Grand Canyon Monitoring and Research Center

Fiscal Year 2016 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 (FY) 2016 Annual Accomplishment Report. This report is prepared primarily for the Bureau of Reclamation to account for work conducted and products delivered in FY16 and to inform the Technical Work Group (TWG) of science support provided to the Glen Canyon Dam Adaptive Management Program (GCDAMP). It includes a summary of accomplishments, shortcomings, and recommendations related to projects included in GCMRC's FY16 Work Plan for the GCDAMP[1]. The report also includes budget summaries for each project as well as a separate budget for logistics operations. In addition to project costs, budgets show funds carried forward from FY15, shortfalls in funding due to lower than projected Consumer Price Index values, and funds to be carried forward to FY17.

[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.

FY 2016 Project Report for the Glen Canyon Dam Adaptive Management Program

Project 2: Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem

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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, suspended-sediment concentration, and particle size at 8 mainstem and 16 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 real time. The high-resolution suspended-sediment data collected under this project are used to construct the mass-balance sediment budgets used by managers to trigger HFE under the 2012–2020 High-Flow Protocol. Details of this ongoing project (including descriptions of the data-collection locations) are provided in the GCMRC 2015–17 Triennial Work Plan.

Science Question 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 FY16, 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/*. 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 and duration curves (this is a new tool completed this year).

2) Publication of 3 peer-reviewed interpretive papers. The interpretive papers published during FY16 focused on: a physically based method for using multi-frequency acoustics to measure suspended-sediment concentration and grain size in the Colorado and other rivers, and turbidity in the Colorado River.

Six additional peer-reviewed publications will be completed during the remaining period of the 2015-17 Work Plan, 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."

Selected FY16 results:

During FY16, all monitoring data required by this project, including those required to trigger and design the Nov. 2016 HFE, were collected. Processing of all data is complete and all data have been uploaded to and are available at our website, except for laboratory analyses of some of the suspended-sediment data from automatic pump samplers (this task will be completed by the end of February 2017, as is the usual schedule for this project). The large amount of data collected and analyzed by this project makes it impossible to synthesize all results herein. Thus, all data and user-interactive tools for visualizing the data are available at our website, with a synthesis of only selected key parameters provided in Table 1. Years in which demonstrable change in sand mass (i.e., years in which sand was gained or lost) occurred in the selected reaches are indicated by bold type.

Table 1. Status of selected key parameters in the CRE during the last 5 years

	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016
Median Colorado River (CR) discharge at Lees Ferry	12,500 cfs	10,700 cfs	9,800 cfs	12,100 cfs	12,400 cfs
June-Oct Paria River sand input	690,000 metric tons	1,900,000 metric tons	1,200,000 metric tons	1,600,000 metric tons	880,000 metric tons
Upper Marble Canyon sand budget	**+480,000 ±130,000 metric tons**	**+1,400,000 ±320,000 metric tons**	+160,000 ±250,000 metric tons	-130,000 ±240,000 metric tons	+210,000 ±390,000 metric tons
Lower Marble Canyon sand budget	**+89,000 ±39,000 metric tons**	**+140,000 ±84,000 metric tons**	**+500,000 ±120,000 metric tons**	**+220,000 ±140,000 metric tons**	**+130,000 ±130,000 metric tons**
Eastern Grand Canyon sand budget	-29,000 ±90,000 metric tons	-110,000 ±190,000 metric tons	**-310,000 ±150,000 metric tons**	**-850,000 ±230,000 metric tons**	**-350,000 ±180,000 metric tons**
Water temperature exceeded 10% of the time in CR below the LCR (RM 66)	14.4^{o} C	12.8^{o} C	15.2^{o} C	14.9^{o} C	14.6^{o} C
Turbidity exceeded 10% of the time in CR above the LCR (RM 61)	66 FNU	158 FNU	68 FNU	149 FNU	100 FNU
Median and max. CR specific conductance (a proxy for salinity) at Lees Ferry	665 µS/cm at 25^{o} C 805 µS/cm at 25^{o} C	737 µS/cm at 25^{o} C 890 µS/cm at 25^{o} C	832 µS/cm at 25^{o} C 960 µS/cm at 25^{o} C	751 µS/cm at 25^{o} C 884 µS/cm at 25^{o} C	737 µS/cm at 25^{o} C 867 µS/cm at 25^{o} C
Median and min. CR dissolved oxygen at Lees Ferry	8.2 mg/L 5.9 mg/L	7.9 mg/L 5.6 mg/L	7.5 mg/L 5.5 mg/L	7.9 mg/L 5.0 mg/L	7.7 mg/L 5.1 mg/L

In addition to the collection, processing, and web posting of all monitoring data, presentation of 5 papers at professional science meetings, and completion of 3 peer-reviewed publications, we completed and released on our website the duration-curve tool promised in the 2015–17 Triennial Work Plan. This new tool allows the user to plot (in linear or log space) the percentage of time that any continuously monitored parameter is equaled or exceeded during any user-selected time period. This new way of plotting data on our website is incredibly powerful and allows the user to (1) quickly visualize the amount of time any value of any parameter occurs, and (2) quickly determine of the maximum, minimum, and median (i.e., 50th-percentile) values of any parameter over any time period. To use this new tool, please:

1) Go to any monitoring station.

2) Select a parameter to plot.

3) Input the time period to plot.

4) Click "Build Graph."

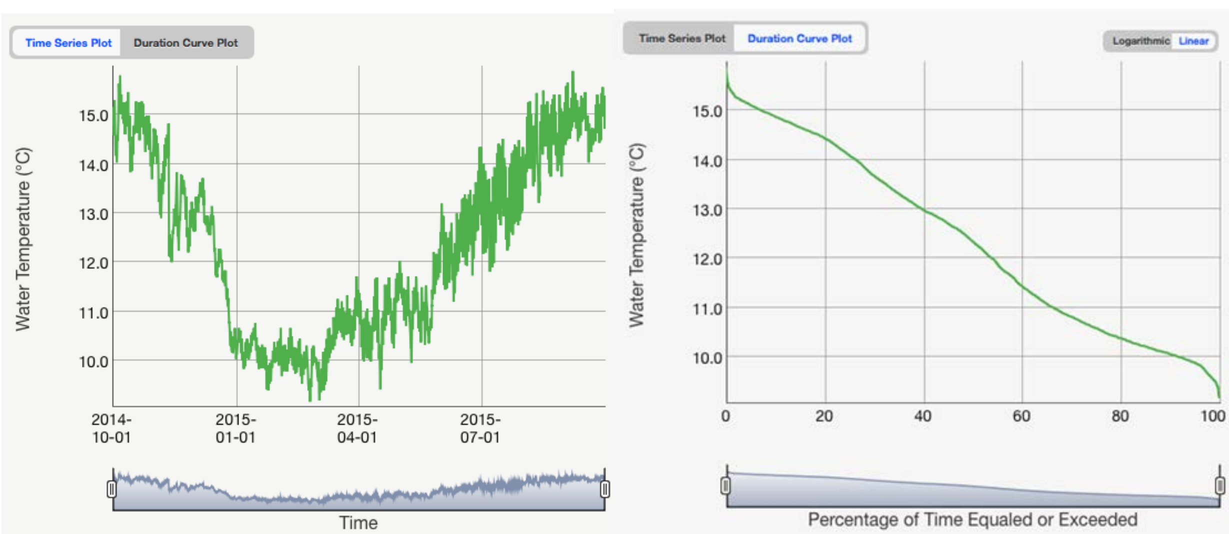
5) After time series plot appears in the window, click "Duration Curve Plot."

6) If the option is given, select a linear or logarithmic y-axis depending on your preference. Using the logarithmic y-axis yields a smoother duration curve at lower values of the plotted parameter.

7) Slider below plot can be used to zoom in to a smaller range for the x-axis.

8) Red ball and line can be dragged across the plot with mouse to see values along curve.

Below are a time-series plot (left) and a duration-curve plot (right) for water temperature during FY15 in the Colorado River near river mile 66 below the mouth of the Little Colorado River.



Suggestions and rationale for next steps:

It is recommended that this project continue in its current form because: (1) the stage, discharge water quality, and sediment data collected by this project in the CRE are the basic data used by every other project funded by the Glen Canyon Dam Adaptive Management Program, and (2) the data collected by this project are used to trigger, design, and evaluate HFEs under the 2012–2020 High-flow protocol and operations under the LTEMP EIS.

	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 and duration curves. These capabilities are unique in the world.	ongoing	updated every month	updated every month	*http://www.gcmrc.gov/discharge_qw_sediment/* *http://cida.usgs.gov/gcmrc/discharge_qw_sediment/*
Online realtime database	Discharge and water-quality data collected at 9 gaging stations by the Utah and Arizona Water Science Centers under project are posted to the web every hour.	n/a	hourly	n/a	*http://waterdata.usgs.gov/nwis*
Abstracts presented at professional meetings	American Geophysical Union abstract for 2015 Fall Meeting entitled "Flash Floods, Sediment Transport, and the Geomorphic Transformation of Moenkopi Wash, AZ." Presentation made at AGU in December 2015.	FY16	Dec. 2015	Dec. 2015	Topping, D.J., and Dean, D.J., 2015, Flash Floods, Sediment Transport, and the Geomorphic Transformation of Moenkopi Wash, AZ: Abstract H51E-1419 presented at 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.
	American Geophysical Union abstract for 2015 Fall Meeting entitled	FY16	Dec. 2015	Dec. 2015	Grams. P.E., Buscombe, D., Hazel, J.E., Kaplinksi, M.A., and

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	"Patterns of Channel and Sandbar Morphologic Response to Sediment Evacuation on the Colorado River in Marble Canyon, Arizona." Presentation made at AGU in December 2015.				Topping, D.J., 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, AGU, San Francisco, Calif., 14-18 Dec.
	American Geophysical Union abstract for 2015 Fall Meeting entitled "Measurement of sediment loads during flash flood events: 14 years of results from a six stream monitoring network on the southern Colorado Plateau." Presentation made at AGU in December 2015.	FY16	Dec. 2015	Dec. 2015	Griffiths, R.E., and Topping, D.J., 2015, Measurement of sediment loads during flash flood events: 14 years of results from a six stream monitoring network on the southern Colorado Plateau: Abstract H51E-1416 presented at 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.
	American Geophysical Union abstract for 2015 Fall Meeting entitled "Interpreting Hydraulic Conditions from Morphology, Sedimentology, and Grain Size of Sand Bars in the Colorado River in Grand Canyon." Presentation made at AGU in December 2015.	FY16	Dec. 2015	Dec. 2015	Rubin, D.M., Topping, D.J., Schmidt, D.J., Grams, P.E., Buscombe, D., East, A.E., and Wright, S.A., 2015, Interpreting Hydraulic Conditions from Morphology, Sedimentology, and Grain Size of Sand Bars in the Colorado River in Grand Canyon: INVITED Abstract EP41D-01 presented at

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.
Abstracts presented at professional meetings (continued)	International Association for Hydro-Environment Engineering and Research abstract for River Flow 2016, Proceedings of the Eighth International Conference on Fluvial Hydraulics entitled "Long-term continuous acoustical suspended-sediment measurements in rivers – Theory, evaluation, and results from 14 stations on five rivers." Presentation made in July 2016.	FY16	Jul. 2016	Jul. 2016	Topping, D.J., Wright, S.A., Griffiths, R.E., and Dean, D.J., 2016, Long-term continuous acoustical suspended-sediment measurements in rivers – Theory, evaluation, and results from 14 stations on five rivers, in Constantinescu, G., Garcia, M., and Hanes, D., eds., River Flow 2016, Proceedings of the International Conference on Fluvial Hydraulics, St. Louis, Missouri, USA, July 11-14, 2016, ISBN 978-1-138-2913-2, p. 520-522.
Journal articles and other major pubs.	U.S. Geological Survey Professional Paper entitled "Long-term continuous acoustical suspended-sediment measurements in rivers—Theory, application, bias, and error."	FY16	May 2016	May 2016	Topping, D.J., and Wright, S.A., 2016, Long-term continuous acoustical suspended-sediment measurements in rivers—Theory, application, bias, and error: U.S. Geological Survey Professional Paper 1823, 98 p., *http://dx.doi.org/10.3133/pp1823*.
	International Association for Hydro-Environment Engineering and Research proceedings article for	FY16	Jul. 2016	Jul. 2016	Topping, D.J., Wright, S.A., Griffiths, R.E., and Dean, D.J., 2016, Long-term continuous

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	River Flow 2016, the Eighth International Conference on Fluvial Hydraulics entitled "Long-term continuous acoustical suspended-sediment measurements in rivers – Theory, evaluation, and results from 14 stations on five rivers."				acoustical suspended-sediment measurements in rivers – Theory, evaluation, and results from 14 stations on five rivers, in Constantinescu, G., Garcia, M., and Hanes, D., eds., River Flow 2016, CD-ROM Proceedings of the International Conference on Fluvial Hydraulics, St. Louis, Missouri, USA, July 11-14, 2016, ISBN 978-1-138-2913-2 for set of Book and CD-ROM, ISBN 978-1-315-64447-9 for eBook PDF, p. 1510-1518 on CD-ROM.
	U.S. Geological Survey Fact Sheet entitled "Water clarity of the Colorado River—Implications for food webs and fish communities."	FY16	Nov. 2016	Sep. 2016	Voichick, N., Kennedy, T., Topping, D., Griffiths, R., and Fry, K., 2016, Water clarity of the Colorado River—Implications for food webs and fish communities: U.S. Geological Survey Fact Sheet 2016-3053, 4 p., *http://dx.doi.org/10.3133/fs20163053*.

Project 2	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$659,000	$5,000	$52,000	$0	$496,000	$85,798	**$1,297,798**
Actual Spent	$493,844	$9,738	$165,949	$0	$466,626	$80,230	**$1,216,388**
(Over)/Under Budget	**$165,156**	**($4,738)**	**($113,949)**	**$0**	**$29,374**	**$5,568**	**$81,410**

FY15 Carryover	**$44,657**	**CPI Decrease**	**($65,706)**	**FY16 Carryover**	**$60,361**

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

- Salary costs decreased due to charging to other reimbursable projects and vacancies.
- Operating expenses increased due to replacing broken instruments.
- Suballocations to other USGS cost centers increased due to sending additional funds to CIDA.
- Carryover will be used to send funds to CIDA, to replace old instruments and to offset FY17 shortage.

FY 2016 Project Report for the Glen Canyon Dam Adaptive Management Program

Project 3: Sandbars and Sediment Storage Dynamics: Long-term Monitoring and Research at the Site, Reach, and Ecosystem Scales

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SUMMARY

Sandbar Monitoring and Research (elements 3.1.1, 3.1.2, 3.1.3, 3.1.4, and 3.3)

The overall objectives of the sandbar monitoring and research project elements in the FY15–-17 work plan are to track sandbar and campsite size and abundance as they are affected by individual High-Flow Experiments (HFEs, or "controlled floods") and successive HFEs and intervening dam operations. These projects are designed to evaluate whether the HFE protocol is having the intended effect of increasing sandbar size and abundance. Research elements of this project are designed to advance general understanding of eddy sandbar dynamics to improve capacity to predict the effects of dam operations on sandbars.

Annual changes in sandbars and campsites were measured by repeat topographic surveys at 47 long-term monitoring sites in September/October 2015 and September/October 2016. Remote cameras installed at 43 of these sites record daily changes in sandbar size. The repeat topographic surveys show that, in October 2015, approximately 11 months after the 2014 HFE (the 3rd HFE released as part of the HFE protocol), the total volume of sand within sandbar monitoring sites was greater than before the start of the protocol in Marble Canyon and Grand Canyon (Figure 1). The surveys demonstrate that the HFE protocol was resulting in net deposition and the erosional trend that occurred in the 1990s and early 2000s is no longer occurring. Data from the 2016 monitoring trip are currently being processed and will be available at the January 2017 Annual Reporting meeting.

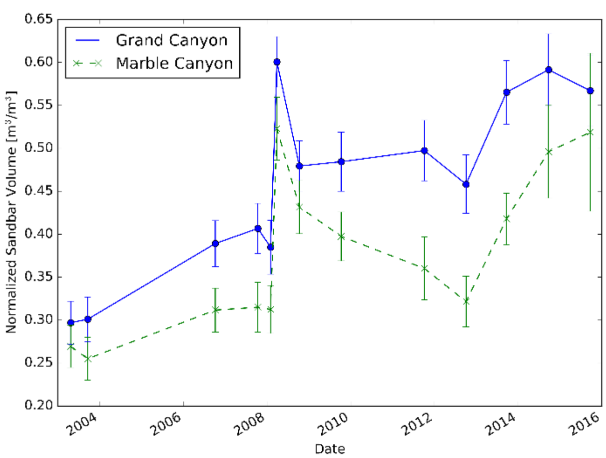

Figure 1. Average normalized sand volume for 19 long-term sandbar monitoring sites in Marble Canyon (River Mile 0 to 62) and 20 sites in Grand Canyon (River Mile 62 to 225). Each point is the average is for all monitoring sites in each segment with error bars showing standard error. The normalization is the ratio of the volume measured at a given date to the maximum observed for the entire monitoring record.

Only partial results from the November 2016 HFE are available at this time. Preliminary inspection of images from 14 remote camera sites between Phantom Ranch and Diamond Creek (River Mile 225) show substantial net deposition at 9 sites (Figure 2) and erosion or no net change at 5 sites. Images from the remaining 29 remote cameras will be collected on the next GCMRC river trip in late January.

Figure 2. Photographs showing sandbar deposition that occurred during the November 2016 HFE at sandbar on river right approximately 119 miles downstream from Lees Ferry. The pre-HFE photo (left) was taken on November 7, 2016 and the post-HFE photo (right) was taken on November 13.

During FY16, significant progress has also been made in research-oriented projects, which include developing methods for automated analysis of the remote camera images, evaluation of structure-from-motion (SfM) methods for measuring sandbar topography, geochemical composition of HFE sand deposits, and sandbar modeling. A preliminary method for automated measurement of sandbar area from remote camera images has been developed and is being applied at selected sites. We anticipate presenting results showing weekly or monthly changes in sandbar area for selected sites by the end of FY17.

The SfM photogrammetry method allows "surveying" sandbar topography with ordinary digital cameras. We have developed an operational method for collection of images using a camera mounted on a 5-m pole and are in the process of evaluating errors in the method when compared to conventional topographic surveys. Preliminary results indicate the method provides high-resolution data over the unvegetated portions of the sandbars with a level of effort similar to that required for a conventional survey. Collection of images from an aerial platform (such as an unmanned aerial vehicle) would likely make the method more efficient [14].

We have analyzed the geochemical composition of HFE sand deposits using X-ray fluorescence in an effort to independently estimate the source of the sand contained in the deposits. Preliminary results indicate that sand derived from the Paria River can be distinguished geochemically from sand found in old pre-dam deposits. Results from a multi-variate mixing model suggest that recent HFE deposits consist of approximately 50% recent Paria River sand and 50% other sand, which may include old pre-dam sand and sand from other tributaries [6, 7, 8].

The goal of the sandbar modeling project element is to improve our understanding of the factors that contribute to spatial variability in sandbar response to HFEs and other flows and use this information to improve the sandbar monitoring design and better predict sandbar response to dam operations. In FY16, we delineated groupings of sandbar sites using a statistical analysis based on sandbar response metrics, geomorphic metrics, and vegetation abundance. This analysis connects sandbar behavior with easily measured site characteristics and will be used to predict response at sites not currently included in the set of long-term monitoring sites. The grouping distinguishes sites that tend to have less vegetation and substantial deposition caused by HFEs from sites that have more vegetation and less HFE deposition. Preliminary results from numerical flow modeling at these sites suggests that vegetation encroachment decreases flow strength in parts of the eddy, which may impede sand transport and sediment deposition [1, 11, 12, 13].

Sand Storage Monitoring and Research (elements 3.2, 3.4, and 3.5)

The goal of the sediment storage project is to track trends in the quantity of sand stored 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 and studies to improve methods for measuring sand storage, bed composition, and sand transport.

The specific goals for the first two years of the FY15–17 work plan were to map the river channel in Glen Canyon (FY15) and map the river channel in upper Marble Canyon (FY16). The entire river channel between Glen Canyon Dam and Lees Ferry was mapped and the data have all been processed. These data have been used for flow modeling to support Project 5 and evaluation of the "Hidden Slough" site where green sunfish were found in 2015. Final maps for this reach and analysis that compares the 2015 measurements to previous measurements made in 2000 will be completed in FY17. In May 2016, we mapped the river bed and banks in Upper Marble Canyon (River Mile 0 to 32). These data are currently being processed and we expect to have preliminary results and comparisons with measurements made in 2013 by the end of FY17. In support of mapping efforts, we have expanded and evaluated the accuracy of the geodetic control network. Local accuracy is within 3.4 cm at the 95% confidence level, which provides the ability to integrate studies and support sandbar and sand storage monitoring.

In addition to mapping the river bed in Upper Marble Canyon, we evaluated methods for measuring bed-sand thickness using low-frequency "chirp" sonar. With the instrument we evaluated, we were able to estimate sand thickness in locations where there was approximately 2 m of sand or less. These data represent a significant first step in the effort to develop an absolute estimate of sand storage. In 2017, we will evaluate the feasibility of using more powerful instruments that might penetrate greater sand thicknesses. However, these instruments are designed for deployment in deep marine environments and may be difficult to use successfully in the Colorado River.

Progress was also made on two additional research components of Project 3. For the bedload transport project (Project 3.4), we collected measurements of bedload transport during the November 2016 HFE on the Colorado River near Diamond Creek. These data, along with data collected in 2015, are being used to develop a new bedload transport model that will predict bedload as a function of streamflow and sediment parameters that are routinely measured at sediment monitoring stations. This information is expected to reduce the uncertainty in estimates of sand loads made in Project 2. For the bed classification project component (joint with Project 10), we have continued to advance methods for processing high-resolution bathymetric data [4, 5] and we have developed methods to classify bed sediment composition from low-cost sidescan sonar images [3,10]. These methods will be used to develop bed-sediment composition maps that correspond with fish sampling efforts in April 2014 and April 2015. These data will be used to evaluate changes in reach-average habitat conditions over the duration of native and non-native fish sampling projects.

Publications and Presentations:

1. Alvarez, L., Schmeeckle, M., Grams, P.E., accepted pending revision, A Detached Eddy Simulation Model for the Study of Lateral Separation Zones along a Large Canyon-Bound River, J. Geophys. Res. Earth Surf., 121, doi:10.1002/2016JF003895.

