APPENDIX J:

RECREATION, VISITOR USE, AND EXPERIENCE TECHNICAL INFORMATION AND ANALYSIS

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The Glen and Grand Canyons of northern Arizona provide a unique experience of extraordinary geologic landscapes, diverse wildlife and vegetation, and over 12,000 years of human history for visitors from across the globe. The area offers a variety of recreational activities including flatwater and whitewater boating, hiking, and angling. This Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Draft Environmental Impact Statement (DEIS), developed by the Bureau of Reclamation (Reclamation) and the National Park Service (NPS), has identified the recreational experience goal as being to "maintain and improve the quality of recreational experiences for the users of the Colorado River ecosystem. Recreation includes, but is not limited to, flatwater and whitewater boating, river corridor camping, and angling in Glen Canyon" (Section 1.4). Past recreational studies have shown that Glen Canyon Dam operations can affect the experience of recreationalists in the downstream Glen and Grand Canyons (Bishop et al. 1987; Hall and Shelby 2000; Stewart et al. 2000; Roberts and Bieri 2001). In an effort to quantitatively assess the downstream impacts on recreational activities of the LTEMP alternatives, six performance metrics were created to address recreational concerns. This appendix explains the metrics and compares the performance of the LTEMP alternatives as indicated by the metrics.

The alternatives encompass 19 long-term strategies, which include various combinations of experimental components (Appendix C). A full range of potential hydrologic and sediment conditions were modeled for the 20-year LTEMP period. Twenty-one potential Lake Powell in-flow scenarios (known as hydrology traces) for the 20-year LTEMP period were used to generate twenty-one 20-year hourly release patterns for each alternative and long-term strategy. In addition to these twenty-one hydrology traces, three 20-year sequences of sediment inputs from the Paria River sediment record were analyzed that represented low, medium, and high sediment conditions. In combination, the twenty-one hydrology traces and three sediment traces resulted in an analysis that considered sixty-three possible hydrology-sediment conditions.

In the presentation of results below, LTEMP alternatives are identified by the alternative letter designation (Alternatives A through G) and, if the alternative includes multiple long-term strategies, a number designation (1 through 6, depending on the number of long-term strategies for an alternative) that denotes a particular long-term strategy within an alternative. See Appendix C for descriptions of the long-term strategies.

J.1 RECREATIONAL EXPERIENCE METRICS

The analysis of potential impacts on recreational experience is based primarily on the evaluation of six quantitative metrics that were developed for the assessment, but also on more qualitative information and experience of GCNRA and GCNP staff and on the studies that served as the basis for quantitative metrics. The metrics were developed through consultation with subject matter experts, findings in published papers and reports, and with consideration of comments from the Cooperating Agencies.

J.1.1 Grand Canyon Metrics

Of the six evaluation metrics, four address issues important to visitor use and experience in Grand Canyon National Park (GCNP) downstream of Lees Ferry, while the remaining two metrics address the Glen Canyon reach between the dam and Lees Ferry. The metrics are:

- *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).

- *Navigational Risk Index:* Measure of navigation difficulty based on the number of days during which the daily minimum flow was less than 8,000 cfs (also used as input to the assessment of campsite crowding and encounters with other groups).

- *Fluctuation Index:* Measures the degree to which combinations of flows and fluctuations are within a range identified as preferable by experienced boat guides.

- *Time Off River Index:* Relates the level of flows to visitors being able to spend time ashore visiting attractions.

J.1.2 Glen Canyon Metrics

- *Glen Canyon Rafting Metric:* Estimates the number of visitors unable to participate in day rafting in Glen Canyon due to high flows.

- *Glen Canyon Inundation Metric:* Accounts for flows that impact recreational sites and recreational uses within the Glen Canyon reach.

Some of the metrics evaluate non-tangible, qualitative aspects of the recreational experience. Such metrics may be based on results of recreational surveys of visitor experience under various flow and fluctuation conditions, which overlap dam operations under LTEMP alternatives (Hjerpe and Kim 2001). These and other metrics used in the analyses and described elsewhere in this DEIS (see Appendices B and C) based on relative performance are expressed as an index having values from 0 to 1, where increasing values indicate increasing performance with respect to the associated resource goal. Metrics employing an index include the Camping Area Index (CAI), Navigational Risk Index (NRI), the Fluctuation Index (FI), the Time Off River Index (TORI), and the Glen Canyon Inundation Metric (GCIM). The Glen Canyon Rafting Metric (GCRM) is the only metric that uses an absolute scale. It is the number of potential lost visitor trips for day-use rafts in Glen Canyon due to high flows during high-flow experiments (HFEs).

The metrics all rely on the hourly Glen Canyon Dam discharge computed by the GTMax-Lite model (Reclamation 2007) with the incorporation of a sediment analysis (Russell and Huang 2010) to account for HFE implementation (Appendix E). GTMax-Lite produces a trace (20 years of hourly discharge) for each combination of hydrology and tributary sediment traces input into the model. For each metric, all 7 alternatives and any associated long-term strategies were analyzed for all 63 traces (see Section 4.1 for more detail). The following sections explain the calculation of recreation metrics for an individual trace.

In all metrics but the GCRM, the index value is weighted to emphasize seasons with greater recreational use over the course of a year. Percent of annual recreation use was determined to be 15% in the winter months of November, December, January, and February; 31% in the spring and fall months of March, April, September, and October; and 54% in the summer months of May, June, July, and August (based on monthly visitation statistics presented in https://irma.nps.gov/Stats/Reports/Park/GRCA).

J.2 METRIC DEFINITIONS, ANALYSIS METHODS, AND RESULTS

J.2.1 Camping Area Index

Campsites are primarily located on sandbars along the shoreline of the river, and they provide open, flat areas ideal for camping. Crucial for multi-day trips, campsites can limit the visiting capacity (the number of people to maintain a desired natural visitor experience) for high-demand downstream rafting trips (Kearsley et al. 1994). The management of campsites is therefore of particular concern to river managers (NPS 2006). To meet the visitor capacities established in the NPS Colorado River Management Plan, it is necessary to develop and retain medium (16–25 people) and large (>25 people) campsites, which maintain and potentially improve visitor experience based on preferences expressed in surveys of visitors. Commercial and private trip leaders preferred large beaches for camping compared to smaller beaches (Stewart 2000). A study by Kaplinski and others monitoring campsites from 1998 to 2012 reported a decrease of average campsite area by 36% with any decrease in area noted at 29 out of the 37 study sites (Kaplinski et al. 2014).

Dam operations have been shown to have significant effects on campsite area. HFEs have proven to temporarily increase campsite area due to sandbar deposition (Grams et al. 2010; Hazel et al. 2010). In the Grand Canyon Monitoring and Research Center (GCMRC) *Fiscal Year 2014 Annual Project Report* (GCMRC 2015), Kaplinski and others concluded, “sandbar deposition associated with high flows results in increases in campsite area, while post-HFE erosion causes decreases in campsite area.” Currently, it is perceived that lower discharge reduces erosion to campsites, while also exposing campsites that are covered at higher discharges. A decrease of discharge from 25,000 cfs to 15,000 cfs during normal flows increased campable area by 73%; a further increase of 46% in campable area was seen when discharges further decreased to 8,000 cfs (Kearsley and Warren 1993).

J.2.1.1 Camping Area Index—Methods

The Camping Area Index (CAI) evaluates the conditions conducive to increased camping area in the Grand Canyon, which is a function of the amount of sand deposited and retained and campsite area exposure as a function of river level (flow rate). The output from the Sand Load Index (SLI), which simulates sediment conditions between RM 0 and 30 provides a proxy for indicating whether the alternatives are likely to create the conditions conducive to creating/retaining campsite area (Appendix E). The CAI is the product of the SLI and a Seasonally Weighted Flow Factor (SWFF):

$$CAI = Average(SWFF)_{2014-2033} \times SLI$$

Both the SLI and SWFF are indices ranging from 0 to 1, as is the resulting CAI, where a value of 1 indicates the greatest potential to increase camping area. As the metric output is a generalization of sediment conditions throughout the canyon, it does not predict conditions at any particular site. Erosion is not taken into account in the CAI. Daily flow level is accounted for in the SWFF, as discussed below. Lower flows provide more camping area (i.e., there is more camping area at 8,000 cfs than at 25,000 cfs because more sand is exposed at lower flows [Kearsley and Warren 1993]). The minimum flow within the daytime period (7 am to 7 pm) is 8,000 cfs under most LTEMP alternatives.

The SLI is an index of the potential sand deposited on sandbars along the river channel in Marble and Grand Canyons above normal stage elevations (31,500 cfs). The SLI is calculated as the ratio of the cumulative sand load at flows greater than 31,500 cfs relative to the total cumulative sand load at all flows modeled (Appendix E). The sand load, or the mass of sand in transport by the river, is calculated at RM 30 and is computed by a version of the Sand Budget Model (Wright et al. 2010) for the 20-year LTEMP period. A larger SLI (on a scale of 0–1), indicates a greater potential for sediment deposition. The SLI was calculated using the following equation:

$$SLI = \frac{\sum_{2014-2033} \mathit{Sand\ Load\ at\ dam\ discharges} > 31{,}500\ cfs}{\sum_{2014-2033} \mathit{Sand\ Load\ at\ all\ dam\ discharges}}$$

The SWFF is a yearly value representing the relative amount of river bank exposure available for camping areas dependent on the Glen Canyon discharge. Low river flows will expose more campsite area while higher flows will submerge campsite area and potentially cause erosion (Kearsley and Warren 1993). Flows above 8,000 cfs are considered to increasingly reduce camping area and to submerge most campsite areas at 31,500 cfs. Camps above 25,000 cfs are considered high campsites in Kaplinski (2014). With no data on the exact location of all campsites relative to the river, an informed assumption is made here. The daily maximum flow is used to evaluate the extent to which flows may cover campsites at any point in the day.

