediment terraces due to wetting and undercutting the Glen Canyon reach that supports recreation facilities and campsites.

Because of the relatively high number of HFEs and moderate fluctuations, Alternative D is expected to benefit campsite area—as reflected in the Camping Area Index—more than Alternatives A, B, and E, and less than Alternatives C, F, and G (Figure 4.10-1). However, the relatively high number of HFEs could adversely affect Hualapai recreational facilities in the western Grand Canyon.

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative D that could produce short-term effects on recreation; these include proactive spring HFEs, extended duration HFEs, mechanical removal of trout in the Little Colorado River reach, testing and implementing TMFs, and testing and implementing sustained low flows to improve benthic invertebrate production and low summer flows to improve recruitment of humpback chub. Although the direct effects on recreation of these experimental elements generally occurs from disruption of day-rafting over the duration of the experiment, long-term indirect benefits for recreation may accrue from the adoption of successful treatments, including potentially improved campsite area and improved aquatic food base that supports the trout fishery.

Implementing a proactive spring HFE and longer duration HFEs would disrupt day-rafting operations, cause a temporary increase in lost visitor opportunities, disrupt visitor trip schedules, and result in a loss of concessioner revenue. Proactive spring HFEs have potential to conserve sediment and slightly increase or help maintain camping area over the long term.

Mechanical trout removal activities, although triggered infrequently, might limit visitor access to portions of the river for several days over several months when they occur.

TMFs are intended to decrease trout abundance, which might reduce angler catch rate; however, it could also result in an increased number of larger fish in the fishery in the Glen Canyon reach. Such effects would be expected to be fairly short term due to the dynamic nature of the fishery. TMFs are expected to be triggered in 4 years over the 20-year LTEMP period, compared to no TMFs under Alternative A (Table 4.8-2).

Low summer flows would be tested only twice and only in the second 10 years of the 20-year LTEMP period. Flows of 8,000 cfs or less would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by commercial rafters and fishing guides because of low flows. Testing sustained low flows to improve benthic invertebrate production would similarly involve steady flows on every weekend from May through August (34 days total). The flow on weekends would be held to the minimum flow for that month. Testing would not be conducted in the first 2 years of LTEMP. Effects on recreation would be similar to those for low summer flows.

In summary, Alternative D would have almost 4 times the number of HFEs as Alternative A and similar daily fluctuation levels. The number of larger trout and trout catch rates would be similar to Alternative A. Few navigation concerns would exist, similar to Alternative A. However, the number of lost rafting trips due to HFEs would be about seven times that of Alternative A. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.5 Alternative E

Alternative E is expected to result in an estimated number of rainbow trout and trout emigrants near the low end of alternatives and similar to Alternative A, with the second-highest expected number of large rainbow trout (about 830 fish) in the trout fishery below Glen Canyon Dam after Alternative B (Section 4.4.3.3). Angler catch rates similar to those under Alternative A would be expected. Angler satisfaction under Alternative E is projected to be similar to that under Alternative A and under all other alternatives except Alternative F, which has somewhat reduced expected satisfaction due to high flows during peak fishing season.

Under Alternative E, there would be an estimated 17 HFEs that would disrupt angling and boating, an intermediate number among the alternatives. The down-ramp rate of this alternative is 1.7 times that of Alternative A, but it is not expected to create an issue for anglers. The Fluctuation Index (Figure 4.10-1) indicates that whitewater rafting satisfaction would be lower than under all other alternatives except Alternative B, while the Navigation Index (Figure 4.10-1) is lower than all other alternatives except Alternative B.

The more frequent HFEs under this alternative would result in a small impact and would result in an estimated 177 lost day-rafting visitor opportunities (Figure 4.10-1), an increase of 146 over Alternative A. In addition, under Alternative E, the larger mean number of HFEs is expected to result in an increase in adverse impacts on sediment terraces in the Glen Canyon reach that supports recreation facilities and campsites, compared to Alternative A.

Because of the relatively high number of HFEs under Alternative E, this alternative is expected to benefit campsite area (Figure 4.10-1) more than Alternatives A and B, but somewhat less than Alternatives C, D, F and G. However, HFEs could adversely affect Hualapai recreational facilities in the western Grand Canyon.

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative E, including mechanical removal of trout in the Little Colorado Reach, testing and implementing TMFs, and testing low summer flows in the second 10 years of the LTEMP period.

The impacts of mechanical removal of trout in the Little Colorado reach would be similar to those described under Alternative A. Overall, there is a low probability that this action would be triggered during the LTEMP period based on the expected number of trout in the Little Colorado River reach. The impacts of TMFs, estimated to occur in 3 of 20 LTEMP years, would be the same as discussed for Alternative B.

The impacts of testing low summer flows would be the same as discussed under Alternative C. When they are tested, summer flows of 8,000 cfs would result in a short-term increase in available camping area, a decrease in rafter time off river for exploration, potentially more difficult navigation, and potential loss of business by fishing guides due to angler perception of less-desirable fishing conditions.

In summary, Alternative E would have 3 times as many HFEs as Alternative A and similar daily fluctuations. The number of large trout would be higher than under Alternative A, while catch rates would be similar. Few navigation concerns would exist, but slightly more than under Alternative A. The number of lost rafting trips due to HFEs would be 3 to 4 times that of Alternative A, but still a small fraction of total rafting trips. Camping area is expected to increase somewhat due to the effects of HFEs, compared to an expected reduction under Alternative A. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.10.3.6 Alternative F

The steady daily flows of Alternative F are expected to result in higher numbers of trout and increased angler catch rates, but the lowest number of large trout of all alternatives (600 fish). In addition, this alternative does not include any trout management actions (i.e., mechanical removal and TMFs). Overall angler satisfaction under Alternative F, however, is anticipated to be lowest of all alternatives due to high flows during peak fishing season (Section 4.14.2.1). In addition, Alternative F has the highest number of HFEs (39) of all alternatives, including a 1-day HFE in early May in all years without a sediment-triggered spring HFE and an annual 7-day 25,000-cfs flow at the end of June that would occur during prime fishing months, which would also adversely impact fishing.

With most daily flows near or above 8,000 cfs, navigability is expected to be relatively high (Figure 4.10-1). Thus, conditions are anticipated to be satisfactory for boaters most of the time, except during HFEs. An anticipated mean annual loss of 919 day-use rafting opportunities due to HFEs (Figure 4.10-1) is the largest such loss of any alternative and about 20 times that of Alternative A. In addition, the large number of HFEs in Alternative F would tend to increase erosion of sediment terraces in the Glen Canyon reach that support recreation facilities and campsites.

With a high number of HFEs and steady monthly flows, Alternative F has a high likelihood of benefitting campsite area (Figure 4.10-1). Steady daily flows would result in predictable availability of campsites. However, usable campsite area would be reduced somewhat compared to Alternative G, due to high seasonal flows in March through June under Alternative F. Overall, the alternative would benefit total campsite area. However, the relatively high number of HFEs could adversely affect Hualapai recreational facilities in the western Grand Canyon.

There are no experimental elements in this alternative, other than HFEs, that could affect recreation.

In summary, Alternative F would have the greatest number of HFEs of all alternatives. The fewest large trout are expected under this alternative, but highest catch rates. Very few navigability concerns would exist from low flows and no safety or convenience concerns from daily fluctuations. However, the most lost rafting trips due to HFEs would occur, about 20 times the number under Alternative A. Alternative F is expected to be the second most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. It would have no interference with recreation from testing and implementing experimental actions beyond those related to HFEs.

4.10.3.7 Alternative G

With regard to Glen Canyon angling, Alternative G would have the second-lowest number of large trout (700 fish), but trout abundance and angler catch rates would be high. Angler satisfaction under this alternative is expected to be slightly less than that under Alternative A and similar to that under all other alternatives, except Alternative F, which is expected to result in somewhat reduced angler satisfaction due to high flows during peak fishing season (Section 4.14.2.1).

The steady monthly flows under Alternative G would be consistently within the preferred range for anglers, near 10,000 cfs, and few daily flows below 8,000 cfs reflect high navigability under Alternative G (Figure 4.10-1).

The relatively high number of HFEs under this alternative would result in an anticipated annual loss of 512 visitor rafting opportunities over the LTEMP period (Figure 4.10-1); more than 10 times larger than under Alternative A. The number of HFEs would result in a higher tendency to erode sediment terraces that support recreation facilities and campsites compared to all alternatives but Alternative F.

Because of the high number of HFEs under Alternative G, and its steady monthly and daily flows, it has the highest likelihood of any alternative of benefiting total campsite area (Figure 4.10-1). Because Alternative F has lower flows in summer and fall months, that alternative may result in greater useable camping area during those months than under Alternative G. Thus, the two alternatives may be considered equals with respect to campsite crowding.

In addition to sediment-triggered spring and fall HFEs, several experimental elements are featured in Alternative G, including proactive spring HFEs in April, May, or June; extended-duration HFEs; mechanical removal of trout in the Little Colorado Reach; and testing and implementation of TMFs.

Implementing a proactive spring HFE and extended-duration HFEs would disrupt day-rafting operations, cause a small temporary increase in lost visitor opportunities, disrupt visitor trip schedules, and result in a loss of concessioner revenue. Proactive spring HFEs have the potential to conserve sediment and slightly increase or help maintain camping area over the long term. Relatively frequent HFEs could impact Hualapai recreational facilities in the western Grand Canyon.

The impacts of mechanical trout removal activities would be similar to those described under Alternative A. Based on the expected number of trout in the Little Colorado River reach, Alternative G has an estimated three such removals, the greatest number triggered during the LTEMP period of all alternatives (Table 4.8-2).

The impacts of testing and implementing TMFs would be similar to those described for Alternative B. Based on the anticipated higher trout recruitment levels, Alternative G is expected trigger TMFs in 11 of 20 LTEMP years (Table 4.8-2), the highest number of all alternatives.

In summary, Alternative G would have fewer large trout than Alternative A, but catch rates would be higher. Very few navigability concerns would exist from low flows and no safety or convenience concerns from daily fluctuations. There would be about 10 times more lost rafting trips due to HFEs than under Alternative A. Alternative G is expected to be the most beneficial of all alternatives with respect to increasing camping area due to the effects of HFEs and reduced erosion. Interference with recreation from testing and implementing experimental elements would be greater than under Alternative A.

4.11 WILDERNESS

This section presents the potential impacts on wilderness and visitor wilderness experience. Background information on the wilderness qualities evaluated in this analysis appears in Section 3.15. There are also references to Section 4.10, Visitor Use and Experience.

> **Issue:** How do the alternatives affect wilderness and visitor wilderness experience?
>
> **Impact Indicators:**
>
> - Opportunities for solitude at campsites and on the river
> - Preservation of natural conditions as reflected by naturalness of flow
> - Rafters' time available for onshore exploration
> - Visual and noise disturbances from administrative uses

4.11.1 Analysis Methods

The analysis of impacts on wilderness and visitor wilderness experience downstream of Glen Canyon Dam was based on an assessment of alternative-specific differences in four indicators of the quality of visitor wilderness experience: opportunities for solitude at campsites and on the river; preservation of natural conditions as reflected by naturalness of flow; opportunities for experiencing wilderness as indicated by the amount of time rafters have for exploration; and visual and noise disturbances. These indicators are evaluated qualitatively and comparatively as they relate to the differing properties or features of the seven alternatives.

The effects of the alternatives on campsite crowding and its effect on visitor wilderness experience was evaluated through consideration of the tendency of flow patterns and experimental flows (mainly HFEs) under the various alternatives to build beaches and thus potentially increase campsite area. The likelihood of rafters encountering other groups at rapids was evaluated based on the expected frequency of daily flows less than 8,000 cfs, a flow level associated with rafting delays at rapids as rafters scout conditions or wait for higher flows. Flows of 8,000–9,000 cfs have been identified by commercial guides as the minimum level necessary to safely run the river with passengers (Bishop et al. 1987; Stewart et al. 2000).

The naturalness of flows was evaluated by determining the magnitude of daily flow fluctuations under alternatives as compared to fluctuation levels perceived to be less natural, generally greater than 10,000 cfs as identified by Bishop et al. (1987). Stewart et al. (2000) found that daily fluctuations of 5,000–8,000 cfs under MLFF were not an issue for most recreational use, but they did not address fluctuations above 10,000 cfs. Opportunities for rafters to explore attraction sites or enjoy personal time at camp were evaluated by determining the effects of flow on river travel duration and the amount of off-river time available each day. Finally, the effects of noise and visual disturbance of wilderness values was evaluated by considering the number of HFEs, TMFs, trout removals, and the relative number of administrative trips expected under the alternatives.

The metrics described in Section 4.10 were used as input to the evaluation of effects on wilderness experience. The potential for beach building used the Camping Area Index to evaluate the effects of campsite availability and size on potential crowding and opportunities for solitude (Figure 4.10-1a); the Navigation Risk Index was used to evaluate potential crowding at rapids (Figure 4.10-1d); the Fluctuation Index was used to evaluate the naturalness of flows(Figure 4.10-1c); and the Time-Off-River Index was used to evaluate the opportunity for onshore exploration (Figure 4.10-1b). The effects of HFEs, TMFs, trout removal, and other experimental actions were evaluated from estimates of the expected frequency of such actions for the alternatives. Using these metrics and supporting information, it was possible to rank the alternatives with respect to their relative effects on associated wilderness values. The details of the methodology used to produce metric values and detailed results are presented in Appendix J.

4.11.2 Summary of Impacts

In Section 3.15, wilderness character is described as having four qualities: untrammeled, natural, undeveloped, and providing for outstanding opportunities for solitude or a primitive and unconfined form of recreation. In describing the wilderness values and visitor experiences within GCNP that are to be preserved and protected, GCNP's General Management Plan states that "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).

Dam operations and management activities considered under LTEMP alternatives can affect these wilderness values and the quality of the wilderness river experience for river visitors. As dam operations affect beach retention or building, operations under the alternatives can affect campsite crowding and solitude. Similarly, low daytime flows less than 8,000 cfs can increase crowding at rapids. Although these are conceivable effects on wilderness experience and have been modeled for the alternatives, such effects would detract only slightly from an overall wilderness experience in the study area, and differences in the effects of alternatives would be difficult to discern.

Wilderness experience may also be affected by high daily fluctuations that appear to be greater than what would occur naturally. Fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river (Bishop et al. 1987). TMFs and HFEs would also present less natural conditions to visitors. However, daily fluctuations under MLFF and the proposed alternatives are generally constrained to near or less than 10,000 cfs and thus would have at most a small effect on perceptions of naturalness, differences in which would be difficult to discern among fluctuating flow alternatives; the steady flow Alternatives F and G would have no such effects.

Overall flow level can also affect the wilderness experience through effects on the duration of rafting trips and thus the time available for onshore exploration. However, because there is little difference among the alternatives in time off river (Figure 4.10-1b), this measure is not discussed further in this analysis.

Finally, resource management actions, (i.e., administrative actions) including experimental vegetation restoration under all alternatives but Alternative A; mechanical removal of trout, which is allowed under some alternatives; and other experimental work and administrative trips common to all alternatives can affect visitor experience by increasing encounter rates, placement and use of equipment, and noise from motorized equipment. Such effects would be infrequent and short term and would affect relatively few visitors. Vegetation actions, even though they would conform to minimum tool use requirements, may have short-term negative effects during disturbance but long-term positive effects on wilderness by returning native vegetation and hence wilderness character. Effects on wilderness experience of the LTEMP alternatives are summarized and compared in Table 4.11-1 and analyzed in the discussions that follow.

Campsite crowding has been reduced since the implementation in 2006 of the CRMP (NPS 2005a), but campsite area and campsite size was decreasing (Kaplinski et al. 2010) prior to adoption of the HFE protocol in 2011 (Reclamation 2011b). Alternatives that do not reverse the trend of loss in campsite area eventually would have an adverse effect on wilderness qualities because of increases in crowding at remaining campsites. On the basis of the number of HFEs anticipated under each of the alternatives (Section 4.3), Alternatives F and G are expected to result in the greatest benefit to visitor wilderness experience with respect to opportunity for solitude, because of a greater likelihood of increasing and retaining campsite area (Section 4.10.2). Alternatives C, D, and E rank just below Alternatives F and G, while Alternatives A and B rank lowest with regard to camping area as a consequence of having the fewest HFEs. Under Alternative A (the No Action Alternative), HFEs would not be implemented after the HFE protocol expired in 2020.

On the basis of allowable within-day fluctuation, Alternatives B and E would have more frequent occurrences of very low flows (about 60% of days), including in the periods of peak recreational use, and therefore would tend to result in more crowding at rapids as rafters stop to scout rapids or wait for flows to rise. Alternatives D and A would be similar to each other and comparable to current conditions (about 50% of days with low flows), while Alternatives F, C, and G would have the fewest days with low flows (about 5% to 30% of days), and would result in the lowest chances of encountering other groups. Although these comparisons are easily made on the basis of the flow patterns of the alternatives, the actual effects on crowding at rapids may be small overall, and small differences noted between alternatives may not be significant.

Daily flow fluctuations in excess of 10,000 cfs have been identified as creating less natural conditions on the river. The effect of such flow fluctuations on wilderness experience was evaluated using the fluctuation index (Section J.2.3 in Appendix J) developed from maximum “tolerable” fluctuations preferred by whitewater rafters (Table 3.10-2), which are generally less than 10,000 cfs and depend on overall flow level (Bishop et al. 1987). The fluctuation index is presented in Section 4.10, where it is used to evaluate effects of fluctuations on whitewater rafting. It is used here as a surrogate for effects on perceived natural conditions in the Grand Canyon. Alternatives F and G, which employ steady flows, have fluctuation index values near 1.0, indicating no within-day fluctuations. Fluctuating flow Alternatives A, C, and D would be similar to each other, with most fluctuations within the preferred range; they would have fluctuation index values of 0.79, 0.93, and 0.74, respectively. Alternatives B and E would

TABLE 4.11-1 Summary of Impacts of LTEMP Alternatives on Wilderness Experience

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions. Declining camping area following cessation of HFEs would reduce opportunity for solitude; intermediate effects on crowding at rapids and levels of fluctuations; lowest disturbance from experimental actions.	Relative to Alternative A, similar decline in camping area, somewhat more crowding at rapids, greatest level of fluctuations, greater disturbance from non-flow actions, especially under experimental hydropower improvement flows.	Relative to Alternative A, reversal of camping area decline, somewhat less crowding at rapids, lower level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, similar crowding at rapids, similar level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, most crowding at rapids, higher level of fluctuations, greater disturbance from non-flow actions.	Relative to Alternative A, reversal of camping area decline, less crowding at rapids, no fluctuations, greater disturbance from non-flow actions, but no mechanical removal of trout.	Relative to Alternative A, greatest reversal of camping area decline, least crowding at rapids, no fluctuations, greater disturbance from non-flow actions.
Campsite crowding as indicated by the camping area index (CAI)	No change from current conditions; lack of HFEs after 2020 would lead to continued declining size and number of campsites and could result in further crowding and adverse effects on solitude; CAI = 0.14 out of 1.	Relatively few HFEs and large fluctuations could result in continued declining trend in campsite area, and could result in crowding and adverse effects on solitude similar to Alternative A; CAI = 0.15.	More frequent HFEs and lower fluctuations could increase campsite area, reduce crowding, and improve solitude compared to Alternative A; CAI = 0.38.	Similar to Alternative C; CAI = 0.36.	More frequent HFEs than Alternatives A and B, but fewer than other alternatives. Higher fluctuations than all but Alternative B. Combination would result in an increase in campsite area relative to Alternatives A and B, but lower than other alternatives; CAI = 0.30.	The combination of frequent HFEs and steady seasonally adjusted flows are expected to result in an increase in campsite area and reduction in campsite crowding compared to Alternative A. Steady flows also aid trip planning, helping to avoid crowding; CAI = 0.41.	The combination of frequent HFEs and steady year-round flows are expected to result in the largest increase in campsite area and least campsite crowding of all alternatives. Steady flows also aid trip planning, helping to avoid crowding; CAI = 0.45.

TABLE 4.11-1 (Cont.)

Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Encounters with other groups at rapids due to low flows (8,000 cfs) as indicated by the navigation index (NI)	No change from current conditions; intermediate rank among alternatives; NI = 0.50 out of 1.	More encounters than Alternative A; NI = 0.39.	Fewer encounters than Alternative A; NI = 0.75.	Similar effect as Alternative A; NI = 0.45.	Most encounters due to highest frequency of low flows; NI = 0.37.	Fewer encounters than Alternative A because steady flows mostly above 8,000 cfs; NI = 0.71.	Fewest encounters because of steady flows nearly always above 8,000 cfs; NI = 0.96.
Effect of daily fluctuations as indicated by the fluctuation index (FI)	No change from current conditions; intermediate effect among alternatives, FI =0.79 out of 1	Highest effect, FI = 0. 42 .	Almost no effect, FI = 0.93	Similar to Alternative A, FI = 0.74	Second-highest effect, FI = 0.57.	No effect; steady daily flows, FI = 1.0	No effect; steady daily flows, FI = 0.98
Disturbance from non-flow actions: vegetation management, mechanical removal of trout, and administrative trips	No change from current conditions; no vegetation restoration actions, few mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions; and few mechanical removals of trout.	Higher effects than Alternative A, due to vegetation restoration actions and potentially more mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions and more mechanical removals of trout.	Higher effects than Alternative A due to vegetation restoration actions and potentially more mechanical removals of trout.	Lower effects than Alternative A due to absence of mechanical removals of trout, but greater effects due to vegetation restoration actions.	Higher effects than Alternative A due to vegetation restoration actions and more mechanical removals of trout.

have the lowest fluctuation index values, indicating the lowest frequency of fluctuations within the preferred range (Figure 4.10-1). Alternative D would include testing of sustained steady flows for invertebrate production during weekend days from March through August, and these steady flows would reduce any impacts of fluctuations on wilderness experience on those days. Because most daily fluctuations under all alternatives are below the 10,000-cfs level (flows ≥10,000 cfs were identified as being perceived as less natural by Bishop et al. 1987), the fluctuation index, which was developed for whitewater rafting for effects of fluctuations on such factors as navigation and camping, is not a perfect surrogate for evaluating perceived naturalness of flows. Visitors would be expected to notice that high daily fluctuations are not natural; however, the overall effects of such perceptions on wilderness experience are likely fairly small.

A metric (time off river) was developed to quantify the relative amount of time rafters would have to explore and enjoy wilderness at the end of each day (Section 4.10.1). Roberts and Bieri (2001) demonstrated that groups spent 50% less time off river at a flow of 8,000 cfs, compared to a flow of 19,000 cfs. Evaluation of the flow patterns of the LTEMP alternatives demonstrated that there would be very little difference among alternatives for this metric, except under Alternative F, which has elevated flows during the peak boating season. This similarity among alternatives is likely due to the fact that each has similar mean annual flows of between 10,000 and 15,000 cfs.

Non-flow experimental actions, including mechanical removal of trout, experimental vegetation restoration activities, and administrative trips related to monitoring and data collection needed for the GCDAMP. Mechanical removal trips would also present less natural conditions to visitors related to noise and visual disturbances. Vegetation restoration activities, proposed by NPS as an experimental, pilot effort to determine the effectiveness of vegetation control and restoration efforts, would occur under all alternatives except for Alternative A. They would temporarily adversely affect wilderness experience while the activities were ongoing and until restoration activities were discontinued, either because they had achieved a level of success that produced natural vegetation communities, or because they were ineffective.

Alternative A would have the lowest impacts from non-flow experimental actions, because vegetation restoration is not included in the alternative. Alternative F would have impacts that were slightly higher than Alternative A, but lower than the remaining alternatives, because this alternative does not employ mechanical trout removal. Alternatives B, C, D, E, and G would have the highest levels of such impacts, which would be comparable under these alternatives.

Considering the effects of flow fluctuation overall, the steady flow Alternatives F and G would rank as having generally lower adverse effects on wilderness experience than the fluctuating flow alternatives, because the latter alternatives have effects on a daily basis. This advantage is reduced somewhat, but not entirely, by the higher frequency of HFEs under Alternative F and of HFEs and TMFs under Alternative G as compared to the fluctuating flow Alternatives A–E. Of the fluctuating flow alternatives, Alternative A would have the lowest effects from fluctuating flows due to moderate daily fluctuations, few HFEs, and no TMFs. Alternatives B, C, D, and E would have comparable effects from fluctuations, with Alternative B having the greatest effect from high daily fluctuations, but the fewest HFEs of these alternatives.

Considering sand retention and potential increase in sandbar area, which is also an effect of flows and flow fluctuations, benefits related to sand retention and increases in sandbar area would be lowest under Alternatives A and B, which would have relatively few HFEs that would build bars and relatively high fluctuating flows that would erode bars. Benefits would be intermediate under Alternatives C, D, and E, which have more HFEs to build sandbar area than Alternatives A and B. Benefits would be greatest under Alternatives F and G, which would have steady flows and the most frequent HFEs. Crowding and loss of solitude would decrease with increasing sandbar area.

While the metrics discussed above provide an analytical tool to evaluate and differentiate the LTEMP alternatives with regard to effects on visitor wilderness experience, actual differences for most visitors would be small and many of the disturbances evaluated—including HFEs, TMFs, mechanical trout removals, and vegetation management—would be infrequent, short-term actions that would not affect most visitors. In addition, few visitors would be expected to experience more than one of these disturbances, as a given action of one type typically excludes the other actions at a given time (e.g., a TMF would not occur at the same time as an HFE or likely within the time period of a single trip).

4.11.3 Alternative-Specific Impacts

The following Section provides descriptions of impacts summarized above as they are expected to occur under each of the LTEMP alternatives. The alternatives are compared in terms of the relative rankings of the various wilderness experience effects and measures considered, rather than in absolute terms.

4.11.3.1 Alternative A (No Action Alternative)

Under Alternative A (the No Action Alternative), the HFE protocol would expire in 2020. It is expected that implementation of the protocol up to its expiration would help reverse the ongoing trend of declining campsite area, but the declining trend would resume after the protocol expired. Any increase in crowding would reduce opportunities for solitude and primitive, unconfined recreation under this alternative.

Alternative A, with a navigation index of 0.50 (Figure 4.10-1), ranks in the middle of the LTEMP alternatives, indicating a relatively high tendency for low flows to lead to encountering other groups at rapids under Alternative A. The navigation index is a seasonally weighted measure of the frequency of minimum daily flows greater than 8,000 cfs, identified as the flow below which navigation risks increase (Appendix J.2.2).

Similarly, Alternative A ranks in the middle of alternatives with regard to daily fluctuation levels, with a fluctuation index of 0.79 (Figure 4.10-1); a majority of days would be within the daily range of fluctuations preferred by whitewater rafters (Section J.2.3 in Appendix J), which would also maintain a sense of naturalness as identified by Bishop et al. (1987). This ranking is consistent with allowed daily fluctuations under the respective alternatives. With respect to experimental flows, Alternative A has the lowest projected number of HFEs and no TMFs that would negatively affect wilderness experience.

Alternative A would have the second lowest impacts on wilderness experience from non-flow actions overall among the alternatives. Alternative A has no TMFs, a low expected number of mechanical removal trips, and no experimental vegetation restoration actions. The number of administrative trips expected under this alternative would be comparable to that of other alternatives.

In summary, Alternative A has the lowest potential to increase campsite area and a corresponding decrease in visitor solitude, and a moderate tendency for crowding at rapids due to periods of lower flows. Alternative A would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and has the lowest adverse effects from non-flow experimental actions on wilderness experience as a result of having the lowest combined number of such actions.

4.11.3.2 Alternative B

Alternative B would have a relatively low potential to retain and build sandbar area, similar to that for Alternative A, and would be expected to continue a long-term trend of increasing campsite crowding due to erosion. The low tendency to retain sand and build beaches is attributable to the low number of projected HFEs over the 20-year LTEMP period (an average of 7.2) and high daily fluctuations. Any increase in crowding would reduce opportunities for solitude under this alternative.

Alternative B, with a navigation index of 0.39 (Figure 4.10-1), has one of the highest tendencies for low flows to lead to encountering other groups at rapids. Any such effect, however, would lead to only small effects on wilderness experience, because frequency of encounters would be slightly increased, short term, and low impact.

Alternative B, with a fluctuation index of 0.42 (Figure 4.10-1), would have the fewest days within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987), resulting in a high relative potential to reduce a sense of naturalness among the alternatives. With respect to experimental flows, Alternative B has the second lowest projected number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative B would be higher than under Alternative A, but comparable to, or in the case of mechanical removals of trout less than, those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short-term and to affect relatively few visitors each year. Vegetation restoration would also have a slight long-term potential benefit from restoring wilderness character via native vegetation.

In summary, Alternative B has the second lowest potential to increase campsite area and preserve visitor solitude, while having among the highest tendencies for crowding at rapids due to low flows. Alternative B would have among the highest adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to, or lower than, most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.3 Alternative C

Alternative C is expected to have a relatively high potential to retain sand and build sandbar area (exceeded only slightly by Alternatives F and G) and is expected to reverse the trend in declining campsite area. This high potential results from the high frequency of HFEs (an average of 21.3 over the LTEMP period) and moderate within-day fluctuations in flow. This increase in camping area would improve opportunities for solitude.

Alternative C, with a navigation index of 0.75 (Figure 4.10-1), has a relatively low tendency for encounters at rapids, and thus a relatively low potential to affect solitude.

Alternative C, with a fluctuation index of 0.93 (Figure 4.10-1), ranks third among alternatives; most days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative C has the second-highest projected number of HFEs and a moderate to high number of TMFs that would negatively impact wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative C would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year.

In summary, Alternative C has a relatively high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative C would have among the lowest adverse effects on wilderness experience from daily flow fluctuations and experimental flows, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.4 Alternative D (Preferred Alternative)

Alternative D is expected to have a relatively high potential to retain sand and build sandbar area, similar to Alternatives C, F, and G, and is expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average of 21.1), similar to Alternative C, and moderate within-day fluctuations. This increase in camping area would improve opportunities for solitude.

Alternative D, with a navigation index of 0.45 (Figure 4.10-1), would be comparable to Alternative A with regard to encounters at rapids, and would represent little change from current conditions.

Alternative D, with a fluctuation index of 0.74 (Figure 4.10-1), ranks fifth among alternatives, just below Alternative A; a majority of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a correspondingly low potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative D has the second-highest projected number of HFEs (tied with Alternative C) and a moderate number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative D would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year.

In summary, Alternative D has a relatively high potential to increase campsite area and preserve visitor solitude, while having a moderate tendency for crowding at rapids due to low flows. Alternative D would have moderate adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.5 Alternative E

Alternative E is expected to have a moderate potential to retain sand and build sandbar area, slightly lower than Alternatives C, D, F, and G, and would be similarly expected to reverse the trend in declining campsite area. This moderate potential results from a medium number of projected HFEs over the next 20 years (an average of 17.1) and daily fluctuations somewhat higher than Alternatives A, C, and D, but lower than Alternative B. This increase in camping area would improve opportunities for solitude under this alternative.

Alternative E, with a navigation index of 0.37 (Figure 4.10-1), would have the highest tendency for low flows to lead to encountering other groups at rapids relative to the other alternatives.

Alternative E, with a fluctuation index of 0.57 (Figure 4.10-1), ranks sixth among alternatives, above only Alternative B; about half of days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and a high relative potential to reduce a sense of naturalness due to high daily flow fluctuations. With respect to experimental flows, Alternative E has a moderate number of HFEs and a moderate number of TMFs that would negatively affect wilderness experience

The number of non-flow experimental actions and administrative trips under Alternative E would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year.

In summary, Alternative E has a moderate potential to increase campsite area and preserve visitor solitude, while having a relatively high tendency for crowding at rapids due to low flows. Alternative E would have relatively moderate to high adverse effects from daily flow fluctuations and experimental flows on wilderness experience, and is comparable to most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.6 Alternative F

Alternative F is expected to have the second-highest potential to retain sand and build beach area and would be similarly expected to reverse the trend in declining campsite area. This high potential results from a high number of projected HFEs over the next 20 years (an average of 38.1) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows under this alternative will aid in trip planning, which will also help avoid crowding.

Alternative F, with a navigation index of 0.71 (Figure 4.10-1), would have lower tendency for low flows to lead to encountering other groups at rapids than other alternatives, except Alternatives C and G.

Alternative F, with a fluctuation index of 1.0 (Figure 4.10-1), ranks highest among alternatives; essentially all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative F has the highest number of HFEs but no TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative F would be higher than under Alternative A, but lower than those under other alternatives because this alternative would not feature mechanical trout removal. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year.

In summary, Alternative F has a high potential to increase campsite area and preserve visitor solitude, while having a low tendency for crowding at rapids due to low flows. Alternative F would have no adverse effects from daily flow fluctuations but some effects from the highest number of HFEs on wilderness experience, and is lower than most other alternatives with respect to adverse effects of non-flow experimental actions on wilderness experience.

4.11.3.7 Alternative G

Alternative G is expected to have the highest potential to retain sand and build sandbar area and would be most likely of all alternatives to reverse the trend in declining campsite area. This high potential results mainly from a high number of projected HFEs over the next 20 years (an average of 24.5) and steady flows. This increase in camping area would improve opportunities for solitude under this alternative. Steady flows will aid in trip planning, which will also help avoid crowding.

Alternative G, with a navigation index of 0.96 (Figure 4.10-1), would have the lowest tendency of all alternatives for low flows to lead to encountering other groups at rapids.

Alternative G, with a fluctuation index of 0.98 (Figure 4.10-1), ranks second among alternatives, slightly below Alternative F; nearly all days would be within the daily range of fluctuations preferred by whitewater rafters, which also maintains a sense of naturalness as identified by Bishop et al. (1987) and effectively no potential to reduce a sense of naturalness due to high daily flow fluctuations under this steady-flow alternative. With respect to experimental flows, Alternative G has the second-highest number of HFEs and highest number of TMFs that would negatively affect wilderness experience.

The number of non-flow experimental actions and administrative trips under Alternative G would be higher than under Alternative A, but comparable to those under other alternatives. As for other alternatives, the effects of these actions on wilderness experience are expected to be localized and short term, and to affect relatively few visitors each year.

In summary, Alternative G has a high potential to increase campsite area and preserve visitor solitude, while having the lowest tendency for crowding at rapids due to low flows. Alternative G would have no adverse effects from daily flow fluctuations, but some effects from the second-highest number of HFEs on wilderness experience; it is comparable to all alternatives except Alternatives A and B with respect to adverse effects of HFEs and comparable to other alternatives with respect to effects of non-flow experimental actions on wilderness experience.

4.12 VISUAL RESOURCES

> **Issue:** How do the alternatives affect visual resources?
>
> **Impact Indicators:**
>
> - The heights of the calcium carbonate rings surrounding Lake Mead and Lake Powell
> - Exposure of lake deltas in Lake Mead and Lake Powell
> - Exposure of Cathedral-in-the-Desert in Lake Powell
> - Changes in vegetation and sandbar size

This section describes the assessment of the potential effects of the alternatives on visual resources, concentrating on changes that could occur to the water, select geological features, and areas of riparian vegetation along the shore lines of the Colorado River, Lake Powell, and Lake Mead.

Visual resources are important to visitor enjoyment of GCNRA, GCNP, and LMNRA, and the conservation of visual resources is an important component of federal management activities for these areas. For this reason, it is important to understand how dam operations and non-flow management actions may affect visual resources within the project area. Indictors of effects on visual resources include the height of the calcium carbonate ring surrounding Lake Mead and Lake Powell, the exposure of lake deltas in Lake Mead and Lake Powell, the exposure of Cathedral-in-the-Desert in Lake Powell, and potential impacts associated with changes in vegetation and water color, clarity, and surface appearance.

Calcium carbonate deposits form at the water line and are typically visible at lake elevations below full pool, where they create a bathtub ring effect. They are generally lighter in color than the walls without calcium carbonate deposits. This creates visual contrast that may result in visual impacts. The calcium carbonate deposits around both Lake Powell and Lake Mead will be more or less exposed as lake levels rise and fall; however, the exposure will be most affected by future hydrology. In order to quantify the extent of visibility of the calcium carbonate rings, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled, and from this the potential range in height of the exposed calcium carbonate ring (the distance from the top of the ring to the water level) was determined. Projected elevations were compared against both lakes at full pool. Lake Powell is considered at full pool at 3,700 ft AMSL. Lake Mead is considered at full pool at 1,221 ft AMSL.

Our analysis indicates that the lake elevations would vary very little under the different alternatives, resulting in very little difference in the potential maximum height of the calcium carbonate ring. For Lake Powell, the potential difference in the maximum height of the ring varies approximately 1 ft among the alternatives. For Lake Mead, the potential difference in the maximum height of the ring varies approximately 3 ft among the alternatives. The calcium carbonate deposits produce a visual contrast regardless of their height and size and make up only a portion of the view in both lakes, and the overall difference in visual impacts among the alternatives as a result of exposure of the rings would be negligible.

Lake deltas appear as expansive, eroding sediment deposits that become more visible as the water level in the reservoir decreases. They are considered a visual detraction (Reclamation 2007a). The size of a lake delta is directly affected by the mass of sediment delivered to the delta, and its exposure is directly affected by lake elevation. Lake deltas within Lake Powell and Lake Mead will be more or less exposed as lake levels fall and rise; however, the exposure of the lake deltas will be most affected by future hydrology. The increased visibility of lake deltas creates increased visual contrast and may result in visual impacts. In order to quantify the extent of the visibility of lake deltas, the average end-of-month elevation of each reservoir over the 20-year LTEMP period was modeled to determine if lake deltas would be more or less exposed in each of the reservoirs.

The analysis indicates that Lake Powell elevations would vary approximately 1 ft among the alternatives, while Lake Mead elevations would vary approximately 2 ft among the alternatives. Lake deltas produce visual contrast regardless of their height and size and make up a very small part of the views in both lakes. On the basis of predicted variation in lake elevations, there would be little, if any, difference in the exposure of lake deltas in either lake among the alternatives, and the overall difference in visual impact among the alternatives as a result of exposure of lake deltas would be negligible.

Cathedral-in-the-Desert is a prominent geological feature in Lake Powell that attracts many visitors when exposed. The feature is exposed when the Lake Powell reservoir elevation is ≤ 3,550 ft AMSL (Reclamation 2007a). Because of the attention Cathedral-in-the-Desert receives when it is exposed, the exposure of this feature could be perceived as a positive impact or benefit. To determine the potential exposure of Cathedral-in-the-Desert, the average number of months per year that Lake Powell's end-of-month elevation was ≤ 3,550 ft AMSL over the 20-year LTEMP period was modeled. Our analysis indicates that Cathedral-in-the-Desert would be potentially exposed an average of 2 months per year over the 20-year LTEMP period under all alternatives, and the overall difference in visual impact between the alternatives would be negligible for Cathedral-in-the-Desert and similar attractions within the lake basin.

Vegetation plays an important role in the scenic experience along the Colorado River. Vegetation increases the visual interest of many places where it occurs by adding variety in color and texture in contrast to the river, rocks, and bare canyon walls. Flow variations and non-flow management actions can alter the type and frequency of vegetation along the corridor (see Section 3.6.2 and Section 4.6). Changes in vegetation could result in different levels of color and texture in contrast to the surrounding landscape, but it is difficult to predict how this could affect a visitor's visual experience and is not expected to vary significantly among alternatives. It is not possible to predict what types of vegetation are more appealing than others to recreationists. Individuals are often influenced by their personal experiences and/or expectations, and what is visually pleasing to one individual may not be to another. Potential impacts on vegetation were assessed based on professional judgment and the riparian vegetation assessment presented in Section 4.6.

Although frequent visitors to the Canyons, such as Tribal members, river guides, scientists, and anglers, will likely notice a change in plant states and sandbar size, it is not certain that an individual participating in a once-a-year or once-in-a-lifetime river trip will notice any change unless there are vegetation management activities underway during visitor trips. Visitors standing at scenic overlooks with views of the river may notice vegetation or sandbars in the corridor, but they will be unlikely to notice a change in vegetation state or sandbar size from these locations, given their distance from the river. Therefore, visual impacts on the canyons from changes in vegetation or sandbar size are expected to be negligible under all alternatives.

