# Project O: Is Timing Really Everything? Evaluating Resource Response to Spring Disturbance Flows

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## 2. Project Summary and Purpose

The purpose of Project O is to evaluate whether a spring-timed disturbance flow will improve resources in the Colorado River Ecosystem (CRe). The proposed spring-timed disturbance flow is not to be confused with the sediment-triggered High Flow Experiments (HFEs), which are one of the principal experimental flows recognized in the Long-Term Experimental and Management Plan Final Environmental Impact Statement (LTEMP FEIS; U.S. Department of Interior, 2016a) and its associated Record of Decision (LTEMP ROD; U.S. Department of Interior, 2016b). The cornerstone of this project is a potential ~~FY2021 or later~~ test of a spring disturbance flow hydrograph developed by the FLow Ad Hoc Group (FLAHG). The FLAHG hydrograph is a direct outgrowth of the group's December 2019 charge, which states the FLAHG shall work:

> *…with GCMRC to evaluate opportunities for conducting higher spring releases that may benefit high value resources of concern to the GCDAMP (recreational beaches, aquatic food base, rainbow trout fishery, hydropower, humpback chub and other native fish, cultural resources, and vegetation), fill critical data gaps, and reduce scientific uncertainties. As a starting point, the FLAHG shall consider the benefits of and opportunities for conducting higher spring releases within power plant capacity.*

The proposed hydrograph is a 5-day low flow necessary for maintenance on Glen Canyon Dam (GCD) followed by a 4.5-day high flow pulse within ~~flow~~ base operations constraints specified by the ROD (Figure 1). This combination of desiccation at low flows followed by scour at higher flow is hypothesized to disturb benthic habitats to a much greater extent than either the low or higher flow alone (Kennedy and others 2020).

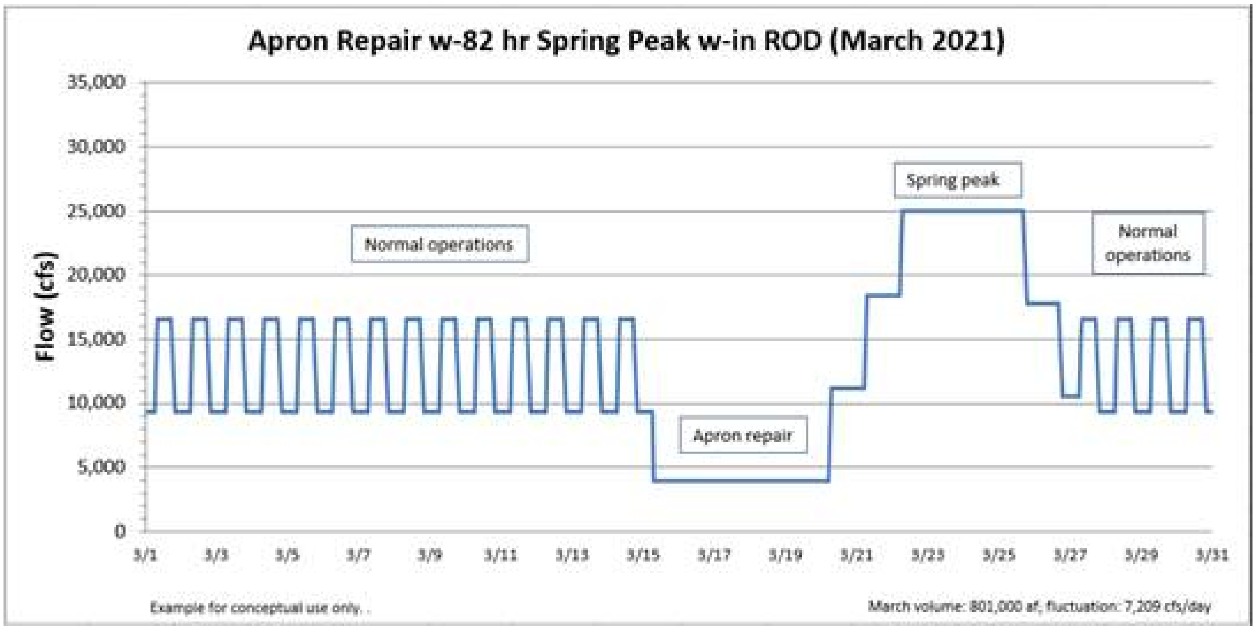


Figure 1. Conceptual hydrograph developed by the FLAHG for possible testing ~~in FY2021~~.

The hydrograph developed and recommended by the FLAHG will be used to evaluate whether a spring-timed disturbance flow enhances resources in the CRe. The FLAHG hydrograph may~~will~~ also be used to: 1) evaluate whether an extended period of low flows in the spring windy season, followed by a pulse flow, enhances transport of sand to inland dunefields and archaeological sites (Project Element O.3); 2) track physiological responses of key riparian plant species and identify how physiological responses to flows may favor some riparian plant species over others (Project Element O.4); 3) evaluate native and invasive fish response (Project Elements O.6 and O.7); 4) estimate the impact of a low flow disturbance to recreational angling (Project Element O.8), hydropower (Project Element O.9), and sandbars and campsites (Project Element O.10); and 5) use of decision support tools to help synthesize findings and identify logical next steps in adaptive management experimentation (Project Element O.11; note that funding for O.11 is being sought from a different source than other project elements, see Budget Justifications).

The period of work for this project will be two fiscal years that begin in the fiscal year the spring disturbance flow is implemented. For planning purposes here, we define these as Year 1 and Year 2 ~~time period as FY2021-22 but recognize that the flow may not be implemented in 2021~~. In ~~FY2021~~ Year 1 this project seeks funding mainly from the C.5 Experimental Management Fund. Note that Reclamation retains decision-making authority for the allocation of funds from the C.5 Experimental Management Fund. In ~~FY2022~~ Year 2 we will seek funding from TWP carryover funds from prior years, or through annual review of the TWP, or through other

Reclamation considerations~~unspent capital from the Experimental Fund or other areas of the program~~ (see Budget Tables in Budget Justifications). Requests to support Project O through the Experimental Management Fund should be considered in context with other requests from the Experimental Management Fund (i.e. including, but not limited to Projects A.4, B.6.1-5, and J.3).~~The decision to fund the project from the Experimental Fund would follow guidelines established for other projects requesting funding from this source.~~

As with LTEMP flow experiments,~~T~~ the ~~decision~~ process to plan and implement the spring disturbance flow would ~~also follow guidelines for other experiments (e.g., HFEs) that request funding from the Experimental Fund in that the implementation process for the experiment would~~ involve evaluation of resource conditions and expected effects by the Glen Canyon~~a~~ T~~t~~echnical T~~t~~eam followed by Glen Canyon ~~a Glen Canyon Adaptive Management Plan (GCDAMP) l~~Leadership T~~t~~eam consideration~~decision~~. Research and monitoring proposed herein may change if conditions warrant. The decision of whether to implement the spring disturbance flow will be made by the Secretary of the Interior or their Designee. ~~It should be noted that other LTEMP experiments may occur in the same fiscal year as the proposed spring disturbance flow. For instance, if conditions were favorable for a sediment-triggered spring HFE in FY2021~~Year 1~~, Project O might be repurposed to study this potentially larger magnitude spring flow disturbance. These contingencies raise significant challenges from a science planning perspective and thus the plan proposed herein may change if conditions warrant.~~

## 3. Hypotheses and Science Questions

The types of hypotheses that can be tested in the spring disturbance flow will depend upon the flow that occurs and the specific timing of the flow. If the proposed FLAHG hydrograph is implemented, Project O describes studies that will determine whether this spring disturbance flow enhances Colorado River resources including those that are identified in the FLAHG charge. For example, Project O will test the hypothesis that disturbance of benthic (river bottom) habitats in spring enhances the LTEMP resources goals such as the goal of Natural Processes (i.e., food base) of the Colorado River (Figure 2). The FLAHG hydrograph may also help reduce uncertainties regarding the LTEMP goal for Recreational Experience including a range of recreational uses from upriver fishing to downriver white water. For example, it may address concerns expressed by the Hualapai Tribe of poor navigation in the western Canyon as a result of sand accumulation, an important issue affecting the Tribe's recreational boating enterprise and socioeconomic well-being. It is hypothesized that the spring disturbance flow may help to temporarily clear the channel immediately prior to the high use summer boating season, perhaps to a greater extent than a fall HFE. The spring disturbance flow could impact other LTEMP resource goals. For example, Project O includes study elements related to aquatic macrophytes, brown trout, riparian vegetation, cultural resources, and fish movement and migration. Even in the absence of large magnitude biological or physical impacts across these resources, elements

O.3-O.10 may help to identify linkages between flows and the broader ecosystem that could reduce uncertainty critical to implementation of other proposed experimental flows (Figure 3) specified in the LTEMP (U.S. Department of the Interior, 2016a,b).

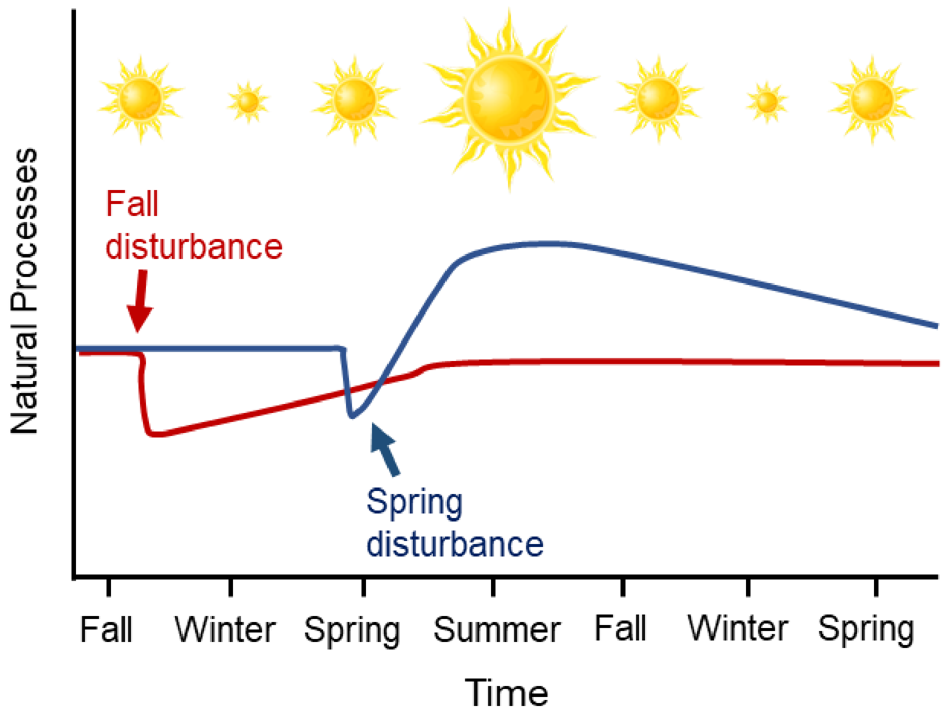


Figure 2. Hypothesized response of Natural Processes to the seasonal timing of flow disturbances. Fall disturbance flows are thought to cause an immediate reduction in natural processes (e.g., rates of algae and insect production), which gradually recovers to pre-disturbance levels. Flow disturbance in spring is hypothesized to also cause an immediate reduction in natural processes, but the processes of algae and invertebrate production quickly rebounds and eventually exceed pre-disturbance levels. See main text for further detail.

