# Grand Canyon Monitoring and Research Center

# Fiscal Year 2015 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 2015 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 FY15 Work Plan for the GCDAMP.[1]

[1] This information is preliminary or provisional and is subject to revision. It is being provided to meet the need for timely best science. The information has not received final approval by the U.S. Geological Survey (USGS) and is provided on the condition that neither the USGS nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.

**Project 2: Stream Flow, Water Quality, and Sediment Transport in the Colorado River Ecosystem**



| | | | |
|---|---|---|---|
| **Program Manager** (PM) | David Topping | **Principal Investigator(s)** (PI) | David Topping, USGS, GCMRC<br>Ron Griffiths, USGS, GCMRC<br>Dave Dean, USGS, GCMRC |
| **Email** | *dtopping@usgs.gov* | | |
| **Telephone** | (928) 556-7396 | | |



**SUMMARY**


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 GCDAMP 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 HFE protocol. Details of this ongoing project (including descriptions of the data-collection locations) are provided in the GCMRC 2015–17 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 2015, this question was addressed through:

(1) Maintenance and continual updating of the database and website at *http://www.gcmrc.gov/discharge_qw_sediment/* or *http://cida.usgs.gov/gcmrc/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 5 peer-reviewed interpretive papers. The interpretive papers published during 2015 focused on: a physically based method for using multi-frequency acoustics to measure suspended-sediment concentration and grain size in the Colorado River, how dam operations affect the sediment resources within Marble Canyon, why direct measurements are required to know the

sediment supply from smaller tributaries that have been deemed possible important suppliers of sand based on estimates, the design of a database and user-interactive web site to serve the data provided by this project.

Most of the subsidiary science questions listed in the 2015–17 Triennial Work Plan have their basis in the above fundamental question. Thus additional publications completed during the remaining period of the 2015–17 Work Plan will use the data collected during the period of the 2013–14 work plan and 2015 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 2015–17 Triennial Work Plan:

"During FY15–17, we propose to continue to serve project data and user-interactive sediment budgets through this website. In addition, work will continue to add additional data streams to this website and expand the user-interactive tools. Chief among the new tools to be developed are user-interactive duration curves. Duration curves are one of the most useful and powerful tools for conveying complicated hydrologic and water-quality datasets. We have successfully used duration curves to analyze changes in stage, discharge, and turbidity for various periods and reaches in the CRe (Topping and others, 2003; Voichick and Topping, 2014). Once the duration-curve tool is added to the website, the user will be able to plot the percentage of time any parameter served on our website is equaled or exceeded for any user-specified period.

In addition to the collection and serving of the basic stream-flow, water-quality, and sediment-transport data, time is spent in this project interpreting the data and reporting on the results and interpretations in peer-reviewed articles in the areas of hydrology, water quality, and sediment transport. The interpretive papers published by this project are designed to address key questions relevant to river management, especially to management in the GCDAMP (see proposed publication list below). The data collected in this project form the basis of the collaborations listed in the next section. All of the projects funded in the areas of physical science, biology, and socioeconomics require the data collected by this project. During FY15–17, several peer-reviewed journal articles and USGS reports will be published on the following topics:

- Analysis of Paria River and Little Colorado River hydrology 1920s-present with implications for long-term sediment management in the CRe (*lead author Topping, to be completed during FY15–16*)
- Geomorphology, hydraulic geometry, and sediment transport in the Paria River (*lead author Topping, to be completed during FY17*)
- Analysis of a decade of measurements of sediment transport in the lesser tributaries: Do the lesser tributaries matter to CRe sediment mass balance? (*lead author Griffiths, to be completed during FY15*)
- Multiple articles on the linkage among hydrology, sediment transport, and geomorphic change in the Little Colorado River, with implications for aquatic and riparian habitat in the lower Little Colorado River (*lead author Dean, to be completed during FY16–17*)

- Evaluation of effects of 2008-2016 dam operations on sediment storage dynamics within the CRe (*lead author Topping, to be completed during FY17*)

In addition to these major publications, additional data reports and interpretive reports will be published by project personnel and USGS cooperators."

This project is on track to complete on schedule all of the above promised products as well as the data products listed in the 2015–17 Triennial 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 7 mainstem monitoring locations and 8 major tributary locations and 8 lesser tributary monitoring locations during FY15 (suspended sediment is monitored at a subset of 5 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 continued ability to serve data at a 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 in Flagstaff go down. The design and programming of new features for the website occupied most of the time on this project during 2015. The existence of the database and website has allowed much greater efficiency and productivity in this project (with time for many more peer-reviewed interpretive publications) during the first year of 2015-17 work plan than existed in the past.

Specifically, progress was made on many fronts within the Streamflow, Water Quality, and Sediment Transport Project during FY15, with multiple accomplishments.

1) Much effort was spent during FY15 on refinements to the database and website, with many new datasets uploaded. 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 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, the web site allows user interactive sand budgets to be constructed for all 6 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.

Work began during FY15 on the programming and design of the new "duration-curve tool" promised in the 2015–17 work plan. This tool should be completed and released on the website before the end of FY16. Work also began on the development of an ftp site within the website at which all data from sediment-transport research river trips will be available to be downloaded.

The servers supplying data to this website are housed at 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 automatic pump samplers and from the last of multiple large floods on the Paria River in summer-fall 2015 (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 2014 HFE 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. All discharge measurements from the 2014 HFE have been processed with stage-discharge ratings verified or adjusted as necessary; all suspended-sediment and bed-sediment samples from the 2014 HFE have been processed and uploaded to the website. These can be plotted or downloaded on demand.

4) 15-minute stage, discharge, and water temperature data (updated in realtime) and other QW data from the 9 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) 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-**c**ollection location.

6) Five major peer-reviewed reports were published during 2015: a journal article published in the American Geophysical Union journal EOS - Transactions of the American Geophysical Union, and four Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings papers. These reports are listed below.

7) Substantial progress was made on the publication a book describing a new physically based method for making accurate continuous measurements of suspended sediment in rivers using acoustics.  This book has been reviewed and revised.  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."  This book should be approved as a U.S. Geological Survey Professional Paper by mid-winter.

8) Two abstracts were published and presented at the 2014 Fall Meeting of the American Geophysical Union and three abstracts were submitted for presentation at the 2015 Fall Meeting of the American Geophysical Union.  An additional extended abstract was also submitted for the 2016 River Flow Conference, an international meeting to be held in 2016 in Saint Louis, MO.

9) Substantial progress was made on research aimed at better understanding sediment transport and its linkages to geomorphology in the Little Colorado River basin and sediment delivery from the Little Colorado River to the CRE.  The first part of this research effort has been largely focused on Moenkopi Wash, a tributary to the Little Colorado River that was historically responsible for the highest sand concentrations measured in the Little Colorado River.  This research is being conducted because recent data suggest that the sand delivery from the Little Colorado river to the CRE has decreased over time and that the loss of Moenkopi Wash as a major sand supplier to the Little Colorado River could be a chief cause of this reduction.  This research has led to an abstract that will be presented at the 2015 Fall Meeting of the American Geophysical Union and will lead to a peer-reviewed publication to be completed during FY 2016.

10) Continued 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 2015, 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 2016–-2017 period of the 2015–17 workplan.  As of December 2015, the only unit-value stage and discharge dataset remaining to be uploaded is the 1924–1996 period of record at 09382000 Paria River at Lees Ferry, AZ.  Interpretive journal articles utilizing these data to aid in river management will be published as described in the 2015–17 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).

| |
|---|
| 09401280 Moenkopi Wash near Tuba, AZ Entire period of station record processed and available on website (1926-1941).<br>09401400 Moenkopi Wash near Tuba City, AZ Entire period of station record processed on website (1941-1954, 1965-1977).<br>09401500 Moenkopi Wash near Cameron, AZ Entire period of station record processed and available on website (1954-1965).<br>09402000 Little Colorado River near Cameron, AZ Entire period of station record processed on website (1947-present).<br>09402500 Colorado River near Grand Canyon, AZ Entire period of station record processed on website (1923-present).<br>09403000 Bright Angel Creek near Grand Canyon, AZ Entire period of station record processed on website (1924-1974, 1991-1993).<br>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 maintained 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/*<br><br>*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* |
| Abstracts presented | 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. | FY15 | Dec. 2014 | Dec. 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: Abstract EP32A-06 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec. |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | American Geophysical Union abstract for 2014 Fall Meeting entitled "Deciphering Paria and Little Colorado River flood regimes and their significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon." Presentation made at AGU in December 2014. | FY 15 | Dec. 2014 | Dec. 2014 | Jain, S., Topping, D.J, and Melis, T.S, 2014, Deciphering Paria and Little Colorado River flood regimes and their significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon: Abstract H51J-0743 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec. |
| Journal articles and other major pubs | Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Physically based method for measuring suspended-sediment concentration and grain size using multi-frequency arrays of single-frequency acoustic-Doppler profilers" | FY15 | April 2015 | April 2015 | Topping, D.J., Wright, S.A., Griffiths, R.E., and Dean, D.J., 2015, Physically based method for measuring suspended-sediment concentration and grain size using multi-frequency arrays of single-frequency acoustic-Doppler profilers: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, pp. 834-846, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf. |
| | Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Reconciliation of flux-based and morphologic-based sediment budgets" | FY15 | April 2015 | April 2015 | Grams, P.E., Buscombe, D., Topping, D.J., Hazel, J.E., Jr., and Kaplinski, M., 2015, Reconciliation of flux-based and morphologic-based sediment budgets: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 1144-1155, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf. |
| | EOS, Transactions of the American Geophysical Union journal article entitled "Building sandbars in the Grand Canyon" | FY16 | June 2015 | June 2015 | Grams, P. E., Schmidt, J. C., Wright, S. A., Topping, D. J.,Melis, T. S., and Rubin, D. M. ,2015, Building sandbars in the Grand Canyon, EOS, Transactions of the American Geophysical Union, v. 96, n. 11, p. 12–16, https://eos.org/features/building-sandbars-in-the-grand-canyon |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Inaccuracies in sediment budgets arising from estimations of tributary sediment inputs: An example from a monitoring network on the southern Colorado Plateau" | FY15 | April 2015 | April 2015 | Griffiths, R.E., and Topping, D.J., 2015, Inaccuracies in sediment budgets arising from estimations of tributary sediment inputs: An example from a monitoring network on the southern Colorado Plateau: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 583-594, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf. |
| | Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "User-interactive sediment budgets in a browser: A web application for river science and management" | FY15 | April 2015 | April 2015 | Sibley, D., Topping, D.J., Hines, M., and Garner, B., 2015, User-interactive sediment budgets in a browser: A web application for river science and management: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 595-605, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf. |

| **Project 2** | **Salaries** | **Travel & Training** | **Operating Expenses** | **Cooperative Agreements** | **To other USGS Centers** | **Burden 13.633%** | **Total** |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $619,000 | $5,000 | $50,000 | $0 | $480,000 | $91,886 | **$1,245,886** |
| **Actual Spent** | $592,994 | $9,828 | $45,520 | $10,795 | $453,381 | $88,712 | **$1,201,229** |
| **(Over)/Under Budget** | **$26,006** | **($4,828)** | **$4,480** | **($10,795)** | **$26,619** | **$3,174** | **$44,657** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $$59,500, will be used to offset FY16 & FY17 shortages.
$10,800 Cooperative Agreement to Northern Arizona University - LCR Geomorphology.

| **Project 3: Sandbars and Sediment Storage Dynamics: Long-term Monitoring and Research at the Site, Reach, and Ecosystem Scales** | | | |
|---|---|---|---|
| **Program Manager** (PM) | Paul Grams | **Principal Investigator(s)** (PI) | Paul Grams, USGS, GCMRC<br>Daniel Buscombe, USGS, GCMRC<br>Erich Mueller, USGS, GCMRC<br>Joel Sankey, USGS, GCMRC<br>Joseph Wheaton, Utah State Univ.<br>Brandon McElroy, Univ. Of Wyom.<br>Mark Schmeeckle, Ariz. State Univ.<br>Joe Hazel, No. Ariz. Univ.<br>Matt Kaplinski, No. Ariz. Univ.<br>Keith Kohl, USGS, GCMRC |
| **Email** | *pgrams@usgs.gov* | | |
| **Telephone** | (928) 556-7385 | | |

**SUMMARY**

**Introduction**

In FY15, scientists from Project 3 collected all of the data on sandbars and in-channel sediment storage that was described in the FY15–17 Triennial Work Plan (TWP) during one project-specific downstream river trip and additional short trips to Diamond Creek and Lees Ferry. 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. Below, we summarize specific accomplishments by project element.

**Summary of Progress by Project Element**

**<u>3.1.1 Sandbar monitoring</u>** – Joe Hazel, Matt Kaplinski, Rob Ross, Bob Tusso, Tim Andrews, Paul Grams, Daniel Buscombe, Erich Mueller

Sandbar and campsite monitoring was completed by conducting topographic surveys at 47 long-term monitoring sites in September/October 2014 and September/October 2015. The repeat topographic surveys show that, in October 2014, approximately 11 months after the 2013 HFE (the 2$^{nd}$ HFE released as part of the new HFE protocol), the median size of sandbar monitoring sites and associated campsite area had continued to increase. The surveys demonstrated that the HFE protocol was resulting in net deposition and the erosional trend evident in the 1990s and early 2000s was being offset by sand being redistributed to the channel margins above stage levels reached by normal dam operations. Sandbar response to recent HFEs was reported in a 2015 publication [Ref.

2], which was originally an FY16 product in the work plan. Data from the 2015 monitoring trip are currently being processed and will be available at the time of the January 2016 Annual Reporting meeting.

Changes in campsite area are tracked by measuring the areas within camp boundaries that are used for camping. These surveys have been collected annually from 1998 to 2015. Previous analysis has shown that erosion and deposition of sand are the primary mechanisms that cause either increases or decreases in the 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. Results from the 2013, 2014, and 2015 surveys will be presented at the January 2016 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*), the 2013 HFE (*http://www.gcmrc.gov/gis/sandbartour2013/index.html*), and the 2014 HFE (*http://www.gcmrc.gov/gis/sandbartour2014/index.html#*), were posted to the web for public viewing within weeks of the water receding. Immediately after the 2014 HFE, 58% of the sandbars were larger than their pre-HFE condition (14% were smaller, and 29% exhibited negligible change). Three months later, 30% were still enlarged, while 20% were smaller and 50% about the same size. By October 2015, eleven months after the 2014 HFE, 58% of the sandbars were back to the pre-HFE size, while 42% were smaller (none of the sandbars were still substantially larger than they were before the 2014 HFE).

Development of a method to use the remote camera images to measure sandbar area at monthly intervals is ongoing. Stable rectifications for 22 mile and 30 mile sandbars are complete. In FY15, data were collected at almost all remote camera locations to allow registering the images and correction for camera movements during maintenance operations. This work was presented at a professional meeting and described in a proceedings paper [Ref. 11]. Difficulties in developing methods for automatically detecting sandbars from images using image processing techniques has delayed the submission of the planned journal article on the development of these methods. The development of a reliable unsupervised (fully automated) or partially supervised (minimal user input) method to segment sandbars in rectified images is crucial to the success of this technique because manual segmentation of sandbars is slow and subjective. We aim to resolve these difficulties, finalize and publish the method this coming year.

A comprehensive report on the long-term sandbar monitoring data [Hazel and others, *in prep*] was expected to be completed in 2015. Substantial progress was made in 2015, including a revision of all stage-discharge relations using data collected between 2006 and 2014. The relations, previously published in a 2006 Open-File Report, are now available to researchers as an easily accessed

Lookup Table in Excel. The migration of the twenty-five year database from outdated survey software to a modern ESRI geodatabase 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/). Now that database integrity has been solidified, we anticipate the report will be ready for review by January 31, 2015.

**3.1.2 Sandbars from Remote sensing** – Joel Sankey, Rob Ross, Paul Grams

*Sand Classification*
In FY15 we hired a geospatial data analyst to complete final edits of classifications of exposed sand above the elevation of the 8,000 $ft^3/s$ stage (high-elevation sand) within more than 1,300 large eddies along the Colorado River in the overflight imagery acquired in 2002 and 2009. Change detection analysis of these datasets is underway and we will present the results at the Annual Reporting Meeting in winter of 2016. We will analyze the changes as a function of landform units within the geomorphic basemap (produced in this project element during FY15). In FY16 we will transition to producing a classification of high-elevation sand within the more than 1,300 large eddies in the overflight imagery acquired in 2013.

*Analysis of Sandbar Area in Select Reaches, 1935–2009*
We compiled existing geomorphic maps derived from aerial imagery for six reaches between Lees Ferry (River mile [RM] 0) and Furnace Flats (~RM 70), spanning dates from 1935 to 1996 at irregular temporal intervals. The existing maps for April 1996 (post high-flow experiment [HFE]) were updated with shorelines derived from 2002, 2005, and 2009 imagery, extending the analysis to a 74-year period.

Sand area was calculated from these maps, and was tabulated for three periods, comprising pre-dam (1965), post-dam/pre-high-flow experiment (HFE) (1973-March 1996), and post-dam/post-HFE (April 1996-2009) datasets. Comparison of area of exposed sand measured from imagery to area of exposed sand measured by total station survey at 15 long-term monitoring sites measured within two weeks of aerial imagery collection shows a root-mean square (RMS) error of about 2%, indicating excellent agreement between the two data sets.

Sandbar area is generally greater in the images collected during the post-dam/post-HFE period than in the post-dam/pre-HFE period, and there is a negative correlation between sandbar area and time elapsed since the last controlled flood. The average responses only show the mean among the image collection dates, and are not necessarily representative for the time period. Because of this sensitivity to time of image acquisition and because all images were collected at different intervals relative to the most recent controlled flood, it is not possible to identify a trend in sandbar area with time between 2002 and 2009. The apparent trend between 2002 and 2009 is most likely attributable to the shorter elapsed time between the 2008 controlled flood and the 2009 images.

Because the volume of sand above the reference discharge of 227 m3/s is only a small fraction of the sand in storage, and sandbar area can increase without increases in volume, changes in sandbar area determined from analysis of aerial images cannot be interpreted to reflect changes in total sand storage. Thus, although the images showed larger area of sandbars in the post-dam period with controlled floods than in the post-dam period before controlled floods, this does not mean that there was more sand in the system during this period.

This study involves only a subset of the reaches comprising the entire length of the Colorado River in Marble and Grand Canyons, downstream from Glen Canyon Dam. These findings may not, therefore, be representative of the entire system. These findings are reported in Ross and Grams [Ref. 9].

*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 1,368 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.

*Development of Geomorphic Base Map*

We have completed draft geomorphic base maps for four reaches of the Colorado River, from Lees Ferry (RM 0) to National Canyon (RM 167), delineating deposits, features related to deposits, and channel proximity to these deposits and features. These features are created from 2009 imagery, with features created as polygons overlaying imagery using ESRI ArcGIS software. These maps were field-checked in September and October of 2015 and final editing is in progress. Following completion of these maps, the reaches between RM 167 and 270 and between Glen Canyon Dam and Lees Ferry will be mapped.

These geomorphic base maps will be used to provide information about canyon-wide distribution and characteristics of eddies, sandbars, and other features to assess variability in sandbar area and population, representativeness of other monitoring efforts, and groupings of sandbars by morphology and flood response. Assessment of the variability in sandbars will be done, in part, by integrating the geomorphic base maps with the aerial orthophoto analysis being conducted on ~1,400 EDZs between Lees Ferry and Pierce Ferry, making it possible to relate changes to specific sandbar morphology.

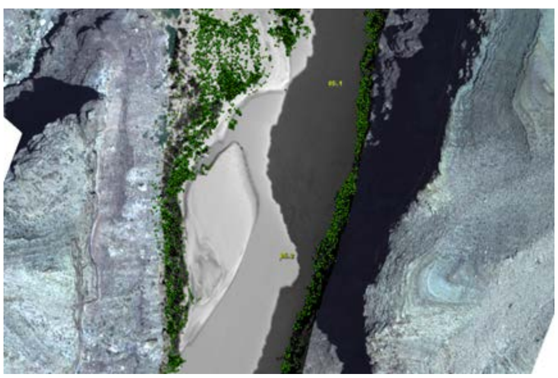
**3.1.3 Rapid topographic surveys with digital images using structure-from-motion (SFM) photogrammetry** – Joseph Wheaton, Rebecca Rossi, Daniel Buscombe, Paul Grams

The objective of this work element is to develop and evaluate a methodology for low-cost and rapid monitoring of sandbars with a camera using structure-from-motion (SFM) multiple-view-stereo photogrammetry, to support geomorphic change detection. Work on the project began in September of 2014 and we hired a graduate research assistant, Rebecca Rossi, to lead this effort. Rebecca has had an incredibly productive first year on the project and has tested and refined image acquisition and post-processing methods and completed three river trips to acquire imagery and ground control data. In Fall 2014, we experimented with several different camera platforms, acquisition techniques and carried out a successful field campaign in conjunction with the sandbar mapping trip. Over the Fall and Winter, Rebecca post processed the data collected on that trip and compared the tradeoffs between different sampling techniques, lighting conditions, and post-processing environments. Based on her findings, she drafted a field acquisition protocol to test the extent to which such acquisition could be successfully undertaken through citizen science efforts. She trained a number of volunteers and teenagers and tested these methods on an early summer Grand Canyon Youth trip. Over the summer, she analyzed those data as well as numerous experiments she conducted in Logan, Utah to refine and improve the sampling protocol. She was able to isolate techniques that didn't work and/or were less efficient, and hone in on a protocol in which two individuals can sample most sandbars in 30 to 90 minutes, which was done in parallel with traditional NAU total station surveys at each sandbar on the fall 2015 sandbar monitoring trip. Now that her acquisition techniques have been refined, she has a draft field acquisition protocol and is working on her first manuscript to document the workflow. She has been working on a series of accuracy assessments and comparisons with total-station surveys that will result in error models for each of the SFM surveys. The final protocol will lay out clear guidelines for how to robustly and rapidly acquire imagery to support SFM with a pole-mounted camera, and then post process data to produce deliverables including a cleaned high resolution point cloud, bare-earth DEM, surface roughness map, orthorectified high resolution imagery, and an error model concurrent with the DEM.

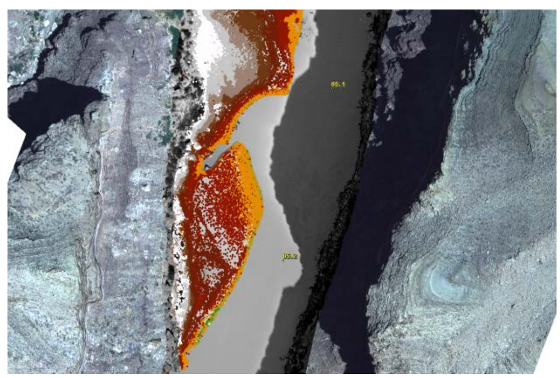
**3.1.4 Analysis of historical images at select monitoring sites** – Tom Gushue, Rob Weber, Joe Hazel, Paul Grams

As of September 2015, 12 of the 45 long-term sandbar monitoring sites have been processed using photogrammetry methods to extract digital terrain models (DTMs) from 1984 aerial photography. Terrestrial land surveys of these sites began in 1990, with some survey dates having bathymetric surveys beginning in 1996. The current project work to extend terrestrial measurements of these sandbar sites began in 2013, with four new sites scheduled to be processed each year. Site selection for performing photogrammetry work has been limited on the availability and number of ground control points (GCPs) for any one site. The GCPs must be collected as part of total station surveys that are the basis for the on-going sandbar site monitoring project. The remoteness and extreme environment of Grand Canyon places limits on field data collection efforts.

One of the most critical steps in the project workflow is the extraction of surface elevations from the orthorectified photographs. This is accomplished in ERDAS Imagine using their proprietary Automated Terrain Extraction (ATE) software module. For some sandbar monitoring sites, an insufficient number of elevations were being generated on the relatively flat, bright portions of the sandbars. In FY15, we obtained a demonstration license for a new version of the ATE software module. This new module includes more sophisticated settings and algorithms for deriving 3-D point clouds from stereo pair photography. Early results from using the new module are very promising with point cloud data containing hundreds to thousands of more points on the actual sandbars in the 1984 photography with the most improvement occurring on the relatively flat, low elevation portions of the exposed sandbar. Additional work is required to further refine the methods involved with using this new software. Once the new workflow is established, we will reprocess previously completed sites. Reprocessing will only involve running the new ATE module; most of the previous work (locating and converting 1984 images; define photogrammetric block; collecting, processing and assigning Ground Control Points, identifying and assigning Tie Points, solving block triangulation parameters, etc.) will not have to be redone.



Results from "old" ATE module (RM065)



Results from enhanced ATE module (RM065)

**<u>3.2. Sand Storage Monitoring</u> –** Paul Grams, Matt Kaplinski, Joe Hazel, Keith Kohl, Daniel 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 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’ (places with hard rock geology whose position can be considered stable) 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*

The acoustic bed-sediment classification method using Multi Beam Echo Sounder (MBES) data developed during the last workplan has been published [Buscombe and others, 2014a; 2014b], considerably refined and successfully applied to all data collected during channel mapping of RM30-61 during 2009 and again in 2012. This bed sediment grain size information has been factored into estimates of changes in sand storage, in order to better constrain uncertainties in calculated sediment budgets [Ref. 8]. The technique has now also been successfully applied to channel mapping data collected in RM0–30 during 2013. The theoretical development of acoustic methods for classification of bed sediments using MBES backscatter data has continued [Refs. 5 and 18] as well as computational developments [Ref. 3] that make the technique faster to implement and more amenable to widespread application. We have developed a new underwater camera system that will enable us to collect better underwater imagery for the purposes of calibrating and validating acoustic bed sediment classification methods for complex sediment mixtures (e.g. sand and gravel, gravel and boulders, sediment and vegetation, etc).

We have also developed and published a technique to classify bed texture using low-cost sidescan sonar [Refs. 4, 6 and 22]. In addition, we are developing an acoustic method by which to detect and classify submerged vegetation. To that end, we conducted fieldwork in Glen Canyon in December 2014 and again in October 2015 to collect concurrent sonar and underwater video data, in order to establish a baseline map of submerged vegetation. The acoustic method looks promising and if successful will enable large-scale mapping of benthic vegetation, which is a dominant control on the food base in Glen Canyon. We have begun work on a video-editing software tool specifically for vegetation mapping using merged sonar and underwater video data. In FY16, this work will also help us classify bed sediments reliably in the presence of significant coverage of submerged vegetation using both MBES and sidescan based techniques, by expanding our methods for mapping bed composition to include submerged vegetation.

In addition to developing a new underwater video system, we have collected grain size data using our existing underwater camera system during 2 visits to Western Grand Canyon this year (in support of project 3.4). We had decided to delay the planned report on grain-size measurements using the eyeball system, 2000 – present, until 3 things had happened: 1) a reanalysis of all sediment imagery collected to date with a consistent and updated analysis method; 2) a reorganization of all data in a consistent manner; and 3) the development of a new web-browser-based application for analyzing sediment imagery for grain size. These 3 tasks are now complete, so we are now able to start on the report, which will be completed within the first half of FY16.

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 [Ref. 8].

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

**3.3 Sandbar Modeling** – Erich Mueller, Mark Schmeeckle, Daniel Buscombe, Paul Grams

The goal of this project element is to improve our understanding of the factors that contribute to spatial variability in sandbar response to HFEs and other dam operational flows. In FY15, we began a systematic effort to document and quantify the controls on different site behavior, building on the work of Grams and others (2013) that identified different relations between discharge and sand volume at different sites. For this analysis, we have collaborated closely with ecologists from Project 11 on the retrospective analysis of coupled sandbar-riparian vegetation dynamics. Additionally, we recruited an externally funded Masters student from Delft University to model hydraulic-vegetation feedbacks on eddy sandbars in support of Projects 3.3 and 11.3. We have also continued to refine a new 3-dimensional Large Eddy Simulation (LES) model for eddy hydraulics (Alvarez, 2015; Alvarez and others, accepted pending revision), and applied the model to six sites in Lower Marble Canyon (LMC).