NPS management actions that are being proposed in the river corridor of Glen and Grand Canyons as well as on Hualapai lands, such as nonnative plant removal, native plant revegetation, and mitigation at cultural sites, may have effects on the visual environment. These effects are associated primarily with the alteration of the forms, colors, and textures of vegetation, both immediately after implementation of management activities and over longer time periods, because of changes in species composition, but, as discussed above, the visual effects of changes in vegetation type and cover would be negligible.

Based on this analysis, the effects are considered negligible for all of the visual resources indicators and would not vary among the alternatives.

4.13 HYDROPOWER

This section describes the potential impacts of changes in Glen Canyon Dam operations on the economic value of the powerplant's capacity and energy production. Impacts are measured in terms of changes in regional power system capacity expansion pathways,[10] in overall system-level electricity production costs, and in the amount of generation and associated economics at the Hoover Dam Powerplant. This section also discusses how changes in system resources and operations affect both wholesale electricity rates paid by utilities that purchase firm capacity and energy from Western and the retail electricity rates paid by entities that contractually receive and consume capacity and energy from Glen Canyon Dam.

Issue: How do alternatives affect hydropower resources?

Impact Indicators:

- Changes in the amount (MWh) and dollar value of hydropower generation at Glen Canyon Dam
- Changes in SLCA/IP marketable capacity
- Changes in capital and operating costs that Western's customers incur to serve their loads
- Changes in residential electricity bills of Western's customers
- Changes in generation and economics at Hoover Dam.

4.13.1 Analysis Methods

This section describes the methods used to estimate the impact of alternative Glen Canyon Dam operating criteria on the economic value of its hydropower resources and to estimate the impacts on retail electricity rates charged by entities that purchase power from the Salt Lake City Area Integrated Projects (SLCA/IP or federal preference power). This section also describes the methods used to estimate the impact of alternative operating criteria at Glen Canyon Dam on Hoover Dam generation and economics.

[10] A capacity expansion pathway is a specification of the size, timing, and type of generating units to be constructed over a specified planning horizon.

4.13.1.1 Hydropower Resource and Capacity Expansion Impacts

For each of the proposed alternative operating criteria, the hydropower impact analysis estimated the net present value (NPV) of the cost of meeting future energy and capacity demands of utilities (customers) that have long-term firm (LTF) contracts to purchase power from Western's SLCA/IP facilities (Section 3.13) and compared these costs to the NPV of costs under the existing operating criteria (Alternative A, the No Action Alternative).

A number of models and spreadsheet tools were used for the analysis, including:

- *Colorado River Simulation System (CRSS)* simulated future hydrological conditions for the six large SLCA/IP facilities that include the Seedskadee Project (Fontenelle) and the five Colorado River Storage Project (CRSP) facilities; namely, Glen Canyon Dam, Flaming Gorge Dam, and the Aspinall Cascade (Blue Mesa, Morrow Point, and Crystal Dams).

- *Sand Budget Model* scheduled the type and timing of HFEs at Glen Canyon Dam and reallocated monthly water release volumes from CRSS, and revised monthly elevations to enable higher water releases during months with HFEs. Another type of experiment at Glen Canyon Dam, TMFs, were also added at this stage.

- *GTMax-Lite* optimized the economic value of hourly energy produced at the five largest CRSP facilities. This model determined an hour-by-hour pattern of both generation (in MWh) and water releases (in cfs) that satisfied the operating constraints imposed by each alternative, such as up/down ramp rates, maximum change in the release over a rolling 24-hour period, maximum hourly release, and others. This model consisted of two configurations: one for Glen Canyon Dam and one for the remaining four CRSP facilities and Fontenelle.

- *AURORAxmp (Aurora)* simulated the operation of the power system modeled in the analysis and was also used to project hourly spot market prices in the Western Interconnect. The model can be run in the capacity expansion mode, in which the paths to model projected system capacity expansion meet future electricity demands, or in the unit dispatch mode, to simulate powerplant unit operations needed to serve the load and to minimize total electricity production cost. The model was developed by EPIS, Inc., and is commonly used by utilities throughout the United States.

- *Other specialized models and spreadsheet models* developed for the LTEMP analysis included:
  - Representative Trace Tool: selected the most representative trace or hydrological future of all traces simulated by CRSS and the Sand Budget Model (SBM).

- Hydropower Outage Model: simulated unit outages, both scheduled maintenance and forced outages, at the six large SLCA/IP facilities.
- Hourly Load Forecast Algorithm: determined hourly loads of Western's customers over the study period.
- Western Marketable Capacity spreadsheet: estimated the amount of firm capacity from all SLCA/IP facilities that Western could offer its customers at an assumed risk preference or exceedance level.

More detail on each model and tool can be found in Appendix K, Sections K.1.4 and K.1.5.

A number of simplifying assumptions were made for the hydropower analysis, as follows:

- The geographic scope of the analysis was limited to the service territories of utilities with which Western currently has LTF electricity contracts. Limiting the analysis to Western's customers allows the analysis to concentrate on the systems most affected by a DEIS alternative with an adequate level of fidelity to obtain good estimates of economic impacts. In addition, the hourly economic value of energy which drives much of SLCA/IP operations was estimated by a tangential modeling task that encompasses the entire Western Interconnect.

- Given the comparative insignificance of Glen Canyon Dam power generation relative to the amount of electricity in the Western Interconnect power grid, the analysis assumes that the operation of Glen Canyon Dam has an insignificant influence on the marginal value of electricity in the system as a whole.

- Western's customers are separated into two categories: large and small. Large customers, which comprise about 75% of firm capacity and energy sales, were modeled more rigorously than small customers. The eight largest customers are Deseret Generation and Transmission Cooperative (Deseret), the Navajo Tribal Utility Authority (NTUA), Salt River Project (SRP), Utah Associated Municipal Power Systems (UAMPS), Utah Municipal Power Agency (UMPA), Platte River Power Authority, Tri-State Generation and Transmission Association (Tri-State), and Colorado Springs Utilities (CSU). There are about 130 remaining "small customer" entities accounting for the remaining 25% of LTF sales. Individually, each small customer receives less than 2.5% of the total, but proportionally, the CRSP resource is on average a much larger component of the customer's total resource portfolio than the larger customers.

- The CRSS model was used to project 105 monthly hydrological traces over a 48-year period from 2013 through 2060 for three sediment traces, namely, high, moderate, and low. Each trace contains a unique historical chronological time sequence of hydrological conditions. Therefore, hydrological conditions are deterministic, and it is extremely unlikely that any one trace will ever be repeated. Of these 105 traces, a common set of 21 was used to estimate the level of marketable/firm capacity of the CRSP plants and the Fontenelle powerplant. To estimate the hourly value of Glen Canyon Dam energy production, the AURORA model was run in dispatch mode using a representative hydrological trace. The trace chosen best met a set of criteria for being "representative," and included a significant distribution of hydrological conditions that are very similar to the hydrological distribution of the 21 traces. Also, the mean of the representative trace is approximately equal to the mean of all 21 traces. Furthermore, the AURORA model run will only use the moderate sediment trace, which was estimated to have a 63.1% chance of occurring. Using a single sediment trace greatly expedites model runs by reducing the number of cases to be examined.

- This analysis uses the GTMax-Lite model to simulate the hourly operation of Glen Canyon Dam and the remaining hydropower facilities that comprise both the CRSP and Fontenelle powerplant. This model was designed specifically for the LTEMP DEIS and consists of two configurations. One configuration models only the operation of Glen Canyon Dam, and the other configuration models the remaining aforementioned facilities. This is a simplification for power production because Western schedules and Reclamation dispatches all of the CRSP power units concurrently and incorporate some operating goals and guides that are not represented by GTMax-Lite.

- The methodology assumes that the electrical utilities being modeled engage in unfettered exchange with perfect information about the entire system when it comes to exchanging electrical energy and sharing capacity. In reality, each utility makes its own autonomous decisions with imperfect knowledge about competing utilities. Transmission constraints are also not explicitly modeled; neither are institutional nor regulatory obstacles to trade.

Figure 4.13-1 shows the modeling sequence and data flows for the power systems analysis. The following section briefly describes the methodology; a more detailed discussion of the methodology can be found in Appendix K, Sections K.1.4 and K.1.5.

Another noteworthy assumption is that "emergency exception criteria" as stipulated under the 1996 Record of Decision will continue under all LTEMP alternatives. Therefore, Glen Canyon Dam will be allowed to operate outside of minimum and maximum flow limits, daily change constraints, and both maximum hourly up- and down-ramp rates in the event of a power system emergency (e.g., grid energy imbalance events).

Alternative-specific Glen Canyon Dam operating criteria would affect the timing of powerplant additions in the SLCA/IP system and system operation. Both would result in economic impacts that are measured by the AURORA model—the core tool used for power systems analysis. If the operating criteria under each alternative result in a reduction in peak output from Glen Canyon Dam, new generating capacity would be needed elsewhere in the

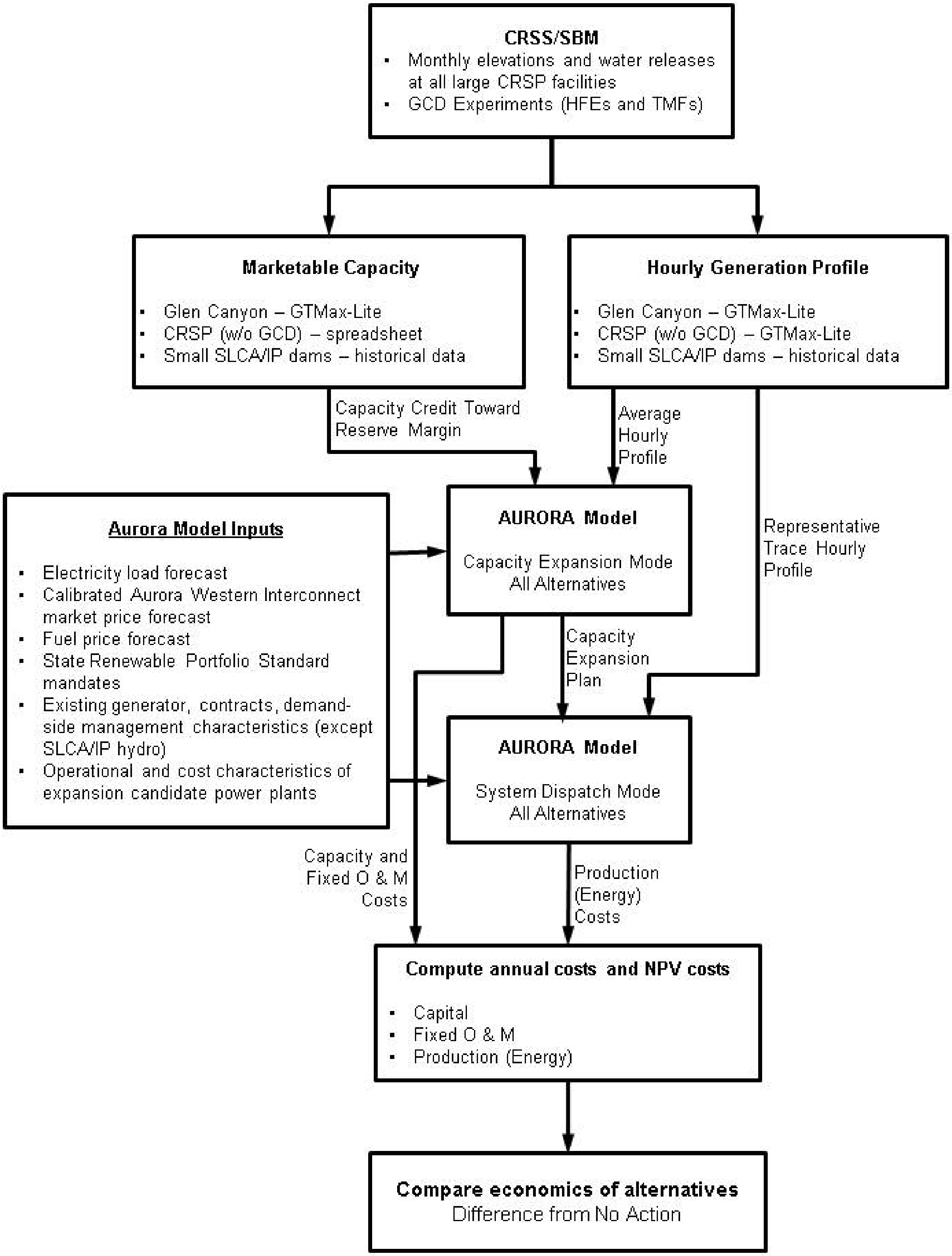

FIGURE 4.13-1 Flow Diagram of the Power Systems Methodology Used in the LTEMP DEIS

system to meet SLCA/IP peak loads. Alternative operating criteria could also change the timing of Glen Canyon Dam generation, i.e., less power generated in the high price peak demand hours of the day and more generated in the low price off-peak hours. Such a change in hydropower operation may cause other powerplants, typically fossil-fuel thermal units, to increase generation in peak hours and decrease generation in off-peak hours. The differences in the timing of new resources and in the way the system is dispatched mean that the cost of reliably meeting SLCA/IP loads over the 20-year LTEMP period would differ from system operations under the existing operating criteria. Therefore, for each alternative, AURORA was used for two major purposes: (1) to determine the capacity expansion pathway over time during the study period for a joint Western/LTF customer system; and (2) to perform a least-cost unit commitment and system dispatch for a given expansion pathway and a single representative hydrology future or trace.

Considerable amounts of data were needed for the AURORA model runs, including:

- Hourly electricity load forecasts for all Western's LTF customer utilities

- Western Interconnect electricity market price forecasts (spot market prices were projected using a configuration of AURORA representing the entire Western Interconnect and a spreadsheet model that calibrated those prices to historical 2013 observations at the Palo Verde market hub, which is the hub closest to Glen Canyon Dam)

- Fuel price projections

- State-mandated renewable resource requirements

- Characteristics of contracts that customer utilities have with other utilities and with other Western offices other than SLCA/IP

- Characteristics of demand-side management programs

- Operational and cost characteristics of powerplants owned by customer utilities

- Operational and cost characteristics of powerplants customer utilities may be considered for system expansion to meet future loads

More details on data sources and how data was generated can be found in Appendix K, Sections K.1.6.1 and K.1.6.3.

Although the AURORA model has its own database of powerplant characteristics, fuel price projections, and hourly load profiles for a number of areas within the entire Western Interconnect, these data were compared to publicly available data sources to verify accuracy and consistency. Such data sources include those available from the Energy Information Administration (EIA) as well as integrated resource plans (IRPs) that Western's customers provide Western or post on their company website. Since the methodology modeled Western's eight large customers in detail, it was necessary to carefully examine the powerplant characteristics in the AURORA inventory and benchmark them against data compiled by EIA and in IRPs.

Due to the complexities of SLCA/IP hydropower operating criteria and mandates unrelated to power production, AURORA could not model the dispatch of these resources at a level of detail that is required for this study. Therefore, the GTMax-Lite model and other spreadsheet models were used to project powerplant-specific hourly production levels over the study period. The results of these models were input to AURORA as a time series of fixed hourly energy injections into the power grid. Data for these models for each alternative came from the CRSS model and the Sand Budget Model and included monthly reservoir elevations and water release volumes and also the type and timing of experiments at Glen Canyon Dam. Outages, both scheduled maintenance and forced outages, at Glen Canyon Dam and the other large SLCA/IP facilities were modeled. Since alternatives only targeted the operation of Glen Canyon Dam, the generation at all other SLCA/IP was typically the same in every alternative. However, in some situations, when Glen Canyon Dam could not provide spinning reserves and/or regulation services, a portion or all of these grid services were provided by powerplants in the Aspinall Cascade, affecting operations of these facilities.

SLCA/IP marketable/firm capacity was an input to the AURORA expansion model. Marketable capacity is the amount of hydroelectric capacity that Western is obligated to provide to LTF customers regardless of the state or condition of SLCA/IP resources. It is also the amount of capacity credited toward meeting the system reserve margin, the spare capacity above the annual coincidental peak of the electric power system modeled. For this study, the reserve margin was assumed to be 15%, which is a typical value in the Western Interconnect. Because Western markets the capacity and energy produced by all 11 SLCA/IP facilities as a package, marketable capacity was determined for the entire facility group. The GTMax-Lite model results were used to compute the capacity contribution from Glen Canyon Dam, while a spreadsheet using CRSS and Sand Budget Model results were used to compute the contribution from the other large CRSP facilities. Historical data were used to compute marketable capacity from the small SLCA/IP facilities; namely, Deer Creek, Elephant Butte, Towaoc, McPhee, and Molina. Because alternatives only affected Glen Canyon Dam's operation under almost all circumstances, only the contribution of Glen Canyon Dam to marketable capacity varied by alternative.

Western must carefully choose the level of marketable capacity it offers because it is obligated to supply this LTF capacity to its customers regardless of hydrological conditions. If SLCA/IP resources are unable to supply the specified amount of capacity, Western must purchase power to cover the shortfall. Western is exposed to market risks because the future of both reservoir conditions and the operating state of generating units are not known with certainty. Risk exposure is measured as the probability that Western will not be able to meet its LTF obligations during peak summer load months. A retrospective study performed by Argonne on marketable capacity currently offered by Western over the last 10 years shows that it markets capacity at a 90% exceedance level. That is, Western has enough SLCA/IP capacity to meet its obligation 90% of the time. Therefore, this LTEMP analysis used an exceedance level of 90% to determine marketable capacity. Marketable capacity at 50% and 99% exceedance levels were also modeled, and these results are presented in Appendix K, Section K.1.10.4.

Hourly generation profiles from all SLCA/IP facilities were an input to both the AURORA expansion and dispatch models. The hourly profile based on the average of all 21 hydrology traces is input to the expansion model, and the hourly profile based on the representative trace is input to the dispatch model. The appropriate configuration of GTMax-Lite is used to compute the hourly generation profiles for Glen Canyon Dam and for the other large CRSP facilities.

The results of the AURORA expansion model run in expansion mode were capacity expansion plans for each alternative over the study period. The plans specify the type of plant built (such as combustion turbines, combined cycle plants, coal plants, nuclear powerplants, etc.), the capacity of the plant, and the year it begins operating. The model also computed the annual capacity investment and fixed operation and maintenance (O&M) costs for the new units over the study period. The AURORA model was given a wide selection of plants from which to choose future capacity additions, including conventional and advanced natural gas combustion turbines, conventional and advanced gas/oil combined cycle plants, scrubbed and pulverized coal plants, integrated gasification combined cycle plants, nuclear powerplants, wind turbines, and solar thermal and photovoltaic powerplants. More details on the powerplant expansion candidates and their cost and performance characteristics are provided in Appendix K, Section K.1.6.3.

The capacity expansion plan for each alternative was an input to the AURORA run in dispatch mode to simulate the operation of the system for every hour in the entire study period for a single hydrological future or trace, which is known as the representative trace. Because the dispatch was run for only a single hydrological trace, selection of the trace is very important. Trace 14 was selected as the representative trace. More detail on the method used to select the representative trace can be found in Appendix K, Attachment K-3.

Results of the AURORA dispatch model consisted of costs to produce the electrical energy to meet the system load demand. Production costs are the sum of powerplant fuel costs, variable O&M costs, and cost of power purchased from the spot market. Results from the AURORA expansion and dispatch models (namely, capital, fixed O&M, and production or energy costs) were combined to determine the total annual costs for each alternative. The net present value stream of costs was also calculated to facilitate comparison of each alternative to Alternative A. This single lump-sum value was based on a discount rate of 3.375%, a rate that is used by Reclamation for cost-benefit studies of projects. A second discount rate of 1.4%, a nominal or real discount rate, was used in a sensitivity study; the results of which are presented in Appendix K, Section K.1.10.5.

4.13.1.2 Wholesale Rate Impacts

The economic impact of changed operations at the Glen Canyon Dam Powerplant on electrical power production and value is the impact—measured in dollars—on the economy. It includes the system cost of changing the value of electrical power produced at Glen Canyon Dam as a result of changing the timing and routing of water releases. It also includes the expense of constructing (or savings resulting from forgoing construction of) additional electrical generators because of changes in firm SLCA/IP federal hydropower capacity. Wholesale rates[11] impacts describe how these economic impacts are distributed to utilities that purchase Glen Canyon Dam electrical power from the federal government at the SLCA/IP rate. The change in SLCA/IP rate among alternatives reflects the economic costs of altered Glen Canyon Dam operations.

Western sets rates as low as possible consistent with sound business principles to repay the federal government's investment in generation and transmission facilities in addition to specific non-power costs that power users are legislatively required by Congress to repay, such as irrigation costs that are beyond the irrigators' ability to repay. Sales of federal electric power and transmission repay all costs (including interest) associated with generating and delivering the power. Western prepares a power repayment study (PRS) for each specific power project to ensure the rates are sufficient to recover expenses.

It is assumed that Western will pay all of the economic costs associated with an alternative and adjust firm electric service (FES) rates to pass these costs onto its FES customers. These costs include all net purchased power, capital costs, fixed O&M costs, and interest expense. Interest expense is calculated by multiplying each investment's prior year unpaid balance by the appropriate interest rate. Computations of total purchase power for each alternative are based on projections of total hourly generation from all SLCA/IP hydropower resources and hourly FES customer loads. The difference between hourly generation and load is resolved by hourly non-firm energy transactions at an energy price projected by the power systems economic analysis. All capital costs and fixed O&M costs associated with a reduction in Glen Canyon Dam Powerplant capacity are also paid by Western and passed on to its customers via adjustments to FES wholesale rates. See Appendix K, Section K.2, for more detailed information on the PRS and wholesale rate modeling process.

Several calculations were performed to determine the impact of the LTEMP DEIS alternatives on the SLCA/IP rate. Three rates were calculated for each of the seven alternatives: (1) a firm energy rate, (2) a firm capacity rate, and (3) a composite rate. The SLCA/IP FES rate is the price paid per unit of product sold by Western's CRSP Management Center to its SLCA/IP FES customers. These calculations and analyses were performed by Western CRSP Management Center staff.

Western markets SLCA/IP electrical power under firm, long-term contracts. Under these contracts, Western is required to deliver this electrical power to federal points of delivery regardless of hydrological conditions or changes in the operational criteria of the SLCA/IP hydropower plants. The current FES marketing contracts expire on September 30, 2024. For the

[11] The term "rate" will be used rather than "price." This is the standard convention for wholesale electrical commodities. Rate is the price charged for an energy unit, whether capacity or energy. Rate is often used to describe wholesale prices because it is the price of wholesale units and not necessarily the units used for retail sales.

period following 2024, Western is currently engaged in developing a marketing plan. This requires a formal public process in compliance will applicable federal law.

Several assumptions had to be made in order to estimate LTEMP DEIS impacts. First, it was assumed that Western will continue with its current SLCA/IP obligations until the current marketing period ends and the existing contracts expire.[12] This requires that Western deliver the same amount of electrical power and energy to SLCA/IP customers until the end of fiscal year (FY) 2024, regardless of the alternative analyzed. Recognizing uncertainties about Western's future marketing of SLCA/IP resources between 2025 and 2034, net firming expenses for the post-2024 time period were analyzed under two sets of assumptions. These are as follows:

1. A continuation of existing SLCA/IP FES contract commitments between FY 2025 and FY 2034 (referred to as No Change or "NC" in Section 4.13.2.4); and

2. A reduction in SLCA/IP FES contract commitments so that net firming expenses are equal to $0 between FY 2025 and FY 2034. This means, for the numbers included in the SLCA/IP power repayment study, zero dollars of firming expense and zero additional dollars of revenue from market sale or from available hydropower sales (referred to as Resource Available or "RA" in Section 4.13.2.4).

These two assumptions constitute "bookends" regarding the outcomes possible in the development of the post-2024 marketing plan.[13] These bookends are for modeling purposes only. They represent a very broad range of possible FES obligations of electrical power in the post-2024 marketing period. The bookends will almost certainly encompass the actual rate impact, once the post-2024 marketing plan is completed. It should be noted that the establishment of these bookends is not an attempt to predict or to anticipate Western's choice prior to the conclusion of the required public process.

4.13.1.3 Retail Rate Impacts

Western markets power to utilities serving approximately 5.8 million retail customers in Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming (Reclamation 2012d). Customers are small and medium-sized towns that operate publicly owned electrical systems, irrigation cooperatives, and water conservation districts; rural electrical associations or

[12] There is a provision in the existing SLCA/IP contracts to modify the FES obligations upon a 5-year notice to SLCA/IP customers. However, considering the probable timing of new operating criteria for the Glen Canyon Dam following the completion of the LTEMP DEIS and the issuance of a ROD a 5-year notice would not be significantly different than the end of the current marketing period.

[13] Western could choose a post-2024 SLCA/IP FES obligation of electric power that exceeds its current obligation. However, prior to completion of the required public process it would be difficult to determine what the higher obligation would be that could be considered a reasonable bookend.

generation and transmission cooperatives who are wholesalers to these associations; federal facilities such as Air Force bases, universities, and other state agencies; and Indian Tribes.

The effect of reductions in available generating capacity at Glen Canyon Dam under each of the alternatives on retail electricity rates and bills for customers of municipal, cooperative, and other entities receiving power from Western was estimated in four steps. First, a detailed database of retail revenues and sales was developed for 226 utility systems that directly or indirectly receive an allocation of Salt SLCA/IP preference power including American Indian Tribes. This database was combined with aggregate production costs (variable O&M costs, purchased power, and fuel expenses), capital investments for capacity additions, and fixed O&M costs derived from the AURORA analysis. Second, capacity additions were converted to revenue requirements using a carrying charge analysis (see Appendix K, Section K.3.1) along with the capital cost of different investments. Third, the cost of changing Glen Canyon operations under each alternative was distributed to each retail utility system by simulating the Western SLCA/IP capacity and energy allocation process. Fourth, overall rate impacts to individual utility systems (including Tribal Systems) were allocated to residential and non-residential consumers to compute retail rate and bill impacts. The process of using a carrying charge analysis along with aggregate production costs does not require SLCA/IP wholesale rates. Use of production costs and carrying charges results in somewhat higher rate impacts than estimation that uses SLCA/IP wholesale rates.

The objective of the retail rate impact analysis is to measure the change in electric bills that consumers who ultimately use electricity in their homes or businesses will incur because of changes in the way Glen Canyon Dam operates. Retail rate impacts can be measured directly from the change in capacity and energy costs that are computed in the power systems analysis along with the utility carrying charges. This direct method of computing retail rate impacts involves allocating changes in energy and capacity cost to distribution systems and then dividing the cost changes by retail revenues. All of the economic impacts come from the capacity cost (including fixed O&M) and energy cost changes (including ancillary service values). Using this method, additional evaluation of Western wholesale rates is unnecessary to derive retail rate impacts (although direct use of SLCA/IP wholesale rates computed by Western would result in lower impacts). The power systems simulations combined with the carrying charge rate analysis applied to new capacity resulting from Glen Canyon Dam operation changes measures impacts on wholesale power cost that must ultimately be attributed directly to retail ratepayers. Appendix K includes an example demonstrating the intuitive result that the method of directly computing retail rates or alternatively using a multi-step process of using capacity and energy costs to first evaluate Western wholesale rates results in an appropriate measured retail rate impact, even though measured rate impacts are lower through using SLCA/IP rates computed by Western.

While the process of computing retail rate impacts from the capacity and energy cost changes implies changes in capacity allocation, under current contract provisions with customer utilities, Western may maintain the same capacity allocation to each customer entity. Given this contractual obligation, Western rather than the individual utilities may have to replace the lost capacity at Glen Canyon Dam by purchasing the shortfall from other sources. Eventually, these increased costs would be passed on to entities who are allocated preference power and rates would have to be increased because of capacity and energy cost. This process of assuming that Western would pay for the capacity and energy costs associated with changes in Glen Canyon Dam operations results in the same retail rate impacts as the assumption that the wholesale cost impacts are simply paid by the utilities themselves as long as Western would pass on the costs as they are incurred. If Western would defer the cost increases, the changes in energy and capacity costs would still be paid, but with a temporary deferral that would presumably include financing costs. Attempting to incorporate potential deferral strategies in Western's wholesale rate policy is neither appropriate nor practical in assessing retail rate impacts. For example, if capacity costs and production costs increase, but Western incurs the cost for a period of years but then later increases the rate including cost of capital, it would not be appropriate to include the deferral in the rate impacts. Finally, in order to provide a relative benchmark indication of the effects of Glen Canyon Dam capacity cost changes on costs incurred to purchase power, the average aggregate capacity and energy costs are measured relative to amount of money that Western currently collects from capacity and energy allocations (see Appendix K for details).

4.13.1.4 Hoover Dam Impacts

Hoover Dam is located about 370 mi downstream of Glen Canyon Dam. Changes from current monthly water release volumes under LTEMP alternative operating criteria could impact pool elevations in Lake Mead, and these in turn could impact Hoover Dam Powerplant firm capacity and energy generated by water releases through its turbines. A modeling tool of Hoover Powerplant monthly operations was developed to provide estimates of impacts of the LTEMP DEIS alternatives on Hoover Powerplant economics. The tool, referred to here as the Hoover Powerplant Model, computes two economic metrics; namely, firm capacity and energy, both in terms of NPV, for each alternative and compares the results.

To perform the analysis data on monthly water releases from Hoover Dam, end-of-month elevations at Lake Mead were obtained from CRSS and the Sand Budget Model for all 21 hydrology traces for each alternative over the study period. Using information from Reclamation, algorithms were developed relating reservoir elevation to reservoir storage and to maximum powerplant capacity. The Hoover Powerplant Model used this information to determine the difference in monthly generation between Alternative A and each of the other alternatives for all 21 hydrology traces. The Western Interconnect electricity market price forecasts, which are identical to the prices used in the Aurora model simulation of Western's eight large customers, were used in the Hoover Powerplant Model to compute the value of the generation from the Hoover Powerplant. The value of monthly generation was computed by multiplying the monthly energy generation by the market price of electricity, accounting for the difference in price between energy generated in peak hours versus off-peak hours. Based on information from Reclamation, it was assumed that 95% of generation at the Hoover Powerplant takes place in peak hours and only 5% in off-peak hours.

The Hoover Powerplant Model also computed the firm capacity available from the Hoover Powerplant based upon the relationship between reservoir elevation and maximum powerplant output derived from data provided by Reclamation. The maximum monthly capacity was computed for all 21 hydrology traces over the study period. It was assumed that below a pool elevation of 1,050 ft the maximum output is zero, and above an elevation of 1,205 ft the maximum output remains constant at 2,075 MW, which is the maximum powerplant capacity. To be consistent with the Glen Canyon Powerplant power systems analyses, this analysis assumed that the firm hydropower capacity of the Hoover Powerplant is based on the 90th percentile exceedance level in the peak month of August. More details on the modeling methodology and the results are presented in Appendix K, Section K.4.

4.13.2 Summary of Hydropower Impacts

This section and Table 4.13-1 summarize the potential impacts of alternative operating criteria on Glen Canyon Dam's hydropower resources. These impacts are measured in terms of changes in both powerplant capacity and generation and associated economic value. Impacts are analyzed from an overall systems perspective in which least-cost electricity production costs are computed and regional power system capacity expansion pathways are determined. This section also discusses how changes in system resources and operations, caused by operational changes at Glen Canyon Dam, impact the retail electricity rate that Western's wholesale customers charge to their end-use customers. Table 4.13-1 does not include the rate impacts on American Indian Tribes; they are discussed separately in Appendix K, Section K.3.

4.13.2.1 Monthly Water Release Impacts

Differences among LTEMP alternatives do not occur from annual water release volumes, but rather from the routing and timing of these water releases during monthly, daily, and hourly timeframes. The total volume of water released from Glen Canyon Dam over the 20-year LTEMP period is essentially identical under all LTEMP alternatives. Also, differences among alternatives in annual water release volumes are less than 1%. However, alternatives significantly impact the timing of water releases within a year. For example, as compared to Alternative A, Alternative F releases much higher water volumes during March, April, May, and June and much lower water volumes during July and August. Alternatives also impact the daily profile of water releases. Changes in operating criteria such as maximum and minimum release restrictions and mandates that limit water release changes over time result in very different release patterns during most days. For example, Alternative F requires water releases from Glen Canyon Dam to be at a constant rate an entire day. In contrast, Alternative A allows powerplant operators to change water release levels during a day such that power production more closely matches wholesale rate customer energy requests and/or in response to the market price of electricity.

Lastly, alternatives affect the routing of water releases from the dam. Water is typically released through one or more of the powerplant's eight turbines to produce electricity. However, dependent on the pressure exerted by the water elevation in Lake Powell, turbines have a limited amount of water that can flow through them during an hour. Also, the generating capacity of a unit indirectly limits the flow of water through it. Therefore, whenever a water release is required to exceed the combined flow capabilities of the generating units that are in operation, some of the water is released through bypass tubes and spillways. These non-power releases produce no

TABLE 4.13-1 Summary of Impacts of LTEMP Alternatives on Hydropower Resources

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current condition. Second highest marketable capacity and sixth-lowest total cost to meet electric demand over the 20-year LTEMP period. No change in average electric retail rate or average monthly residential electricity bill. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 3.8% increase in marketable capacity and 0.02% decrease in total cost to meet electric demand over the 20-year LTEMP period. Small decreases in both the average electric retail rate and the average monthly residential electricity bill in the year of maximum rate impact. No change in the value of generation at Hoover Dam.	Compared to Alternative A, 17.5% decrease in marketable capacity and 0.41% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 2.0% increase in the value of generation at Hoover Dam	Compared to Alternative A, 6.7% decrease in marketable capacity and 0.29% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.0% increase in the value of generation at Hoover Dam	Compared to Alternative A, 12.2% decrease in marketable capacity and 0.25% increase in total cost to meet electric demand over the 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.2% increase in the value of generation at Hoover Dam	Compared to Alternative A, 42.6% decrease in marketable capacity (lowest of alternatives) and 1.2% increase (highest of alternatives) in total cost to meet electric demand over the 20-year LTEMP period. Highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 4.1% increase in the value of generation at Hoover Dam	Compared to Alternative A, 24.2% decrease in marketable capacity and 0.73% increase in total cost to meet electric demand over 20-year LTEMP period. Increase in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. 1.4% increase in the value of generation at Hoover Dam
Impacts on Generation and Capacity							
Annual average daily generation (MWh)[a]	11,599 (no change from current condition)	11,567 (0.3% decrease)	11,506 (0.8% decrease)	11,477 (1.1% decrease)	11,521 0.7% decrease	11,379 (1.9% decrease)	11,403 (1.7% decrease)
SLCA/IP Marketable capacity (MW)[b]	737.2 (no change from current condition)	765.3 (3.8% increase)	608.1 (17.5% decrease)	687.6 (6.7% decrease)	647.0 (12.2% decrease)	423.1 (42.6% decrease)	558.2 (24.2% decrease)
SLCA/IP Replacement Capacity (MW)[c]	Not applicable	–28.1	129.1	49.6	90.2	314.1	179.0

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Generation and Capacity (Cont.)							
System-level generating capacity additions (MW)[d]	4,820 (no change from current condition)	4,820 (no change from current condition)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,050 (4.8% increase)	5,280 (9.5% increase)	5,050 (4.8% increase)
Impacts on Power System Economics							
SLCA/IP system-wide production cost ($million)[e]	34,228 (no change from current condition)	34,221 (0.02% decrease)	34,255 (0.08% increase)	34,270 (0.1% increase)	34,249 (0.06% increase)	34,373 (0.4% increase)	34,345 (0.3% increase)
SLCA/IP Capital cost ($million) for capacity expansion[e]	1,643 (no change from current condition)	1,635 (0.5% decrease)	1,746 (6.3% increase)	1,696 (3.2% increase)	1,703 (3.7% increase)	1,882 (14.5% increase)	1,769 (7.7% increase)
Fixed O&M cost ($million) for capacity expansion[e]	345 (no change from current condition)	344 (0.3% decrease)	363 (5.2% increase)	354 (2.6% increase)	355 (2.9% increase)	385 (11.6% increase)	366 (6.1% increase)
Total cost ($million)[e]	36,216 (no change from current condition)	36,200 (0.04% decrease)	36,364 (0.41% increase)	36,320 (0.29% increase)	36,307 (0.25% increase)	36,640 (1.2% increase)	36,480 (0.73% increase)
Difference in Total Costs ($million) Relative to No Action	Not applicable	–16	148	104	91	424	264
Local Hydropower Value ($million)[f]	2,662 (no change from current condition)	2,657 (0.2% decrease)	2,614 (1.8% decrease)	2,613 (1.8% decrease)	2,620 (1.6% decrease)	2,540 (4.6% decrease)	2,556 (4.0% decrease)
Impacts on Wholesale Rates							
Energy ($/kWh)							
NC[g]	13.52	13.54	13.99	13.94	13.84	15.67	16.07
RA[h]	13.40	13.22	14.55	13.78	14.01	16.86	15.22
Average	13.46	13.38	14.27	13.86	13.93	16.27	15.65
Capacity ($/kW)							
NC	5.74	5.75	5.94	5.92	5.88	6.66	6.83
RA	5.69	5.62	6.18	5.85	5.95	7.16	6.50
Average	5.72	5.69	6.06	5.89	5.92	6.91	6.67

TABLE 4.13-1 (Cont.)

Impact Indicator	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Impacts on Electric Retail Rate Payers							
Percent change in retail rates (maximum impact year)[i]	No change from current conditions	–0.27% 2029	0.43% 2025	0.39% 2023	0.50% 2027	1.21% 2018	0.64% 2025
Change in monthly residential bill (maximum impact year)[j]	No change from current conditions	–$0.27	$0.40	$0.38	$0.47	$1.02	$0.59
Impacts on Hoover Powerplant Economics							
Total value of generation ($million)[k]	2,362.3 (0% change)	2,362.3 (0% change)	2,408.6 (2.0% increase)	2,384.2 (1.0% increase)	2,390.2 (1.2% increase)	2,451.1 (4.1% increase)	2,392.0 (1.4% increase)
Change in value of generation ($million)[k]	No change from current conditions	Same as Alternative A	46.4	21.9	27.9	88.8	29.7

a Average daily Glen Canyon Dam generation under representative hydrological conditions.

b Marketable capacity is calculated based on all 21 hydrology traces with median sediment input (sediment trace 2), which has the highest likelihood of occurrence. It is calculated at the 90% exceedance level, which means if Western was contractually obligated to provide this amount of LTF capacity in the peak month of August, it would meet that obligation 90% of the time.

c Lost capacity is the difference between the marketable capacity in Alternative A and the marketable capacity of another alternative; it represents the capacity that would need to be replaced somewhere in the power system if that alternative was implemented.

d Additional generation capacity required under the LTEMP alternatives for Western's customers over the 20-year LTEMP period to not only meet future load demand but also account for loss/gain in capacity at Glen Canyon Dam due to the alternative operating constraints.

e Net present value ($million 2015) of costs to meet total system electric demand over 20-year study period for all SLCA/IP customers under representative trace. Discount rate is 3.375%.

f Net present value of electricity generated at Glen Canyon Dam over the 20-year LTEMP period ($million 2015).

g NC = no change from current LTF commitment levels.

h RA = commitment level equals available SLCA/IP federal hydropower resource.

i The unweighted average percent changes in retail rates relative to Alternative A across all systems with available data for the year with the highest percentage impact.

j The average change in residential electric bills (2015 dollars) relative to average residential bills in Alternative A for the year with the maximum rate impact (residential bills are not weighted by utility size).

k Net present value of electricity generated at Hoover Dam over the 20-year LTEMP period ($million 2015).

energy and are referred to as spilled water. Each alternative has a unique set of HFE specifications that affect the frequency and duration of Glen Canyon Dam water spill volumes.

Spilled water can also occur under very low (i.e., dry) hydropower conditions when the Lake Powell elevation is below a minimum turbine water intake level. All of the water is released through bypass tubes and, therefore, no electricity is produced until the water level rises to a minimum intake level.

