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Glen Canyon Dam Adaptive Management Program Triennial Budget and Work Plan—Fiscal Years 2025-2027

Revised Preliminary Draft

**Prepared in cooperation with the Glen Canyon Dam Adaptive Management Program**

Prepared by

U.S. Geological Survey

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Revised Preliminary Draft: April 2, 2024

**U.S. Department of the Interior**

**U.S. Geological Survey**

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Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

1. Investigators

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1. Project Summary and Purpose

The primary linkage between Glen Canyon Dam operations and the characteristics of the physical, biological, and cultural resources of the Colorado River ecosystem (CRe) downstream from Glen Canyon Dam is through the stage, discharge, water quality, and sediment transport of the Colorado River. This project makes and interprets the basic measurements of these parameters at locations throughout the CRe. Project A thus collects the physical data that directly link dam operations to all resources in the downstream CRe. The data collected by this project are used to implement the High-Flow Experiment (HFE) Protocol (i.e., trigger and design HFE hydrographs), to evaluate the reach-scale sand mass-balance response to the HFE Protocol (U.S. Department of Interior, 2011; Grams and others, 2015), and to evaluate the downstream effects of releases conducted under the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) (U.S. Department of Interior, 2016a, b). Two of the metrics proposed to evaluate LTEMP management for sediment are measured by this project.

The data collected by Project A are also used by many of the other physical, ecological, and socio-cultural projects funded by the Glen Canyon Dam Adaptive Management Program (GCDAMP). In addition to supporting the LTEMP sediment goal, the basic data collected by this project supports the following nine LTEMP goals: aquatic food base, archaeological and cultural resources, humpback chub, hydropower and energy, invasive fish species, natural processes, rainbow trout fishery, recreational experience, and riparian vegetation. Most of the project funds support basic data collection at USGS gaging stations, with the remainder funding data interpretation. Roughly 64% of the proposed budget covers basic data collection, with the remaining 36% supporting salaries for serving the data and for interpretive work (i.e., publications). The funds requested under this proposal cover ~75% of the costs required to collect data at the network of USGS gaging stations used by this project. An additional approximately $200,000 to support this network is provided directly to the USGS Arizona Water Science Center from funds appropriated by Congress for the USGS, the Bureau of Reclamation, and from funds provided by the Arizona Department of Water Resources.

Project A is designed to provide measurements of stage (i.e., water-surface elevation), discharge (i.e., streamflow), water quality, and suspended sediment at sufficiently high temporal resolutions (~15-minute) to resolve changes in these parameters and to allow accurate determination of suspended-sediment loads for use in sediment budgeting (Grams and others, 2019; Topping and others, 2021). The proposed monitoring under this project is similar to that conducted over the last 18 years. Work conducted under the previous work plan, currently provisionally accepted at the Journal of Geophysical Research pending minor revision, indicates that sand storage in the channel and sandbars of the CRe is not likely sustainable unless tributary sand inputs remain well above average and dam releases remain slightly below average. The work proposed in this current work plan is therefore that required to address this important conclusion.

1. Hypotheses and Science Questions

There are two key hypotheses that guide the monitoring and research conducted under Project A. These hypotheses directly address the LTEMP sediment goal and also the nine other LTEMP goals listed in the previous section.

* Glen Canyon Dam can be operated such that the sand resources in the CRe are sustainable.
* Glen Canyon Dam can be operated such that the other CRe resources affected by dam operations can be sustainably managed. In this usage, “dam operations” refers to the amount and quality of the water released from the dam, where “amount” refers to stage and streamflow, and “quality” refers to temperature, salinity, turbidity, and dissolved oxygen.

These hypotheses are paraphrased from the LTEMP EIS and from earlier goals, information needs, and strategic science questions formulated by the GCDAMP. The first of these two guiding hypotheses is tested using the continuous mass-balance sand budgets (Element A.3) constructed using 15-minute streamflow data (Element A.1) and suspended-sand data (Element A.3). Although the second hypothesis guides data collection in Project A, this hypothesis is tested by the other GCDAMP-funded projects.

1. Background

See upcoming full work plan.

1. Proposed Work

The work proposed herein is similar to that conducted under the previous work plan. Although the data-collection aspects of this project are somewhat reduced, new interpretive products are planned to address the guiding hypotheses and to build on the conclusions of the work funded during FY 2021–24.

The Project A data-collection network was developed and made progressively more efficient over the last 24 years. It is the cheapest, most-efficient monitoring network required to address the LTEMP sediment goal and support nine other LTEMP goals. This network relies extensively on 1) new technologies to automatically monitor streamflow, water quality, and sediment; and 2) cost sharing to reduce costs while not sacrificing the data accuracies required by the LTEMP goals.

Research on the Colorado and on other rivers has shown that, to be meaningful, measurements of stage, discharge, water temperature, specific conductance, turbidity, dissolved oxygen, and suspended sediment must be made at temporal intervals shorter than those over which these parameters vary. Owing to the effects of dam operations and tributary floods, substantial changes in all of these parameters occur over timescales less than one hour (Wiele and Smith, 1996; Wiele and Griffin, 1998; Topping and others, 2000b, 2003, 2010; Voichick and Wright, 2007; Voichick, 2008; Wright and others, 2009; Voichick and Topping, 2010, 2014; Grams and others, 2019). Project A was therefore designed to provide measurements of stage, discharge, water quality, and suspended sediment at the required accuracies and sufficiently high temporal resolutions (~15-minutes) to capture the variability in these parameters. Specifically, for suspended sediment, this temporal resolution was chosen to be shorter than the sub-hourly data interval required to know both the sign and magnitude of change in sediment budgets (Grams and others, 2019). Collection of data at 15-minute intervals is the USGS standard. Months to years of data collected at this resolution easily fit on modern dataloggers, result in less processing time in the office, and reduce financial costs to the project. In addition, the efficiencies of such largely automatic data collection require less field time, such that only two river trips are now required annually for this project.

A map showing the locations at which data are collected/utilized by Project A can be viewed at: <https://www.gcmrc.gov/discharge_qw_sediment/stations/GCDAMP>. Note that the GCDAMP does not fund the data collection at all stations on this map. The data collected/utilized by Project A are used to evaluate the near-realtime effects of all LTEMP dam releases on stage, discharge, water quality, sediment transport, and sediment storage in the CRe (U.S. Department of Interior, 2016a, b). The continuous mass-balance sand budgets provide the measurement-based "ground-truthing" of the Sand Mass Balance Index (SMBI) developed in Appendix E of the LTEMP EIS (U.S. Department of Interior, 2016a). Higher values of the SMBI in the LTEMP EIS were taken as indicators of increased sand storage in the CRe, with increases in sand storage indicating an increase in the sand available to be deposited in sandbars during HFEs. In addition, the sand-transport data and mass-balance sand budgets from Project A are used to trigger HFEs, design the hydrograph of HFEs, and evaluate the effects of HFEs on sand storage in the CRe, as described by U.S. Department of Interior (2016a).

All data collected by Project A are served and can be downloaded at our website at: <https://www.gcmrc.gov/discharge_qw_sediment/>. At this website, the user can construct plots in time-series or duration-curve format. In addition, the user can construct interactive plots of the mass-balance sand budgets for the six CRe reaches, with user-defined uncertainty.

Project Elements

The following three project elements fund a large proportion of the salaries of 13 USGS scientists and technicians in the GCMRC, AZ Water Science Center, UT Water Science Center, and KS Water Science Center (database and website during FY 2025 before this work transitions to a GCMRC employee in Project K), and also fund smaller proportions of the salaries of 10 other USGS scientists and technicians.

Project Element A.1. Stream Gaging and Hydrologic Analyses

This element partially funds the collection, serving, and interpretation of continuous 15-minute measurements of stage and discharge on the main-stem Colorado River at USGS streamflow gaging stations located at river miles (RM) 0, 30, 61, 87, 166, and 225, and at gaging stations on the major tributaries and in a representative subset of the smaller tributaries. 65% of the budget for Element A.1 funds salary for the field and office time required to operate gaging stations and funds the office time for serving data and working on peer-reviewed interpretive publications. Finally, ~6% of the budget in Element A.1 is used to maintain Project A’s database and website; during FY 2025-27, a small amount of this funding will be used to improve download capabilities on the website, including allowing the user to download discharge measurements.

Most of the streamflow data collected under this element are used to support the LTEMP sediment goal, and to design and evaluate HFEs. Of the gaging stations funded by Project A, only the Little Colorado River above the mouth near Desert View, AZ station is not used to support the LTEMP sediment goal; this singular and most-expensive gaging station is used almost solely to support the LTEMP humpback chub goal. The suspended-sand flux is the product of the instantaneous water discharge and suspended-sand concentration. This flux is augmented to account for sand bedload and then integrated over time to calculate the sand load over any given time interval. These loads on the Colorado River and tributaries are used to construct the continuous mass-balance sand budgets described in Element 3.

It is impossible to construct these budgets without accurate streamflow gaging stations on the Colorado River and its key sand-supplying tributaries. In decreasing order of their sand-supply magnitude, based on measurements since 2010, these tributaries are: 1) the Paria River, 2) the Little Colorado River, 3) the combined smaller tributaries in Lower Glen Canyon and Upper Marble Canyon (RM -15 to 30), 4) the combined smaller tributaries in East Central Grand Canyon (RM 87 to 166), 5) the combined smaller tributaries in West Central Grand Canyon (RM 166 to 225), 6) Havasu Creek, 7) Kanab Creek, 8) the combined smaller tributaries in Eastern Grand Canyon (RM 61 to 87), and 9) the combined smaller tributaries in Lower Marble Canyon (RM 30 to 61) (Topping and others, 2021). We have therefore designed the Project A gaging-station network to focus resources in a manner appropriate relative to each tributary’s importance as a sand source.

We have taken a “burden-sharing” approach to operating the streamflow gaging stations in the CRe owing to insufficient staff at the GCMRC. For example, three of the Colorado River stations are operated by GCMRC staff and three are operated by AZ Water Science Center (WSC) staff. The FY 2025 gross costs (including overhead) to the GCDAMP for the surface-water record at each gaging station, the USGS science center operating each station, and the main LTEMP sediment-goal purpose of the streamflow data at each station are listed in Table 1 (to appear in next draft of the work plan). All gaging stations funded by this element are used to directly address LTEMP goals. Although the streamflow gaging stations on the tributaries do not directly monitor the downstream effects of Glen Canyon Dam operations, these gaging stations are required to monitor the tributary sand supply. Monitoring the tributary sand supply is required to separate the effects of tributary sand-supply events from the effects of dam operations on the sand resources in the CRe. In addition to the collection and serving of stage and discharge data at gaging stations, a large part of the budget for Element A.1 supports hydrologic/geomorphic interpretive work in support of the LTEMP sediment, humpback chub, and natural processes goals as described below.

Project Element A.2. Continuous Water-Quality Parameters

This element funds the collection, serving, and interpretation of continuous 15-minute measurements of water temperature, specific conductance (a measure of salinity), turbidity, and dissolved oxygen at the outlet of Glen Canyon Dam and at the above-mentioned six main-stem Colorado River gaging stations. This element also funds episodic measurements of specific conductance associated with suspended-sediment samples collected in tributaries (these measurements are intrinsic to the laboratory methods for processing the suspended-sediment samples and therefore cost nothing). Roughly 70% of the budget for Element A.2 funds salary for the field and office time required for making the water-quality measurements and funds the office time for serving the data. Approximately 13% of the budget in Element A.2 is used to maintain Project A’s database and website.

All water-quality measurements are made using standard USGS methods. Under this element 15-minute measurements of water temperature, specific conductance, turbidity, and dissolved oxygen are made using YSI multi-parameter sondes in the Colorado River located at the outlet of Glen Canyon Dam and at the gaging stations located at RM 0, 30, 61, 87, 166, and 225. See Voichick and Wright (2007), Voichick (2008), and Voichick and Topping (2010, 2014) for detailed descriptions of these sondes and measurements. In addition, 15-minute measurements of water temperature are made at three additional stations on the Colorado River and at stations near the mouths of the Paria and Little Colorado rivers, and Bright Angel, Kanab, and Havasu creeks.

Data collected under Element A.2 are routinely used in publications led by investigators in other GCDAMP-funded projects and investigators of projects external to GCDAMP. The seasonal median turbidity in each river reach is the proposed metric used to evaluate LTEMP management for the silt-and-clay component of fine sediment.

Project Element A.3. Sediment Transport and Budgeting

This element funds the collection, serving, and interpretation of continuous 15-minute measurements and episodic measurements of suspended sediment and bed sediment at the above-mentioned gaging stations on the Colorado River and its tributaries. In addition, this project element funds interpretive work in regard to the sand supply from the Paria and Little Colorado rivers, and interpretive work in regard to the effect of dam operations on the sediment resources in the Colorado River between Glen Canyon Dam and Lake Mead. Roughly 60% of the budget for Element A.3 funds salary for the field, laboratory, and office time required to collect and process sediment data, and also funds the office time for serving data and working on peer-reviewed interpretive publications. In addition, Element A.3 fully funds the field component of the phosphorous monitoring of Project E in the Paria and Little Colorado rivers. The continuous suspended-sediment measurements at the six main-stem Colorado River gaging stations, and the episodic suspended-sediment measurements in the tributaries are all used in the construction and evaluation of mass-balance sand budgets, and are used to trigger, design, and evaluate HFEs. Finally, ~8% of the budget in Element A.3 is used to maintain Project A’s database and website.

All measurements funded under Element A.3 are made using standard USGS (Edwards and Glysson, 1999) and other peer-reviewed methods. Under this element, continuous two-frequency acoustical suspended-sediment measurements are made in the Colorado River at the gaging stations located at RM 30, 61, 87, 166, and 225 using the method of Topping and Wright (2016). In addition to informing river management in the GCDAMP, our acoustical method pioneered in the Colorado River is now being used to inform river management across the United States and in Europe. The continuous measurements are used to calculate the sand loads used in sand budgeting, and also used to calculate continuous measures of bed-sand grain size. Because these grain-size values indicate periods of sand enrichment and depletion, they are critical in determining how observed changes in the amount of sand in a reach relate to dam operations. This information allows knowing whether sand erosion or deposition is driven more by dam operations or simply by the longitudinal positions of tributary-generated sand waves in the Colorado River.

In addition to the measurements on the main-stem Colorado River, episodic suspended-sediment measurements are made at the tributary gaging stations funded under Element A.1. These measurements are used in conjunction with models (after Topping, 1997) to determine the near-realtime sediment inputs from the Paria and Little Colorado rivers used in sand budgeting.

On the other tributaries, these measurements are used to document the sand, silt, and clay supply from the other major and lesser tributaries and to refine the long-term estimates of the importance of these other tributaries for supplying sediment to the CRe. Most of the sediment work on tributaries utilizes automatic samplers and has a large payoff in information for relatively low cost.

In addition to the collection of the sediment-transport data, this element fully funds the web-based construction and analysis of continuous mass-balance sand budgets for the CRe using the suspended-sediment measurements on the Colorado River and its tributaries. In addition to being used to evaluate the effects of LTEMP dam releases on the CRe, these mass-balance sand budgets are used in collaboration with the Bureau of Reclamation to trigger, plan, and evaluate HFEs (Grams and others, 2015; U.S. Department of Interior, 2016a). HFEs are triggered and designed on the basis of the Paria-supplied sand that accumulates in Marble Canyon during fall and spring implementation windows (U.S. Department of Interior, 2016a). This process involves using many suspended-sediment samples collected in the Paria River (quickly processed through the GCMRC sediment laboratory) in combination with discharge data (funded under Element A.1) and initial model estimates (after Topping, 1997) to determine the near-realtime continuous sand supply from the Paria River. The Bureau of Reclamation then uses this information, along with information on planned dam releases, as input to the sand-routing model of Wright and others (2010).

As more suspended-sediment measurements get processed through the laboratory (work funded by this element), the uncertainty is reduced in the calculated Paria River sand supply, and additional model runs are made by the Bureau of Reclamation. As time progresses, the Bureau of Reclamation's model-predictions of sand retention in Marble Canyon are compared against the actual measured sand retention in the continuous mass-balance sand budgets funded under this project element. Because the predictions of the sand-routing model of Wright and others (2010) may be off by a factor of 2, this comparison allows reality-based redesign of each planned HFE hydrograph. Finally, after the completion of each HFE, these sand budgets allow quick post-facto evaluation of the longitudinal effects of each HFE on the sand resources in the CRe in support of the LTEMP sediment goal. The annual sand mass balance in each river reach is one of the proposed metrics used to evaluate LTEMP management for the sand component of fine sediment.

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1. Budget







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Project B: Sandbar and Sediment Storage Monitoring and Research

1. Investigators

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1. Project Summary

The purposes of this project are to a) track the effects of individual High-Flow Experiments (HFEs) on sandbars and campsites, b) monitor the cumulative effect of successive HFEs and intervening operations on sandbars and sand conservation, and c) investigate the interactions between dam operations, sand transport, and eddy sandbar dynamics. These objectives are accomplished by annual measurements at long-term sandbar monitoring sites (B.1), measurements of changes in riverbed sand storage and studies of riverbed dynamics (B.2), maintenance of a geodetic control network (B.3), and development of streamflow, sediment transport, and sandbar response models (B.4). Field activities that would occur for monitoring condition-dependent experimental actions such as HFEs are also described (B.5). Results from this project are used to evaluate progress towards meeting the Long-Term Experimental and Management Plan (LTEMP) goal, to “Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes.” (U.S. Department of the Interior, 2016).

Project Element B.1. Sandbar and Campsite Monitoring with Topographic Surveys and Remote Cameras

If the LTEMP experiment to study an HFE with lower downramp rate (U.S. Department of the Interior, 2016) is implemented, we will investigate the impact of HFE hydrograph shape on sandbar morphology. Because this work is contingent on the implementation of the experiment, funding for logistics and data analysis are in Experimental Project Element B.5.

Project Element B.2. Bathymetric and Topographic Mapping for Monitoring Sediment Storage and Riverbed Dynamics

The purpose of this project element is to monitor the annual status and long-term trends of sandbars and campsites in Glen, Marble, and Grand Canyons.

The results will be used to evaluate the effects of dam operations, including HFEs, on sandbars and related resources and will include reporting of the proposed sandbar metrics for LTEMP. We will continue annual measurements at 45 long-term monitoring sites with topographic surveys that will be used to compute sandbar area and volume (Hazel and others, 2022) and usable campsite area at a subset of 37 sites (Hadley and others, 2018). We will evaluate replacing up to three of the sites that are no longer sensitive to dam operations owing to vegetation expansion with sites that may be of greater interest, such as sites with active vegetation management. This project will also include maintenance of remote cameras for daily monitoring at 42 sites (Grams and others, 2018), and we will begin replacing the camera systems that were designed in 2007 with updated systems. The sandbar database and website for serving sandbar data and images will be maintained and improved (U.S. Geological Survey, 2024). Data collection for this project will occur on one non-motorized river trip each year. In cooperation with Project C, we will continue to investigate the interactions between sandbars and vegetation by working on a coupled model for sandbar and vegetation change. This information could be used to understand why some sites are more or less likely to have vegetation expansion and could also be used to choose sites for vegetation management. This project also includes support for the Grand Canyon River Guides Adopt-a-Beach program, which provides an assessment of campsite condition from the perspective of river guides.

