Grand Canyon Monitoring and Research Center

Fiscal Year 2014 Annual Project Report

for the

Glen Canyon Dam
Adaptive Management Program

Contents

Introduction

Following is the Grand Canyon Monitoring and Research Center's (GCMRC) Fiscal Year 2014 Annual Accomplishment Report. This report is prepared primarily for the Technical Work Group (TWG) of the Glen Canyon Dam Adaptive Management Program (GCDAMP). It includes a summary of accomplishments, shortcomings, and recommendations related to projects included in GCMRC's FY14 Work Plan for the GCDAMP.

Project &Title			
Project A: Sandbars and Sediment Storage Dynamics: Long-term Monitoring and Research at the Site, Reach, and Ecosystem Scales			
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Introduction

In FY14, scientists from Project A collected all of the data on sandbars and in-channel sediment storage that was described in the FY13–14 Biennial Work Plan (BWP) during two project-specific river trips. Findings published or presented in the past year describe the condition of sandbars and document the dynamics of local and reach-scale changes in sediment storage on the river bed. We expect that these advances coupled with advances in modeling capabilities will lead to a better understanding of processes governing sandbar deposition and erosion and an improved capacity for predicting sandbar response. Below, we first summarize findings in the context of the science questions presented in the FY13–14 BWP. In the following section, we summarize specific accomplishments by project element. We conclude the report with a summary of major findings.

Project Summary by Science Questions

Listed below, are the seven monitoring and research questions presented in the Project A description in the FY13–14 Work Plan, followed by a summary of recent findings.

1. *What is the long-term net effect of dam operations, including high flows, on changes in high-elevation sandbar area and sand storage (i.e., the sand above the 8,000 ft^3/s stage)? These changes are relevant to camping beaches, riparian vegetation, backwater habitat, and control the supply of bare sand that is redistributed by wind.*

   In October 2013, approximately 11 months after the 2012 high-flow experiment (HFE), the median size of sandbar monitoring sites in Marble Canyon had increased from the low point measured one year earlier. Topographic surveys and images from remote cameras indicate that the fall 2012 and 2013 HFEs resulted in increases in sandbar size in both Marble Canyon and Grand Canyon. These results indicate that the HFE Protocol is causing increases in sandbar size. However, it is still too early in the Protocol implementation to determine whether the repeated HFEs are resulting in a cumulative increase in sandbar size. Analysis of May 2002, May 2005, and May 2009 aerial images for select reaches do not indicate a significant trend (increase or decrease) in sandbar area above the 8,000 ft^3/s elevation. Analysis of these images together with images taken following the 1996 HFE indicate that sandbar area visible on these images is a function of the elapsed time between a HFE and image acquisition, supporting the hypothesis that sandbars will be larger, on average, with more frequent HFEs. Data from the 2014 monitoring trip and images from the 2014 HFE will be available at the time of the January 2015 Annual Reporting meeting and are expected to provide additional information to further address questions on the immediate and long-term effects of HFEs on sandbars.

2. *What is the long-term net effect of dam operations, including high flows, on changes in low-elevation sand storage and bed sediment texture (the sand below the 8,000 ft^3/s stage)? These changes are relevant to backwaters and other aquatic habitat, the foundation of eddy sandbars, and as the source of sediment that fuels transport and determines whether the use of high flows is sustainable.*

   Repeat mapping of the river channel has demonstrated that changes in sand storage are highly variable from one storage location (eddy) to the next (Grams and others, 2013). Repeat mapping of sandbars and the river channel in lower Marble Canyon (river mile (RM) 30 to 61) shows scour of the river bed and decreases in sandbar volume between May 2009 and May 2012. Most of this erosion occurred during the 2011 equalization flows and most of the sediment loss was from the river bed in the channel rather than from eddies or sandbars above the 8,000 ft^3/s stage. The magnitude of this sediment loss was less than the average annual input of sand from the Paria River. This suggests that, despite the large amount of sediment evacuation caused by equalization flows, most of the evacuated sediment likely consisted of recently accumulated Paria River sand inputs rather than older deposits of pre-dam sediment. Analysis of this repeat map that includes more than 80 large sandbars in this segment has also been used to evaluate the representativeness of the long-term monitoring sandbars. This analysis shows that the mean change in sandbar elevation at the long-term monitoring sandbars (the Northern Arizona University monitoring sites) was consistent with the mean response at all sandbars mapped in the 2009 and 2012 channel mapping efforts.

3. *What are the relative proportions of pre-dam sediment (sediment that entered the Colorado River before dam completion) and post-dam sediment (sediment from tributaries that has entered the Colorado River following dam completion) present in deposits formed by dam operations, including HFEs? Do the proportions of pre- and post-dam fine sediment indicate depletion of non-renewable pre-dam fine sediment from storage or accumulation of tributary-derived post-dam fine sediment? This question is relevant to determining whether the use of HFEs is sustainable.*

   The FY13–14 BWP included a study to investigate the use of sediment geochemistry to distinguish recent inputs of Paria River sand from older Colorado River sand deposits. The goals of the study were to determine whether the sources of sediment to Marble Canyon could be distinguished geochemically, and to use such geochemical signatures to determine whether relic pre-dam Colorado River sediment was eroded and incorporated into newly-formed sandbars. We have analyzed samples of sand from the Paria River and sand from the Colorado River upstream from the Paria River confluence to characterize the geochemistry of “end members” of sand that are the potential sources of sand for sandbars built by HFEs. We also collected samples of sediment deposited by the November 2012 HFE in May 2013. Analysis of the geochemistry of HFE deposits in Marble Canyon showed that the concentration of the geochemical tracers was outside the range that occurred in the end-member samples from the Paria River and pre-dam Colorado River. Therefore, it is not yet possible to quantitatively estimate the relative proportion of Paria River and pre-dam Colorado River sand present in the HFE deposits. The concentrations of the geochemical tracers are, however, more similar to the concentrations in the Paria River samples than in the pre-dam Colorado River samples. This suggests that the sand comprising the HFE deposits is more similar to Paria River sand than pre-dam Colorado River sand and is consistent with the intention of the HFE Protocol to build sandbars using mostly sand derived from recent Paria River inputs.

4. *What are the causes of variability in sandbar response to controlled floods and other dam operations (i.e. why do sandbars respond differently from place to place to the same flow and sediment supply conditions?), and how does vegetation affect sandbar response? This builds on sandbar monitoring (Question 1) to support prediction of sandbar response.*

   An understanding of the factors that contribute to spatial variability in sandbar response to actions such as HFEs is needed to improve our capacity to predict sandbar response in the future. We have identified that sandbar size (expressed as sand volume) at many sites is controlled by discharge and that there are different relations between discharge and sand volume at different sites (Grams and others, 2013). This indicates that differences in site characteristics that influence local hydraulics significantly affect sandbar size for a given flow and sediment supply. To investigate the linkages between site characteristics and sandbar response, we have worked on the development of a new 3-dimensional model for eddy sandbar formation (Alvarez and others, *in review*) that demonstrates that there are important processes controlling the transport, deposition, and erosion of sand in eddies that are not captured in more simplified modeling approaches.

5. *What is the spatial distribution of bed sediment texture, and how does it affect primary production, fish habitat, and sediment transport modeling? This builds on low elevation sand monitoring (Question 2) to support sediment transport and biological prediction.*

   In the two years of the FY13–14 BWP, we developed an automated process for the classification of river bed material texture from multibeam sonar data (Buscombe and others, *in press a and b;* Buscombe and others, *in review*). This procedure is now being used in the computation of reach-scale sand budgets and in the characterization of aquatic habitat. Thus, results from this work were incorporated in the development of the FY15–17 Triennial Work Plan (TWP) and will be an integral component of carrying out work in the sediment storage project (Project 3) and the project investigating linkages between physical habitat and trout populations (Project 10).

6. *Can we relate changes in the spatial distribution of bed sediment texture to observed changes in suspended sand concentrations and grain size? This would enable use of the continuous record of suspended sediment to infer changes in bed sediment composition for use in modeling of sediment transport and primary production.*

   In FY13–14, we completed joint measurements of suspended-sediment concentration, bed-sediment grain size, water velocity (to estimate bed shear stress), and bathymetry to investigate the relative contributions to the large (several order-of-magnitude) range in observed suspended sand concentrations for a given water discharge. We also published a journal article (Grams and Wilcock, 2014) that provides a theoretical framework and simple model for relating suspended-sediment transport with bed-sand coverage. The paper also presents an approach for predicting the transport and migration of fine sediment through coarse-bedded rivers. Next steps will include testing the Grams and Wilcock (2014) model that is based on flume experiments with the field data collected in FY13–14.

7. *How have changes in sandbar size, sandbar characteristics (e.g., slope, roughness), and vegetation cover affected the Marble and Grand Canyon camping beach resource? This builds on sandbar monitoring (Question 1) to address the recreation resource.*

   Between 2002 and 2009, expansion of riparian vegetation has resulted in a11% increase in the proportion of area within camp boundaries covered by vegetation. However, not all of the area within camp boundaries is used for camping. Therefore, we also track changes in "campsite areas," which are defined as flat areas within camp boundaries that are used for camping. In an analysis of causes for change in campsite areas, we found that erosion and deposition of sand are the primary mechanisms that cause either increases or decreases in area. Thus, while vegetation expansion is responsible for net long-term (decade scale) decline in the open areas within camp boundaries, changes in sandbar topography are the main source of inter-annual variability in campsite area. Sandbar deposition associated with high flows results in increases in campsite area, while post-HFE erosion causes decreases in campsite area.

Detailed Summary of Progress by Project Element

A.1.1 Sandbar monitoring – Joe Hazel, Matt Kaplinski, Rob Ross, Bob Tusso, Tim Andrews, Paul Grams, Dan Buscombe, Erich Mueller

Sandbar monitoring was completed by conducting topographic surveys at 47 long-term monitoring sites in September/October 2013 and September/October 2014. In October 2013, approximately 11 months after the 2012 HFE, the median size of sandbar monitoring sites in Marble Canyon had increased from the lowest point since the 2008 HFE that was measured one year earlier. These surveys show that the fall 2012 and 2013 HFEs resulted in increases in sandbar size in both Marble Canyon and Grand Canyon. Data from the 2014 monitoring trip is being processed and will be available at the time of the January 2015 Annual Reporting meeting.

Sandbars are also monitored at 43 locations by remote cameras. These provide high-resolution images of sandbars and other important features five times daily at each site. A photographic record at some of the sites exists as far back as the early 1990s. Using the photos, qualitative analyses of sandbar size can be made more quickly, frequently, and inexpensively than ground-based field surveys. The imagery is particularly valuable for rapid analysis of geomorphic events such as controlled high flows or tributary flash floods. Before and after images from the 2012 HFE (*http://www.gcmrc.gov/gis/sandbartour2012/index.html*) and the 2013 HFE (*http://www.gcmrc.gov/gis/sandbartour2013/index.html*) were posted to the web for public viewing within weeks of the water receding. Images from the 2014 HFE will be downloaded in early January and posted by the time of the Annual Reporting meeting.

A comprehensive report on the long-term sandbar monitoring data (Hazel and others, *in prep*) was expected to be completed in 2014. Substantial progress was made in 2014, and it is now expected that the report will be ready for review by January 31, 2015. The report has been delayed, in part, by our decision to restructure our data processing work flow and create an online database for sandbar data. Creation of this database involved the reprocessing of all sandbar surveys conducted from 1990 to present. The database is now complete and accessible to the public. The web interface allows any user to visualize and download the sandbar data for each monitoring site (*http://www.gcmrc.gov/sandbar/*).

A.1.2 Sandbars from Remote sensing – Phil Davis, Joel Sankey, Rob Ross, Paul Grams

The 2013 Image Overflight

The four-band imagery and the digital surface models from the May 2013 overflight were delivered by the contractor in November 2013. The initial processing of the four-band imagery at GCMRC to prepare the imagery for mosaicking into USGS map tile format was completed in 2014. The mosaicking began in October 2014 and is anticipated to be completed by summer of 2015.

Analysis of Sandbar Area in Select Reaches, 1935-2009

We have completed the analysis of 2002 and 2009 images for sandbar area in select reaches in Marble Canyon and eastern Grand Canyon. This analysis shows that sandbars visible on images collected between 1996 and 2009 were generally larger than sandbars on images collected between 1965 and 1996. This analysis does not indicate that there is more sand in the system now, because the 1996 to 2009 images depict conditions shortly following HFEs. This does indicate that the 1996, 2004, and 2008 HFEs resulted in a larger area of sandbars than shown in images from the post-dam period before the 1996 HFE. Sandbar area has also been mapped at all large sand storage locations in Marble Canyon and Grand Canyon from the 2002 and 2009 images. Analysis of these results is in progress.

Analysis of 2002 and 2009 Four-Band Image Data

This project component is focused on producing maps of high-elevation (8,000-45,000 ft^3/s) sand area. Mapping of exposed high-elevation sand within 1368 sites that include most large sandbar deposition zones and camp sites throughout the river corridor has been completed for the 2009 imagery and is currently being completed for the 2002 imagery. In addition to sand, classes of vegetation, water, bedrock, boulders, cobbles, smooth surfaces, and rough surfaces have been mapped for the 2002 and 2009 imagery. The water and vegetation maps were successfully completed in previous years. Mapping of the bedrock, boulders, cobbles, and smooth and rough surface classes were completed in 2013 and 2014 with an autonomous (unsupervised) classification method that also mapped the high elevation sand class. No further processing, accuracy assessment or analyses of the non-sand classes are planned.

In order to produce the best maps of high-elevation sand possible, the autonomous classification method is used to map sand, then the maps are manually edited, and the edited maps are evaluated with an accuracy assessment. The manual edit and accuracy assessment have been completed for the 2009 imagery. The manual edit is still being completed for the 2002 imagery, however, the accuracy assessment has been completed for that portion of the 2002 sand maps that have been manually edited. The accuracy assessments evaluated the ability of the high elevation sand maps to predict the area of sand that was independently surveyed at 50 monitoring sites from the NAU sandbar time-series. The results from the survey conducted most coincident in time to the particular overflight were used for comparison. The 2009 high-elevation sand maps predict the area of surveyed sand that was not covered by the vegetation in the respective imagery with 88 % classification accuracy. The combination of the 2009 high-elevation sand and vegetation maps predicted the area of surveyed sand (including that covered by vegetation) with 92 % classification accuracy. The completed 2002 high-elevation sand maps can be evaluated with survey data from 30 of the monitoring sites. The 2002 maps predict the area of surveyed sand that was not covered by the vegetation with 83 % classification accuracy. The combination of the 2002 high-elevation sand and vegetation maps predicted the area of surveyed sand (including that covered by vegetation) with 87 % classification accuracy.

Anlayis of digital surface models acquired from 2002, 2009, 2013 overflights

Digital surface models (DSMs) were produced from airborne automated digital photogrammetry data acquired during the aerial overflights of 2002, 2009, and 2013 for the 450 km length of Glen and Grand Canyon at steady Colorado River discharge of 8,000 ft^3/s. The DSM data have 1-m cell resolution with vertical ellipsoid heights reported to the nearest 10 cm, and are sectioned into U.S. Geological Survey map quadrangles. The data were not initially processed to remove effects of vegetation or other surface cover on topographic elevation values. The data were evaluated by Phil Davis during 2013 and 2014. One important step of this evaluation was to determine the amounts by which the data are offset vertically above true ground level. Each dataset was then further processed to adjust elevations by the vertical offsets. Vertical accuracy of the offset-adjusted 2002, 2009, and 2013 data were 0.23, 0.24, and 0.14 m respectively (reported as root mean square error of ellipsoid height differences between DSM and ground survey measurements). The 2002 accuracy assessment was based on fewer (n = 308) ground survey measurements than the assessments for the 2009 (n = 6,175) and 2013 (n = 5,854) data. Phil Davis has produced a first draft of a USGS report on the detailed analyses, offset adjustment methodology, assessment of accuracy and precision, and comparisons among the three datasets. These data will be used in 2015 and 2016 to investigate topographic characteristics of high-elevation sand deposits.

A.1.3 Campsites – Matt Kaplinski, Dan Hadley, Paul Grams, Rod Parnell

Between 2002 and 2009, expansion of riparian vegetation has resulted in a11% increase in the proportion of area within camp boundaries covered by vegetation. However, not all of the area within camp boundaries is used for camping. Therefore, we also track changes in "campsite areas," which are defined as flat areas within camp boundaries that are used for camping. In an analysis of causes for change in campsite areas, we found that erosion and deposition of sand are the primary mechanisms that cause either increases or decreases in area. Thus, while vegetation expansion is responsible for net long-term (decade scale) decline in the open areas within camp boundaries, changes in sandbar topography are the main source of year-to-year variability in campsite area. Sandbar deposition associated with high flows results in increases in campsite area, while post-HFE erosion causes decreases in campsite area.

A MS thesis describing this work was completed and we are in the process of reformatting that thesis into a USGS report, which will be in review by the end of 2014. Monitoring of campsite area and collection of repeat photographs has continued. Based on the results of the FY13–14 research project, we have revised monitoring methods to better track causes of changes in campsite area.

We continued to monitor campsite condition in cooperation with the Grand Canyon River Guides (GCRG) through their "Adopt-a-Beach" program. In 2014, GCRG collected repeat photographs at 43 different camping beaches with contributions from at least 34 river guides. This collection of photographs provides a record since 1996 of the conditions at many of the most heavily used camping beaches from the perspective of river guides

A.1.4 Sandbar Change, 1984-1990 – Tom Gushue, Rob Weber, Joe Hazel, Paul Grams

The goal of this project element is to create digital terrain models (DTM) using digital photogrammetric techniques for sandbar monitoring sites from 1984 photographs. The end result will allow comparison of the size (area and volume) of sandbars from the old photographs with conditions since monitoring began in 1990. In FY14, five sites were fully processed using photogrammetry techniques to extract a DTM from scanned aerial photography captured in October 1984. Additional time was devoted this past year to refining the techniques used in order to improve on the number and distribution of mass points produced in the bright sand areas of the 1-band (black-and-white) images. By running a second iteration for each site that is more closely focused on the bright sand, we have been able to improve point resolution in the DTMs by approximately 40%.

Since January 2013, twelve sandbar monitoring sites have been completely processed for area and volumes of the sandbar conditions in October 1984. Accuracy assessments have been completed for eight of these sites with DTM vertical accuracies falling within the acceptable 95% confidence level required by the Federal Geographic Data Committee's National Standards for Spatial Data Accuracy (NSSDA) for all but two sites (RM 43 and RM 56). For these two sites we were limited in the number of quality check points available to perform the accuracy assessment and so we were forced to rely on ground control points which were not used (i.e. rejected) by the DTM extraction process. This issue can be easily resolved by acquiring approximately ten more ground control points at each site during the next sandbar monitoring trip.

Initial findings are that sandbar area and volume above the stage elevation of 8,000 ft^3/s was much greater in 1984 for at least four of the sites that have been processed. The extreme example is the sandbar located at RM 47 (Saddle Canyon) which was 70% greater in area and volume in 1984; whereas the others were 10 to 50% greater in size. While the sample size is small, these results are encouraging for extending the sandbar monitoring data series back to 1984, or other years of interest, with aerial photography and DTM extraction. This would allow stakeholders an expanded reference when considering present sandbar condition and allow comparison of the six experimental high flows that have occurred to date with the largest and longest post-dam high flow that occurred in 1983-84.

A report is in preparation and will be submitted for review in January 2015.

A.2.1 Sand Storage Monitoring – Paul Grams, Matt Kaplinski, Joe Hazel, Keith Kohl, Dan Buscombe

The purpose of the sediment storage monitoring element of this project is to track long-term trends in sand storage to provide a robust measure of management objectives regarding fine sediment conservation. In other words, this project provides the direct measure of changes in sand storage in the channel and in eddies over the time scale of long-term management actions, such as the HFE protocol. An additional purpose of this project is to track the location of changes in sand storage between the channel and eddies and between high- and low-elevation deposits. This monitoring involves repeat measurements of the river bed and banks over long reaches.

Data Collection

In 2014, we mapped 19.7 of the 27.4 miles (72%) of river channel that comprise lower Marble Canyon and eastern Grand Canyon. (RM 61 to 87). Collection of these data involved 49 multibeam sonar surveys, 53 singlebeam sonar surveys, and 84 total station surveys. We also collected 4,051 subaqueous grain size images for grain-size analysis at 1,784 locations. Using similar methods, 106 subaerial grain-size images were collected at five sandbars. In addition, 41 remote, daily cameras were serviced and the data downloaded. There were six pit excavations made at nine sandbars for sedimentological interpretation of the 2013 HFE deposits. The deposits were sampled for vertical grain size trends. On this trip, 34 panels were photographed and surveyed at five sandbars for oblique photo orthorectification and 115 new hardpoints were identified and surveyed for rectification of historical images and accuracy analysis of current datasets.

Data Processing

Final processing and generation of digital elevation models for data collected in 2009 and 2012 for the reach between RM 30 and the Little Colorado River (RM 61) is complete. To date, 36 of the 87 total station surveys collected on the May 2013 channel mapping trip have been processed. The raw data have been edited for errors and blunders and coordinates generated in AZ state plane coordinates. Topographic surfaces were modeled from these data to generate maps for 13 of the 30 miles surveyed on the river. While these data have not been analyzed for changes with other surveys, a qualitative assessment of sandbars on the river trip is that erosion of newly built bars following the November 2012 HFE had been largely minimal in the six months following the event The other data collected in 2013, including bathymetric surveys, are currently being processed and we anticipate that DEMs of the entire river segment will be completed by March 2015.

Results and Analysis

Repeat mapping of the river channel has demonstrated that changes in storage are highly variable from one storage location (eddy) to the next. Repeat mapping of sandbars and the river channel in lower Marble Canyon (RM 30 to 61) shows scour of the river bed and decreases in sandbar storage volume between May 2009 and May 2012. Most of this erosion occurred during the 2011 equalization flows and most of the sediment loss was from the river bed in the channel rather than from eddies or higher elevation sandbars. The magnitude of this sediment loss was less than the average annual input of sand from the Paria River. This suggests that, despite the large amount of sediment evacuation caused by equalization flows, most of the evacuated sediment was likely recently accumulated Paria River sand inputs rather than older deposits of pre-dam sediment. Analysis of this repeat map that includes more than 80 large sandbars has also been used to evaluate the representativeness of the long-term monitoring sandbars in this reach. One manuscript describing these results is in review, others are in preparation.

We have developed new methods to automate mapping bed texture using acoustic backscatter and published these methods in journal articles.

A.2.2 Bed-material Characterization – Dan Buscombe, Bob Tusso, Paul Grams, Matt Kaplinski

In the two years of the FY13–14 BWP, we have developed an automated process for the classification of river bed material texture from the multibeam sonar data. This procedure is now being used in the computation of reach-scale sand budgets and in the characterization of aquatic habitat. Specific accomplishments this year include:

1. Collection of grain-size data and multibeam sonar data in May 2014, between RM 61 and 87, in order to properly validate a sediment classification algorithm from multibeam echosounder backscatter.
2. The acoustic sediment classification algorithm has been published in two technical articles in a major journal. These articles outline the approaches currently being taken to classifying sediments using acoustic backscatter (Buscombe et al., *in press a* and *b*).
3. Towards operational use, there has been continual development and optimization of sediment classification software, principally for speed, error checking, and generality.
4. The sediment classification algorithm has been refined to use random forests rather than decision trees. These are both similar machine learning techniques, but random forests provide a more stable sediment estimate in our case.
5. The acoustic classification has been applied to data collected in the RM 30 to 61 reach mapped in 2012, to provide rough estimates of bed sediment type (sand versus gravel and rock). Results were briefly presented at the AMWG meeting in August.
6. The backscatter data collected in the RM 30 to 60 reach mapped in 2009 was unsuitable and therefore a new sediment classification algorithm was developed utilizing elevation (topography) data alone.
7. This new classification has been applied to data collected in the RM 30 to 61 reach mapped in 2009, to provide rough estimates of bed sediment type (sand versus gravel and rock). Results from both 2009 and 2012 will be presented at the American Geophysical Union Fall Meeting in December 2014 and the January Annual Reporting meeting.
8. The acoustic classification will next be applied to data collected in the RM 61 to 87 segment mapped in 2011 and 2014, and the RM 0 to 30 segment mapped in 2013
9. Further work is required to provide estimates of uncertainties in sediment type estimates.
10. Further work is required to be able to distinguish between relative proportions of sand and gravel over small patches ("mixtures" of sediment types). A new underwater camera system is required to provide the necessary data to test an acoustic technique for sediment mixtures. Such a system would need to auto-focus the bed from distances of more than a meter to a few

millimeters, and is currently in the design/testing phase.

A.3 Sandbar Modeling – Mark Schmeeckle, Laura Alvarez, Paul Grams

An understanding of the factors that contribute to spatial variability in sandbar response to actions such as HFEs is needed to improve our capacity to predict sandbar response in the future. We have identified that sandbar size (expressed as sand volume) at many sites is controlled by discharge and that there are different relations between discharge and sand volume at different sites (Grams and others, 2013). This indicates that differences in site characteristics that influence local hydraulics significantly affect sandbar size for a given flow and sediment supply. To investigate the linkages between site characteristics and sandbar response, we have worked on the development of a new 3-dimensional model for eddy sandbar formation (Alvarez and others, *in review*).

The new 3-dimensional model represents a significant advancement in modeling flow patterns in eddies. The model predicts flow velocity and 3-dimensional flow structures better than previous models, and a rigorous verification of the model demonstrates good predictive capability. Flow structures captured by this model include fluctuations in the magnitude and direction of flow near the bed along the margin that separates eddies from the main channel. These flow structures are very likely important mechanisms that contribute to sediment exchange between eddies and the main channel.

The 3-dimensional model has been coupled with a 3-dimensional suspended sediment model as well as a model for grain-size evolution of the riverbed. The pattern of erosion and deposition has been found to not only depend on the supply of sand from upstream to a particular reach, but also on the spatial variation of grain-size in the bed at the scale of an individual lateral separation eddy. Typically, the riverbed below rapids and pools contain little if any fine grain sediments, and sorting of sizes is apparent at pool exits and within lateral separation eddies. Given that sediment transport relations are highly sensitive to grain-size, within-reach sorting is an essential element of modeling sediment transport in eddies. The mixing layer model of grain-size sorting is currently being tested at Eminence and Willie Taylor eddies. Qualitatively the spatial pattern of grain-size distribution is promising. This pattern should be quantitatively tested against the multibeam bed-sediment methodology of Buscombe and others (*in press*).

Although these accomplishments do not fully achieve the goal of this project in the FY13–14 BWP, which was to explain the causes of site-to-site variability in sandbar response, they represent significant progress that we expect to contribute to advancement in the current FY15–17 TWP.

A.4 Flow-Sediment Interactions – David Rubin, Dan Buscombe, Paul Grams

This research project aims to address the question: "what are the relative contributions to the large (several order-of-magnitude) range in observed suspended sand concentrations for a given water discharge?" Addressing this question requires joint measurements of suspended-sediment concentration, bed-sediment grain size, water velocity (to estimate bed shear stress), and bathymetry. In FY13–14, we completed joint measurements of suspended-sediment concentration, bed-sediment grain size, water velocity (to estimate bed shear stress), and bathymetry. Capitalizing on continuing improvements in acoustic estimates of suspended-sediment concentration and grain size (Topping and Wright, in prep.), bed-sediment classification using multibeam data (Buscombe et al., 2014 a, b), and open-source software for analysis of acoustic-Doppler current profiler (ADCP) data in rivers (Parsons et al., 2013), we are now well poised to investigate the relative contributions to the large (several order-of-magnitude) range in observed suspended sand concentrations for a given water discharge. We also published a journal article (Grams and Wilcock, 2014) that provides a theoretical framework and simple model for relating suspended-sediment transport with bed-sand coverage. The paper also presents an approach for predicting the transport and migration of fine sediment through coarse-bedded rivers. Next steps will include testing the Grams and Wilcock (2014) model that is based on flume experiments with the field data collected in FY13–14.

<u>A.5 Sediment Fingerprinting</u> – Renee Takesue, Paul Grams

The goals of the sediment geochemistry study are to determine whether the sources of sediment to Marble Canyon can be distinguished geochemically, and to use such geochemical signatures to determine whether relic pre-dam Colorado River sediment is being eroded and incorporated into newly-formed sandbars. We have analyzed samples of sand from the Paria River and sand from the Colorado River upstream from the Paria River confluence to characterize the geochemistry of "end members" of sand that are the potential sources of sand for sandbars built by HFEs. We also collected samples of sediment deposited by the November 2012 HFE in May 2013. Analysis of the geochemistry of HFE deposits in Marble Canyon showed that the concentration of the geochemical tracers was outside the range that occurred in the end-member samples from the Paria River and pre-dam Colorado River. Therefore, it is not yet possible to estimate the relative proportion of Paria River and pre-dam Colorado River sand present in HFE deposits. The concentrations of the geochemical tracers are, however, more similar to the concentrations in the Paria River samples than in the pre-dam Colorado River samples. This suggests that the sand comprising HFE deposits is more similar to Paria River sand than pre-dam Colorado River sand.

In 2014, we expanded the sediment-geochemical study to include additional samples of sand from upstream reaches of the Paria River and three minor tributaries on the north rim of Marble Canyon. These additional samples made it possible to establish a rigorous geochemical end member composition for Paria River sand, and to identify possible inputs from minor tributaries.

Material that was previously used to define the end member for Paria River sand was collected near the river mouth, and could have contained pre-dam Colorado River sediment from natural floods of the Colorado River. The new Paria-upstream geochemical data show that the Paria-mouth sand had a mean composition that was intermediate between Paria-upstream and Colorado River sand, indicating it was not a pure end member. Calcium and barium contents showed that river terraces near Lonely Dell contained 25-30% Colorado River sand. With the addition of new Paria-upstream samples, this end member is now very well constrained, and five elements were identified as likely source-signatures: barium (Ba), calcium (Ba), potassium (K), rubidium (Rb), and sodium (Na). In addition to geochemical compositions, sediment grain-size distributions were determined for Paria-upstream sediment.

One of the three small tributaries sampled had elevated calcium (Ca) and magnesium (Mg) contents, reflecting the influence of limestone on the sand geochemistry. HFE sand deposits in some of the downstream sandbars also had elevated Ca concentrations, suggesting that these sandbars received material from minor tributaries incised into the Kaibab Limestone. If it is assumed that these deposits contained no pre-dam Colorado River sand, then elevated Ca concentrations suggest that up to19% of the sand in these deposits was derived from small tributaries downstream from the Paria River.

The geochemical compositions of the five geochemical source-indicators of sand in HFE deposits generally fell outside the range defined by the Paria and Colorado end member compositions. The factors causing this discrepancy must be determined and constrained before pre-dam Colorado River sand geochemical signatures can be interpreted in HFE deposits. Possible explanations include adsorption of clay particles on the sand and selective transport of certain mineral grains. We are currently investigating these issues by re-analyzing the samples from HFE deposits after they have been leached to remove any adsorbed phases and by comparing the mineralogy of Paria source material to HFE deposits.

<u>A.6 Control Network and Survey Support</u> – Keith Kohl, Joe Hazel, Paul Grams

An accurate geodetic control network is required to support nearly every aspect of this project as well as other GCMRC monitoring projects. The purpose of the control network is to ensure that spatial data acquired on all projects are collected with accurate and repeatable spatial reference. We are in the process of documenting the GCMRC control network in a report which will describe the purpose, collection methods, reference systems, coordinates resulting from least-squares adjustment procedures, and estimated errors of rim, primary, secondary, and tertiary levels of geodetic control. Specific control network and survey support activates in 2014 are summarized below:

- USGS leveling data were analyzed and adjusted along with data previously collected by National Geodetic Survey (NGS) to improve the National Spatial Reference System (NSRS)—the coordinate system that defines latitude, longitude, height, scale, gravity, and orientation throughout the United States. Processing and adjusting of these leveling data for the Grand Canyon improved vertical positions for 700 existing bench marks in Arizona and Utah. An additional 346 more bench marks originated directly from the effort. These marks are published in the NGS integrated database and are available online at http://www.ngs.noaa.gov/cgi-bin/ds_proj.prl under Survey Project ID: L27947 and will aid in the development of NGS's next geoid height model.
- Project element A.2 was supported by equipment preparation, software, control coordinates and survey files. This project involved occupation and processing of measurements from 80 control points between the Little Colorado River and Bright Angel Creek. One of the goals of the channel mapping trip was to reduce the uncertainty of control points (benchmarks) in Grand Canyon National Park by conventional survey traverse. By "closing" a traverse (unbroken line-of-site observations) between two locations, we can determine positions and estimate errors in the network. Using the data collected during this effort, a continuous conventional traverse now exists from Glen Canyon to Phantom Ranch (104 miles), along with 15 miles along the Little Colorado River, upstream from the confluence with the Colorado River. This was the first continuous traverse of several areas with electronic angle and distance measurements.
- Equipment and support was obtained for a new Continuously Operating Reference Station (CORS) at the Grand Canyon Emergency Services Building on the South Rim of Grand Canyon. GCMRC acquisition of an Arizona State grant will provide NGS support for data acquisition, storage, and archive of global navigation satellite system (GNSS) data. The station will provide survey-grade measurements and coordinates with a single dual frequency GNSS receiver and cellular data link.
- Terrestrial lidar (Project J) was supported by projecting and scaling of ground control survey measurements to Arizona State Plane Coordinate System.
- Sandbar monitoring (Project element A.1) was supported with survey control, survey equipment and field support.
- Project B was supported by surveys of tributary gages with GNSS and terrestrial equipment.
- All survey coordinates, estimated errors, and measurements have been updated in a control database for GIS integration.

Conclusions

Project A (now Project 3 in the FY15–17 TWP) consists of a set of integrated studies designed to (a) track the effects of individual HFEs on sandbars and within-channel sediment storage, (b) monitor the cumulative effect of successive HFEs and intervening operations, and (c) advance general understanding of sediment transport and eddy sandbar dynamics. In the FY13–14 BWP, efforts in six project elements resulted in the completion of several data sets, a new online sandbar database, 20 publications that are complete or in review, and eight additional publications that are in preparation and near completion.

The analysis of the repeat maps of the channel and sandbars for lower Marble Canyon has yielded, for the first time, a comprehensive and robust view of changes in sediment storage and sandbars for a significant portion of the Colorado River ecosystem in Grand Canyon. These results show that between May 2009 and May 2012, a period with high-volume dam releases (equalization flows), there was widespread evacuation of sediment from the channel and decreases in sandbar size.

The response at the subset of 18 long-term monitoring sites in this reach was similar to the response observed among the 84 large sandbars mapped in 2009 and 2012. These results improve our confidence in the annual sandbar monitoring for this segment. However, other segments, especially those downstream from RM 87, have relatively fewer monitoring sites. Thus, we have much less confidence in the degree to which the annual sandbar monitoring is representative of average response in those reaches. These findings prompted the initiation of a project in the FY15–17 TWP to explore “rapid” survey methods to increase the sample size.

In the initial two years of the HFE Protocol, which follows the 2011 equalization flows, sandbar monitoring results indicate that each HFE (prior to Nov. 2014) has had the intended effect of building sandbars throughout Grand Canyon National Park. Paria River sand inputs during this period have been average or above average and dam releases have been relatively low, resulting in a positive or neutral sand mass balance throughout Grand Canyon National Park (Project B). Sandbar monitoring results, coupled with sand mass balance observations, indicate that the HFE Protocol is resulting in increases in sandbar size without causing net sediment export from the Colorado River ecosystem. These results suggest that it may be possible to “recover” from the sediment evacuation associated with one season of equalization flows when those flows are followed with relatively large Paria River sand inputs and average or below average annual release volumes. The effect of high dam-release volumes on sandbars constructed by a HFE will be evaluated with data collected in 2015, when extended high-volume releases are expected to next occur.

Progress was also made on several research projects in the FY13–14 BWP.

