**Science Plan in Support of the Preferred Alternative of the Long-Term Experiment and Management Plan Environmental Impact Statement**

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**Introduction**

The purpose of this document is to describe a strategy by which monitoring and research data in the natural and social sciences will be collected, analyzed, and provided to the Department of the Interior (DOI), its bureaus, and to the Glen Canyon Dam Adaptive Management Program (GCDAMP) between 2016 and 2036. This is the performance period of the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS). The preferred alternative of the LTEMP EIS describes various data collection, analysis, modeling, and interpretation efforts to be conducted by the U.S. Geological Survey’s Grand Canyon Monitoring and Research Center (GCMRC), partner agencies, and cooperators that will inform decisions about operations of Glen Canyon Dam and management of downstream resources. Data collection, analysis, modeling, and interpretation activities are described in this Science Plan, and the specific activities will be described in GCMRC’s Triennial Work Plans that will be developed during the LTEMP performance period and will be reviewed and recommended by the GCDAMP and approved by the Secretary of the Interior.

The GCDAMP consists of several components, the primary committee being the ***Adaptive Management Work Group*** (AMWG). This federal advisory committee is composed of 25 agencies and stakeholder groups and is chaired by the ***Secretary of the Interior’s Designee***. The AMWG makes recommendations to the Secretary of the Interior concerning operations of Glen Canyon Dam and other management actions that are intended to fulfill some obligations of the Grand Canyon Protection Act. The ***Technical Work Group*** (TWG) is a subcommittee of the AMWG and provides technical advice to the AMWG. It is composed of technical and science representatives from the same agencies and stakeholder groups who serve on the AMWG. The ***GCMRC*** is the primary science support agency to the GCDAMP and the ***Science Advisors Program*** provides independent science reviews and advice at the request of the GCDAMP.

The plan proposed here necessarily depends on: 1) the protocol for decision-making and the requirements for scientific data reporting described in the LTEMP EIS; 2) the priorities or requirements from the DOI agencies for resource management and information established through DOI National Environmental Policy Act (NEPA) processes, 3) the priorities for resource management and information needs established by various federal and state resource management agencies and the GCDAMP; 4) scientific understanding about the linkage between the status of those resources and operations of Glen Canyon Dam; and, 5) the need to resolve existing scientific uncertainties about the linkage between dam operations and the condition of resources. We note that resource management prioritization is fundamentally a public policy decision and is not the responsibility of the GCMRC. It is, however, the responsibility of the GCMRC to describe the nature of scientific understanding, the nature of scientific uncertainty, and the risk of making resource management decisions in the face of existing scientific uncertainty. The goals of science activities in the next 20 years are to inform operational decisions regarding Glen Canyon Dam operations described in the LTEMP EIS and the final Record of Decision (ROD), resolve remaining scientific uncertainties, and to monitor resource trends that are affected entirely, or in part, by dam operations.

**The Study Area**

The primary research and monitoring activities of the GCMRC are conducted in the Colorado River ecosystem between Glen Canyon Dam and the upstream end of Lake Mead reservoir. The 25 river kilometers (RKM) or 16 river miles (RM) [[1]](#footnote-1) between the dam and Lees Ferry, AZ, are in Glen Canyon and are managed by the National Park Service (NPS) as Glen Canyon National Recreation Area (GCNRA). There are 446 RKM (277 RM) between Lees Ferry and Pearce Ferry on Lake Mead. The upstream 100 km (62 miles) of this segment is physiographically defined as Marble Canyon; the downstream parts are in Grand Canyon. Grand Canyon National Park (GCNP) manages these segments with the exception of western-most portion of Grand Canyon where the Colorado River was until recently impounded in Lake Mead. This segment is managed by Lake Mead National Recreation Area (LMNRA). The Colorado River ecosystem for the segments identified above also include Tribal lands. Boundaries of these lands are described in the LTEMP EIS (DOI 2016) as follows:

“The western boundary of the Navajo Indian Reservation lies near the Colorado River from Lake Powell through Glen and Marble Canyons. However, various orders and statutes reserved and withdrew land within one-quarter mile of the Colorado River to the United States for power purposes. The Kaibab Paiute Indian Reservation is on the plateau north of GCNP. The Havasupai Indian Reservation surrounds upper Havasu Creek, immediately south of GCNP. The Hualapai Indian Reservation comprises the southern portion of western Grand Canyon, adjacent to GCNP.”

The lateral extent of the study area extends from the river upslope to include all areas inundated by historic operations of Glen Canyon Dam, higher alluvial terraces that were formed and inundated by the Colorado River in the late 19th and 20th centuries, and nearby hillslopes whose stability or characteristics are affected by changes in the adjacent alluvial deposits. Examples of hillslope environments affected by changes in alluvial deposits are those aeolian deposits that are primarily composed of fine sediment transported by wind from river sand bars. The study area also includes several tributaries many of which are important to native and nonnative fish populations.