As an initial step in understanding spatial variability in bar response, we developed preliminary sandbar groupings of similar response and long-term evolution for the NAU monitoring sites. In FY15, we focused our efforts on eddies with well-defined reattachment bars, with particular focus on LMC. Our analysis showed that eddy sandbar behavior, in terms of HFE response and discharge-volume relations, was strongly linked to the degree of riparian vegetation establishment on bar surfaces. Geomorphic mapping of the entire LMC reach shows that the proportion of eddy area stabilized by vegetation is negatively correlated with water surface slope and the rate of stage change with discharge. Less vegetated sites are more dynamic; they tend to build open sandbars during HFEs, and show greater topographic variability in the eddy compared to the main channel. In contrast, deposition of open sandbars is limited where vegetation establishment has decreased channel width (c.f. Sankey and others, 2015). Changes in sand storage in the main channel are greater than storage change in the eddy at these lower gradient sites, and controlled floods tend to evacuate sand that has accumulated on the bed.

In light of these results, we developed LES hydraulic models for six sites in LMC exhibiting different fan-eddy geometries and different degrees of vegetation establishment. Those results demonstrate how both eddy geometry and bar stabilization can influence patterns of eddy hydraulics. For example, eddy velocities are greatest in the most dynamic eddies – those sites where sandbars build and erode rapidly. By contrast, eddy velocities are lower at sites with greater vegetation encroachment, and, in some cases, we see a fundamental change in eddy hydraulics resulting from channel narrowing in the eddy. Overall, these modeling results are consistent with our interpretation of the empirical data. Initial results from this work will be presented at the American Geophysical Union conference in December, 2015 and a journal article will be prepared in FY16. Further work will include a more detailed retrospective analysis of sandbar-vegetation response at selected bars in collaboration with Project 11.3, development of a simple predictive model of sandbar response (some initial development having occurred in FY15), and further implementation of flow modeling specific to both vegetation effects (Delft student) and channel geometry (LES model).

**A.4 Connecting total sand transport, bed morphodynamics, and sand budgets in Grand Canyon** –Daniel Buscombe, Brandon McElroy, Thomas Ashley, Matt Kaplinski, Paul Grams

We have carried out repeat high-resolution bathymetric and flow-field surveys over sand bedform fields in a selected reach (near Diamond Creek in Western Grand Canyon), during 2 field campaigns (March and July 2015) over a range of discharges. This has proved very successful, and the data collected are allowing us to estimate bedload and bed sand fluxes associated with the deformation and migration of bedforms by applying, and modifying where necessary, existing numerical techniques and theory. Initial results suggest that, at least at Diamond Creek over the range of flows studied, that bedload contributes more to total load than previously thought. However, we have evidence that suggests this isn't necessarily true everywhere at all times. In 2016, we will finalize the estimates for bedload flux from these measurements and collect additional measurements during a high flow when/if a high flow occurs. Initial results from this work will be presented at the American Geophysical Union conference in December, 2015 and a journal article will be prepared in FY16.

**3.5 Control Network and Survey Support** – Keith Kohl, Rob Ross, 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. The

GCMRC control network report describes the purpose, collection methods, reference systems, coordinates and estimated errors resulting from least-squares adjustments of rim, primary, secondary, and tertiary levels of geodetic control. Specific control network and survey support activates in 2015 are summarized below:

- A new Continuously Operating Reference Station (CORS) at the Grand Canyon Emergency Services Building on the South Rim of Grand Canyon was installed. A second CORS station outside of Tuba City, AZ was also added to the network. GCMRC acquisition of an Arizona State grant provides NGS support for data acquisition, storage, and archive of global navigation satellite system (GNSS) data. These stations provide the most accurate control available and efficient collection and archival protocols. *http://www.ngs.noaa.gov/CORS/*
- Project element 3.1.1 (Sandbar monitoring) was supported with survey control, survey equipment and field support. Most remote cameras from Project element 3.1.2 have been positioned for image rectification.
- Project element 3.1.3 (Structure-From-Motion) was supported by delivering required coordinates for fiducial targets.
- Project element 3.1.4 (Historical imagery rectification) was supported by delivery of reference coordinates of photo-identifiable fixed points visible in 1983/1984 and 2013 imagery datasets.
- Project element 3.2 (Channel Mapping) was supported by equipment preparation, software, control coordinates, survey files, and the positioning of 31 navigation stations for the Glen Canyon mapping project. There are currently 85 control points in the network upstream of the Lees Ferry gage with height accuracies better than 6cm at 95% confidence. The network has been extended to published NAVD88 benchmarks W405 (PID GP0118) and Y405 (PID GP0115) on Glen Canyon Dam.
- Project 2 (Sediment Transport) was supported by positioning navigation stations and gage reference for USGS gage 09404200 Colorado River above Diamond Creek near Peach Springs.
- Project 4 (Terrestrial LiDAR) was supported by projecting and scaling of ground control survey measurements to Arizona State Plane Coordinate System.
- Project 11 (Vegetation Monitoring) was supported by delivering stage information for sample plots at 45 sites.
- GNSS and terrestrial surveys of tributary gages (Project 2) were performed at Tanner Wash.
- All survey coordinates, estimated errors, and survey measurements collected through 2015 have been archived in a comprehensive ESRI GIS database (Project 14).

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Project Element 3.1 – Sandbar Monitoring | | | | | |
| Online data | Data from long-term sandbar monitoring sites, web interface | Annual | Jan. 2015; 2016 | -- | *http://www.gcmrc.gov/sandbar/* |
| data | Data from long-term sandbar monitoring sites | Annual | Jan. 2015; 2016 | -- | Presented at Jan. 2015 reporting meeting; will be presented at Jan. 2016 reporting meeting. |
| photos | Images from daily remote camera monitoring of sandbars, web interface | Annual | Jan. 2015; 2016 | -- | Photos uploaded to website following each HFE: *http://www.gcmrc.gov/sandbar/* |
| Article | New High Flow Protocol Contributes to Sandbar Gains in Grand Canyon | FY16 | Jun. 2015 | -- | Publication: [2] |
| Map/report | Geomorphic base map | FY15 | | May 2016 | Mapping in progress, report in preparation |
| report | Methods for measuring sandbar areas and volumes from remote camera images | FY15 | April 2015 | July 2016 | Publication: [11] and additional publication to be produced in 2016 |
| | Project 3.1.3: No FY2015 products. Updates to be provided at annual meeting and professional meetings. | | | | Presentation: [25] |
| Project Element 3.2 – Sand Storage Monitoring | | | | | |
| report | Report and maps for RM 0 to 30 (mapped in 2013) | FY15 | | March 2016 | Data nearly complete. Report in preparation. |
| report | Report and maps for eastern Grand Canyon (RM 61 to 87, mapped in 2011 and 2014) | FY15 | | June 2016 | Data processing delayed (see above). |
| report | Report/journal article on geomorphic changes in eastern Grand Canyon, 2011 | FY15 | | Aug. 2016 | Delayed owing to processing delay. |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | to 2014 | | | | |
| repor t | Report on bed-sediment grain-size measurements using the eyeball system, 2000 – present | FY15 | | June 2016 | Deferred pending methods finalization (see above) |
| Project Element 3.3 – Sandbar Modeling | | | | | |
| | No FY2015 products. Updates to be provided at annual meeting and professional meetings. | | | | Presentations: [16;24] |
| Project Element 3.4 – Bedload | | | | | |
| | No FY2015 products. Updates to be provided at annual meeting and professional meetings. | | | | Presentations: [17;23] |
| Project Element 3.5 – Control Network and Survey Support | | | | | |
| | No FY15 products. | | | | Data collected and processed on schedule. |

| | **List of Publications and Presentations** |
|---|---|

**FY 2015 Project 3 Publications (published or submitted for review as of Nov. 12, 2015)**


1. Alvarez, L.V. (2015) Turbulence, Sediment Transport, Erosion, and Sandbar Beach Failure Processes in Grand Canyon. Ph.D. Dissertation, Arizona State University, Tempe, AZ, 176pp. *http://repository.asu.edu/items/30069*
2. Grams, P. E., J. C. Schmidt, S. A. Wright, D. J. Topping, T. S. Melis, and D. M. Rubin (2015), Building Sandbars in the Grand Canyon, EOS, Trans. Am. Geophys. Union, 96(11), 12–16. *https://eos.org/features/building-sandbars-in-the-grand-canyon*
3. Buscombe, D., 2016, Spatially explicit spectral analysis of point clouds and geospatial data. Computers and Geosciences 86, 92-108, 10.1016/j.cageo.2015.10.004. *http://www.sciencedirect.com/science/article/pii/S0098300415300704*
4. Buscombe, D., P. E. Grams, and S. M. C. Smith (2015), Automated Riverbed Sediment Classification Using Low-Cost Sidescan Sonar, J. Hydraul. Eng., 06015019, doi:10.1061/(ASCE)HY.1943-7900.0001079.

*http://ascelibrary.org/doi/abs/10.1061/(ASCE)HY.1943-7900.0001079*

5. Buscombe, D., P. E. Grams, M. A. Kaplinski, R. Tusso, and D. M. Rubin (2015), Hydroacoustic signatures of Colorado riverbed sediments in Marble and Grand Canyons using multibeam sonar, in Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 1066–1077, Reno, Nev. *http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf*
6. Buscombe, D., P. E. Grams, T. S. Melis, and S. M. C. Smith (2015), Large river bed sediment characterization with low-cost sidescan sonar: Case studies from two settings in the Colorado (Arizona) and Penobscot (Maine) Rivers, in Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 1273–1277, Reno, Nev. *http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf*
7. Buscombe, D., Rubin, D.M., Lacy, J.R., Storlazzi, C., Hatcher, G., Chezar, H., Wyland, R. and Sherwood, C., 2014, Autonomous bed-sediment imaging-systems for revealing temporal variability of grain size. Limnology and Oceanography: Methods, 12, 390 - 406. *http://www.aslo.org/lomethods/locked/2014/0390.pdf*
8. Grams, P. E., D. Buscombe, D. J. Topping, J. E. J. Hazel, and M. Kaplinski (2015), Use of flux and morphologic sediment budgets for sandbar monitoring on the Colorado River in Marble Canyon, Arizona, in Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 1144–1155, Reno, Nev. *http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf*
9. Ross, R. P., and P. E. Grams (2015), Long-term monitoring of sandbars on the Colorado River in Grand Canyon using remote sensing, in Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 86–96, Reno, Nev. *http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf*
10. Sankey, J.B., Ralston, B.E., Grams, P.E., Schmidt, J.C., and Cagney, L.E., 2015, Riparian vegetation, Colorado River, and climate--Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation: Journal of Geophysical Research Biogeosciences, online , doi:10.1002/2015JG002991. http://onlinelibrary.wiley.com/doi/10.1002/2015JG002991/full
11. Tusso, R. B., D. Buscombe, and P. E. Grams (2015), Using oblique digital photography for alluvial sandbar monitoring and low-cost change detection, in Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 79–85, Reno, Nev. *http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf*
12. Alvarez, L., Schmeeckle, M., Grams, P.E., accepted pending revision, Turbulence Resolving Modeling of Lateral Separation Zones along a Large Canyon-Bound River using Detached Eddy Simulation Technique, J. Geophysical Res. Earth Surface.

**FY 2015 Presentations at Professional Meetings**

13. Buscombe, D., Grams, P., 2014, Topographic and Acoustic Estimates of Grain-Scale Roughness from High-Resolution Multibeam Echo-Sounder: Examples from the Colorado River in Marble and Grand Canyons, Abstract EP44B-02 presented at 2014 Fall Meeting, American Geophysical Union San Francisco, CA, 15-19 Dec.

14. Grams, P., Schmidt, J., Topping, D., 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, Abstract EP32A-06 presented at 2014 Fall Meeting, American Geophysical Union San Francisco, CA, 15-19 Dec.
15. Mueller, E.R., Schmidt, J., Topping, D. Shafroth, P., Grams, P., 2014, Geomorphic response in the Limitrophe reach of the Colorado River to the 2014 delta pulse flow, United States and Mexico, Abstract EP32A-07 presented at 2014 Fall Meeting, American Geophysical Union San Francisco, CA, 15-19 Dec.

**Planned FY 2016 Presentations at Professional Meetings**

16. Alvarez, L., Schmeeckle, M., Grams, P., and Moreno, H., 2015, A Model of Turbulence, Sediment Transport and Morphodynamics of Lateral Separation Zones in Canyon Rivers using Detached Eddy Simulation Technique, Abstract EP51A-0902 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
17. Ashley, T., McElroy, B., Buscombe, D., Grams, P., Kaplinski, M., Examining the Relationship Between Suspended Sand Load and Bedload on the Colorado River Using Concurrent Measurements of Suspended Sand and Observations of Sand Dune Migration, Abstract EP53A-0933 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
18. Buscombe, D., Grams. P.E., (2016) Stochasticity of riverbed backscattering, with implications for acoustical classification of non-cohesive sediment using multibeam sonar. PROCEEDINGS OF RIVERFLOW 2016, THE 8TH INTERNATIONAL CONFERENCE ON FLUVIAL HYDRAULICS, St. Louis, Missouri, July 2016.
19. Buscombe, D., Wheaton, J., Hensleigh, J., Grams, P., Welcker, C., Anderson, K., Kaplinski, M., 2015, Addressing scale dependence in roughness and morphometric statistics derived from point cloud data, Abstract H41E-1365 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
20. Chapman, K., Parnell, R., Smith, M., Grams, P., Mueller, E., 2015, Use of Composite Fingerprinting Technique to Determine Contribution of Paria River Sediments to Dam-Release Flood Deposits in Marble Canyon, Grand Canyon, Abstract EP23E-03 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
21. Grams, P., Buscombe, D., Hazel, J., Kaplinski, M., Topping, D., 2015, Patterns of Channel and Sandbar Morphologic Response to Sediment Evacuation on the Colorado River in Marble Canyon, Arizona, Abstract EP33A-1035 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
22. Hamill, D., Buscombe, D., Wheaton, J.M., Melis, T.S., Grams. P.E., (2016) Bed texture change detection in large rivers from repeat imaging using recreational grade sidescan sonar. PROCEEDINGS OF RIVERFLOW 2016, THE 8TH INTERNATIONAL CONFERENCE ON FLUVIAL HYDRAULICS, St. Louis, Missouri, July 2016.
23. Kaplinski, M., Buscombe, D., Ashley, T., Tusso, R., Grams, P., McElroy, B., Mueller, E., 2015, Observations of Sand Dune Migration on the Colorado River in Grand Canyon using High-Resolution Multibeam Bathymetry, Abstract EP54B-03 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
24. Mueller, E., Grams, P., Hazel, J., Schmeeckle, M., 2015, Linkages between controlled floods, eddy sandbar dynamics, and riparian vegetation along the Colorado River in Marble Canyon, Arizona, Abstract EP32A-02 presented at 2015 Fall Meeting, American

Geophysical Union San Francisco, CA, 14-18 Dec.
25. Rossi, R., Buscombe, D., Grams, P., Wheaton, J., 2015, From Hype to an Operational Tool: Efforts to Establish a Long-Term Monitoring Protocol of Alluvial Sandbars using 'Structure-from-Motion' Photogrammetry, Abstract EP51B-0912 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.
26. Rubin, D., Topping, D., Schmidt, J., Grams, P., Buscombe, D., East, A., Wright, S., 2015, Interpreting Hydraulic Conditions from Morphology, Sedimentology, and Grain Size of Sand Bars in the Colorado River in Grand Canyon, Abstract EP41D-01 presented at 2015 Fall Meeting, American Geophysical Union San Francisco, CA, 14-18 Dec.

| Project 3 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $549,700 | $5,900 | $46,000 | $500,600 | $48,000 | $97,034 | **$1,247,234** |
| **Actual Spent** | $510,428 | $6,064 | $46,458 | $508,051 | $48,000 | $91,989 | **$1,210,990** |
| **(Over)/Under Budget** | **$39,272** | **($164)** | **($458)** | **($7,451)** | **$0** | **$5,045** | **$36,244** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $49,600, will be used to offset FY16 & FY17 shortages.

**Project 4: Connectivity along the fluvial-aeolian-hillslope continuum**

| **Program Manager** (PM) | Joel Sankey | **Principal Investigator(s)** (PI) | Joel Sankey, USGS GCMRC;<br>Helen Fairley, USGS GCMCRC;<br>Amy East, USGS PCMSC;<br>Joshua Caster, USGS GCMRC |
|---|---|---|---|
| **Email** | *jsankey@usgs.gov* | | |
| **Telephone** | (928) 556-7289 | | |

**SUMMARY**

The rate and magnitude of wind transport of sand from active channel sandbars to higher elevation valley margins potentially affects the stability of archaeological sites and the characteristics of other cultural and natural resources. The degree to which valley margin areas are affected by upslope wind redistribution of sand is called "connectivity". Connectivity is affected by several factors including the sand source as well as physical and vegetative barriers to sand transport. The primary hypothesis of this project is that high degrees of connectivity lead to potentially greater archaeological site stability.

This project is composed of two integrated elements; the first (4.1) is a research element, and the second (4.2) is a monitoring element. The research element (4.1) consists of two sub-elements that are landscape scale analyses that will examine the connectivity between attributes of the active channel and geomorphic processes and patterns at higher elevations (above the 45,000 ft3/s stage) at several temporal and geographic scales. In the monitoring element (4.2), the entire year FY15 was invested to develop and draft a long-term plan to monitor the geomorphic condition of archaeological sites in the Colorado River corridor. The monitoring plan will be implemented in years 2 and 3 (2016 and 2017, respectively) of the triennial work-plan effort.

The project elements and sub-elements are:

(4.1) *Quantifying connectivity along the fluvial-aeolian-hillslope continuum at landscape scales*

(4.1.1) *Examine landscape-scale spatial variability using a combination of remote sensing and GIS analyses*

(4.1.2) C*onduct visual interpretation of historical oblique photos to assess whether hypothesized changes due to dam operations are supported by photographic evidence.*

(4.2) *Monitoring of cultural sites in Grand and Glen Canyons*

Please note that there was a third sub-element (4.1.3) in Project 4 of the Triennial Work Plan which was not funded and therefore not pursued by GCMRC staff in FY15.

*Monitoring Activities*

In FY15 no formal monitoring was conducted outside of the continued operation of weather stations established for Project J. A three-day lidar monitoring training exercise was conducted in Glen

Canyon to help transition future lidar monitoring work from contractors at external USGS science centers (e.g., B. Collins et al.) to GCMRC (Sankey and Caster). During this training exercise:

- Site topography was measured with terrestrial lidar at 3 archaeological sites: AZ C:02:0032, C:02:0075, and C:02:0077.

Weather stations continued to operate at Glen Canyon and Marble–Grand Canyon under the previous Project J protocol and permit from the 2013–14 biennial workplan:

- Weather data were collected at six stations, one at Ferry Swale in Glen Canyon and one at Lees Ferry and one each at the four Marble-Grand Canyon archaeological sites AZ C:05:0031, C:13:0321, B:10:0225, and G:03:0072. Stations collected measurements at 4-minute resolution of rainfall, wind speed and direction, temperature, barometric pressure, and relative humidity.
- 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.

*Overview of Weather Monitoring Data Context and Continuity*

In FY15, weather conditions were monitored at select archaeological sites using six weather stations deployed between Ferry Swale (Glen Canyon, RM -11) and upstream of Diamond Creek (deployed at RM 223). The weather parameters, equipment specifications, and station configuration were identical to those used in previous years (2007 through 2011) and are described in multiple reports (Draut and others, 2009a; 2009b, Dealy and others, 2010; Caster and others, 2014). Weather data collected from 2007 through 2013 were made available to the public in a spreadsheet format following the publication of Caster and others' (2014) open-file report. Data collected during FY15 is being processed and will be appended to the (Caster and others, 2014) open-file report. These data are part of an on-going record of weather events that are being used to understand conditions leading to localized landscape changes at archaeological sites within the Colorado River Corridor (Draut and Rubin, 2008;Collins and others, 2009; 2012; 2014; in press). Supplementary photographs from stationary cameras in the vicinity of three of the six operational weather stations have provided visual evidence for the connection between recorded weather events and land surface changes.

Prior to USGS weather monitoring efforts within the river corridor, landscape changes were documented and were related to weather events observed in the region (Hereford and others, 1993; Melis and others, 1994; Hazel and others, 2008). During FY15, daily rainfall from USGS weather stations in the Colorado River corridor were paired with David Topping's rain gauge network and National Oceanic and Atmospheric Administration's cooperative observer (NOAA COOP) stations to establish relationships between weather within the canyon and above the canyon rim as well as to synthesize a long term record of rainfall intensity within Grand and Marble canyons. The results of this analysis have been presented in a conference poster (Caster and others, 2014) and a USGS Scientific Investigations Report (SIR; Caster and Sankey, in review). The presented findings indicated that daily rainfall and rain intensity between the stations in the canyon were similar, but stations in western Grand Canyon tended to receive statistically more rainfall in the late fall through winter seasons. Caster and Sankey's (in review) SIR also appeared to corroborate Collins and other's (in press) work on minimal rainfall runoff thresholds, which provide useful criteria for identifying potential erosion-inducing storm events within the observed and synthesized record developed for the SIR (Caster and Sankey, in review). The results of both of these reports are significant for our understanding of the relative influences of weather vs. dam operations on geomorphic surface changes observed at archaeological sites. The proposed continual monitoring of weather will be instrumental in refining these results and assessing how future management practices affect river corridor terrestrial resources.

*Summary of Reports and Products*

In the FY15–17 Triennial Work Plan (TWP), Project 4 stated intentions to complete the following reports and publications from our work during 2015:

1. Technical paper (and conference presentation): Preliminary findings of the geospatial analysis of 4.1 will be published in a technical paper and presented at the SEDHYD conference in April 2015. Sankey lead.
2. Peer-reviewed manuscript (and conference presentation): The utility of site specific weather monitoring data for understanding landscape scale processes that are analyzed in 4.1 and 4.2 will be presented at AGU and then will be developed into a publication. Caster will lead.
3. Monitoring plan will be written and reviewed by stakeholders.
4. Annual report on the progress of the project with relevant results, maps, and graphics will be prepared for stakeholders.

Number one was accomplished in the conference presentation and proceedings publication by Sankey et al. for the 2015 SEDHYD/FISC conference. Number 2 was accomplished by the AGU presentation by Caster and subsequent USGS Scientific Investigations Report that is now in review by Caster and Sankey. Number 3 was accomplished by the entire project team and is described in detail in the project 4.2 accomplishments section of this report. Number 4 is this annual report.

An additional very important report was completed in FY15. It was led by Amy East with co-authors who comprise the rest of the Project 4 and (previous) Project J science teams. The report is the USGS Professional Paper “Conditions and processes affecting sand resources at archaeological sites in the Colorado River Corridor below Glen Canyon Dam, Arizona”. This report has completed peer and department review and is being processed by the USGS editorial staff.

*Summary of Project Funds Expenditure*

In FY15, we spent $33,390 less on salaries than planned, because scientists on the project were successful in receiving additional external grant funding to support research. We spent almost all of the $9,000 planned for travel to attend conferences and meetings where we gave presentations, as well as to do some fieldwork. We planned $10,000 in operating expenses and spent $19,000 more than planned. This extra expenditure was largely due to the purchase of lidar data processing software (ISITE software by the company MAPTEK; $23,340). The software purchase was planned for FY16, and we decided that because we had realized savings in salaries in FY15 to go ahead and purchase the software this year so that we could begin using it right away. We spent $16,160 less than planned to fund our USGS cooperator Amy East. Amy received some additional salary from her own USGS science center this year and reduced the amount she had asked from us accordingly. Overall, we spent $37,252 less than planned during FY15 which we will carry over to FY16. We worked throughout FY15 to identify ways in which we could realize some carryover for FY16 because of the projected shortfalls in FY16 and FY17. The carryover will be used to cover those projected shortfalls.

Summary of Progress in Individual Project Elements (FY15 work):

**Project Element 4.1. Connectivity along the fluvial-aeolian-hillslope continuum**

Project 4.1 proposes to quantify relationships between the distribution of sand within the active river channel and the distribution of higher elevation river-derived ("aeolian") sand to identify what environmental factors related to dam operations control the location and size of aeolian sand deposits that are found above the maximum controlled flood stage.

*Sub-element 4.1.1 (Joshua Caster and Joel Sankey)*

The sub-element 4.1.1 investigation focused on identifying statistical relationships between (1) the distribution of active and inactive (with respect to aeolian transport) areas of river-derived sand (RDS; units mapped by Amy Draut East during FY12/FY13) above the active river channel, and (2) the distribution of remotely mapped sand, vegetation, and topographic characteristics within and above the controlled flood stage. In FY15 we completed a great deal of GIS and statistical analyses to characterize these relationships for the remotely mapped characteristics of the 2009 overflight data and for the six project "j" reaches (i.e., project J of FY13 and FY14).

Below is a summary of the key preliminary interpretations and resulting hypotheses from spatial and statistical analyses to-date for this part of the 3 year workplan. The summary below has been divided into five sections. Section 1 presents the key results of analyses of the distribution of RDS above the maximum regulated flood stage (45,000 cfs). Sections 2 and 3 present the results of analysis of sand, vegetation, and topographic characteristics below the maximum flood stage that are hypothesized to have a relationship to the distribution of RDS above 45,000 cfs. Section 4 summarizes the conceptual model of the most important landscape characteristics believed to affect RDS distribution (derived from the synthesis of analyses conducted in the first three sections). Section 5 presents the potential implications of these analyses. The following sections are preliminary interpretations and hypotheses – and should be considered as such – that will be further investigated during FY16 and FY17 before being published in a peer-reviewed format.

Section 1: Spatial Distribution of River-Derived Sand

- River-derived sand (RDS) units within the river corridor of six study reaches are located within 400 meters of the shoreline inundated by the active river channel maximum elevation (45,000 CFS discharge shoreline)
- Each reach has a different distribution of RDS, however, on average RDS active units are located two times closer to the active river channel compared to RDS inactive units (within 150 meters vs. 300 meters on average from the active river channel, respectively).

Section 2: Differences below the Active Channel Elevation Associated with River-Derived Sand

- There is significantly more mapped channel vegetation (MCV) within the active river channel (below 45,000 CFS shoreline) in the vicinity of inactive RDS units compared to active RDS units.
- The mean slope and standard deviation of slope (topographic roughness) within the active river channel are significantly greater for inactive RDS units than for active RDS units.
- There is significantly more mapped channel fluvial sand (MCS) area than mapped channel vegetation (MCV) within the active river channel in the vicinity of active RDS units. MCS

area was nearly two times greater than the area of MCV for most distance and flow elevation intervals below active RDS units.

- Consideration of dominant wind direction does not appear to explain differences between RDS units. In general, statistical relationships are not appreciably stronger when wind direction is considered.