The primary purpose of this project element is to track trends in sandbar conditions and sand storage over the time scale of LTEMP to provide an evaluation of whether the supply of sand (the sum of recent tributary inputs and background storage) necessary for building sandbars is increasing, decreasing, or stable and a robust measure of high-elevation sandbar change. The results will be used to evaluate the outcome of the flow regime adopted in the LTEMP with respect to sandbar building and sand conservation. The monitoring data will also be used to compute proposed LTEMP metrics for high-elevation sandbars and sand mass balance by river segment. Changes in sand storage are tracked over long river segments, providing a spatially explicit quantification of changes in the channel, eddies, and sandbars (Grams and others, 2013; 2019). Measurements of sand storage in the river channel are critical because that information will be needed to explain the observed trends in sandbar area and volume and whether HFEs should be conducted more frequently or less frequently than prescribed in the LTEMP. This information will also be needed to assess whether the implemented flow regime is able to achieve sediment-related goals. Additionally, this project includes mapping of riverbed substrate composition and studies of riverbed dynamics in response to HFEs and dam operations. Results from these studies are used to better understand aquatic habitat and how dam operations affect riverbed conditions in specific river segments.

For this three-year work plan, we propose to conduct repeat bathymetric and topographic mapping for the segment between RM 30 and 87 on two separate motorized trips in the three-year work plan (in FY 2025 and FY 2027).

We also propose to map riverbed substrate in the segment between Glen Canyon Dam and Lees Ferry, and investigate the potential for detecting and mapping smallmouth bass nests in that reach. These data, together with data collected for other segments in previous work plans, will be used to provide a 12-year assessment of LTEMP sediment-related goals and objectives in 2028. In FY 2026, we will work in collaboration with Project L to support ground-truth data collection, which will include measurement of a water surface and riverbed profile on a motorized trip during the proposed overflight.

We will also continue evaluation of riverbed response to dam operations in Western Grand Canyon that was initiated in the FY 2021-2023 work plan. This work will involve annual monitoring of the 3-mile study reach that begins at RM 273 (Experimental Project Element B.5 includes additional surveys bracketing HFEs), development of a sediment budget for Western Grand Canyon, and monitoring the stability of Pearce Ferry Rapid.

Project Element B.3. Control Network and Survey Support

The purposes of this project element are to establish and maintain the framework for high-accuracy change detection. This project element ensures that geospatial data collected across all projects of the program are accurately referenced, precisely defined, and can be reliably compared with past and future datasets. Additionally, in FY 2026, this project element will provide substantial support to the remote sensing overflight (see Project L).

Project Element B.4. Streamflow, Sediment, and Sandbar Modeling

The purposes of this project element are to maintain and continue development of sediment routing and sandbar response models and to develop a new streamflow model for the Colorado River between Lees Ferry (RM 0) and Phantom Ranch (RM 87). The sand routing and sandbar models are used to compute the proposed LTEMP metrics for sand mass balance and sandbars in a predictive framework and are thereby used for planning management actions such as High-Flow Experiments (HFEs) and are also used to evaluate the potential outcomes of proposed changes in dam operations, including hourly, daily, monthly, and annual releases.

Development of new streamflow models for the reach between RM 0 and RM 87 is needed because existing models (Wiele and Griffin, 1997; Magirl and others, 2008) are based on estimated “synthetic” channel geometry, which means that while they can reliably predict discharge, they cannot be used to predict water depths, streamflow velocity, or bed shear stress. Predictions of these quantities are necessary for spatially explicit predictions of sediment, nutrient or veliger transport and quantification of physical habitat for fishes, riparian and in-stream vegetation, and invertebrates (including mussels). We propose to develop and calibrate a two-dimensional, hydraulic model for Marble Canyon, where extensive channel mapping data are available. The model will be used to provide the necessary boundary conditions required to run and validate morphodynamic sandbar models which are required to better understand the feedbacks between vegetation encroachment and sandbar dynamics, and to provide flow depth and velocity relations for habitat characterization. A similar model was developed for the reach between Glen Canyon Dam to Lee Ferry (Wright and others, 2024) that has proved useful for a range of ecosystem studies.

We will also continue work on a new fine sediment (silt and clay) routing model that was started in the FY 2021-2023 work plan, and we will continue to make improvements to the Mueller and Grams (2021) sandbar model. The new fine sediment model will be refined for use predicting turbidity in future scenarios, with the goal of interdisciplinary integration to predict gross primary productivity, phosphorous loads, and fish population dynamics. Improvements to the Mueller and Grams (2021) model will focus on developing more realistic relations for the erosion rate, to better capture the response of sandbars to potential operations such as smallmouth bass flows, and design ramp rates for high flow experiments.

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1. Budget







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Project C: Riparian Vegetation Monitoring and Research

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1. Project Summary and Purpose

Riparian plant communities are key components of the value and function of river systems in drylands. Rivers support unique plant species not found elsewhere in desert environments. The presence of riparian plants increases regional biodiversity, supports traditional plant resources, and creates unduplicated habitats. Riparian plant communities are inextricably linked to physical processes and biological communities of the Colorado River ecosystem (CRe) between Glen Canyon Dam and Lake Mead. The traits and life histories of the individual plant species that make up riparian plant communities determine the nature of sediment/plant interactions and the services or inconveniences provided to wildlife and recreationists.

In the CRe, many aspects of Glen Canyon Dam derived flow patterns are major drivers of riparian plant presence and abundance, and thus the characteristics of riparian plant communities. Flow patterns are layered on top of floristic differences along the river, such that plant communities in Glen Canyon, Marble Canyon, eastern Grand Canyon, and western Grand Canyon respond to dam operations in unique ways. Operational and experimental flows in the CRe have been designed for meeting water delivery agreements, producing power, promoting or hindering fish populations, redistributing sediment inputs, and stimulating macroinvertebrate production. Each of these flow patterns impact riparian plant community resources by favoring some species over others and flow patterns could be designed to support plant community goals.

The proposed elements in this project address Goal 11 of LTEMP, which is related to maintaining diverse native riparian plant communities and quality wildlife habitat. Elements C.1 and C.4 additionally link to Goals 6 (Recreational Experience) and 7 (Sediment) by evaluating the complex linkages among plants, river flows, and sediment. Element C.5 identifies scientific support of ongoing LTEMP vegetation experimental removals conducted by NPS. Specifically, Element C.1 collects and summarizes annual monitoring data that identify if the LTEMP riparian vegetation goal is being met. A newly proposed aspect of this element aims to develop measures of wildlife habitat quality in collaboration with the Navajo Natural Heritage Program (NNHP). Element C.2 addresses the LTEMP riparian vegetation goal by experimentally evaluating plant physiological responses to steady vs. daily-fluctuating flows in the context of lower Lake Powell elevations.

Element C.3 synthesizes data from Elements C.1 and C.2, as well as broad-scale regional datasets, to determine which dam-derived flows would be most likely to create plant communities that meet the characteristics desired in Goal 11. Element C.4 associates plant traits with sediment movement under different hydrological conditions to assess if and how plant encroachment is related to changes in channel width, thus linking together a suite of LTEMP goals. Element C.5 provides river management support to NPS and Tribal stakeholders, including continuing assistance with non-flow management actions being implemented by Glen Canyon National Recreation Area and Grand Canyon National Park. A newly proposed aspect of this element evaluates if the expansion of common reed (*Phragmites australis*) in the CRe is related to a recent introduction of the non-native lineage or expansion of the native lineage due to dam operations. Element C.6 proposes to measure key physiological responses of plant species of interest during experimental flows.

1. Proposed Work

Project Element C.1. Ground-based Riparian Vegetation Monitoring

Monitoring the status and trends of native and non-native plant species in the CRe provides the data for the Goal 11 metrics: native species richness, ratio of native to non-native species cover, and total native species cover. Annual measurement of plant species cover and composition will be characterized for (1) multiple geomorphic features representative of the CRe and (2) long-term monitoring sandbars and campsites surveyed as a part of Project B. These data form the basis of vegetation status and trends reporting and the underlying data for modeling efforts. Stratified-random sampling of multiple geomorphic features provides a thorough assessment of vegetation composition, cover, richness, and native to non-native species dominance on an annual basis throughout the CRe. Long-term monitoring sandbars and campsites provide a focused assessment of the impacts of vegetation on recreational resources, and an opportunity for integration of vegetation and sediment dynamics.

The desire to maintain wildlife habitat is explicitly stated in Goal 11, but evaluating wildlife habitat quality requires different vegetation assessments than are needed for determining the diversity and productivity of native plant species. A method for evaluating vegetation as wildlife habitat is needed if this part of the goal is to be assessed. Bird habitat is of interest to Navajo stakeholders, is a primary consideration in other southwestern riparian areas, and has been assessed previously in the CRe. In collaboration with the NNHP Zoologist, the annual vegetation monitoring program will be leveraged to evaluate the quality of bird habitat currently supported by Glen Canyon Dam operations. This project will begin by reevaluating methods previously used in the CRe and coordinating with bird habitat monitoring efforts along the lower Colorado River. These methods will be compared with a plant trait-based approach to determine if current vegetation monitoring protocols could be paired with trait data to sufficiently characterize bird habitat. To evaluate bird use of riparian vegetation, the NNHP will develop methods to characterize bird communities in the CRe.

The habitat and bird monitoring efforts will be coordinated such that the data can be analyzed jointly. The goals and methods of these efforts will be tailored to the needs of stakeholders from traditionally affiliated Tribal Nations, particularly Navajo Nation.

Project Element C.2. Mechanistic Experiments with Plant Species of Interest

To predict how unprecedented changes to Glen Canyon Dam operations will alter riparian plant communities (for example, dropping below power pool), we need an understanding of how common and uncommon plant species respond to conditions not experienced in the field. The complex effects of daily and seasonal fluctuations in river flow, coupled with the dual roles of water as both a resource (depth to water table) and stressor (inundation duration) are difficult to tease apart from annual observational data alone. Manipulative experiments under controlled conditions outside of the CRe are a cost-effective way to identify effects of distinct components of dam operations on plant performance. Preliminary results of a pilot study conducted in 2023 indicated substantial responses to daily fluctuating moisture conditions that varied among species, and between day- and night-time peaks. This suggests that a loss of daily fluctuation due to declining Lake Powell elevations could have strong impacts on the plant communities in the CRe. Moving forward, we are proposing to continue experiments related to daily fluctuating flows to evaluate how the loss of hydropower generation due to declining Lake Powell elevations would impact riparian plant communities. To do so, we’ll improve our experimental set-up and physiological monitoring and expand the replication and number of species tested. Our field-based monitoring and modeling data provide explicit predictions about which species benefit from, or are inhibited by, daily fluctuating flows. However, these predictions cannot be verified without controlled experiments. We will use these data to design experiments that allow us to differentiate impacts of daily fluctuations from other dam- and non-dam-related processes in structuring riparian plant communities in the CRe.

Project Element C.3. Predictive Modeling of Vegetation Responses to Dam Operations

This project element will conduct forward-looking modeling efforts to identify the flow conditions that would optimize the vegetation objectives listed in Goal 11. Specifically, we will ask “What are the flow conditions necessary to achieve the stated vegetation goals?” The metrics identified for Goal 11 will be used to frame the outcomes of this modeling. Predicting vegetation responses to flow regime requires understanding how riparian vegetation responds to many different flow regimes across broad scales. Lags in vegetation responses to hydrological events and the lack of interannual flow variability in the CRe create the need to use data derived from regional collaborations and manipulative experiments that expand the range of biophysical parameters used to construct vegetation models. This project element will integrate ground-based vegetation monitoring (Element C.1), manipulative experiments (Element C.2), and existing regional data on riparian vegetation composition and hydrographs using advanced statistical modeling.

Addressing this question necessarily requires a broader set of modeling techniques and datasets beyond our historical monitoring to assess the potential impacts of a broader range of flow scenarios. By looking outside the box of flow conditions that have occurred in the CRe over recent decades, we can identify dam operations that will benefit vegetation objectives while minimizing negative impacts on other resources, similar to inventive solutions that have been proposed for other resources in the recent past.

Project Element C.4. Biogeomorphic Linkages between Streamflow, Sediment Transport, and Vegetation Composition

Vegetation can exert a strong influence on channel change because plants reduce flow velocity and shear stress, often resulting in sediment deposition. Thus, changes in vegetation composition – that is, changes in vegetated area and stem density caused by vegetation expansion or a change in species – can have a dramatic impact on geomorphic processes on and near the channel banks. This project element links aspects of Goal 2 (river flow pattern alteration), Goal 6 (river corridor camping), Goal 7 (sediment area and distribution), and Goal 11 (ecologically appropriate vegetation). First, we will build on recent assessments of channel morphology and vegetation change by incorporating 2021 aerial imagery collected by Project L into analyses that examine if changes in vegetation area and composition are a likely driver of channel change. We will then measure physical plant traits (stem density, frontal area) of different species, and incorporate these data within 2D hydraulic models to evaluate the relative effects of different plant species on channel-margin flow velocity and shear stress to determine which plants exert the strongest influence over channel margin hydraulics, and therefore, geomorphic change. This element will be done collaboratively with Projects B and L. In addition to integrating key elements of the CRe ecosystem (flows, sediment, and vegetation), results of this work can help identify desirable plant communities and inform LTEMP vegetation removal experiments (see Element C.5).

Project Element C.5. Vegetation Management Decision Support

The LTEMP identified the need for experimental vegetation management to be conducted in the CRe. These efforts are being led by Glen Canyon National Recreation Area and Grand Canyon National Park through funding from Elements C.7 and C.8 of the FY 2021-23 Reclamation Triennial Work Plan (Project E.6 and E.7 of the FY 2025-27 Reclamation Triennial Work Plan) and monitored by FY 2025-27 GCMRC Triennial Work Plan Project D.3. Thus far, the experimental vegetation treatments have focused on vegetation removal to support recreational and sociocultural resources but plans for revegetation with native species are included. This project element supports GCMRC Principal Investigator participation in regular meetings about site selection, monitoring, and experimental treatment plans. We will collaborate on GCMRC Project D.3 and continue to facilitate NPS work as needed.

Common reed is a culturally and ecologically important riparian grass. The native lineage of common reed (*Phragmites australis* ssp. *americanus*) is frequent in springs and along rivers in the southwestern U.S. A non-native lineage (*P. australis* ssp. *australis*) has spread throughout the U.S., dramatically altering the ecology of wetlands and riparian areas.

The expansion of the non-native lineage into the desert southwest has been confirmed outside of the Grand Canyon region, but it is unknown if it has arrived in the CRe. Common reed has expanded in the CRe, particularly since 2009. This expansion is likely due to dam operations but could also be related to the arrival of a non-native lineage. The arrival of the non-native lineage impacts vegetation removal and restoration decisions for the above-mentioned experimental vegetation treatments and thus has direct management implications. The definitive method for determining the native or non-native status of common reed stands is to genetically test samples. In collaboration with representatives from Tribal Nations and NPS units affiliated with the GCDAMP, this project element will conduct genetic testing and morphological assessments of common reed stands within the CRe. Through combined funding sources, this project will include stands along the Colorado River (GCDAMP funding) and throughout the Glen, Marble, and Grand Canyon regions (NPS funding).

1. Budget







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Project D: Effects of Dam Operations and Experimental Vegetation Management for Archaeological Sites

1. Investigators

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1. Project Summary

The Long-Term Experimental and Management Plan (LTEMP) (U.S. Department of the Interior, 2016a) goal for Archaeological and Cultural Resources is to maintain the integrity of potentially affected National Register of Historic Places (NRHP)-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

Project D addresses this LTEMP goal by quantifying changes in the physical condition of river corridor archaeological sites in Grand Canyon as a function of 1) dam operations, 2) experimental vegetation management, and 3) interacting natural processes. While the dam and its operation are not the only sources of change affecting the CRe and associated archaeological sites, this project focuses on studying and monitoring dam effects, in keeping with the mandates of the 1992 Grand Canyon Protection Act (GCPA) and consistent with the monitoring plan for cultural resources developed by GCMRC in 2015 and Reclamation’s 2018 Historic Preservation Plan (Bureau of Reclamation, 2018). The ongoing and experimental dam operations and vegetation management (non-flow) actions of interest are those that are undertaken under the Record of Decision for the Glen Canyon Dam Long-Term Experimental and Management Plan final Environmental Impact Statement (LTEMP ROD; U.S. Department of the Interior, 2016b) through 2036.

Three-quarters of the 362 river-corridor archaeological sites in Grand Canyon National Park (GCNP depend on river-derived sand for their geomorphic context, and the vast majority of those sites are now deprived of sand resupply in the modern, dam-controlled river system. Sankey and others (2023) reported that most archaeological sites in GCNP along the Colorado River are eroding, and at increased environmental risk of erosion, from six decades of operations of Glen Canyon Dam. Aeolian geomorphology-based site classification monitoring shows that the wind-driven supply of river-derived sand, essential for covering sites and maintaining their geomorphic context, has decreased for most archaeological sites since 1973 owing to effects of long-term dam operations on river sediment supply and riparian vegetation expansion on sandbars. Drainage geomorphology-based site classification monitoring shows that the proportion of sites affected by gullying processes controlled by the base-level of the Colorado River in Grand Canyon has increased since 2000.

These fundamental changes to landscape processes affecting archaeological site context and integrity limit the ability of the National Park Service (NPS) to achieve environmental management goals to maintain or improve site integrity in-situ.

Archaeological site monitoring results illustrate some of the negative impacts of human river management and gully erosion on site condition and the physical integrity of prehistoric and historic archaeological sites. However, monitoring and research also demonstrate that windblown river sand can help to offset erosion impacts on archaeological site condition. Targeted riparian vegetation removal on sandbars may provide an environmental management opportunity to increase windblown sand supply from sandbars to archaeological sites, and thus increase in-situ preservation potential on a site-specific basis. The effectiveness of vegetation management might theoretically be increased when coupled with HFEs to rebuild sandbars, or with periodic low river flows to expose sandbars, which in both cases are the sources of windblown sediment supply. In 2023, for the first time, experimental vegetation management and an HFE were implemented in combination in the same year in Grand Canyon. Barring environmental management actions to increase in-situ preservation potential, sites along the Colorado River will likely continue to erode, leaving site-specific excavations as the only remaining option for preserving archaeological site information before it is lost, although this approach falls short of stated environmental-management goals.

1. Proposed Work

Project Element D.1. Monitoring the Effects of Dam Operations on Archaeological Sites (modified ongoing study)

During FY 2025-27, GCMRC will continue long-term monitoring of archaeological sites using lidar to report on *LTEMP Cultural Resources Metric 1.2 Lidar Topographic Change Detection*. The purpose of this monitoring is to quantify the effects of dam operations and other factors on the geomorphic condition of a sample of archaeological sites in the Colorado River corridor in Grand Canyon National Park that are within the area of potential effect of Glen Canyon Dam operations. Geomorphic changes are determined from lidar topographic surveys repeated at individual sites according to an established three-year rotational schedule. The total sample size is approximately 40 archaeological sites, with 12-14 sites monitored each year of the three-year work plan.

Other activities that this ongoing project element will contribute to include the following.

* Monitoring data acquired by this Project Element (D.1) are used for research conducted in Project Element D.3 (see below) to evaluate effects of LTEMP non-flow actions and other experimental vegetation management on archaeological sites.
* GCMRC and NPS will conduct a collaborative analysis of archaeological site monitoring data acquired by both agencies for sites within the area of potential effect of Glen Canyon Dam operations. NPS reports on *LTEMP Cultural Resources Goal Metric 1.1 Site Integrity*, and USGS reports on *Metric 1.2 Lidar Topographic Change Detection* and *Metric 1.3 Fluvial Sediment Connectivity and Drainage Classifications*. Collaborative analysis can identify what the relationships are between the monitoring information acquired by NPS to determine site integrity and the data acquired by GCMRC to measure geomorphic and site classification changes.
* An interdisciplinary element proposed in Project L, in collaboration with Projects B and D, will explore utility of existing remotely sensed data for measuring system-wide changes in high-elevation sand deposits. This interdisciplinary project will leverage the long-term lidar monitoring topographic change detection results acquired by Project Element D.1 as a basis for checking the accuracy of high elevation sand estimates using photogrammetric data.
* Modeling efforts funded externally (i.e., not funded by the GCDAMP) through USGS Mendenhall Post-doctoral Fellow program will model river sand transport and high-elevation sand deposition with specific consideration to archaeological site preservation potential. The Mendenhall program modeling project will leverage long-term monitoring data acquired by Project Element D.1.