Although the focus of GCMRC activities is explicitly on this study area, scientific insights that potentially inform management decisions come from a wider range of localities. The natural stream-flow regime of the Colorado River in the study area has been changed such that flood flows are smaller, base flows are larger, and daily fluctuations occur as a result of operations to generate hydro-electric power. Typically, releases from Lake Powell reservoir have stable thermal regimes, with warmer winter temperatures, colder summer temperatures, and an overall narrow annual range of temperatures. Trapping of the incoming sediment load produced in the Upper Colorado River basin is inevitable in a reservoir as large as Lake Powell. Thus, downstream sediment transport is much less than in pre-dam times. The combination of changes in stream-flow regime and sediment trapping leads to perturbation of the river’s sediment mass balance equilibrium and shifts the river towards geomorphic processes that tend to evacuate fine sediment. Ecological processes have also been affected by these geomorphic changes. Decreased sediment loads and resulting increased water clarity have shifted the aquatic food base from one based primarily on terrestrial (i.e., allochthonous) inputs to one that largely derives energy from aquatic primary producers (i.e., autochthonous) like algae and diatoms. Clear water with colder average temperatures and narrower annual temperature ranges has favored introduced cold-water fishes like Rainbow Trout (*Oncorhynchus mykiss)* over warm-water native species like Humpback Chub (*Gila cypha)*. Reductions in the magnitude of flood flows has lowered the stage level, thus reducing shoreline area regularly inundated by the river. This has resulted in less area available to riparian adapted species and allowed encroachment of native and nonnative upland vegetation into riparian areas.

**Goals of the Glen Canyon Dam Adaptive Management Program**

The Colorado River ecosystem is a complex suite of physical, chemical, and biological attributes and processes. Some ecosystem attributes are valued by humans, and we typically refer to these attributes as “resources.” Although some resources are solely valued because they are part of the natural environment, other resources are of archaeological, cultural, or recreational value, and some are important for their use by modern society, such as hydroelectricity. Some attributes of the natural environment, such as wildlife and fish populations, are intrinsically valued in their own right. Other attributes, such as bare sand bars, are intrinsically valued by some people and are important to others for their linkage to resources such as campsites, their role in preserving archaeological sites, or as habitat for native species. Ecosystem resources are maintained by ecosystem processes, such as sediment transport, evapotranspiration, and interspecific competition, but their status and value is also subject to human activities and perceptions.

The target resources of the GCDAMP have changed with time. In 1988, the Glen Canyon Environmental Studies (GCES) identified seven “critical resources” that primarily concern biology and recreation – Humpback Chub, common native fish, Rainbow Trout, camping beaches, riparian vegetation and wildlife, white-water boating, and trout fishing (U. S. Department of the Interior, 1988, p. 17). The underlying physical and biological attributes and processes that create and maintain these critical resources were recognized, and GCES research focused on sediment transport, hydrology, terrestrial biology, aquatic biology, and dam operations. The GCMRC’s 1997 Strategic Plan defined nine resources: water, sediment transport, fishes, vegetation, wildlife and habitat, endangered and other special status species, cultural resources, recreation, and hydropower. Schmidt et al. (1998) distinguished these resources as either relicts of the pre-dam river ecosystem or artifacts of the post-dam river ecosystem.

Many academics and agency professionals have commented that river restoration programs should be guided by clearly articulated goals (Palmer et al., 2005). These goals have been articulated most recently within the LTEMP EIS in section 1.4 and in the LTEMP Record of Decision. There is also a larger set of goals that were expressed by the GCDAMP as Desired Future Conditions (DFCs) that were adopted by the AMWG in 2012. These DFCs are described in four categories – ecosystem, power, cultural resources, and recreation. In many cases, the LTEMP goals and objectives and the DFCs describe mutually exclusive conditions. Given that the LTEMP goals and objectives and DFC describe mutually exclusive conditions, we have used the LTEMP goals and objectives and the DFCs to provide guidance about the concerns of different GCDAMP stakeholders and the topic areas that ought to be the focus of scientific monitoring and research activities.

**Management Program for Glen Canyon Dam Operations Defined by the Preferred Alternative of the LTEMP EIS and in the LTEMP Record of Decision**

Implementation of the LTEMP EIS and management of Glen Canyon Dam operations will require close cooperation and coordination among decision makers, resource managers, stakeholders, and scientists. Information regarding the status and responses of resources of interest must be provided at a range of time intervals (i.e., monthly, biannually, yearly, decadal) to inform the decision-making process that also operates on many different time scales. These decisions concern implementation or suspension of experiments, management actions involving other aspects of dam operations, or management actions that do not involve dam operations. Key resources specifically identified in the Preferred Alternative include 1) water quality and water delivery; 2) Humpback Chub; 3) sediment; 4) riparian ecosystems; 5) historic properties and traditional cultural properties; 6) Tribal concerns; 7) hydropower production and the Basin Fund; 8) the Rainbow Trout fishery, and 9) recreation. The broad scope of these resources necessitates information input from a variety of sources such that managers are fully informed prior to making decisions concerning High Flow Experiments (HFEs), actions to manage trout populations, or other activities identified in the Preferred Alternative and the final ROD. GCMRC and its cooperators are the primary providers of information on physical resources like water quality and sediment and biological resources like native and nonnative fishes, the aquatic food base, and riparian ecosystems. GCMRC is also positioned to provide information on cultural and socioeconomic aspects of some resources including historic and traditional cultural properties, hydropower, and recreation. Additional information on these and other resources will need to be provided by other entities including Tribes, agencies, and stakeholders.

***Operations strategies***

Most of the reservoir operations strategies (referred to as “condition-dependent and experimental elements”) proposed in the Preferred Alternative of the LTEMP EIS are focused on management of sediment-dependent resources. These include: 1) HFEs in the fall whose duration is 96 hours or less; 2) extended-duration HFEs in the fall that might last up to 250 hours; 3) HFEs in the spring whose duration is 96 hours or less; and 4) HFEs of up to 24 hours in the spring that would occur in water years when more than 10 million acre feet (MAF) of water was being released from Lake Powell. In aggregate, implementation of these strategies are intended to increase the size and abundance of eddy sandbars throughout the study area, especially in upper and lower Marble Canyon. In all cases, the maximum magnitude of HFEs is to be 45,000 ft3/s (1,274 m3/s).