Section 3: Predicting River-Derived Sand Unit Area with Associated Active Channel Elevation Features

- The best predictive models for river-derived sand (RDS) unit area incorporated predictor variables derived from topographic slope and the area inundated by river flows of specific magnitude:
    - To predict RDS active unit area, the best models used mapped channel vegetation area within 40 meters of an RDS active unit, area inundated between the 41,000 and 45,000 cfs flow elevations, standard deviation of slope within 10 meters of the active channel elevation (45,000 cfs), and mean slope between the minimum flow elevation (8,000 cfs) and 20,000 cfs flow elevation.
    - To predict RDS inactive unit area, the best models used mapped channel vegetation area within 40 meters of an RDS inactive unit, remotely mapped vegetation between the active channel elevation (45,000 cfs) and 97,000 cfs flow elevation, and mean and standard deviation of slope between the 41,000 cfs and 45,000 cfs flow elevations.

Section 4: Hypotheses Developed from Analyses

- Using the results of the statistical analyses (in sections 1-3), a preliminary conceptual model was developed to explain the distribution and relative abundance of river-derived sand (RDS) units. The model suggests that:
    1. River corridor sections with greater area inundated by flows between 8,000 cfs and 45,000 cfs have greater RDS unit area.
    2. River corridor sections with low angle and topographically smooth slopes between 8,000 cfs and 20,000 cfs flow elevations and between 41,000 cfs and 45,000 cfs flow elevations have greater RDS unit area.
    3. River corridor sections with more mapped channel sand (MCS) than mapped channel vegetation (MCV) have greater RDS active unit area.
    4. River corridor sections with topographic conditions that promote continued up-slope wind-blown sand transport have greater RDS unit area than sections with topographic conditions that promote wind-blown sand transport parallel to the active channel.
    5. For RDS area that is located directly adjacent to the active channel maximum elevation (45,000 cfs), fluvially sourced sand may contribute to RDS unit volume regardless of the dominant wind direction. Wind direction might play a more important role in the up-slope transport for RDS units located further away from the active river channel.
- Some analyses of the conceptual model hypotheses have been completed using comparisons of historical aerial photography (2009 and 1965 – shortly following dam construction) with overlays of RDS units. Observations from comparing recent imagery with the 1965 imagery suggest that:
    1. No one river corridor segment or reach fit within all five ideal model parameters (hypotheses).
    2. Area of RDS deposits that are located adjacent to areas that have high ratios

of MCS to MCV (> 1.9:1) were not necessarily larger and did not always consistently show evidence of greater area of active RDS in the present or in 1965.

3. In general, there were not a lot of examples of RDS inactive units that appeared to have been a great deal more active in 1965.

Section 5: Some specific implications of the analyses that we want to investigate further in FY16 and FY17

- For areas with a close association to the active river channel and a fluvial sand source, dominant wind direction may not necessarily be a significant limiting factor to sand transport if topographic and vegetative conditions are right. Dominant wind direction may be a more significant factor in limiting sand transport the further from the active channel elevation a location may be.
- Because RDS active units tend to be located upslope of shorelines that have more MCS than MCV area, we preliminarily hypothesize that vegetation removal might be a viable means to promote up-slope wind transport in certain locations where an adjacent fluvial sand source exists, and:
    1. RDS active units exist and are upslope of shorelines with MCS area less than or equal to MCV area, or
    2. RDS inactive units exist with one or more of the five characteristics described within the conceptual model, or
    3. RDS inactive units exist that show evidence of possible greater activity in the 1965 aerial imagery

*Sub-element 4.1.2 (Helen Fairley)*

In sub-element 1.2., we are analyzing historical oblique photographs to ascertain the degree to which environmental conditions at or near cultural sites have changed during the past > 50 years by comparing conditions in areas that appear to have functioned as aeolian landscapes in the past compared to current conditions. This work involves visual comparisons of historical oblique imagery and current surface conditions (e.g., visual evaluations of more or less soil crust, vegetation cover, etc.). Historical photos are being examined and qualitatively assessed in terms of whether the historical imagery shows more or less open sand bars, cryptobiotic crust cover, and vegetation cover within areas that appear to have served as aeolian source areas to cultural sites and within specific cultural site locations. The current state of the cultural sites and aeolian sand areas are being similarly assessed based on more recent site photos as well as recent site descriptions (e.g., from site investigation work completed in 2013 and 2014). One anticipated outcome of this analysis will be an estimate of the proportion of cultural sites for which the potential influence of aeolian sand inputs has changed from pre-dam to recent post-dam time, relative to changes in environmental characteristics including vegetation and biologic crusts.

In FY15, initial efforts focused on locating and assessing the suitability of existing historical photo collections for this analysis effort. As described for Project 12, where a similar type of analysis is being carried out to assess changes in vegetation species important to tribes, an assessment of the historical Desert Laboratory's repeat photography collection revealed that only the Stanton collection was sufficiently well-documented with repeat photographic matches and sufficiently well-organized to allow for the analysis to proceed without having to conduct considerable pre-analysis preparation work; therefore, the analysis conducted to date has focused exclusively on the Stanton photographic collection and the matches obtained by Dr. Robert Webb and colleagues in 1990–1992 and in 2010–2011. (Although we also planned to match photographs collected by the 1923 Birdseye expedition as part of this project, this work had to be postponed due to the cancellation of the August vegetation monitoring trip following the tragic death of our colleague Daniel Sarr.) As of the end of September, 2015, approximately 28% of the Stanton collection (representing approximately 1/3 of the river corridor) had been analyzed, covering 128 individual views and 256 matched images collected between the base of Glen Canyon Dam and the Little Colorado River confluence area. While still a work in progress, the analysis completed to date shows that aeolian source areas have diminished significantly during the past 120 years, in terms of two factors: 1) change in the size (volume) and abundance of sand bars, and 2) dramatic increase in the amount of riparian vegetation cover below the old high water line. With regard to the second factor, the photographs show that the amount of vegetation cover increased dramatically between 1889–1890 and 1990–1992 in the formerly active river channel below the mesquite line; more surprising perhaps is that the matched photographs from the 1990s and 2010–2011 show a significant increase in lower elevation riparian vegetation, with almost every photograph from 2010–2011 showing increases of dense shrubby vegetation (especially Baccharis sp. and Salix exigua) infilling what was formerly—in the early 1990s—open or partially open sand bars and sandy shorelines. It remains to be seen whether this same pattern holds up in the central and western reaches of Grand Canyon.

**Project Element 4.2. Monitoring – plan development (Entire Project 4 Team)**

The primary objective for Project Element 4.2 in FY15 was to draft a monitoring plan in response to stakeholders' request for establishing a long-term, systematic strategy for assessing effects of dam operations on archaeological sites due to flow and non-flow actions. The purpose of this document was to provide a means for collecting information useful in Reclamation's effort to maintain National Historic Preservation Act (NHPA) compliance under the Long Term Experimental and Management Plan (LTEMP). The proposed draft monitoring plan is designed to address specific target points outlined by BOR and NPS that were summarized in the Project 4 proposal of the Triennial Work Plan (M. Barger, email communication, May 19 2014, to J. Sankey; J. Balsom, email communication, July 7, 2014, to J. Schmidt, H. Fairley, G. Knowles). As NPS archaeologists and Tribal representatives monitor cultural resource site integrity, the proposed draft plan focuses on strategies for quantitative assessment of effects of geomorphic processes associated with dam operation on archaeological site condition. One important focus of the plan is to monitor whether, and how much, HFE sand is transported by wind to a representative sample of archaeological sites and what effect wind-transported sand has on surface stability.

Work towards the development of this monitoring plan began in October, 2014 with a review of federal monitoring programs in-place at Grand Canyon as well as around the United States by GCMRC project staff. Following inner-department dialogue, drafting of the plan began in November, 2014 and continued through June, 2015, when NPS and BOR collaborators provided initial inter-agency comments. During July, 2015, GCMRC, NPS, and BOR team members met to discuss comments and revisions and it was decided that the plan had reached a stage sufficient for review by all stakeholders. On August 21, 2015 GCMRC project staff hosted a meeting for all stakeholders to provide comments and suggestions for the draft monitoring plan. Following this meeting, revisions were made to the draft monitoring plan based on stakeholder input and were re-submitted for review to all parties on October 8, 2015. GCMRC received written comments on October 30, 2015 and is currently revising and finalizing the monitoring plan.

Implementation of the finalized monitoring plan was proposed for FY16 and FY17 in the Triennial Work Plan. To increase efficiency and maintain the proposed monitoring schedule, efforts were made by GCMRC project staff to refine these monitoring strategies prior to implementation. During April, 2015 initial tests of a newly acquired terrestrial lidar unit, owned by GCMRC, were conducted at three sites within Glen Canyon. Following data collection, advanced geographic information system (GIS) analysis of these data was conducted and a formal procedure for data collection, processing, and storage was established. Discussions on the extent of monitoring are on-going, but it is believed that implementation for the draft plan will be on schedule.

**References**


Caster, J., and Sankey, J. B., in review, Variability in rainfall at monitoring stations and derivation of a long-term rainfall intensity record in the Grand Canyon Region, Arizona, USA, U.S.. Geological Survey Scientific Investigations Report 2015-XXX, 56 p.

Caster, J., Sankey, J. B.., Draut, A., Fairley, H., Collins, B., and Bedford, D., 2014, Dryland precipitation variability and desertification processes: An assessment of spatial and temporal rain variability within the Grand Canyon, Arizona, American Geophysical Union abstracts with programs H51E-0656

Caster, J., Dealy, T., Andrews, T, Fairley, H., Draut, A., and Sankey, J., 2014, Meteorological data for selected sites along the Colorado River Corridor, Arizona, 2011–13: U.S. Geological Survey Open-File Report 2014-1247, 56 p.

Collins, B.D., Minasian, D., and Kayen, R., 2009, Topographic change detection at select archeological sites in Grand Canyon National Park, Arizona, 2006–2007: U.S. Geological Survey Scientific Investigations Report 2009–5116, 58 p.,

Collins, B.D., Corbett, S.C., Fairley, H.C., Minasian, D., Kayen, R., Dealy, T.P., and Bedford, D.R., 2012, Topographic change detection at select archeological sites in Grand Canyon National Park, Arizona, 2007–2010: U.S. Geological Survey Scientific Investigations Report 2012–5133, 77 p.

Collins, B.D., Corbett, S.C., Sankey, J.B., and Fairley, H.C., 2014, High-Resolution Topography and Geomorphology of Select Archeological Sites in Glen Canyon National Recreation Area, Arizona: U.S. Geological Survey Scientific Investigations Report 2014–5126, 31 p.

Collins, B.D., Bedford, D., Corbett, S.C., Cronkite-Ratcliff, C., and Fairley, H.C., in press, Meteorologic and anthropogenic effects on archeological site change in Grand Canyon, Arizona: Earth Surface Processes and Landforms.

Dealy, T.P., Draut, A.E., and Fairley, H.C., 2014, 2010 weather and aeolian sand-transport data from the Colorado River corridor, Grand Canyon, Arizona: U.S. Geological Survey Open-File Report 2014- 1135, 90 p.

Draut, A.E., Andrews, T., Fairley, H.C., and Brown, C.R., 2009a, 2007 weather and aeolian sandtransport data from the Colorado River corridor, Grand Canyon, Arizona: U.S. Geological Survey Open-File Report 2009-1095, 110 p.

Draut, A.E., Sondossi, H.A., Hazel, J.E., Jr., Andrews, T., Fairley, H.C., Brown, C.R., and Vanaman, K.M., 2009b, 2008 weather and aeolian sand-transport data from the Colorado River corridor, Grand Canyon, Arizona: U.S. Geological Survey Open-File Report 2009-1190, 98 p

Draut, A.E., and Rubin, D.M., 2008, The role of eolian sediment in the preservation of archeologic sites along the Colorado River in Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1756, 71 p.

Hazel, J.E., Jr., Kaplinski, M., Parnell, R.A., and Fairley, H.C., 2008, Aggradation and degradation of the Palisades gully network, 1996 to 2005, with emphasis on the November 2004 high-flow experiment, Grand Canyon National Park, Arizona: U.S. Geological Survey Open-File Report 2008-1264, 14 p.

Hereford, R., Fairley, H.C., Thompson, K.S., and Balsom, J.R., 1993, Surficial geology, geomorphology, and erosion of archeologic sites along the Colorado River, eastern Grand Canyon, Grand Canyon National Park, Arizona: U.S. Geological Survey Open-File Report 93-517, 46 p.

Melis, T.S., Webb, R.H., Griffiths, P.G., and Wise, T.J., 1994, Magnitude and frequency data for historic debris flows in Grand Canyon National Park and vicinity, Arizona: U.S. Geological Survey Water Resources Investigations Report 94-4214, 285 p.

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| USGS SIR | Variability in rainfall at monitoring stations and derivation of a long-term rainfall intensity record in the Grand Canyon Region, Arizona, USA | N/A | 5/11/15 | TBD | This report has completed peer and department review and is being processed by the USGS editorial staff |
| USGS Professiona l Paper | Conditions and processes affecting sand resources at archaeological sites in the Colorado River Corridor below Glen Canyon Dam, Arizona | N/A | 6/9/15 | TBD | This report has completed peer and department review and is being processed by the USGS editorial staff |
| Poster Presentatio n | When it Rains it Pours: Implications of weather monitoring results for rainfall runoff at archaeological sites in Glen, Marble and Grand Canyons | 1/21/14 | 1/5/14 | 1/21/14 | This poster was presented at the January Annual Reporting Meeting in Phoenix, AZ |
| Poster Presentatio n | Dryland precipitation variability and desertification processes: An assessment of spatial and temporal rain variability within the Grand Canyon, Arizona | 12/19/1 4 | 10/03/14 | 12/19/14 | This poster was presented at the fall AGU meeting in San Francisco, CA |
| Oral Presentatio n | Gully annealing by fluvially-sourced aeolian sand: Remote sensing investigations of connectivity along the fluvial-aeolian-hillslope continuum on the Colorado River | 1/1/15 | 12/22/15 | 4/21/15 | This conference presentation was presented at the Federal Interagency Sedementation and Hydrologic Modeling joint conference in Reno, NV |
| Proceedings Paper | Gully annealing by fluvially-sourced aeolian sand: Remote sensing investigations of | 1/1/15 | 12/22/15 | 1/28/15 | This was published in the proceedings of the Federal Interagency Sedementation and |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | connectivity along the fluvial-aeolian-hillslope continuum on the Colorado River | | | | Hydrologic Modeling joint conference in Reno, NV |
| Oral Presentation | Designing a monitoring program to inform adaptive management of cultural resources in the context of a changing climate: an example from Glen and Grand Canyons, Arizona. | 10/8/15 | 7/1/15 | 10/8/15 | This was presented at the 13th Biennial Conference of Science & Management on the Colorado Plateau in Flagstaff, AZ |
| Poster Presentation | *A landscape-scale assessment of archaeological-site condition and preservation in the Colorado River Corridor, Grand Canyon, Arizona* | 11/3/15 | 7/30/15 | 11/3/15 | This poster was presented at the annual GSA meeting in Baltimore, MD |
| Poster Presentation | *A landscape-scale assessment of archaeological-site condition and preservation in the Colorado River Corridor, Grand Canyon, Arizona* | 11/3/15 | 7/30/15 | 11/3/15 | This poster was presented at the annual GSA meeting in Baltimore, MD |
| Oral Presentation | Sand resources and monitoring at archaeological sites in Glen and Grand Canyons | 2/27/15 | 2/27/15 | 2/27/15 | HFE workshop oral presentation |
| Oral Presentation | Project J Summary: Conditions and processes affecting sand resources at archaeological sites | 1/20/15 | 1/20/15 | 1/20/15 | 2014 Annual Reporting Meeting presentation |

| Project 4 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $197,800 | $9,000 | $10,000 | $0 | $84,900 | $29,556 | **$331,256** |
| **Actual Spent** | $164,410 | $8,438 | $29,212 | $0 | $68,740 | $27,547 | **$298,348** |
| **(Over)/Under Budget** | **$33,390** | **$562** | **($19,212)** | **$0** | **$16,160** | **$2,009** | **$32,908** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $37,200, will be used to offset FY16 & FY17 shortages.
Purchased I-Site Studio software in FY15 rather than FY16.

| Project 5: Foodbase Monitoring and Research | | | |
|---|---|---|---|
| **Program Manager** (PM) | Theodore Kennedy | **Principal Investigator(s)** (PI) | Theodore Kennedy, USGS, GCMRC<br>Jeff Muehlbauer, USGS, GCMRC<br>Charles Yackulic, USGS, GCMRC<br>Scott Miller, BLM/USU<br>David Lytle, OSU<br>Scott Wright, USGS, CWSC<br>Mike Yard, USGS, GCMRC |
| **Email** | *tkennedy@usgs.gov* | | |
| **Telephone** | (928) 556-7374 | | |

**SUMMARY**

In FY15, the foodbase group: 1) continued monthly monitoring of invertebrate drift, insect emergence and algae production in Glen Canyon, 2) we collaborated with the Natal Origins project to collect invertebrate drift samples during each of their quarterly sampling trips, 3) we conducted nearly continuous monitoring of insect emergence in Marble and Grand Canyon in collaboration with citizen scientists, 4) we compiled and began analyzing existing data on the aquatic foodbase in tailwaters throughout the western US, 5) we collected drift and benthic invertebrate data from 7 tailwaters in the Colorado River basin, 6) we initiated citizen science monitoring in targeted segments of the upper Colorado River basin, and 7) conducted pilot studies on egg-laying locations of aquatic insects in Glen Canyon. Significant progress was also made in analyzing and interpreting these data, with six different manuscripts that incorporate foodbase data being submitted and accepted for publication in FY15 (see products, below).

Monthly monitoring of drift and emergence in Glen Canyon in FY15 demonstrated that prey availability varies seasonally, with prey availability being relatively high in April, May, and June, and considerably lower during other months of the year. Overall, prey size was always small with average lengths between 3-5 millimeters. Long-term drift monitoring data from Glen Canyon spanning five years (2009–2013) were incorporated into a trout bioenergetics model that demonstrated prey availability and prey size limit the maximum size of rainbow trout in Glen Canyon (see Dodrill manuscript in press). Additionally, invertebrate drift data from Natal Origins sites demonstrate that prey availability is playing a role in controlling trout growth rates among sites and seasons (see Yard manuscript in press). A total of 154 invertebrate drift samples, 3000 sticky trap samples, 52 benthic invertebrate samples, and 230 fish gut samples were processed by the foodbase lab in FY15.

Algae production data from Grand Canyon were synthesized in a journal article that was published in FY15. Similar to prior investigations into algae production, we found that turbidity and light were the dominant control of algae production. But our analyses of continuous algae production estimates derived from dissolved oxygen monitoring also revealed that cloudy days had a measurable impact

| |
|---|
| on algae production by reducing ambient light. Our analyses also showed that water temperature and hydropeaking had a measurable but comparatively minor role in controlling algae production in Marble and Grand Canyons (see article by Hall and others). In FY15, Yackulic also participated in one workshop with a USGS Powell Center working group on developing new approaches for modeling and analyzing dissolved oxygen data. These efforts will inform approaches for modeling dissolved oxygen monitoring data that are being collected in Glen, Marble, and Grand Canyons.<br><br>In FY15, we continued collaborating with professional river guides as part of a citizen science project to monitor the emergence of aquatic insects from Marble and Grand Canyons. Because the river guiding season runs from April through October, this citizen science project allows us to quantify insect emergence during much of the growing season. By working with several companies that outfit private boaters for rafting trips, we were also able to extend the coverage of our citizen science efforts in FY15 to include months when professional river guides are not present (i.e., February, March, November, and December). A total of 1,300 light trap samples were processed by the foodbase lab in FY15.<br><br>Pilot studies on the egg-laying locations of aquatic insects were conducted in Glen Canyon by the foodbase group, and both egg-laying and egg mortality experiments were conducted by Scott Miller (Utah State University) in the Flaming Gorge tailwater, which has a more diverse assemblage of aquatic insects than are present in Glen Canyon. These preliminary investigations demonstrate that many types of aquatic insects lay their eggs at or along river shorelines. Additionally, the egg mortality study conducted by Miller demonstrated that even short-term desiccation (i.e, 4 hours) caused almost 100% mortality of aquatic insect eggs. Collectively, these studies on the preferred egg-laying locations of aquatic insects and the effect of desiccation on mortality of insect eggs are consistent with the hypothesis put forward in the triennial workplan that daily hydropeaking may be an important control of aquatic insect production and diversity. |
| |

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Journal article | Mercury and selenium accumulation in the Colorado River food web, Grand Canyon, USA. | | | | Walters, D.M., E. Rosi-Marshall, T.A. Kennedy, W.F. Cross, and C.V. Baxter. 2015. “Mercury and selenium accumulation in the Colorado River food web, Grand Canyon, USA.” *Environmental Toxicology and Chemistry* 34, no. 10 (2015): 2385-2394. |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | | | | | |
| Journa l article | Turbidity, light, temperature, and hydropeaking control primary productivity in the Colorado River, Grand Canyon | | | | Hall, R.O., C.B. Yackulic, T.A. Kennedy, M.D. Yard, E.J. Rosi-Marshall, N. Voichick, and K.E. Behn. "Turbidity, light, temperature, and hydropeaking control primary productivity in the Colorado River, Grand Canyon." *Limnology and Oceanography* 60, no. 2 (2015): 512-526. |
| Journa l article | Flow management and fish density regulate salmonid recruitment and adult size in tailwaters across western North America. | | | | Dibble, K. L., C. B.Yackulic, T. A. Kennedy, and P. Budy. In press "Flow management and fish density regulate salmonid recruitment and adult size in tailwaters across western North America."*Ecological Applications* (2015). |
| Journa l article | Evaluating potential sources of variation affecting Chironomidae catch rates on sticky traps | | | | Smith, J., J Muehlbauer, and T Kennedy, in press, “Evaluating potential sources of variation affecting Chironomidae catch rates on sticky traps.” *Marine and Freshwater Research* |
| Journa l | Seasonal and | | | | Yard, M.D., J Korman, C Walters, and T |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| article | spatial patterns of growth of rainbow trout in the Colorado river in Grand Canyon AZ. | | | | Kennedy *In press*, Seasonal and spatial patterns of growth of rainbow trout in the Colorado river in Grand Canyon AZ. *Canadian journal of fisheries and aquatic sciences.* |
| Journa l article | Prey size and availability limit maximum size of rainbow trout in a large tailwater: insights from a drift-foraging bioenergetics model. | | | | Dodrill, M., C Yackulic, T Kennedy, and J Hayes, In press, “Prey size and availability limit maximum size of rainbow trout in a large tailwater: insights from a drift-foraging bioenergetics model.” *Canadian journal of fisheries and aquatic sciences* |
| Outrea ch Article | Moth mystery hour | | March 2015 | | Metcalfe, A., T.A. Kennedy, and C. Fritzinger. “Moth mystery hour.” Boatman’s quarterly review 28 no. 2 (2015): 15-16. |
| Presen tation | Big flood, small flood, spring flood, fall flood: how controlled flood timing affects food web response in the Glen Canyon Dam tailwater | | May 2015 | | Kennedy, TA, J. Muehlbauer, M. Dodrill, A. Copp, M. Yard, May 2015. “Big flood, small flood, spring flood, fall flood: how controlled flood timing affects food web response in the Glen Canyon Dam tailwater.” Annual meeting of the Society for Freshwater Science, Milwaukee, WI |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Presen tation | Little bugs, big data, and Grand Canyon: light trapping by citizen scientists yields insights into Colorado River aquatic insect dynamics. | | August 2015 | | Kennedy, TA, J. Muehlbauer, D. Lytle, C. Yackulic, E. Kortenhoeven, A. Metcalfe, August 2015. "Little bugs, big data, and Grand Canyon: light trapping by citizen scientists yields insights into Colorado River aquatic insect dynamics." 4th Biennial Meeting of International Society for River Science, LaCrosse, WI |
| Presen tations | There is more than one way to shade a river: contrasting effects of canyon orientation and water clarity on aquatic invertebrate densities | | August 2015 | | Muehlbauer, J.D., TA Kennedy, E.W. Kortenhoeven, and J.T.Smith, August 2015. "There is more than one way to shade a river: contrasting effects of canyon orientation and water clarity on aquatic invertebrate densities." Annual meeting of the Ecological Society of America, Baltimore, MD. |
| Presen tations | Hg and Se accumulation in the Colorado River food web. | | June 2015 | | Walters, D.W. and T.A. Kennedy, June 22, 2015. "Hg and Se accumulation in the Colorado River food web." Briefing for the Assistant Secretary for Water and Science, and leadership from Bureau of Reclamation and National Park Service |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Presentations | Hg and Se accumulation in the Colorado River food web | | July 2015 | | Walters, DW and TA kennedy, July 6, 2015, “Hg and Se accumulation in the Colorado River food web.” Briefing for Grand Canyon National Park staff. |
| Presentations | Hg and Se accumulation in the Colorado River food web. | | July 2015 | | Walters, DW and TA Kennedy, July 9, 2015. “Hg and Se accumulation in the Colorado River food web.” Briefing for Arizona Department of Environmental Quality, Arizona Department of Game and Fish, and Bureau of Reclamation staff. |
| | Long-term drift monitoring reveals changes in foodbase since 2008 flood | | January 2015 | | Kennedy, T.A., M. Dodrill, A. Copp, and J. Muehlbauer, January 2015. “Long-term drift monitoring reveals changes in foodbase since 2008 flood.” Annual reporting meeting, Technical Work Group, Phoenix, AZ. |
| | Lees Ferry foodbase: status, trends, and next steps. | | February 2015 | | Kennedy, T.A., February 2015. “Lees Ferry foodbase: status, trends, and next steps.” Trout unlimited, Grand Canyon chapter, Northern Arizona Flycasters joint meeting, Flagstaff, AZ. |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | Foodbase response to three High Flow Experiments. | | February 2015 | | Kennedy,T.A. February, 2015. "Foodbase response to three High Flow Experiments." Adaptive Management Work Group, HFE workshop, Salt Lake City, UT. |
| | Citizen science light trapping results: an emerging story about bugs and river management. | | March 2015 | | Kennedy,T.A., E. Kortenhoeven, A. Metcalfe, March 2015. "Citizen science light trapping results: an emerging story about bugs and river management." Guides training seminar, Marble Canyon, AZ. |
| | Where have the mayflies gone? | | May 2015 | | Kennedy, TA, May 2015. "Where have the mayflies gone?" Lees Ferry trout fishery meeting, convened by AZGFD and TRCF, Marble Canyon, AZ. |

| Project 5 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $339,000 | $12,300 | $20,600 | $36,100 | $18,800 | $51,784 | **$478,584** |
| **Actual Spent** | $333,006 | $15,182 | $22,298 | $25,086 | $18,152 | $51,261 | **$464,985** |
| **(Over)/Under Budget** | **$5,994** | **($2,882)** | **($1,698)** | **$11,014** | **$648** | **$523** | **$13,599** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $21,600.

| **Project 6: Mainstem Colorado River Humpback Chub Aggregations and Fish Community Dynamics** | | | |
|---|---|---|---|
| **Program Manager** (PM) | David Ward | **Principal Investigator(s)** (PI) | David Ward, USGS, GCMRC<br>Mike Dodrill, USGS, GCMRC<br>Luke Avery, USGS, GCMRC<br>Brian Healy, NPS<br>Kirk Young, USFWS<br>Randy VanHaverbeke, USFWS<br>David Rogowski, AZGFD<br>Karin Limburg, State Uni. Of NY. |
| **Email** | *dlward@usgs.gov* | | |
| **Telephone** | (928) 556-7280 | | |

**SUMMARY**

**Project Element 6.1. Monitoring humpback chub aggregation relative abundance and distribution**

Mainstem fish sampling was conducted in September of 2015, in cooperation with the USFWS and AZGFD. During this trip, we sampled both within and outside of defined humpback chub aggregations in order to characterize the fish community with emphasis on humpback chub. Multiple gear types including hoop netting, electrofishing, and seining were used in order to capture adult, sub-adult, and juvenile humpback chub. While only preliminary information is available for hoop netting and electrofishing at this time, we can more fully report on the catches from seining. Backwater and mainstem beach faces were sampled with seines wherever feasible from Lees Ferry to Pearce Ferry. This approach proved very effective at capturing small bodied native fish including humpback chub, bluehead sucker, flannelmouth sucker, and speckled dace. A variety of nonnative fish were also captured including rainbow trout, fathead minnows, channel catfish, common carp, red shiner, and plains killifish. Approximately 3500 fish were captured including 210 humpback chub ranging in size from 26 mm to 371 mm total length. Humpback chub were captured across a large spatial extent including in Western Grand Canyon. A tablet computer with an automated data entry GUI was used in the field to record the seine data. This expedited the fish processing, allowing more information to be collected during the trip.