Modeled daily flows are assigned a 0–1 index value, referred to as the daily flow factor (FF_{Daily}):

$$FF_{Daily} = \begin{Bmatrix} \text{if } Q_{max} \leq 8{,}000 \text{ cfs;} & 1 \\ \text{if } 8{,}000 < Q_{max} < 31{,}500\ cfs; & 1.34 - 0.0000425 \times Q_{max} \\ \text{if } Q_{max} \geq 31{,}500 \text{ cfs;} & 0 \end{Bmatrix}$$

where Q_{max} refers to the daily maximum discharge released from the Glen Canyon Dam in cfs and FF_{Daily} is equal to the value in the right column if the equation in the left column is satisfied.

The yearly index value (SWFF) is the ratio of the index values for each season:

$$\text{SWFF} = \left\{0.15\left(\frac{\sum_{\text{winter}} FF_{daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{\text{spring\&}fall} FF_{daily}}{\sum Days_{spring\&fall}}\right) + 0.54\left(\frac{\sum_{\text{summer}} FF_{daily}}{\sum Days_{summer}}\right)\right\}$$

J.2.1.2 Camping Area Index—Results

CAI values for all 19 LTEMP long-term strategies are shown in Figure J-1. All of these have higher CAI values than Alternative A (no-action alternative). Long-term strategies B2, C3, E3, E5, and E6 rank below Alternative A. With the exception of B2, HFEs are not conducted for these long-term strategies, and therefore flows above 31,500 cfs, the primary mechanism for sediment deposition, occur rarely, if at all. Experimentally increased flow fluctuations (hydropower improvement flows) under B2 cause it to rank below Alternative A.

The CAI is fairly insensitive to SWFF because SWFF values typically range only between 0.55 and 0.77. Consequently, the CAI is strongly dependent on the SLI, and therefore to the number of HFEs under a given alternative or long-term strategy (see Appendix E). The strong dependence of CAI on SLI can be seen by comparing Figure J-1 and Figure J-2.

Alternative G has the highest CAI, a value 3.2 times that of Alternative A. This result is attributed to the highest number of HFEs and relatively even year-round daily flows under Alternative G, conditions conducive to conserving sediment and increasing camping area through deposition and retention of sediment. Ranking second-highest, Alternative F, with a CAI 2.9 times that of Alternative A, has low flows in non-summer months and more 96-hour HFEs than other long-term strategies.

Long-term strategy B2 has a slightly reduced CAI compared to B1 attributable to testing of hydropower improvement flows under B2, which reduces CAI through reductions in both SLI and SWFF. The CAI for long-term strategy C4 is reduced relative to that for C1 and C2 due to the absence of spring HFEs and proactive spring HFEs under C4, which reduces its SLI value. C3 is much reduced owing to the absence of spring or fall HFEs, as noted above.

The CAI for long-term strategy D4 is not significantly different from D1, D2, D3, or C1, based on a test of differences between means using a three-factor analysis of variation (ANOVA)

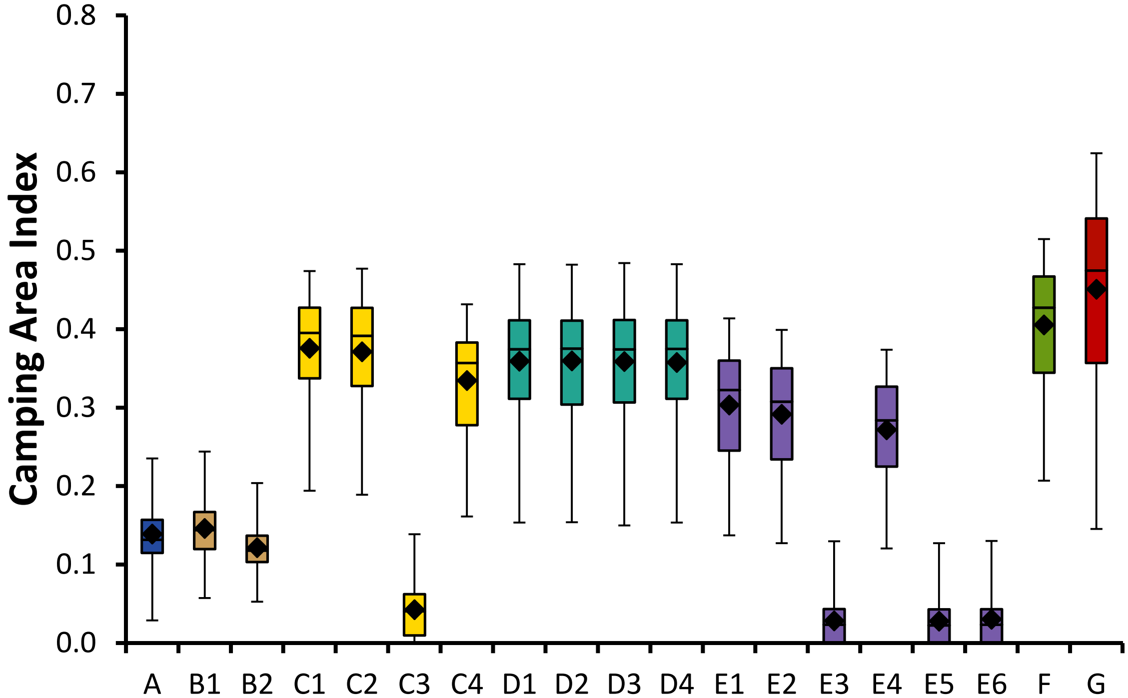

FIGURE J-1 Camping Area Index for LTEMP Long-Term Strategies (Increasing values indicate increasing camping area. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

followed by Tukey's Studentized Range Test. This indicates that low summer flows under D1, D2, and D3 have no effect on CAI, nor does sustained low flows for benthic invertebrate production under D2 or the absence of trout management flows under D3.

The CAI for long-term strategy E4 is slightly lower than that for E1 and E2, indicating a small reduction in sediment retention for E4 due to the absence of spring HFEs in the second 10 years of the LTEMP period, which are conducted under E1 and E2. As noted above, E3, E5, and E6 do not include spring or fall HFEs, explaining their low CAI values.

J.2.2 Navigational Risk Index

Navigating the Colorado River downstream of Glen Canyon Dam at low flows, especially at rapids, can cause difficulties for oar and motor trips. A survey conducted by Bishop et al. (1987) of commercial oar and motor guides indicated that flow levels below 9,200 cfs and 8,400 cfs, respectively, began to compromise boater safety. In the Bishop et al. (1987) study, guides were simply asked for minimum levels of flow for running safely with passengers. Survey respondents noted that at these flows, boat accidents related to exposed rocks are much more probable. A similar survey by Shelby et al. (1992) reported nearly the same

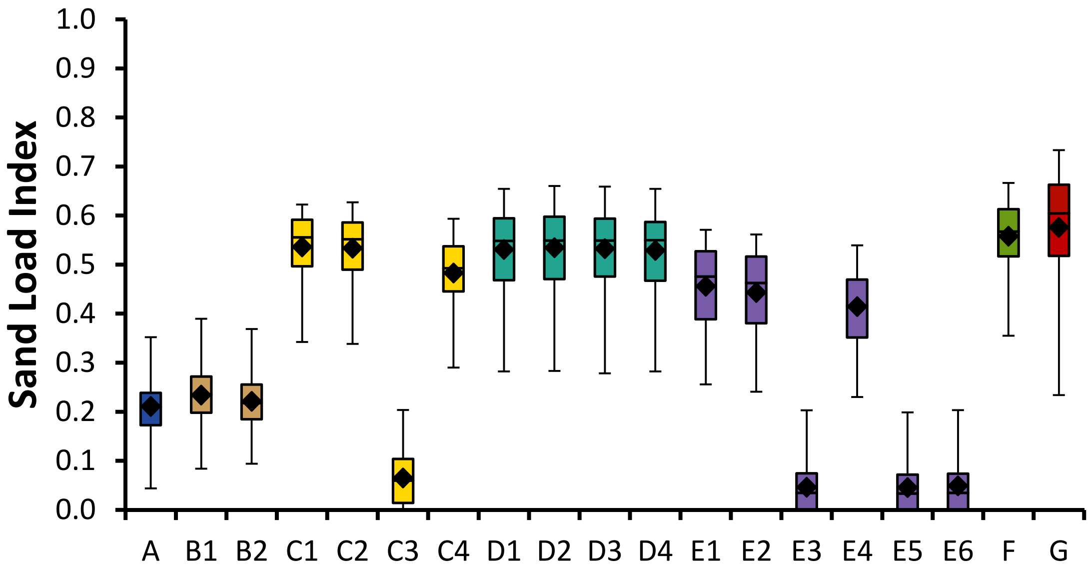

FIGURE J-2 Sand Load Index (see Appendix E) for LTEMP Long-Term Strategies (Increasing values indicate more sediment deposited along river banks. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

values as Bishop et al. (1987), and a more recent survey by Stewart et al. (2000) had similar findings with oar and motor river guides identifying approximately 8,100 cfs and 7,800 cfs, respectively, as minimum flows for what they considered safe river trips. Exposures to experimental low flows of 8,000 cfs in the summer of 2000 further supported the guides' perceptions of potentially dangerous flows, with double the number of boating accidents reported than the previous year, mostly associated with hitting exposed rocks (Ralston 2011).