4.13.2.2 Hydropower Power Generation and Capacity Impacts

The first section of Table 4.13-1 summarizes the impacts of changes in Glen Canyon Dam operations under each alternative on hydropower generation and capacity. Under Alternative A, the average daily generation at Glen Canyon Dam over the 20-year study period is projected to be 11,599 MWh under representative conditions; that is, the monthly water releases and generation levels expected under one of the 21 analyzed hydrology traces, trace 14, which was considered representative of the full range of annual inflow volumes over the 20-year LTEMP period. On average, this represents 72.8% of the generation produced by all SLCA/IP hydropower resources over the 20-year LTEMP study period. With the remaining alternatives, generation would vary between 11,567 MWh under Alternative B (a reduction of 0.3% compared to Alternative A) to 11,379 MWh under Alternative F (a reduction of 1.9%) under representative conditions (Table 4.13-1). These relatively small differences (i.e., less than 2%) in average daily generation among the alternatives are not due to the amount of water released from the dam, but largely attributed to differences in the amount of water routed through bypass tubes to conduct HFEs, which, as described in the previous section, does not generate electricity.

Although there is little difference in annual average daily generation at Glen Canyon Dam among the alternatives, there are monthly differences. Under representative hydrological conditions, average daily generation under Alternative A ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,511 MWh in January (Figure 4.13-2). Although generation under Alternative B would be similar to Alternative A between June and August, slightly less electricity would be generated during January through May, and during October through December. In contrast with Alternatives A and B, all other alternatives (except for Alternative F, which is discussed later) have less average daily generation in the summer months of June, July, and August when electricity demand is at its peak. Alternatives C, D, E, and G have a higher average daily generation in the spring months of March, April, and May than Alternatives A and B, with Alternative C generally having the highest values. Alternatives D, E, and G have higher average daily generation in the fall months of October and November compared to Alternatives A and B. However, in September, October, and November, Alternative C has a considerably lower average daily generation than almost any other alternative. In the winter months of December, January, and February, Alternatives A and B typically have a higher average daily generation than most other alternatives.

Generation under Alternative F would result in the most deviation from Alternative A, with a shifting of annual peak generation from the mid-summer months to late spring/early

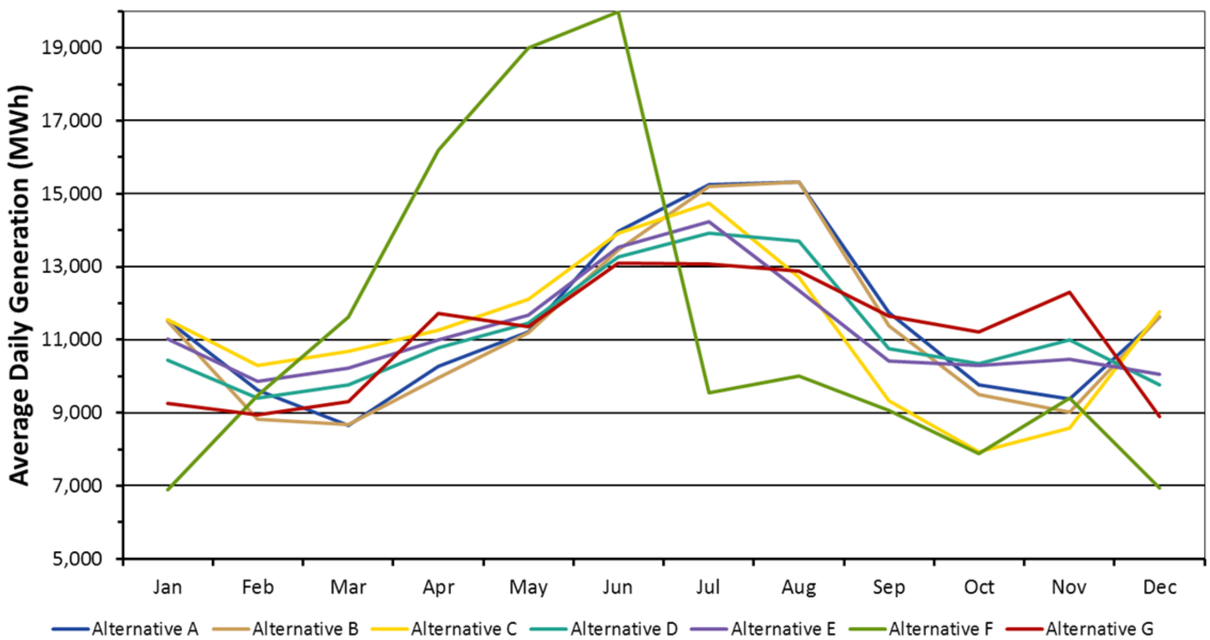

FIGURE 4.13-2 Average Daily Glen Canyon Dam Generation under Representative Hydrological Conditions under LTEMP Alternatives

summer, producing a maximum of 19,995 MWh in June, significantly higher than the peak output under Alternative A (Figure 4.13-2). By contrast, generation during the summer would fall considerably, to a low of 9,708 MWh in July, exceeding 9,000 MWh in August, September, and November and falling to just over 6,900 MWh in December and January.

Although the Glen Canyon powerplant is rated at 1,320 MW, it has been operationally restricted since 1996 and is rarely allowed to produce that amount of power (Veselka et al. 2010). This is due to several factors such as the number of units that are operable, the reservoir elevation, grid reliability considerations, and reservoir operating criteria. The latter is most important for the purposes of estimating economics under different LTEMP alternatives. However, it can produce at rated capacity during extremely high hydropower conditions and during high peak release HFEs (i.e., about 33,000 cfs and higher).

As shown in Table 4.13-1, under Alternative A, there would be about 737 MW of capacity available from the entire SLCA/IP to meet peak system loads. This capacity is based on the assumption that 90% of the time this amount of capacity or more would be available when the system peak loads occur. Under Alternatives C, D, E, F, and G, the marketable capacity would decrease to between 687.6 MW under Alternative D to 423.1 MW under Alternative F.

Except for Alternative B, under which the capacity is 28.1 MW higher than Alternative A, all other alternatives would provide approximately 50 MW to 314 MW less capacity—that is, a reduction that ranges from of 6.7% to 42.6% compared to Alternative A. Capacity differences mainly stem from the level of Glen Canyon Dam operational flexibility (daily change, ramp rates, etc.) and monthly water release volumes that are allowed under each alternative in conjunction with both reservoir elevations and monthly water release levels. Operations under Alternative B allow the highest level of flexibility, while Alternatives F and G, which require steady flows each day, restrict capacity. This lost capacity would need to be replaced somewhere in the SLCA/IP system.

SLCA/IP marketable capacity affects the amount and timing of generating units that will be constructed in the future to reliably meet forecasted increases in electricity demand in the service territories of Western's customer utilities and to replace the retirement of existing powerplant generating capacity. Under Alternative A, an estimated 4,820 MW of new capacity would be built by Western's customer utilities. System capacity expansion additions are phased in over time such that a minimum 15% capacity reserve margin is attained in each year of the 20-year LTEMP period. Under alternatives with less SLCA/IP marketable capacity, more new generating capacity must be built and the capacity would need to be built sooner. Under Alternative B, 4,820 MW of new capacity would also be added by the end of the LTEMP period; however, because Alternative B has slightly more marketable capacity available, one new generating unit would need to be constructed a year later than under Alternative A. All other alternatives have less marketable capacity than Alternative A. Under Alternatives C, D, E, and G, 5,050 MW of new capacity would be required (an increase of 230 MW, or 4.8%, compared to Alternative A), and under Alternative F, 5,280 MW of new capacity would be required (an increase of 460 MW, or 9.5%) (Table 4.13-1). Also note that because the capacity is built in sizes/increments that exceed the amount lost, system capacity expansion differences among the alternatives do not typically match the amount of lost capacity. Appendix K, Section K.1.10.2, provides more details and illustrations of alternative impacts on capacity expansion timing and total new construction.

It is assumed that Western's eight largest wholesale customers make decisions and function as a single aggregate system, and that they would build enough capacity to reliably meet their total aggregate demands. The modeling of this power system assumes a very high level of cooperation and coordination among Western and its LTF power customers. Capacity expansion planning, unit commitment schedules, and least-cost hourly dispatch for the entire system were based on a "single operator/decision maker" model. This is a higher level of cooperation and coordination than what actually occurs.

4.13.2.3 Economic Impacts

The power systems economic analysis primarily measures the impacts of LTEMP alternatives on the cost of generating energy to meet system electricity demands and to build sufficient capacity to meet these demands reliably. In doing so, the analysis accounts for system interactions and reactions. For example, when Glen Canyon Dam increases its output, the power system analysis estimates the generation response (i.e., decrease) of other on-line powerplants in the system. The economic impacts are not limited to any one individual system component, but rather to the collective impacts on all components in the system over the entire study period. Focus is also placed on economic differences among alternatives rather than on their absolute values. Impacts measured include production costs that are incurred hourly on a continuous ongoing basis and capacity expansion costs that occur as needed, and therefore much less frequently.

Capacity expansion cost components include capital investment costs, interest, and other expenses that are accrued during the time period that a generating unit is constructed, and also fixed O&M costs. Since newly constructed capacity will operate long past the end of the 20-year LTEMP period, these costs along with interest during construction (IDC) are annualized and incurred from the time the unit comes on-line until the end of the study period. Similarly, O&M costs for new units are only incurred during the study years that the units operate. Since the primary focus of the analysis is on cost differences among alternatives, fixed O&M costs for existing powerplants are not included, since it is assumed that these costs are identical among all alternatives. In this regard, it should be noted that the AURORA model retirement schedule is identical across all alternatives.

The cost of serving system loads (the production cost) under each alternative over the 20-year LTEMP period is shown in the second section of Table 4.13-1. Costs are expressed in NPV to allow differences in the timing of generation to be normalized, using a 3.375% discount rate. Except for Alternative B, total energy production cost would increase under all alternatives compared to Alternative A, with increases varying from $21 million (a 0.06% increase) under Alternative E to $145 million (a 0.4% increase) under Alternative F. System-level production cost differences are a function of timing and routing of Glen Canyon Dam water releases.

In general, turbine water releases and associated generation, which occur when they have the highest economic value, would decrease overall system-wide production costs. System energy value in this context is the amount of money that is expended to serve all of the system electricity demand. When the demand is low, it is served by generating units that have low production costs; however, as electricity demand increases, units that are more expensive to operate are brought on-line to serve this higher (or incremental) load. Therefore, there is a direct relationship between the cost of serving more demand and the incremental cost to serve it. In this economic analysis, the incremental cost to serve one more MWh of demand, electricity price, and economic value are used synonymously.

When Glen Canyon Dam produces energy during periods of the year when loads and prices are high, the power its produces offsets generation from more expensive units that would have otherwise been utilized. In effect, this lowers overall system production costs. Likewise, system production costs are lower when Glen Canyon generates energy during times of the day when it has the highest economic value. Alternatives with the most operational flexibility also have the highest economic value. This flexibility allows Glen Canyon Dam operators to generate more energy (that is, release more of the limited water resource) during times of the day when prices are highest and reduce generation when prices are low. Appendix K, Section K.1.10, provides more details on market prices and the timing of Glen Canyon Dam power production under each alternative.

Lastly, it should be noted that because water releases are limited, releases that bypass the generators (such as in the case of most HFEs) not only have no power system economic value, but also detract from turbine water releases, and hence both power production and value. In summary, the economic value of Glen Canyon Dam power generation is highest when water is released through powerplant turbines to produce energy which offsets generation that would have otherwise been produced by generating units that are expensive to operate. The economic impacts of HFEs and other experiments, including low summer flows, TMFs, and sustained low flows for invertebrate production are included in the estimates of impacts under each alternative. Additional discussion of the cost of experiments is presented in Section K.1.10.3 of Appendix K.

The cost of building new capacity (or capital costs) to meet the 15% system reserve margin discussed in the previous section is also shown in the second section of Table 4.13-1. The table also shows fixed O&M costs associated with the new construction. Both costs are expressed in NPV.

Based on AURORA model runs and a review of both Western's customers' IRPs and the IRPs of surrounding utility systems, new capacity additions consist of advanced natural gas-fired combined cycle plants (400 MW) and advanced natural gas-fired combustion turbines (230 MW). Capacity expansion pathways are carefully chosen for each alternative and consist of a mix of new technologies that is consistent with those found in the IRPs of Western's large customers and also with Energy Information Administration (EIA) forecasts of future generation capacity in the Western Interconnect (see Appendix K, Section K.1.6.2, for more details).

Total cost, including capital, fixed O&M, and production costs, is also shown in the second section of Table 4.13-1. The cost is expressed in NPV using a 3.375% discount rate. Based on representative hydrological conditions, the total system cost to reliably supply electric demand during the 20-year LTEMP period under Alternative A would be just over $36.2 billion, with a decrease of about $16 million (or 0.04%) in the cost under Alternative B. Although Alternative B has slightly lower monthly generation than Alternative A, its total system cost is lower because it has a higher firm capacity. The higher firm capacity delays the construction of an natural gas combustion turbine plant by a year compared to Alternative A. With slightly higher spring and slightly lower summer average daily flows under Alternatives C, D, E, and G compared to Alternative A, total costs would be slightly higher, ranging from about $36.3 billion under Alternatives D and E (an increase of about 0.3% compared to Alternative A) to over $36.6 billion under Alternative F (an increase of 1.2%), which would have higher spring and early summer flows, and lower late summer and fall flows, than Alternative A.

The local value of only Glen Canyon Dam energy production under each alternative is presented in the second section of Table 4.13-1. It is based on hourly generation levels and the local value of energy injections into the electric grid by Glen Canyon Dam. The ranking and cost differences among these alternatives do not match overall system results because they only focus on Glen Canyon Dam. There is little consideration of system-level interactions and reactions. Note that capital and fixed O&M costs are also not included. All alternatives have reductions in the local value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period compared to Alternative A. Smaller reductions in value occur under Alternatives B, C, D, and E; losses in value vary from $5 million (a 0.2% reduction) under Alternative B to $49 million (a 1.9% reduction) under Alternative D. Alternatives F and G have larger reductions in value; namely, $122 million (a 4.6% reduction) and $106 million (a 4.0% reduction), respectively.

4.13.2.4 Change in FES Wholesale Rates

Through some combination of changed SLCA/IP rates under the NC bookend or lower SLCA/IP commitment levels under the RA bookend, FES utilities that receive SLCA/IP preference power will be impacted as a result of changed operations at Glen Canyon Dam. Under the NA bookend, Western would absorb the economic costs (or reap the benefits) of an alternative and adjust FES rates accordingly, passing costs/benefits to its customers. At the other end of the spectrum, SLCA/IP commitment levels would be adjusted to reflect hydropower resource attributes/capabilities under the RA bookend and FES customers would respond through adjustments to their system dispatch and future resource expansion paths.

For each alternative, Western computed the impact of each alternative in terms of single energy and capacity rates that are applied over the entire 2015 through 2034 LTEMP period. This deviates from Western's normal 5-year forecast in order to accurately capture each alternative's rate impacts. Table 4.13-1 shows FES customer rates estimated by Western RPS studies under both NC and RA bookend marketing structures. The energy and capacity rates reflect Western's current method of billing. SLCA/IP FES customers are billed monthly for the amount of energy used and for their capacity allocation. See Appendix K, Section K.2, for more detailed information on FES wholesale rate results.

This analysis is not a description of policy or an attempt to predict Western's post-2024 marketing plan. This set of bookend results is intended to reflect the range of reasonable possibilities. It is reasonable that Western would continue existing commitment levels to ensure continued customer access to the transmission associated with the energy. Moreover, it is also reasonable to believe that Western would establish post-2024 marketing plan commitments that exactly follow the power resource available at the SLCA/IP power system. For the final LTEMP DEIS, assumptions concerning post-2024 commitment levels may be revised to duplicate the range of impacts examined in the economic analysis.

4.13.2.5 Retail Rate and Bills Impacts

System-wide production costs, fixed operation and maintenance costs of new capacity and the financing cost associated with building new plants must be incurred by entities that receive SLCA/IP preference power. Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam ultimately increases retail rates and bills of residential and non-residential customers. The retail rate impacts experienced by utility systems are not uniform across different utility systems that receive federal preference power. Differential retail rate impacts on particular systems from LTEMP alternatives are largely driven by the amount of power that is allocated from SLCA/IP relative to the quantity of other power that is produced or purchased by a particular system. If utility systems are allocated a large amount of SLCA/IP capacity and energy, but because of their large size, this allocation is a small fraction of the overall amount of power purchased, the retail rate impacts tend to be small. The relative dependence on SLCA/IP capacity and energy varies by a wide margin across entities that receive allocations. SLCA/IP energy allocation as a percent of retail sales range from 0.05% for SRP up to 62% for the City of Meadow (a member of UAMPS). Impacts on the utility systems that are most impacted are presented in Appendix K, Section K.3. This appendix also describes impacts on Tribal systems.

The third section of Table 4.13-1 shows impacts on retail electric rates and monthly residential electricity bills for Western's preference power customers compared to Alternative A. The change in retail rates and the average change in monthly residential bills are both in the year of maximum rate impact. Both metrics are not weighted by utility size; that is, each utility serving retail customers has the same weight. More detailed analyses of retail rates and residential bills are provided in Appendix K, Section K.3.

The average change in the retail rate varies from a decrease of 0.27% in Alternative B to an increase of 1.21% in Alternative F. The average change in the monthly residential electricity bill varies from a decrease of $0.27 in Alternative B to an increase of $1.02 in Alternative F. Both metrics are the average in the year of maximum rate impact. The electric bill reduction in Alternative B is due to a delay of one year in constructing a new natural gas-fired combustion turbine compared to Alternative A. Similarly the electric bill increase in Alternative F is due to the construction of two new natural gas-fired combustion turbines over the 20-year LTEMP period compared to Alternative A. Retail rate and residential bill impacts are computed from adjusting data in the power systems analysis for municipal and cooperative carrying costs and not from SLCA/IP wholesale prices. If estimated wholesale prices are used instead of adjusting power systems cost, the measured rate impacts would be lower.

4.13.2.6 Impacts of LTEMP Alternatives on Hoover Dam Power Economics

The Hoover Powerplant Model used projected Lake Mead reservoir elevations over the 20-year LTEMP period to estimate monthly maximum physical output levels for the Hoover Powerplant for all 21 hydrology traces. Assuming the firm capacity at the Hoover Powerplant is based on the 90th percentile exceedance level in the peak load month of August, the model found that for all alternatives the Lake Mead elevation is below the active pool level of 1,050 ft more than 10% of the time. Therefore, because no generation is possible more than 10% of the time in August, no firm capacity (or a firm capacity of zero) can be assigned to any alternative (see Section K.4 in Appendix K).

The Hoover Powerplant Model computed the change in economic value of Hoover Powerplant energy production attributed to each LTEMP alternative by multiplying the change in monthly energy production by monthly market prices of energy as projected by the AURORA model. Estimates are made for each month of the 20-year LTEMP period for all 21 hydrology traces. To compare LTEMP alternative economics on a consistent basis, the NPV of Hoover benefits were computed using a 3.375% annual discount rate, which is the same rate used for computing the NPV of SLCA/IP costs. The result of NPV calculations for the Hoover Powerplant is shown for each alternative in Figure 4.14-4. The NPV benefit for Hoover ranges from nearly zero for Alternative B to about $89 million for Alternative F.

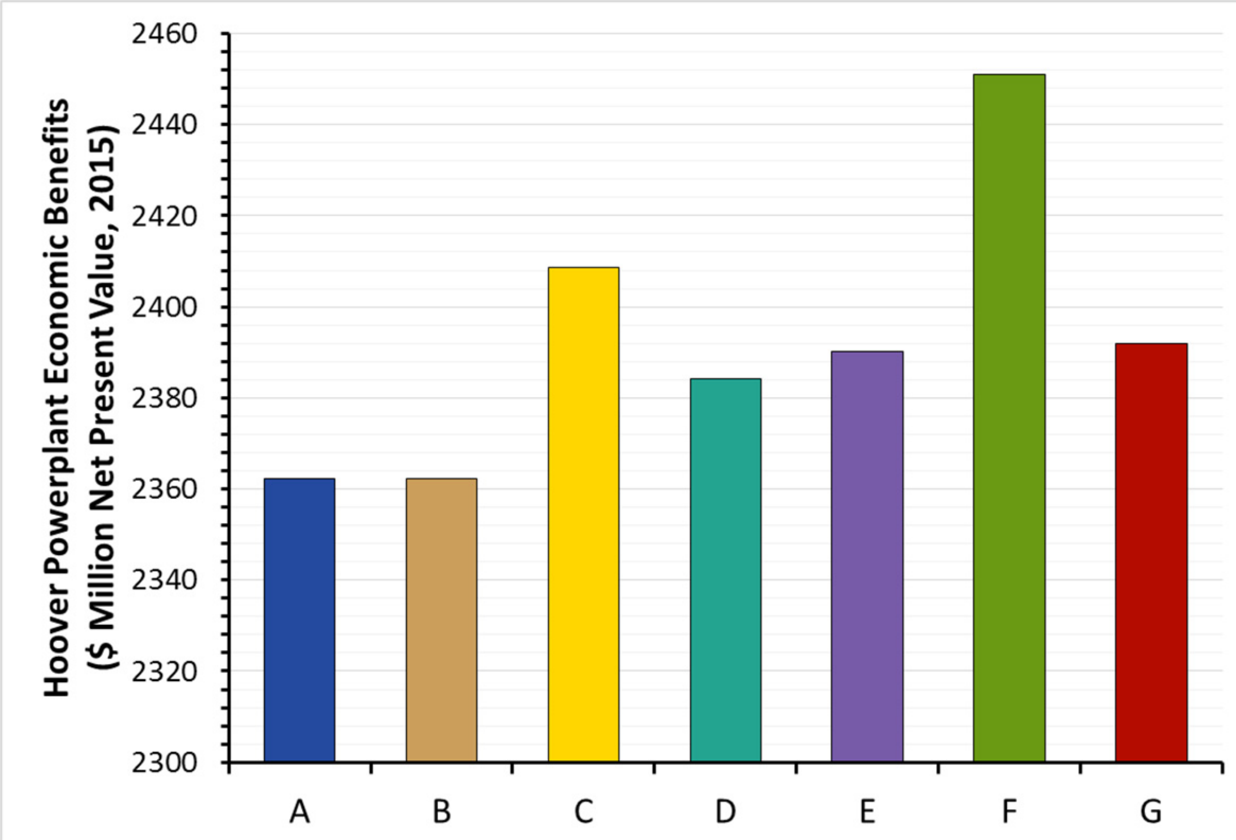

FIGURE 4.13-3 Total NPV of Hoover Powerplant Benefits over a 20-Year Period under LTEMP Alternatives

4.13.3 Alternative-Specific Impacts

4.13.3.1 Alternative A (No Action Alternative)

Average annual daily generation at Glen Canyon Dam is currently 11,599 MWh under representative hydrological conditions. Average daily generation ranges from 8,640 MWh in March to 15,410 MWh in August, before falling to 9,375 MWh in November, and then increasing to 11,606 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,662 million, and would not change under Alternative A. SLCA/IP marketable capacity is currently 737.2 MW at the 90% exceedance level. Average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity would not change under Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative A over the 20-year LTEMP period. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative A would be just over $36.2 billion.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on the wholesale rates Western charges its FES utility customers, retail rates charged by Western's customer utilities, or the electric bills paid by their residential customers. The average wholesale energy rate of the two bookend cases was estimated to be $13.46/kWh and the average capacity rate was estimated to be $5.72/kW.

In summary, Alternative A would have the second-highest marketable capacity from SLCA/IP and tied with Alternative B for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the second-lowest total cost to meet electric demand over that period, and there would be no change in either the average electric retail rate or the average monthly residential electricity bill. There would be no change in the value of generation produced at Hoover Dam.

4.13.3.2 Alternative B

Average annual daily generation at Glen Canyon Dam would be 11,567 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 8,665 MWh in March to 15,405 MWh in August, before falling to 9,046 MWh in November, and then increasing to 11,608 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,657 million, a decrease of $5 million, or 0.2%, compared to Alternative A as explained below. SLCA/IP marketable capacity would be 765.3 MW at the 90% exceedance level, which is a 28 MW, or 3.8%, increase compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and a slight increase in SLCA/IP marketable capacity compared to Alternative A under Alternative B.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 4,820 MW of new capacity built under Alternative B over the 20-year LTEMP period. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet electric demand under Alternative B would be $36.2 billion.

Under Alternative B, there would be a small reduction in capital and operating costs associated with new capacity relative to Alternative A. Although the total amount of capacity added over the 20-year LTEMP period is the same as Alternative A, there would be a 1-year delay in constructing a new natural gas-fired combustion turbine. This delay accounts for the slightly lower total cost of Alternative B compared to Alternative A. Also because of the construction delay, the average electricity retail rate could drop by 0.27% and the average monthly residential electricity bill could be reduced by an average of $0.27. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13,38/kWh, which is a decrease of $0.08/kWh (–0.6%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.69/kW, which is a decrease of $0.03/kW (–0.5%) compared to Alternative A.

In summary, Alternative B would have the highest marketable capacity from SLCA/IP of any alternative and would be tied with Alternative A for the smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would decrease compared to Alternative A. There would be a decrease in the average electric retail rate and in the average monthly residential electricity bill compared to Alternative A in the year of maximum rate impact. There would be no change in the value of generation produced at Hoover Dam.

4.13.3.3 Alternative C

Average annual daily generation at Glen Canyon Dam would be 11,506 MWh under representative hydrological conditions. Average daily generation under would range from 10,292 MWh in February to 14,855 MWh in July, before falling to 7,971 MWh in October, and then increasing to 11,739 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,614 million, a decrease of $48 million, or 1.8%, compared to Alternative A. SLCA/IP marketable capacity would be 608.1 MW at the 90% exceedance level, which is a 129 MW or 17.5% decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity under Alternative C compared to Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative C over the 20-year LTEMP period. An additional gas turbine would be needed during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative C would be almost $36.4 billion.

Because of the additional gas turbine the average retail electric rate would increase about 0.43% and the average monthly residential electricity bill would increase by an average of $0.40. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $14.27/kWh, which is an increase of $0.81/kWh (6.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.06/kW, which is an increase of $0.35/kW (6.0%) compared to Alternative A.

This alternative would produce a total benefit of $46 million over the 20-year LTEMP period compared to Alternative A because of the increase in the economic value of energy produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly water releases at Glen Canyon Dam.

In summary, Alternative C would have the fifth-highest marketable capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the fifth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would increase compared to Alternative A. It would have the fourth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.4 Alternative D (Preferred Alternative)

Average annual daily generation at Glen Canyon Dam would be 11,477 MWh under representative hydrological conditions. Average daily generation would range from 9,392 MWh in February to 14,051 MWh in July, before falling to 10,381 MWh in October, and then increasing to 11,052 MWh in November (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,613 million, a decrease of $49 million, or 1.8%, compared to Alternative A. SLCA/IP marketable capacity would be 687.6 MW at the 90% exceedance level, which is a 49.6 MW, or 6.7%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity under Alternative D compared to Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative D over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative D would be just over $36.3 billion.

Because of the additional gas turbine the average retail electric rate would increase about 0.39% and the average monthly residential electricity bill would increase by an average of $0.38. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.86/kWh, which is an increase of $0.4/kWh (3.0%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.89/kW, which is an increase of $0.17/kW (3.0%) compared to Alternative A.

This alternative would have a total benefit of $22 million over the 20-year LTEMP period compared to Alternative A because of the increase in the economic value of energy produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly water releases at Glen Canyon Dam.

In summary, Alternative D would have the third-highest marketable capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also has the fourth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would increase compared to Alternative A. It has the third-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fifth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.5 Alternative E

Average annual daily generation at Glen Canyon Dam would be 11,521 MWh under representative hydrological conditions. Average daily generation would range from 9,858 MWh in February to 14,352 MWh in July, before falling to 10,332 MWh in October, and then increasing to 11,008 MWh in January (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,620 million, a decrease of $42 million, or 1.6%, compared to Alternative A. SLCA/IP marketable capacity would be 647.0 MW at the 90% exceedance level, which is a 90 MW, or 12.2%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and SLCA/IP marketable capacity under Alternative E compared to Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative E over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative E would be just over $36.3 billion.

Because of the additional gas turbine the average retail electric rate would increase about 0.50% and the average monthly residential electricity bill would increase by an average of $0.47. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $13.93/kWh, which is an increase of $0.47/kWh (3.5%) compared to Alternative A. The average wholesale capacity rate was estimated to be $5.92/kW, which is an increase of $0.2/kW (3.5%) compared to Alternative A.

This alternative would have a total benefit of $28 million over the 20-year LTEMP period compared to Alternative A because of the increase in the economic value of energy produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly water releases at Glen Canyon Dam.

In summary, Alternative E would have the fourth-highest marketable capacity from SLCA/IP of the alternatives and would be tied for the third-smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the third-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would increase compared to Alternative A. It would have the fifth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the fourth-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.6 Alternative F

Average annual daily generation at Glen Canyon Dam would be 11,379 MWh under representative hydrological conditions. Average daily generation under representative hydrological conditions would range from 6,918 MWh in January to 19,995 MWh in June, before falling to 7,891 MWh in in October, and then increasing to 9,495 MWh in November and falling to 6,911 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year study period under representative conditions would be $2,540 million, a decrease of $122 million, or 4.6%, compared to Alternative A. SLCA/IP marketable capacity would be 423.1 MW at the 90% exceedance level, which is a 314 MW, or 42.6%, decrease compared to Alternative A. There would therefore be large decreases in average annual daily generation in summer and winter months that have the highest electricity prices and a large decrease in SLCA/IP marketable capacity under Alternative F compared to Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 5,280 MW of new capacity built under Alternative F over the 20-year LTEMP period. Two additional gas turbines are built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative F would be just over $36.6 billion.

Because of the two additional gas turbines the average retail electric rate would increase about 1.21% and the average monthly residential electricity bill would increase by an average of $1.02. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $16.27/kWh, which is an increase of $2.81/kWh (21%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.91/kW, which is an increase of $1.2/kW (21%) compared to Alternative A.

This alternative would have a total benefit of $89 million over the 20-year LTEMP period compared to Alternative A because of the increase in the economic value of energy produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly water releases at Glen Canyon Dam.

In summary, the operating constraints of Alternative F would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the lowest marketable capacity (or the seventh highest) from SLCA/IP of all alternatives and the most new capacity needed over the 20-year LTEMP period. It also would have the highest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would increase compared to Alternative A; in fact, this alternative would have the largest increase in wholesale rates of all alternatives. It would the highest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact.

It would have the largest increase in value of generation at Hoover Dam compared to Alternative A.

4.13.3.7 Alternative G

Average annual daily generation at Glen Canyon Dam would be 11,403 MWh under representative hydrological conditions. Average daily generation under would range from 8,932 MWh in February to 13,256 MWh in June, before falling to 8,827 MWh in December (Figure 4.13-2). The value of electricity generated by Glen Canyon Dam over the 20-year LTEMP period under representative conditions would be $2,556 million, a decrease of $106 million, or 4.0%, compared to Alternative A. SLCA/IP marketable capacity would be 558.2 MW at the 90% exceedance level, which is which is a 179 MW, or 24.3%, decrease compared to Alternative A. There would therefore be slight decreases in average annual daily generation and hydropower value at Glen Canyon Dam and a large decrease in SLCA/IP marketable capacity under Alternative G compared to Alternative A.

Forecasted increases in electricity demand in the service territories of Western's customer utilities and the planned retirement of existing powerplants result in 5,050 MW of new capacity built under Alternative G over the 20-year LTEMP period. An additional gas turbine is built during the LTEMP period compared to Alternative A. Assuming representative hydrological conditions, the total cost (including capital, fixed, and variable costs) to meet system electric demand under Alternative G would be almost $36.5 billion.

While the capital and operating costs borne by Western customer utilities to replace generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by customer utilities under Alternative G and, consequently, changes in the electric bills of residential customers, impact on electric bills paid by residential customers of Western's customer utilities would be less than 1%.

Because of the additional gas turbine the average retail electric rate would increase about 0.64% and the average monthly residential electricity bill would increase by an average of $0.59. Both metrics are the average in the year of maximum rate impact.

The average wholesale energy rate was estimated to be $15.65/kWh, which is an increase of $2.19/kWh (16%) compared to Alternative A. The average wholesale capacity rate was estimated to be $6.67/kW, which is an increase of $0.95/kW (17%) compared to Alternative A.

This alternative would have a total benefit of $30 million over the 20-year LTEMP period compared to Alternative A because of the increase in the economic value of energy produced at Hoover Dam due to the changes in Lake Mead reservoir elevations resulting from the monthly water releases at Glen Canyon Dam.

In summary, the operating constraints of Alternative G would require a steady flow from Glen Canyon Dam every month of the year. This alternative would have the sixth-highest marketable capacity from SLCA/IP of all alternatives (the second lowest after Alternative F) and would be tied for the third smallest amount of new capacity needed over the 20-year LTEMP period. It also would have the sixth-lowest total cost to meet electric demand over that period. Both the wholesale energy and capacity rates charged by Western would increase compared to Alternative A; in fact, this alternative would have the second-largest increase in wholesale rates of all alternatives. It would have the sixth-lowest change in both average retail electric rate and average monthly residential electricity bill in the year of maximum rate impact. It would have the second-largest increase in value of generation at Hoover Dam compared to Alternative A.

4.14 SOCIOECONOMICS AND ENVIRONMENTAL JUSTICE

This section describes the potential impacts of changes in dam operations on the recreational use values and nonuse values placed on recreational resources by individuals that visit, or may never visit, Lake Powell, Lake Mead, and the Grand Canyon. It also describes the potential regional economic impacts of changes in recreational visitation in a six-county region, and the potential impacts on low-income and minority populations in an 11-county region in the vicinity of the lakes and river corridor, and in eastern Arizona and northwestern New Mexico. The section also describes the regional economic impacts of changes in customer utility electricity bills and of expansion in electricity generation capacity that would occur as a result of changes in dam operations, as well as the potential impacts of changes in utility bills on low-income and minority populations, including tribal populations, in the seven-state region in which power generated at the Glen Canyon powerplant is marketed.

Issue: How do alternatives affect socioeconomics and environmental justice?

Impact Indicators:

- Recreational use values associated with current and potential levels of visitation
- Nonuse (or passive use) economic value associated with the preferences of nonusers
- Employment and income impacts resulting from changes in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures
- High, adverse, and disproportionate impacts of changes in dam operations on low-income and minority populations

4.14.1 Analysis Methods

This section describes the methods used to estimate changes in recreational use values and non-use (or passive use) economic value that would result from changes in dam operations; the methods used to estimate the economic impacts of change in recreational visitation, customer utility electricity generation capacity expenditures, and residential electricity bill expenditures; and methods used to estimate the impacts of changes in dam operations on low-income and minority populations.

4.14.1.1 Recreational Use Values

The economic significance of recreational resources on the Colorado River can be measured both in terms of economic welfare, or consumer surplus, which is the amount of value a consumer of a good or service receives over and above that which would be paid for the good or service in the marketplace. However, as recreational activities are often not a market good, the characteristics of the demand for recreational resources cannot be based on the demand for recreational resources in the marketplace. Accordingly, consumer surplus is often referred to as *non-market value*, which includes both use value and non-use value (also called passive use value).

Estimation of recreational use values associated with potential changes in recreational resources under each of the alternatives relies on the benefits transfer method. This method involves the application of existing recreational use value estimates for a particular time period, site, level of resource quality, or combination thereof to a situation for which data are not available. The traditional benefits transfer approach to valuing recreation has been to employ existing use values studies conducted at an existing site, adjusting estimates to account for inflation. Transferring use value estimates from older studies rely on finding a study area with the same recreation activity in a similar geographic area as the study site, meaning that the preferred approach is to employ statistical recreation models developed for a study site; such models are used in conjunction with coefficients from an existing site to estimate recreation visitation and/or value at the study site, allowing the model transfer technique to improve the validity of the results compared to the use value transfer approach.

Because statistical models have been developed for estimating recreation value per trip for two of the three river reaches in the LTEMP study area—Glen Canyon and Upper Grand Canyon—and models estimating recreation use have been developed for Lake Powell and Lake Mead, while other studies have estimated values per trip for recreation use of Lake Powell and Lake Mead, the benefits transfer methods provides a useful and reliable approach to estimating river use values and lake visitation.

Visitation levels at the reservoirs were estimated using Neher et al. (2013) and then evaluated using the approach described in Gaston et al. (2014). The net economic value of recreation was then estimated for Lake Powell and Lake Mead, using the Lake_Full program; the GCRec_Full program was used to estimate the economic value for recreation on the three reaches of the Colorado River—Glen Canyon (from Glen Canyon Dam to Lees Ferry at RM 0), Upper Grand Canyon (from Lees Ferry to Diamond Creek at RM 225), and Lower Grand Canyon (from Diamond Creek to Lake Mead). These programs and the benefits transfer method are described in Appendix L. A review of use value estimates associated with Lake Powell, Glen Canyon, Upper Grand Canyon, Lower Grand Canyon, and Lake Mead can be found in Gaston et al. (2014).

In addition to use values, there may also be significant non-use values associated with lake and river resources in the Grand Canyon. A review of non-use valuation studies is provided in Section L.1.2 of Appendix L. The NPS is conducting a survey to determine non-use values associated with recreational resources along the Colorado River Corridor located in the Upper and Lower Grand Canyon. The proposed survey uses a stated choice method (conjoint analysis) to estimate changes in passive use values associated with the impacts on riparian areas occurring under each alternative. The survey will be conducted by the University of Montana and will be administered to households selected from two samples, a national sample including all U.S. households, and a regional sample consisting of households within the Glen Canyon Dam region receiving power from Western, including all utilities receiving power from the Glen Canyon Dam. More information on the proposed survey can be found in Appendix L. The results of this survey were not available for this DEIS, but they may be available for inclusion in the final EIS.

4.14.1.2 Recreational Economic Impacts

The economic impacts of changes in recreational activity under each alternative are estimated using changes in visitor expenditures associated with various types of recreational activities, including angling, rafting, and boating, as well as spending on food and beverages, restaurants, fishing and boating equipment, gasoline for vehicles and boats, camping fees or motel expenses, guide services, and fishing license fees. Impacts occurring under each alternative are estimated for the six-county region in which the majority of recreational expenditures are likely to occur, and includes Coconino County and Mohave County in Arizona, and Garfield County, Kane County, San Juan County, and Washington County in Utah. Although a large number of visitors to Lake Mead come from the western side of the Colorado River in Clark County, Nevada, their share of expenditures on lake recreation in Clark County is not known. Expenditures are therefore assumed to occur in the six counties included in the analysis. Although the addition of Clark County to the analysis would likely produce slightly larger lake recreation employment and income impacts under each of the alternatives, it would not affect relative differences among the alternatives. Economic impacts include both direct and secondary effects of changes in expenditures that may occur on employment and income, and were estimated using the IMPLAN analysis tool (IMPLAN Group, LLC 2014). More information on the data and methods used, and a review of studies of the economic impacts of recreation activities in Glen Canyon, Grand Canyon and the surrounding area can be found in Section L.1.3 of Appendix L.

4.14.1.3 Electricity Bill Increase and Generation Capacity Expansion Impacts

Under each LTEMP alternative, the regional economic impacts of the eight largest Western customer utilities constructing and operating additional powerplants to replace energy and capacity losses from Glen Canyon Dam, and the resulting changes in customer utility electricity prices, were analyzed for the seven-state region in which Western markets power. This region includes Arizona, Colorado, Nebraska, Nevada, New Mexico, Utah, and Wyoming. Estimates of the required additional powerplant capacity were taken from the AURORAex model results (see Appendix K), and data on gas powerplant construction and operating expenditures, including materials, equipment, services, direct and indirect labor, by technology, size, and location were taken from the JEDI model (NREL 2015). Data on changes in retail electricity rates charged by the eight largest Western customer utilities, and the resulting changes in residential customer bills, were also included in the analysis (see Appendix K for a description of the retail rate analysis). IMPLAN input-output models (IMPLAN Group, LLC, 2014) (see Section L.1 of Appendix L), were used to estimate the regional economic impacts of additional generating capacity and changes in electricity prices; a separate IMPLAN model represents each of the seven states in the Western power marketing area. Note that the alternatives could affect the seasonal pattern of Lake Mead elevations, and thus power generation and capacity at Hoover Dam. However, such effects at Hoover Dam are anticipated to be relatively small (Section 4.13).