2. Ashley, T., McElroy, B., Buscombe, D., Grams, P., and Kaplinski, M., 2016, Estimating bedload from gage data to improve flux-based sediment budgets, Presentation at Geological Society of America Fall Meeting, Denver, CO.
3. Buscombe, D., in review, PyHum: Python toolbox for shallow water physical habitat assessment using recreational grade sidescan sonar. Environmental Modeling and Software
4. 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*
5. Buscombe, D., and Grams, P.E., 2016. Stochasticity of riverbed backscattering, with implications for acoustical classification of non-cohesive sediment using multibeam sonar. Proceedings of the 8th International Conference on Fluvial Hydraulics, St. Louis, Missouri, July 2016.
6. Chapman, K., Parnell, R. A., Smith, M. E., Grams, P. E., Mueller, E. R., 2015, Use of composite fingerprinting technique to determine contribution of Paria River sediments to dam-release flood deposits in Marble Canyon, Grand Canyon, AZ: Abstract EP23E-03 presented at 2015 Fall Meeting, AGU, San Francisco, California, 14-18 December.
7. Chapman, K., 2016, Quantifying tributary-supplied sediment contribution to experimental flood deposits in Marble Canyon, AZ, presented at 2016 Hydro Research Fellow Roundtable Meeting, HydroVision International, Minneapolis, Minnesota, 26-29 July.
8. Chapman, K., Parnell, R. A., Smith, M. E., Grams, P. E., Mueller, E. R., 2016, Evaluating the effectiveness and long-term sustainability of experimental floods on the Colorado River in the Marble Canyon reach of Grand Canyon, AZ, presented at the 2016 Fall Meeting, GSA, Denver, Colorado, 25-28 September.
9. 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*
10. Hamill, D., Buscombe, D., et al., 2016, Towards bed texture change detection in large rivers from repeat imaging using recreational grade sidescan sonar. Proceedings of the 8th International Conference on Fluvial Hydraulics, St. Louis, Missouri, July 2016.
11. Mueller, E.R., Grams, P.E., Hazel, Jr., J.E., and Schmidt, J.C., 2016, Variability of eddy sandbar response during two decades of controlled flooding along the Colorado River in Grand Canyon. Geological Society of America Annual Meeting, Denver, CO. Sept. 2016.
12. Mueller, E.R., Grams, P.E., Topping, D.J., Schmidt, J.C., Wright, S.A., Melis, T.S., Rubin, D.M., Hazel, Jr., J.E., and Kaplinski, M., 2016, Science-based strategies for experimental flooding in Grand Canyon. National Conference on Ecological Restoration, Coral Springs, FL. Apr. 2016.
13. Mueller, E.R., Grams, P.E., Hazel, J.E. Jr., and Schmidt, J.C. (in preparation) Linkages between eddy sandbar dynamics and riparian vegetation during two decades of controlled flooding along the Colorado River in Grand Canyon. *Invited manuscript for Sedimentary Geology*
14. Rossi, R., Buscombe, D., Grams, P., and Wheaton, J., 2016, From Hype to an Operational Tool: Efforts to Establish a Long-Term Monitoring Protocol of Alluvial Sandbars using ‘Structure-from-Motion’ Photogrammetry, Presentation at 2016 Fall Meeting, AGU, San Francisco, CA.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
data	Project 3.1.1: Data from long-term sandbar monitoring sites	Annual	Jan. 2016; 2017	--	To be presented at annual reporting meeting and *www.gcmrc.gov/sandbar*
photos	Project 3.1.1: Images from remote camera monitoring of sandbars	Annual	Jan. 2016; 2017	--	Website: *www.gcmrc.gov/sandbar*
article	Project 3.1.1: New High Flow Protocol Contributes to Sandbar Gains in Grand Canyon	FY16	Jun. 2015	--	Publication: [9]
map/report	Project 3.1.2: Geomorphic base map and map of high elevation sand from 2013 images	FY16		Apr. 2017	Mapping in progress, report in preparation
	Project 3.1.3 and 3.1.4: No FY16 products.				Presentations: [14]
report	Project 3.2: Report on acoustic detection of submerged aquatic vegetation	FY16	2016	Aug. 2017	Publication [3]; Presentations [5, 10]; additional publication expected in 2017
report	Project 3.2: Spatially explicit spectral analysis of point clouds	FY16	2016		Publication [4]
report	Project 3.2: Report and maps on sand storage change in Glen Canyon	FY16		Jun. 2017	Data processing complete maps and report in progress.
article	Project 3.3: Article on flow modeling	FY16	2016		Publication [1]
report	Project 3.3: Article on generalized sandbar groupings.	FY16		Jan. 2017	Article [13]; Presentations [11;12]
	Project 3.4: No FY16 products.				Presentation [2]

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
report	Project 3.5: Report on geodetic control including GPS observations and leveling data.	FY16		Feb. 2017	Report in review.

Project 3	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$581,400	$5,900	$46,000	$448,900	$20,000	$89,355	**$1,191,555**
Actual Spent	$462,856	$16,735	$136,892	$505,898	$27,379	$89,050	**$1,238,810**
(Over)/Under Budget	**$118,544**	**($10,835)**	**($90,892)**	**($56,998)**	**($7,379)**	**$305**	**($47,255)**

FY15 Carryover	**$81,793**		**CPI Decrease**	**($60,327)**		**FY16 Carryover**	**($25,789)**

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

- Salary costs decreased due to receiving non-AMP funds.
- Operating Expenses increased due to Purchase of new sonar and navigation system for river bed mapping (shared purchase between AMP, non-AMP & USGS funds). Construction of new underwater camera system for bed surface grain size cost more than planned.
- Cooperative Agreement Expenses increased due to increased involvement by cooperators.
- Shortfall will be made up in FY17.

FY 2016 Project Report for the Glen Canyon Dam Adaptive Management Program

Project 4: Connectivity Along the Fluvial-Aeolian-Hillslope Continuum: Quantifying the Relative Important of River-Related Factors that Influence Upland Geomorphology and Archaeological Site Stability

Program Manager (PM)	Joel Sankey	**Principal Investigator(s)** (PI)	Joel Sankey, USGS, GCMRC Amy East, USGS, PCMSC Helen Fairley, USGS, GCMRC Josh Caster, USGS, GCMRC Alan Kasprak, USGS, GCMRC
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SUMMARY

Project 4. Overview

Dam-released flows affect the deposition and retention of sand bars that serve as sources for other sand resources throughout the Colorado River ecosystem. Wind transport of sand from sandbars located near the active river channel to higher elevation valley margins can, in turn, affect the geomorphic condition of archaeological sites and the characteristics of other cultural and natural resources in the ecosystem. The degree to which valley margins are affected by upslope wind redistribution of river-derived sand is called sediment "connectivity" (Figure 1). Connectivity is affected by several factors including the amount of sand supplied as well as physical and vegetative barriers to sand transport. The primary hypothesis of this project is that high degrees of connectivity lead to greater archaeological site stability and increase the potential for preservation in place of buried archaeological features via aeolian sand deposition and/or mitigation of gully erosion.

Figure 1. Conceptual overview of geomorphic processes that are important for sediment connectivity

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; both of these are landscape scale analyses that examine the connectivity between attributes of the active channel and geomorphic processes and patterns at higher elevations (above the 45,000 ft^3/s stage) at several spatiotemporal scales. In the monitoring element (4.2), all of 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 was then implemented in FY16 and will be continued in FY17 through the triennial work plan (TWP).

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 TWP which was not funded and therefore not pursued by GCMRC staff during the implementation of the TWP.

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

Project element 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

In FY16 we published a seminal USGS Professional Paper entitled "Conditions and Processes Affecting Sand Resources at Archaeological Sites in the Colorado River Corridor Below Glen Canyon Dam, Arizona" which is based on work completed during Project 4 of the TWP, Project J of the 2013/14 Biennial Work Plan (BWP), and by other related projects during the previous ~10 years.

Key findings presented in the professional paper are that under current dam operations elevated baseflows and infrequent HFEs without large sediment-rich floods (i.e., greater than 45,000 ft^3/s) promote the expansion of riparian vegetation onto bare sand and limit the duration of time that sand is subaerially exposed and therefore available for aeolian transport. This in turn results in landscapes above the stage of HFEs that contain less active aeolian sand and are therefore more erodible by rainfall runoff than they could be if the dam were operated differently. We determined from lidar topographic surveys that most sites lost sand from erosion during 2006–2014 and that sand loss from erosion exceeded aeolian deposition of river-derived sand for these sites. Nonetheless, we also determined that many archaeological sites exist in source-bordering aeolian dunefields that are clearly coupled with upwind river sand supplies (sandbars) and it is also clear that river-sourced sand deposition at such sites is a time-dependent process and the outer limit of that process may extend for many years after any individual HFE.

Since the implementation of the current HFE protocol, HFEs have occurred at a relatively high frequency (i.e., once annually in 2012, 2013, 2014, and 2016). The question of how higher frequency HFEs will affect sediment connectivity and geomorphic condition at archaeological sites that are geomorphically coupled to the active river channel is currently unanswered (e.g., was not answered in the professional paper) but is very important for understanding the impacts of the HFE protocol on sandy landscapes above the 45,000 ft^3/s stage. Thus during FY15 and FY16 we initiated a study of new and archived data to understand the impact of HFEs on aeolian landscapes within the context of our focus on connectivity. In particular, the findings of the professional paper together with this new work suggest that the current protocol of near-annual HFEs in conjunction with targeted vegetation removal could eventually lead to net sediment deposition at some archaeological sites and source-bordering dunefields and thereby increase the potential for preservation in place of buried archaeological features at these locations.

The wealth of topographic data collected during the FY15–17 TWP, FY13–14 BWP, and previous research and monitoring efforts along the Colorado River over the past ~10 years make it possible for us to examine, for the first time, the effect of contrasting dam operation regimes (i.e., hydrographs) on the geomorphic response or sediment budget of selected sand resources and archaeological sites. In this regard, we focused on two avenues of research in FY15 and 16. Our first task was to develop a robust, reproducible, and automated approach for analyzing these large volumes of archived topographic data in the form of original software. These novel tools are in the process of being published in peer-reviewed literature, but are already being used in Project 4 research and monitoring to determine the changes in geomorphic condition at archeological sites during the current HFE protocol.

Our second research effort focuses on analyses of the individual and coupled roles of (a) flow regime and (b) vegetation encroachment on the amount of sand exposed (i.e., available) for aeolian transport and preservation of archaeological sites. The analyses integrate data from topographic surveys, vegetation mapping, and aeolian sediment mapping, along with bathymetric and aerial image-based sand mapping from Project 3 of the TWP for a 30-mile reach of the Colorado River in Lower Marble Canyon. Preliminary findings from this research indicate that hydrologic alteration by Glen Canyon Dam has reduced the areal extent of sand available for aeolian transport by 14% compared with the pre-dam period, with an additional 20% reduction in sand area resulting from vegetation encroachment onto surfaces previously covered by bare sand that has occurred since completion of Glen Canyon Dam through present day. One important reason for conducting these analyses is to inform where and how targeted vegetation removal might be useful for increasing sediment connectivity between the active river channel and other landscapes in the canyon.

Sub-element 4.1.2

In sub-element 4.1.2., 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 to current conditions. Analyses focus on whether the historical photos shows more or less open sand bars, cryptobiotic crust cover, and vegetation cover within areas that appear to have served as sources of aeolian sand to cultural sites and landscapes with concentrations of cultural sites (Figure 2). The current state of cultural sites and aeolian landscapes 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.

Figure 2. View of boat beach near Phantom Ranch. Top photo by E.C. LaRue in August 26th 1923, bottom by A.H. Fairley May 5th 2016. Red arrow points towards Bright Angel ruin which was partially buried by aeolian sand and excavated in 1969. Note growth of riparian vegetation which currently restricts sand transport from beach to ruin.

In FY16, we continued to locate and assess the suitability of existing historical photo collections for this analysis effort and on analyzing photographs from the Stanton photographic collection and matches of the Stanton photographs obtained by Dr. Robert Webb and colleagues in 1990–1992 and in 2010–2011. We also obtained digital copies of the 1923 USGS Birdseye expedition. During the May 2016 monitoring river trip, we took high resolution digital matches of approximately 40 of the 1,923 images. By the end of September, 2016, approximately 35% of the Stanton collection had been analyzed. While this is still a work in progress, the analysis completed to date confirms that aeolian source areas along the Colorado River have diminished significantly during the past 120 years due to two principal factors: 1) reduction in the size (volume) and abundance (number and extent) of river-deposited sand bars, and 2) increases in riparian vegetation below the old high water line. With regard to the second factor, the photographic analysis demonstrates that the amount of vegetation cover in the formerly active river channel below the mesquite line not only increased between 1889–1890 and the early 1990s, but that it has continued to increase dramatically since 1990–1992 as a result of dam operations.

Project Element 4.2. Monitoring plan development and implementation

The primary objective for Project Element 4.2 in FY15 and FY16 was to draft and subsequently implement a monitoring plan in response to stakeholders' request for "establishing a long-term, systematic strategy for assessing the effects of dam operations on archaeological sites due to flow and non-flow actions." The purpose of the document (see Monitoring Plan product below) 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 monitoring plan is designed to address specific target points outlined by BOR and NPS that were summarized in the

Project 4 proposal of the TWP (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 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 to what degree, HFE sand is transported by wind to a representative sample of archaeological sites and to also quantify the effect of this wind-transported sand on surface stability.

In May 2016 we completed the first monitoring trip under this plan during which we conducted lidar topographic surveys of 7 archaeological sites in source-bordering dunefields along the Colorado River in Grand Canyon and completed drainage classifications at more than 100 sites. We have completed the processing and summary of geomorphic change at all of the lidar survey sites by using the new software that we developed as part of project element 4.1 (see products by Kasprak et al., in review, journal manuscript, software, and data). We are now completing the analysis of these data with a post-hoc analysis of previous surveys acquired during the period of the contemporary HFE protocol (i.e., spanning the 2012, 2013, and 2014 HFEs) using the same software to ensure reproducibility of our analyses. Results indicate that all of the sites with upwind HFE sandbar sources and with data spanning the HFE protocol time period, experienced some influx of windblown sand from HFE sandbars and that approximately half of the sites were net depositional,.

We will complete another monitoring trip in May 2017 during which we propose to revisit most of the sites surveyed in 2016 and also survey several new sites as well. We will also complete drainage classifications for the remaining sites that have yet to be classified and then report on those monitoring data. Continuing this monitoring into the future and also analyzing the new data with the existing time series of surveys for several of the sites will allow us to continue to report on whether, and to what degree, HFE sand is transported by wind to a sample of archaeological sites and what effect wind-transported sand has on surface stability.

In addition, Project Element 4.2 entailed the continued operation of weather stations at six sites throughout Glen, Marble and Grand Canyons:

- 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.

In February, the Project 4 team also worked in Glen Canyon with GLCA Archaeology staff to visit and classify all river corridor archeological sites using both the aeolian and drainage classification systems. A confidential report was drafted by the Project 4 team and is currently in review with GLCA archaeology staff. The purpose of the classification and report is to provide resource managers with a technical summary and review of modern landscape processes affecting each river corridor cultural site in the Glen Canyon National Recreation Area downstream of Glen Canyon Dam. A similar report was completed for river corridor sites in Grand Canyon National Park during the 2013–14 BWP.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Paper	Beyond Compliance: Designing a Monitoring Program to Document Downstream Dam Effects at Archaeological Sites in Glen and Grand Canyons, Arizona.			Spring 2017	To be submitted in December to Advances in Archaeological Practice journal Authors are: Fairley, Sankey, East, Collins, Caster, Kasprak
Journal Paper	Geomorphic Process from Topographic Form: Automating the Interpretation of Repeat Survey Data in River Valleys			Spring 2017	Currently in review at Earth Surface Processes and Landforms journal Authors are: Kasprak, Caster, Bangen, Sankey
Dataset and Software	"Software and Example Datasets for the Automated Classification of Geomorphic Processes in Repeat Topographic Survey Data"			Spring 2017	Currently in review with USGS. Authors are: Kasprak, Caster, Bangen, Sankey
Confidential Interagency Technical Report	Modern landscape processes affecting cultural sites in the Colorado River corridor below Glen Canyon Dam, Glen Canyon National Recreation Area, Arizona			Spring 2017	Currently in review with Glen Canyon National Recreation Area Archaeology Staff Authors are: East, Sankey, Fairley, Caster, Kasprak
USGS Professional Paper	Conditions and processes affecting sand resources at archeological sites in the Colorado River corridor below Glen Canyon Dam, Arizona: U.S. Geological Survey Professional Paper 1825		May 2016		East, A.E., Collins, B.D., Sankey, J.B., Corbett, S.C., Fairley, H.C., and Caster, J., 2016, Conditions and processes affecting sand resources at archeological sites in the Colorado River corridor below Glen Canyon Dam, Arizona: U.S. Geological Survey Professional Paper 1825, 104 p., http://dx.doi.org/10.3133/pp1825.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Paper	Relations between rainfall–runoff-induced erosion and aeolian deposition at archaeological sites in a semi-arid dam-controlled river corridor		May 2016		Collins, B.D., Bedford, D.R., Corbett, S.C., Cronkite-Ratcliff, C., and Fairley, H.C. (2016) Relations between rainfall–runoff-induced erosion and aeolian deposition at archaeological sites in a semi-arid dam-controlled river corridor. Earth Surf. Process. Landforms, 41(7): 899–917. doi: 10.1002/esp.3874.
Monitoring Plan	Draft plan for monitoring effects of geomorphic processes at archaeological sites in Grand & Glen Canyon		Jan. 2016		Draft provided to stakeholders in Fall/Winter, 2016 Authors are: Sankey, Fairley, Caster, East
USGS Scientific Investigations Report	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 2016-5012		Feb 2016		Caster, J., Sankey, J.B., 2016. 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 2016-5012, 40 p., https://pubs.er.usgs.gov/publication/sir20165012

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
USGS Open File Report and Dataset	Meteorological data for selected sites along the Colorado River Corridor, Arizona, 2011–13: U.S. Geological Survey Open-File Report 2014-1247			Spring 2017	New data is appended every other year to this report: Caster, J., Dealy, T., Andrews, T, Fairley, H., Draut, A., Sankey, J., and Bedford, D., 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., http://dx.doi.org/10.3133/ofr20141247
Conference Presentation	Fairley, H.C., Sankey, J.B. and Caster, J., 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. Presented at Colorado Plateau Biennial Conference, Flagstaff, AZ.			Oct 2015	
Conference Presentation	Caster, J., Kasprak, A., and Sankey J. B., But what does it mean? Geomorphic process attribution in DEMs-of-Difference derived from repeat lidar. Presented at USGS Lidar Science Innovation Workshop, Fort Collins, Co.		Aug 2016		

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Conference Presentation	Kasprak, A., Caster, J., Bangen S., and Sankey J.B., 2016, So much data, so little time: automating the interpretation of repeat topographic survey data in river valleys, Presented at U.S. Geological Survey Postdoctoral and New Scientists Colloquium, Menlo Park, CA.			Sept 2016	
Conference Presentation	Fairley, H.C., Sankey, J.B. East, A.E., and Caster, J.M., Sustaining sites in a sediment-deprived system: designing a monitoring program to assess Glen Canyon dam effects on downstream archaeological sites in Grand Canyon, Arizona. Presented at Geological Society of America, September, 2016, Denver. CO.			Sept 2016	
Conference Presentation	Caster, J., Kasprak, A., and Sankey J. B., Automating the mapping and measurement of geomorphic response to regulated river flows: A case study in Grand Canyon, AZ, Presented at the Geological Society of America annual conference, Denver, Co.		Oct 2016		

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Conference Presentation	Kasprak A., Buscombe D, Caster J., Grams P.E., and Sankey, J.B., 2016, The individual and additive effects of vegetation encroachment and hydrologic alteration on sediment connectivity in Grand Canyon, Presented at 2016 AGU Fall Meeting, San Francisco, CA.			Dec 2016	
Conference Presentation	Sankey J., Kasprak A., Caster J., and Bangen S., 2016. Geomorphic Process from Topographic Form: Automating the Interpretation of Repeat Survey Data to Understand Sediment Connectivity for Source-Bordering Aeolian Dunefields in River Valleys. Presented at 2016 AGU Fall Meeting, San Francisco, CA.			Dec 2016	
Webex Presentation to Brief the Assistant Secretary for Water and Science	East, Collins, Sankey, Corbett, Fairley, Caster, Conditions and processes affecting sand resources at archaeological sites in the Colorado River Corridor. May, 2016.		May 2016		
Webex Presentation to the Cultural Resources Stakeholders of the GCDAMP	East, Collins, Sankey, Corbett, Fairley, Caster, Conditions and processes affecting sand resources at archaeological sites in the Colorado River Corridor. May, 2016.		May 2016		

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Webex Presentation to the TWG	East, Collins, Sankey, Corbett, Fairley, Caster, Conditions and processes affecting sand resources at archaeological sites in the Colorado River Corridor. May, 2016.		June 2016		
Presentation at the 2016 Annual Reporting Meeting	Caster, J, Sankey, J.B., East, A., Fairley, H., and Kasprak, A., Refining our understanding of sand distribution along the fluvial-aeolian-hillslope continuum: Preliminary results of Project 4 FY2015 GIS analysis, GCDAMP annual reporting meeting, Phoenix, AZ		Jan 2016		

Project 4	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$285,000	$14,000	$63,000	$0	$87,300	$43,378	**$492,678**
Actual Spent	$248,585	$13,659	$21,670	$0	$109,900	$34,021	**$427,835**
(Over)/Under Budget	**$36,415**	**$341**	**$41,330**	**$0**	**($22,600)**	**$9,357**	**$64,843**

FY15 Carryover	**$32,908**		**CPI Decrease**	**($24,944)**		**FY16 Carryover**	**$72,807**

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

- Salary costs decreased due to successfully acquiring external (non-AMP) funds.
- Operating expenses decreased due to buying camera and software with FY15 funds.
- Funds to other USGS cost centers increased to provide salary for archival and transfer of legacy dataset of archeological site lidar surveys from 2006 to 2014.
- Carryover will be used to cover remote sensing analyses.

Project 5: Foodbase Monitoring and Research

Program Manager (PM)	Theodore Kennedy	**Principal Investigator(s)** (PI)	Theodore Kennedy, USGS, GCMRC Jeff Muehlbauer, USGS, GCMRC Charles Yackulic, USGS, GCMRC Scott Miller, BLM/USU David Lytle, OSU Scott Wright, USGS, CWSC Mike Yard, USGS, GCMRC
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SUMMARY

Overview: Aquatic insects represent the primary prey for endangered humpback chub, rainbow trout, and countless other types of wildlife living in and along the Colorado River in Glen and Grand Canyons. The objectives of Project 5 are to: 1) determine why mayflies, caddisflies, and stoneflies are virtually absent from the Colorado River downstream of Glen Canyon Dam, 2) track the status and trends of the existing invertebrate foodbase, and 3) monitor rates of algae production.

Accomplishments: Our group completed a major data synthesis demonstrating that daily fluctuations in discharge associated with hydropeaking (load following) from Glen Canyon Dam are partially responsible for the absence of mayflies, stoneflies, and caddisflies from the Colorado River. This synthesis represents comprehensive work toward the majority of individual project elements outlined in Projects 5.1.1-8 and 5.2.1 in the workplan. The results of this synthesis were published in the journal *BioScience* and are summarized in Figure 1. Additional work towards all of these project elements will continue into FY17.

In our *BioScience* synthesis, we used multiple lines of evidence to determine how hydropeaking affects aquatic insect populations. One key line of evidence in this synthesis was the finding that

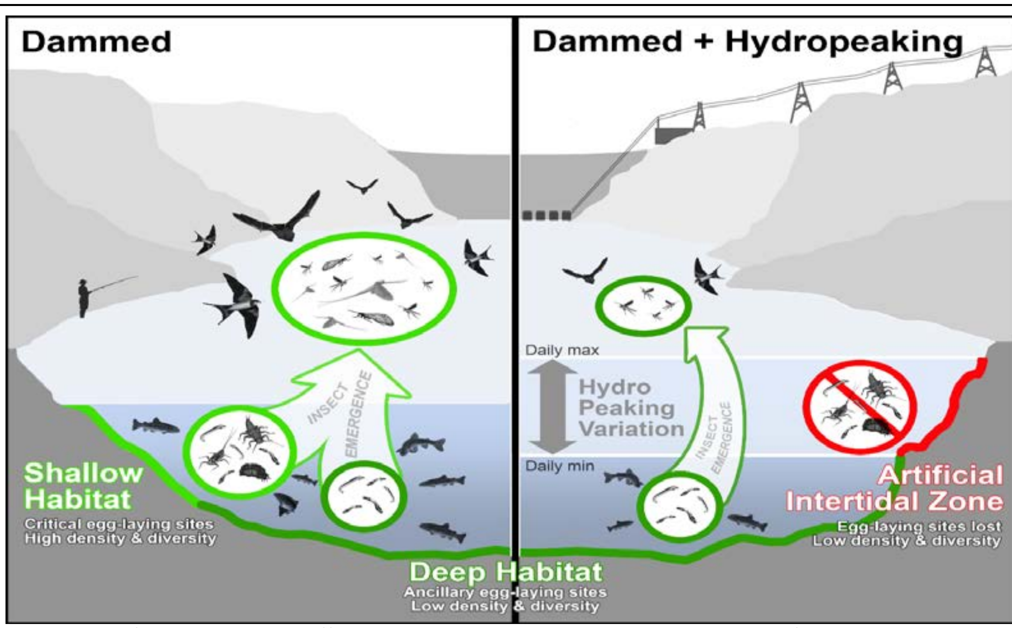

Figure 1. Conceptual model of how hydropeaking affects aquatic insects. Aquatic insects are ubiquitous in freshwaters and are the primary prey for myriad species of wildlife living in and along rivers. These insects have complex life cycles that include a terrestrial winged adult life stage, whereas egg, larval, and pupal stages are aquatic. Ecologically important insect groups such as mayflies, stoneflies, and caddisflies cement their eggs along river-edge habitats, making them especially sensitive to hydropeaking and other dam water management practices that affect these edge habitats. Adapted from Kennedy and others (2016).

aquatic insect eggs experience high mortality when they are exposed to brief periods of desiccation (see Figure 2). These experiments were conducted by Scott Miller's research group using eggs collected downstream of Flaming Gorge Dam. We also found that most aquatic insects tend to lay their eggs along river banks, where such desiccation occurs under hydropeaking. Another key line of evidence in the *BioScience* synthesis came from our aquatic insect monitoring efforts in Grand Canyon. Since 2012 we have been monitoring the adult life stages of aquatic insects in Grand Canyon by collaborating with river guides, educational groups, and private boaters. Each night in camp, these citizen scientists deploy a simple light trap along the river edge. Using a dataset of over 2500 of these samples collected from 2012–2014, we demonstrated that midge abundance in Grand Canyon is affected by the timing of hydropeaking waves (see Figure 3). This research was highlighted in a perspectives essay published in *Science* (http://science.sciencemag.org/content/353/6304/1099), the top scientific journal in the world.