J.2.2.1 Navigational Risk Index—Methods

To assess the risk due to difficulties of motor rigs navigating rapids at lower flows, the risk (frequency) of daily minimum discharges that are ≤8,000 cfs was determined for each season. To account for the variance in use between the seasons, the yearly value is averaged with weights corresponding to recreational use as used above for SWFF in calculating the CAI. The annual risk was calculated as:

$$Risk = \left\{ 0.15\left(\frac{\sum_{\text{winter}} Days_{min}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{\frac{\text{spring}}{\text{fall}}} Days_{min}}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{\text{summer}} Days_{min}}{\sum Days_{summer}}\right) \right\}$$

where $Days_{min}$ is the number of days when flows were <8,000 cfs, $Days_{winter}$ is the number of days in the winter, $Days_{spring/fall}$ is the number of days in the spring and fall, and $Days_{summer}$ is the number of days in the summer.

The index is the complement of the risk, where 1 indicates 100% of minimum daily flow above 8,000 cfs and is therefore the least risk to river navigators. Thus, the NRI for a single input trace for the LTEMP period of 2014–2033 is as follows:

$$NRI = Average(1 - Risk)_{2014-2033}$$

While Alternatives A through E restrict minimum flows to 8,000 cfs during day hours (7 am to 7 pm), flows during night hours (7 pm to 7 am) can drop to 5,000 cfs, and these low flows can affect downstream boaters during daylight hours well after the change in discharge rate occurs at the dam due to the transit time required for the change to reach downstream locations. The calculation of daily minimum flow was therefore inclusive of the entire 24-hour period.

J.2.2.2 Navigational Risk Index—Results

NRI values for each alternative are shown in Figure J-3. Long-term strategies C1–C4, D2, F, and G have higher values than Alternative A, while D1, D3, and D4 are only slightly lower than Alternative A. Long-term strategy B2 has the lowest NRI value owing to high flow fluctuations and low minimum flows, while B1 and E1–E6 are also lower than Alternative A.

Alternative G has year-round steady flows of approximately 11,000 to 13,000 cfs, rarely dipping below 8,000 cfs, resulting in an NRI approaching 1 (lowest risk). Alternative F, which also has steady daily flows, has high flows in the months of February through June and lower flows running near or below 8,000 cfs in July through January. However, for the historic water volumes modeled (typically greater than 8.23 maf), higher releases would sometimes occur for equalization purposes at the end of the water year. Primarily for this reason, the average days with flows above 8,000 cfs actually outnumber the days below it for Alternative F. On average, Alternative F has an NRI almost 1.5 times that of Alternative A.

For alternatives with fluctuating flows, the size of daily fluctuations generally differentiates between alternatives, while experimental features drive differences between long-term strategies within alternatives. Daily fluctuations under Alternative C are lower than those under Alternatives A, D, E, and B, resulting in fewest occurrences of flows less than 8,000 cfs and the highest NRI value (lowest risk) of the fluctuating-flow alternatives. The relative ranking of these alternatives in Figure J-3 generally reflects the size of daily fluctuations, which determines the frequency of flows less than 8,000 cfs.

Within alternatives, long-term strategy B2 has a lower NRI (higher risk) than B1 due to high fluctuations and flows less than 8,000 cfs associated with experimental hydropower improvement flows not included in B1. For the same reasons, B2 has the lowest NRI (highest risk) of all long-term strategies. C2 has a slightly lower NRI than C1, C3, and C4 due to the

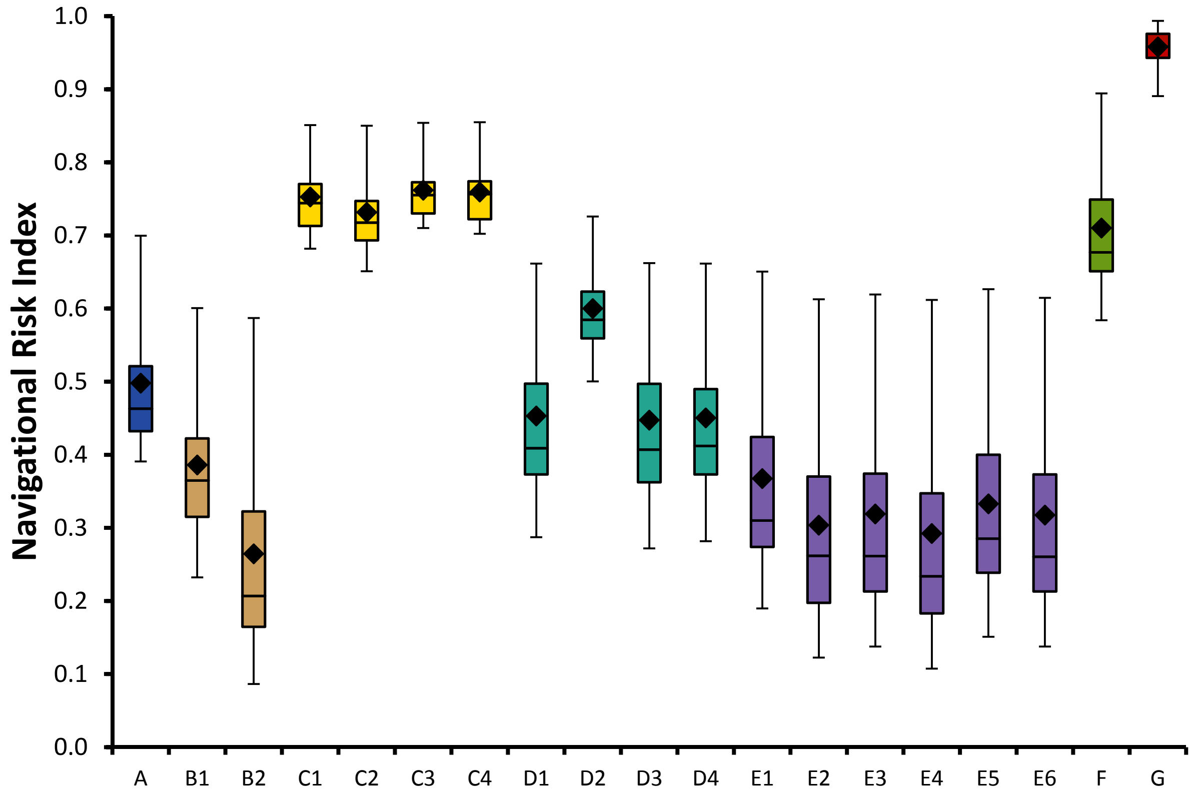

FIGURE J-3 Navigational Risk Index Values for the LTEMP Long-Term Strategies (Increasing values indicate improving navigation conditions. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

inclusion of low summer flows, which allows minimum daily flows as low as 5,000 cfs. Low weekend flows to promote benthic invertebrate production during May–August under long-term strategy D2 increase the overall minimum flow during those months, elevating the NRI relative to D1, D3, and D4. Absence of low summer flows under E1, E3, E4, and E6 elevates the NRI for these long-term strategies slightly compared to E2 and E5.

J.2.3 Fluctuation Index

Whitewater rafting guides surveyed by Bishop et al. (1987) indicated that moderate (8,000–25,000 cfs) and severe (1,000–33,500 cfs) daily fluctuations are potentially problematic for rafting trips. Fluctuations can complicate mooring at campsites, and running rapids, and can increase the unpredictability of flows. Bishop et al. surveyed guides and private trip leaders with experiences of both large fluctuations (greater than 15,000 cfs) and steady flows and documented the ranges of tolerable fluctuations at various river flow levels, as shown in Table J-1.

TABLE J-1 Reported Mean Tolerable Daily Changes in Flow Levels for Commercial Motor Guides, Commercial Oar Guides, and Private Trip Leaders[a]

River flow (cfs)	Tolerable Fluctuations (cfs)
5,000–8,999	2,400–*3,400*[b]
9,000–15,999	3,900–*4,800*
16,000–31,999	6,400–*7,200*
32,000 and up	7,900–*9,800*

[a] Table modified from Table 4-7 of Bishop et al. 1987.

[b] Italicized values indicate the maximum tolerable fluctuation threshold used in the Fluctuation Index.

J.2.3.1 Fluctuation Index—Methods

Table J-1 is the basis for the Fluctuation Index (FI). It is assumed that (1) the river flow ranges shown in the left-hand column of Table J-1 are based on the mean daily flow and that (2) the maximum tolerable fluctuation threshold (italicized flow values in Table J-1) serves as the level above which fluctuations become increasingly more unacceptable to river users.

A daily flow factor (FF) value of 0–1 was computed using Table J-1 and the mean flow for a given day. The daily flow factor is 1 if the fluctuations are within the acceptable range. Above the threshold, daily FF goes linearly to zero as the fluctuation increases to 10,000 cfs. Daily fluctuation levels greater than 10,000 cfs are clearly noticeable and have strong adverse effects on river users (Bishop et al. 1987). The daily FF is computed as follows, where Q_{avg} is the daily mean flow, Q_{range} is the daily fluctuation, and Q_{tol} is the tolerable fluctuation threshold:

$$FF_{daily} = \left\{ \begin{array}{ll} \text{if } Q_{range} \leq \quad Q_{tol} & 1 \\ \text{if } Q_{range} > \quad Q_{tol} & \\ \quad where\ 5{,}000 < Q_{avg} < 8{,}999 & 1.515 - (0.00015 \text{ x } Q_{range}) \\ \quad where\ 9{,}000 < Q_{avg} < 15{,}999 & 1.923 - (0.00019 \text{ x } Q_{range}) \\ \quad where\ 16{,}000 < Q_{avg} < 31{,}999 & 3.571 - (0.00036 \text{ x } Q_{range}) \\ \quad where\ Q_{avg} > 32{,}000 & 50 - (0.005 \text{ x } Q_{range}) \end{array} \right\}$$

The annual FI is the sum of daily FFs weighted by season according to recreational use, with seasonal weights being the same as for the NRI:

$$FI_{annual} = \left\{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{spring/fall}}\right) + 0.54\left(\frac{\sum_{summer} FF_{Daily}}{\sum Days_{summer}}\right)\right\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$FI = Average\ (FI_{annual})_{2014-2033}$$

J.2.3.2 Fluctuation Index—Results

The results of the FI are shown in Figure J-4. Differences between alternatives reflect differences in levels of daily flow fluctuations under the respective operational regimes. Alternatives F and G have FIs approaching 1 due to the absence of daily fluctuations; G is slightly lower, as it includes trout management flows in years when trout recruitment is high. Alternatives C, A, D, E, and B have rankings in order of increasing levels of daily fluctuations.