**Project Element 6.2. Humpback chub aggregation recruitment studies**

This Project element seeks to increase our understanding of humpback chub recruitment dynamics at wide-spread locations within the mainstem Colorado River using a variety of techniques including otolith microchemistry and traditional sampling techniques. Building on prior studies of water chemistry and otolith microchemistry of juvenile humpback chub, we collected water samples throughout the mainstem Colorado River and tributaries in order to identify isotopic or chemical signatures that may be used to identify areas of humpback chub spawning and recruitment. Although we did not deliberately take any humpback chub for otolith microchemistry, a small number of incidental mortalities, along with surrogate species, are available. These samples have been sent to Karin Limburg (State University of New York) for analysis. We continue to work with cooperators, such as the NPS, to collect and preserve any incidental mortalities that could contribute to this work. Additionally, We collected ultrasound images of humpback chub to determine if they develop eggs in the mainstem Colorado River. Female humpback chub with eggs were observed in ultrasound images at several mainstem locations. The ultrasound image collection is part of a thesis being developed by Morgan Brizendine (University of Arizona), with a peer-reviewed publication expected after completion of the thesis, documenting these findings.

**Project Element 6.3. Monitoring mainstem humpback chub aggregations using PIT-tag antenna technology**

We deployed 7 portable PIT tag antennas at each sampling site during the Sept 2015 sampling trip to monitor humpback chub at known aggregations. These antennas detected humpback chub, flannelmouth sucker, and other PIT tagged species. The antennas represent an additional source of information on PIT tagged species and an exciting new area of study to increase our understanding of native fish distribution and ecology. Genetic samples (small fin clips) were collected from humpback chub in order to support research by Wade Wilson (USFWS). Understanding the genetic make-up of fish in mainstem aggregations will provide information on relatedness and possibly identify areas of likely recruitment. Overall, the variety of sampling strategies and gears we used provides timely information on the status of fish populations and informs decisions on both the operation of Glen Canyon Dan and non-flow actions.

**Project Element 6.4. System Wide Electrofishing**

**Goals and Objectives**: The primary goal of the “System Wide Electrofishing” program 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 . 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.

**Summary of progress:**

In 2015 we completed three mainstem sampling trips. A stratified random sampling approach was used to obtain a representative sample of the river’s fish community that is susceptible to electrofishing. Catfish are generally not sampled adequately using electrofishing, thus angling is used to capture catfish. Similarly Humpback Chub are also not very amenable to electrofishing, and as other project elements monitor Humpback Chub, this project does not address Humpback Chub distribution and abundance. In the two spring/summer system wide trips 593 sites were sampled with 3709 fish captured. During the fall sampling trip from Diamond Creek to Pearce Rapids electrofishing was hampered by high levels of turbidity (>8000 NTUs), while 96 sites were sampled only 382 fish were captured.

**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 fish (Flannelmouth Sucker and Speckled Dace) 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 Rainbow Trout. Rainbow Trout CPUE has significantly declined over the past three years.

**Rainbow Trout Monitoring in Glen Canyon**

**Goals and Objectives:** The goal of "Rainbow Trout Monitoring in Glen Canyon" 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.

Monitoring activities funded (boat electrofishing trips):

- Spring trip: 17-20 March 2015, 40 standard sample sites
- Summer trip: 6-10 July 2015, 40 standard sample sites, plus an additional 11sites for nonnatives
- Fall trip: 5-8 October 2015, 37 standard sample sites

**Summary of progress:** We completed three sampling trips in 2015, sampling 117 standard sites in total and capturing 2576 fish (excluding the nonnative sampling). Nonnative sampling in July of 2015 revealed 43 Green Sunfish in the slough at river mile -12. This triggered a response by the cooperating agencies to conduct a removal effort using seines, electrofishing and ultimately the use of Rotenone (in November) to remove these invasive fish from the "slough" and "upper slough".

**Summary of trends**: Rainbow trout continue to dominate the fish community within the Lees Ferry reach, comprising 97.0% of the catch (electrofishing). Rainbow Trout have maintained a self-sustaining population since the mid-1990s. Relative abundance, as measured by electrofishing catch per unit effort (CPUE), has fluctuated greatly since AGFD began standardized sampling in 1991. CPUE of rainbow trout was the highest ever recorded in 2011-2012, but has declined since 2012. 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 the system can maintain from its limited food base. Relative condition (Kn) of Rainbow Trout during our summer sampling has historically been above one (average Kn).Last year (2014) fish Kn was below one during all three sampling efforts (spring, summer, fall). This year there was an improvement with subadult (306-405 mm) and adult fish (>405 mm) condition above one during summer sampling.

**<u>Project Element 6.5. Brown trout natal origins through body pigmentation patterns in the Colorado River</u>**
This project was not funded in the FY15-17 triennial work plan.

**<u>Project Element 6.6. Mainstem translocation of humpback chub</u>**
*Funded in FY17*

**<u>Project Element 6.7 Rainbow Trout Early Life Stage Surveys</u>**

Field activities for the Rainbow Trout Early Life Stage Survey (RTELSS) in 2015 consisted of redd surveys for estimation of spawning magnitude, and electrofishing sampling for estimation of population dynamics

Redd Surveys

A total of 11 redd surveys were conducted through the period December 2014 through June 2015. A total of 1,630 redds were observed, with the overall estimate of 1,331 redds created for the season. The overall pattern of redd distribution was similar to past years, though the peak was a couple weeks past what is typical. In past years the peak has occurred around mid to late March. The peak in distribution for 2015 was nearer to early to mid-April. There was a significant decrease in the number of adult fish caught on Natal Origins trips between January and April. Anecdotal reports from anglers indicate the decrease occurred from February to March. It is possible that adult fish that may not have matured to spawning condition under high densities did so after the observed decrease in adult numbers. This may explain the delayed peak in the distribution of redds deposited.

Another curious pattern in the redd distribution was a high degree of fluctuation between surveys. Typically what is observed is a steady increase in counts until the peak is reached, followed by a steady decline in numbers. Beginning in February 2015 counts began bouncing up and down between surveys, with a general trend of increasing numbers through May. This pattern appears to continue beyond May, though with a general trend of decreasing numbers, but not enough surveys were conducted after May to confirm this (Table 1).

**Table 1**. Dates of the 11 redd surveys conducting in 2015 and the number of redds observed for each of those surveys.

| Redd Surveys for 2015 | |
|---|---|
| Date of Survey | Number of Redds Observed |
| 12/13/2014 | 25 |
| 1/16/2015 | 49 |
| 2/3/2015 | 160 |
| 2/20/2015 | 133 |
| 3/6/2015 | 209 |
| 3/24/2015 | 167 |
| 4/3/2015 | 252 |
| 4/21/2015 | 194 |
| 5/12/2015 | 281 |
| 6/2/2015 | 160 |
| 6/17/2015 | 178 |

In other years the “zero” count (count low enough to be considered the end of the spawn) for the tail end of the distribution never occurred beyond June. This did not happen in 2015 and logistical constraints prohibited further surveys in July or beyond. The protraction of the spawn may also have been a result of late developing spawning adults.

*Electrofishing Surveys*

Three electrofishing surveys have been conducted in 2015, with a final one planned for mid-November. Age-0 population estimates for July, August, and September are 50,000 (18,000 Lower Confidence Interval (LCI); 20,000 Upper Confidence Interval (UCI)), 174,000 (48,000 LCI; 62,000 UCI), and 34,000 (9,000 LCI, 8,000 UCI), respectively. The estimate for September is likely inaccurate. Natal Origins sampling that occurred in September and October indicates numbers of age-0 fish are still high. The discrepancy is attributed to different methods of shocking between programs and their relative efficacies in an environment of increasing density of *Potamogetan* along shoreline habitat. Taking information from both programs, hatch success and long-term survival appear to be high for age-0 fish. This may be attributable to low densities of adult fish.

**Project Element 6.8. Lees Ferry Creel Survey**

**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 but is not limited to catch rates, gear type, species composition, harvest, and satisfaction with experience.

**Summary of progress:** As of this report, we have collected data for 2015 up to the end of September. Data for October through December 2015 will be analyzed and included in our annual report, to be submitted in 2016. Sampling days were stratified by month (6 days) and by weekday (2 days) and weekend (4 days). AGFD has been working with Lucas Bair at GCMRC on an economic study of the Lees Ferry fishery; this has included supplementary creel days in the spring and fall,

| |
|---|
| along with collecting angler address data during AGFD creels for a follow up survey. As of September 2015 we have conducted angler surveys on 57 days (including supplemental surveys).<br><br>**Summary of trends:** Catch per unit effort (CPUE) levels for boat anglers is significantly less this year than last year (paired T-test; P = 0.0303). As of September 63.5 % of the anglers were from Arizona and the rest from out of state (or country). Half (50.1 %) of the boat anglers interviewed used a guide. For calendar year 2014 we conservatively estimated about 10,908 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 4.23, and 3.46 (on a scale of 0-5) for boat and shore line anglers respectively. |
| |

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Journal Article | Avery, L. A., Korman, J., and Persons, W. R. (2015) *Effects of Increased Discharge on Spawning and Age-0 Recruitment of Rainbow Trout in the Colorado River at Lees Ferry, Arizona*. **North American Journal of Fisheries Management.** Online. | | Aug. 2015 | | |
| Thesis | Brizendine, Morgan 2015. Use of ultrasonic imaging to evaluate egg maturation of humpback chub *Gila cypha* . MS Thesis, University of Arizona | | | Dec. 2015 | |
| Journal Article | Bair, L.S., D.L. Rogowski, and C. Neher. In-review. Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate the Influence of Seasonality. North American Journal of Fisheries Management. | | Oct 2015 | | |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

| Project 6 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $187,000 | $4,900 | $29,100 | $290,000 | $0 | $38,829 | **$549,829** |
| **Actual Spent** | $192,555 | $4,212 | $17,078 | $265,057 | $0 | $37,105 | **$516,007** |
| **(Over)/Under Budget** | **($5,555)** | **$688** | **$12,022** | **$24,943** | **$0** | **$1,724** | **$33,822** |

| **COMMENTS** *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)* |
|---|
| Carryover: $40,300, will be used to offset FY16 & FY17 shortages. |

| Project 7: Population Ecology of Humpback Chub in and around the Little Colorado River | | | |
|---|---|---|---|
| **Program Manager** (PM) | Charles Yackulic | **Principal Investigator(s)** (PI) | Charles Yackulic, USGS, GCMRC<br>Kirk Young, USFWS<br>Kim Dibble, USGS, GCMRC<br>Mike Yard, USGS, GCMRC<br>Maria Dzul, USGS, GCMRC<br>David Rogowski, AZGFD<br>Randy VanHaverbeke, USFWS<br>Dennis Stone, USFWS<br>David Ward, USGS, GCMRC<br>Jeff Muehlbauer, USGS, GCMRC<br>Josh Korman, EcoMetric Research<br>Ted Kennedy, USGS, GCMRC |
| **Email** | *cyackulic@usgs.gov* | | |
| **Telephone** | (928) 556-7379 | | |

**SUMMARY**


The goals of this project are to:

1) Monitor humpback chub in the lower 13.6 km of the Little Colorado River (LCR) and Colorado River reference site (river mile (RM) 63.0-64.5)
2) Estimate recruitment and outmigration from the LCR by marking juvenile humpback chub throughout the lower 13.6 km of the LCR in July.
3) Develop field and analytical techniques to better use remote technologies for detecting passive integrated transponder (PIT) tags to address questions of trap avoidance and to potentially minimize future handling of chub.
4) Develop new non-lethal tools for measuring the health and condition of humpback chub in the field.
5) Undertake targeted, cost-effective research to understand mechanisms underlying observed population processes, including the roles of high CO2 at base flow, gravel limitation, parasites, and the aquatic food base.
6) 6) Continue to develop models that integrate findings from the above projects.

We have made progress with respect to all of these goals. Standard monitoring in both the LCR and Colorado River reference site (i.e., “JCM” site) continued this year and data are currently being analyzed to determine parameters (e.g., abundance, survival) of direct relevance to the GCDAMP. Spring sampling in the LCR led by Fish and Wildlife Service and Arizona Game and Fish suggests that the number of adult humpback chub in the LCR was substantially lower this year, which can be explained via three hypotheses: A) a large proportion of humpback chub, which are known to skip spawn (Yackulic et al., 2014; Pearson et al., 2015), may have chosen to not spawn this year, B) humpback chub adults may have exhibited higher than average mortality between the 2014 and 2015 spawning seasons, or C) standard monitoring trips may have missed the timing of this year’s spawn. Informal analysis of data from the fixed PIT tag array in the LCR suggests a similar timing of

migration in 2015 as in the year before, suggesting that the third hypothesis is unlikely. Examination of adult fish condition, based on data collected in the mainstem JCM reach, suggests that adults were in poor condition in the months leading up to the spawn, lending support to hypotheses A and B. Currently, we believe that hypothesis A is most likely, based on the assumption that adult humpback chub generally have low mortality rates and because it seems likely that humpback chub would forego spawning when they were generally in poor condition. However, given uncertainty in adult numbers and the difficulties of measuring adult chub in the mainstem Colorado, we will not be certain which hypothesis is most likely until after this coming spring. Despite a low number of adult spawners, analyses based on sampling of juvenile humpback chub in July, suggest that juvenile abundance was approximately ~50% greater than in either of the two prior years (~20,000 as compared to 14,000 and 11,000 in 2013 and 2014).

We have made some progress in developing analytical techniques to better use remote technologies; however, progress has been limited by competing demands on analysts' time for other GCDAMP related priorities, as well as reduced funding in FY15 for the statistical modelling group. Substantial progress has been made in the development of non-lethal tools for measuring condition of humpback, with lab trials completed and analysis of results underway. Research into the roles of $CO_2$, gravel limitation, parasites and the aquatic food base are all progressing without delays. Lastly, development of statistical models to understand humpback chub population dynamics is progressing with particular emphasis placed on better understanding the environmental drivers of humpback chub growth in this fiscal year and with two publications on humpback chub growth submitted to peer-reviewed journals. We are optimistic that if rainbow trout abundances remain low for the coming year, that we will be able to gain a better understanding of the relationship between humpback chub survival and rainbow trout abundance.

Specific findings from monitoring and research projects:

*Long term monitoring in the LCR*

In 2015, four monitoring trips were conducted by USFWS, Arizona Game and Fish, and volunteers to monitor the spring and fall population status of humpback chub in the LCR. These trips occurred during April/May, and September/October. During the April/May trips, it was estimated that there were 3,999 (SE = 314) humpback chub ≥150 mm in the lower 13.6 km of the LCR. Of these fish, it was estimated that 3,078 (SE = 246) were adults ≥200 mm. As mentioned above, these numbers were significantly lower than abundance estimates obtained since 2008, however, the reason why is not known. An additional mark-recapture effort (abundance results forthcoming) was conducted during the September/October timeframe. Interestingly, catches of humpback chub ≥150 mm and ≥200 mm during the September trip were the highest since this project began in fall 2000. We captured 1,131 unique chub ≥150 mm and 661 unique chub ≥200 mm during the September trip. Our next highest September catch of unique chub ≥150 mm and ≥200 mm was 774 and 578 fish, respectively, in fall 2010, suggesting that the decline in abundance seen during spring 2015 was more likely due to a large portion of chub temporarily remaining in the mainstem rather than entering the LCR to spawn. Unfortunately, flooding, very high turbidities, and low catch rates of chub during the October 2015 recapture trip might weaken our fall population estimate, which is forthcoming. On the positive side, production of the 2015 age-0 cohort appeared to be relatively strong, and despite the flooding, 303 age-0 chub were captured during October and translocated to above Chute Falls.

*Juvenile chub monitoring in the Colorado River research site*

In 2015, river trips sampled humpback chub near the LCR-Colorado River confluence in January, April, July, and September as part of the juvenile chub monitoring (JCM) project. These trips used two gears (slow-shock electrofishing and hoopnets) to capture fishes. All humpback chub > 99mm total length (TL) were marked with passive integrated transponder (PIT) tags, and all humpback chub between 40-99mm TL were marked using visual implant elastomer (VIE). In total, JCM trips captured 1,652 humpback chub > 99mm TL (compared to 819 in 2014) and 1,396 chub between 40-99mm TL (compared to 1,502 in 2014). Specifically, in 2015 catch of humpback chub>99mm TL by trip was as follows: 210 (Jan), 64 (Apr), 454 (Jul), and 924 (Sep). In addition, trip-specific catch of humpback chub between 40-99mm TL was as follows: 73 (Jan), 227 (Apr), 238 (Jul), and 858 (Sep).

*Pre-monsoon juvenile chub sampling in the LCR*

From June 26 to July 8, 2015 three teams completed two passes of the LCR using multiple gears. 3,633 juvenile chub (40 – 99 mm) were marked with VIE as part of this effort (compared to 2,399 and 2,426 juvenile chub in 2013 and 2014). Juvenile chub were found throughout the sampled area, but were most abundant in middle reaches. The majority of the marked fish were between 40 and 60 mm and the average total length of juvenile chub was 55.2 mm (compared to 50.3 mm in 2013 and 56.3 mm in 2014).

*Remote PIT tag array monitoring*

The remote PIT tag array continues to be plagued by technical difficulties and, when functioning, to provide unique pertinent information. There were several months over the winter and early spring during which the lower array was not functioning as the batteries had failed. These batteries were replaced in April and there have been no known issues since, though communication with the system has been limited since late June. Problems with the remote communications component of the MUX antenna system have prevented any remote data download since the end of June. Data were downloaded directly in October and one problem was resolved then, however we are still troubleshooting a second problem, which will require replacing aging equipment at the rim relay station and a site visit to the array inside the gorge. The data that was collected through June indicates similar timing for this year's spawning migration; however, the magnitude of the migration appears to have been much less. The total number of humpback chub detections at the upstream array only for the January to June period (where detection was unique on a daily basis) for years 2012 through 2015 were 3,745, 4,090, 4,755, and 1,961, respectively.

*Food web monitoring in the LCR*

Six invertebrate sampling trips were completed in the LCR in FY15: in October 2014 and March, April, May, June, and September 2015. Trips represent an intensive 4-day sampling effort involving 4 people deploying and collecting traps throughout the 21-km perennial reach of the LCR. A total of 872 sticky traps, benthic samples, and light traps were collected during these trips, representing ~

50,000 collected insect individuals. Newly-derived results from the previous year's (2014) sampling indicated pronounced patterns in insect density and diversity throughout the LCR, with greater numbers of both in the reach upstream of Chute Falls, particularly low numbers near Salt Camp, and otherwise a general decline proceeding downstream from the LCR's perennial source at Blue Spring to its confluence with the mainstem Colorado River. The data also showed seasonal patterns in insect availability, with a strong peak in April. Thus, 2015 sampling was structured to provide confirmatory evidence for these findings, including the addition of a March sampling trip to verify the April peak, and the deployment of light sensors to examine canyon shading and water turbidity as potential influences on the observed longitudinal diversity and density patterns.

Analysis of fish diets collected over 5 trips (2012–2015) from the lower reach of the LCR is nearing completion. Gut contents from over 450 fish were collected, including humpback chub (>100 mm, via nonlethal lavage) and juveniles and adults of the other native and nonnative fishes occupying this segment. Sampling encompassed an array of seasonal and hydrological conditions; clear summer baseflow, summer monsoonal flooding, fall flooding and spring flooding, and clear winter baseflow. Preliminary results reveal high levels of omnivory in native fishes and reliance upon a large array of food items of both aquatic and terrestrial origin. Both within and across seasons, adult humpback chub had the most diverse diets (75 different food resources identified, 1.5-2X more than any other species) and exhibited heavy use of terrestrially-derived resources; the latter was true even under summer, clear-water conditions when chub consumed similar amounts of invertebrates of terrestrial and aquatic origin. Normalized measures of total mass of gut contents varied with season/hydrologic condition and were highest during and immediately following a summer flood, 42% lower during summer clear-water, and 77% and 85% lower for fall and winter, respectively; observations that suggest chub and other native fishes experience patterns of "feast and famine" in the LCR. Results from this study will help assess the potential competition for food (e.g., there is substantial dietary overlap among fishes for limited aquatic invertebrate resources) and shed light on the relative roles of the LCR and mainstem Colorado River in sustaining populations of chub and other native fishes.

*Effects of high CO2 on chub early life history*

CO2 concentrations were mapped within the LCR from Horse Trail to the confluence with the Colorado River on May 22-May 25, 2015 using an Oxyguard portable CO2 meter. CO2 concentrations above Blue Springs are low enough to support fish (<10 mg/l). At blue springs CO2 concentrations increased to 310 ppm and remained above 30 mg/l until RKM 16. Carbon dioxide concentrations decrease gradually from Salt camp (11 ppm) to 5 ppm near the confluence. In general CO2 concentrations were found to be significantly lower than measurements previously reported using titration methods. Richard Wanty (USGS Geochemist) from Denver will be assisting us next year to rectify these discrepancies. Laboratory studies are underway to evaluate native and nonative fish tolerance to high CO2 during early life stages. These results will be compared to measured CO2 levels in the LCR at base flow to evaluate potential impacts of CO2 on fish populations.

*Asian tapeworm monitoring*

Tapeworm monitoring was conducted in the LCR at Boulders camp from May 25-29, 2015. Forty-eight humpback chub (35 – 388 mm TL) were treated with two doses of Praziquantel at 6 mg/l. Only

14 Asian tapeworms were recovered from 5 fish. No fish under 100 mm TL were infested. This represents a significantly lower infestation rate than was found during the 2005 sampling. Three juvenile humpback chub died during the treatment and holding procedure. All other fish were released alive following treatment.

*Bioelectrical Impedance Analysis*

Laboratory trials to develop a non-lethal tool to quantify the condition of humpback chub were completed in FY15. Laboratory trial focused on different fish size classes, temperatures, and feeding treatments (ad libitum, restricted). To develop this as an accurate tool that can be applied in the field, BIA measurements were compared to measures of proximate composition (% lipid, protein, etc.). To estimate the level of mortality for fish subjected to BIA measurements, we conducted mortality trials. Analysis of BIA, proximate composition, and mortality data is currently underway and a manuscript will be produced in FY16

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Journal article | C Finch, Pine WE, Yackulic CB, Dodrill MJ, Yard M, Gerig BS, Coggins LG, and Korman J (2015) *Assessing Juvenile Native Fish Demographic Responses to a Steady Flow Experiment in a Large Regulated River*. **River Research and Applications.** Online | | Mar. 2015 | | |
| Journal article | MJ Dodrill, CB Yackulic, B Gerig, WE Pine, J Korman and C Finch (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**. Online | | Oct. 2014 | | |
| Journal article | MC Dzul, CB Yackulic, DM Stone, DR Van Haverbeke (2014) *Survival, growth, and movement of subadult humpback chub, Gila cypha, in the Little Colorado River, Arizona.* **River Research and Applications**. Online | | Dec. 2014 | | |
| Journal article | DL Ward, and R Morton-Starner (2015) *Effects of water temperature and fish size on predation vulnerability of juvenile humpback chub to rainbow and brown trout.* | | | Nov. 2015 | |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | **Transactions of the American Fisheries Society.** In Press | | | | |
| Journal article | | | | | Pillow, M.J. 2015. Spring 2015 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report: 14-24 April and 19-29 May 2015. Delivered July 2015 |
| Journal article | | | | | Stone. D.M. and M.J. Pillow. 2015. Fall 2015 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report: 22 Sept - 1 Oct and 23 Oct – 1 Nov 2015. To be delivered Dec 2015 |
| Journal article | | | | | 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 2015. Annual Report. To be delivered Jan 2016. |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | | | | | |
| Conference presentation | CB Yackulic (2015) *Population dynamics of Humpback Chub that spawn in the Little Colorado River: drivers and their implications for management.* **Biennial Conference on Science and Management on the Colorado Plateau**. Flagstaff, AZ. | | Oct. 2015 | | |
| Conference presentation | MC Dzul, and CB Yackulic (2015) *Using environmental covariates to predict growth in two contrasting environments: a growth assessment of an endangered desert fish.* **Biennial Conference on Science and Management on the Colorado Plateau**. Flagstaff, AZ. | | Oct. 2015 | | |
| Conference presentation | JD Muehlbauer, TA Kennedy, EW Kortenhoeven, JT Smith (2015) *Longitudinal and temporal patterns of food availability for endangered humpback chub*, Gila cypha, *in the Little Colorado River, Arizona.* **Desert Fishes Council Annual Meeting**, Death Valley, NV. | | Nov. 2015 | | |
| Conference presentation | JD Muehlbauer, TA Kennedy, EW Kortenhoeven JT Smith (2015) *There's more than* | | Aug. 2015 | | |

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | *one way to shade a river: contrasting influence of canyon orientation and water clarity on aquatic invertebrate densities.* **Ecological Society of America Annual Meeting**, Baltimore, MD. | | | | |
| Conference presentation | KL Dibble, M Yard and DL Ward (2015) Development of a non-lethal tool to assess the physiological condition of endangered fish species in Grand Canyon, USA. **American Fisheries Society**, Portland, OR. | | Aug. 2015 | | |

| Project 7 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $508,600 | $15,000 | $61,100 | $555,000 | $0 | $96,362 | **$1,236,062** |
| **Actual Spent** | $451,614 | $12,611 | $39,105 | $545,000 | $0 | $84,969 | **$1,133,300** |
| **(Over)/Under Budget** | **$56,986** | **$2,389** | **$21,995** | **$10,000** | **$0** | **$11,393** | **$102,762** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $119,700, will be used to offset FY16 & FY17 shortages.
Didn't buy all planned equipment this FY.

| **Project 8: Experimental Actions to Increase Abundance and Distribution of Native Fishes in Grand Canyon** | | | |
|---|---|---|---|
| **Program Manager** (PM) | David Ward | **Principal Investigator(s)** (PI) | David Ward, USGS, GCMRC<br>Brian Healy, NPS<br>Clay Nelson, NPS<br>Emily Omana, NPS<br>Kirk Young, USFWS<br>Dennis Stone, USFWS<br>Randy VanHaverbeke, USFWS<br>David Rogowski, AZGFD<br>Scott VanderKooi, USGS, GCMRC |
| **Email** | *dlward@usgs.gov* | | |
| **Telephone** | (928) 556-7280 | | |


**SUMMARY**

This project encompasses two ongoing management actions, a protocol evaluation panel review of fish monitoring and research efforts and two new projects funded in 2017. The protocol evaluation panel will take place in FY16 or 17. Specific findings from the funded monitoring and research projects are listed below.