Three other operations strategies are proposed in the Preferred Alternative that target aspects of the aquatic ecosystem. These strategies include: 1) low summer flows; 2) sustained low flows for benthic invertebrate production; and, 3) trout management flows (TMFs). Aquatic-ecosystem-focused operations strategies are designed to benefit Humpback Chub either directly or indirectly. Low summer flows, which may only occur in the second 10 years of the LTEMP period, are intended to warm river temperatures such that growth rates of young Humpback Chub increase, which in turn is hypothesized to improve survival rates and help increase recruitment into the adult population. Low flows to benefit benthic invertebrate production are proposed to occur on summer weekends to mitigate a hypothesized recruitment limitation of some aquatic insects. Mortality of insect eggs laid along the river shoreline may be unnaturally high because of fluctuating flows associated with hydroelectric operations result in a relatively large varial zone. Proposed flows could benefit Humpback Chub directly and indirectly. Direct benefits would occur if aquatic food base productivity and diversity increase due to reductions in flow fluctuations on weekends, thereby providing more and higher quality food resources for Humpback Chub. Indirect benefits would occur if Rainbow Trout resident in Glen Canyon benefit from these same operational changes and thus become less likely to emigrate downstream into Marble Canyon. Trout management flows are also intended to reduce downstream movement of trout by reducing the density of Rainbow Trout in Glen Canyon by creating a flow regime that strands young-of-year (YOY) fish.

We also note that these operations may have negative consequences. Low summer flows and flows to benefit benthic invertebrate production could create conditions that benefit warm-water nonnative fishes or trout, which in turn, could harm Humpback Chub. Direct harm to Humpback Chub, Razorback Sucker (*Xyrauchen texanus*), and other native fishes could also occur due to stranding caused by TMFs. Finally, these operations may affect the study area’s fine sediment mass balance or the distribution of fine sediment deposits.

**Monitoring and Research Activities in Support of the Preferred Alternative of the LTEMP EIS**

A number of monitoring and research activities are required for the implementation of the LTEMP EIS and its successful execution during the next 20 years. Decisions about initiating, continuing, or ending specific management actions or operations identified in the Preferred Alternative are dependent upon the status and responses of key resources. Here we provide an overview of activities that GCMRC proposes to be conducted in order to provide the necessary information to decision makers regarding decisions to initiate a management action (hereafter referred to as “triggers”), decisions to abandon a particular course of action (hereafter referred to as “off ramps”), and evaluations of the effectiveness of experiments and actions conducted during the period of performance of the LTEMP EIS.

***Monitoring activities specific to implementation of seasonal and annual operating decisions for reservoir releases***

Implementation of each experimental element of the Preferred Alternative is to be triggered by specific ecosystem conditions, and the decision not to implement any of these elements is to be based on assessment of other ecosystem resource conditions. Specifically, fall HFEs, extended-duration HFEs, and spring HFEs are all to be triggered by “sufficient Paria River sediment input.” Proactive spring HFEs are to be triggered by planned equalization reservoir releases greater than 10 MAF. Greatly reduced fluctuations for a few weeks immediately after a fall HFE are proposed to occur whenever fall HFEs occur, but this management action does not have a different trigger than does the trigger for fall HFEs.

In all cases, these experimental actions can be abandoned if specific resource conditions so dictate. The off-ramps for normal duration HFEs are that these controlled floods “are not effective in building sandbars” or “have unacceptable adverse impacts on the trout fishery, Humpback Chub population, or other river resources.” Thus, timely data collection, analyses, and reporting of fine sediment inputs and of the status of key ecosystem resources (e.g., Humpback Chub, nonnative fishes) are fundamental parts of implementation of these experimental elements of the Preferred Alternative.

Spring or fall HFEs are to be triggered by sufficient inputs of sand from the Paria River. The implementation program for these “sediment triggered” HFEs is described in Appendix P of the LTEMP EIS (DOI, 2016) and is unchanged from the HFE Protocol EA (DOI, 2012) which established the experimental protocols to manage limited sediment resources in Marble and Grand Canyons with repeated HFEs (up to two per year) as conditions warranted. The measurement strategy to define these triggers involves the continuous measurement of river stage of the Paria River in order to estimate the hydrograph of each flood event, automated and field collection of suspended sediment samples of the flooding Paria River, laboratory analyses of those samples to determine the concentration and grain sizes of suspended sediment, and application of a model that predicts total sediment transport of clay, silt, and sand during each flood. These data are used to estimate the total amount of sand delivered to the Colorado River during each “sediment accounting season,” and these data are compared with similar data collected by acoustic sensors, automated samplers, field samples, laboratory analyses, and sensor data calibration for Colorado River gaging stations. The mass balance of sand in different parts of Marble and Grand Canyons are determined and reported to the Bureau of Reclamation who subsequently estimates sand transport during controlled floods of different potential duration and magnitude using numerical models. Implementation of the protocol is described by Grams et al. (2015), and all data used in this protocol is accessible to the public at GCMRC’s website (www.gcmrc.gov).