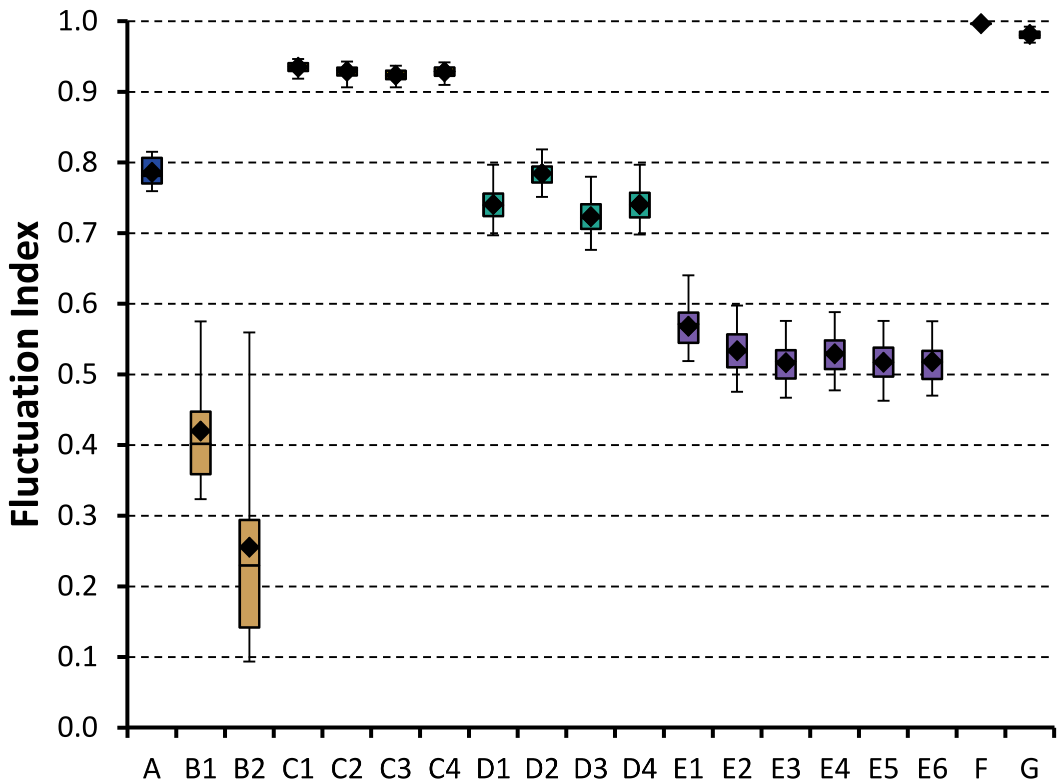

FIGURE J-4 Fluctuation Index for LTEMP Long-Term Strategies (Increasing values indicate more days have tolerable fluctuation levels. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

Alternative A and all long-term strategies under Alternatives C, D, and E have average index values above 0.5, indicating a high proportion of daily fluctuations that are within the tolerable range. Long-term strategy B1 has an annual FI value roughly half that of Alternative A, while B2 has a value roughly a third of Alternative A. Tests of hydropower improvement flows, particularly during highly weighted summer months, reduce B2 relative to B1, while high fluctuation levels overall contribute to low FI values for B1 and B2. Steady, low weekend flows to promote benthic invertebrate production during May through August elevate the FI for D2 relative to D1, D3, and D4. The slightly higher FI values for long-term strategies E1 and E2 relative to E3–E6 can be attributed to the inclusion of both spring and fall HFEs in EI and E2. Water released for HFEs is not available for load following, thus reducing fluctuations and raising the FI. Likewise, E4, which includes fall but no spring HFEs, has a slightly elevated FI compared to E3, E5, and E6, which have no HFEs.

J.2.4 Time Off River

For rafting visitors, time off river to visit attractions and for other activities is important to the recreational experience (Stewart et al. 2000). Low river flows reduce travel speed for boats. Below a flow of about 10,000 cfs, there may be problems getting to camp on time and not enough time for stops at scheduled locations (Shelby et al. 1992).

J.2.4.1 Time Off River Index—Methods

The Time Off River Index (TORI) is computed using a daily flow factor (FF), which is an index from 0 to 1 that uses a flow threshold of 10,000 cfs. The daily FF is computed as follows, where the value within the brackets in the right column is assigned to the FF if the equation in the left column is satisfied, and where Q_{avg} is the average daily discharge:

$$FF_{Daily} = \begin{Bmatrix} \text{if } Q_{avg} \leq 10{,}000; & 0 \\ \text{if } 10{,}000 < Q_{avg} < 31{,}500; & 0.0000465 \times Q_{avg} - 0.465 \\ \text{if } Q_{avg} \geq 31{,}500; & 1 \end{Bmatrix}$$

The annual TORI is the sum of the weighted seasonal index values. The seasonal index is the mean of the FF for all days within a given season, as above for NRI and FI:

$$TORI_{annual} = \{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{\mathrm{summer}} \mathrm{FF}_{\mathrm{daily}}}{\sum Days_{summer}}\right)\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$TORI = Average\ (TORI_{annual})_{2014-2033}$$

J.2.4.2 Time Off River Index—Results

Figure J-5 shows the TORI results for all long-term strategies. TORI values for all of the long-term strategies have similar mean and quartile values, due to similar average flows among the alternatives. The exception is the TORI for Alternative F, which is notably higher than for other alternatives. This difference is largely due to elevated flows during March–June under Alternative F, which falls within moderately to highly weighted seasons in the annual TORI computation. Figure J-6 shows elevated average daily discharge rates during March–June for Alternative F relative to the other alternatives. For all other long-term strategies, there would be negligible differences in time off river from current conditions.

J.2.5 Glen Canyon Rafting Use

Day-rafting trips in Glen Canyon are a popular visitor attraction of Glen Canyon National Recreation Area. These day-rafting trips regularly run as full-day, half-day, and rowed trips during March 1 to December 1. Glen Canyon rafting trips are not sensitive to flow levels (Bishop et al. 1987) and can generally operate during all releases up to powerplant capacity

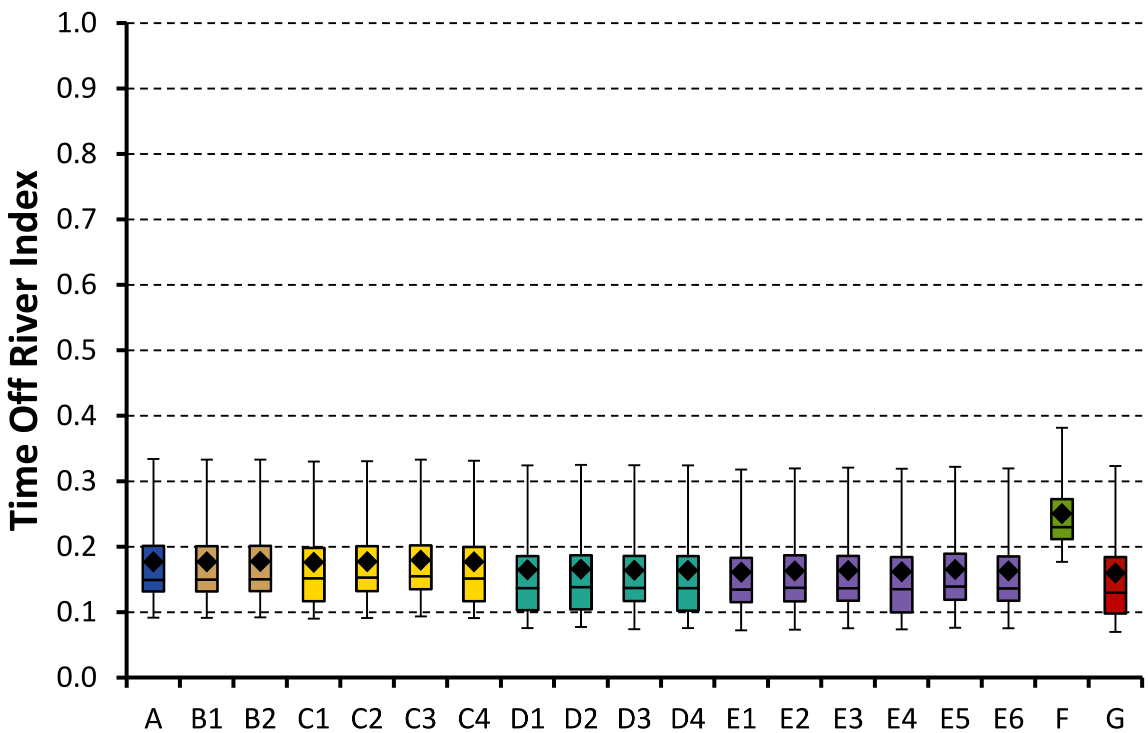

FIGURE J-5 Time Off River Index for LTEMP Long-Term Strategies (Increasing values indicate more time off river. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