4.14.1.4 Environmental Justice

The analysis of potential environmental justice impacts follows guidelines described in the Council on Environmental Quality's (CEQ's) *Environmental Justice Guidance under the National Environmental Policy Act* (CEQ 1997). Because it is likely that under the alternatives considered here the most important impacts resulting from changes in dam operations would be impacts on recreation, the analysis was undertaken for an 11-county region in which the majority of recreational expenditures are like to occur (including Apache County, Coconino County, Mohave County, and Navajo County in Arizona; Cibola County, McKinley County, and San Juan County in New Mexico; and Garfield County, Kane County, San Juan County, and Washington County in Utah). Other potential impacts related to environmental justice include changes in Tribal electricity retail rates, and impacts on Tribal resources and values. Using CEQ guidelines, the impact assessment determined whether each alternative would produce impacts that are high and adverse. If impacts were high and adverse, a determination was made as to whether these impacts would disproportionately affect minority and low-income populations by comparing the proximity of locations where any high and adverse impacts are expected with the location of low-income and minority populations. If impacts are not high and adverse, there can be no disproportionate impacts on minority and low-income populations.

4.14.2 Summary of Impacts on Socioeconomics and Environmental Justice

Table 4.14-1 summarizes the impacts for recreational use values, recreational economic impacts, and environmental justice.

4.14.2.1 Recreational Use Values

Recreational resources in Lake Powell, Lake Mead, and the Grand Canyon produce significant mean annual use values, with recreational activities in Lake Mead and Lake Powell constituting almost 97% of overall use value under each alternative (Table 4.14-2). Use values are presented in terms of net present value, to allow for differences in the distribution of use values between activities over time. Total mean annual use value created by all lake and river recreational activities amounts to $14,619.8 million under Alternative A (No Action Alternative), values which would decline slightly to between $14,598.7 million under Alternative F and

TABLE 4.14-1 Summary of Impacts of LTEMP Alternative on Socioeconomics and Environmental Justice[a]

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of socioeconomic impacts	No change from current conditions in use values, or economic activity with no change in lake levels or river conditions.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation compared to Alternative A. Increases in use values and economic activity associated with Lake Mead recreation. Increased economic activity from lower residential electric bills compared to Alternative A.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.	Compared to Alternative A, declines in use values and economic activity associated with Lake Powell recreation, and in use values associated with some forms of river recreation. Increases in use values associated with Upper and Lower Grand Canyon private boating and in use values and economic activity associated with Lake Mead recreation. Increased economic activity from capacity expansion, and reduced activity from higher residential electric bills.

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
***Use Values*[a]**							
Lake Powell							
	No change from current conditions in use values ($5,016 million) because no change in water levels	Same as Alternative A	Potential declines in use values of 0.7% (to $4,983 million) associated with lower water levels	Potential declines in use values of less than 0.4% (to $4,997 million) associated with lower water levels	Potential declines in use values of less than 0.5% (to $4,990 million) associated with lower water levels	Potential declines in use values of 1.1% (to $4,961 million) associated with lower water levels	Potential declines in use values of 0.4% (to $4,997 million) associated with lower water levels
Glen Canyon							
	No change from current conditions in use values ($68.8 million) with no changes in river conditions	Potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 4.7% (to $19.2 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 3.4% (to $19.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 13.3% (to $17.4 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions	Potential decline in use values for angling of 6.2% (to $18.9 million) and no change in day-use rafting ($48.7 million) associated with changes in river conditions
Upper Grand Canyon							
	No change from current conditions in use values ($355.8 million) with no changes in river conditions	Potential decline in use values for private whitewater boating of 3.5% (to $66.5 million) and commercial whitewater boating of 5.8% (to $270.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 1.5% (to $67.9 million) and commercial boating of 9.0%, (to $261.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 1.3% (to $68.0 million) and commercial boating of 11.3%, (to $254.4 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 2.3% (to $67.4 million) and commercial boating of 12.9%, (to $249.9 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 0.4% (to $69.2 million) and decline for commercial boating of 2.3%, (to $280.2 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 0.6% (to $68.5 million) and commercial boating of 13.7%, (to $247.6 million) associated with changes in river conditions

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Use Values[a] (Cont.)							
Lower Grand Canyon	No change from current conditions in use values ($64.8 million) with no changes in river conditions	Potential decline in use values for private whitewater boating of 2.0%, (to $3.6 million) for commercial 1-day boating of 4.6% (to $44.0 million); for overnight trips of 5.2% (to $0.52 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions	Potential decline in use values for private whitewater boating of 3.4% (to $3.6 million), for commercial 1-day boating of 9.6% (to $41.7 million), for overnight trips of 11.5% (to $0.49 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 1.9% (to $3.8 million), decrease for commercial 1-day boating of 8.1% ($42.3 million), decrease for overnight trips of 11.7% (to $0.48 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 0.6% (to $3.7 million), decrease for commercial 1-day boating of 10.0% (to $41.5 million), decrease for overnight trips of 14.0% (to $0.47 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 13.3% (to $4.2 million), decrease for commercial 1-day boating of 1.2% (to $45.5 million), decrease for overnight trips 8.9% ($0.46 million); no change for commercial flat-water boating ($14.5 million) associated with changes in river conditions	Potential increase in use values for private whitewater boating of 6.8% (to $3.9 million), decrease for commercial 1-day boating of 8.0% (to $42.4) million); decrease for overnight trips of 13.2% (to $0.42 million); no change commercial flat-water boating ($14.5 million) associated with changes in river conditions
Lake Mead	No changes from current conditions in use values ($9,114.5 million) with no change in water levels	Potential decrease in use values of 0.002% (to $9,114.3 million) associated with higher water levels	Potential increase in use values of 0.3% (to $9,145.2 million) associated with higher water levels	Potential increases in use values of 0.3% (to $9,139.7 million) associated with higher water levels	Potential increases in use values of 0.3% (to $9143.5 million) associated with higher water levels	Potential increases in use values of 0.5% (to $9,157.5 million) associated with higher water levels	Potential increases in use values of 0.3% (to 9,143.3 million) associated with higher water levels

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic Impacts[b]							
Lake Powell							
	No change in direct and indirect employment (2,444 jobs) and income ($99.7 million)	Same as Alternative A	Declines in direct and indirect employment (to 2,430 jobs) and income (to $99.1 million) of 0.6%	Declines in direct and indirect employment (to 2,435 jobs) and income (to $99.3 million) of 0.4%	Declines in direct and indirect employment (to 2,433 jobs) and income (to $99.2 million) of 0.5%	Declines in direct and indirect employment (to 2,418 jobs) and income (to $98.6 million) of 1.1%	Declines in direct and indirect employment (to 2,435 jobs) and income ($99.3 million) of 0.4%
Glen Canyon, Upper, and Lower Grand Canyon							
	No change in direct and indirect employment (156 jobs) and income ($3.6 million) associated with any river-based recreational activities	Same as Alternative A	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities	No change in direct and indirect employment and income associated with any river-based recreational activities
Lake Mead							
	No change in direct and indirect employment (5,099 jobs) and income ($208.0 million)	Same as Alternative A	Increases in direct and indirect employment (to 5,116 jobs) and income (to $208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,114 jobs) and income (to $208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%	Increases in direct and indirect employment (to 5,124 jobs) and income (to $209.0 million) of 0.5%	Increases in direct and indirect employment (to 5,115 jobs) and income (to $208.6 million) of 0.3%

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Economic Impacts*[b] *(Cont.)							
Seven-State Region							
	No additional generation capacity construction and operation beyond existing capacity expansion plans, which would create 9,519 jobs and $841.7 million in income during construction and 1,019 jobs and $69.4 million in income during operation. No change in Western customer utility electricity rates.	No increases in Western customer utility generation capacity construction and operation direct and indirect employment and income impacts compared to Alternative A. Negligible decreases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 10,286 jobs) and income (to $909.6 million) of 8.1% compared to Alternative A, and increases in operations employment (to 1,114 jobs) and income (to $75.7 million) of 9.3% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income	Increase in Western customer utility generation capacity direct and indirect construction employment (to 9,895 jobs) and income (to $875.3 million) of 3.9% compared to Alternative A, and increases in operations employment (to 1,065 jobs) and income (to $72.5 million) of 4.5% compared to Alternative A; negligible increases in customer utility electricity rates, leading to minor impacts on employment and income

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice							
Overall summary of environmental justice impacts	No change from current conditions. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 3.0 years and 0.4 years, respectively, of LTEMP period; financial impacts related to electricity sales similar to those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 6.5 years and 2.8 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 11.0 years and 2.9 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. No disproportion-ately high and adverse impacts on minority or low-income populations.	TMFs and mechanical removal triggered in up to an average of 2.6 years and 1.7 years, respectively, of LTEMP period; financial impacts related to electricity sales would be similar to those under Alternative C. No disproportion-ately high and adverse impacts on minority or low-income populations.	No impact; TMFs and mechanical removal not allowed under this alternative; financial impacts related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A. No disproportion-ately high and adverse impacts on minority or low-income populations.	Highest impact of all alternatives; TMFs and mechanical removal triggered in an average of 11.0 years and 3.1 years, respectively, of LTEMP period; financial impacts related to electricity sales would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A. No disproportionately high and adverse impacts on minority or low-income populations.
Tribal commercial and flat-water boating river boat rentals	No impacts expected with no changes in river visitation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Tribal retailing in vicinity of GCNRA and GCNP	No impacts expected with no changes in river visitation	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A
Tribal marina operators	No impacts expected	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Some impacts expected; decrease of 1.1% in visitation	Same as Alternative A
Access or damage to culturally important plants and resources	Negligible impacts	Same as Alternative A	Same as Alternative A	Same as Alternative A	Same as Alternative A	Some damage and reduced access to resources; increase in time off river	Same as Alternative A
Effects on Tribal values associated with TMFs and mechanical extraction of trout in proximity to sacred places of emergence	Negligible impacts, with no TMFs and infrequent trout removal actions (average 0.1 years of LTEMP period)	TMFs and mechanical removal triggered in up to an average of 3.0 years and 0.4 years, respectively, of LTEMP period	TMFs and mechanical removal triggered in up to an average of 6.5 years and 2.8 years, respectively of LTEMP period	TMFs and mechanical removal triggered in up to an average of 11.0 years and 2.9 years, respectively, of LTEMP period	TMFs and mechanical removal triggered in up to an average of 2.6 years and 1.7 years, respectively, of LTEMP period	No impact; TMFs and mechanical removal not allowed under this alternative	Highest impact of all alternatives; TMFs and mechanical removal triggered in an average of 11.0 years and 3.1 years, respectively, of LTEMP period

TABLE 4.14-1 (Cont.)

Socioeconomic Impact Indicators	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Environmental Justice (Cont.)							
Financial impacts on Tribes related to electricity sales	No impacts expected	Impacts would be similar to those on non-Tribal customers and those under Alternative A	Impacts on Tribes would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.	Impacts on Tribes would be similar to those under Alternative C.	Impacts on Tribes would be similar to those under Alternative C.	Impacts would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A	Impacts would be slightly higher (as much as $1.34/MWh) than those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A

[a] Use values for alternatives are presented in Table 4.14-2.

[b] Employment and income values associated with recreational expenditures are presented in Tables 4.14-4 and 4.14-5, respectively. Employment and income associated with generation capacity are presented in Table 4.14-6, and residential electricity bills are presented in Table 4.14-7.

1 **TABLE 4.14-2 Mean Annual Net Economic Value of Recreation Associated with LTEMP**
2 **Alternatives[a]**

	Mean Annual Net Economic Value ($ Million Net Present Value, 2015) for each Alternative						
Location and Activity	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Lake Powell							
General recreation	5,016.0	5,016.0	4,983.3	4,996.6	4,990.1	4,961.0	4,997.1
Glen Canyon							
Angling	20.1	19.4	18.9	19.2	19.4	17.4	18.9
Day-use rafting	48.7	48.7	48.7	48.7	48.7	48.7	48.7
Upper Grand Canyon							
Private whitewater boating	68.9	66.5	67.9	68.0	67.4	69.2	68.5
Commercial whitewater boating	286.9	270.2	261.2	254.4	249.9	280.2	247.6
Lower Grand Canyon							
Private whitewater boating	3.7	3.6	3.6	3.8	3.7	4.2	3.9
Commercial whitewater boating, 1-day trips	46.1	44.0	41.7	42.3	41.5	45.5	42.4
Commercial whitewater boating, overnight trips	0.55	0.52	0.49	0.48	0.47	0.46	0.42
Commercial flat-water boating	14.5	14.5	14.5	14.5	14.5	14.5	14.5
Lake Mead							
General recreation	9,114.5	9,114.3	9,145.2	9,139.7	9,143.5	9,157.5	9,143.3
All activities	14,619.8	14,598.0	14,585.3	14,587.6	14,579.1	14,598.7	14,585.3

[a] Use values are based on historical direct natural flow hydrology, weighted by sediment flow condition.

Source: Gaston et al. (2014).

3

$14,579.1 million under Alternative E, the latter of which is a decline of 0.3% compared to Alternative A.

Mean annual use values for general recreation in Lake Powell would fall slightly from $5,016 million under Alternative A to between $4,997.1 million under Alternative G and $4,961.0 million under Alternative F the latter of which represents a decline of 1.1%. Potential declines in use values under each alternative would come primarily as a result of lower reservoir water levels, which would mean exposed beaches and mudflats, reducing the quality of the recreational experience. There would be no change in use values associated with Alternative B compared to Alternative A. For Lake Mead, general recreation use values would increase slightly, from $9,114.5 million under Alternative A to between $9,139.7 million under Alternative D to $9,157.5 million under Alternative F, the latter of which is an increase of 0.5%. Higher use values would primarily result from higher reservoir water levels covering previously exposed mudflats and beaches, improving the quality of the recreational experience. There would be a slight decrease in use values associated with Alternative B compared to Alternative A.

Although river-based recreation activities produce less mean annual use value than lake-based activities, there would be more variation among alternatives. Differences between each alternative and Alternative A, where high flow experiments are restricted, are primarily due to the extent to which larger fluctuations in flow associated with each alternative are shifted to seasons of the year that are more popular with visitors.

Angling use values in Glen Canyon would decline from $20.1 million under Alternative A to between $19.4 under Alternative E to $17.4 million under Alternative F, the latter representing a decline of 13.3%. Use values associated with commercial whitewater boating in the Upper Grand Canyon would fall from $286.9 million under Alternative A to between $280.2 million under Alternative F and $247.6 million under Alternative G, the latter representing a 13.7% decline. Mean annual use value generated by 1-day commercial whitewater boating trips in the Lower Grand Canyon would fall from $46.1 million under Alternative A to between $45.5 million under Alternative F and $41.5 million under Alternative E, the latter of which represents a decline of 10.0%.

Private whitewater boating in the Upper Grand Canyon produces $68.9 million in use values under Alternative A, values that would increase to $69.2 million under Alternatives F, an increase of 0.4%, and fall to between $68.5 million under Alternative G and $66.5 million under Alternative B, a decrease of 3.5%. Private whitewater boating in the Lower Grand Canyon would decrease from $3.7 million under Alternative A to $3.6 million for Alternative B and C, and increase to between $3.7 million under Alternative E, and $4.2 million under Alternative F, an increase of 13.3%,

Day-use rafting in Glen Canyon would generate $48.7 million in use value under each of the alternatives, commercial boating overnight trips would produce $0.5 million under each alternative, while commercial flat-water boating in the Lower Grand Canyon would produce $14.5 million under each alternative. Use values for either activity would not change under any of the alternatives, because demand for these activities would not be affected by river levels or fluctuations in river flow.

With the exception of changes in use value associated with commercial whitewater overnight boating trips and commercial flat-water boating in the Lower Grand Canyon, changes in use value for all other forms of river recreation were statistically significant at the 90% confidence level under each alternative, while changes in use value associated with lake recreation were not statistically significant under any of the alternatives.

4.14.2.2 Recreational Economic Impacts

The regional economic impacts of recreation in Lake Powell, Lake Mead, and the Grand Canyon are closely tied to visitation levels for each recreational activity. By far the most significant recreational resource is Lake Mead, which drew almost 6 million individual trips in 2012, 72.0% of the total number of trips to these areas (Table 4.14-3). Lake Powell drew 1.9 million trips, or 23.0% of the total, while there were 0.2 million individual Grand Canyon river trips in 2012 (2.5% of the total). Of the river-based recreational activities, commercial flat-water boating in the Lower Grand Canyon, below Diamond Creek, drew the largest number of individual trips (95,520 individual trips, or 46.0% of the total number of individual river trips), followed by day-use rafting in Glen Canyon (53,578 individual trips, 25.8% of the total) and 1-day white water boating below Diamond Creek (28,748 individual trips, 13.8% of the total). Commercial whitewater boating in the Upper Grand Canyon drew 17,384 individual trips, or 8.4% of total river trips.

Recreational expenditures by visitors to Lake Powell and Lake Mead, and to the Upper and Lower Grand Canyon, create substantial employment and income in the six-county area in Arizona and Utah (Tables 4.14-4 and 4.14-5). Boating in Lake Mead currently produces 5,099 total (direct and indirect) jobs and $208 million in total income (direct and indirect) annually; boating on Lake Powell produces 2,444 total jobs and $99.7 million in income. Over the 20-year LTEMP period, annual direct and indirect economic activity would fall to between 2,435 jobs and $99.3 million in income for Alternative G and 2,418 jobs and $98.6 million in income for Alternative F, for Lake Powell, with increases of between 5,115 jobs and $208.6 million in income for Alternative G, and 5,124 jobs and $209.0 million in income for Alternative F for Lake Mead. Changes in employment under Alternative F resulting from changes in recreation at Lake Powell would represent a decrease of 1.1% in compared to Alternative A, and an increase of 0.5% under Alternative F at Lake Mead. There would be no change in recreational economic impacts associated with Alternative B compared to Alternative A.

Because current NPS regulations restrict the number of river boating trips that can be taken, with a long waiting list for private boating permits and a large number of commercial passengers who cannot be accommodated due to these restrictions (Gaston et al. 2014), the analysis assumes that the number of angling and whitewater boating trips would not change as a result of any of the alternatives, meaning that the regional economic impacts for river recreation under each of the alternatives would be the same as for Alternative A. The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs annually and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and

TABLE 4.14-3 Recreational Visitation by Activity in Lake Powell, Upper and Lower Grand Canyon, and Lake Mead, 2012

Location	Activity	Number of Annual Individual Trips
Lake Powell	General recreation	1,914,768
Glen Canyon	Angling	4,925
	Day-use rafting	53,578
Upper Grand Canyon	Private white water boating	5,978
	Commercial white water boating	17,384
Lower Grand Canyon	Private white water boating	1,445
	Commercial white water boating, one-day trips	28,748
	Commercial white water boating, overnight trips	100
	Commercial flat-water boating	95,520
Lake Mead	General recreation	5,991,767
Total	All activities	8,114,213

Source: Gaston et al. (2014).

TABLE 4.14-4 Mean Annual Employment Associated with Recreational Expenditures under LTEMP Alternatives

Location and Activity	Annual Employment (Number of Full-Time Equivalent Jobs[a]) under LTEMP Alternatives						
	A	B	C	D	E	F	G
Lake Powell							
General Recreation	2,444	2,444	2,430	2,435	2,433	2,418	2,435
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	156	156	156	156	156	156	156
Lake Mead							
General Recreation	5,099	5,099	5,116	5,114	5,115	5,124	5,115
Total							
All Activities	7,699	7,699	7,700	7,704	7,702	7,697	7,706

[a] To accurately estimate employment, which may include part-time or overtime working, full-time equivalent (FTE) jobs are used. These are the total number of hours worked in a particular activity divided by the number of regular working hours in a year.

Source: IMPLAN Group, LLC (2014).

TABLE 4.14-5 Mean Annual Income Associated with Recreational Expenditures under LTEMP Alternatives

	Annual Income ($million, 2013) under LTEMP Alternatives						
Location and Activity	A	B	C	D	E	F	G
Lake Powell							
General Recreation	99.7	99.7	99.1	99.3	99.2	98.6	99.3
Glen Canyon, Upper, and Lower Grand Canyon							
Angling, Private and Commercial Boating	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Lake Mead							
General Recreation	208.0	208.0	208.6	208.6	208.6	209.0	208.6
Total							
All Activities	311.3	311.3	311.3	311.5	311.4	311.2	311.6

Source: IMPLAN Group, LLC (2014).

$0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts. A total of 156 jobs and $3.6 million in income are currently produced annually across all river recreational activities under Alternative A, with the same annual impacts expected under each alternative.

4.14.2.3 Customer Utility Electricity Generation Capacity and Residential Rate Increase Impacts

Although there would be no change in Glen Canyon Dam capacity under Alternative A, forecasted increases in the demand for electricity and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built by the eight largest Western customer utilities under Alternative A over the 20-year study period. Under Alternative B, 4,820 MW of additional capacity would also be added, while a reduction in available generating capacity at Glen Canyon Dam under Alternatives C, D, E, and G would mean that alternative generating capacity would be required by Western customer utilities to replace lost hydropower capacity. An additional 5,050 MW would be required under Alternatives C, D, E, and G (an increase of 4.8% compared to Alternative A), with 5,280 MW needed under Alternative F (an increase of 9.5%) (see Section 4.13.2.3).

Using estimated capital and operating costs associated with providing additional capacity under each alternative for the eight largest Western customer utilities, the economic impacts of construction and operation of additional capacity are shown in Table 4.14-6. Under Alternative A, powerplant construction would produce an estimated 9,519 total (direct and

TABLE 4.14-6 Seven-State Economic Impacts[a] under LTEMP Alternatives of Additional Generating Capacity for the Eight Largest Customer Utilities, 2015–2033

	Alternative						
Parameter	A	B	C	D	E	F	G
Construction							
Employment (FTEs)	9,519	9,519	9,895	9,895	9,895	10,286	9,895
Earnings ($Million 2015)	841.7	841.7	875.3	875.3	875.3	909.6	875.3
Operations							
Employment (FTEs)	1,019	1,019	1,065	1,065	1,065	1,114	1,065
Earnings ($Million 2015)	69.4	69.4	72.5	72.5	72.5	75.7	72.5

[a] Impacts assume average hydrological conditions, and that powerplants would use advanced oil/gas combined cycle or advanced combustion turbine technology. Construction impacts are total impacts over a 3-year construction period; operations impacts are average annual impacts.

Source: IMPLAN Group, LLC (2014).

indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative A would create 1,019 total jobs and $69.4 million in annual earnings. Alternative B would also require the same capacity as Alternative A, with 9,519 jobs and $841.7 million in earnings created directly and indirectly in the seven states. Operations would produce 1,019 total jobs and $69.4 in earnings per year. Alternatives C, D, E, and G would require slightly more additional capacity than Alternative A, producing 9,895 total construction and 1,065 total operations jobs, an increase of 3.9%, $875.3 million in construction earnings, and $72.5 annually during operations. The largest impacts of capacity additions would be under Alternative F, where 10,286 total jobs, an increase of 8.1%, and $909.6 million in earnings would be produced during construction, and 1,114 jobs and $75.7 million would be produced annually in earnings during operations. It should be noted that the alternatives could affect the seasonal pattern of Lake Mead elevations and, thus, power generation and capacity at Hoover Dam, and the associated impacts described here for Glen Canyon Dam. However, such effects related to Hoover Dam generation are anticipated to be relatively small (Section 4.13).

Costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently, changes in the electric bills of residential customers. Although there is considerable variation in the amount of power sold by Western to customer utilities, ranging from 0.8% of customer utility power sales with Salt River Project to 23.7% with Navajo Tribal Utility Authority among the eight largest customer utilities, only 7.3% of power sales for all eight of the largest customer utilities comes from Western, meaning that the cost of additional capacity required under each alternative to replace capacity lost at Glen Canyon Dam has only negligible impacts (average less than 2% in maximum impacts year) on electric bills paid by residential customers of the eight largest Western customer utilities. Two groups of utilities that are allocated a large fraction of their generation resources from SLCA/IP projects are Tribal utilities and other small utilities. These groups would be affected more by capacity expansion differences among alternatives than others; Tribal utilities (Navajo and Cocopah) would experience up to a 2.8% increase in retail rates, while small utilities with the largest impact would experience up to a 3.1% increase in retail rates (see Appendix K for additional detail).

Although the economic impacts of changes in retail electricity rates and the corresponding impacts on residential customer bills would be dependent on the timing and magnitude of capacity expansion required under each alternative, changes in customer rates under each alternative are small. Table 4.14-7 shows the average annual losses in economic activity in the seven-state region for the eight largest customer utilities. Impact data are based on the aggregation of bill increases across the eight largest customer utilities, weighting by individual utility power sales compared to total power sales for all eight utilities. Changes in retail rates range from a decrease of 0.27%% under Alternative B to an increase of 1.21% under Alternative F (Table 4.13-1).

The impact of these increases on employment and income in the seven-state region would range from less than 10 total (direct and indirect) jobs lost and $0.3 million in earnings lost under Alternative E to 41 jobs and $1.9 million in earnings lost under Alternative F. A slight decrease in electric bills under Alternative B would mean small increases in employment (less than 10 jobs) and earnings (an increase of $0.1 million).

4.14.2.4 Environmental Justice Impacts

Changes in river and lake recreational visitation might disproportionately impact low-income and minority populations including Tribal communities, both in the counties in the vicinity of the GCNRA and GCNP, and in the seven-state area in which power from Glen Canyon Dam is marketed.

TABLE 4.14-7 Average Annual Impacts on Economic Activity from Changes to Residential Electricity Bills of Largest Eight Customer Utilities, 2015–2033, Relative to Alternative A

	Alternative					
Parameter	B	C	D	E	F	G
Changes to employment (FTE jobs) compared to Alternative A	An increase in up to 10 new jobs	A reduction of 23 jobs	A reduction of 10 jobs	A reduction of 10 jobs	A reduction of 41 jobs	A reduction of 25 jobs
Changes to earnings ($2015Million) compared to Alternative A	An increase of $0.1 in earnings	A loss of $1.0 in earnings	A loss of $0.4 in earnings	A loss of $0.3 in earnings	A loss of $1.9 in earnings	A loss of $1.2 in earnings

Source: IMPLAN Group, LLC (2014).

Eleven-County Region

There were a large number of low-income and minority individuals in the 11-county region as a whole in the 2010 Census, with 38.0% of the population classified as minority, and 12.7% classified as low-income using data from the 2008–2012 American Community Survey. However, the number of minority or low-income individuals does not exceed state averages by 20 percentage points or more, and does not exceed 50% of the total population in the area. This means that for the 11-county region as a whole, there are no minority or low-income populations based on the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. 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. Minority individuals exceed 50% of the total population in Apache County and Navajo County, Arizona; Cibola County, McKinley County, and San Juan County, New Mexico; and in San Juan County, Utah, indicating that there are minority populations in each of these counties based on county level data in the 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. Because 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.

A large number of census block groups in the vicinity of the GCNRA and GCNP with low-income and minority populations could be affected if changes in visitation levels produced impacts that were high and adverse. In Coconino County, Arizona, a number of block groups have populations where the percentage of minorities is more than 20 percentage points higher than the state average. These are located in the eastern part of the county on the Navajo Nation Indian Reservation and Hopi Indian Reservation, in the western part of the county, including the Havasupai Indian Reservation and the Hualapai Indian Reservation, which are also located in one block group in eastern Mohave County, Arizona. One census block group in Page, Arizona, also has a minority population which is more than 50% of the total. There are a number of census block groups in San Juan County, Utah, where more than 50% of the total population is minority. These are located in the southern portion of the county and include the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation.

There are a large number of census block groups in the vicinity of GCNRA and GCNP where the percentage of low-income individuals is more than 20 percentage points higher than the state average. These are located in (1) Coconino County, Arizona, on the Navajo Nation Indian Reservation and the Hopi Indian Reservation; (2) Navajo County, Arizona, on the Navajo Nation Indian Reservation, which also contains the Fort Apache Indian Reservation; (3) eastern Mohave County, Arizona, on the Hualapai Indian Reservation; and (4) southeastern and southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation. There are also a number of census block groups in the 11-county area where more than 50% of the total population is below the poverty level. These are located in (1) the eastern part of Coconino County, Arizona, on the Navajo Nation Indian Reservation and Hopi Indian Reservation; (2) southwestern San Juan County, Utah, on the Navajo Nation Indian Reservation and the Ute Mountain Indian Reservation; (3) the northern parts of Navajo County and Apache County, Arizona; and (4) southwestern Navajo County on the Fort Apache Indian Reservation.

Changes to river recreation could impact Tribes in the vicinity of GCNRA and GCNP. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe, for employment and income, but as Table 4.14-5 shows, there are negligible differences expected among the alternatives. NPS regulates the number of river boating trips that can be taken, with a set number of river trip launches per year, meaning that none of the alternatives are expected to impact overall levels of recreational river visitation. Although differences in time off river for river trips among the alternatives, or differences in stage levels, could change visitation patterns, either of these leading to potential damage and reduced access to culturally important plants and resources, these impacts are expect to be negligible for all alternatives except Alternative F, which may have a slight increase in the potential for effects to cultural sites based on more time off river (see Table 4.14-5). Changes to river stage levels, such as those caused by HFEs, could temporarily restrict Tribal access to culturally important resources, such as springs, minerals, and plants. Similar impacts may also occur if recreational visitors spend more time away from destination campsites with inundation by higher water levels (Section 4.8), but these impacts are expected to be small. Higher water levels may have positive impacts from flushing out springs that have cultural significance to Tribal members, such as Pumpkin Springs (Section 4.9).

Temporary changes in access to culturally important Tribal resources and other areas of significance to tribes may also impact Tribal members. As described in Section 4.9, for those Tribes that hold the Canyons to be a sacred space, the plant and animal life are integral elements without which its sacredness would not be complete. The Zuni, in particular, have established a lasting familial relationship with all aquatic life in the Colorado River and the other water sources in the Canyons (Dongoske 2011a). They consider the taking of life through the mechanical removal of trout or TMFs to be offensive, and to have dangerous consequences for the Zuni. The confluence of the Colorado River and the Little Colorado River is considered a sacred area because of its proximity to places identified in traditional Tribal narratives as the locations of the Zuni and the Hopi emergence into this world and other important events. The killing of fish in proximity to sacred places of emergence is considered desecration, and would have an adverse effect on the Grand Canyon as a Zuni Traditional Cultural Property. The Zuni have expressed their view on this subject in Section 3.9.6. As shown in Table 4.14-1, there are differences among alternatives in the frequency of TMFs and mechanical removal of trout; Alternatives A and F would have the fewest of these actions, and Alternatives D and G the most.

In addition, fluctuations in lake levels could impact Tribes and resources managed by them, such as the Navajo Antelope Point marina operations. As shown in Section 4.8, there are negligible differences among all alternatives for impact to the Antelope Point marina, except under Alternative F, which shows a small difference from Alternative A (1.1%). As presented in Table 4.8-3, impacts on tradespeople making and selling jewelry and souvenirs to the traveling public along various routes in the region, primarily those in the vicinity of GCNRA and GCNP, are likely to be negligible, with no differences between the alternatives.

Seven-State Region

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. However, the number of minority or low-income individuals 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 seven-state region as a whole, there are no minority or low-income populations based on 2010 Census, the 2008–2012 American Community Survey data, and CEQ guidelines. 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 and CEQ guidelines, 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 Tribal members in the seven-state area, many of whom reside on Indian Reservations. Many of these individuals have low-income status.

Tribal members receive a significant portion of their electricity from Western, 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 SLCA/IP; this includes power from Glen Canyon Dam (see Section K.4 in Appendix K). Nine Tribes operate their own electric utilities and receive power directly from Western; the remaining 48 have a benefit crediting arrangement. In a benefit crediting arrangement, the Tribe's electric service supplier takes delivery of the SLCA/IP allocation and in return gives an economic benefit or a payment to the tribe.

Tribes may be financially affected in one of three ways by the LTEMP alternatives: (1) a change in the rate they pay for SLCA/IP electric power if they operate their own utility; (2) a change in the payment they receive from their electric service provider if they have a benefit crediting arrangement; or (3) a change in both the payment they receive from their supplier for the benefit crediting arrangement and the electric rate their supplier charges if their supplier also receives an SLCA/IP allocation.

The benefit credit is computed by taking the difference between the SLCA/IP rate and the supplier rate and multiplying it by the Tribe's SLCA/IP allocation. Because the SLCA/IP rate is generally lower than the supplier's rate, the difference between the rates is considered a benefit by the Tribe and is the financial equivalent of a direct delivery of electricity.

Tribes whose supplier also receives a SLCA/IP allocation have a second financial impact. The retail electricity rate their supplier charges could change as a result of an alternative. The retail rate impact is computed by taking the difference in retail rates between an alternative and Alternative A and multiplying by the total electrical use on the Tribe's reservation. Therefore, the financial impact on these Tribes is the sum of the Tribal benefit credit and the retail rate impact.

The financial impact of all alternatives would be relatively small, but the impact on Tribal members would be greater than on non-Tribal residential customers (Table 4.14-8; see Section K.4 in Appendix K for a description of the analysis and results). Differences in impacts on the three groups are as follows:

- Tribal customers receiving power from a non-Tribal utility with an associated benefit credit: Financial impacts (increases in retail rates and reductions in benefit credit) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.63/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.05 (net benefit), $0.91, $0.68, $0.58, $3.26, and $2.84/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Tribal customers that purchase from Tribal-owned utilities: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of $0.00/MWh under Alternative B to $1.72/MWh under Alternative G. Alternatives C, D, E, and F would produce an increase in financial impact of $0.37, $0.31, $0.24, and $1.53/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of $0.02, $0.44, $0.39, $0.30, $2.00, and $2.37/MWh under Alternatives B, C, D, E, F, and G, respectively.

- Non-Tribal customers: Financial impacts (increases in retail rates) would range from an average increase (compared to Alternative A) of –$0.02/MWh (net benefit) under Alternative B to a $0.67/MWh increase under Alternative F. Alternatives C, D, E, and G would produce an increase in financial impact of $0.22, $0.15, $0.13, and $0.38/MWh, respectively. The Tribe with the maximum impact would experience financial impacts of –$0.07 (net benefit), $0.62, $0.41, $0.38, $1.86, and $1.07/MWh under Alternatives B, C, D, E, F, and G, respectively.

In summary, for the majority of resource areas, impacts on minority and low-income individuals are likely to be negligible. Commercial whitewater and flat-water boating below Diamond Creek is important to the Hualapai Tribe for employment and income, but there are expected to be negligible economic differences expected among the alternatives. Fluctuations in lake levels affecting the Navajo Antelope Point marina operations are expected to be negligible under all alternatives except Alternative F, which shows a small difference from Alternative A. Impacts also are likely to be negligible on tradespeople making and selling jewelry and souvenirs to the traveling public along routes in the vicinity of the Grand Canyon itself, with no differences between the alternatives.

TABLE 4.14-8 Financial Impacts on Tribal and Non-Tribal Electricity Customers

Parameter	Average Value under Alternative A ($/MWh)	Change from Alternative A					
		Alternative B	Alternative C	Alternative D	Alternative E	Alternative F	Alternative G
Tribal Customers with Benefit Credit (48 Utilities)							
Average Retail Rate ($/MWh)	91.82	–0.01	0.08	0.05	0.05	0.23	0.13
Average Benefit Credit ($/MWh)	8.84	–0.01	–0.27	–0.24	–0.18	–1.23	–1.45
Total of Retail and Benefit Impacts ($/MWh)	82.98	0.00	0.37	0.31	0.24	1.53	1.63
Maximum Impact: Hopi Tribe	72.67	–0.05	0.91	0.68	0.58	3.26	2.84
Tribal Customers without Benefit Credit (nine Utilities)							
Average Retail Rate ($/MWh)	95.09	0.00	0.40	0.33	0.26	1.63	1.72
Maximum Impact: Ak-Chin Indian Community	83.10	0.02	0.44	0.39	0.30	2.00	2.37
Non-Tribal Customers (142 Utilities)							
Average Retail Rate ($/MWh)	92.15	–0.02	0.22	0.15	0.13	0.67	0.38
Maximum Impact	73.74	–0.07	0.62	0.41	0.38	1.86	1.07

Differences in time off river and differences in stage levels, such as those caused by inundation during HFEs, could lead to damage and reduced Tribal access to culturally important plants and resources. However, the impacts are expected to be negligible for all alternatives except Alternative F, which may lead to a slight increase in impacts on cultural sites.

The financial impacts on Tribal members would be greater than those on non-Tribal residential customers, especially under Alternatives F and G. Financial impacts of other alternatives are all less than $1.00/MWh.

4.14.3 Alternative-Specific Impacts

4.14.3.1 Alternative A (No Action Alternative)

Use values associated with recreation in Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon are substantial and current use values would not change under Alternative A. Use values associated with general recreational activities in Lake Mead ($9,114.4 million) and Lake Powell ($5,016 million) constitute almost 97% of the value created by lake and river resources in the affected area under Alternative A. Under Alternative A, commercial and private whitewater boating would produce $286.9 million and $68.9 million in use value, respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Recreational expenditures by visitors to Lake Powell, Lake Mead, and the Upper and Lower Grand Canyon create substantial employment and income in the six-county area in Arizona and Utah. Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and the largest amount of income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period.

The largest river recreation impacts are from 1-day commercial whitewater boating trips below Diamond Creek, which produces 61 jobs and $1.4 million in income, and commercial whitewater trips in the Upper Grand Canyon (37 jobs and $0.8 million in income). Angling (19 jobs and $0.5 million in income) in Glen Canyon, and day-use rafting (commercial flat-water boating) (19 jobs and $0.4 million in income) below Diamond Creek would produce smaller impacts.

A total of 7,699 jobs and $311.3 million in income would be produced annually across all lake and river recreational activities under Alternative A over the 20-year LTEMP period.

Although no additional generating capacity would be required under Alternative A as a result of changes in Glen Canyon Dam operations among the eight largest Western customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative A over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants with Alternative A would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be no change in Glen Canyon Dam operations as a result of Alternative A, there would be no impact on retail rates charged by the eight largest Western customer utilities or the electric bills paid by their residential customers, or subsequent impacts on employment or income, in the seven-state region.

In summary, with no change in lake levels or river conditions under Alternative A, there would be no change from current conditions in use values, economic activity, residential electricity bills, or environmental justice.

4.14.3.2 Alternative B

Under Alternative B, total use values associated with recreation in Lake Mead and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while remaining unchanged for Lake Powell (Table 4.14-2). General recreational activities in Lake Mead would produce $9,114.3 million in use value and $5,016.0 million at Lake Powell, while commercial and private whitewater boating would produce $270.2 million (5.8% decrease) and slightly less than $66.5 million (3.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Under Alternative B, recreational expenditures by visitors and the number of jobs and income that would be created would be the same as under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,543 jobs and $307.7 million in income annually over the 20-year LTEMP period. Impacts on river-based recreational activities would be the same as those under Alternative A.

Because Alternative B would feature the same monthly volumes as Alternative A, there would be no change in use value and economic impact associated with lake-based recreational activities. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily due to larger fluctuations in flow that would occur in seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative B compared to Alternative A.

Although additional generating capacity would not be necessary under Alternative B as a result of changes in Glen Canyon Dam operations among the eight largest Western customer utilities, forecasted increases in the demand for electricity in the service territories of the eight largest customer utilities and the planned retirement of existing powerplant generating capacity would mean that an estimated 4,820 MW of new capacity would be built under Alternative B over the 20-year LTEMP period, as would be the case for Alternative A. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,519 total (direct and indirect) jobs in the seven-state region, and $841.7 million in earnings. Operation of new powerplants under Alternative B would create 1,019 total jobs and $69.4 million in annual earnings associated with new jobs.