In FY16 our collaboration with citizen scientists yielded 1,343 new light trap samples from throughout Grand Canyon towards Projects 5.1.1 and 5.2.1. In this fiscal year we also completed pilot egg laying studies in support of Project 5.1.5 throughout Glen Canyon, and throughout Marble and Grand Canyons during a river trip from October 7-24.

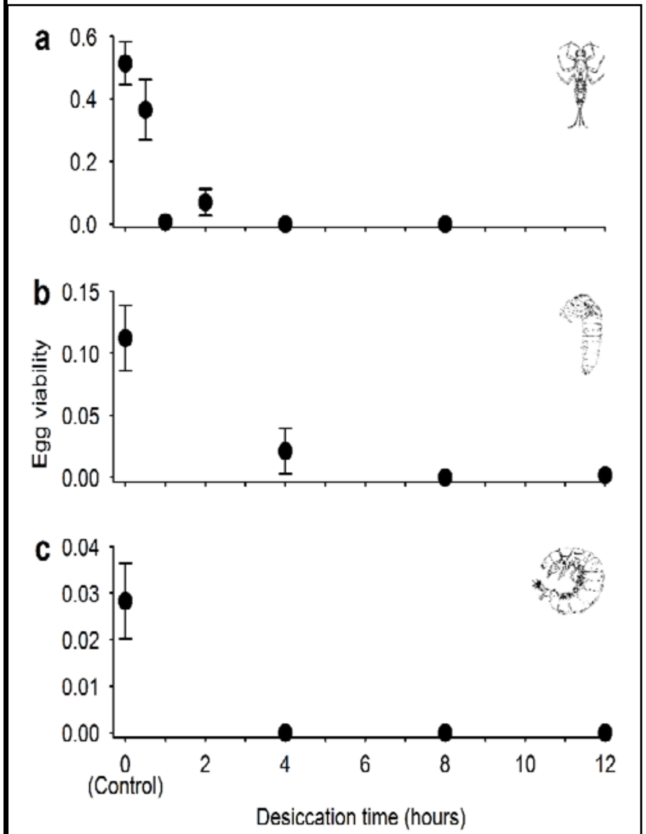

Figure 2. Aquatic insect eggs die after short periods of drying, such as along the banks of a hydropeaking river. Graph shows egg viability (number of hatched eggs/total eggs) after desiccation for eggs of (a) a type of mayfly (*Baetis* sp.), and two types of caddisfly (b: *Brachycentrus*; c: *Hydropsyche*). Adapted from Kennedy and others (2016).

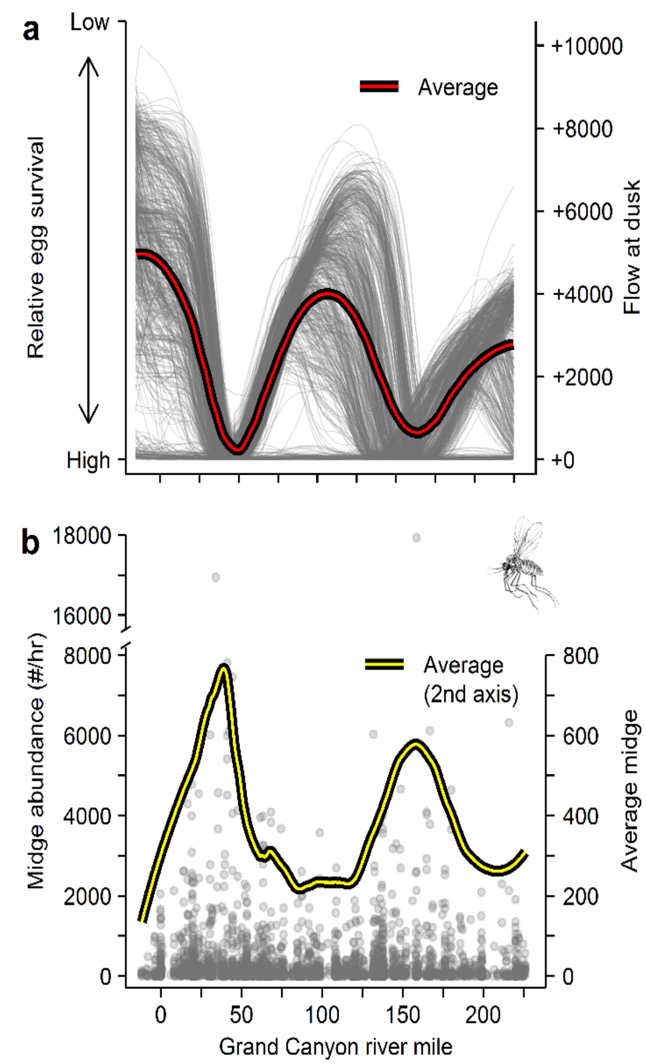

Figure 3. The timing of hydropeaking waves determines insect abundance in Grand Canyon. Hydropeaking waves released from the Dam propagate downstream, and at river miles 50 and 165 daily flow minima occur at dusk when insect egg laying occurs (a). Midge abundance peaks at these same river miles, because of variability in egg survival, with average abundance more than three times greater at locations where the daily flow minima coincide with peak egg-laying activity (b). Adapted from Kennedy and others (2016).

Our group has also gained international recognition for the revolutionary improvements to aquatic invertebrate sampling in support of our research. These include sticky traps that can be rapidly deployed and analyzed, as evidence by the 1,832 sticky trap samples our group collected in Glen, Marble, and Grand Canyons in FY16 in support of Projects 5.2.1, 5.2.2, and 5.2.4. Sticky traps represent a cheap, and effective monitoring tool for assessing the condition of the aquatic foodbase (published in *Marine and Freshwater Research*, see Figure 4). We have also developed methods for quantifying the accuracy of invertebrate drift measurements (see Figure 5). This allows us to directly compare drift data from across rivers where different drift net deployment techniques are often required (i.e., staking nets to cobble bars in smaller rivers vs. deploying nets from a boat in larger rivers). This sampling issue previously prevented comparison of foodbase conditions across tailwaters, including across segments of the Colorado River downstream of Glen Canyon Dam. The results of this analysis are being published in the *Canadian Journal of Fisheries and Aquatic Sciences*. Using these new methods, our group collected 278 invertebrate drift samples from throughout Glen, Marble, and Grand Canyon in support of Projects 5.2.1-5. All these methods, including light traps, sticky traps, and drift, are included in the invertebrate sampling chapter for the new edition of the seminal textbook Methods in Stream Ecology. Thus, these new methods will likely become the standard for sampling aquatic invertebrates in rivers globally.

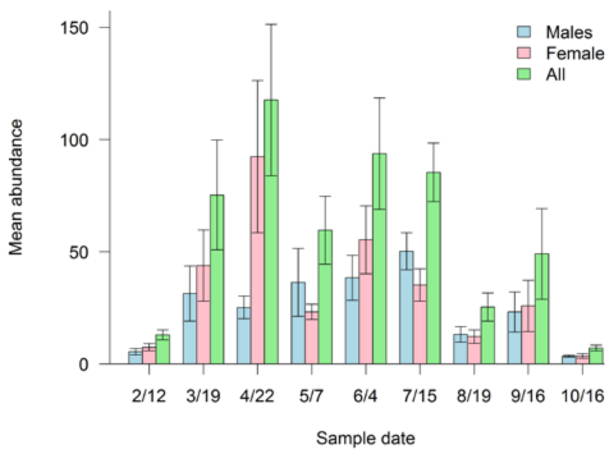

Figure 4. Seasonal variation in abundance of midges in the Lees Ferry reach downstream of Glen Canyon Dam, grouped by sex for the year 2014. Height of bars represents the average midge catch per sticky trap (n=48 sticky traps deployed throughout Lees Ferry per sampling date). The error bars represent one standard error. Data for May (5/7) were likely biased low due to unseasonably windy and rainy weather. Adapted from Smith and others (2016).

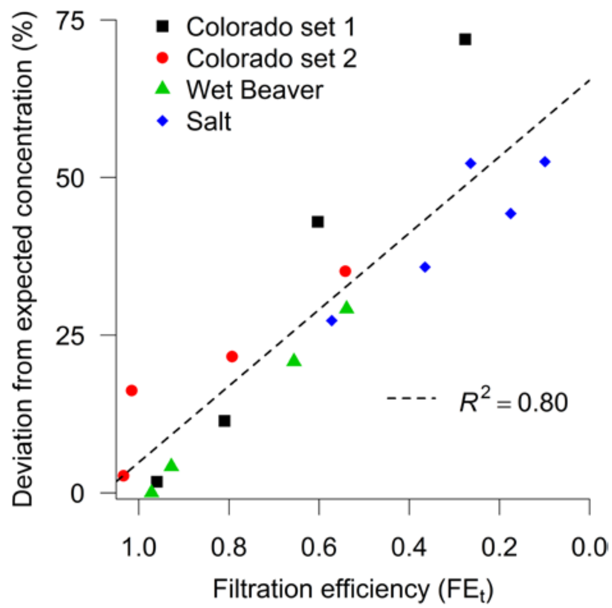

Figure 5. Graph showing the relationship between filtration efficiency of drift nets (a measure of clogging) and the reliability of drift concentration estimates. A filtration efficiency of 1 represents an unclogged drift net. Adapted from Muehlbauer and others (In press).

Significant progress has also been made towards the objectives of Project 5.3, Monitoring algae production in Glen, Marble, and Grand Canyon. A draft manuscript synthesizing controls of algae production in Glen Canyon is currently undergoing review (see Project 5.3.1). In collaboration with GCMRC's water quality monitoring program we have continued collecting dissolved oxygen data from river miles 0, 30, 61, 89, 166, and 225; we now have 5-8 years of continuous data from each of these sites (see Project 5.3.2). In FY16, Charles Yackulic participated in a national USGS working group on estimating algae production from dissolved oxygen data. Through his involvement in this working group, new models for estimating algae production that are faster and more flexible have been developed (see Project 5.3.3). These algae production models are currently being implemented with our Colorado River data.

Next Steps: The main conclusion from our *BioScience* synthesis was that it might be possible to mitigate negative effects of hydropeaking on aquatic insects by stabilizing flows every weekend during periods of peak insect activity. Our proposed flow experiment was also highlighted in the *Science* article mentioned above as an example of how minor tweaks to flow management policies have the potential to lead to major improvements in river health. Thus, next steps are to design a research and monitoring program specifically tailored to evaluating the effectiveness of 'bug flows'. Regardless of when bug flows are implemented, we propose continued research and monitoring of the invertebrate prey base supporting humpback chub, rainbow trout, and native fish populations.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal article	Deleterious effects of net clogging on the quantification of stream drift.				Muehlbauer, J.D., Kennedy, T.A., Copp, A.J. & Sabol, T.A. (In Press) Deleterious effects of net clogging on the quantification of stream drift. *Canadian Journal of Fisheries and Aquatic Sciences.*
Book chapter	Macroinvertebrate drift, adult insect emergence and oviposition.				Baxter, C.V., Kennedy, T.A., Miller, S.W., Muehlbauer, J.D. & Smock, L.A. (In Press) Macroinvertebrate drift, adult insect emergence and oviposition. Chapter 21 in: *Methods in Steam Ecology* (Eds F.R. Hauer & G.A. Lamberti), 3rd edition.
Magazine article	Hydropower waves, insect eggs, and citizen science.				Kortenhoeven, E.W., Muehlbauer, J.D., & Kennedy, T.A. (2016). Hydropower waves, insect eggs, and citizen science. Boatmen's Quarterly Review 29: 19-22.
Journal article	Incorporating temporal heterogeneity in environmental conditions into a somatic growth model.				Dzul, M.C., Yackulic, C.B., Korman, J., Yard, M.D. & Muehlbauer, J.D. (2016) Incorporating temporal heterogeneity in environmental conditions into a somatic growth

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					model. *Canadian Journal of Fisheries and Aquatic Sciences*. DOI: *10.1139/cjfas-2016-0056*
Journ al article	Phenology and life history plasticity of the angel lichen moth (Cisthene angelus) in Grand Canyon, AZ, USA.				Metcalfe, A.N., Kennedy, T.A. & Muehlbauer, J.D. (2016) Phenology and life history plasticity of the angel lichen moth (Cisthene angelus) in Grand Canyon, AZ, USA. *The Southwestern Naturalist*. 61: 233-240. DOI: *10.1029/SWNAT-D-16-00038.1*
Journ al article	Evaluating potential sources of variation in Chironomidae catch rates on sticky traps.				Smith, J.T., Muehlbauer, J.D. & Kennedy, T.A. (2016) Evaluating potential sources of variation in Chironomidae catch rates on sticky traps. *Marine and Freshwater Research*. 67: 1987-1990. DOI: *10.1071/MF15189*
Journ al article	Flow management for hydropower extirpates aquatic insects, undermining river food webs.				Kennedy, T.A., Muehlbauer, J.D., Yackulic, C.B., Lytle, D.A., Miller, S.W., Dibble, K.L., Kortenhoeven, E.W., Metcalfe, A.N. & Baxter, C.V. (2016) Flow management for hydropower extirpates aquatic insects, undermining river food webs. *BioScience*. 77: 561–575. DOI: *10.1093/biosci/biw059*
Journ al article	Prey size and availability limits maximum size of rainbow trout in a large tailwater: insights from a drift-foraging bioenergetics model.				Dodrill, M. J., Yackulic, C. B., Kennedy, T. A., & Hayes, J. W. (2016). 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 Sciences*, *73*(5), 759-772.
Journ al article	Resource subsidies between stream and terrestrial ecosystems under global change.				Larsen, S., Muehlbauer, J.D. & Martí, E. (2016) Resource subsidies between stream and terrestrial ecosystems under

	PRODUCTS/REPORTS				
Type	Title	Due Date	Date Delivered	Date Expected	Citations/Comments
					global change. *Global Change Biology* 22: 2489–2504. DOI: *10.1111/gcb.13182*
Presentation	Flow management for hydropower extirpates aquatic insects, undermining river food webs.				TA Kennedy, May 3, 2016, Flow management for hydropower extirpates aquatic insects, undermining river food webs. WebEx briefing for Glen Canyon Dam Adaptive Management Working Group.
Presentation	Flow management for hydropower extirpates aquatic insects, undermining river food webs.				TA Kennedy, April 29, 2016, Flow management for hydropower extirpates aquatic insects, undermining river food webs. WebEx briefing for Bureau of Reclamation, National Park Service, and US Fish and Wildlife Service staff.
Presentation	Flow management for hydropower extirpates aquatic insects, undermining river food webs.				TA Kennedy, April 21, 2016, Flow management for hydropower extirpates aquatic insects, undermining river food webs. WebEx briefing for Jennifer Gimble, Assistant Secretary for Water and Science.
Presentation	Hg and Se accumulation in the Colorado River food web				TA Kennedy, November 23, 2015, Hg and Se accumulation in the Colorado River food web, Briefing for Lake Mead Ecosystem Work Group, Las Vegas, NV (invited)
Presentation	Hg and Se accumulation in the Colorado River food web				Walters, DW and TA Kennedy, October 21, 2015, Hg and Se accumulation in the Colorado River food web, Briefing for Technical Work Group, Glen Canyon Dam Adaptive Management Program, Phoenix, AZ.
Presentation	Longitudinal and temporal patterns of food availability for endangered				Muehlbauer, J, T. Kennedy, E. Kortenhoeven, A. Metcalfe, November 2015 Longitudinal

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	humpback chub, Gila cypha, in the Little Colorado river, Arizona				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, CA
Presentation	Little bugs, big data, and Grand Canyon.				Kennedy TA, J.Muehlbauer, D. Lytle, C.Yackulic, E. Kortenhoeven, A. Metcalfe, November 2015, Little bugs, big data, and Grand Canyon. Desert Fishes Council Annual Meeting, Death Valley, CA
Presentation	Flow management for hydropower extirpates aquatic insects, the foundation of river food webs.				Kennedy, TA, Muehlbauer JD, Yackulic CB, Lytle DA, Miller SW, Dibble KL, Kortenhoeven E, Metcalfe AN, Baxter CV. May 2016. Flow management for hydropower extirpates aquatic insects, the foundation of river food webs. Society for Freshwater Science Annual Meeting: Sacramento CA.
Presentation	Dammed and adrift: patterns of invertebrate drift throughout Colorado River Basin tailwaters.				Muehlbauer, J.D., Kennedy, T.A., 2016. Dammed and adrift: patterns of invertebrate drift throughout Colorado River Basin tailwaters. Society for Freshwater Science Annual Meeting: Sacramento CA.

Project 5	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$381,400	$12,500	$21,200	$29,800	$19,400	$50,635	**$514,935**
Actual Spent	$342,738	$11,568	$39,224	$25,086	$19,038	$47,909	**$485,563**
(Over)/Under Budget	**$38,662**	**$932**	**($18,024)**	**$4,714**	**$362**	**$2,726**	**$29,372**

FY15 Carryover	**$15,098**	**CPI Decrease**	**($26,071)**	**FY16 Carryover**	**$18,399**

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

- Salary costs decreased due to backfilling vacancies with lower graded personnel and receiving non-AMP funds.
- Operating expenses increased due to greater participation in citizen science program than expected.
- Carryover will be used to purchase microscope & imaging system and water quality monitors to measure algae production.

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 Mike Dodrill, USGS, GCMRC Luke Avery, USGS, GCMRC Brian Healy, NPS Kirk Young, USFWS Randy VanHaverbeke, USFWS David Rogowski, AZGFD Karin Limburg, State Uni. Of NY.
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SUMMARY

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

During 27 August-13 September 2016, one mainstem river trip was conducted to monitor humpback chub with hoop nets and seines. This trip sampled fish within the boundaries of several known historic aggregations of humpback chub (i.e., LCR, Lava-Chuar-Hance, Bright Angel, Stephen Aisle, Middle Granite Gorge, Havasu, and Pumpkin), as well as sampling opportunistically at several localities outside of known aggregations (e.g., at a recently discovered group of humpback chub near river mile (RM) 35, and at several sites in western Grand Canyon where an increase in humpback chub densities have been detected). In 2015 and 2016, the aggregation trips have also included seining of backwaters throughout Grand Canyon, and have deployed portable antennae technology. The primary purpose of these annual trips has been to construct a long term catch per unit effort (CPUE) index of humpback chub in the mainstem Colorado River, both within and outside of defined aggregation localities, in fulfillment of conservation measures. A major long term finding of this study has been that since 2006 there have been significant increases in CPUEs of humpback chub at most aggregation localities, as well as at non aggregation sites (Fig 1). Additionally, we have detected increases in the relative abundances of humpback chub stemming from translocation efforts into Shinumo and Havasu creeks, and have detected either new aggregations/populations of humpback chub (e.g., 35 Mile locality, western Grand Canyon), or detected expansion of previously known aggregations (e.g., 35 Mile, Shinumo, Havasu, Pumpkin). In 2016, we captured an unprecedented number of humpback chub in western Grand Canyon from all size classes (Figure 1). Data from these trips have also demonstrated that obtaining absolute abundance information is likely to be a very costly endeavor in terms of effort and expense should that avenue be pursued. Finally, these trips gather information on other members of the fish community.

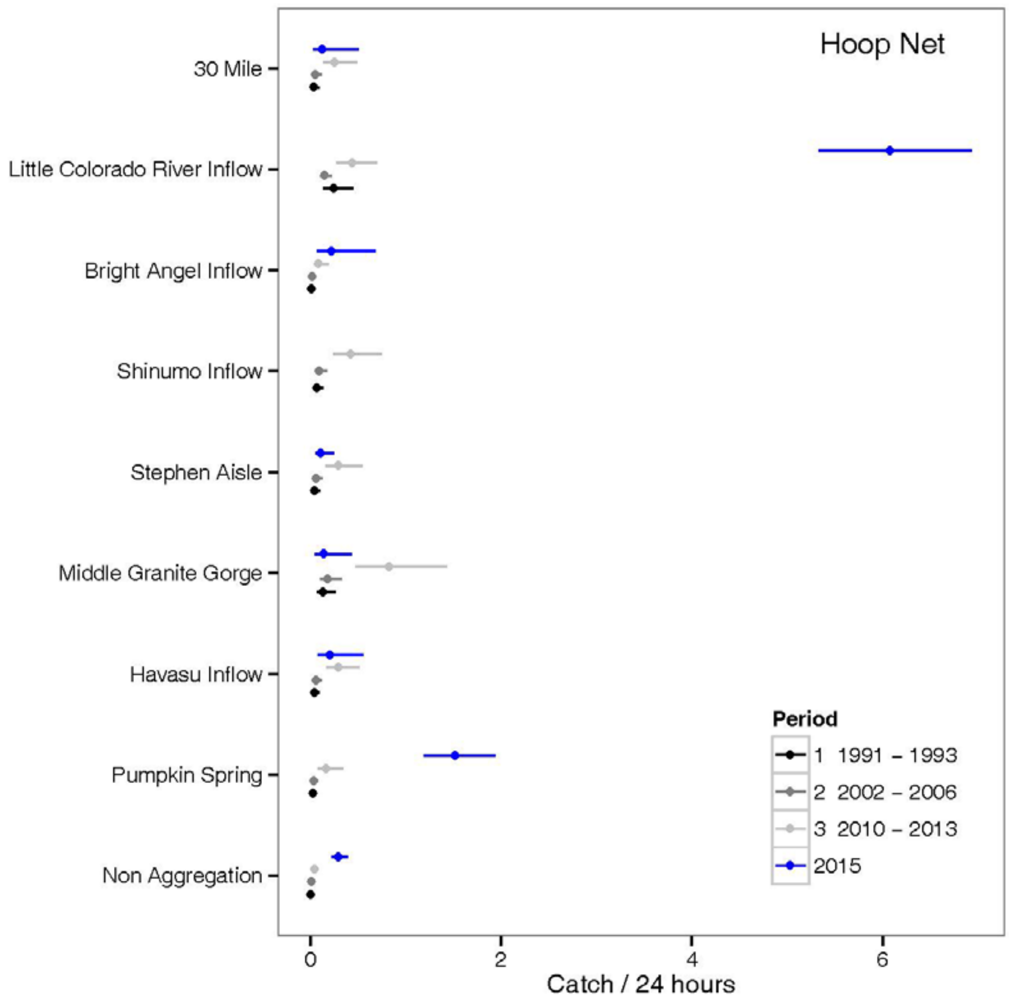

Figure 1. Catch per unit effort index of humpback chub captured in hoop nets from 1991-1993, 2002-2006, 2010-2013, and 2015. Note, 2016 data is still being analyzed.