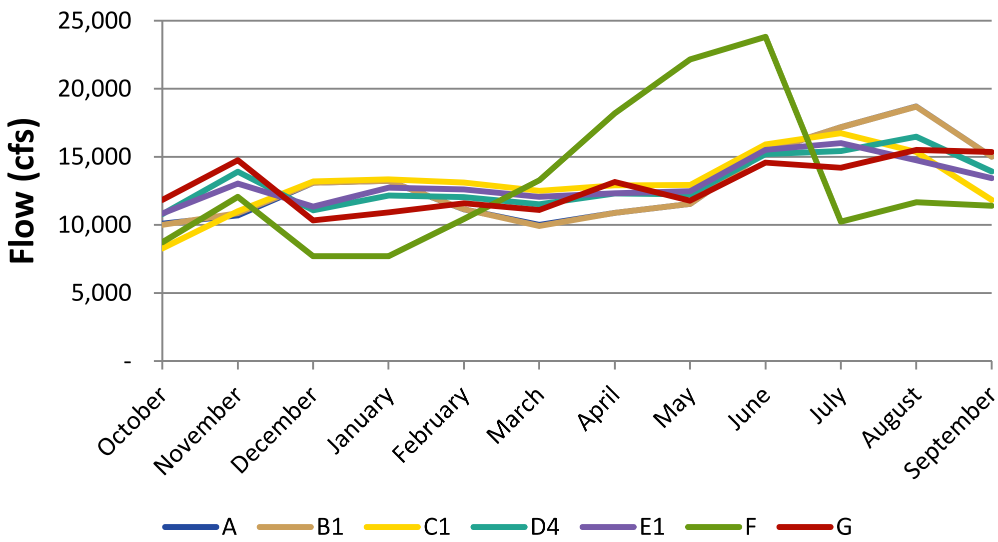

FIGURE J-6 Average Daily Discharge for All Modeled Traces and Years under LTEMP Alternatives

(31,500 cfs). However, when HFEs are run and the bypass tubes are activated, the turbulence at the loading dock is too great to safely load passengers and the commercial operator, Colorado River Discovery, ceases day-use rafting operations (Grim 2012).

J.2.5.1 Glen Canyon Rafting Use Metric—Methods

The Glen Canyon Rafting Use Metric (GCRM) represents the number of visitors unable to take day-rafting trips due to HFEs. Monthly passenger logs for Colorado River Discovery from 2011 to 2012 (Blais 2014) were used to estimate the number of daily passengers (*ADV*) for the months in which HFEs occur (March, April, May, October, and November). Data from 2013 was available but was not included because roadway closures that year potentially impacted visitor numbers. HFEs in spring and fall are possible each year. Estimates of the average daily rafting visitor count for lost trips from spring and fall HFEs are approximately 155 and 68, respectively. Thus, spring HFEs would have a much greater impact than fall HFEs due to higher rafting use in spring (more than double the passengers affected for a given HFE duration).

HFEs require day-raft concessioners to pull the boats from the water or relocate them. Therefore, the number of days lost for Glen Canyon rafting because of an HFE (D) is equal to the HFE duration plus 2 days prior and 2 days post HFE ($D = T_{HFE} + 4$ days) required to de-mobilize and re-mobilize rafting operations. The total number of lost rafting days (D) is multiplied by the estimated visitors per day (*ADV*) to calculate the number of passengers unable to raft due to an HFE. Note that, unlike the other recreation metrics in this appendix, the Glen Canyon Rafting Use Metric (GCRM) is a measure of an absolute effect, the actual number of annual lost visitor trips, as opposed to a relative index.

The operational 24-hr, 45,000 cfs spring high flow under Alternative F is taken into account in this analysis. No other high flows, such as equalization flows, except those distinctly defined as HFEs are considered. For each modeled year, there is the potential for a spring HFE, a fall HFE, or both to occur. The GCRM is calculated as follows for each HFE event.

$$GCRM_{HFE} = ADV\left[\frac{visitors}{day}\right] \times D\ [days]$$

If there are two HFEs within a single year, the number of passengers unable to raft is summed as in the following equation:

$$GCRM_{annual} = \sum_{yearly} GCRM_{HFE}$$

The final metric value is the average number of passengers unable to raft the Glen Canyon reach for the 20-year LTEMP modeling period (2014 to 2033) due to HFEs:

$$GCRM = Average\ (GCRM_{annual})_{2014-2033}$$

J.2.5.2 Glen Canyon Rafting Use Metric—Results

Figure J-7 shows GCRM values for LTEMP alternatives and long-term strategies. As the metric is based on the number of HFEs, the GCRM closely resembles the pattern of HFEs under each alternative. This can be seen by comparing the GCRM values in Figure J-7 with the average HFE count in Figure J-8. Not shown for Alternative F is the annual 24-hr high flow that occurs in years without a spring HFE. This further contributes to increases the GCRM, resulting in the highest number of lost visitor trips for Alternative F. As spring trips have a higher number of passengers than fall trips, spring HFEs have a larger impact on lost visitor trips than do fall HFEs.

As they do not include HFEs, long-term strategies C3, E3, E5, and E6 incur no lost visitor rafting trips. With few HFEs and mostly fall HFEs, long-term strategies A and B1 and B2 have the next fewest lost trips on average, while C4 and E4 have only slightly more, due mainly to the absence of spring HFEs under these long-term strategies. E1 and E2 have more lost trips than E4 due to spring HFEs in the second 10 years of the LTEMP period that do not occur under E4. Long-term strategies C1–C2 and D1–D2 have similar numbers of lost visitor trips owing to similar numbers and durations of HFEs. Alternative G has the second highest number of lost trips at roughly 500 annually, due to a high number of HFEs, an estimated 24.5 over the 20-year LTEMP period, including HFEs of 96 hr or longer duration. Finally, Alternative F has the highest number of lost visitor trips, on average over 900 annually, due to the highest number of HFEs, an estimated 38.1 over the 20-year LTEMP period, including the annual 24-hr release in all summers of years without a spring HFE. In addition, roughly two-thirds of HFEs under Alternative F are of 96-hr duration, representing a large number of days closed to rafting.

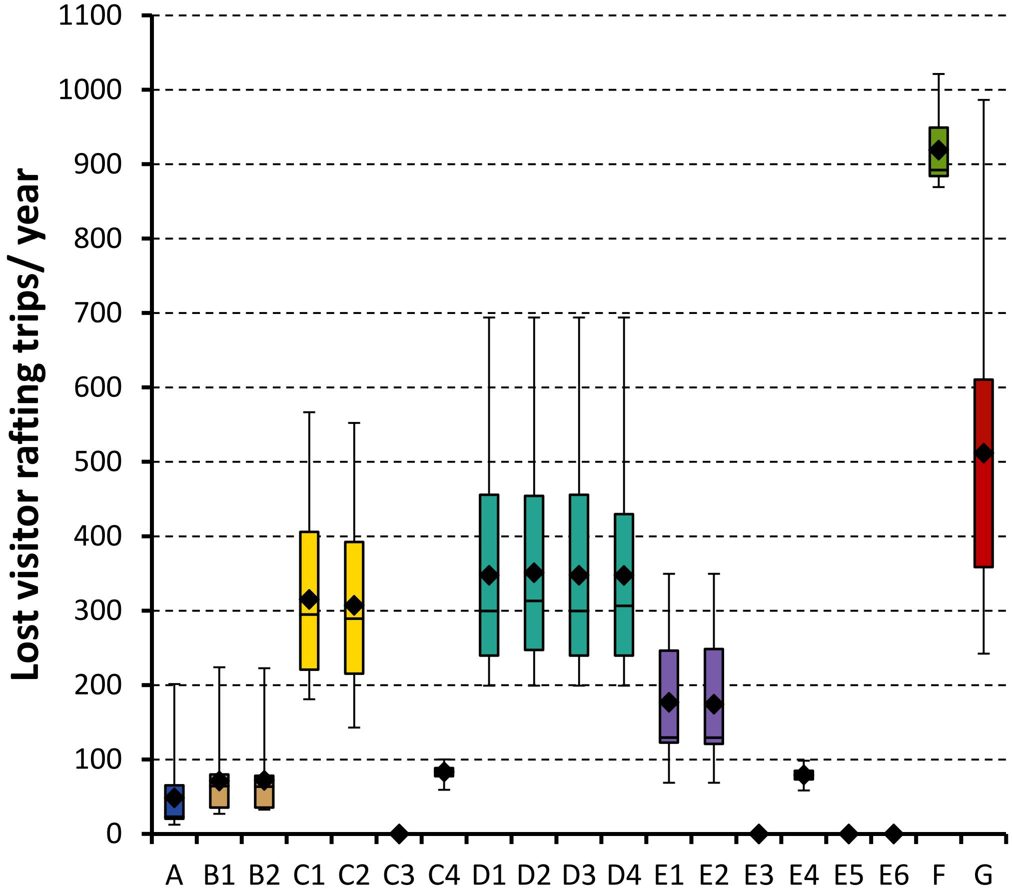

FIGURE J-7 Glen Canyon Rafting Metric for All LTEMP Long-Term Strategies (Values are estimated annual lost visitor rafting trips. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

J.2.6 Glen Canyon Inundation Metric

The 15-mi stretch of Glen Canyon, from the Glen Canyon Dam to Lees Ferry, along the Colorado River is a hub for recreation within Glen Canyon National Recreation Area. Due to its unique geography, Lees Ferry is the only place directly accessible by car to visitors in hundreds of miles of canyon country. It is therefore an ideal location for boating, fishing, swimming, kayaking, camping, and hiking activities by visitors. However, these activities are directly downstream of the Glen Canyon Dam, and can be impacted by dam operation.