## 4. Background

The pre-dam Colorado River was characterized by spring snow-melt floods that often exceeded 100,000 $ft^3/s$, flash flood flows during the summer monsoon season, and extended periods of low flows from the fall through early spring. This seasonally variable flow regime was an important driver of ecological processes in the CRe, and the fish populations that evolved in the CRe were adapted to frequent flow disturbances, particularly during the spring and summer months. ~~Construction~~ Regulation of the Colorado River by GCD eliminated the annual spring high flow disturbances, increased base flow, and eliminated periods of low flows while substantially increasing intraday flow variation.

Disturbance is a critical natural process for many biological and physical resources in streams and rivers (Resh and others, 1988; Poff and others, 1997). For example, by temporarily disrupting ecosystem structure and changing the availability of substrates and resources, disturbance can help to maintain native biological diversity in streams and rivers (Bunn and Arthington, 2002; Carlisle and others, 2017). The magnitude of the disturbance, for example the extent of drying at low flow or the proportion of the bed that is mobilized at high flows, is an important determinant of how ecosystems will be affected by a given disturbance (Lake, 2010). Additionally, disturbance frequency and timing (e.g., spring vs. fall) can also influence the rate and trajectory of ecosystem recovery from disturbance (Lytle and Poff, 2004). In fact, a national synthesis of flow and biological data from over 700 streams and rivers in the lower 48 states found that healthy communities of native aquatic invertebrates and fish were most often present where flood disturbance still occurred, and where flood timing was seasonally appropriate (i.e., similar to the natural condition; Carlisle and others 2017).

The LTEMP ROD seeks to identify both flow and non-flow actions that could be implemented to improve resource condition and continue to meet the requirements of the Grand Canyon Protection Act. ~~High Flow Experiments (~~HFEs~~)~~ are one type of flow-action described in the LTEMP that were intended to improve sediment resources among other things. The protocol for implementing HFEs was developed in 2012 (U.S. Bureau of Reclamation, 2011) and was based upon insights and knowledge gained from testing HFEs in March/April 1996, November 2004, and March 2008 (Webb and others 1999, Melis 2011). These early HFEs indicated that retention of fine sediment above the elevation of average base flow would be maximized with fall-timed HFEs (given the seasonality of sediment inputs) and thus most HFEs are triggered by sediment conditions.

In contrast, many biological resources of the CRe including natural processes appeared to be maximized with spring-timed HFEs (Wright and Kennedy, 2011). At the time the HFE protocol was developed, it was unclear whether biological resources would be affected by fall HFEs, because virtually no biological monitoring occurred during the November 2004 HFE (Kennedy and Ralston 2011). All predicted resource responses were highly uncertain, even for sediment, so the HFE protocol was designed to resolve these uncertainties through frequent testing of both spring and fall HFEs (Wright and Kennedy, 2011). To test both spring and fall HFEs, the HFE protocol proposed using two sediment accounting periods. These sediment accounting periods track the quantity of new Paria River sand available for building beaches in Marble Canyon, and HFEs would only be triggered if the quantity of new sand is large. This approach to triggering HFEs, coupled with state-of-the-art sediment monitoring (Project A, TWP FY2021-23), eliminates the risk of unintentionally scouring sediment resources from Marble Canyon during an HFE (Wright and Kennedy, 2011).

Since the HFE protocol was established, fall HFEs have been triggered by sediment conditions six times (2012, 2013, 2014, 2015, 2016, and 2018) while no spring HFEs have been triggered since 2008. Note that although there were sufficient sediment inputs for a fall HFE~~s~~ in 2015, none occurred owing to concerns about spreading green sunfish from a reproducing population discovered in late summer 2015 in a Glen Canyon side channel disconnected from the mainstem at lows flows. Testing of 5 fall HFEs over the past 8 years has benefitted sediment resources and reduced uncertainties concerning sandbar response to HFEs in general (Figure 3). However, testing of fall HFEs since 2012 is also correlated with increased immigration of brown trout into Glen Canyon (Runge and others 2018) and critical uncertainties concerning the role of spring HFEs in achieving biological resource objectives remain unanswered (Figure 3).

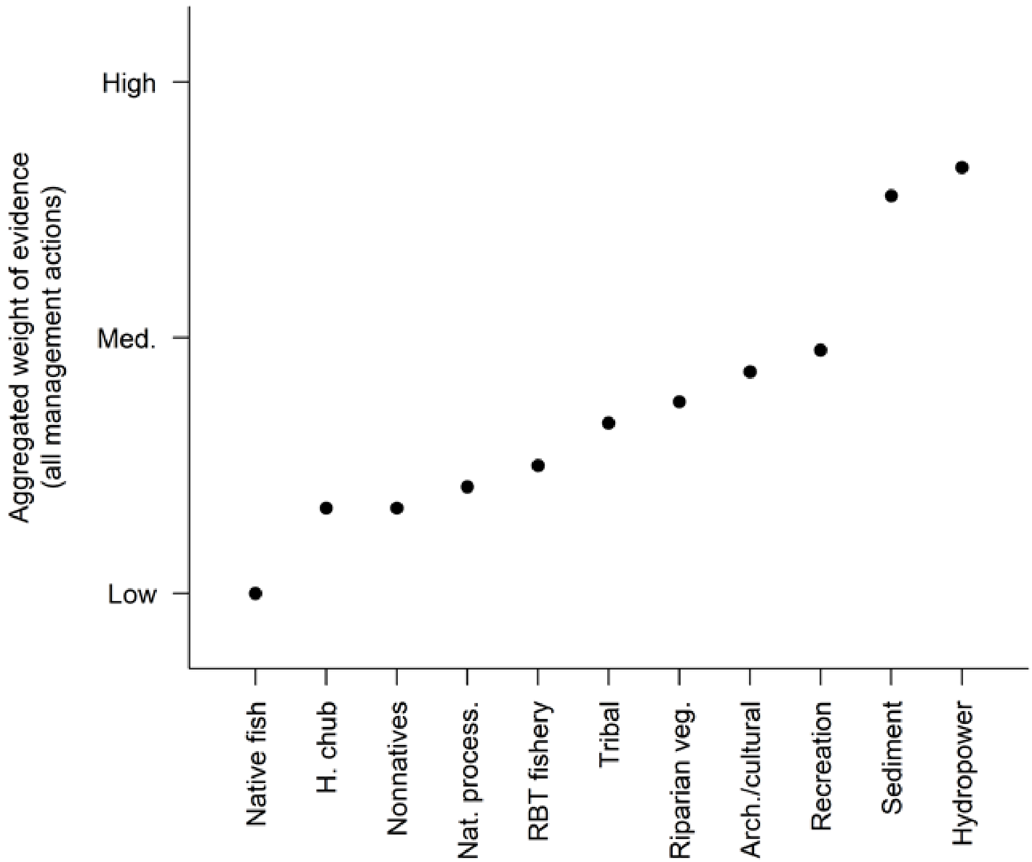


Figure 3. LTEMP goals associated with fish and aquatics (left side of graph) have some of the highest levels of critical uncertainty (i.e., lowest weight of evidence) concerning the role of flow disturbance timing in achieving objectives. Points represent the average weight of evidence from the 2020 Knowledge Assessment aggregated across the 3 management actions that were considered (i.e., FLAHG hydrograph, Spring HFE, Fall HFE). Goal ordering along x-axis is from lowest-to-highest weight of evidence. See FLAHG Predicted Effects document for details of the 2020 Knowledge Assessment.~~).~~

## 5. Development of Project O

Project O was not part of early drafts of the GCMRC Triennial Budget and Work Plan (TWP) FY2021-23. During early writing of the TWP, the ideas surrounding the spring disturbance flow were still being developed through the FLAHG and no definitive work plan for studying the flow had been developed by GCMRC. The Technical Work~~ing~~ Group (TWG) of the GCDAMP reviewed an early version of the TWP in June 2020 for recommendation to the Secretary of Interior. During that review, a motion was advanced that recommended revisions to the TWP, one of which was the inclusion of a project in the next draft that addressed the charge of the FLAHG. Thus, a new project, Project O, was added to the next draft of the TWP that addressed the charge of the FLAHG. The version of the TWP including Project O was submitted to the Adaptive Management Work~~ing~~ Group (AMWG) in August 2020.

Review of the TWP, including Project O, was done by the AMWG in a meeting in August 2020. The review resulted in a recommendation by the AMWG to the Secretary of Interior that Project O be removed from the TWP and submitted as a separate proposal. This recommendation was made because the AMWG indicated that Project O had not received sufficient review by the TWG and AMWG stakeholders prior to the August meeting. Also, Project O was requesting funds solely from the Experimental Management Fund and AMWG believed that it was therefore more appropriate for Project O to be submitted outside the TWP, as is done with other proposals requesting funding from the Experimental Management Fund.

Following the AMWG meeting, Project O was submitted to AMWG stakeholders for review and comment. Comments were received up until September 25, 2020. The comments and suggested edits have been reviewed by GCMRC and incorporated into this revised version of Project O. In addition to review by individual stakeholders, the Budget Ad Hoc Group (BAHG) of the TWG convened two meetings to discuss the work and budget proposals in Project O. These meetings occurred on September 21 and September 24, 2020. The outcome of these meetings resulted in the following changes to Project O including: 1) a prioritization of Project O elements based on resource and budget considerations (Table 1), and 2) identification of funding sources for Project O elements by year. The prioritization and funding of Project O elements that resulted from the BAHG meetings helped guide GCMRC in preparing the latest version of the Project O proposal.