During FY 2025-27, GCMRC will not monitor changes to archaeological site classifications to report on *LTEMP Cultural Resources Metric 1.3 Fluvial Sediment Connectivity and Drainage Classifications*; that metric is reported on an approximately decadal time interval and will be completed in a subsequent work plan.

Project Element D.2. Monitoring Landscape-Scale Ecosystem Change with Repeat Photography (continued ongoing study)

During FY 2025-27, GCMRC will continue compiling a record of ecological changes affecting the cultural landscape and archaeological sites within the river corridor using repeat photography. In FY 2015-17, GCMRC initiated a pilot effort to monitor vegetation and geomorphic changes in the riparian zone using repeat photography. The initial results of this pilot photo matching effort proved to be highly informative and useful for a variety of GCMRC projects. Not only do the matched images visually document and illustrate the dramatic changes in river corridor vegetation, they also document the ongoing loss of open sand areas throughout the river corridor as well geomorphic changes to shorelines, campsites, and the river corridor as a whole. This information is useful for reconstructing the pre-dam conditions under which archaeological sites and cultural landscapes existed prior to emplacement of Glen Canyon Dam. Therefore, GCMRC has continued acquiring matches of historical imagery during subsequent years, relying heavily on volunteer labor and logistical support from Element D.1 to accomplish the field work, and with post-field work photo-processing accomplished exclusively by volunteer labor.

To date, photo matching efforts have focused on replicating photographs taken in 1923 during the USGS Birdseye Expedition and images taken 50 years later (in 1973) during an NPS-sponsored campsite inventory project. We have also re-matched numerous photographs taken during the 1889-1890 Stanton expedition. Over the next three years, we plan to fill in temporal gaps in the photographic record, focusing initially on matching approximately 70 black-and-white images taken by Barry Goldwater during his 1940 river trip through Grand Canyon. Another important photograph collection we recently became aware of was compiled by Bill Belknap during a 1964 low-water trip through Grand Canyon. The Goldwater images will be valuable to match because they were taken by a highly skilled photographer during a period of lower flows and lower magnitude floods than the earlier Birdseye and Stanton images; therefore, they can provide a useful comparison of pre-dam riparian vegetation conditions closer to the time of dam construction and under somewhat different flow conditions compared to photographs from 1890 and 1923. The Belknap photos, also taken by a skilled photographer, provide a visual record of the river corridor immediately after the dam was completed, during exceptionally low water conditions. Neither the Goldwater images nor the Belknap images have been previously matched, to our knowledge.

In FY 2025-27, we will continue to create high quality, accurate matches of these and other historical images to provide a high resolution, detailed visual record of decadal-scale ecosystem changes that can be used and analyzed by a variety of monitoring projects for years into the future. In addition to matching images, we will continue to collect detailed information on species-level vegetation change within each matched view. As in the past, matching of these images will occur in conjunction with previously scheduled GCMRC research and monitoring trips and will be heavily reliant on volunteer labor to minimize project costs once the images and vegetation data have been acquired. We will re-organize, analyze, and ultimately publish the results of this work and make the imagery available to stakeholders and the public through GCMRC’s website.

Project Element D.3. Evaluating Effects of LTEMP Non-Flow Actions and Other Experimental Vegetation Management on Archaeological sites (modified ongoing study)

GCMRC will collaborate with NPS, the Hopi Tribe, and other interested parties, to study effects of experimental vegetation management, with a specific focus on LTEMP non-flow actions that may affect archaeological site preservation. There are four components proposed by GCMRC for this collaborative work:

1. Continue evaluating effects of any ongoing NPS experimental management at six pilot study sites where NPS removes invasive vegetation annually on river sandbars. GCMRC’s research question is whether removal or reduction of riparian vegetation barriers located between river sandbars and archaeological sites can measurably increase the resupply of aeolian sediment to archaeological sites. The Lees Ferry Paria Beach restoration project and associated downwind archaeological sites will be added as a seventh monitoring location in FY 2025-27.
2. Apply lessons learned during FY 2021-24, to propose and evaluate improved experimental management actions based on different vegetation removal strategies, strategic plantings, and sediment capture using minimally invasive methods. GCMRC seeks to collaborate with NPS, the Hopi Tribe, and other interested parties on this work.
3. Through collaboration with the Hopi Tribe, NPS, and others, explore the applicability of traditional dryland farming knowledge and soil management practices for achieving archaeological site preservation goals.
4. Explore site restoration potential relative to degree of sandbar vegetation encroachment. The pilot sites evaluated in #1 above are all associated with sandbars in early stages of vegetation encroachment. In FY 2025-27, we propose to evaluate additional study sites exhibiting much later vegetation encroachment stages to determine whether they can be effectively restored using similar experimental management techniques or whether different approaches to vegetation management may be warranted.

Note that in the FY 2021-23 work plan, the precedent to collaborative work proposed above was supported by GCMRC Project D.1 to fund USGS efforts, and Reclamation Projects C.7 and D.3 to fund NPS efforts. For FY 2025-27, a similar funding strategy is proposed for USGS and NPS, but in this work plan, we (GCMRC) have broken out the vegetation management experimental study (this Element, D.3) from the long-term monitoring Project Element (D.1) to clarify the different objectives involved with each study. For FY 2025-27 the related Reclamation projects are titled E.6 Experimental Vegetation Management – Grand Canyon and D.3 Cultural Resources Monitoring – Grand Canyon.

Project Element D.4. Pilot Study to Evaluate Potential to Extract Cultural and Ecological Information from Colorado River Deposits Using eDNA and Pollen (new study)

In the GCDAMP, past studies of the sediment resource have mainly focused on the physical dynamics of particles ranging in size from clay to boulders, with an emphasis on tracking the storage and redistribution of fine sediment (e.g., sand, silt and clay) within and immediately adjacent to the active river channel; however, the sediment resource is much more than just a physical attribute of the CRe. It also serves as a vehicle for nutrient cycling, provides a substrate for plants, influences the types and distribution of vegetation and wildlife habitat in the river corridor, and serves as a matrix for preserving archaeological sites *in situ*. In addition, the pre-dam Colorado River sediments are an untapped and largely unexplored repository of information about the pre-dam ecology of the river corridor. This information has the potential to inform on the characteristics and attributes of the prehistoric cultural landscapes which formed the original context for the hundreds of archaeological sites present in the river corridor today.

This cultural landscape remains largely unstudied and undocumented, especially in terms of the many prehistoric cultural activities and attributes that shaped the river corridor environment through time, including the development of agricultural fields and irrigation features that are believed to have been central aspects of the prehistoric cultural landscape in eastern and central Grand Canyon.

In FY 2025-26, we propose to collaborate with the NPS and interested Tribes to undertake a pilot study to examine the types of pre-dam environmental information that potentially can be extracted from pre-dam sedimentary deposits, with a focus on extracting ancient eDNA for the purpose of characterizing the prehistoric vegetation community and cultural landscape at various points in the past. In addition, we intend to use this pilot study to determine whether eDNA can be used to document the presence of ancient horticulture fields and identify specific cultigens. Past studies using standard palynological methods have produced evidence of maize agriculture possibly dating back more than 3,000 years ago; if this evidence can be substantiated through independent methods, such as eDNA, it would demonstrate that the Colorado River corridor in Grand Canyon contains some of the earliest evidence for maize horticulture anywhere on the Colorado Plateau. Other previous studies have produced evidence of cotton cultivation in association with ~1,000-year-old habitation sites, indicating that Grand Canyon may also have been one of the earliest sources for locally-grown cotton on the Colorado Plateau. Despite this pollen evidence, however, current knowledge of the extent and locations of horticultural activity in the CRe remains largely non-existent. This study has the potential to shine new light on several aspects of the archaeological record and the information potential embedded within the pre-dam sedimentary deposits in Grand Canyon that have never been previously studied.

To accomplish this pilot study, we propose to sample pre-dam river sediments at three locations in eastern Grand Canyon. These locations will be selected based on having appropriate characteristics for horticulture in the past and being most likely to preserve ancient eDNA, e.g., very fine-grained, water-laid sediments deposited preferably in an anaerobic environment. We propose to core the deposits and collect several samples from each core. The cores will be sampled for both eDNA and pollen, so that the results of both methods can be compared and to ensure that we can recover environmental information from pollen even if eDNA is not well-preserved. In addition, we will date the samples using either a radiocarbon dating method (if organic material is present in the sediment) or Optically Stimulated Luminescence (OSL).

Project Element D.5. Monitoring Rock Art (Petroglyphs, Pictographs) with Photogrammetry and Lidar (new study)

In response to concerns by tribal members of GCDAMP and at the request of the LTEMP Cultural Programmatic Agreement (PA) signatories, GCMRC will continue work to evaluate potential hazards to rock art (petroglyphs, pictographs) site conditions and collect data to monitor their changes.

An FY 2023 pilot study – which was unfunded, but GCMRC undertook at the request of the LTEMP Cultural PA – demonstrated the utility of photogrammetry and lidar for these purposes at a single petroglyph site (C:06:0005; “Supai Man”). There are additional rock art sites and structural remains for which these monitoring procedures could be applied throughout the Colorado River Corridor.

To best meet the needs of tribal members of GCDAMP and the LTEMP Cultural PA, this project element is designed to be responsive to identified priorities during FY 2025-27. During FY 2025, GCMRC will write a report detailing the 2023 findings from lidar monitoring at the petroglyph site C:06:0005. The initial results of this study demonstrated that rock art sites are vulnerable to a variety of hazards, including potential for direct effects of dam operations from inundation as well as indirect effects associated with visitor access and biochemical weathering. Collection of detailed monitoring records, as with the ground-based lidar and photogrammetry in this study, provides an important foundation for identifying these hazards, providing a baseline condition assessment, and monitoring future changes in site condition. During FY 2026, these detailed monitoring efforts will be either be repeated at this site or conducted at other locations identified as priorities by LTEMP Cultural PA signatories. As part of this data collection effort, we will offer opportunities for tribal members to participate, see, and learn about collecting these types of data where there is interest in applying it within tribal monitoring programs. During FY 2027, GCMRC will report on additional monitoring work conducted in FY 2026.

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Project E: Controls on Ecosystem Productivity: Nutrients, Flow, and Temperature

1. Investigators

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1. Project Summary and Purpose

Ecosystem metabolism, or the rate of organic material fixation (accumulation) or depletion from an ecosystem, is key to understanding the energetic basis of food webs (Bernhardt and others, 2018; Rüegg and others, 2021). The two key components to riverine ecosystem metabolism are aquatic primary production, and ecosystem respiration. Aquatic primary production, or the “green” food web, converts sunlight, carbon dioxide and water into simple carbohydrates via photosynthesis. Ecosystem respiration, or the “brown” food web, represents the decomposition and/or consumption of organic material by microbes, aquatic insects, fishes, or other animals. In the Colorado River downriver of Glen Canyon Dam (GCD), fishes are food limited (Cross and others, 2011) and energy (carbon) produced by autotrophs within the river is a preferred food source relative to energy from tributaries and riparian inputs (Wellard Kelly and others, 2013). Aquatic primary production, and the aquatic insect community this production supports, is the main source of fish production in Glen Canyon throughout the year (Cross and others, 2011). Primary producers (specifically diatoms) are also a preferred food source downstream, although the role of non-algal (tributary/terrestrial) “brown” carbon sources can also be an important driver of the food availability near tributary junctions and during flood pulses such as occur during monsoon season (Cross and others, 2011; Sabo and others, 2018; Wellard Kelly and others, 2013). Rates of primary production (green food web) are an important control on flannelmouth sucker (*Catostomus latipinnis*) growth rates in Marble and Grand Canyon (Hansen and others, 2023), and an additional positive turbidity effect may indicate the role of the “brown” food web in fueling growth.

Phosphorus (P) is a key nutrient that can limit organismal growth and metabolic rates. There are several lines of evidence that suggest P is a key control on rates of ecosystem metabolism and food web dynamics in the Colorado River. Lake Powell retains disproportionately more P than other key nutrients like nitrogen and silica (Kelly, 2001), creating ecosystem P limitation (Gloss, 1977).

We now have strong evidence of food web P limitation in Glen Canyon. P predicts rainbow trout recruitment better than flow-based metrics used to predict recruitment for the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) (U.S. Department of the Interior, 2016; Yackulic 2020). The density of aquatic insects in Glen Canyon are positively correlated with P availability at the annual scale (Korman and others, 2021), and bioenergetic modeling demonstrates that the Glen Canyon rainbow trout (*Oncorhynchus mykiss*) population is strongly regulated by rates of aquatic insect prey production, which is in turn controlled by P concentrations being released from the reservoir (Yard and others, 2023). In Marble and Grand Canyons, the relationship between P and ecosystem productivity is still emerging. Outside of periods when tributaries are flooding for extended periods, the availability of aquatic insect drift and the condition of native fishes are positively related to seasonal rates of gross primary production near the Little Colorado River, highlighting the important role for aquatic primary production even 120 km downstream of the dam (Deemer, 2020). In dark sediment incubations conducted in both Glen Canyon and Grand Canyon, pH-mediated P release from sediments consistently led to increases in total protein production (Deemer and others, 2023a), suggesting that the “brown” food web is also limited by P.

Understanding the controls on Colorado River ecosystem production is an important step towards better managing the aquatic food base. For example, the canyon-wide increase in gross primary production (GPP) due to springtime low and steady weekend bug flows (Deemer and others, 2022) was estimated to increase rates of flannelmouth sucker growth by 1.6 mm per month, or approximately the same effect as warming the river by 1.1 degrees Celsius (Hansen and others, 2023), demonstrating a measurable link between a dam management strategy and native fish populations. During 2022 and 2023, the river has experienced unprecedented water quality conditions (U.S. Geological Survey, 2024), further underscoring the need to understand how abiotic factors interact to affect the base of the food web. The role of temperature verses other abiotic factors as controls on ecosystem metabolic rates is a key question in ecology (Battin and others, 2023; Bernhardt and others, 2018) and considerable uncertainty exists regarding how the green and brown food web in Grand Canyon will respond to temperature change. In Glen Canyon, P may limit decomposition rates even as waters warm (Scholl and others, 2024). While rates of primary production during clear water conditions appear to scale with river water temperatures at some locations and times, this relationship sometimes falls apart suggesting P limitation (U.S. Geological Survey, 2024). Overall, Project E is designed to capture and link changes in primary productivity and decomposition to changes in bottom-up drivers such as light, temperature, flow, and nutrients and to further develop links between these bottom-up drivers and higher trophic levels.

In the FY 2025-27 TWP, we propose to revise three elements from the FY 2021-23 TWP and add a new element that focuses on ecosystem metabolism in the Western Grand Canyon. Several sub-elements propose to leverage data collected during the last work plan (mass balance P budgeting in E.1; vegetation mapping in Glen Canyon and GPP modeling exercises in E.2; bioenergetics modeling in E.4).

Several new sub-elements propose to explore P uptake by primary producers during turbid, high P conditions (E.1), to characterize producer-specific metabolic rates via in-situ chamber experiments (E.2), to examine the role of litter decomposition in the Western Grand Canyon food web (E.3), and to install a new water quality sonde in Western Grand Canyon concurrent with the new Columbine gage that can support GPP and ecosystem respiration measurements (E.3).

1. New and Continuing Research Studies

Project Element E.1. Phosphorus Budgeting in the Colorado River

This project element aims to characterize the major sources and storage sites for P in the Colorado River as well as to understand controls on P export from the system. We propose to leverage samples collected and analyzed during the last work plan to develop site-specific relationships between P and suspended sediment concentrations. These relationships will then be used to construct a mass balance P model, which we expect we can extend across tens of years where suspended sediment concentrations have been measured but P has not. On shorter time scales relevant to primary production, tributary storms can be a significant source of biologically available P to the Colorado River (Deemer and others, 2023a), and may serve as a direct source of P to benthic producers, given that algal taxa living in low-P environments can rapidly increase P uptake rates and store excess P when it becomes available (“overplus uptake”; Rier and others, 2016). P captured by this process may offset some of the negative impact of increased turbidity on productivity by boosting growth after such events have passed. This process would also redirect additional P from downstream export into local food webs. We propose to examine this process downstream of major tributaries and determine both the scale of excess P uptake and how it varies among distinct algal producers (e.g., diatom and cyanobacterial benthic communities). Ultimately, this element will inform GPP modeling efforts described in E.2, allowing us to link P to rates of primary production (especially in further downriver sections where tributary inputs potentially override the influence of variation in the P in dam releases).

Project Element E.2. Rates and Composition of Primary Producers in the Colorado River

This project element provides the underlying modeling to support the natural processes GPP metric and aims to disentangle the drivers of both rates and types of riverine primary production, and their link back to fish production. Such an effort is particularly challenging given interactive and delayed effects and given different levels of information on the potential drivers. For example, monsoonal storm pulses that place temporary light availability constraints on rates of primary production (Hall and others, 2015) may also be delivering significant amounts of P to the mainstem (Deemer and others, 2023a). In a second example, at times of high P outflow from Glen Canyon Dam, elevated production of a dominant food source, diatoms, may suppress macrophyte production (via shading) obscuring the link between overall productivity and higher trophic levels. Assessing primary production drivers is further complicated by producer community composition and trends therein.

Distinct producer communities vary in their contribution to secondary production (Krist and Charles, 2012), their responses to dam operations (Benenati and others, 1998) and changing environmental conditions upstream (autecological preference for increasing temperature; Blinn and others, 1989), and production of labile carbohydrate exudate (stalk biomass from nuisance diatom species *Didymosphenia geminata* and *Cymbella mexicana*, known throughout the Colorado River downstream of GCD; Spaulding, personal observations).

This project aims to disentangle some of these drivers of ecosystem production by combining the highly resolved long-term information about riverine turbidity, silt and clay concentrations, solar inputs, discharge, and GPP (via continuous oxygen and temperature measurements – data that are collected as parts of the Lake Powell project, Project A.2, and Project E), with improved additional information about P (Element E.1), and the relative role of distinct algal communities (multiple diatom ecological guilds, cyanobacterial mats, macrophytes) in shaping whole river production. To assess the latter, we propose multiple projects that more finely resolve primary producer dynamics beyond bulk, reach-scale averages. These include 1) estimation of group-specific metabolic rates via in-situ chamber experiments, which leverage investments made in the current work plan to study fish energetics; 2) continuation of machine learning-based vegetation mapping in Glen Canyon; 3) surveying benthic diatom diversity downstream of Lees Ferry, which would align with ongoing eDNA surveys of emerging fish parasites and pathogens (Project I, Element I.3), and would additionally help establish a baseline for multiple nuisance diatom taxa ahead of possible temperature change in the reach; and 4) leverage a long-term phytoplankton composition dataset (Deemer and others, 2023b) to assess the role that reservoir phytoplankton have on downstream production dynamics.