Surveys of users have indicated that the most ideal recreational conditions for Glen Canyon are flows from 8,000 to 20,000 cfs. Bishop et al. (1987) and Stewart et al. (2000) reported that anglers preferred a constant flow of about 10,000 cfs, while more recent information indicated Lees Ferry anglers preferred constant flows from 8,000 to 16,000 cfs

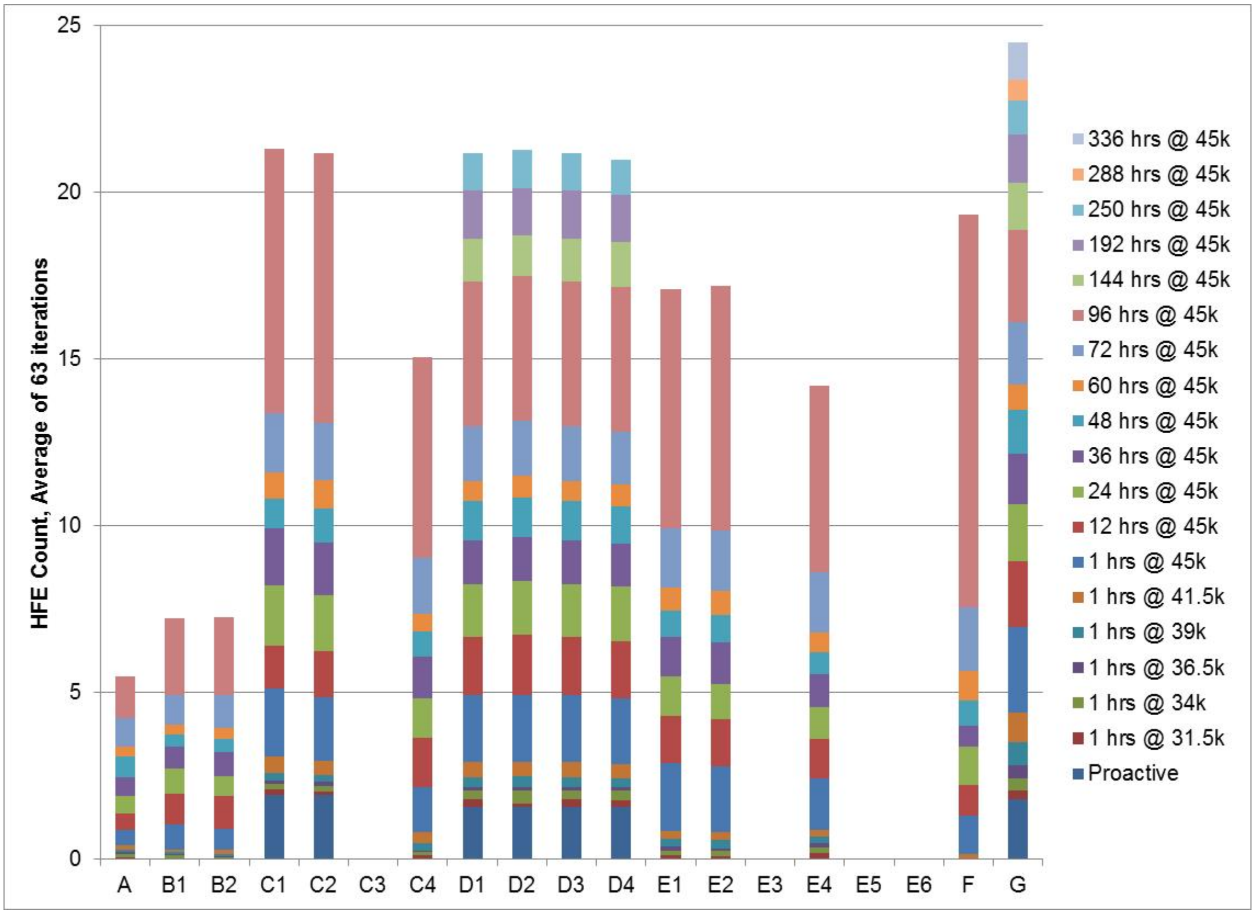

FIGURE J-8 Average Number of HFEs in the 20-Year LTEMP Period for LTEMP Long-Term Strategies

(Gunn 2012). Flows within the 8,000 to 20,000 cfs range are ideal for shoreline access for boaters, who primarily only report poor conditions or water level issues with extremely high or low flows. For example, the Colorado River Discovery day rafting service reported operating issues with flows below 3,000 cfs and inoperable conditions when bypass tubes are in operation (above 31,500 cfs), as they create too much turbulence below the dam (Grim 2012). Flows at or below 8,000 cfs may allow tamarisk tree growth and, as observed in the low summer flows of 2000 (Hjerpe and Kim 2001), may make prime angling spots impenetrable. At flows above 20,000 cfs, reduced participation in upstream fishing has been observed (McGinnis 2014).

J.2.6.1 Glen Canyon Inundation Metric—Methods

The Glen Canyon Inundation Metric (GCIM) represents the percentage of time that flow is at preferred levels for recreational experiences within the canyon, 8,000 to 20,000 cfs. Table J-2 presents a summary of recreational response to various discharge rates. This information was used in the computation of the Glen Canyon Inundation Metric as follows. A flow factor (FF) value from 0 to 1 is computed as a function of daily maximum discharge and

TABLE J-2 Recreation Response to Daily Maximum Flow

Flow (cfs)	Recreational Response
<3,000	Flows below 3,000 cfs are poor for boating and fishing.
3,000–8,000	Flows for fishing and boating get progressively better up to 8,000 cfs.
8,000–20,000	Flows are optimal for boating, fishing, and shoreline access.
20,000–31,500	Flows above 20,000 cfs get progressively worse for fishing and shoreline access.
>31,500	Flows above 31,500 cfs are poor for rafting, campable area, shoreline access, and fishing, and can adversely impact onshore recreational facilities.

the noted recreation responses, with higher values representing improved recreational experience. Daily FF values for discharges of 3,000 to 8,000 cfs and 20,000 to 31,500 cfs ranges were assigned values based on linear interpolation from 0 to 1 and 1 to 0, respectively. The daily FF is assigned as shown below, where the value in the right column within the brackets is assigned to FF if the equation in the left column is satisfied. Q_{max} refers to the daily maximum discharge released from the Glen Canyon Dam in cfs:

$$FF_{Daily} = \begin{cases} \text{if } Q_{max} \leq 3{,}000 \text{ cfs;} & 0 \\ \text{if } 3{,}000 < Q_{max} < 8{,}000\ cfs; & (Q_{max} \times 0.0002) - 0.60 \\ \text{if } 8{,}000 < Q_{max} < 20{,}000\ cfs & 1 \\ \text{if } 20{,}000 < Q_{max} < 31{,}500\ cfs; & 2.74 - (0.0000870 \times Q_{max}) \\ \text{if } Q_{max} \geq 31{,}500 \text{ cfs;} & 0 \end{cases}$$

An overall annual mean index value for the 20-year modeling period was computed for each alternative and used as the performance metric.

$$GCIM_{annual} = \{0.15\left(\frac{\sum_{winter} FF_{Daily}}{\sum Days_{winter}}\right) + 0.31\left(\frac{\sum_{spring/fall} FF_{Daily}}{\sum Days_{\frac{spring}{fall}}}\right) + 0.54\left(\frac{\sum_{\text{summer}} \text{FF}_{\text{daily}}}{\sum Days_{summer}}\right)\}$$

An overall annual mean index value for the 20-year modeling period was calculated as follows:

$$GCIM = Average\ (GCIM_{annual})_{2014-2033}$$

J.2.6.2 Glen Canyon Inundation Metric—Results

Results for the GCIM for LTEMP long-term strategies are shown in Figure J-9. Results are similar for all of the long-term strategies, except for Alternative F and, to a lesser extent, B2. Overall, index values are all high, above 0.9 for all but Alternative G, which has a mean value of about 0.85. Such high values indicate that discharge rates are in a range preferred for a variety of recreational activities most of the time under all alternatives and long-term strategies. The index value for Alternative F is reduced due to the large number of HFEs overall and to the high percentage of 96-hr HFEs, which together produce a relatively high number of days annually with flows above preferred levels. Similarly, high flows during hydropower improvement tests under B2 reduce its index value relative to B1 and most other long-term strategies. Other long-term strategies have values very close to that for Alternative A, with small deviations both higher and lower.