All activities needed to implement spring and fall HFEs in terms of estimates of fine sediment inputs, transport, and mass balance are included in GCMRC’s Fiscal Years (FY) 2015–17 Triennial Work Plan. Under the operating procedures of the GCDAMP, a new Triennial Work Plan will be proposed for FY 2018–20; and subsequent Triennial Work Plans will be developed for following 3-year periods. GCMRC intends to continue implementing its program of measuring fine sediment delivery from major and minor tributaries, transport by the Colorado River, delivery of that fine sediment to Lake Mead, and computation of the fine sediment mass balance of various segments of the Colorado River in the study area in future Triennial Work Plans such that information needs identified in the LTEMP EIS Preferred Alternative are met. The fine-sediment monitoring program described above is adequate to support decision-making about implementation of all proposed HFEs (fall, long-duration fall, spring, proactive spring), because the needed data are no different than for implementation of the existing HFE Protocol. It is recognized that new technologies for the measurement and estimation of fine sediment inflows to the Colorado River will be developed during the 20-year duration of the LTEMP, and GCMRC expects to incorporate new technological and analytical advances into its future monitoring program.

Monitoring of sandbars constitutes a significant part of the FY 2015–17 Triennial Work Plan. This work includes annual topographic monitoring of some sandbars, daily photography of other sandbars, and experimental evaluation of alternative technologies for measuring sandbar topography. Another aspect of this work is the development of an integrated monitoring protocol that makes explicit the uncertainty associated with generalizations about the average characteristics of sandbars in different parts of the study area.

GCMRC will continue to propose these types of monitoring activities in future Triennial Work Plans, although the mix of various spatial and temporal scales of effort is expected to change. The focus of GCMRC is on development of spatially robust characterizations of average sandbar area and volume in different parts of the study area and to distinguish how these characteristics differ between those parts where there are few campsites and where there are many campsites. GCMRC will also propose strategies for serving all these data in an on-going way to stakeholders in its website.

***Monitoring and research activities specific to assessment of the effectiveness of specific management actions relative to geomorphology***

Applied science monitoring activities are partly focused on informing decisions about those dam operations intended to maintain and/or increase the size of sand bars throughout Marble and Grand Canyons. These bars typically occur in eddies downstream from rapids and are used as campsites by river runners. The frequency of eddy sandbars is larger where the Colorado River is relatively wide, such as in lower Marble Canyon, and is less where the Colorado River is relatively narrow, such as in Upper Granite Gorge. Thus, monitoring of sandbar characteristics must distinguish the characteristics among the different river segments of Marble and Grand Canyon, because the average sandbar characteristics for the entire study area typically differ from the characteristics of sand bars in shorter segments.

Another aspect of implementation of the various experimental elements is the regular assessment of the effectiveness of these actions. The commitment to provide these data is mandated in the Preferred Alternative in the following statements:

“For these experiments, effectiveness would be monitored and the experiments would be terminated or modified only if sufficient evidence suggested the treatment was ineffective or had unacceptable adverse impacts”; and,

“All experimental treatments would be closely monitored for adverse side effects.”

Some experiments must be monitored and their effects compared with the effects of other actions. For example, the off-ramp for long-duration fall HFEs is to be based on determining if the sandbars built by a long-duration HFE “were no bigger than those created by shorter-duration HFEs.” The off-ramp for proactive spring HFEs is that these controlled floods “were not effective in building sandbars;” criteria or standards will need to be developed by GCMRC in collaboration with the GCDAMP regarding how effectiveness in this context is to be determined. The Preferred Alternative also provides an off-ramp from TMFs if there are “unacceptable adverse impacts on … other resources.” The magnitude and timing of daily fluctuations during TMFs is such that there is a potential for accelerated sandbar erosion caused by these flows. Thus, the effects of TMFs on sandbar erosion must be monitored.

These assessments provide a challenge to GCMRC science, because measurements and predictions of the effectiveness of reservoir operations potentially require measurements of a number of river processes. Examples include temporal changes in suspended sediment concentration during floods, longitudinal changes in suspended sediment concentration in different parts of the study area, lateral changes in concentration in eddy deposition zones, comparison of the topography of sandbars on different days of a controlled flood to determine day-to-day changes in the deposition rate of fine sediment in eddies, and comparison of the topography of sand bars in different parts of the study area. These kinds of studies were conducted during the 1996 Controlled Flood (Webb et al., 1999) and during some other controlled floods (Melis, 2011), but have not been conducted since the HFE Protocol was implemented in 2012 due to the considerable effort and expense required. GCMRC believes it important to conduct studies that synoptically consider changes in sediment transport, eddy sandbar deposition, or eddy sandbar erosion to determine the effectiveness of long-term and proactive HFEs. Given the expense of these studies and uncertainty as to when these types of HFEs may be triggered, GCMRC suggests establishing a contingency fund as part of future Triennial Work Plans. Such a fund would support synoptic measurement programs during and after any extended duration fall HFE or proactive spring HFE to evaluate whether or not significant sandbar deposition occurred relative to the results of recent 96-hour HFEs conducted under the HFE Protocol. GCMRC commits to proposing a formal program for monitoring and analysis of the specific experiments of the LTEMP in the next Triennial Work Plan. Approaches may include expansion of its structure-from-motion topographic measurement program as a strategy to quickly collect field topographic data that will be useful in the analysis for rates of post-flood erosion needed to evaluate the effectiveness of reduced daily fluctuations immediately after fall HFEs.

Assessment of long-term trends in sandbar size and other geomorphic attributes of the Colorado River, like alluvial terraces in Glen Canyon, is also needed. The Preferred Alternative establishes a decision point 10 years after implementation of the LTEMP EIS to continue operations or trigger alternative actions that is dependent on this information. Decadal-scale trends in sandbar size will be evaluated by analysis of the annual sandbar monitoring data (described previously). Additional information could be provided by analysis of images collected by periodic (every 4 to 10 years) remote sensing missions that may be proposed in future Work Plans. Collection and analysis of annual sandbar monitoring data and analysis of existing remote sensing data are included in the FY 2015–17 Triennial Work Plan. The need, as well as the timing and scope of potential future remote sensing missions, will need to be addressed in the planning and development of future Work Plans.