- An investigation of the mechanisms responsible for changes in campsite area shows that vegetation expansion is responsible for net long-term (decade scale) decline in the open areas within camp boundaries and that changes in sandbar topography are the main source of inter-annual variability in campsite area.
- Initial results from a study of sediment geochemistry suggest that HFE-deposited sandbars are more similar to sand from the Paria River than sand from pre-dam Colorado River deposits. However, because there is large variability on the composition of HFE-deposits, further work is required to quantify the relative proportions of source sediments.
- We have developed a methodology for creating accurate digital elevation models from aerial photographs and applied the method to 12 long-term sandbar monitoring sites. This will allow comparison of sandbar size following recent HFEs to sandbar size following the much larger floods of the mid-1980s.
- Understanding of sandbar variability has been advanced by examining the relation between changes in sandbar volume relative to flow conditions and progress has been made towards the development of a new model for flow and sediment transport in eddies.
- An automated method for classification of bed sediment texture based on backscatter from multibeam sonar was developed and implemented. The method is being applied for use in tracking changes in sand storage and characterization of bed condition relevant to aquatic primary productivity and fish habitat.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Project Element A.1 – Sandbar Monitoring					
data	Data from long-term sandbar monitoring sites	Annual	Jan. 2014; 2015	Jan. 2014; 2015	Presented at Jan. 2014 reporting meeting; will be presented at Jan. 2015 reporting meeting. Published in online database: *http://www.gcmrc.gov/sandbar/*
photos	Images from daily remote camera monitoring of sandbars	Annual	Dec. 2013 &Dec. 2014		Photos uploaded to website following each HFE: *http://www.gcmrc.gov/sandbar/* Presentation: [38]
Article	New High Flow Protocol Contributes to Sandbar Gains in Grand Canyon			Jan. 2015	Publication: [7]
Article	The influence of controlled floods on fine sediment storage in debris fan-affected canyons of the Colorado River basin				Publication: [16]
Article	To Re-photograph or Not, That is the Question: The Adopt-A-Beach Program Marches On		Dec. 2013		Publication: [15]
Article	Citizen Science and Stewardship in Grand Canyon		2014		Publication: [11]
data	Map, showing extent of sandbars in selected reaches for 1988	Year 1			This was not completed. See project A.1.2. Replaced with item in next line.
data	Maps, showing extent of sandbars in selected reaches in Marble Canyon and eastern Grand Canyon (Product in lieu of map of sandbars from 1988 images)		Dec. 2014		http://www.gcmrc.gov/research_areas/sediment_geomorphology/data_remote_sensing/ xxx.gdb.zip

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
data	Map, showing extent of sandbars throughout CRE in 2013	Year 2		Aug. 2015	*in progress*
report	Report on system-wide sandbar monitoring, 1988-2013	Year 2		Jan. 2015	Publication: [18] Publication in preparation: [27]
report	Report on the geomorphic attributes of camping beaches	Year 2	Nov. 2014	Jan. 2015	Publication: [10] Publication in preparation: [23]
report	Report on the extended sandbar monitoring time series (1984 to present) based on use of old air photos	Year 2		Jan. 2015	Publication in preparation: [26]
Project Element A.2 – Sand Storage Monitoring					
Journal Article	Report on changes in sediment storage, RM 30 to RM 61, titled: *Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design*	Year 1	Feb. 2013	Mar. 2014	Publication: [8] Publication: [6] Publication in preparation: [22]
USGS Fact sheet	*A sand budget for Marble Canyon, Arizona--implications for long-term monitoring of sand storage change*		Aug. 2013		Publication: [5]
data	Data from sediment storage monitoring, RM 30 to RM 61	Year 1	Aug. 2014	Jan. 2014	http://www.gcmrc.gov/research_areas/sediment_geomorphology/data_channel_mapping/CM_2009_DEM.gdb.zip AND http://www.gcmrc.gov/research_areas/sediment_geomorphology/data_channel_mapping/CM_2012_DEM.gdb.zip

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
data	Data from sediment storage monitoring for long reach mapped in 2013	Year 2		Mar. 2015	*in progress*
data	Data from sediment storage monitoring for long reach mapped in 2014	After Year 2		Mar. 2016	*in progress*
data	Maps of bed texture for each of the long reaches mapped in the sediment storage monitoring project	Year 2		Jan. 2015	http://www.gcmrc.gov/research_areas/sediment_geomorphology/data_channel_mapping/ BedClass_LMC.gdb.zip
report	Report on bed material characterization	Year 2		Jan. 2015	Publication: [1] Publication: [2] Publication: [3] Publication: [4] Presentation: [29] Presentation: [31]
Project Element A.3 – Sandbar Modeling					
report	Report on eddy sandbar variability(eddy modeling)	Year 2		Jan. 2015	Publication: [6] Publication: [21] Presentation: [29]
Project Element A.4 – Flow-sediment Interactions					
report	Report on interaction between bed sediment and suspended sediment	Year 2	Feb. 2014	Jan. 2015	Publication: [9]
Project Element A.5 – Sediment Fingerprinting					
report	Report on geochemical signature of pre-dam sediment	Year 2		Jan. 2015	Publication in preparation: [28] Presentation: [37]
Project Element A.6 – Control Network and Survey Support					
data	USGS Data Rescue of Historical Leveling Data around Grand Canyon				http://www.ngs.noaa.gov/cgi-bin/ds_proj.prl Survey Project ID: L27947
Products that support other GCMRC Projects					

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
USGS report	*Nearshore thermal gradients of the Colorado River near the Little Colorado River confluence, Grand Canyon National Park, Arizona, 2010*		Mar. 2013		Publication: [17]
USGS Fact sheet	*Nearshore Temperature Findings for the Colorado River in Grand Canyon, Arizona—Possible Implications for Native Fish*		Nov. 2013		Publication: [19]

	List of Publications and Presentations

FY 2013/14 Project A Publications (published or submitted for review as of Nov. 18, 2014)

1. Buscombe, D., P.E. Grams, and M. Kaplinski, *in press*, Characterizing riverbed sediments using high-frequency acoustics 1: Spectral properties of scattering. Journal of Geophysical Research Earth Surface.
2. Buscombe, D., P.E. Grams, and M. Kaplinski, *in press*, Characterizing riverbed sediments using high-frequency acoustics 2: Scattering signatures of Colorado River bed sediments in Marble and Grand Canyons. Journal of Geophysical Research Earth Surface.
3. Buscombe, D., P.E. Grams, and S. Smith, *in review*, Automated riverbed sediment classification using low-cost sidescan sonar. Journal of Hydraulic Engineering.
4. Buscombe, D. P.E. Grams, M.A. Kaplinski, R. Tusso, and D.M. Rubin, *in review*, Hydroacoustic signatures of Colorado riverbed sediments in Marble and Grand Canyons using multibeam sonar, *in* SEDHYD 2015 (10^{th} Federal Interagency Sedimentation Conference and 5^{th} Federal Interagency Hydrologic Modeling Conference), Reno, Nev., April 19-23.
5. Grams P. E., 2013, A sand budget for Marble Canyon, Arizona--implications for long-term monitoring of sand storage change, U.S. Geological Survey Fact Sheet 2013–3074, 4 p., *http://pubs.usgs.gov/fs/2013/3074/*.
6. Grams, P.E., Buscombe, D., Topping, D.J., Kaplinski, M., Hazel, J.E., Jr., *in review*, Use of flux and morphologic sediment budgets for sandbar monitoring on the Colorado Rver in Marble Canyon, Arizona, *in* SEDHYD 2015 (10^{th} Federal Interagency Sedimentation Conference and 5^{th} Federal Interagency Hydrologic Modeling Conference), Reno, Nev., April 19-23.
7. Grams, P.E., J.C. Schmidt, S.A. Wright, D.J. Topping, T.S. Melis, and D.M. Rubin, *in review*, New High Flow Protocol Contributes to Sandbar Gains in Grand Canyon, EOS.
8. Grams P. E., D. J. Topping, J. C. Schmidt, J. E. Hazel Jr., and M. Kaplinski (2013), Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design, J. Geophys. Res. Earth Surf., 118, 361–381, doi:10.1002/jgrf.20050. http://onlinelibrary.wiley.com/doi/10.1002/jgrf.20050/full
9. Grams, P.E. and P.R. Wilcock, 2014, Transport of fine sediment over a coarse, immobile riverbed, Journal of Geophysical Research: Earth Surface, 119(2), 188-211, doi:

10.1002/2013JF002925, *http://dx.doi.org/10.1002/2013JF002925*

10. Hadley, D.R., 2014, Geomorphology and vegetation change at Colorado River campsites, Marble and Grand Canyons, AZ, MS Thesis, http://www.gcmrc.gov/library/reports/Physical/Fine_Sed/Hadley_Thesis_Final.pdf.
11. Hamilton, Lynn, 2014, Life's a Beach: Citizen Science and Stewardship in Grand Canyon, in "Outdoors in the Southwest: An Adventure Anthology," Andrew Gulliford, ed., University of Oklahoma Press, Norman, p. 365-368.
12. Kaplinski, M., J.E. Hazel Jr., P.E. Grams, and P.A. Davis, 2014, Monitoring Fine-Sediment Volume in the Colorado River Ecosystem, Arizona: Construction and Analysis of Digital Elevation Models, USGS Open-file Report 2014-1052, 36 p. http://pubs.usgs.gov/of/2014/1052/.
13. Kaplinski, M., J. Hazel, R. Parnell, D.R. Hadley, and P. Grams, 2014, Colorado River campsite monitoring, Grand Canyon National Park, Arizona, 1998-2012, USGS Open-file Report: 2014-1161, 32 p. http://pubs.usgs.gov/of/2014/1161/.
14. Kennedy, T. A., Yackulic, C. B., Cross, W. F., Grams, P. E., Yard, M. D. and Copp, A. J., 2014, The relation between invertebrate drift and two primary controls, discharge and benthic densities, in a large regulated river: Freshwater Biology, v. 59, p 557-572, doi: 10.1111/fwb.12285.
15. Lauck, Zeke, 2013, To Re-photograph or Not, That is the Question: The Adopt-A-Beach Program Marches On: Boatman's Quaterly Review, Winter 2013-2014, 26, 4, p. 21-23, http://www.gcrg.org/bqr.php.
16. Mueller, E.R., P.E. Grams, J.C. Schmidt, J.E. Hazel, Jr, J.S. Alexander, and M. Kaplinski, 2014, The influence of controlled floods on fine sediment storage in debris fan-affected canyons of the Colorado River basin, Geomorphology, v. 226, p. 65-75, doi: 10.1016/j.geomorph.2014.07.029.
17. Ross, R., and Grams, P.E., 2013, Nearshore thermal gradients of the Colorado River near the Little Colorado River confluence, Grand Canyon National Park, Arizona, 2010: U.S. Geological Survey Open-File Report 2013–1013, 65 p. *http://pubs.usgs.gov/of/2013/1013/*.
18. Ross, R. and Grams, P.E., *in review*, Long-term monitoring of sandbars on the Colorado River in Grand Canyon using remote sensing, *in* SEDHYD 2015 (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), Reno, Nev., April 19-23.
19. Ross, R.P., and Vernieu, W.S., 2013, Nearshore Temperature Findings for the Colorado River in Grand Canyon, Arizona—Possible Implications for Native Fish: U.S. Geological Survey Fact Sheet 2013-3104, 4 p., http://dx.doi.org/10.3133/fs20133104.
20. Sankey, J.B., B.E. Ralston, P.E. Grams, J.C. Schmidt, and L.E. Cagney, *in review*, Riparian vegetation, Colorado River, and climate: five decades of spatio-temporal dynamics in the Grand Canyon with river regulation. Journal of Geophysical Research Biogeosciences.

FY 2013/14 Project A Publications (in preparation as of Nov. 18, 2014)

21. Alvarez, L.V., Scmeeckle, M.W., and Grams, P.E., Turbulence Resolving Modeling of Lateral Separation Zones along a Large Canyon-Bound River using Detached Eddy Simulation Technique, for Water Recources Research.
22. Grams and others, A Sand budget for the Colorado River in Lower Marble Canyon for GSA Bulletin.
23. Hadley, D.R. and Grams, P.E., 2014, Geomorphology and vegetation change at Colorado River

campsites, Marble and Grand Canyons, Arizona, USGS Scientific Investigations Report.

24. Kaplinski and others, Topographic and bathymetric maps of the Colorado River in lower Marble Canyon, 2009 and 2012. USGS Open-file Report.
25. Hazel and others, Sandbar Monitoring at Selected Sites, Colorado River in Glen, Marble and Grand Canyons, Arizona, 1990-2013, USGS Scientific Investigations Report.
26. Hazel and others, extended sandbar monitoring time series (1984 to present) based on use of old air photos
27. Ross and Grams, Long-term Monitoring of Sandbars on the Colorado River in Grand Canyon using Remote Sensing, USGS Scientific Investigations Report.
28. Takesue, R., and others, Using geochemical tracers to identify the source material for sandbars deposited by dam-released floods on the Colorado River in Grand Canyon.

FY 2013/14 Presentations at Professional Meetings

29. Alvarez, L.V, and Schmeeckle, M.W., Numerical Model of Turbulence, Sediment Transport, and Sediment Cover in a Large Canyon-Bound River, AGU Fall Meeting, Dec. 2013, Talk, http://abstractsearch.agu.org/meetings/2013/FM/sections/EP/sessions/EP24B/abstracts/EP24B-07.html
30. Buscombe, D. [presenter]; Paul E. Grams; Matthew A. Kaplinski, Acoustic Scattering by an Heterogeneous River Bed: Relationship to Bathymetry and Implications for Sediment Classification using Multibeam Echosounder Data, AGU Fall Meeting, Dec. 2013, Talk, *http://abstractsearch.agu.org/meetings/2013/FM/sections/EP/sessions/EP41E/abstracts/EP41E-06.html*
31. Buscombe, D., P.E. Grams, T.S. Melis, and S.M. Smith, *in review*, large river bed sediment characterization with low-cost sidescan sonar: case studies from two settings in the colorado (arizona) and penobscot (maine) rivers, *in* SEDHYD 2015 (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), Reno, Nev., April 19-23.
32. Czarnomski, N. [presenter], Wheaton, J.M., Grams, P.E.; Hazel, J.E.; Kaplinski, M.A.; Schmidt, J.C., Framework for Assessing Dynamism and Persistence of Eddy-Sandbar Complexes in the Grand Canyon, AGU Fall Meeting, Dec. 2012, Poster, http://abstractsearch.agu.org/meetings/2012/FM/sections/H/sessions/H31E/abstracts/H31E-1169.html
33. Grams, P.E. [presenter]; Daniel Buscombe; Joseph E. Hazel; Matthew A. Kaplinski; David J. Topping, Reconciliation of Flux-based and Morphologic-based Sediment Budgets, AGU Fall Meeting, Dec. 2013, Talk, http://abstractsearch.agu.org/meetings/2013/FM/sections/EP/sessions/EP33E/abstracts/EP33E-01.html
34. Grams, P.E. [presenter]; John Schmidt; Charles Yackulic; David J. Topping, Error and Uncertainty in High-resolution Quantitative Sediment Budgets, AGU Fall Meeting, Dec. 2012, Poster, http://abstractsearch.agu.org/meetings/2012/FM/sections/EP/sessions/EP31C/abstracts/EP31C-0825.html
35. Kaplinski, M.A. [presenter]; Joseph E. Hazel; Paul E. Grams; Daniel Buscombe; Dan Hadley; Keith Kohl, Constructing a morphologic sediment budget, with uncertainties, for a 50-km segment of the Colorado River in Grand Canyon, AGU Fall Meeting, Dec. 2013, Poster,

http://abstractsearch.agu.org/meetings/2013/FM/sections/EP/sessions/EP43B/abstracts/EP43B-0844.html

36. Mueller, E.R. [presenter]; Paul E. Grams; John C. Schmidt, The effect of controlled floods on decadal-scale changes in channel morphology and fine sediment storage in a debris-fan affected river canyon, AGU Fall Meeting, Dec. 2013, Poster, http://abstractsearch.agu.org/meetings/2013/FM/sections/EP/sessions/EP33C/abstracts/EP33C-0923.html
37. Takesue, R.K., Rubin, D.M., and Grams, P.E., 2014, Assessing erosion and re-deposition of relic (pre-dam) sand in modern Colorado River sandbars from geochemical tracers, Geological Society of America Annual Meeting in Vancouver, Canada, October 18-22, 2014, *https://gsa.confex.com/gsa/2014AM/webprogram/Paper248268.html*
38. Tusso, R.B., D. Buscombe, and P.E. Grams, in review, Using oblique digital photography for alluvial sandbar monitoring and low-cost change detection, *in* SEDHYD 2015 (10th Federal Interagency Sedimentation Conference and 5th Federal Interagency Hydrologic Modeling Conference), Reno, Nev., April 19-23.

Project A	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$601,002	$9,600	$53,000	$347,100	$137,700	$85,685	**$1,234,087**
Actual Spent	$504,686	$12,165	$85,531	$504,818	$37,970	$83,473	**$1,228,643**
(Over)/Under Budget	**$96,316**	**($2,565)**	**($32,531)**	**($157,718)**	**$99,730**	**$2,212**	**$5,444**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Purchased additional scientific equipment.

Funded cooperative agreements rather than hiring USGS staff and sending funds to other USGS centers.

Project &Title			
Project B: Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem			
Program Manager (PM)	David Topping	**Principal Investigator(s)** (PI)	David Topping, USGS GCMRC
Email	*dtopping@usgs.gov*		
Telephone	(928) 556-7396		

The Streamflow, Water Quality, and Sediment Transport Core Monitoring Project is focused on high-resolution monitoring of stage, discharge, water temperature, specific conductance, dissolved oxygen, turbidity, and suspended-sediment concentration and particle size at a number of mainstem and tributary sites located throughout the Colorado River Ecosystem (CRE). These data are collected to address Glen Canyon Dam Adaptive Management Program GOAL 7 and are used to inform managers on the physical status of the Colorado River in the CRE and how this physical status is affected by dam operations in near realtime. The high-resolution suspended-sediment data collected under this project are used to construct the mass-balance sediment budgets used by managers to trigger controlled floods under the 2012-2020 High Flow Experiment (HFE) protocol. Details of this ongoing project (including descriptions of the data-collection locations) are provided in the GCMRC FY13–14 Biennial Work Plan, and in the FY15–17 Triennial Work Plan.

Science Questions Addressed:

The Streamflow, Water Quality, and Sediment Transport Core Monitoring Project addresses the following fundamental science question in an ongoing manner:

> "How do operations at Glen Canyon Dam affect flows, water quality, sediment transport, and sediment resources in the CRE?"

During the period of the FY13–14 Biennial Work Plan, this question was addressed through:

1. Development of the new database and website at *http://www.gcmrc.gov/discharge_qw_sediment/* described in detail below. All stage, discharge, water quality (water temperature, specific conductance, turbidity, dissolved oxygen), suspended-sediment, and bed-sediment data collected at all active and inactive monitoring stations on the Colorado River and its tributaries are posted at this website. User-interactive tools at this website allow visualization and downloading of these data and the construction of sand budgets (as described below).
2. Publication of five peer-reviewed interpretive papers and 18 USGS Water-data reports. The interpretive papers published during the period of the FY13-14 Biennial Work Plan focused on: how dam operations affect the sediment resources within Marble Canyon and how best to monitor the sediment resources in Marble Canyon, how dam operations affect groundwater flow within sandbars and thus possibly affect sandbar stability, how dam operations affect turbidity in the Colorado River, how biases in older suspended-sediment samplers previously used in the Colorado River in earlier phases of this project affected the older sand-transport data collected by this project, and how to design a monitoring program to best measure the sediment supply from smaller tributaries deemed possible important suppliers of sand in the 1995 EIS.

Most of the subsidiary science questions listed in the FY15–17 Triennial Work Plan have their basis in the above fundamental question. Thus additional publications completed during the period of the FY15–17 Triennial Work Plan will use the data collected during the period of the FY13–14 Biennial Work Plan and also address this fundamental question, with perhaps the most important of these publications having the working title "Evaluation of the effects of 2008-2016 dam operations on sediment storage dynamics within the CRE."

Promised products:

The following list of promised products is taken verbatim from the FY13–14 Biennial Work Plan:

"Products from this project are as follows:

1. 2–3 peer-reviewed journal articles or interpretative USGS reports per year during FY13–14
2. Annual data reports for the 9 USGS streamflow gaging stations funded by this project and operated by the Arizona and Utah Water Science Centers
3. Real-time posting (updated every 1–4 hours) to the world-wide-web of the stage, discharge, and water-quality parameters measured at the 9 USGS streamflow gaging stations operated by the Arizona and Utah Water Science Centers
4. Real-time to monthly posting to the world-wide web of the stage, discharge, water-quality parameters (temperature, specific conductance, turbidity, dissolved oxygen), suspended-sediment concentration, and suspended-sediment grain size distribution at the monitoring stations operated by the Grand Canyon Monitoring and Research Center (through cooperation with the Center for Integrated Data Analytics)
5. Monthly to bi-monthly updates of the mass-balance sediment budgets posted to the world-wide web for 5 reaches of the Colorado River in Marble and Grand Canyons (through cooperation with the Center for Integrated Data Analytics)"

As described in detail below, all of these products were delivered during the period of the FY13–14 Biennial Work Plan.

Detailed list of accomplishments/products:

In summary, this project coordinated the collection of stage, discharge, water-quality, and sediment-transport monitoring data at seven mainstem monitoring locations and eight major tributary locations and eight lesser tributary monitoring locations during 2013 and 2014 (suspended sediment is monitored at a subset of five mainstem and 16 tributary monitoring locations). At all sites, acoustic instrument calibrations have been finalized and are actively being verified, with out-of-sample errors calculated. This work has resulted in the ability to serve data at a new website and update it on a daily to monthly basis (depending on the monitoring station). The two urls to use to access this new website are: *http://www.gcmrc.gov/discharge_qw_sediment/* or *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*.

The second url provides backup access to the website in case the local web servers at GCMRC go down. The design and programming of this new website and the new database required to drive it occupied most of the time on this project during 2013 and 2014. The existence of this new database and website will allow much greater efficiency and productivity in this project (with time for many more peer-reviewed interpretive publications) during the period of the FY15–17 Triennial Work Plan.

Specifically, progress was made on many fronts within the Streamflow, Water Quality, and Sediment Transport Project during the period of the FY13–14 Biennial Work Plan, with multiple major accomplishments.

1. The single most significant accomplishment during the period of the FY13–14 Biennial Work Plan was the completion of the new database and website. This website provides access to all of the current and legacy data collected by the Streamflow, Water Quality, and Sediment Transport Project and to all of the historical unit-value gage height and discharge data collected

by the USGS at USGS gaging stations with water quality (QW) and sediment data relevant to the CRE. The user-interactive tools available at this website to visualize and operate on the data are unique in the world.

Twice daily, the database driving the website automatically uploads data from the USGS realtime gaging stations within the CRE and performs sediment-load computations using the latest data. This approach allows river managers to make decisions based on the most accurate and recent data available.

The website allows user-interactive plotting and downloading of all data for any time period for which data are available. In addition to user-interactive plotting, this new web site allows user interactive sand budgets to be constructed for all six reaches of the Colorado River in the CRE between Lees Ferry and the Lake Mead delta. These user-interactive sand budgets allow the user to modify the contribution of bedload and to modify the uncertainties in the data. This ability allows managers to evaluate "how well the sand budgets need to be known" in their decision-making process. The user-interactive sediment load calculations and sediment budgets at the website have become integral to the Bureau of Reclamation's implementation of the 2012–2020 HFE Protocol.

The servers supplying data to this new website have been moved to the USGS EROS Data Center in South Dakota for greater security and IT service (meaning the websites will be less likely to go down or experience catastrophic loss of data).

2. All monitoring data required by this project were collected. Processing of all data is complete and all data have been uploaded to and are available at the website, except for laboratory analyses of some of the suspended-sediment data from the fourth of four large floods on the Paria River in summer 2014 (this task will be completed by the end of February 2015, as is the usual schedule for this project).
3. Discharge measurements, suspended-sediment samples, and bed-sediment samples were collected during the November 2012, 2013, and 2014 HFEs at multiple sites on the Colorado River: Lees Ferry, RM30, RM61, the Grand Canyon gaging station at RM87, RM166, and the above Diamond Creek gaging station at RM225. During the 2012 HFE, these measurements were made by personnel stationed at five sites (all but RM30). During the 2013 and 2014 HFEs, this labor-and cost-intensive effort was scaled back, with personnel only being stationed at Lees Ferry and the Grand Canyon gaging station. Automatic suspended-sediment samplers, acoustic measurements, and automatic stage sensors were used to constrain the flow and sediment conditions during the 2013 and 2014 HFEs at the other four sites. All discharge measurements from the HFEs have been processed with stage-discharge ratings verified or adjusted as necessary; all suspended-sediment and bed-sediment samples from the 2012 and 2013 HFEs have been processed and uploaded to the website. These can be plotted or downloaded on demand. The sediment samples from the 2014 HFE have begun to be processed through the GCMRC sediment laboratory and uploaded to the website (to be completed by late spring 2015).
4. 15-minute stage, discharge, and water temperature data (updated in realtime) and other QW data from the nine gaging stations maintained by the USGS Arizona and Utah Water Science Centers under this project are available at *http://www.gcmrc.gov/discharge_qw_sediment/*, *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*, or *http://waterdata.usgs.gov/nwis*.
5. Indirect discharge measurements were completed by the USGS Arizona Water Science Center for the peaks of the largest Paria River floods of 2013 and 2014. These time-consuming measurements were deemed essential to ensure the highest possible accuracy for the sand loads of the Paria River required to implement the HFE Protocol.

6. 15-minute stage, discharge, water temperature, specific-conductance, turbidity, dissolved oxygen and suspended-sediment-concentration and grain-size data from the stations maintained by GCMRC under this project have been processed and are served at the new website at *http://www.gcmrc.gov/discharge_qw_sediment/* or *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*. These data are updated as frequently as every month, depending on data-collection location.
7. Five major peer-reviewed reports (a journal article published in the Journal of Geophysical Research-Earth Surface, two USGS Scientific Investigations Reports, and two USGS Open-File Reports) were published on normal core-monitoring tasks. These reports are listed below.
8. Substantial progress was made on the publication of a journal article and a book describing new methods for making accurate continuous measurements of suspended sediment in rivers using pump, acoustic, and laser-diffraction methods. The journal article is 95% complete and is to be submitted to the Journal of Geophysical Research - Earth Surface by the time of the January 2015 Annual Reporting Meeting. The authors of this journal article are David J. Topping and Scott A. Wright and it is entitled "Long-term continuous acoustic suspended-sediment measurements in rivers." The book is roughly 70% complete and will be submitted for consideration as either an American Geophysical Union Monograph or as a USGS Professional Paper in late winter-spring 2015. The authors of the book are David J. Topping, Scott A. Wright, Ronald E. Griffiths, and David J. Dean and it is entitled "Acoustic, laser-diffraction, and pump methods for measuring the concentration and grain-size distribution of suspended sediment in rivers at high temporal resolution over multi-year timescales: Theory, calibration, and error." It was hoped that both of these products would be published during the period of the FY13–14 Biennial Work Plan, but because of the high complexity of the subject matter (with extensive new theoretical development) additional time was required.
9. Four abstracts were published and presented at the 2013 Fall Meeting of the American Geophysical Union and two abstracts were published and presented at the 2014 Fall Meeting of the American Geophysical Union.
10. Annual water-data reports for the data collected during 2012 and 2013 were published by the Arizona and Utah Water Science Centers.
11. Substantial progress was also made on completing the delivery of the historical periods of record for unit-value stage and discharge for USGS gaging stations with QW and sediment data relevant to the CRE. As of December 2014, the following historical periods of record have been processed and are available at *http://www.gcmrc.gov/discharge_qw_sediment/* or *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*. All other historical periods of record for unit-value stage and discharge for USGS gaging stations with QW and sediment data relevant to the CRE will be delivered during the period of the 2015-2017 workplan. These stations include the 1924-1996 period of record at 09382000 Paria River at Lees Ferry, AZ, and 1926-1941 09401280 Moenkopi Wash near Tuba, AZ. Interpretive journal articles utilizing these data to aid in river management will be published as described in the FY15–17 Triennial Work Plan.

09380000 Colorado River at Lees Ferry, AZ Entire period of station record processed and on website (1921-present).
09381500 Paria River near Cannonville, UT Entire period of station record processed and on website (1951-1956, 2001-2006).
09401000 Little Colorado River at Grand Falls, AZ Entire period of station record processed on website (1926-1960, 1994-1995).
09401240 Moenkopi Wash near Shonto, AZ Entire period of station record processed and available on website (1974-1975)
09401250 Moenkopi Wash near Moenkopi, AZ Entire period of station record processed and available on website (1974-1976).

09401260 Moenkopi Wash at Moenkopi, AZ Entire period of station record processed and available on website (1976-present). 09401400 Moenkopi Wash near Tuba City, AZ Entire period of station record processed on website (1941-1954, 1965-1977). 09401500 Moenkopi Wash near Cameron, AZ Entire period of station record processed and available on website (1954-1965). 09402000 Little Colorado River near Cameron, AZ Entire period of station record processed on website (1947-present). 09402500 Colorado River near Grand Canyon, AZ Entire period of station record processed on website (1923-present). 09403000 Bright Angel Creek near Grand Canyon, AZ Entire period of station record processed on website (1924-1974, 1991-1993). 09403780 Kanab Creek near Fredonia, AZ 1964-1977 on website. 1978-1980 remaining to be processed.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Online database and web-based applications	Discharge, sediment transport, water-quality, and sand-budget data are served through the GCMRC website. A web-based application has been implemented to provide stakeholders, scientists, and the public with the ability to perform interactive online data visualization and analysis, including the on-demand construction of sand budgets. These capabilities are unique in the world.	ongoing	updated every month	updated every month	*http://www.gcmrc.gov/discharge_qw_sediment/* *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*
Online realtime database	Discharge and water-quality data collected at 9 gaging stations by the Utah and Arizona Water Science Centers under project are posted to the web every hour.	n/a	hourly	n/a	*http://waterdata.usgs.gov/nwis*

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Abstracts	American Geophysical Union abstract for 2013 Fall Meeting entitled "Accurate sediment budgets in rivers require high-resolution discharge-independent measurements of suspended-sediment concentration." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Topping, D.J., Griffiths, R.E., Dean, D.J., Wright, S.A., Rubin, D.M., Garner, B.D., Sibley, D.M., and Reinke, T.A., 2013, Accurate sediment budgets in rivers require high-resolution discharge-independent measurements of suspended-sediment concentration: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Measurements of sediments loads in small, ungaged, basins may be required to accurately close sediment budgets: An example from a monitoring network on the southern Colorado Plateau." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Griffiths, R.E., and Topping, D.J, 2013, Measurements of sediments loads in small, ungaged, basins may be required to accurately close sediment budgets: An example from a monitoring network on the southern Colorado Plateau: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Reconciliation of Flux-based and Morphologic-based Sediment Budgets." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Grams, P.E., Buscombe, D., Hazel, J.E., Kaplinski, M.A., and Topping, D.J, 2013, Reconciliation of Flux-based and Morphologic-based Sediment Budgets: EOS, Transactions, American

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Warm Season Storms, Floods, and Tributary Sand Inputs below Glen Canyon Dam: Investigating Salience to Adaptive Management in the Context of a 10-Year Long Controlled Flooding Experiment in Grand Canyon National Park, AZ, USA." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Jain, S., Melis, T.S., Topping, D.J, Pulwarty, R.S., and Eischeid, J., 2013, Warm Season Storms, Floods, and Tributary Sand Inputs below Glen Canyon Dam: Investigating Salience to Adaptive Management in the Context of a 10-Year Long Controlled Flooding Experiment in Grand Canyon National Park, AZ, USA: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2014 Fall Meeting entitled "The Role of Sediment Budgets in the Implementation and Evaluation of Controlled Floods to Restore Sandbars along the Colorado River in Grand Canyon, Arizona." Presentation made at AGU in December 2014.	FY 2014	August 2014	August 2014	Grams, P.E., Schmidt,J.C., and Topping, D.J., 2014, The Role of Sediment Budgets in the Implementation and Evaluation of Controlled Floods to Restore Sandbars along the Colorado River in Grand Canyon, Arizona: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2014 Fall Meeting entitled "Deciphering Paria and Little Colorado River flood regimes and their	FY 2014	August 2014	August 2014	Jain, S., Topping, D.J., and Melis, T.S., 2014, Deciphering Paria and Little Colorado River flood regimes and their

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon." Presentation made at AGU in December 2014.				significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon: EOS, Transactions, American Geophysical Union.
Journal articles and other major pubs	Journal of Geophysical Research article entitled "Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design"	FY 2013	February 2013	February 2013	Grams, P.E., Topping, D.J., Schmidt, J.C., Hazel, J.E., Jr., and Kaplinski, M., 2013, Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design: Journal of Geophysical Research: Earth Surface, v. 118, 18p., doi:10.1002/jgrf.20050, *http://onlinelibrary.wiley.com/doi/10.1002/jgrf.20050/pdf*
	USGS Scientific Investigations Report entitled "Evaluation of intake efficiencies and associated sediment-concentration errors in US D-77 bag-type and US D-96-type depth-integrating suspended-sediment samplers"	FY 2013	Sept. 2013	Sept. 2013	Sabol, T.A., and Topping, D.J., 2013, Evaluation of intake efficiencies and associated sediment-concentration errors in US D-77 bag-type and US D-96-type depth-integrating suspended-sediment samplers: U.S. Geological Survey Scientific Investigations Report

Type	PRODUCTS/REPORTS				
	Title	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					2012–5208, 88 p., http://dx.doi.org/10.3133/sir20125208, *http://pubs.er.usgs.gov/publication/sir20125208*
	USGS Open-File Report entitled “Transient simulation of groundwater levels within a sandbar of the Colorado River, Marble Canyon, Arizona, 2004”	FY 2013	Sept. 2013	Sept. 2013	Sabol, T.A., and Springer, A.E., 2013, Transient simulation of groundwater levels within a sandbar of the Colorado River, Marble Canyon, Arizona, 2004: U.S. Geological Survey Open-File Report 2013-1277, 22 p., *http://dx.doi.org/10.3133/ofr20131277*
	USGS Scientific Investigations Report entitled "Extending the turbidity record—making additional use of continuous data from turbidity, acoustic-Doppler, and laser diffraction instruments and suspended-sediment samples in the Colorado River in Grand Canyon"	FY 2014	May 2014	July 2014	Voichick, N., and Topping, D.J, 2014, Extending the turbidity record—making additional use of continuous data from turbidity, acoustic-Doppler, and laser diffraction instruments and suspended-sediment samples in the Colorado River in Grand Canyon: U.S. Geological Survey Scientific Investigations Report 2014–5097, 31 p., *http://pubs.er.usgs.gov/publication/sir20145097*
	USGS Open-File Report entitled “Design of a sediment-monitoring gaging network on	FY 2014	July 2014	July 2014	Griffiths, R.E., Topping, D.J., Anderson, R.S., Hancock, G.S., and

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	ephemeral tributaries of the Colorado River in Glen, Marble, and Grand Canyons, Arizona”				Melis, T.S., 2014, Design of a sediment-monitoring gaging network on ephemeral tributaries of the Colorado River in Glen, Marble, and Grand Canyons, Arizona: U.S. Geological Survey Open File Report 2014–1137, 21 p., *http://pubs.er.usgs.gov/publication/ofr20141137*
Reports	2012 Annual USGS Water-Data Reports	2-28-2013	2-28-2013	2-28-2013	*http://wdr.water.usgs.gov/wy2012/pdfs/09380000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09381800.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09382000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09402000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09402300.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09402500.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09403850.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09404115.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09404200.2012.pdf*

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	2013 Annual USGS Water-Data Reports	2-28-2014	2-28-2014	2-28-2014	*http://wdr.water.usgs.gov/wy2013/pdfs/09380000.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09381800.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09382000.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09402000.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09402300.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09402500.2013.pdf* http://wdr.water.usgs.gov/wy2013/pdfs/09403850.2013.pdf *http://wdr.water.usgs.gov/wy2013/pdfs/09404115.2013.pdf* *http://wdr.water.usgs.gov/wy2013/pdfs/09404200.2013.pdf*

Project B	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$539,700	$0	$51,500	$517,100	$74,070	$82,573	**$1,264,943**
Actual Spent	$603,235	$5,370	$76,430	$0	$509,546	$77,704	**$1,272,285**
(Over)/Under Budget	**($63,535)**	**($5,370)**	**($24,930)**	**$517,100**	**($435,476)**	**$4,869**	**($7,342)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Unterestimated salary, travel & training, and operating expenses in workplan.
Erroneously budgeted for cooperative agreements rather than to send funds to other USGS centers.

Project & Title			
Project C: Water-Quality Monitoring of Lake Powell and Glen Canyon Dam Releases			
Program Manager (PM)	William Vernieu	**Principal Investigator(s)** (PI)	William Vernieu, USGS GCMRC
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Project Summary

GCMRC conducts a long-term water-quality monitoring program of Lake Powell and Glen Canyon Dam (GCD) releases. This project is funded entirely by Reclamation from water and power revenues and receives no monetary support from the Glen Canyon Dam Adaptive Management Program. In addition to direct funding of the program, Reclamation also provides support in terms of laboratory analyses and field assistance.

The Lake Powell monitoring program was designed to determine status and trends in the quality of water in Lake Powell and GCD releases, determine the effect of meteorology, climate patterns, hydrology, and dam operations on reservoir hydrodynamics and the quality of water ultimately released from GCD, and provide predictions of future conditions.

Science Questions

Examination of the body of existing data from the Lake Powell water-quality monitoring program has led to the identification of various processes that affect the quality of water in Lake Powell and GCD releases. These processes dictate the movement of water through the reservoir, changes to the quality of inflows moving through the reservoir, stratification patterns, and the conditions in the reservoir forebay that dictate withdrawal patterns and the quality of releases to the downstream environment. Based on identification of these processes, the following science questions have been developed:

What factors determine the fate of inflow currents moving through the reservoir?

In most years winter inflows form density currents that move along the bottom of the reservoir. Depending on their density relative to the receiving waters of the reservoir, they will either continue to flow along the reservoir bottom displacing older water upwards to entrainment in GCD releases, or flow into intermediate layers of the reservoir, leaving the deepest water stagnant. The displacement of deep water by density currents is an important mixing process for the reservoir. Without this displacement, deep water gradually becomes depleted in oxygen and could become anoxic over time, causing problems by generating hydrogen sulfide and releasing contaminants from sediments. At this time, it is not completely understood what conditions result in a complete underflow or an interflow of these density currents.

How is reservoir and GCD release water affected by drought-induced drawdown of Lake Powell?

Distinct changes in the quality of GCD releases have been observed during times of reservoir drawdown. This primarily results in the warm surface layers of the reservoir being brought closer to the penstock withdrawal elevation, resulting in the warming of releases downstream. However, reservoir drawdown also results in the resuspension of deltaic sediment in the inflow areas. This sediment has a significant oxygen demand from decaying organic material and can severely reduce oxygen concentrations in inflow currents passing over the delta. Depending on the degree of reservoir drawdown, the volume of inflows moving across the delta, the quality of deltaic sediments, and release patterns from GCD, the water released from GCD can become hypoxic and affect fish and other aquatic life immediately below the dam.

What effect do high-flow releases have on reservoir stratification patterns and GCD release water quality?

During periods of releases above GCD powerplant capacity, water is withdrawn from GCD through the river outlet works, which bypass the GCD powerplant, drawing water from an elevation approximately 100 ft deeper in the reservoir. Depending on the time of year and stratification patterns present in the reservoir at that time, the magnitude and duration of high-flow releases, and the elevation of the reservoir, high-flow releases may evacuate large volumes of water from selected elevations in the reservoir and may act to facilitate existing mixing processes in the reservoir. Additionally, high-flow releases may result in a rapid reservoir drawdown of several feet, causing exposure and resuspension of deltaic sediments. It has been proposed that this resuspension may act to increase nutrient concentrations and facilitate primary production in these inflow areas.

How do underwater landslide deposits affect sedimentation patterns, hydrodynamics, and the quality of reservoir water?

Major landslide deposits have been observed in all of the main tributary arms of the reservoir. These most likely were formed by lubrication of clay-bearing geological formations during the early filling stages of the reservoir, causing structural failure and collapse of overlying formations, which can fill the mainchannel of the reservoir and block movement of sediment and water. This can block upstream sediment from moving downstream, effectively extending the life of the reservoir, but can also cause the stagnation of water upstream of the deposits. Two such deposits have recently been identified in the Escalante arm and can explain persistent anoxia observed in this area.

How can reservoir simulation modeling be incorporated to model processes in the reservoir to replicate past patterns, determine the relative effects of various processes on observed conditions, and predict future changes to reservoir and GCD release water quality?

Currently, reservoir simulation modelling is performed by the Upper Colorado Regional Office of Reclamation to predict future GCD release temperatures. Development of the model has not progressed substantially beyond its current use. Further enhancements to the model, use of the model by other entities to address other questions, and its increased application to simulating hydrodynamic and water-quality processes could be valuable in addressing factors affecting significant reservoir processes and prediction and evaluation of future conditions in relation to dam operations and climate change.

How will the increase in quagga mussel populations affect the plankton community structure of the reservoir and the amount of biomaterial released downstream?

Reproducing quagga mussel populations have recently been confirmed at Lake Powell and could increase dramatically in future years. These filter-feeding organisms filter large quantities of water which could have a significant impact on primary and secondary production in the reservoir. The completion of analysis of a large backlog of plankton samples will establish a pre-invasion baseline on which future impacts of mussel invasion may be compared.

Monitoring Activities

Water-quality monitoring was conducted by Reclamation from 1965 to 1996, and has been conducted by GCMRC since that time. The current program consists of monthly sampling in the forebay area immediately upstream of GCD and in the GCD tailwater, quarterly surveys of the entire reservoir, and continuous monitoring of GCD releases. Quarterly reservoir surveys are conducted within a six-day time period. Monitoring consists of vertical depth profiles of temperature, specific conductance, dissolved oxygen, pH, turbidity, and chlorophyll concentrations at up to 35 locations on the reservoir. Sampling for major ion concentration and nutrients occurs at a subset of these locations. In addition, biological samples for chlorophyll, phytoplankton, and zooplankton are collected near the surface of selected stations and near the penstock withdrawal zone in the forebay. Since 1998, longitudinal profiles of bottom elevation have been collected in the inflow areas of the reservoir to determine the distribution and movement of sediments in the reservoir.