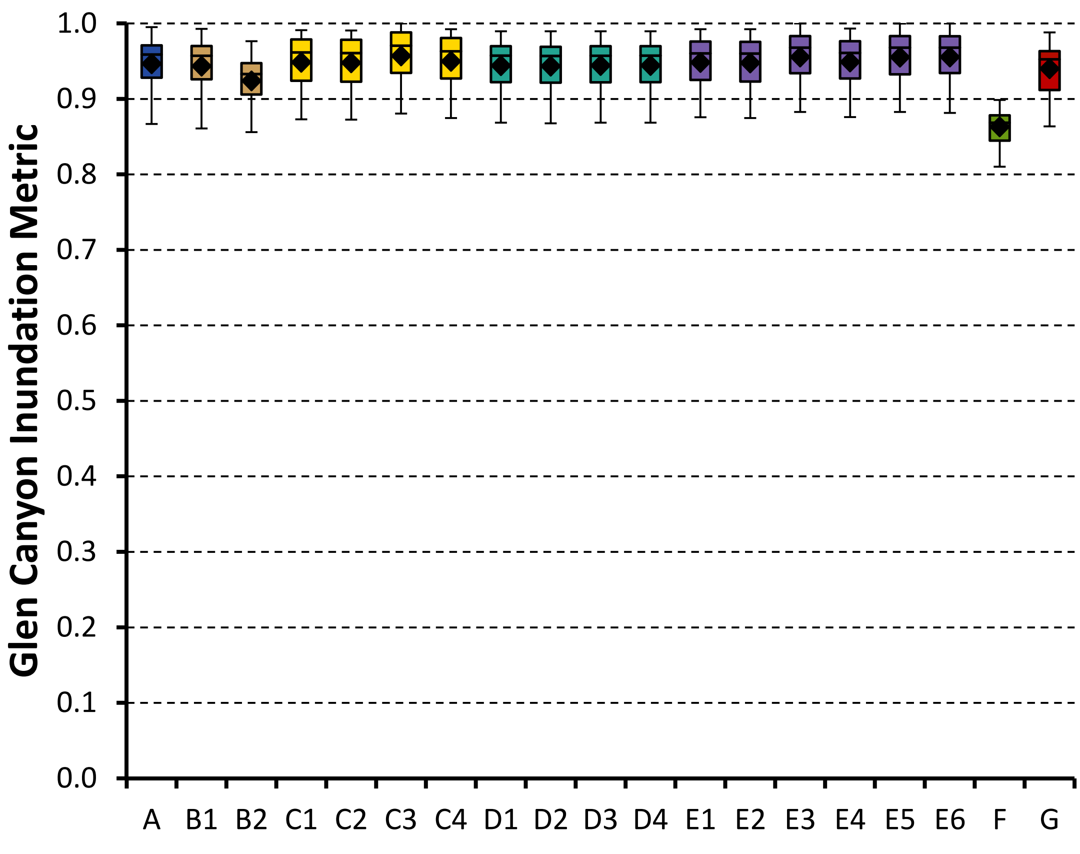

FIGURE J-9 Glen Canyon Inundation Metric for All LTEMP Long-Term Strategies (Increasing values indicate increasing frequency of flow levels preferred for recreation. Note that diamond = mean; horizontal line = median; lower extent of box = 25th percentile; upper extent of box = 75th percentile; lower whisker = minimum; upper whisker = maximum.)

J.3 LAKE POWELL AND LAKE MEAD DOCK ACCESS

Lower-than-normal lake levels have been occurring in Lake Powell upstream of the Glen Canyon Dam and in Lake Mead, which lies at the end of the 277-mi stretch of the Colorado River through GCNP. At Lake Powell, low lake elevation has rendered some boat launch sites inaccessible, and, in October 2005, NPS completed a General Management Plan (GMP) Amendment for Low Water Conditions and Finding of No Significant Impact (NPS 2005), which identified a strategy for low-water operations. This amendment ensured the maintenance of the boat launch sites at Lake Mead despite low water levels by either extending or relocating existing launch ramps and marinas so as to be functional down to an elevation of 1,050 feet above mean sea level (AMSL). Similarly, at Lake Powell, a connection channel called Castle Rock Cut, located directly across from Wahweap Bay from the Stateline launch ramp, became inaccessible at lake levels below an elevation of 3,580 ft AMSL in 2014 (Elleard 2014).

Modeled end-of-month lake elevations from 63 historical traces were compared against these two elevations (1,050 ft AMSL for Lake Mead and 3,580 ft AMSL for Lake Powell) to determine the percentage of time that lake levels would potentially fall below these critical levels. The percentage of traces where monthly lake elevation fell below critical elevation for any month within a season over the 20-year LTEMP period for Lake Powell is shown in Figure J-10 for the recreational summer seasons of May, June, July, and August and in Figure J-11 for the recreational fall and spring months of March, April, September, and October. Figures J-12 and J-13 show the analogous percentages for Lake Mead. Note that since these figures were generated by recasting past hydrology, they show the potential future variability and range of lake elevation conditions relative to the access reference elevations, but they do not predict conditions for any particular future year or year-to-year trends. Thus, the year dates on the *x* axis have meaning only in the sense that they show a hypothetical future 20-year period.

These graphs show that monthly lake elevations fall on or below critical elevations during spring and summer months for roughly 22% of historical trace simulations for Lake Powell and roughly 25% of historical trace simulations for Lake Mead for all alternatives and long-term strategies over the LTEMP period. Table J-3 shows the percentages for all alternatives. While rates of access issues are substantial, the difference among alternatives is small, indicating overall impacts at the launch sites of Lake Mead or the Castle Rock Cut connection channel in Lake Powell are driven mainly by hydrology. At Lake Powell, on average over all seasons, all alternatives have slight increases in access impacts relative to Alternative A. Conversely, at Lake Mead, all alternatives exhibit slight decreases in access issues compared to Alternative A. It is not clearly the case, but this behavior might be the result of Alternative A having the lowest number of HFEs of all alternatives. Large volumes of water taken from Lake Powell for an HFE might temporarily drop the lake level below the access threshold when the lake level is near the threshold, while similarly reducing the frequency of access issues at Lake Mead, which receives an input pulse from an HFE.

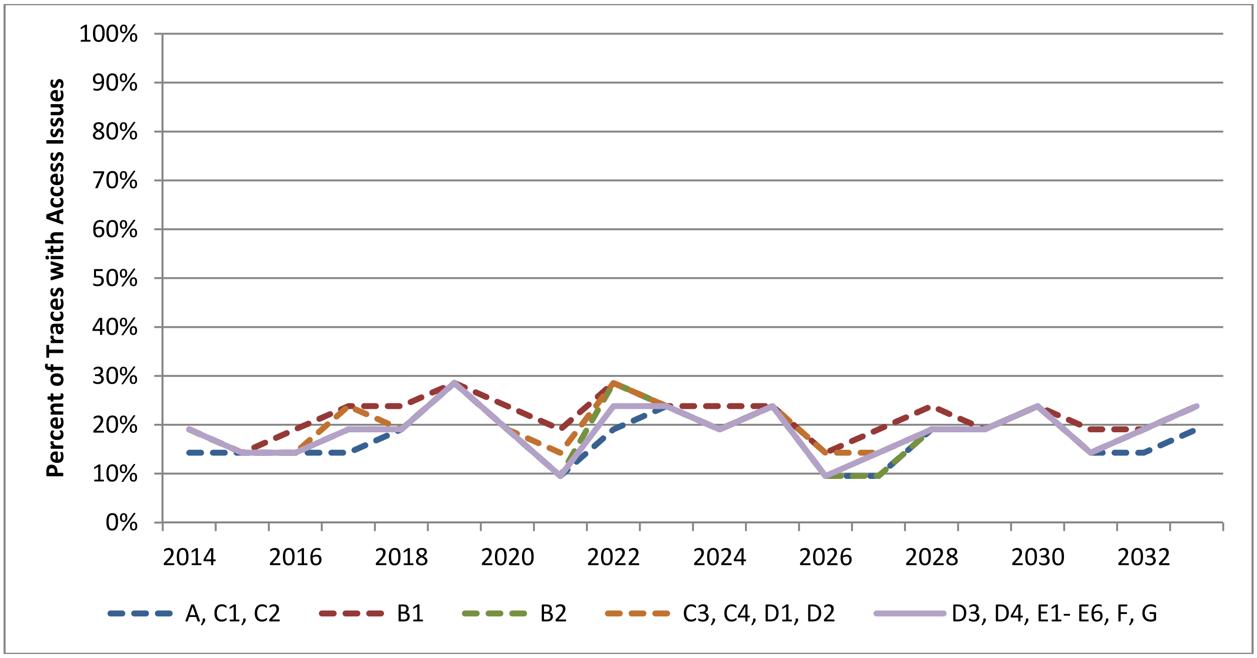

FIGURE J-10 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Summer Season

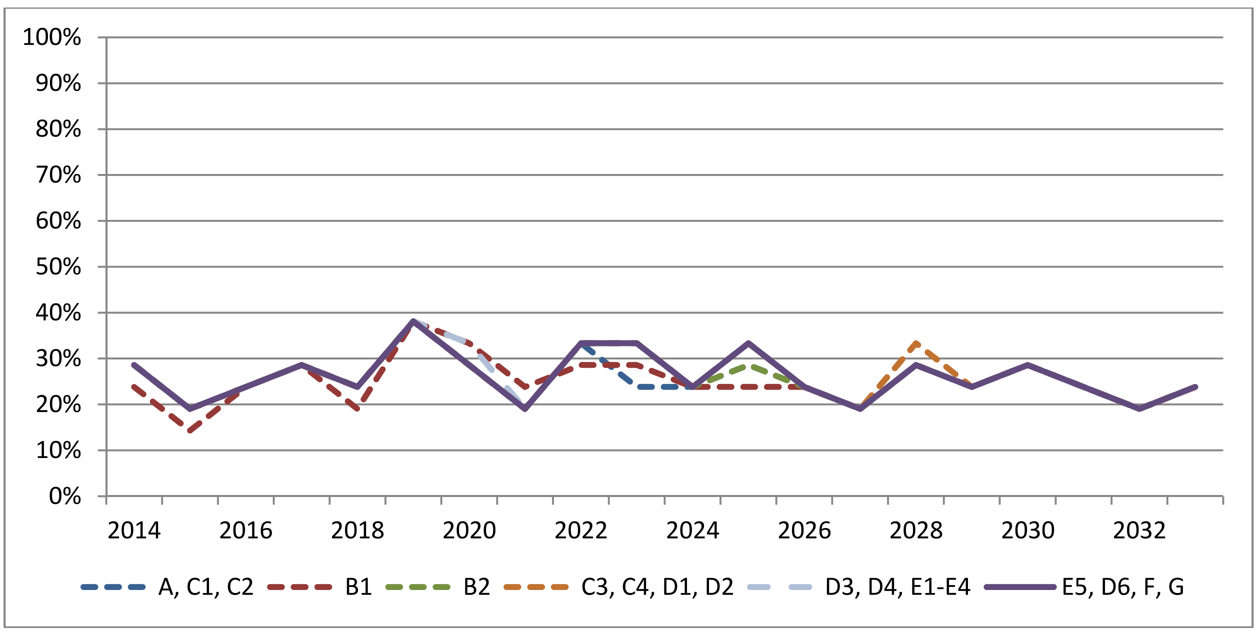

FIGURE J-11 Percentage of Traces Lake Powell Elevation Equal to or below 3,580 ft AMSL for the Fall and Spring Seasons