Estimates of long-term changes in sand mass balance may also be useful in determining the effectiveness of reservoir operations. Decadal-scale changes in sand mass balance can be determined by analysis of the mass-balance sand budgets computed from continuous measurements of sand flux of long segments of the Colorado River. Alternatively, analysis of repeat maps of the river bed in long river segments or a combination of these methods may also provide a means of detecting long-term changes in sand mass balance. Once fully developed, repeat mapping will likely be more accurate than estimates from continuous measurements of sand flux. This approach should reveal the magnitude of changes in sand storage as well as where those changes occur with levels of uncertainty that are appropriate for long-term monitoring. Uncertainty in the mass balance computed from measurements of sand flux used for HFE planning accumulates such that changes in storage over years to decades may be indeterminate. Baseline data consisting of bathymetric and topographic maps of the river bed have been collected for all river segments between Glen Canyon Dam and RKM 140 (RM 87). By the end of FY 2017, baseline data will be collected for the segment between RKM 267 and 362 (RM 166 and 225). Collection of data for the segment between RKM 140 (RM 87) and RKM 267 (RM 166) will be proposed in the FY 2018–20 Triennial Work Plan. If this method proves successful, analysis of repeat maps based on data collected between 2015 and 2020 could be used to evaluate sand mass balance in support of the decision 10 years after implementation to continue or alter operations.

***Monitoring and research activities specific to assessment of the effects of specific management actions relative to fish, aquatic, and riparian resources***

The implementation and continuation of all of the proposed experiments and actions identified in the Preferred Alternative are contingent on the responses of one or more biological resources. These responses are identified as conditions in triggers, decision points, and off-ramps (see LTEMP EIS Table 2–9 and Figure 2–21) and primarily focus on Humpback Chub and Rainbow Trout. These responses include specific conditions such as “No increase in growth and recruitment of Humpback Chub” and “Little or no reduction in” trout density near the Little Colorado River. Another condition concerns trout recruitment affected by some treatments as well as the more generic conditions such as “unacceptable adverse impacts on the trout fishery, Humpback Chub population, or other resources” that are listed in all but one treatment. Other resources that could trigger or suspend actions if responses or changes were observed, include appearance of or increases in warm-water nonnative fishes or undesired changes in the characteristics of the aquatic food base or riparian vegetation community. Conditions for these resources include increases in warm-water nonnative fishes near the Little Colorado River, “no observed benefit to food base,” and riparian vegetation “control and restoration techniques not effective or practical.”

Monitoring of native and nonnative fishes will need to be able to provide information on a number of parameters including distribution, abundance, and vital rates like growth, survival, and recruitment. Multiple life-history stages of Humpback Chub will need to be monitored in support of the LTEMP EIS. The abundance of sub-adult and adult Humpback Chub in the reach of the Colorado River that includes the confluence of the Little Colorado River (RKM 91-106; RM 57-66) and the Little Colorado River downstream from Blue Spring will need to be estimated on an annual basis. Specific trigger levels for sub-adult and adult abundance will be identified by the U.S. Fish and Wildlife Service in its Biological Opinion for the LTEMP EIS. Growth rates of Young of Year (YOY) Humpback Chub as well as recruitment rates will also need to be monitored. Although growth rates are not specified as an information need in the Preferred Alternative until the second decade of the LTEMP EIS, it is important to have baseline data from the first decade such that long-term trends can be determined. These data could also be used to improve understanding of the relation between growth rates of YOY Humpback Chub and subsequent recruitment into the sub-adult or adult life stages.

Monitoring of Rainbow Trout will need to occur at several locations and include multiple life-history stages. The recent increase in Brown Trout (*Salmo trutta*) abundance in Glen Canyon indicates similar monitoring of this piscivirous species will also need to occur. Given the need to understand the effects of HFEs, TMFs, and other experimental flows on Rainbow Trout and Brown Trout population dynamics, the monitoring approach must be sufficiently robust to detect changes in distribution, reproduction, survival, recruitment, and growth. The primary Colorado River reaches of interest are in Glen Canyon (RKM -25-0; RM -16.0-0) and just downstream from the Little Colorado River confluence (RKM 102-105; RM 63.5-65.2). Glen Canyon is the segment including most of the spawning habitat for Rainbow Trout and has the highest densities of this species downstream from Glen Canyon Dam; Glen Canyon is also the location of the recreational sport fishery and where Brown Trout spawning and rearing has recently been observed. Monitoring of Rainbow Trout and Brown Trout in this segment will need to include reproduction rates, YOY abundance, survival, growth, and distribution, as well as abundance, growth, and condition of yearling to adult fish. The status of the sport fishery will also be monitored. The reach downstream of the Little Colorado River has the highest densities of young Humpback Chub in the main stem and is the reach with the highest risk for predation and competition between these species. Given this, the abundance, size-class distribution, and residence time of Rainbow Trout and Brown Trout in this reach will be monitored. Marble Canyon is also of interest given its role as a migration corridor between Glen Canyon and the Little Colorado River (RKM 0-98; RM 0-61) as well as an additional spawning area for Rainbow Trout. Monitoring of Rainbow Trout in Marble Canyon will include abundance, distribution, movement rates, and size-class distribution.