Project Element E.3. Understanding the Energetic Basis of the Food Web in Western Grand Canyon

This is a new project element that aims to understand controls on the base of the food web in Western Grand Canyon. In the western Grand Canyon, humpback chub (*Gila cypha*) populations have increased dramatically in the last decade, but the underlying causes for this change are unknown. One hypothesis is that warming water temperatures are supporting a more productive food base. All else being equal, warming water temperatures are expected to increase rates of heterotrophic metabolism and decomposition (brown food web) faster than rates of primary production (O’Connor and others, 2009; Demars and others, 2011), suggesting that the brown food web is serving as an important conduit for fish food in this part of the river. Alternatively, a recent revisitation of decomposition rates in Glen Canyon suggests that low P concentrations suppressed decomposition rates during 2022 warmwater releases, leading to no detectable difference in the decomposition rate of two litter types despite ~10 degree C warmer temperatures (Scholl and others, 2024). This project aims to quantify rates and drivers of primary production and ecosystem respiration in the Western Grand Canyon leveraging a new gage site near Columbine\*.

We also propose targeted decomposition experiments to understand controls on detritivore vs. microbe-driven decomposition and how changes in temperature, nutrient availability, and litter quality may influence food availability for higher trophic levels. By pairing integrative estimates of ecosystem metabolism with finer-scale decomposition measurements, our approach will offer a uniquely holistic perspective on the energetic pathways underpinning food webs in Western Grand Canyon.

\*The costs for continuance of the Columbine gage are currently integrated into this element’s budget and represent 72% of the non-salary costs proposed for this element. The gage will be used for a number of purposes. It currently provides stage information to ongoing monitoring in the reach and the stage information will also be used in the development of a streamflow model for the reach above Pearce Ferry Rapid. The gage can also serve as a method for monitoring changes to Pearce Ferry Rapid. Pearce Ferry Rapid is the hydraulic control for the upstream reach, likely extending upstream to about mile 250 (Suprise Canyon). Continuous measurements of water-surface elevation in this reach above the rapid are, therefore, critical for monitoring both the maintenance of the rapid and the potential erosion of the rapid.

Project Element E.4. Linking Ecosystem Metabolism to Higher Trophic Levels

The goal of this project is to develop ecosystem models that incorporate data collected at multiple trophic levels. This modeling will leverage ecosystem production rates estimated in Project Elements E.2 and E.3. together with estimates of consumption by fish populations to understand how bottom-up and top-down processes interact to drive ecosystem dynamics. This type of approach was recently taken to understand energetic constraints on the rainbow trout population in Glen Canyon (Yard and others, 2023). The modeling will combine estimates of species and size class specific somatic growth rates with estimates of basal metabolism to estimate energetic demand for individual fish, which will then be scaled up with species and size class specific abundance estimates to estimate the consumption required to support observed abundances and growth rates. These estimates of consumption will then be compared with estimates of energy production at lower trophic levels (i.e., ecosystem metabolism) or invertebrate availability (i.e., drift measurements) accounting for the transfer efficiency of energy across trophic levels to understand how changes in energy production impact fish population dynamics.

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

**Project F: Aquatic Invertebrate Ecology**

1. Investigators

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1. Project Summary and Purpose

The primary focus of Project F is continuation of long-term monitoring needed to track invertebrate population and ecosystem response to implementation of the Long-Term Experimental and Management Plan (LTEMP; U.S. Department of the Interior, 2016). Project F is tracking ecosystem response to the LTEMP using citizen science monitoring of aquatic insects and bat activity (F.1), monitoring of invertebrate drift (F.1 and F.2), monitoring of invertebrate communities in tributary streams using eDNA (F.3), and through diet and stable isotope analysis of invertebrate and fish feeding habits (F.4).

Research and monitoring of invertebrates described in Project F also provides essential context and data that are used by other projects. For example, invertebrate monitoring data are used by Project E (controls on ecosystem productivity) to identify the extent to which changing nutrient levels are propagating up through the food web. Invertebrate monitoring data also aid interpretation of seasonal and annual trends in humpback chub (*Gila cypha*) (Project G) and rainbow trout (*Oncorhynchus mykiss*) (Project H), because aquatic invertebrates represent the food base for both species of fish. Project F also integrates and uses data from other projects, particularly Project A (streamflow, water quality, and sediment transport), to identify how changing environmental conditions affect invertebrate populations.

1. Proposed Work

Project Element F.1. Aquatic Invertebrate Monitoring in Marble and Grand Canyons

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Aquatic invertebrates exhibit movements and behaviors that are ecologically important, not only because these processes are critical to invertebrate life cycles and population dynamics, but because these movements make invertebrates vulnerable to predation by wildlife populations. For instance, although most stream invertebrates are benthic (bottom dwelling), invertebrates are also regularly found drifting with the river current. This process of drift is essential to invertebrate dispersal and colonization and therefore critical to population maintenance of these animals (Brittain and Eikeland, 1988). Similarly, of the many insect stream invertebrates, nearly all transition to becoming winged, air-breathing adults via emergence. Each of these are critical stages in invertebrate life cycles (Huryn and Wallace, 2000), but also processes by which they become vulnerable to fishes and terrestrial food webs, often serving as prey for animals like birds, bats, spiders, and lizards (Baxter and others, 2005).

This project element focuses on identifying links between Glen Canyon Dam operations, environmental conditions (e.g., tributary flooding, water temperature), and the downstream aquatic food base. We focus our efforts on monitoring invertebrate populations during periods of movement (i.e., emergence and drift), because these drift and emergence data can be used to make inferences about the health and status of invertebrate populations (Kennedy and others, 2014; Kennedy and others, 2016) and also provide a direct measure of the food base available to humpback chub, rainbow trout, and other wildlife populations (see Projects G and H, especially).

The main thrust of F.1 is the citizen science monitoring of emergent aquatic insects, where river guides, education groups, private boaters, and other citizen scientists deploy a simple light trap each night in camp to collect samples of adult aquatic insects that have emerged from the Colorado River (Kennedy and others, 2016; Metcalfe and others, 2021). Laboratory processing of citizen science light trap samples includes counting and identifying aquatic insects to family or genus, whereas terrestrial insects are identified to order or family.

Starting in 2017 we began partnering with citizen scientists to monitor bat acoustic activity in conjunction with insect monitoring. These bat monitoring data have documented 19 species of bats and shown that bat activity is strongly and positively related to the abundance of aquatic flies (Metcalfe and others, 2023).

Finally, as part of F.1, we will also monitor invertebrate drift (#/m3 and g/m3) in the Colorado River throughout Marble and Grand Canyons during annual river trips in spring. As part of these annual monitoring trips, which began in 2017 prior to the first Bug Flows experiment, invertebrate drift samples will be collected every ~ 5 river miles. This type of strategic monitoring of drift throughout Marble and Grand Canyon complements more spatially and temporally extensive citizen science monitoring.

Project Element F.2. Aquatic Invertebrate Monitoring in Glen Canyon

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This element is a continuation of monthly Glen Canyon monitoring program that has been ongoing since 2007. It represents a valuable long-term dataset for identifying status and trends in the aquatic food base supporting rainbow trout populations in Glen Canyon (e.g., Korman and others, 2017; Korman and others, 2021). This monitoring is carried out using published methods developed by the food base group (Copp and others, 2014; Kennedy and others, 2014; Smith and others, 2014; Baxter and others, 2017; Muehlbauer and others, 2017).

Invertebrate drift is sampled 10 times per year at 5 sites distributed from Glen Canyon Dam (RM -16) to the Lees Ferry boat ramp (RM 0) using methods described in Kennedy and others (2014). This dataset allows us to understand and model changes in invertebrate drift over time. Because rainbow trout and humpback chub are both predominantly drift-feeders, these data provide a direct measure of the food most available to these fishes. Drift data are also more tightly correlated to larval aquatic insects on the bed of the river “the benthos” (Statzner and Resh, 1993); as such, these data provide a useful metric in comparing conditions in the CRe to other streams and rivers that are monitored using more traditional benthic sampling. Such benthic sampling is generally infeasible in the CRe due to safety concerns.

Adult aquatic insects are also monitored during these monthly sampling trips using sticky traps (Smith and others, 2014) and light traps (Kennedy and others, 2016). Sticky traps are deployed at 10 different locations roughly evenly distributed from near Glen Canyon Dam (RM -16) to the Lees Ferry boat ramp (RM 0). At each of these sampling 10 locations, sticky traps are deployed on both the right and left riverbank, which allows us to evaluate whether adult insect abundance varies as a function of canyon shading/sunlight. Additionally, at each sampling location, one trap faces downstream to capture insects that are flying upstream, and one trap faces upstream to capture insect that are flying downstream (i.e., 40 sticky traps per month). Light traps are deployed at 3 locations in Glen Canyon (RM -12, -6, and -3.5). Because sticky traps and light traps are placed at the same locations on every sampling trip, they provide a robust metric for assessing monthly changes in adult aquatic insect activity, particularly in response to changing environmental conditions or flow experiments.

Project Element F.3. Aquatic Invertebrate Monitoring of Grand Canyon Tributaries

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This element involves monitoring the aquatic invertebrate community within tributary streams in Grand Canyon using environmental DNA (eDNA). These tributary streams are important spawning and rearing habitat for native fishes, and some are also sites of humpback chub translocations. For this reason, understanding the diversity of aquatic food base resources available to these fishes can influence decisions about whether to translocate more fishes into these streams, and in identifying candidate streams for future translocations. Further, tributaries represent sources of aquatic insects that could recolonize the mainstem Colorado River. Understanding the locations of these aquatic insect populations therefore provides insight into where we might first expect to see sensitive ephemeroptera (mayfly), plecoptera (stonefly) and trichoptera (caddisfly) taxa colonizing the mainstem.

Water samples for eDNA analysis of invertebrate diversity have been collected annually on April food base monitoring river trips described in Element F.1 starting in 2021. These samples have been processed and analyzed by cooperators at Oregon State University and show that tributaries in Grand Canyon support more diverse invertebrate communities compared to the mainstem Colorado River (Lytle and others, 2023). Notably, eDNA monitoring of invertebrate diversity in tributaries has documented roughly twice the number of invertebrate genera compared to traditional benthic surveys of invertebrates (Lytle and others, 2023). Archived eDNA water samples dating back to 2021 and new samples that will be collected during FY 2025-27 can also be used to detect the presence/absence of non-native invertebrates and fishes whose ranges and distribution are expanding or contracting.

Project Element F.4. Fish Diet Studies

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Current food base monitoring approaches were informed by detailed food web studies and invertebrate and fish diet analysis of samples collected from 2006–2009 (Cross and others, 2013; Kennedy and others, 2013). These studies identified that algae fuels growth of invertebrate populations everywhere, even at muddy downstream sites where algae are scarce (Wellard Kelly and others, 2013). Based on these insights, GCMRC scientists and collaborators developed techniques for continuously monitoring the algae-portion of the food base using dissolved oxygen budgeting (see Project E), which has shed light on the role of dam operations and environmental factors in regulating algae growth (Hall and others, 2015). Early diet studies also identified that aquatic insects were key prey for native and desired non-native fishes (Cross and others, 2013; Zahn Seegert and others, 2014), but the overall low production and diversity of aquatic insects in the CRe appeared to be a major constraint on fish populations overall (Kennedy and others, 2013). Thus, GCMRC scientists developed new techniques for studying the invertebrate-portion of the food base, including citizen science light trapping of the understudied adult life stage of aquatic insects (Kennedy and others, 2016).

To assess feeding habits of native and non-native fishes, we will focus on non-lethal methods in line with tribal concerns regarding the taking of life. Specifically, we will collect fin clips from fishes to analyze for stable isotopes and we will collect fecal samples for DNA analysis. Carbon and nitrogen stable isotope analysis of fin clips provide a non-lethal indication of long-term feeding habits including the trophic position of fish and the relative importance of algae vs. terrestrial detritus to fish production overall. This long-term information on general feeding habits obtained from stable isotopes complements the detailed “snapshot” of feeding habits that we will obtain from DNA analysis of fish feces. Additionally, as part of F.4, we will conduct gut content analysis on smallmouth bass (*Micropterus dolomieu*) and green sunfish (*Lepomis cyanellus*) specimens that are collected in course of removal efforts to describe their feeding habits (see Project I).

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1. Budget







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Project G: Humpback Chub Population Dynamics Throughout the Colorado River Ecosystem

1. Investigators

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1. Project Summary and Purpose

The FY 2025-27 Triennial Work Plan coincides with a period that will likely present new challenges to managing fishery resources within the Colorado River ecosystem in Grand Canyon. Most of our knowledge of humpback chub in Grand Canyon comes from studies that occurred under colder water conditions in the mainstem Colorado River, even though warming of the mainstem river by a few degrees in recent years has led to large changes in fish communities in Grand Canyon (e.g., increase/expansion of humpback chub in western Grand Canyon, first observations of juvenile YOY from several warmwater non-natives) providing further evidence that water temperature is a key driver of fish communities. The rules that will determine Lake Powell elevations and annual release volumes are unknown, and future hydrologic conditions are uncertain, making it difficult to predict how much time will be spent at lower reservoir elevations at which releases through penstocks will be as warm or warmer than releases in 2022 and 2023. Additionally, modifications to LTEMP flows are being proposed that may lead to increased frequency of spring-timed HFEs, as well as flows to disadvantage warmwater non-natives including smallmouth bass that may have direct and indirect impacts on humpback chub and other native fishes. Project G is designed to estimate the effects of managed, and unmanaged, drivers on the growth survival, survival, and juvenile production of humpback chub to quantify impacts of management (in the context of unmanaged variation) and improve our ability to forecast future population dynamics. Project G is also designed to estimate state variables (abundance, distribution) for the Biologic Opinion and as metrics for the GCDAMP.

Many project elements in Project G are long-term monitoring projects to estimate humpback chub abundances at various life stages throughout different parts of Grand Canyon. In addition, monitoring from fixed sites (e.g., juvenile chub monitoring [JCM]-east, JCM-west, lower LCR) provides estimates of vital rates (e.g., survival, growth, movement) which can allow us to forecast population dynamics under different management scenarios.

Past data collected by these monitoring projects provide a baseline for comparison under past and future climate scenarios and can also provide information about if (how) potential increases in warmwater non-native fishes (e.g., smallmouth bass, green sunfish, walleye) affect humpback chub population dynamics. For this reason, continuing long-term monitoring is a priority in Project G for FY 2025-27.

In FY 2025-27, we hope to address a key uncertainty for population prediction in western Grand Canyon – is adult survival actually lower in western Grand Canyon relative to eastern Grand Canyon? Research during the FY 2020-22 work plan found that adult apparent survival in the western Grand Canyon was lower than survival in eastern Grand Canyon, however, estimates of apparent survival cannot separate survival from permanent emigration. We propose to deploy submersible antennas across various monitoring projects to spatially expand and randomize detection probability within Grand Canyon (Project Element G.9) so that biologists have more information about humpback chub movement patterns in western Grand Canyon. This information will allow biologists to determine whether low apparent survival estimates of adults in Grand Canyon is largely due to emigration (i.e., movement out of the sample site) or whether it is due to higher mortality.

Additionally, monitoring outlined in Project G will help document whether high age-0 production of humpback chub in 2022 and 2023 in the Colorado River ecosystem experience resource limitation, density-dependence, and natural population fluctuations in the near future. In both JCM-east and JCM-west, monitoring efforts have documented strong cohorts (i.e., lots of age-0 fish) in 2022 and 2023, years when adult humpback chub abundances were also high. It is unknown whether juvenile humpback chub born in 2022 and 2023 will successfully recruit to the adult population, or whether resource limitation and density-dependence will cause high mortality of these fish, similar to the population decline documented for rainbow trout in 2014 and 2015 that occurred after a large production pulse in 2011. Similarly, the LCR had high production of age-0 humpback chub in spring 2023, but these fish were all of small size and it is unknown how many from this cohort will survive winter in the LCR.

In summary, Project G includes project elements to estimate abundances required by the 2016 Biological Opinion (G.1, G.2, G.3, G.4) by monitoring humpback chub in the LCR-spawning population by sampling the LCR and JCM-east reach in the Colorado River (Project Elements G.2, G.3). Because humpback chub are federally threatened, the Biological Opinion helps with compliance of the Endangered Species Act. Additionally, this project includes sampling in western Grand Canyon via continuation of mark-recapture in the Fall Canyon reach and extensive spatial sampling via the aggregation trips (Project Elements G.5, G.6). Mark-recapture data from these trips will be supplemented with data from autonomous PIT tag antennas (Project Elements G.4, G.9), such as the LCR multiplexer array and submersible antennas, as these technologies have proven effective at detecting larger adults.

The FY 2025-27 work plan proposes continuation of Chute Falls translocations and monitoring by the USFWS (Project Element G.7) to continue to monitor the effectiveness of this conservation action for increasing adult abundance and to evaluate whether there is natural reproduction/recruitment above Chute Falls, especially in years without preceding winter floods. Lastly, we propose one new project element (G.8) to do a preliminary assessment of humpback chub in the upper LCR (river kilometers (rkm) ~32.5) to evaluate spatial distribution, habitat associations, and source/sink dynamics in this newly discovered habitat for humpback chub. Data collected from the above-mentioned field efforts will be analyzed to help learn more about humpback chub life history and to guide management efforts (Project Element G.1).

1. Proposed Work

Project Element G.1. Humpback Chub Population Monitoring

Evaluate population dynamics using mark-recapture data

We will develop and refine models using data from existing (and ongoing) field sampling to help inform management efforts and conservation actions for humpback chub. Proposed foci for modeling efforts include: 1) estimating abundance of various size classes in the LCR-spawning population as defined in the Biological Opinion (LTEMP ROD; U.S. Department of the Interior, 2016) to inform the need for management alternatives (e.g., trout removals, translocations) for maintaining humpback chub abundances of 7000-9000 near the LCR, 2) developing an occupancy model that accounts for detection probability to look at long-term, large-scale changes to humpback chub distribution with the Colorado River ecosystem (proposed metrics), 3) including antenna detections from a wide geographic area in Grand Canyon to obtain a better estimate of adult survival in JCM-west (i.e., to differentiate emigration from mortality), 4) estimate abundance of humpback chub adults in western Grand Canyon based on data collected by humpback chub aggregations sampling trips (proposed metrics), 5) estimate the effects of environmental covariates on demographic parameters (e.g., survival, growth, movement), which may help predict humpback chub responses to management actions and future scenarios.

Project Element G.2. Annual Spring/Fall Abundance Estimates of Humpback Chub in the Lower 13.6 km of the LCR

USFWS sampling trips

The USFWS has been conducting four sampling trips into the LCR each year since 2001, and this data set is used to estimate humpback chub abundance at different life stages. These abundance estimates document substantial temporal changes to adult population size since 2000, most notable of which is the increase in adult abundance that has occurred since 2007. This project element will continue into the next work plan to help assess the health of the LCR-spawning humpback chub population and to inform potential management actions, such as the triggers for trout removal.

This project element informs the tier for triggers as part of the Biological Opinion (LTEMP ROD; U.S. Department of the Interior, 2016), which is linked to management alternatives (e.g., trout removals, translocations). This project element also informs proposed metrics for humpback chub, other native fishes, and non-native invasives.

Project Element G.3. Juvenile Chub Monitoring (JCM) near the LCR Confluence

Sampling trips to the JCM-east reach and lower LCR

This project element is a continuation of previous monitoring work that commenced in 2012 and includes three annual sampling trips to the JCM-east reach as well as one annual sampling trip to the lower LCR to estimate abundance and outmigration of age-0 humpback chub born the previous spring. Data from these trips provide information about age-0 production in the LCR, age-0 outmigration to the JCM-east reach, and life-stage specific abundance estimates from the Colorado River and LCR. These life-stage specific estimates can help predict future changes to adult humpback chub population size. This project element informs the tier for triggers as part of the Biological Opinion (LTEMP ROD; U.S. Department of the Interior, 2016), which is linked to management alternatives (e.g., trout removals, translocations). This project element also informs proposed metrics for humpback chub, other native fishes, and non-native invasives.