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. A suite of major, minor, and trace elements along with oxygen and carbon isotopes were analyzed. Although year to year variability is present, the mainstem Colorado River water is more "self-similar" throughout the canyon compared to tributaries. Tributaries with warmer more carbonated water tend to be elevated in heavy isotopes of both oxygen and carbon. Although we did not deliberately take any humpback chub for otolith microchemistry, a small number of incidental mortalities (10 fish less than 50mm total length), are available from 2016. We expect a report documenting preliminary findings from the otolith microchemistry in early 2017. Available findings, to date, show that stontium to calcium ratios are some of the best markers to discriminate between mainstem and tributary residency. Barium to calcium, magnesium to calcium, and zinc to calcium are also possible markers of tributary versus mainstem residency. However, these elements have shown elevated ratios in many fish species near the otolith core, likely related to incorporation of maternal fluids in the developing eggs, which may confound their use in this application. We continue to work with cooperators, such as the NPS, to collect and preserve any incidental mortalities that could contribute to this work.

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

We deployed 8 portable passive integrated transponder (PIT) tag antennas at 14 sampling locations during a September 2016 sampling trip to monitor humpback chub and other tagged fishes within or between known humpback chub aggregation localities (35 Mile, LCR, Tanner, Bright Angel [Schist Fist], Stephen Aisle, Middle Granite Gorge, above Kanab [Keyhole], Havasu, Fern Glen, 196 Mile, Fall Canyon, Pumpkin Spring, Bridge Canyon, and Surprise Canyon areas). These antennas detect tagged fish, including humpback chub and flannelmouth sucker; many that would otherwise go undetected at sampling locations. For example in 2016, 372 humpback chub and 329 flannelmouth sucker were detected with the antennas, representing 42% and 13% of the unique catches on the trip, respectively (Table 1). This technique represents an exciting new area of study to increase our understanding of the ecology and distribution of native fish in Grand Canyon. Additionally, we continued to collect genetic samples (small fin clips) from all humpback chub (excluding those from the LCR aggregation) to be analyzed 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 Dam and non-flow actions.

Table 1. Detections and percent detections of fish with hoop nets, PIT-tag antennas and with both gear types during mainstem aggregation trip 2016.

		Unique PIT Tag Contacts/Captures by Gear									
Species		BHS	BNT	CRP	FBH*	FMS	FRH**	HBC	RBT	UNK	Total
Hoop Net Only	Captures	4	0	4	5	2,096	2	451	0	0	2,562
	% of Total	*80%*	*0%*	*50%*	*100%*	*82%*	*67%*	*51%*	*0%*	*0%*	*74%*
Antenna Only	Contacts	1	1	4	0	329	1	372	3	91	711
	% of Total	*20%*	*100%*	*50%*	*0%*	*13%*	*33%*	*42%*	*100%*	*100%*	*21%*
Antenna and Hoopnet	Cap/Contact	0	0	0	0	119	0	62	0	0	181
	% of Total	*0%*	*0%*	*0%*	*0%*	*5%*	*0%*	*7%*	*0%*	*0%*	*5%*
Total (n)		5	1	8	5	2,544	3	885	3	91	3,454

BHS=bluehead sucker, BNT=brown trout, CRP=carp, *FBH=possible flannelmouth-bluehead hybrid, FMS=flannelmouth sucker, HBC=humpback chub, RBT=rainbow trout, UNK=unknown sucker.

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 CPUE) from our surveys can be used to interpret trends in abundance and distribution of native and nonnative fish within this reach. As humpback chub are not adequately sampled with electrofishing gear and no other program conducts a system wide monitoring program for this species we added a hoop net sampling component to our monitoring. In addition during sampling trips, once below the Little Colorado River inflow we use angling to sample for catfish each evening at camp.

Summary of progress:

In 2016 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 was susceptible to electrofishing or baited hoop nets. In the two spring/summer system wide trips approximately 639 sites were electrofished with 4,031 fish captured. During the fall sampling trip from Diamond Creek to Pearce Ferry Rapid electrofishing was hampered by high levels of turbidity (>4,000 NTUs), thus we set more hoop nets (81 nets set) and did minimal electrofishing (22 sample sites). In total 319 hoop nets were set during the three trips capturing 1,561 fish. Flannelmouth suckers dominated the catch for both electrofishing and hoop nets, with 55 and 72% percent of the fish captured respectively. We captured 179 humpback chub via baited hoop nets and the results are presented in the figure below (Figure. 1).

Monitoring activities funded (boat electrofishing/hoop net trips):

- Spring trip I: 6-21 April 2016
- Spring trip II: 19 May – 3 June 2016
- Diamond Down trip: 7-11 October 2016

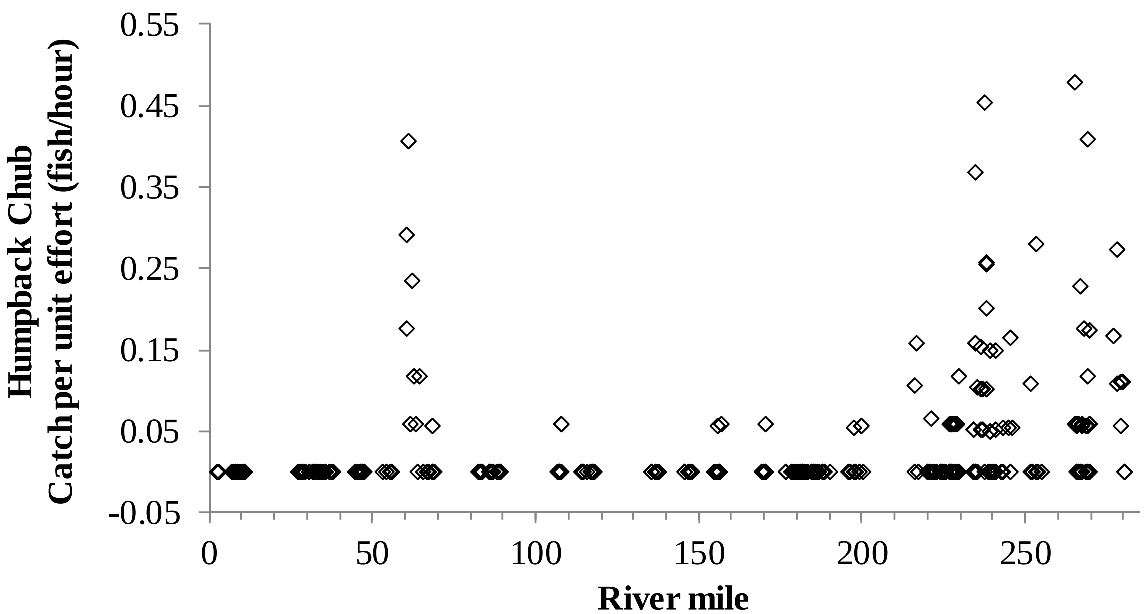

Figure 2. Catch per unit (fish/hour) of humpback chub captured via baited hoop nets (n=319) in 2016 by river mile (RM) from Arizona Game and Fish Department system wide sampling of the Colorado River from Lees Ferry (RM 0 to Pearce Ferry Rapid RM 281.4)

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, reach wide catch rates for most fish species remained stable over the past five years (no statistically significant trends), with the exception of rainbow trout. Rainbow trout CPUE has significantly declined over the past three years. Hoop netting results revealed that humpback chub are quite common below Diamond Creek (river mile 225) to Pearce Ferry Rapid (RM 281.4). All age/size classes were represented and all humpback chub captured in the reach (below RM 225) were untagged (no recaptures) with the exception of two fish in our fall sampling. These two recaptures were initially tagged by USFWS a month previous below RM 225. The numbers and CPUE of humpback chub caught below RM 225 is equivalent to what we see around the Little Colorado River. These results indicate that these humpback chub are not utilizing the Little Colorado River or any of the traditional "aggregation sites" (Valdez and Ryell 1995), where 50-80% of the humpback chub captured are recaptures.

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. Boat electrofishing is utilized to obtain a representative sample of the fish community within this 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.

Summary of progress: We completed three sampling trips in 2016, sampling 113 standard sites in total and capturing 2145 fish (excluding the nonnative sampling). During nonnative sampling in July of 2016 we captured three Walleye and did not capture any Green Sunfish in the slough at river mile -12.

Monitoring activities funded (boat electrofishing trips):

- Spring trip: 15-18 March 2016, 36 standard sample sites
- Summer trip: 18-22 July 2016, 40 standard sample sites, plus an additional 11 sites for nonnatives
- Fall trip: 13-16 September 2016, 42 standard sample sites

Summary of trends: Rainbow trout continue to dominate the fish community within the Lees Ferry reach, comprising 94.8% of the catch (standard electrofishing), with brown trout comprising 3.3 % of the catch, compared to 2.1 and 0.55% in 2015 and 2014 respectively. The increase in brown trout during these years was primarily from one age class, young of the year. Typically in past years we caught very few brown trout with most of those as adults. This increase in recruitment over the past three years is unusual. It is currently unclear what causative factor or factors are related to this increase in brown trout. Potential causes identified to date include direct and indirect effects of reduced rainbow trout density since late 2014, growth and maturation facilitated by abundant food resources in the form of young trout prior to this decline, improved spawning and rearing conditions due to 2012, 2013, and 2014 fall high flow events, or some combination of these or other unidentified factors. Currently there is little evidence to support any one hypothesis concerning changes in brown trout abundance in the Lees Ferry reach.

Rainbow trout have maintained a self-sustaining population since the mid-1990s. Relative abundance, as measured by electrofishing CPUE, has fluctuated greatly since AGFD began standardized sampling in 1991. CPUE of rainbow trout was the highest ever recorded in 2011–2012, but has declined since 2012. In addition, the percent of large rainbow trout in the system has declined as has the median size of reproductively active trout. This suggests there were more rainbow trout in the system (based on higher CPUE) than the system was able to maintain during 2011-2014, from a limited food base. Relative fish condition (Kn) for rainbow trout reached a record low (~ 0.8) in fall of 2014, and has been increasing since then, concurrently with the decrease in relative numbers of rainbow trout. Condition of rainbow trout in 2016 has been very good with some of the highest levels of condition (~1) in adult (12 to 16 inches) and big fish (Kn~ 1.1: > 16 inches) observed in the past 25 years. While the percent young of the year (YOY) in the fall catch was relatively high (87%), the CPUE of YOY was only 1.85 fish/hour, thus not at levels of concern (as in 2011).

<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- Discussion will occur at December cooperators meeting about implementation of this project

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

Goals and Objectives: The primary objective of the RTELSS study is to monitor the response of the age-0 population of Rainbow trout in Lees Ferry to variations in Glen Canyon Dam operations and to naturally occurring disturbances to the Colorado River in Glen Canyon.

Summary of progress: Field activities for the Rainbow Trout Early Life Stage Survey (RTELSS) in 2016 consisted of redd surveys for estimation of spawning magnitude, and electrofishing sampling for estimation of population dynamics. Due to staffing vacancies, the normal sampling schedule for this project was truncated from 11 redd surveys conducted in previous years to 5 surveys. However, surveys were scheduled monthly over historic peak spawning times to best capture changes in redd abundance and distribution.

Summary of trends:

Redd Surveys

Five redd surveys were conducted from February 2016 through May 2016. We observed 2,087 redds and generated an overall estimate of 1,893 redds created for the season. The magnitude and patterns of redd distribution was similar to past years, although the peak was a couple weeks later than is typical. In past years the peak has occurred around mid to late March or early April. The peak in distribution for 2016 appeared to be mid-April, but there is some uncertainty about the exact timing of the peak due to fewer sampling occasions (Table 1).

Table 2. Dates of the 5 redd surveys conducting in 2015 and the number of redds observed for each of those surveys.

Redd Surveys for 2016

Date of Survey	Number of Redds Observed
2/19/2016	58
3/17/2016	538
4/11/2016	616
5/2/2016	503
5/24/2016	372

In most years the "zero" count (count low enough to be considered the end of the spawn) for the tail end of the distribution doesn't occur beyond June. Due to logistical constraints, resources were allocated to electrofishing efforts in June and not additional redd surveys. In addition to the late peak in redds observed in mid-April, we observed a relatively high number of redds late into May. This suggests the spawn may have continued later in the season than previously observed, possibly the result of late developing spawning adults.

Electrofishing Surveys

Four electrofishing surveys were conducted in 2016. Age-0 population estimates for June, July, August, and November are 147,000 (47,000 Lower Confidence Interval (LCI); 56,000 Upper Confidence Interval (UCI)), 367,000 (77,000 LCI; 82,000 UCI), 183,000 (34,000 LCI, 33,000 UCI)), and 34,000 (10,000 (LCI); 10,000 (UCI)) respectively. No survey was conducted in September due to logistical constraints. Population estimates for July were much higher than seen in previous years, similar to what was observed in 2012.

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, of both boat and shoreline anglers. Information obtained includes but is not limited to catch rates, gear type, species composition, harvest, and satisfaction with angling experience.

Summary of progress: As of this report, we have collected data for 2016 up to 20 October 2016. Data for October through December 2016 will be analyzed and included in our annual report, to be submitted in 2017. Sampling days were stratified by month (6 days) and by weekday (2 days) and weekend (4 days). As of the end of October 2016 we have conducted angler surveys on 60 days, and interviewed 1,106 anglers. From June 2015 to June 2016 a game camera was installed at Lees Ferry recording images of the boat launch area to provide a better estimate of boat anglers for the days and hours when we do not have a technician present.

Summary of trends: As of the end of October 2016, rainbow trout CPUE levels for boat anglers was significantly less in 2016 (0.668 fish/hour) compared to 2015 (1.31)(matched paired T-test by month; P = 0.0022). Average boat angler CPUE for rainbow trout to date was 0.668 fish/hour and 0.197 fish/hour for the walk-in area (n=953 and 153 respectively). Both values represent relatively large reductions in CPUE compared to the record highs observed 2011–2014 (> 2.0 fish/hour).

As of 30 October 2016, 71.8% of the interviewed anglers were from Arizona and the rest from out of state (or country). Almost half (49.6%) of the boat anglers interviewed used a guide.

For calendar year 2015 we conservatively estimated about 8,450 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 3.95, and 3.15 (on a scale of 0-5) for boat and walk-in anglers respectively, angler satisfaction has declined in the past three years. Based on a preliminary analysis of our game camera data we are underestimating boat angler use by 32 and 38 % by weekday and weekend respectively. Based on the game camera data the boat angler use estimate would increase from 5,954 [5103, 6805] to 7,999 [7148, 8851].

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	*Effects of Increased Discharge on Spawning and Age-0 Recruitment of Rainbow Trout in the Colorado River at Lees Ferry, Arizona.*		Aug. 2015		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 35: 671-680**
Report	Colorado River Fish Monitoring in Grand Canyon, Arizona – 2015 Annual Report.		Feb 2016	Report	Rogowski, D.L., R.J. Osterhoudt, L.K. Winters, and P.N. Wolters. Colorado River Fish Monitoring in Grand Canyon, Arizona – 2015 Annual Report.
Report	Status of the Lees Ferry Rainbow Trout Fishery 2015 Annual Report		March 2016	Report	Winters, L.K., D.L. Rogowski, and P.N. Wolters. Status of the Lees Ferry Rainbow Trout Fishery 2015 Annual Report
Thesis	Use of ultrasonic imaging to evaluate egg maturation of humpback chub *Gila cypha*		Oct 2016		Brizendine, Morgan 2015. Use of ultrasonic imaging to evaluate egg maturation of humpback chub *Gila cypha* . **MS Thesis, University of Arizona**
Journal Article	Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate the Influence of Seasonality.		Oct 2016		Bair, L.S., D.L. Rogowski, and C. Neher. 2016 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 36:6 1229-1239**

Open File Report	Colorado River Fish Monitoring in Grand Canyon, Arizona. 2002-14 Humpback Chub Aggregations. USGS Open File Report.			Dec. 2016	Persons, W. R., D. R. Van Haverbeke, and M. J. Dodrill. 2016. Colorado River Fish Monitoring in Grand Canyon, Arizona. 2002-14 Humpback Chub Aggregations. USGS Open File Report.

Project 6	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$180,100	$5,700	$21,200	$290,000	$0	$33,505	**$530,505**
Actual Spent	$143,030	$2,838	$15,323	$265,057	$3,743	$27,267	**$457,258**
(Over)/Under Budget	**$37,070**	**$2,862**	**$5,877**	**$24,943**	**($3,743)**	**$6,238**	**$73,247**

FY15 Carryover	**$33,821**		**CPI Decrease**	**($26,859)**		**FY16 Carryover**	**$80,209**

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

- Salary costs decreased due to vacancies.
- Cooperative agreements decreased due to coops funded from another project.
- Carryover will be used to offset FY17 shortage.

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 Kirk Young, USFWS Kim Dibble, USGS, GCMRC Mike Yard, USGS, GCMRC Maria Dzul, USGS, GCMRC David Rogowski, AZGFD Randy VanHaverbeke, USFWS Dennis Stone, USFWS David Ward, USGS, GCMRC Jeff Muehlbauer, USGS, GCMRC Josh Korman, EcoMetric Research Ted Kennedy, USGS, GCMRC
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SUMMARY

Introduction

The overall objectives of this project are to track the current status of humpback chub populations and to continue to improve our ability to predict how dam management and other management actions, as well as other important sources of variation, will affect humpback chub populations dynamics, and ultimately adult abundances.

Background

A well-designed mark-recapture monitoring program has been in place in the Little Colorado River (LCR) since the fall of 2000, led by US Fish and Wildlife Service. An adequate monitoring program of humpback chub in the Colorado River around the LCR took longer to develop and lack of such a program hindered earlier attempts to understand the impacts of dam management (i.e., 2000 LSSF experiment) and nonnative fish removal (2003–2006) on humpback chub population dynamics. In particular, it was recognized that more emphasis needed to be placed on the dynamics of smaller size classes (~40-100 mm) of humpback chub in the CR. Starting in 2009, the Near Shore Ecology (NSE) project developed a framework for monitoring that has since been continued as the Juvenile Chub Monitoring (JCM) project. Since 2012, we have developed models that integrate data collected in the LCR with data collected by the JCM and NSE projects to provide a holistic picture of the humpback chub population dynamics (Yackulic and others, 2014). This work has illustrated the importance of variation in vital rates between the LCR and CR, as well as important movement phenomena (e.g., skip-spawning) that biased previous attempts to estimate adult abundance because of a population modelling issue known technically as “temporary emigration.” (In short, the majority of adult humpback chub are captured during spawning in the LCR, however, some proportion of adults chose not to spawn every year and this is known to lead to negative biases in abundance estimates). While the multistate approach to population modelling addresses this issue, there are other potential sources of biases and uncertainties (in particular, long-term hoop net avoidance) that we are seeking to address through new technologies and new modelling approaches.

One of the primary goals of this project is to improve our ability to forecast humpback chub population dynamics and inform management decisions. In support of the LTEMP process, we integrated versions of this humpback chub population model with models of rainbow trout population dynamics to provide predictions under various management alternatives and including various uncertainties (Yackulic, Korman, and Coggins – LTEMP appendix; Runge et al., 2015). Critical examination of simulations used in LTEMP provides important clues as to important areas of uncertainty in forecasting population dynamics of humpback chub (and rainbow trout), and thus important areas for research. In particular, uncertainty in juvenile production and outmigration plays an important role, as does uncertainty in rainbow trout flow-recruitment relationships. Uncertainty in relationships between temperature and humpback chub population dynamics was less important in LTEMP simulations because the LTEMP alternative did not differ in their implications for temperature (i.e., under LTEMP alternatives temperature was a random variable that was the same across alternatives, as opposed to something that was actually managed in any alternative). Nonetheless, we expect that changes in water temperature and other aspects of water quality (turbidity, nutrients) that are related to dam management decisions and broader drivers (Quagga, climate, structural deficit, etc.) will likely be one of the dominant drivers of future humpback chub population dynamics. In addition, recent research in collaboration with Lucas Bair has revealed the potential importance of uncertainty in various humpback chub vital rates in determining efficient trout removal triggers (including whether trout removal is necessary – See Project 13.3).

Specific goals of this project in the triennial work plan are to:

1) Monitor humpback chub in the lower 13.6 km of the 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) Test 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) Continue to develop models that integrate findings from the above projects and provide meaningful predictions to guide adaptive management.

Key hypotheses being tested include:

1) To what extent, do rainbow trout affect the growth and survival of juvenile humpback chub, and ultimately humpback chub adult abundances?

2) To what extent, does temperature affect the growth and survival of juvenile (and older size class) humpback chub, and ultimately humpback chub adult abundances

3) To what extent, does translocation of humpback chub population augment the adult population of humpback chub?

4) To what extent, are humpback chub dynamics in the Colorado River, driven my conditions in the LCR? In particular, how does juvenile production and outmigration from the LCR vary and what are the drivers of this variation?

5) To what extent, do other physical (turbidity and nutrients) and biological (primary production, insect densities) factors drive humpback chub population dynamics?

6) Are estimates of adult humpback chub abundances biased because older, larger humpback chub avoid hoopnets (i.e., is there long-term trap avoidance behavior)?

7) Are estimates of adult humpback chub abundances biased because of unmodelled heterogeneity in skip-spawning rate and/or heterogeneity in detection probability?

Summary of activities and results from various project elements Field Sampling

Spring and fall monitoring in the LCR

Based on data from the spring trips, the population of humpback chub ≥150 mm in the lower 13.6 km of the LCR was estimated to be 4,850 (Standard Error (SE) = 376) and the adult population (≥200 mm) was estimated to be 3,974 (SE = 314). These numbers represents a slight increase compared to the significant decline observed in spring 2015, however the point estimates remain lower than any estimates since 2007. In the fall it was estimated that there were 4,053 (SE = 232) Humpback Chub ≥150 mm in the lower 13.6 km of the LCR, of which 1,665 (SE = 132) were adults.

JCM monitoring in the CR

Preliminary estimates of humpback chub juvenile survival suggest reasonably high annual survival, but with high uncertainty. Fish condition for adult humpback chub (>200 mm) was poor throughout 2016 and has been since mid-2014 and is likely linked to lower abundances of spawning adults in the last two springs in the LCR. More thorough analyses of abundances and survival across size classes are ongoing.

Pre-monsoon juvenile chub survey in the LCR

Juvenile humpback chub abundances were extremely low in 2016 (3,000 - SE = 500) compared to 2013 (16,000 - SE = 2,400), 2014 (9,000 – SE = 700) and 2015 (25,000 – SE = 2,500). As a result, juvenile outmigration into the mainstem was likely very low this year, however, we are still analyzing these data.

Development of models and field approaches to PIT antennae

Use in the LCR

Using a combination of Natal Origins data and PIT array detections in the LCR, we developed a model that estimates that hundreds of rainbow trout overwintered in the LCR during the winter of 2013–2014. The PIT array in the LCR continues to function, however there are indications that it may only function fully for 1-2 more years. We are beginning to explore cheaper alternatives for replacing the PIT array in future years that may provide as good or better information. A paper detailing the model and results was recently submitted for publication. USFWS has already experiment with portable antennas with good success.

Use in the JCM reach of the Colorado River

Whereas JCM monitoring was designed for monitoring early life stages of humpback chub, it has always detected very few adults, one factor that leads to high uncertainty in humpback chub adult abundances. During the September JCM trip we employed portable antennas in the Colorado River for the first time with the hope of improving detection of larger adults that may avoid hoopnets or the habitats in which hoopnets can easily be deployed. The early results are promising. These antennas detected more than 4 times as many unique adults as compared to hoopnets, including 16 adult humpback chub that have not been detected anywhere within the system in the last eight years. We are working to integrate these data into our population models.