**<u>Project Element 8.1. Efficacy and Ecological Impacts of Trout Removal at Bright Angel Creek</u>**

Trout removal using elecrofishing occurred in the mainstem Colorado River near the confluence with Bright Angel Creek from Feb 4 - 20, 2015. This experimental action is being conducted in collaboration with Grand Canyon National Park, consistent with the NPS Comprehensive Fisheries Management Plan and related compliance documents. The removal effort was re-scheduled to February to avoid conflicts with the 2014 High Flow Experiment and associated logistical constraints. Unfortunately, turbid conditions again made electrofishing efficacy and capture probability low. Crews removed 391 rainbow trout and 84 brown trout. All harvested fish were cleaned, vacuum sealed in bags, and frozen for human consumption.

The timing of the 2015 Bright Angel removal trip (February) occurred later than in 2014 (November), making direct comparisons of trout captures difficult, but numbers did decrease from 828 to 391for rainbow trout, and 222 to 84 for brown trout, from 2014 to 2015, respectively. Both years experienced turbid water for the majority of sampling, although 10 depletions were completed in 2015 compared to only 5 depletions in 2014. The apparent decrease in trout abundance seems to also coincide with decreases in trout observed throughout Glen and Marble Canyons, and a significant reduction of trout within BAC. This reduction in numbers also corresponds to poor condition observed in rainbow trout in our study area as well as declining condition observed throughout the system since 2014 from Arizona Game and Fish monitoring data. Conversely, the number of native fish caught in the same area increased from 41 to 270 for flannelmouth sucker, and 33 to 120 for bluehead sucker from 2014 to 2015, respectively. Increases in the catch of native species are likely due to a combination of increased sampling in 2015 compared to 2014 (5 to 10 depletions), and sampling effort occurring later in the spring when flannelmouth sucker spawn in Bright Angel Creek. Increases in the catch of native fish may also be the result of increased native fish abundance in the area because of ongoing nonnative fish removal by the Park Service within Bright Angel Creek. Additional years of data will be needed to evaluate this hypothesis, but the results to this point appear promising.

**Project Element 8.2. Translocation and monitoring of Humpback chub above Chute Falls in the Little Colorado River**

The goals of this project are to:

1) Annually translocate at least 300 juvenile humpback chub from lower portions of the Little Colorado River (LCR) to above Chute Falls in the LCR.
2) Annually monitor the abundance of humpback chub above river kilometer (rkm) 13.6 km in the LCR. This includes monitoring in a small reach of river known as the Atomizer reach (rkm 13.6-14.1) and the reach of river known as the Chute Falls reach (rkm 14.1 km- 17.7).

This project is a direct attempt to conduct a conservation measure to translocate humpback chub to upstream of rkm 13.6 in the Little Colorado River (LCR) (USFWS 2008, 2011), and is intended to increase growth rates and survivorship, expand the range, and ultimately augment the LCR humpback chub aggregation in Grand Canyon. In addition, this project provides managers with an annual index of abundance and trend of humpback chub residing above rkm 13.6.

*Translocation:*
Efforts to translocate humpback chub upstream of Chute Falls in the LCR have been ongoing since 2003 (Figure xx). To date, approximately 2,969 juvenile (~80-130 mm TL) humpback chub have been translocated to upstream of Chute Falls. Of these, 303 humpback chub were released above Chute Falls (at rkm 16.2) on November 1, 2015. The project is identified as a Conservation Measure in the 2011 Biological Opinion. Our monitoring activities also coincide with joint efforts with the National Park Service to collect juvenile or larval humpback chub for transport to the Southwest Native Aquatic Research and Recovery Center (SNARRC), destined for grow out and release into Shinumo and Havasu Creeks. This year, during May 2015, approximately 300 larval humpback chub were collected and transported to SNARRC.

*Monitoring:*
From 2006–2009, two pass mark-recapture population estimates of humpback chub were conducted upstream of rkm 13.6 in the Atomizer Falls and Chute Falls reaches of the LCR. During these trips, capture probability data was obtained. From 2010–2015, this set of capture probability data was used to annually estimate the abundance of humpback chub above rkm 13.6 (Figure xx). During 2015, a trip was conducted during 19–28 May to estimate abundances of humpback chub upstream of rkm 13.6 in the LCR. For 2015, was estimated that there were 247 humpback chub ≥100 mm (SE = 55) in the Chute Falls reach, and 435 ≥100 mm (SE = 80) in the Atomizer Falls reach. Of these, it was estimated that there were 29 humpback chub ≥200 mm (SE = 6) in the Chute Falls reach, and 177 ≥200 mm in the Atomizer reach (SE = 30). Results have also indicated unusually rapid growth of translocated fish, and high apparent survival.

A.

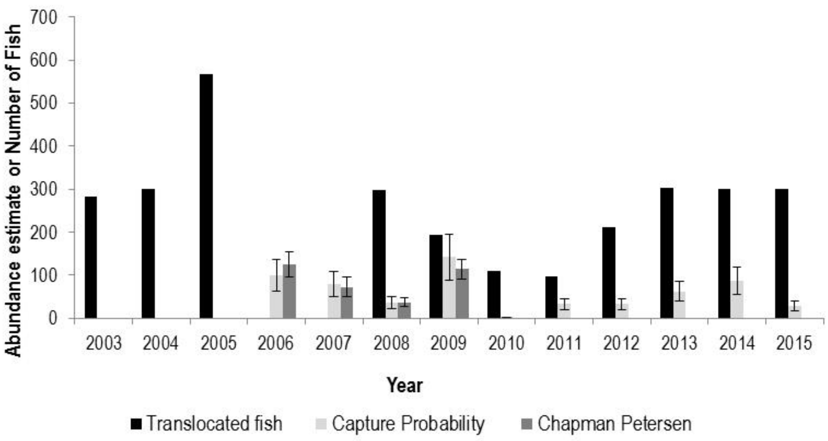



Figure A. Numbers of humpback chub that have been translocated upstream of Chute Falls since 2003 (black bars), and abundances (±95% CI) of adult humpback chub (≥ 200 mm) in upper reach upstream of Chute Falls (river km [rkm] 14.1 to 17.7) since summer 2006, and

B.

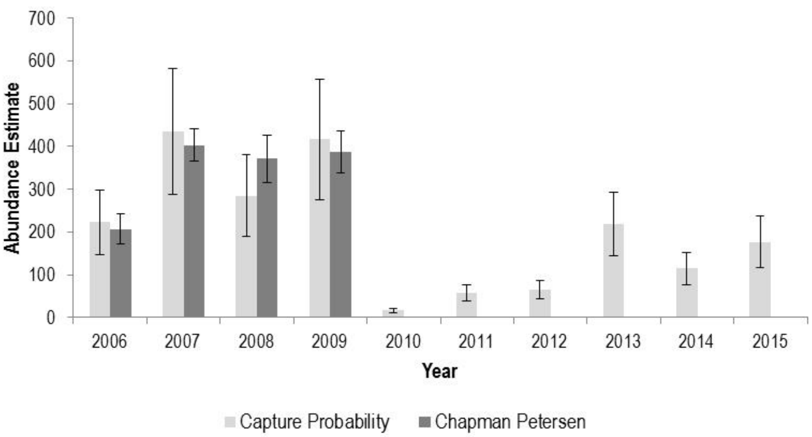



Figure B. Abundances (±95% CI) of adult humpback chub in lower reach downstream of Chute Falls (rkm 13.57 – 14.1) since summer 2006. Note, abundances for both upper and lower reaches are shown as those estimated with Chapman Petersen mark-recapture (dark grey bars) and those estimated using capture probability data (light grey bars) derived from the 2006-2009 Chapman Petersen mark-recapture efforts.

*Project Element 8.3.Glen Canyon Dam Adaptive Management Program Fisheries Research, Monitoring, and*
*Management Actions Protocol Evaluation Panel*
Project element funded in FY 16 or 17.

**Project Element 8.4. Little Colorado River Invasive Aquatic Species Surveillance**
*Project element funded in FY 17.*

| **Project Element 8.5. Genetic monitoring of Humpback chub in Grand Canyon**<br>*Project element funded in FY 17.* |
|---|
| |

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Trip Report | Bright Angel Creek inflow trout reduction pilot study. Trip Report, 4-20 February 2015. | | Aug 2015 | | |
| Trip Report | Stone, D.M. 2015. Spring 2015 Monitoring of Humpback Chub (*Gila cypha*) and Other Fishes above Lower Atomizer Falls in the Little Colorado River, Arizona. Trip Report 19-29 May 2015. | | July 2015 | | |
| Trip Report | Stone. D.M. and M.J. Pillow. 2015. Fall 2015 Monitoring of Humpback Chub (*Gila cypha*) and<br>other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report: 22 Sept - 1 Oct and 23 Oct – 1 Nov 2015. | Dec 2015 | | Dec 2015 | Trip Report |
| Annual Report | 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 2015. | Jan 2016 | | Jan 2016 | |

| Project 8 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $53,700 | $0 | $7,500 | $68,200 | $0 | $10,389 | **$139,789** |
| **Actual Spent** | $50,957 | $104 | $355 | $68,151 | $0 | $9,054 | **$128,622** |
| **(Over)/Under Budget** | **$2,743** | **($104)** | **$7,145** | **$49** | **$0** | **$1,335** | **$11,167** |

| **COMMENTS** *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)* |
|---|
| Reduced salary costs due to lower actual burden rate.<br>Carryover: $13,100, will be used to offset FY16 & FY17 shortages. |

| **Project 9: Understanding the Factors Determining Recruitment, Population Size, Growth, and Movement of Rainbow Trout in Glen and Marble Canyons** | | | |
|---|---|---|---|
| **Program Manager** (PM) | Mike Yard | **Investigator(s)** (I) | Mike Yard, USGS, GCMRC<br>Kim Dibble, USGS, GCMRC<br>Josh Korman, Ecometric Research<br>Charles Yackulic, USGS, GCMRC<br>Ted Melis, USGS, GCMRC<br>David Rogowski, AZGFD<br>Ted Kennedy, USGS, GCMRC<br>David Ward, USGS, GCMRC<br>Mike Dodrill, USGS, GCMRC<br>Dan Buscombe, USGS, GCMRC<br>Paul Grams, USGS, GCMRC<br>Tom Gushue, USGS, GCMRC |
| **Email** | *myard@usgs.gov* | | |
| **Telephone** | (928) 556-7377 | | |

**SUMMARY**


**<u>Project Element 9.1. Rainbow Trout Population Dynamics – Ongoing Modelling and Future Monitoring</u>**

In 2015, multiple cooperators AGFD (Project Element 6.8) and Ecometric (Project Element 9.2) have continued to collect monitoring data on the Lees Ferry fishery to provide long-term status and trend information. All of these data are to be evaluated to determine whether or not conventional catch-per-unit indices or other types of sampling approaches are appropriate for meeting long-term monitoring needs of the GCDAMP. In FY16, GCMRC in conjunction with the Science Advisors program is convening a protocol evaluation panel (PEP; see Project Element 8.3) to review the fisheries monitoring program. The development of this fisheries monitoring plan is a collaborative process that involves current cooperators (USFWS, NPS, AGFD, and Ecometric, Inc.). Upon final review, PEP recommendations are to be incorporated into the new monitoring project and implemented in FY17.

**<u>Project Element 9.2. Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam/Natal Origins</u>**

The primary goal of the Natal Origins Project (NO) is to estimate abundance, movement, growth, and survival of age-0 and older rainbow trout (RBT) between Glen Canyon Dam and the Little Colorado River (LCR) confluence area. Research and monitoring objectives are to quantify the extent of trout movement from Lees Ferry into Marble Canyon and the LCR confluence area. And to determine the physical and biological factors responsible for trout movement (density, food, growth, turbidity, HFEs, etc.).

In FY15, the NO project completed four downstream river trips (Jan, Apr, Jul, and Sep 2015, 21-day trips) and two fall-Glen Canyon trips (Oct and Dec 2014, 10-day trips). A total of 19,108 RBT were

captured and 10,639 RBT were newly marked and released with PIT-tags on the four downstream river trips. This represents a 46% decrease in total catch compared to the previous year (2014). RBT abundance in all five NO study reaches has declined substantially since initiating the study (2012), current trout densities observed in reach I (Glen Canyon) and IVb (below LCR) were approximately 15,000 and 100 fish/km, respectively. The latter trout density (113 fish/km - 2015 average estimate) in IVb is well below one of the triggering criterion defined in the Biological Opinion (2011) for determining when nonnative fish control will take place near the LCR. In comparison to past years, this is a substantial reduction in the total number of fish caught and tagged and likely reflects a change in RBT recruitment from migrants as well as a decrease in the overall survival. Results based on the Jolly-Seber model indicate a decreasing trend in the 90-day survival rate estimates made across years between September and April. The 90-day survival rate estimates averaged across all reaches for the Sep14-Apr15 interval was 0.27, which is substantially less compared to 0.75 and 0.64 for Sep12-Apr13 and Sep13-Apr14 intervals, respectively. Reduced trout growth and condition in the late-spring and summer (April-September) of 2014 led to decreases in trout survival throughout the entire river system that affected larger sized fish disproportionately. Although trout abundance levels have been reduced across all of the NO reaches, the remaining RBT appear to have recovered and are demonstrating better seasonal growth and condition (reaches I-III).

Two papers were recently published on the findings of RBT abundance, survival, movement, and growth from Project F.6 in FY13–14 Biennial Work Plan. In summary, the vast majority of rainbow trout exhibited very limited movement based on differences between release and recapture locations. Of the across-trip recaptures where release and recapture locations were known, the average movement distance was 0.45 km downstream, and 95% of recaptures moved no more than 2.6 km upstream and 5.2 km downstream. There were rare cases where fish moved longer distances. Restricting inferences to RBT that moved more than 20 km, approximately 70% moved in a downstream direction. Based on all sampling efforts, including fall Glen Canyon trips, only 158 of 8,166 recaptures (1.9%) were from reaches other than the one they were released in. Restricting the analysis to marks released and recaptured on downstream trips only resulted in a large reduction in recaptures for fish released upstream of Lees Ferry, though the conclusion of limited across-reach movement still holds. There were only 142 across-reach recaptures in this restricted data set used by the across-reach movement model, with more than half resulting from exchange between reaches IVa and IVb, which are relatively close together. With respect to predicting immigration to IVa and IVb from upstream sources, there were only 33 cases where marked trout were released in Glen Canyon or reaches II and III and later recaptured in reaches near the LCR.

Estimated across-reach movement percentages indicated very limited movement between most reaches. An average of only 1% of trout marked in reaches I, II, or III were estimated to move to reaches other than the ones they were released in. There was more exchange between reaches IVa and IVb due to their closer proximity, and estimated movement proportions indicated a greater tendency for trout to move downstream from IVa to IVb (7.8%) compared to moving upstream (1.7%). Movement proportions from reaches I-III to reaches near the LCR suggest very limited movement from Glen Canyon to the LCR, and a higher probability of moving from locations in Marble Canyon to the LCR with decreasing distance. Predicted and estimated recruitment to reaches near the LCR were in close agreement. The Jolly-Seber model estimated that 16,200 rainbow trout recruited to reaches IVa and IVb over the study period. The mean of the posterior distribution of the predicted immigration to these reaches from upstream sources, determined by the across-reach movement model, was 17,400 trout. Reach-specific results were also in close agreement. Locations closer to reaches near the LCR (lower Marble Canyon) made larger contributions to immigration relative to more distant sources (Glen Canyon and upper and middle Marble Canyon), even though abundance at the more distant source locations was much higher. In reach IVa, the vast majority of immigration came from the section represented by reach III. The majority of immigration to reach IVb was from approximately equal contributions from sections represented by III and IVa.

These past results and future findings (FY15–16) will be used to help further inform future analyses planned to determine what effects physical and biological factors have on RBT abundance, survival, movement, and growth over the 75 mile-long study area between Glen Canyon Dam to just downstream of the LCR confluence.

Manuscript in progress related to this project topic.

Korman, J. and M.D. Yard. Effects of abiotic and biotic factors on electrofishing capture probabilities. In Preparation. Canadian Journal of Fisheries and Aquatic Sciences.

**Project Element 9.3. Exploring the Mechanisms behind Trout Growth, Reproduction, and Movement in Glen and Marble Canyon using Lipid (fat) Reserves as an Indicator of Physiological Condition**

Field data collection was completed in FY15 during fish sampling associated with the Natal Origins Project (9.2). Approximately 100 rainbow and 25 brown trout were sampled during each trip and muscle, liver, and hindgut tissue excised in the field. All samples were processed in the laboratory and lipids were extracted from each tissue sampled using gravimetric extraction techniques. At the present time, data acquisition and a preliminary analysis is complete. A more in-depth analysis that includes information from the food base (stomach contents; drift) as well as other biological and physical factors is planned this winter, and one manuscript associated with Project 9.3 will be submitted for peer-review in FY16.

**Project Element 9.4. Comparative study on the feeding morphology of drift feeding fish (NOT FUNDED)**

The funding source for this project is undetermined. This project element will not be conducted in FY15–17.

**Project Element 9.5. Meta-analysis, and the development of reactive distance relationships for encounter rate model.**

The objective of this project element contains two parts: (1) determine the effects of varying light intensity and prey size on fish reactive distances; and (2) develop an encounter rate model for drift feeding fish that accounts for varying reactive distances and prey availability within the range of channel depths and light levels encountered in Glen and Marble Canyons. An extensive literature search on all known published data on reactive distances (i.e., distance a prey item can be visually detected) of visual sight-feeding fish was performed. We will evaluate literature and quantitatively summarize regression slopes obtained from independent studies, either published as relationships or through extraction of data from graphs and tables.

**Project Element 9.6. Evaluation of Turbidity (in terms of TSS) as a potential Glen Canyon Dam operations management tool to constrain rainbow trout populations and reduce predation/competition on juvenile humpback chub**

We have constructed 4 recirculating artificial stream systems at the US Forest Service Rocky Mountain Research Station in Flagstaff Arizona.  These stream systems are capable of maintaining turbidities of

50 – 200 FNU in suspension for 30 days or more without deterioration in water quality. Rainbow trout have been collected from Lees Ferry, acclimated to laboratory conditions, treated for parasites, and PIT tagged. Controlled laboratory experiments to evaluate the magnitude and duration of turbidity required to negatively impact rainbow trout survival will commence this winter.

Publication in progress related to this project topic.

Ward, DL., R. Morton-Starner, and B. Vaage. Effects of turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout. In Review. Journal of fish and Wildlife Management. (expected publication date April 2016)

**Project Element 9.7. Application of a bioenergetics model in a seasonally turbid river**

In order to understand the linkages between food availability, physical habitat, and rainbow trout growth, we continue to develop and refine a drift-foraging bioenergetics model. These types of models often include nonlinear descriptions of ecological processes and may be sensitive to how model inputs, such as invertebrate drift, are summarized. This is due to a mathematical property of nonlinear equations, known as Jensen's inequality. By using simulations and two case studies, we have shown that drift-foraging models can be biased by alternative descriptions of invertebrate drift (a key input to the model), resulting in either an over or underestimation of available energy for fish growth.

These findings are reported in a manuscript under review (Dodrill and Yackulic, In Review). This information will help guide the application of process based models to understand the role of turbidity in influencing rainbow trout foraging and growth.

**Project Element 9.8. Mechanisms that Limit Rainbow and Brown Trout Growth in other Western Tailwater Systems**

We explored data from dams that had a long time series of high-quality fishery data (20+ years) to assess the mechanisms behind salmonid growth as they relate to dam operations. We determined that dams exhibiting a long time series of information were limited, but included the tailwaters in which we originally intended to apply bioenergetics models to in the second part of Project 9.8. Therefore, we combined the first and second parts of this project into one project aimed at understanding what drives rainbow and brown trout population dynamics in tailwaters across the western US (e.g., temperature, food availability, flow, density, etc.). Since we needed growth data, we used stock assessment software (FiSAT II) and modal progression analysis combined with a series of linear regressions to convert length-frequency data to fish growth (weight gain) data. In addition, we used pit tag data to calculate fish growth from two tailwaters. We then used the Wisconsin bioenergetics model to assess how temperature and estimated prey availability and energy density influence age-1 brown trout consumption in tailwaters downriver of multiple dams (Flaming Gorge, Holter, Navajo and Yellowtail). Brown trout consumption results, however, were uninteresting (i.e., nearly constant over time), and subsequent concerns about using lagged consumption as a predictor variable in brown trout adult length models resulted in a decision to forgo use of these data in the manuscript. In addition, we were unable to successfully apply bioenergetics models to rainbow trout growth data across tailwaters due to inherent flaws in the underlying data that were beyond our ability to predict at the start of this project.

However, during this effort we amassed a large amount of tailwater temperature and reservoir data that we can use to assess what physical factors (including reservoir fullness, air temperature, and precipitation/snowpack levels) influence low and high temperature events in tailwaters across major River Basins in the intermountain West. We are currently analyzing this data and have incorporated temperature data into existing rainbow and brown trout models published in FY15 associated with Project H.4 in the FY13-14 Biennial Work Plan. This effort provides the opportunity to assess what physical factors have influenced tailwater temperature profiles in the past two decades, how temperature has influenced rainbow and brown trout recruitment and growth, and how tailwater temperatures and trout may respond to future climate warming. A manuscript associated with Project 9.8 will be submitted for peer-review in FY16.

Publication in progress related to this project topic.

Dodrill, M. J and C. B. Yackulic. Alternative Ways to Summarize Invertebrate Drift Data Influence Predictions from Drift-Foraging Bioenergetics Models. In Review. Canadian Journal of Fisheries and Aquatic Sciences.

**Project Element 9.9. Effects of High Experimental Flows on Rainbow Trout Population Dynamics**

The objective of this project element is to determine the effects of multiple fall HFEs and other potential management actions, such as the Fall Steady Flow treatments on rainbow trout populations in Glen Canyon. The study is designed to estimate changes in age-0 trout densities and survival during pre- and post-flood periods, and then compare estimates between years with and without experimental floods. A manuscript will be submitted for peer-review in FY17 upon the completion of the Natal Origin project (Project Element 9.2).

**Project Element 9.10. Examining the Effects of High Flow Experiments on the Physiological Condition of Age-0 and Adult Rainbow Trout in Glen Canyon**

Field sampling was conducted pre- and post-flood in FY15 associated with RTELSS (September 25-26, 2014; Project 6.7), and the HFE Fall Mark Trips (October 21-31, December 4-14, 2014; Project 9.9). These samples will be compared to non-HFE samples collected in FY16 during the RTELSS and HFE Fall Mark Trips (November 14-15 and December 1-10, 2015, respectively). At the present time, pre-flood age-0 rainbow trout are being ground in the laboratory in preparation for lipid analysis. In winter FY16, samples from HFE and control years will be extracted and spotted on thin layer chromatography plates to quantify lipid classes. Otoliths will be removed from post-flood fish and pre- and post-flood growth rates will be calculated using the width between daily increments. These data will be analyzed and a manuscript submitted in FY17.

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Journal Article | Movement, Abundance, and Survival of Rainbow Trout in the Colorado River in | | | | Korman, J., M.D. Yard, and C.B. Yackulic. Movement, Abundance, and Survival of Rainbow Trout in the Colorado |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | Grand Canyon. | | | | River in Grand Canyon. *Canadian Journal of Fisheries and Aquatic Sciences*. 10.1139/cjfas-2015-0101. |
| Journal Article | Seasonal and Spatial Patterns of Growth of Rainbow Trout in the Colorado River in Grand Canyon | | | | Yard, M.D., J. Korman, C. J. Walters, and T.A. Kennedy. Seasonal and Spatial Patterns of Growth of Rainbow Trout in the Colorado River in Grand Canyon, AZ. *Canadian Journal of Fisheries and Aquatic Sciences*. 10.1139/cjfas-2015-0102. |
| Journal Article | Flow management and fish density regulate salmonid recruitment and adult size in tailwaters across western North America | | | | Dibble, K.L., C.B. Yackulic, T. Kennedy, and P. Budy. *In Press*. Flow management and fish density regulate salmonid recruitment and adult size in tailwaters across western North America. *Ecological Applications*. http://dx.doi.org/10.1890/14-2211.1 |
| Journal Aritcle | Prey Size and Availability Limits Maximum Size of Rainbow Trout in a Large Tailwater: Insights from a Drift-Foraging Bioenergetics Model | | | | Dodrill, M. J., C. B. Yackulic, T. A. Kennedy, and J.W. Hayes. In Press. Prey Size and Availability Limits Maximum Size of Rainbow Trout in a Large Tailwater: Insights from a Drift-Foraging Bioenergetics Model. Canadian Journal of Fisheries and Aquatic |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | | | | | Sciences. |
| Journal Article | Effects of turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout. In Review. Journal of fish and Wildlife Management. | | | April 2016 | Ward, DL., R. Morton-Starner, and B. Vaage. Effects of turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout. In Review. Journal of fish and Wildlife Management. |
| Presentation | Small Prey and Temperature Jointly Limit Maximum Size of Rainbow Trout: Insights from a Drift-Foraging Bioenergetics Model | | August 18, 2015 | | Dodrill, M. J., C. B. Yackulic, and T. A. Kennedy. 2015. Small Prey and Temperature Jointly Limit Maximum Size of Rainbow Trout: Insights from a Drift-Foraging Bioenergetics Model. American Fisheries Society National Meeting: Portland, Oregon, USA. |
| Presentation | Small Prey and Temperature Jointly Limit Maximum Size of Rainbow Trout: Insights from a Drift-Foraging Bioenergetics Model | | Oct. 7, 2015 | | Dodrill, M. J., C. B. Yackulic, T. A. Kennedy, and J.W. Hayes. 2015. Small Prey and Temperature Jointly Limit Maximum Size of Rainbow Trout: Insights from a Drift-Foraging Bioenergetics Model. Biannual Conference of Science on the Colorado Plateau: Flagstaff, Arizona, USA. |
| Presentation | Seasonal and Spatial Patterns of Growth of Rainbow Trout in the Colorado River in Grand Canyon. | | Aug. 18, 2015 | | Yard, M., Korman, J. Walters, C., and Kennedy, T. 2015. Seasonal and Spatial Patterns of Growth of Rainbow Trout in the Colorado River in Grand |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | | | | | Canyon. 145th Annual Meeting, American Fisheries Society, Portland, OR. |
| Presentation | Movement, abundance, survival and growth of rainbow trout (*Oncorhynchus mykiss*) in the Colorado River in Grand Canyon. | | Oct. 7, 2015 | | Yard, M.D., and Korman, J. 2015. Movement, abundance, survival and growth of rainbow trout (*Oncorhynchus mykiss*) in the Colorado River in Grand Canyon. 13th Biennial Conference of Science and Management, on the Colorado Plateau and Southwest Region. Northern Arizona University, Flagstaff, AZ. |

| Project 9 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $370,200 | $6,800 | $91,000 | $190,000 | $0 | $69,502 | **$727,502** |
| **Actual Spent** | $364,398 | $4,633 | $47,794 | $195,602 | $0 | $62,694 | **$675,121** |
| **(Over)/Under Budget** | **$5,802** | **$2,167** | **$43,206** | **($5,602)** | **$0** | **$6,808** | **$52,381** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $65,000, will be used to offset FY16 & FY17 shortages.
Didn't buy all planned equipment this FY.

**Project 10: Where does the Glen Canyon Dam Rainbow Trout Tailwater Fishery End? – Integrating Fish and Channel Mapping Data below Glen Canyon Dam**

| | | | |
|---|---|---|---|
| **Program Manager** (PM) | Ted Melis | **Investigator(s)** (I) | Ted Melis, USGS, GCMRC<br>Dan Buscombe, USGS, GCMRC<br>Mike Yard, USGS, GCMRC<br>Josh Korman, EcoMetric Research<br>Paul Grams, USGS, GCMRC<br>Tom Gushue, USGS, GCMRC |
| **Email** | *tmelis@usgs.gov* | | |
| **Telephone** | (928) 556-7282 | | |

**SUMMARY**

**Introduction**

In FY15, scientists from Project 10 collected all of the acoustic data, bed imagery, and shoreline imagery that was described in the FY15–17 Triennial Work Plan (TWP) during 2 downstream river trips (in April and July 2015), and additional short trips to Lees Ferry (in December 2014, and April, July and October 2015). Findings published or presented in the past year describe progress principally in the development of various methods to collect and process sidescan sonar imagery, and grain-size analysis of sediments. Below, we summarize specific accomplishments by project element.