Prioritization of Project O elements, as recommended by the BAHG on October 8, 2020, is shown in Table 1. The prioritization is shown by tiers; however, the ordering of elements within each tier does not indicate priority. Requests to support Project O through the Experimental Management Fund should be considered in context with other requests from the Experimental Management Fund (i.e. including, but not limited to Projects A.4, B.6.1-5, and J.3). ~~Prioritization of elements in Project O by tiers was conducted because, as already indicated, other LTEMP experiments may occur in the same fiscal year to the proposed spring disturbance flow. For instance, if conditions were favorable for a sediment-triggered spring HFE in FY2021Year 1, then Project O might be repurposed to study this potentially larger magnitude spring flow disturbance. Thus, i~~If the full annual amount of funding under the Experimental Management Fund ~~were~~ is not available for Project O, consideration of funding for Project O elements should be done in accordance with the recommendation developed by the BAHG on October 8, 2020

(Table 1). Implementation and funding then the prioritization shown in Table 1 could guide the funding of project elements. These contingencies uncertainties raise significant challenges from a science planning perspective and thus the plan proposed herein may change if conditions warrant.

**Table 1. Project O Element Prioritization Recommended by BAHG**

Tier 1 - Project O elements considered very important for understanding the effects of the proposed spring disturbance flow

- Project Element O.1. Does Disturbance Timing Affect Food Base Response?
- Project Element O.5. Mapping Aquatic Vegetation Response to a Spring Pulse Flow

Tier 2 - Project O elements considered important for understanding the effects of the proposed spring disturbance flow

- Project Element O.2. Bank Erosion, Bed Sedimentation, and Channel Change in Western Grand Canyon
- Project Element O.6. Brown Trout Early Life Stage Response to a Spring Pulse Flow
- Project Element O.7. Native Fish Movement in Response to a Spring Pulse Flow

Tier 3 - Project O elements considered somewhat important for understanding the effects of the proposed spring disturbance flow

- Project Element O.3. Aeolian Response to a Spring Pulse Flow
- Project Element O.4. Riparian Vegetation Physiological Response
- Project Element O.8. Do Disturbance Flows Significantly Impact Recreational Experience?
- Project Element O.11. Decision Analysis

Tier 4 - Project O elements not prioritized

- Project Element O.9. Are There Opportunities to Meet Hydropower and Energy Goals with Spring Disturbance Flows? (funded in TWP FY2021-23)
- Project Element O.10. Sandbar and Campsite Response to Spring Disturbance Flow (funded in TWP FY2021-23)

Review by the BAHG also provided an indication of appropriate funding sources for Project O. The BAHG indicated that funding under the Experimental Management Fund for certain aspects of work in Project O may be inappropriate, and these included: 1) multi-year commitments as the decision to use the Experimental Management Fund is made on a year-by-year basis, 2) monitoring for experiments or activities that are planned for and funded through the TWP instead of the Experimental Management Fund, and 3) salaries for positions lasting more than one year as this may lead to unreasonable expectations of work securityfunding continuity. In addition, the BAHG indicated that funding for Project Element O.11 should be sought from the C.4 Science Advisors Program (see TWP FY2021-23).

In the year that the spring disturbance flow is implemented (e.g., FY2021Year 1), funding for all project elements except O.11 would be provided by requested from the Experimental Management Fund. Reclamation retains decision-making authority for the allocation of funds from the C.5 Experimental Management Fund. In Year 1 Project Element O.11 will seek funding from TWP carryover funds from prior years, or through annual review of the TWP, or through other Reclamation considerations. Likewise, inIn Year 2, funding for O.1 and O.2 will be sought from TWP carryover funds from prior years, or through annual review of the TWP, or through other Reclamation considerations. An annual review will occur to determine the availability and appropriateness of this funding source for the work in question. Opportunities to leverage external resources and support from Program partners will be considered and explored by GCMRC and Reclamation for Year 2 funding. It should be noted that funding for a third year of data analysis and modeling is required for Project Element O.2 in order for it to be successfully completed; however, at this time a funding source has not been identified.

In the subsequent year (e.g., FY2022Year 2), funding for elements O.1 and O.2 will be sought from either unspent funding in the Experimental Fund or unspent funding in other program sources carried over from the preceding year while C.4 Science Advisors Program funding will be sought for O.11. As with other funding requests from the Experimental Fund, an annual review will occur to determine the availability and appropriateness of this funding source for the work in question.

# 6. Proposed Work

## Project Element O.1. Does Disturbance Timing Affect Food Base Response?

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Jeffrey D. Muehlbauer, Research Ecologist, USGS, GCMRC
Daren Carlisle, Eco-Flows Program Manager, USGS, Water Mission Area
David Lytle, Professor, Oregon State University, Department of Integrative Biology
Scott Wright, Research Hydrologist, USGS-California Water Science Center

This element focuses on quantifying food base response to spring disturbance flows that will likely be tested in FY2021-23. It focuses most specifically on the studies associated with the FLAHG hydrograph associated with apron repair low flows described in Figure 1 but is intended to be flexible enough to accommodate a potential Spring HFE, should that occur. Due to the relative lack of prior spring-timed flow experiments, any spring disturbance in the CRe would have very high potential for learning about ecosystem responses in general, and aquatic invertebrate communities in particular.

To date, any CRe-specific knowledge of food base responses to spring-timed disturbance is based upon learning from the March 2008 Spring HFE and, to a lesser extent, the first HFE, which was tested in April 1996. The March 2008 HFE was particularly well studied and appeared to stimulate the aquatic food base by scouring senescent algae and reducing the abundance of New Zealand mud snails. The food base that re-colonized the Colorado River in the months following the 2008 HFE was dominated by fast-growing, nutritious algae and fast-growing aquatic insect species including midges and blackflies.

However, that spring HFE occurred over a decade ago, at a time when underlying ecological conditions associated with lake levels, fish populations, aquatic algae and macrophyte densities, and New Zealand mud snail colonization levels were potentially very different than they will be in FY2021-23. Additionally, aquatic food base monitoring in spring 2008 was just getting underway that year, whereas now we have a >12-year dataset to contrast any food base responses against. Additionally, our long-term dataset will now allow us to contrast such a spring disturbance against a history of fall HFEs. In contrast to the 2008 Spring HFE, for instance, the five fall HFEs tested from 2012-present appear to have had neutral-to-negative impacts on the food base by potentially facilitating expansion of aquatic macrophytes and increasing abundance of New Zealand mud snails.

Outside the CRe, a recent synthesis of flow and invertebrate data from streams and rivers throughout the nation led by co-investigator Carlisle found that spring high flows are one of the most important factors contributing to diverse and productive aquatic insect assemblages (Carlisle and others, 2017). This synthesis research suggests that a spring flow disturbance in the CRe may be anticipated to have very different effects on the ecosystem and the aquatic food base relative to fall HFEs. Importantly, based on this synthesis, impacts from a spring disturbance in the CRe are predicted to be positive in terms of promoting increased abundance of desirable aquatic insect groups, which are critical to fishes and river food webs (Kennedy and others, 2016).

This element includes funding for tracking food base response to the FLAHG/GCRMC hydrograph in ~~FY2021~~ Year 1 (Figure 1). Due to logistical constraints, we will focus our sampling efforts in and around Lees Ferry. Specifically, we propose to sample aquatic insect drift intensively at four time periods: just prior to the low flow associated with apron repair, during the low flow, during the subsequent high flows after apron repair, and during the base flows immediately after the high flow. Sampling would occur over the course of 1-2 weeks at 5-10 sites throughout Glen Canyon and Upper Marble Canyon. Sites will be identical to our regular monitoring sites spaced roughly equidistant from GCD (starting at River Mile [RM] -15) to the head of Badger Rapid (RM 8), allowing us to contrast food web impacts above and below the Paria River confluence. The objectives of this sampling are twofold:

1) Quantify invertebrate export resulting from spring flow disturbance. Specifically, quantify the extent to which nonnative New Zealand mud snails are exported or suffer high mortality as a result of these flows, and the extent to which patterns of midge, blackfly, and *Gammarus* drift differ from baseline conditions in past spring seasons and during prior, fall HFEs.
2) Quantify organic matter export resulting from drying during apron repair and subsequent flushing during high flows, which may have concomitant impacts on aquatic insect habitat and food resources.

Existing monitoring efforts and sample collections river-wide using citizen science light traps and GCRMC staff-led drift sampling, as well as Glen Canyon monthly drift sampling will provide important information for quantifying the ecosystem responses to spring disturbance as well (see Projects F.1 and F.2). Our research specific to this project element is designed to pair with these datasets. These monitoring datasets are expected to enable us to track food base response to spring disturbance in the late spring and summer following the disturbance and in subsequent years and will be the main mechanism for monitoring long-term change.

### Outcomes and Products

- Journal article synthesizing food base and natural process response to FLAHG hydrograph.
- Data summaries presented at GCMRC's Annual Reporting Meeting to the GCDAMP.

## Project Element O.2. Bank Erosion, Bed Sedimentation, and Channel Change in Western Grand Canyon

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Matt Kaplinski, Research Associate, NAU
Robert Tusso, Hydrologist, USGS, GCMRC
Keith Kohl, Geodesist, USGS, GCMRC

Erosion of sediment from high banks and subsequent remobilization during dam operations, including during HFEs, in the Colorado River arm of Lake Mead Delta, presents significant navigation and management issues in the western part of Grand Canyon. All large reservoirs trap incoming sediment, and post-dam sedimentation in Lake Mead has been periodically studied since the completion of Hoover Dam in 1935. Current and projected decline in water supply and total allocation of Colorado River water would suggest that Lake Mead and Lake Powell are likely to stay well below full pool for the foreseeable future, converting the upstream parts of these reservoirs to riverine reaches that are rapidly evolving and redistributing sediment from the upper to lower parts of the delta.

Thus, river-reservoir system management must consider the effects of erosion and redistribution of both this legacy sediment and the sediment continually supplied from upstream. Currently, little is known about how the rate and magnitude of vertical incision and lateral erosion of Lake Mead Delta deposits by the Colorado River is affecting long-term channel stability and morphological evolution. Furthermore, little is known about whether GCD operations prescribed by LTEMP, including HFEs, affect river channel dynamics in this reach.