Determining the utility of Bioelectrical Impedance Analysis (BIA) analysis

The purpose of this project was to determine the effectiveness of Bioelectrical Impedance Analysis (BIA), a nonlethal technique used in many other fish species, for estimating physiological condition of humpback chub (and related species). We completed laboratory trials using hatchery-raised humpback chub, bonytail, and roundtail chub in FY15 and prepared a manuscript in FY16, which is currently under review. Although fish exhibited low mortality using BIA, it did not substantially improve our estimates of fish condition beyond those generated using accurate length and wet mass measurements. However, in the absence of wet mass data, or when wet mass measurements are highly erroneous (due to environmental factors such as high wind or water on the scale), BIA became a more reliable tool for estimating fish condition.

Research into mechanisms underlying population dynamics

Asian tapeworm monitoring

Tapeworm monitoring was conducted in the LCR at Boulders camp from May 23-26, 2016. Of 36 humpback chub treated for tapeworm, only 10 were found to be infected with a total burden of only 17 Asian tapeworms (a mean of 1.7 per fish). Infestation rate of humpback chub in the LCR has been very low for the last 2 years and appears to be much lower than was found during 2005–2007 sampling. All fish were released alive following treatment.

LCR Foodbase Research

In 2016, the foodbase research group made five, four-day trips into the LCR, concurrent with USFWS and GCMRC humpback chub monitoring trips in April, May, June, September, and October in order to better understand links between food availability and humpback chub population dynamics and growth. Objectives and sampling effort for these trips were consistent with previous efforts in 2014 and 2015, including sticky trap sampling of adult emergent aquatic insects, benthic sampling of aquatic invertebrate larvae, and light trap sampling at the four camps. Data from previous efforts was used to show the strong links between food availability and humpback chub growth in the LCR (Dzul et al., 2016 CJFAS). We plan to submit an insect-focused journal article in FY17.

Potential for CO2 limitation

CO2 concentrations have been measured within the LCR from Horse Trail (RKM 30) to the confluence with the Colorado River using a variety of techniques and are known to be extremely high between Blue Springs (RKM 20.8) and RKM 16 (but lower in the small perennial flow about Blue Springs and in the lower LCR). There is some disagreement in actual CO2 concentrations, with electronic probes suggesting lower concentrations than titration methods, however, these general trends remain. As part of this project element, laboratory studies evaluated native and nonnative fish tolerance to high CO2 levels for both juvenile and adult fishes. Rainbow and brown trout had the lowest CO2 tolerances (90 and 100 mg/l respectively) and bullhead catfish (200 mg/l) and fathead minnow (256 mg/l) had the highest tolerance with native fishes being intermediate. Humpback chub eggs hatched and larval fish survived at CO2 levels below 25 mg/l (RKM 14), but deposition of calcite and suffocation of eggs may play a larger role in fish recruitment than actual CO2 concentration. CO2 tolerance of all of the fishes we tested appear to be able higher than CO2 levels naturally found within the lower 16 km of the LCR. It does not appear likely that CO2 dynamics control fish populations in this area.

Model development

A paper detailing an improved statistical model for estimating effects of environmental factors on growth and applying the approach to understand drivers of growth in sub-adult humpback chub was published in CJFAS. We found that food availability and temperature were the primary drivers of growth in the LCR and turbidity and temperature played equal roles in humpback chub growth in the JCM reach. Another paper developing a novel approach for estimating abundance from the PIT array and ancillary data was submitted to CJFAS and estimates that a few hundred rainbow trout entered the LCR during the winter of 2013-2014. While rainbow trout have occasionally been found in the LCR, these results suggests that rainbow trout seasonal use of the LCR may be much greater than previously assumed. A manuscript detailing a joint mark-recapture model for juvenile humpback chub and rainbow trout is in the final stages of preparation and is expected to be submitted in early 2017. The model accounts for various sources of uncertainty (uncertainty in rainbow trout abundances, uncertainty from un-modeled environmental covariates, effects of environmental factors including turbidity and temperature) and estimates a statistically significant, negative effect of rainbow trout on humpback chub survival. The effect is moderate in comparison to other potential drivers (e.g., temperature), but is sufficient to affect long-term humpback chub population dynamics and adult abundances. Estimates from this model are being used as part of project 13.3 to develop tools for supporting management decisions in an effort led by Lucas Bair.

Synthesis and next steps

The population dynamics of humpback chub are relatively slow, particularly in the Colorado River. As a consequence, recruitment failure in one or a few years should not lead to an overreaction from managers, as a few bad years can quickly be erased by a couple very good years. On the other hand, if the status of the population declines to a point that is unacceptable due to inaction, the population will be slow to recover and may require much more intensive management interventions. Poor juvenile recruitment this year is particularly unfortunate because rainbow trout abundances in the Colorado River near the LCR confluence are currently quite low, and humpback chub juvenile survival is directly linked to rainbow trout abundances (Yackulic et al., in prep). Thus we are currently in a window to add humpback chub after many years of high rainbow trout abundances, when juvenile chub survival was low (despite fairly good recruitment to the Colorado River). Previously, it has been hypothesized that poor humpback chub recruitment years in the LCR are associated with lack of flooding during the Jan. 1 to May 31 seasonal window (Van Haverbeke et al., 2013). Flooding in 2016 occurred relatively early in this window, but was greater in magnitude than in some years that have had good recruitment, in disagreement with this hypothesis. Furthermore, past estimates of humpback chub recruitment in the LCR occurred after monsoons and thus conflated two processes–juvenile recruitment and outmigration during the monsoons (when most outmigration occurs – Yackulic et al., 2014). It is now clear that there is substantial variation in both these processes. Over the four years of pre-monsoon surveys there has been substantial variation in juvenile recruitment, and over the eight years of study in the JCM there has been considerable variation in juvenile recruitment (juvenile recruitment to the JCM reach represents a portion of the outmigration from the LCR). Since recruitment and outmigration rates play such substantial roles in humpback chub population dynamics and may determine whether some management actions, like mechanical removal, are even necessary and if necessary how they should be timed to maximize chub benefits, we plan to continue the pre-monsoon surveys both in FY17 and the next work plan.

Trends in adult humpback chub over the last two and a half years are not good. Fish condition of adult humpback chub in the JCM reach has been poor and fewer adults have spawned in the last two years than in any period since 2007. Since detection probabilities for adults are low in the mainstem, it is not clear whether lower spawner abundances reflect a decline in actual adult abundances system-wide, or merely a decline in spawning rates (i.e., a lower proportion of adults have chosen to spawn). PIT-tag antennas deployed in the mainstem show great promise and may soon provide us with data to distinguish these hypotheses. We plan to work on developing models to understand temporal variation in skip-spawning rates in FY17 and in the next work plan. Recent declines in adult condition (and perhaps lowered rates of spawning) have likely been driven by a declining foodbase. Decreased invertebrate drift suggested much lower food availability in 2015 and 2014 as compared to 2012 and 2013. 2016 data is still being processed. In turn, preliminary estimates suggest that gross primary production in Marble Canyon, estimated from dissolved oxygen, may have been lower in recent years as compared to 2013 and 2014, suggesting a bottom-up decline, ultimately driven by factors related to the nutrient concentrations of water released through Glen Canyon Dam. A primary focus of research in FY17 and proposed research in the next work plan will be to better understand how nutrients and other aspects of releases from Glen Canyon Dam affect primary production and determine whether these affects cascade up through the food web, ultimately affecting condition and population dynamics of both rainbow trout and humpback chub.

Over the last two years, we have explored a number of hypotheses related to fish population dynamics in the LCR. CO2 limitation does not appear to be as big a factor as previously believed–a manuscript on these results will be submitted in 2017. Therefore, we do not expect the need for further research on this topic in the next work plan. With respect to Asian tapeworm monitoring, more years of data are needed to determine how infestation rates vary and whether they impact humpback chub dynamics over longer time spans. This monitoring is relatively cheap and will likely be proposed to continue in the next work plan, perhaps with additional work in the mainstem. We have found that seasonal and spatial patterns in food availability are likely linked to spatio-temporal variation in humpback chub growth and abundances, however, data are still being analyzed to determine if there is inter-annual variation. Intensive field work associated with this project is complete. We may, however, propose a downscaled version of monitoring associated with ongoing fish monitoring projects in future years.

We have seen enormous gains in our understanding of humpback chub dynamics in the Colorado River around the LCR coinciding with the establishment of the JCM study area, including an ability to link management actions and environmental variation to population processes. This understanding of population dynamics and drivers allows us to predict how the quantity managers are primarily interested in, humpback chub adult abundances, will respond to management actions and environmental variation (i.e., the modelling framework developed for LTEMP by Yackulic, Korman, and Coggins). Recently, there have been signs that humpback chub populations are increasing in other parts of Grand Canyon, however, we have little to no understanding of what is driving these increases, and if, or how, we can sustain these increases. If we could understand the factors driving these increases and determine that there was a distinct population from the LCR aggregation, this could potentially radically change management of humpback chub downstream of Glen Canyon Dam. For these reasons, and given the success of the JCM/NSE approach, we propose to explore JCM-like sampling at a fixed site in western Grand Canyon in FY17 and the next work plan.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	CB Yackulic, *et al*. (in prep) *Joint mark-recapture population modeling of interacting species*			2017	
Journal Article	L Bair, CB Yackulic, *et al*., (in prep) *Enhancing native species population viability via cost-effective invasive species control in the Grand Canyon, USA.*			2017	
Journal Article	JD Muehlbauer, TA Kennedy, CB Yackulic, & EW Kortenhoeven (in prep) *Dual light controls on aquatic insect densities throughout a large river.*			2017	
Journal Article	MC Dzul, CB Yackulic, J Korman, and T Andrews. (submitted) *Estimating animal abundance using continuous detection data from PIT arrays placed near the confluence of two rivers.* **Canadian Journal of Fisheries and Aquatic Sciences.**			2017	
Journal Article	KL Dibble, M Yard, DL Ward, and CB Yackulic. (in review) *Does bioelectrical impedance analysis accurately estimate the condition of threatened and endangered desert fish species?* **Transactions of the American Fisheries Society**			2017	
Journal Article	M.C. Dzul, C.B. Yackulic, J. Korman, M.D. Yard, and J.D. Muehlbauer (2016) *Incorporating temporal heterogeneity in environmental conditions into a somatic growth model*. **Canadian**		2016		

	Journal of Fisheries and Aquatic Sciences. DOI: 10.1139/cjfas-2016-0056. Online				
Journal article	MC Dzul, CB Yackulic, DM Stone, DR Van Haverbeke (2016) *Survival, growth, and movement of subadult humpback chub, Gila cypha, in the Little Colorado River, Arizona.* **River Research and Applications**. 32: 373–382.		2016		
Journal article	C Finch, Pine WE, Yackulic CB, Dodrill MJ, Yard M, Gerig BS, Coggins LG, and Korman J (2016) *Assessing Juvenile Native Fish Demographic Responses to a Steady Flow Experiment in a Large Regulated River.* **River Research and Applications.** 32: 763–775		2016		
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.* **Transactions of the American Fisheries Society 144(6) 1184-1191.**		2015		
Journal article	MJ Dodrill, CB Yackulic, B Gerig, WE Pine, J Korman and C Finch (2015) *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**. 31: 1203–1217		2015		
Professiona l Report	Runge, M.C., LaGory, K.E., Russell, K., Balsom, J.R., Butler, R.A., Coggins, J.L.G.,		2015		

	Grantz, K.A., Hayse, J., Hlohowskyj, I., Korman, J., May, J.E., O'Rourke, D.J., Poch, L.A., Prairie, J.R., VanKuiken, J.C., Van Lonkhuyzen, R.A., Varyu, D.R., Verhaaren, B.T., Veselka, T.D., Williams, N.T., Wuthrich, K.K., Yackulic, C.B., Billerbeck, R.P. & Knowles, G.W. (2015) Decision analysis to support development of the Glen Canyon Dam long-term experimental and management plan. *Scientific Investigations Report*, pp. 80. Reston, VA.				
Conference Presentatio n	DL Ward, B. Vaage, K. Sheehan, and C. Nelson (2016). Effects of elevated Carbon Dioxide on fish populations within the Little Colorado River in Grand Canyon. 48th Annual Meeting of the Desert Fishes Council, Nov 15-19, 2016, Albuquerque, NM.		Nov. 2016		
Conference presentatio n	CB Yackulic (2016) *Determining the relative roles of environmental drivers and competition in the population dynamics of Rainbow Trout and Humpback Chub to inform management of Glen Canyon Dam*. **World Congress on Natural Resource Modelling**. Flagstaff, Arizona.		July 2016		
Invited Seminar	CB Yackulic (2016) Managing for endangered species in novel ecosystems. Cary Institute of Ecosystem Studies. Millbrook, New York.		March 2016		

Conference presentatio n	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 presentatio n	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 presentatio n	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		

Project 7	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$603,400	$13,300	$52,400	$555,000	$0	$96,828	**$1,320,928**
Actual Spent	$538,288	$12,170	$133,160	$452,093	$0	$95,481	**$1,231,193**
(Over)/Under Budget	**$65,112**	**$1,130**	**($80,760)**	**$102,907**	**$0**	**$1,347**	**$89,735**

FY15 Carryover	**$102,781**		**CPI Decrease**	**($66,877)**		**FY16 Carryover**	**$125,639**

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

- Salary costs decreased due to vacancies and some employees working on non-AMP projects.
- Operating expenses increased due to sending funds to a university through a research work order vs. a cooperative agreement and purchasing field equipment.
- Cooperative agreements decreased due to sending funds to a university through a research work order vs. a cooperative agreement.
- Carryover will be used to maintain employees and to offset FY17 shortage.

Project 8: Experimental Actions to Increase Abundance and Distribution of Native Fishes in Grand Canyon

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SUMMARY

This project encompasses two ongoing management actions, a protocol evaluation panel review and two new projects funded in 2017. The protocol evaluation panel took place in August of 2016. Specific findings from the funded monitoring and research projects are listed below.

Project Element 8.1. Efficacy and Ecological Impacts of Trout Removal at Bright Angel Creek

Goals and Objectives: The objective of this project is to evaluate the feasibility and efficacy of brown trout removal in and around Bright Angel Creek using electrofishing, and assess the response of native fish to brown trout removal. This experimental action is being conducted in collaboration with Grand Canyon National Park, consistent with the National Park Service (NPS) Comprehensive Fisheries Management Plan and related compliance documents.

Summary of progress: Trout removal using boat mounted electrofishing has occurred in the mainstem Colorado River near the confluence with Bright Angel Creek annually since 2013–2014, with a trip scheduled for January 29 – Feb 5, 2017 (Table 1).

Summary of trends: Bright Angel Creek inflow removal efforts have varied in scope and intensity from year to year, making direct comparisons of trout captures difficult. In 2013–2014, 5 depletion passes were conducted over approximately 9 km (Zoroaster to Horn Creek). In 2015–2016, 10 depletion efforts were focused on the 4-km section from Bright Angel Creek inflow to Horn Creek (where th majority of fish were captured during the previous year's sampling). In 2016-2017, efforts were further reduced to 5 depletion passes between Bright Angel Creek inflow to Horn Creek. Turbid conditions were present for the majority of each sampling effort.

Trout catches decreased from 1,709 trout in 2013–2014 to only 25 trout in 2015–2016. In contrast, native fish catches increased over this same period, with 294 native fish captured in 2015–2016 up from 132 in 2013–2014 (Table 1). The apparent decrease in trout abundance near the Bright Angel Creek confluence also coincides with decreases in trout observed throughout Glen and Marble Canyons and a significant reduction of trout within Bright Angel Creek. This reduction also corresponds to poor condition observed in rainbow trout in our study area as well as throughout the system since 2014 (see Project 6 and 9 reports). 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. These changes may also represent increased native fish abundance as a result of ongoing nonnative fish removals by this project and the NPS in Bright Angel Creek. A system-wide decline in trout abundance related to poor condition could also be a factor.

Table 1. Catch summaries for each species by trip (BNT = Brown Trout, RBT = Rainbow Trout, FMS = Flannelmouth Sucker, BHS = Bluehead Sucker, HBC = Humpback Chub, SPD = Speckled Dace, CRP + Common Carp, BBH = Black Bullhead, PKF = Plains Killifish, FHM = Fathead Minnow)

Trip	BNT	RBT	FMS	BHS	HBC	SPD	CRP	BBH	PKF	FHM
2013-2014	332	1377	90	40	1	1	18	1	1	1
2014-2015	84	391	270	120	0	0	8	0	0	0
2015-2016	9	16	204	88	2	0	5	0	0	0
2016-2017	Sampling scheduled for January 29th to February 5th, 2017									

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. To date, approximately 3,106 juvenile (~80-130 mm TL) humpback chub have been translocated upstream of Chute Falls (Figure 1). Of these, 137 humpback chub were released above Chute Falls (at rkm 16.2) on October 27, 2016. The project is identified as a Conservation Measure in the 2011 Biological Opinion. Our monitoring activities also coincide with joint efforts with the NPS 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.

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 2010–2016, this set of capture probability data was used to annually estimate the abundance of humpback chub upstream of rkm 13.6 (Figure 2). During 2016, a trip was conducted during 17-25 May to estimate abundances of humpback chub upstream of rkm 13.6 in the LCR. We estimated there were 319 humpback chub ≥100 mm (SE = 71) in the Chute Falls reach, and 475 ≥100 mm (SE = 88) in the Atomizer Falls reach. Of these, it was estimated that there were 118 humpback chub ≥200 mm (SE = 22) in the Chute Falls reach, and 331 ≥200 mm in the Atomizer reach (SE = 57). Results have also indicated unusually rapid growth of translocated fish, and high apparent survival.

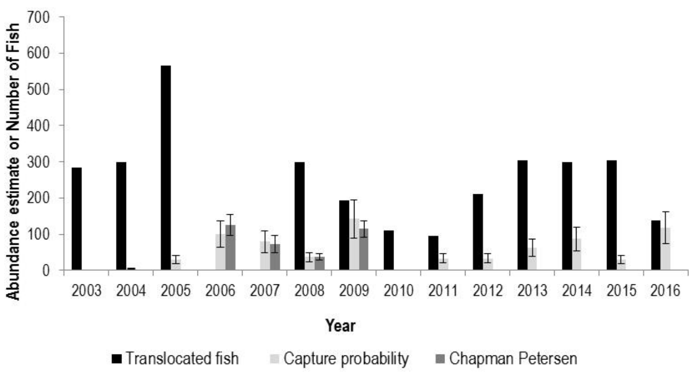

Figure 1. Numbers of humpback chub that have been translocated upstream of Chute Falls since 2003 (black bars), and estimated abundances (±95% CI) of adult humpback chub (≥ 200 mm) in upper reach upstream of Chute Falls (river km [rkm] 14.1 to 17.7).

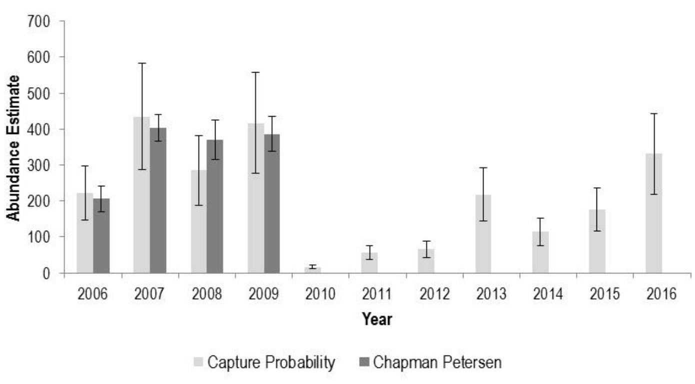

Figure 2. Abundances (±95% CI) of adult humpback chub in lower reach downstream of Chute Falls (rkm 13.6 – 14.1) since summer 2006. Note, abundances for both above below Chute Falls are shown as those estimated with Chapman Petersen mark-recapture (dark grey bars) and those estimated using capture probability 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

A Protocol Evaluation Panel was convened in Flagstaff, AZ on August 2-5, 2016. The Panel members consisted of 5 subject experts, Andrew Casper, PhD - Illinois Natural History Survey, Keith Gido, PhD - Kansas State University, Donald Jackson, PhD - University of Toronto, James Petersen, PhD - Oregon State University, Oregon Cooperative Fish and Wildlife Unit, and Frank Rahel, PhD - University of Wyoming. Panelists heard presentations on all aspects of fish monitoring, research, and management actions currently being conducted in the Colorado River Ecosystem and then participated in discussions with scientists and stakeholders at the USGS Science Center in Flagstaff and at Lees Ferry. The final report with recommendations from the panelists is expected this winter.

Project Element 8.4. Little Colorado River Invasive Aquatic Species Surveillance
Project element funded in FY17.

Project Element 8.5. Genetic monitoring of Humpback chub in Grand Canyon
Project element funded in FY17.

	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. 2016. Spring 2016 Monitoring of Humpback Chub (*Gila cypha*) and Other Fishes above Lower Atomizer Falls in the Little Colorado River, Arizona. Trip Report 17-25 May 2016.		July 2016		
Trip Report	Stone, D.M. and M.J. Pillow. 2016. Fall 2016 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report: 20-30 Sept and 18-28 Oct 2016. *In prep.*	Nov 2016		Nov 2016	
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 2016.	Jan 2017		Jan 2017	
USGS Report	2016 Protocol Evaluation Panel Review of fish monitoring, research and management actions in the Colorado River Ecosystem			Jan 2017	

Project 8	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$61,400	$0	$5,100	$88,200	$0	$10,615	**$165,315**
Actual Spent	$25,465	$180	$3,000	$70,888	$0	$5,559	**$105,092**
(Over)/Under Budget	**$35,935**	**($180)**	**$2,100**	**$17,312**	**$0**	**$5,056**	**$60,223**

FY15 Carryover	**$11,167**		**CPI Decrease**	**($8,370)**		**FY16 Carryover**	**$63,020**

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

- Reduced salary costs due to vacancies.
- Cooperative agreements decreased due to PEP Panel funded from project 15.
- Carryover will be used to offset FY17 shortage.

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 Kim Dibble, USGS, GCMRC Josh Korman, Ecometric Research Charles Yackulic, USGS, GCMRC Ted Melis, USGS, GCMRC David Rogowski, AZGFD Ted Kennedy, USGS, GCMRC David Ward, USGS, GCMRC Mike Dodrill, USGS, GCMRC Dan Buscombe, USGS, GCMRC Paul Grams, USGS, GCMRC Tom Gushue, USGS, GCMRC
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SUMMARY

Project Element 9.1. Rainbow Trout Population Dynamics – Ongoing Modelling and Future Monitoring

In 2016, GCMRC in conjunction with the Science Advisors program convened a protocol evaluation panel (PEP; see Project Element 8.3) to review the fisheries monitoring program. Multiple cooperators AGFD (Project Element 6.8) and Ecometric (Project Element 9.2), USFWS (Project Element 7.3), and GCMRC presented data and provided expert opinion on the long-term status and trend information for native and nonnative species. All of these fishery data, technical reports, and scientific papers were evaluated to determine whether or not conventional catch-per-unit indices or other types of sampling approaches were appropriate for meeting long-term monitoring needs of the GCDAMP. 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. The PEP report is to be finalized by December 2016.

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

Identifying the factors that control the abundance and movement of rainbow trout near the Little Colorado River (LCR), and effects of trout on humpback chub, are considered one of the more critical information needs of the Glen Canyon Dam Adaptive Management program (GCDAMP). The Natal Origins (NO) project was designed to better understand rainbow trout population dynamics by evaluating linkages between populations in the Lees Ferry reach and other downstream reaches in Marble and Eastern Grand Canyons (Fig 1). Toward that goal, alternative sampling and analytical methods were developed for estimating abundance, survival, recruitment and capture probability. The primary research 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, high flow experiments (HFEs), etc.).