In the event mechanical removal of trout is triggered, monitoring will occur to determine if this management action is effective in reducing trout densities and maintaining these densities at low levels. Mechanical removal of trout, and any associated monitoring, will occur in reaches immediately upstream and downstream from the Little Colorado River confluence (potentially from RKM 80-106; RM 50–66). In recognition of Tribal concerns regarding the taking of life in the Canyon, beneficial uses would be found to the extent practicable for fish harvested during any mechanical removal effort. Approaches similar to those employed by GCNP for trout removal in and near Bright Angel Creek will be used.

Nonnative fishes, particularly warm-water species, pose a direct and real threat to Humpback Chub and other Colorado River native fishes. Monitoring will occur to detect the appearance of previously absent species (e.g., Smallmouth Bass, *Micropterus dolomieu*) or the expansion in abundance or distribution of extant nonnative fishes (e.g., Green Sunfish, *Lepomis cyanellus*). Monitoring will occur in the entire Colorado River from Glen Canyon Dam to Lake Mead. Glen Canyon and the reach just upstream from Lake Mead will be monitored closely due to their proximity to known sources of warm-water nonnative fishes. In addition, the lower Little Colorado River and the Colorado River near the Little Colorado River confluence will be monitored carefully since the upper reaches of the Little Colorado River are known sources of warm-water nonnative fishes, and these areas have the highest densities of all life stages of Humpback Chub in Grand Canyon.

Monitoring of fisheries resources as described in GCMRC’s Triennial Work Plan for FY 2015–17 will provide most, but not all, of the information related to Humpback Chub, Rainbow Trout, Brown Trout, and warm-water nonnative fishes required for implementation of the LTEMP EIS. Meeting all of the information needs necessary to implement the Preferred Alternative will require revisions in the timing and frequency of some sampling efforts as well as the addition of monitoring not described in the Triennial Work Plan. For example, data from the Rainbow Trout Early Life Stage Study (RTELSS) will be essential for evaluating the effectiveness of TMFs. The current study design for RTELSS as described in the FY 2015–17 Triennial Work Plan may, however, be inadequate and need revision in order to provide the necessary data to determine if TMFs can be an effective means of controlling trout recruitment. The planned end of the Juvenile Chub Monitoring and Natal Origins of Rainbow Trout studies in FY 2017 leave large gaps in the sources of key pieces of information on Humpback Chub and Rainbow Trout population dynamics, distribution, movement, growth and other information required by the Preferred Alternative beginning in FY 2017. These and other topics were included in the review of the GCDAMP fisheries program conducted in August 2016 by a panel of experts external to the program. Recommendations from this Protocol Evaluation Panel (PEP) are expected in early FY 2017 and will inform GCMRC and cooperating agencies regarding best practices and methods as well as appropriate levels of effort required for future monitoring of Humpback Chub, Rainbow Trout, Brown Trout, and other native and nonnative fishes of interest in Glen and Grand Canyons. In future work plans, GCMRC intends to continue the implementation of its program to monitor the population dynamics, distribution, movements, growth and other information regarding key species like Humpback Chub and Rainbow Trout. We will also add monitoring of emerging species of interest like Brown Trout and Green Sunfish in the various segments of the Colorado River and important tributaries in the study area such that information needs in the LTEMP EIS Preferred Alternative are met.

The aquatic food base will need to be monitored to determine if experimental treatments lead to increased productivity of the existing prey base of midges and blackflies and/or increases in the diversity of the prey base such as colonization of the mainstem by orders Empheroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies), collectively identified as EPT. Monitoring of key life-stages of aquatic insects, particularly larvae and adults, will be needed as will sampling over a broad geographic range. Focused studies of egg-laying locations of aquatic insects and egg-mortality will be conducted at selected sites. Data on the species composition and distribution of adult insects and timing of emergence is needed for the entire river corridor between Glen Canyon Dam and Lake Mead and will be collected as part of an ongoing project. These efforts are described in GCMRC’s Triennial Work Plan for FY 2015–17 and will provide the information required for implementation of the LTEMP EIS. Since implementation of experimental low flows to benefit benthic invertebrates will not occur during the first two years when TMFs are evaluated, these specific monitoring activities will be described in the FY 2018–20 Triennial Work Plan and in subsequent Work Plans. Continued monitoring of invertebrate drift in Lees Ferry and Marble Canyon may also be included in future Work Plans if there is interest in improving the understanding of how experimental operations affect drivers of Rainbow Trout growth, survival, and movement. This information could also be used to help determine how these effects cascade upwards through trophic interactions to affect wildlife (e.g., bird, bat, reptile) populations. Likewise, continuation of low-cost approaches for monitoring algae production involving development of dissolved oxygen budgets that are currently being conducted in collaboration with GCMRC’s water quality monitoring program may also be proposed because these data inform trends in invertebrate and fish populations.

No flow-related treatments designed to restore riparian vegetation are proposed as part of the LTEMP EIS. Instead, restoration activities like exotic plant removal, establishing sources of native plants, native species plantings, controlling vegetation encroachment at campsites, and helping protect cultural sites through vegetation management are proposed to be implemented and evaluated. NPS will lead these efforts in cooperation with Tribes and GCMRC. Given that these activities would occur at specific locations that have not yet been identified, specifics about monitoring these actions including the scope, intensity, and duration will necessarily need to be determined once proposals for specific actions are developed.