Reservoir sampling is conducted from the Uniflite limnology vessel, which has been in use since 1970. Fuel pump problems resulted in the cancellation of a reservoir survey in June 2014. In August 2014, an engine mount failed, which resulted in the breakage of a drive shaft. The August 2014 survey and subsequent forebay surveys were completed using a National Park Service vessel. The Uniflite was repaired for use in the December 2014 survey.

Since the beginning of FY13, nine forebay surveys and four reservoir-wide surveys were conducted in addition to pre-HFE and post-HFE monitoring in November 2013 and November 2014. A reservoir survey in June 2014 was aborted because of mechanical problems. The beginning dates of these surveys are shown below.

11/06/13	forebay and pre-HFE
11/15/13	post-HFE
12/05/13	full reservoir survey
01/29/14	forebay
03/01/14	full reservoir survey
03/31/14	forebay
04/23/14	forebay
06/06/14	forebay (aborted full reservoir survey)
07/15/14	forebay
08/01/14	full reservoir survey
09/04/14	forebay
10/10/14	forebay
11/07/14	forebay
11/19/14	post-HFE
12/10/14	full reservoir survey

Data from monitoring activities consists of the results of field observations of meteorological conditions, Secchi depth measurements, and vertical depth profiling. Results from the analysis of chemical and biological samples are usually received within two months of collection. These data are entered into GCMRC's water quality database (WQDB) (Vernieu, 2014) for subsequent statistical and graphical analysis.

A major effort to improve data accessibility was initiated in 2014. This project involves the migration of the existing MS Access database to an Oracle database platform and the development of a website to serve as a clearinghouse for Lake Powell water-quality data. This website will have the capability of providing data through ad hoc queries, generated through a map-based interface, and the graphical display of various types of data. This system will generate time-series graphs of GCD release water-quality parameters, reservoir elevations, GCD discharge for selected dates; graphs of vertical depth profiles from individual locations; and three-dimensional isopleth plots of depth profiles for the entire reservoir on a single date, or for a single location through time. It is anticipated that this system will also be capable of disseminating similar data for other Colorado River basin reservoirs when fully developed.

Progress and Accomplishments

The USGS Data Series Report DS-471, Historical physical and chemical data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1964–2012 (http://pubs.er.usgs.gov/publication/ds471), was revised to include data collected from Lake Powell through 2013. This report contains the historical record of physical and chemical data collected from Lake Powell since 1965 and also describes the WQDB. The report is currently being prepared for publication by the USGS Science Publishing Network and is anticipated to be finalized in early 2015.

The publication of a biological data report describing phytoplankton, zooplankton, and chlorophyll data collected from Lake Powell from 1990 through 2009 has been delayed. The current draft is in final review and is expected to be published in early 2015. The completion of a contract for the analysis of a backlog of biological samples is expected by the end of 2014. This will result in a complete history of Lake Powell plankton data, including the initial stages of the recent quagga mussel invasion. An analysis of these data would include identifying trends in biomass and community structure of zooplankton and phytoplankton populations and identifying potential factors that affect these populations.

The data management system for Lake Powell data is in the process of being revised, with an eventual product being the development of a web-based data portal with a map-based user interface and linkage to the WQDB. Discussions have taken place between GCMRC staff and the USGS Wisconsin Science Center's Internet Mapping group, the Upper Midwest Environmental Sciences Center, and the Center for Integrated Data Analytics to provide an integrated set of tools for querying and displaying summary graphs and tables showing Lake Powell reservoir elevations and 24-month projections, GCD discharge, GCD release water quality, selected reservoir depth profiles, and isopleth figures displaying temperature, conductivity, dissolved oxygen or other parameters for the entire reservoir at a single point in time or as a time series for a given station.

Current Conditions

Hydrology - Lake Powell received 10.38 million acre feet (maf; 96 % of average) of unregulated inflow in water year (WY) 2014, significantly higher that inflows observed in 2012 and 2013 (45 and 47 % of average, respectively). Reservoir levels reached a peak of 3609.7 ft on July 9, 2014, compared to a peak of 3602.2 ft in 2013. At the end of WY2014, Lake Powell's surface elevation was 3,605.5 ft with storage of 12.29 maf, or 51% of full capacity. This compares with a surface elevation of 3,591.3 ft, and storage of 10.93 maf (45 % of capacity) at the end of WY2013, an increase of 1.4 maf.

Releases for WY2014 totaled 7.48 maf, with operations under the Mid-Elevation Release Tier of the Interim Guidelines. Releases for WY2013 totaled 8.232 maf, with Lake Powell operating under the Upper Elevation Balancing Tier. A High-Flow Experiment (HFE) was conducted in November 2014, in which 37,500 ft^3/s was released for a 96-hour period and Lake Powell's surface elevation decreased by approximately 2.5 ft.

Operations for WY15 will fall under the Upper Elevation Balancing Tier with a total annual release volume of 9.0 maf projected after an April 2015 adjustment. Based on the 24-month study of October 8, 2014, Lake Powell is projected to reach a minimum surface elevation of 3,597.08 ft at the end of March 2015, and a maximum surface elevation of 3,625.39 ft at the end of June 2015. The surface elevation at the end of WY14 is projected to be 3,613.86 ft.

Glen Canyon Dam Release Temperature - Glen Canyon Dam release temperatures from 2003-2010 were above normal due to low reservoir elevations resulting from extended drought conditions in the Upper Colorado River Basin. In 2012 and 2013, release temperatures were representative of long-term average temperatures observed from 1990-2002, because of relatively higher reservoir elevations and low inflow volumes. Because of lower reservoir conditions in 2013 and 2014, combined with a higher inflow volume in 2014, release temperatures returned to above-average levels during the summer and fall of 2014, with temperatures exceeding 14°C on November 1, 2014.

Lake Powell Limnology - A winter underflow density current was observed in spring 2014, which caused a significant freshening of hypolimnetic dissolved oxygen concentrations near Glen Canyon Dam. This process happens most years, but did not happen in 2006, 2009, or 2012. Lake Powell reached a minimum elevation of 3,574.18 ft on April 13, 2014, less than 20 ft higher than the minimum level reached in 2005. This caused further downstream movement of the sediment deltas. Because of this, the points at which inflow tributaries met the reservoir were the farthest downstream on record since the early filling stages of the reservoir. No significant changes to downstream release patterns or stratification within Lake Powell were observed as a result of the November 2013 and November 2014 HFEs. The National Park Service detected larval quagga mussels in Lake Powell in the fall of 2012, and adult quagga mussels were discovered in Lake Powell marina areas in early 2013. Data from a backlog of biological samples is expected to be published in 2015, which will form a baseline to document the effects of this invasion.

Program Support

A five-year agreement for continued support of the Lake Powell water-quality monitoring program was developed with Reclamation in 2013 and provides funding for staff, supplies and maintenance of the Uniflite vessel and other equipment, and sample analysis. Dale Robertson of the USGS Wisconsin Science Center continues to collaborate on this project, assisting with data interpretation, development of an interpretive synthesis of the published data, and coordination of web-based data portal for Lake Powell water quality. In addition to direct funding of the Lake Powell program, Reclamation also provides approximately $180,000 in in-kind support for sample analysis and field assistance.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentations	Biological Data for Water in Lake Powell and from Glen Canyon Dam Releases, Utah-Arizona, 1990–2009		10/30/2013		North American Lake Management Society 33rd International Symposium, San Diego, CA
Presentations	Lake Powell after Fifty Years - Patterns and Processes		3/29/2014		Grand Canyon River Guides Training Seminar, Hatchland, AZ
Reports	Vernieu, W.S., Historical physical and chemical data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1964–2013(ver. 3.0, expected February 2015)	FY2014		February 2015	Vernieu, W.S., Historical physical and chemical data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1964-2013 (ver. 3.0, expected February 2015: U.S. Geological Survey Data Series 471, 55p., http://pubs.usgs.gov/ds/471/.
Reports	Biological Data for Water in Lake Powell and from Glen Canyon Dam Releases, Utah-Arizona, 1990–2009	FY2014		March 2015	In final review.

Project C	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$185,100	$7,400	$34,800	$0	$0	$25,783	**$253,083**
Actual Spent	$116,703	$4,398	$30,073	$0	$0	$17,148	**$168,321**
(Over)/Under Budget	**$68,397**	**$3,002**	**$4,727**	**$0**	**$0**	**$8,635**	**$84,762**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Delays hiring personnel.

Project & Title			
Project D: Mainstem Humpback Chub Aggregation Studies and Metapopulation Dynamics			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	William Persons, USGS GCMRC; David L. Ward, USGS GCMRC; D.R. VanHaverbeke, USFWS; Scott Bonar, USGS/U. Arizona; Karin Limburg, State U. New York
Email	*svanderkooi@usgs.gov*		
Telephone	(928) 556-7376		

Summary of FY13–14 Goals and Objectives

The overall objective of Project D was to yield a more rigorous monitoring program to better understand the ecology of humpback chub aggregations in Grand Canyon, including whether downstream reaches in Grand Canyon are capable of supporting self-sustaining populations of humpback chub. In August 2004, the Glen Canyon Adaptive Management Program (GCDAMP) Adaptive Management Work Group identified that the Priority 1 question for the program was "Why are humpback not thriving, and what can we do about it? How many humpback chub are there and how are they doing." Whereas several other monitoring projects address humpback chub abundance, recruitment and survival in and near the Little Colorado River (LCR), this project was intended to provide information regarding the abundance and status and trends of humpback chub at aggregations not associated with the LCR.

The project had three elements: (D1) **i**mproving aggregation sampling to develop more rigorous approaches to monitor aggregations, (D2.1) determining natal origins of humpback chub using otolith microchemistry, and (D2.2) determining adult reproductive condition and reproductive potential of humpback chub using ultrasonic imaging and Ovaprim®. Element D1 was intended to develop abundance estimates at aggregations and to continue long-term monitoring to support the Non-Native Fish Control Environmental Assessment and associated Biological Opinion.

Project D Science Questions

Project Element D1 was designed to make progress toward addressing the following questions:

- *GCDAMP Priority Questions:* Why are humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing.

Project Element D1 was also designed to contribute towards addressing the following core monitoring information need:

- *Core Monitoring Information Need:* Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the Colorado River.

Project Elements D2.1 and D2.2 were designed to make progress toward addressing the following questions:

- *Strategic Science Question:* To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?

- *Science Advisors Summary Science Question:* What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young of year and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

Specifically, element D2.1 planned to investigate the use of otolith isotope ratios and microchemistry to identify natal origins of humpback chub captured in the mainstem; and element D2.2 used ultrasonic imaging to evaluate egg maturation of humpback chub captured in the Little Colorado River, the mainstem Colorado River, and Shinumo and Havasu Creeks.

Monitoring Activities

In FY14, the following monitoring activities occurred in Marble-Grand Canyon:

July 19 – August 4, 2014. Fish were sampled by hoopnet and trammel net at three areas associated with known aggregations and at 12 areas not associated with aggregations. Hoopnets were fished at all 15 areas, trammel nets were only fished at four areas.

September 5 – September 22. Fish were sampled by hoopnet and trammel net at seven locations associated with known aggregations and at two locations not associated with aggregations. Hoopnets were fished at seven locations and trammel nets were only fished at two locations. Ultrasonic images were taken of adult humpback chub larger than 200 mm total length during both sampling trips.

Progress Answering Science Questions

In this section we summarize progress made in answering the Project D science questions. Additional details are included in project elements listed below and will be included in a final report in preparation.

Project element D1 has only partially succeeded in answering the questions "*Why are humpback not thriving, and what can we do about it?*" and *"How many humpback chub are there and how are they doing?*".

Data collection has been completed, and analysis of these data is ongoing. There is evidence that abundance of humpback chub has increased in the last decade, with population estimates ranging from approximately 6,000 to 12,000 adults (Van Haverbeke and others, 2013; Yackulic and others, 2014). However, we were unable to generate abundance estimates for specific aggregations by sampling during two trips per year. Our attempt to use a river-wide pooled capture probability to estimate abundance from catches did not withstand critical peer review. We examined catch rates (catch per unit effort) since 1990 at aggregations and non-aggregation locations and found an increase in catch rates during 2010-2013 over 1990-1993 and 2002-2006 (Persons and others, *in review*). We also evaluated translocations to Shinumo and Havasu Creeks as a management action to increase abundance of humpback chub in the mainstem Colorado River. Translocated humpback chub comprised approximately 70% and 35% of the total catch of humpback chub near Shinumo and Havasu Creeks respectively, suggesting that translocations are contributing to humpback chub abundance in the mainstem. (Fig. 1). In addition, two fish stocked in Shinumo Creek have returned to the LCR and were detected by passive integrated transponder (PIT) tag antennas. Project D1 has also contributed information about the distribution of humpback chub in the mainstem Colorado River. The discovery of large numbers of adult chub near RM (River Mile) 35 suggests the possibility of a new “aggregation”, or expansion of the 30-Mile aggregation. In addition, based on sampling at areas not associated with aggregations, chub are more widely distributed in the mainstem than was detected during previous decades (Figs. 2, 3).

Project element D2.1was intended to address questions “*To what extent are adult populations of native fish controlled by…spawning and incubation in the mainstem*” using otolith microchemistry and isotope ratios. Unfortunately we have been unable to deliberately collect and preserve young-of-the-year humpback chub from the mainstem because of permitting and tribal consultation issues to help address this question. We have redirected this effort to examine surrogate species and water samples from select tributaries to evaluate if those tributaries have unique chemical signatures that might be used in the future to identify humpback chub spawned in those locations. We are also coordinating with Grand Canyon National Park and BioWest, Inc. to properly preserve any humpback chub which are accidently killed during razorback sucker sampling activities in western Grand Canyon during 2015 so that their otoliths can be extracted for analysis.

Project elements D2.1 and D2.2 also address the GCDAMP Science Advisors summary science questions: “*What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, adult maturation?*”

Ultrasonic images of several hundred adult humpback chub from many locations in the mainstem, as well as in the LCR and Havasu and Shinumo Creeks, indicated that adult female humpback chub are able to produce eggs in the mainstem Colorado River. In 2013 approximately 33% of humpback chub examined from the mainstem Colorado River, 52% of chub examined from the Little Colorado River, and 23% of chub examined from Havasu Creek were females with eggs. In addition, during 2013 and 2014, three female humpback chub which expressed eggs were captured near the 30-Mile aggregation and one was collected near Pumpkin Springs (RM 215) (GCMRC unpublished data).

Summary of Reports and Products

The Biennial Work Plan for FY13–14 listed the following reports and publications from our Project D work:

	PRODUCTS/REPORTS				
Element	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
D1	Capture probability estimates to allow inferences about abundance estimates to be drawn from a long-term monitoring program of catch-per-unit.	FY13 and FY14	June 2013		USGS Open File Report submitted for external review. Methods using pooled capture probabilites were rejected by reviewers.
D1	Catch per unit effort estimates at four aggregations (30 mile, LCR, Shinumo	FY13 and FY14	Nov. 2013 and Nov. 2014		Data have been entered and preliminary analysis is

	PRODUCTS/REPORTS				
Element	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	Creek and Havasu Creek).				complete.
D1	Catch per unit effort estimates at four aggregations (Shinumo Creek, Havasu Creek, Middle Granite Gorge, Pumpkin Springs)	FY13 and FY14	Nov. 2013 and Nov. 2014		Data have been entered and preliminary analysis is complete.
D1	Estimates of humpback chub abundance at mainstem aggregations exclusive of the LCR aggregation.	FY13 and FY14	Nov. 2013		Abundance estimates were generated but were deemed unsuitable for publication.
D1	Long-term monitoring plan and protocols to guide future, cost-effective monitoring program published in the peer reviewed literature.	FY14		March 2015	In preparation.
D1	One Administrative report	FY14		January 2015	Results presented at Desert Fishes Council annual meeting, Flagstaff, AZ November, 2013
D1	One article submitted to a peer review journal.	FY14		Dec. 2014	First submission was rejected, working on second submission, Persons and others, in preparation
D2.1	Final report and recommendation for use of otolith microchemistry and isotope ratio techniques as part of long term monitoring	FY14		FY15	Delayed due to lack of specimens to examine.
D2.1	Dissertation with a chapter as a peer review publication detailing use of techniques to identify natal origins of humpback chub from the mainstem Colorado River downstream of the LCR.	FY14		FY15	Delayed due to lack of specimens to examine.

	PRODUCTS/REPORTS				
Element	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
D2.2	Final report/MS thesis chapter suitable for publication presenting results of Ultrasound and Ovaprim studies.	FY14		FY15	Results presented at Desert Fishes Council annual meeting, Flagstaff, AZ November, 2013. Additional field season needed to implement Ovaprim studies.

Project D	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$57,700	$1,000	$13,100	$185,400	$0	$13,706	**$270,906**
Actual Spent	$61,929	$15	$719	$166,595	$43,398	$12,106	**$284,762**
(Over)/Under Budget	**($4,229)**	**$985**	**$12,381**	**$18,805**	**($43,398)**	**$1,600**	**($13,856)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
PIT tags purchased by BOR. Funds were suballocated to the USGS Cooperative Research Unit rather than the University as a Coop.

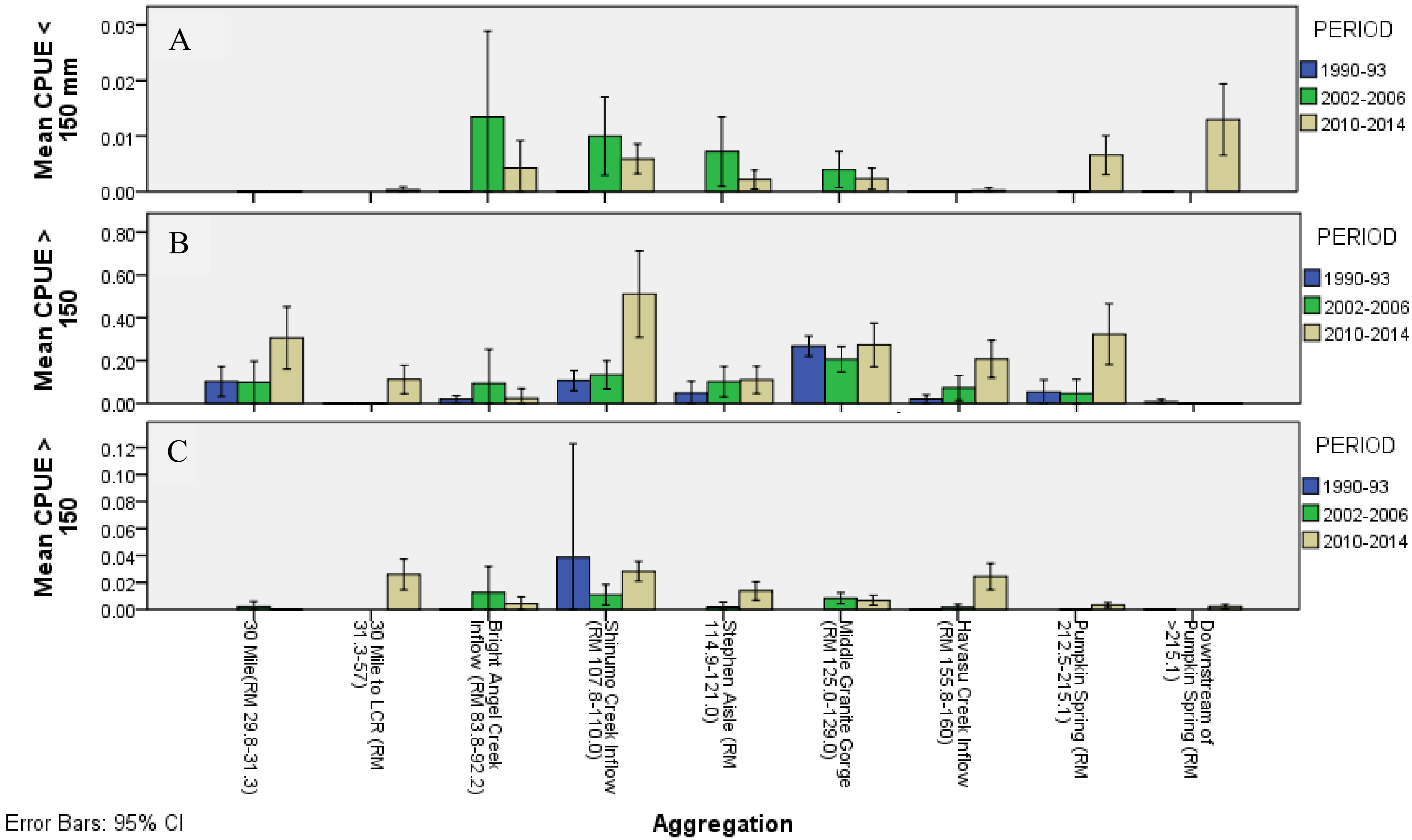

Figure 1. Mean catch per unit effort (CPUE) of humpback chub < 150 mm TL per hour for hoop net (Panel A) and CPUE of humpback chub ≥ 150 mm TL per hours for hoop net (Panel B) and trammel net (Panel C) at eight humpback chub aggregations, 1990-2013. Error bars represent 95% confidence intervals of the mean.

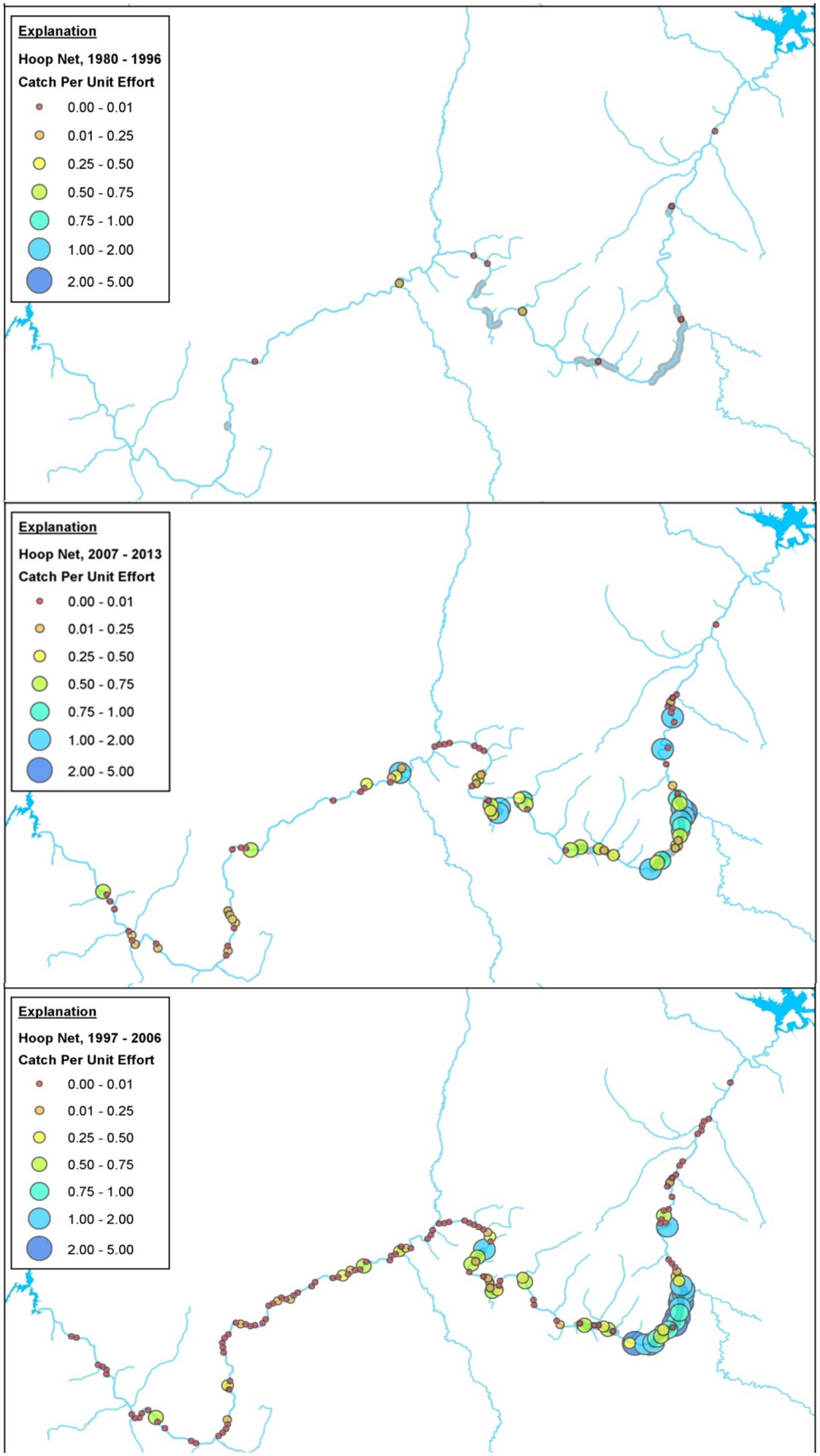

Figure 2. Mean catch per unit effort of humpback chub by hoop net, 1986-1993, 1997-2006, and 2007-2013.

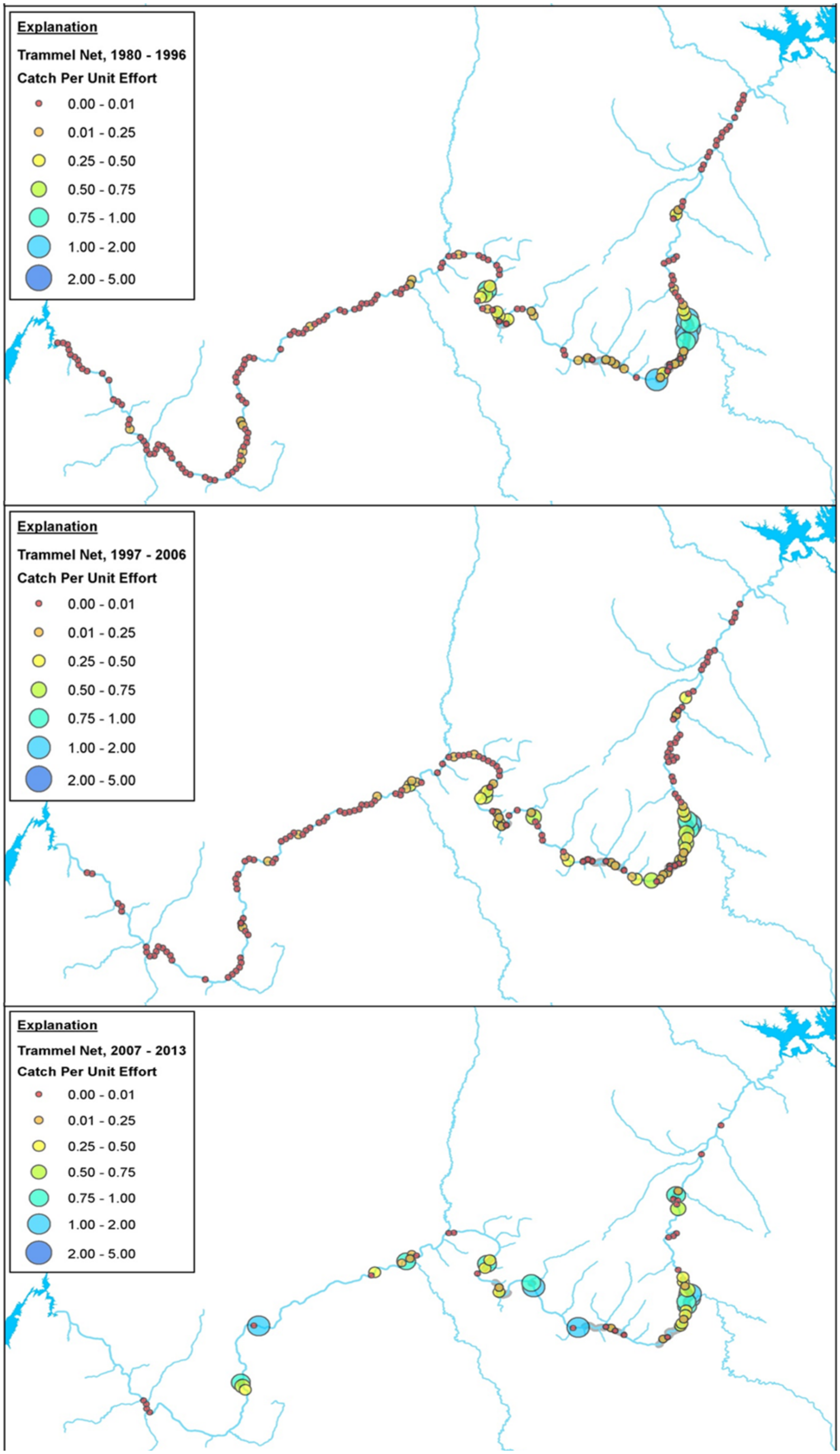

Figure 3. Mean catch per unit effort of humpback chub by trammel net, 1986-1993, 1997-2006, and 2007-2013.

Project &Title			
Project E: Humpback Chub Early Life History in and Around the Little Colorado River			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Charles Yackulic, USGS GCMRC; Theodore Kennedy, USGS GCMRC; Colden Baxter, USU; Bill Pine, UF; Dennis Stone, USFWS; Craig Stricker, USGS; D.R. VanHaverbeke USFWS; David Walters, USGS; Rich Wanty, USGS; Mike Yard, USGS GCMRC
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The goals of this project are to:

1. estimate growth, survival, and movement of juvenile humpback chub in the Little Colorado River (LCR) by marking young-of-year humpback chub each year in the LCR in July,
2. describe food web structure and assess the potential for food limitation within the LCR, and
3. conduct data analysis and modeling that will integrate findings from the above efforts and ongoing standardized monitoring to determine the relative roles of LCR hydrology, intraspecific and interspecific interactions, and mainstem conditions in humpback chub juvenile life history and adult recruitment.

We have made significant progress with respect to all of these goals and have communicated many of these results through presentations and contributions to modelling efforts for the Long Term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS) process and through manuscripts that are already published (e.g., Yackulic et al., 2014), in the final stages of review (Dzul et al., in press), or in preparation (e.g., temperature/trout modelling – Yackulic et al.). While we had hoped to conclude foodbase data collection in FY13–14, the start of this project was delayed. However, we expect results from this project to be available early in the FY15–17 working period. No peer-reviewed publications have been produced from the food base work yet; however, we still expect multiple publications will result from this effort. We have produced four peer-reviewed publications (Yackulic et al., 2014; Dodrill et al., 2014, Dzul et al., in press; Finch et al., in review) as part of project element E.3 despite having to make large unanticipated contributions to the LTEMP EIS modelling effort.

Some of the specific questions we addressed with this project (in italics), and the associated progress are:

1. *To what extent do survival and growth in the LCR aggregation vary annually and spatially?*

   Yackulic et al., 2014, Dodrill et al., 2014, Finch et al., in review and Dzul et al., in press address different aspects of question 1 in different parts of the system. Yackulic focuses on gross differences between the LCR and Colorado River across sizes, but ignores interannual variability, Dodrill focuses on habitat selection by chubs in the mainstem, Finch focuses on temporal variation in juvenile survival in the Juvenile Chub Monitoring (JCM) reach, and Dzul focuses on temporal and spatial variation in sub-adult growth and survival in the LCR. In addition, we have provided information at the GCMRC Annual Reporting meeting each year to indicate that survival declined between 2009–12 and remained low in 2012–13. Survival estimates will be presented at the January 2015 Annual Reporting meeting once all the data have been quality checked.

2. *What are the drivers of observed variation in survival and growth?*
   Dzul et al. (and Van Haverbeke et al.) discuss the importance of flooding in the LCR, and modelling to support the LTEMP process. Yackulic et al. (currently in preparation) addresses the roles of temperature and trout in driving growth and survival in the JCM reach.

3. *To what extent does outmigration of humpback chub from the LCR vary over time?*
   Multiple lines of evidence suggest outmigration rates vary considerably and have been low in the last two years. We now have the data to make very good estimates for the last two years; these estimates will be included in Yackulic et al. (in preparation). With additional sampling planned for FY15–17, we believe we will have a much better understanding on this important population process in the next few years.

The main foci of activities in FY13–14 were collecting new data in the LCR, managing humpback chub data collected through the Natal Origins/Juvenile Chub Monitoring project (Project Elements F.3 and F.6), and analyzing existing data to better understand humpback chub population dynamics. We have now undertaken two pre-monsoon (late-June/early-July) trips to mark juvenile humpback chub in the LCR system-wide (Project Element E.1) in order to inform estimates of juvenile recruitment and outmigration. We undertook one additional fish diet trip and completed five invertebrate sampling trips to better understand seasonal and spatial variation in benthic and emergent insect densities in the LCR (E.2). These trips occurred concurrent with humpback chub sampling as part of Project Element E.1 or alongside US Fish and Wildlife Service (USFWS) humpback chub sampling trips (Project Element F.4.1). Substantial progress was also made in understanding and modelling humpback chub population dynamics in and around the LCR, including work to support the LTEMP EIS process—especially modelling of the impacts of temperature and trout on humpback chub vital rates.

In July of 2013 and 2014, three teams completed two passes of the Little Colorado River over a 10-day period using multiple gears. In 2013 2,406 juvenile chub (40 – 99 mm) were marked with visual elastomer tags (VIE) as part of this effort and in 2014, 2,460 juvenile chub were marked. In both years, juvenile chub were found throughout the sampled area, but were less common in the upper portion of the sample river (i.e., Salt camp). The majority of the marked fish were between 40 and 60 mm and the average total length of juvenile chub was 50.3 mm in 2013 and 56.3 mm in 2014. While we are still analyzing data, a preliminary analysis based on recaptures by the Natal Origins/Juvenile Chub Monitoring and USFWS monitoring in the LCR suggests lower rates of outmigration to the Colorado River between July and September than was previously estimated using recapture data for fish marked at Boulder's Camp alone from 2009–11. We estimate there were 14,000 juvenile chub in 2013 and 11,000 in 2014, however, these results are also preliminary.

In 2014, cooperators from Idaho State University completed the last of 6 fish diet studies for the entire fish assemblage in the LCR. Diet sampling encompassed the entire LCR fish assemblage (i.e., humpback chub, bluehead and flannelmouth suckers, speckled dace, channel catfish, red shiner, fathead minnow, common carp, plains killifish, rainbow and brown trout). To date, approximately half of the **367** fish diet samples have been processed. Diet studies will be published in a Masters Thesis in December 2015, with additional journal publications to follow.

Building upon preliminary aquatic insect data collected in July 2013, we initiated more intensive studies on the invertebrate assemblage throughout the LCR in 2014. Specifically, sticky traps and light traps used to catch adult aquatic insects and benthic kick net samples to collect aquatic larvae were deployed throughout the LCR from Blue Spring to the Confluence in April, May, June, September, and October by GCMRC personnel, including a post-doctoral researcher who was hired to assist with Project E in May 2013. Data from 2013 indicated that densities of adult aquatic insects declined along a downstream gradient in the LCR from Salt Camp to Boulders Camp. To date, approximately 800 samples (representing thousands of insects) have been collected, with most of the sample lab processing expected to be completed in early 2015. Preliminary qualitative analysis indicates that this pattern may also hold for 2014, with particularly high densities and diversities of invertebrates collected at sites upstream of Chute Falls. Sampling will continue on a similar schedule in 2015 to build a more robust, inter-annual dataset

In FY13–14 we published one study of humpback chub population dynamics in the LCR aggregation focusing on gross differences in survival and growth between the Colorado River and the LCR over the period 2009-12, as well as movement patterns between these areas (Yackulic et al., 2014). This analysis was synthesized data collected by USFWS monitoring efforts in the LCR, the Near Shore Ecology (NSE) project (see GCMRC FY11–12 workplan) and data collected in 2012 by the Natal Origins/Juvenile Chub monitoring project. We also have a manuscript in the final stages of review which analyzes spatial and temporal variation in abundance, survival, and growth of age-1 fish in the LCR using data collected by USFWS monitoring efforts (Dzul et al., in press). Lastly, we initiated an effort that modified the general model of population dynamics in the LCR aggregation in order to link growth and survival in the Colorado River to temperature and estimates of trout abundance. Estimates from this model were compared to historical trends and used to develop a simulation model to support the LTEMP EIS process. We plan to write a manuscript on this subject after we have re-analyzed the relationships with all of the 2014 data. In addition, we have worked with scientists of the NSE project to publish two manuscripts, one looking at densities in different habitats in the NSE/JCM study reach (Dodrill et al., in press) and the other focusing on variation in survival over time in this reach (Finch et al., in review).

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Peer-reviewed Journal Article	A quantitative life history of endangered humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival		Early 2014		Yackulic, C.B., Yard, M.D., Korman, J., and Van Haverbeke, D.R. (2014). A quantitative life history of endangered humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival. *Ecology and Evolution.*
Peer-reviewed Journal Article	Survival, growth, and movement of subadult humpback chub, Gila cypha, in the Little Colorado River, Arizona			Early 2015	Dzul M.C., Yackulic C. B., Stone D.M., and Van Haverbeke D.R. (in press). Survival, growth, and movement of subadult humpback chub, Gila cypha, in the Little Colorado River, Arizona. *River Research and Applications.*
Peer-reviewed Journal Article	Do management actions to restore rare habitat benefit native fish conservation? Distribution of juvenile native fish among shoreline habitats of the Colorado River.		Available in Early View.		Dodrill M. J., Yackulic, C.B., Gerig B., Pine W.E., Korman J., and Finch C. (2014). Do management actions to restore rare habitat benefit native fish conservation? Distribution of juvenile native fish among shoreline habitats of the Colorado River. *River Research and Applications.*
Peer-reviewed Journal Article	Assessing juvenile fish population demographic responses to a steady flow experiment in a highly regulated large river ecosystem: A test in the Colorado River below Glen Canyon Dam.			Early 2015	Finch C. G., Pine W.E., Yackulic C.B., Yard M., Dodrill M.J., Gerig B.S., Coggins L.G., and Korman J. (in press). Assessing juvenile fish population demographic responses to a steady flow experiment in a

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					highly regulated large river ecosystem: A test in the Colorado River below Glen Canyon Dam. *River Research and Applications.*
Presentation	Spatial and temporal variation in vital rates of an endangered fish in a desert stream. Ecological Society of America. Sacramento, CA.		Aug. 2014		Presented by Dzul at Ecological Society of America meeting.
Presentation	A quantitative life history of humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival		Nov. 2013		Presented by Yackulic at Desert Fishes Council.
Presentation	Variation in vital rates in a partial migratory system in a modified river network: Humpback chub in the lower Colorado River		May 2013		Presented by Yackulic at Euring Analytical Conference (Mark-recapture conference)
Presentation	Disentangling residency and migration in a partial migratory system where detection is much less than one		Aug. 2013		Presented by Yackulic at Ecological Society of America meeting.
Presentation	Assessing variation through space and time in the vital rates of humpback chub in the Little Colorado River		Nov. 2013		Presented by Dzul at Desert Fishes Council.
Presentation	A native fish capitalizes on allochthonous resources delivered by		May 2014		Presented by ISU student Behn at Joint Aquatic Science Meeting.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	seasonal, scouring floods in a desert river				

Project E	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$226,900	$5,900	$25,800	$36,100	$77,200	$30,416	**$402,316**
Actual Spent	$238,767	$8,890	$8,004	$11,520	$70,956	$29,345	**$367,483**
(Over)/Under Budget	**($11,867)**	**($2,990)**	**$17,796**	**$24,580**	**$6,244**	**$1,071**	**$34,834**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Additional staff hired to meet additional workload caused by sequestration related hiring delays in FY13.
PIT tags purchased by BOR.
Coop to Idaho State not funded until Nov. 2014.