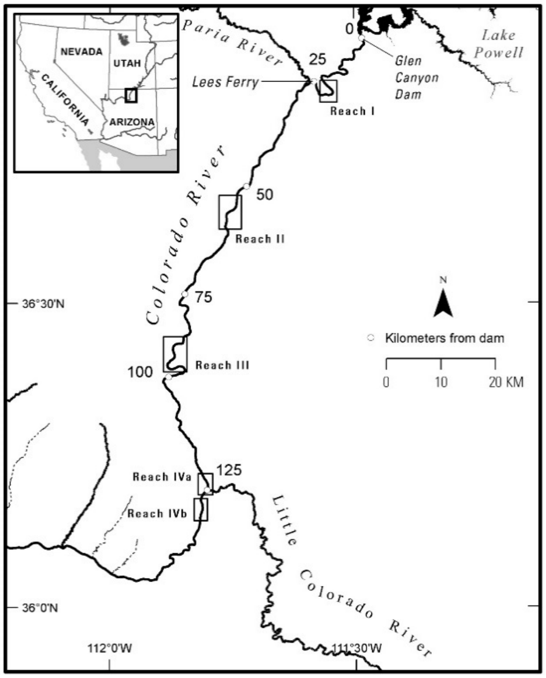

Figure 1 Map of the study area showing the location of the five reaches sampled: I) Lees Ferry, II) House Rock, III) Buckfarm, IVa) upstream of the Little Colorado River, and IVb) downstream of the Little Colorado River. Numbers beside the mainstem Colorado River denote river kilometers downstream of Glen Canyon Dam.

Stakeholders in the GCDAMP often ask specific questions about the effects of a variety of flows on biological resources, and whether or not current monitoring programs are capable of addressing these questions. For that reason, the NO project used estimates of rainbow trout capture probability from a global open population model for Lees Ferry, which does not include density dependent effects, and estimates of capture probability from a density dependent model, to back calculate abundance of rainbow trout in the Glen Canyon tailwater using AGFD's historic time series of boat electrofishing catch-per-unit-effort (CPUE). The main objective of this analysis is to determine if the effects of fish size and density on capture probability result in different long-term trends in abundance relative to the trend based on the uncorrected CPUE time series. The results determined that surveys based on a CPUE index have utility for monitoring long-term trends in abundance, but may be too imprecise and potentially biased to evaluate population response to flow and habitat changes over shorter time scales. Failure to account for effects of fish density on catchability in the uncorrected CPUE index led to a 3-fold underestimate in the maximum extent of variation in abundance over the period of record, and resulted in unreliable estimates of relative change in critical years (Fig 2). Essentially, the CPUE index overestimated the relative abundance when actual abundance was very low, and underestimated relative abundance when actual abundance was very high. These results suggest that stronger inferences can be extracted from sporadically delivered flow treatments or naturally occurring events if they are assessed using mark-recapture- rather than CPUE-based surveys.

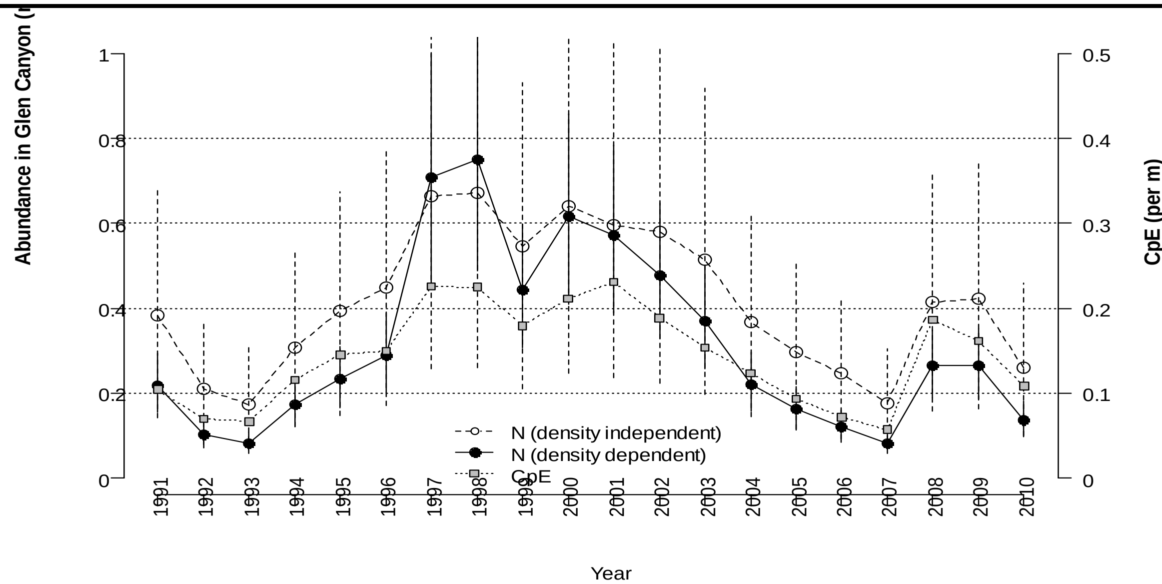

Figure 2. Comparison of estimated rainbow trout abundance (total of all size classes, N) trends and the Catch per Effort (CpE) trend in Glen Canyon. For predicted abundance values, points represent the mean of posterior distributions and vertical lines denote 80% credible intervals. Estimated abundance is based on expanding CpE by size-stratified capture probability estimates or by capture probabilities determined by the density-dependent relationship.

In FY16, the NO project completed the last of its four scheduled downstream river trips (Jan, Apr, Jul, and Sep 2016, 21-day trips) and including three fall-Lees Ferry trips (Oct and Dec 2015, & Oct 2016, 10-day trips). Trout densities throughout all the study reaches continues to remain low relative to the initial density estimates made across reaches in 2012 (Fig 3). But unlike previous year's (2013-2014), trout growth and condition are higher and remain elevated across multiple seasons, particularly during the late-summer and fall. As previously reported, reduced growth in 2014 occurred when trout biomass was relatively low compared to the start of the study, indicating that availability of prey had declined. Reduced growth affected multiple life history stages and processes, all potentially causing negative feedbacks that would regulate the abundance and biomass of the trout population, including: higher mortality of larger fish; lower rates of recruitment in years when growth was reduced; and lower rates of sexual maturation the following year. Additionally, NO project results show that inter annual variation in survival rates of post-recruit life stages can have very substantive effects on population trends. We estimated that the abundance of rainbow trout in Glen Canyon declined by 10-fold over the five-year study period. Although trout abundance levels have been reduced across all of the reaches sampled (see Fig. 1), the remaining rainbow trout appear to have recovered and are demonstrating better seasonal growth and condition. In Lees Ferry, elevated growth throughout the fall of 2015 and winter of 2016 led to excellent reproductive condition for the remaining adult fish. Although the total number of potential spawners in 2016 was limited due to lower abundance levels their reproductive success was higher than in past years (with the exception of the 2011 cohort) resulting in higher densities of age-0 fish (Fig 3). Increased growth rates and likely survival culminated into a very strong year class that is recruiting into the adult population, and outcome that will likely increase the abundance of catchable sized fish in the Lees Ferry trout population over the next few years.

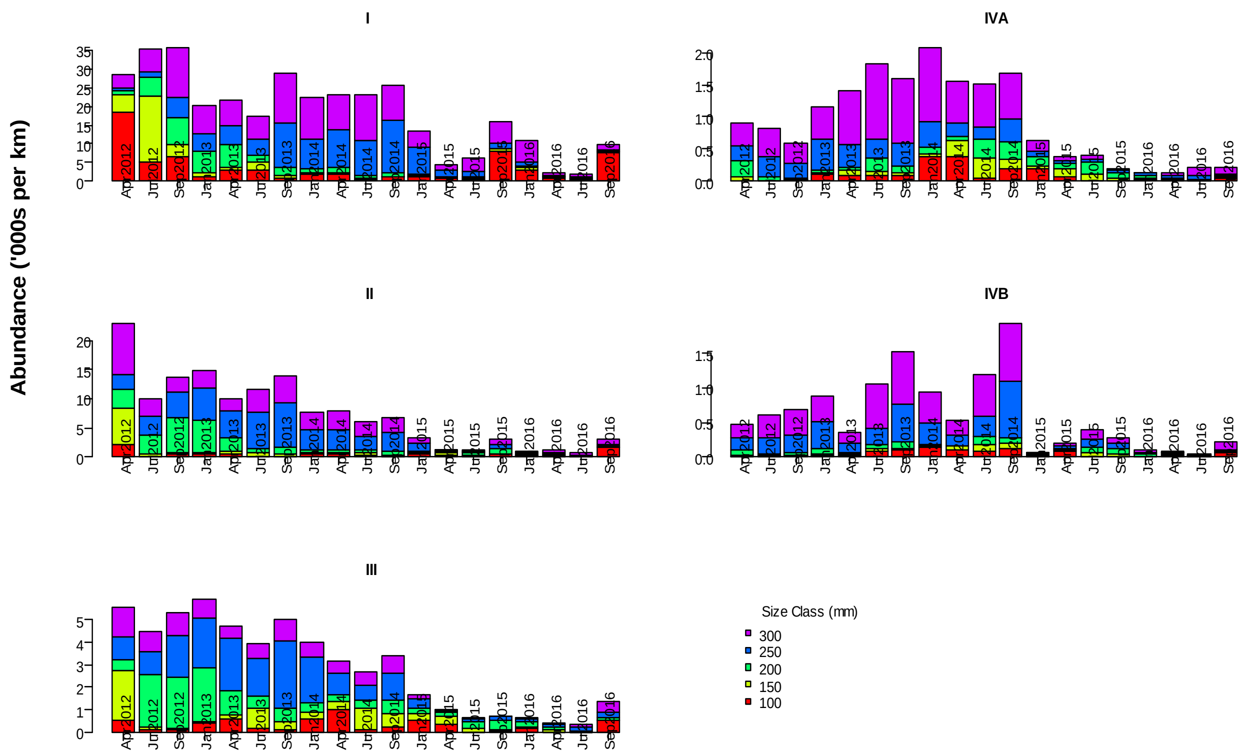

Figure 3. Estimated abundance of rainbow trout by 50 mm size class by reach (see Fig. 1 for reach locations) and trips.

Over the past 5 years, the NO study has reported on trout movement from Lees Ferry into Marble Canyon and the LCR confluence area. Earlier results indicate that there was limited outmigration of rainbow trout from Lees Ferry into Marble Canyon, with the exception of the 2011 age-0 cohort that likely moved prior to the start of the study (based on larger taggable sized fish [≥ 75 mm fork length]). Recapture information for across-reach movement percentages indicate very limited movement between most reaches. And on average only 1% of tagged trout in reaches I, II, or III were estimated to move between reaches other than the ones they were released in. The analyses and inferences were based on recapture data that showed there was a higher probability of trout moving from locations in Marble Canyon to the LCR, rather than directly from Lees Ferry to the LCR. Although the proportion of fish emigrating from upstream reaches down to the LCR was very small, all of the recruitment into reaches near the LCR that drove the increasing trout population trend can be explained by immigration from the upstream sources in Marble Canyon. Similarly, abundance estimates for reaches I, II, and III showed declining trends in trout abundance due to limited recruitment from either trout movement or local reproduction. In contrast, downstream reaches (IVa and IVb) demonstrated gradual increases in trout density that can be explained entirely by estimated immigration into the lower reaches. Initially, the upstream populations were large and therefore provided enough immigration to increase the abundance of the relatively small population of trout residing upstream and downstream of the LCR. By 2015, following the system-wide decline and collapse of trout across all study reaches there was inadequate downstream movement from upstream sources to maintain higher densities in reaches IVa and IVb.

On the July 2016 trip, age-0 trout (< 125 mm FL) made up 25%, 7%, and 1% of the total electrofishing catch in reaches I, II, and III, respectively. In comparison, the percentages of age-0 trout that comprised the total electrofishing catch on the September 2016 trip increased to 62%, 78%, and 64% in reaches I, II, and III, respectively. It is quite likely that age-0 trout emigrated out of Lees Ferry into the upper Marble Canyon section sometime between July and September 2016. Reach comparisons of length frequency distributions for age-0 fish were all similar in size among all reaches. This represents a paradox, as there is no past evidence of local reproduction in reach II over the study period, and only limited local reproduction in reach III. Also, over 60% of age-0 fish remained well below the passive integrated transponder (PIT) taggable size. Most of the downstream movement from Lees Ferry appears to be episodic with the majority of emigration due to large recruitment events (2011 and 2016) of age-0 fish into upper Marble Canyon, or secondarily from long-distance movement of larger fish (e.g., April and September 2014). The long-distance movement of larger trout into the LCR region was likely in response to poor growth and reduced survival, a response similarly reported by Coggins et al. (2011) where net immigration rates were elevated during 2003–2004. These same years also corresponded to periods when the overall trout population declined system-wide.

A system-wide increase of trout followed by a rapid decline is characteristic of a boom-bust cycle. The recent decline in trout (2012-2016) would be novel if not for other boom and bust cycles that have previously occurred in the Glen Canyon trout population (1989-1992 and 2002-2006) (Arizona Game and Fish Dept., unpublished data; Makinster et al. 2010). When we reevaluated AGFD's historical trend data for the Glen Canyon fishery, using a time-series of average annual CPUE, it corresponded strongly with the variation in average annual surface elevation of Lake Powell and nutrients levels (1990-2015) supplied to the river outflow. During the limited period of this study, annual inflows into Lake Powell from the major upstream sources of the Green River, Colorado River and San Juan rivers were well below the average annual runoff level, which resulted in a drawdown of the reservoir volume. Historically, the total annual inflow from the three riverine sources (flow record, 1984-2015) has ranged from a maximum volume of 21,107 million cubic meters (MCM) to a low of 510.6 MCM. Since the post filling period (1963-1980), the reservoir volume has varied annually and corresponds in time with three periods of declining trout CPUE, and two periods of increasing CPUE. Reservoir limnology and inflow hydrology govern the quantity of nutrients that are supplied to the downstream river segments of Glen and Grand canyons. Phosphorous levels are critical for aquatic primary production, but in this system phosphorous levels are often measured at or below detectable levels (25% of WQ period of record). Some invertebrates, specifically *Gammarus* and certain species of Chironomids utilize primary producers like algae as refuge and for food resources. Preliminary results based on trout bioenergetic demand (daily prey intake) (Fig 4), and invertebrate drift availability would indicate that annual production of invertebrate prey declined over the NO study interval (2012-2016). Our inference on causation is weak and needs to be strengthened or falsified with better experimental designs and manipulations that address specific hypotheses a-priori rather than a reliance on retrospective analysis of CPUE trends.

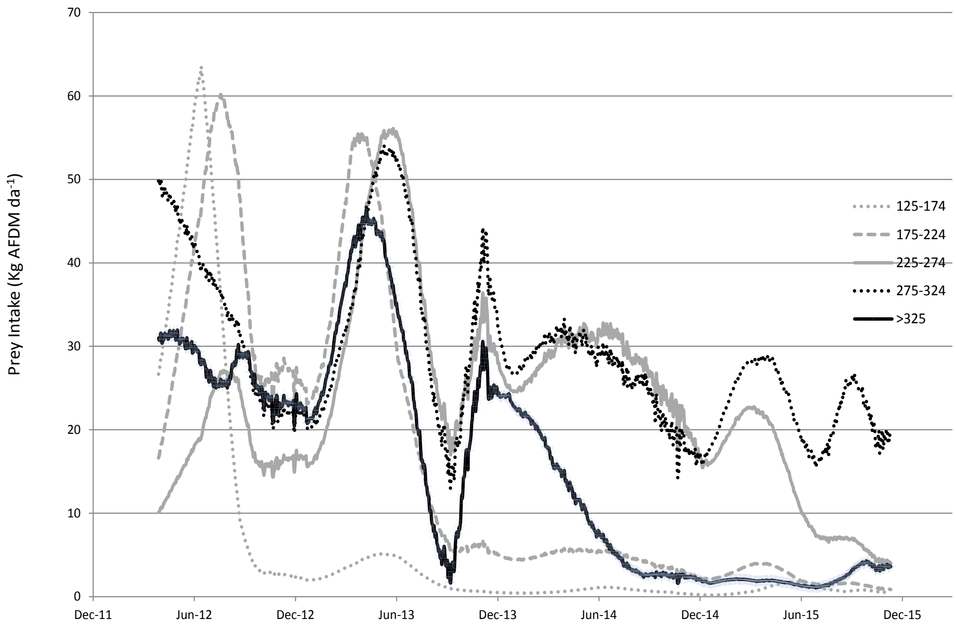

Figure 4. Total daily prey intake by rainbow trout estimated for the six size classes (125-174 mm, 175-224 mm, 225-274 mm, 275-324 mm, ≥ 325 mm) over the study period (2012-2015). Estimates of invertebrate prey consumed per day are expressed in units of weight (Kg of ash free dry mass [AFDM] per day).

Our analysis indicates that there can be considerable inter-annual variation in prey supply for trout, and that this supply will not always be sufficient to sustain the trout population. Our hypothesis is that reduced invertebrate production in 2014 was driven by lower concentrations of nutrients in the water released from Glen Canyon Dam. Increasing prey production is an obvious way to avoid future collapses, but factors that likely control it, such as reservoir inflow and elevation, are largely determined by climate variation and cannot be controlled by managers. Thus, limiting trout recruitment (age-0), or at least avoiding very large recruitment events, is a more viable strategy to avoid future collapses. Owing to these findings, GCMRC considers it warranted to reexamine and further improve on the current water quality program, particularly the sampling frequency and precision of analyses used. Future work plans (FY18-20) should place greater emphasis on studying nutrient limitations, since phosphorous is an essential limiting nutrient in most aquatic ecosystems, particularly those that rely heavily on photosynthesis to support higher trophic levels. Additionally, we propose to maintain a mark-recapture program focused in Glen Canyon to determine effects from HFEs and potential trout management flows (TMF) that cannot be adequately addressed solely by CPUE based monitoring programs.

Two papers have recently been submitted for publication (entitled “Trends in recruitment, abundance, survival, and growth over a boom-and-bust cycle of a rainbow trout tailwater population.”, and “On the Catchability of Fish Populations and Interpretation of Catch per unit effort Trends”), and a third manuscript on prey consumption and bioenergetic demand is in progress (entitled “Invertebrate production estimates from bioenergetic demand by rainbow trout in the Colorado River in Grand Canyon”).

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

The purpose of this project was to determine whether the ability of adult trout to acquire and store energy from the prey base is a potential mechanism behind spatial and temporal differences in growth, reproduction, and movement of rainbow and brown trout in Glen and Marble Canyons. Field data collection was completed in FY15 during fish sampling associated with the Natal Origins Project (9.2). Approximately 100 rainbow trout and 25 brown trout were sampled during each trip and muscle, liver, and hindgut tissue excised in the field.

In FY16 we analyzed all samples these 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 (e.g., 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 prepared for submittal to a peer-reviewed journal in FY17.

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

This project element was not funded.

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.

We are currently analyzing the data and are preparing to develop a manuscript associated with these results in 2017. The paper will be submitted to a peer-reviewed journal at the end of FY17.

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

The objective of this project is to determine what level and duration of turbidity might be necessary to negatively effect, or prevent persistence of, rainbow trout in lower Marble Canyon and to determine whether turbidity levels in the mainstem Colorado River could be manipulated so as to limit rainbow trout survival downstream of the Paria River.

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 formazin nephelometric units (FNU) in suspension without deterioration in water quality. PIT-tagged rainbow trout were collected from Lees Ferry, acclimated to laboratory conditions, and placed into the laboratory apparatus with abundant live feed. Two streams were maintained at low turbidities of 50 -100 FNU and two streams held clear water. To date, we have only completed a single replicated trial with adult rainbow trout, but additional trials will take place this winter and spring. Rainbow trout from the turbid tanks gained an average of 9.6 grams over the 30-day trial while trout from the turbid tanks lost an average of 23 grams over the same time period (Fig. 5). From a laboratory experimental perspective, it does appear that relatively low levels of turbidity (<100 FNU) could be used as a management tool to disadvantage trout in as little as 30 days, although additional replicates and sizes of fish need to be evaluated. Evaluations of historic turbidity levels below the confluence of the Paria River and potential links to fluctuations in trout populations and trout condition are currently being examined.

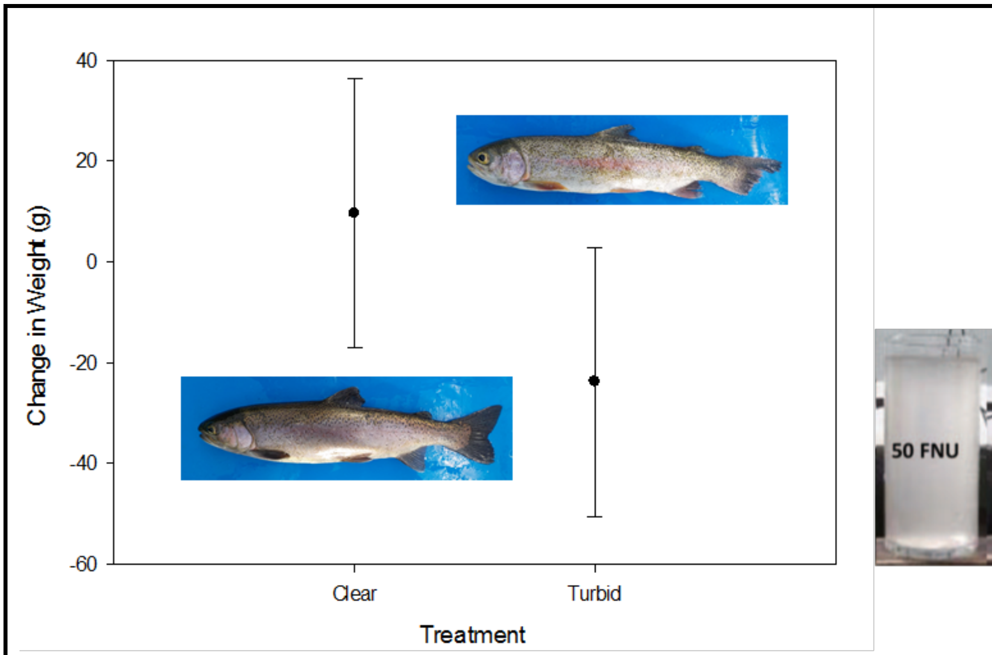

Figure 5. Effects of low level turbidity (<50 FNU) on rainbow trout as measured by mean change in weight during a 30-day laboratory trial. Error bars indicate 95% confidence intervals around the mean change in weight.

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

Prior drift-foraging bioenergetics approaches applied to rainbow trout at Lees Ferry have elucidated the importance of invertebrate prey to trout growth. This project element looks to expand this work and explore how other factors including turbidity influence conditions for rainbow trout growth. We continue to refine these process-oriented models in order to improve our ability to predict how trout may respond to changing physical and biological conditions. We have advanced these modeling approaches by identifying important biases that drift-foraging models have in relation to model structure and input (Dodrill and Yackulic 2016). Additionally, we have used information collected during Natal Origins (Project 9.2) trips on invertebrate drift rates (Project Element 5.2.2) and rainbow trout diets to assess prey selectivity of rainbow and brown trout. This is accomplished using a discrete choice model, fit within a Bayesian modeling framework. The modeling approach allows us to quantify factors influencing prey selection, including prey size, identity, and how prey selection changes in response to turbidity.