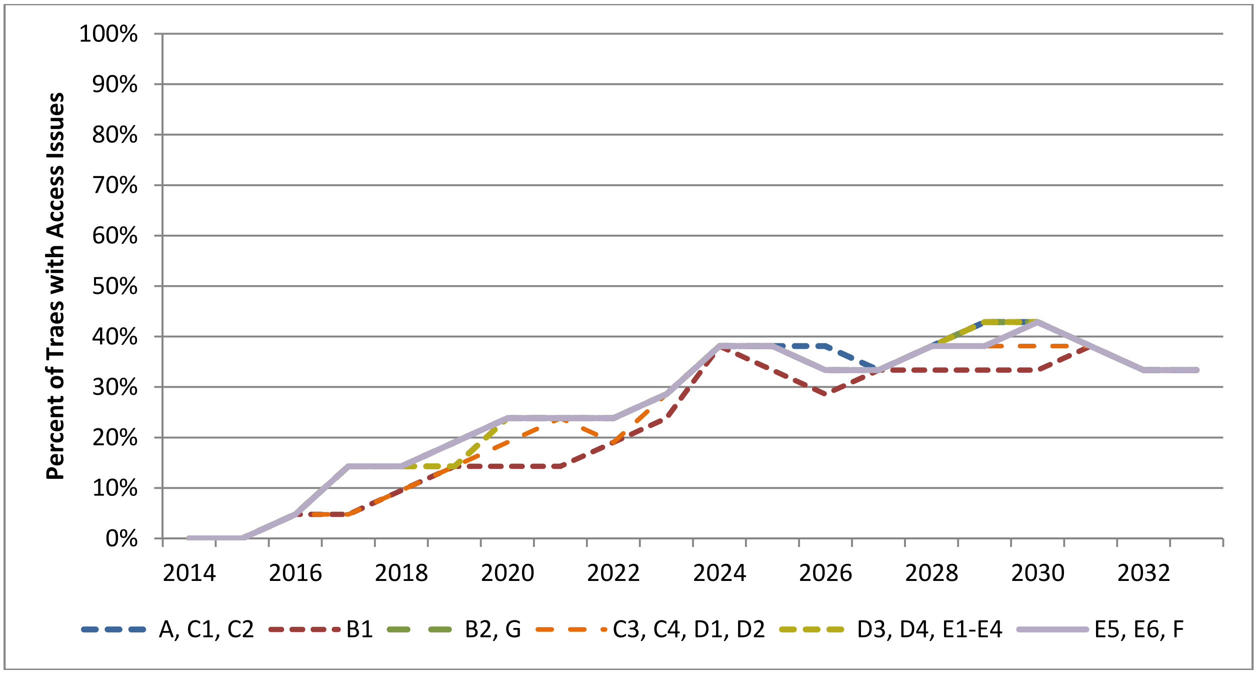

FIGURE J-12 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Summer Season

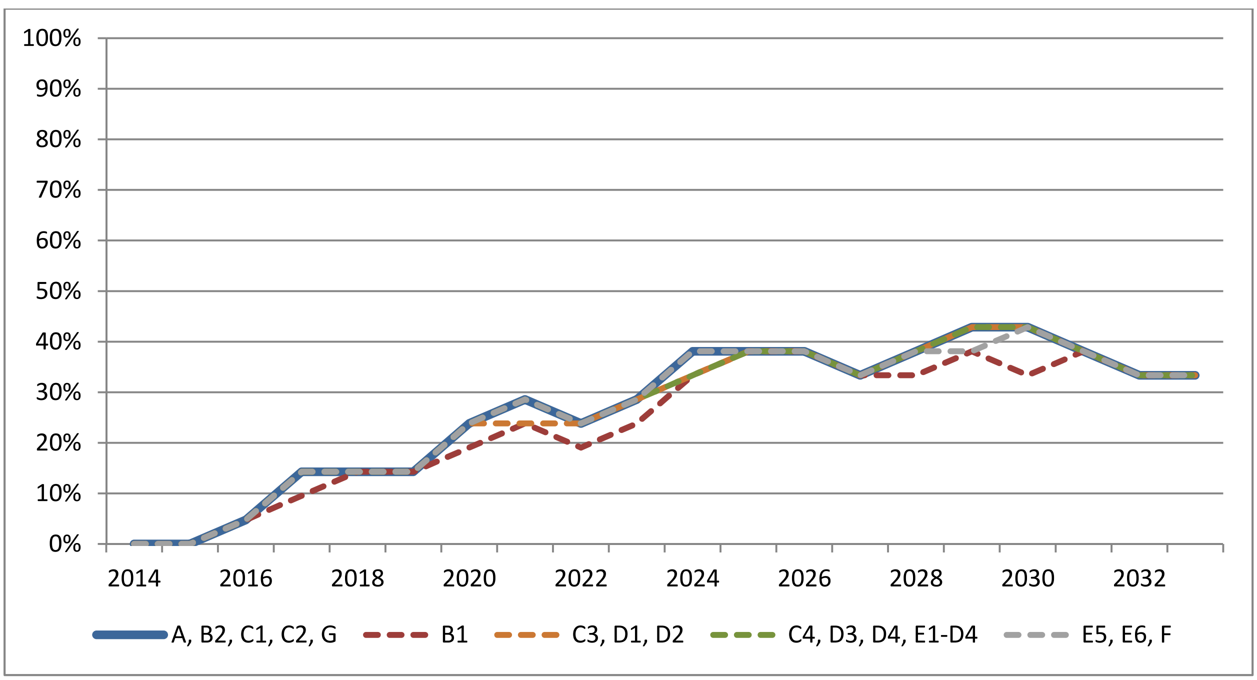

FIGURE J-13 Percentage of Traces Lake Mead Elevation Equal to or below 1,050 ft AMSL for the Fall and Spring Seasons

TABLE J-3 Summary of Recreation, Visitor Use, and Experience Metrics

Alternative/ Long-Term Strategy	CAI	NRI	FI	TORI	GCRM	GCIM	Lake Powell[a]	Lake Mead[a]
A	0.14	0.50	0.79	0.18	49	0.95	0%	0%
B1	0.15	0.39	0.42	0.18	71	0.94	2.5%	-10.6%
B2	0.12	0.26	0.26	0.18	72	0.92	4.4%	-3.5%
C1	0.38	0.75	0.93	0.18	315	0.95	0.37%	-0.31%
C2	0.37	0.73	0.93	0.18	307	0.95	0.37%	-0.31%
C3	0.04	0.76	0.92	0.18	0	0.96	5.5%	-4.4%
C4	0.33	0.76	0.93	0.18	83	0.95	5.5%	-4.1%
D1	0.36	0.45	0.74	0.16	347	0.94	4.7%	-3.5%
D2	0.36	0.60	0.78	0.16	351	0.94	5.5%	-4.1%
D3	0.36	0.45	0.72	0.16	347	0.94	5.1%	-2.5%
D4	0.36	0.45	0.74	0.16	347	0.94	5.1%	-2.5%
E1	0.30	0.37	0.57	0.16	177	0.95	5.1%	-1.3%
E2	0.29	0.30	0.53	0.16	174	0.95	5.1%	-2.5%
E3	0.03	0.32	0.52	0.16	0	0.96	5.1%	-1.3%
E4	0.27	0.29	0.53	0.16	79	0.95	5.1%	-1.3%
E5	0.03	0.33	0.52	0.17	0	0.96	4.7%	-2.5%
E6	0.03	0.32	0.52	0.16	0	0.96	4.7%	-2.5%
F	0.41	0.71	1.00	0.25	919	0.86	4.7%	-2.5%
G	0.45	0.96	0.98	0.16	512	0.94	4.7%	-1.9%

[a] Percentage difference from Alternative A in frequency of access issues; Alternative A has predicted access issues in 21.75% of future seasons for Lake Powell and 25.48% of future seasons for Lake Mead based on historical hydrology.

J.4 SUMMARY

Values for the means of the six metrics and frequency of Lake Powell and Lake Mead access issues discussed above are summarized in Table J-3. An index of 0 to 1 is used for CAI, NRI, FI, TORI, and GCIM, while GCRM is the estimated number of actual visitor trips lost due to HFEs. Access issues for Lake Powell and Lake Mead are the percent differences from Alternative A in the expected frequency of traces in which lake elevation falls below access thresholds in at least one month in either the spring–fall or summer seasons. The values shown in the table are mean values for 63 modeled hydrology–sediment conditions. Quartile values and minimum and maximum values for the six metrics can be seen in the respective box-and-whisker plots (Figures J-1 to J-9).

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