***Monitoring and research activities specific to assessment of the effects of specific management actions relative to other resources***

In addition to the resources discussed at length above, other resources of interest specifically identified in the Preferred Alternative include historic and traditional cultural properties, Tribal concerns, hydropower production and the Basin Fund, and recreation. As noted previously, GCMRC is positioned to help provide information on cultural and socioeconomic aspects on the effects of experimental elements identified in the LTEMP EIS on some of these resources. These efforts, however, will require cooperation and collaboration with Tribes, agencies, and stakeholders since information on these and other resources beyond the scope of GCMRC science activities will necessarily need to be provided by these other entities.

Project 12 aims to quantify changes in the distribution and abundance of culturally-important plants.

Although no specific experimental treatments for historic or traditional cultural property preservation are identified in the LTEMP EIS, it does include experimental HFEs and other operations designed to build and retain sandbars and non-flow actions intended to manage vegetation in relation to cultural sites. Continued monitoring of the degree to which aeolian transport of HFE-derived sand affects archaeological site condition, as described in the FY 2015–17 Triennial Work Plan, will provide quantitative measurements of one of the effects of flow actions identified in the Preferred Alternative on historic and traditional cultural properties in GCNRA and GCNP. GCMRC proposes to continue measuring changes in site condition due to aeolian transport of HFE-derived sand as well as gullying and slumping in the study area in future work plans. Other projects from the current work plan, such as quantifying changes in the distribution and abundance of culturally-important plants, may be proposed in future work plans pending the outcome of ongoing work.

The implementation and continuation of all proposed experiments and actions identified in the Preferred Alternative are contingent on the responses of one or more socioeconomic metrics. These metrics include specific conditions such as “unacceptable impacts to” resources of Tribal importance, hydropower production and the Basin Fund, or recreational interests in annual implementation decisions as well as the consideration of Tribal concerns regarding actions if successful (see LTEMP EIS Table 2-9, DOI, 2016). Discussions with Tribes will be needed to determine when resource conditions are unacceptable to them. Monitoring and research of socioeconomic impacts, in support of the LTEMP EIS and any coordination and consultation with the Tribes that may occur, will be able to provide general information on a number of parameters. These may include, but are not limited to, Tribal preferences and economic values as well as recreational preferences, regional expenditures and economic values related to resource impacts from sediment and aquatic resource treatments.

Monitoring and research of Tribal perspectives will need to occur for individual Tribes on a periodic basis. Tribes may have specific culturally determined perspectives that change over time as the state of resources downstream from Glen Canyon Dam change and experimental sediment and aquatic resource treatments are implemented adaptively as part of the LTEMP EIS. Any work on Tribal perspectives will need to be conducted in close coordination with each Tribe involved. Monitoring of recreation will need to include angling, whitewater boating and potentially other recreational groups on a periodic basis. Given the need to understand the effects of HFEs, TMFs, and other experimental flows on angling in Glen Canyon National Recreation Area and whitewater floating in Grand Canyon National Park, the monitoring approach must be sufficiently robust to detect changes in preferences, regional expenditures and economic values associated with each recreational activity. The primary Colorado River reaches of interest are in Glen Canyon (RKM -25-0; RM -16.0-0), the location of the recreational sport fishery, and Marble and Grand Canyons (RKM 0-445; RM 0-277), the location of whitewater floating.

Meeting all of the LTEMP EIS information needs regarding socioeconomic resources may require a continuation of recreation and Tribal related monitoring and research described in GCMRC’s FY 2015–17 Triennial Work Plan. Additional monitoring and research of socioeconomic resources may also be needed. For example, as resource conditions and recreational and Tribal preferences change, periodic surveys, building on past work, would be needed to evaluate and address recreational impacts and Tribal concerns related to experimental treatments. The Economic Values of Recreational Resources along the Colorado River – Grand Canyon Whitewater Floater and Glen Canyon Angler Values study in the current Triennial Work Plan will provide information and identify additional information needs related to recreational preferences, regional expenditures and economic values required by the Preferred Alternative beginning in FY 2017. In addition since implementation of Tribal Perspectives for and Values of Resources Downstream of Glen Canyon Dam is only beginning in FY 2017, continued research activities will need to be included in the FY 2018–20 Triennial Work Plan. GCMRC may propose additional projects in future Work Plans to continue to implement its program of monitoring and research of recreational preferences, regional expenditures, and economic values and Tribal perspectives (preferences and economic values) of resources in various segments of the Colorado River and key tributaries in the study area such that information needs in the LTEMP EIS Preferred Alternative are met.

***Assessment and reporting of short- and long-term effects of reservoir operations***

Although HFEs may occur more than once per year, it is not possible for GCMRC to provide any sort of formal reporting on resource condition more frequently than once per year due to the substantial potential reporting expectations in the LTEMP Preferred Alternative. For example, an off-ramp to each experimental action is to be based on either 1) a lack of desired resource response or 2) “unacceptable resource conditions,” and different experimental actions might occur once or twice in any year. The large number of resources of interest and variety of potential actions in any given year precludes GCMRC from evaluating the responses and condition of all resources of interest or from providing a formal reporting for each action on less than an annual basis. To keep managers and stakeholders informed, GCMRC will instead establish a web-based “living document” on its homepage – similar in structure to data presently served concerning stream flow, sediment transport, water quality, and sandbar characteristics – where status of resource data are available for review by the public. These data will, at a minimum, include time series of changes in sandbar area and volume based on annual sandbar surveys and time-lapse photographs of various sandbar monitoring sites that specifically highlight changes in sandbar characteristics associated with particular experiments. These data will be accompanied by an annual interpretative statement of the trends of sandbars that will be updated at the time of each year’s Annual Reporting meeting. Similar data will be provided regarding Humpback Chub populations, Rainbow Trout populations and the associated fishery, the aquatic food base, and other resources of interest.