Project & Title			
Project F: Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and the Lower Little Colorado River			
Program Manager	Scott VanderKooi	**Principal Investigators**	William Persons, USGS GCMRC; Charles Yackulic, USGS GCMRC; Luke Avery, USGS GCMRC; David Rogowski, AZGFD; Josh Korman, Ecometric; Kirk Young, USFWS; Dana Winkelman, Col. State Univ.; Brian Healy, GCNP
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Project F, "Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and the lower Little Colorado River" is comprised of 15 elements and encompasses monitoring of fish, anglers, aquatic invertebrates, benthic algae and primary productivity. Project F also includes stock assessment and estimating humpback chub abundance, detecting rainbow trout movement, and sampling fish stomach contents and invertebrate drift. During 2014 there were four collaborative fish monitoring river trips and four natal origins/juvenile humpback chub monitoring trips. There were also four Little Colorado River monitoring trips and one translocation trip.

Summary of FY13–14 Goals and Objectives

The overall objective of Project F is to provide long-term monitoring data to the Glen Canyon Dam Adaptive Management Program (GCDAMP).

Two recent Environmental Assessments and an associated Biological Opinion, as well as the GCDAMP 2013-2014 Work plan and Budget (Bureau of Reclamation and U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2010; Bureau of Reclamation, 2011; U.S. Fish and Wildlife Service, 2011), mandate monitoring the status and trends of adult humpback chub in the Little Colorado River (LCR) near the confluence, in the mainstem Colorado River (see Mainstem Humpback Chub Aggregation, Project D), and at areas where humpback chub have been translocated. The Biological Opinion defines triggers to determine when nonnative fish control will take place near the LCR. Triggers are related to the abundance of adult and juvenile humpback chub, survival rates of juvenile humpback chub, abundance of rainbow trout and brown trout, and river temperature. The following monitoring projects contribute data and information required by the Environmental Assessments and Biological Opinion to determine if elements and conditions of the trigger are met.

Project F Science Questions

This project directly addresses the following goals identified by the GCDAMP:

- **Goal 2:** Maintain or attain a viable population of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats.

- **Goal 4:** Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.

In August 2004, the GCDAMP Adaptive Management Work Group reviewed these goals and identified priority questions. This project addresses the top priority question:

- **Priority 1:** Why are humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing?

In this section we summarize progress made in answering the Project F science questions. Additional details are provided in the project element (F.1–F7.4) summaries below.

Project Element F.1 System Wide Electrofishing
David Rogowski, Fishery Biologist, Arizona Game and Fish Department

Goals and Objectives:
The primary goal of the System Wide Electrofishing project is to monitor the status and trends of native and nonnative fish that occur in the Colorado River ecosystem via boat electrofishing from Lees Ferry to Lake Mead. Lees Ferry monitoring (Glen Canyon Dam to Lees Ferry) is discussed in a different subsection below (F.2.1). The purpose of this program is to obtain a representative sample of the fish community within the Colorado River. Results (species composition and relative abundance measured as catch per unit effort (CPUE)) from our surveys can be used to interpret trends in abundance and distribution of native and nonnative fish within this reach.

Science Questions:

- **SSQ 1-8.** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?
- **CMIN 2.4.1**. Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River.
- **CMIN 2.6.1.** Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.

Monitoring activities funded (boat electrofishing trips):

- Downstream trip I: 3-16 April 2014, 239 sample sites
- Downstream trip II: 24 May – 6 June 2014. 213 sample sites
- Fall Diamond Creek downstream trip: 20-24 October 2014, 95 sample sites

Summary of progress:
In 2014 we completed three mainstem sampling trips, with 547 sites sampled and 6,244 fish captured. A stratified random sampling approach with a slight modification was used in 2014 to obtain a better representation of the river's fish community. Specifically, sample site selection was modified to improve spatial distribution. In addition, we utilized the same 250-m sample sites as other cooperators and researchers. From this sampling approach we obtain a representative sample of the fish community that is susceptible to electrofishing. Channel catfish are generally not sampled

adequately using electrofishing, thus angling is used to capture catfish. Similarly adult humpback chub are also not very susceptible to electrofishing, and as other project elements monitor humpback chub, this project does not address humpback chub distribution and abundance. Our fall sampling trip from Diamond Creek downstream to Pearce Ferry was affected by high turbidity levels (~500 NTUs) in 2014. Additionally, a new contract for boatmen may have affected our results as most boat operators in 2014 had little to no experience electrofishing.

Summary of trends:

Nonnative rainbow trout continue to dominate the fish community within Lees Ferry and Marble Canyon reaches of the Colorado River and begin declining in abundance (e.g. lower CPUE) near the Little Colorado River confluence. Native flannelmouth sucker and bluehead sucker begin dominating the fish community downstream of the confluence with the Little Colorado River. In general, catch rates for most fish species remained stable over the past five years, with the exception of bluehead suckers. Bluehead sucker CPUE has significantly declined over the past five years, after increasing from 2002 to 2010. The reasons for the decline are unknown, although it should be noted that electrofishing may not adequately sample the bluehead sucker population.

Reports and products:

- Annual Report for 2013 submitted to GCMRC, annual report for 2014 is in preparation and will be submitted in winter 2015.
- 2014 trip reports completed and submitted to GCMRC
- Data from each river trip was compiled and submitted to GCMRC as a separate MS Access database file
- Abstracts submitted to present at the AZ-NM American Fisheries Society Joint Annual Meeting in 2015

Project Element F.2.1. Rainbow Trout Monitoring in Glen Canyon

David Rogowski, Fishery Biologist, Arizona Game and Fish Department
Lisa Winters, Fishery Biologist, Arizona Game and Fish Department

Goals and Objectives:

The goal of the Rainbow Trout Monitoring in Glen Canyon project is to monitor the status and trends of rainbow trout abundance and distribution in the Colorado River reach between Glen Canyon Dam and Lees Ferry via boat electrofishing to obtain a representative sample of the fish community within the reach. The general objectives are to monitor the trout fishery to determine status and trends in relative abundance (catch per unit effort), population structure (size composition), distribution, reproductive success, growth rate, relative condition (Kn) and overall recruitment to reproductive size in response to Glen Canyon Dam operations. In addition, we conduct one night of nonnative sampling in July within this reach to monitor nonnative species.

List of general and strategic science questions (SSQ), core monitoring information needs (CMIN), research information needs (RIN):

- **CMIN 4.1.2.** Determine annual proportional stock density of rainbow trout in the Lees Ferry reach.
- **CMIN 4.1.4.** Determine annual growth rate, standard condition (Kn), and relative weight of

rainbow trout in the Lees Ferry reach.

- **RIN 4.1.1.** What is the target proportional stock density (that is, tradeoff between numbers and size) for rainbow trout in the Lees Ferry reach?
- **CMIN 2.4.1.** Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River

Monitoring activities funded (boat electrofishing trips):

- Spring trip: 18-21 March 2014, 36 sample sites
- Summer trip: 14-18 July 2014, 55 sample sites
- Fall trip: 30 September- 3 October 2014, 40 sample sites

Summary of progress:

We completed three sampling trips in 2014, sampling 131 sites in total and capturing 4,207 fish (excluding the nonnative sampling). In 2014, we changed our sampling sites to the (stratified, random) 250-m sites that are used by other cooperators and researchers. This should improve comparisons among the different monitoring and research projects occurring in the Lees Ferry reach. Nonnative sampling in July of 2014 only revealed a few walleye close to the dam. Various mark-recapture events were conducted over the past few years to derive population estimates of rainbow trout. These mark-recapture events were discontinued as they did not produce any estimable population values for the areas sampled.

Summary of trends:

Rainbow trout continue to dominate the fish community within the Lees Ferry reach, comprising 98-99% of the catch (electrofishing). Rainbow trout have maintained a self-sustaining population since the mid-1990s. Relative abundance, as measured by electrofishing CPUE, has fluctuated greatly since AGFD began standardized sampling in 1991. Rainbow trout CPUE was the highest ever recorded in 2011-2012, but has started to decline the past two years (2013-2014). The percent of large fish in the system has declined as has the median size of reproductively active fish. In general, we believe there are more rainbow trout in the system (based on higher CPUE) than can be maintained due to a limited food base. Rainbow trout Kn during summer sampling has historically been above 1.0 (average Kn). However, the average fish condition was substantially lower for each of the three sampling events in 2014. Population size of adult rainbow trout is dependent on recruitment of young of the year fish, which is likely dependent on operations of Glen Canyon Dam (i.e., when variation in flow is reduced there are more and smaller size fish within the reach). For example, exceptional recruitment years have occurred when there were relatively steady higher flows in the spring (2008, 2011) which created shallow shoreline habit that increased survival of young of the year fish.

Reports and products:

- Annual Report for 2013 submitted to GCMRC, annual report for 2014 is in preparation and will be submitted in winter 2015.
- 2014 trip reports completed and submitted to GCMRC
- Data from each river trip was compiled and submitted to GCMRC as a separate MS Access database file
- Presentation made at Desert Fishes Council 2014 Annual Meeting in Mexico by D. Rogowski

- Abstracts submitted to present at the AZ-NM American Fisheries Society Joint Annual Meeting in 2015

Project Element F.2.2. Rainbow Trout Early Life Stage Studies
Luke Avery, Fishery Biologist, USGS/GCMRC
G.D. Foster, Logistic Support, USGS/GCMRC
Josh Korman, President, Ecometric Research, Inc.
Matt Kaplinski, Research Associate, NAU

Goals and Objectives

The Rainbow Trout Early Life Stage Study (RTELSS) was designed to detect the response of the Lees Ferry age-0 rainbow trout population to experimental nonnative fish suppression flows in years 2003-2005. The value of the information was recognized and the RTELSS has continued as a monitoring project. As a long-term monitoring project it provides a running dataset enabling detection of changes in the age-0 population and in spawning activity in response to any changes in the environment, including stochastic events and experimental flows.

Goal four of the GCDAMP states that a naturally reproducing population of rainbow trout is to be maintained to the extent practicable while minimizing impact on downstream native fish populations. Manipulation of Glen Canyon Dam discharge is one of the tools available to managers to accomplish this goal. Few experimental flows are actually designed to manage for or elicit a response in the Lees Ferry rainbow trout population. Regardless, the population does respond to changes in its environment and responses to experimental flows designed for other purposes have been detected via this and other monitoring projects. The information gathered over the course of the RTELLS enables investigators to intelligently design flow experiments that may enhance or diminish rainbow trout rearing conditions.

The Arizona Game and Fish Department is responsible for the monitoring of the adult rainbow trout population in Lees Ferry. Though this program often detects responses in the adult population similar to those in the juvenile population, it is a delayed detection, as their methods are not designed to efficiently capture smaller fish. Additionally, detection of a response in the adult population does not necessarily get at the mechanism behind the response. Monitoring of the juvenile population, as well as spawning activity, provides a clearer picture of how the rainbow trout population responds to various flow patterns. This picture becomes more complete still with information gathered from the complimentary foodbase monitoring program.

Early detection of cohort strength has proved useful in the recent past. The Rainbow Trout Natal Origins project depends largely on the detection of fish throughout Glen and Marble Canyons that are PIT tagged as juveniles in Glen Canyon. This requires a large number of fish to be tagged during fall trips designed for this purpose. With the year’s cohort strength being detected in the spring and tracked through the summer and early fall by the RTELSS, investigators have an idea of how much effort will be necessary to get out a sufficient number of tags.

Early detection of a year’s cohort strength could also provide management opportunities. To minimize downstream migration and to maximize angling opportunities, the Lees Ferry rainbow trout population must be maintained within certain maxima and minima (which are not yet fully understood). A reduction or increase of an adult population of rainbow trout will likely prove to be more difficult than a reduction or increase of a juvenile population, particularly as tools are limited. With early detection of cohort strength, and a better understanding of juvenile population response to various flow conditions, recruitment of juveniles can be either enhanced or diminished depending on the state of the current adult population.

Goals and Science Questions Addressed

The RTELSS Project was designed to directly address the following goals, scientific questions, and information needs:

- **GCDAMP Goal 4:** Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.
- **CMIN 2.4.1**. Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River.

The RTELSS indirectly addresses the following scientific questions and information needs by providing information for other projects:

- **Strategic Science Question 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

  Project element F2.2 provides information on the response of age-0 rainbow trout to GCD operations, which affects the adult population.

- **CMIN 4.1.4.** Determine annual growth rate, standard condition (Kn), and relative weight of rainbow trout in the Lees Ferry reach.

  Growth of age-0 rainbow trout is determined. Growth of juvenile fish affects overwinter survival and recruitment into the adult population.

  - **RIN 4.2.1.** What is the rate of emigration of rainbow trout from the Les Ferry reach?
  - **RIN 4.2.3.** How is the rate of emigration of rainbow trout from the Lees Ferry reach to below the Paria River affected by abundance, hydrology, temperature, and other ecosystem processes?

  Project Element F2.2 tracks abundance of age-0 rainbow trout. Rate of rainbow trout emigration may be partially driven by density of the juvenile population.

  - **EIN 2.4.1.** How does the abundance and distribution of nonnative predatory fish species and their impacts on native fish species in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

  The RTELSS project tracks responses of age-0 rainbow trout to experiments performed under the Record of Decision, unanticipated event, or other management action.

Monitoring Activities

Monitoring activities funded for FY14 include rainbow trout spawning surveys/redd counts in winter and spring and juvenile rainbow trout monitoring in spring, summer and fall. A total of 10 redd surveys were conducted in the Glen Canyon reach of the Colorado River in the months of

December through June. A total of five, two-night long electrofishing trips were conducted; one in each of the months June-September and one in November. In years 2010-2013 only four electrofishing trips were conducted with no trip occurring in June. Patterns in the population estimates led to a suspicion that the peak estimate that typically occurs in July may have occurred in June in some of those years, and so an additional trip in June was added to the protocol. The peak estimate did indeed occur in June in 2014, and so the additional trip in June will occur in future years as well.

In addition to field activities, growth analysis is conducted in the lab. Otoliths are extracted from specimens collected on each age-0 sampling trip. Age of specimens is obtained from otoliths and age to length ratios give us estimates of growth.

Progress Answering Science Questions

The RTELLS provides information that illuminates the mechanisms behind rainbow trout population fluxes. For example, with information gathered by the RTELSS we could know if a failed cohort was the result of either low spawning activity or low early survival, or we could know if a large cohort was the result of increased spawning activity and/or increased survival. By tying success or failure of a spawn or level of recruitment to Glen Canyon Dam discharge we are able to answer questions regarding the effect of Glen Canyon Dam flows on the overall population structure of rainbow trout.

Questions more directly addressed by the RTELSS are those aimed at understanding bottom-up controls of the Lees Ferry rainbow trout population. More specifically it addresses how Glen Canyon Dam discharge affects spawning success and early survival and growth. Most stakeholders are already familiar with the effects of the 2008 High Flow Experiment (HFE) and with the 2011 equalization flows. The more recent flow events are the fall HFEs that have occurred in 2012, 2013, and quite recently in 2014. It is too early to draw any concrete conclusions, but it appears that these fall HFEs may be having a positive effect on spawning activity.

The RTELSS is a monitoring program, and provides general and continuous information on the state of the juvenile rainbow trout population and provides a baseline against which to compare year to year dynamics which enables the detection of responses to any given event, particularly changes in Glen Canyon Dam discharge.

A total of ten redd surveys were conducted in FY 2014 in the months of December through June. The estimate of the number of redds created over the spawning season was 2,069. This was higher than estimates in most other years, as was the 2013 estimate of 2,668 redds created (Table 1). This is potentially in response the fall HFEs that occurred in 2012 and 2013. It should be noted, however, that similar numbers of redds were estimated for 2004, a year that did not follow a fall HFE. A similar magnitude and duration HFE occurred in November 2014, thus redd survey information collected in 2015 will provide additional data to help clarify what effects fall HFEs may have on rainbow trout reproduction in Glen Canyon.

	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Total surveys	Total redd count	Estimated # of redds
2004	1	1	1	2	2	1	2		1	11	3596	2316
2006		1	1	2	2	2	2	1		11	165	90
2007		1	1	1	1	1	1	1		7	1186	1215
2008		1	2	2	2	1	1	1		10	2741	1875
2009	1	1	1	2	2	2	2			11	3078	1713
2010			1	1	1	1	1			5	891	896
2011		1	2	1	2	2	1			9	4433	3062
2012		1	1	2	2	1	1			8	2296	1875
2013		1	1	2	2	1	1	1		9	3613	2668
2014		1	1	2	2	2	1	1		10	3471	2069
											Mean	1778

Table 1. Number of redd surveys conducted in each month of each survey year, with the total number of surveys for the year, total number of redds counted for the year, and the estimated number of redds actually created for the year.

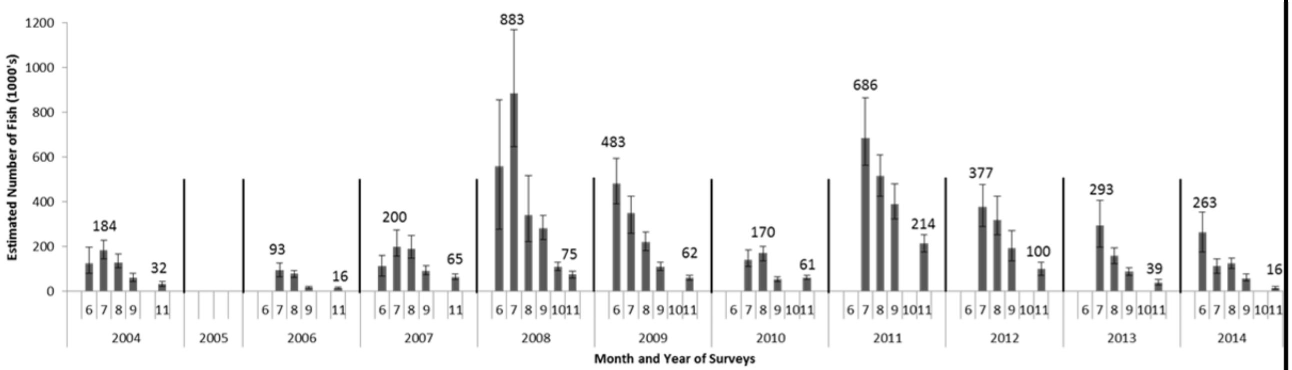

Figure 1. Population estimates with 95% confidence intervals for trips occurring in June through November for all years with available data. Not all years have data available for all months, but a minimum of July through September and November are represented for all years. The y-axis is the estimated number, in thousands, of age-0 fish. The x-axis shows the month (number) of each estimate for each year.

Juvenile rainbow trout abundance estimates have decreased yearly since 2011, a year of high equalization flows and a strong cohort year (Figure 1). Though it is possible that the fall HFE's are having a positive effect on spawning activity, there seems to be little to no effect on survival and recruitment. Mortality for the July to November period is higher for 2013 and 2014 than that of all other years except 2008. Additionally, November abundance estimates for 2013 and 2014 are similar to, or lower than, November estimates of most other years (Table 2). The November abundance estimate of 16,000 age-0 rainbow trout for 2014 was lower than all other years except 2006 (Table 2, Figure 1).

In most years the peak juvenile rainbow trout abundance occurs in July, with the exception of 2009 (June) and 2010 (August). For years 2010-2013 no juvenile sampling occurred in the month of June, so it is unknown if the peak abundance occurred in June of these years. A June trip did occur in 2014 and the peak abundance for the year did occur in June.

Year	July Population Estimate (Thousands)	November Population Estimate (Thousands)	Mortality Rate for July-November (% day^{-1})
2004	184	32	0.0061
2006	93	16	0.0063
2007	200	65	0.0043
2008	883	75	0.0086
2009	350	62	0.0070
2010	140	61	0.0034
2011	686	214	0.0043
2012	377	100	0.0055
2013	293	39	0.0074
2014	113	16	0.0074

Table 2. July (peak) and November population estimates for each year and the estimated instantaneous mortality rate for the July-November period.

Generating an abundance estimate at or near the peak for the year has implications for estimates of mortality through the year. In years without June estimates, we assume the peak abundance occurred in July and so use the difference between that estimate and the November value to estimate mortality through the year. If the peak abundance actually occurs in June, then the mortality estimate will be biased low. For example, estimated mortality for the June-November period in 2014 was 0.0088% per day. In comparison, mortality estimated for July-November 2014 was somewhat lower at 0.0074%.

Capturing the peak abundance can also have implications on mechanistic conclusions drawn. Again using 2014 as an example, without a June estimate we may have concluded hatch success was low for the year since the July abundance estimate was low despite high spawn activity. However, with a June estimate we know hatch success was not low, but mortality from June to July was high.

Otoliths extracted from specimens collected in the 2014 sampling year are still being processed so no growth information is yet available.

Summary of Reports and Products

The FY13–14 biennial work plan states that this project will produce reports presenting annual results in the context of previous results and relating early rainbow trout survival to dam operations. This is fulfilled by this annual reporting. Annual reporting is supplemented with presentation of data at various appropriate conferences.

A manuscript regarding the effects of the 2011 equalization flows was submitted to the North American Journal of Fisheries Management in September. A revised manuscript was submitted in October and is currently under review.

Project Element F2.3. Lees Ferry Angler Surveys

David Rogowski, Fishery Biologist, Arizona Game and Fish Department
Lisa Winters, Fishery Biologist, Arizona Game and Fish Department

Goals and Objectives:

The cold tailwater below Glen Canyon Dam is an important recreational fishery for rainbow trout. The goal of the Lees Ferry Angler Surveys project is to monitor the status of the fishery and estimate angler use by conducting angler surveys to obtain a representative sample of the recreational angling community that utilizes this resource. AGFD uses a stratified random sampling approach to select a subset of days for interviews, and interviews both boat and shoreline anglers. Information obtained includes catch rates, gear type, species composition, harvest, and satisfaction with experience.

List of general and strategic science questions (SSQ), core monitoring information needs (CMIN), research information needs (RIN):

- **SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?
- **RIN 4.1.1.** What is the target proportional stock density (that is, tradeoff between numbers and size) for rainbow trout in the Lees Ferry reach?

Monitoring activities funded (interview days):

- 71 days of angler interviews were scheduled for 2014

Summary of progress:

In past years, selection of sample days was stratified evenly by weekday and weekend within a month (three days for each). An analysis of angler data for the last three years revealed more variation in angler use on weekends compared to weekdays. Consequently, we have changed the stratification of sample days to improve estimates of angler use statistics by shifting sampling to two weekdays per month and four weekend days per month (began in fall 2014). As of this report, we have collected data for 2014 up to the end of October. Data for November and December 2014 will be analyzed and included in our annual report, to be submitted in winter 2015.

Summary of trends:

Catch per unit effort for boat anglers for the past three years are the highest recorded since monitoring began in 1991. Note that previous to 2011, angler surveys primarily focused on boat anglers and not shore based anglers (shore-based anglers typically have lower catch rates). Each year approximately 70% of the anglers have been from Arizona and the rest from out of state (or country). We also queried anglers whether they would rather catch more, smaller trout or fewer, larger trout and consistently 75% preferred catching more fish over fewer larger fish. Additionally, the Lees Ferry fishery remains primarily a catch and release fishery with very few fish harvested. Finally, in 2013 we estimated about 7,700 angler use days for the Lees Ferry fishery. Angler use is defined as one angler fishing one day, regardless of the length of time spent that day. There has been a significant decline in angler use of the fishery since 2002, despite angler satisfaction remaining high with a score of 4.84, and 4.52 (on a scale of 1-5) for boat and shore line anglers, respectively.

Reports and products:

- Annual Report for 2013 submitted to GCMRC, Annual Report for 2014 is in preparation and will be submitted in winter 2015.
- Working with L. Bair (GCMRC-USGS) on a manuscript on economic impact of fishing at Lees Ferry based on data from angler surveys to be submitted spring 2015.

Project Element F.3. Mainstem Monitoring of Native and Nonnative Fishes near the LCR Confluence Juvenile Chub Monitoring

Michael Yard, Fishery Biologist, USGS/GCMRC
Maria Dzul, Fishery Biologist, USGS/GCMRC
Josh Korman, President, Ecometric Research, Inc.
D.R. VanHaverbeke, Fishery Biologist, USFWS

The primary goal of this project is to collect data for use in estimating state variables (abundance and occupancy) and vital rates (survival, growth, immigration and emigration) of juvenile humpback chub near the LCR confluence area (63.4 to 64.9 river mile (RM)). Sampling in the Colorado River was restricted to a ~3 km section of the river downstream of the confluence. Vital rates and abundances of smaller size classes provide a leading indicator of future adult population size and can help answer questions about the relative roles of recruitment, temperature and rainbow trout in driving humpback chub population dynamics. These data are combined with data from seasonal sampling in the LCR (April-May, September-October; Project F.4.1; and July Project E.1) and analyzed in a multistate framework (Project E.3; Yackulic et al., 2014; Yackulic et al., in prep). Upon capture, humpback chub are measured and marked following visual examination or electronically scanned for prior marks from either visual implant elastomer (VIE, < 100 mm total length) or passive integrated transponders (PIT ≥ 100 mm TL). In 2014, four mark-recapture trips were conducted (January, April, July, and September; 9 da/trip) concurrent with Natal Origin trips (Project Element F.6.) using multiple passes and a combination of gear types that include hoop nets (8-passes) and electrofishing (3-passes). In 2014, a total of 3,537 native fish were caught consisting of 422 bluehead sucker, 421 flannelmouth sucker, 2,625 humpback chub, and 69 speckled dace ; and 2,506 nonnative fish were caught consisting of 27 brown trout, 18 carp, 143 fathead minnow, 4 plains killifish, 2,294 rainbow trout, 2 red shiner, 15 black bullhead, and 3 channel catfish. For humpback chub, 1,613 new VIE tags (fish <100 mm TL) were administered as new marks, and 764 unique PIT-tags (fish ≥ 100 mm TL) were either administered as new marks or recaptured from previous trips. Future work will focus on exploring annual variation in vital rates, and movement and growth among the two river systems.

Project Element F.4.1. Annual Spring and Fall Humpback Chub Abundance Estimates in the Lower 13.6 km of the Little Colorado River

Kirk Young, Fishery Biologist, U.S. Fish and Wildlife Service
D.R. Van Haverbeke, Fishery Biologist, U.S. Fish and Wildlife Service

Goals and Objectives.

This project provides direct support to GCDAMP priority question 1: Why are humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing?

Spring and fall closed population abundance estimates provide annual estimates of abundance of adult humpback chub (≥ 150 mm and ≥ 200 mm total length(TL)), and during some years provides abundance estimates of other native fishes (Coggins and others, 2006; Coggins, 2007; Van Haverbeke, 2010; Van Haverbeke and others, 2013). The project also marks juvenile humpback chub (< 100 mm TL) with VIE tags in the fall to assist (Project E).

Science Questions.
Project F.4.1 addresses two Core Monitoring Information Needs (CMINs), and contributes toward Strategic Science Question (SSQ) 1-1.

- **CMIN 2.1.2.** Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the LCR.

Project F.4.1 determines length stratified Chapman modified Peterson closed population estimates of humpback chub (e.g., ≥100 mm, ≥150 mm, and ≥200 mm in the lower 13.57 km of the LCR during the spring and fall. The Project also determines a Chapman Petersen population estimate of age 0 humpback chub (40-99 mm) during fall.

- **CMIN 2.6.1.** Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.

This project tracks relative abundance (CPUE) of flannelmouth sucker and bluehead sucker in the LCR during spring, and during some years provides abundance estimates of other native fishes (Van Haverbeke and others, 2010).

- **SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?

This project contributes data toward modeling efforts to address SSQ 1-1.

Monitoring Activities

During 2014, four 10-day helicopter supported monitoring trips were conducted in the lower 13.6 km of the LCR. These trips occurred during April, May, September, and October.

Progress Answering Science Questions

Since 2000, a series of two-pass, closed mark-recapture efforts have been conducted in the spring and in the fall in the LCR to track the abundance and trend of humpback chub (Van Haverbeke et al. 2013). During spring 2014 the provisional estimated abundance of humpback chub ≥150 mm in the lower 13.57 km of the LCR was 7,983 (SE = 456). Of these fish, it was estimated that 5,784 (SE = 390) were ≥200 mm. These numbers indicate that the spring spawning abundances of humpback chub have remained relatively stable or have continued to increase since experiencing significant post-2006 increases (Figure 2-A). A similar post-2006 pattern for humpback chub has been seen during the fall (Figure 2-B). During fall 2014 the provisional estimated abundance of humpback chub ≥150 mm in the lower 13.57 km of the LCR was 3,956 (SE = 433). Of these fish, it was estimated that 2,266 (SE = 313) were ≥200 mm. A provisional estimate of 3,910 (SE = 1,406) humpback chub in the 40-99 mm size class was obtained for the LCR in fall 2014.

Summary of Reports and Products

Annual reports with spring and fall abundance estimates of humpback chub in the lower 13.6 km of the LCR will be submitted to GCMRC by January 31, 2015. The following trip reports and all data have been submitted to GCMRC as of the writing of this report. In addition, presentations have been given at the Arizona/New Mexico Chapter of American Fisheries Society, Colorado River

Aquatic Biologists, Society, Desert Fishes Council, and Upper Basin Aquatic Biologists meeting.

Pillow, M.J. 2014. Spring 2014 Monitoring of Humpback Chub (*Gila cypha*) and Other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report Little Colorado River 15-25 April 2014 and 13-23 May 2014. Prepared for Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fish and Wildlife Conservation Office, Flagstaff, AZ. Interagency Acquisition No. 01-3022-R1009 (Task 1), Document No. USFWS-AZFWCO-FL-14-04. 10 pp.

Stone. D.M. and M.J. Pillow. 2014. Fall 2014 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report Sept. 22-30 and Oct. 21-30, 2014. Prepared for U.S. Geological Survey Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fish and Wildlife Conservation Office, Flagstaff, Arizona. November 2014. Interagency Acquisition No. 01-3022-R1009 (Tasks 1&2), Document No. USFWS-AZFWCO-FL-15-01. 15 pp.

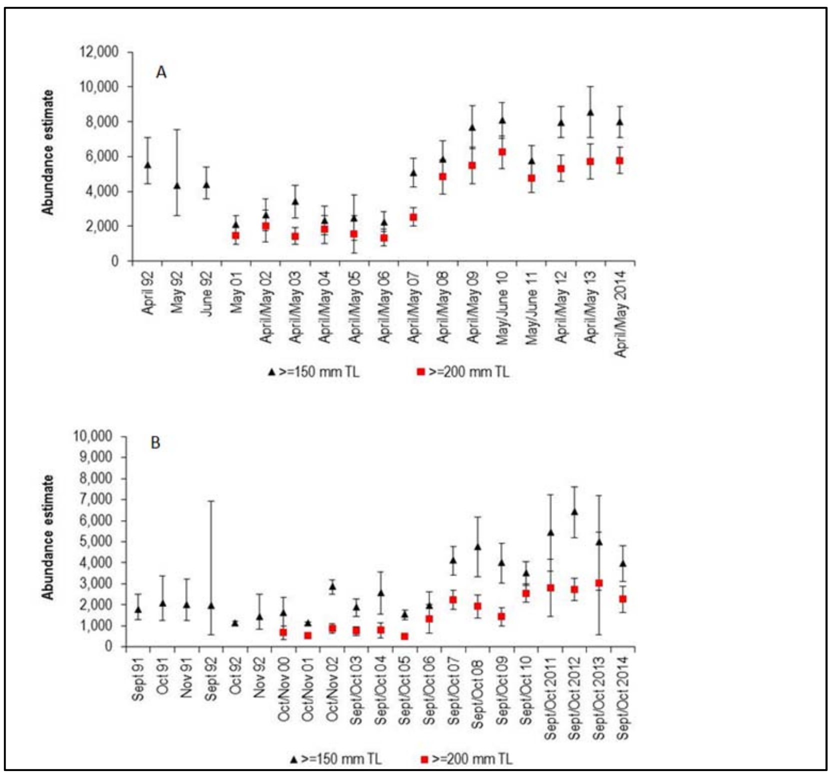

Figure 2. Abundance estimates (± 95% CI) of humpback chub ≥150 mm and ≥200 mm between 2000-2014, Little Colorado River (A) spring and (B) fall. Comparable closed abundance estimates of humpback chub ≥150 mm in the Little Colorado River during 1991 and 1992 are from (Douglas and Marsh, 1996).

Project Element F.4.2. Monitoring Native and Nonnative Fishes in the Lower 1.2 km of the Little Colorado River

David Rogowski, Fishery Biologist, Arizona Game and Fish Department
Robin Osterhoudt, Fishery Biologist, Arizona Game and Fish Department

Goals and Objectives:

The purpose of Project element F.4.2., Monitoring Native and Nonnative Fishes in the Lower 1.2 km of the Little Colorado River, is to examine the status and population trends of the fish community in this reach of the LCR, particularly the endangered humpback chub. Our goal is to obtain a representative sample of the fish community within the reach and summarize sampling effort and fishes captured (e.g. species, catch rates, length distributions). The general objective is to monitor the fish community via unbaited hoopnets during peak movement upstream to spawning grounds in the spring. These hoopnets are not random samples but are fixed sampling sites, or as near as possible depending on flow and changes in sediment. As humpback chub rely on the LCR as their primary spawning and rearing habitat, the continuation of Arizona Game & Fish Department's long term monitoring program (initiated in 1987) establishes context through which response of fishes over time can be interpreted and evaluated.

List of general and strategic science questions (SSQ), core monitoring information needs (CMIN), research information needs (RIN):

- **CMIN 2.1.2**. Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the LCR.

- **CMIN 2.6.1**. Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.

Monitoring activities funded (hoop netting):

- One helicopter supported sampling trip: 18 April to 13 May 2014

Summary of progress:

In 2014 we completed one, 26-day LCR hoopnet sampling trip. This sampling comprised 286 net-sets and 6,800 hours of effort, comparable effort to the previous decade of monitoring. We captured over 1,600 native and nonnative fish, consisting of 8 species. Nets were set at standardized locations throughout the lower 1,200 meters of the LCR to obtain a representation of the rivers' fish community that is susceptible to hoop nets. Large humpback chub may exhibit hoop net avoidance, as do large catfish and carp. Other project elements monitor humpback chub via PIT tags, and are not addressed here. Our spring sampling trip had relatively normal levels of turbidity and flow, and was therefore not negatively affected by river conditions.

Summary of trends:

Native fish species continue to dominate the lower 1,200 m fish community in 2014, with over 97% of fish caught consisting of humpback chub, flannelmouth sucker, bluehead sucker, and speckled dace. Catch rates of humpback chub were approximately 1.5 fish per 24 hours, lower than 2013, but not significantly different over the long term study. Juvenile, subadult, and adult size classes were all represented; juvenile fish (< 150 mm TL) were poorly represented compared to previous years. Flannelmouth sucker and bluehead sucker were both caught at rates around 1.4 fish/24 hours, not significantly different than in the past five years. Speckled dace catch rates continue to decline since a peak in 2006. Nonnative fish continue to be captured within the reach in small quantities; fathead minnow, red shiner, black bullhead, and rainbow trout were all present in 2014.

Reports and products:

- Annual Report for 2013 submitted to GCMRC. Annual Report for 2014 is in preparation and will be submitted in winter 2015.
- 2014 trip report completed and submitted to GCMRC.
- Data was compiled and submitted to GCMRC as a separate MS Access database file.

Project Element F.4.3. Translocation and Monitoring above Chute Falls

Kirk Young, Fishery Biologist, U.S. Fish and Wildlife Service
Dennis Stone, Fishery Biologist, U.S. Fish and Wildlife Service
Mike Pillow, Fishery Biologist, U.S. Fish and Wildlife Service

Goals and Objectives

Project F.4.3 provides direct support for the GCDAMP Adaptive Management Work Group priority question 1: Why are humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing? Project F.4.3 conducts annual monitoring in the LCR upstream of river kilometer (rkm) 13.57, and provides managers with an annual index of abundance and trend of humpback chub. In addition, Project F.4.3 is a direct attempt to conduct a conservation measure to translocate humpback chub to upstream of rkm 13.57 in the LCR (USFWS 2008, 2011), intended to increase growth rates and survivorship, expand the range, and ultimately augment the LCR humpback chub aggregation in Grand Canyon.

Efforts to translocate humpback chub upstream of Chute Falls on the LCR and to monitor their status have been ongoing annually since 2003. Approximately 6,670 juvenile (80 – 130 mm TL) humpback chub have been translocated upstream of Chute Falls to date. Beginning in 2006, two-pass mark recapture population estimates of humpback chub were conducted upstream of Chute Falls and Lower Atomizer Falls at rkm 13.57. Early results suggested rapid growth of translocated fish, although few adult humpback chub (≥ 200 mm) have been caught upstream of Chute Falls since 2009. The project is identified as a Conservation Measure in the 2011 Biological Opinion.

Science Questions

Project F.4.3 informs Core Monitoring Information Need

- **CMIN 2.1.2** Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the LCR as well as

- **SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?.

Monitoring Activities

During 2014, a trip was conducted during 13-20 May to estimate abundances of humpback chub upstream of rkm 13.57 in the LCR. Additionally during this trip, larval humpback chub were collected from the lower 13.57 km of the LCR and were successfully transported to the USFWS Southwestern Native Aquatic Resources & Recovery Center for grow out and eventual translocation into Shinumo or Havasu creeks in 2015. Finally, during the Project Element F.4.1 October monitoring trip in the lower 13.57 km of the LCR, 300 juvenile humpback chub (80-135 mm) were successfully collected and translocated to above Chute Falls, being released at rkm 16.2.

Progress Answering Science Questions

The project obtained size stratified May/June 2014 population estimates of humpback chub ≥100 and ≥200 mm in the upper LCR river corridor upstream of rkm 13.57 (Figure 3). The project also provides additional information related to size, species composition, sexual condition and characteristics, and frequency of external parasites (*Lernaea cyprinacea*), as well as physical parameters of the LCR (i.e., temperature and turbidity).