Project Element G.4. Remote PIT Tag Array Monitoring in the LCR

Assessing humpback chub movement and improving detection of large fish

Previous work suggests that models fit to mark-recapture data from physical captures (i.e., mainly hoop nets and electrofishing) underestimate survival and movement probabilities compared to models that include both data from physical captures and autonomous PIT antenna detections (Dzul and others, 2021). This project element funds maintenance of a multiplexer array (MUX) located in the LCR ~1.7 rkm upstream of the confluence. This project element improves the precision of abundance estimates for triggers (i.e., mechanical removals) as part of the Biological Opinion (LTEMP ROD; U.S. Department of the Interior, 2016), which is linked to management alternatives (e.g., trout removals, translocations).

Project Element G.5. Monitoring Humpback Chub Aggregation Relative Abundance and Distribution

Canyon-wide sampling of fish throughout Grand Canyon with an emphasis on humpback chub

Compared to JCM-east and JCM-west sampling, humpback chub aggregations trips sample fish over a wider spatial area that encompasses sites within Marble Canyon and Grand Canyon, including humpback chub hotspots as well as less frequently monitored locations. Humpback chub aggregations sampling will include 1 sampling trip per year to visit aggregations sites and some non-aggregations sites to help assess how temporal patterns in abundance vary spatially.

Additionally, we propose to add an additional boat to accompany an existing sampling trip (e.g., aggregations trip, eDNA trip) to seine backwaters throughout Grand Canyon for small-bodied native and non-native fishes. To obtain more updated information about capture probabilities, particularly how capture probabilities of baited hoop nets are influenced by warmer water temperatures, we propose adding an extra Diamond-down sampling trip in FY 2026. This project element informs proposed metrics for humpback chub, other native fishes, and non-native invasives.

Project Element G.6. Juvenile Humpback Chub Monitoring – West

USGS established a fixed monitoring site in western Grand Canyon, Fall Canyon reach (also referred to as JCM-west) in fall 2017. We propose to continue monitoring fish in Fall Canyon reach by conducting three sampling trips per year (May, July, October). These three annual visits to JCM-west occur during the same sampling trip as monitoring of JCM-east, so that the two fixed Grand Canyon sites are visited during the same trip. Monitoring JCM-west will allow scientists to estimate survival, growth, and abundance of humpback chub in western Grand Canyon, and these estimates will be compared to that of LCR-spawners in JCM-east to learn about how humpback chub will respond to management actions and future conditions (i.e., potential increase in non-native fishes). This project element informs proposed metrics for humpback chub, other native fishes, and non-native invasives.

Project Element G.7. Chute Falls Translocations

Management (and monitoring) to increase humpback chub adult abundance in the LCR-spawning population

Models developed under the FY 2018-20 work plan suggest that humpback chub translocated above Chute Falls experience fast growth and high survival and that Chute Falls translocations are a beneficial management tool for increasing abundance of humpback chub. In addition, biologists have documented numerous unmarked subadult humpback chub, indicating that humpback chub may be spawning and recruiting above Chute Falls. Accordingly, under this work plan we propose to continue Chute Falls translocations and monitoring. This requires adding one additional camp (3-4 people) during the May USFWS sampling trip for monitoring work, and additional people and helicopter time during the October trip to catch and translocate fish from the lower LCR to above Chute Falls. We also propose adding extra personnel on the October translocation trip to monitor Chute Falls for juvenile humpback chub in fall. This project element is a management action and has been used as a Tier-1 trigger response as described in the Biological Opinion (LTEMP ROD, U.S. Department of the Interior, 2016).

Project Element G.8. Sampling of springs in the upper LCR

Sampling of the upper LCR (~ 32 river kilometers from confluence) for humpback chub

In the past, fish monitoring of the LCR has focused primarily on areas where humpback chub are known to occur (i.e., downstream of Blue Springs, located 21 rkm above the confluence with the Colorado River), with upstream sections less frequently monitored. Above Blue Springs, flow in the LCR is intermittent until reaching the White Mountains, near the headwaters of the LCR. When the LCR is not flooding, this intermittent section of the LCR is comprised of numerous springs interspersed through patches of dry riverbed, and when floods occur, the increased flow coming down the LCR corridor connects this intermittent segment to the rest of the LCR. This intermittent habitat has been recognized as a potential source of non-native species getting washed downstream from the upper LCR but it has not been considered to be suitable habitat for native fishes moving upstream from Blue Springs. Accordingly, biologists from USFWS were surprised to capture both juvenile and adult humpback chub in this stretch of river (~rkm 32.5) as part of their non-native fish surveys in June 2023 (funded in Project I in the FY 2021-23 TWP).

The LCR experienced large floods during the winter of 2022-2023, and it is unknown whether humpback chub found in the upper LCR in June 2023 were recent transplants from the lower reaches (i.e., swam up from the lower LCR during the 2023 flood), or whether humpback chub have persisted in these spring habitats for numerous years. Furthermore, if humpback chub are recent transplants, it is unknown how long can they persist/reproduce in these patchy spring habitats or whether these fish are likely to die shortly after upstream movement and subsequent isolation. This project aims to understand habitat use and movement dynamics of humpback chub in the upper LCR, and will help evaluate: 1) to what extent (if any) LCR population estimates of humpback chub are biased due to restricted spatial sampling (i.e., lower LCR only), 2) whether movement into the upper LCR acts as a source of mortality for adult HBC in flood years (i.e., adults swim up, get stranded in springs, and eventually die), and 3) whether upstream springs can act as refugia for humpback chub if the mainstem Colorado River warms is invaded by non-native warmwater piscivores (e.g., smallmouth bass, walleye, green sunfish) that may threaten recovery. Additionally, fish surveys of the upper LCR would continue to help biologists evaluate to what extent these springs act as sources of non-native fishes that can seed the lower LCR during floods.

We propose two 5-day trips to the upper LCR in FY 2025 (1 in spring, 1 in fall) to evaluate the spatial distribution of humpback chub and other fishes in the intermittent flow habitats of the upper LCR. These trips will be conducted when the LCR is at baseflow so that springs can be more effectively sampled. In addition to using methods to capture fishes, this trip will also collect water samples containing environmental DNA to help evaluate native and non-native fishes that may be present but not captured. This project element could inform whether humpback chub translocations into upper pools in the LCR would be an appropriate conservation action that could be used to address Tier-1 triggers associated with the Biological Opinion (LTEMP ROD; U.S. Department of the Interior, 2016).

Project Element G.9. Movement in western Grand Canyon from system-wide antenna monitoring

Increase use of submersible antennas throughout Grand Canyon to detect fishes in less-frequently sampled river reaches

Because the Colorado River in Grand Canyon cannot be sampled in its entirety, biologists must frequently make assumptions about fish movement in order to fit population models to estimate abundance and survival. Often, movement out of a study site (i.e., permanent emigration) is confounded with mortality so that biologists can only obtain estimates of ‘apparent’ survival (i.e., probability a fish survives and remains in the study site). Apparent survival estimates of fishes in JCM-west are relatively low for adult humpback chub, suggesting either increased emigration or increased mortality of adult humpback chub in western Grand Canyon compared to near the LCR. Estimates of apparent survival can impair population inference, because movement and mortality have different implications for population dynamics. By searching for marked fishes in river reaches that are less frequently visited by fish monitoring trips, biologists would learn more about fish movement patterns and this updated information could be used to improve population models.

We propose purchasing 8-10 submersible antennas that could be deployed on numerous scientific trips (e.g., Arizona Game and Fish SWEF trips that randomly sample reaches) and 4-5 submersible antennas that could be deployed by river boatmen as part of a citizen science project to help collect data about movement of fishes. These antennas would be baited, deployed overnight throughout a section of river, and collected the following morning. Citizen scientists would be paid for data collection (fee TBD).

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Project H: Salmonid Research and Monitoring Project

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1. Project Summary

The Long-Term Experimental and Management Plan (LTEMP; U.S. Department of the Interior, 2016) provides the necessary long-term framework for assessing specific operations at Glen Canyon Dam, including experimental flows as well as other types of management actions conceived during and implemented over the next 20-year period. The LTEMP includes a goal for the rainbow trout (*Oncorhynchus mykiss*) fishery in Glen Canyon: *“Achieve a healthy high-quality recreational rainbow trout fishery in GCNRA and reduce or eliminate downstream trout migration consistent with NPS fish management and ESA compliance.”* For these reasons, the Salmonid Research and Monitoring Project, was developed having the long view, to inform stakeholders and management responses to unanticipated and emerging risks (e.g., brown trout [*Salmo trutta*]; Runge and others, 2018). Rapidly changing conditions related to basin-wide water management and upstream reservoir dynamics have led to occurrences of low dissolved oxygen, warming temperatures, and new warmwater non-native species invasions in Glen Canyon requiring additional quantitative monitoring sensitive to these changes ( Dibble and others, 2021; Bruckerhoff and others, 2022; Eppehimer and others, 2024). Water quality and temperature changes influence populations of salmonids in Glen Canyon (Korman and others, 2021; Korman and others, 2023). Given these new developments, it is unclear whether the new invasions of warmwater non-native species will disrupt the balance between salmonids and endangered native fishes downstream, and the rainbow trout fishery in Glen Canyon.

In general, the study design described in the previous two work plans (FY 2018-20, FY 2021-23 Triennial Work Plans [TWP]) is still relevant for addressing management questions posed in the LTEMP, with similar designs likely relevant to the GCDAMP long into the future.

Importantly, recent changes in the water quality and temperatures discharged from Glen Canyon Dam as reservoir storage in the Colorado River basin declines may potentially impact salmonid populations (Bruckerhoff and others, 2022; Healy and others, 2023). Operational changes designed to respond to warmwater non-native fish invasions and other ecological changes are being proposed by Reclamation (e.g., SEIS, Bureau of Reclamation, 2024). Additionally, GCDAMP stakeholders have requested the GCMRC consider and reduce overlapping projects to enhance monitoring and research efficiencies and optimize information gathering for decision-making. We recognize monitoring and research related to LTEMP salmonid goals needs to be precise and sensitive to anticipated short- and long-term ecosystem changes. Thus, some modifications to this project are proposed for the 2025-2027 TWP.

The type of quantitative approach ongoing and proposed herein is appropriate for understanding large and complex ecosystems, particularly, when quantifying drivers of rainbow trout and brown trout population dynamics. This research project proposes to evaluate (1) the effect of ongoing ecological changes (i.e., temperature, dissolved oxygen, warmwater species invasion) on trout somatic growth, reproduction, recruitment, and survival, (2) effects of spring and fall high flow events (HFEs) on trout recruitment, dispersal, and growth, (3) factors controlling trout recruitment and dispersal into Marble Canyon and Little Colorado River (LCR) reaches, (4) factors controlling the quality of the trout fishery (growth, sexual maturity, and angler catch rates), and (5) factors regulating brown trout and other non-native fish population dynamics, as well as efficacy of an incentivized brown trout harvest program. Summarized below are monitoring and research elements that address the primary study objectives.

1. Ongoing (modified) Monitoring Studies

Project Element H.1. Trout Monitoring in Glen Canyon

The objective of this project element is to monitor the basic fish population characteristics, including relative abundance, size composition, distribution, and recruitment of rainbow trout and brown trout. In past work plans, the monitoring program used catch-per-unit effort (CPUE) metrics designed to be able to detect population level changes over a five-year or greater time scale; however, for the FY 2025-27 work plan we propose to combine staffing resources and electrofishing-based monitoring trips between H.1 and H.2 to enable more precise and sensitive mark-recapture monitoring, while also adding days onto 2 monitoring trips (June and October) for non-native fish species surveillance (an additional downstream electrofishing monitoring trip is proposed in lieu of Lees Ferry CPUE trips as well; see Project I). In total (including H.1 and H.2), trout monitoring trips will be reduced from 8 to 4, compared to the previous work plan. Despite these changes, CPUE will continue to be calculated from data collected during the remaining 4 mark-recapture-focused trips.

The Lees Ferry Creel Survey and Arizona Game and Fish Department (AGFD) Citizen Science Project (FY 2021-23 and previous TWPs), which directly evaluates the quality and changes in the recreational experience of angling in the rainbow trout fishery in the Lees Ferry, Glen Canyon National Recreation Area is proposed to continue.

AGFD will continue conducting a citizen science project that utilizes fishing guides to collect length data on fishes caught by their clients to reduce bias in angler catch quality (i.e., number of fish ≥ 14” and fish ≥ 20”).

1. Continuing (modified) Research Studies

Project Element H.2. Trout Reproductive and Growth Dynamics Fieldwork

This is a research project referred to as the Trout Reproductive and Growth Dynamics (TRGD) project, which is designed to determine the effects of LTEMP ROD flows on the recruitment of young-of-year (YOY) rainbow and brown trout in Glen Canyon, growth rates of juvenile and adult trout, and dispersal of YOY trout from Glen Canyon to Marble Canyon. Another central objective of TRGD is to increase our understanding of the key factors (e.g., trout density and recruitment, prey availability, nutrients, temperature, dissolved oxygen, etc.) that control abundance and growth of the Glen Canyon trout population(s) to better predict the effects of management actions and environmental changes. This improved understanding could inform decisions related to future management of the trout fishery, or lead to the identification of policies other than flow manipulation that could benefit the Lees Ferry fishery and limit the downstream dispersal of rainbow trout to the LCR, and controlling recently established brown trout numbers (Runge and others, 2018). For purposes of study replication, a multi-reach mark-recapture sampling design was established having two sub-reaches, each with an assigned 3-km length (sum 24% areal coverage). Trout species (and potentially other species) will continue to be marked with a passive-integrated transponder (PIT) tag, and recapture data will be analyzed to estimate demographic parameters using appropriate mark-recapture models (e.g., robust design, Kendall, and others, 1995; e.g., Korman and others, 2021). We will also continue to monitor dissolved oxygen levels in the Lees Ferry reach to understand how temporal and spatial variation relates to trout growth, body condition, and demographic rates.

This spatial coverage has allowed for the replication necessary for assessing experimental flow effects (Korman and others, 2021; Korman and others, 2023), and allows the TRGD program to maintain the necessary long-term analysis (comparisons and contrasts) associated with the Natal Origin project (2012-2017; FY 2015-17 TWP, Project Elements 9.1, 9.2, and FY 2018-20 TWP). Data from the TRGD project are used to inform development of a spatially stratified open population model for rainbow trout (Korman and Yard, 2017a; Korman and others, 2017b), and a population model for brown trout (Runge and others, 2018; Yackulic and others, 2020).

These models provide estimates of how experimental flows and riverine conditions influence survival and recruitment of early YOY, as well as other size-classes of trout that may exhibit compensatory response in the population. Trout dispersal out of Glen Canyon will continue to be monitored in Marble Canyon, as well as trout population dynamics and near the LCR confluence in conjunction with humpback chub (*Gila cypha*) monitoring (Project G). Lastly, monitoring population dynamics of brown trout provides the means to assess incentivized take harvest measures by National Park Service (Project Element H.3).

For the FY 2025-27 work plan, we propose to minimize project costs and avoid monitoring during periods of elevated stress to trout when low dissolved oxygen or high temperatures have been observed to occur (fall), by reducing the total number of electrofishing monitoring trips in Element H.1 and H.2 from 8 to 4 trips (also see Project H.1 description above).

Project Element H.3. Salmonid Modeling

Salmonid modeling priorities in this work plan include 1) estimating the efficacy of incentivized harvest on brown trout (by updating brown trout population model and incorporating harvest data) to inform managers and Project J, 2) reassessing the brown trout hypotheses explored in Runge and others (2018) using data collected in recent years and based on natal origins and movement studies (Healy and others, 2022; Akland, 2023), 3) continuing to develop models to predict recruitment and outmigration of rainbow and brown trout - outmigration of trout and other non-native fishes from Lees Ferry to downstream areas, including tributaries, can enhance resilience of non-native salmonid populations (Healy and others, 2023) and is seen as detrimental to native fish conservation goals (Yackulic and others, 2018; Healy and others, 2020), 4) estimating population dynamics of rainbow and brown trout in the Lees Ferry reach in response to experimental flows and environmental conditions, and 5) develop a workflow and analytical approach for calculating LTEMP metric scores for salmonids related to rainbow trout and non-native fish goals. Finally, we plan to finish the development of manuscripts using reproductive status data collected in the previous work plan, which revealed that condition-effected sexual maturation rate appears to play an important role in regulating annual recruitment. Understanding this relationship may help us develop a more reliable method for forecasting and responding to large recruitment events.

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Project I: Non-Native Invasive Species Monitoring and Research

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1. Project Summary and Purpose

Maintaining self-sustaining native fish populations within the Colorado River and minimizing the presence and expansion of aquatic invasive species are two resource goals outlined in the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) and associated Biological Opinion (BiOp) for the operation of Glen Canyon Dam (U.S. Department of Interior, 2016a, b; U.S. Fish and Wildlife Service, 2016). These two resource goals are closely linked together in that non-native warmwater fishes are largely incompatible with Colorado River native fishes (Marsh and Pacey, 2005; Minckley and Marsh, 2009). Non-native warmwater sport fishes prey upon juvenile native fishes, and once established, can cause rapid disappearance of native fishes (Moyle and others, 1986). In both the upper and lower Colorado River Basins, warmwater predatory fishes are implicated in the lack of recruitment and subsequent population declines of native fishes (Mueller, 2005; Martinez and others, 2014). Outside of pre-invasion preventative measures, control methods are typically most cost effective and successful when invasions are detected early (Leung and others, 2002; Dawson and Kolar, 2003). A robust monitoring and research program increases the likelihood that a new invasion will be detected early and that management actions can be taken to control pest species.

In 2022, warmwater non-native fishes including smallmouth bass (*Micropterus dolomieu*), green sunfish (*Lepomis cyanellus*), and walleye (*Sander vitreus*) were captured in unprecedented numbers in the Colorado River downstream from Glen Canyon Dam during routine fish monitoring efforts by state and federal agencies. Reservoir levels in Lake Powell had precipitously declined during a multi-decadal drought, resulting in reservoir releases from the warmer epilimnion (top layer) and upper metalimnion (middle layer) of the lake. Biological activity and fish production is highest in the warmer epilimnion of Lake Powell, so as reservoir levels dropped more fish were entrained and moved through the penstocks into the downstream river. Warmer reservoir releases likely supported higher survival and successful reproduction of warmwater entrained fishes including smallmouth bass (Bruckerhoff and others, 2022; Dibble and others, 2021; Eppehimer and others, 2024). Smallmouth bass are a species of high concern to resource managers because they are highly piscivorous and have led to population-level declines in native species in regions where they have been introduced (Loppnow and others, 2013).

In the FY 2025-27 TWP, we propose to revise or replace the three monitoring and research Project Elements from the FY 2021-23 TWP and add a new element on modeling. The focus of Project I will primarily be on invasive species [except for Project Element I.1, which focuses on both native and non-native fishes]. Modeling work on native fishes will move to a new Project (N) to address the LTEMP goal focused on ‘Other Native Fish Species’. In total, the number of project elements in Project I will increase by one in the FY 2025-27 TWP relative to the FY 2021-23 TWP. We propose to continue long-term, standardized monitoring conducted by the Arizona Game and Fish Department (AGFD) throughout the Colorado River from Lees Ferry (RM 0) to Pearce Ferry (RM 281) for the combined purposes of tracking the status of native and non-native fishes, as well as identifying new invasive aquatic species (Project Element I.1).