**Summary of Progress by Project Element**

**10.1. *Refine Humminbird® Sidescan Sonar and Other Channel Mapping Methods to Support Fish and Foodbase Research*** – Daniel Buscombe, Daniel Hamill, Ted Melis, Michael Yard

The purpose of the 10.1 element of this project is to complete sidescan sonar mapping/imaging methods. An additional purpose of this project is to finalize a protocol for sidescan data collection. This monitoring involves collection and analysis of data, and algorithm development for determining changes in the areal extents of sand and gravel bed surface sediment types using low-cost, easy-to-use sidescan sonar technology, where drifting benthic organisms and spawning trout are monitored in Glen and Marble Canyon study segments.

We have published two manuscripts on research and development of new methods for using Humminbird® sidescan sonar instruments for imaging channel-bed sediment type and sediment changes in channel margin settings to support aquatic resource monitoring [Refs. 1 and 2]. There is one more article detailing technical advances in data processing from low-cost sidescan sonar, authored by Buscombe and proposed for 2016 [Ref. 4]. There is one article on evaluation of bed substrate classifications using sidescan sonar, authored by Hamill and others, proposed for late 2016 or early 2017 [5].

Specifically, the following objectives have been met:

- We have defined protocols for the best use of sidescan sonar to quantify spatial area of sand and gravel bed sediments of the Colorado River channel

- We have developed completely or partially supervised bed sediment classification algorithms using existing sidescan data, at high resolution with continuous coverage, based on calibrated echo strengths and texture (spatial pattern) of echoes [Refs 1 and 2]
- Initial validation of these methods using concurrent video observations and sediment classifications based on multibeam backscatter (where available) is complete, and a systematic validation is in progress [Refs 1, 5, and 9]
- We have developed the computational advances necessary for correcting a boat-mounted sidescan sonar transducer for yaw instabilities (yaw) [Ref 4]. Correcting for heave, roll, pitch and roll, and evaluating the effects on sidescan sonar image quality, using data collected in Upper Marble Canyon in 2013 and eastern Grand Canyon in 2014, is pending
- We have evaluated the sensitivities in corrected geo-referenced sidescan amplitudes to uncertainties in attenuation due to sediment or gradients in sediment concentration, transducer location and boat heading, with a publication pending [Ref 4]
- We have developed the computational means by which sidescan can be corrected for bed slope effects when bed bathymetry is available, with a publication pending [Ref 4]

The evaluation of the automated substrate classification technique necessitates other techniques and developments associated with Project 3. The following relevant advances made there are summarized below (see the annual report for Project 10 for more details):

- The continuing refinement  and application of the acoustic bed-sediment classification method using Multi Beam Echo Sounder (MBES)
- The theoretical and computational development of acoustic methods for classification of bed sediments using MBES backscatter data
- The development of a new underwater camera system that will enable us to collect better underwater imagery for the purposes of calibrating and validating acoustic bed sediment classification methods for complex sediment mixtures (e.g. sand and gravel, gravel and boulders, sediment and vegetation, etc).
- The ongoing development an acoustic method by which to detect and classify submerged vegetation. To that end, we conducted fieldwork in Glen Canyon in December 2014 and again in October 2015 to collect concurrent sonar and underwater video data, in order to establish a baseline map of submerged vegetation. The acoustic method looks promising and will enable large-scale mapping of benthic vegetation, which is a dominant control on the food base in Glen Canyon.

**10.2. *Collecting New Channel-Bed Humminbird® Sidescan Sonar and Digital Channel Margin Imagery, and Analyzing Channel-Margin Geometry, and Shoreline Responses to Flow Variation using Channel Map Data to Support Natal Origins of Rainbow Trout and Juvenile Humpback Chub Research*** – Ted Melis, Tom Gushue, Daniel Buscombe, Daniel Hamill, Mike Yard, Paul Grams, Josh Korman

Element 10.2. of this project has 5 key objectives which are summarized below:

1. Use of Glen Canyon Channel Map to Support Aquatic Modeling Research - Project 3 element 3.2, channel topographic and bed-sediment type map for Glen Canyon, data collected in 2015 will be used with flow model (Project 5) to support primary production model, and assessment of channel margins and shorelines in task 3, below,
2. Document Geometry of Glen Canyon Channel Margins and Grain Size – in 2015-16, the proportion of low-angle channel margins (less than 11 degree slopes) known to be used by

juvenile trout in Glen Canyon,

3. Document Geometry of Marble and eastern Grand Canyon Channel Margins – using existing channel data from previously mapped segments of Marble and Eastern Grand Canyon within NO study sites, we will estimate the proportion of low-angle channel margins (less than 11 degrees) for comparison with results from task #3 above,
4. Determining the Time-Varied Proportion of Sand and Gravel in Deeper Channel – through use of new and existing channel-map data, we will estimate the time-varied spatial distributions (2012-16) of sand and gravel areas on the Colorado River bed surface that may support rainbow trout spawning in NO study sites 1 - 4b,
5. Determining Time-Varied Proportion of Channel Margin Types in NO Study Sites – to assess possible influences on fish catch rates in NO study reaches #1 - 4b between 2012-16, associated with changing shoreline and near-shore sand deposits (low elevation eddy and lower channel sandbars) that may result from tributary sand inputs combined with high flow dam operations.

Sidescan sonar and shoreline imagery was collected in NO reach #1 in December 2014, and April, July and October 2015. Sidescan sonar and shoreline imagery was collected in NO reaches #2, 3, and 4 in April and July 2015. Additional data collection in support of Project 10 was carried out by members of Project 3. This data collection included (see the annual report for Project 3):

- In May 2014, 19.7 of the 27.4 miles (72%) of river channel that comprise lower Marble Canyon and eastern Grand Canyon (RM 61 to 87) were mapped. Almost the entire channel was imaged using sidescan sonar.
- In November 2014 (and various short trips throughout 2015), the river channel in Glen Canyon (RM -15 to 0) was mapped in its entirety.
- In December 2014, acoustic data and underwater video was collected along transects in a control reach in Glen Canyon above and below -4 mile bar. The transects were repeated again in October 2015.

A summary of analyses in support on the above objectives carried out in FY15 is below:

- We have begun to evaluate changes in distributions of bed deposits along NO sampled shorelines between 2013 and 2015, using sidescan imagery,
- We have documented surficial grain size distributions of gravel bars associated with fish monitoring shorelines using digital images collected at approximately the 8,000 $ft^3/s$ shoreline elevation at each sample site. Size distributions have been determined and these data have been evaluated to identify longitudinal trends in grain size along channel margins used by trout between GCD and Lees Ferry [Ref. 6],
- The new grain size data on coarse-sediment deposits throughout the Glen Canyon segment (island and channel-margin bars between 6,000 and 8,000 cfs flow stage elevations) were presented at the 13$^{th}$ Biennial Colorado Plateau Conference in October 2015 by Crouch et al.),
- Preliminary analysis of gravel grain size throughout Glen Canyon indicates a fining in gravels of lateral bar between Glen Canyon Dam and Lees Ferry, and there is a poor correlation between gravel grain size and rainbow trout spawning activity (redds data from RTELSS monitoring) – poster available upon request,
- Longitudinal patterns in median river temperature and turbidity along the Colorado River between Lees Ferry and the Little Colorado River were also evaluated relative rainbow trout abundance and condition, and these preliminary observations were reported in April 2015 to the Technical Workgroup (see presentation slides from that meeting),
- A 2D flow model for all of Glen Canyon has been completed and validated by the CA Water

Science Center (see annual report for Project 5),
- Preliminary results of sand and gravel areas on the Colorado River bed surface that may support rainbow trout spawning in NO study sites 1 - 4b, using sidescan sonar data.

The preliminary USGS report in 2015 on slope analyses of existing 2004 & 2009 full-channel topography of Glen Canyon related to proportion of low and high-angle channel margins (lead: Melis and Gushue) has been delayed, owing to staffing changes (Melis taking a position at SBSC as deputy director, and Gushue losing his GS-9 Geographer technical support).

**10.3. *Integrated Time Series Analysis of Physical Channel Mapping, Quality-of Water, and Natal Origins of Rainbow Trout and Juvenile Humpback Chub Catch and Diet Data*** – Ted Melis, Mike Yard, Josh Korman, Daniel Buscombe

Element 10.3. has one objective: Synthetic Analysis of Rainbow Trout Catch and Physical Data – Integrating, in 2017, five years of physical (segment-scale channel geometry, changes in areal bed surface sand coverage, and variations in flow patterns, total suspended sediment flux and water temperature) and biological (the aquatic food base, in terms of invertebrate drift) and rainbow trout responses; analyses developed through an integration workshop approach. There are no deliverables associated with this element FY15.

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Project Element 10.1 – ***Refine Humminbird® Sidescan Sonar and Other Channel Mapping Methods to Support Fish and Foodbase Research*** | | | | | |
| Data | Data from 3 years of sidescan imaging in Glen Canyon | FY 15 | Jan. 2016 | -- | Will be presented at Jan. 2016 reporting meeting. |
| Report | Manuscript on research and development of new methods for using sidescan sonar instruments for imaging channel-bed sediment type and sediment changes in channel margin settings to support aquatic resource monitoring | FY15 | September 2015 | | Publication: [1] and additional publication [2] |
| Project Element 10.2 – ***Collecting New Channel-Bed Humminbird® Sidescan Sonar and*** | | | | | |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| ***Digital Channel Margin Imagery, and Analyzing Channel-Margin Geometry, and Shoreline Responses to Flow Variation using Channel Map Data to Support Natal Origins of Rainbow Trout and Juvenile Humpback Chub Research*** | | | | | |
| Report | Preliminary USGS report in 2015 on slope analyses of existing 2004 & 2009 full-channel topography of Glen Canyon related to proportion of low and high-angle channel margins (Melis and Gushue) | FY15 | | March 2016 | Delayed. Report in preparation. |
| Data and report | New topographic and channel-bed sediment type maps collected in 2015 and proposed to be available for further analyses by 2016 | FY16 | | November 2016 | Data collected, processing started. Map/report on schedule |
| Project Element 10.3 – ***Integrated Time Series Analysis of Physical Channel Mapping, Quality-of Water, and Natal Origins of Rainbow Trout and Juvenile Humpback Chub Catch and Diet Data*** | | | | | |
| | No FY15 products. | | | | Data collected and processed on schedule. |

| Project 10 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $123,500 | $5,000 | $0 | $0 | $0 | $17,518 | **$146,018** |
| **Actual Spent** | $86,472 | $1,096 | $425 | $65,393 | $0 | $13,958 | **$167,345** |
| **(Over)/Under Budget** | **$37,028** | **$3,904** | **($425)** | **($65,393)** | **$0** | **$3,560** | **($21,327)** |

| **COMMENTS** *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)* |
|---|
| Reduced salary costs and increased cooperative agreement costs due to sending funding to Utah State University for student rather than USGS employee. Also, the cooperative agreement was front loaded so FY16 & FY17 costs will be lower. |

| **Project 11: Riparian Vegetation Monitoring and Analysis of Riparian Vegetation, Landform Change and Aquatic-Terrestrial linkages to Faunal Communities** | | | |
|---|---|---|---|
| **Program Manager** (PM) | Barbara Ralston | **Principal Investigator(s)** (PI) | Barb Ralston, USGS, GCMRC<br>Daniel Sarr, USGS, GCMRC<br>Joel Sankey, USGS, GCMRC<br>Paul Grams, USGS, GCMRC<br>Charles Yackulic, USGS, GCMRC<br>Ted Kennedy, USGS, GCMRC<br>Jeff Muehlbauer, USGS, GCMRC<br>David Merritt, USFS<br>Patrick Shafroth, USGS, Fort Collins<br>Joe Hazel, NAU<br>Emily Palmquist, USGS, GCMRC<br>Laura Cagney, NAU<br>Todd Chaudhry, NPS<br>Dustin Perkins, NPS<br>John Spence, NPS |
| **Email** | *bralston@usgs.gov* | | |
| **Telephone** | (928) 556-7389 | | |

**SUMMARY**

**Goals and Objectives FY15–17**

Riparian vegetation affects physical processes and biological interactions along the channel downstream of Glen Canyon Dam. The presence and expansion of riparian vegetation promotes bank stability, diminishes the magnitude of scour and fill during floods, and has a role in wildlife habitat and recreational values. This project utilizes annual field measurements and digital imagery for integrated monitoring of changes in vegetation assessed within a hydro-geomorphic context. Research elements of this project utilize the monitoring data to explore the utility of plant response-guilds to probabilistically evaluate and assess wildlife habitat, and integrate the response guilds with a 22-year topographic survey record for retrospective analyses of topographic change of 20 sandbars.

This project builds upon accomplishments associated with the FY13–14 Work Plan, provides information that support stakeholder needs as identified by guiding documents developed by the Adaptive Management Program, and furthers our understanding of the role of riparian vegetation in ecosystem processes in a regulated river ecosystem.

The objectives and elements of this monitoring and research project are:

1. Measurement and analysis of plant cover and species presence to assess change as related to the geomorphic setting, elevation above the channel, and flow regime (Project Element 11.1)

2. Mapping changes in woody vegetation at the landscape scale through image processing, classification, and analysis (Project Element 11.2)
3. Utilizing vegetation response-guilds for integrated research of sandbars and riparian vegetation (Project Element 11.3)
4. Use multiple sampling approaches and historic data sets to quantify the strength of aquatic-terrestrial linkages and the relative importance of vegetation change and aquatic production in driving the population dynamics of a subset of the terrestrial fauna (Project Element 11.4).
5. A review and assessment of nonnative plant control and native plant restoration efforts along regulated segments of the Colorado and Rio Grande Rivers (Project Element 11.5).

**Project Element 11.1. Ground-based Vegetation Monitoring**

*Objectives*

- To annually collect vegetation data (presence, cover) within a geomorphic and hydrologic framework downstream of Glen Canyon Dam.
- To use the traits of the plants found to identify plant response-guilds.
- Data and results are collected and described in a manner that can be utilized by multiple stakeholders for monitoring approaches, use by Tribal stakeholders, and for use in basin-wide riparian vegetation monitoring programs overseen by the National Park Service's Northern Colorado Plateau Network Inventory and Monitoring Program.

*Activities that support monitoring*

Annual vegetation sampling trips in 2015 occurred in Glen Canyon in August and Grand Canyon in late September. Data collection consisted of 1$m^2$ plots that quantified plant species cover. Plots were set within a hydro-geomorphic setting [(sandbar, channel margin, debris fan) and stratified by the fluctuating zone (<25,000 $ft^3$/s), active floodplain (25,000-45,000 $ft^3$/s), and inactive floodplain (>45,000 $ft^3$/s)].

*Summary of Progress*

Plot sampling that was coincident with sandbar monitoring (Project 3) occurred in late September/early October of 2015. Plot sampling for vegetation at other sites occurred in early August 2015 in Glen Canyon. A Grand Canyon portion that sampled random sites was only partially completed in August 2015. Plot data from the long-term monitoring sandbars will be used to provide vegetation cover metrics, as well as be used as a validation data set for models of guild occurrence probabilities. The data from all trips in 2015 are being entered. Data summaries for 2014 are included in figures in this report. Summaries for 2013–2015 will be available in January 2016.

A manuscript describing the process used to identify flow-response guilds is in development with a draft in review by December 2015. Delays associated with vegetation response-guild identification are attributed to the delayed hiring and the tragic loss of Daniel Sarr. Collaborators are in the process of completing the manuscript developed by Dr. Sarr for review and publication. We anticipate developing posters for the January Annual Reporting Meeting that illustrate the status of vegetation

based on plot sampling and the response-guild development. The latter will include the development of exceedance probability curves for each identified guild.
Other efforts related to monitoring include:

- The development of a monitoring protocol for ground-based sampling (FY15, Project 11.1) to be submitted for review in December 2015.
- Using the 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 total foliar cover, woody cover, and non-native cover, each divided into three river segments and three hydrologic zones (Tables 1-3) provide details about where exotic species are most numerous, the status of cover among hydrologic zones, and how cover varies throughout the river corridor. Though these summary data are generated annually, general patterns of change will be analyzed on a 5-year basis. For woody vegetation, this 5-year summary information can be used to validate information observed from landscape scale vegetation monitoring (Element 11.2).

*Information summarized from the 2014 sampling efforts include*:

- Total percent foliar cover in 2014 was lowest in the Eastern Grand Canyon segment of the Colorado River. Among hydrologic zones, the active floodplain (>25,000 and <45,000 cfs) had the greatest foliar cover across river segments with Marble and Western Grand Canyon having comparable mean percent cover values (fig. 1). The active channel in Western Grand Canyon (<25,000 cfs) had the greatest variability in total cover among the river segments, possibly associated with Bermuda grass (*Cynodon dactylon*).
- Among geomorphic features (channel margins, debris fans, sandbars), total foliar cover was generally greater on channel margins (fig. 2). Mean cover on channel margins was greater in Marble Canyon and Western Grand Canyon compared to Eastern Grand Canyon.
- The mean percentage of woody cover among hydrologic zones followed a similar pattern of total foliar cover where cover was greatest within the active floodplain (fig. 3). Among the river segments, the mean percent cover of woody vegetation was greatest in the Marble Canyon segment, while the percent cover in Eastern and Western Grand Canyon segments were more similar to each other. Mean percent cover of woody vegetation in the active channel was low and approximately the same across river segments.
- The mean percent cover of woody vegetation was generally greatest on debris fans followed by channel margins (fig. 4). Woody vegetation cover on sandbars was greatest in the Marble Canyon segment.
- Exotic species cover was greatest in Western Grand Canyon and within this river segment, mean cover was similar across hydrologic zones (fig. 5).
- Within Western Grand Canyon, mean cover of non-native species was greatest on channel margins (fig. 6).
- *Cynodon dactylon* and *Bromus rubens* were the two most frequently encountered species in

plots in 2014 (Table 1, fig 7). Woody species frequently encountered in the active channel are coyote willow (*Salix exigua)* and saltcedar (*Tamarix* sp.).

*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. Frequency data (Table 1) 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 1) 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, figs 1-7).

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. The vegetation plot data from the long-term monitoring sandbar sites can be used to assess woody vegetation expansion or decrease within the active channel, because they are sampled yearly and there is reliable stage discharge information for each sandbar. 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 the most frequently encountered plants in the AF are shrubs 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.

**Project Element 11.2. Periodic landscape scale vegetation mapping and analysis using Remotely Sensed Data**

*Objectives*

- To produce an accurate classification of vegetation from the imagery acquired with the remote sensing overflight in 2013.

- To quantify stability and changes in vegetation composition from the classifications of vegetation completed for imagery acquired in 2002 to 2013.
- To cross-walk the composition of vegetation in the image-based classes from 2013 and 2002 with composition of response guilds identified in Element 11.1.
- To detect and map tamarisk leaf beetle effects for remotely sensed vegetation canopies from overflight imagery from 2009 to 2013.

*Summary of Progress*

The 2013 image mosaic process has been completed and as of November 2015, the vegetation classification described in Objective 1 is underway. We anticipate reporting on the initial classification of total vegetation for select reaches at the Annual Reporting Meeting in January 2016. A manuscript focused on work completed in Glen Canyon NRA for Objective 4 was submitted October 2015 to the journal Photogrammetric Engineering and Remote Sensing for review. The map dataset of tamarisk defoliation in Glen Canyon for Objective 4 will be published through the USGS in conjunction with the journal manuscript. The thesis (Ash Bedford – NAU) focused on Objective 4 will likely be defended in spring 2016. A Ph.D. candidate at the University of Arizona completed vegetation analysis of 2009 imagery. The methodology used for classification is described in a publication submitted to the journal Remote Sensing of Environments in August, 2015 for review. These data add another vegetation class data set for change analysis at the landscape scale.

**Project Element 11.3 Influence of sediment and vegetation feedbacks on the evolution of sandbars in Grand Canyon since 1991 (FY15–17)**

*Objectives*

- To understand the interplay between hydrology, vegetation and sediment dynamics among 20 sandbars for a 23-year period (1991 to 2013) by using long-term sandbar monitoring data, instantaneous discharge record, sediment transport information, intermittent vegetation sampling data, riparian plant response guilds, and aerial and oblique repeat photography.

*Summary of Progress*

Progress in this project has included discussions with key researchers in Project A to determine how they are approaching element 3, which is complementary with this project. We are identifying historic data that can be used to identify vegetation on a surface for a given year. We are also developing exceedance probability curves for species that can be applied on subsequent years to identify trajectories for vegetation change. This information can be used to create a rule based approach for predicting vegetation change. Work is focused on a single sandbar to determine the overall steps required to reconstruct vegetation change and subsequently understand sandbar change.

**Project Element 11.4 Linking dam operations to changes in riparian biodiversity – the potential significance of vegetation change and insect emergence**

*Objectives*

- Build a strong conceptual basis for understanding and analyzing linkages between flow

management and riparian biodiversity in the Colorado River ecosystem
- Determine the degree to which populations of terrestrial animals respond to spatial and temporal variation in aquatic insect emergence along the Colorado River, with an initial focus on the Glen and upper Marble Canyons.
- Identify whether long-term changes in vegetation have influenced populations of terrestrial consumers, particularly birds and terrestrial insects in Glen Canyon.
- To the extent possible, determine the links between terrestrial fauna and vegetation-flow response guilds.

*Summary of Progress*

Progress in this element was substantial, particularly given the limited funding available for this project element in FY15. We worked with John Sabo, Arizona State University, an expert in aquatic-terrestrial linkages, to identify a graduate student that will lead work associated with this element and ASU is contributing additional funds to support that student. In collaboration with the student, we have begun to outline sampling to be undertaken in the spring and summer of 2016. Frequent meetings among project team members as well as re-analysis of historical data, especially bird and insect data, gave us a better understanding of the strengths and limitations of these data and a better sense of which aspects of the larger proposed project we should focus on given funding constraints. Based on the efforts, we plan to focus primarily on questions 3-5 in FY16 and 17. The goals of this project remain to focus first on Glen Canyon and Upper Marble Canyon and then, based on learning in these areas, implement similar research downstream in conjunction with citizen scientists or other interested parties.

**Project Element 11.5. Science Review Panel of Successes and Challenges in Non-native Vegetation Control in the Colorado River and Rio Grande Watersheds**

*Objectives*
- To convene a science expert review panel composed of natural resource managers and riverine research scientists to examine successes and challenges in non-native vegetation control in the Colorado River and Rio Grande watersheds, and to seek recommendations from that group as to how to plan a scientifically-based riparian management control program applicable to the Colorado River ecosystem in Glen, Marble and Grand Canyons.

*Summary of Progress*

A 2-day workshop was held in Flagstaff, AZ from June 23-25. The workshop approached restoration in a multi-scale framework (local to watershed scale) in the assessment of restoration efforts. Presenters had experience in the upper and lower Colorado River Basin as well as the upper and lower Rio Grande Basins. Presenters were encouraged to submit an extended abstract that will be compiled into an Open-File Report (OFR) and electronically accessible to the public. A few abstracts remain to be revised and submitted for subsequent copy editing and publication. An anticipated publication date is Spring 2016. Included in the OFR will be recommendations elicited from the participants and a list of accessible resources.

| |
|---|
| A second workshop with resource managers from Glen Canyon and Grand Canyon was proposed to discuss restoration/revegetation approaches in FY16, pending availability of funds for travel. |
| |

| | **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 -2015 | Draft Jan 2016 | TBD | May 2016 | Data from 2012-14 are entered. Data entry for 2015 completed by Jan 2015. Delayed analysis and decision about format and venue for releasing information- report vs. web product. |
| Presentations | Plant Guild and Functional Group Frameworks in Riparian and Wetland Management and Restoration: Models and Applications | | May/June 2015 | | Presentation and organized symposium at Society of Wetland Scientists in Providence, R.I. |
| Journal | *Developing Riparian Vegetation-Flow Response Guilds for the for the Colorado River Ecosystem in Grand Canyon, Arizona* | | Draft anticipated Dec 2015 | May 2016 | Unexpected loss of lead author. |
| Journal | *Matrix of plant-ecological traits* | Extra product No date | submitted Dec 2015 | August 2016 | Lead author E. Palmquist. This is a manuscript that is a outgrowth of the guild identification project. |
| Journal | *Applications of guilds for riparian management in a regulated river* | Extra product No date | Draft anticipate May 2016 | | Lead author D. Merritt (USFS). This is a manuscript that is a outgrowth of the guild identification project. |
| Journal | Remote sensing of tamarisk biomass, insect herbivory, and defoliation: novel methods and applications in the Grand Canyon region, | | Draft submitted October 2015 to Photogra | March 2017 | Lead author T. Sankey (NAU) |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | Arizona, USA | | mmetric Engineering and Remote Sensing | | |
| Journal | A new remote sensing approach to map riparian vegetation of the Colorado River Ecosystem, Grand Canyon area | | Draft submitted August 2015 to Remotes Sensing of Environments | Spring 2016 | U. AZ manuscript and dissertation |
| Journal | Riparian vegetation, Colorado River, and climate--Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation | Oct 2013 | From FY13-14 plan | Published August 2015 | Sankey, J.B., Ralston, B.E., Grams, P.E., Schmidt, J.C., and Cagney, L.E., 2015, Riparian vegetation, Colorado River, and climate--Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation: Journal of Geophysical Research Biogeosciences, online, http://dx.doi.org/10.1002/2015JG002991. |
| Dataset | USGS 2015 J Sankey Riparian Vegetation and Colorado River | | | June 2015 | https://www.sciencebase.gov/catalog/item/5575b3c1e4b08f9309d4bafc |
| Open-file Report | Case Studies of Riparian and Watershed Restoration in the Southwestern United States: Principles, Challenges, and Successes | Draft June-Sept 2015 | Draft for review Nov. 2015 | Publication April 2016 | Lead author B. Ralston.<br>Workshop was held in June 2015 instead of February which delayed development |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | | | | | of draft OFR. |

| Project 11 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $241,800 | $8,000 | $5,500 | $126,000 | $6,700 | $38,585 | **$426,585** |
| **Actual Spent** | $217,466 | $9,848 | $6,722 | $108,460 | $0 | $35,160 | **$377,656** |
| **(Over)/Under Budget** | **$24,334** | **($1,848)** | **($1,222)** | **$17,540** | **$6,700** | **$3,425** | **$48,929** |

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

Reduced salary costs due to lower actual burden rate.

Carryover: $54,800, will be used to offset FY16 & FY17 shortages.