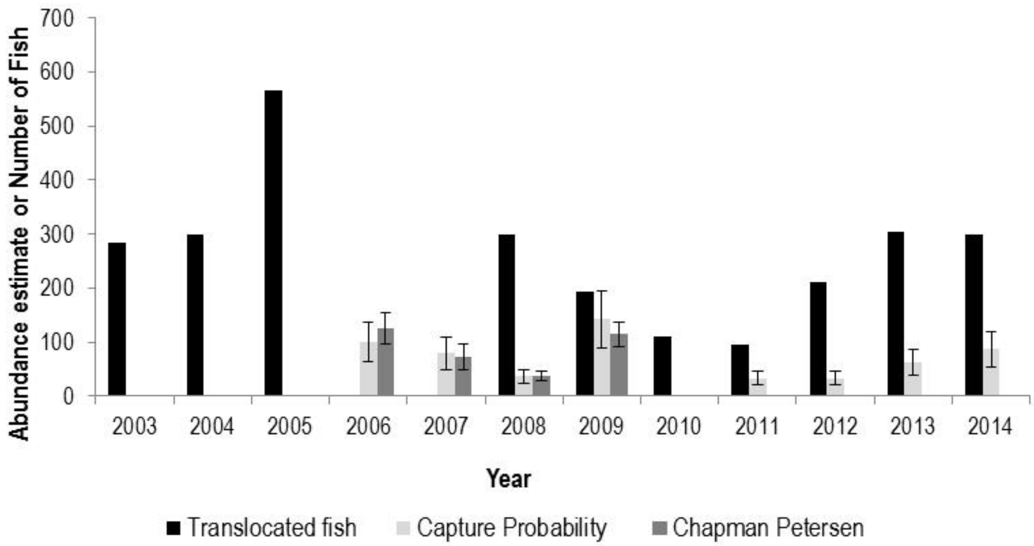

Figure 3. Numbers of humpback chub that have been translocated above Chute Falls since 2003, and abundances of adult humpback chub (≥200 mm) above Chute Falls as estimated using closed Chapman Petersen mark-recapture methods (2006-2009) and as estimated by using capture probability data (2006-2014).

Since 2006, monitoring has been conducted in the reaches of the LCR above Lower Atomizer Falls (from 13.57 to about 18 rkm) to monitor the abundances and trend of humpback chub (Van Haverbeke 2010). During May 2014, a monitoring trip was conducted to continue this effort. A total of 2,879 fish were captured, of which 345 were humpback chub, 2,529 were speckled dace, and 3 were fathead minnow. Provisional results estimated there were 140 (SE = 26) humpback chub ≥100 mm in the reach of river between 13.57 and 14.1 rkm (Figure 3). Of these fish, it is estimated that 114 (SE = 20) were ≥200. Above Chute Falls (14.1 to 17.87 km) provisional results indicated that there were 246 (SE = 54) humpback chub ≥ 100 mm. Of these fish, it was estimated that 87 (SE = 17) were ≥200 mm.

Additionally, USFWS successfully translocated 300 juvenile humpback chub to above Chute Falls in October 2014 (Figure 3). Since 2003, the project has demonstrated that humpback chub can successfully be translocated. This has greatly assisted with other translocation efforts in Grand Canyon by serving as a logistical model and by the refinement of collecting and transport methods. For example, this year larval humpback chub were collected for eventual translocation to Havasu and Shinumo creeks, which will have less impact on the population (Pine and others, 2013) and is more cost effective. Humpback chub translocated to above Chute Falls have high growth rates, and many of these individuals eventually migrate into the lower sections of the LCR. The project has also shown that humpback chub can ascend Chute Falls (as indicated by the captures five adult humpback chub that have migrated above Chute Falls), and that humpback chub may successfully spawn and offspring survive above Chute Falls (as suggested by the captures of three non-translocated age-0 humpback chub found above Chute Falls in 2007). As such, the potential still exists for establishment and successful spawning by humpback chub above Chute Falls. Most importantly, the project demonstrates that the LCR above Chute Falls successfully functions as habitat for rearing and recruitment of translocated humpback chub. Additional results on how the USFWS has answered the questions for Project F.4.3 can be found in the following trip report, or in the annual report to be submitted to GCMRC by Jan 31, 2015. Additionally, USFWS is working on submission of a manuscript treating the Chute Falls translocation and monitoring efforts.

Summary of Reports and Products

A translocation framework for Grand Canyon has been prepared and is in review: Van Haverbeke, D.R., K.L Young, and B. Healy. 2014. Translocation and refuge framework for humpback chub (*Gila cypha*) in Grand Canyon. 52 pp.

Stone, D.M. 2014. Spring 2014 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes above Lower Atomizer Falls in the Little Colorado River, Arizona. Trip Report for May 13-20, 2013 monitoring trip of translocated Humpback Chub in the Little Colorado River, Arizona. Prepared for U.S. Geological Survey Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fish and Wildlife Conservation Office, Flagstaff, AZ. Interagency Acquisition No. 01-3022-R1009 (Task 2), Document No. USFWS-AZFWCO-FL-14-03. 12 pp.

Van Haverbeke, D.R. K. Young, D.M. Stone and M.J. Pillow. *In prep*. Mark recapture and fish monitoring activities in the Little Colorado River in Grand Canyon from 2000 to 2014. Annual Report.

In addition, presentations have been given, and will continue to be given as travel permits, covering these topics at the Arizona/New Mexico Chapter of American Fisheries Society, Colorado River Aquatic Biologists, Society, Desert Fishes Council, and Upper Basin Aquatic Biologists meeting.

Project Element F.4.4. PIT Tag antenna monitoring

William Persons, Fishery Biologist, USGS/GCMRC
Dana Winkelman, Professor, Colorado State University

Summary of FY13/14 Goals and Objectives

The object of project element F4.4 was to compile and analyze data from a PIT-tag antenna system in the LCR approximately 2 km upstream from the confluence with the mainstem Colorado River. The antenna system reads PIT tags from fish as they pass the station, and data can be used to provide information on timing of movement and survival of PIT tagged native fishes.

The overarching goal of the project was to investigate answer **SSQ 1-8:** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?

Monitoring Activities

In FY14, the following monitoring activities took place in the LCR:

- May 5 – 13, site visit with scheduled USFWS monitoring trip. Installed small antennas at LCR rkm 9.05 and 8.65, checked USFWS antenna at rkm 8.68; replaced several cables and multiplexor computer at large antenna arrays near confluence.
- June 26 – July 2, site visit with GCMRC humpback chub marking trip. Repaired and maintained small antennas, replaced several cables and tuned large antenna arrays.
- October 21-31, site visit with scheduled USFWS monitoring trip. Repaired communications equipment with Tim Andrews, tuned and checked large antenna arrays, trained Luke Avery in operation of Multiplexor computers and tuning antennas.

Progress Answering Science Questions

Data from the large antenna arrays were downloaded on a regular basis to the Flagstaff GCMRC office where data were formatted and appended to the GCMRC master fish capture database. At the time of this writing there were more than 150,000 PIT-tag detections in the database which consists of more than 1,000,000 fish capture records.

PIT-tag antennas installed near the confluence of the LCR functioned well during 2014, six of the 11 large antennas performed well during the entire year (through November) two antenna were disconnected; two antennas performed well except during high flows in September, and two antennas performed poorly during most of the year. One of the two multiplexor computers was replaced during April and sent for repairs. Cables were replaced on three antennas, a bank of eight batteries was replaced, and improvements were made to the remote communications system in September.

During Jan 1 – November 18, 2014, 4,863 unique humpback chub were detected (Table 1). There were 891 fish which were not in the GCMRC database, some of which were likely trout tagged as part of the Natal Origin project (Element F.6).

Kristen Pearson, Colorado State University, completed her Master's Thesis using data from the antenna (Pearson, 2014). She modeled tradeoffs between standardized hoop net monitoring in the LCR and PIT-tag antenna detections in estimating humpback chub abundance. She reported that hoop-net sampling can be reduced and supplemented with array detections without negatively affecting estimability of adult humpback chub survival, given detection efficiency of the array remains sufficiently high. Incorporating antenna detections into standardized closed population estimates does not appear to be feasible at present, although antenna detections can contribute to other types of population estimation methods. Pearson (2014) also reported that humpback chub in the LCR do not spawn every year, and have an average breeding cycle of every 2.12 years, conditional on survival.

Products and Reports:

Pearson, K.N., 2014, Sampling methodology tradeoffs--evaluating monitoring strategies for the endangered humpback chub *(Gila cypha)* in the Little Colorado River, Arizona: Fort Collins, Colo., Colorado State University, M.S. thesis, 71 p.

Species	2009	2010	2011	2012	2013	2014	Total
Humpback chub	935	424	965	3,352	3,171	4,864	13,711
Bluehead sucker	205	76	555	1,448	1,823	1,623	5,727
Flannelmouth sucker	234	119	514	1,023	1,362	1,215	4,463
Missing species code	10	3	10	71	409	894	1,394
Channel catfish	0	0	4	6	8	10	28
Unidentified	3	0	0	13	4	7	27
Common carp	0	1	1	1	5	4	12
Brown trout	0	0	1	2	1	0	4
Flannelmouth - razorback sucker hybrid	0	0	0	1	0	1	2
Black bullhead	0	0	0	1	0	0	1
Rainbow trout	0	0	0	0	1	0	1
Total	1,387	623	2,050	5,918	6,784	8,618	25,370

Table 3. Number of unique fish detected each year at PIT-tag antennas near the LCR confluence, 2009-2014.

Project Element F.5 Stock Assessment and Age Structured Mark Recapture Model humpback chub abundance estimates
Charles Yackulic, Research Statistician, USGS/GCMRC

Reporting for Project Element F.5 has been incorporated into Project E.

Project Element F.6. Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam/Natal Origins
Josh Korman, Fishery Biologist and Statistician, Ecometric Research, Inc.
Mike Yard, Fishery Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
David Rogowski, Fishery Biologist, Arizona Game and Fish Department

In response to USFWS Biological Opinion (2012), the primary goal of this project is to estimate abundance, movement, growth, and survival of age-0 and older rainbow trout between Glen Canyon Dam and the LCR confluence area. Research and monitoring objectives are to determine the physical and biological factors responsible for trout movement (density, food, growth, turbidity, HFEs, etc.) and to quantify the extent of trout movement from Lees Ferry into Marble Canyon and the LCR confluence area. In 2013, four ‘downstream’ mark and recovery trips (January, April, July, and September; 15 days/trip) were conducted at Lees Ferry (-5.5 to -2.1 RM), House Rock (17.2 to 20.6 RM), Buckfarm (38.2 to 41.6 RM), Above LCR (60.2 to 61.2 RM) and Below LCR (63.4 to 64.9 RM). Two additional mark and recovery trips (10 days/trip) sampling the entire shoreline of Glen Canyon (-15.5 to 0.0 RM) were conducted in October and December 2013. More than 190,000 rainbow trout have been captured over 16 trips between November 2011 and September. 2014. Over 68,000 trout have been PIT tagged, and more than 8,500 of these PIT-tagged fish that were at large for at least one month have been recaptured. The large sample size allows for strong inference about movement, abundance, survival, and growth of rainbow trout over the 75 mile-long study area between Glen Canyon Dam to just downstream of the LCR confluence.

Total abundance over the entire study area was estimated to be approximately 1.5 million trout at the start of the study (April 2012) and has declined to less than 1,000,000 on the most recent trips (September 2014). Trout abundance in Glen Canyon and House Rock are extremely high with peak values of approximately 25,000 and 15,000 fish/km, respectively. Averaged across trips, more than 75% of the abundance in the study area was located in Glen Canyon and upper Marble Canyon with only 8% of the abundance near the LCR. Abundance estimates below the LCR (Reach IVb) indicate that trout numbers have exceeded the threshold level specified in Biological Opinion for eight of the 11 downstream trips conducted to date (April 2012 – September 2014), with abundance on the two most recent estimates more than two-fold higher than the threshold.

Rainbow trout abundance declined in Glen Canyon and in upper and middle Marble Canyon over the study period, while the population grew in reaches near the LCR. This pattern was caused by reduced recruitment in upstream reaches and immigration from upstream to downstream locations. The extent of rainbow trout movement was limited, with only 1% of over 8,000 recaptures making movements greater than 12 miles. Downstream movement was more prevalent than upstream movement and long distance movement varied between cohorts and over time. The majority of emigration from Glen Canyon came from the 2011 age-0 cohort marked at the start of the study, and the majority of long-distance movement occurred between April and September 2014. All of the recruitment to reaches near the LCR that drove its increasing population trend could be explained by immigration from upstream sources with the majority of the immigration coming from middle and lower Marble Canyon. Although the proportion of fish emigrating from upstream reaches to the LCR was very small, the upstream populations were large and therefore provided enough immigration to increase abundance at the LCR. Length frequency analysis provided strong evidence for local reproduction in Buckfarm and Above LCR reaches, though the contribution of that production to total abundance is uncertain.

Recapture data indicates that trout growth rates are highest for reaches in Marble Canyon and lowest in Lees Ferry and below the LCR. In Lees Ferry, growth occurs in spring and summer and there is almost no growth in fall and winter. In Marble Canyon and eastern Grand Canyon, growth is restricted to the spring owing to higher turbidity between July and October. Low growth in fall and winter in all reaches is likely driven by seasonal variation in the availability of drifting invertebrates. Relative condition factor followed a seasonal pattern driven by food availability, with highest condition in spring and summer, dropping condition in fall, and lowest condition in winter. In Lees Ferry, peak condition (typically July) has declined from about 1.15 to 0.95 from 2012 to 2014, respectively. Condition for larger fish (>225 mm) has been considerably lower than for other size classes since January 2014. Condition of larger fish on the last two trips (September and October 2014) has been around 0.9 and is the lowest on record for the study. The drop in condition is likely driven by reduced food availability caused by lower food production and competition for food resources. In Glen Canyon, low condition through the fall of 2014 and winter of 2015 may reduce the fraction of fish which will spawn in the spring of 2015, and may also reduce their survival rate. These potential future effects should be visible based on current GCMRC monitoring programs (RTELSS, NO).

Project Element F.7 Foodbase Monitoring
Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC

This Project Element is a "Core" monitoring project to provide basic information on aquatic foodbase organisms. This project contributes data to address three Core Monitoring Information Needs:

- **CMIN 1.1.1**. Determine and track the composition and biomass of primary producers below Glen Canyon Dam in conjunction with measurements of flow, nutrients, water temperature, and light regime.
- **CMIN 1.2.1.** Determine and track the composition and biomass of benthic invertebrates below Glen Canyon Dam in conjunction with measurements of flow, nutrients, water temperature, and light regime.
- **CMIN 1.5.1.** Determine and track the composition and biomass of drift in the Colorado River in conjunction with measurements of flow, nutrients, water temperature, and light regime.

Project Element F.7 was also designed to make progress toward addressing the following Strategic Science and Science Advisors questions:

- **SSQ 1-1** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?
- **SSQ 5-4** What is the relative importance of increased water temperature, shoreline stability, and food availability on the survival and growth of young of the year and juvenile native fish?
- **SA 1.** What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young of year and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?

In FY14 the Foodbase Program collected and processed over 1000 insect emergence monitoring samples from throughout Glen, Marble and Grand Canyons with the help of citizen scientists, we developed a new sticky trap for monitoring adult aquatic insects and are developing automated methods for processing these samples, we continued monitoring of invertebrate drift and algae production in Glen, Marble, and Grand Canyons, we conducted studies on rates of drift net clogging that will inform monitoring of invertebrate drift throughout the Colorado River Basin, and we implemented new bar-coding procedures for tracking samples from collection through to processing and archiving.

Project Element F.7.1 Linking Invertebrate Drift with Fish Feeding Habits
Invertebrate drift sampling

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Adam Copp, Ecologist, USGS/GCMRC

In 2014, we processed a significant backlog of Glen Canyon monitoring samples that developed starting in 2012 associated with large numbers of new drift samples that were collected as part of the Natal Origins project. At present, drift samples from monthly monitoring in Glen Canyon have been processed for the period 2007-2013. Preliminary analysis of these long-term monitoring data, which include two HFEs (March 2008 and November 2012), indicates that flood timing may play a role in invertebrate response to HFEs. Specifically, the spring-timed HFE in 2008 led to large reductions in mudsnails, worms, and gammarus, and midges and blackflies increased in the months following this disturbance. Large increases in midges and blackflies in the months following the 2008 HFE fueled large increases in rainbow trout growth and production. In contrast, the fall-timed HFE in 2012 does not appear to have significantly reduced the abundance of mudsnails or gammarus, and the 2012 HFE does not appear to have led to increases in midges or blackflies either. In Glen Canyon, mudsnails typically reproduce over the winter months, such that in the fall the snails that are present are large (>4 mm, similar in size to small gravels) while in the winter and early spring small snails dominate (~0.5 mm, similar in size to coarse sand). Reductions in mudsnail biomass, in particular, may be necessary for midges and blackflies to benefit from HFEs, because mudsnails can attain extremely high biomass and may be usurping diatoms and other algal foods that are necessary to fuel midge and blackfly growth. Thus, long term drift monitoring data indicate that fall-timed HFEs may be less effective at reducing mudsnail biomass than spring-timed HFEs, because in the fall mudsnail populations are dominated by large individuals that are less susceptible to scour.

In 2014, we conducted experiments to assess the specific clogging rates of our drift nets. Filtering efficiency represents the water velocity through the drift net relative to ambient stream water velocity. Prior studies by GCMRC's water quality group have demonstrated that when the filtering efficiency of suspended sediment samplers is <90%, estimates of suspended sediment concentrations become biased high. This occurs because in situations where filtering efficiency is low, water begins moving around the sampler but sediment continues to enter the sampler because of its greater mass and density. Thus, concentration estimates become biased high because the sampler is not actually collecting a 'representative' parcel of the water. Invertebrate drift monitoring protocols employed on the Colorado River since 2007 were informed by these sediment studies on filtering efficiency, and have involved short duration samples (5 minutes or less) to ensure that filtering efficiency of invertebrate drift nets is always >90%. However, many published studies of invertebrate drift involve sample durations between 120-240 minutes, and it is possible that low filtering efficiency of nets creates a systematic bias in these data. Thus, comparing drift estimates for the Colorado River with drift estimates for other tailwaters in the basin requires understanding whether potential issues of net clogging might be inherent to existing monitoring data from other segments.

Project Element F.7.2 Citizen Science Monitoring of Emergent Aquatic Insects
Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Adam Copp, Ecologist, USGS/GCMRC
Colden Baxter, Idaho State University

Our group began sampling emergent insects using light traps in 2012. The traps consist of a 15 cm fluorescent lamp affixed to a shoebox-sized plastic container containing 250 ml of ethanol, which is set at the water's edge for one hour at dusk. A major benefit of sampling emergent insects is that they serve as a proxy for aquatic invertebrate benthic and drift biomass, or the food base available to fish. Unlike benthic and drift samples, however, emergent insect light traps can be deployed quickly with minimal equipment or hazard, and are processed very rapidly in the lab (i.e., 30 minutes per sample, compared to 4 hours per drift sample). On account of these benefits, we have been providing Grand Canyon river guides with light trap kits since summer 2012, and the samples collected by these "citizen scientists" have resulted in an unprecedented spatial-temporal ecological dataset throughout >200 miles of the Colorado River in Grand Canyon.

In 2014, citizen scientists collected 1,280 such light trap samples from February through November. Also in 2014, we began monitoring insect emergence in Glen Canyon using light traps that we deployed during regular monitoring trips. Light traps were outfitted with timers so they could be deployed throughout Glen Canyon, where citizens are not readily available to conduct nightly light trapping. Four automated light traps were deployed at different locations in Glen Canyon as part of monthly foodbase monitoring starting in February. These data will allow us to compare insect emergence patterns in Glen Canyon with similar light trap samples collected in Marble and Grand Canyon.

Emergent insect sticky trapping and image analysis

Although the emergent insect light trapping effort has been very successful, this gear is not ideal for addressing all our group's research questions. In particular, light traps actively attract insects and collect insects for an hour at dusk; they do not collect insects that may be flying at other times of day, and may bias counts toward insects that are more attracted to light such as caddisflies. Thus, we have also developed a new sticky trap and pole mount, which can be deployed quickly even in remote locations and collects insects passively for days or even weeks. Existing sticky trap methods using acetate sheets were time-consuming to deploy because they had to be prepared in the field, which limited the spatial extent of sticky trap arrays that could be deployed on river trips. Our trap consists of a 15 cm Petri dish coated with a non-drying adhesive (Tanglefoot gardening glue), which is attached to a custom-made steel pole. Traps can also be attached to the pole to face in four directions. This allows determination of insect flight direction, which is useful for inferring the origins of captured insects (e.g., upstream, downstream, or from a tributary). Another major benefit of sticky traps is that they can be processed very quickly in the lab (i.e., 5 minutes per sample for a well-trained technician). In 2014, sticky trap arrays were deployed throughout Glen Canyon once per month beginning in February. Additionally, sticky trap arrays that spanned mainstem-tributary junctions were deployed at multiple locations throughout Marble and Grand Canyon during our foodbase monitoring river trip in June. In total, the foodbase group collected 2,900 sticky trap samples in 2014.

Our group is also developing procedures for automated processing of sticky trap samples using image analysis to further reduce sample processing times. High resolution pictures of each trap are taken with a digital camera equipped with a macro lens. GIS and statistical software are then 'trained' to identify and count the insects captured on each trap. Development of these methods is ongoing, but should be finished in early 2015. Initial results suggest that automated image processing cuts sample processing time in half (i.e., ~2 minutes per sample including image capture and post-processing), with insect identification accuracy >90%.

Project Element F.7.3 Primary Production Monitoring

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Adam Copp, Ecologist, USGS/GCMRC
Bob Hall, Biologist, University of Wyoming

We have continuously monitored the dissolved oxygen at two locations in Glen Canyon since 2008, and dissolved oxygen has been monitored at 5 locations in Marble and Grand Canyon since 2009 in collaboration with GCMRCs water quality program. Using detailed dissolved oxygen budgeting approaches, we are able to estimate rates of algae production for entire reaches of river using these data. In 2014, data from Marble and Grand Canyon for the period 2008-2011 were analyzed and used to identify the factors that most strongly control algae production. These investigations revealed that suspended sediment and cloud cover strongly and negatively affect algae production by reducing light penetration through the water column and reducing the amount of light that reaches the river surface, respectively. Hydropeaking and water temperature also affect rates of algae production in the Colorado River, but the effect is much smaller than for suspended sediment and clouds.

Sample barcoding and sample tracking

Our group implemented a barcode labeling and sample tracking system in late 2012 to manage the large and diverse number of ecological samples we collect, store, and process. Each sample is given a unique barcode, which is scanned into an asset database along with its sample attributes at the time of collection using a portable, handheld computer. The handheld computers are synced with a central tracking database; sample information, especially storage location, is easily updated throughout the life of the sample using the handheld computer (i.e., long-term storage, temporary storage, sample processing, archiving, and disposal). To date, over 11,000 samples have been labeled and tracked using this bar-coding system. The unique sample identifier contained within each barcode is referenced within an Access database to streamline data entry. Overall, we have experienced increases in lab productivity due to decreases in error associated with sample labeling and label transcription. The tracking system also facilitates reporting on sample burdens, project progress, and storage capacity. Field data collection has also become more efficient, allowing us to collect more samples per site visit.

Sample processing throughput

Our group is currently using barcodes to track the status of >11,000 samples that are in various stages, from sample collection, to storage, to active processing, to analyzed sample archiving. Since barcoding was initiated in 2012, we have collected an average of 900 drift samples per year, which will be reduced to ~650 samples per year in FY15–17 with reduced sampling effort for the Natal Origins project. Earlier inefficiencies created a large backlog of samples that we are still processing, but at current rates of 4 hours of processing time per sample we expect our FY15–17 drift processing capacity to be ~600 samples per year.

We have also processed ~3,000 light trap samples since 2012, at a rate of roughly one sample every 30 minutes. Finally, we have collected ~5,000 sticky traps since 2012. Most of the sticky trap samples have not yet been processed because the automated image processing protocol for their analysis is still in active development; however, early tests indicate that processing time should ultimately be only 2 minutes per sample.

Publications

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Presentations

Copp, A.J., Kennedy, T.A., and Muehlbauer, J.D., 2014, Don't get clogged up: using net filtration efficiency to inform deployment length in drift studies, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.
Kennedy, T., Muehlbauer, J., and Yackulic, C., 2014, Foodweb update, Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting: Phoenix, Arizona, USA.
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Project F	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$344,000	$9,000	$102,300	$1,077,700	$0	$83,976	**$1,616,976**
Actual Spent	$537,367	$13,437	$85,336	$1,255,782	$5,918	$109,831	**$2,007,669**
(Over)/Under Budget	**($193,367)**	**($4,437)**	**$16,964**	**($178,082)**	**($5,918)**	**($25,855)**	**($390,693)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Additional staff hired to meet additional workload caused by sequestration related hiring delays in FY13.
PIT tags purchased by BOR.
Cooperative Agreement to Ecometric was delayed from FY13, but was awarded in FY14.
Sent funds to Western Fisheries for PIT tag array work.

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<table>
<tr><th colspan="4">Project &Title</th></tr>
<tr><td colspan="4">Project G: Interactions Between Native Fish and Nonnative Trout</td></tr>
<tr><td>Program Manager (PM)</td><td>Scott VanderKooi</td><td rowspan="3">Principal Investigator(s) (PI)</td><td rowspan="3">David Ward, USGS GCMRC; Mike Yard, USGS GCMRC; Scott VanderKooi, USGS GCMRC; Brian Healy, NPS; Clay Nelson, NPS; Emily Omana, NPS; Melissa Trammel, NPS; David Speas, BOR</td></tr>
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Project Element G.1. Laboratory Studies to Assess the Effects of Trout Predation and Competition on Humpback Chub

This project was designed to answer general questions about potential impacts that rainbow and brown trout may have on humpback chub populations in Grand Canyon, and to quantify how environmental characteristics such as water temperature and turbidity alter predation relationships between trout and humpback chub. There were three specific project objectives:

1. Determine to what extent fish size, water temperature and turbidity influences predation vulnerability of humpback chub to rainbow and brown trout.
2. Determine the potential effects competition with rainbow and brown trout may have on humpback chub growth.
3. Determine if rainbow trout present more or less of a predation threat to juvenile chub than predation by adult chub. We outline below how we have made progress in answering each of these questions.

Objective 1: Determine to what extent fish size, water temperature and turbidity influences predation vulnerability of humpback chub.

Predation on juvenile native fish by introduced rainbow trout and brown trout is considered a significant threat to the persistence of endangered humpback chub in the Colorado River in Grand Canyon. Diet studies of rainbow trout and brown trout in Grand Canyon indicate that these species do eat native fish, but population level impacts are difficult to assess because predation vulnerability is highly variable depending on the sizes of the prey and predators and the physical conditions under which the predation interactions take place. We conducted laboratory experiments to evaluate how short term predation vulnerability of juvenile native fish changes in response to fish size, water temperature, and turbidity using captive reared humpback chub, bonytail, and roundtail chub. Juvenile chub (45 to 90 mm total length (TL)) were exposed to rainbow and brown trout (190 – 400 mm TL) at 10, 15, and 20 °C in the laboratory to measure predation vulnerability as a function of water temperature and fish size. At 15 °C, turbidities ranging from 0 to 150 formazin nephlometric units (FNU) (mixed from either Little Colorado River or Paria River mud) were used to measure how predation vulnerability changes under a variety of turbidity conditions.

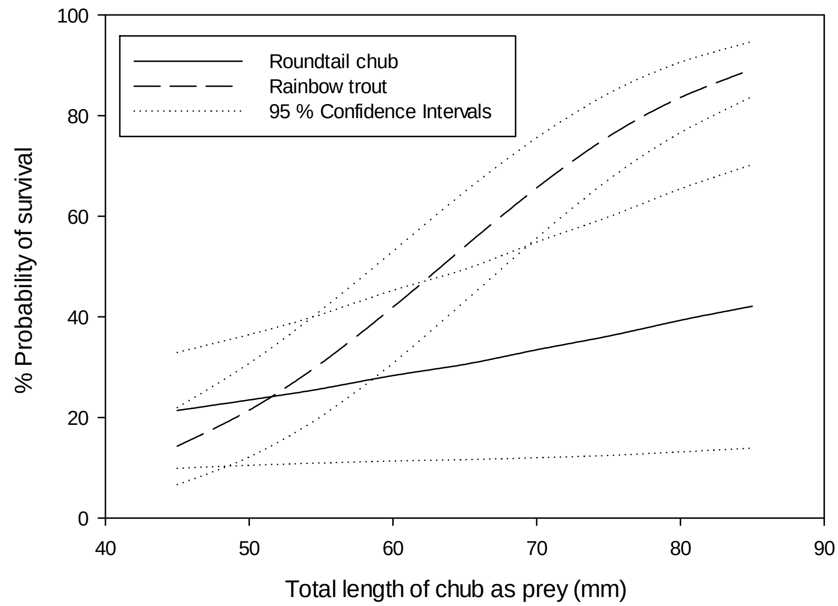
Brown trout were highly piscivorous at all sizes and water temperatures with no significant reductions in predation vulnerability detected at turbidities up to 150 FNU. For rainbow trout, each 1 °C increase in water temperature decreased short term predation vulnerability of juvenile humpback chub by about 5%. Turbidity as low as 50 FNU was also found to reduced predation vulnerability of chub to rainbow trout by 63% (95% confidence interval = 43 - 82%). Our results indicate that relatively small changes in both predator and prey size, as well as increases in water temperature and turbidity can significantly alter predation dynamics of rainbow trout preying on humpback chub, but predation dynamics of brown trout are much less likely to be impacted. Understanding the effects of predation by trout on endangered humpback chub is critical in evaluating management options aimed at preservation of native fishes in Grand Canyon. These laboratory results indicated that little can be done to reduce chub vulnerability to brown trout but that management actions that allow for reduced sizes of rainbow trout, faster growth rates of small humpback chub, or increased mainstem turbidity may warrant further investigation as tools to reduce predation vulnerability of humpback chub to rainbow trout.

Objective 2: Determine the effects of competition with rainbow and brown trout on growth of humpback chub.

Introduced rainbow trout and brown trout inhabit many of the same environments as endangered humpback chub in the Colorado River in Grand Canyon. Competition for limited food resources between these introduced trout species and humpback chub has the potential to negatively impact chub populations in Grand Canyon. We evaluated competitive interactions between humpback chub and trout in four separate, 30-day laboratory trials at 16 °C using 12 replicate artificial stream systems and various sizes of trout and chub. The different size combinations allowed us to evaluate competitive interactions among a wide range of potential fish sizes. Passive integrated transponder (PIT) tagged fish were fed a maintenance ration of 2% body weight per day and monitored for changes in weight. Small humpback chub (114 mm mean TL) lost 4% body weight when held in systems with adult rainbow trout (247 mm mean TL) while control humpback chub increased in body weight by 18% over the same time period. Size matched roundtail chub (236 mm mean TL) (as a surrogate for humpback chub) and rainbow trout (259 mm mean TL) showed a similar pattern, and lost 4% body weight with trout and gained 1% body weight without trout (although differences were not statistically significant). Small humpback chub (109 mm mean TL) lost 4% of their body weight when held in systems with small brown trout (111 mm mean TL), whereas humpback chub without brown trout increased in body weight by 9% over the same time period. These data suggest young humpback chub in Grand Canyon could suffer reduced growth rates because of competitive interactions with either adult rainbow trout or juvenile brown trout.

Objective 3: Determine if rainbow trout present more or less of a predation threat to juvenile humpback chub than predation by adult chub.

This assessment of potential impacts of predation by adult chub on juvenile chub gives context with which to evaluate predation by nonnative fishes and allows for an assessment of the relative impacts of predation by rainbow trout on the humpback chub population in Grand Canyon. We conducted four overnight laboratory trials at 20 °C, utilizing 16 adult roundtail chub (as a surrogate for adult humpback chub) and 48 juvenile bonytail to evaluate cannibalism of small chub by adult chub. Interestingly small chub appear more vulnerable to predation by large chub than to similar sized rainbow trout (See figure below). This suggests that density dependent predation dynamics within the Little Colorado River, related to adult chub feeding on juvenile chub may be an extremely important regulator of humpback chub recruitment which warrants further evaluation.



Percent probability of survival for juvenile chub (60 mm TL) exposed to predation by adult roundtail chub (260 mm TL) or rainbow trout (260 mm TL) at 20 °C in overnight laboratory trials.

Project Element G.2. Efficacy and Ecological Impacts of Brown Trout Removal at Bright Angel Creek

Introduced brown trout are known to prey upon juvenile native fish in Grand Canyon and may adversely impact recruitment of juvenile humpback chub that disperse downstream from the Little Colorado River. A multi-year, brown trout removal treatment using electrofishing is currently being conducted in collaboration with the National Park Service to evaluate the efficacy and feasibility of using mechanical removal to reduce brown trout populations in this area. In 2013, mechanical removal of brown trout occurred in both Bright Angel Creek and in the 8.45 km section of the mainstem Colorado River surrounding Bright Angel Creek between Zoroaster Rapid (RM 85) and Horn Creek Rapid (RM 91). Mainstem removal efforts took place from Nov 19-Dec 1. Researchers conducted a 5-pass depletion over the entire sampling area using two 16' sport boats configured for electrofishing and removed 1,370 rainbow trout and 336 brown trout during this 10-day effort. All fish were processed for human consumption. Turbid water and low flow conditions prevalent during the sampling period impeded electrofishing efforts. Although the results from the first year of effort were confounded by high turbidity, this pilot study was successful in determining the logistical needs to conduct a large scale trout removal effort in the Bright Angel inflow area, and provided important information to help refine future removal efforts. Recommendations include focusing future removal efforts in those areas that contain the highest densities of trout to ensure the highest catches with the least amount of effort. The 2014 trout removal effort at the Bright Angel Creek inflow has been re-scheduled to take place in early 2015 so as to alleviate constraints related to sampling gear availability and avoid conflicts with the High-Flow Experiment conducted in November 2014.

Project G Summary

Many key questions related to humpback chub recruitment and survival remain unclear because of the cost and difficulties of conducting studies in remote locations like Grand Canyon and in isolating confounding factors present in natural systems. The laboratory studies conducted in project G have provided a cost-effective alternative to field research and have allowed us to quickly isolate and replicate individual factors that alter survival of juvenile humpback chub. For a given size of juvenile humpback chub, we can now quantify and predict how survival will change as a result of changes in mean trout size, water temperature, or turbidity. This information will be very useful in evaluating the potential effectiveness of various management actions aimed at conservation of native fishes in Grand Canyon. In general, humpback chub size when exiting the Little Colorado River has the largest effect on subsequent survival, followed by water clarity. These studies indicate that brown trout are much more effective predators that rainbow trout under a wide variety of environmental conditions. For this reason, continued field efforts (similar to those conducted in project G2) to reduce brown trout populations near Bright Angel Creek appear warranted.

Project G.1 funds were expended without deviation as outlined in the FY13-14 workplan.

Project G will result in four peer reviewed publications and one agency report as listed below.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Effects of Water Temperature and Fish Size on Predation Vulnerability of Juvenile Humpback Chub to Rainbow and Brown Trout	Dec. 2014		Dec. 2014	Manuscript in draft form - ready for internal review prior to journal submission.
Journal Article	Effects of Turbidity on Predation Vulnerability of Juvenile Humpback Chub to Rainbow and Brown Trout	Dec. 2014		Jan. 2015	Manuscript currently in preparation. All data analyis completed and writing is in progress
Journal Article	An experimental evaluation of competition between trout and humpback chub	Dec. 2014		Jan. 2015	Final lab trial will end on Nov. 17th. Difficulties in obtaining the correct sizes of fish specimens caused delay in completion of the data acquisition phase of this project.
Journal Article	A laboratory evaluation of tagging related mortality and tag loss in juvenile humpback chub *(Not part of the FY 13-14 work plan, but conducted to address a specific Fish and Wildlife Service need related to ongoing PIT tagging of humpback chub in Grand Canyon).*	N/A	Nov 2004		Ward et al. 2015. A laboratory evaluation of tagging related mortality and tag loos in juvenile humback chub. North American Journal of Fisheries Managemetn. *In Press*
Park Service/ USGS annual Report	Efficacy and feasibility of brown trout mechanical removal in the mainstem Colorado River near Bright Angel Creek	March 2014	Feb 2014		Nelson C., D. Ward, B. Healy and E.O. Smith. 2014. Bright Angel Creek inflow trout reduction Pilot study – Trip Report.

Project G	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$152,200	$4,000	$23,700	$0	$0	$20,406	**$200,306**
Actual Spent	$148,636	$5,201	$21,442	$0	$0	$19,882	**$195,162**
(Over)/Under Budget	**$3,564**	**($1,201)**	**$2,258**	**$0**	**$0**	**$524**	**$5,144**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Project &Title			
Project H: Understanding the Factors Limiting the Growth of Large Rainbow Trout in Glen and Marble Canyons			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Theodore Kennedy, USGS GCMRC; Charles Yackulic, USGS GCMRC; Mike Yard, USGS GCMRC; Mike Anderson, AGFD; Luke Avery, USGS GCMRC; Robert Hall, Uni WY; Josh Korman, Ecometric; Scott Wright, USGS Cal. Water Science Center; William Persons, USGS GCMRC
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The overarching objective of this project was to identify the factors that limit the growth of large rainbow trout. Each element of this project served to evaluate one or more hypotheses that can explain the absence of large trout from Glen Canyon. Hypotheses that were evaluated in the course of this project are:

- ***Hypothesis 1*** *The strain of rainbow trout present in Glen Canyon is incapable of growing to large sizes (i.e., >20 inches).*
- ***Hypothesis 2*** *The current prey base, composed chiefly of midges and black flies, can support the growth of smaller rainbow trout, but does not provide enough energy to allow for growth in large rainbow trout.*
- ***Hypothesis 3*** *The growth of large rainbow trout is limited by exploitative competition for limited prey items.*
- ***Hypothesis 4*** *Operational constraints that occurred in 1990 limit the growth of large rainbow trout.*

Project H.1 Laboratory growth studies

Laboratory studies (Project H.1) to evaluate whether the genetic strain of rainbow trout in Glen Canyon limits their growth were initiated in FY13 and continued in FY14. This element directly tested the validity of Hypothesis 1. Trout eggs were collected from Lees Ferry and hatched and reared in the laboratory to produce a cohort of known disease-free fish. Juvenile rainbow trout from three other genetic strains (Hoefer, Bel Aire, and Fish Lake triploid) were obtained from hatcheries. Adult Lees Ferry fish were held in 3 artificial streams, and three additional artificial streams were used to rear each strain in isolation. Results from this trial indicate that under these conditions, Lees Ferry Rainbow growth is similar to the other rainbow trout strains, and Lees Ferry rainbow trout are capable of growing to large size (i.e., >20 inches).