These data can be used to determine the distribution of invasive fishes throughout Glen and Grand Canyons and detect evidence of local reproduction through use of length-frequency histograms (via modal progression analysis). We propose to pursue kinship genetic analysis to evaluate the relatedness of individual smallmouth bass and determine whether there is evidence of local recruitment (i.e., most individuals captured near the slough are siblings or half-siblings), or if there is evidence of entrainment (i.e., most individuals captured near the dam represent a greater number of parent-offspring pairs; Project Element I.2).

We would like to re-focus an existing Project Element (I.3) to detect emerging threats in the Colorado River Ecosystem (CRe), which may include non-native fishes, parasites, disease, crayfish, gastropods, mollusks, and other invasive aquatic species. One of the primary methods proposed to detect such threats in this work plan will be the use of environmental DNA (eDNA), which is a method that will reduce handling of aquatic organisms through the collection of water samples and fish fecal matter. Last, we propose to add a new Project Element (I.4) that focuses entirely on modeling non-native fish data from GCMRC, NPS, AGFD, USFWS, and other cooperators.

This modeling will support refinement of existing smallmouth bass models, help determine the effectiveness of flow and biological management actions, and provide science to support discussions of offramps laid out in the Invasive Fish Species Strategic Plan (Smallmouth Bass Ad Hoc Group, 2023). We also propose to develop a workflow process for an occupancy model in collaboration with Projects H, G, and N that models native and non-native fish detection throughout the CRe for the purpose of reporting out to the GCDAMP on LTEMP metrics. If flows to disadvantage smallmouth bass are implemented per the preferred alternative in the LTEMP SEIS, and there is sufficient high-quality data, we will analyze monitoring data to evaluate the effectiveness of smallmouth bass flows and collect larval fishes to determine hatch dates. We propose to fund SEIS-related smallmouth bass modeling and hatch date analyses using the Experimental Fund.

Other efforts to increase detections of non-native fishes in this TWP include the addition of a boat to the fall USFWS humpback chub (*Gila cypha*) aggregations sampling trip to seine backwaters for non-native fishes and collect eDNA samples (Project Elements G.5 and I.3), Juvenile Chub Monitoring in Eastern and Western Grand Canyons (Project Elements G.3 and G.6), USFWS humpback chub aggregations sampling (Project Element G.5), and testing the use of submersible antennas with citizen scientists to detect pit-tagged fish in less visited areas (new Project Element G.8). Increasing our understanding of smallmouth bass diet is also proposed to continue during this work plan (see Project Element F.4), and we plan on including non-native fishes in a study to determine basal metabolic rates of fishes that will inform development of ecosystem models proposed in Project Element E.4. Other fishery monitoring efforts conducted by the National Park Service and other partners augment work funded through GCDAMP to detect non-native fishes in Glen and Grand Canyons. These combined efforts provide important additional detection information of invasive aquatic species throughout the CRe.

1. Proposed Work

Project Element I.1. System-wide Native Fishes and Invasive Aquatic Species Monitoring

The objective of this project element is to provide long-term data on the longitudinal distribution and status of the fish community in the mainstem Colorado River from Lees Ferry (RM 0) to Pierce Ferry (RM 281). These data could be used in the development of proposed Metric 10, which is focused on detecting the presence and reproduction of aquatic invasive species. AGFD will conduct up to two spring system-wide fish monitoring trips from Lees Ferry to Pearce Ferry in FY 2025-27, and we propose to add a new system-wide sampling trip in fall that is timed when non-native detections are likely to be highest during the warmest months of the year. Discussions are currently underway, but this trip could replace or be coordinated with the existing fall trip that samples the last 15 miles of river upstream from Pearce Ferry Rapid, since that area would be covered by the proposed new fall system-wide sampling trip.

AGFD trips will use a combination of standardized electrofishing, hoop-netting, and/or angling, potentially combined with a new method in this work plan (submersible portable antennas, see Project Element G.9) to increase detections of pit-tagged native and non-native fishes in areas less frequently sampled. In addition, we propose to add additional nights of non-native fishes surveillance in the Lees Ferry reach during the June and October TRGD trips in association with a proposed combined AGFD/USGS trout monitoring project (see Project Elements H.1 and H.2).

Previously, this non-native fish surveillance was conducted in association with AGFD’s trout monitoring project to increase detection of new invasive fishes entrained through the penstocks. This monitoring will be focused in areas known to harbor invasive fishes, such as the area directly downstream from the dam, the slough at -12 mile, and other areas with warmer water or spring inputs. Additional randomly sampled sites may be added to increase spatial coverage beyond the two fixed TRGD sites.

Project Element I.2. Estimating Kinship and Spawner Abundance of Warmwater Non-Natives

Kinship analysis relies on genetic samples from individuals (which can be released alive or removed) to provide estimates of the number of full siblings (same mother and father), half siblings (same mother or father), and other relationships (e.g., parent offspring pairs) in the sampled set of individuals. Given large enough sample sizes, kinship analyses can also be used to fit close-kin mark-recapture models that estimate spawner abundance and survival even when individuals are being removed (e.g., for exploited populations, or in the case of smallmouth bass in Lees Ferry reach that are being actively removed). Even if sample sizes are not sufficient for these types of estimates, kinship grouping (e.g., did most individuals derive from a small number of parent pairings or is there evidence of large numbers of parent pairings) and spatial patterns in grouping (e.g., are most individuals captured near the slough siblings or half-siblings of larval fish collected in the slough indicating local recruitment, do individuals removed from near the dam represent a greater number of parent pairings suggesting entrainment) could help to better clarify the relative extent of entrainment versus local production of smallmouth bass, especially when combined with other ongoing studies. In FY 2023, the Bureau of Reclamation funded pilot work outside the GCDAMP to understand the kinship of smallmouth bass removed during 2022 to determine how related individuals were to each other. GCMRC sent genetic material from these smallmouth bass to collaborators (Drs. Megan Osborne and Thomas Turner) at the University of New Mexico, Turner Aquatic Conservation Lab to test whether analysis using microsatellite markers could provide estimates of relatedness among individual smallmouth bass. This analysis is ongoing, however preliminary results are expected soon and samples from 2023 have already been prepared for additional genetic analysis. Results of the preliminary analysis may suggest that development of more precise markers using Single Nucleotide Polymorphisms (SNPs) would provide better resolution or may suggest that further microsatellite analysis is sufficient. Both microsatellites and SNPs are methods used to identify individual genotypes and their variation among individuals, but SNPs have been found to be a more powerful tool in understanding relatedness among individuals of a fish population (Hauser and others, 2011).

In the FY 2025-27 work plan, we propose to use kinship genetic analysis to better understand the ongoing invasion by smallmouth bass and potentially estimate spawner abundance and survival. This work will provide important information on reproduction dynamics and larval sources for a species that has the potential to prey on ESA-listed species downstream. This work would benefit from additional genetic sampling of individuals above Lake Powell as well as continued analysis of individuals captured through monitoring and removal efforts in the CRe. Kinship analysis requires sampling of only one generation, whereas parentage analysis requires information from both the offspring and parents, and we may also explore parentage analysis if sufficient numbers of adults are sampled. If successful, we could expand this approach to other non-native fish species with increasing catch rates (e.g., walleye).

In addition, we propose to analyze genetic samples from green sunfish in Lees Ferry using parentage and kinship analysis, and if possible fit close-kin mark-recapture models to compare estimates of abundance and survival to estimates from a concurrent traditional mark-recapture study. We would like to pursue this paired approach because it is difficult to obtain estimates of abundance with removal data, and we may not have enough statistical power to detect population change unless a management action leads to a large decrease in non-native fish. Thus, using close-kin information may represent an innovative method to obtain abundances with removal data that could lead to improvements in model precision. Close-kin mark-recapture models are still fairly novel within the broader field, so this comparison will help us better understand the potential to use this technique for other rarer species (e.g., smallmouth bass, walleye). The traditional mark-recapture analysis would rely on pit-tagging and releasing green sunfish captured as part of the AGFD/TRGD project described in Project Elements H.1 and H.2.

Project Element I.3. Identifying Emerging Threats to the Colorado River Ecosystem Using Environmental DNA

Responding quickly to invasions before populations become large and established is the least expensive and most effective way to control invasive species (Leung and others, 2002). Environmental DNA has become a reliable and cost-effective tool that resource managers can use to detect rare non-native species prior to population expansion. In aquatic environments, fish continually shed cellular material into the water via reproduction and feces that can persist in the environment for several weeks. This cellular material can be collected via water sample and DNA can be extracted from cells collected in the environment in which an organism lives, rather than directly from the animals themselves. This reduces or eliminates fish handling and stress (can be a concern for non-target species) and allows managers to detect species at the early stages of invasion, species with low susceptibility to capture, or species residing in habitat areas outside of the range of standard sampling methods.

The warmwater non-native aquatic species currently present in the Colorado River are only a fraction of the potential invasive fish species that could establish, especially if fishes continue to be entrained from Lake Powell into warming Colorado River waters.

New, emerging threats to the CRe, such as new invasive species, parasites, or disease, also have the potential to affect fish and wildlife populations and human health. In the FY 2025-27 TWP, we propose to use eDNA combined with traditional sampling methods to identify and characterize emerging threats to the CRe that could compete with or prey on ESA-listed species.

This could include projects that use quantitative Polymerase Chain Reaction (qPCR) or metabarcoding methods to 1) identify new non-native species of concern in GLCA and GRCA including fishes, crayfish, gastropods, and mollusks; 2) determine the distribution of smallmouth bass from Glen Canyon Dam to the LCR in early summer to refine the geographic extent of cooling needed to suppress smallmouth bass with flows in the LTEMP SEIS; 3) monitor pools in the upper LCR in conjunction with humpback chub monitoring to detect invasive species that could be washed down into the LCR and CR during monsoon season (see Project Element G.8); 4) test the efficacy of seining for detecting non-native fishes in backwaters in conjunction with the USFWS humpback chub aggregations sampling (see Project Element G.5); 5) identify species at depth in Lake Powell that could be entrained at various reservoir elevations and provide species confirmation on fishes being entrained into GCD penstocks (e.g., studies on entrainment using acoustics near the mouth of GCD penstocks, and methods to sample entrained fishes being released downstream, are in the pilot phase [personal communication: Jeremy Hammen, Reclamation]); and 6) use fecal and water samples containing eDNA paired with traditional sampling techniques to monitor Asian Tapeworm in humpback chub and other parasites and pathogens in native and non-native fishes in the mainstem river and the LCR in response to changing conditions (per the 2016 BiOp; U.S. Fish and Wildlife Service, 2016). Data on species distribution and relative abundance (using eDNA copy number) will be modeled in an occupancy framework, which can also be used as data in proposed Metric 10 that is focused on detecting invasive aquatic species in the CRe.

Project Element I.4. Modeling Population Dynamics and Improving Forecasting Tools for Smallmouth Bass and Other Non-Native Fishes

This new project element will focus on modeling non-native fish data from federal and state agencies and other cooperators (e.g., GCMRC, NPS, AGFD, USFWS, BioWest), combined with laboratory work that will be used to refine models. Modeling projects in this project element could include: 1) updating forecasting tools for smallmouth bass using new data or information that could improve models; 2) comparing population estimates from traditional mark-recapture models with close-kin mark-recapture models; 3) if data is of sufficient quality, determining the effectiveness of management actions on non-native fish populations [including modal progression analysis to assess growth of all life stages, and CPUE]; 4) developing a workflow process for an occupancy model that evaluates data from Projects H, G, and I to report on a standard set of LTEMP metrics; 5) analyzing data from lab studies on the effects of turbidity and temperature on early life stages of smallmouth bass and other non-native fishes, and incorporate findings into models if relevant; and 6) providing science to support discussions of offramps laid out in the Invasive Fish Species Strategic Plan (Smallmouth Bass Ad Hoc Group, 2023).

While we propose to fund the above work through this project element, we also propose additional SEIS work to be funded through the Experimental Fund. We plan on analyzing system-wide monitoring data collected by state and federal partners to evaluate the effectiveness of smallmouth bass flows.

This may include modal progression analysis to determine growth rates of various life stages of non-native fish, assessment of CPUE and/or abundance, and determination of hatch dates for fish to determine if smallmouth bass were produced before, during, or after LTEMP SEIS flow implementation.

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Project J: Socioeconomic Research

1. Investigators

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1. Project Summary and Purpose

In the Long-term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) “recreational experience” and “Tribal resources” are goals that require social and economic monitoring and research to better understand the impacts of management actions related to the operation of Glen Canyon Dam on these resources (U.S Department of Interior, 2016). While there has been some monitoring and research related to these goals (Bair and others, 2016; Neher and others, 2017; Neher and others, 2018), there is a need for long-term social and economic monitoring and research within the Glen Canyon Dam Adaptive Management Program (GCDAMP). This project contains elements that aim to establish long-term monitoring and research needs for the “recreational experience” and “Tribal resources” goals in the LTEMP EIS. This includes improving monitoring and modeling of recreational activities, in collaboration with the National Park Service (NPS) and Arizona Game and Fish Department (AGFD), and a focused effort on the integration of Tribal cultural benefits knowledge, through Tribal led monitoring activities, into decision-making in the GCDAMP.

Related to monitoring and research and in support of goals in the LTEMP EIS, an objective in the LTEMP EIS is to “determine the appropriate experimental framework that allows for a range of programs and actions, including ongoing and necessary research, monitoring, studies, and management actions in keeping with the adaptive management process.” The important phrase in this objective is the identification of necessary monitoring, research and management actions while keeping with the adaptive management process. To further this objective, this project includes an element to conduct research related to integrated modeling of biological, physical and economic systems, with a focus on value of information analysis. The latter effort improves the ability of GCDAMP to evaluate management actions and prioritize monitoring and research.

Project Element J.1. Integrated Models for Adaptive Management

Project Element J.1 will build on the integrated modeling of rainbow trout and humpback chub population dynamics, evaluating cost-effective invasive species management alternatives that meet humpback chub viability goals (Bair and others, 2018; Donovan and others, 2019), and the assessment of the economic costs of experimental flows such as trout management and smallmouth bass flows (U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2024). Continued development of integrated models also provides opportunities to conduct assessment of the value of information gained from monitoring and research within the GCDAMP and the continued development of metrics integral to predictive modeling.

This element addresses the humpback chub (*Gila cypha*), rainbow trout (*Oncorhynchus mykiss*) fishery and non-native invasive species goals in the LTEMP ROD, along with compliance activities, by improving our understanding of the dynamics between fisheries resources and impacts of management actions. These modeling methods reduce uncertainty important to and specify triggers that inform proposed management actions in the LTEMP ROD, using the GCDAMP’s proposed metrics for the program.

Sub-element: Integrated models for adaptive management

The integrated modeling sub-element will focus on integrated modeling of native and invasive fishes in Glen and Grand Canyon, leveraging ongoing bioeconomic modeling of the system (Bair and others, 2018; Donovan and others, 2019; U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2024). The project sub-element will emphasize the development of guidance for data collection efforts within the complex bioeconomic system with a continued focus on environmental flow research and hydropower operations at Glen Canyon Dam, invasive species monitoring efforts, management for viable endangered species populations, and other socio-economic stakeholder objectives. This systematic approach for the prioritization of program activities is needed in order to improve the efficiency of how monitoring and research resources are allocated. This is consistent with the GCDAMP fisheries review panel’s recommendation that the program, “adopt [a] decision theoretic approach to adaptively manage the rainbow trout fishery and humpback chub population” (Casper and others, 2016). A decision-theoretic approach to adaptive management is when a “predictive model or set of models are created that represent alternative ideas of how the system works” and those priors are evaluated through predicted or actual future resource states (Casper and others, 2016). This approach would allow the GCDAMP to prioritize monitoring and research by identifying the relative efficiency of learning opportunities, while also acquiring information on management actions, including those proposed in the LTEMP ROD.

Current research includes the exploration of which uncertainties in humpback chub population parameters have the greatest implications for management decisions (i.e., quantitative adaptive management model) and the explicit trade-offs (efficacy and cost) between trout management flows and rainbow trout removals at the Little Colorado River.

Continued predictive modeling of multiple resource goals is important as conditions in the Colorado River change, and reducing uncertainties, through application of predictive models, could significantly improve opportunity for cost-effective management. For example, focused effort on one dimension of uncertainty reduction, such as invasive species monitoring, is at the expense of efforts allocated toward other management actions, such as monitoring and research related to experimental dam releases for ecosystem restoration. This work aims to clarify the value of each of these actions and the tradeoffs between them while reducing uncertainty about ecosystem health and function. These efforts also support the analysis expected of short-term rapid response in the Invasive Species Strategic Plan (Smallmouth Bass Ad Hoc Group, 2023), evaluating cost of time and resources dedicated to plan implementation and the costs of management actions into the future.

Sub-element: Value of information analysis

Adaptive management is an information problem (Doremus, 2010). Its goal is to improve management through reducing uncertainty in our understanding of the structure of environmental systems. Some uncertainties we can’t reduce, and the benefits of reducing other uncertainties do not outweigh the costs of experimental management actions. It’s the remaining uncertainties that are worth learning more about. Using value of information (VoI) analysis to characterize uncertainty and identify which uncertainties are worth paying attention to is a way to prioritize monitoring and research when funding is limited (Bolam and others, 2019). We propose the application of VoI analysis in the GCDAMP to assist in the prioritization of monitoring and research. This type of analysis is an important step in adaptive management, where assessing the value of learning is a necessary component for the effective and efficient management of resource goals (Doremus, 2010; Runge and others, 2011). In this sub-element, we will leverage recent advances in predictive modeling across LTEMP EIS resource goals and the pending establishment of metrics for the analysis. It is recommended that this analysis be guided by researchers in this project but led by an external group of experts in adaptive management and VoI analysis, recognizing the possible conflict of interest and challenging nature of this proposed research.

Sub-element: Hydropower metrics

Hydropower generation in the Colorado River Storage Project (CRSP) is an important resource in the electricity sector’s Western Interconnect. Hydropower facilities are flexible sources of energy with low variable costs and a relatively clean source of energy (Waldo and others, 2021). Beyond ancillary services, the role of CRSP energy at Glen Canyon Dam, is to replace more costly energy generation during on-peak periods of demand, reducing economic costs. In addition, if the capacity of GCD is constrained during times when capacity requirements are limiting, additional construction of energy generating units must be planned in the system, increasing economic costs. There are also external costs (e.g., emissions in the electric sector) that may be considered in the estimation of the economic value of hydropower.

As part of the development of metrics for the LTEMP EIS resource goals, a hydropower metric, the economic value of hydropower, was proposed that combines the components of economic cost of energy, capacity, and emissions. This project sub-element will further develop the capacity of GCMRC to report on the economic value of hydropower on an annual basis (U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2024). The methods developed in this sub-element, when possible, will be based on publicly available data and provide a readily accessible tool to provide estimates of the change in economic value of hydropower based on changes in the economic cost of energy, capacity, and emissions over a defined time period and a given operational management scenarios of Glen Canyon Dam. These components of the hydropower metric will also be utilized in the other two sub-elements in this project, “integrated modeling for adaptive management” and “value of information analysis,” to refine the program’s ability to evaluate monitoring and research priorities and evaluate trade-offs across management alternatives.

Project Element J.2. Recreation Monitoring and Research

Project Element J.2 will develop predictive modeling capability for assessment of recreational experience and regional recreational spending under different future management scenarios, as recommended by the GCMRC Socioeconomic Research Review Panel (Hamilton and others, 2010). This research will build on simulation models of recreational activities (Roberts and others, 2002; Gaston and others, 2015) and the estimation of recreational preferences for flows by anglers in Glen Canyon and whitewater rafters in Grand Canyon (Bair and others, 2016; Neher and others, 2017). This project element will also continue to support the NPS in the design and evaluation of the Glen Canyon National Recreation Area (GLCA) brown trout incentivized harvest program.