We hypothesize that bank erosion rates have increased in recent years as a result of reservoir drawdown and bed incision, and that following initial channel incision, rapid bluff erosion caused bed sedimentation and channel widening which may promote further bank erosion. As bank erosion progresses and the incised river channel widens, we may expect a decrease in sediment supply and a stabilization of the channel planform inset within the delta deposits. In this case, we hypothesize that vegetation will eventually stabilize bars and form a floodplain inset within the high banks composed of Lake Mead Delta sediments. This sequence of incision, widening, and stabilization has been described for a number of degrading river systems (Simon and Rinaldi, 2006). Changes in reservoir level, changes in the downstream base-level control associated with knickpoint migration, and changes in streamflow and sediment delivery from upstream all affect the rates of these processes and could cause the cycle of adjustment to repeat.

The upstream end of Lake Mead that is within Grand Canyon National Park is the final reach for many Grand Canyon river trips and is the centerpiece of river running operations by the Hualapai Tribe. This section of the Colorado River in Grand Canyon is perhaps the busiest section of the river, in terms of boat traffic, in the National Park. It is increasingly difficult for the Hualapai Tribe to maintain docks for their upstream fleet, and bed sedimentation often causes boat beaching and difficulty accessing the Pearce Ferry boat ramp. The delta deposits also inhibit natural campground development because there are few beaches adjacent to the steep banks.

The sediments of the Lake Mead Delta extend upstream to approximately the location of Separation Rapid in Grand Canyon, about 40 river miles upstream from Pearce Ferry. Since 2000, Lake Mead water levels have declined approximately 40 meters. The Colorado River has subsequently incised through newly exposed delta sediments, persistently eroding tall banks of fine-grained lake and delta deposits. Erosion of these banks delivers sediment to the river resulting in ever-shifting sandbars throughout much of the river corridor between Separation Rapid and Pearce Ferry. Downstream from Pearce Ferry the path of the incised channel does not follow its pre-reservoir course and the Colorado River flows over a ledge of poorly consolidated bedrock (Pearce Ferry Rapids). This ledge (knickpoint) creates a significant navigation hazard and provides the downstream base-level for the incising section of the lower Colorado River in Grand Canyon National Park, and thus plays an important role in regulating incision and sediment evacuation from upstream reaches.

The primary objectives of this research are to:

1) Quantify the rates and spatial patterns of vertical incision and lateral bank erosion of former reservoir sediment in the now riverine reach of the Lake Mead Delta;

2) Examine the patterns of bed-elevation change in a selected segment during a high flow pulse (HFE or release at or near powerplant capacity);

3) Identify potential linkages between river channel change and bed sedimentation to increased sediment supply from banks and lateral channel migration; and

4) Identify whether a spring disturbance flow might exacerbate or mitigate boat navigation problems associated with bed-sediment accumulation.

In order to address the above research questions, we intend to study channel response to dam operations in a short (~1 to 3 km) study reach (to be selected) downstream from Quartermaster Canyon. We will work with the Hualapai Tribe to select a specific reach that is critical for boat navigation. In the first part of our analysis, we propose to use available remote sensing data sets to document historical changes in bank and river channel morphology. The second part of the analysis will include collection of repeat surveys of the riverbed within the selected study reach before, during, and following a dam-released flow pulse. The repeat surveys will allow quantification of the magnitude and spatial distribution of channel morphological change associated with the flow pulse and the return to normal dam operations. This analysis will be conducted by using the field data to develop a streamflow and sediment transport model for the study reach. The model will allow evaluating bed response in a predictive framework to determine whether there are systematic changes in bed elevation caused by dam operations. Because similar issues exist upstream along the deltas of the Colorado and San Juan arms of Lake Powell, this research project also could provide guidance for management of other large reservoirs in the Colorado River Basin.

We hypothesize that the flow pulse would transport sediment through and out of the study reach, temporarily scouring a deeper channel that would refill with sediment upon return to normal operations. The purpose of the study is to determine if this scour occurs and how long the scoured condition persists. We would expect a stronger scour signal with a larger and longer flow pulse. Although we would expect a larger signal to be caused by an HFE, there is value in conducting the experiment around any flow pulse. In either case, the field data will be used to develop and calibrate a flow and sediment transport model.

The drawback to conducting the experiment around a smaller flow pulse is that if scour was not observed for that event, it would not mean scour does not occur during larger flow pulses and it may be necessary to repeat the experiment during a larger flow pulse. The advantage of conducting the study around a smaller pulse flow is that if a response is observed, we would learn about how a release that is within the range of powerplant capacity operations might be used to manage sediment in this reach. In order to ensure progress in the study, we propose to collect the field data during the first flow pulse to occur in ~~the TWP FY2021-23~~Year 1. Thus, if a sediment-triggered HFE occurs in ~~fall 2020~~fall of Year 1, we propose to collect the field data during that event. If an HFE does not occur in ~~fall 2020~~fall of Year 1, we propose to collect the field data during the flow pulse of approximately 25,000 $ft^3/s$ that is currently being planned to occur in ~~spring 2021~~Year 1. If data are collected during an HFE in ~~fall 2020~~fall of Year 1, we will still make supplemental observations during the ~~spring 2021~~Year 1 flow pulse. If a Year 1 fall ~~2020~~ HFE does not occur and data are first collected during the ~~spring 2021~~Year 1 spring flow pulse, we will then make supplemental observations during a fall HFE should one occur in ~~2021 or 2022~~Year 1 or Year 2.

The shifting sandbars of the Colorado River where it flows through Lake Mead Delta sediments presents a considerable navigational hazard. This is an extremely challenging environment for bathymetric mapping because of very shallow and highly turbid water. The required field data for this project are repeat measurements of channel bathymetry and bank topography for the selected 1- to 3-km study reach. We will use a very low draft, wide-angle, dual-lidar and multibeam sonar system specially designed for swath mapping in shallow water, collecting swath data up to 10 times the water depth and lidar topography of sediment banks up to 100 m away. To prepare for collecting data in the study reach, one additional trip will be made in advance to establish local survey control. Up to five sets of bathymetric measurements will be collected: 1) before the flow pulse, 2) once during the flow pulse, 3) immediately following the flow pulse, 4) approximately one month following the flow pulse, and 5) approximately four months following the flow pulse. Each survey will consist of measurements of the channel with multibeam sonar and measurements of the exposed banks with lidar and/or conventional total station. If measurements are made during a fall ~~2020~~ Year 1 HFE, the 5th set of measurements will also be used as the initial set of measurements for monitoring the ~~spring 2021~~Year 1 spring flow pulse. An additional two to four sets of measurements will be made during and following the ~~2021~~ Year 1 spring flow pulse.

Although the work in this project is scheduled to occur in only two fiscal years~~, FY2021-22~~, it should be noted that the effort associated with data processing, analysis, and modeling will take longer. Complete results and interpretations from this work are not expected until the end of ~~FY2023~~Year 3. Thus, an additional year of work beyond ~~FY2022~~ Year 2 is needed to complete the work in this project element. Funding for this additional year is not currently included in the budget and has not yet been identified.

### Outcomes and Products

- Repeat bathymetric maps (digital elevation models or DEMs) of western Grand Canyon study reach.
- Report/journal article on bank erosion, bed sedimentation, and channel response to HFEs on the Colorado River in western Grand Canyon.

## Project Element O.3. Aeolian Response to a Spring ~~Pulse~~ Disturbance Flow

Joel Sankey, Research Geologist, USGS, GCMRC
Helen Fairley, Archaeologist/Social Scientist, USGS, GCMRC

GCMRC has monitored effects of high flows conducted during the HFE Protocol that began in 2012, on source-bordering aeolian dunefields that contain archaeological sites within Grand Canyon National Park. There are 57 large, source-bordering aeolian dunefields along the Colorado River in Grand Canyon and another 60 similarly large areas of unvegetated sand located at high elevations outside of the active river channel. Many of those dunefields and high elevation sand areas contain archaeological sites. While HFEs do not directly inundate most of these areas, they do resupply them with river sand by rebuilding upwind sandbars.

Sankey and others (2018) show that the relative success of HFEs as a regulated-river management tool for resupplying sediment to dunefields that contain archaeological sites is analogous to the frequency of resupply observed for river sandbars. Dunefield sediment storage increased cumulatively when HFEs were conducted consistently on an annual basis from 2012 to 2014. However, sediment storage more commonly decreased during one-year hiatuses from HFEs such as occurred in 2015 (Sankey and others, 2018), as well as more recently in 2017 and 2019. GCMRC used these research and monitoring results to help design experimental vegetation removal treatments to increase aeolian sediment supply from HFE sandbars to several dunefields that host archaeological sites. Those vegetation removal treatments were implemented by the NPS in 2019 and will be completed again by NPS in 2020 and 2021 in Grand Canyon (see Project D.1 and Reclamation Projects C.7-C.8).

Each of the HFEs examined by Sankey and others (2018) occurred in the fall; however, the spring season exhibits the most frequent competent winds in Grand Canyon, a disconnect that has potentially large, but as yet uninvestigated, implications for dunefield resupply. Even though sandbars that serve as dunefield sediment source areas occur in predictable locations along the river, their size can vary substantially over sub-annual timescales due to sediment resupply during controlled floods and subsequent fluvial erosion that typically occurs during the intervening periods. For example, it is possible for a large sandbar to form during a fall controlled flood, but then erode by fluvial processes and become a much smaller sediment source area by the time of the spring windy season; spring is typically a dry, windy time of year when, between April and early June, aeolian sand-transport rates exceed rates over the rest of the year by 5–15 times (Draut and Rubin, 2008). The last spring-time-controlled flood occurred in 2008 in the Grand Canyon and was obviously not analyzed as part of the study by Sankey and others (2018). However, measurements taken at one site before and following the 2008 spring HFE demonstrate how a large volume of sand was mobilized and rapidly moved upslope immediately following that spring HFE. Transfer of the HFE sediment to upslope dunefields continued incrementally for several years after that 2008 spring HFE (Figure 4).