Project H.2.1 Developing a mechanistic model of primary production

New modeling and analyses were conducted to evaluate the links among dam operations, environmental conditions, and a key component of the foodbase—algae. This project evaluated Hypothesis 4 by describing how operations affect the base of the food web. Daily rates of algae production were estimated using dissolved oxygen measurements from throughout Marble and Grand Canyon. We analyzed these algae production data using mechanistic models of primary production to identify the strength of potential controlling variables including turbidity, cloud cover, water temperature, and hydropeaking. In Marble and Grand Canyon, turbidity is the dominant control of algae production. Cloud cover, although rare in Grand Canyon, also had a strong negative effect on algae production, because clouds reduce the amount of light reaching the river surface. Water temperature only weakly affected rates of algae production. Daily changes in discharge associated with hydropeaking also negatively affected rates of algae production, but the effect size was small in comparison to turbidity and clouds, and hydropeaking only affected rates of algae production when turbidity was high. These mechanistic models are currently being adapted and will be used to analyze a continuous time series dataset of algae production for Glen Canyon that spans multiple High Flow Experiments (2008-2014).

Project H.2.2 Characterizing invertebrate drift

We continued analysis of invertebrate drift data collected throughout Glen Canyon to identify controlling factors. This project provided information needed to evaluate Hypotheses 2, 3, and 4. Invertebrate drift was quantified at 25 stations throughout the 25 km long Glen Canyon tailwater segment in October 2012 and May 2013. We have linked these drift measurements to empirical measurements of water column shear stress (the force that the water exerts on the stream bed), taken at the location of each drift sample and 250 m upstream of each drift sampling location (50 total profiles). Invertebrate drift concentrations varied strongly throughout the Glen Canyon reach, and much of this variation can be explained by localized differences in shear stress. Invertebrate species composition in the drift also varied with shear stress, suggesting that shear stress exerts a differential control on drift initiation that varies by species. These results indicate that shear stress is an important physical control on benthic macroinvertebrate drift, even at shear stress values lower than those required for bed sediment mobilization. The empirical relationship between shear stress and drift can be used to predict drift concentrations at different discharges, and also inform habitat-specific prey density estimates used in bioenergetics models for drift-feeding trout.

Project H.3 Developing a bioenergetics model for large rainbow trout

Bioenergetics models have been adapted and used to evaluate how prey availability affects lifetime growth potential of rainbow trout in Glen Canyon. This project directly addresses Hypothesis 2, and also provides information needed to evaluate Hypotheses 3 and 4. The foraging sub-model estimates daily consumption by rainbow trout based on invertebrate drift concentrations measured in Glen Canyon, while explicitly accounting for swimming costs (as a function of fish size and water temperature), and the differential detection and capture efficiency of invertebrate prey items based on the size of both fish and prey. The bioenergetics component of the model estimates trout growth based on this consumption within the physiological bounds imposed by environmental conditions. We have evaluated a set of physical and biological scenarios and compare these with current conditions (existing drift concentrations). These scenarios include; increased availability of specific invertebrate taxa (e.g. *Gammarus*), shifting available prey biomass to larger sizes while maintaining the same overall prey biomass, increasing and decreasing invertebrate drift concentrations under both "warm" and "cool" temperature regimes, and mimicking the invertebrate drift conditions following the 2008 high flow experiment.

Model output from prey availability scenarios conclusively demonstrates that the maximum size of rainbow trout in Glen Canyon is limited by the quantity and size of invertebrates present in the drift. Specifically, under the base drift scenario, maximum weight/length of trout predicted by the model approximately matches the average size of trout observed in Glen Canyon. Not surprisingly, decreasing drift concentrations among all size classes of prey led to a decrease in maximum length of trout. Maximum predicted length of trout increased in the scenario where drift of all prey sizes was increased. Likewise, maximum predicted length of trout also increased in the scenario where the size distribution of drift was increased but overall drift concentrations (i.e., mg/m^3) remained the same as the base condition. Next steps in bioenergetics modeling include expanded model validation comparing predicted trout growth with empirical growth estimates and expanding scenarios to include downstream locations where physical conditions (e.g. turbidity) may contrast with conditions at Lees Ferry.

Project H.4 Learning from other tailwaters—a synthesis of tailwaters in the United States

We collected fishery and other types of monitoring data (e.g., subdaily discharge, foodbase, water temperature, etc.) from regulated rivers in the Colorado River Basin (CRB) and beyond to evaluate links between trout population dynamics and flow regimes. This project evaluated Hypotheses 3 and 4. We expanded the focus to include both rainbow and brown trout because these two species have divergent life history strategies and likely respond differently to changes in dam operations, and both species are present and competing in tailwaters across the West. In general, we found that discharge primarily influenced rainbow and brown trout recruitment, with stable flows promoting larger year classes, and high discharges during spawning season (winter for brown trout and spring for rainbow trout) contributing to weaker year classes. Rainbow and brown trout length was negatively related to fish density, with tailwaters that supported lower densities of fish generally having larger fish. Hydropeaking was also included in the best performing models of trout length: the effect was negative (hydropeaking was negatively related to maximum length), but the effect size was small in comparison to trout density.

Summary

Collectively, the results of Project H have served to identify factors that limit growth of large rainbow trout. Specifically, laboratory growth studies (Project H.1) indicate Hypothesis 1 is false, because the genetic strain of fish present in Glen Canyon is capable of growing to a large size. Studies on invertebrate drift (Project H.2.2) demonstrate that prey size is small throughout Glen Canyon, but local shear stress conditions play an important role in determining the concentrations of prey that are present in the drift. Using these drift data as an input variable in bioenergetics modeling (Project H.3) demonstrates that Hypothesis 2 is plausible, because maximum predicted size of trout increased under the scenario where drift biomass is constant but the size distribution of the prey was increased. Thus, small average prey size alone is sufficient to explain the absence of large rainbow trout in Glen Canyon. However, results of the tailwater synthesis indicate trout population size is inversely related to the maximum size of adult trout across 29 western tailwaters; thus, Hypothesis 3 is also plausible. The tailwater synthesis results are inconsistent with Hypothesis 4, because trout length is inversely related to hydropeaking across 29 western tailwaters. However, the effect of hydropeaking was small in comparison to the effects of trout density.

If increasing the maximum size of rainbow trout in Glen Canyon is desired, results of Project H suggest there are two logical next steps in the adaptive management process: 1) evaluating policies that seek to increase the diversity and species richness of the invertebrate prey base and/or 2) evaluating policies that seek to reduce the density of rainbow trout.

Publications

Copp, A.J., Kennedy, T.A., and Muehlbauer, J.D. 2014, Barcodes are a useful tool for labeling and tracking ecological samples: *Bulletin of the Ecological Society of America* v. 95, no. 3, 293-300.

Dibble, K.L., C.B. Yackulic, T.A. Kennedy, P. Budy, *In Review,* Flow management and fish density regulate salmonid recruitment and adult size in 29 tailwaters across western North America, *Ecological Applications*

Hall, R.O., Yackulic, C.B., Kennedy, T.A., Yard, M.D., Rosi-Marshall, E.J., Voichick, N., Behn, K.E., In press, Turbidity, light, and hydropeaking control gross primary production in the Colorado River, Grand Canyon: *Limnology and Oceanography*.

Kennedy, T.A., Yackulic, C.B., Cross, W.F., Grams, P.E., Yard, M.D., and Copp, A.J., 2014, The relation between invertebrate drift and two primary controls, discharge and benthic densities, in a large regulated river: *Freshwater Biology*, v. 59, no. 3, p. 557–572.

Smith, J.T., Kennedy, T.A., and Muehlbauer, J.D., 2014, Building a better sticky trap: description of an easy-to-use trap and pole mount for quantifying the abundance of adult aquatic insects: *Freshwater Science*, v. 33, no. 3. pp. 992-997.

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Presentations

Copp, A.J., Kennedy, T.A., and Muehlbauer, J.D., 2014, Don't get clogged up: using net filtration efficiency to inform deployment length in drift studies, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.

Dibble, K.L., Yackulic, C.B., Kennedy, T., and Budy, P., 2013, What factors drive salmonid growth in tailwater ecosystems? A synthesis of data on salmonid population dynamics and dam operations across the Western United States, Annual Colorado River Fish Cooperator’s Meeting: Flagstaff, Arizona, USA.

Dibble, K.L., Yackulic, C.B., Kennedy, T., and Budy, P., 2014, Context and comparison: status of tailwater fisheries in the Western United States, Annual Reporting Meeting to the Glen Canyon Dam Adaptive Management Program: Phoenix, Arizona, USA.

Dibble, K.L., Yackulic, C.B., Kennedy, T., and Budy, P., 2014, Factors influencing the size of salmonids in regulated river systems: a synthesis of data from the Western United States, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.

Dibble, K.L., Yackulic, C.B., Kennedy, T., and Budy, P., 2014, An examination of the processes that regulate fish size downriver of dams in the Western United States, American Fisheries Society Annual Meeting: Quebec City, Canada.

Dodrill, M.J., Yackulic, C.B., Kennedy, T.A., 2014, Development of a drift-foraging and bioenergetics model for rainbow trout in the Lees Ferry tailwater, Joint Aquatic Sciences

Meeting: Portland, Oregon, USA.
Dodrill, M.J., Yackulic, C.B., Kennedy, T.A., 2014, Developing a bioenergetics model for large rainbow trout. Annual Colorado River Fish Cooperator's Meeting: Flagstaff, Arizona, USA.
Kennedy, T., Muehlbauer, J., and Yackulic, C., 2014, Foodweb update, Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting: Phoenix, Arizona, USA.
Kennedy, T.A., Muehlbauer, J.D., and Yackulic, C.B., 2014, Flow management alters rates of insect emergence from the Colorado River in Grand Canyon, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.
Muehlbauer, J.D., Kennedy, T.A., and Yackulic, C.B., 2013, Shear stress and benthic densities control spatial variation in invertebrate drift concentrations throughout Glen Canyon, Annual Colorado River Fish Cooperator's Meeting: Flagstaff, Arizona, USA.
Muehlbauer, J.D., Kennedy, T.A., and Yackulic, C.B., 2013, Shear stress drives local variation in invertebrate drift in a large river, American Geophysical Union Fall Meeting: San Francisco, California, USA.
Muehlbauer, J.D., Kennedy, T.A., Smith, J.T., Sankey, J.B., and Kortenhoeven, E.W., 2014, Advances in emergent insect sampling: new sticky trap designs and automated sample processing, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.
Payn, R.A., Hall Jr., R.O., Marshall, L.A., Kennedy, T.A., and Poole, G.C., 2014 Gross primary production is a primary control on the credibility of gas exchange rates inferred directly from dissolved oxygen data, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.
Smith, J.T., Muehlbauer, J.D., and Kennedy, T.A., 2014, Determining the effects of insect pheromone release on sticky trap catch rates, Joint Aquatic Sciences Meeting: Portland, Oregon, USA.
Yard, M.D., Dibble, K.L., and Dodrill, M., 2014, Factors affecting RBT size in Lees Ferry: where have all the big fish gone? Presentation to Federation of Flyfishers to inform development of the Lees Ferry Fishery Management and Research Plan: Flagstaff, Arizona, USA.

Project H	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$338,300	$25,400	$55,600	$20,600	$0	$48,179	**$488,079**
Actual Spent	$362,747	$16,596	$19,579	$0	$49,000	$45,250	**$493,172**
(Over)/Under Budget	**($24,447)**	**$8,804**	**$36,021**	**$20,600**	**($49,000)**	**$2,929**	**($5,093)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Additional staff hired to meet additional workload caused by sequestration related hiring delays in FY13.
PIT tags purchased by BOR.
Funds were suballocated to the USGS CA Water Science Center rather than as a Coop.

Project &Title			
Project I: Riparian Vegetation Studies: Response Guilds as a Monitoring Approach, and Describing the Effects of Tamarisk Defoliation on the Riparian Community Downstream of Glen Canyon Dam			
Program Manager (PM)	Barbara Ralston	**Principal Investigator(s)** (PI)	Barbara Ralston, USGS GCMRC; Phil Davis, USGS GCMRC; Joel Sankey, USGS GCMRC; Todd Chaudhury, NPS; Lori Makarick, NPS; David Merritt, USFWS; Dustin Perkins, NPS
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Project I Goals and Objectives FY13–14

At a basic level, the goal of Project I in FY13–14 was to use ground-based and remotely sensed vegetation data to inform stakeholders about vegetation response to Glen Canyon Dam operations. The project incorporated spatial (1m^2 plots to canyon-wide imagery) and multi-temporal scales (annual sampling to quadrennial overflight imagery) to assess vegetation change for herbaceous species cover (that can change annually) as well as the expansion or contraction of woody vegetation, which is detectable at a multi-year scale. An exploratory component of Project I incorporated the use of vegetation response-guilds into the monitoring framework. This approach expands basic monitoring metric such as average species cover and species richness by incorporating a group-response component into the framework for assessing vegetation change. The response-guilds approach identifies plant groups based on similar adaptations to geomorphic and hydrologic attributes (e.g., substrate holding capacity, inundation frequency). The groupings cross plant genera so that multiple species can be used to infer vegetation response to hydrologic changes. Knowing the general hydrologic response for a group or guild of plants and quantifying the frequency of occurrence of guilds along the river corridor can be a metric to infer directional response of vegetation to hydrology.

The three elements of Project I contribute to the overarching goal of assessing changes in vegetation with element objectives and associated science questions (formulated around the stakeholder information needs) directing data collection and analyses to meet the goal. Each project element, the associated science questions, and objectives are provided here.

The strategic science questions and monitoring information needs that Project I supported are below:

SSQ 2-1. Do dam-controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?

SSQ 5-7. How do warmer releases affect viability and productivity of native/nonnative vegetation?

The primary information needs addressed by these projects are CMINs 6.1.1., 6.2.1, 6.5.1, and 6.6.1, which are summarized as the following:

- Determine and track the abundance, composition, distribution, and area of terrestrial native and nonnative vegetation species in the CRe
- Determine parameters and metrics to be measured, and the information needs that address each element

- Determine how the abundance, composition, and distribution of the OHWZ, NHWZ, and sand beach community have changed since dam closure (1963), high flows (1984), interim flows (1991), and the implementation of ROD operations (RIN 6.2.1, 6.3.1, 6.4.1, 6.5.1, 6.5.2, 6.5.3)

Element I.1.1. Monitor Vegetation and Channel Response using Response Guilds and Landscape Scale Vegetation Change Analysis

Objective: To use plot samples from annual vegetation surveys to identify vegetation status metrics and plant-response guilds

Science Questions

- What is the status of riparian vegetation and what is the short and long-term response of vegetation among varied geomorphic settings?
- What are the resulting guilds of riparian species found along the CRE and are the groups useful tools to infer directional responses of vegetation to changes in hydrology and substrate?

Activities that support monitoring

Annual vegetation sampling trips in 2012–14. Data collection consisted of $1m^2$ plots that quantified plant species cover. Plots were set within hydro-geomorphic setting [(sandbar, channel margin, debris fan) and fluctuating zone (<25,000 ft^3/s), active floodplain (25,000-45,000 ft^3/s), and the inactive floodplain (>45,000 ft^3/s)].

Summary of Progress

Plot sampling that was coincident with sandbar monitoring (Project A) occurred in October of 2012, 2013 and 2014. Plot sampling for vegetation at other sites occurred in August 2013 and 2014. The plot data from the sandbars were used to identify response-guilds and provide vegetation monitoring metrics for sandbars (see tables 1-4). The data from the August trips in 2013 are entered but remain to be summarized. A report detailing the vegetation monitoring metrics for the river corridor (plant cover, frequency, richness) is in development with a draft for review anticipated by December 2014.

A manuscript of the process used to identify response-guilds is in development with a draft in review by December 2014. Delays associated with both annual vegetation status from ground-based sampling and vegetation response-guild identification are attributed to delayed hiring associated with both the technician and post-doctoral positions (government closure and reduce personnel available for hiring process). Both of these positions were filled in the second and third quarters of 2014. Much of the progress associated with this project element was accomplished in the last two quarters of FY14. We anticipate developing posters that illustrate the status of vegetation based on sampling and the response-guild development. Subsequent efforts related to monitoring include the development and review of a monitoring protocol for ground-based sampling (FY15, Project 11.1) and using the vegetation plot data to develop a vegetation community classification that can be used in the vegetation mapping effort also scheduled for FY15–17 (Element 11.2).

Highlights from the data collected include:

- Collaborations with NPS Inventory and Monitoring Network were established and sharing of methods and practices continues.
- General metrics of herbaceous and woody cover, % exotics and richness divided into three river segments and three hydrologic zones (Tables 1-3) provides details about where exotic

species are most numerous and the status of cover among hydrologic zones. This later information, particularly for woody vegetation is information that can be used to validate information observed from landscape scale vegetation monitoring (Element I.1.3).

Information summarized in the tables include:

- Exotic species richness (# of exotic species) on sandbars declined with distance from Glen Canyon Dam, but total species richness was greatest in the Marble Canyon segment (Table 1).
- Woody vegetation cover was greatest in the Active Floodplain (AF) (Table 2)
- The AF was also associated with higher species richness than either of the other hydrologic zones (i.e., active channel, inactive floodplain) (Table 2).
- Though there are differences in cover between years, these differences are potential influenced by sampling efforts to identify all plants that might occur among sandbars for the response-guild work and should be viewed conservatively.
- Species frequency results suggest that *Tamarix* which is common throughout the corridor was most common in the active floodplain and inactive floodplain (Table 3).
- Arrowweed (*Pluchea sericea*) was more frequently encountered in plots downstream of the Little Colorado River (Table 3). This may be an indication of drier habitats or less disturbance.
- Coyote willow (*Salix exigua*) decreases in frequency of encounters downstream (Table 3). The presence of coyote willow may be an indication of more disturbance and greater water availability either through unregulated flows from the Paria and Little Colorado River or differences in substrate (water holding capacity of sediment) among these river segments.

Information that vegetation monitoring provides to the stakeholders

The monitoring approach that segments the river corridor into three sections provides stakeholders with general plant trends with distance downstream: treating the river corridor as a single river segment diminishes the ability to view trends across the river corridor. A decline in species richness with distance downstream may be an indication of a corresponding reduced disturbance. Similarly, frequency data (Table 3) informs stakeholders about which species may dominate the landscape. If particular species are frequently encountered but also are less desirable, then these species may become the focus of a management action. Frequency information provides a gauge of how species occurrence may change over time. The segmentation of the river also helps to identify areas that may be targeted for management actions. For example, camelthorn (*Alhagi maurorum*) comes into the river corridor from the Little Colorado River, but our data (Table 3) indicate that it is more frequently encountered in the Western Grand Canyon. Crews that may go to sandbars to remove camelthorn may need to focus their efforts in Western Grand Canyon than within Eastern Grand Canyon. Alternatively, removal of camelthorn in Eastern Grand Canyon if it is has been a focused effort, may be showing success. In a similar vein, coyote willow (*Salix* exigua) is a native species that was frequently encountered in Marble Canyon and Eastern Grand Canyon, but less frequently in Western Grand Canyon. The distribution of this species may be of interest to tribal stakeholders. The system-wide sampling with river segmentation (Marble Canyon, Eastern Grand Canyon and Western Grand Canyon) provides stakeholders a sense of how the river as a whole and each river segment is changing over time (Table 1, 3).

Knowing where species occur along a disturbance/hydrologic gradient (e.g., daily inundation vs. potentially inundated by an HFE vs. never inundated) also informs managers about the efforts that may be required to affect changes in vegetation and how vegetation may respond to changing hydrology. If the Active Channel (AC) shows increases in woody vegetation over time this may be an indication of reduced monthly volumes or decrease fluctuation (i.e., reduced disturbance) resulting in woody vegetation expansion. Because the same sandbars are sampled every year and there is reliable stage discharge information for each sandbar, the vegetation plot data from these sites can be used to assess woody vegetation expansion or decrease within the active channel. Woody vegetation expansion into the active channel has implications for available campable area. The type of woody vegetation among hydrologic zones also has implications for wildlife habitat in terms of structural diversity. If in the AF the most frequently encountered plants are shrub or grasses (e.g., arrowweed or sand dropseed (*Sporobolus cryptandrus*) and less often trees, then bird habitat may change and the bird assemblage also change. The lateral segmentation of the riverbank based on hydrology and the longitudinal segmentation of the river provides stakeholders with two-dimensional information about the increase or decline of herbaceous and woody species that can be used in vegetation management decisions.

Information that sampling data provides to vegetation-response guild development

We propose to use the sampling data to identify vegetation-response guilds that provide a tool to assess vegetation change in a hydrologic framework. We used morphological and physiological trait data for 111 species that occurred among the plots to identify cohesive vegetation response groups. Because the location of each sampling plot for the sandbar sites was surveyed, we have spatial locations that can be reference along a hydrologic gradient and can be used, to some extent, to validate our guild or group identification. The classification process is still being refined but preliminary analysis identified seven guilds (Table 4, two xerophytic, two mesophytic, and three hydrophytic). Similarly to the information gained from the frequency of encounters for individual species, the frequency of encounters of plants within guilds can be used to characterize vegetation change in a hydrologic sense. For example if the frequency of the drought tolerant woody plant guild (Guild C) increased in the active floodplain or the active channel then it might be inferred that upland, drought adapted plants were responding to reduced monthly volumes and occupying areas previously dominated by a more mesic guild. Because multiple species are represented by a single guild, information about vegetation response can be applied at a larger scale (multiple sandbars or other geomorphic setting) than the single sandbar from which plot data are obtained. Guilds strengthen the information gained from plot and site sampling by providing an additional metric to assess changes in riparian vegetation either among river segments within Grand Canyon or potential across the Colorado River Basin.

Element I.1.2. State and Transition Model Development for Response Guilds

Objective: To use identified guilds in a conceptual model framework to explain anticipated vegetation response to operations.

Summary of Progress

A workshop was held and vegetation states were refined. This modeling effort went forward in the absence of guilds being identified. Instead, vegetation groups were identified based on previous vegetation mapping efforts. State and transition models (STM) were developed for debris fans, channel margins and sandbars. The transition rules were identified and the model was adopted by Argonne Labs for the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) as a tool to evaluate vegetation response to alternative flow options. The model was expanded and attempts made to use the 2002 vegetation map as a tool to validate response, but limited analysis of 2009 imagery made this effort less successful. An outcome of the modeling effort includes a recognition that flow alternatives were limited in their ability to effectively remove vegetation.

Element I.1.3. Periodic Landscape Scale Vegetation Mapping and Change Analysis using Remotely Sensed Data

Objective: To use identified guilds in a conceptual model framework to explain anticipated vegetation response to operations.
Science Questions: What is the multi-temporal trend in riparian vegetation along the Colorado River in Glen and Grand Canyon?

Activities that support monitoring
Image processing that extracted total vegetation to assess vegetation change throughout the river corridor supported monitoring.

Summary of Progress
Total gross vegetation from 2009 imagery was compared with 2002 as well as from segments of the river from 1963 to 1992. Analysis involved dividing the channel into hydrologic zones that were coincident with the history of river regulation and quantifying percent of vegetated area change along the river corridor. The results indicated that woody vegetation expansion at elevations on the banks below discharges 45,000 ft^3/s increased significantly following the implementation of interim flow associated with the EIS for Glen Canyon Dam operations in 1991. Specifically, vegetation expansion at lower elevations was greater for time periods with smaller peak flows and elevated base flow which occurred during 2002-2009 (Fig. 1). Also, analysis shows that short pulses of high flow, such as the controlled floods of the Colorado River in 1996, 2004, and 2008, do not keep vegetation from expanding onto bare sand habitat. The extended discharges in the mid-1980’s show the opposite effect where vegetation was lost due to immediate removal or drowning and subsequent removal or burial. The rate of increased vegetated area between 2002 and 2009 was also significant. The response of vegetation located at elevations above 45,000 ft^3/s to decadal changes in local precipitation was also observed in gross vegetation change. The results of this analysis are presently in revision following submission to a peer-reviewed journal. Subsequent analysis of gross vegetation may focus on differences in total vegetation among sandbars, channel margins and debris fans. Changes in vegetation classes remain to be completed. Change analysis of vegetation at the vegetation class was given to a Ph.D. candidate in remote sensing analysis at U. of AZ. The change analysis is currently underway and should be completed in early 2015 as a part of a dissertation. Work in FY15–17 will involve analysis of vegetation change from 2013 imagery and classification of the vegetation to produce an updated vegetation map that can be compared with 2002.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Data-Series Report	Riparian Vegetation Distribution and Cover Patterns From Lees Ferry to Pearce Ferry for years 2012 -2013	Oct 2014	Draft anticipated Dec 2014	Draft anticipated Dec 2014/ March 2015-final	Delayed hires, delayed analysis and completion of report
Presentations	Colorado River, vegetation and climate: five decades of spatio-temporal dynamics in the Grand Canyon following river regulation		Oct 2014	Oct 2014	Presentation/poster at Adaptive Management August Meeting in Flagstaff, AZ 2013; Biennial Conference of Science and Management on the Colorado Plateau; American Geophysical Union Fall Meeting 2013
Open-file Report	*Developing Riparian Vegetation-Flow Response Guilds for the for the Colorado River Ecosystem in Grand Canyon, Arizona*	Oct 2013	Draft anticipated Dec 2014	March 2015 - final	Delayed hires, delayed analysis and completion of report. 2013 field data was added to analysis to increase robustness of guild identification.
Journal manuscript	Patterns of plant distributions along the Colorado River downstream from Lees Ferry	Draft in FY15		Not included as expected deliverable	Lead author E. Palmquist. This is a manuscript that is a outgrowth of the plot data collected in FY13-14.
Open-file Report	State-and-transition prototype model of riparian vegetation downstream of Glen Canyon Dam, Arizona: U.S	Oct 2013	March 2014		Ralston, B.E., Starfield, A.M., Black, R.S., and Van Lonkhuyzen, R.A., 2014, State-and-transition prototype model of riparian vegetation

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					downstream of Glen Canyon Dam, Arizona: U.S. Geological Survey Open-File Report 2014-1095, 26 p., *http://dx.doi.org/10.3133/ofr20141095*.
Journal Manuscript	Riparian vegetation, Colorado River, and climate: five decades of spatio-temporal dynamics in the Grand Canyon with river regulation	Oct 2014	Draft submitted Aug 2014 to Journal of Geophysical Research: Biogeosciences	Spring/summer 2015	Manuscript is in revision following receipt of reviewer comments with resubmission expected in December/January of FY15

Project I	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$133,400	$3,800	$4,000	$28,000	$0	$16,856	**$186,056**
Actual Spent	$115,390	$5,434	$5,416	$50,693	$0	$15,840	**$192,773**
(Over)/Under Budget	**$18,011**	**($1,634)**	**($1,416)**	**($22,693)**	**$0**	**$1,016**	**($6,717)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Delays hiring personnel.
Funded PhD Student to conduct remote sensing analysis through a Coop. with the Park Service.

Percent vegetation cover and species richness for the three river segments of the Colorado River in Grand Canyon in 2012 and 2013. SD = standard deviation, Min = minimum value, Max = maximum value.

YEAR		2012				2013			
River Segment	**Plant Variable**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
Marble Canyon N=10	**Total Foliar**	35.0	16.0	17.4	62.5	56.0	13.6	36.6	78.4
	Herbaceous	14.1	9.3	0.0	32.4	19.6	12.2	3.6	39.0
	Woody	20.8	10.5	2.2	36.3	36.4	18.0	16.6	72.4
	Exotic	14.2	8.4	0.5	27.2	27.4	18.0	2.8	58.1
	Richness	23	12	3	46	25	9	11	37
	# Exotic	6	4	1	11	7	3	2	11
	# Native	14	6	2	25	15	5	7	22
	No ID	3	3	0	10	3	2	1	6
Eastern Grand Canyon N=9	**Total Foliar**	45.8	25.2	16.1	85.3	45.8	11.0	31.4	66.5
	Herbaceous	15.5	16.4	0.1	45.1	9.6	5.2	1.9	19.7
	Woody	30.3	11.9	10.6	44.9	36.2	9.7	20.5	46.8
	Exotic	18.9	19.5	0.1	54.0	16.5	10.0	3.6	35.0
	Richness	17	8	2	28	21	6	10	29
	# Exotic	4	2	1	6	5	2	3	8
	# Native	12	6	1	20	14	5	7	19
	No ID	2	2	0	5	2	1	0	3
Western Grand Canyon N=5	**Total Foliar**	58.3	31.0	14.2	91.9	50.0	15.8	22.2	59.7
	Herbaceous	26.9	21.8	0.0	57.8	19.3	12.5	0.7	34.7
	Woody	31.4	11.7	14.2	43.5	30.6	7.0	21.5	37.5
	Exotic	21.3	17.7	0.0	39.4	17.1	12.9	0.3	35.7
	Richness	14	8	3	25	18	10	10	33
	# Exotic	3	2	0	5	5	3	1	9
	# Native	10	7	3	20	12	6	7	21
	No ID	1	1	0	2	1	1	0	3

Percent of vegetation cover and species richness for each hydrologic zone in each river segment of the Colorado River in Grand Canyon for years 2012 and 2013. AC = active channel, AF = active floodplain, IF = inactive floodplain. SD = standard deviation, Min = minimum value, Max = maximum value. Total foliar = percent cover of all vegetation, Herbaceous = percent cover of herbaceous vegetation, Woody = percent cover of all woody vegetation, Exotic = percent cover of all exotic vegetation, Richness = number of species recorded, # Exotic = number of exotic species recorded, # Native = number of native species recorded, No ID = number of species recorded that could not be identified.

	River Segment	**Marble Canyon**								**Eastern Grand Canyon**								**Western Grand Canyon**							
	Year	**2012**				**2013**				**2012**				**2013**				**2012**				**2013**			
Hydrologic Zone	**Plant Variable**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
AC	**Total Foliar**	13	11	0	36	36	23	8	76	2	2	0	4	20	13	1	37	16	19	0	46	33	24	0	58
	Herbaceous	9	10	0	35	25	21	1	62	1	1	0	4	10	13	0	37	15	19	0	46	28	20	0	51
	Woody	4	5	0	17	11	17	0	56	1	1	0	3	10	11	0	28	0	0	0	0	5	6	0	14
	Exotic	3	4	0	9	14	15	0	46	1	1	0	4	4	6	0	17	2	2	0	5	15	18	0	44
	Richness	10	7	0	23	13	7	4	25	3	2	0	5	8	5	2	18	3	3	0	8	4	5	0	12
	# Exotic	2	3	0	9	4	3	0	9	0	1	0	1	2	2	1	6	0	1	0	1	1	2	0	3
	# Native	6	4	0	12	8	4	2	13	2	2	0	4	5	2	1	9	2	3	0	4	3	3	0	8
	No ID	1	1	0	3	2	1	0	3	0	1	0	1	1	1	0	3	0	0	0	1	0	0	0	1
AF	**Total Foliar**	42	23	13	78	60	13	42	87	59	40	21	126	60	18	39	94	84	43	22	139	57	30	7	79
	Herbaceous	18	14	0	40	20	16	1	49	23	31	0	93	10	5	3	17	41	37	0	99	21	16	0	44
	Woody	24	13	2	42	40	19	11	75	35	21	12	72	50	17	24	83	43	12	22	52	36	19	7	54
	Exotic	17	15	0	40	28	20	1	59	19	33	0	105	18	15	1	52	32	29	0	60	25	19	0	53
	Richness	14	8	3	40	15	6	6	24	10	5	1	15	11	4	6	18	8	5	1	13	11	5	5	19
	# Exotic	4	3	1	10	4	3	1	8	3	2	0	5	3	2	1	6	2	2	0	4	4	2	0	6
	# Native	9	5	1	16	9	3	5	13	7	4	1	11	8	3	3	12	5	3	1	8	7	4	3	12
	No ID	1	1	0	3	2	1	0	4	1	1	0	2	0	1	0	2	0	1	0	2	1	1	0	2
IF	**Total Foliar**	48	20	23	89	72	31	41	120	64	25	20	93	50	25	13	100	72	39	24	114	49	11	34	59
	Herbaceous	15	10	1	32	11	7	1	23	13	13	0	34	11	7	3	20	24	19	0	45	10	12	2	28
	Woody	33	21	4	77	61	35	18	112	51	21	16	70	39	26	6	98	48	21	24	69	39	13	26	55
	Exotic	21	15	1	46	38	37	0	94	26	23	0	60	23	19	0	45	28	28	0	69	5	8	0	18
	Richness	11	7	3	27	10	4	3	17	10	6	2	18	11	6	3	19	10	6	3	19	13	7	7	24
	# Exotic	3	1	1	4	2	1	0	4	3	2	1	5	2	1	0	4	2	2	0	4	2	2	0	6
	# Native	7	4	2	15	7	3	3	12	7	5	1	13	10	4	3	14	7	5	3	15	10	4	6	17
	No ID	2	3	0	8	1	1	0	4	0	1	0	2	1	1	0	3	0	1	0	1	1	1	0	1

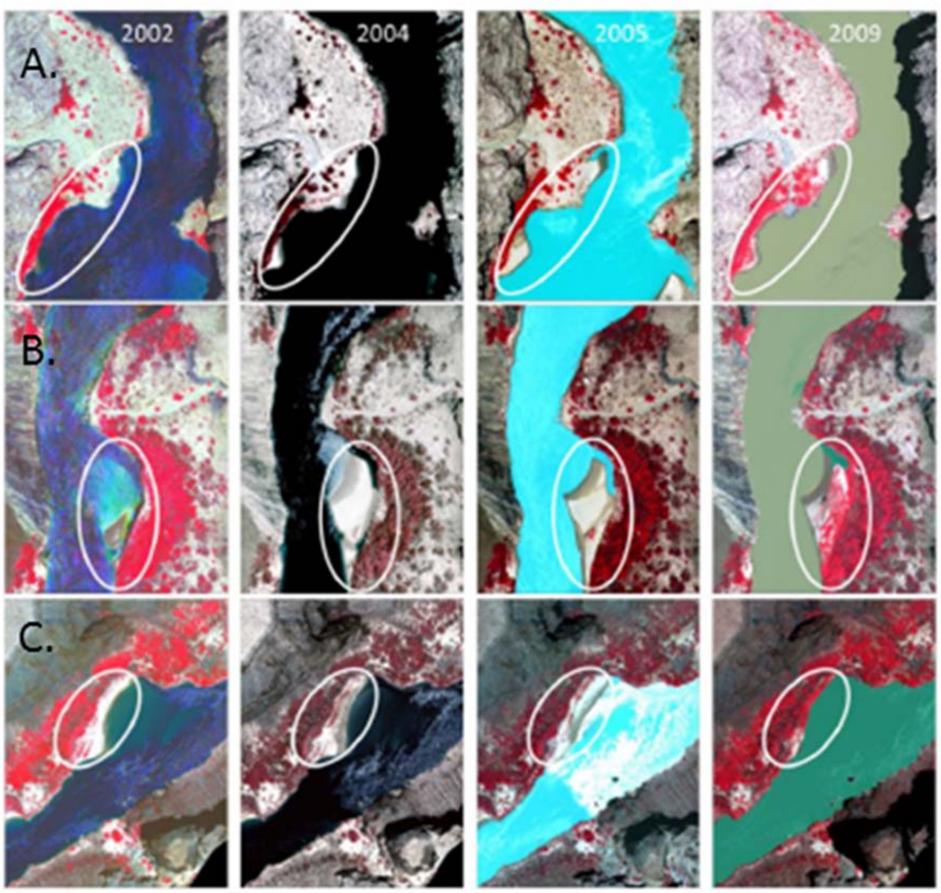
Ten most frequent species for each category with the species frequency adjacent to the species name based on combined 2012 and 2013 sandbar sampling data.

Overall		**Marble Canyon**		**Eastern Grand Canyon**		**Western Grand Canyon**		**Active Channel**		**Active Floodplain**		**Inactive Floodplain**	
Tamarix sp.	0.88	*Tamarix* sp.	0.97	*Tamarix sp.*	0.88	*Cynodon dactylon*	0.89	*Baccharis emoryi*	0.50	*Tamarix* sp.	0.72	*Tamarix* sp.	0.65
Bromus rubens	0.78	*Baccharis emoryi*	0.91	*Bromus rubens*	0.78	*Tamarix sp.*	0.81	*Equisetum hyemale*	0.48	*Bromus rubens*	0.57	*Bromus rubens*	0.62
Baccharis emoryi	0.66	*Bromus rubens*	0.78	*Baccharis salicifolia*	0.69	*Bromus rubens*	0.78	*Salix exigua*	0.48	*Baccharis emoryi*	0.53	*Pluchea sericea*	0.45
Equisetum hyemale	0.56	*Salix exigua*	0.78	*Sporobolus cryptandrus*	0.66	*Pluchea sericea*	0.70	*Tamarix* sp.	0.39	*Pluchea sericea*	0.49	*Sporobolus flexuosus*	0.40
Pluchea sericea	0.54	*Equisetum hyemale*	0.66	*Aristida spp.*	0.66	*Baccharis emoryi*	0.49	*Cynodon dactylon*	0.35	*Equisetum hyemale*	0.43	*Cynodon dactylon*	0.35
Salix exigua	0.51	*Sporobolus cryptandrus*	0.63	*Baccharis emoryi*	0.63	*Equisetum hyemale*	0.46	*Baccharis salicifolia*	0.32	*Salix exigua*	0.38	*Bromus* spp	0.35
Sporobolus cryptandrus	0.50	*Muhlenbergia asperifolia*	0.63	*Salix exigua*	0.59	*Alhagi maurorum*	0.46	*Euthamia occidentalis*	0.29	*Cynodon dactylon*	0.38	*Aristida* spp.	0.35
Baccharis salicifolia	0.47	*Euthamia occidentalis*	0.63	*Equisetum hyemale*	0.59	*Baccharis sergiloides*	0.43	*Phragmites australis*	0.27	*Baccharis salicifolia*	0.36	*Sporobolus cryptandrus*	0.32
Cynodon dactylon	0.43	*Dicot* sd	0.56	*Pluchea sericea*	0.50	*Aristida* spp.	0.38	*Pluchea sericea*	0.24	*Sporobolus cryptandrus*	0.34	*Isocoma acradenia*	0.27
Sporobolus flexuosus	0.42	*Carex* spp	0.56	*Sporobolus contractus*	0.47	*Acacia greggii*	0.38	*Melilotus officinalis*	0.24	*Phragmites australis*	0.21	*Stephanomeria pauciflora*	0.27

List of Seven Putative Flow-Response Guilds

Guild A : Drought intolerant Clonal Wetland Plants (e.g., *Agrostis, Juncus, Salix*)
Guild B : Large seeded woody and herbaceous plants (e.g., *Acacia, Fraxinus, Xanthium*)
Guild C : Drought tolerant woody plants (e.g., *Atriplex, Prosopis, Ephedra, Lycium*)
Guild D : Drought tolerant (upland) weedy generalists (e.g., *Achnatherum, Bromus*)
Guild E : Moderately drought tolerant salt tolerant generalists (e.g. *Agrostis, Pascopyrum, Tamarix*)
Guild F : Baccharis Group?-Moderately drought tolerant largely woody generalists (e.g., *Baccharis, Artemisia*)
Guild G: Drought intolerant, forbs and grasses (e.g., *Euthamia, Andropogon*)

Time series of imagery from three locations (A.)126 km, (B) 131 km and (C) 319 km downstream from Glen Canyon Dam along the Colorado River in Grand Canyon showing vegetation change from 2002 to 2009. Vegetation expansion is primarily confined to low elevation eddy bars. The rates of vegetation expansion varied among sites.