Sub-element: Recreation modeling

The Grand Canyon Protection Act (GCPA) of 1992 states that, “long-term monitoring of Glen Canyon Dam shall include any necessary research and studies to determine the effect of the Secretary's actions under section 1804(c) on the…recreational…resources of Grand Canyon National Park and Glen Canyon National Recreation Area” (GCPA, sec. 1805(b)). This research element addresses the language in the GCPA and the “Recreational Experience” resource goal in the LTEMP ROD, by undertaking monitoring and research to inform management. Ongoing research has established the importance of flow attributes to recreational users in Glen and Grand Canyons (Bair and others, 2016; Duffield and others, 2016; Neher and others, 2017; 2018). This research has also demonstrated the temporal stability of recreational preferences for flow attributes over several decades of dam operations (Bishop and others, 1987; Neher and others, 2017). However, there has been no effort to incorporate these research findings into a model of recreational use patterns and experience in Glen and Grand Canyons, as recommended by a GCMRC Economics Pannel (Hamilton and others, 2010).

This research effort will integrate past research in recreation trip simulation in the Grand Canyon (Roberts and others, 2002) with the economic metrics developed in stated preference surveys (Bishop and others, 1987; Bair and others, 2016; Neher and others, 2018).

This approach provides improved assessment of recreational experience, including the ability to assess recreational experience as impacted by proposed management actions in the LTEMP ROD and under different future hydrology. Developing a recreational experience model also allows for the assessment of various aspects of trip behavior that are important to the management of other resources in Glen and Grand Canyons, such as archeological resources, and the regional assessment of recreational spending. Development of the recreational trip model will require collaboration with NPS and AGFD to manage existing, and design and implement the collection of additional, recreation data important to the management of recreational resources. These efforts will focus on the design of best practices for collaborative data collection including prioritizing the collection of data to inform management.

Sub-element: Brown trout incentivized harvest

This project sub-element will support the NPS GLCA in the continued design, implementation, and monitoring of the impacts of an incentivized harvest program to reduce brown trout abundance in Lees Ferry. The limited research on aquatic incentivized harvest programs means that how and to what degree Lees Ferry anglers respond to harvest incentives is uncertain (Best, 2006). While there is a significant amount of learning that occurred in the first three years of the program, effective and efficient management of the program requires improved understanding of angler response to monetary incentives, social norms, and the amount and type of information available to anglers. This element’s objective is to reduce uncertainty surrounding program design by continued monitoring and research of the harvest incentive under a range of conditions. Reducing uncertainty in angler response to harvest incentives will ultimately improve the NPS’s ability to cost-effectively manage invasive fishes in the Colorado River ecosystem.

Project Element J.3. Tribal Resources Research

The cultural benefits of ecosystems make important contributions to the wellbeing of Tribal communities that are part of the GCDAMP. However, it has been a challenge within the GCDAMP to include these contributions in research products that inform decision-making. Specifically, it is difficult to represent relational or holistic values of cultural benefits through existing approaches to monitoring, research, and evaluation of management alternatives (Hoelting and others, 2023). Project Element J.3 aims to utilize a decision-support framework (Hoelting and others, 2023) to systematically identify opportunities for improved integration of cultural benefits and their associated plural values and human-nature relationships (Hoelting and others, 2024a, Hoelting and others, 2024b). The framework supports expanded thinking about the diversity of forms in which cultural-benefits-knowledge can be conveyed, and the available opportunities within the GCDAMP to learn from and integrate these knowledge forms into the adaptive management process.

We intend to evaluate the application of the framework within the GCDAMP, in collaboration with interested Tribal partners and ongoing Tribal monitoring programs. This process includes close collaboration with Tribal stakeholders in the evaluation of ongoing monitoring programs, translation of monitoring results into decision relevant knowledge products, and the integration of these knowledge products into broader aspects of the decision process within the GCDAMP. By identifying decision-relevant cultural-benefits-knowledge and the products that result, we seek to integrate this information into decision-making in the GCDAMP.

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1. Budget







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Project K: Geospatial Science, Data Management and Technology Project

1. Investigators

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1. Project Summary and Purpose

A crucial component of any long-term adaptive management program is the proper management and accessibility of its data resources necessary for measuring the status, trends, and experimental results related to the program’s objectives. The data collected through the U.S. Geological Survey’s Grand Canyon Monitoring and Research Center (GCMRC) are a vital resource used to determine the status of the natural resources identified through the Glen Canyon Dam Adaptive Management Program (GCDAMP) and to make timely decisions on dam operations. Proper data management and data accessibility is crucial to protect the significant GCDAMP investment spent over more than two decades in collecting these data. The primary purpose of this project is to provide high-level support to GCDAMP-funded science efforts in the disciplines of geospatial science, data management, database administration, and emerging information technologies.

Shifts in the geospatial and information technology industries are pushing the boundaries on how data can be managed and made accessible to outside entities. Much of this change is driven by advances in technology—from improved sensors for monitoring the Earth to increased digital data storage capacity to newer computer systems designed for processing large data sets more efficiently to the greater emphasis of the “Internet of Things” where the reliance of web-based technologies have revolutionized our world.

A common thread for the different aspects of this project is to continue to advance GCMRC’s ability to leverage many of these new technologies for the benefit of the Center, the science projects described within this work plan, and the larger adaptive management program. Work performed within this project makes it possible to share important information about trends in resources of the Colorado River ecosystem to the GCDAMP through web-based, interactive tools and mapping products, allowing the GCDAMP to make better informed, time-sensitive decisions on experimental and management actions under the 2016 Long-Term Experimental and Management Plan (LTEMP) and the associated Record of Decision (ROD) (U.S. Department of Interior, 2016).

1. Proposed Work

Project Element K.1. Enterprise GIS, Geospatial Analysis and Processing

Work performed within this element will continue to provide the same Geographic Information System (GIS) services that have been consistently provided to the Center for previous work plans. This project is continually striving to improve upon GCMRC’s ability to manage its expanding data resources. For several years the main focus was on designing, developing and maintaining consistent and accurate geospatial data sets, workflows and analyses in support of science projects. In fiscal years 2025-27, this project will continue to support research and monitoring projects by providing geospatial expertise to most projects on field mapping methods, development of customized maps, sample site unit definition and selection, GIS layer development and metadata review, Python programming, and GIS tool development and support. GIS staff support also involves the oversight and supervision of science project staff with GIS-related tasks including, spatial analysis in support of projects, training for staff and cooperators in GIS data entry and database management concepts, data processing techniques, production of printed maps and online map products, error troubleshooting, and other basic GIS methods and techniques.

Key aspects of the work performed in this element include the processing and analysis of large, complex geospatial data sets that often benefit multiple projects. This work is evident in past triennial work plans, and one example is the processing and analysis methods employed to the Glen Canyon channel map data set (Kaplinski and others, 2022). Specific tasks performed through GIS staff included processing derived data sets from the 2013 Digital Surface Model (DSM) to remove vegetation from the surface, thus creating a bare-ground elevation surface to be used in conjunction with field-based topography and bathymetry elevation data to make a composite channel map. The final data sets were then incorporated into GCMRC’s Enterprise GIS system and served online through a variety of endpoints. These data were then also supplied to the other monitoring efforts to help guide those data collection and analysis efforts. In FY 2024, the Python scripts used to create channel mapping datasets were updated for compatibility with ArcGIS Pro and now function as custom geoprocessing tools to streamline data analysis process.

This project maintains an enterprise GIS platform that is built upon Environmental Systems Research Institute (ESRI) ArcGIS Portal and Server applications and used for maintaining existing online data resources. Data services developed through this online system can then be shared through multiple endpoints including cloud-based content delivery systems, custom web applications hosted on-premises, and through other applications that can integrate spatial data with resource-specific monitoring data to provide users greater context on the trends and conditions of the Colorado River ecosystem. During FY 2021-23, a repository of Python scripts was developed to convert and move large batches of data to the on-premise Postgres database, from Postgres to the cloud, and from the cloud to ArcGIS Online.

This workflow can significantly improve access to data for stakeholders and the public while reducing the time spent by project staff to work data through this process. During the FY 2025-27 TWP cycle, we will continue to expand on content that is available through this system and work to improve existing functionality, as well as develop new, web-based analytical tools for interacting with and interpreting GCMRC’s data.

Additional GIS Administration tasks related to science support include the testing and migration of computer systems to newer versions of the most commonly used GIS/Remote Sensing software, maintaining licensing information, and/or working with Information Technology (IT) staff to ensure all licenses, software, extensions, add-ons, and custom applications work properly.

Project Element K.2. Data Management and Database Administration

During the last three years this project has worked towards addressing the need to expand concepts developed in GIS to other data resources across GCMRC. This includes the further development of an integrated spatial and tabular relational database environment for the Center. To this end, Project K will continue to incorporate much of the relational database work in support of other science projects defined in this work plan. By building the expertise and capacity in data management, data acquisition, and relational database administration within one group, this project is better aligned to provide more comprehensive support to resource-specific science efforts and to the larger GCDAMP community.

Database Administration

Work proposed within this project element include the continued maintenance of existing relational databases in support of LTEMP related science efforts, and in some cases, the design and development of new databases for projects or resources. Existing, resource-specific databases that have been developed and managed through this project include Sandbar Area and Volume, Riparian Vegetation Survey, Geodetic Network Control, and Lake Powell Water Quality. For the FY 2025-27 TWP, the primary focus will be on the full documentation, redesign and re-implementation of the existing Fish Monitoring database. The Fish Monitoring database is one of the most important data resources maintained by GCMRC, and this project is now better positioned to greatly improve the entire workflow process for storing, reviewing, analyzing and accessing fish and aquatic information. The migration of all project data to relational databases will continue throughout this next triennial work plan. The shift in how we approach our data resources will provide a consistent and stable platform for conducting much of the monitoring and research activities within this work plan and beyond.

Cloud-based Data Management

Since 2017, this project has led GCMRC’s efforts to adopt and use cloud-based environments for providing better access to its data and applications. By working with the USGS Cloud Hosting Solutions (CHS) team, the Project K has continued to lead the way for GCMRC in expanding the use of the Amazon Web Services (AWS) cloud environment for leveraging cost effective, advanced cloud computing solutions, application development and deployment, and providing access to information through some of the most advanced data serving systems available for natural resource monitoring today.

Modern application of enterprise databases involves standardized source control of all application components, advance system configuration of both local desktop and server environments, and the proper deployment and management of AWS cloud-based components. There are many benefits to leveraging these cloud environments for science applications. They offer scalable resources, many of which only incur costs while the components are being accessed. The cost of server maintenance, security, data/application availability, storage, and redundancy are all managed by AWS, thus reducing the amount of time needed internally for information technology staff to perform these duties. It is proposed this project will continue to lead GCMRC in adoption of a hybrid-cloud strategy for future data management and application development, as well as explore the other data management solutions being provided through the U.S. Geological Survey and the Department of the Interior.

Project Element K.3. Data Telemetry and Field Engineering

Many of the technologies that GCMRC’s science relies on have advanced over the past two decades. This trend is expected to continue and likely accelerate in the coming years. Efforts within this project strive to stay engaged in relevant technological advancements, and in some cases, be on the leading edge of these changes.

In FY 2017, GCMRC’s Geospatial Science and Technology Project became involved with an Internet of Things (IoT) Sensor pilot project to test the feasibility of connecting sensors deployed in the field to the AWS – Cloud Hosting Solutions cloud environment. This pilot work required the reconfiguration of an existing field sensor system (Vaisala weather station) already deployed at Lees Ferry and development of two-way communication capabilities with the sensor and data logger via cellular transmission to the Amazon cloud. The main objective was to demonstrate the ability to automate the transmission of data from the field to the cloud at some predefined interval, and to allow users to subscribe to “alerts” based on defined data values that would then perform some other action -- in this case send a text message regarding extreme air temperature alerts. We successfully achieved this initial goal in 2018, and presented our work at the inaugural USGS Sensor Summit workshop in Denver. Our IoT efforts have now expanded to include the transmission of IoT data from water quality instruments located at the Lees Ferry Gage Station, RM 0 and the outflow of the Glen Canyon Dam, RM –15.7, and fish pit tag scan data from the Little Colorado River.

In February of 2023 we tested and deployed the first low earth orbit (LEO) satellite telemetry dish in the USGS at the Phantom Ranch gaging station. Following the success of this effort, LEO telemetry dishes were installed at the 30 and 61-mile sediment gaging stations in August 2023, replacing the legacy geostationary satellite dishes and significantly increasing data download dependability and speed. In late 2023 and early 2024 we have worked to join the beta program for SpaceX’s new direct to cell telemetry system. Direct to cell telemetry technology is the likely to be the biggest breakthrough in remote sensor telemetry in decades, fundamentally changing the way that science is conducted in Grand Canyon and opening up the possibility of connecting all sensors to the cloud for real-time data transmission and error identification. The objective for continuing this work into FY 2025-27 is to leverage this new telemetry technology to develop and install systems for connecting non-telemetered sensors to the cloud and serve as much data as possible in real-time to scientists and stakeholders. Further we plan to work with Project B to develop a new generation of sandbar monitoring cameras that is compatible with direct to cell telemetry, to upload sandbar images in real-time and allow for rapid identification of camera issues.

This project element also tracks the technical support and electrical engineering expertise provided to other research projects described in this work plan. The type of work performed in this element is varied and must at times adjust to respond to emerging needs within projects or critical responses to system failures. Listed below are applicable examples of projects and tasks . Some work performed in this element inherently benefits the Center as a whole by improving upon the design and development of common components used by most remote monitoring systems deployed by GCMRC.

1. Project A: Streamflow, water quality, and sediment transport
2. Project G: Humpback chub population dynamics
3. Project H: Aquatic ecology and food base monitoring
4. References

Kaplinski, M., Hazel, J.E. Jr, Grams, P.E., Gushue, T., Buscombe, D.D., and Kohl, K., 2022, Channel mapping Glen Canyon Dam to Lees Ferry in Glen Canyon National Recreation Area, Arizona - Data: U.S. Geological Survey data release, <https://doi.org/10.5066/P98GFP93>.

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1. Budget







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Project L: Overflight remote sensing in support of GCDAMP and LTEMP

1. Investigators

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1. Project Summary

This project seeks to analyze, interpret, and acquire overflight remote sensing data along the Colorado River from the forebay of Glen Canyon Dam to Lake Mead at Pearce Ferry, including major tributaries. The imagery and derivative data products from overflight remote sensing are used either directly or indirectly by every science project proposed in each GCDAMP Triennial Work Plan (TWP) to address every resource goal of the LTEMP (US Department of Interior, 2016a, b). Table 1 lists the primary datasets from overflight missions and the derivative products used by science projects to address resource goals. Table 1 also provides links to recent examples of these datasets and products. During FY 2021-24, Project L acquired new remote sensing data from an overflight mission implemented in 2021, and then processed and published those data. The 2021 overflight was the latest in a rich archive of airborne remote sensing in the Grand Canyon in support of the GCDAMP and LTEMP (see <https://www.usgs.gov/centers/southwest-biological-science-center/science/airborne-remote-sensing-grand-canyon>). During FY 2025-27, this project will analyze and interpret data from the 2021, and previous, overflights for collaborative science efforts with other projects (A, B, C, D) in this work plan to address resource goals. This project will also implement the next overflight mission in order to maintain a long-term, system-wide, remote sensing data record that includes approximately three digital image and topographic datasets per decade to answer science questions about the relationships of dam operations and landcover changes in the Colorado River Ecosystem (CRe) at decadal timescales.

**Table 1.** Summary of primary datasets and examples of derived products from overflight missions used by GCDAMP science projects to achieve LTEMP resource goals. Please follow hyperlinks for examples.

|  |  |
| --- | --- |
| **Primary datasets produced from overflight missions** | |
| [Multispectral Imagery](https://doi.org/10.5066/P9BBGN6G) | Digital Topography |
| **Products derived from primary datasets** | |
| [Website](https://www.usgs.gov/centers/sbsc/gcmrc) content and [online maps](https://grandcanyon.usgs.gov/gisapps/cmv-app-master-wret/viewer/index.html) | Cartographic products   * River map books * Publication maps |
| Fish sampling unit system for mainstem Colorado River | Humpback chub and juvenile monitoring system for Little Colorado River |
| [Colorado River centerline and river mile system](https://www.sciencebase.gov/catalog/item/5b2185ace4b092d96528747b) | Flowlines   * [Extracted from low-flow water's edge (~8,000 ft3/s) in overflight imagery](https://doi.org/10.5066/F7PZ5799) * [Modelled from overflight topography and water surface elevation data](https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=721001c63d91458883340f05c68c55f4) |
| [Land cover and landform mapping and change detection](https://www.usgs.gov/centers/sbsc/science/riparian-remote-sensing-colorado-river-and-grand-canyon-region)   * [water](https://doi.org/10.5066/F7PZ5799), [sand](https://doi.org/10.5066/P99TN424), [vegetation land cover](https://doi.org/10.5066/F7K64GJF) * geomorphic basemap | [Vegetation species classification](https://doi.org/10.5066/P9OUB1RS) |
| Campsite delineation   * [Campsite atlas](https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=0f9f6575bfee406cac6593b293883665) | Topography data   * [Topographic change detection](https://doi.org/10.5066/F73776X6) * Hydrologic flow modeling. |

1. Proposed Work

Project Element L.1. Analysis and Interpretation of Overflight Remote Sensing Data (modified ongoing study)

During FY 2025-27 GCMRC will produce and publish CRe landcover classification maps derived from analysis of the recently published the [orthomosaic of high-resolution multispectral imagery](https://doi.org/10.5066/P9BBGN6G) acquired during the 2021 overflight. GCMRC will conduct change detection analysis of the digital imagery, topography, and landcover datasets derived from the 2021 and prior overflights. This work will support the three following interdisciplinary efforts.

* Measure system-wide changes in high-elevation sand deposits using remote sensing digital topography acquired by Project L during the FY 2021-24 work plan, and previously, in collaboration with Projects A, B, C, and D.

The volume of high elevation sand (that is, the sand above the stage of 25,000 ft3/s) is a combination of sand deposited by pre-dam floods, sand deposited by HFE’s, and river sand transported by wind from lower elevations and deposited at higher elevations. In the absence of HFE’s, high-elevation sand can be eroded or deposited by wind, eroded by rainfall-driven runoff from canyon walls and hillslopes, or stabilized by vegetation. However, it is primarily through HFE’s that any substantial high-elevation sand may be deposited by the Colorado River. Project B measures the volume of high-elevation sand annually at 45 long-term sandbar monitoring sites. However, it is unknown whether these 45 sites are diagnostic of system-wide conditions. Project D measures the volume of high-elevation sand, including sand at even higher elevations than measured in Project B, during ground-based light detection and ranging (lidar) surveys repeated approximately every three years at sandbars and dunefields associated with approximately 40 archaeological sites. However, it is similarly unknown whether those sites are diagnostic of system-wide conditions. Thus, we propose to analyze system-wide digital surface models constructed from photogrammetry of overflight imagery in 2021, 2013, 2009, and 2002 to evaluate high-elevation sand conditions within the CRe between Lees Ferry and Diamond Creek. This analysis would be done in collaboration with Projects B and D to determine if system-wide high-elevation sand conditions agree with or diverge from high-elevation sand conditions at the long-term monitoring sites. This would provide needed information to report on LTEMP Sediment Resource Goals, determine whether additional sites need to be monitored to sufficiently track high-elevation sand volumes, and assess whether system-wide overflight remote sensing derived high-elevation sand measurements are a useful method for measuring this important monitoring variable.