Because there would be slightly more Glen Canyon Dam generation capacity under Alternative B, retail rates charged by the eight largest Western customer utilities and the electric bills paid by their residential customers would fall, meaning the addition of less than 10 total (direct and indirect) jobs and an increase of $0.1 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative B, and the impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to implementation of TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be similar to those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative B, there would be a decline in use values associated with Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating commercial whitewater 1-day trips, and Lake Mead recreation compared to Alternative A. There would be no change in use values associated with Lake Powell recreation, Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with Lake Powell and Lake Mead recreation, or river recreation. There would be an increase in economic activity as a result of lower residential electric bills compared to Alternative A.

4.14.3.3 Alternative C

Under Alternative C, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities would produce $9,145.2 million (0.3% increase) in use value at Lake Mead and $4,983.3 million (0.7% decrease) at Lake Powell, while commercial and private whitewater boating would produce $261.2 million (9.0% decrease) and $67.9 million (1.5% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Under Alternative C, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,544 jobs and $307.7 million in income annually over the 20-year LTEMP period, a difference of 0.04% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,700 jobs and $311.3 million in income would be produced annually across all lake and river recreational activities under Alternative C over the 20-year LTEMP period.

Differences in use value and economic impact associated with lake-based recreational activities under Alternative C compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily due to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative C compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative C, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest Western customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative C over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, and $875.3 million in earnings. Operation of new powerplants under Alternative C would create 1,065 total jobs, a difference of 3.9% compared to Alternative A, and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative C would only have negligible impacts on electric bills paid by residential customers of the eight largest Western customer utilities, and would mean the loss of 23 total (direct and indirect) jobs and $1.0 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative C there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, Lower Grand Canyon private whitewater boating, and commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. Increased economic activity would result from customer utility capacity expansion compared to Alternative A, and reduced economic activity would come as a result of higher residential electric bills.

4.14.3.4 Alternative D (Preferred Alternative)

Under Alternative D, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,139.7 million (0.3% increase) in use value and $4,996.6 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $254.4 million (11.3% decrease) $68.0 million (a 1.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Under Alternative D, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those for Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all lake and river recreational activities under Alternative D over the 20-year LTEMP period.

Reductions in use value and economic impact associated with lake-based recreational activities under Alternative D compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience, as well as reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative D compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative D, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest Western customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated

5,050 MW of new capacity would be built under Alternative D over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants under Alternative D would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative D would have impacts on electric bills paid by residential customers of the eight largest Western customer utilities and would mean the loss of less than 10 total (direct and indirect) jobs and $0.4 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators or Tribal retailing in the vicinity of GCNRA and GCNP under Alternative C, and the impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative D there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.5 Alternative E

Under Alternative E, total use values associated with recreation in Lake Powell and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.5 million (0.3% increase) in use value and $4,990.1 million (0.5% decrease) at Lake Powell, while commercial and private whitewater boating would produce $249.9 million (12.9% decrease) and $67.4 million (a 2.3% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Under the Alternative E, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,546 jobs and $307.8 million in income annually over the 20-year study period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,702 jobs and $311.4 million in income would be produced annually across all lake and river recreational activities under Alternative E over the 20-year LTEMP period.

Small reductions in use value and economic impact associated with lake-based recreational activities under Alternative E compared to Alternative A would result primarily from changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the shifting of monthly volumes away from seasons of the year that are more popular with visitors. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels or fluctuations in flow under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative E compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative E, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest Western customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative E over the 20-year LTEMP period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants under Alternative E would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative E would only have negligible impacts on electric bills paid by residential customers of the eight largest Western customer utilities, and would mean the loss of less than 10 total (direct and indirect) jobs and $0.3 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative E, and the impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) than those on non-Tribal customers, and those under Alternative A.

In summary, under Alternative E there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon private whitewater boating, commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values and economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.6 Alternative F

Under Alternative F, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,157.5 million (0.5% increase) in use value and $4,961.0 million (1.1% decrease) at Lake Powell, while commercial and private whitewater boating in the Upper Grand Canyon would produce $280.2 million (2.3% decrease) and $69.2 million (0.4% increase), respectively; other activities in the Lower Grand Canyon would produce lower use values.

Under Alternative F, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,542 jobs and $307.6 million in income annually over the 20-year LTEMP period, a difference of 0.02% compared to Alternative A. Impacts on the various river-based recreational activities would be the same as those under Alternative A. A total of 7,697 jobs and $311.2 million in income would be produced annually across all lake and river recreational activities under Alternative F over the 20-year LTEMP period.

Small reductions in use value and economic impact associated with lake-based recreational activities under Alternative F compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in the quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the large shifts in monthly volumes; although the high volumes of May and June would result in higher use value during those months, the very low flows for much of the rest of the year would result in lower use value at those times. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative F compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative F, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest Western customer utilities, and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,280 MW of new capacity would be built under Alternative F over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 10,286 total (direct and indirect) jobs in the seven-state region, a difference of 8.1% compared to Alternative A, and $909.6 million in earnings. Operation of new powerplants under Alternative F would create 1,114 total jobs and $75.7 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative F would only have negligible impacts on electric bills paid by residential customers of the eight largest Western customer utilities, and would mean the loss of 41 total (direct and indirect) jobs and $1.9 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative F, although changes in lake visitation would be sufficient to affect Tribal marina operators. Access or damage to culturally important plants and resources would also be affected under Alternative F. No impacts on Tribal values related to TMFs or mechanical removal of trout would occur because these actions are not allowed under this alternative. Financial impacts on Tribes related to electricity sales would be slightly higher (<$1.00/MWh) from those on non-Tribal customers, and would be greater (as much as $3.26/MWh) than those under Alternative A.

In summary, under Alternative F there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values in Upper and Lower Grand Canyon private whitewater boating and in use values economic activity associated with Lake Mead recreation. There would be increased economic activity from customer utility capacity expansion compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.14.3.7 Alternative G

Under Alternative G, total use values associated with recreation in Lake Powell, and the Upper and Lower Grand Canyon would decrease slightly relative to Alternative A, while increasing for Lake Mead (Table 4.14-2). General recreational activities in Lake Mead would produce $9,143.3 million (0.3% increase) in use value and $4,997.1 million (0.4% decrease) at Lake Powell, while commercial and private whitewater boating would produce $247.6 million (13.7% decrease) and $68.5 million (a 0.6% decrease), respectively, in the Upper Grand Canyon; other activities in the Lower Grand Canyon would produce lower use values.

Under Alternative G, recreational expenditures by visitors and the number of jobs and income that would be created in the six-county area in Arizona and Utah would be similar to those under Alternative A (Tables 4.14-4 and 4.14-5). Private boating in Lake Mead and Lake Powell would produce the largest number of jobs and income, amounting to 7,550 jobs and $308.0 million in income annually over the 20-year LTEMP period, a difference of 0.1% compared to Alternative A. Impacts on river-based recreational activities would be the same as those under Alternative A. A total of 7,706 jobs and $311.6 million in income would be produced annually across all lake and river recreational activities under Alternative G over the 20-year LTEMP period.

Small reductions in use value and economic impact associated with lake-based recreational activities under Alternative G compared to Alternative A would come primarily as a result of changes in reservoir water levels, which would mean differences in exposure of beaches and mudflats, and consequently a change in quality of recreational experience and reduced visitor spending. Changes in use values associated with Glen Canyon angling and Upper and Lower Grand Canyon private whitewater boating and commercial whitewater boating 1-day trips would be primarily related to the equal monthly volumes that would occur year-round, and consequently lower flows during the more popular summer months. Use values for Glen Canyon day-use rafting, Lower Grand Canyon commercial overnight boating trips, and commercial flat-water boating would not change, because demand for these activities would not be affected by river levels under this alternative. With no changes in visitation for any of the river-based activities, there would be no change in the economic impact of these activities under Alternative G compared to Alternative A.

In addition to changes in generation and marketable capacity resulting from changes in Glen Canyon Dam operations under Alternative G, there would also be forecasted increases in the demand for electricity in the service territories of the eight largest Western customer utilities and the planned retirement of existing powerplant generating capacity, meaning that an estimated 5,050 MW of new capacity would be built under Alternative G over the 20-year study period. Using estimated capital and operating costs associated with providing additional capacity, powerplant construction would produce 9,895 total (direct and indirect) jobs in the seven-state region, a difference of 3.9% compared to Alternative A, and $875.3 million in earnings. Operation of new powerplants with Alternative G would create 1,065 total jobs and $72.5 million in annual earnings associated with new jobs.

Although costs associated with replacing generation capacity no longer provided at Glen Canyon Dam would mean changes in retail rates charged by Western customer utilities, and consequently changes in the electric bills of residential customers, the cost of additional capacity required to replace capacity lost at Glen Canyon Dam under Alternative G would have impacts on electric bills paid by residential customers of the eight largest Western customer utilities, and would mean the loss of 25 total (direct and indirect) jobs and $1.2 million in earnings in the seven-state region.

With no change in river visitation there would be no impacts on Tribal river boat rental operators and Tribal retailing in the vicinity of GCNRA and GCNP under Alternative G, and the impacts of changes in lake visitation on Tribal marina operators would be negligible. Access or damage to culturally important plants and resources would be negligible, but impacts on Tribal values related to TMFs and mechanical removal of trout would be adverse. Financial impacts on Tribes related to electricity sales would be higher (as much as $1.34/MWh) from those on non-Tribal customers, and would be greater (as much as $2.84/MWh) than those under Alternative A.

In summary, under Alternative G there would be a decline in use values associated with Lake Powell recreation, Glen Canyon angling, Upper Grand Canyon private and commercial whitewater boating, and Lower Grand Canyon commercial whitewater 1-day trips compared to Alternative A. There would also be a decline in economic activity associated with Lake Powell recreation. There would be no change in use values associated with Glen Canyon day-use rafting, Lower Grand Canyon commercial whitewater boating overnight trips, or commercial flatwater boating. There would also be no change in economic activity associated with river recreation. There would be an increase in use values for Lower Grand Canyon private whitewater boating and in use values and economic activity associated with Lake Mead recreation. There would also be increased economic activity from customer utility capacity expansion, compared to Alternative A, and reduced economic activity as a result of higher residential electric bills.

4.15 AIR QUALITY

This section describes potential impacts of the LTEMP alternatives on ambient air quality in the immediate vicinity of GCNP and over the 11-state study area within the Western Interconnect, where the air quality would potentially be affected by the proposed action. The regional air quality setting is described in Section 3.15.

Issue: How do alternatives affect emissions from other facilities and air quality in the Grand Canyon area and in the 11-state study area?

Impact Indicators:

- Visibility effects from sulfates and nitrates
- SO_2 and NO_x emissions

4.15.1 Analysis Methods

Glen Canyon Dam hydropower generation does not generate air emissions. However, dam operations can affect emissions within the SLCA/IP system, which is referred to here as "the system." It also impacts emissions and ambient air quality over the 11-state Western

Interconnect region, which includes Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, because hydropower generation offsets generation from other generating facilities (i.e., coal-fired, natural gas-fired,) in the Western Interconnect. Differences among alternatives in the amount of generation at peak demand hours could affect regional air emissions, if lost generation was offset by generation from coal, natural gas, or oil units. The above discussion would also apply to Hoover Dam; the alternatives could affect the seasonal pattern of Lake Mead elevations and, thus, power generation at Hoover Dam. However, such effects at Hoover Dam are anticipated to be relatively small (Section 4.13).

Air quality issues within the study area are discussed in Section 3.15 and notably include visibility degradation in Federal Class I areas. Coal, natural gas, and oil units emit SO_2 and NO_x, which are precursors to sulfate and nitrate aerosols, respectively. These aerosols play an important role in visibility degradation by contributing to haze. Among anthropogenic sources, sulfate is a primary contributor to regional haze in the Grand Canyon, and nitrate is a minor contributor. Effects on visibility are analyzed through a comparison of regional SO_2 and NO_x emissions under the various alternatives.

To compute total air emissions under the alternatives, emissions were summed from all generating facilities in the SLCA/IP system. This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities (results are discussed in Section 4.13). Emissions were computed according to the estimated electricity generation of each facility and for electricity traded on the spot market under each alternative by calendar year. The spot market represents the interface of the system with the greater Western Interconnect region and accounts for effects of Glen Canyon Dam operations outside of the system. For individual powerplants in the system, pollutant emission factors (in pounds per megawatt-hour [lb/MWh]) available in the *Emissions & Generation Resource Integrated Database* (eGRID) (EPA 2014a) were used to compute emissions. For unspecified powerplants (e.g., long term contract), composite emission factors were employed that are representative of power generation from all types of powerplants currently in operation over the Western Interconnect. Composite emission factors are estimated to be 0.74 and 1.07 lb/MWh for SO_2 and NO_x, respectively. For spot market purchases and sales, composite emission factors were used that are representative of power generation from gas powerplants currently in operation over the Western Interconnect, based on the assumption that spot market generation is primarily to serve peak loads. Composite emission factors are estimated to be 0.0083 and 0.266 lb/MWh for SO_2 and NO_x, respectively. For advanced natural-gas-fired simple cycle and combined cycle generating units to be built in the future, emission factors in EIA (2013) were used: 0.001 lb/MMBtu for SO_2 for both simple cycle (0.0098 lb/MWh) and combined cycle (0.0064 lb/MWh); 0.03 lb/MMBtu (0.29 lb/MWh) for simple cycle and 0.0075 lb/MMBtu (0.048 lb/MWh) for combined cycle for NO_x. Note the difference in the expression of emission factors employed from different sources. Emission factors for existing plants and the spot market are based on emissions per electricity output, while those for future plants are based on emissions per heat energy input (fuel burned). To make comparable estimates, the thermal efficiency of the plant must be taken into account for the latter case.

Potential impacts on regional ambient air quality associated with dam operations are compared in terms of air emissions among alternatives relative to air emissions for Alternative A (No Action Alternative).

4.15.2 Summary of Impacts

The geographic area of potential impacts consists of the GCNP vicinity and the 11-state Western Interconnect region. Table 4.15-1 presents potential impacts on ambient air quality that would likely result from each alternative. Due to very small differences in SO_2 and NO_x precursor emissions, negligible differences are expected among the alternatives with regard to visibility and haze in the region.

Differences in emissions, and thus in impacts on air quality, under the LTEMP alternatives depend on four factors that may act to increase or decrease total emissions under a given alternative. These factors include:

- Total electricity generation at Glen Canyon Dam;
- Generation profile as characterized by the hourly, daily, and monthly release pattern;
- Amount and timing of needed replacement capacity needed to offset reduced Glen Canyon Dam capacity; and
- Amount of exports and imports of electricity to and from the spot market.

As total generation decreases, overall emissions increase because compensating generation includes a component of combustion sources within the system. The differences among the alternatives in total generation are relatively small (<2%), and are related to differences in the amount of water that bypasses the turbines during HFEs.

The generation profile of alternatives reflects the degree to which generation can meet peak demand. During low load periods Glen Canyon Dam electricity production displaces generation from baseload units such as coal-fired units that tend to have high emission rates in pounds (lb) of emissions per MWh generated; on-peak Glen Canyon generation displaces peaking unit production, typically natural gas-fired combustion turbines, which have lower emission rates than coal plants. Alternatives that have greater Glen Canyon Dam peaking generation have reduced Glen Canyon Dam baseload generation and vice versa, given approximately equal total flow volumes among the alternatives. Thus, fluctuating flow alternatives with greater Glen Canyon Dam peaking power and lower baseload power tend to result in higher SO_2 and NO_x emissions system-wide due the greater use of coal-fired facilities within the system to compensate for reduced baseload generation at Glen Canyon Dam. Coal-fired facilities have approximately an order of magnitude higher SO_2 and significantly higher

TABLE 4.15-1 Summary of Impacts of LTEMP Alternatives on Visibility and Regional Air Quality

Air Quality	Alternative A (No Action Alternative)	Alternative B	Alternative C	Alternative D (Preferred Alternative)	Alternative E	Alternative F	Alternative G
Overall summary of impacts	No change from current conditions	Negligible increase in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 emissions and no change in NO_x emissions compared to Alternative A	No change in SO_2 emissions and negligible increase in NO_x emissions compared to Alternative A	Negligible increase in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 and NO_x emissions compared to Alternative A	Negligible decrease in SO_2 and negligible increase in NO_x emissions compared to Alternative A
Visibility[a]	No change from current conditions	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A	No change from Alternative A
Air Quality in 11-State Western Interconnect Region							
SO_2 emissions (tons/yr)[b]	42,465	42,471	42,463	42,465	42,466	42,448	42,453
	No change from current conditions	Negligible increase (0.01%)	Negligible reduction (–0.01%)	No change from current conditions	Negligible increase (<0.005%)	Negligible reduction (–0.04%)	Negligible reduction (–0.03%)
NO_x emissions (tons/yr)[b]	78,496	78,501	78,496	78,503	78,500	78,487	78,498
	No change from current conditions	Negligible increase (0.01%)	No change from current conditions	Negligible increase (0.01%)	Negligible increase (<0.005%)	Negligible reduction (–0.01%)	Negligible increase (<0.005%)

[a] Visibility effects are estimated from expected changes in the emissions of sulfate and nitrate precursors, SO_2 and NO_x.

[b] Total air emissions and percent change in emissions (compared to Alternative A) from combustion-related powerplants in the system averaged over the 20-year LTEMP period.

Source: EPA (2014b).

NO_x emissions than gas-fired facilities for a given amount of generation. Coal plants also produce more CO_2, a greenhouse gas, than do gas-fired plants. Effects of greenhouse gas emissions are discussed in Section 4.16.

The amount and timing of needed replacement capacity can also have an effect on total emissions. Steady flow alternatives, which do not include load following have reduced effective capacity, or maximum generating level, which must be compensated for by the construction and operation of new generation facilities in the system to meet current and future demands during peak load periods. New capacity is required sooner under steady flow alternatives (Section K.1.10.2 in Appendix K). New units would tend to be cleaner, more efficient, and less expensive to operate and therefore would tend to displace generation from higher emitting old units that serve the same type of duty (i.e., peaking unit) and would thus tend to reduce system emissions slightly relative to fluctuating flow alternatives. Construction of new capacity and retirement of existing plants are included in the hydropower analysis (Section 4.13) and in this air quality analysis.

The relative amounts of exports and imports to and from the spot market also can affect total emissions. Alternatives with greater net exports (sales) from the SLCA/IP system to the spot market tend to have greater total emissions since fossil-fired powerplants in the SLCA/IP system tend to have higher emission rates than Western Interconnect powerplants in states which purchase the electricity, mostly in California. When the system buys external energy to serve electricity demand, it needs to produce less power from its own internal resources thereby reducing pollutants emitted by the system. Conversely, when the system sells power to the Western Interconnect, it increases power production to support the spot energy transaction. Emissions associated with spot market sales are accounted for because unit-level generation for all facilities in the system (including the amount required for a sale) is multiplied by plant-level emission factors. On the other hand, this exported energy via a spot market transaction will reduce both generation and emissions in the overall 11-state Western Interconnect.

These factors have relatively small effects on emissions, and operate in sometimes opposing directions with regard to total system emissions of SO_2, NO_X and CO_2. Thus, although total emissions under the various alternatives are relatively similar, the relative differences result from a complex combination of these four factors that can only be understood through detailed modeling of emissions from individual generating facilities within the system under each of the alternatives. The following paragraphs present the results of such modeling.

Electricity generation averaged over the LTEMP period at Glen Canyon Dam for each alternative is shown in Figure 4.15-1. Little difference exists among alternatives, which range from 4,178 to 4,255 GWh per year. Other powerplants in the system can be fossil fuel–fired, renewable, hydro, or nuclear, and they depend on Glen Canyon Dam to provide uninterrupted power to their customers; power generation is thus similarly unchanged among alternatives. Under Alternative A, total SO_2 and NO_X emissions in the system averaged over the 20-year LTEMP period are estimated to be about 42,465 tons/yr and 78,496 tons/yr, which amount to about 10% and 3.0%, respectively, of total SO_2 and NO_X emissions over the Western Interconnect region (see Table 3.16-3). Thus, air emissions from power generators in the system are moderate contributors to total emissions in the Western Interconnect region. As shown in Table 4.15-1, air emissions under other LTEMP alternatives are similar to those under Alternative A. Differences from Alternative A range from –0.04 to 0.01% for SO_2 and from –0.01 to 0.01% for NO_X. Differences in average annual emissions range from –18 to 5 tons/yr for SO_2 and –10 to 6 tons/yr for NO_X, compared to those for Alternative A. Therefore, potential impacts of dam operations under various alternatives on regional air quality would be very small.

Table 4.15-2 presents a breakdown of emission sources by generation technology type for the generation facilities within the system and includes emissions for energy traded on the spot market using a composite emission factor for facilities in the Western Interconnect region. The table also shows power generation from Glen Canyon Dam under the various alternatives relative to Alternative A, which produces the most energy. Alternatives F and G produce

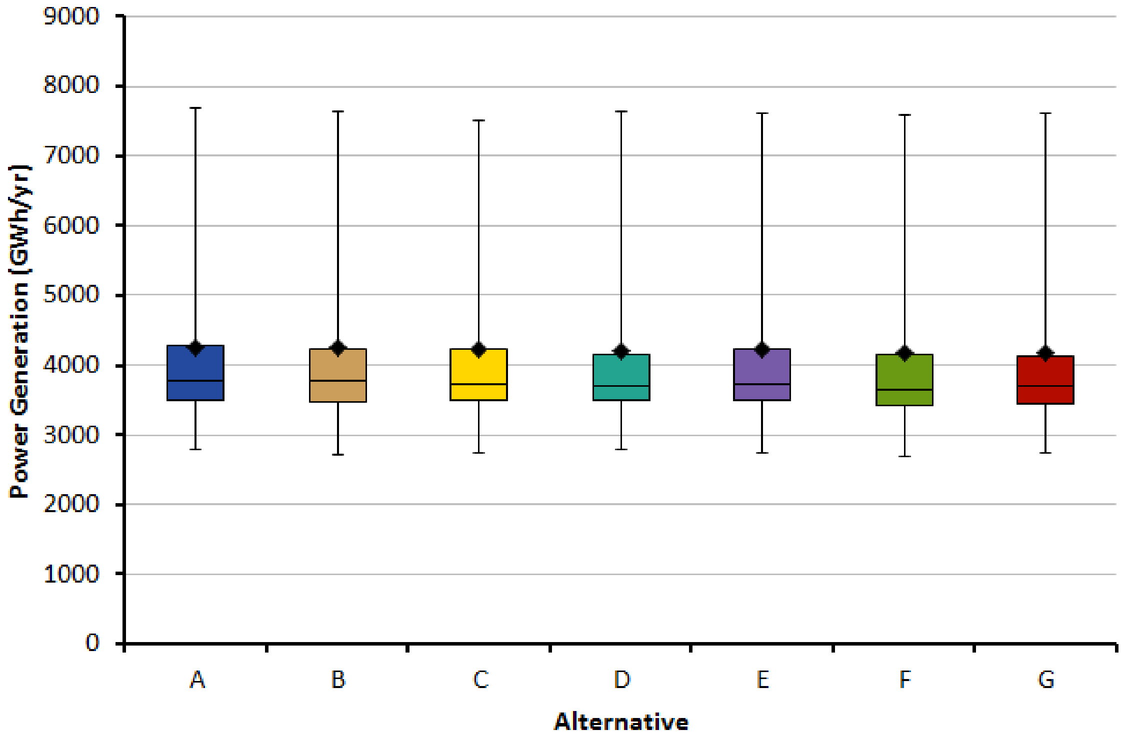

FIGURE 4.15-1 Annual Power Generation by Alternative over the 20-Year LTEMP Period (Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

relatively less hydropower energy than Alternative A (98.3% and 98.2%, respectively) because they have more HFEs in which a portion of released water bypasses the powerplant turbines.

SO_2 and NO_x emissions within the system are dominated by steam turbine technologies, mainly coal-fired powerplants (Table 4.15-2). Considering generation by facilities within the system (approximately 35 primary facilities), the differences among alternatives in estimated emissions are miniscule, ranging over only 0.05% for SO_2 and 0.02% for NO_x (system subtotal). Estimated differences among alternatives reflect slight differences in the contributions from various powerplant technologies; these are attributed to small differences in baseload and peaking energy provided by Glen Canyon Dam. Gas turbine peaking plant technologies produce lower SO_2 and lower NO_x emissions than baseload coal-fired plants. Thus, offsetting gas turbine peaking power with hydropower from Glen Canyon Dam has a potentially lower effect on total system emissions than does offsetting coal-fired baseload with baseload energy from Glen Canyon Dam.

This effect may be seen by comparing emissions subtotals by technology type under fluctuating flow and steady flow alternatives. For both SO_2 and NO_x, steam turbine (coal plant) emissions are slightly lower under Alternatives F and G, reflecting possible reductions in baseload emissions from coal plants offset by increased baseload energy from Glen Canyon Dam, even though these two alternatives generate <2% less Glen Canyon Dam energy than the

TABLE 4.15-2 Distributions of SO_2 and NO_x Emissions Averaged over the 20-Year LTEMP Period by Alternative

Generation Type	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Total Glen Canyon Dam Power Generation Relative to Alternative A (MW-hr/day) (% of Alternative A)	11,650 (100%)	11,616 (99.7%)	11,566 (99.3%)	11,525 (98.9%)	11,571 (99.3%)	11,449 (98.3%)	11,438 (98.2%)
SO_2 Emissions (tons per year)							
System Power Generation							
Combined Cycle	44	44	44	44	44	44	44
Composite[a]	606	607	606	607	607	608	606
Gas Turbine	13	13	13	13	13	15	14
Internal Combustion	1	1	1	1	1	1	1
Steam Turbine	41,805	41,810	41,802	41,804	41,805	41,785	41,792
System Subtotal	**42,469**	**42,474**	**42,467**	**42,469**	**42,470**	**42,452**	**42,457**
Spot Market[b]							
Sales (emissions subtracted)	–16	–15	–16	–16	–16	–16	–16
Purchases (emissions added)	12	12	12	12	12	12	12
Spot Market Subtotal	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**	**–4**
Total (System + Spot Market)	**42,465**	**42,471**	**42,463**	**42,465**	**42,466**	**42,448**	**42,453**
NO_x Emissions (tons per year)							
System Power Generation							
Combined Cycle	655	654	656	657	656	658	658
Composite[a]	869	870	869	870	870	871	869
Gas Turbine	271	265	282	278	277	307	300
Internal Combustion	24	24	24	24	24	24	24
Steam Turbine	76,800	76,806	76,796	76,799	76,801	76,766	76,781
System Subtotal	**78,620**	**78,620**	**78,626**	**78,629**	**78,628**	**78,626**	**78,632**
Spot Market Sales[b]							
Sales (emissions subtracted)	–499	–492	–509	–503	–506	–520	–514
Purchases (emissions added)	375	374	378	377	378	381	380
Spot Market Subtotal	**–124**	**–118**	**–130**	**–126**	**–128**	**–139**	**–134**
Total (System + Spot Market)	**78,496**	**78,501**	**78,496**	**78,503**	**78,500**	**78,487**	**78,498**

a Unspecified generation type.

b "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnect. Sales result in a net credit to total Western Interconnect emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnect. Emissions related to these purchases are added to the total emissions in the Western Interconnect.

fluctuating flow alternatives. Likewise, SO_2 emissions for gas technologies are slightly higher for Alternatives F and G, reflecting increased peaking generation from gas plants compensating for lack of peaking ability under these two alternatives.

The effects of the spot market on total system emissions are shown in Table 4.15-2. The spot market contribution to emissions is small (about <0.2% of total emissions from the system); however, for NO_x the spot market contributes about 60% more than the in-system component to differences among alternatives (21 tons/yr and 13 tons/yr, respectively). The spot market has no effect on differences in SO_2 emissions, since spot market emissions are very small and similar (4 tons/yr) (Table 4.15-1). The spot market component is shown as a negative value in the table, reflecting a net export of power from the system. When power is exported (i.e., sold) to a utility outside of the system, it is assumed that the purchaser will generate less energy from its own power resources, resulting in lower total emissions in the Western Interconnect region. Therefore, we apply an emissions credit for energy that is bought by utilities outside of the system. Because we do not model external utilities in detail, we cannot pinpoint the exact source of this emission reduction. Therefore, we use composite emission factors representative of power generation in the 11-state Western Interconnect region. Note, however, that since we model all generating resources within the system we are accounting for the increased generation and hence emissions associated with the exported energy.

Net NO_x emissions related to spot market sales and purchases are lowest (greatest negative value) for the steady flow Alternatives F and G, and highest for the fluctuating flow Alternatives B and A. Net SO_2 spot market emissions are essentially the same across alternatives. This result can be explained by considering in-system generation selling to the spot market. Under steady flow Alternatives F and G, the Glen Canyon Dam powerplant does not provide peaking power, while under fluctuating flow Alternatives A-E it does. Since spot market sales typically serve peak demand, NO_x emissions from sales to the spot marker are therefore higher for Alternatives F and G, since other, typically gas-fired, facilities in the system provide peak generation. Such facilities generate NO_x emissions, but very little SO_2, so there is no effect on the latter emission.

Given the very small differences in the estimated emissions after considering all of the factors discussed above and in light of the uncertainty of emissions modeling, it may be concluded that emissions would be similar under all of the alternatives.

4.15.3 Alternative-Specific Impacts

Although differences are expected in potential ambient air quality and associated impacts among the various alternatives, potential air quality impacts are anticipated to be negligible. The modeled differences among alternatives are presented below. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively.

4.15.3.1 Alternative A (No Action Alternative)

Under Alternative A (No Action Alternative), annual power generation at Glen Canyon Dam would range from 2,781 to 7,677 GWh, with an average of 4,225 GWh, over the 20-year LTEMP period. Coal-fired steam plants account for the vast majority of these emissions; that is about 98% of both SO_2 and NO_x emissions. In addition, total LTEMP-related annual air emissions from power generation, system emissions plus changes in the Western Interconnect would range from 41,392 to 42,991 tons/yr with an average of 42,465 tons/yr for SO_2, and from 77,121 to 80,005 tons/yr with an average of 78,496 tons/yr for NO_x. These annual-average emissions for SO_2 would be about 10% and for NO_x would be about 3.0% of the total air emissions over the Western Interconnect region (see Table 3.16-3).

4.15.3.2 Alternative B

Under Alternative B, total LTEMP-related annual-average air emissions are 42,471 tons/yr for SO_2 and 78,501 tons/yr for NO_x; these values are about 0.01% higher than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative B and Alternative A.

4.15.3.3 Alternative C

Under Alternative C, total LTEMP-related annual-average air emissions are 42,463 tons/yr for SO_2 and 78,496 tons/yr for NO_x; these values are about 0.01% lower than and the same as those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than or the same as those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative C and Alternative A.

4.15.3.4 Alternative D (Preferred Alternative)

Under Alternative D, total LTEMP-related annual-average air emissions are 42,465 tons/yr for SO_2 and 78,503 tons/yr for NO_x; these values are the same as and about 0.01% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.9% of that under Alternative A. Total annual emissions from power generation in the region are the same as or slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative D and Alternative A.

4.15.3.5 Alternative E

Under Alternative E, total LTEMP-related annual-average air emissions are 42,466 tons/yr for SO_2 and 78,500 tons/yr for NO_X; these values are about <0.005% higher than those under Alternative A, respectively. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative E and Alternative A.

4.15.3.6 Alternative F

Under Alternative F, total LTEMP-related annual-average air emissions are 42,448 tons/yr for SO_2 and 78,487 tons/yr for NO_X; these values are about 0.04 and 0.01%, respectively, lower than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative F and Alternative A.

4.15.3.7 Alternative G

Under Alternative G, total LTEMP-related annual-average air emissions are 42,453 tons/yr for SO_2 and 78,498 tons/yr for NO_X; these values are about 0.03 and <0.005%, respectively, lower and higher than those under Alternative A. Annual-average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Total annual emissions from power generation in the region are slightly lower or higher than those under Alternative A, due to the combined effects of the four factors described in Section 4.15.2. Consequently, there would be negligible differences in impacts on regional ambient air quality between Alternative G and Alternative A.

4.16 CLIMATE CHANGE

> **Issue:** How could the LTEMP affect or be affected by climate change?
>
> **Impact Indicators:**
>
> - Changes in CO_2 and other GHG emissions under different LTEMP alternatives
> - Climate-driven changes in hydrology and sediment inputs over the 20-year LTEMP period

There is the potential for the LTEMP to affect climate change indirectly through changes in dam operations, and for dam operations under the LTEMP to be affected by climate change. Although each of the LTEMP alternatives would generate approximately the same amount of electrical power,[14] there are relatively large differences in the monthly and within-day pattern of releases that affect hydropower capacity. These differences in available capacity affect how other power facilities in the region respond to changes in demand, and in this way can affect the total system emission of carbon dioxide (CO_2) and other greenhouse gases (GHGs) (Section 4.15 describes the effect of Glen Canyon Dam operations on the power system and the emissions of criteria pollutants). In addition to these potential effects on climate change, operations over the 20-year LTEMP period could be affected by climate-driven changes in hydrology (inflow patterns and evaporation rates) and sediment inputs. Reductions in inflow due to changes in precipitation and increases in evaporation rates resulting from increases in temperature could result in decreases in the elevation of Lake Powell, with subsequent reductions in power generation resulting from decreased head, and potentially an increase in the frequency of dropping below the power pool.

4.16.1 Analysis Methods

4.16.1.1 Effects of LTEMP Alternatives on Climate Change

The buildup of heat-trapping GHGs can over time warm Earth's climate and result in adverse effects on ecosystems and human health and welfare. Thus, cumulative GHG emissions can be used as a surrogate to assess climate-change impacts. Such effects would be global and are not particularly sensitive to GHG source locations because GHGs are mostly long-lived and spread across the entire globe.

Glen Canyon Dam operation does not generate GHG emissions, but dam operations can indirectly affect climate change, regionally and globally, through varying contributions to the total mix of power generation in the region, which also includes coal-fired, natural gas–fired, hydroelectric, nuclear, and renewable generation sources. For the purposes of this analysis, the principal GHG of concern is CO_2, which accounts for more than 99% of GHG emissions related to power generation. However, facility- or technology-specific GHG emission factors also

[14] The relatively small expected differences among alternatives in the amount of total annual generation relate to the alternative-specific frequency of HFEs. Approximately 14,000 cfs of a 45,000-cfs HFE would be released through the bypass tubes, which do not generate power. Alternatives differ substantially in the frequency of HFEs (Section 4.2).

consider other GHGs, such as methane (CH_4) and nitrous oxide (N_2O), albeit to a small degree. The above discussion would also apply to Hoover Dam, since the alternatives could affect the seasonal pattern of Lake Mead elevations, and, thus, power generation at Hoover Dam. However, such effects at Hoover Dam are anticipated to be relatively small and have been found to generally offset corresponding effects at Glen Canyon Dam (Section 4.13, thus reducing differences among alternatives, but not changing the ranking of effects.

To compute total GHG emissions under the alternatives, emissions were summed from all generating facilities primarily affected by Glen Canyon Dam operations, referred to as "the system," as was done for SO_2 and NO_x for the air quality analysis (Section 4.15). This analysis was based on the analysis performed for hydropower, which estimated electrical power contributions for the same facilities, the results of which are discussed in Section 4.13. GHG emissions were computed according to the estimated annual electricity generation of each facility and for electricity traded on the spot market under each alternative. For individual powerplants, GHG emission factors (in lb/MWh) available in eGRID (EPA 2014a) were used to compute GHG emissions. For unspecified powerplants (e.g., long-term contract), composite emission factors representative of power generation from all types of powerplants that are currently in operation over the 11-state Western Interconnect region (Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming) were employed. A composite emission factor for GHGs is estimated to be 963 lb/MWh (0.437 MT/MWh) for CO_2 equivalent (CO_2e).[15] For spot market purchases and sales, a composite GHG emission factor for gas powerplants operating in the Western Interconnect was used, and was estimated to be 888 lb/MWh (0.403 MT/MWh) CO_2e. For advanced natural gas–fired generating units projected to be built in the future, an emission factor from the EIA (2013) of 117 lb/MMBtu (0.053 MT/MMBtu) for CO_2 was used for both simple-cycle (1,141 lb/MWh [0.518 MT/MWh]) and combined cycle (752 lb/MWh [0.341 MT/MWh]) units.

Potential impacts on climate change associated with dam operations are evaluated for the LTEMP alternatives though a comparison of GHG emissions to those for Alternative A (no action alternative).

4.16.1.2 Effects of Climate Change on Hydrology and Downstream Resources

The effects of climate change on hydrology were treated as an uncertainty in the analyses of hydrology and downstream resource impacts, rather than by means of a full-fledged climate analysis and adaptation approach. The LTEMP DEIS has the more limited scope of evaluating future dam operations, management actions, and experimental options to provide a framework for adaptively managing Glen Canyon Dam over the next 20 years to protect and minimize adverse impacts on downstream natural and cultural resources in GCNRA and GCNP. Accordingly, DOI used a sensitivity analysis approach to see how robust the alternatives would be with regard to their impact on resources under climate change.

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[15] CO_2e is a measure used to compare the emissions from various GHGs on the basis of their global warming potential, 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 (usually 100 years).

The Basin Study (Reclamation 2012e) suggested there could be significant increases in temperature and decreases in water supply to the Colorado River system below Glen Canyon Dam over the next 50 years, driven by global climate change. The magnitude of these changes is uncertain. In addition, there could be changes to sediment input (especially from the Paria and Little Colorado Rivers), driven by complex local and regional climate changes, but the direction and magnitude of these changes are uncertain. Water supply, sediment supply, and temperature are important factors that affect all of the resources under consideration in the LTEMP DEIS.

The approach used in this DEIS treats climate change as an external uncertainty and analyzes the robustness of the alternatives to uncertainties in the water and sediment inputs. This approach required: (1) use of 21 hydrologic and 3 sediment scenarios based on historic conditions; (2) estimation of the likelihood of the scenarios under climate change; and (3) analysis of the impacts of alternatives under all hydrologic and sediment scenarios. The approach analyzed how robust the alternatives would be to climate change-driven hydrologic and sediment inputs. For the climate-change analysis, the 21 hydrologic traces used in the LTEMP analysis were weighted according to their frequency of occurrence (based on mean annual inflow to Lake Powell) in the Basin Study's 112 simulations. Figure 4.16-1 shows the weights assigned to each hydrologic trace. As shown in Figure 4.16-2, the 21 hydrologic traces were not representative of the full range of expected inflow variation under a climate-change scenario and did not include the driest traces expected under climate change. About 30% of the forecast distribution was not captured by the historic traces. Details of the approach are presented in Appendix D.

Modeling results for downstream resource effects were generated for the 21 historic hydrology traces and 3 historic sediment traces. For the analyses presented in Sections 4.2 through 4.10, the hydrology traces were weighted equally to represent their equal probability of occurrence in the absence of climate change. The climate-change weights shown in Figure 4.16-1 were applied to the modeled results for each trace to represent their probability of occurrence under climate change.

4.16.2 Summary of Impacts

4.16.2.1 Effects of LTEMP Alternatives on Climate Change

Table 4.16-1 presents total estimated GHG emissions within the system for each alternative. These emissions are an indication of the potential relative impact of the alternatives on climate change.