Project &Title			
Project J: Monitoring of Cultural Resources at a Small Scale and Defining the Large-Scale Geomorphic Context of those Processes			
Program Manager (PM)	Helen Fairley	**Principal Investigator(s)** (PI)	Helen Fairley, USGS GCMCRC; Amy Draut, USGS PCMSC; Brian Collins, USGS; Sky Corbett, USGS; David Bedford, USGS; Phil Davis, USGS GCMRC; Joel Sankey, USGS GCMRC
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The objective of Project J was to better understand and quantify effects, and potential effects, of Glen Canyon Dam operations on river-corridor archaeological sites and their surrounding landscapes. The project had three elements:

(J1) monitoring the extent of, and understanding processes of, archaeological-site erosion in a sediment-starved reach, Glen Canyon;

(J2) measuring rates and processes of landscape change at a comparable number of Marble–Grand Canyon sites selected for their apparent potential responsiveness to controlled-flood sand supply, through topographic change detection and weather monitoring, and comparing results to changes at Glen Canyon sites; and

(J3) defining the extent and relative importance of gully formation and annealing by aeolian sand, in a landscape-scale context.

An overarching goal of the project was to better understand the landscape context of cultural resources in general, and to evaluate the potential influence of erosive geomorphic processes and dam-controlled sand supply on river-corridor landscapes and associated cultural sites. As such, this study also aimed to quantify the number and proportion of river-corridor cultural sites that potentially receive windblown sand supply after controlled floods.

Project J Science Questions

Project J was designed to make progress toward addressing the following overarching research question:

- Are archaeological sites in the Colorado River corridor through Glen, Marble, and Grand Canyons eroding or changing faster or in a significantly different manner than they would if Glen Canyon Dam was operated differently than it has been?

As an important step toward that objective, one part of Project J addressed the specific question,

- What number, and what proportion, of cultural sites in the Colorado River corridor potentially receive aeolian sand supply from controlled flood flows?

In addition, Project J was concerned with measuring site-scale topographic change and linking those measurements with observations and measurements of larger landscape processes. Elements J1 and J2 focused on measuring topographic changes, and evaluating those changes relative to local weather conditions at 8 specific archaeological sites (4 sites in Glen Canyon, and 4 in Marble–Grand Canyons), whereas element J3 evaluated processes occurring at a landscape scale using field mapping, remote-sensing analysis, and modeling.

The J1 element of this study focused on the Glen Canyon reach because of its relative sediment starvation compared to Marble and Grand Canyons. Sites in Glen Canyon have been thought to be potentially more susceptible to the effects of reduced aeolian sediment supply, and past observations have suggested that gully erosion in Glen Canyon has progressed more substantially than in Marble–Grand Canyon. Site-specific measurements of landscape change at 4 select Glen Canyon archaeological sites addressed the following questions:

- How do rates of landscape change at Glen Canyon sites compare with those in Marble–Grand Canyon?
- Are geomorphic and/or weather conditions in Glen Canyon such that sites are more vulnerable to erosion there than in sediment-richer Marble–Grand Canyon?

The J2 project element addressed landscape change at 4 sites in Marble–Grand Canyons that, from past work, were known to have an appropriate combination of geomorphic setting, wind direction, and adjacent controlled-flood sand deposits to potentially receive aeolian sand supply after 45,000-ft^3/s flows. This phase of the study addressed the questions,

- Is the magnitude of aeolian deposition at four appropriately situated archaeological sites sufficient to outpace erosion caused by intense rainfall and gullying events?
- In areas with active aeolian sand supply, do sites that undergo significant gully erosion (more than 30 cm downcutting) undergo net topographic lowering such that cultural resources are affected?

Because gully development had been thought to be linked to aeolian sand activity, the J3 project element posed the following questions and associated testable hypotheses using landscape-scale field and remote-sensing analyses:

- *Question*: How does the relative abundance of active and inactive aeolian sand vary in different regions of the Colorado River corridor?
  Hypothesis: The proportion of river-derived sand that is active with respect to aeolian transport will be less in wide reaches of the river corridor and greater in narrower reaches of the river corridor.
- *Question:* How does the degree of gully incision differ in sand deposits that are active vs. inactive with respect to aeolian sand transport?
  Hypothesis: Gullies will be larger and longer-lived in inactive aeolian sand than in active aeolian sand areas.
- *Question*: To what extent does aeolian sand transport counteract gully erosion in Marble and Grand Canyons?
  Hypothesis: Aeolian sand substantially limits gully erosion of river-corridor sand deposits in Marble–Grand Canyon such that the potential extent of gully development will be greater than the actual extent.

Monitoring Activities

In FY14, the following monitoring activities occurred in Glen Canyon:

- Site topography was measured with terrestrial lidar at 4 archaeological sites: AZ C:02:0032, C:02:0035, C:02:0075, and C:02:0077.
- Weather data were collected at two stations, one at Ferry Swale and one at Lees Ferry. Stations

collected measurements at 4-minute resolution of rainfall, wind speed and direction, temperature, barometric pressure, and relative humidity.

The following monitoring activities were conducted in Marble–Grand Canyon:

- Site topography was measured with terrestrial lidar at four archaeological sites: AZ C:05:0031, C:13:0321, B:10:0225, and G:03:0072.
- At the same four sites, weather stations collected data at the same resolution and with the same parameters listed above
- At sites C:05:0031, C:13:0321, and B:10:0225, stationary cameras took photographs once per day to record qualitative information about the timing and nature of landscape change.

Progress Answering Science Questions

In this section we summarize progress made in answering the Project J science questions. Additional details are provided in the project element (J1–3) summaries below, and we will elaborate substantially upon our findings in a forthcoming final report intended to be submitted in winter 2015 as a USGS Professional Paper manuscript.

Regarding the overarching question: *Are archaeological sites in the Colorado River corridor through Glen, Marble, and Grand Canyons eroding or changing faster or in a significantly different manner than they would if Glen Canyon Dam was operated differently than it has been?*

We find that the answer is yes, some archaeological sites are subject to increased risk of gully erosion in the absence of large, sediment-rich controlled floods to supply fluvial and aeolian sand. Of the >350 river-corridor archaeological sites between Lees Ferry and Separation Canyon, many of the approximately 260 sites that have river-derived sand as an integral part of their geomorphic context appear to be at greater-than-natural erosion risk. We infer increased erosion risk as a result of the lower-than-natural flood magnitude, frequency, and sediment supply of the recent controlled-flooding protocol, and the reduction of available open, dry sandbar area available for wind redistribution under current normal (non-flood) dam operations. Thus, many sites are at increased erosion risk as a result of a combination of reduced sand supply (both fluvial and aeolian sand supply) through lack of sufficiently large, sediment-rich floods in the postdam river corridor, higher average base flows being released from the dam compared to predam conditions, and increased riparian vegetation growth (which forms local barriers to aeolian sand transport) in the absence of larger and more frequent floods. We have found that gully prevalence is greater in sand landscapes that are inactive with respect to aeolian transport (findings of J3, discussed below). Because Marble–Grand Canyon contains a lower-than-natural proportion of active aeolian sand landscapes—that is, geomorphic settings in which gully development apparently can be limited by the annealing action of windblown sand (a combination of the findings of Draut, 2012, and element J3, below)—we infer that if dam operations were to increase the supply of sand available for windblown transport and also decrease riparian vegetation, the prevalence of active aeolian sand landscapes likely would increase. We propose that in such a situation, the prevalence of gully development through those landscapes and archaeological sites could correspondingly decrease. We find that the number and proportion of archaeological sites with high potential to receive windblown sand from modern fluvial sandbars are lower today (2013–2014) than in the mid-1980s, and also lower today than in 1996. We infer that this resulted from (1) a lack of sediment-rich flows that were large enough to both deposit sandbars at elevations above the 45,000-ft^3/s stage (imposing positional differences in where fluvial sand can accumulate, compared to fluvial deposition at larger flood flows) and large enough to remove riparian vegetation that can impede aeolian sand transport, (2) vegetation growth in some areas that has covered formerly open sand sources, and (3) river erosion of some formerly open (as well as some vegetated) sand sources. Ultimately, the river-corridor landscape context of many cultural sites is altered fundamentally by the lack of large sediment-rich flows with decadal-scale return intervals (on the order of 200,000 ft^3/s); the geomorphic context in which dozens of sites were formed cannot be replicated in the absence of such large floods. In Glen Canyon, it appears that sites are less affected by loss of aeolian sand supply than in Marble–Grand Canyons, because aeolian sedimentary processes were apparently less prevalent there even in predam time (in terms of either site-formation context or the potential to limit gully development). We infer that in Glen Canyon, landscape evolution and gully development may be affected more substantially by lowered base level after dam completion than by lost sediment supply or regional weather patterns, as weather conditions alone cannot explain the advanced degree of gully incision there (findings of J1 and J2, below).

Regarding the question *What number, and what proportion, of cultural sites in the Colorado River corridor potentially receive aeolian sand supply from controlled flood flows?*

We have answered this question for all archaeological sites known to us between Lees Ferry and Separation Canyon (355 sites). As of this writing, we have not yet attempted to conduct a similar site classification for Glen Canyon National Recreation Area (GCNRA).

We developed a classification system to rank archaeological sites according to their potential for receiving aeolian sand supply after postdam high flows, as follows (Figure 1):

Type 1: Sites with an adjacent, upwind fluvial sand deposit formed by a recent high flow, and with no evident barriers that would hinder aeolian sand transport from the flood deposit toward the archaeological site.

Type 2: Sites with an adjacent, upwind, active or recently formed fluvial sandbar or flood deposit, but with a barrier separating the fluvial deposit from the archaeological site. Such barriers may not eliminate sand movement from fluvial deposit to archaeological site, but are likely to inhibit aeolian transport.

2a: Vegetation barrier present (may be riparian vegetation or higher-elevation, non-riparian upland vegetation).

2b: Topographic barrier present (usually a tributary channel, but in several cases a steep bedrock cliff).

2c: Both vegetation and topographic barriers present.

Type 3: Sites without an adjacent, upwind, active or recently formed fluvial sandbar or flood deposit, even though the river level from the recent high flow inundated areas upwind of the archaeological site (i.e., where an upwind shoreline exists for a recent high flow, but that flow did not leave a sand deposit).

Type 4: Sites without an adjacent, upwind active or recently formed fluvial sandbar or flood deposit, and where there is no upwind shoreline corresponding to any recent high flows. The geomorphic context of these sites involves river-derived sand deposited by pre-dam floods (larger than 97,000 ft^3/s) or aeolian deposits reworked from large pre-dam floods.

Type 5: Sites in the river corridor at which Colorado River-derived sand is absent or irrelevant to the geomorphic context. Sites in this category are situated directly on bedrock, talus, or tributary debris-flow material.

Thus, types 1–4 include archaeological sites at which river-derived sand is integral to the geomorphic context. Of the 355 river-corridor sites analyzed, 263 sites were of types 1–4, whereas the remaining 92 sites were of type 5 (unrelated to river-derived sand). As shown in Figure 2, we successfully categorized each river-corridor site at three time intervals: the present day (through field visits in which we evaluated site geomorphic context, dominant wind direction, and the presence of recent controlled-flood sandbars), immediately after the 1996 controlled flood (using aerial photographs taken in April 1996), and the mid-1980s (using aerial photographs taken in 1984 and 1985). Figure 2 shows the number of sites that potentially receive unimpeded aeolian sand transport from fluvial sandbars (type 1), those that receive aeolian sand supply with impediments in the form of vegetation or topographic barriers (type 2), and those that apparently do not receive aeolian sand, owing to lack of upwind sand sources in spite of an upwind recent flood shoreline (type 3) or a lack of appropriate prevailing wind direction (type 4). In FY14 these data and classification metrics were used to compile a river-corridor atlas, and a written report (East, 2014) provided to the Bureau of Reclamation and National Park Service to inform ongoing discussions regarding the area of potential effect of Glen Canyon Dam operations.

Two science questions drove project element J1:

- *How do rates of landscape change at Glen Canyon sites compare with those in Marble and Grand Canyons?*
- *Are geomorphic and/or weather conditions in Glen Canyon such that sites are more vulnerable to erosion there than in sediment-richer Marble and Grand Canyons?*

Efforts to answer these J1 research questions are ongoing. Change-detection data collected during three monitoring episodes form the basis for this analysis: September 2012 (terrestrial lidar at four sites); July 2013 (airborne lidar collected between river miles (RM) -14.5 and -6, including the four sites), and November 2013 (terrestrial lidar at four sites). To date, all the data from these three monitoring episodes have been processed, and a preliminary report on the results of change detection were presented to GCNRA staff in June 2014. A USGS Scientific Investigation Report was produced in FY14 describing and comparing the resolution of change detection that is possible using terrestrial lidar, airborne lidar, and photogrammetry. Analysis has been completed of all terrace-based gullies in the airborne lidar data set, and 425 gullies have been identified using a flow-based algorithm. Gully prevalence will subsequently be analyzed in comparison to that in Grand Canyon, and rates of change at the four monitored sites in Glen Canyon will be compared with rates of change detected in four sites from Marble–Grand Canyon (element J2).

We have undertaken a comprehensive comparison of all available rainfall records from the Glen, Marble, and Grand Canyon region, including comparison of Project J data (and earlier GCMRC weather data collected between 2003 and 2011) with rain gages operated by David Topping's research group, as well as NOAA COOP stations. From these data sources, we generated a regional assessment of decadal-scale precipitation regimes (Fig. 3). From these analyses we infer that, over the past six decades, weather conditions in Glen Canyon have not been more conducive to landscape erosion than have weather conditions in Marble–Grand Canyon (Fig. 4). Thus, we infer that if the extent of gully erosion is indeed greater in Glen Canyon than in Marble–Grand Canyon (which will be determined by the lidar-data analysis that is presently ongoing), this would be caused by differences in landscape processes other than rainfall intensity.

Work on element J2 is addressing the following two questions:

- *Is the magnitude of aeolian deposition at four appropriately situated archaeological sites sufficient to outpace erosion caused by intense rainfall and gullying events?*
- *In areas with active aeolian sand supply, do sites that undergo significant gully erosion (more than 30 cm downcutting) undergo net topographic lowering such that cultural resources are affected?*

As of this writing, data collection has been completed, and analysis of these data is under way. In March 2014, an administrative report was prepared documenting topographic changes observed between the 2012 and 2013 data sets. Analysis of changes between the 2013 and 2014 terrestrial-lidar data sets at the four monitored sites in Marble–Grand Canyon is currently in progress. These analyses will be presented in the final project report intended to be submitted for review in winter 2015. Meanwhile, a journal article that is currently in review (Collins and others, in review) has shown that between 2006 and 2010, more wind and water erosion occurred at the studied archaeological sites in Grand Canyon than aeolian deposition, even at those sites that are favorably positioned to receive wind-blown sand from HFE sand bars. Although that analysis covered only a four year time span (2006–2010) and 13 sites, these data suggest that under current dam operations, sandbar replenishment by wind may be insufficient to offset the amount of erosion that is occurring due to a combination of aeolian and precipitation-runoff erosion. These results were presented by Collins and others at the January 2014 Annual Reporting meeting, and a subset of these results were presented at the Society for American Archaeology's annual meeting in Austin, Texas, by Fairley (Fairley and others, 2014).

Analysis of weather data collected from the four Grand Canyon stations in use for Project J is complete and up to date, and has indicated some important rainfall events that caused landscape change at these sites. Using daily photographs from stationary cameras, we detected instances of gully formation (site C:05:0031) and gully enlargement (site B:10:0225), and measured the rainfall events inferred to have caused those gullying events (Figs. 5, 6). When combined with high-resolution change detection from the forthcoming lidar data analyses, we expect to be able to quantify the magnitude of landscape change from aeolian processes and gullying (rainfall runoff), in order to provide detailed answers to the J2 science questions.

Project element J3 posed and answered three research questions. Salient results were published in a peer-reviewed journal article in 2014 (Sankey and Draut, 2014), and are summarized here briefly (see description of J3, below, for additional details on methods and findings).

- *Question*: How does the relative abundance of active and inactive aeolian sand vary in different regions of the Colorado River corridor?
  Hypothesis: The proportion of river-derived sand that is active with respect to aeolian transport will be less in wide reaches of the river corridor and greater in narrower reaches of the river corridor.

This hypothesis and question were formulated to investigate whether wider reaches of the river corridor, i.e., those with the greatest archaeological-site density and also the locations of widest predam fluvial terraces, would be the most prone to site degradation from gully development. (A recently published study by Pederson and O'Brien, 2014, shows that the incidence of archaeological sites undergoing "acute erosion" is indeed greatest in the widest reaches of Grand Canyon). We mapped abundance of river-derived sand that is active and inactive with respect to aeolian sand transport over six river reaches (four of which were completed during Project J, in FY13; two had been completed before Project J began): Glen Canyon from RM -6 to -13 (GLCA), lower Marble Canyon from RM 44–61 (Eminence to LCR reach, EmLCR), and Grand Canyon from RM 66–71 (Furnace Flats, FF), 87–99 (Upper Granite Gorge, UGG), 116–130 (Stevens-Conquistador Aisle, SCA), and 207–210 (Granite Park, GP). We found that although the narrowest reach (Upper Granite Gorge) did contain a greater proportion of active aeolian sand than wider reaches such as Furnace Flats or Granite Park, river-corridor width did not correspond directly with the proportion of active aeolian sand (Fig. 7). The SCA reach, of intermediate width, contained the highest proportion of active aeolian sand. We inferred that prevailing wind direction, in addition to accommodation space for storing large predam flood sediment deposits, is an important factor in determining the proportion of active aeolian sand landscapes; the SCA reach is unusual in the canyon in containing a section several miles long with dominant wind direction oriented inland toward river left, rather than approximately parallel to the river orientation (Fig. 8). Thus, by mapping sand distribution and general wind patterns in the canyon, we have been able to differentiate a combination of factors that contribute to aeolian sand activity, and (as described below) propensity for gully development, for various regions of the river corridor.

- *Question:* How does the degree of gully incision differ in sand deposits that are active vs. inactive with respect to aeolian sand transport?
  Hypothesis: Gullies will be larger and longer-lived in inactive aeolian sand than in active aeolian sand areas.

We found that gullies are less prevalent in sand deposits that are active with respect to aeolian sand transport than in those that are inactive with respect to aeolian transport. Through a combination of field mapping of active and inactive aeolian sand and a remote-sensing algorithm for gully detection that we verified through field-checking of potential gully flow paths (Sankey and Draut, 2014), we determined that gullies occupy less of the landscape area in active aeolian sand deposits than in inactive sand deposits (Fig. 9). This finding supports the hypothesis above. Regarding the part of this hypothesis concerned with gullies being longer-lived (temporally) in inactive sand deposits, we determined that the temporal and spatial detectability of gullies in the photographic record is not adequate to determine longevity systematically in very many cases. However, we did use the historical aerial photographic record to examine the fate of several hundred remotely sensed gullies over time (at time steps 1984, 2002, and 2009). We looked for evidence of infilling by aeolian sand over time, or gully obliteration owing to vegetation growth, as mechanisms for gully annealing. Results showed that 1–3 %, or up to 11 gullies, of the gullies that terminated in aeolian sand showed obvious indication of aeolian annealing over time, and an additional 1% (3 gullies) showed evidence of aeolian sand annealing in conjunction with vegetation encroachment (Sankey and Draut, 2014). Thus, we concluded that the historical temporal record contains evidence of gullies, although relatively few in this field setting, that have annealed over time and so are less evident today than in the past.

- *Question*: To what extent does aeolian sand transport counteract gully erosion in Marble and Grand Canyons?
  Hypothesis: Aeolian sand substantially limits gully erosion of river-corridor sand deposits in Marble and Grand Canyons such that the potential extent of gully development will be greater than the actual extent.

Our findings supported this hypothesis (Sankey and Draut, 2014), and suggest that if the proportion of active aeolian sand in the canyon (which is already less than inferred natural conditions would allow; Draut, 2012) were to decrease further, the extent of gully development likely would increase correspondingly. However, as discussed above, even under optimal conditions, aeolian sand action in the river corridor today may not be sufficient to offset erosion currently occurring at Marble–Grand Canyon archaeological sites (Collins and others, in review).

Gullies terminate more commonly in active aeolian sand than in inactive sand (Sankey and Draut, 2014), which is consistent with field observations that topographic depressions such as gullies and tributary channels effectively trap aeolian sand. Gullies occupy a substantially lower proportion of the landscape area within active aeolian sand deposits compared to inactive sand deposits (Fig. 9A), and the proportion of gully area in our study reaches decreases significantly with increasing active aeolian sand area (Fig. 9B). In the original Project J work plan, we had intended also to investigate this final question with a landscape-evolution model that would have compared actual field and remotely-sensed gully prevalence with modeled (predicted) gully prevalence. The modeling component of element J3 remains incomplete owing to a medical situation with one of our research scientists. Initial work has been undertaken, but it is unclear as of this writing whether modeling results will be incorporated into the Project J final analysis.

Overview of Weather Monitoring Data Context and Continuity

In FY14, weather conditions were monitored at select archaeological sites using six weather stations deployed between Ferry Swale and RM 223. The weather parameters, equipment specifications, and station configuration were identical to those used in previous years (2007 through 2011). In the case of the four Marble–Grand Canyon stations, four locations were reoccupied that had been instrumented for the same purpose previously (also in the years 2007 through 2011); one of those sites, C:05:0031, was also a study site for earlier weather-data collection by Draut and Rubin (2008) from 2003 through 2006. The weather data have been analyzed and are the subject of a report in press currently (Caster and others, in press). Thus, these data will form part of an ongoing record of weather events in Grand Canyon National Park that follows earlier data collection by Draut and Rubin (2008, and earlier reports cited therein) and Draut and others (2009a, 2009b, 2010). We also completed in FY14 a report that was begun by former GCMRC employee Tim Dealy (Dealy and others, 2014), to provide maximal continuity of these records for public access. These data have been used during FY14 in conjunction with data collected by David Topping's research group and by NOAA COOP weather stations, to infer long-term records of rainfall amount and intensity, allowing us to compare regional weather patterns that may have contributed to greater archaeological-site degradation in Glen Canyon compared to Marble–Grand Canyon. As discussed above and shown in Figs. 3 and 4, the trends indicated by these data comparisons indicate that the substantial gully erosion of Glen Canyon sites cannot be attributed to a more intense rainfall regime there compared to Marble–Grand Canyon.

Summary of Reports and Products

In the FY13–14 Biennial Work Plan (BWP), Project J stated intentions to complete the following reports and publications from our work:

- Trip reports to be prepared after each river trip to fulfill National Park Service (NPS) permit requirements. *Trip reports were completed and submitted to NPS after both Project J river trips, in spring 2013 and spring 2014. In addition, an oral report on FY14 work was provided to GCNRA staff by Collins, Corbett, and Fairley in June 2014.*
- Weather data to be served via GCMRC website. *Data from not only Project J weather monitoring (2011–2013) but also data going back to 2007 will be available as downloadable appendices of an Open-File Report currently in press (Caster and others, in press). Data collected in 2014 will be part of a separate report prepared in 2015, as data collection is continuing through the end of 2014.*
- A USGS report to describe technical aspects (methods and data results) of the weather monitoring component of Project J. *This has been completed for data up through the end of 2013, has been reviewed, and is in press as of October 2014, see reference for Caster and others below (currently in the queue of publications in the EPN office). Data collected in 2014 will be part of a separate report prepared in 2015, as data collection is continuing through the end of 2014.*
- An Open-File Report summarizing progress on development of a geomorphic model. *An outline of this report was prepared during FY14 before the project scientist leading this effort began an unforeseen extended medical leave. The modeling portion of Project J is currently on hold. However, some results of this modeling effort have been incorporated into a journal article by Collins and others that is currently in review.*
- An interim Open-File Report in FY15 summarizing results of the first two years of the pilot monitoring project, followed by a comprehensive report on results of Project J. *Instead of preparing two separate reports (one an interim report, as we mentioned in the BWP), we are*

preparing one comprehensive final report that will be submitted for review in winter 2015 as a USGS Professional Paper. However, an interim administrative report documenting changes to Grand Canyon sites between 2012 and 2013 was prepared in March 2014, and we are currently developing a separate report documenting the changes to the Glen Canyon sites using the terrestrial and airborne lidar data sets from September 2012, July 2013, and November 2013.

- Journal article intended for FY15 on results of aerial imagery analysis, including use of historical imagery to detect changes in gully erosion patterns, and active vs. inactive aeolian sand mapping. *This was completed and published in FY14 (ahead of schedule) in the journal Geomorphology; see Sankey and Draut 2014 reference below.*
- Publication on airborne lidar as a landscape-scale change-detection tool. *This was completed and published in FY14 as a USGS Scientific Investigations Report; see reference for Collins and others, 2014, below.*
- Results to be presented at TWG and AMWG meetings as appropriate. *Project J results have been delivered by oral presentations to the TWG and AMWG meetings as expected during the course of the project.*
- Results to be presented at major national scientific meetings such as the American Geophysical Union, to ensure that the findings are shared with the scientific research community and may inform other river- and environmental-management programs. *Results from Project J have been presented at the American Geophysical Union conference in 2013 (Sankey and Draut, 2013) and Society for American Archaeology conference in 2014 (Fairley and others, 2014). Abstracts on Project J work have also been submitted to the Federal Interagency Sedimentation Conference to be held in 2015 in Reno, NV, and the Parks for Science, Science for Parks conference to be held in Berkeley, CA, in March 2015.*
- An additional report not mentioned in the BWP was completed in FY14 summarizing the archaeological-site classification process (East, 2014), as well as a mapbook showing actual site classifications; these were provided to the Bureau of Reclamation and National Park Service for use in ongoing discussions to define the area of potential effect of dam operations.

Summary of Project Funds Expenditure

In FY14, after negotiating a waiver for the hiring restrictions that had been in place since the start of Sequestration in March 2013, GCMRC hired geographer Joshua Caster. Caster then became a Project J member several months into the fiscal year. Because we had originally planned to fill the position in FY13, we had planned for a full year of salary, but only needed to cover about 8 months in FY14. Therefore, we spent approximately $25,000 less in GCMRC salaries than originally planned. Owing to bureau-wide travel restrictions, we also spent approximately $13,000 less on travel and training in FY14 than originally planned. A cooperative agreement with Northern Arizona University to support a student assistantship to assist us with analyzing weather data was also planned for FY14. Because this agreement was set up in the previous fiscal year for the same purpose and was delayed by a year, the assistantship funding from FY13 was used in FY14, and the FY14 funds were carried over into FY15. Finally, approximately $9,000 intended to support the J3 modeling effort did not get spent due to an unanticipated medical emergency that arose with the scientist in charge of that work. All of the underspent funds were subsequently pooled and reallocated to pay for the purchase of a ground-based lidar scanner, which accounts for the excess expenditure in the equipment and operating expenses category. At the end of the fiscal year, the carryover balance for Project J was approximately $7,000.

Summary of Individual Project Elements (FY14 work):

Project Element J.1. Cultural Site Monitoring in Glen Canyon

Helen Fairley, USGS/GCMRC
Brian Collins, USGS Geology, Minerals, Energy and Geophysics Science Center
Skye Corbett, USGS Geology, Minerals, Energy and Geophysics Science Center

This component of Project J measured rates and processes of landscape change at four archaeological sites in Glen Canyon located on alluvial terraces, at least one of which is known to have experienced erosion during controlled floods of approximately 45,000 ft3/s . Measurement of landscape change, and the weather events (wind and rainfall) to which landscape change can be attributed, depends on data collected at weather stations and from high-resolution terrestrial lidar surveys. During FY14, the investigators conducted fieldwork over a four-day field session in November 2013, in which terrestrial lidar surveys (high-resolution topographic surveys) were completed successfully at sites AZ C:02:0032, C:02:0035, C:02:0075, and C:02:0077. (These four study sites had also been scanned by terrestrial lidar in 2012, and are encompassed by the airborne lidar survey completed in July 2013, providing three specific points in time over two years for assessing landscape change at those places). During November 2013, we downloaded data from the weather station on the Paria alluvial fan (Lees Ferry station) and we installed a new weather station upstream from site AZ C:02:0077 (Ferry Swale station). Additional maintenance and downloading of data from these two stations was also done at the necessary intervals (every few months) over the course of FY14.

All lidar data collected during FY14 have been processed by Corbett in Menlo Park, and preliminary change detection results were shared via an oral, in-person presentation with GCNRA staff in June 2014. Results of the weather-data analysis through end of 2013 have been compiled by Caster into a USGS report (Caster and others, in press). The results of these various analyses are currently being written up by Collins and others, with a report expected to be ready for peer review by the end of 2014.

Project Element J.2. Monitoring of Select Cultural Sites in Grand Canyon

Helen Fairley, USGS/GCMRC
Joshua Caster, USGS/GCMRC
Brian Collins, USGS Geology, Minerals, Energy and Geophysics Science Center
Skye Corbett, USGS Geology, Minerals, Energy and Geophysics Science Center
David Bedford, USGS Geology, Minerals, Energy and Geophysics Science Center

This part of Project J measured rates and processes of landscape change at four archaeological sites in Marble–Grand Canyon that are known to receive windblown sand from sandbars enlarged by controlled floods of 45,000 ft3/s . Measurement of landscape change, and the weather events (wind and rainfall) to which landscape change can be attributed, depends on data collected at weather stations, from camera stations taking daily photographs, and from high-resolution terrestrial lidar surveys. During 2014 the investigators conducted fieldwork on a river trip in late April and early May. The work conducted on that trip supported both J2 and J3 components and is summarized here; full details are provided in the trip report that was sent to NPS at the end of May 2014.

During the April–May river trip, terrestrial lidar surveys (high-resolution topographic surveys) were completed successfully at sites AZ C:05:0031, C:13:0321, B:10:0225, and G:03:0072. (These four study sites had also been scanned by terrestrial lidar in 2006-2007 and 2010, and earlier for Project J in 2013, providing a longer-term basis for assessing landscape change at those places). We downloaded data and conducted maintenance work at weather stations at each of those four sites, and downloaded and maintained stationary cameras at C:05:0031, C:13:0321, and B:10:0225. Additional maintenance work was also done at these stations during river trips in cooperation with other projects in summer

2014. Lidar data collected during the spring 2014 trip are currently being processed by Corbett in Menlo Park and are being compared with previous surveys at those study sites to analyze sediment volume gain or loss, and mechanisms of landscape change. Processing of weather data and stationary camera photos is up to date (work by Caster), and along with comparisons with weather data from canyon-rim stations and other regional data collection by David Topping's research group and NOAA, has been used successfully to analyze regional weather patterns that contribute to landscape change at cultural sites (Figs. 3–6). Results of the weather-data analysis through end of 2013 have been compiled by Caster into a USGS report (Caster and others, in press).

Also as part of the April–May 2014 river trip, Project J personnel collaborated with NPS archaeologist Jennifer Dierker to visit approximately 80 archaeological sites. The purpose of those site visits was to make observations of locally dominant wind direction (based on geomorphic features, such as wind ripple, sand shadow, and dune orientations) and geomorphic context to classify the sites as part of the river-corridor site-classification effort described above (Figs. 1, 2). After completion of the river trip, those field analyses were combined with office-based aerial photographic work to extend the site classification effort back to two earlier time intervals, the mid-1980s and spring 1996 (Fig. 2).

Project Element J.3. – Defining the Extent and Relative Importance of Gully Formation and Annealing Processes in the Geomorphic Context of the Colorado Ecosystem

Amy East, USGS Santa Cruz
Joel Sankey, GCMRC
David Bedford, USGS Menlo Park

Element J3 evaluates the role of aeolian sand in the larger landscape context of limiting and annealing gully erosion, particularly erosion which may compromise archaeological sites. As discussed above, this phase of the project involved remote sensing efforts to detect potential gullies, and field mapping in select reaches to both confirm the accuracy of remotely sensed gullies and to demarcate areas of river-derived sand that are active or inactive with respect to aeolian transport. The data collection effort for J3 was largely completed during FY13, and so in FY14 efforts focused on analyzing and compiling the data into a journal article, now published (Sankey and Draut, 2014). The results were also presented at the January 2014 Annual Reporting meeting, and were presented by Sankey in a major international conference (Sankey and Draut, 2013, American Geophysical Union fall meeting, San Francisco, Calif.). Sankey has also submitted an abstract on this study to the Federal Interagency Sedimentation Conference to be held in 2015 in Reno, Nevada. East has submitted an abstract to the Parks for Science conference on collaborative NPS science partnerships, to be held in Berkeley, Calif., in March 2015.

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Project J	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$83,000	$24,800	$13,000	$8,000	$325,000	$13,942	**$467,742**
Actual Spent	$55,944	$8,409	$59,548	$1,200	$315,631	$14,090	**$454,822**
(Over)/Under Budget	**$27,056**	**$16,391**	**($46,548)**	**$6,800**	**$9,369**	**($148)**	**$12,920**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Delays hiring personnel and reduced travel.
Contributed to purchase of terrestial LIDAR system.

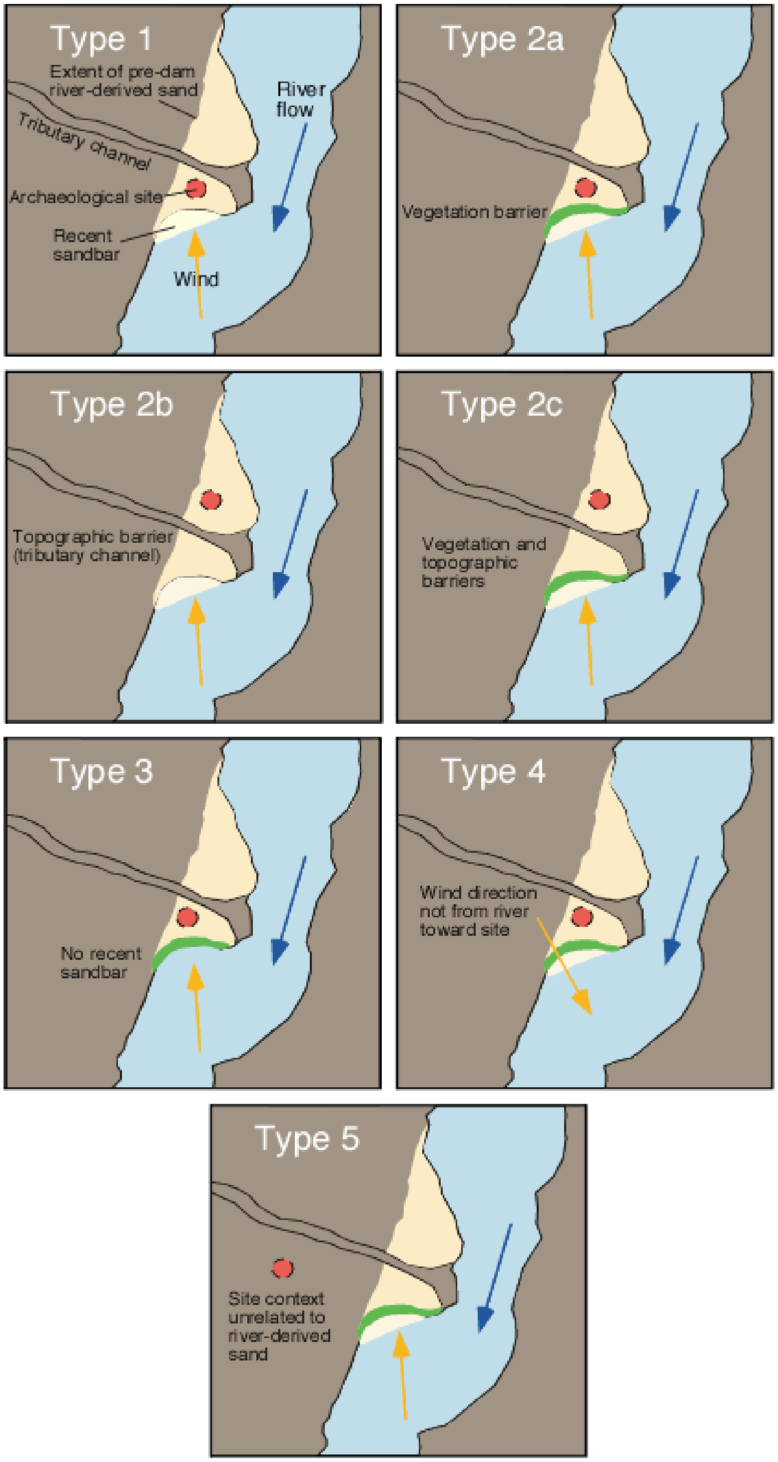


Figure 1. Classification system developed during Project J to rank river-corridor archaeological sites according to their potential to receive aeolian sand from modern fluvial sandbars. See text for details.

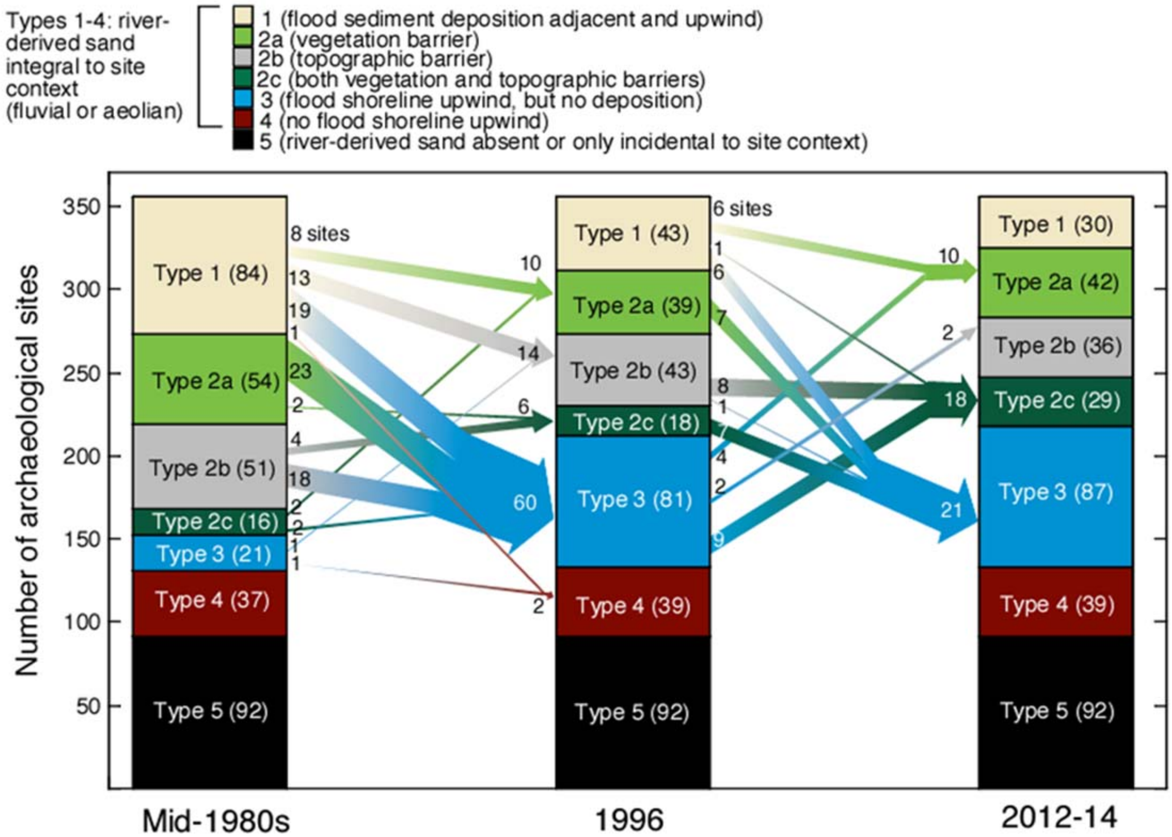


Figure 2. Site classifications determined for 355 river-corridor archaeological sites between Lees Ferry and Separation Canyon, for time intervals in the mid-1980s, immediately after the 1996 controlled flood, and after the 2012–2013 controlled floods. Arrows indicate sites that changed categories from one time interval to the next.