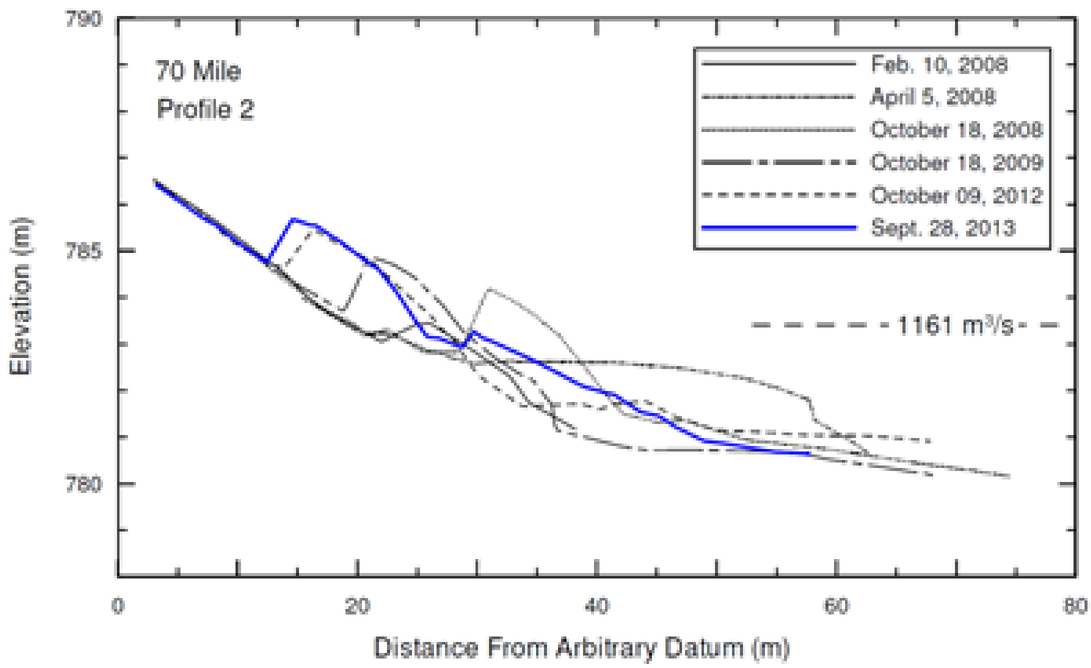


Figure 4. Survey profiles of an aeolian dune that formed from a sandbar after the spring 2008 HFE. From 2008 to 2013, the dune formed and then migrated inland from the river channel (i.e., migrated towards the datum of “0” on the x-axis).

In addition to timing of controlled floods, daily fluctuations in river discharge have potentially large implications for fluvial-aeolian sediment exchange at our sites. Kasprak and others (2018) recently quantified the influence of river stage on the areal extent of sand available for aeolian transport. The results of that study revealed the importance of low river flows in exposing sand for aeolian transport along the river corridor: since closure of the dam, roughly 1/3 of the unvegetated sand area has been found at stages below the regularly-occurring lowest flows of 8,000 $ft^3$/s. Taken together with the decoupled timing between the spring windy season and the fall controlled floods in Grand Canyon, we hypothesize that, in the future, transfer of sediment from the river channel to dunefields and archaeological sites could be markedly increased through the use of spring high flows followed by subsequent low flows that expose sand for aeolian transport. The proposed spring disturbance flow is not ideally designed to test this hypothesis but will provide an opportunity to evaluate how changes in exposed sand area affect aeolian transport rates.

The low flow portion of the spring disturbance (FLAHG) hydrograph may temporarily increase aeolian transport of sand from the river channel to archaeological sites in dunefields by increasing the amount of exposed sand available for aeolian transport by as much as 400% (Kasprak and others in review; Kasparak and others 2018; Sankey and others 2018). However, the duration of the low flow is short and so effects on aeolian transport are expected to be minor. Although the high flow portion of the hydrograph will decrease the supply of sand available for aeolian transport, the duration of high flows is also short, so any reductions in aeolian transport are expected to be temporary and minor. March is also typically one of the wettest months of the year, reducing the potential for wind transport of sand.

No major impacts to dunefields with archaeological sites are anticipated if the Spring FLAHG hydrograph is implemented. Although the FLAHG hydrograph is not predicted to have a major impact on dunefields that contain archaeological sites, the FLAHG hydrograph represents a valuable opportunity to study how changes in flow expose more bare sand area and may affect rates of potential aeolian transport of sand from the river channel to adjacent dunefields. We propose to conduct research during the FLAHG spring flow at a combined archaeological-dunefield-sand bar monitoring site from Project D.1 where NPS is also considering conducting riparian vegetation removal through the LTEMP vegetation management project, which could increase the aeolian transport of sand from the sandbar to adjacent archaeological site. We propose to leverage the FLAHG flow to measure sand drying rates, change in exposed subaerial sand, and aeolian sediment transport potential during the extended low flow of 4,000 $ft^3$/s and subsequent high flow at the study site.

## Outcomes and Products

- Results reported at GCMRC's Annual Report and Annual Reporting Meeting to the GCDAMP.

## Project Element O.4. Riparian Vegetation Physiological Response

Emily Palmquist, Ecologist, USGS, GCMRC
Brad Butterfield, Associate Research Professor, Northern Arizona University, Center for Ecosystem Science and Society

Dam operations influence riparian plant species differently, depending in part on drought and flood tolerance. Riparian plant species in the CRe represent a gradient of river flow dependencies (McCoy-Sulentic and others, 2017), such that individual flow scenarios can positively impact some species while negatively impacting others. In the context of a FLAHG hydrograph, low flows of 4,000 $ft^3/s$ for 5 days could dry out obligate wetland plant species (plants strongly dependent on river flows, like willows, sedges, rushes), potentially reducing their survival (Gorla and others, 2015). A spike flow of approximately 25,000 $ft^3/s$ will provide water to riparian plants established further away from the river during the time of year that they start to grow. We expect that for many species this spike would have a positive impact, at least for a short period after the flow (Ralston, 2010). A short spike could be detrimental to flood intolerant (typically drought tolerant) plant species (Stromberg and others, 1991; Banach and others, 2009), but such species are unlikely to be inundated by a 25,000 $ft^3/s$ or lower flow.

It is unknown if the combined impacts of low flows for five days followed by a spike flow varying in volume over 4.5 days will: 1) negatively influence both flood tolerant and intolerant species, 2) favor either flood tolerant or drought tolerant species over the other, 3) positively influence both flood and drought tolerant riparian species, or 4) have no measurable impact on riparian plants. However, our prediction is that obligate wetland species will be negatively impacted by the low flows, whereas other species will not be significantly impacted by the combined low/high flows. The primary focus of riparian vegetation research during a FLAHG spring flow is to evaluate physiological responses of a subset of species before, during, and after the experimental flows. This study is designed to complement the experiments described in Project C.2. Field-based physiological measurements like those proposed in Project C.2 provide a valuable comparison between field conditions and the controlled conditions of mesocosms.

We propose to select a subset of species from those listed in Project C.2 (Figure 5), depending on availability of those species at accessible river sites. The species selected will represent both flood tolerant and drought tolerant species and will likely include arrowweed (*Pluchea sericea*), coyote willow (*Salix exigua*), Emory's baccharis (*Baccharis emoryi*), tamarisk (*Tamarix spp.*), Emory's sedge (*Carex emoryi*), and available *Juncus* spp. The daily measurements will include those of the mesocosm experiments: stomatal conductance, stem water potential, relative humidity, leaf turgor, and soil moisture. Measurements will be collected daily starting two days prior to the experimental flows through two days after.

The target location for this work will be in and around Lees Ferry. If, however, weather conditions result in a late start to the spring growing season and the target species are unlikely to be fully leafed out and active at the time of the FLAHG flows, we will relocate to the area near Phantom Ranch. Plants will be active in that river segment during the FLAHG flows but are less desirable simply due to logistics.

## Outcomes and Products

- Data integrated into Project C monitoring, experiment, and modeling analyses to help inform journal publication conclusions.
- Data summaries presented at GCMRC's Annual Reporting Meeting to the GCDAMP.

## Project Element O.5. Mapping Aquatic Vegetation Response to a Spring ~~Pulse~~ Disturbance Flow

Kimberly Dibble, Fish Biologist, USGS, GCMRC
Mike Yard, Fish Biologist, USGS, GCMRC
Charles Yackulic, Research Statistician, USGS, GCMRC
Dan Buscombe, USGS, Western Ecological Research Center, Santa Cruz, CA
Robert Tusso, Hydrologist, USGS, GCMRC

A unique opportunity exists to apply a tool developed in the FY2015-17 and FY2018-20 workplans to answer research questions related to proposed spring-timed experimental flows released from GCD. In Project Element E.2, imagery analysis of underwater photos using machine learning techniques is allowing GCMRC scientists to understand the composition and cover of aquatic macrophytes, macroalgae, and bryophytes in Glen Canyon at two established transects in the upper (~-13 RM) and lower (~-4 RM) sections of this reach in the Colorado River. This imagery is the first of its kind related to aquatic vegetation composition and cover. It is anticipated that information gained from this project will serve as a baseline to answer questions related to the effects of dam operations on primary producers, whether that be long-term responses in the aquatic vegetation community, or short-term responses to disturbance effects such as HFEs, Trout Management Flows (TMFs), and other proposed flows.

~~In spring 2021 or 2022, a~~A 5-day steady 4,000 ft$^3$/s flow has been proposed for GCD apron repair work. This low, steady flow will be immediately followed by a higher flow up to power plant capacity (~25,000 $ft^3/s$). This could disturb the littoral edge through prolonged desiccation followed by subsequent scour leading to aquatic vegetation removal. We anticipate that the low, steady flow associated with apron repair work will dewater approximately 20-25% of the channel Glen Canyon-wide and up to ~50% of the bars closest to the dam relative to typical maximum flows in March (Wright, unpub. data). We hypothesize this prolonged desiccation at the littoral edge followed by an increase in sheer stress will have a greater effect on macroalgal species such as *Chara*, *Cladophora*, and *Ulothrix*, while rooted macrophytes and bryophytes located deeper in the channel will be less affected by dewatering and subsequent scour (e.g., Benenati and others, 1998). The magnitude of this effect will be dependent on the degree to which atmospheric conditions and solar radiation heat the littoral edge habitat.

We hypothesize the scour and cleaning of cobble associated with the pulse flow will facilitate re-growth of diatom assemblages that are more palatable to invertebrate consumers such as *Gammarus lacustris*, Simuliidae, and Chironomidae (e.g., Cross and others, 2011, 2013; Korman and others, 2011). This could stimulate higher trophic levels (e.g., rainbow trout), but the magnitude and trajectory of the effect will be dependent on whether this disturbance stimulates regrowth of a high-quality diatom assemblage as occurred following the spring HFE in March 2008 (see Project Element O.1). The proportion of invertebrate production attributable to diatoms was roughly equivalent in the years prior to and after the 2008 spring HFE, and invertebrate production declined by about half immediately following the flood. However, high-quality invertebrate prey supported by diatoms increased in the drift during the months following the spring HFE, and those items were consumed at a higher rate by age-0 and 1 rainbow trout, thus increasing rainbow trout production (Cross and others, 2011, 2013).