For estimating GHG emissions attributable to Glen Canyon Dam operations, projected power generation at the dam was averaged over the 20-year LTEMP period (Figure 4.15-1). Little difference exists among the alternatives, which range from 4,178 to 4,255 GWh per year, amounting to 1.8%. Power generation from other powerplants in the system and in the Western

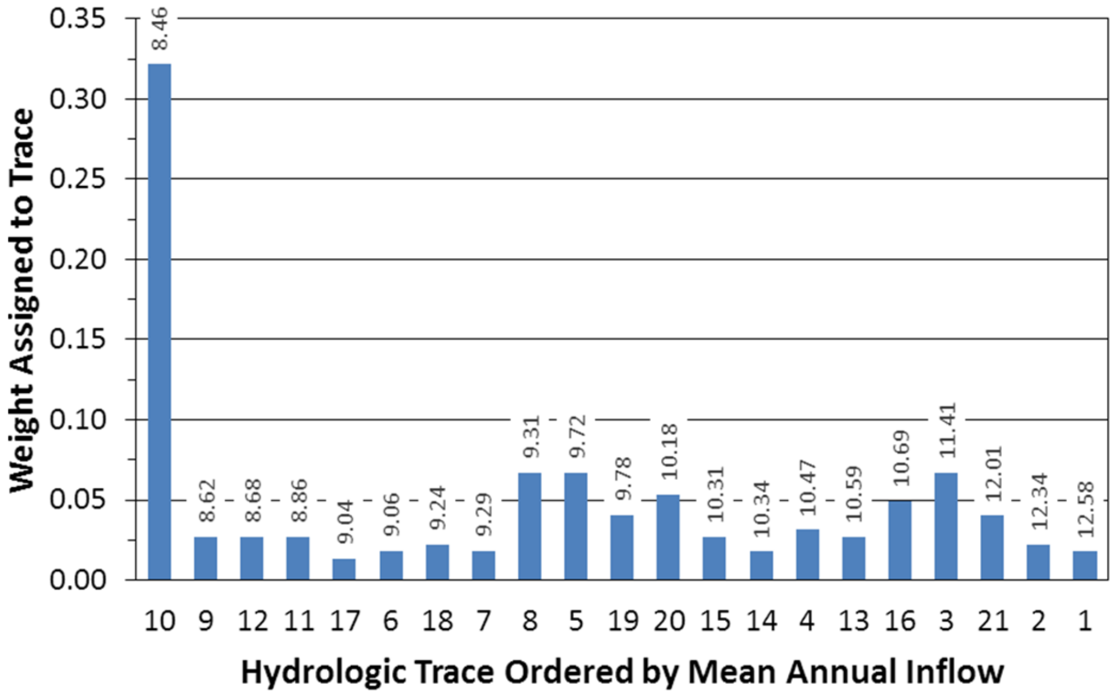

FIGURE 4.16-1 Weights Used To Reflect the Expected Frequency of Hydrologic Conditions under Climate Change (Numbers at top of bars are mean annual inflow of each trace in million acre-feet.)

Interconnect region also would be similar among alternatives. For Alternative A (no action alternative), total GHG emissions in the system averaged over the 20-year LTEMP period are estimated to be about 55,177,668 MT/yr, which amounts to about 4.5% and 0.81% of total GHG emissions over the Western Interconnect region and the United States, respectively (Table 3.15-3, Section 3.15.3). Thus, GHG emissions from power generation are relatively small contributors to total GHG emissions in the region.

GHG emissions under other LTEMP alternatives would have negligible differences from those under Alternative A, ranging from an increase of 5,900 MT/yr (Alternative B) to 44,522 MT/yr (Alternative F), considering total emissions (system generation plus spot market sales and purchases). On a percentage basis, differences from Alternative A would range from 0.011% to 0.081%. The system includes 35 power generation facilities analyzed individually. The spot market reflects the effects of Glen Canyon Dam operations on the larger Western Interconnect region and represents an offset of about 1% of system emissions (Table 4.16-1).

In light of the 1.8% range in Glen Canyon Dam hydropower generation under the alternatives, and assuming that reduction in power generation at Glen Canyon Dam is made up by other generation facilities in the system, the smaller range in GHG emissions of only 0.081% suggests that reduced hydropower energy from, for example, Alternatives F and G does not result in a corresponding increase in GHG emissions from compensating generation at other

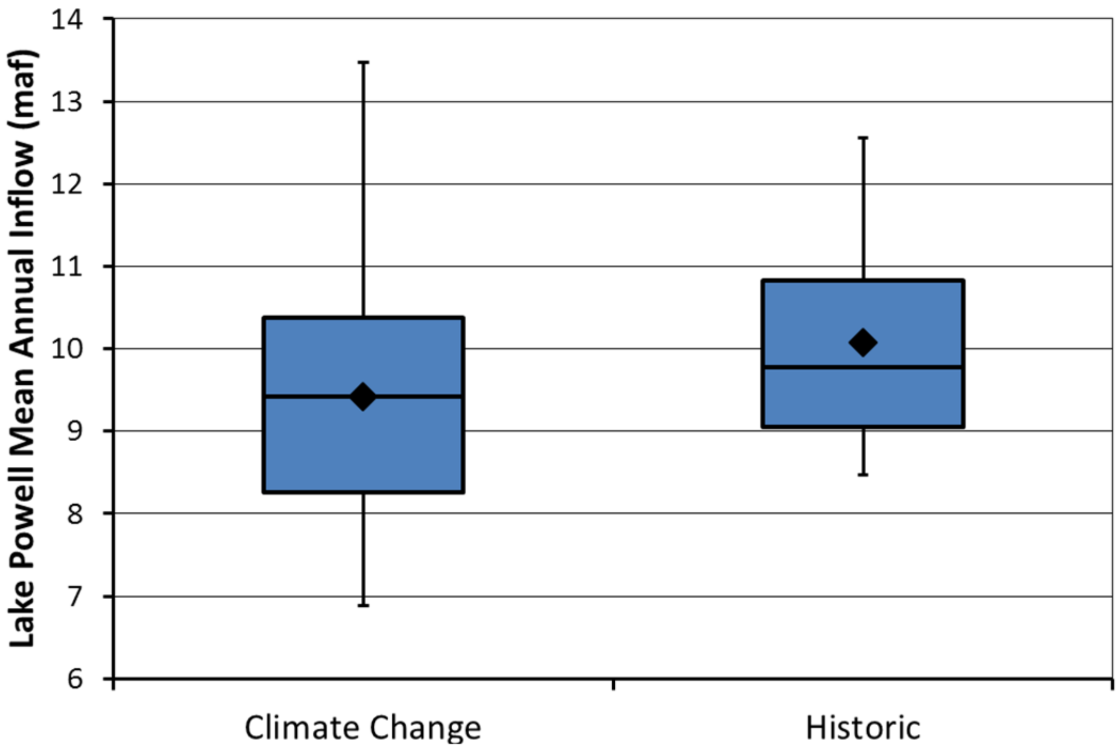

FIGURE 4.16-2 Mean Annual Inflow Showing the Mean, Median, 75th Percentile, 25th Percentile, Minimum, and Maximum Values for 112 Climate-Change Inflow Traces and 21 Historic Inflow Traces (Means were calculated as the average for all years within each of the traces. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

thermal powerplants in the system. This result may be explained by examining the effects of powerplant mix and capacity expansion on emissions under the various alternatives. With respect to powerplant mix, the Glen Canyon Dam powerplant under the steady-flow Alternatives F and G does not serve peak loads, but does so under the fluctuating-flow Alternatives A through E, offsetting GHG emissions from other peaking facilities in the system, mainly gas turbines. Conversely, steady-flow alternatives can provide a higher level of baseload power, which can offset emissions from other baseload facilities in the system, mainly coal-fired facilities with relatively high GHG emissions compared to gas turbines. More detailed discussion of these factors is presented in Section 4.15.2.

Reviewing projected GHG emissions at specific powerplants within the system, the steady-flow Alternatives F and G are expected to produce lower GHG emissions from coal-fired plants (categorized as steam turbine technologies) and higher GHG emissions from gas turbine plants as compared to the fluctuating-flow Alternatives A through E. This comparison supports the conclusion that Alternatives F and G tend to offset a relatively greater amount of baseload power at combustion facilities in the system than do Alternatives A through E, while the latter alternatives offset relatively more emissions from gas turbines that provide peaking power.

1 **TABLE 4.16-1 Summary of Impacts of LTEMP Alternatives on GHG Emissions**

	GHG Emissions by Alternative (MT/yr)[a,b]						
GHG Emissions Source	A (No Action Alternative)	B	C	D (Preferred Alternative)	E	F	G
Overall summary of impacts	No change from current conditions.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.	Negligible increase in GHG emissions compared to Alternative A.
System power generation							
Combined cycle	5,871,619	5,867,894	5,875,470	5,878,837	5,876,226	5,880,006	5,885,763
Composite[c]	711,604	712,068	711,574	712,296	712,186	713,199	711,081
Gas Turbine	622,805	611,925	661,049	646,520	647,637	730,920	695,498
Internal combustion	1,726	1,721	1,680	1,728	1,711	1,688	1,706
Steam turbine	48,344,640	48,348,638	48,341,590	48,343,248	48,344,880	48,319,488	48,332,026
System subtotal	55,552,395	55,542,246	55,591,363	55,582,629	55,582,640	55,645,301	55,626,074
Spot market[d]							
Sales (emissions subtracted)	-1,512,509	-1,493,787	-1,543,444	-1,525,109	-1,536,444	-1,577,799	-1,560,383
Purchases (emissions added)	1,137,782	1,135,108	1,147,910	1,143,056	1,147,975	1,154,687	1,152,937
Spot market subtotal	**-374,727**	**-358,679**	**-395,534**	**-382,053**	**-388,469**	**-423,112**	**-407,447**
Total emissions (system + spot market)[e]	**55,177,668**	**55,183,567**	**55,195,829**	**55,200,576**	**55,194,171**	**55,222,189**	**55,218,627**
	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Change in Total Emissions	0	5,899	18,161	22,908	16,503	44,521	40,959
		0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase
Difference from Alternative A (MT/yr)	0	5,900	18,161	22,908	16,503	44,522	40,960
Total emissions as % of total U.S. GHG emissions[f]	No change from current conditions	0.011% increase	0.033% increase	0.042% increase	0.030% increase	0.081% increase	0.074% increase

Footnotes on next page.

TABLE 4.16-1 (Cont.)

[a] GHG emissions are expressed in CO_2e.

[b] GHG emissions (metric tons) from combustion-related powerplants in the system or in the region averaged over the 20-year LTEMP period. To convert from metric ton to ton, multiply by 1.1023.

[c] Unspecified generation type.

[d] "Sales" refers to sales of power by system utilities to non-system utilities within the Western Interconnect. Sales result in a net credit to total Western Interconnect emissions, because the sales result in a reduction in emissions from those non-system utilities that are purchasing the power. "Purchases" refers to purchases by system utilities from non-system utilities within the Western Interconnect. Emissions related to these purchases are added to the total emissions in the Western Interconnect.

[e] The 2014 CEQ Draft Guidance on GHG Emissions state in regard to GHG emissions that warrant quantitative disclosure: "In considering when to disclose projected quantitative GHG emissions, CEQ is providing a reference point of 25,000 metric tons of CO_2-e emissions on an annual basis below which a GHG emissions quantitative analysis is not warranted unless quantification below that reference point is easily accomplished. This is an appropriate reference point that would allow agencies to focus their attention on proposed projects with potentially large GHG emissions."

[f] U.S. total GHG emissions at 6,810.3 million MT/yr CO_2e in 2010 (EPA 2013d).

Similarly, with respect to the effects of future capacity expansion, new thermal powerplants constructed to replace reduced capacity under Alternatives F and G would utilize technologies that are more efficient than most existing thermal powerplants and would produce less GHG emissions. Excess energy produced by these new plants sold to the spot market could displace generation and emissions at less efficient combustion units in the Western Interconnect region, resulting in a net reduction of emissions overall relative to fluctuating-flow alternatives in which Glen Canyon Dam utilizes some of its capacity to serve peak load. The combined effects of new capacity and differences in the thermal powerplant mix under the various alternatives result in negligible differences in total GHG emissions among alternatives.

GHG emissions under the alternatives can also be compared to total U.S. GHG emissions at 6,810.3 million MT CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions relative to total U.S. GHG emissions are less than 1% and range from 0.8102 (Alternative A) to 0.8109% (Alternative F). Therefore, potential impacts of dam operations under various alternatives on climate change are expected to be negligible.

CO_2, CH_4, and N_2O are emitted from the reservoirs associated with the Glen Canyon Dam, Lake Powell, and Lake Mead. For example, CH_4 from large dams accounted for about 4% of human-caused climate change (Lima et al. 2008). GHG emissions from biomass decay, including CH_4, in such reservoirs, have been a subject of recent debate (Pacca and Horvath 2002). Through consumption of atmospheric CO_2 by photosynthesis in plankton and aquatic plants in reservoirs, net CO_2 emissions from dam operations may be small, and uptake by reservoirs can occasionally exceed emissions. Emissions of CH_4 are possible from turbines and spillways and downstream of dams.

4.16.2.2 Effects of Climate Change on Hydrology and Downstream Resources

As discussed in Section 4.16.1.2, the climate-change analysis approach used the historic hydrology as its basis, but gave greater weight to drier years to represent their expected increased frequency of occurrence under a climate-change scenario. As shown in Figure 4.16-2, this approach underestimated the occurrence of the driest years, but it allows a determination of the robustness of the alternatives to climate-change uncertainty.

Figure 4.16-3 presents the differences between historic and climate-change-weighted values of mean daily flow and mean daily change in flow for the LTEMP alternatives as a percentage of the historic values for the 25th percentile and mean of the two variables. Negative values indicate a decrease in the value under the climate-change scenario, while positive values indicate an increase under the climate-change scenario. Of the values examined (minimum, maximum, 25th percentile, 50th percentile, 75th percentile, and mean), the 25th percentile (representing flow under drier conditions) was the most affected. There was no difference between historic and climate-change-weighted minimum and maximum values, but this is an artifact of the weighting approach used. Because mean monthly volume equals the mean daily flow times the number of days in each month, the percentage differences in that variable are identical to those shown for mean daily flow in Figure 4.16-3. The following conclusions can be drawn from the patterns observed in Figure 4.16-3:

- The 25th percentile values of mean daily flow (and mean monthly volume values) would be very similar from October through March under climate-change and historic scenarios for all alternatives. The differences for all alternatives between historic and climate-change scenarios would increase month-by-month through August. The trend is toward lower mean daily flows under climate change, which reaches a maximum difference of about 10% to 18% (decrease from historic values) in August. In general, the differences among alternatives with respect to the effects of climate change on mean daily flow would be similar.

- Mean values of mean daily flow (and values of mean monthly volume) would follow a pattern similar to that of the 25th percentile values of mean daily flow, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternative F in July and August, when flow would be even lower with climate change than under other alternatives.

The 25th percentile values of mean daily change under the climate-change scenario would be very similar to historic values from October through June for all alternatives, but would be higher than historic for July, August, and September for all alternatives except for the steady-flow Alternatives F and G. Under the drier conditions of climate change and lower mean daily flows, there is more flexibility to provide a wider range of flows within a day and still meet other operational constraints. It should be noted that the differences in mean daily change would be less than 1,000 cfs.

FIGURE 4.16-3 Differences between Historic and Climate-Change-Weighted Values of Mean Daily Flow and Mean Daily Change in Flow by Month for LTEMP Alternatives

- Mean values of mean daily change would follow a pattern similar to that of the 25th percentile values of mean daily change, but the differences between historic and climate-change scenarios would not be as great. The differences would be greatest under Alternatives A, B, and D in August, when daily change would be even higher with climate change than under other alternatives.

The monthly increase in climate-change effects in mean daily flow and mean monthly volume results from operation of the dam based on the inflow forecast for the water year. Typically, operations in October, November, and December use volumes for an 8.23-maf year, with adjustments made in later months as forecasts indicate a drier or wetter year (Figure 4.2-1). Early forecasts (e.g., January) are subject to considerable uncertainty, and it is usually not until the April forecast that a reasonable identification of the annual volume can be made. Using this operational strategy under climate change would result in less water needing to be released after April, and therefore an increasing deviation from the historic pattern.

These differences in hydrology would influence the relative effect of LTEMP alternatives on resources, but, in general, the analysis conducted for this DEIS indicates the differences would be relatively small and not differ greatly among alternatives. Table 4.16-2 provides an overview of the expected effects on downstream resources. Under climate change, the impacts of most or all LTEMP alternatives would be less on sediment resources, humpback chub, trout, riparian vegetation, Grand Canyon cultural resources, Tribal values, and most recreation metrics, but there would be a reduction in the value of hydropower generation and capacity and an increase in impacts on Glen Canyon cultural resources.

4.16.3 Alternative-Specific Impacts

Although there are expected to be minor differences in the emissions of GHGs among the various alternatives, potential impacts on climate change are anticipated to be negligible. Minor differences among alternatives are presented below. Detailed information on alternatives and hydropower assumptions and modeling can be found in Sections 2.3 and 4.13, respectively. The effects of climate change on hydrology and downstream resources are also presented.

4.16.3.1 Alternative A (No Action Alternative)

Under Alternative A (no action alternative), annual power generation would range from 2,781 to 7,677 GWh, with an average of 4,255 GWh over the 20-year (2014–2033) period. Total annual GHG emissions in the system related to power generation at the Glen Canyon Dam would range from 52,014,751 to 59,909,459 MT (from 57,336,449 to 66,038,875 tons), with an average of 55,177,668 MT (60,822,967 tons). These annual average GHG emissions would be about 4.5% and 0.81%, respectively, of the total GHG emissions over the Western Interconnect region and in the United States (see Table 3.15-3 and Section 3.15.3).

Based on the modeling performed and climate change weights applied to account for the greater likelihood of drier conditions under climate change, the following conclusions can be made. Temperature suitability for native and nonnative fish would be improved and impacts on humpback chub lessened. The overall number of trout is expected to decline, but the number of large trout would be higher than under historic hydrology. The impacts on native vegetation would be less. There would be a greater potential for impacts on cultural resources in both Glen Canyon and Grand Canyon, but an improvement in Tribal values for all metrics evaluated. Most recreation metrics would reflect greater impacts under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.2 Alternative B

Under Alternative B, total annual average GHG emissions are 55,183,567 MT (60,829,471 tons), which is about 0.011% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.7% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative B being different from that of Alternative A. Consequently, there are negligible differences between Alternatives B and A with regard to their impacts on climate change.

TABLE 4.16-2 Expected Impact of LTEMP Alternatives on Downstream Resources under Climate Change Compared to Those under Historic Conditions

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Hydrology	
Mean monthly volume and mean daily flow	Decrease in spring and summer, especially for Alternative F, with August being the month with the greatest departure from historic (11–19% reduction in 25th percentile values)
Mean daily change	Increase in July and August, especially for Alternatives A, B, and D (1–17% increase in fluctuating flow alternatives)
Sediment	
Sand load index (bar-building potential)	Increase (2–4%) under Alternatives C–G; decrease (–2 to –3%) for Alternatives A and B
Sand mass balance	Increase (4–9%) under all alternatives
Aquatic ecology	
Temperature suitability—humpback chub	Increase under all alternatives (but especially Alternative F) in upstream reaches (RM 30–119); decrease at RM 157 under Alternatives A, B, and D, and all alternatives (except for Alternative F) at RM 213
Temperature suitability—other native fish	Similar pattern as temperature suitability for humpback chub, but decrease at RM 157 only under Alternatives A and B; all alternatives would have decrease at RM 213
Temperature suitability—coldwater nonnative fish	Increase under all alternatives at RM 0; decrease in all other downstream reaches
Temperature suitability—warmwater nonnative fish	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Temperature suitability—aquatic parasites	Increase under all alternatives at RM 0, with decreasing differences at increasing distance from the dam; decrease at RM 225 under all alternatives
Minimum number of adult humpback chub	Increase (0.2–2%) under all alternatives
Trout catch rate (age 2+, no./hr)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout outmigrants	Increase (0.2–4%) under Alternatives C, D, E, and G; decrease (–1 to –4%) under Alternatives A, B, and F
Trout abundance (age 1+)	Increase (1–4%) under Alternatives C, D, E, and G; decrease (–1 to –3%) under Alternatives A, B, and F
Number of trout >16 in. total length	Increase (0.4–2%) under Alternatives A, B, C, and F; decrease (–0.1 to –1%) under Alternatives D, E, and G

TABLE 4.16-2 (Cont.)

Resource and Impact Indicator	Expected Impact of Climate Change on Impact Indicator Relative to Historic Conditions[a]
Riparian vegetation	
Native species diversity and cover (index, higher is better)	Increase (1%) under Alternatives A, B, D, and E; decrease (–0.2 to –1%) under Alternatives C, F, and G
Cultural resources	
Effect of flows on Glen Canyon resources (index, higher is better)	Decrease under all alternatives (–10 to –17%)
Wind transport of sand to protect resources (index, higher is better)	Increase (3–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–1 to –2%)
Tribal values	
Riparian vegetation diversity	Increase (0.2–2%) under all alternatives, but Alternative F (–0.2%)
Marsh index (higher is better)	Increase (1–34%) under all alternatives
Mechanical removal of trout (lower is better)	Increase (2%) under Alternative G; decrease (–6 to –16%) under Alternatives A, B, and D; no removal under Alternatives C, E, and F
TMFs (lower is better)	Decrease (–7 to –17%) under Alternatives B, C, D, E, and G; no TMFs under Alternatives A and F
Recreation	
Camping area index (higher is better)	Increase (4–5%) under Alternatives C, D, E, F, and G; decrease under Alternatives A and B (–0.02 to –2%)
Fluctuation index (higher is better)	Decrease (–0.1 to –4%) under Alternatives A–E; no change in steady flow Alternatives F and G
Glen Canyon rafting use (number of passenger days lost due to HFEs)	Increase (0.1%) under Alternative F; decrease (–0.2 to –8%) under Alternatives A–E and G
Glen Canyon inundation index (higher is better)	Increase (0.5–0.8%) under all alternatives
Hydropower	
Annual net present value of generation	Decrease (–3%) under all alternatives
Net present value of capacity	Decrease (–2 to –4%) under all alternatives

[a] These results were obtained by applying the climate weights for each trace shown in Figure 4.16-1 to the modeling results presented in the various resource sections of Chapter 4 (Sections 4.2–4.13).

Under Alternative B, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative A.

4.16.3.3 Alternative C

Under Alternative C, total annual average GHG emissions are 55,195,829 MT (60,842,987 tons), which is about 0.033% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. However, total annual emissions are slightly higher than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative C being different from that of Alternative A. Consequently, there are negligible differences between Alternatives C and A with regard to their impacts on climate change.

Under Alternative C, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher Sand Load Index values and an improved sand mass balance. Temperature suitability would be improved, and impacts on humpback chub lessened. The overall number of trout and the number of large trout are expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.4 Alternative D (Preferred Alternative)

Under Alternative D, total annual average GHG emissions are 55,200,576 MT (60,848,219 tons), which are about 0.042% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.9% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative D being different from that of Alternative A. Consequently, there are negligible differences between Alternatives D and A with regard to their impacts on climate change.

Under Alternative D, the impacts of climate change on sediment resources would be reduced by climate change resulting in higher Sand Load Index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be higher than under historic hydrology, but the number of large trout would be lower. The impacts on native vegetation would be slightly lower. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.5 Alternative E

Under Alternative E, total annual average GHG emissions are 55,194,171 MT (60,841,159 tons), which are about 0.030% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 99.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative E being different from that of Alternative A. Consequently, there are negligible differences between Alternatives E and A with regard to their impacts on climate change.

Under Alternative E, the impacts of climate change on sediment resources, humpback chub, trout, native vegetation, cultural resources, Tribal values, recreation, and hydropower would be very similar to those under Alternative D.

4.16.3.6 Alternative F

Under Alternative F, total annual average GHG emissions are 55,222,189 MT (60,872,044 tons), which are about 0.081% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.3% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. This is caused by the power generation mix for Alternative F being different from that of Alternative A. Consequently, there are negligible differences between Alternatives F and A with regard to their impacts on climate change.

Under Alternative F, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher Sand Load Index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout is expected to be lower than under historic hydrology, but the number of large trout would be higher. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in Grand Canyon. There would be an improvement in Tribal values related to marsh vegetation, but a decrease in those related to overall riparian diversity. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.16.3.7 Alternative G

Under Alternative G, total annual average GHG emissions are 55,218,627 MT (60,868,117 tons), which are about 0.074% higher than those under Alternative A. Annual average power generation at Glen Canyon Dam under this alternative is estimated to be about 98.2% of that under Alternative A. Thus, total annual emissions are slightly lower than those under Alternative A, due to the factors discussed in Section 4.16.2.1. Consequently, there are negligible differences between Alternatives G and A with regard to their impacts on climate change.

Under Alternative G, the impacts of climate change on sediment resources would be reduced by climate change, resulting in higher Sand Load Index values and an improved sand mass balance. Temperature suitability would be improved and impacts on humpback chub lessened. The overall number of trout, including the number of large trout, is expected to be higher than under historic hydrology. The impacts on native vegetation would be slightly greater. There would be a greater potential for impacts on cultural resources in Glen Canyon, but a lower potential in Grand Canyon. There would be an improvement in Tribal values for all metrics evaluated. Most recreation metrics would show improvement under climate change compared to historic hydrology. There would be a reduction in the value of hydropower generation and capacity.

4.17 CUMULATIVE IMPACTS

The CEQ defines a cumulative impact as "the impact on the environment that results from the incremental impact of [an] action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or nonfederal) or person undertakes such other actions" (40 CFR 1508.7). The assessments summarized in this section place the direct and indirect impacts of the alternatives, presented in the preceding sections of Chapter 4, into a broader context that takes into account the range of impacts of all actions within the Colorado River corridor, from Lake Powell and the Glen Canyon Dam downstream and west to Lake Mead, and the broader Colorado River Basin region (e.g., in the case of climate change).

4.17.1 Past, Present, and Reasonably Foreseeable Future Actions Affecting Cumulative Impacts

Past and present (ongoing) actions in the project area have been accounted for in the baseline conditions described for each resource in Chapter 3. Ongoing and reasonably foreseeable future actions considered in the cumulative impact analysis include the projects, programs, and plans of various federal agencies and other entities as described in the following sections. Many of these projects, programs, and plans reflect shared management objectives and cooperation among federal and state agencies, American Indian Tribes, and stakeholders groups that are intended to facilitate more effective and efficient management of the resources in the LTEMP project area. Past, present, and reasonably foreseeable future actions are described in the following sections and summarized in Table 4.17-1.

TABLE 4.17-1 Impacting Factors Associated with Past, Present, and Reasonably Foreseeable Future Actions and Basin-Wide Trends in the LTEMP Project Area

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions		
Flaming Gorge Dam Operations (Reclamation 2006a)	Flow modifications to achieve more natural flows and temperatures (to preserve and protect fish species) in the Green River, a major tributary of the Colorado River	Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River, to achieve flows (peak flows, durations, and base flows) and temperature regimes that mimic a more natural hydrograph to protect and recover downstream endangered fish species and their designated critical habitat (Reclamation 2006a).
Aspinall Unit Operations (Reclamation 2012f)	Flow modifications to simulate more natural spring flows and moderate base flows in the lower Gunnison River, a tributary to the Colorado River	The Aspinall Unit consists of Blue Mesa, Morrow Point, and Crystal dams, reservoirs, and powerplants on the Gunnison River, a tributary of the Colorado River. Reclamation published a ROD in 2012 detailing its decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River. Under the ROD, the Aspinall Unit is operated to meet specific downstream spring peak flow, duration flow, and base flow targets (at the USGS Whitewater gage), as outlined in the project's DEIS preferred alternative. Base flow is maintained to provide adequate fish passage at the Relands Fish Ladder on the Gunnison River near its confluence with the Colorado River.
Interim Guidelines (Reclamation 2007a,b)	Determines the annual volume for release from Glen Canyon Dam through a release tier calculation	The interim guidelines were established for a 20-year period (through 2026) to improve management of the Colorado River by considering water deliveries to Lakes Powell and Mead and to provide more predictability in water supply to users in the Basin states (especially the Lower Basin). They incorporate shortages to increase reservoir storage; coordinated operation of lakes Powell and Mead to minimize shortages in the Lower Basin and avoid the risk of curtailments of use in the Upper Basin; and water conservation in the Lower Basin to increase retention in Lake Mead. The guidelines have improved water supply conditions compared to continued implementation of previous guidelines and criteria; no specific measures to avoid or mitigate minor adverse impacts were identified. Annual volumes may impact recreation economics and water quality in Lake Mead and Lake Powell and water temperatures in the Colorado River; equalization years may increase trout populations below Glen Canyon Dam and increase sandbar erosion. Effects are expected to be independent of the LTEMP alternatives.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Tamarisk Management and Tributary Restoration (GCNP) (NPS 2002a,b, 2014g)	Reduction of tamarisk trees in the project area Increased diversity of native plant species	The NPS continues its efforts to eradicate tamarisk in the GCNP with the goal of restoring more natural conditions inside the canyons along the Colorado River in the GCNP. Over the past 10 years, the NPS has completed work in 130 project areas, removing more than 275,000 tamarisk trees from over 6,000 ac. Although control methods have been effective, overall return of native diversity has been slow. NPS anticipates overall beneficial effects on native vegetation, soil characteristics, water quality, wetlands, wildlife, wilderness, and visitor experience (NPS 2002b). Adverse impacts are expected to be negligible to minor and short in duration (with the exception of microbiotic soil crusts). No significant adverse effects on threatened, endangered, and sensitive species or ethnographic resources are expected. NPS monitors and mitigates the impacts of tamarisk management on an ongoing basis.
Colorado River Management Plan (NPS 2006b,d)	Established visitor capacity based on size and distribution of campsites Year-round use provides opportunities for a variety of visitor experiences including motorized and non-motorized trips that range from 6 to 25 days	The goal of the CRMP is to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through the GCNP by establishing visitor capacity based on size and distribution of campsites, overall resource conditions, and visitor experience variables. Recreational use patterns are based on daily, weekly, and seasonal launch limits and seasonal differences in commercial and noncommercial levels. The plan also established a 6.5 month non-motorized season. The actions would have beneficial effects on cultural resource sites, traditional cultural properties, ethnobotanical resources, and other elements important to Tribal assessments of canyon environmental health. Beneficial impacts on commercial operators (revenues and profits) and adjacent lands were also anticipated. Impacts on visitors' use and experience were determined to be negligible to moderate and adverse to beneficial, depending on perspective and desired experience. Adverse impacts on natural resources (biological soil crusts, aquatic resources at attraction sites, special status species, and the soundscape) would range from negligible to major.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Backcountry Management Plan (for GCNP) (NPS 1988[a])	Allocates and distributes backcountry and wilderness overnight use in campsites along the Colorado River	The goal of the BCMP is to protect and preserve the park's natural and cultural resources and values and integrity of wilderness character by providing a framework for consistent decision making in managing the park's backcountry, providing a variety of visitor opportunities and experiences for public enjoyment in a manner consistent with park purposes and preservation of park resources and values and providing for public understanding and support of preserving fundamental resources and values for which Grand Canyon was established. Proposed actions would address both beneficial and adverse effects to: wildlife populations and habitat by minimizing human-caused disturbances and habitat alteration, minimizing impacts to native vegetation, reducing exotic plant species spread, and preserving fundamental biological and physical processes; enhancing wilderness character and values; developing and implementing an adaptive management process that includes monitoring natural, cultural, and experiential resource conditions and responding when resource degradation has resulted from use levels; preserving and protecting natural soil conditions by minimizing impacts to soils from backcountry recreational activities; minimizing adverse chemical, physical, and biological changes to water quality in tributaries, seeps, and springs; and preserving cultural resource integrity and condition.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Abandoned Mine Lands Closure Plan (NPS 2010b)	Closure of mine openings	The NPS will address health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 AMLs in GCNP. Closure of mine openings[b] would have a long-term beneficial impact on historic structures by protecting mine features from vandalism; however, impacts associated with closure construction activities (installing gates, grates, or cupolas or moving earth, rocks, or tailings piles), while localized, would range from negligible to mostly minor, with some possible moderate adverse (i.e., measurable and perceptible) effects. Beneficial impacts would also be expected on bats and other wildlife by providing protection from disturbance, although NPS notes that closure construction could have minor long-term adverse effects, especially to other wildlife that use the openings for nesting, denning, or shade (effects would be partially mitigated by avoiding closing mine features that are used by a listed species). Because several AML sites are located near trails and river access points in GCNP, they are easily accessible by visitors (although no safety incidents have been documented). Impacts of AML closure, therefore, are expected to be beneficial overall because they would reduce the likelihood of injury from visitor access. Visitors wishing to experience bats and other wildlife, however, may incur localized short-term negligible to minor adverse effects (especially during closure construction when small areas would be closed to visitors). NPS notes that other sites would remain open to visitors, thus affording other opportunities to experience bats and wildlife and mitigating these impacts.
Fire Management Plan (GCNP) (NPS 2012f)	Reduction of wildfire risk in GCNP Ecosystem Restoration	The NPS manages wildland fire risk in GCNP using an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). It also supports the objects of the Resource Management Plan (NPS 1997). This plan may have beneficial or adverse impacts related to fire reduction, such as decreased runoff of sediments, decreased flooding, maintaining or restoring habitat in uplands.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Past and Present (Ongoing) Actions (Cont.)		
Uranium Mining and Public Lands Withdrawal (DOI 2012b)	Withdrawal of federal lands in the Grand Canyon region from location and entry Continued exploration and mining on state and private lands	In January 2012, the Bureau of Land Management (BLM) withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period. The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). It would have no effect on the exploration and development of any non-federal lands within its exterior boundaries; the withdrawal area would remain available for the development of federal leasable and salable minerals. Active exploration for uranium on state and private lands in the region would not be affected by the withdrawal. Potential impacts of uranium mining are currently difficult to quantify because of the uncertainties of subsurface water movement, radionuclide migration, and biological exposure pathways. Based on its study of groundwater near historic uranium mining sites in northern Arizona, the USGS concluded the likelihood of adverse impacts on water resources (from water use and degradation or impairment) is likely to be low, but if water resources were affected, the risk to the greater ecosystem, Tribes, and tourists could be significant (Bills et al. 2010; DOI 2012b).
Comprehensive Fisheries Management Plan (below Glen Canyon Dam) (NPS 2013e)	Potential stocking of sterile rainbow trout in Lees Ferry Translocation of native fish species Removal of high-risk nonnative fish from areas important for native fish Beneficial use of all nonnative fish removed Implementation of an experimental adaptive strategy for evaluating the suitability of razorback sucker in western portions of the Grand Canyon	The main purpose of the plan is to maintain a thriving native fish community within GCNP while also maintaining a highly valued recreational trout fishery community in the Glen Canyon reach. The actions would have a beneficial effect on native and endangered fish populations, as well as visitor experience (by avoiding quality decline of the rainbow trout fishery), and no significant adverse effect on public health, public safety, or threatened or endangered species. They would, however, contribute to long-term ethnographic resource cumulative impacts resulting from fish management (specifically euthanizing fish), which constitutes an adverse effect under Section 106 of the NHPA. This effect would be mitigated to the extent possible through an MOA between the NPS, SHPO, and Tribes (NPS 2013h).
Lower Colorado River Multi-Species Conservation Program (DOI 2005)	Management of take permits (while conserving critical habitat and protecting threatened and endangered species)	The program is a cooperative species conservation effort between federal and non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development and to provide the basis for incidental take permits while conserving critical habitat and working toward the recovery of threatened and endangered species. Potential beneficial impacts to special status species in Lower Basin.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions		
Special Flight Rules in the Vicinity of GCNP, AZ (14 CFR Part 93, Subpart U)	Reduction of noise in GCNP	Rules to be established to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (PL 100-91). Would establish a system of routes, altitudes, flight allocations and flight free zones in the air space in and around GCNP.
Lake Powell Pipeline Project (UBWR 2015)	Construction/operation of pipeline and penstock Construction/operation of hydropower stations Construction/operation of transmission lines Increased water withdrawal from Lake Powell (adjacent to Glen Canyon Dam)	The Utah State legislature has authorized the UBWR to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. The proposed pipeline is currently being evaluated for potential effects on water storage in Lake Powell and related resources, the availability of water for downstream users, habitat conditions, and aquatic species and resources, including sport fisheries (UBWR 2011a,b).
Grand Canyon Escalade (Confluence Partners, LLC 2012a)	Construction/operation of multiple elements (tramway, riverwalk, road, parking lots, and buildings) Increased visitor foot and motorized traffic Increased jobs and gross revenues (to the Navajo Nation)	The Navajo Nation has proposed the 420-ac development project on the Grand Canyon's eastern rim, on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking lots. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts to the local economy through increased tourism and job creation.
Red Gap Ranch Pipeline (City of Flagstaff City Council 2013)	Increased groundwater withdrawal from the C-aquifer on the Coconino Plateau Construction/operation of multiple elements (wells, roads, pipelines, and a treatment facility)	In anticipation of a future water supply shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 acre-feet of groundwater each year from the C-aquifer on the Coconino Plateau. A NEPA review, currently underway, is evaluating the impacts of groundwater withdrawal from the aquifer on base flow feeding the Little Colorado River, Clear Creek, and Chevelon Creek, which ultimately flow into the Colorado River. It is also evaluating the impacts of groundwater conveyance on biological and cultural resources on the Red Gap Ranch property.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Reasonably Foreseeable Future Actions (Cont.)		
Page-LeChee Water Supply Project (NPS 2009b)	Construction/operation of water intakes and pumping station Construction/operation of a conveyance pipeline Increased water withdrawal from Lake Powell (in the Chains area)	The Page-LeChee would improve the existing water supply system for the city of Page and the LeChee Chapter of the Navajo Nation. It would increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA.
Four Corners Power Plant (FCPP) and Navajo Mine Energy Project (OSMRE 2015a, b)	Reduced NO_x and PM pollutants emissions	The FCPP, located just north Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), consists of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities. The proposed lease amendment would extend the life of the powerplant to 2041. Under the proposed alternatives, air emissions would not exceed NAAQS and deposition impacts with 50 km (31 mi) of the FCPP are expected to be negligible. The Arizona Public Service Company plans to close three units (Units 1, 2, and 3) and install SCR controls on the remaining two units (Units 4 and 5) to reduce NO_x and PM pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b).
Clean Power Plan Proposed Rule (EPA 2014b)	Reduced CO_2 emissions	The Clean Power Plan Proposed Rule would reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The draft plan would establish state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b). The EIA (2015) estimates the proposed rule would result in a reduction of U.S. power sector CO_2 emissions to about 1,500 million MT/yr by 2025 (levels not seen since the early 1980s). The plan is expected to be finalized in 2015.

TABLE 4.17-1 (Cont.)

Actions	Impacting Factors	Description of the Action and Its Effect(s)
Human Activities Affecting Climate		
	Increased temperatures (air and surface water) Increased variability in precipitation and stream flows Drought conditions and water loss (through evaporation and evapotranspiration) Increased risk of wildfires Decreased snowpack and stream flows (due to less late winter precipitation and snowpack sublimation) Seasonal shifts in snowmelt and high stream flows (to earlier in the year) Increased flooding potential (due to earlier snowmelt) Decreased spring and summer runoff (due to decreased snowpack) Lowered lake levels (Lakes Powell and Mead) Increased agricultural water demand (due to increased temperatures) Reduced agricultural yields Insect outbreaks Increased wildfires Reduced plant and animal diversity (widespread tree mortality) Heat threats to human health	The southwest is already experiencing the effects of climate change, with the decade from 2001 to 2010 being the warmest on record (Garfin et al. 2014; World Meteorological Organization 2014; NAS 2007). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern. Changes in temperature and precipitation patterns could take a toll on the diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation. The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014).

[a] New BCMP expected to be implemented with ROD in 2016.

[b] NPS notes that except for backfilling, most closure types would be reversible, thereby reducing the impacts of closure on those sites eligible for the *National Register* (NPS 2010b).

4.17.1.1 Past and Present (Ongoing) Actions

There are numerous actions documented in decisions, plans, policies, and initiatives that relate directly or indirectly to the operation of Glen Canyon Dam and management of the Colorado River ecosystem (see Section 1.10). These actions are listed below, and establish the current conditions or baseline for the LTEMP.

Flaming Gorge Dam Operations

Since 2006, Reclamation has modified its operation of the Flaming Gorge Dam on the Green River, a major tributary of the Colorado River upstream of Lake Powell, to achieve flows (peak flows, durations, and base flows) and temperature regimes that mimic a more natural hydrograph to protect and recover downstream endangered fish species and their designated critical habitat (Reclamation 2006a).