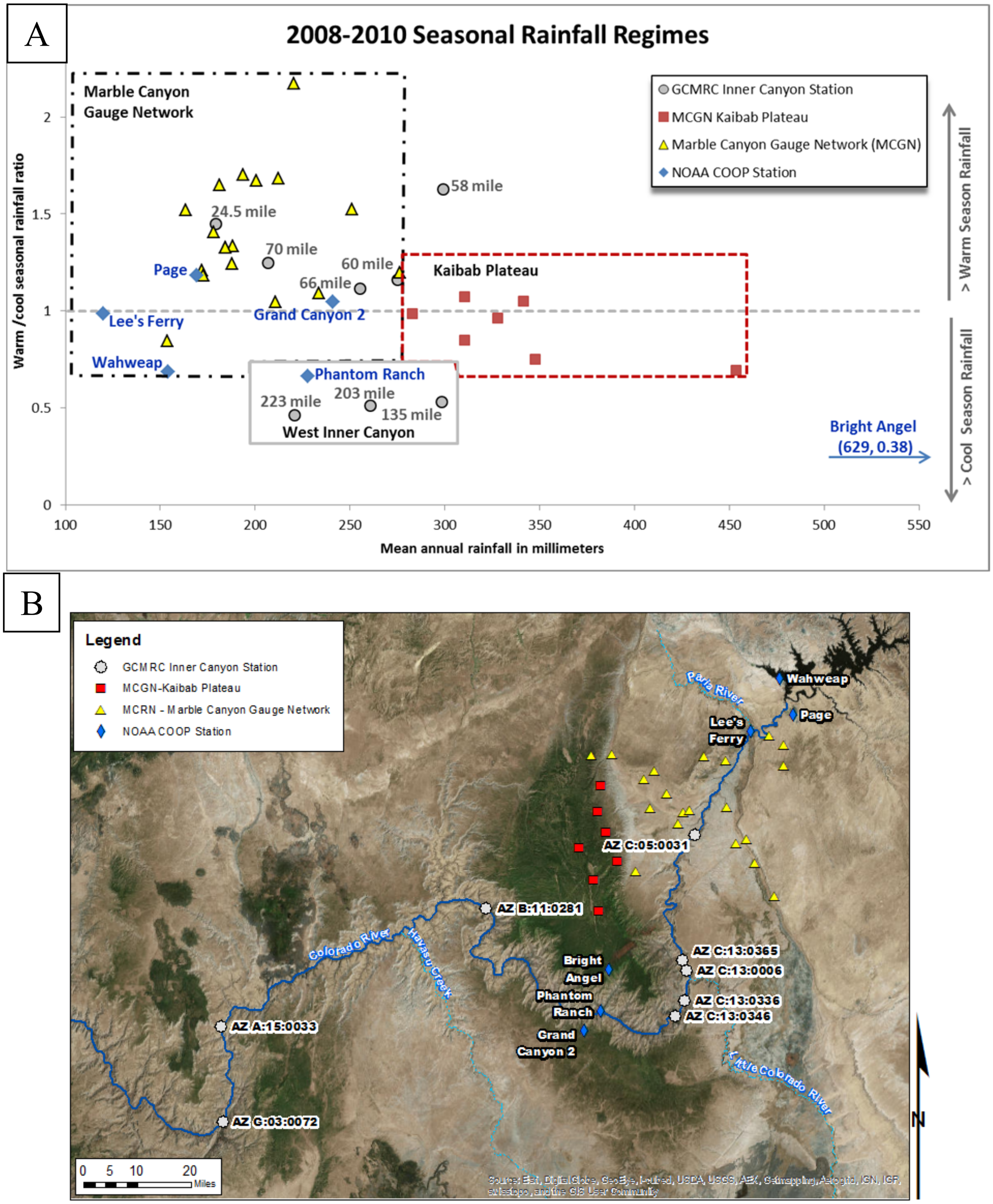


Figure 3: **(A)** Seasonal rainfall regimes as defined by the ratio of warm season to cool season rainfall plotted against mean annual rainfall for 2008 – 2010. Boxed categories were estimated by geographic location and rainfall characteristics. GCMRC Inner Canyon Stations are located along the Colorado River within the Grand Canyon, Arizona. The Marble Canyon Gauge Network (MCGN) is a system of rain gauges located outside of the canyon along tributary channels of the Colorado River. NOAA COOP Stations are part of a weather monitoring network that are independent of, but report to, the National Weather Service. The Bright Angel Ranger's NOAA COOP station is not plotted in the graph as it extended outside of the typical range of values. X and Y values for Bright Angel have been provided for reference. Boxed categories were estimated for the MCGN by geographic location and rainfall characteristics as a method to evaluate GCMRC and NOAA COOP stations. **(B)** Distribution of station categories within the study area.

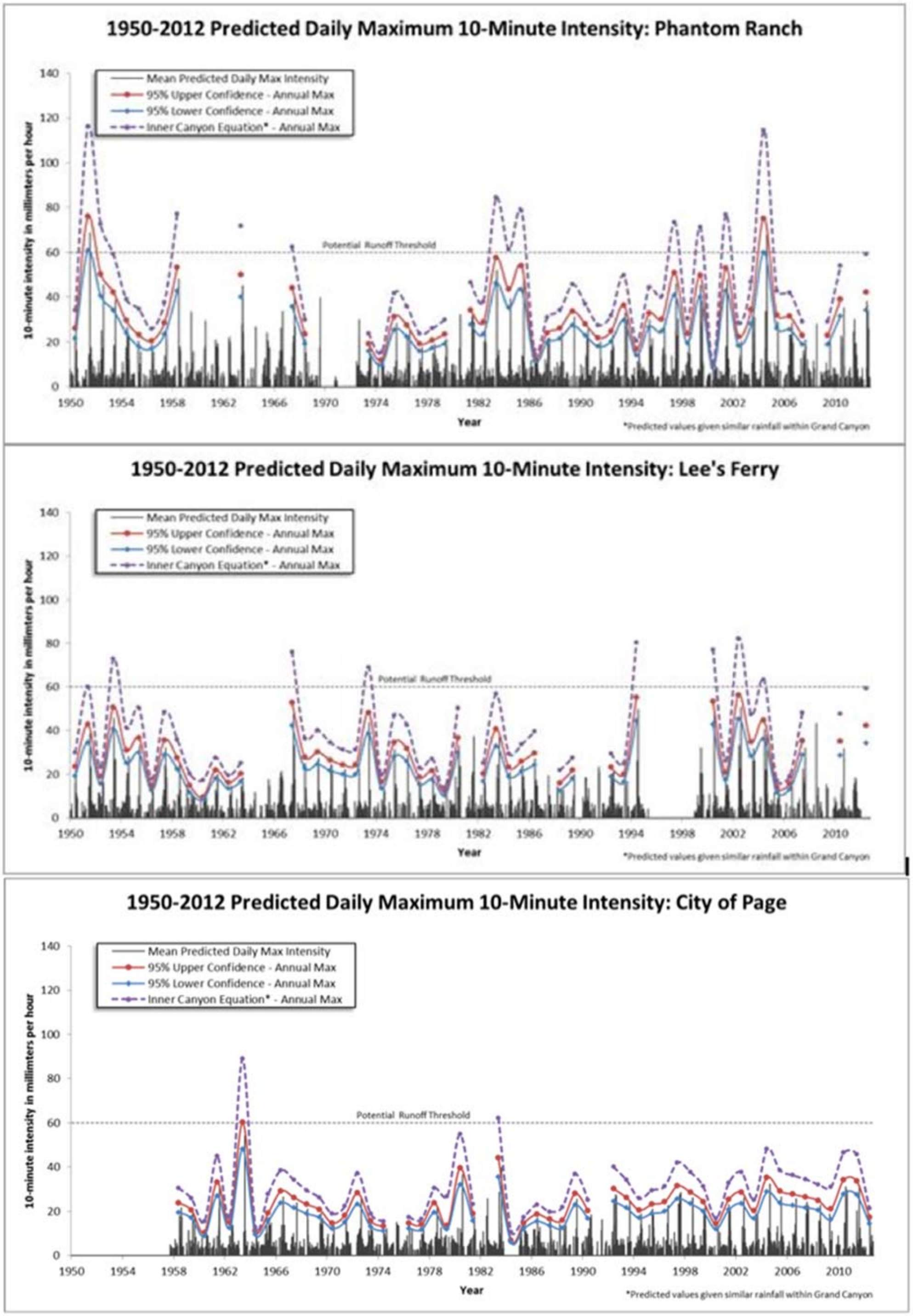
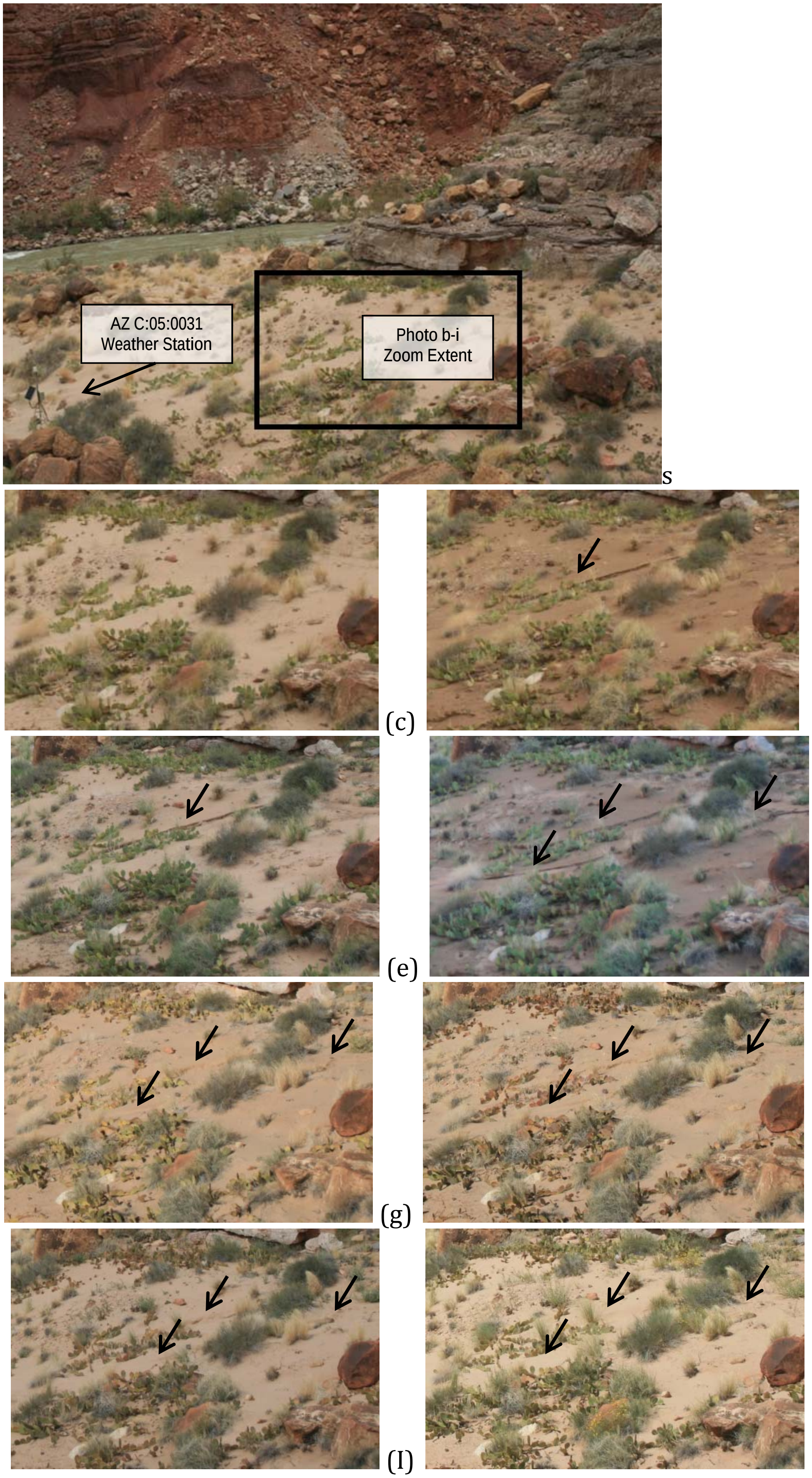


Figure 4. Comparison of rainfall intensity at Phantom Ranch, Lees Ferry, and Page, AZ, for the period 1950–2012, estimated using data from NOAA COOP weather stations. Data indicate that the Glen Canyon area experienced less-intense rainfall than did Marble–Grand Canyon (findings consistent with weather data collected for Project J), indicating that precipitation regime since 1950 has not predisposed Glen Canyon sites to greater erosion risk than those in Marble–Grand Canyon.



(a) s

(b) (c)

(d) (e)

(f) (g)

(h) (I)

(j)

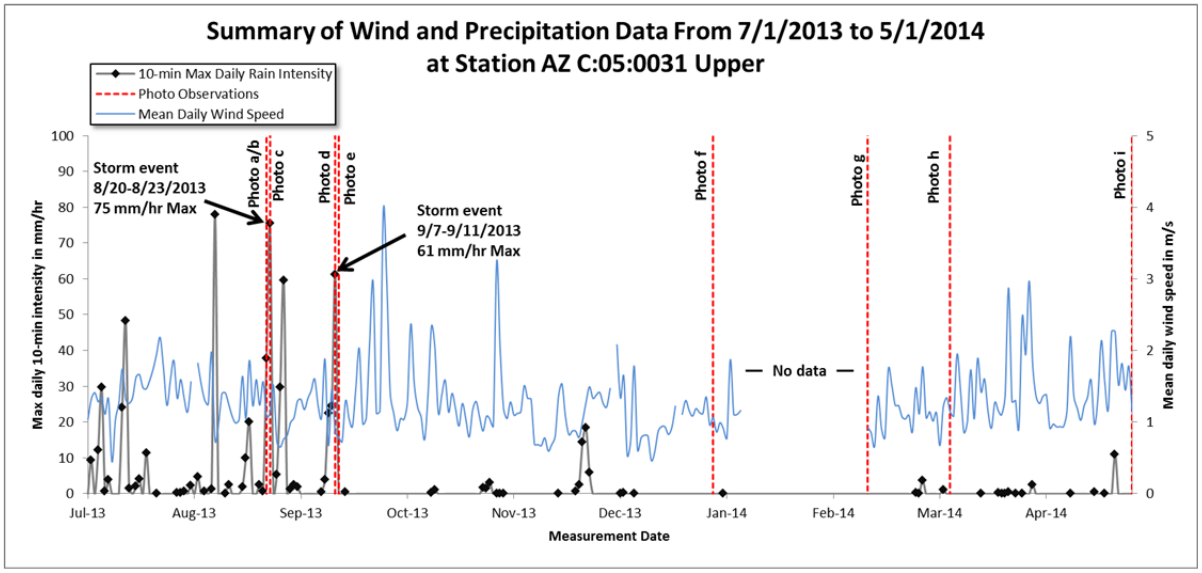
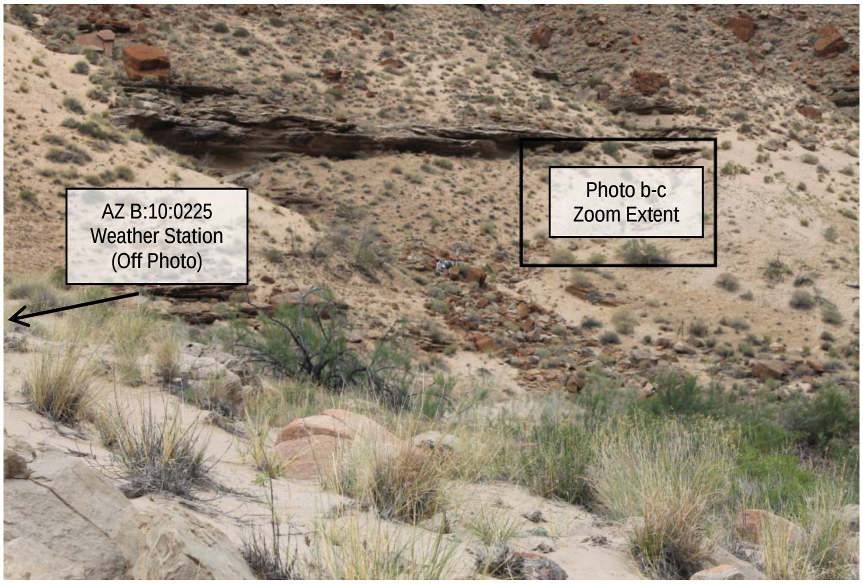


Figure 5. Select stationary camera photos from Site AZ C:05:0031. **(a)** Is a photograph of the AZ C:05:0031 site location on 8/22/2013 showing the proximity of the weather station to the area of interest in (b)-(i). **(b)** Zoomed photo extent on 8/22/2013 between 1500 and 1600 hours (3 PM and 4 PM). **(c)** Zoomed photo extent on 8/23/2013 between 0700 and 0800 hours. Arrow indicates apparent erosional feature. **(d)** Zoomed photo extent on 9/11/2013 between 15000 and 1600 hours. Arrow indicates previously identified erosional feature. **(e)** Zoomed photo extent on 9/12/2013 between 0700 and 0800 hours. Arrows indicate previously identified and new erosional features. **(f)** Zoomed photo extent on 12/30/2013 between 1300 and 1400 hours. Arrows indicate previously erosional features. **(g)** Zoomed photo extent on 2/13/2014 between 1400 and 1500 hours. Arrows indicate previously erosional features. **(h)** Zoomed photo extent on 3/9/2014 between 1300 and 1400 hours. Arrows indicate previously erosional features. **(i)** Zoomed photo extent on 5/1/2014 between 1300 and 1400 hours. Arrows indicate previously erosional features. **(j)** Time-series plot of maximum daily 10-minute rain intensity and mean wind speed recorded at the AZ C:05:0031 weather station. Rainfall events believed to be associated with the development of erosional features observed in (c) and (e) have been noted.



(a)

(b)

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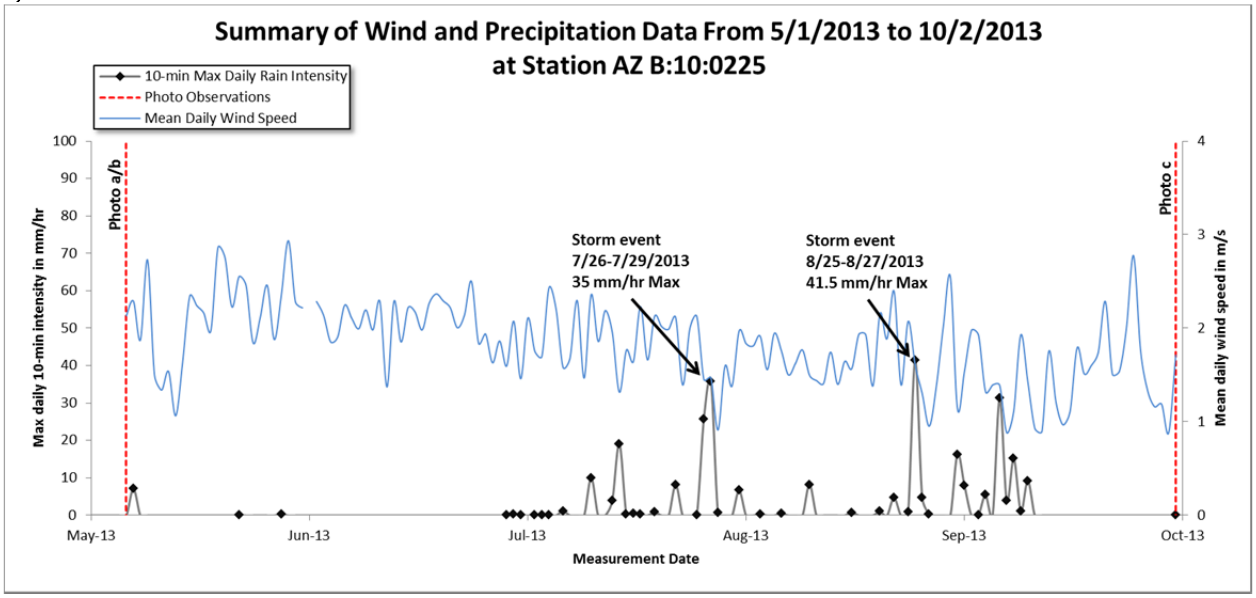

Figure 6. Select stationary camera photos from Site AZ B:10:0225. **(a)** Is a photograph of site AZ B:10:0225 on 5/6/2013 showing the approximate direction to the weather station and the location of the area of interest in (b)-(c). **(b)** Zoomed photo extent on 5/6/2013 between 1400 and 1500 hours. **(c)** Zoomed photo extent on 10/2/2013 between 1200 and 1300 hours. Arrows indicate apparent erosional features. **(d)** Time-series plot of maximum daily 10-minute rain intensity and mean wind speed recorded at the B:10:0225 weather station. Rainfall events believed to be associated with the development of erosional features observed in (c) have been noted.

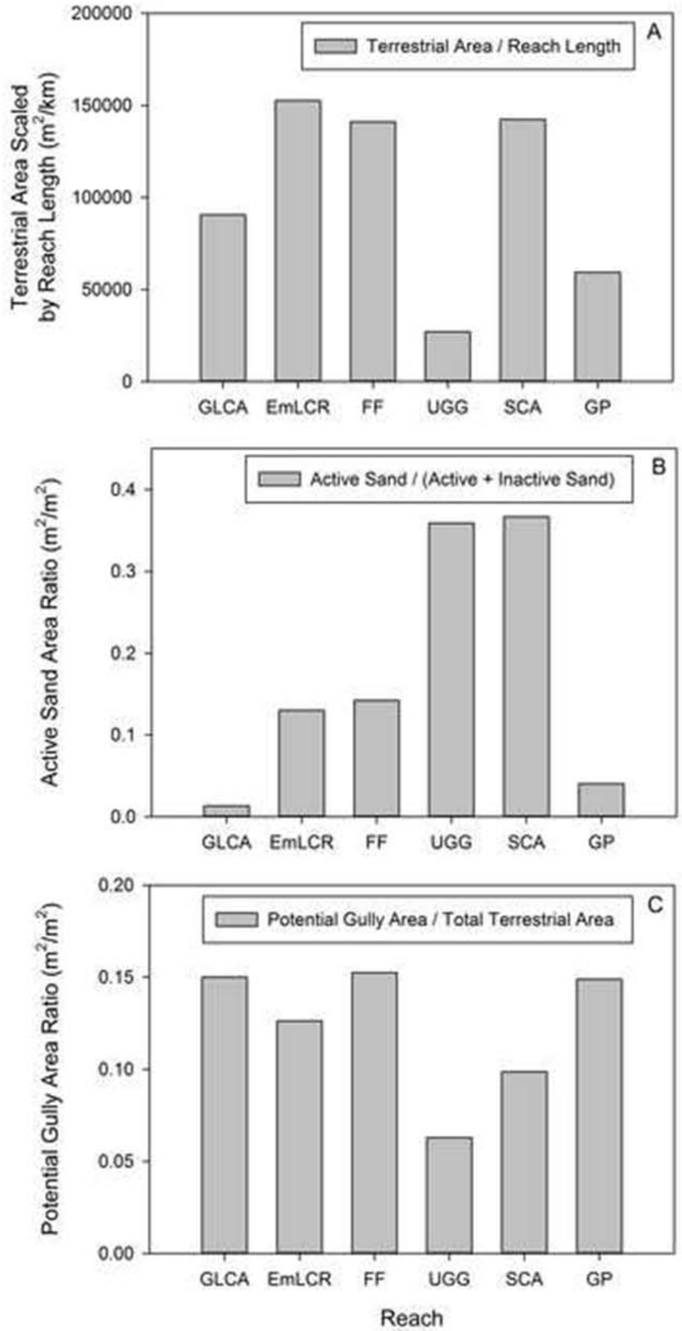

Figure 7. (A) Terrestrial area of Colorado River-derived sediment between the contemporary active channel of stage elevation 45,000 cfs and the upslope transition to bedrock or talus (reaches are wider when terrestrial area is larger), scaled by reach length. (B) Active aeolian sand area ratio. (C) Potential gully area ratio, summarized by reach. See Sankey and Draut (2014) for complete description of methods and findings.

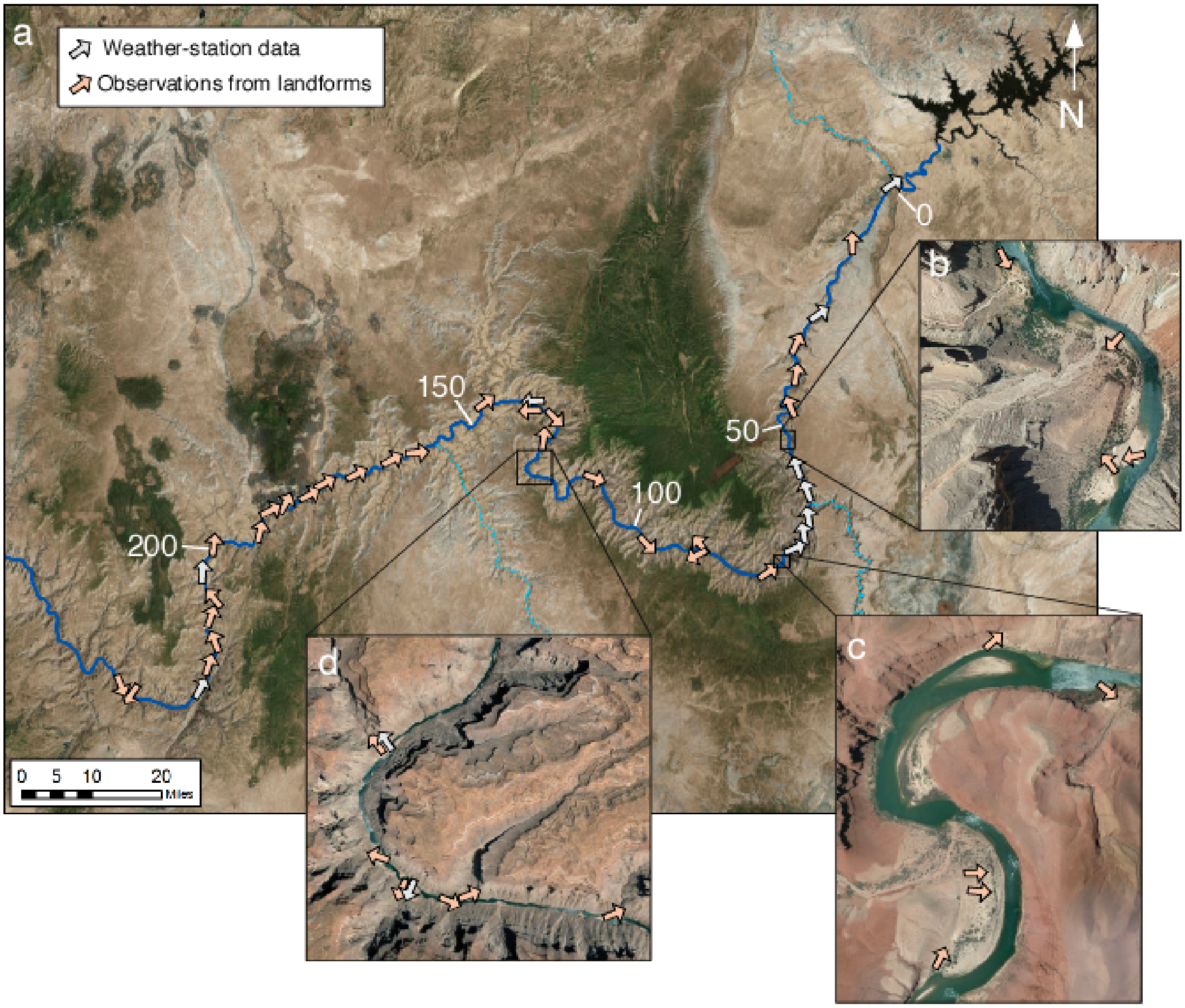

Figure 8. (a) Dominant wind directions inferred in Marble-Grand Canyon from weather-station measurements (gray arrows) or geomorphic features (pink arrows). River miles, measured downstream from Lees Ferry, in white text. Throughout most of the canyon a wind direction oriented toward upstream prevails, although with local variations particularly around confluences of large tributaries such as (b) Nankoweap and (c) Unkar; and (d) tight bends in canyon orientation. For clarity, additional observations that duplicated those shown in (a) were omitted, including approximately 40 locations between RM 65 and 71 and approximately 15 locations between RM 170 and 225. This graphic represents the current, most comprehensive understanding of dominant wind directions throughout the canyon, and although local variations are illustrated for (b), (c), and (d), there are probably also many other locations of high local variability that have not been observed or studied to date.

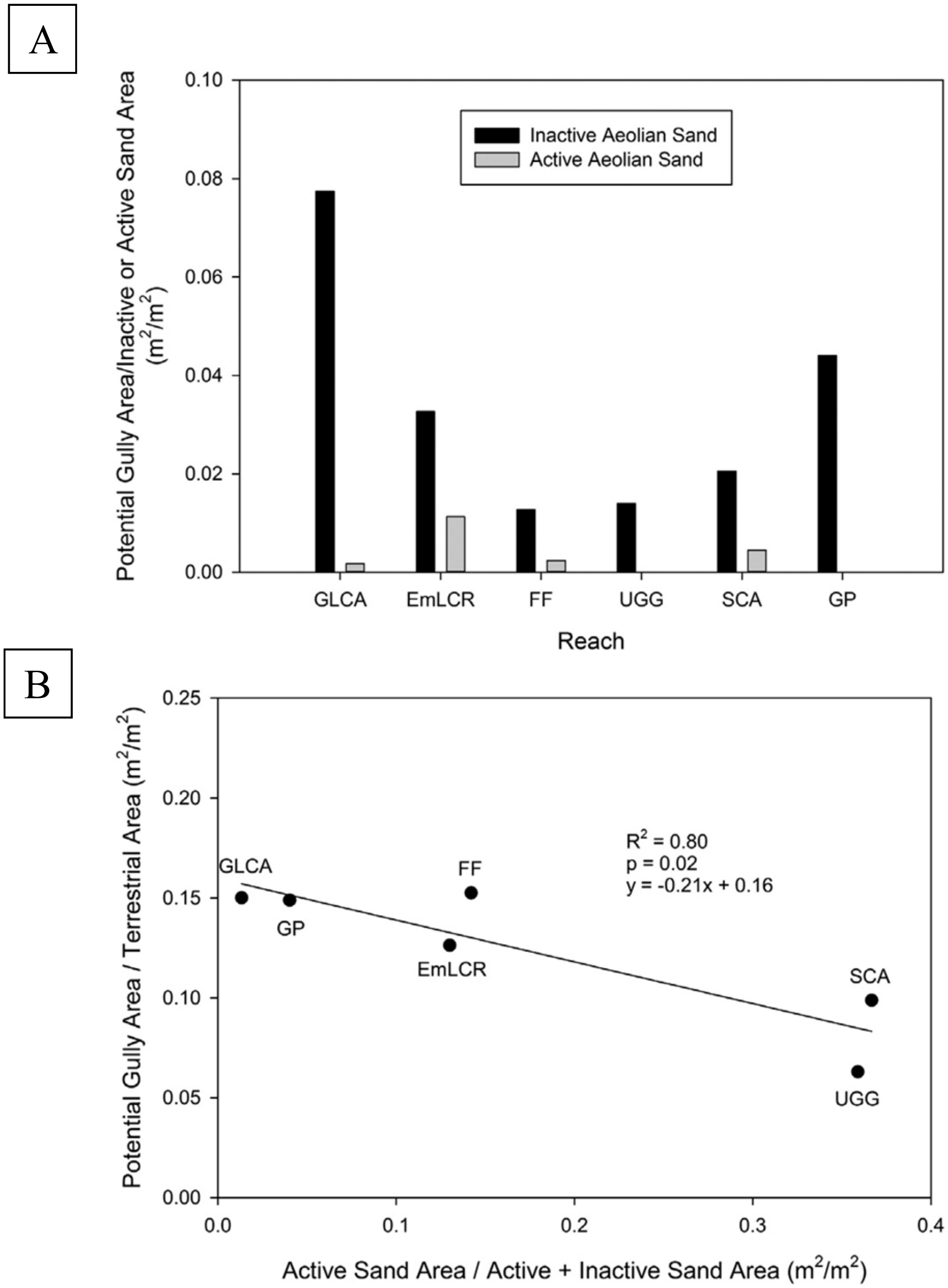

Figure 9. A. Inferred (remotely sensed) potential gully area per mapped sand unit (active or inactive with respect to aeolian sand transport) for the six study reaches. Comparison of the potential gully area within active or inactive aeolian sand indicated that there was significantly more gully area within inactive sand units than active sand units (paired t-test p=0.03). **B.** Relationship of potential gully area ratio and active sand area ratio by reach. See Sankey and Draut (2014) for complete description of methods and findings.

Project and Title			
Project K: GCMRC Economist and Support			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Lucas Bair, USGS, GCMRC
Email	*svanderkooi@usgs.gov*		
Telephone	(928) 556-7100		

The Grand Canyon Monitoring and Research Center hired Lucas Bair in FY13. The funding that was received in FY13–14 supported his salary as well as travel and training. Based on guidance from the AMWG, TWG, and GCDAMP, work activities were identified throughout FY14.

In FY14, Mr. Bair and cooperating researchers initiated mission critical recreational economics research with carryover funds from the FY13–14 Biennial Work Plan, including delivery of Technical Workgroup presentations to familiarize GCDAMP stakeholders with the subject and highlight benefits to the program, development of survey instruments for Department of Interior and Office of Management and Budget review, and coordination with Arizona Game and Fish Department and Grand Canyon National Park on sampling design.

Mr. Bair developed a conceptual research program plan for mission critical socioeconomic issues faced by the GCDAMP for the FY15–17 Triennial Work Plan. The proposed research was developed through collaboration with stakeholders, science advisers, sister agencies, and cooperators/collaborators.

Mr. Bair consulted federal agencies and scientific colleagues on matters associated with river science and river management in other river segments or systems including serving as the lead reviewer of the LTEMP EIS power system analysis and utility rate analysis, and GCMRC review of the National Park Service passive use economics survey.

Project K	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$154,500	$24,000	$1,000	$0	$0	$20,361	**$199,861**
Actual Spent	$105,284	$2,248	$110	$241,305	$0	$19,449	**$368,396**
(Over)/Under Budget	**$49,216**	**$21,752**	**$890**	**($241,305)**	**$0**	**$912**	**($168,535)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Overbudgeted personnel costs and reduced travel.
Cooperative agreement with U of Montana for Angler Intercept Survey with FY13 carryover and FY14 salary and travel efficiencies.

Project and Title			
Project M: USGS Administration			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Scott VanderKooi, USGS, GCMRC
Email	*svanderkooi@usgs.gov*		
Telephone	(928) 556-7376		

During the Fiscal Year 2014, this budget covered the salaries for the communications coordinator, librarian, and budget analyst, as well as monetary awards for GCMRC personnel. The vehicle section covers the GSA vehicles that all of GCMRC use for travel and field work. The money was used for the monthly lease fee, mileage cost, and any costs for accidents and damages. This project also helps pay leadership personnel salaries, some travel and training for the Chief, Deputy Chief, and salaries for two program managers. This section also covers the costs of IT equipment for GCMRC. Logistics base cost covers salaries and travel/training.

Project M	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$868,800	$52,500	$163,000	$73,700	$0	$125,203	**$1,283,203**
Actual Spent	$623,968	$19,462	$139,797	$37,316	$0	$89,961	**$910,504**
(Over)/Under Budget	**$244,833**	**$33,038**	**$23,203**	**$36,384**	**$0**	**$35,242**	**$372,699**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Obligated the majority of the GCMRC Chief's FY14 salary to Utah State University in FY13 & Budget Analyst salary paid by USGS.
Sequestration/Campaign to Cut Waste reduced travel.
Coop to NAU was only partially funded in FY14, the rest has been funded in FY15.

Logistics	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$251,300	$14,700	$973,600	$0	$0	$140,608	**$1,380,208**
Actual Spent	$240,045	$1,172	$1,362,925	$0	$0	$181,958	**$1,786,100**
(Over)/Under Budget	**$11,255**	**$13,528**	**($389,325)**	**$0**	**$0**	**($41,350)**	**($405,892)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*

Sequestration/campaign to cut waste limited overtime and travel.
Conducted additional river trips and higher helicopter rates due to BOR helicopter major maintenance.
Had to extend the old river operations contract while negotiating the new contract and then had to fund the new contract.

Project and Title			
Project N: Incremental Allocations in Support of Quadrennial Overflights			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	
Email	*svanderkooi@usgs.gov*		
Telephone	(928) 556-7376		
In FY14, there was no money allocated nor was an overflight conducted.			

GIS	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.343%	Total
Budgeted Amount	$668,754	$1,800	$199,028	$58,453	$0	$100,390	**$1,028,425**
Actual Spent	$557,484	$118	$136,282	$171,860	$0	$83,863	**$949,606**
(Over)/Under Budget	**$111,270**	**$1,683**	**$62,746**	**($113,407)**	**$0**	**$16,527**	**$78,819**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Received additional funds from DOD for Phil Davis' salary. Carryover will be used for his salary in FY15. No contribution to overflight fund. Sent funds to NAU for Photogrammetry and Tech Spt for Joint Research as a Cooperative Agreement.

Logistics Operating Expenses	
Satellite Communications	$15,000
Helicopter	$67,000
Log Spt Contracts (HS Spt, Mango, River Cans Cleaned	$928,000
Other Services	$17,000
Maintenance	$52,000
Misc. Supplies	$9,000
Food	$56,000
Vehicle Parts/Supplies	$88,000
Fuel	$26,000
Equipment	$75,000
WCF Deposit	$30,000
Total	**$1,363,000**