We propose to use this unique opportunity (coupled with advances in Project Element E.2 in TWP FY2021-23) to understand how a spring disturbance flow affects the dominant primary producers in Glen Canyon, with a secondary objective of determining the scale at which we might be able to do so. This would be designed as a before and after-impact study, with one trip immediately prior to the low flow (e.g., late February or early March), one trip immediately after the higher flow (e.g., late March or early April), and one trip in June to detect vegetation response and recovery. Images from the June trip will be compared to baseline images from 2016 and 2019 that were taken in years lacking a spring disturbance flow. If we can detect a change in aquatic vegetation cover and/or composition on a short-term scale (i.e., one season), then that result will inform the frequency at which we should undergo aquatic vegetation surveys (Project Element E.2). For example, if we can detect change within a season over multiple trips, this method could be considered a sensitive tool for detecting vegetation community responses to dam operations and would further our understanding of factors that drive primary production in Glen Canyon (Project E).

## Outcomes and Products

- Analysis of flow impacts to aquatic vegetation composition, distribution, and cover with an assessment of recovery trajectory along transects spanning the littoral edge to mid-channel.

- Peer-reviewed journal article describing pulse flow effects on aquatic vegetation communities in Glen Canyon. Results will also be included in the GCMRC's Annual Report.

- Presentation to stakeholders at GCMRC's Annual Reporting Meeting to the GCDAMP and/or at a scientific conference.

## Project Element O.6. Brown Trout Early Life Stage Response to a Spring ~~Pulse~~ Disturbance Flow

Kimberly Dibble, Fish Biologist, USGS, GCMRC
Laura Tennant, Fish Biologist, USGS, GCMRC
Clay Nelson, Fish Biologist, USGS, GCMRC
Michael Yard, Fish Biologist, USGS, GCMRC
Josh Korman, Fish Biologist, President, Ecometric Research Inc.

This project builds on knowledge gained from Project Element H.3, "Brown Trout Early Life Stage Survey" (BTELSS), particularly as related to the effects of spring-timed experimental flows on the early life stages of brown trout. In March 2008 a spring HFE was implemented with a sustained flow release ~40,000 $ft^3/s$ for 60 hours with the primary objective of building sandbars in Grand Canyon (Korman and others, 2011).

This experimental flow was planned in a time period when rainbow trout spawn and eggs and alevins are in gravel redds, but it was not expected to influence young-of-year (YOY) trout incubation success or abundance. Contrary to this hypothesis, results indicated that rainbow trout hatched just before and up to one month after the spring HFE had lower survival rates relative to those hatched after mid-April (Korman and others, 2011). Survival was higher for fish hatched after the controlled flood, such that abundance of YOY rainbow trout was 4.4 and 2.5 x higher than expected in July 2008 and 2009, respectively. Increased survival has been attributed to an improvement in habitat conditions for eggs (e.g., scour of fine sediment from the substrate leading to better oxygenation), combined with increased food resources for emerging trout due to a higher quality algal assemblage that grew after the flood (see Project Elements O.1 and O.5; Korman and others, 2011; Cross and others 2011, 2013).

A spring ~~pulse~~disturbance flow is planned ~~for March 2021 or 2022~~ in conjunction with GCD apron repair work, which may include a steady 4,000 ft$^3$/s flow for five days followed by a higher pulse flow up to power plant capacity (~25,000 ft$^3$/s). This experimental flow is proposed for the same month as the 2008 spring HFE, and as such, the FLAHG hydrograph has the potential to moderately affect the rainbow trout fishery in Lees Ferry. However, the strength of the effect on rainbow trout will likely depend on the response of the food base to the proposed flow (see Project Element O.1). While the 2008 spring HFE resulted in an increase in recruitment in Lees Ferry, that flow also occurred during a time period where phosphorus was higher in the system. As such, there is high uncertainty on the effect of the FLAHG flow on aquatic vegetation/diatoms which comprise the food base and the rainbow trout fishery.

For brown trout, a spring disturbance flow in March is unlikely to affect spawning timing or success since this species spawns from mid-October to early February. However, we are unsure what effect a low steady flow followed by a higher sustained pulse flow could have on brown trout emergence timing, survival, growth, and abundance since brown trout peak emergence occurs in March, depending on incubation temperature (Figure 5). Colder temperatures in winter and early spring (up to ~11°C) delay egg maturation and hatch, such that the brown trout emergence peak occurs ~March 15. Warmer temperatures (up to ~14°C) shift peak emergence to ~March 1 (Figure 5). Thus, the timing of the flow relative to winter and early spring temperatures ~~in 2021 or 2022~~ will likely affect the vulnerability of recently hatched or newly emerged brown trout to the FLAHG flow.

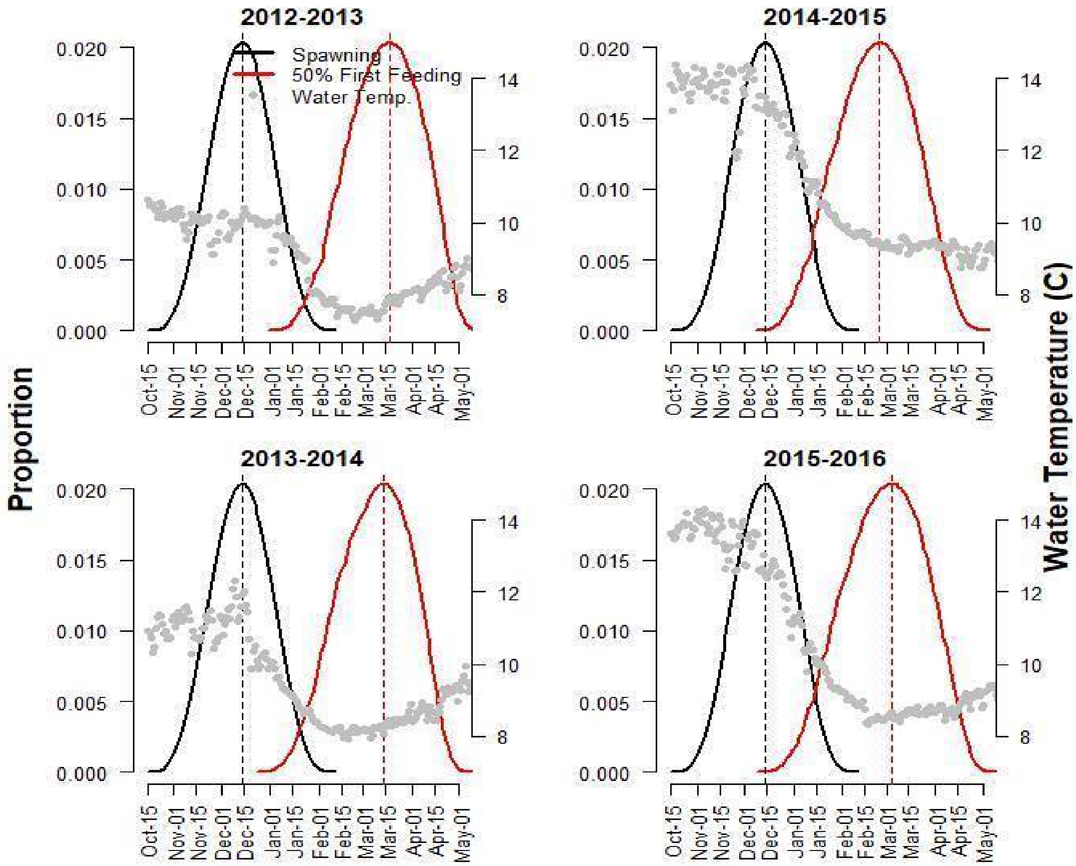


Figure 5. Predicted emergence timing of YOY brown trout (red line) relative to incubation temperatures in Glen Canyon based on an approximation of brown trout spawning period. At colder incubation temperatures (e.g., 2012-13, 2013-14) peak emergence is expected ~March 15th. At warmer incubation temperatures (e.g., 2014-15, 2015-16) brown trout peak emergence is expected ~March 1st (Korman and Yard, unpublished data).

While a low steady flow timed during peak emergence could improve short-term swim-up and growth conditions for brown trout fry, we anticipate an energetic cost for newly emerged brown trout fry during the ~~pulse~~ spring disturbance flow. Therefore, we plan on collecting data during the year of the spring ~~pulse~~ disturbance flow and comparing results to a non-flow year using the methods outlined in Project Element H.3, which will improve understanding of how spring flow configurations may affect brown trout in their early life history stages. Results will be compared to age-1 brown trout catch from the TRGD project in fall of ~~2022~~ Year 2 for comparison, which would be an indicator of brown trout recruitment strength following the spring ~~pulse~~ disturbance flow (Project Element H.2).

## Outcomes and Products

- Data to support the management of brown trout in Glen Canyon including habitat use preferences. Results will include an assessment of how spring experimental flows affect brown trout hatch date, emergence timing, and the growth, survival, and relative abundance of the cohort relative to the strength of the recruitment signal the following year.

- Peer-reviewed journal article describing early life history information and the habitat preferences of brown trout. Results will also be included in the GCMRC's Annual Report.

- Presentation to stakeholders at GCMRC's Annual Reporting meeting to the GCDAMP and/or at a scientific conference.

## Project Element O.7. Native Fish Movement in Response to a Spring ~~Pulse~~ Disturbance Flow

Kirk Young, Fish Biologist, USFWS, Arizona Fish and Wildlife Conservation Office
Charles Yackulic, Research Statistician, USGS, GCMRC
Randy Van Haverbeke, Fish Biologist, USFWS, Arizona Fish and Wildlife Conservation Office
Maria Dzul, Fish Biologist, USGS, GCMRC
Kimberly Dibble, Fish Biologist, USGS, GCMRC

This project element focuses on quantifying the response of native fish (humpback chub and flannelmouth sucker) to a spring disturbance flow ~~scheduled for 2021 or 2022~~. This flow is being designed by the FLAHG and includes a steady multi-day low flow (~4,000 $ft^3/s$) associated with GCD apron repair work followed by a higher steady pulse flow at or near power plant capacity (~25,000 $ft^3/s$). In the Upper Basin and in eastern Grand Canyon, telemetry studies and mark-recapture data have generally demonstrated high site fidelity of humpback chub (Project Element G.3) (Gerig and others, 2014; Kaeding and others, 1990; Paukert and others, 2006). Further, during a beach building flow in 1996, GCD releases of 1,274 $m^3/sec$ (~27,000 $ft^3/s$) had little effect on the distribution, abundance, or movement of flannelmouth sucker and humpback chub around the Little Colorado River (LCR; Valdez and others, 2001). However, a large and expanding population of humpback chub has established in western Grand Canyon in habitats where these fish may have different responses to the proposed spring disturbance flow due to unique habitats and warmer water temperatures. Native fishes such as flannelmouth sucker and humpback chub are known to move into the LCR in late February and early March in anticipation of spawning, and fish that spawn in western Grand Canyon may have similar timing in their movement (Valdez and Ryel 1995; Weiss and others, 1998; USFWS 2017).