These finding are reported in a manuscript in preparation (Dodrill et al. In Prep) which is to be submitted to Canadian Journal of Fisheries and Aquatic Sciences. Knowledge of prey selection patterns in relation to turbidity can then be incorporated into drift-foraging bioenergetics approaches. 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

The purpose of this project was to continue to develop a broader understanding of the links between dam operations and rainbow and brown trout population dynamics by synthesizing data from tailwaters across the western United States. We published the results of our first tailwater synthesis project in FY15 (funded in the FY13-14 work plan), which examined the influence of physical and biological variables on rainbow and brown trout recruitment and adult size in tailwaters across the western U.S. However, due to limited data we could not evaluate the potential influence of water temperature on trout population dynamics. Ongoing drought in the region has led to highly-publicized reductions in reservoir storage and raised concerns about potential reductions in minimum flows, which may result in large changes in thermal regimes as reservoir storage drops. Therefore, in FY16 we built on the body of knowledge gained from our first synthesis in two ways. First, we added water temperature data to models using a subset of tailwaters included in the first synthesis to better understand how temperature influences trout population dynamics and how populations may respond to future drought and warming conditions. We analyzed data both within and among ten large western U.S. tailwaters and found that water temperature was inversely related to reservoir capacity, such that water temperatures increased when reservoir levels dropped. Consequently, rainbow trout recruitment increased in years and in tailwaters exhibiting higher temperatures, but adult rainbow and brown trout size decreased with higher temperatures. These results suggest that drought-induced temperature increases in western U.S. tailwaters will enhance trout recruitment at the expense of adult size. A publication associated with these results entitled "Drought induced warming in tailwaters of the Western U.S. increases trout recruitment at the expense of maximum size" is currently under review at Canadian Journal of Fisheries and Aquatic Sciences.

Second, we used water temperature, air temperature, and reservoir storage data from the past three decades in the Colorado River Basin and from other western tailwaters to quantify how past climate shifts (from drought conditions to large precipitation events) influence water temperatures downriver of a variety of dam types throughout the intermountain West. Specifically, we examined how different types of dams may nonlinearly influence the magnitude and seasonality of tailwater temperatures, which has important implications for managing trout populations and maintaining endangered fish populations in a changing climate. We found that water temperatures downriver of shallow or run-of-the-river dams are already close to equilibrium with air temperatures, so decreases in reservoir size resulting from drought may not substantially influence tailwater fisheries in those systems. However, penstocks from large storage dams such as Glen Canyon Dam are likely to draw water from closer to the reservoir surface during a drought, substantially increasing tailwater temperatures downstream that may benefit endangered fish populations.

We are currently preparing a manuscript associated with these results entitled "Warmer and drier: predicting future thermal regimes in regulated rivers based on past drought conditions" which will be submitted to a peer-reviewed journal in FY17.

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

This information has management implications, particularly below Glen Canyon Dam where rainbow trout dynamics are central to understanding how to manage a functional sport fishery at Lees Ferry and its downstream relationship to native fish conservation in Grand Canyon. The primary objective of this project is to assess the effectiveness of GCDAMP policy actions that directly influence rainbow trout abundance, survival, recruitment, and movement in response to HFEs. An experimental comparison of pre- and post-flood responses are appropriate for assessing hydraulic effects to biota, but only partly addresses the fluvial mechanism that underlie this policy action (refer to Project 10, using an inter disciplinarian approach to determine HFE effects). Preliminary results suggests that there might have been a HFE effect on monthly growth rates of rainbow trout, particularly when we compare seasonal growth differences based on weight change (Fig. 6, shows changes in estimated monthly growth rate for a 200 mm trout across three seasonal growing periods). We observed slightly negative trout growth during two of the three fall intervals that span the same time period when a HFE was conducted. Secondly, we have observed positive growth during the fall of 2015, a year when a HFE was not conducted. Unfortunately, we are uncertain whether or not the observed growth differences can be partly or entirely ascribed to a hydraulic effect related to HFEs. Based on trout recaptures there is no indication that fish moved or were displaced by any of these HFEs. If there was a flow effect it likely acted on the benthic invertebrate community; and secondarily, on trout by reducing the invertebrate prey available following the flow disturbance. Unfortunately, the cause and effect relationship between the 2014 HFE and trout growth is confounded by what appears to be a much larger effect that was also occurring at the same time on the benthic invertebrate community, likely over multiple years (nutrient hypothesis). Project 9.2, previously reported that trout growth declined incrementally over each year, particularly over most of 2014 (Korman et al. 2016, Yard et al. 2016). However, by the early fall period of 2014 the remaining trout that survived (Fig. 3) showed elevated growth during the start of fall, the time interval just prior to the third HFE. This is an interesting response since the fall season is typically less productive because of reduced primary production and increased demand for prey due to elevated fall temperatures. Yet it is notable that once trout densities were substantively reduced from their former levels (Fig. 3), trout growth increased. Was this growth response due to the overall reduction in trout prey demand or an actual increase in benthic invertebrates? Nevertheless, this positive trout growth response was brief, since we observe a trout growth reduction post-flood. In contrast, the fall period in 2015 showed no reduction in trout growth, the only year that lacked a HFE. This same year also had low trout densities and elevated invertebrate drift concentrations. Because there are numerous independent factors that are likely confounding these results, additional replication is required to determine the causal mechanism for limited trout growth. It highlights the importance of making comparisons between pre- and post-flood and between years with and without HFEs. Toward that goal, a fish monitoring trip is planned in early January 2017 to determine if there was a decrease in trout growth during the fall that included the 2016 HFE.

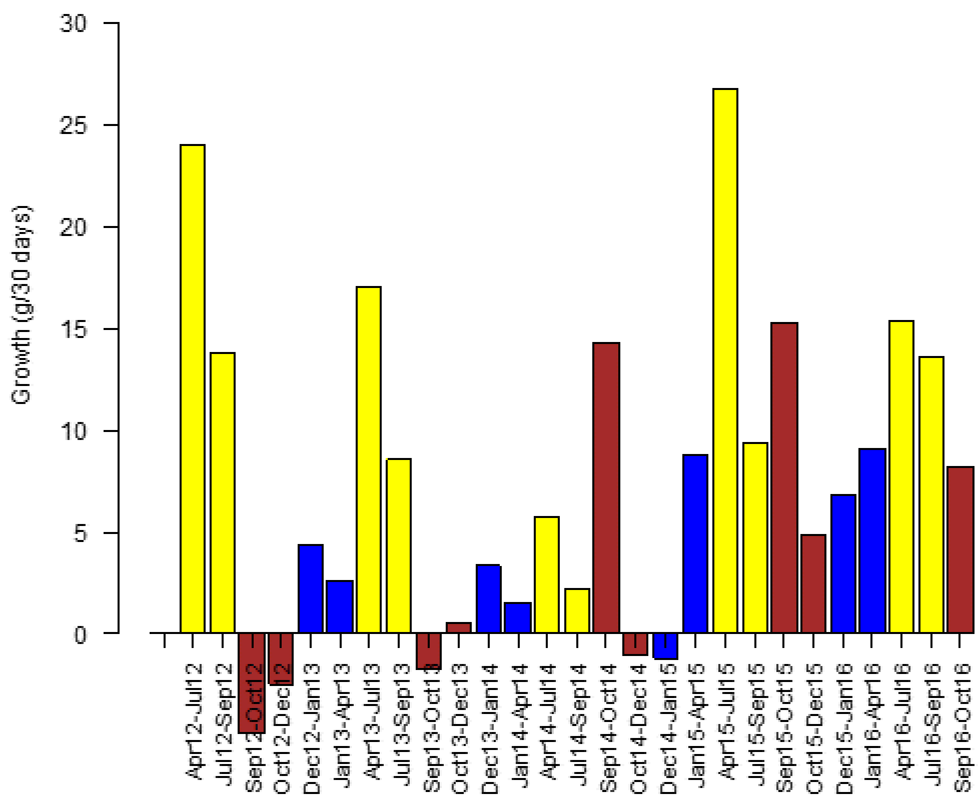

Figure 6. Trend data for growth of rainbow trout in Lees Ferry (April 2012 to September 2016). The bars show mean monthly growth rates (g/30 days) over sampling intervals, estimated for a 200 mm (fork length) rainbow trout, where colors represent seasonal growing periods (yellow = late spring and summer, brown = fall, and blue = winter and early spring).

For more detail on addressing future questions in 2017 related to HFE effects, refer to Project 10.

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

The purpose of this project is to examine the effects of low, steady fall flows followed by a potentially energetically-costly HFEs on the physiological condition of age-0 rainbow trout in Glen Canyon. We collected trout from September to December in 2013-2015 to compare pre- and post-flood samples to those collected during a control (non-HFE) year. In FY16 we extracted otoliths from post-flood samples, prepared them for microstructural analysis, and calculated the daily growth rate of fish associated with various types of flows before and after each flood using patterns embedded in otoliths. In addition, we sent pre-flood, post-flood, and control fish samples to an independent laboratory to quantify their physiological condition using sensitive biochemical indicators (triglyceride, cholesterol, phospholipid, total lipid). These data will be compared to food base data collected prior to, during, and after each flood, as well as recruitment data the following spring, to determine whether physiology plays a role in the influence of HFE's on rainbow trout population dynamics in Lees Ferry. These data will be analyzed and a manuscript will be submitted to a peer-reviewed journal in FY17.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Nonlinear relationships can lead to bias in biomass calculations and drift-foraging models when using summaries of invertebrate drift data.		May 2016	Sept 2016	Dodrill, M. J and C. B. Yackulic. 2016. *Environmental Biology of Fishes* 99.8-9: 659-670.
Journal Article	Prey Selection by Rainbow Trout in a Large River Ecosystem in Relation to Physical and Biological Factors.		July 2017		*In prep*. Dodrill, M. J., C. B. Yackulic, T. A. Kennedy and M. D. Yard.
Journal Article	Drought induced warming in tailwaters of the Western U.S. increases trout recruitment at the expense of maximum size.		July 2016	Feb 2017	*In review*. Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. *Canadian Journal of Fisheries and Aquatic Sciences*
Journal Aritcle	Warmer and drier: predicting future thermal regimes in regulated rivers based on past drought conditions.		Feb 2017		*In prep*. Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. *Global Change Biology*
Journal Article	Effects of turbidity on predation vulnerability of juvenile			June 2016	Ward, DL., R. Morton-Starner, and B. Vaage. 2016. *Journal of fish and*

	humpback chub to rainbow and brown trout.				*Wildlife Management* 7: 1-8
Journal Article	Effects of water temperature and fish size on predation vulnerability of juvenile humpback chub to rainbow and brown trout.			Nov. 2015	DL Ward, and R Morton-Starner 2015. *Transactions of the American Fisheries Society* 144(6) 1184-1191.
Journal Article	Factors controlling the abundance of rainbow trout in the Colorado River in Grand Canyon in a reach utilized by endangered humpback chub.			Jan. 2016	Korman, J., M.D. Yard, and C.B. Yackulic. *Canadian Journal of Fisheries and Aquatic Sciences*. 73: 105–124
Journal Article	Seasonal and Spatial Patterns of Growth of Rainbow Trout in the Colorado River in Grand Canyon			Jan. 2016	Yard, M.D., J. Korman, C. J. Walters, and T.A. Kennedy. *Canadian Journal of Fisheries and Aquatic Sciences*. 73: 125–139
Journal Article	Trends in recruitment, abundance, survival, and growth over a boom-and-bust cycle of a rainbow trout tailwater population.		Nov. 2016		*In review*. Korman, J., and M.D. Yard. *Transactions of the American Fisheries Society*
Journal Article	On the Catchability of Fish Populations and Interpretation of Catch per unit effort Trends		Dec. 2016		*In review*. Korman, J., and M.D. Yard. *Transactions of the American Fisheries Society*
Journal Article	Invertebrate production estimates from bioenergetic demand by rainbow trout in the Colorado River in Grand Canyon				*In prep.* Yard, M.D., J. Korman, C. J. Walters, and M.J. Dodrill.
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. *Ecological Applications.*
Presentation	Bioenergetic modeling of Glen Canyon rainbow trout fishery—Exploring effects of temperature, trout population size and		Jan. 2016		Yard, M.D., and J. Korman. 2016. GCMRC Annual Reporting Meeting, Phx. AZ.

	biomass on the benthic invertebrate consumption.				
Presentation	Natal Origins of Rainbow Trout Project years 1-4 (Nov '11 – Dec ' 15)		Jan. 2016		Korman, J., and M.D. Yard. 2016. GCMRC Annual Reporting Meeting, Phx. AZ.
Presentation	Boom-and-Bust Cycles in Glen Canyon's Rainbow Trout Population		Mar. 2016		Yard, M.D., and J. Korman. 2016. Lees Ferry Guide Meeting, Marble Cyn., AZ
Presentation	Consequences of an altered hydrologic regime for Colorado River fishes in Grand Canyon		Aug. 2016		Ward, D.L. 2016. 146th annual meeting of the American Fisheries Society, August 21-25, 2016, Kansas City, MO
Presentation	Drought increases trout recruitment at the expense of adult size in tailwaters downriver of dams in Western North America.		Aug. 2016		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 2016 American Fisheries Society Annual Meeting. Kansas City, MO.
Presentation	The influence of drought and climate change on water temperature and trout population dynamics in Western U.S. tailwaters.		Aug. 2016		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 2016. GCDAMP, Fisheries Program Review, Protocol Evaluation Panel.
Presentation	Using bioenergetics models to determine how water temperature and food consumption influence *Oncorhynchus mykiss* and *Salmo trutta* growth in western U.S. tailwaters.		Oct. 2015		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 2016. 13th Biennial Conference of Science and Management on the Colorado Plateau and Southwest Region.

Project 9	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$361,200	$5,000	$84,000	$190,000	$0	$59,647	**$699,847**
Actual Spent	$350,153	$4,119	$100,675	$140,000	$0	$58,716	**$653,663**
(Over)/Under Budget	**$11,047**	**$881**	**($16,675)**	**$50,000**	**$0**	**$931**	**$46,184**

FY15 Carryover	**$58,249**	**CPI Decrease**	**($35,433)**	**FY16 Carryover**	**$69,000**

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

- Salary costs decreased due to contracting lipid analysis rather than doing in-house.
- Operating expenses increased due to contract for lipid analysis rather than doing in-house.
- Cooperative agreement costs decreased due to reaching funding cap on 5 year agreement with Ecometric.
- Carryover will be used to offset FY17 shortage.

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)	Dan Buscombe, USGS, GCMRC Mike Yard, USGS, GCMRC Josh Korman, EcoMetric Research Paul Grams, USGS, GCMRC Tom Gushue, USGS, GCMRC Scott, Wright, USGS
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SUMMARY

The goal of Project 10 is to promote collaborative efforts between physical and biological scientists using an interdisciplinary approach. This project was to help inform resource managers on the Glen Canyon Dam Adaptive Management Program (GCDAMP), and in the development of the Long Term Experimental Management Plan Environmental Impact Statement (LTEMP) for Glen Canyon Dam operations, and on how specific dam operations influence the river's bed-sediment type, inundation of channel margins used by fish, and other aquatic organisms. This information has management implications, particularly between Glen Canyon Dam and Lees Ferry where rainbow trout are important as a sport fishery and relative to native fish conservation in Grand Canyon. The primary researcher, Ted Melis, Physical Scientist, responsible for leading and completing Project 10 has been promoted to Deputy Director of Southwestern Biological Science Center. The loss of this key person has potentially jeopardized the successful completion of this project. For this reason a revised proposal was submitted that identifies how the stated study objectives and deliverables are to be met as specified in the original proposal (see: *http://www.usbr.gov/uc/rm/amp/amwg/mtgs/14aug27/Attach_06d.pdf).*

The revised proposal is to provide a clear direction and means to meet the stated objectives in Project 10, with a focus towards policy related questions. Successful completion of Element 10.3 is largely dependent on the continuation of the data collection activities, analysis, and synthesis by original investigators listed in Project 10, with a slight modification in budget to account for the involvement of two additional cooperators J. Korman of Ecometric Research (Vancouver, BC), and Scott Wright, Research Hydrologist, U.S. Geological Survey, California Water Science Center.

<u>Project Element 10.1. Imaging channel-bed, bed-texture, and change detection</u>

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 continued refining the methods for sidescan data processing developed in FY2016 and are now implementing those methods in an open source software package. That software performs automated classifications of bed composition into broad Wentworth-style grouping of sediments (i.e. sand, gravel, boulders) by a statistically-based texture analysis [Buscombe in review, Hamill et al. 2016]. We are currently processing the data to develop 30-bed classification maps for sidescan sonar surveys collected during 4 sampling trips between April 2014 and April 2015 in the Natal Origins study reach 4a. These data will provide objective quantification of riverbed composition at temporal and spatial scales that are consistent with fish sampling program.

Project Element 10.2. Analyzing Channel-Margin Geometry, and Shoreline Responses to Flow Variation using Channel Map Data

The purpose of this project is to conduct the slope analyses related to proportion of low and high-angle channel margins. The geospatial data to be used for processing and analyzing the channel-margin geometry and supplying spatial characteristics, such as slope criteria, has been dependent on the development and delivery of the channel map digital elevation model (DEM) created and processed under the Geomorphology project (Project 3). These data now exist at an acceptable resolution (1-meter) for the Glen Canyon reach, and initial tests have been run on how best to merge these data with the airborne digital surface model (DSM) elevation collected in May 2013 as part of the remote sensing overflight. Additionally, in order to use the airborne data from 2013, elevations in vegetated areas needed to be removed and interpolated so that the two merged data sets are both representing bare earth elevations. This task was accomplished in 2016. Once these data sets (airborne topography and combined channel map topography) are merged, then a slope map will be generated for the entire reach and characterized as low- and high-angle areas. These data will then be overlayed with fish sampling unit data as described in Project Element 10.3.

Project Element 10.3. Synthetic Analysis of Rainbow Trout Catch and Physical Data

Purpose of *Element* 10.3, is to integrate 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. Data from the first two project elements, *Elements 10.1 and 10.2,* are on schedule and findings will be available for analyses. Other sources of data are to come from Project 9.2, entitled “Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam/Natal Origins”, which is now available since fieldwork has been concluded (end of FY16).

Hypotheses being tested include:

1) We hypothesize that sediment supply sources like Honey Draw, Ferry Swale, -9 Mile Draw, Waterhole Canyon contribute fines (sands and gravels) to the channel-bed that are available for transport and deposition along channel margins during experimental high flows. The spatial distribution of fish densities, size-structure, survival, growth, and condition are influenced by these cumulative loads, flow fields, and channel margin deposits. Sedimentation is likely to have a greater effect on the availability aquatic food resources and by extension indirectly on trout.
2) Higher water velocities during HFEs have the potential to displace trout downstream. We will compare the location of individually-tagged fish before and after HFEs to evaluate whether downstream movement caused by HFE’s is occurring.
3) HFE’s have the potential to reduce benthic biomass and lower drift densities. If this occurs, rainbow trout growth may be reduced following HFE’s. We will compare growth rates before and after HFE’s to determine whether this is occurring.
4) Fine sediment loads from tributaries like Ferry Swale and Waterholes Canyon, combined with reduced water surface gradient due to downstream controls by effecting the quality of benthic habitat for invertebrates which in turn control the growth, condition, and abundance of rainbow trout in Lees Ferry.

The available data are to be integrated, analyzed and synthesized into a number of manuscripts and prepared for publication by FY17. Topics cover: 1) Direct and indirect effects of high-flow experimental (HFE) on the

rainbow trout fishery, and 2) Spatial patterns in growth, condition, survival, and abundance of rainbow trout in Lees Ferry. Lastly, 3) a white paper describing optimal levels for trout management flows.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Manu script	Direct and indirect effects of high-flow experimental (HFE) on the rainbow trout fishery.	Sep. 2017			
Manu script	Spatial patterns in growth, condition, survival, and abundance of rainbow trout in Lees Ferry.	Sep. 2017			
Repor t	Determining optimal levels for conducting trout management flows.	Sep. 2017			
					Hamill, D., Buscombe, D., et al., 2016, Towards bed texture change detection in large rivers from repeat imaging using recreational grade sidescan sonar. Proceedings of the 8th International Conference on Fluvial Hydraulics, St. Louis, Missouri, July 2016.
					Buscombe, D., in review, PyHum: Python toolbox for shallow water physical habitat assessment using recreational grade sidescan sonar. Environmental Modeling and Software

Project 10	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	urden 11.983%	Total
Budgeted Amount	$129,800	$5,000	$0	$0	$0	$16,153	**$150,953**
Actual Spent	$50,502	$10,000	$0	$25,204	$0	$8,006	**$93,712**
(Over)/Under Budget	**$79,298**	**($5,000)**	**$0**	**($25,204)**	**$0**	**$8,147**	**$57,241**

FY15 Carryover	**($21,327)**		**CPI Decrease**	**($7,643)**		**FY16 Carryover**	**$28,271**

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

- Salary costs decreased due to sending funds to Utah State University for student rather than USGS employee.
- Cooperative agreements increased due to sending funds to Utah State University for student rather than USGS employee. Also, the cooperative agreement was front loaded so FY17 costs will be lower.
- Carryover will be used to offset FY17 shortage.

Project 11: Riparian Vegetation Monitoring and Analysis of Riparian Vegetation, Landform Change and Aquatic-Terrestrial Linkages to Faunal Communities

Program Manager (PM)	Barbara Ralston	**Investigator(s)** (I)	Barb Ralston, USGS, GCMRC Daniel Sarr, USGS, GCMRC Joel Sankey, USGS, GCMRC Paul Grams, USGS, GCMRC Charles Yackulic, USGS, GCMRC Ted Kennedy, USGS, GCMRC Jeff Muehlbauer, USGS, GCMRC David Merritt, USFS Patrick Shafroth, USGS, Fort Collins Joe Hazel, NAU Emily Palmquist, USGS, GCMRC Laura Durning, NAU Todd Chaudhry, NPS Dustin Perkins, NPS John Spence, NPS
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SUMMARY

Goals and Objectives FY15–17

Riparian vegetation is an important part of the Colorado River ecosystem in that it influences sediment deposition and retention, is key habitat for wildlife, can reduce campable area, adds beauty to the landscape, and creates shade and windbreaks. This project aims to monitor changes to riparian vegetation using field-collected data and digital imagery (11.1, 11.2), assess possible feedback loops between vegetation and sediment on sandbars (11.3), and quantify links among riparian vegetation, terrestrial wildlife, and the aquatic ecosystem (11.4). Additionally, this project facilitated a review of success and failures in riparian restoration efforts to inform potential restoration in Grand Canyon (11.5).

Project Element 11.1 Ground-based Vegetation Monitoring

Ground-based (field collected data) vegetation monitoring is conducted to quantify changes in cover and composition of riparian vegetation. Changes in the amount and kind of vegetation can alter biodiversity, affect the interactions with flows and sediment, influence visitor experiences and overall, affect ecosystem functioning.

This element of project 11 measures and analyses plant cover and species presence to assess change as related to the geomorphic setting, elevation above the channel, and flow regime. The specific objectives of the element are:

1. To annually collect vegetation data (presence, cover) within a geomorphic and hydrologic framework downstream of Glen Canyon Dam.

2. Use the traits of the plants found to identify plant response-guilds.

Figure 2. Vegetation cover is generally lower between the LCR and National Canyon. Shown is a debris fan at river mile 112.8R on 8/31/2016

3. Collect data and describe results in a manner that can be utilized by multiple stakeholders, such as for monitoring approaches used 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.

Monitoring was conducted August – October in 2015 and 2016 in both Glen Canyon National Recreation Area (GCNRA) and Grand Canyon National Park. In 2016, data was collected at 89 randomly selected sample sites between river mile -15.5 and 240, as well as 43 long-term monitoring sites. Both the random site and long-term monitoring site data from 2016 are currently being entered and error checked. Data from 2012 – 2015 are available for use. Summaries of the 2014 and 2015 data indicate that vegetation cover remained relatively unchanged. Total foliar cover tends to be lowest between river miles 61 and 160, but woody vegetation cover is fairly constant along the length of the study area. While total foliar cover is generally higher on channel margins than on debris fans and sandbars, woody vegetation is notably higher on sandbars in Marble Canyon than in river segments downstream of the Little Colorado River. Nonnative species cover is highest between river miles 160 to 240, likely due to *Cynodon dactylon* (Bermuda grass). *Tamarix* spp. (Salt Cedar, Tamarisk) is particularly high in cover on channel margins in Marble Canyon. A species list and summary of the 2016 data will be available at the annual reporting meeting in January 2017.

Figure 3. Woody vegetation is greater on sandbars in Marble Canyon than downstream of the LCR. Shown in Nautiloid (river mile 35.iL) on 10/3/2016.