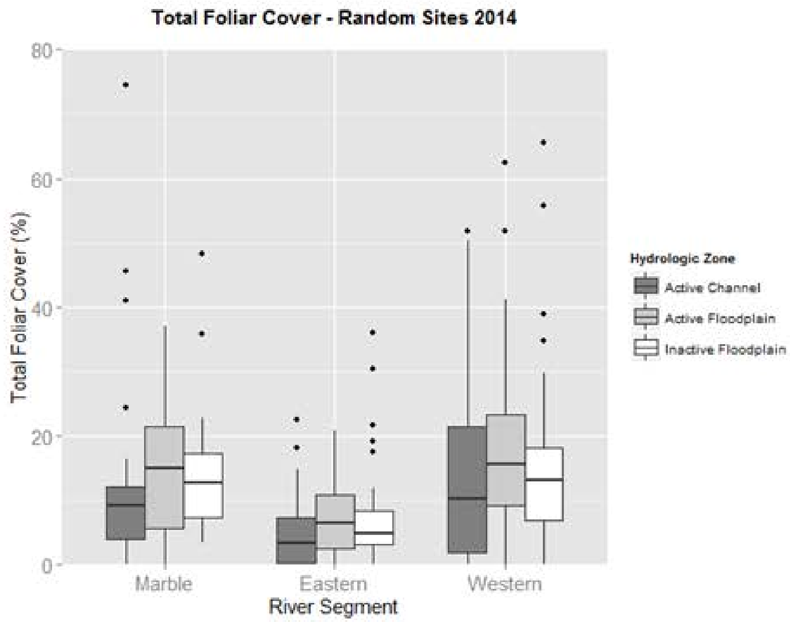



Figure 1. Mean percent cover of total cover by hydrologic zone.

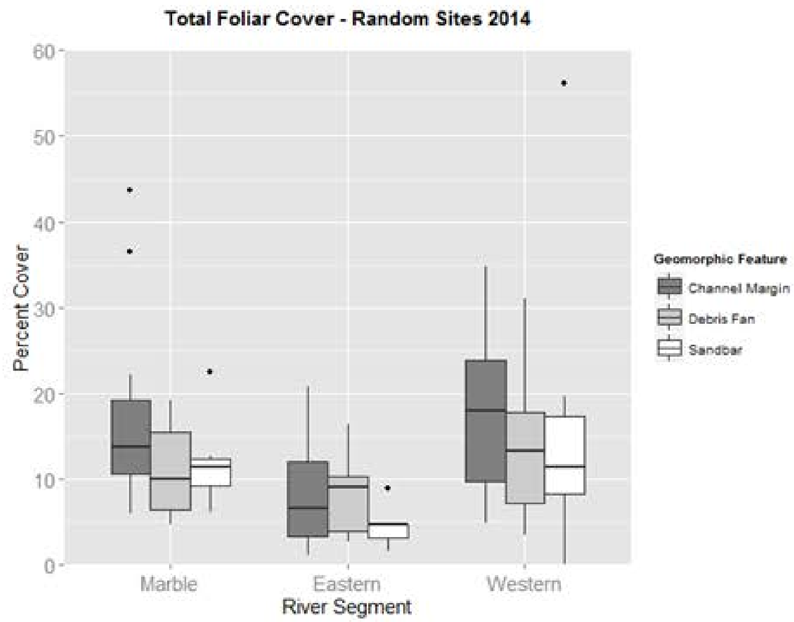



Figure 2. Mean percent cover of total cover by geomorphic feature.

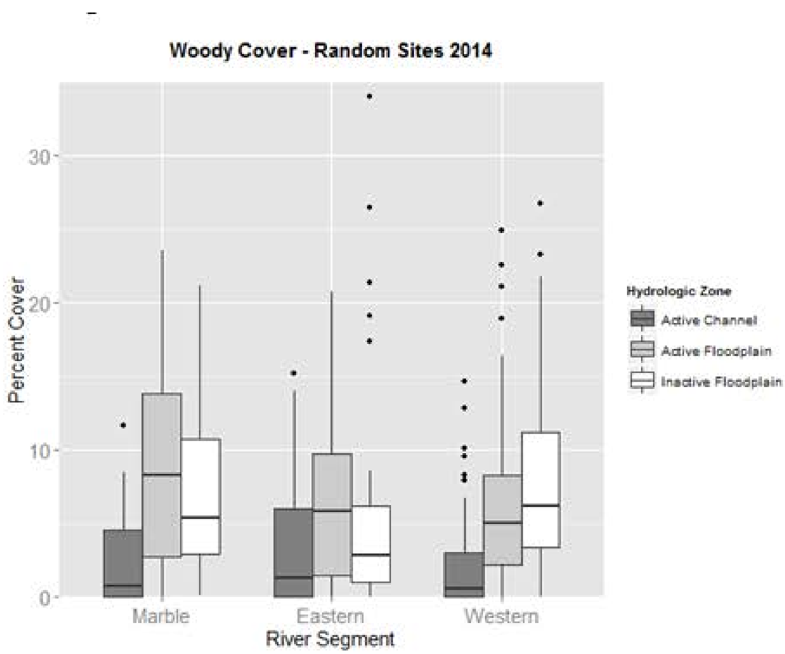



Figure 3. Mean percent cover of woody vegetation by hydrologic zone.

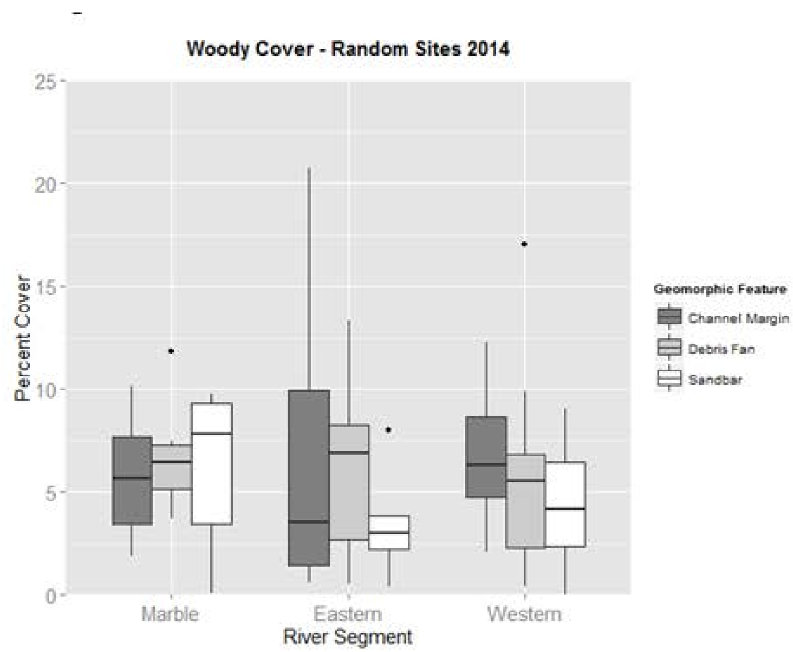
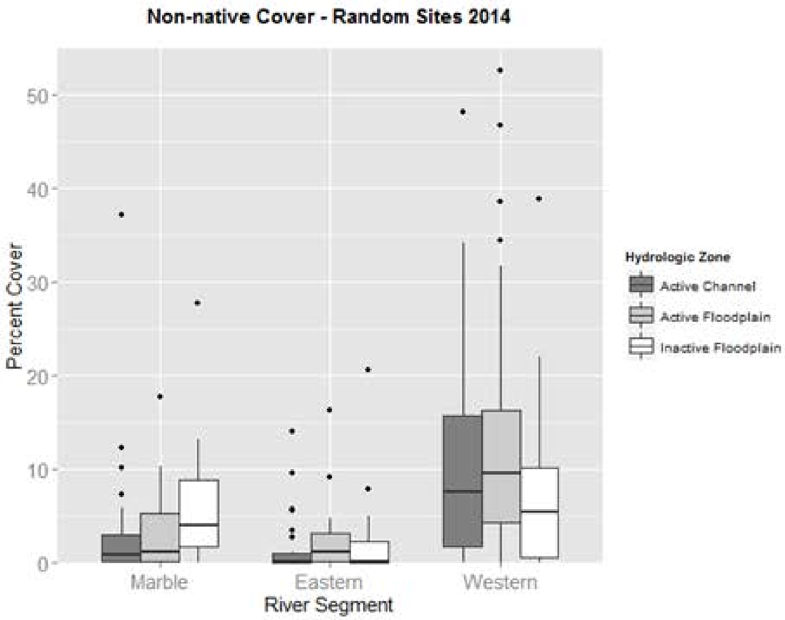



Figure 4. Mean percent cover of woody vegetation by geomorphic feature.



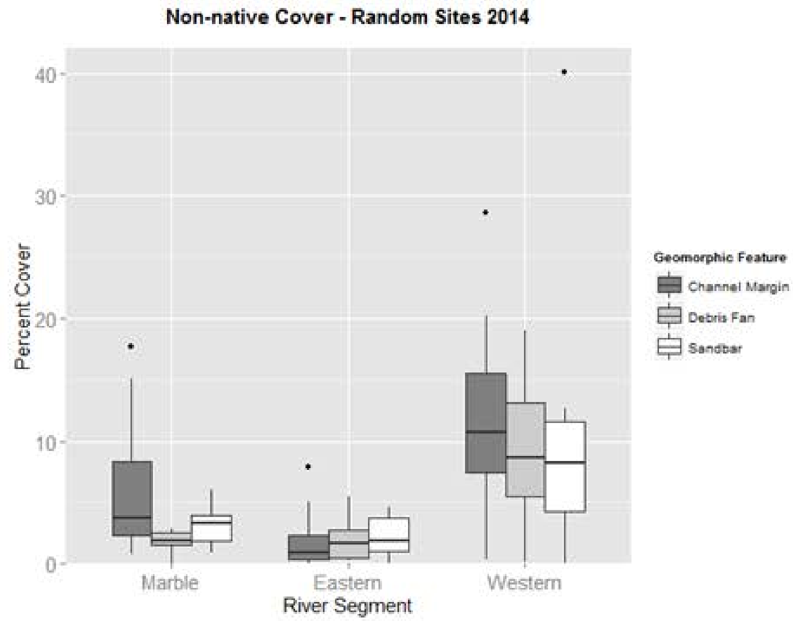




Figure 5. Mean percent cover of non-native vegetation by hydrologic zone.

Figure 6. Mean percent cover of non-native vegetation by geomorphic feature.

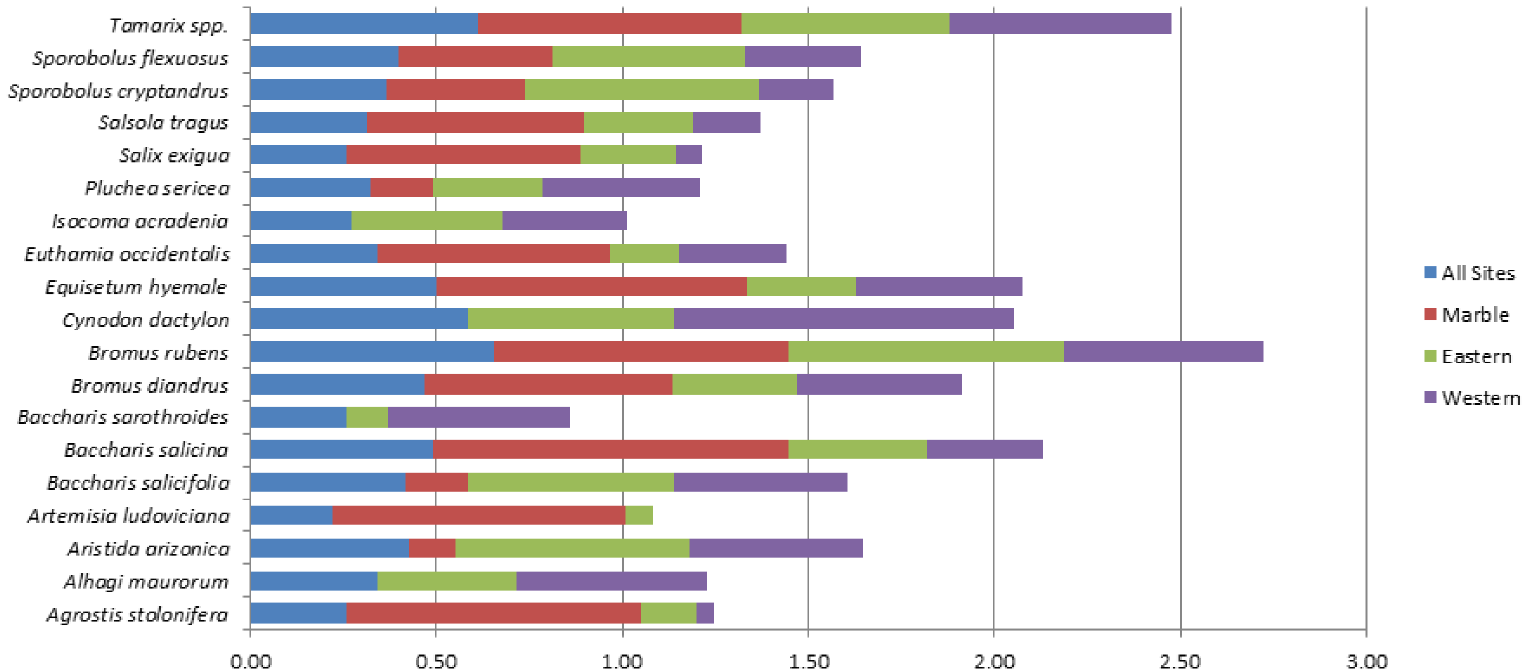



Figure 7. Bar graph of frequently encountered plant species in sample plots from Lees Ferry to Lake Mead in August 2014. Frequencies are for the whole river length (Overall), river segments (Marble, Eastern and Western Grand Canyon).

**Table 1. Ten most frequently encountered species in sample plots from Lees Ferry to Lake Mead, AZ. Frequencies are for the whole river length (Overall), river segments and hydrologic zones**

| Overall | | Marble Canyon | | Eastern Grand Canyon | | Western Grand Canyon | | Active Channel | | Active Floodplain | | Inactive Floodplain | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Bromus rubens* | 0.66 | *Baccharis salicina* | 0.96 | *Bromus rubens* | 0.74 | *Cynodon dactylon* | 0.91 | *Cynodon dactylon* | 0.54 | *Cynodon dactylon* | 0.52 | *Bromus rubens* | 0.61 |
| *Tamarix* spp. | 0.61 | *Equisetum ×ferrissii* | 0.83 | *Sporobolus cryptandrus* | 0.63 | *Tamarix* spp. | 0.60 | *Equisetum ×ferrissii* | 0.48 | *Tamarix* spp. | 0.35 | *Cynodon dactylon* | 0.42 |
| *Cynodon dactylon* | 0.58 | *Bromus rubens* | 0.79 | *Aristida arizonica* | 0.63 | *Bromus rubens* | 0.53 | *Baccharis emoryi* | 0.36 | *Baccharis salicina* | 0.34 | *Bromus diandrus* | 0.39 |
| *Equisetum hyemale* | 0.50 | *Agrostis stolonifera* | 0.79 | *Tamarix* spp. | 0.56 | *Alhagi maurorum* | 0.51 | *Euthamia occidentalis* | 0.28 | *Bromus diandrus* | 0.33 | *Tamarix* spp. | 0.38 |
| *Baccharis salicina* | 0.49 | *Artemisia ludoviciana* | 0.79 | *Baccharis salicifolia* | 0.56 | *Baccharis sarothroides* | 0.49 | *Baccharis salicifolia* | 0.25 | *Alhagi maurorum* | 0.32 | *Aristida arizonica* | 0.37 |
| *Bromus diandrus* | 0.47 | *Tamarix* spp. | 0.71 | *Cynodon dactylon* | 0.56 | *Aristida arizonica* | 0.47 | *Alhagi maurorum* | 0.25 | *Bromus rubens* | 0.31 | *Sporobolus flexuosus* | 0.35 |
| *Aristida arizonica* | 0.43 | *Bromus diandrus* | 0.67 | *Sporobolus flexuosus* | 0.52 | *Baccharis salicifolia* | 0.47 | *Agrostis stolonifera* | 0.25 | *Pluchea sericea* | 0.29 | *Alhagi maurorum* | 0.23 |
| *Baccharis salicifolia* | 0.42 | *Euthamia occidentalis* | 0.63 | *Isocoma acradenia* | 0.41 | *Bromus diandrus* | 0.44 | *Salix exigua* | 0.22 | *Baccharis salicifolia* | 0.27 | *Isocoma acradenia* | 0.23 |
| *Sporobolus flexuosus* | 0.40 | *Salix exigua* | 0.63 | *Baccharis salicina* | 0.37 | *Equisetum hyemale* | 0.44 | *Melilotus officinale* | 0.19 | *Equisetum ×ferrissii* | 0.27 | *Sporobolus cryptandrus* | 0.22 |
| *Sporobolus cryptandrus* | 0.36 | *Salsola tragus* | 0.58 | *Alhagi maurorum* | 0.37 | *Pluchea sericea* | 0.42 | *Tamarix* spp. | 0.19 | *Baccharis sarothroide s* | 0.20 | *Pluchea sericea* | 0.22 |

| Project 12: Changes in the Distribution and Abundance of Culturally-Important Plants in the Colorado River Ecosystem: A Pilot Study to Explore Relationships between Vegetation Change and Traditional Cultural Values | | | |
|---|---|---|---|
| **Program Manager** (PM) | Helen Fairley | **Investigator(s)** (I) | Helen Fairley (PI), USGS, GCMRC<br>Peter Bungart, Hualapai Tribe<br>Tony Joe, Navajo Nation<br>Michael Yeatts, Hopi Tribe<br>Daniel Sarr, USGS, GCMRC<br>Charles Yackulic, USGS, GCMRC |
| **Email** | *hfairley@usgs.gov* | | |
| **Telephone** | (928) 556-7285 | | |

**SUMMARY**

**Introduction**

Project 12 aims to answer a single, broad research question: How have culturally-valued vegetation attributes of the riparian landscape of the Colorado River corridor changed since closure of Glen Canyon Dam, and how have those changes (whether partially or wholly due to dam operations) affected cultural resource values that are important to tribes?

This overarching question has two components, and each requires a different approach; therefore Project 12 encompasses two elements with inter-related goals: 1) an assessment of changes in vegetation in the Colorado River corridor below Glen Canyon Dam that are relevant to some of the expressed cultural interests of Native American AMP tribes, and 2) an assessment of how those changes may have affected (either positively or negatively) culturally-important aspects of the landscape valued by these same groups. The primary objectives of the first element are three-fold: 1) engage tribes in a collaborative research effort to identify changes in the riparian ecosystem of the Colorado River corridor that may have affected or are affecting cultural values and resources that contribute to the identification of Grand Canyon as a Traditional Cultural Property; 2) compile and synthesize data about riparian vegetation and specific species of cultural importance to tribes from a variety of existing sources, including but not limited to previous GCES-era studies, existing GCMRC and tribal monitoring data, published articles, historical journals and oblique historical imagery, and 3) analyze these existing data to evaluate the distribution and comparative abundance of targeted (culturally-important) plant species in past decades throughout the river corridor landscape as compared with current conditions.
The second component of this project proposes to use the information obtained in Element 12.1 to develop culturally-appropriate methods for eliciting tribal perspectives about the changes that have occurred to the landscape and culturally-important important plant species and evaluate how those changes may have affected landscape values important to the tribes. Specific methods to be employed in project element 12.2 will be determined collaboratively with tribal participants after they have had a chance to review the results of Element 12.1 and have engaged in further discussion about possible future methodological approaches. Element 12.1 was initiated in the winter of FY15 and is ongoing in the fall of 2015; thus, this report focuses on progress and accomplishments specifically related to Project Element 12.1.

**First Workshop**

On February 18-19, 2015, GCMRC hosted the first of two workshops planned for Project 12. As described in the original project proposal of the FY15–17 work plan, the purpose of this first workshop was to review and discuss the goals of the project, identify plant species of mutual interest to multiple tribes, identify work that has already been completed related to plant species of interest to the tribes, and discuss and refine methods for compiling and analyzing available data related to the targeted species for this pilot study. The workshop was well attended by representatives from the five AMP tribes, plus GCMRC vegetation program staff (Sarr, Palmquist, Ralston), staff from Grand Canyon National Park and the Bureau of Reclamation, and Dr. Larry Stevens from the Museum of Northern Arizona and Grand Canyon Wildlands Council. During the workshop, GCMRC's riparian ecologist (Sarr) reviewed data currently being collected for Project 11 and discussed some ways that these data could be analyzed to provide information relevant to tribal interests. Representatives from the Hualapai Tribe and Southern Paiute Consortium reviewed how they were monitoring vegetation change in the river corridor and how they currently use historical imagery in their monitoring programs to assess changes from tribal perspectives. Ralston presented information about the status and ecology of mesquite in the river corridor, while Stevens presented an overview of existing data on change in the distribution and abundance of Goodding Willow, plus an overview of the ecology of Phragmites. Fairley reviewed the goals and objectives of Project 12 and presented a list of plant species from the river corridor that had been identified as being culturally-important to three or more AMP tribes. A discussion followed the presentation of this preliminary species list, and it was subsequently agreed that the 14 perennial riparian species that were of mutual interest to 3 or more AMP tribes was the appropriate list on which to focus the Project 12 pilot study (see Table 1.)

Table 1. Targeted riparian species of the Project 12 pilot study

Goodding willow (*Salix gooddingii)*
Cottonwood (*Populus fremonti*)
Netleaf Hackberry (*Celtis reticulata)*
Honey Mesquite (*Prosopis glandulosa*)
Coyote willow (*Salix exigua*)
Seep willow (*Baccharis emoryi, B.salicifolia*)
Apache plume (*Fallugia paradoxa*)
Prince's plume (*Stanleya pinnata*)
Arrowweed (*Pluchea sericea*)
Common reed (*Phragmites australis)*
Cattail (*Typha sp*.)
Horsetail (*Equisetum sp*.)
Dropseed (*Sporobolus* sp.)
Indian Rice Grass (*Achnatherum hymenoids*)

**Data Compilation and Analysis**

In spring 2015, using the input from the first workshop, Fairley began compiling existing data on the list of 13 targeted species, drawing upon a variety of existing information sources. Data sources included prior GCES-era and GCDAMP-sponsored research articles and reports, GCMRC and tribal monitoring program data, historical river runner journals, and repeat photographs of historical imagery from the Colorado River corridor in Glen and Grand Canyons. Working in collaboration with Project Co-lead Peter Bungart, Fairley and Bungart began researching the availability of historical imagery, starting with the collections of repeat photography housed at the Desert Laboratory Repeat Photography collection in Tucson, Arizona. Fairley quickly discovered that only a relatively small portion of the historical imagery planned for analysis in Project 12 had been previously scanned, analyzed and organized sufficiently to allow the proposed analysis to proceed immediately. Specifically, Fairley learned that only the historical photographs from the 1889–1890 Stanton expedition and matches obtained by Robert Webb in 1990–1992 and 2010–2011 were sufficiently well-organized to allow the analysis to proceed without needing to invest considerable additional time and effort to scan the images and organize the associated files. For example, Fairley found that the photographs from the 1923 Birdseye expedition had not been systematically matched in most cases, nor scanned at sufficiently high resolution to permit field use; this created an unanticipated additional work load for the Project PIs which needed to be addressed before the 1923 photographs could be matched in the field and analyzed for vegetation change. Furthermore, upon arriving in Tucson to begin the photographic analysis, Fairley learned that the entire Desert Laboratory Repeat Photography collection needed to be moved to a new location before the end of FY15; as a result, Fairley became temporarily side-lined with arranging for a new home for this historic photography collection and later, with helping to move the collection from Tucson to Flagstaff during the late summer of 2015. Fairley also arranged to hire an individual to scan and organize the Birdseye photographs and other historical photographs of the Grand Canyon so they could be matched and analyzed at a later date. Meanwhile, Bungart was able to obtain scans of many of the Birdseye expedition photographs through the USGS library archives in Denver. In addition to working with these two historical photography collections, in March 2015, Bungart and Fairley visited Grand Canyon National Park and sorted through historical images housed at the Division of Science and Resource Management and the Grand Canyon Study Collection, obtaining numerous low resolution scans of many river corridor imagers with the intention of matching them on future river trips in Grand Canyon.

After identifying the whereabouts of historical photographs and assessing their condition and suitability for documenting vegetation changes, Fairley began applying analytical methods previously developed by Robert Webb (1996) to evaluate vegetation changes by comparing the 1890 Stanton photos with 1990–1992 replicates and also comparing the 1990–1992 matches with duplicate images obtained in 2010–2011. The analysis identified whether the plants of interest to the tribes were present in any of the photographs, were located in the same areas as in the past, and whether their abundance had increased or decreased in each photograph using a simple ranked scale (e.g., no apparent increase/decrease, small increase or decrease (less than ~25% difference in numbers of individuals or total cover) or large increase or decrease (>25% difference). Fairley also kept track of changes in the context of where the plants occurred, noting any apparent physical changes to local context associated with observed plant changes (e.g., differences in presence or absence of sand deposits, evidence of debris flows or rock falls, changes in biological soil crust cover, etc.) By the end of September, 2015, a total of 128 historical photographs and a total of 256 matches representing approximately a third of the river corridor (from river mile -15.0 through river mile 62) had been systematically evaluated. The analysis completed to date shows that low elevation riparian vegetation increased dramatically between 1889/1890 and the early 1990s, and that woody riparian shrubs -- specifically *Baccharis sp*. and *Salix exigua*—continued to increase significantly between the early 1990s and 2010–2011. *Celtis reticulata* increased between 1889/90 and the early 1990s, but did not increase thereafter, while *Salix gooddingii* has decreased since 1889/90. It remains to be seen whether these preliminary observations hold up for the central and western reaches of Grand Canyon.

In addition to working with the Desert Laboratory historical photograph collection, in spring 2015, Fairley visited the Marriott Library at the University of Utah and compiled observations about the presence of willow trees and other plant observations recorded by clients of pioneering river runner Norm Nevills between 1938 and 1948. In summer 2015, Bungart visited the University of Michigan library and obtained copies of the original 1938 journals of Elzada Clover, the first botanist to study plants along the Colorado River in Grand Canyon. We intend for these historical observations to be integrated with the other sources of information as work on this project continues in FY16.

**August 2015 River Trip**

In late August 2015, Fairley and Bungart, along with former Grand Canyon National Park botanist Melissa McMaster, accompanied GCMRC's Project 11 vegetation monitoring trip, with the intention of matching photographs from the 1923 Birdseye expedition and analyzing vegetation change using these matched images. Due the tragic death of GCMRC ecologist Daniel Sarr on the third day of the trip, only 17 photographs were successfully relocated and matched before the trip was abruptly cancelled. Although we plan to complete this photo-matching work on future GCMRC river trips, it is unlikely that this work can be completed in time to include analysis results in the Project 12 pilot study. One unanticipated discovery that came to light during the August 2015 river trip was a previously undocumented inscription from the 1923 USGS expedition; this inscription appeared to mark a survey position and the location from which one of the 1923 photographs had been taken.