The Preferred Alternative calls for a comprehensive, decadal-scale assessment of the impact of reservoir operations on sandbar resources and on the status of Humpback Chub with respect to river temperature. These assessments are specifically mandated in Fig. 2-20, the decision tree for operational decisions concerning sediment resources, and Fig. 2-21, the decision tree for operational decisions regarding aquatic resources. The former figure shows that an assessment will be provided that addresses the question: “Does monitoring indicate sandbar area and volume are maintained or increased in the first 10 years with no unacceptable effects on sand mass balance in Marble Canyon?” If this question is answered in the negative, as stated in Figure 2-20, then DOI should, “… perform applicable planning processes for sediment augmentation and/or adjust operations, triggers … to increase sediment conservation.” The latter figure indicates that temperature effects on Humpback Chub will be evaluated after 10 years to determine if additional actions or experiments are necessary. If this question is answered in the negative, as stated in Figure 2-21, then, managers will “Consider conducting low flow experiment, applicable planning processes for TCD [i.e., Temperature Control Device] or adjust operations, triggers (based on learning) to increase recruitment.” In each case, if either question is answered in the positive, then the respective activities described in the LTEMP Preferred Alternative for sediment or aquatic resources are to continue for another decade. Thus, these assessments of changes in the size and abundance of sandbars and of changes in fine sediment mass balance in Marble Canyon and of Humpback Chub status with particular focus on the effect of temperature are critical.

Because of the importance of these assessments, GCMRC will publish each 10-year assessment as a peer-reviewed US Geological Survey report. Although management recommendations will not be made, these scientific reports will explicitly address the issues of 1) decade-scale changes in sandbar area and volume, 2) decade-long changes in sand mass balance, and 3) decade-long changes in Humpback Chub status in relation to temperature. Sandbar and sand mass balance data will be reported in the context of short-term variability, shorter segment-scale attributes of sandbars and sand mass balance, and multi-decade trends in sandbar area and volume. Humpback Chub data will be reported in the context of juvenile and sub-adult growth rates and subsequent effects on recruitment rates into sub-adult and adult life stages. Preliminary analysis of these data will commence as early as 2022, which is 10 years after initiation of the HFE Protocol and Nonnative Fish Control EAs, and the final report will be issued in 2026, approximately 10 years after adoption of the LTEMP Preferred Alternative. During the period between 2022 and 2026, GCMRC will make annual presentations to GCDAMP stakeholders regarding its preliminary findings regarding these issues.

***Predictions of the effects of specific management actions on resources***

The Preferred Alternative makes reference to predictions about the anticipated effects of some experimental actions. Specifically,

“Prior to implementation of any experiment, the relative effects of the experiment on…resource areas will be evaluated and considered”; and,

“…implementation of experimental treatments would continue throughout the LTEMP period…except in years when it was determined that the proposed experiment could result in unacceptable adverse impacts on resource conditions.”

The LTEMP does not provide guidance concerning the specificity of these predictions; however, the focus of these predictions in the context of LTEMP is primarily on anticipating unacceptable outcomes. Nevertheless, it is imperative that GCMRC continue to refine its predictive capacity to anticipate the outcome of future controlled floods and other experimental actions.

For example, GCMRC scientists have utilized a GIS-based stage elevation model to predict the area within the boundaries of archaeological sites that would be inundated by a 45,000 ft3/s (1,274 m3/s) controlled flood. We intend to test and validate these predictions by measuring the actual locations and extent of inundation that occurs in conjunction with future high flows of this magnitude, with a focus on specific archaeological sites that have been identified as being susceptible to direct flow effects. These empirical data will allow for the refinement of the stage elevation model and our capacity to predict potential direct impacts from future flow events.

**The time frame for data collection and reporting required to implement the Preferred Alternative of the LTEMP EIS**

GCMRC will provide data and analysis so that the GCDAMP can advise and the DOI can implement various decisions and actions of the Preferred Action of the LTEMP EIS. Specifically,

1) Prior to any action or experiment, data sufficient for resource “evaluation and consideration” will be provided by data served on the GCMRC website, briefings to the TWG, and briefings to DOI agencies;

2) Monthly, GCMRC will provide data as needed during Bureau of Reclamation dam operations conference calls;

3) During the spring and fall sediment accounting periods, fine sediment input data will be provided on the GCMRC website and these data will be available to all stakeholders;

4) Annually, GCMRC will provide requested data to the Bureau of Reclamation in support of development of the annual hydrograph;

5) Annually, GCMRC will provide data, analysis, and long-term status of key resources reports at its Annual Reporting meeting (this meeting is held as part of the January TWG meeting and is open to the public);

6) After sufficient testing, as soon as two years, GCMRC will provide an evaluation of TMFs (this report will be provided as a USGS peer-reviewed report);

7) After two years, GCMRC will provide data necessary to support other aspects of decisions regarding implementation of spring HFEs and of proactive spring HFEs;

8) After two years, GCMRC will provide data necessary to design experiments and data collection related to weekend sustained low flows;

9) After one decade, GCMRC will evaluate changes in the status of Humpback Chub populations in relation to river temperature (this report will be provided as a USGS peer-reviewed report); and,

10) After one decade, GCMRC will evaluate changes in sand bar area and volume and distinguish the role of dam operations in causing those changes (this report will be provided as a USGS peer-reviewed report).

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1. Locations are provided in River Mile, a location system that has been used since the 1920s and indicates the distance, in miles, downstream from Lees Ferry, or the distance, in negative values, upstream from Lees Ferry. [↑](#footnote-ref-1)