Aspinall Unit Operations

The Aspinall Unit, managed and operated by Reclamation (in cooperation with various other federal agencies), consists of Blue Mesa, Morrow Point, and Crystal Dams, Reservoirs, and Powerplants on the Gunnison River, a tributary of the Colorado River upstream of Lake Powell. It was originally authorized by the Colorado River Storage Project Act of 1956. In 2012, Reclamation published a Record of Decision (ROD) that details the decision to modify reservoir operations (beginning in 2012) to avoid jeopardizing endangered fish species and their designated critical habitat by allowing higher and more natural downstream spring flows and moderate base flows in the lower Gunnison River (Reclamation 2012g).

Interim Guidelines for Coordinated Operation of Lake Powell and Lake Mead

Management of the Colorado River system must adhere to the various treaties, decrees, statutes, regulations, contracts, and agreements that are collectively known as the Law of the River (Table 1-2). The Law of the River applies mainly to the allocation, appropriation, development, and exportation of the waters within the Colorado River Basin (Reclamation 2012a). In 2007, Reclamation (in cooperation with the Bureau of Indian Affairs [BIA], U.S. Fish and Wildlife Service [FWS], NPS, Western, and the United States Section of the International Boundary and Water Commission) completed an EIS and ROD to propose and adopt specific interim guidelines to address water shortages for the Colorado River Lower Basin and to coordinate operations for Lakes Powell and Mead, especially under drought and low reservoir conditions. These guidelines were established for a 20-year period, which would extend through 2026. The objectives of the interim guidelines are to (1) improve Reclamation's management of the river by considering the effects of water deliveries to Lakes Powell and Mead on water storage and supply, power production, recreation, and other resources; (2) provide users of Colorado River water, especially those in the Lower Basin states, more predictability in future water deliveries, especially during drought and low-reservoir conditions; and (3) provide other mechanisms of storage and delivery of water supplies in Lake Mead to increase the flexibility in meeting water use needs in the Lower Basin states. In addition, the interim guidelines require the Basin states to address future controversies through consultation and negotiation before resorting to litigation (Reclamation 2007a,b).

Drought conditions in the Colorado River Basin between 2000 and 2007, coupled with increased demands for Colorado River water supplies, resulted in decreased reservoir storage in the basin from 55.8 million ac-ft in 1999 (94% of capacity) to 32.1 million ac-ft in 2007 (54% of capacity). The interim guidelines incorporate three main elements: (1) shortages to conserve reservoir storage; (2) coordinated operation of Lakes Powell and Mead on the basis of specified reservoir conditions to minimize shortages in the Lower Basin and avoid the risk of curtailments of use in the Upper Basin; and (3) water conservation in the Lower Basin to increase retention of water in Lake Mead. The interim guidelines presented in Section XI of the ROD (Reclamation 2007b) define "normal conditions" in Lake Mead as lake levels above elevation 1,075 ft AMSL and below elevation 1,145 ft AMSL. They quantify surplus and shortage conditions against these levels and define apportionments to Lower Basin states on this basis.

Tamarisk Management and Tributary Restoration Project at Grand Canyon National Park

The NPS continues its efforts to eradicate tamarisk in side canyons, tributaries, developed areas, and springs above the pre-dam water level in GCNP (NPS 2002a,b, 2014g). Tamarisk is a nonnative shrub that was introduced to the United States in the 19th century as an erosion control agent. Since its introduction, the plant has spread throughout the west and has caused major changes to natural ecosystems. The shrub reached the GCNP in the 1920s and by the time Glen Canyon Dam was completed in 1963, it had become a dominant riparian zone species along the Colorado River. The NPS's ongoing goal is to restore more natural conditions inside canyons along the river in GCNP and to prevent further loss or degradation of existing native biota. To this end, restoration biologists use an adaptive strategy to manage and control tamarisk in the GCNP. Control measures involve a combination of mechanical and chemical methods tailored to site-specific conditions and plant size. These include pulling, cutting to stump level, applying herbicide, and girdling (leaving the dead tree in place for wildlife habitat) (NPS 2014g).

The tamarisk leaf beetle (*Diorhabda* spp.) was not intentionally introduced, but was discovered in 2009 near Navajo Bridge and at RM 12, and at several locations, including Lees Ferry, in 2010. It is currently found throughout Glen and Grand Canyons (Section 3.6.2). The beetle causes early and repeated defoliation of tamarisk, eventually resulting in mortality. Although the beetle has been associated with widespread defoliation of some tamarisk communities along the river, its long-term effects on tamarisk abundance and distribution in Glen and Grand Canyons is not currently known.

Colorado River Management

The CRMP specifies the actions that NPS follows to protect resources and visitor experience while enhancing recreational opportunities on the Colorado River through GCNP (NPS 2006a,b). The CRMP describes management goals for two geographic sections of the Colorado River: (1) Lees Ferry to Diamond Creek, and (2) Diamond Creek to Lake Mead. The selected action for the Lees Ferry to Diamond Creek section (RM 0 to 226) defines mixed motor/no motor seasons and reduces the maximum group size for commercial groups. It establishes use patterns based on daily, weekly, and seasonal launch limits, provides year-round noncommercial use and a 6.5 month non-motorized use period during the shoulder and winter seasons. Management of the Lower Gorges section from Diamond Creek to Lake Mead (RM 226 to 277) involves cooperation between the NPS and the Hualapai Tribe, and provides opportunities for shorter whitewater and smoothwater trips (NPS 2006b).

Backcountry Management Plan

The Backcountry Management Plan defines the concepts, policies, and operational guidelines NPS follows to manage visitor use and protect natural resources in the backcountry and wilderness areas of the GCNP (NPS 1988). The objectives of the Backcountry Management Plan are to provide a variety of backcountry recreational visitor opportunities that are compatible with resource protection and visitor safety. The plan supports the objectives of the CRMP and is currently undergoing revision. A Draft EIS on the proposed plan was recently issued (NPS 2015b).

Abandoned Mine Lands Closure Plan

In 2010, the NPS finalized an EA that evaluated methods to correct health and safety hazards (vertical holes, unstable and falling rock, pooling water, and unsuitable air) at 16 abandoned mine lands (AMLs) in GCNP (NPS 2010b). The resources affected by AML closure are historic structures (mine features such as adits, shafts, and cairns, among others) and districts, bats and other wildlife (including federally listed species and species of management concern), visitor experience (including health and safety), and wilderness.

Fire Management at Grand Canyon National Park

The NPS manages wildland fire risk in GCNP through its Fire Management Program, as detailed in its Fire Management Plan (NPS 2012d). The Fire Management Plan employs an adaptive management process to address the areas of firefighting, rehabilitation, hazardous fuels reduction, community assistance, and accountability. Implementation of the plan meets the park goals and objectives for managing park resources and visitor experiences, as identified in the General Management Plan (NPS 1995). The Fire Management Plan also supports the objectives of the Resource Management Plan (NPS 1997). These include protecting human health and safety and private and public property; restoring and maintaining park ecosystems in a natural and resilient condition; interpreting and educating Tribes, stakeholders, and the public about the importance of the natural fire regime; and promoting a science-based program that relies on current and best-available information, as described in Table 3.2 of NPS (1995).

Uranium Mining and the Northern Arizona Withdrawal of Public Lands

Uranium mineralization in the Grand Canyon region is associated with geologic features called breccia pipes. A breccia pipe is a cylindrical, vertical mass of broken rock (breccia) that typically measures tens of meters across and hundreds of meters vertically. There are 1,300 known or suspected breccia pipes in the Grand Canyon region (Spencer and Wenrich 2011). Development of uranium minerals associated with breccia pipes dates back to the 1940s. By the late 1980s, more than 71 breccia pipes had been found to contain ore-grade rock (DOI 2012b). As of 2010, over 23 million lb of uranium (U_3O_8) had been produced from nine breccia pipes (Spencer and Wenrich 2011); the estimated mean undiscovered uranium endowment for the region is about 933.6 million lb (Otton and Van Gosen 2010)

In January 2012, the Bureau of Land Management (BLM) withdrew from location and entry under the Mining Law of 1872 approximately 1,006,545 ac of federal land in northern Arizona for a 20-year period (DOI 2012b). The withdrawal includes 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel). The purpose of the land withdrawal is to protect the natural, cultural, and social resources in the Grand Canyon watershed from adverse effects related to locatable mineral exploration and development (i.e., uranium mining). The withdrawal would have no effect on the exploration and development of any non-federal lands within its exterior boundaries (with the exception of about 23,993 ac of split estate lands where locatable minerals are owned by the federal government), and the withdrawal area would remain available for the development of federal leasable and salable minerals (e.g., oil and gas leases and sand and gravel permits). The public land laws would still apply (DOI 2012b).

Although 3,156 mining claims predate BLM's notice of withdrawal in 2009, most of these did not have valid existing rights at the time of the notice and, therefore, cannot be developed during the withdrawal period. The BLM estimates that 11 mines, including four existing uranium mines, could still be developed under the full withdrawal, a level similar to that in the 1980s when the high price of uranium spurred interest in mining (DOI 2012b). Arizona State land parcels and private lands in the region could also be developed (NPS 2013k). Thus, uranium mining, while reduced, will continue throughout the withdrawal period.

Active exploration for uranium in the region is currently focused on state and private lands located within the Cataract Canyon/Havasu Creek surface and groundwater basins, to the south of GCNP. These lands are adjacent to the Havasupai Reservation, Hualapai Reservation, and the Kaibab National Forest, and are operated near the Boquillas Ranch and other private lands owned by the Navajo Nation (NPS 2013k).

Comprehensive Fisheries Management below Glen Canyon Dam

The NPS is implementing its Comprehensive Fisheries Management Plan for all fish-bearing waters in GCNP and GCNRA below Glen Canyon Dam. The plan was developed in coordination with the Arizona Game and Fish Department, the FWS, Reclamation, and the USGS GCMRC; its purpose is to maintain a thriving native fish community within GCNP, while also maintaining a highly valued recreational trout fishery in the Glen Canyon reach, defined as the 16.5 mi of river downstream from Glen Canyon Dam on the Colorado River in the GCNRA, including Lees Ferry and the mouth of the Paria River (NPS 2013e).

The Plan's actions include stocking sterile rainbow trout in Lees Ferry (when there are fishery declines); translocation of native fish species, including the humpback chub; removal of high-risk nonnative fish from selected areas important for native fish; beneficial use of all nonnative fish removed; and the implementation of an experimental adaptive strategy to evaluate the suitability of razorback sucker in western portions of the Grand Canyon (NPS 2013h).

Lower Colorado River Multi-Species Conservation Program

The Lower Colorado River Multi-Species Conservation Program (LCRMSCP) implements and coordinates the Secretary of the Interior's statutory responsibilities under the ESA (DOI 2005). The program is a cooperative species conservation effort between six federal agencies (Reclamation, BIA, NPS, BLM, Western, and the FWS) and numerous non-federal entities within the states of Arizona, California, and Nevada. Its goal is to accommodate water diversions and power production while optimizing opportunities for future water and power development (lead agency: Reclamation) and to provide the basis for incidental take permits (lead agency FWS) while conserving critical habitat and working toward the recovery of threatened and endangered species as well as reducing the likelihood of additional species being listed. Measures to mitigate the impacts of the incidental take of species covered under the Program are contained in its Habitat Conservation Plan (LCRMSCP 2004). The Habitat Conservation Plan and other program information are available at http://www.lcrmscp.gov/index.html.

4.17.1.2 Reasonably Foreseeable Future Actions

Special Flight Rules in the Vicinity of Grand Canyon National Park

The NPS will establish new rules to substantially restore natural quiet at GCNP in accordance with the National Parks Overflights Act of 1987 (P.L. 100-91). The rules would create a system of routes, altitudes, flight allocations, and flight-free zones in the air space in and around GCNP.

Lake Powell Pipeline Project

In 2006, the Utah State legislature passed the Lake Powell Pipeline Development Act to authorize the Utah Board of Water Resources (UBWR) to build a pipeline to transfer water from Lake Powell to the Sand Hollow Reservoir near St. George, Utah, to meet water demand in southwestern Utah. The proposed project would consist of (1) building and operating 139 mi of 69-in. diameter pipeline and penstock, 35 mi of 30-in. to 48-in. diameter pipeline, and 6 mi of 24-in. diameter pipeline; (2) a combined conventional peaking and pumped storage hydropower station; (3) five conventional in-pipeline (booster) hydropower stations; and (4) transmission lines. The booster pumping stations along the length of the pipeline would provide the 2,000-ft lift needed to move the water over the high point within the Grand Staircase-Escalante National Monument. From the high point, water would flow through a series of hydroelectric turbines to make use of the 2,900-ft drop in elevation from the high point to the end of the pipeline in St. George (UBWR 2015; FERC 2011). The Lake Powell intake would be located near the south end of the lake adjacent to Glen Canyon Dam (UBWR 2011a). UBWR plans to have its licenses, permits, and ROD issued sometime in 2015 so construction can begin in 2020 (water delivery would not begin until 2025) (UBWR 2015).

Grand Canyon Escalade

Private developers have proposed to the Navajo Nation, a 420-ac development project, known as the Grand Canyon Escalade, on the Grand Canyon's eastern rim on the western edge of the Navajo reservation at the confluence of the Little Colorado and Colorado Rivers. The development would include a 1.4-mi-long, eight-person tramway (gondola) to transport visitors 3,200 ft from the rim to the canyon floor. On the rim, the development would include retail shops, restaurants, a museum, a cultural/visitor center, a hotel, multiple motels, a lodge with patio, roads, and parking for cars and RVs. It would also include a restaurant, gift shops, an amphitheater, and a riverwalk (with an elevated walkway) along the canyon floor. Analysis for this project has not been conducted, so impacts have not been fully determined; however, the construction and operation of the Escalade project could result in adverse impacts on natural and cultural resources in the areas of the Little Colorado River confluence, wilderness, visual resources, and resources of importance to multiple Tribes. It could also result in beneficial impacts to the local economy through increased tourism and job creation.

Red Gap Ranch Pipeline

In 2006, Reclamation completed a study that projected a water supply shortfall of about 3,370 acre-feet/year for the City of Flagstaff (and other towns in Coconino County) by the year 2050 (Reclamation 2006b). To address its shortfall, the City of Flagstaff has purchased property on the Red Gap Ranch (about 34 mi to the east), on which it plans to develop new municipal wells to augment its current supply. The wells would withdraw up to 8,000 acre-feet of groundwater each year from the C-aquifer (on the Coconino Plateau) and send it via pipeline to the City (City of Flagstaff City Council 2013). Because the pipeline crosses federal land and is partially funded with federal dollars, the proposed project is currently undergoing a NEPA review (EA). The scope of the EA is to evaluate the impacts of groundwater withdrawal on the base flow that feeds the Little Colorado River, Clear Creek, and Chevelon Creek (which ultimately feed the Colorado River), as well as the impacts the conveyance of groundwater (including the construction of pipelines, roads, and a treatment facility) could have on biological and cultural resources on the Red Gap Ranch property.

Page-LeChee Water Supply Project

The Page-LeChee water supply project is a water supply facility providing domestic water supply for the city of Page and the LeChee Chapter of the Navajo Nation (NPS 2009b). The proposed project would improve the existing system (consisting of three pumps operating at 3,050 gpm) and increase the capacity of water already drawn from Lake Powell; it would include water intakes, a pumping station, and a conveyance pipeline located on the GCNRA (from Lake Powell to a tie-in point on the existing system near U.S. 89 between the Glen Canyon rim and the water treatment plant in Page).

Four Corners Power Plant and Navajo Mine Energy Project

The Office of Surface Mining Reclamation and Enforcement (OSMRE) has completed a final EIS for the lease amendment with the Navajo Nation that would extend the life of the Four Corners Power Plant (FCPP) to 2041 (OSMRE 2015a, b). The FCPP, located just north Fruitland, New Mexico (about 160 mi east of Glen Canyon Dam), consists of five pulverized coal-burning steam electric generating units with a total generating capability of 2,100 MW and other ancillary facilities, including Morgan Lake and Morgan Lake Dam, fly ash storage silos and bottom ash dewatering bins, three switchyards, an intake canal, and access road (OSMRE 2015b). As part of the proposed action, the Arizona Public Service Company would close three units (Units 1, 2, and 3) and install selective catalytic reduction (SCR) controls on the remaining two units (Units 4 and 5) to reduce NO_x and particulate matter (PM) pollutants that contribute to regional haze and visibility issues (to benefit the 16 Class 1 Federal Areas, including the GCNP, within 300-km (186-mi) radius of the facility (OSMRE 2015b). The proposed action would also include the renewal of the transmission line right-of-way that connects the powerplant to the power grids in Arizona and New Mexico and the development of a new 5,600-ac mine area, the Pinabete Mine Permit area, to supply coal to the powerplant for up to 25 years (beginning July, 2016). The Pinabete Mine area is a surface coal mining and reclamation operation located near the existing Navajo Mine in San Juan County, New Mexico (OSMRE 2015c).

EPA's Clean Power Plan Proposed Rule for Existing Powerplants

The Clean Power Plan Proposed Rule is being developed by the U.S. Environmental Protection Agency (EPA) under Section 111(d) of the Clean Air Act (CAA) to reduce atmospheric carbon by limiting the CO_2 emissions from existing fossil-fuel fired powerplants in the United States. The final plan, released in October 2015, establishes state-by-state carbon emissions rate reduction targets with the aim of reducing emissions from the power sector to about 30% below 2005 levels by 2030 (EPA 2014b, 2015c). The EIA (2015) estimates the proposed rule would result in a reduction of power sector CO_2 emissions to about 1,500 million MT/yr by 2025, levels not seen since the early 1980s. The plan is expected to be finalized in 2015.

4.17.2 Climate-Related Changes

The southwest is already experiencing the effects of climate change (Garfin et al. 2014). The decade from 2001 to 2010 was the warmest on record, with temperatures almost 1.1°C higher than historic averages (Garfin et al. 2014; World Meteorological Organization 2014). Precipitation trends are more variable across the region, but drought-induced water shortages in the Colorado River Basin are a growing concern, prompting federal and state agencies, Tribes, and other stakeholders to develop adaptation and mitigation strategies to address imbalances between water supply and demand in the coming years (Garfin et al. 2014; NAS 2007; Reclamation 2007b, 2012c). Section 4.16 provides a discussion of climate change as related to the LTEMP.

Higher temperatures in the Colorado River Basin have resulted in less precipitation falling and being stored as snow at high elevations in the Upper Basin (the main source of runoff to the river), increased evaporative losses, and a shift in the timing of peak spring snowmelt (and high streamflow) to earlier in the year (NAS 2007; Christensen et al. 2004; Jacobs 2011). These effects in turn have exacerbated competition among users (farmers, energy producers, urban dwellers), as well as effects on ecological systems, during a time when due to a rapidly rising population water demand has never been higher (Garfin et al. 2014). The combination of decreasing supply and increasing demand will present a challenge in meeting the water delivery commitments outlined in the Colorado River Compact of 1922 (apportioning water between the Upper and Lower Basins) and the United States–Mexico Treaty of 1944 (which guarantees an annual flow of at least 1.5 million ac-ft to Mexico). In 2007, DOI adopted interim guidelines (Reclamation 2007b) to specify modifications to the apportionments to the Lower Basin states in the event of water shortage conditions (see section above).

Changes in temperature and precipitation patterns attributed to climate change could also take a toll on the region's rich diversity of plant and animal species (e.g., widespread loss of trees due to wildfires). Other possible effects include forest insect outbreaks, reduced crop yields, and an increased risk of heat stress and disruption to electric power generation (during summer heat waves). The recreational economy could also be affected by a shorter snow season and reduced streamflow (Garfin et al. 2014). Such effects are likely to continue well into the foreseeable future (NAS 2007).

4.17.3 Cumulative Impacts Summary by Resource

The following sections discuss the past, present, and reasonably foreseeable future actions, including the LTEMP alternatives, that could contribute to cumulative impacts on resources within the project area. Table 4.17-2 provides a summary of these contributions by resource area.

TABLE 4.17-2 Summary of Cumulative Impacts and Incremental Contributions under LTEMP Alternatives

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Water Resources	Colorado River between Glen Canyon Dam and Lake Mead; lakes Powell and Mead	Projected future changes in flow due to increased water demand (as a result of population growth and development), and decreased water supply, drought, and increased water temperature attributed to climate change could be the greatest contributors to adverse impacts on Colorado River flows, storage in lakes Powell and Mead, and water quality (temperature and salinity). The 2007 Interim Guidelines are improving water supply conditions through increased water conservation efforts, which should provide more predictability in water supply to users in the Basin States (especially the Lower Basin). They are also improving water temperature and water quality in lakes Powell and Mead.	The proposed action is consistent with the 2007 Interim Guidelines for annual water deliveries. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions. With the exception of Alternative B, the LTEMP alternatives would result in slightly greater summer warming and a slightly increased potential for bacteria and pathogens along shorelines.
Sediment Resources	Colorado River between Glen Canyon Dam and Lake Mead; inflow deltas in lake Mead	Potential future hydrology in the Colorado River (as determined by the 2007 Interim Guidelines), including the effects of climate change, could affect tributary sediment delivery (supply), fine sediment transport, sandbar formation, and lake delta formation over the long term. Glen Canyon Dam and Lake Powell trap most of the mainstem Colorado River sediment supply (post-dam sediment supplies less than 10% of the pre-dam supply). Implementation of HFEs could result in an improvement in sandbar building.	LTEMP alternatives are expected to improve sediment conditions to varying degrees by conserving sediment and building sandbars at higher elevations. Alternatives with the most HFEs (Alternatives C, D, E, F, and G) have the highest sandbar building potential. Alternative A has the lowest sandbar building potential. The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Natural Processes	Colorado River ecosystem in Glen, Marble, and Grand Canyons	Projected future changes in flow due to increased water demand (as a result of population growth and development) and decreased water supply (and sediment supply), drought, and increased water temperature attributed to climate change would contribute to adverse impacts on natural processes through changes in Colorado River flows, sediment supply, and temperature. Implementation of HFEs could result in an improvement in sandbar building.	Compared to Alternative A, Alternatives C, D, F, and G are expected to increase sediment conservation, increase the stability of nearshore habitats, and provide slightly warmer water temperatures. The proposed actions contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Aquatic Ecology	Colorado River between Glen Canyon Dam and Lake Mead	Aquatic resources would be affected by changes in flow due to increased water demand (as a result of population growth and development); decreased water supply, drought, and increased water temperature attributed to climate change; and other foreseeable actions (related to fish management and uranium mining). Drought conditions (and actions such as the Lake Powell pipeline project) would result in lower reservoir elevations and benefits to aquatic resources associated with warmer release temperatures. Warmer water temperatures, however, could also result in adverse effects if they increase the distribution of nonnative species adapted to warm water (e.g., fish parasites). 2007 Interim Guidelines determine annual volume and equalization years may increase trout production and river temperature both of which may impact HBC populations. Translocation of native fish species (humpback chub) from the Little Colorado River to other tributaries within the Grand Canyon would have a beneficial (protective) impact on aquatic resources.	Alternatives with higher fluctuation levels (Alternatives B and E) have lower trout numbers and slightly higher humpback chub numbers, but less nearshore habitat stability and aquatic productivity. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Vegetation	Riparian zone along the Colorado River between Glen Canyon Dam and Lake Mead	Lower regional precipitation with climate change would result in a shift to more drought-tolerant species in the New High Water Zone; those in the Old High Water Zone would continue to decline. Drought conditions would favor nonnative tamarisk (which is tolerant of drought stress). However, tamarisk control efforts by the NPS and possibly the effects of the tamarisk leaf beetle and splendid tamarisk weevil would increase tamarisk mortality and improve conditions for native shrubs over time. Feral burros contribute to impacts on riparian vegetation in the Old High Water Zone (by reducing vegetation and decreasing species diversity); recreational visitors may also contribute to vegetation loss and the introduction of exotic plant species.	Most alternatives, including Alternative A, result in a decrease in native community cover and wetlands. Alternative D is the only alternative that results in an overall improvement in vegetation. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wildlife	Colorado River corridor between Glen Canyon Dam and Lake Mead	Cumulative impacts on aquatic resources and riparian vegetation (as described in the above entries) affect riparian and terrestrial wildlife. Wildlife may also be affected by other future actions and basin-wide trends. Increased water demand and lower flows downstream of Glen Canyon Dam could stress riparian and wetland vegetation, affecting both wildlife habitats and the wildlife prey base. Warmer discharges (attributed to climate change) would likely increase algae and invertebrates, increasing the prey base for some species. Vegetation management could adversely affect birds in the short term, but are expected to provide benefits in the long term. Wildlife disturbance could result from various actions, including uranium mining, the Grand Canyon Escalade Project, and recreational activities (hiking, rafting, fishing, and camping). Habitat loss is a concern for those projects involving the construction of roads, effluent ponds (mining), and buildings.	Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less-even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Cultural resources	Cultural sites within Glen and Grand Canyons	Cultural resources are in an ongoing state of deterioration and natural erosive processes continue to destabilize these sites. Visitor traffic to GCNP exacerbates deterioration as artifacts exposed by erosion are moved or removed from the site. These effects are offset by enforcement of NPS's Backcountry Management Plan. It is not clear whether erosive processes will increase (with intense precipitation events) or decrease (with decreased precipitation) in the project area as a result of climate change. Ongoing dam operations may affect sediment availability, resulting in wind transport effects on GCNP cultural sites and reservoir shoreline cultural sites.	Alternatives with extended-duration HFEs (Alternatives D and G) could adversely impact terraces that support cultural resources in Glen Canyon. Alternatives with more HFEs (e.g., Alternatives C, D, E, F, and G) could provide for greater protection of sites by providing more sand for wind transport to these sites. The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Tribal resources	Glen, Marble, and Grand Canyons	Many Tribes 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. Development related to projects like the Lake Powell Pipeline and uranium mining in the region, as well as fish/vegetation management practices, have ongoing adverse impacts on Tribe members. Actions and basin-wide trends affecting aquatic life, vegetation, and wildlife (as described above) would also affect resources of value to Tribes. Continued use of the riparian zone by visitors has the potential to damage places of cultural importance to the Tribes.	All alternatives except Alternative F include either mechanical removal of trout or TMFs and may have an adverse impact to Tribes. Therefore, every alternative but Alternative F would contribute to cumulative impacts.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Recreation, visitor use and experience	Colorado River and associated recreational sites between Glen Canyon Dam and Lake Mead	The HFE protocol has had a beneficial effect on camping and beach access (and therefore visitor use and experience) because it has a direct effect on sediment transport and deposition. Other actions taken by the NPS, as described in various management plans (tamarisk management, GCNP backcountry, noise and special flight rules, fire), also benefit visitor use and experience. The CRMP (which regulates boating and rafting) and the Comprehensive Fisheries Management Plan and Non-Native Fish Control Program are protective of natural/cultural resources and also have long-term beneficial effects on recreation and visitor experience. Warming water temperatures (and reduced flows below Glen Canyon dam) attributed to climate change could affect the health of the trout fishery below the dam, thus contributing to adverse cumulative impacts on recreation.	Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). The proposed action's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions.
Wilderness	Colorado River and associated recreational and wilderness sites between Glen Canyon Dam and Lake Mead	The HFE protocol and other actions taken by the NPS, as described in various management plans (the CRMP, tamarisk management, GCNP backcountry, noise and special flight rules, fire) would benefit wilderness values and experience (although noise and visual effects associated with some actions diminish these values over the short term). The Grand Canyon Escalade would contribute to adverse impacts on visitors seeking solitude or a wilderness experience due to its visual and noise effects and the presence of infrastructure, all of which are incompatible with the character of GCNP. Basin-wide effects related to climate change (e.g., reduced water availability) could diminish wilderness values and experience by reducing opportunities for solitude.	Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. The program's contribution to cumulative impacts, however, would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Visual resources	Shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead; shorelines of lakes Powell and Mead; and the general landscape in the project area	Projected future declines in lake levels due to increased water demand, decreased water supply, the planned Lake Powell Pipeline project, and drought attributed to climate change could increase the likelihood of exposure of calcium carbonate rings and sediment deltas in lakes Powell and Mead. Infrastructure associated with the Lake Powell Pipeline project (pipeline, facilities, viewing platforms, and transmission lines), uranium mining, vegetation changes, and elements of the Grand Canyon Escalade development would also add to visual contrast and noticeable changes in the existing landscape.	LTEMP alternatives do not vary with respect to their impacts on visual resources. the proposed action’s contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions
Hydropower	Utilities and their customers who purchase power generated by Glen Canyon Dam Western Area Power Administration, Upper Colorado Basin Fund, environmental programs funded by CRSP power revenues; Upper Basin State apportionment-funded projects	Increased demand for electricity in the service territories of the eight largest Western customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years. Changes in operations at Glen Canyon Dam since construction of the facility have resulted in reductions in generating capacity. Changes in operations under LTEMP alternatives could reduce available generating capacity further, necessitating the purchase of lost capacity from other sources and increasing the wholesale power rates to entities allocated preference power. This would consequently increase customer utility capacity costs and residential utility bills over time.	Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher generation value and capacity, especially if more water is released in the high-demand months of July and August. However, the proposed action’s contribution to cumulative impacts would be small compared to the effects of past, present, and reasonably foreseeable future actions.

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Socioeconomics and environmental justice	Six-county region in the vicinity of the Colorado River between lakes Powell and Mead; recreational resources, including Lake Powell, Lake Mead, and the Grand Canyon (Colorado River)	Projected future changes in lake levels and river flow due to increased water demand, decreased water supply, and drought attributed to climate change could be the greatest contributors to adverse impacts on the recreational use values associated with fishing, day rafting, and whitewater boating. The Grand Canyon Escalade would likely increase recreational visitation and expenditure rates along the Colorado River. The annual release volume from Glen Canyon Dam, as determined by the 2007 Interim Guidelines, also affects recreation economics. NPS regulates the number of boating trips (specified in the CRMP and the Comprehensive Fisheries Management Plan). Therefore, regional economics of these activities are not expected to change in the foreseeable future.	LTEMP alternatives result in relatively minor changes in use value and economic activity associated with lake and river recreation, and in residential retail rates. Environmental justice issues are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), or result in increased economic impacts on Tribes associated with the cost of electricity (Alternatives F and G). The proposed action's contribution to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

TABLE 4.17-2 (Cont.)

Resource/System	Region of Influence	Contributors to Cumulative Impacts	Contributions of LTEMP Alternatives to Cumulative Impacts
Air quality and climate change	GCNP and the 11-state Western Interconnection region	The construction of new (and the renewal of existing) fossil fuel-fired powerplants to meet increased energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change (which increase the potential for wildfires and dust storms), could increase visibility degradation in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility degradation (haze) in the region, including GCNP. Other significant contributors would include wildfires, controlled burns, windblown dust, and emissions from metropolitan areas (manufacturing, coal-fired powerplants, and combustion sources like diesel engines). Hydropower generation at Glen Canyon Dam does not generate air emissions; however, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units. Under baseline operations (Alternative A), emissions of SO_2 and NO_x generated by powerplants affected by Glen Canyon Dam operations would be about 9.9% and 3.0% of the total emissions over the Western Interconnection region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline. Increases in GHG emissions associated with changes in operations under LTEMP alternatives would be negligible. The EPA's Clean Power Plan Proposed Rule would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants. The closure of three coal-burning units at the FCPP would reduce levels of NO_x and PM pollutants that contribute to regional haze and visibility issues in the GCNP.	LTEMP alternatives are expected to have negligible differences with respect to their impacts on air emissions including GHGs. The contribution of the proposed action to cumulative impacts would be negligible compared to the effects of past, present, and reasonably foreseeable future actions

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The physical presence and design constraints of Glen Canyon Dam have created a new baseline condition for resources within the Colorado River corridor, from Lake Powell and the dam downstream and west to Lake Mead. Current safety and design requirements limit flow through the dam to no more than 45,000 cfs, about 53% of its historical maximum flow. Management of water flow within the river system is also constrained by the various treaties, decrees, statutes, regulations, contracts, and agreements that are collectively known as the Law of the River. Recent drought conditions in the Colorado River Basin have necessitated further regulation (i.e., the 2007 Interim Guidelines) to reduce apportionments to the Lower Basin states during periods of declining reservoir storage. The water supply and demand equation is further stressed by the challenges of increasing demand in the seven Basin States (due to a rising population) and the temperature variability and drought attributed to climate change, which are projected to reduce flows into the foreseeable future.

As described in resource-specific sections in this chapter, the LTEMP alternatives are expected to differ in the types and magnitude of impacts on specific resources. Against the backdrop of past, present, and reasonably foreseeable future actions, however, the incremental effects of the LTEMP alternatives, as described in the following sections, are expected to be relatively minor contributions to cumulative impacts along the Colorado River corridor or within the basin at large.

4.17.3.1 Water Resources

Although LTEMP alternatives differ in monthly, daily, and hourly flows all alternatives comply with the 2007 Interim Guidelines. As a consequence, the impacts of alternatives do not vary in their contribution to cumulative impacts on water supply and delivery.

Current water quality conditions and characteristics of Lake Powell (Section 3.2.2.1), Colorado River below Glen Canyon Dam (Section 3.2.2.2), and Lake Mead (Section 3.2.2.3) reflect the effects of past and present (ongoing) actions. Before Glen Canyon Dam was constructed, the river was characterized by wide natural fluctuations in water quality characteristics (e.g., temperature, salinity, turbidity, and nutrients). In the post-dam era, these variations are moderated and the river has seen an overall improvement in water quality. Future water quality would likely be affected most by increased water demand and climate change. Although most alternatives would likely result in a slightly increased potential for bacteria and pathogens along shorelines, the contribution of continued operations under the LTEMP to cumulative impacts on water quality is expected to be negligible regardless of which alternative is selected.

As the population in the Basin States grows and expands, municipal, industrial, and agricultural water demand continues to increase. In its 2013 study, Reclamation concluded that the total consumptive use and loss (i.e., surface water and groundwater depletions and evaporative losses) for the Arizona portion of the Upper Colorado River Basin (covering about 6,900 mi^2) was 35,037 ac-ft, more than half of which is water pumped directly from Lake Powell and used by the Navajo Generating Station (Reclamation 2014e).

Urban runoff, industrial releases, and municipal discharges are considered some of the leading nonpoint sources of contaminants to surface waters (EPA 2004). Areas of intensive agriculture can have an adverse effect on the water quality as a result of the salinity, nutrients, pesticides, selenium, and other trace elements that are common constituents in agricultural runoff. As a result, water management and efficient water use (as is the goal of the 2007 Interim Guidelines) become important variables in the Colorado River supply and demand equation (Beckwith 2011). The interim guidelines have improved water supply conditions through increased water conservation efforts, which in turn are providing more predictability in water supply to users in the Basin States (especially the Lower Basin).

The general picture for climate change, as it relates to Colorado River Basin hydrology, includes decreased inflow to the reservoir system (e.g., lower precipitation) and greater losses (e.g., evapotranspiration associated with higher temperatures and increased demand from the growing population). Climate change is expected to result in more frequent and severe drought conditions in the Southwest. Meeting increasing water needs (e.g., the Lake Powell Pipeline project and the Page-LeChee water supply project) will likely lead to lower reservoir levels in Lake Powell, which may already be affected by increased evaporation associated with higher air temperatures. As discussed in Section 4.2.2, decreasing the elevation of Lake Powell can lead to warmer water discharges from Glen Canyon Dam and increased water temperatures downstream.

4.17.3.2 Sediment Resources

The construction and presence of Glen Canyon Dam has affected Glen, Marble and Grand Canyons by (1) reducing the sediment supply, and by (2) reducing the annual peak flows. Among the actions considered under LTEMP, HFE releases (which are highest under Alternatives C, D, E, F, and G) have the greatest impact on sediment resources (and sandbar building potential), although variability in hydrology or sediment supply from tributary inputs has a greater impact than HFEs. Cumulative impacts that affect this variability in hydrology and sediment supply (such as climate change) have the potential to affect sediment resources in the future.

It has been estimated that the post-dam sand supply to Marble Canyon is less than 10% of the pre-dam supply (Topping et al. 2000a; Topping, Rubin, Nelson et al. 2000; Wright, Schmide et al. 2008), with the majority of the sediment evacuation between the dam and Phantom Ranch (RM 87) occurring during the three decades following dam construction. The reduced sediment supply would move downstream at different rates in the various LTEMP alternatives, but sediment supply to Marble and Grand Canyons would not differ among the alternatives. The 1996 ROD modifications to the flow regime resulted in benefits for the building and retention of sandbars

Future climate change implications on sediment resources are highly variable and cannot be accurately quantified. Conceptually, climate change can affect the sediment resource in two ways: by changing the hydrology in the drainage area upstream of Glen Canyon Dam, and by changing the hydrology in the drainage area downstream of Glen Canyon Dam, especially in the drainage area of primary sediment contributors such as the Paria River and the Little Colorado

River. A drier future hydrology in these drainage areas could decrease the availability of sand in Marble and Grand Canyons.

4.17.3.3 Natural Processes

Cumulative impacts on natural processes (water flow, water temperature, and sediment supply) reflect those discussed under water resources (Section 4.17.3.1) and sediment resources (Section 4.17.3.2). Although some of the LTEMP alternatives could affect these resources (e.g., potential sandbar growth through implementation of HFE releases, which is greatest under Alternatives C, D, E, F, and G), the incremental effects of the alternatives are not anticipated to contribute significantly to cumulative impacts on natural processes along the Colorado River corridor or within the basin at large. Implementation of HFEs could result in an improvement in sandbar building over the long term. Climate change (and its effects on water flow, water temperature, and sediment supply), however, would likely have a greater effect on natural processes than any of the LTEMP alternatives.

4.17.3.4 Aquatic Ecology

Section 3.5.1 describes the current conditions of the aquatic food base in the Colorado River downstream of Glen Canyon Dam. The current state of the aquatic food base reflects the effects of past and present (ongoing) actions; Section 4.5.3 discusses potential impacts of the various LTEMP alternatives. The aquatic food base may also be affected by other reasonably foreseeable actions, particularly climate change, dam modification, water use, introduction of nonnative species, and uranium mining.

Population growth, industrial development, and the warming associated with climate change will act in concert to increase demand for water (Schindler 2001). Climate change is also expected to result in more frequent and severe drought conditions in the Southwest, which will continue to tax water supplies. Combined with increased evaporation associated with higher temperatures, meeting water needs would lead to lower reservoir levels in Lake Powell. The Lake Powell Pipeline Project would also contribute to lower Lake Powell reservoir elevations (FWS 2011c). Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. The Red Gap Ranch Pipeline, which would withdraw groundwater contributing to the base flow of the Little Colorado River, could reduce habitat availability and suitability in the Little Colorado River with subsequent adverse effects on humpback chub and designated critical habitat, although the magnitude of these impacts have not been quantified.

Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; FWS 2011c). Lower levels of Lake Powell may also result in increases in the composition and density of zooplankton downstream of Glen Canyon Dam, because waters would be withdrawn closer to the surface (Reclamation 1995). However, warmer temperatures, particularly in winter, may allow many invertebrate species to complete their life cycles more quickly (Schindler 2001). For example, if stream temperatures are raised by only a few degrees in winter, many aquatic insects that normally emerge in May or June may emerge in

February or March and face death by freezing or be prevented from mating because of being inactivated by low air temperatures. In addition, increases in stream temperatures may cause an exaggeration in the separation of the emergence of males and females (e.g., males may emerge and die before females emerge) (Nebeker 1971). Temperatures above the optimum can lead to the production of small adults and lower fecundity (Vannote and Sweeney 1980).

Warmer water temperatures can expand the distribution of nonnative species adapted to warmer temperatures. This includes fish parasites such as the Asian tapeworm, anchor worm, and nonnative crayfish. Increased zooplankton due to climate change may increase abundance of cyclopoid copepods. All cyclopoid copepod species appear to be susceptible to infection by, and therefore serve as intermediate hosts for, the Asian tapeworm (Marcogliese and Esch 1989). Crayfish can prey on fish eggs and larvae and can diminish the abundance and structure of aquatic vegetation such as filamentous algae through grazing (FWS 2011c). Nonnative crayfish are present in Lake Powell (northern or virile crayfish [*Orconectes virilis*]) and Lake Mead (red swamp crayfish [*Procambarus clarkii*]). Warmer temperatures may allow the crayfish to expand into the mainstem of the Colorado River either downstream of Lake Powell or upstream of Lake Mead.