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Presentation | *Changes in the Distribution and Abundance of Culturally-Important Plants in the Colorado River Ecosystem: A Pilot Study to Explore Relationships between Vegetation Change and Traditional Cultural Values.* | | 2/18/15 | | Fairley, H.C., Bungart, P., Joe, T., and Yeatts, M., 2015, *Changes in the Distribution and Abundance of Culturally-Important Plants in the Colorado River Ecosystem: A Pilot Study to Explore Relationships between Vegetation Change and Traditional Cultural Values*. Oral presentation at Project 12 Workshop, Flagstaff, Arizona, February 18, 2015. |
| Presentation | *Changes in the Distribution and Abundance of Culturally-Important Plants in the Colorado River Ecosystem: A Pilot Study to Explore Relationships between Vegetation Change and Traditional Cultural Values.* | | 4/21/15 | | Fairley, H.C. 2015, *Changes in the Distribution and Abundance of Culturally-Important Plants in the Colorado River Ecosystem: A Pilot Study to Explore Relationships between Vegetation Change and Traditional Cultural Values*. Oral presentation at Glen Canyon Dam Adaptive Management Program Technical Work Group meeting, Phoenix, Arizona, April 21, 2015. |
| Presentation | *Dam-induced changes to riparian ecosystems and associated traditional cultural values downstream of* | | 10/8/15 | | Fairley, H.C., 2015, *Dam-induced changes to riparian ecosystems and associated traditional cultural values* |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| | *Glen Canyon Dam, Arizona: a progress report on a pilot study integrating science and traditional ecological knowledge.* | | | | *downstream of Glen Canyon Dam, Arizona: a progress report on a pilot study integrating science and traditional ecological knowledge.* Oral presentation at the 13th Biennial Conference of Science and Management on the Colorado Plateau, Flagstaff, Arizona, October 6, 2015. |

| Project 12 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $19,600 | $5,000 | $2,000 | $15,000 | $0 | $4,076 | **$45,676** |
| **Actual Spent** | $17,888 | $2,176 | $844 | $0 | $0 | $2,850 | **$23,758** |
| **(Over)/Under Budget** | **$1,712** | **$2,824** | **$1,156** | **$15,000** | **$0** | **$1,226** | **$21,918** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $21,900, will be used to offset FY16 & FY17 shortages.

| | | | |
|---|---|---|---|
| **Project 13: Socioeconomic Monitoring and Research** | | | |
| **Program Manager** (PM) | Lucas Bair | **Investigator(s)** (I) | Lucas Bair, USGS, GCMRC<br>Charles Yackulic, USGS, GCMRC<br>John Duffield, Uni. Of Montana<br>Chris Neher, Uni. Of Montana<br>David Patterson, Uni. Of Montana<br>Michael Springborn, UC Davis<br>Craig Bond, Pardee RAND |
| **Email** | *lbair@usgs.gov* | | |
| **Telephone** | (928) 556-7362 | | |

**SUMMARY**

*Summary of FY15–17 Goals and Objectives*

The overall objective of Project 13 is to identify recreational and tribal preferences for, and values of, downstream resources and evaluate how preference and value are influenced by Glen Canyon Dam (GCD) operations. In addition, Project 13 will integrate economic information with data from long-term and ongoing physical and biological monitoring and research studies led by the Grand Canyon Monitoring and Research Center (GCMRC) to develop a decision support system that will improve the ability of the Glen Canyon Dam Adaptive Management Program (GCDAMP) to evaluate and prioritize management actions, monitoring and research.

Project 13 involves three related socioeconomic monitoring and research studies. These studies include: (13.1) evaluation of the impact of GCD operations on regional economic expenditures and economic values associated with angling in Glen Canyon National Recreation Area (GCNRA) downstream from GCD, and whitewater floating in Grand Canyon National Park (GCNP) that begins at Lees Ferry; (13.2) assessment of tribal preference for and value of downstream resources as impacted by GCD operations; and (13.3) development of decision methods, using economic metrics, to evaluate management actions and prioritize monitoring and research on resources downstream of GCD.

*Monitoring/Survey Activities*

**<u>Project Element 13.1</u>**

Angler sampling at Lees Ferry was initiated in the spring of 2015 in cooperation with the Arizona Game and Fish Department. Creel surveys involved intercepting anglers to obtain creel, name, and mailing address information at the boat ramp providing upstream access to Glen Canyon National Recreation Area, walk-in access to the Colorado River above and below the confluence with the

Paria River, and downstream of Lees Ferry including river access points Badger Creek Rapid and on the Navajo Nation north of Arizona State Highway 89A. Creel surveys are continuing into early FY16.
Grand Canyon National Park private whitewater floater name and address information was collected from the National Park Service on October 8, 2015. The sample included 1,425 individuals who participated in whitewater trips in Grand Canyon National Park between September 2014 and August 2015.

**Project Element 13.2**
Project element will be implemented in FY17.

**Project Element 13.3**
Project element requires no monitoring or survey activities.

*Progress Answering Science Questions*

**Project Element 13.1**

Collection and development of Project 13.1 material for submittal to the Office of Management and Budget (OMB) and communication with GCDAMP stakeholders occurred late in FY14 and continued into FY15. Approval from OMB was received August 14, 2015. OMB approval initiated mailing of in-depth surveys to anglers in GCNRA and private whitewater floaters in GCNP. GCMRC and the National Park Service continue to work with the commercial outfitters to obtain commercial whitewater floater name and address information. Mailing of in-depth surveys will continue into calendar year 2016. Data entry and analysis will occur early in calendar year 2016. Manuscripts describing the study results, angler and whitewater floater preferences, regional expenditures, and economic values as affected by operation of GCD, will be completed in FY16 and FY17.

*Highlights from the ongoing data collection include*:

- Collaboration with Arizona Game and Fish Department was established and sharing of methods, practices, and creel survey continues.

**Project Element 13.2**

Project 13.2 is scheduled to be implemented in FY17. Opportunities to introduce and discuss details of Project 13.2 with Tribal representatives to the GCDAMP and Tribal staff were identified in FY15:

- A workshop was held in Flagstaff, AZ on February 20, 2015. The workshop initiated discussion of Project 13.2 with GCDAMP Technical Workgroup Tribal representatives, Lucas Bair from GCRMRC, and cooperators John Duffield and Chris Neher from the University of Montana. Lucas Bair and John Duffield presented on Project 13.2 and discussion followed. Additional workshops with GCMRC researchers, cooperators from the University of Montana and Tribal staff were proposed for FY16.
- Lucas Bair from GCMRC participated in the Tribal-Stakeholder river trip from July 21-27. Attendees included representatives to the GCDAMP including representatives from the

Hualapai Tribe, Pueblo of Zuni, Navajo Nation, Southern, Paiute Consortium, and Hopi Tribe. The river trip provided an opportunity to discuss Project 13.2 and Tribal perspectives associated with resources downstream of GCD.

**Project Element 13.3**

Progress in this project has included collaboration between Lucas Bair and Charles Yackulic of GCMRC, Michael Springborn of UC Davis, Craig Bond of Pardee RAND, and Mathew Reimer of the UA Anchorage. A workshop was held in Flagstaff on July 16, 2015, which led to a draft bioeconomic model to identify the economically preferred management strategy for established nonnative fish, in relation to humpback chub survival. The draft model was reviewed by Carl Walters, Michael Runge and Josh Korman. Model development will continue through FY16, 1) identifying the importance of parameter uncertainty on the sensitivity of cost-effective outcomes in the bioeconomic model; 2) evaluating parameter uncertainty to aid in the identification of the value and prioritization of monitoring and research; and 3) demonstration of how modeling can prioritize future monitoring and research. Model development will continue in FY17 with incorporation of additional management variables and associated costs, such as trout management flows at GCD, to improve humpback chub survival, again identifying the most cost-effective management alternatives under different future scenarios.

*Summary of Reports and Products*

The Triennial Workplan for FY15–17 listed the following publications and related products from our Project 13 work:

| | **PRODUCTS/REPORTS** | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Presentations | Investing in Conservation: Cost-effective adaptive management in the Colorado River Basin | | November 2014 | | L. Bair. Presentation at Upper Colorado River Basin Water Conference in Grand Junction, CO |
| Journal manuscript | Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate | Extra product no date | Draft submitted June 2015 | FY 16 | Lead author L. Bair. This is a manuscript that is an outgrowth of |

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expecte d** | **Citations/Comm ents** |
| | the Influence of Seasonality | | | | Project 13.1 |
| Journal manuscript | Bioeconomic modeling to evaluate and prioritize, monitoring, research and management alternatives published in peer reviewed literature. | FY 15-17 | | FY 16-17 | Lead author L. Bair. In preparation |

| Project 13 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $118,800 | $12,500 | $1,000 | $22,500 | $0 | $18,711 | **$173,511** |
| **Actual Spent** | $103,008 | $4,767 | $23,141 | $15,000 | $0 | $18,298 | **$164,215** |
| **(Over)/Under Budget** | **$15,792** | **$7,733** | **($22,141)** | **$7,500** | **$0** | **$413** | **$9,296** |

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

Reduced salary costs due to lower actual burden rate.
Carryover: $11,800, will be used to offset FY16 & FY17 shortages.
Contracted with one "Cooperator" rather than entering into a cooperative agreement and front loaded FY16 & FY17 funding into contract.

| **Project 14: Geographic Information Systems (GIS) Services and Support** | | | |
|---|---|---|---|
| **Program Manager** (PM) | Tom Gushue | **Investigator(s)** (I) | Tom Gushue, USGS, GCMRC<br>Tim Andrews, USGS, GCMRC |
| **Email** | *tgushue@usgs.gov* | | |
| **Telephone** | (928) 556-7370 | | |

**SUMMARY**

**Introduction**

Geographic Information Systems (GIS) continues to play a critical role in nearly all of GCMRC's science efforts and is prevalent in many of the projects proposed in the FY15–17 Triennial Work Plan (TWP). It is used across disciplines and is itself a powerful tool for integrating geospatial data collected by many different projects. The TWP has provided GCMRC an opportunity to develop a GIS project better designed to successfully function within GCMRC and meet the current and future needs of scientists, managers, and the public alike. Most work performed within this project falls within one of three main tenets: Geospatial Data Analysis, Geospatial Data Management, and Access to Geospatial Data Holdings. These concepts are not new, and have been a part of the GCMRC mission since its inception. This annual report affords us a chance to more clearly defines the work performed in each of these elements, how this work relates to individual science projects, and the GCMRC's overall mission, and accomplishments made over the past year.

**Summary of Progress by Project Element**

**<u>14.1 Geospatial Data Analysis: Support to Science Projects</u>**

The GIS Project continued to support other science projects through geospatial data processing and analysis in FY15. As described in the TWP, this element of the GIS Project has defined linkages to other projects where a high level of GIS support would be required. Most GCMRC project usually required some level of GIS support, and this usually is in the form of database development, GIS layer development, and map outputs created for field use or for presentation and publication purposes. Below are a few more in-depth descriptions of GIS support provided to other GCMRC projects.

*GCMRC River Mile System*

In FY15, the existing GCMRC River Mile System (2002) was updated to account for changes that have occurred in the Colorado River channel below river mile 260 due to a decrease in water levels at Lake Mead. For this section of river, the centerline and associated river mileage has been updated to match the Colorado River channel as it appears in GCMRC's 2013 overflight imagery data. Very little change was noticeable between the two most recent overflight missions (2009 and 2013), and so it was determined that using the most recent (2013) would be the most appropriate choice. The updated river mile system was completed prior to the field season and made available to science efforts working in this section of river.

*Project 6. Mainstem Colorado River fish community dynamics: Extension of Fish Sampling Units*

Related to updating the GCMRC River Mile System, the GIS project also was responsible for updating the Fish Sampling Unit System for the same stretch of river below river mile 260. This update was necessary because of an increased focus on nonnative fish below Diamond Creek with more fish sampling efforts occurring in this reach.

*Project 9. Rainbow Trout in Glen and Marble Canyons: Database support for historical fisheries data*

In addition to the fish sampling unit updates, the GIS project also worked with fish biologists and the fish database administrator to re-analyze past fishing efforts for the Lees Ferry Fisheries and Mechanical Removal efforts conducted in the early 2000s in order to assign spatial statistics to these data records. Once this was accomplished, these earlier fishing efforts could then be analyzed in a similar manner as the on-going mainstem fish sampling projects that take length of shoreline sampled into account when determining fish occupancy metrics. The GIS project's involvement with this effort has helped to consolidate fish sampling efforts so that all samples can be spatially related using a consistent and standard fish sampling unit platform.

*Project 3. Geomorphology: Analysis of historical images at select monitoring sites (3.1.4)*

As part of the GIS project, work continued on processing Digital Terrain Models of sandabars in 1984 that are extracted photogrammetrically from historical aerial photography. In addition to having four sandbar sites processed, new DTM extraction software module was incorporated into the workflow that promises to yield better results than previously achieved on initial DTM generation efforts. This new module, Auto DTM, includes more robust algorithms for finding similarities between stereo pair photographic frames contained within a photogrammetric block. Early tests of this new software module are promising, resulting in denser point clouds than previously generated. (See Project 3, 3.1.4).

*Project 3.5. Control Network and Survey Support: Database support and spatial analysis*

GIS staff worked with Survey lead to fix existing errors in survey control network database. This involved extracting the most recent survey control network for Grand Canyon from the existing database and importing it into a GIS format, developing export files for sharing data, and creating maps for field and publication use. Additionally, GIS staff initiated the beginning stages of migrating survey control network database out of Microsoft Access and into ESRI Geodatabase format. This will serve as a temporary fix prior to designing a new database structure in Oracle for storing, analyzing, and serving Grand Canyon survey control network data.

*Project 11. Riparian Vegetation Monitoring: Geospatial analysis and Site Selection Tool*

The GIS project developed a randomized site selection tool to assist with vegetation transect field work beginning in FY15. Prior to the development of this GIS-based tool, riparian vegetation monitoring was either limited to areas studied by other projects (Long-term sandbar monitoring) or biased due to the lack of sound methods for randomizing this effort. The protocol developed by the GIS team utilizes a geospatial data-driven approach to defining the sampling frame and the specific sites to be eventually selected. GIS utilizes a number of geospatial data layers and a sampling protocol based on a combination of those data layers to randomly select sites along the Colorado River on either river left bank or river right bank between RM -15.6 and RM 240.

*Project 12 Socio-Economic Analysis: Lees Ferry Fisheries Angler Survey Analysis*

The GIS project also worked with GMCRC'S Socio-Economic scientist to develop GIS data sets and perform analysis related to Lees Ferry angler surveys. This involved help helping the scientist better understanding how the data could be used for analysis, what would be the most appropriate ways to present the data, and how the data could best be shared with the public.

**14.2 Geospatial Data Management**

During FY15 the GIS project continued to serve as the Center lead for geospatial data management. This work involved coordinating between GCMRC science staff and the SBSC IT group to provide better support to science projects in the form of more reliable disk storage for data, improved communication of science needs to IT support staff, and an increased focus on high-level data management needs such as web server configurations, database server maintenance, and software installations and upgrades.

It became apparent that weekly meetings were needed to improve IT support to GCMRC science projects and create a better working relationship between IT personnel and science staff. Through these meetings and directly assigned tasks, we were able to ensure that unresolved IT-related work was completed and new challenges that arose were met in an efficient and timely manner. One of the new challenges was to ensure all computer systems adhere to new IT security measures instated by the Department of the Interior and the U.S. Geological Survey. Tasks related to this involved the removal all critical and high vulnerabilities associated with GMCRC's Oracle databases, upgrading several software applications to newer versions, and the removal of expired servers from our system.

Another aspect of this project element is the maintenance and expansion of an Oracle Spatial Database for GCMRC. Due to the IT security issues experienced government wide in FY15, there was a great deal of unplanned work for this element in resolving the critical and high vulnerabilities found in several database servers with only very tight deadlines given. This was achieved only through the coordination provided by the GIS project and the diligent work of database administrators and IT staff involved with this issue.

Also during this past fiscal year, the GIS project was able to expand on the geospatial data hosted by the Oracle Spatial Database. Large, regional data sets available through the database now include the March 2000 CIR overflight data, a new Glen Canyon 2009 1-meter DEM with vegetation removed, and an updated Lake Powell 5-meter DEM and hillshade representing pre-dam topography. Project-based geospatial data added to the database include the updated GCMRC River Mile System, the Fish Sampling Unit System, an updated Survey Control Network data set, and Aquatic Foodbase

Light Trap data from 2012 through 2014.

During FY15, the GIS project was also involved with initiating the new USGS data review process for GCMRC. This work included assisting scientists with proper metadata development, review of spatial data characteristics (fields, values, etc.), and finalization of data review documents related to science publications. The new USGS data management protocols now require that the data used for peer-reviewed publications also go through a standardized review process, and be published alongside the publication.

### 14.3.1 Access to Geospatial Data Holdings – The Geospatial Portal

The GIS Project made significant strides in advancing the Center's ability to host and share geospatial and other scientific data through web-based applications. A great deal of effort was made to build new systems for hosting map services that can be accessed by people outside the Center through different avenues. A large part of this work involved developing the systems (web server architecture, network communication, Oracle database access, and coordination with the USGS ESAS / Firewall team) used to serve geospatial and other data through GCMRC's website. Once these systems were in place, it was then possible to install the necessary software components (ESRI ArcGIS Server, Portal for ArcGIS, etc.) and begin testing web map services and applications. We have now migrated these systems to the latest versions, which in turns provides more functionality to users of GCMRC web applications. The following is a descriptive list (with URLs provided) of new web-based mapping and data exploration applications now available through GCMRC's website.

*A redesigned GCMRC Map and Data Portal page* **(http://www.gcmrc.gov/dasa)**

The Map and Data Portal web page is the gateway to many of GCMRC's data holdings. Available content is segmented according to Resource/Project type and by the nature of the content being served. This web page provides a more organized and modern look, and allows users to find content of interest more efficiently. This page also simplifies the process for adding new content to the site as it becomes available.

*New HFE Sandbar Photo application* **(http://www.gcmrc.gov/gis/sandbartour2014/index.html)**
Available through the GCMRC Map and Data Portal are many new applications, including a revamped way of serving remote camera photographs that bracket the most recent HFEs from Glen Canyon Dam (2012–2014).

*New Grand Canyon GIS Portal application* **(http://grandcanyon.usgs.gov/portal)**

Also in FY15, the GIS project established a new web server for GCMRC that is better designed to server geospatial and scientific data to the public through custom, in-house web applications. One of these new applications is the Grand Canyon GIS Portal. This is an ESRI product that enables the publishing, sharing, editing and downloading of many different kinds of geospatial data.

*New Geospatial Services page* **(http://www.gcmrc.gov/geospatial)**

For GIS users, we now provide access to GCMRC's geospatial data sets through a web services directory page that organizes REST service endpoints by data set and resource type. These services can be used in desktop applications by simply downloading a link (*.lyr) file of any service. They can also be consumed in web applications developed by users outside the GCMRC, or added into a Google Earth session as a layer (*.kmz).

**14.3.2. Access to Geospatial Data Holdings – ESRI's ArcGIS Online (http://www.arcgis.com)**

In FY13–14, GCMRC's GIS staff began using ESRI's online portal service for disseminating data to a much wider audience than ever before. This service, ArcGIS Online, has quickly become one of the most used geospatial content delivery systems available on the web. In FY15–17, we expanded on the data made available to the public through this service. Data and services added to ArcGIS Online include the Citizen Science Aquatic Foodbase Light Trap Map Services and Web Application, Mainstem Fish Sampling Epoch Maps, Humpback Chub Hoop Net Data (1984-2013), Lake Powell Water Quality Station Map Service, and an updated Lake Powell Pre-Dam Topography Map Service. The benefit of using ArcGIS online in addition to hosting our own geospatial portal is that a particular service only needs to be created once by GIS staff, but can then be posted on both GCMRC's website and through ESRI's ArcGIS Online to reach a wider audience.

| Project 14 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $173,762 | $4,000 | $17,400 | $0 | $0 | $26,606 | **$221,768** |
| **Actual Spent** | $160,375 | $3,605 | $21,421 | $0 | $0 | $25,276 | **$210,678** |
| **(Over)/Under Budget** | **$13,387** | **$395** | **($4,021)** | **$0** | **$0** | **$1,330** | **$11,090** |

**COMMENTS** *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Reduced salary costs due to lower actual burden rate.
Carryover: $14,900, will be used to offset FY16 & FY17 shortages.

| Project 15: Administration | | | |
|---|---|---|---|
| **Program Manager** (PM) | Scott VanderKooi | **Investigator(s)** (I) | Scott VanderKooi, USGS GCMRC |
| **Email** | svanderkooi@usgs.gov | | |
| **Telephone** | 928-556-7376 | | |


**SUMMARY**

During the Fiscal Year 2015, 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 part of the salaries of two program managers. This section also covers the costs of IT equipment for GCMRC. Logistics base cost covers salaries and travel/training for logistics staff.


| Project 15 (- Logistics) | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| Budgeted Amount | $511,300 | $30,000 | $227,000 | $79,000 | $0 | $107,112 | **$954,412** |
| Actual Spent | $273,700 | $11,850 | $207,312 | $80,035 | $0 | $69,593 | **$642,490** |
| (Over)/Under Budget | **$237,600** | **$18,150** | **$19,688** | **($1,035)** | **$0** | **$37,519** | **$311,922** |

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

Reduced salary costs due to lower actual burden rate and GCMRC Chief, Deputy Chief and Physical Scientist vacancies.

Carryover: $327,600, will be used to offset FY16 & FY17 shortages.

| Logistics | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $259,300 | $5,000 | $793,200 | $0 | $0 | $144,169 | **$1,201,669** |
| **Actual Spent** | $252,393 | $2,183 | $835,432 | $9,088 | $0 | $148,874 | **$1,247,971** |
| **(Over)/Under Budget** | **$6,907** | **$2,817** | **($42,232)** | **($9,088)** | **$0** | **($4,705)** | **($46,302)** |

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

Operating expenses higher than budgeted.
Cooperative Agreement with Grand Canyon Youth.
Replaced forklift in FY15.

| Project 1: Lake Powell and Glen Canyon Dam Release Water-Quality Monitoring | | | |
|---|---|---|---|
| **Program Manager** (PM) | Scott VanderKooi | **Investigator(s)** (I) | Bill Vernieu (retired as of May 2015) |
| **Email** | *svanderkooi@usgs.gov* | | |
| **Telephone** | 928-556-7376 | | |

**SUMMARY**

**Project Summary**

GCMRC has conducted a long-term water-quality monitoring program of Lake Powell and Glen Canyon Dam (GCD) releases. This project has been funded entirely by Reclamation from water and power revenues and has received no monetary support from the GCDAMP. In addition to direct funding of the program, Reclamation has also provided 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.

Future activities under this project remain uncertain pending the outcome of a project review by Reclamation.

**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 and 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 of 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 100ft 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 extended 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 UC 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 to 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 can filter large quantities of water and 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 with a crew of four and 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, and sampling for major ion concentration and nutrients 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.

Since the beginning of FY15, seven forebay surveys and three reservoir-wide surveys have been conducted, in addition to pre-HFE and post-HFE monitoring in November 2014. The beginning dates of these surveys are shown below.

| | |
|---|---|
| 10/10/14 | forebay |
| 11/07/14 | forebay and pre HFE |
| 11/19/14 | forebay and post-HFE |
| 12/10/14 | full reservoir survey |
| 01/22/15 | forebay |
| 02/20/15 | forebay |
| 03/12/15 | full reservoir survey |
| 04/09/15 | forebay |
| 05/12/15 | full reservoir survey |
| 06/26/15 | forebay |
| 08/04/15 | forebay |
| 10/12/15 | forebay |

The date of the next reservoir-wide survey is unknown due to funding uncertainties and equipment issues.

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 the WQDB database (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. This effort is on hiatus due to the retirement of Bill Vernieu and uncertainty about future funding for this project.

**Progress and Accomplishments**

The publication of a biological data report describing phytoplankton, zooplankton, and chlorophyll data collected from Lake Powell from 1990 through 2009 has been published. Analysis of a backlog of biological samples has been completed by a contractor. This resulted in a complete history of Lake Powell plankton data, including the initial stages of the recent quagga mussel invasion. Potential analyses of these data include identifying trends in biomass and community structure of zooplankton and phytoplankton populations and identifying potential factors that affect these populations.

**Current Conditions**

Hydrology - Lake Powell received 10.17 million acre feet (maf; 94% of average) of unregulated inflow in FY15, similar to the inflow observed in 2014 (96% of average), and significantly higher than inflows observed in 2012 and 2013 (45% and 47% of average, respectively). Reservoir levels reached a peak of 3614.32 ft on July 14, 2015, compared to a peak of 3609.68 ft in 2014. At the end of FY15, Lake Powell's surface elevation was 3,606.01 ft with storage of 12.3 maf, or 51% of capacity. This is similar to the end of FY14 when surface elevation was 3,605.5 ft, and storage was 12.29 maf.

Releases for FY15 totaled 9.0 maf (compared to 7.48 maf total releases for WY2014) with operations under the Upper-Elevation Balancing Tier. A High-Flow Experiment (HFE) was conducted in November 2014, in which approximately 37,500 $ft^3/s$ was released for a 96-hour period and Lake Powell's surface elevation decreased by approximately 2.9 ft.

Operations for FY16 will fall under the Upper Elevation Balancing Tier with a total projected annual release volume of 9.0 maf after an April 2016 adjustment. Based on the 24-month study of October 2015, Lake Powell surface elevation at the end of FY16 is projected to be approximately 3,600 feet with approximately 11.8 maf in storage (48% capacity).

Glen Canyon Dam Release Temperature - Glen Canyon Dam release temperatures from 2003-2010 were above average because of low reservoir elevations resulting from extended drought conditions in the Upper Colorado River Basin. Lower reservoir elevations in 2014 and 2015, combined with a higher inflow volumes, also resulted in above-average release temperatures during the summer and fall of 2014 and 2015, with release temperatures exceeding 14°C in the fall of both years.

Lake Powell Limnology – Unlike in 2014, a winter underflow density current was not observed in spring 2015. These density currents, which are typical cause a significant freshening (i.e. increase) of hypolimnetic dissolved oxygen concentrations near Glen Canyon Dam. Other years when these density currents did not occur were 2006, 2009, and 2012. The National Park Service detected larval quagga mussels in Lake Powell in the fall of 2012. Adult quagga mussels were discovered in Lake Powell marina areas in early 2013 and continue to increase in numbers.

**Program Support**

A five-year agreement for continued support of the Lake Powell water-quality monitoring program was developed with Reclamation in 2013 to provide funding for staff, supplies and maintenance of the Uniflite vessel and other equipment, and sample analysis. Funding was received under this agreement in 2013 and 2014. In addition to direct funding of the Lake Powell program in the approximate amount of $250,000 annually, Reclamation had also provided approximately $180,000 in in-kind support for sample analysis and field assistance. All 2015 activities were conducted using funds carried forward from 2014. With the retirement of Bill Vernieu in May 2015, Reclamation put a hold on the funding proposal GCMRC had submitted for funding in 2015. Reclamation indicated they planned to review the Lake Powell program and decide on its future based on the review's results, In the interim, GCMRC has committed to conducting monthly forebay sampling until remaining funds have been expended. The planned external review of this program funded in the FY2015–17 workplan has been postponed pending the outcome of this review.

| | PRODUCTS/REPORTS | | | | |
|---|---|---|---|---|---|
| **Type** | **Title** | **Due Date** | **Date Delivered** | **Date Expected** | **Citations/Comments** |
| Data series | Biological data for water in Lake Powell and from Glen Canyon Dam releases, Utah and Arizona, 2009-2012 | | 10/6/15 | | Vernieu, W.S., 2015, Biological data for water in Lake Powell and from Glen Canyon Dam releases, Utah and Arizona, 1990–2009: U.S. Geological Survey Data Series 959, 12 p., http://dx.doi.org/10.3133/ds959. |

| Project 1 | Salaries | Travel & Training | Operating Expenses | Cooperative Agreements | To other USGS Centers | Burden 13.633% | Total |
|---|---|---|---|---|---|---|---|
| **Budgeted Amount** | $183,500 | $8,700 | $40,300 | $20,000 | $20,300 | $32,297 | **$305,097** |
| **Actual Spent** | $79,992 | $2,861 | $37,382 | $0 | $0 | $16,392 | **$136,627** |
| **(Over)/Under Budget** | **$103,508** | **$5,839** | **$2,918** | **$20,000** | **$20,300** | **$15,905** | **$168,470** |

| **COMMENTS** *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)* |
|---|
| Carried $166,000 over from FY14 to FY15 and we did not receive any FY16 Funds non-AMP Lake Powell Funds.<br>Carried over $30,000 of non-AMP Lake Powell Funds.<br>Carried over $20,000 of AMP Lake Powell Funds. |