Aquatic habitat and river geomorphology remain altered from Lake Mead sediment deposition near Bridge Canyon (~RM 235) and below. Nevertheless, the abundance of humpback chub (≥100 mm) in the Lake Mead sediment zone is estimated at 2,592 (2,217-2,967 confidence interval [CI]) fish near Bridge City (~RM 239) and 847 (564-1,129 CI) fish near 250-mile, while the flannelmouth sucker population (≥150 mm) is estimated at 5,760 (5,073-6,447 CI) fish near Juvenile Chub Monitoring (JCM)-West site location (Project Element G.5; Van Haverbeke and others, 2020). This differs greatly from the population estimate of humpback chub at Pumpkin Spring near JCM-West from 1990-1993, which was estimated at five adults (Valdez and Ryel 1995). Since the population trajectory of native fishes in western Grand Canyon has increased substantially over the last few years in the presence of altered habitats that differ from eastern Grand Canyon, having data on the distribution and movement of these species in response to spring-timed experimental flows will help in our understanding of drivers that affect newly established or expanding native fish populations.

The Lake Mead formation habitat (~RM 235-284) occupied by humpback chub, flannelmouth sucker, and other native species like razorback sucker is sediment-filled and less heterogeneous than habitats further upriver in Marble and eastern Grand Canyons. As such, deep habitats during a low multi-day steady flow and stable low-velocity habitats during a higher sustained flow are limited, possibly requiring fish to move in response to these changes. We hypothesize that humpback chub and flannelmouth sucker may move larger distances in search of suitable habitat and may not return to their formerly occupied sites. We may see a difference between species, with flannelmouth sucker responding more to the higher steady flow that has qualities of a spring hydrograph during spawning season, which will be concurrent with temperatures in the mainstem and tributaries suitable for spawning and egg development (Weiss and others, 1998; USFWS, 2017). Preliminary assessment of JCM-West mark-recapture data (Project Element G.6) suggests that humpback chub in JCM-West may move in and out of the study reach, consistent with the hypothesis that they are more mobile than in the JCM-East study reach. Thus, we hypothesize that high steady flows may stimulate movement and possibly lead to resettlement as fish search for suitable habitat and food resources. Additional information on fish movement in response to flow and non-flow conditions, especially related to transient fish that just pass through reaches once, may improve estimates of density and abundance for humpback chub in western Grand Canyon.

To answer these questions, we propose the use of sonic tags to track the responses of humpback chub and flannelmouth sucker to the proposed spring disturbance flow. While rare, adult razorback sucker will be included in this study if captured or detected on the remote Submersible Ultrasonic Receiver (SUR) network, since the species also spawns in spring and may respond to simulated flood hydrograph (USFWS, 2018). We propose targeting two study sites, one within the JCM-west reach to economically align with ongoing studies (Project Elements G.5, G.6), and one in the Lake Mead formation area below ~RM 235 that is accessible via up-runs from Pearce Ferry. We propose to sonic tag approximately 35 adult fish per site, and USFWS will sonic tag another 35 fish as a match, for a total of ~70. Approximately half the tags will be inserted into adult flannelmouth sucker, the other half into humpback chub. If we capture any adult razorback sucker, they will receive priority over the other two species since they are rare in the system. The effort will benefit from an array of ~27 remote SURs already in place within Grand Canyon distributed from the LCR to Pearce Ferry to passively track native fish movement. We will also actively track fish at both sites as time and resources allow, combined with analysis of general movement patterns at the JCM-west vs. JCM-east sites to refine mark-recapture modeling (Project Elements G.3, G.6).

*Methods*

Fish will be humanely handled using well-established surgical protocols for safely inserting sonic tags into adult fish species (Karam and others 2012). Sonic tags, weighing ~2% of fish weight and with frequencies that are compatible with NPS/Bio-West razorback sucker study fish, will be surgically implanted. Specifically, wild fish captured will be moved to a mobile surgical station and allowed to acclimate for at least 30 minutes prior to surgery. Each fish will be anesthetized by immersion in approximately 16-L of fresh water with tricaine methanesulfonate (MS222; 125 mg L-1) in a dark container. Once anesthesia has progressed to the desired degree, indicated by cessation of all fin and muscular movements other than weak operculation, the fish will be removed from the container, measured (total length [TL in mm]), weighed (nearest gram [g]), and scanned for a 134.2 kHz PIT tag. The fish will be placed on its dorsum on a wetted towel in a specially constructed cradle and covered with a lightweight, damp cloth. Fresh MS-222 solution will be gently pumped onto the exposed gills to maintain anesthesia for the duration of the procedure. A short (< 3 cm) mediolateral incision will be made slightly anterior and dorsal to the left pelvic fin and an acoustic transmitter sterilized in 70% ethanol will be inserted into the abdominal cavity. A PIT tag will be placed into the cavity if none was detected. The incision will be sutured with 3-4 knots using USSC 3-0 Monos of black monofilament (or equivalent) and a C-14 cutting needle. Following surgery, the wound will be swabbed with Betadine, a 10 mg/kg dosage of Baytril® (enrofloxacin), or other appropriate antibiotic will be injected into the dorsal-lateral musculature to prevent infection. Sonic-tagged fish will be placed into a recovery tank with fresh circulated water, held overnight for recovery, and released the following day.

Sonic-tagged fish will be remotely and passively monitored via the established SUR network at both the JCM-west and western Grand Canyon sites. Detection data will be downloaded from the SURs during existing scheduled cross-purposed trips. Active tracking will occur within existing projects (e.g. JCM-west, aggregation sampling) as time allows and from Pearce Ferry up-runs to western Grand Canyon sites to assess movement before, during, and after the spring disturbance flow. These observations will be compared to flow response literature in eastern Grand Canyon and to data on movement from the JCM-east and JCM-west projects (Project Elements G.3, G.6).

## Outcomes and Products

- An understanding of how a spring disturbance flow affects the movement of native fish, with an assessment of resettlement in areas varying in habitat heterogeneity. Data will also be used to improve estimates of density and abundance for humpback chub in western Grand Canyon by learning more about the movement of transient fish.

- Results will be included in a peer-reviewed journal article describing the effect of the FLAHG flow on movement of native fish in western Grand Canyon. Results will also be included in GCMRC's Annual Report.
- Presentation to stakeholders at GCMRC's Annual Reporting meeting to the GCDAMP and/or at a scientific conference.

## Project Element O.8. Do Disturbance Flows Significantly Impact Recreational Experience?

Lucas Bair, Economist, USGS, GCMRC
Chris Neher, Economist, University of Montana

The objective of this project element is to refine our understanding of recreational preferences for flow attributes specific to spring disturbance flows that will likely be tested in FY2021-23. To accomplish the project element objective, recreational surveys will be conducted in accordance with spring disturbance flow experiments to better understand recreationists' preferences and economic values associated with low steady flows or other flow attributes. Prior to implementation of individual surveys, the Socioeconomic Ad Hoc Group (SEAHG) will convene to review hypotheses proposed by investigators.

Surveys will be conducted to obtain information on recreationists' preferences and economic values associated with flow attributes specific to a spring disturbance flow experiment. Consistent with past research of angler and whitewater boater's flow preferences, the surveys will be designed to elicit economic values using choice experiment instruments in addition to investigation into other quantitative and qualitative metrics of recreationists' preferences and perspectives. Participants will be intercepted immediately prior, during, and following the spring disturbance flow, differing from past recreational surveys (Bishop and others, 1987; Neher and others, 2017), and respondents will either be interviewed on-site or sent a mail survey packet, with a follow-up protocol for non-responders.

The limited temporal nature of the proposed higher spring flow experiments requires that we attempt to intercept the entire population of recreational anglers or whitewater boaters that experience the flow event, either with on-site sampling methods or assistance from the Arizona Game and Fish Department (AGFD) and NPS. For further description of survey methods, see Project J.3. This information is necessary for the GCDAMP to make informed decisions about the tradeoffs that occur, with regard to recreation, when evaluating future higher spring flow experiments.

### Outcomes and Products

- Journal article synthesizing methods and learning associated with angler preferences for flows as related to the FLAHG hydrograph.
- Data summaries presented at a GCMRC's Annual Reporting Meeting to the GCDAMP.

## Project Element O.9. Are There Opportunities to Meet Hydropower and Energy Goals with Spring Disturbance Flows?

Lucas Bair, Economist, USGS, GCMRC

This project element is addressed in Project N. The objective of Project N is to identify, coordinate, and collaborate on design, monitoring, and research opportunities associated with all operational experiments at GCD to meet hydropower and energy resource objectives, as stated in the LTEMP ROD (U.S. Department of the Interior, 2016b). The possibility of higher spring flow experiments will be addressed in Project N. Funding for this element is included in the Project N.1 budget.

## Project Element O.10. Sandbar and Campsite Response to Spring Disturbance Flow

Paul Grams, Research Hydrologist, USGS, GCMRC
Joseph E. Hazel, Jr., Research Associate, NAU
Matt Kaplinski, Research Associate, NAU
Robert Tusso, Hydrologist, USGS, GCMRC
Thomas M. Gushue, IT Specialist, USGS, GCMRC

Because deposition at sandbars and associated campsite area increase is expected to be much lower in response to the ~25,000 $ft^3/s$ or lower pulse flow than occurs during sediment-enriched fall HFEs, extensive field measurements of sandbars and campsites before and after the pulse flow are not planned. Instead, evaluation of the sandbar and campsite response to the pulse flows will rely on daily images from the network of remote cameras that is maintained as part of project B.1. Funding for this element is included in the Project B.1 budget.

## Outcomes and Products

- Images from remote cameras of pre- and post-pulse flow sandbar condition will be posted on the GCMRC website (https://www.usgs.gov/centers/sbsc).

- Analysis of sandbar response to the pulse flow will be provided to Project O decision support team and at GCMRC's Annual Reporting Meeting to the GCDAMP.