As discussed in Section 3.5.1, some nonnative species introductions occurred in order to supplement the aquatic food base (e.g., *Gammarus*, snails, and midges); while accidental introductions have occurred via fish stocking and recreational fishing, often with detrimental effects on both lower trophic levels or fish species (e.g., the New Zealand mud snail and parasitic trout nematode [*Truttaedacnitis truttae*]). The quagga mussel (*Dreissena bugensis*), which is established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach.

Concern has been raised about the diatom *Didymosphenia geminata* (“didymo”) becoming established in the Colorado River. High-density blooms of didymo are frequent in rivers directly below impoundments. In these river reaches, stable flows and fairly constant temperatures favor development of large masses of didymo (see Spaulding and Elwell 2007). Didymo can form nuisance benthic growths that extend for more than 1 km and persist for several months (Spaulding and Elwell 2007). Mayflies, stoneflies, caddisflies, and dragonflies have an inverse relationship with didymo coverage, while midges and aquatic worms dominate didymo-covered areas (Larson and Carreiro 2008). Nevertheless, the presence of didymo has been associated with increased periphyton biomass and increased invertebrate densities and richness (Kilroy et al. 2009; Gillis and Chalifour 2010). Given the large amounts of non-nutritious stalk material present on stream substrates in affected areas, didymo is predicted to have deleterious effects on native fish, especially those that inhabit benthic habitats, consume benthic prey, and nest beneath or between cobbles (see Spaulding and Elwell 2007). Didymo is present in waters from 4 to 27°C (39 to 81°F) (Spaulding and Elwell 2007), so warming would not be a factor in its occurrence in the Colorado River. However, development of didymo blooms likely requires both low mean discharge and variation in discharge. Scouring events usually remove didymo stalk material from substrates (Kirkwood et al. 2007).

Uranium mining peaked in the 1980s in the Grand Canyon region, but there is now a renewed interest due to increases in uranium prices. Increased uranium mining (on state and private lands) could increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Uranium, other radionuclides, and metals associated with uranium mines can affect the survival, growth, and reproduction of aquatic biota.

Aquatic biota and habitats most likely to be affected during mine development and operation are those associated with small, ephemeral, or intermittent drainages. Impacts on aquatic biota and habitats from the accidental release of regulated or hazardous materials into ephemeral drainages would be localized and small, especially if a rapid response to a release is undertaken. The accidental spill of uranium ore into a permanent stream or river such as Kanab Creek would potentially pose a localized short-term impact on the aquatic resources. However, the potential for such an event is extremely low. Most ore solids would settle in the waterbody within a short distance from a spill site (Edge Environmental, Inc. 2009). It is expected that expedient and comprehensive cleanup actions would be required under U.S. Department of Transportation regulations and that an emergency response plan would be in place for responding to accidents and cargo spills (Edge Environmental, Inc. 2009). Overall, the potential for impacts on aquatic biota from an accidental spill would be small to negligible. Spencer and Wenrich (2011) estimated that if an ore load is washed into the Colorado River and is pulverized and dissolved (a scenario that is extremely unlikely to impossible), the uranium concentration in the river would increase from the current 4.0 ppb to only 4.02 ppb (undetectable against natural variations). Predicted no chemical effect concentrations for aquatic vascular plants, aquatic invertebrates, and fish are ≥5.0 ppb; the lowest chronic concentrations are well above that concentration (see Hinck et al. 2010). For these reasons, the impacts from uranium mining on aquatic biota in the Colorado River or its major tributaries would be localized and would not reduce the viability of affected resources.

The incremental effects of the LTEMP alternatives on fish are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Examination of the various hydrologic traces used to model effects of alternatives on aquatic resources indicated that hydrology (i.e., whether a 20-year trace was drier or wetter on average) had a greater influence on the model results than the operational differences among alternatives. Similarly, climate change has the potential to have greater effects on fish resources than any of the alternatives because of its direct influences on hydrologic patterns. For example, more frequent droughts and warmer atmospheric temperatures have the potential to result in greater increases in the temperature of water being released from the dam than the operational actions being considered, and this in turn may improve thermal suitability for humpback chub, humpback chub aggregations, and native fish. However, any subsequent benefits may be offset by increased abundance and expansion of nonnative fish and aquatic fish parasites. There are a number of other actions being taken within the Colorado River Basin that could also contribute to significant cumulative effects on fish populations or fish communities. For example, actions to increase the number of self-sustaining populations of humpback chub within the basin (e.g., translocation of humpback chub from the Little Colorado River to other tributaries within the Grand Canyon) have the potential to increase overall numbers of humpback chub and could provide some level of protection against catastrophic events in the Little Colorado River that could greatly reduce or eliminate the population of humpback chub in the Grand Canyon.

4.17.3.5 Vegetation

In addition to effects of releases from Glen Canyon Dam and NPS's experimental vegetation restoration program, factors that would impact riparian plant communities include the tamarisk leaf beetle (*Diorhabda* spp.) and splendid tamarisk weevil (*Coniatus* spp.), which occur along much of the Colorado River below Glen Canyon Dam. By late 2012, the tamarisk leaf beetle had been found in many locations in the Grand Canyon, with an estimated 70% defoliation at some sites (Johnson et al. 2012). Tamarisk leaf beetle is not expected to have impacts on populations of other plant species, such as native shrubs (Dudley and Kazmer 2005). Fire management policies for GCNP include fuel reduction by removal of dead woody material as well as fire suppression; however, riparian areas are generally avoided (NPS 2012d).

The replacement of tamarisk by other species and the timing of replacement would be affected by flow characteristics as well as site-specific factors. The potential reduction in the dominance of tamarisk in many areas and the decrease in total area of tamarisk-dominated communities along the Colorado River could result in an increase in native species or, more likely, other nonnative species, especially where soils have high nitrogen levels (Hultine et al. 2010; Shafroth et al. 2005, Shaforth, Brown et al. 2010; Belote et al. 2010; Reynolds and Cooper 2011; Uselman et al. 2011; Johnson et al. 2012; Bateman et al. 2013). Many nonnative species are already present along portions of the Colorado River and Lake Mead (Table 4.6-5). Short-term changes in nutrient dynamics in the riparian ecosystem could also occur with increased activity of tamarisk leaf beetles, with subsequent effects on the future development of native or nonnative communities (Uselman et al. 2011). Soil seed banks may contain a high diversity of species and would potentially influence subsequent plant community composition; however, the regrowth of native species may be slow (Reynolds and Cooper 2011; Belote et al. 2010).

As discussed in Section 4.6, hydrologic conditions have a greater effect on native community types in the Fluctuation Zone and New High Water Zone than do the operational characteristics of the LTEMP alternatives. Within each alternative, the occurrence of flows with significant effects on riparian vegetation, such as extended high flows and extended low flows, are determined in large part by the inflow to Lake Powell as a result of hydrologic variation (Section and 4.2). Other events, such as spill flows (flows >45,000 cfs that would necessitate use of the spillway) could have pronounced effects on riparian vegetation, but these too result from hydrologic variation and not characteristics of the alternatives. However, with forecasting capabilities currently used by the Bureau of Reclamation, it is unlikely that spill flows would occur in the future. Within a year, under any alternative, monthly operations may be increased or decreased based on changing annual runoff forecasts, and application of the Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead (Reclamation 2007a).

Feral burros contribute to cumulative impacts on riparian vegetation, especially vegetation in the Old High Water Zone. Researchers documented vegetation impacts from feral burros as early as 1974, noting vegetation destruction and decreases in species diversity. These impacts, along with impacts on soils, remain visible on the landscape today with very little vegetation recovery (Leslie 2004).

Visitation from commercial and private river trips, as well as backcountry hikers and anglers, also can affect vegetation. Visitors have created trails and added to the loss of vegetation in upland and Old High Water Zone areas. Administrative actions such as tamarisk eradication projects and archaeological site monitoring programs can also contribute to vegetation impacts. The intentional or unintentional spread of exotic plant species by humans coming into the area of effect contributes to the current levels of impacts along the Colorado River corridor. This can have localized, adverse, short- or long-term, year-round effects on vegetation by visitors in the riparian zone, and has effects in camping areas, trails, and in popular visitation areas (NPS 2006b).

Riparian ecosystems are expected to be affected by long-term changes in the climate across the Colorado River watershed. Under a climatic trend of lower precipitation, there would likely be fewer years with extended high flows and an increase in the number of years with extended low flows under any of the alternatives. It is also possible that, with lower regional precipitation, there could be fewer sediment-triggered HFEs if the Paria River delivers less sediment. Riparian plants in the Old High Water Zone are expected to continue to decline. The New High Water Zone would tend to experience a shift toward more drought-tolerant species, such as arrowweed and mesquite. Tamarisk is tolerant of drought stress, and has an advantage over native species that require access to groundwater, such as cottonwood and willow, in areas where water tables are lowered. Thus, tamarisk may be maintained under drier climate conditions, although recruitment events may be limited and, as noted above, effects of defoliation may greatly affect tamarisk-dominated communities. Communities that require a shallow water table or relatively frequent inundation, such as marsh, shrub wetland, and cottonwood-willow woodland, would likely decline.

Natural events, such as floods inside canyons and rockfalls, scour vegetation; this can add to the loss of diverse and intact native vegetation and contribute to the spread of invasive, exotic plant species. In addition, as noted in Section 3.6.2, years with unusually high inflow into Lake Powell, such as 1983, may result in emergency dam releases greater than 45,000 cfs that would have major and lasting effects on vegetation (Mortenson et al. 2011; Ralston 2012).

The effects of the LTEMP alternatives on riparian vegetation communities are relatively small compared to the effects of other factors, especially future hydrology. For this reason, the incremental effects of the alternatives on native and nonnative plant species are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives, including Alternative A, are expected to result in a decrease in native community cover and wetlands. Alternative D is the only alternative that is expected to result in an overall improvement in vegetation.

4.17.3.6 Wildlife

Section 3.7 describes the current condition of wildlife in the Grand Canyon, which reflects the effects of past and present cumulative impacts; Section 4.7 discusses the potential impacts the various LTEMP alternatives may have on wildlife. Because the assessment of impacts on wildlife is based partly on an evaluation of impacts on the aquatic food base, fish

(Section 4.5.2), and riparian vegetation (Section 4.6), cumulative impacts on those resources will also result in cumulative impacts on wildlife. Wildlife may also be affected by other reasonably foreseeable future actions and basin-wide trends contributing to cumulative impacts (Sections 4.17.1.2 and 4.17.2), particularly water use, climate change, vegetation management, AML closure, fire, trout management, introduction or spread of nonnative species, human-associated noise and visual disturbance (e.g., from recreation), and uranium mining.

Population and industrial growth, coupled with climate change, will act in concert to increase water demand in the region (Schindler 2001) and lower flows downstream of Glen Canyon Dam. This could stress existing riparian and wetland vegetation, leading to plant community alterations that would affect both wildlife habitats and the wildlife prey base. Climate change would not affect all wildlife species uniformly. Some species would experience distribution contractions and likely shrinking populations while other species would increase in suitable areas and thus possibly experience increases in population numbers. Generally, the warmer the current range is for a species, the greater the projected distributional increase (or lower the projected loss) will be for that species due to climate change (van Riper et al. 2014).

Lowering of Lake Powell elevations can lead to warmer water discharges from Glen Canyon Dam. Warmer water temperatures would likely increase production rates of algae and invertebrates (Woodward et al. 2010; also see FWS 2011c) leading to increases in the prey base for some wildlife species such as amphibians, lizards, waterfowl, insectivorous songbirds, and bats.

Riparian vegetation management activities (e.g., removal of nonnative plants and native plant restoration) would modify the cover, stratification, and distribution of plant communities along the Colorado River. Eradication of tamarisk could affect birds by altering prey availability, increasing nest abandonment and predation, and reducing the quantity of riparian habitat available to breeding birds (Paxton et al. 2011). In the long term, riparian vegetation management may diversify riparian habitats and establish a more productive wildlife community. Additional factors that could affect riparian wildlife habitat include the tamarisk leaf beetle and splendid tamarisk weevil, which occur along much of the Colorado River below Glen Canyon Dam and result in defoliation and mortality of tamarisk (Section 4.17.3.4). Widespread tamarisk mortality would likely result in a net loss in riparian habitat for at least a decade or more (Paxton et al. 2011). It seems unlikely that the effects of large-scale defoliation in areas dominated by tamarisk will be compensated for by use of tamarisk beetles as a food resource by birds (Puckett and van Riper 2014).

The highly flammable tamarisk has created a fire hazard previously absent along the river. This threatens breeding bird populations, as well as other wildlife. In addition, if native or mixed habitat stands burn, monotypic tamarisk will likely recolonize, eliminating the crucial structure necessary for southwestern willow flycatchers and other nesting birds (e.g., thermal buffering through shading becomes insufficient and will be further exacerbated by warming climate trends) (Schell 2005).

The quagga mussel (*Dreissena rostriformis bugensis*), which is currently established in Lake Powell, may develop viable populations in the mainstem of the Colorado River, at least within the Glen Canyon reach. An established population of quagga mussels may increase the prey base available to diving ducks. Warmer temperatures may allow crayfish inhabiting Lake Mead and Lake Powell to expand into the mainstem of the Colorado River, providing an additional prey item for some wildlife species.

In the past, uranium mining led to localized peregrine falcon nest failures in areas such as Kanab Canyon and its multiple side canyons, where numerous mining claims existed (Payne et al. 2010). Although 684,449 ac of federal land administered by BLM north of GCNP (North and East Parcels) and 322,096 ac of federal land administered by the USFS south of GCNP (South Parcel) would be withdrawn from locatable mineral exploration and development (i.e., uranium mining), increased uranium mining on non-federal (state and private) lands remaining open to mining could locally affect wildlife habitat (e.g., habitat loss and fragmentation) and increase the amount of uranium, arsenic, and other trace elements in local surface water and groundwater flowing into the Colorado River (Alpine 2010). Edge habitat associated with uranium mines and associated access roads may provide habitat for brown-headed cowbirds (Payne et al. 2010), which are brood parasites of songbirds. Grazing and recreation, including use of commercial pack-stock, also increase brown-headed cowbird populations (Schell 2005). Habitat loss from uranium mines and associated access roads could affect the distribution and movement of big game mammals (e.g., elk, mule deer, bighorn sheep, and mountain lions), and potentially increase their mortality from vehicle collisions or poaching (Payne et al. 2010). There could be a potential contaminant exposure issue associated with amphibians (or other wildlife) attracted to uranium mine effluent ponds (Payne et al. 2010). In general, any impacts on wildlife from uranium mining would be localized and should not affect the viability of affected resources, especially with the use of best management practices to control mine discharges and proper mine reclamation.

The Grand Canyon Escalade Project and its associated facilities near the confluence of the Little Colorado River could cause both a localized loss of wildlife habitat and source of wildlife disturbance due to human presence. Wildlife species in the Grand Canyon are currently exposed to various sources of manmade noise ranging from human conversation to aircraft flyovers. The potential effects of noise on wildlife include acute or chronic physiological damage to the auditory system, increased energy expenditures, physical injury incurred during panicked responses, interference with normal activities (e.g., feeding), and impaired communication (AMEC Americas Limited 2005). The response of wildlife to noise would vary by species; physiological or reproductive condition; distance; and the type, intensity, and duration of the disturbance. Regular or periodic noise could cause adjacent areas to be less attractive to wildlife and result in a long-term reduction in use by wildlife in those areas. Responses of wildlife to disturbance often involve activities that are energetically costly (e.g., flying or running), altering their behavior in a way that might reduce food intake, communication, and nesting (Hockin et al. 1992; Brattstrom and Bondello 1983; Cunnington and Fahrig 2010; Francis et al. 2009; Maxell 2000).

Recreational activities such as hiking, rafting, fishing, and camping can result in disturbance to wildlife. For example, hikers, rafters, anglers, and researchers can disturb bald eagles; however, southwestern willow flycatchers are not apparently sensitive to rafts or boats passing their breeding sites, but people moving through occupied habitat can disturb the birds or impact a nest (Holmes et al. 2005). Impacts on reptiles and amphibians can include occasional opportunistic collecting or harassment by recreationists. As demand for reptiles in the pet trade increases and collectors seek new sources of supply, many national parks are experiencing problems with illegal reptile collection, especially of rattlesnakes (NPS 2014h). Recreationists can affect birds and other wildlife by removing or modifying vegetation within both the new and old high-water zones (e.g., for campsites and trails) (NPS 2005a).

During winter 1990–1991, more eagles were detected in reaches with low human use compared to reaches with high to moderate human use between Glen Canyon Dam and the Little Colorado River. No eagles were found within 1 km of intensively used areas near Lees Ferry and Navajo Bridge. Repeated flushing by bank fishermen, hikers, or boats could have caused wintering eagles to avoid reaches heavily used by anglers (Brown and Stevens 1997). Winter camping, especially in important eagle activity areas, can disturb bald eagles and has the potential to seriously disrupt a wintering eagle concentration (Sogge and Tibbitts 1994).

The effects of the LTEMP alternatives on wildlife are relatively small compared to the effects of other factors, especially future hydrology, and are not expected to contribute significantly to cumulative impacts along the Colorado River corridor or within the basin at large. Most alternatives would have little effect on most wildlife species. Alternatives with more fluctuations, and less even monthly release volumes (Alternatives A and B), would have greater impact on species that use nearshore habitats or feed on insects with both terrestrial and aquatic life stages.

4.17.3.7 Cultural Resources

The proposed action is not expected to significantly change the ongoing cumulative impacts on historic properties. Past dam operations resulted in transformations to the environment that may contribute to the nature, severity, and rate of erosive forces having the potential to act upon and influence the integrity of these historic properties. The past action primarily affecting these resources was the construction and operation of the Glen Canyon Dam and the resulting loss of sediment in the river channel below the dam.

The river immediately downstream from Glen Canyon Dam was intentionally scoured in 1965 during a series of high-pulse flows. 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). The Glen Canyon Dam has prevented sediment-laden extreme high flows that occurred periodically in the past and allowed for both deposition and erosion at higher elevations, as well as extreme low flows that exposed sandbars and allowed wind transport to higher elevation terraces.

For GCNRA, these transformations include bed incision and reduction in the base level of erosion, sediment evacuation and exposure of terrace faces, and changes in gully type and formation processes. The degree to which these transformations may contribute to impacts on historic properties remains poorly understood, and is the subject of ongoing research. For GRCA, these transformations are primarily tied to loss of low-elevation sandbars and the degradation of the pre-dam river terraces that were home to peoples for the past 10,000 years.

In addition, the effects from visitors remain a persistent issue, although not overarching. The proposed action pertains to the operation of Glen Canyon Dam and does not alter any policies concerning visitor use of the river. The concern over visitor effects is exacerbated by erosion, which continues to expose additional portions of archaeological sites. The more artifacts are exposed at a site, the more opportunities exist for a visitor to pick up an artifact and move it. Only education can make visitors aware of the need to leave the artifacts as they lie.

Historic properties in the APE remain in a continual state of deterioration. The erosive forces that created the Grand Canyon continue to operate throughout both GCNRA and GCNP and continue to destabilize the historic properties found there. The degradation of historic properties due to natural causes remains the biggest challenge faced by historic property managers. Rain events cause gullying and remove the sediment that surrounds the historic properties along the Colorado River. Little can be done to slow these climatic processes although implementing management strategies to stabilize and minimize sediment losses may be effective tools in the future.

4.17.3.8 Tribal Resources

Actions contributing to cumulative impacts on Tribal resources include the continued use or reopening of breccia pipe uranium mines adjacent to the park, the development of new mines on state land lying within the Grand Canyon watershed, continued traffic of visitors to sites sacred to the Tribes, and specific projects, including the Lake Powell Pipeline, the Grand Canyon Escalade, and the Red Gap Ranch Pipeline.

Uranium prospecting and mining in the Grand Canyon watershed could contribute to cumulative effects on Tribes. Uranium mining has the potential to contaminate water sources that supply aquifer systems that feed springs, seeps, and their associated ecosystems within Grand Canyon National Park (GCNP 2013). Many Tribes consider drilling or mining to be wounding the earth (BLM 2011). In 2012, the decision was made to withdraw over a million acres of federal lands surrounding GCNP in northern Arizona from uranium mining for the next 20 years. However, four existing mines were grandfathered and continue to operate intermittently as the price of uranium fluctuates. In addition, the withdrawal of federal lands has resulted in the concentration of new uranium exploration on state lands, some of which are within the Grand Canyon watershed. Past mining has resulted in the contamination of springs and seeps feeding the Grand Canyon, reducing their sacred nature. Uranium mining is currently taking place at sacred sites, including the Red Butte Traditional Cultural Property south of GCNP. Tribes in the region have expressed concern that contamination in the drainage to Havasu Canyon or in other watersheds and aquifers would be devastating to the downstream resources of importance to the Havasupai (Havasupai Tribal Council 2015). However, the LTEMP alternatives do not include any action that would result in water contamination and none are expected to contribute to cumulative impacts.

Continued use of the riparian zone by visitors to the canyons has the potential to result in damage to places of cultural importance to the Tribes. Continued disturbance over time and space could result in the loss of the function and sacredness of traditional cultural places. These potential losses can be partially mitigated by the education of canyon visitors regarding the sanctity of the canyons.

Actions affecting aquatic life, vegetation, and wildlife would also affect resources of value to Tribes (see Sections 4.5, 4.6, and 4.7). For example, changes in the tamarisk population due to the tamarisk leaf beetle and splendid tamarisk weevil, as well as long-term changes in the climate could contribute to cumulative impacts on riparian ecosystems across the Colorado River watershed. A summary of such impacts on Tribal resources is provided in Section 4.9.3.

The Lake Powell Pipeline proposes to carry water from Lake Powell to Sand Hollow Reservoir near St. George, Utah, to help meet water demand in southwestern Utah (UBWR 2011c). Impacts on historic properties have not been assessed for this project. Impacts on other resources of Tribal importance from the pipeline could include loss of some wildlife habitat and temporary loss of vegetation and riparian communities. The Red Gap Ranch Pipeline, which would withdraw and convey groundwater to augment Flagstaff's water supply, could affect springs of importance to Tribes, although the impacts of this action have not yet been assessed.

LTEMP alternatives that include mechanical trout removal or TMFs (all Alternatives except F), may have an adverse effect that would add to the cumulative impacts on Tribal resources (see also Table 4.9-2).

4.17.3.9 Recreation, Visitor Use, and Experience

Section 3.10 presents the recreational resources and activities that could be affected by the LTEMP alternatives. Most of the LTEMP alternatives would result in fewer navigation concerns, lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G). Section 4.10 presents the estimated incremental effects of the alternatives on those recreational resources and activities. The following paragraphs analyze the potential cumulative effects of past, present, and future actions on recreation resources that may also incur incremental effects from the LTEMP alternatives. Other resources analyzed separately that could incur cumulative effects that might also affect recreation include sediment, water quality, and the trout fishery below Glen Canyon Dam.

Some, but not all, of the past and present actions described in Section 4.17.1.1 could have effects on recreation. Such past and present actions that could affect camping and beach access are those that affect sediment transport and deposition. Among these, the 2007 Interim Guidelines affect sediment retention and deposition through required equalization flows, which tend to erode beaches, while the 2011 HFE protocol would benefit beach and campsite building through sediment deposition. Such effects are already captured in the analysis of the LTEMP alternatives, which are subject to the provisions of ongoing programs.

Among ongoing actions that could affect recreation, visitor use, and experience, is the 2006 CRMP, which sets the number of annual launches for commercial and noncommercial boating and rafting.

The Comprehensive Fisheries Management Plan and the Non-native Fish Control Program would protect and benefit recreational fishing below Glen Canyon Dam. These two management programs would limit the effects of the LTEMP alternatives on the recreational fishery. Most of the alternatives incorporate management actions consistent with these plans, including TMFs and mechanical removal of trout. These plans and actions would tend to reduce cumulative impacts on the trout fishery through active management.

Of the reasonably foreseeable future actions, the proposed Grand Canyon Escalade project, including a gondola running from the canyon rim to the canyon floor near the confluence of the Little Colorado River and the Colorado River would contribute to cumulative impacts on recreational resources. The nature of effects, positive or negative, would depend on the perspective of a particular visitor. Users of the facility would benefit from the services offered. Adverse effects on wilderness experience are discussed in Section 4.17.10. Overall, however, effects of the Escalade project on recreationists are expected to be negative, because the vast majority of visitors come to experience natural beauty and solitude, which is incompatible with development within the Grand Canyon.

Climate change could affect recreation resources in a number of ways, some of which would add significantly to effects from ongoing actions and trends discussed. Warming temperatures could reduce runoff and water supply to the Colorado River and increase water demand from municipalities and for cooling, further reducing supply. Reduced availability of water could lower the elevation of Lake Powell, leading to warming and reduced flows below the Glen Canyon Dam. Warming could reduce DO levels in tailwaters. These factors could affect the health of the trout fishery below the dam and could affect boating through lower flows and higher daily fluctuations, as discussed in the previous paragraph. The combination of climate change and increasing water demands from regional population growth could increase the cumulative effects of reduced water availability.

The LTEMP alternatives would vary with respect to recreation, but would not significantly add to cumulative effects on recreation. Most alternatives would result in a reduction in navigation concerns (with the exception of Alternative B), lower catch rates, and increased camping area (with the greatest potential increase in camping area under Alternative G and higher catch rates under Alternatives F and G).

4.17.3.10 Wilderness

Wilderness character, as used in this DEIS, is defined in Section 3.11, as are the wilderness values and experience that may be impacted by LTEMP alternatives. Section 4.11 analyzes potential direct impacts on wilderness values and experience of the alternatives. In this section, potential cumulative effects on wilderness experience caused by other past, present, or future actions in the region are analyzed; aspects of the analysis of cumulative effects on recreation (Section 4.17.3.10) are also relevant to this discussion.

The GCNP Backcountry and Fire Management Plan would tend to benefit visitor use and experience under all the LTEMP alternatives through the protection of wilderness and visual resources and soundscapes, while mitigating to some extent visitor effects on the same resources.

The 2006 CRMP, which regulates commercial and noncommercial boating and rafting, would also tend to enhance visitor experience while protecting natural and cultural resources. By limiting the number of rafters on the river, this plan would protect wilderness experience and solitude. The 2010 Abandoned Mine Closure Plan could also enhance wilderness experience and protect natural resources through restoration of a more natural state. Similarly, the 2012 withdrawal of approximately a million acres of federal land in the vicinity of GCNP from entry for uranium mining would enhance wilderness values regionally by limiting industrial development in areas surrounding the parks.

With respect to foreseeable actions in the study area, the proposed Noise and Flight management alternatives could have a substantial beneficial effect on wilderness values in GCNP. The proposed Grand Canyon Escalade development on 420 acres near the confluence of the Little Colorado and Colorado Rivers could have adverse effects on wilderness values and experience in that area. Visitors seeking solitude or a wilderness experience could be adversely affected by the visual and noise effects and the presence of infrastructure, which is incompatible with the character of GCNP.

Basin-wide trends that could affect wilderness values and experience would be primarily those related to climate change. Wilderness and wilderness experience would be adversely affected to the extent that warming and reduced water availability promote the growth of invasive and nonnative species, which would alter the native character of vegetation. Low water availability could cause crowding and loss of solitude on the river due to reduced navigability and delays at rapids from periodic low flows.

The LTEMP alternatives vary with respect to their impact on wilderness experience. Disturbance from non-flow actions would occur under all alternatives; the most crowding at rapids would occur under Alternative E; alternatives with greater fluctuations (e.g., Alternatives A, B, and E) could affect wilderness character. None of the alternatives would significantly contribute to the cumulative impacts for this resource.

4.17.3.11 Visual Resources

The current condition of visual resources is described in Section 3.12; this reflects the effects of past and present cumulative impacts on resources within the project area. Section 4.12 discussed the potential impacts of the various LTEMP alternatives on visual resources within the project area. Visual resources within the shorelines and waters of the Colorado River between Glen Canyon Dam and Lake Mead, the shorelines of Lake Powell and Mead, and the general landscape of the area may also be affected by reasonably foreseeable actions and basin-wide factors contributing to cumulative impacts, including the Lake Powell Pipeline Project, uranium mining, the Grand Canyon Escalade development, water use, and climate change.

Increased water demands from population and industrial growth, coupled with conditions brought on by climate change such as severe drought and higher temperatures, could lead to lower Lake Powell reservoir levels. In addition, the Lake Powell Pipeline Project would likely result in slightly lower Lake Powell reservoir levels (UBWR 2011a,b). Additional impacts could result from the pipeline alignment, proposed facilities, and transmission lines associated with the Lake Powell Pipeline Project. No new infrastructure is proposed by any of the LTEMP alternatives; however, if water is transferred to Sand Hollow Reservoir from Lake Powell, the water level in Lake Powell could become lower, resulting in a slight increase in the height of the calcium-carbonate ring that surrounds Lake Powell and increasing the exposure of sediment deltas. These actions could also slightly increase the months of exposure of Cathedral-in-the-Desert.

Uranium mining operations have the potential to change the landscape character in the project area. The Grand Canyon Escalade development project includes a gondola, riverwalk, amphitheater, visitor center, and retail complex. The development would be visible from six of the seven eastern viewpoints in GCNP (Confluence Partners, LLC 2012b) and would cause a visual contrast with the surrounding natural environment of the Grand Canyon and Colorado River. Impacts on the landscape under the proposed LTEMP action are negligible and are not expected to contribute to cumulative impacts affecting the landscape character.

4.17.3.12 Hydropower

Power operations and power marketing as they relate to Glen Canyon Dam and the Glen Canyon powerplant are described in Section 3.13; Section 4.13 presented the potential impacts that change in dam operations under the LTEMP alternatives would have on the economic value of hydropower resources and on electricity capacity expansion necessary for the eight largest Western customer utilities to replace lost hydropower generation, as well as the resulting impacts on retail electricity rates charged by the eight largest customer utilities. Increased demand for electricity in the service territories of the eight largest Western customer utilities and planned retirement of existing powerplant generating capacity would require an estimated 4,820 MW of new capacity to be built over the next 20 years (Section 4.13).

The incremental impact of the LTEMP alternatives generating capacity over the 20-year period would be relatively small (<1% of baseline) and variable. Changes in operations at Glen Canyon Dam (relative to current baseline conditions under Alternative A) would reduce available generating capacity at Glen Canyon Dam under all LTEMP alternatives except Alternative B. This reduction in capacity would be replaced by purchases from other sources or construction of new capacity. Since the implementation of MLFF, between 1997 and 2005, the average annual costs associated with these reductions have ranged from $38 million to $50 million, due to operational restrictions (Veselka et al. 2010).

The LTEMP alternatives vary with respect to hydropower production, hydropower capacity, and retail rates, and therefore cumulative impacts. Alternatives with higher fluctuation levels (Alternatives A, B, D, and E) achieve higher values of generation and capacity and lower impacts on retail rates than do alternatives with steadier flows (Alternatives C, F, and G), especially if more water is released in the high-demand months of July and August. Alternatives A and B would have the least effect on the value of generation, the value of capacity, and retail rates, while Alternatives F and G would have the highest.

4.17.3.13 Socioeconomics and Environmental Justice

Actions and basin-wide trends contributing to cumulative impacts in the project area (including Lake Powell, Lake Mead, and the stretch of the Colorado River between them) are those that affect the economic valuation of its recreation resources and its recreational visitation and expenditure rates. Those actions and trends having a high, adverse, and disproportionate impact on minority and low-income populations are also of concern. The most significant trends affecting recreation are those related to climate change (decreased water supply and drought), because they have a direct effect on lake levels (exposed beaches and mudflats) and the seasonal timing of fluctuations in river flow. Regional economics (i.e., expenditures by visitors) for various types of recreational activities, including angling, rafting, and boating, as well as expenditures on gasoline (for vehicles and boats), camping fees or motel expenses, guide services, and fishing license fees are somewhat controlled by NPS regulations; the number of boating trips are controlled as specified in the CRMP and the Comprehensive Fisheries Management Plan cited in Table 4.17-1. These are not expected to change significantly under any of the LTEMP alternatives.

The impact analysis determined on the basis of the 2010 Census that minority or low-income populations exist in some block groups within San Juan (Utah) and Coconino (Arizona) counties (Section 4.14.2.4). Impacts on Tribes are associated with alternatives that incorporate frequent trout control actions (Alternatives C, D, and G), which affect Tribal values, or result in increased economic impacts on Tribes associated with the cost of electricity (especially Alternatives F and G).

4.17.3.14 Air Quality and Climate Change

The current condition of local and regional air quality is described in Section 3.15; Section 4.15 presented the potential impacts of the LTEMP alternatives on visibility within the project area (GCNP and the six-state area). Air quality is affected by air emissions from both natural (e.g., wildfires and windblown dust) and manmade (e.g., power generation from fossil fuel-fired plants) sources. The primary cause of visibility degradation in the region is the scattering and absorption of light by fine particles. Other important contributors to visibility degradation include combustion-related sources, fugitive dust sources, and particulate organic matter. Emissions of SO_2 and NO_x from fossil fuel combustion are the major manmade causes of visibility impairment; these emissions have been substantially reduced in the six-state area in the past decade in response to state and federal requirements (Section 3.15.2).

The construction of new powerplants (and the renewal of existing coal-fired plants permits) to meet energy demands from population and industrial growth in the region, coupled with drought conditions brought on by climate change that could increase the potential for wildfires and dust storms, could increase visibility impacts in the foreseeable future. The natural scattering of light would continue to be the main contributor to visibility impairment (haze) in the region, including GCNP. Other significant contributors to visibility degradation include wildfires, windblown dust, and emissions from metropolitan areas (automobiles, manufacturing, coal-fired powerplants, and combustion sources like diesel engines).

Although hydropower generation at Glen Canyon Dam does not generate air emissions, dam operations can affect ambient air quality by causing a loss of generation that is offset by generation from coal, natural gas, or oil units (Section 4.15.1). Under baseline operations (Alternative A), emissions of SO_2 and NO_x would be about 10% and 3.0% of the total emissions over the Western Interconnect region, respectively. Air quality impacts due to emissions under the other alternatives would be negligible because they would be only slightly increased or decreased relative to the baseline.

The EPA's Clean Power Plan Proposed Rule would have a beneficial impact on the air quality in the region by mandating reductions in CO_2 emissions from fossil fuel-fired powerplants (to 30% below 2005 levels by 2030). The closure of three coal-burning units at the FCPP would also have a beneficial impact by reducing levels of NO_x and PM pollutants that contribute to regional haze and visibility issues in the GCNP.

The incremental impact of the LTEMP alternatives on air quality over the 20-year period is based on the emissions associated with power generation needed from other powerplants to meet uninterrupted power demand of customers in the region. There is negligible difference in the additional power generation needed among the alternatives (4,172 to 4,250 GWh per year); the differences in SO_2 and NO_x precursor emissions are also negligible (Table 4.15-1).

GHG emissions under all the LTEMP alternatives can be compared to total U.S. GHG emissions at 6,810.3 MMt CO_2e in 2010 (EPA 2013d) (Table 4.16-1). Differences in emissions relative to total U.S. GHG emissions are less than 1%, and range from 0.8089% (Alternative A) to 0.8094% (Alternatives F and G). Therefore, potential impacts of dam operations on climate change under the various alternatives are expected to be very small.

4.18 UNAVOIDABLE ADVERSE IMPACTS

On the basis of the assessments presented in Sections 4.1–4.17, each of the alternatives is expected to result in some unavoidable adverse impacts on resources. These adverse impacts result from the flow and non-flow actions included in each alternative and could be minimized through adaptive management and implementation of mitigation measures.

All of the alternatives, including Alternative A, would result in continued reductions in peak hydropower production relative to unconstrained release patterns that more closely match generation with electrical demand due to restrictions on maximum and minimum flow, within-day fluctuation levels, and ramping rates. Steady flow alternatives (Alternatives F and G) would result in the greatest adverse impacts on hydropower value. Alternative B would result in an increase in hydropower energy and capacity compared to Alternative A; Alternatives D and E would produce less energy and capacity than Alternative A; Alternative C would produce less than Alternatives D and E, but more than Alternatives F and G. Alternative F would produce less energy and capacity than any of the alternatives.

Under all of the alternatives, sediment availability in the river channel below the dam would continue to be limited due to the presence of the dam. No operational alternative can reverse the reduction in sediment availability. Because of this sediment-depleted condition, all of the alternatives would continue to produce a net loss of sand from the Colorado River ecosystem. Alternatives C, D, E, F, and G retain more sandbars than Alternative A or Alternative B.

Implementation of mechanical removal of trout and TMFs would represent an unavoidable adverse impact on certain Tribes if these actions are needed to manage the trout fishery and mitigate trout impacts on humpback chub, because these actions are not in keeping with important Tribal values. The adverse impacts of mechanical removal could be mitigated with the provision of beneficial use (e.g., making euthanized fish available for human consumption). Any other mitigation to avoid adverse impacts would need to be identified in discussion with the Tribes.

The remaining unavoidable adverse impacts on certain resources are those associated not with the alternatives themselves; instead, they are consequences of existing constraints on operations (i.e., requirements of the Law of the River and the 2007 Interim Guidelines; Reclamation 2007a), and the presence of Glen Canyon Dam and current dam infrastructure. For example, temperature and sediment impacts of all alternatives are related to the inability of operations themselves to provide for warmer temperatures or restore sediment supplies. Infrastructure changes, which are not within the scope of the LTEMP DEIS, could mitigate those impacts; however, without that infrastructure, these adverse impacts are unavoidable.

4.19 RELATIONSHIP BETWEEN SHORT-TERM USE AND LONG-TERM PRODUCTIVITY

Under all alternatives, different restrictions on flow fluctuations result in tradeoffs between peak hydropower production and productivity of the environment, which is largely related to increased nearshore habitat stability, aquatic food base productivity, and sandbar building downstream from the dam. For example, alternatives that have increased flow fluctuations or uneven monthly release volumes, such as Alternatives A and B, benefit peak hydropower energy and capacity and other resources (such as humpback chub) but result in less habitat stability and sandbar building. Alternatives with steady flows, such as Alternatives F and G, have the greatest reduction in peak hydropower energy and capacity, but result in more habitat stability and sandbar building downstream from the dam, and corresponding benefits for other resources such as recreation, aquatic food base, and trout. As a result, each of the alternatives presents a different balance between impacts on resources that appear to benefit from increased fluctuations and those that benefit from reduced fluctuations. Alternatives C, D, and E represent alternatives with more even monthly release volumes, and in the case of Alternatives C and D, fluctuation levels that are comparable to or lower than those under Alternative A. These alternatives strike a more even balance among resource impacts. However, regardless of the alternative, experimental flow and non-flow actions associated with alternatives (e.g., HFEs, TMFs, mechanical trout removal) would be tested in an attempt to maintain a balance that improves long-term productivity of the environment downstream of Glen Canyon Dam. Similarly, experimental elements of the alternatives are designed to improve our understanding of how resources respond to operations and how management actions can be best used to avoid, minimize, or mitigate impacts on resources and the long-term productivity of resources analyzed in the LTEMP DEIS.

4.20 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES

Any experiment or operation that bypasses Glen Canyon Dam generators (e.g., HFEs that exceed powerplant capacity through generator bypass), or flows that reduce flexibility for peaking power (e.g., lower summer flows), cause an irretrievable loss of hydropower production. In addition, some air quality impacts would occur under alternatives that alter the energy and capacity generated by Glen Canyon Dam, because these changes would necessitate generation from fossil-fuel-fired powerplants to offset loss and early construction of new generating capacity. No other instances of irreversible or irretrievable commitments of resources are expected under any of the alternatives. Although operations, flow actions, non-flow actions, and experiments could result in unexpected impacts on natural and cultural resources, a long-term monitoring program implemented as part of the ongoing Glen Canyon Dam Adaptive Management Program would be used to inform the need for changes in operations and actions to minimize impacts and prevent further impacts on important resources. Safeguards have been incorporated into alternatives, including implementation considerations that would preclude taking specific actions if implementation would result in unacceptable adverse impacts, and off-ramps that would be used to alter operations or stop actions to prevent irreversible losses.

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