LTEMP Goal 2, Metric 1.1 Total Vegetation Cover

This LTEMP metric is determined periodically after each aerial image acquisition by mapping all of the riparian vegetation in the CRe, and thus providing a census-based estimate of total vegetation cover throughout the river corridor. At present, the metric has been calculated from aerial image analysis from 1965 to 2013. A classification map of total vegetation area will be produced from the 2021 overflight imagery during the first year of the work plan and the *LTEMP Goal 2, Metric 1.1 Total Vegetation Cover* will be calculated and reported.

* Contribute landcover change observations for calibration and validation of flow, vegetation, and sediment modeling in support of Projects A, B, C, and D.

Projects A, B, C, and D each include interdisciplinary efforts to better quantify how interactions between river sediment, riparian vegetation, and the flow of water or wind affect long-term changes in the Colorado River channel in response to dam operations. Those efforts require landcover classification maps, and change detection analysis of the maps, derived from overflight remote sensing to either calibrate or validate predictive efforts based on other data acquired by those projects. Project L will provide the necessary mapping and change detection analysis for those efforts.

Project Element L.2. Acquisition of Overflight Remote Sensing Imagery (new element)

During FY 2026, GCMRC will implement a remote sensing overflight to collect high-resolution digital, multispectral imagery and topography of the CRe between Glen Canyon Dam and Lake Mead. To maintain consistency with previously collected digital, orthorectified aerial imagery acquired in 2002, 2009, 2013, 2021 (Davis, 2012; Durning and others, 2016; Sankey and others, 2024), the mission will be conducted during the same time of year (beginning on Memorial Day weekend in the month of May, and lasting for potentially one week or longer depending on weather) and adhere to the same data collection parameters and significant logistical requirements as used in preceding missions.

Specifications for the data acquisition necessitate that dam releases be held at a steady discharge of 8,000 ft3/s (CFS) for the duration of the overflight mission. As such, the proposed overflight would be within the LTEMP flow regime, and we would request from and work with the Bureau of Reclamation and Western Area Power Administration to maintain the steady 8,000 ft3/s discharge for the duration of the data collection period. This flow adjustment is required to maintain consistency with imagery data sets collected in previous years and maximizes subaerial terrain that is not inundated by the river in the imagery. This will allow for highly accurate image classification of landcover, and for image matching and change detection analysis with previous overflight datasets.

For data collection parameters, we require at least the same 4-band wavelength ranges (red, green, blue, and near infra-red), and same or higher spatial resolution (20-cm pixel resolution), using the same or similar equipment (Leica ADS-100 camera mounted in fixed-wing aircraft), with the option of two cameras and aircraft being made available to increase the rate of data collection and reduce the impact on dam operations. Wavelengths and other technical details will be specified with a Scope of Work (SOW) contract to be written by GCMRC scientists during FY 2025. The overflight mission would occur in FY 2026. Imagery will be acquired using the manned aircraft overflight and Leica sensor, as opposed to other satellite-based platforms and sensors, for example, in order to produce a seamless orthomosaic that is cloud and shadow free, synoptically covers the entire CRe during the low steady dam release of 8,000 CFS beginning on the anniversary date of Memorial Day weekend, and that meets the image spatial and spectral resolution requirements stated above.

Project Element L.3. Acquisition of Airborne Lidar in Conjunction with Overflight Remote Sensing Imagery (new element)

During the overflight proposed in Project Element L.2, GCMRC proposes to also acquire Quality Level 1 (QLI) or higher resolution airborne lidar data of the CRe. Lidar is a technology that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. Combined with other data, this generates precise, three-dimensional information about the shape of the Earth’s surface and its characteristics.

GCMRC will work through the contracting process for these data to be acquired by the same contractor and in parallel with the high-resolution multispectral imagery (L.2). GCMRC will partner with the USGS 3D Elevation Program (3DEP; <https://www.usgs.gov/3d-elevation-program>) which is leading an ongoing effort to acquire QL1 airborne lidar data coverage of the entire nation. A large segment of the CRe has yet to be covered by 3DEP. Moreover, 3DEP data acquisition in Grand Canyon to date has not leveraged the low, steady 8,000 CFS flows of the GCDAMP overflight missions. Acquiring these lidar data during the next GCDAMP overflight would ensure that a low steady dam release of 8,000 CFS is maintained during the data collection, which is critical to maximize the potential for monitoring CRe resources with the data (i.e., when they are subaerially exposed and visible, as opposed to underwater in the river channel). QL1 airborne lidar have a much higher spatial accuracy (latitude, longitude, and elevation) than digital topographic data derived from other airborne remote sensing methods, and thus would be extremely valuable for baseline observations and future monitoring of a variety of resources and applications in the CRe.

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

**Project M: Leadership, Management, and Support**

1. Investigators

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1. Project Summary

Project Element M.1 covers partial salaries for the following support staff: Budget Analyst, Public Affairs Specialist, Information Product Data System/Archive Technician, and a Science Data Coordinator. Leadership and management personnel salaries include those for the GCMRC Deputy Chief and Chief, as well as half the salary for one Principal Investigator. Element M.1 also covers GCMRC travel and training costs. GCMRC operating expenses include GSA vehicle costs (e.g., monthly lease fees, mileage costs, and costs for accidents and damage), DOI vehicle costs (e.g., fuel, maintenance, supplies, and replacement costs), and an annual contribution ($25,000) to the GCMRC equipment and vehicles working capital fund.

Project Element M.2 covers salaries for four members of the GCMRC logistics staff. Cooperator funding listed here is for support of the Partners in Science Program with Grand Canyon Youth.

Project Element M.3 covers GCMRC’s information technology equipment and related support costs.

1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Project N: Native Fish Population Dynamics\* (New Project)

\*Note that Project N was previously **Hydropower Monitoring and Research.** That project is no longer continuing, and instead Project N will be a new project, **Native Fish Population Dynamics**.

1. Investigators

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1. Project Summary and Purpose

The Long-term Experimental and Management Plan (LTEMP; U.S. Department of the Interior, 2016)) includes a goal for “other native fishes” (ONF), which applies to razorback (*Xyrauchen texanus*), flannelmouth (*Catostomus latipinnis*), and bluehead (*C. discobolus*) suckers and speckled dace (*Rhinichthys osculus*) in the Colorado River Ecosystem (CRe) including Colorado River tributaries: *“Maintain self-sustaining native fish species population and their habitats in their natural ranges in the Colorado River and its tributaries.”* Monitoring of fishes in the CRe has been conducted for >20 years, and yet few analyses of these data have occurred at a system-wide level to understand basic drivers of ONF population dynamics, how LTEMP flow and non-flow management actions have affected ONF, and whether progress toward the LTEMP goal is being achieved. Also, a comprehensive analysis of efficacy of conservation measures in the LTEMP Biological Opinion (U.S. Department of the Interior, 2016) for razorback sucker is needed. Dam-related flow and non-flow management actions related to the LTEMP Biological Opinion, including high flow experiments, suppression of non-native fishes, or macroinvertebrate flows may influence fish populations in unexpected ways that are both beneficial (Healy and others, 2020; Deemer, 2022; Hansen and others, 2023) and detrimental (Healy and others, 2022c) to LTEMP resource goals.

Further analyses are needed at the population and community level to understand how ONF demographic rates and LTEMP metrics (e.g., proportion of CRe and tributaries occupied by ONF) may respond to management actions.

Significant changes in the CRe are occurring as Glen Canyon Dam discharge becomes warmer in summer due to declining reservoir levels (Dibble and others, 2021), leading to increased reproduction rates and distribution of native fishes (Kegerries and others, 2020; Gilbert and others, 2022; Dzul and others, 2023), and potential declines in cold-water non-native salmonids (Bruckerhoff and others, 2022; Healy and others, 2023). While abundance or catch rates of humpback chub (*Gila cypha*) and ONF have increased (Van Haverbeke and others, 2017; Rogowski and others, 2018), the initiation of new invasions/expansions of warmwater non-native sport fishes may threaten the existing native fish community (Eppehimer and others, 2024). Managers are developing novel flow alternatives to respond to new invasions in the Colorado River (Bureau of Reclamation, 2024) that may also compel managers to consider fish conservation actions focused on tributaries (Bouska and others, 2023). Tributaries have been important to native fish populations when conditions in the mainstem were less conducive to native fish reproduction (Yackulic and others, 2014). Tributaries continue to provide reproduction and potential rearing habitat (Healy and others, 2020; Bonjour and others, 2023) but the relative importance of tributary and mainstem habitats in maintaining ONF populations and meeting LTEMP goals is unclear. Thus, a baseline understanding of system-wide ONF population dynamics is needed to understand drivers of survival, recruitment, and basic ecology to inform management.

Endangered Species Act (ESA)-listed razorback sucker was considered extirpated from the Grand Canyon beginning in the mid-1990s, and despite the presence of adults and evidence of spawning after 2012, the species continues to be rare (Kegerries and others, 2017; Gilbert and others, 2022). Conservation measures in the LTEMP (U.S. Department of the Interior, 2016) are focused on understanding the status and life stage- or habitat-specific vulnerabilities of razorback sucker. Despite documented spawning (Gilbert and others, 2022), no evidence of recruitment from larval to juvenile life stages has been uncovered in the Grand Canyon – it is unclear if the thermal regime, habitat, or other factors limit the razorback sucker in the CRe. Movements of razorback sucker between the Grand Canyon and Lake Mead, where the only population supported by natural reproduction exists (Albrecht and others, 2017; Albrecht and others, 2010), suggests the populations are linked. Adaptive management actions are being considered to both recover razorback sucker in the CRe and Lake Mead and learn about factors limiting their population growth. For example, a three-year pilot-level razorback sucker augmentation project (Healy and others, 2022b) was initiated with the release of passive-integrated transponder (PIT) tagged age-1 razorback sucker in Havasu Creek by the NPS in 2023. Long-distance movements and dispersal of newly released razorback sucker may require a system-wide approach to understanding the fate of both adult and age-1 PIT-tagged fishes (Pennock and others, 2020; Pennock and others, *in press*). GCDAMP interagency monitoring programs have and may continue to detect or capture razorback sucker.

Thus, the Grand Canyon presents a unique opportunity to study larval and juvenile survival, growth, and recruitment in a rapidly changing system with fewer existing predators, which are thought to limit natural recruitment and recovery of razorback sucker in other parts of the Colorado River basin (Marsh and Langhorst, 1988; Marsh and Brooks, 1989; Schooley and Marsh, 2007).

Decisions related to fisheries management actions in the CRe are becoming more difficult under uncertain system-wide change and due to the desire to balance a diversity of values held by Traditionally Associated Tribes and stakeholders, alongside management agency mandates. Department of Interior utilizes predictive models in many decision-making processes for fish management (Runge and others, 2011a; Runge and others, 2018), but adequate models for ONF have not been developed for the CRe and tributaries. In general, predictions of the outcomes of management actions are also plagued by uncertainty (Runge, and others, 2011b). Uncertainty may become increasingly important as new stressors and changes in water quality impact the CRe in ways that may be difficult to predict. Nonetheless, in systems facing rapid change or newly invading fishes, timely decision-making is particularly relevant despite uncertainty in the outcome of taking a management action.

The costs and effort needed to maintain important ecological values are often greater once an invader has become established, for instance (Healy and others, 2023). Managers may wrestle with different sources of uncertainty during decision-making processes, but not all sources of uncertainty in predictions of management outcomes are important. Value of information (VoI) analytical tools can be used to assist managers in understanding the importance of sources of uncertainty to decision-making and quantifying the tradeoffs between making an immediate management decision under uncertainty or waiting to conduct additional research. The development of predictive models based on long-term ONF data, and VoI tools can assist managers and researchers in prioritizing future monitoring to improve the outcomes of LTEMP flow and non-flow management for ONF, while also considering diverse values of AMP stakeholders, agencies, and tribes.

Project N specifically addresses research to understand ONF population dynamics and assess progress toward LTEMP goals for native fishes using a mix of existing data types, and data collected using new technology, to assess management actions. We will incorporate long-term ONF data collected from throughout the CRe by cooperating agencies (also see Projects G and I), including GCMRC, AZGFD, USFWS, NPS, and others in tributaries (Little Colorado River, Bright Angel, Shinumo, and Havasu creeks) and the mainstem Colorado River, to estimate demographic rates (recruitment, survival, population growth), and distribution and abundance using mark-recapture and occupancy models. Mark-recapture modeling has proved to be useful for understanding temporal and spatial variation in survival and growth for humpback chub (Yackulic and others, 2014; Dzul and others, 2023), inferring interspecific interactions between native and non-native species (Yackulic and others, 2018), and understanding the outcomes and influences of management actions on native fish populations (Yackulic and others, 2021; Healy and others, 2022a; Hansen and others, 2023; Healy and Omana Smith, 2023).

Movement rates and the use of tributary and mainstem habitats by ONF will also be assessed using a mix of acoustic and PIT-tag telemetry methods (e.g., Dzul and others, 2022; Bonjour and others, 2023). We will explore the use of new acoustic tagging technology (Mensinger and others, 2024) to understand both movements and predation as a source of mortality to ONF. Results from these modeling efforts will be incorporated into predictive models to assess future management alternatives and support DOI decision-making processes.

The outcome of this project will support the use of monitoring data for key management needs including informing state-dependent decision-making, evaluating the effectiveness of both flow and non-flow management actions with respect to LTEMP goals, and provide a structure for future learning through the identification and prioritization of key uncertainties making decision-making difficult (Lyons and others, 2008). Collaborations between GCRMC, federal and state management agencies, and contract biologists to analyze existing capture, mark-recapture, and passive-integrated transponder (PIT) tag antenna detection data collected over decades from throughout the CRe and tributaries should allow for unprecedented learning related to the ecology of ONF and improved understanding of influences of LTEMP flow and non-flow management actions. The work proposed in Project N is achievable over FY 2025-2027 because most data have already been collected; however, modeling and other work proposed would provide a baseline for future work plans as more demographic data are collected during monitoring efforts described in Projects G, H, and I.

1. Proposed Work

Project Element N.1. Sucker and Dace Distribution and Demographic Modeling

Evaluate population distribution and dynamics using system-wide capture and mark-recapture data

This project element involves 1) using existing data to estimate the probability of occurrence (occupancy) of all ONF to support the evaluation of trends in LTEMP metrics, 2) a synthesis of environmental and mark-recapture data to estimate demographic rates of bluehead and flannelmouth suckers throughout the CRe, and 3) assist NPS and USFWS in estimating growth and survival of razorback sucker released in Grand Canyon as part of a pilot-level augmentation study (2023-2025). Finally, 4) we plan to collaboratively investigate drivers of early life stage dynamics of ONF using larval and small-bodied fish data (2014-present, ASIR, Inc., and BIO-WEST, Inc.) collected in cooperation with Bureau of Reclamation. All four emphasis areas in this project depend on the availability of sufficient data for each of the ONF species. It is particularly uncertain whether sufficient recaptures of razorback sucker released as part of the augmentation project will allow for estimation of growth and survival rates (Project N.3 may also assist managers in understanding the fate of these fish using acoustic telemetry).

Nonetheless, the ultimate objective of Project Element N.1 is to understand and relate long-term variation in environmental (e.g., temperature, watery quality, flow regimes) and biological (e.g., predators, competitor abundance) drivers to ONF demographics (recruitment, survival).

Because native fishes often use both tributary and mainstem habitats for different life history stages, and tributary occupancy may impart an advantage to native fishes, we intend to incorporate both tributary and mainstem interagency data into these analyses. By incorporating system-wide capture or detection data (including through PIT-tag antennas), we may begin to also understand the importance of tributaries and mainstem habitats in supporting native fish populations to inform future management actions.

Project Element N.2. Predictive Modeling and Decision Support for Native Fishes

Development of predictive models and value of information analysis

For Project Element N.2, we will use the results of demographic modeling in Element N.1 to develop predictive models to inform management and decision-making for ONF (e.g., matrix-based models, metapopulation viability model; Healy and others, 2023; Runge and others, 2018). Management decisions may include where and how to focus ONF restoration, augmentation (razorback sucker), or translocation efforts; how to protect native fish populations (e.g., in tributary refuges above barriers); and prioritization of uncertain threats including non-native species, or those related to LTEMP flow actions, among others. GCMRC scientists will work with DOI and state managers, tribes, and GCDAMP stakeholders, as appropriate, to outline decisions to be made related to GCDAMP recommendations for ONF conservation and LTEMP management objectives, facilitate the development of alternatives, and make predictions about the outcomes of different potential management alternatives. We will also identify and prioritize different sources of uncertainty, and the influence of uncertainty on decision-making for ONF using VoI tools such as expected value of perfect information or expected value of partial perfect information. These tools will allow for the prioritization of future research towards critical uncertainties.

Project Element N.3. Evaluating Dispersal and Sources of Mortality of Razorback Sucker Using New Technology

Evaluate dispersal and predation as a source of mortality to razorback sucker released in the Grand Canyon using acoustic telemetry with predation sensors

Razorback sucker recovery is thought to be plagued by low survival of juvenile or subadult fish due to predation by introduced predators in other Colorado River basin populations. Populations of razorback sucker have not grown in the Grand Canyon despite the presence of adults and seasonally warming water temperatures, with lower predator loads in much of the western Grand Canyon where most razorback sucker detections have occurred.

Further, rapid and long-distance dispersal of razorback suckers or other native fishes from release sites can complicate interpretation of survival of translocated fish or outcomes of stocking (Spurgeon and others, 2015; Franssen and others, 2021). Predation by non-native fishes, including by catfishes, smallmouth bass, and others, has been identified as a concern in the existing and future CRe.

Quantifying predation rates, and how the likelihood of predation varies spatially, may assist managers in recovering ONF by identifying areas where predation is likely to occur. For Project Element N.3, we propose to use acoustic telemetry to quantify dispersal from release sites and predation as a source of mortality of age-1 razorback sucker released in the CRe. New acoustic tags equipped with predation sensors will be used to assess the probability of predation and location of predation events following release of razorback sucker, or other fishes, if deemed appropriate. Once consumed by a predator and exposed to stomach acids, predation sensor tags switch emission signals and signify that a predation event has occurred. A network of acoustic receivers will be temporarily (~4-5 month duration) installed near release sites and in other appropriate areas thought to be important for native fishes, to detect movements and predation event signals from acoustic tagged fish. Multistate mark-recapture models will be used to estimate the likelihood of predation across the network (Mensinger and others, 2024). Predation sensor tags are slightly larger than PIT-tags, and the size of fish tagged will be large enough (100-150 mm total length) to avoid predation by humpback chub, but not avoid the gape of most introduced predator sport fishes (e.g., smallmouth bass, salmonids, walleye, catfishes). These tags have been tested and used successfully in Atlantic salmon smolts in rivers of the Northeast United States (Mensinger and others, 2024). We will first review testing results for these tags, identify the type of tag most appropriate for our application, and conduct validation trials as needed (e.g., Schultz and others, 2017).

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1. Budget







\*GCDAMP Special Rate: Rate includes current DOI preferred rate (currently 15%; subject to change) and facilities rate (will vary annually). No USGS bureau overhead is charged (unique to the GCDAMP agreement).

\*\*USGS Contributing Funds: The amount of funds required to cover the subsidy created by the reduced burden rate (i.e., GCDAMP Special Rate). As in previous years, SBSC/GCMRC will request these funds of the USGS cost-share program. These funds are not guaranteed.

Budget Summary



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