## Project Element O.11. Decision Analysis

Michael Runge, Research Ecologist, USGS, Patuxent Wildlife Research Center
Lucas Bair, Economist, USGS, GCMRC
Theodore Kennedy, Research Ecologist, USGS, GCMRC
Charles Yackulic, Research Statistician, USGS, GCMRC

The FLAHG charge is to, 'evaluate opportunities for conducting higher spring releases that may benefit high value resources of concern to the GCDAMP (recreational beaches, aquatic food base, rainbow trout fishery, hydropower, humpback chub and other native fish, cultural resources, and vegetation), fill critical data gaps, and reduce scientific uncertainties. As a starting point, the FLAHG shall consider the benefits of and opportunities for conducting higher spring releases within the operational constraints of the ROD (U.S. Department of Interior, 2016a,b).' There is an opportunity, through decision analysis, to identify the design and timing of spring disturbance flows that may benefit multiple resource goals identified in the LTEMP EIS while minimizing or avoiding negative impacts to the other goals (U.S. Department of Interior, 2016a). To initiate this decision analysis effort the project element leads, in consultation with other Project O scientists and stakeholders, will define the primary FLAHG hydrograph goals or fundamental objectives, identify monitoring metrics that allow for a measured response (positive or negative with reference to the LTMEP EIS resource goals) to a spring disturbance flow, and identify critical uncertainties that either support or preclude the implementation of spring disturbance flows. Implementation of decision analysis will assist in design and timing of spring disturbance flows and the allocation of funding for continued research and monitoring around future flow experiments.

This project element will utilize the multi-criteria decision and value of information analysis that was undertaken in the decision analysis to support development of the GCD LTEMP (Runge and others, 2015). The fundamental resource goals and performance metrics will be utilized to instruct the proposed monitoring and research in the individual project elements and in the allocation of funding within and across project elements. A workshop in ~~FY2022~~ Year 2 will occur following the implementation of the FLAHG hydrograph. The workshop will provide an opportunity to summarize the FLAHG hydrograph results, evaluate trade-offs identified with the spring disturbance flow, and present an overview of the decision process with respect to prioritization of funding for monitoring and research related to this and other potential future spring flow experiments.

### Outcomes and Products

- USGS Open-File Report will be published to summarize the decision analysis process specific to the implementation and analysis of spring disturbance flow and how individual resource results of spring disturbance flow play into inter-disciplinary decision making.

- Peer-reviewed journal article describing the decision analysis process and opportunities to continue to improve implementation of adaptive management within the GCDAMP.

- Results reported in GCMRC's Annual Report and Annual Reporting Meeting to the GCDAMP.

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## 8. Budget

### Budget Justification

Funding in ~~FY2021~~Year 1~~-22~~ for all project elements will be sought through the Experimental Management Fund (C.5 Experimental Management Fund; see TWP FY2021-23) except for Project Element O.11. ~~-~~Note that Reclamation retains decision-making authority for the allocation of funds from the C.5 Experimental Management Fund. Also, requests to support Project O through the Experimental Management Fund should be considered in context with other requests from the Experimental Management Fund (i.e. including, but not limited to Projects A.4, B.6.1-5, and J.3). Additionally, consideration of funding for Project O elements should be done in accordance with the recommendation developed by the BAHG on October 8, 2020.

In Year 1 ~~This p~~Project ~~e~~Element ~~(~~O.11~~)~~ ~~is intended to support decision analysis and stakeholder workshops, and funding for it~~ will ~~be sought from the C.4 Science Advisors Program~~seek funding from TWP carryover funds from prior years, or through annual review of the TWP, or through other Reclamation considerations ~~(see TWP FY2021-23)~~. ~~As with other funding requests from the Experimental Fund, an annual review is will occur to determine the availability and appropriateness of this funding source for the work in question.~~ Likewise, ~~I~~in ~~FY2022~~Year 2, funding for O.1 and O.2 will be sought from TWP carryover funds from prior years, or through annual review of the TWP, or through other Reclamation considerations~~either unspent capital in the Experimental Fund or unspent capital in other sources carried over from the preceding year while Science Advisors Program will be sought for O.11~~. ~~Additionally~~ Opportunities to leverage external resources and support from Program partners will be considered and explored by GCMRC and Reclamation for Year 2 funding. It should be noted that~~,~~ funding for a third year of data analysis and modeling is required for Project Element O.2 in order ~~to~~ for it to be successfully completed ~~this project element~~; however, at this time a funding source has not been identified.

~~If LTEMP experiments, either flow or non-flow, should occur in FY2021 and less funding is available than anticipated, Project O funding would be prioritized by elements according to BAHG recommendations (see Table 1).~~ T~~wo~~hree project elements have funding requests in ~~FY2021~~ Year 2; 1) ~~and FY2022~~ ~~and include~~ $146,563~~98,429~~ ~~in FY2021~~ for O.1 to quantify food base response to spring disturbance flows, 2) ~~and~~ $161,959~~61,626~~ ~~in FY2021~~ for O.2 to identify whether dam operations exacerbate or mitigate boat navigation challenges associated with bed-sediment accumulation in the western Grand Canyon, and 3) $61,359 for O.11 to conduct decision analysis. ~~These~~ Year 2 funding totals include salary for short-term field technicians, travel and training, operating expenses, and logistics. ~~Funding for O.1 and O.2 is also proposed for FY2022 to support sample processing, analysis and synthesis of data, and writing of the food base and sediment studies ($146,563 and $161,959, respectively).~~ The remaining project elements (O.3-O.101) seek funding only in FY2021Year 1.; tThe proposed funding for these elements includes cooperator support, travel and training, operating expenses, logistics, and GCMRC salary for short-term field technician support. However, mIt should be noted that most funding for GCMRC salaries involved in project elements O.3-O.10 is already included in related project elements in Projects A through N in the TWP FY2021-23.

# Budget Tables

| | Year 1 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Project O<br>Is Timing Really Everything? Evaluating Resource Response to Spring Disturbance Flows** | **Salaries** | **Travel & Training** | **Operating Expenses** | **Logistics Expenses** | **Cooperative Agreements** | **To other USGS Centers** | **Burden** | **Total** | **Funding Source** |
| | | | | | | | 14.00% | | |
| O.1. Does disturbance timing affect food base response? | $54,183 | $13,000 | $1,000 | $5,000 | $0 | $12,000 | $10,246 | **$95,429** | Reclamation C.5 |
| O.2. Bank erosion, bed sedimentation, and channel change in western Grand Canyon | $6,835 | $2,000 | $3,000 | $29,687 | $13,875 | $0 | $6,229 | **$61,626** | Reclamation C.5 |
| O.3. Aeolian response to a spring pulse flow | $0 | $1,000 | $10,000 | $0 | $0 | $0 | $1,540 | **$12,540** | Reclamation C.5 |
| O.4. Riparian vegetation physiological response | $6,512 | $350 | $7,500 | $3,000 | $0 | $0 | $2,431 | **$19,792** | Reclamation C.5 |
| O.5. Mapping aquatic vegetation response to a spring pulse flow | $1,709 | $375 | $9,000 | $8,067 | $20,000 | $0 | $3,281 | **$42,432** | Reclamation C.5 |
| O.6. Brown trout early life stage response to a spring pulse flow | $9,373 | $10,850 | $0 | $32,151 | $0 | $0 | $7,332 | **$59,707** | Reclamation C.5 |
| O.7. Native fish movement in response to a spring pulse flow | $0 | $250 | $9,900 | $23,073 | $10,000 | $0 | $4,951 | **$48,174** | Reclamation C.5 |
| O.8. Do disturbance flows significantly impact recreational experience? | $0 | $0 | $0 | $0 | $10,000 | $0 | $300 | **$10,300** | Reclamation C.5 |
| O.9. Are there opportunities to meet hydropower and energy goals with spring disturbance flows? *(funded in N.1)* | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | GCMRC N.1 |
| O.10. Sandbar and campsite response to spring disturbance flow *(funded in B.1)* | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | GCMRC B.1 |
| **Total Experimental Management Fund (C.5)** | **$78,612** | **$27,825** | **$40,400** | **$100,978** | **$53,875** | **$12,000** | **$36,310** | **$350,000** | |
| O.11. Decision analysis | $11,075 | $0 | $0 | $0 | $0 | $27,930 | $1,550 | **$40,555** | TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations |
| **TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations** | **$11,075** | **$0** | **$0** | **$0** | **$0** | **$27,930** | **$1,550** | **$40,555** | |

Note: Actual budget amounts could vary depending on fiscal year of implementation as SBSC overhead rates vary.

| | | | | | Year 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Project O<br>Is Timing Really Everything? Evaluating Resource Response to Spring Disturbance Flows** | **Salaries** | **Travel & Training** | **Operating Expenses** | **Logistics Expenses** | **Cooperative Agreements** | **To other USGS Centers** | **Burden** | **Total** | **Funding Source** |
| | | | | | | | 22.00% | | |
| O.1. Does disturbance timing affect food base response? | $110,297 | $0 | $0 | $0 | $0 | $12,000 | $24,265 | **$146,563** | TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations |
| O.2. Bank erosion, bed sedimentation, and channel change in western Grand Canyon | $109,400 | $1,500 | $0 | $0 | $25,885 | $0 | $25,175 | **$161,959** | TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations |
| O.3. Aeolian response to a spring pulse flow | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.4. Riparian vegetation physiological response | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.5. Mapping aquatic vegetation response to a spring pulse flow | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.6. Brown trout early life stage response to a spring pulse flow | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.7. Native fish movement in response to a spring pulse flow | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.8. Do disturbance flows significantly impact recreational experience? | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | NA |
| O.9. Are there opportunities to meet hydropower and energy goals with spring disturbance flows? *(funded in N.1)* | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | GCMRC N.1 |
| O.10. Sandbar and campsite response to spring disturbance flow *(funded in B.1)* | $0 | $0 | $0 | $0 | $0 | $0 | $0 | **$0** | GCMRC B.1 |
| O.11. Decision analysis | $11,296 | $10,500 | $5,000 | $0 | $0 | $28,667 | $5,895 | **$61,359** | TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations |
| **TWP carryover from previous years, or through annual review of the TWP, or through other Reclamation considerations** | **$230,993** | **$12,000** | **$5,000** | **$0** | **$25,885** | **$40,667** | **$55,335** | **$369,881** | |

Note: Actual budget amounts could vary depending on fiscal year of implementation as SBSC overhead rates vary.