Analysis of the 2014 field collected data identifies three distinct riparian vegetation communities that occur along the river below Glen Canyon Dam. These different communities may respond to dam operations differently. A manuscript identifying, describing, and discussing the importance of these groups to monitoring and research is currently being developed.

A Techniques and Methods document describing the riparian vegetation monitoring methods was submitted for external review. A methods comparison was subsequently conducted in GCNRA in June to address reviewer comments. Initial analyses indicate that these methods are appropriately reliable, but a full analysis will be included in the Techniques and Methods document as an appendix. This will also be accompanied by the result of power analyses, which are being conducted to confirm necessary sample sizes.

Work identifying and refining vegetation-flow response guilds is being continued by collaborators. Collaborators at NAU, funded by USGS through the WaterSMART Program, completed a thesis and are working on two manuscripts for publication that investigate the functional traits of over 100 species that occur along the Colorado River through Grand Canyon. These data allow species to be placed in functional guilds more accurately, which improves the strength of models predicting the frequency of functional guilds in relation to dam operations. Using these newly acquired data, USGS and Forest Service collaborators are reanalyzing the vegetation-flow response guilds and developing models of probable frequencies of those guilds given different flow regimes.

In the next year, we will be moving forward with publishing the Techniques and Methods monitoring protocol, publishing the manuscript describing and evaluating the riparian floristic communities, and completing the manuscripts identifying and modeling the vegetation-flow response guilds. Annual monitoring will take place in Aug – Oct of 2017 in both Glen and Grand Canyons. Continued annual monitoring of riparian vegetation should allow us to examine the influence of flow regime on riparian vegetation cover and composition.

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

The overall goal of this project element is to map changes in woody vegetation at the landscape scale through image processing, classification, and analysis. The specific objectives of the element are:

1. To produce an accurate classification of vegetation from the imagery acquired with the remote sensing overflight in 2013.
2. To quantify stability and changes in vegetation composition from the classifications of vegetation completed for imagery acquired in 2002 to 2013.
3. 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.
4. To detect and map tamarisk leaf beetle effects for remotely sensed vegetation canopies from overflight imagery from 2009 to 2013.

We are on track to accomplish these objectives by the end of the TWP (i.e., during FY17). The methodological steps required to accomplish objectives 1 and 2 were to first complete and publish the mosaic of overflight imagery acquired in 2013 (Durning et al. in press). Next was to complete and publish the total vegetation and river channel classification dataset from the 2013 image mosaic. These datasets are currently in review and nearing official USGS publication. The final step is to complete a classification of important riparian vegetation associations (groups of spectrally similar vegetation species) based on the 2013 image mosaic. This step is currently underway. We have quantified short-term (i.e., 2002 to 2013) and longer-term (1965-2013) stability and changes in total vegetation and presented these results at the Annual Reporting Meeting and the AMWG meeting in 2016. We have shown with this work that riparian vegetation has increased in area since completion of Glen Canyon Dam, and analysis of data acquired during the most recent overflight in 2013 shows that vegetation has continued to increase at elevations as low as below 24,000 CFS. Elevated base flows promote the expansion of riparian vegetation onto bare sand habitat and short pulses of high flow, such as controlled floods, do not keep vegetation from expanding onto bare sand habitat. We plan to quantify stability and changes in vegetation associations between 2002 and 2013 once the 2013 classification is completed in the coming year. We then plan to complete the analyses for objective 3.

Figure 4. Example of the 2013 imagery with automated total vegetation overlay (green). Image location is Colorado River and Little Colorado River confluence.

Finally, we have accomplished a great deal of work related to the fourth objective about detecting and mapping tamarisk leaf beetle effects from overflight imagery acquired in 2009 and 2013. We know for three important reaches of the river (areas surrounding Glen Canyon, Kanab Creek, and National Canyon) how much tamarisk exists based on detailed maps we've developed, and how much of this tamarisk was impacted by the beetle and defoliated during the growing season in 2013. We have shown with this work that the canopy cover of green, healthy tamarisk shrubs decreased from 2009 to 2013 and that this decreased the amount of leaf biomass on the shrubs and increased the amount of leaf biomass shed to the floodplain. We determined that on average, approximately 1/10th to 1/3rd of tamarisk in the study reaches were defoliated by the beetle at the time of the 2013 overflight. During FY17 we will expand the tamarisk defoliation mapping completed in the initial three reaches to the remainder of the river corridor. We also developed a method to make detailed maps of the amount of biomass associated with individual tamarisk trees in the Glen Canyon reach where we used lidar remote sensing data to enable this work. In the future, we hope to develop and implement a remote sensing-based method to monitor and map mortality of beetle-impacted tamarisk.

Eight products (papers, reports, theses, or datasets) from this project element have either already been published or are imminently pending (See table).

Project Element 11.3 Influence of sediment and vegetation feedbacks on the evolution of sandbars in Grand Canyon since 1991

Recent research in other large, eddy-dominated river systems has shown that vegetation influences the deposition of sediment and sediment deposition alters the location and types of riparian vegetation. Feedback loops between vegetation and sediment in Grand Canyon could be influencing the efficacy of high flow experiments and vegetation encroachment on camping areas.

The overall goal of this element is to understand the interplay between hydrology, vegetation and sediment dynamics among 20 sandbars for a 23-year period (1991 to 2013). The specific objectives of the element are:

1. How does establishment of vegetation nearer the channel (below stage at power plant capacity (31,000 ft3/s) influence sediment deposition on sandbars (net deposition and scour) associated with experimental high flows?

2. Does expansion of woody riparian vegetation below stage elevations of power plant capacity (31,000 ft3/s) and associated sediment response decrease shoreline complexity and negatively affect native fish rearing habitat (backwaters) and riparian habitat (compositional and structural complexity)?

3. In a regulated, debris fan-eddy river system, does expanded floodplain development on reattachment bars result in smaller eddy circulation zones and with reduced temporary storage capacity, or do river currents fundamentally change and affect sediment storage and transport capacity?

Data to support this project is being compiled. Historic vegetation data collected by Kearsley *et al* in the late 1990's and early 2000's is being gathered, entered, and assessed for usefulness for this project. Additionally, survey data coincident with the intermittent vegetation data are being located and converted to a useable format.

This work was to be conducted by the Research Ecologist position, which has been vacant since August 2015. As such, this project has not started other than compiling historic data. Related work is being conducted as part of Project 3.3, and this project will incorporate those findings.

FY17 work will begin when a Research Ecologist starts and will have to begin with the FY15 and 16 tasks of parameter identification, determining the best methodology, and preliminary analysis of 4 sandbars. Hiring for the Research Ecologist position is on-going.

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

The overall goal of this subproject is to quantify the strength of aquatic-terrestrial linkages and assess the relative importance of vegetation change and aquatic production in driving the population dynamics of a subset of the terrestrial fauna. The specific objectives of the element are:

1. Build a strong conceptual basis for understanding and analyzing linkages between flow management and riparian biodiversity in the Colorado River ecosystem

2. 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.

3. Identify whether long-term changes in vegetation have influenced populations of terrestrial consumers, particularly birds and terrestrial insects in Glen Canyon.

4. To the extent possible, determine the links between terrestrial fauna and vegetation-flow response guilds.

In FY15, this project had minimal funding. With assistance from John Sabo, an aquatic-terrestrial expert at Arizona State University, we identified a graduate student, Christina Lupoli, who began work associated with this element in FY16 when there was sufficient funding. We were able to leverage funding available by ASU such that Lupoli's funding was half GCDAMP and the rest ASU. In FY16, Lupoli explored different research approaches at a low cost by joining already planned trips to Glen Canyon and downriver. In particular, she joined multiple trips to Glen Canyon Dam by the aquatic food base trip and joined downriver trips by Grand

Canyon Youth, the Riparian Vegetation project and the Aquatic Foodbase project. The focus of research has been on documenting patterns in relative abundance of various terrestrial consumers as well as taking non-lethal tissue samples (i.e., fur from rodents and tail clippings from lizards) to determine the relative importance of terrestrial versus aquatic insects in the diet of these consumers. We are working to develop reliable relative population indices so we can compare patterns of small mammal, birds, bat, and lizard occurrence to patterns of aquatic insect production – both through space and time.

Beginning in April 2016, we also deployed pitfall trap arrays at ten to fifteen sites throughout the Colorado River reach between Glen Canyon Dam and Badger Rapid, concurrent with monthly sticky trap monitoring. The goal of pitfall trapping is to collect terrestrial arthropods, which will be used to quantify the relative magnitude of aquatic resource usage in terrestrial arthropod food webs. Sample collection, processing, identification, and preparation for stable isotope analysis is ongoing. In addition, on downriver trips, tissue samples were taken from 128 lizards across five species (*Uta stansburiana* - Common Side-blotched lizard; *Sceloporus magister* - Desert spiny lizard; *Urosaurus ornatus* - Ornate tree lizard; *Phrynosoma platyrhinos calidiarum* - Southern desert horned lizard; *Aspidoscelis tigris* - Tiger Whiptail) and 75 rodents across four species (*Reithrodontomys megalotis* - Western harvest mouse; *Peromyscus crinitus* - Cactus mouse; *Peromyscus eremicus* - Canyon mouse; *Dipodomys merriami* - Merriam's Kangaroo Rat) and are currently being analyzed alongside samples of vegetation, terrestrial insects, including spiders, and aquatic insects.

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

This workshop took place in June 2015. A publication of the extended abstracts from the riparian restoration workshop is underway. It is anticipated to be available as a USGS Open-File Report in spring 2017. Work on this aspect of the work plan, and several others, has been delayed due to the Research Ecologist position being vacant since August 2015. A second workshop that was proposed has not taken place due to the lack of personnel and funding.

PRODUCTS/REPORTS					
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations Comments**
Dataset	Palmquist, E.C., Ralston, B.E., Sarr, D., Merritt, D., Shafroth, P.B., and Scott, J.A., 2016, Southwestern rip arian plant trait matrix, Colorado River, Grand Canyon, 2014 to 2016-Data: U.S. Geological Survey data release, *http://dx.doi.org/10. 5066/F7QV3JN1*.		Aug 2016		
Journal	Palmquist, E.C., Ralston, B.E., Sarr, D., Merritt, D., Shafroth, P.B., and Scott, J.A., Functional traits and ecological affinities of riparian plants along the Colorado River in Grand Canyon			Early 2017	In press, Western North American Naturalist.
Techni ques and Metho ds	Palmquist, E.C., Ralston, B.E., Sarr, D., and Johnson, T.C., in revision, Monitoring Riparian Vegetation Composition and Cover along the Colorado River downstream of Glen Canyon Dam			Oct 2017	Submitted for review Jan 2016, in revision.
Journal	Sarr, D.A., D.M. Merritt, E. C. Palmquist, J.A. Scott, P.B. Shafroth, B.E. Ralston, TE. Kolb, and M. McCoy-Sulentic, in prep, Riparian flow-response guilds for a large regulated river in the arid southwest			May 2017	Unexpected loss of lead author, currently being completed by collaborators.
Journal	D.M. Merritt, J.A. Scott, E. C. Palmquist, P.B. Shafroth and B.E. Ralston, In prep, Riparian flow-response guilds: a management tool			To be submitted summer 2017	Lead author D. Merritt (USFS), outgrowth of the guild identification project.

PRODUCTS/REPORTS					
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations Comments**
	to predict vegetation change along a regulated river.				
Journal	McCoy-Sulentic, M., Kolb, T., Merritt, D., Palmquist, E., Ralston, B, and Sarr, D., in review, Habitat variation in species-level plant functional traits along the Colorado River, Grand Canyon			Sept. 2017	Submitted to Ecology and Evolution. Project funded by WaterSMART, but contributing to GCMRC riparian vegetation monitoring.
Journal	McCoy-Sulentic, M., Kolb, T., Merritt, D., Palmquist, E., Ralston, B, Sarr, D., and Shafroth, P., in review, Changes in community-level riparian plant traits over hydrologic zones and inundation gradients, Colorado River, Grand Canyon			Sept. 2017	Submitted to Wetlands. Project funded by WaterSMART, but contributing to GCMRC riparian vegetation monitoring.
Journal	Palmquist, E.C., Ralston, B.E., Merritt, D., and Shafroth, P.B., Landscape scale processes influence riparian plant composition along a regulated river: Implications for research and management.			Oct 2017	In prep, to be submitted to Journal of Arid Environments.
Data Series Report	Durning, L.E., Sankey, J.B., Davis, P.A., Sankey, T.T., 2016 (in press). Four-band image mosaic of the Colorado River corridor downstream of Glen Canyon Dam in Arizona, derived from the May 2013 airborne image acquisition: U.S. Geological Survey Data Series ####, xx p.,			Dec. 2016	Currently in press

PRODUCTS/REPORTS					
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations Comments**
	http://dx.doi.org/10.3133/ds ####.				
Dataset	Durning, L.E., Sankey J.B., Davis, P.A., Sankey, T.T., 2016, Four Band Image Mosaic of the Colorado River Corridor in Arizona, 2013, including Accuracy Assessment Data: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F7 TX3CHS			Dec. 2016	Currently in press
M.S. Thesis	Bedford, A. "Remote Sensing of Tamarisk (Tamarix spp.) defoliation by the Tamarisk Leaf Beetle (Diorhabda carinulata) along the Colorado River in Arizona " M.S. Thesis. Northern Arizona University, May 2016		May 2016		Advised by E. Scheifer, T Sankey, J Sankey, B Ralston
Journal Article	Sankey, TT, Sankey, JB, Bedford, A, Horne, R, 2016, Remote sensing of tamarisk biomass, insect herbivory, and defoliation: novel methods and applications in the Grand Canyon region, Arizona, USA. Photogrammetric Engineering and Remote Sensing 82(8), pp. 645-652, doi: 10.14358/PERS.82.8.645		Aug 2016		
Journal Article	Sankey, J. B., B. E. Ralston, P. E. Grams, J. C. Schmidt, and L. E. Cagney (2015), Riparian vegetation, Colorado River, and climate: Five decades of		June 2015		

PRODUCTS/REPORTS					
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations Comments**
	spatiotemporal dynamics in the Grand Canyon with river regulation, Journal of Geophysical Reseach Biogeosciences, 120, 1532–1547, doi:10.1002/2015JG002991.				
Dataset	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 - Data: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F7J67F0P.		June 2015		
Dataset	Durning, et al, in review, 2013 image mosaic total vegetation classification dataset			Jan. 2017	Currently in review
Dataset	Durning, et al, in review, 2013 image mosaic water classification dataset			Jan. 2017	Currently in review
Open-file Report	Ralston, B. and Sarr, D. Case Studies of Riparian and Watershed Restoration in the Southwestern United States: Principles, Challenges, and Successes.			April 2017	Delayed due to loss of D. Sarr

Project 11	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$244,300	$13,500	$7,500	$139,500	$6,800	$35,976	**$447,576**
Actual Spent	$181,180	$4,711	$5,734	$168,279	$0	$28,011	**$387,914**
(Over)/Under Budget	**$63,120**	**$8,789**	**$1,766**	**($28,779)**	**$6,800**	**$7,965**	**$59,662**

FY15 Carryover	**$48,929**	**CPI Decrease**	**($22,660)**	**FY16 Carryover**	**$85,931**

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

- Salary costs reduced due to vacancy.
- Cooperative agreement expenses increased due to additional funding for MS student.
- Costs to other USGS cost centers decreased due to other center direct charging our project.
- Carryover will be used to fill vacancy and catch up on delayed work due to vacancy.

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, USGS, GCMRC Peter Bungart, Hualapai Tribe Tony Joe, Navajo Nation Michael Yeatts, Hopi Tribe Daniel Sarr, USGS, GCMRC Charles Yackulic, USGS, GCMRC
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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 affected cultural resource values that are important to Native American tribes? The intention of this research effort is two-fold: 1) document where and how dam operations have affected culturally-important riparian plants in the Colorado River corridor, and 2) lay a foundation of knowledge to support future restoration work that may be undertaken by the tribes and/or National Park Service to help maintain important qualities of the riparian ecosystem.

As originally conceived, this project involved two elements, each requiring a different approach: 1) an assessment of changes in vegetation in the Colorado River corridor below Glen Canyon Dam that relate to some of the expressed cultural interests of the Native American tribes involved in the Glen Canyon Dam Adaptive Management Program (GCDAMP), thereby creating a bridge between scientific and traditional knowledge systems; and 2) an assessment of how these changes may have affected (either positively or negatively) culturally-important aspects of the landscape valued by these same groups.

The first phase encompassed three primary objectives:

1) engage tribes in a collaborative research effort to identify changes in the riparian ecosystem of the Colorado River corridor that may have affected 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 Glen Canyon Environmental Studies (GCES)-era studies, existing GCMRC and tribal monitoring data, published articles, historical journals and oblique historical imagery; and

3) analyze these data to evaluate the previous distribution and comparative abundance of targeted (culturally-important) plant species throughout the river corridor landscape in comparison with current conditions.

The second phase of this project proposed to use the information obtained in Phase 1 to develop culturally-appropriate methods for eliciting tribal perspectives about the changes that have occurred to culturally-important important plant species and then use those methods to evaluate how the changes may have affected cultural landscape values important to each of the tribes. Specific methods to be employed in Phase 2 were to be determined collaboratively with tribal participants after they have had a chance to review the results of Phase 1 and had engaged in further discussion about possible future methodological approaches. Since initiation of the project in FY15, there has been a significant turn-over in tribal personnel, and several tribes that were formally supportive of this project have recently indicated that they no longer wish to participate in it. In addition the lack of a riparian ecologist at GCMRC throughout FY16, further hampered our ability to complete the project in FY16 as originally envisioned. This project now focuses primarily on completing Phase 1 research objectives and is anticipated to be completed in FY17.

Phase 1 Accomplishments

In February 2015, GCMRC hosted the first of two planned workshops. During this workshop, plant species of mutual interest to multiple tribes were discussed, and a list of plants was identified to be the focus of the pilot study (Table 1).

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

Goodding’s willow (*Salix gooddingii)*
Cottonwood (*Populus fremontii*)
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*)
Arrow-weed (*Pluchea sericea*)
Common reed (*Phragmites australis)*
Cattail (*Typha sp*.)
Horsetail (*Equisetum sp*.)
Dropseed (*Sporobolus* sp.)
Indian Rice Grass (*Achnatherum hymenoids*)

In FY16, Fairley continued worked started in FY15 by compiling available data on this list of 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, and historical river runner journals. In addition, starting in late summer 2015 and continuing in FY16, Fairley located historical imagery that could be analyzed for changes in vegetation through time. In addition to working with an existing collection of matched images from the Desert Laboratory Repeat Photography collection, in November 2015, high-resolution digital scans of several hundred photographs from the 1923 USGS Birdseye expedition were obtained.

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 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. This analysis work began in late summer of 2015, continued intermittently in FY2016, and is ongoing. The analysis identifies whether the plants of cultural value to the tribes are present in the photographs, are located in the same areas as in the past, and whether their abundance has increased or decreased in each photograph according to a simple ranked scale (e.g., no apparent increase/decrease, small increase or decrease (<25% change in numbers of individuals or total cover) or large increase or decrease (>25% change). It also evaluates changes in the physical context of where specific plants grow, 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.)

In addition to the photographic analysis, Fairley began compiling a bibliography of journal articles and other reference materials about each of the targeted species in FY16. Because the aim of this bibliography is to serve as a resource for future restoration efforts along the Colorado River, it primarily focuses on articles that document life history characteristics of each species and their adaptions to specific environmental conditions that encourage or discourage their propagation and long-term survival. For example, studies by Shafroth and others (1998, 2010) discuss how the rate of flood recession affects propagation of Goodding's willow, tamarisk, and cottonwood, and how burial by flood sediments appears to favor the survival of young shoots of native species such as Goodding's willow over tamarisk. For some species, such as cottonwood and phragmites, the available literature is extensive, and in these cases, only a subset of available journal articles is included in the bibliography, while for other species, such arrow-weed, very little published information is currently available. The gaps in available knowledge about specific species highlight areas that could potentially be filled by focused studies conducted through the GCDAMP.

In May 2016, in conjunction with the Project 4 river trip, Fairley worked with a volunteer photographer to begin matching photographs from the 1923 expedition. Approximately 40 photographs have been matched to date. All of them show increases in woody riparian vegetation within the former flood scour zone of the pre-dam Colorado River. Examples of two of these recently obtained matches is provided below (figures 1 and 2).

Figure 1. Matched view at river mile 126.1, right bank. Top photograph by E.C. LaRue, September 6, 1923. Bottom photograph taken by A. H. Fairley on May 10, 2016. Note that the 2016 view of the river is now obscured by dense, woody riparian vegetation dominated by tamarisk, arrow-weed, and seep-willow.

Figure 2. Matched view at river mile 197.0, left bank. Top photograph by E. C. LaRue, September 25, 1923. Bottom photograph taken by A.H. Fairley on May 11, 2016. Note in the 2016 view that the Goodding's willow tree is no longer present and a dense thicket of arrow-weed, and seep-willow now occupies the formerly shaded, open sandy shoreline.

Preliminary Conclusions

As of September 2016, approximately 35% of the Stanton collection had been systematically analyzed. The analysis completed to date shows that riparian vegetation has increased dramatically since 1889/1890 and that it has continued to increase since implementation of the GCDAMP in the mid-1990s. Woody native riparian shrubs -- specifically seep-willow.—increased significantly between the early 1990s and 2010–2011, while coyote-willow and non-native tamarisk increased at a slower rate. Netleaf hackberry increased between 1889/90 and the early 1990s, with diminished increases thereafter, while Goodding's willow has decreased substantially since 1889/90.

While this analysis was underway, Fairley learned that a similar study with a somewhat different (broader biology-focused) emphasis and methodology had been initiated by Dr. Michael Scott and colleagues, using a sample of the Stanton photographs and rematches from the early 1990s and 2010-2011. Fairley subsequently collaborated with Dr. Scott and other coauthors in preparing a book chapter based on the results of this study (Scott et al., in review). Some of the conclusions from analysis of the sample of repeat photographs include the following:

1) Woody riparian vegetation has increased throughout the river corridor in Grand Canyon between the 1990s and 2012. In general, total woody riparian vegetation, including tamarisk, showed increased cover and density during this period in 89.3% of the matched images from 2010-12, with seep-willow increasing in 53.4% of the views over the past 20 years. Previous speculation that coyote willow might gradually replace tamarisk under the post-dam flow regime (Stevens 1989) is not born out by the photographic evidence, as only ~2% of the 2010-2012 photos show noticeable increases in coyote willow. It should be noted, however, that this species can be difficult to detect in photographs with dense riparian vegetation.

2) Gains in riparian vegetation cover over the past two decades were primarily below the maximum stage of post-dam controlled floods (1,274 m^3/s), especially in near-shore locations for species like tamarisk, seep-willow, and arrow-weed.

3) Some of the increase in riparian vegetation in the new high-water zone below the stage of the 1983 flood (2,747 m^3/s) is due to the encroachment of species that are more commonly found in the old high-water zone, such as honey mesquite and desert broom.

4) In contrast to observed vegetation increases, 9.4% of the rematches in 2010-12 show no apparent change, and < 2% of the views show a decrease in woody riparian vegetation cover and density. Photographs that show little or no change are primarily located in narrow, canyon-bound sections of the river corridor, suggesting these settings may not be conducive to the establishment of persistent riparian vegetation.

5) Disconnection of the old high-water assemblage from modern river flows has left certain species like honey mesquite vulnerable to drought stress. The historic photographic evidence, coupled with other lines of evidence (e.g., Sankey et al. 2015), show a decline in vegetated cover in the old high water zone since the early 1990s. The work of Webb (1996) indicates that certain high water zone species such as catclaw acacia (*Acacia greggii*) may be less affected by drought than other long-lived species, such as mesquite.

6) In addition to the natural establishment of riparian vegetation in the new high water zone, some non-native species like tamarisk and Russian-olive (*Elaeagnus angustifolia*) have been deliberately removed from some places in the river corridor while native vegetation has been planted in other locations as experiments or pilot restoration efforts in Marble and Grand Canyons. The artificial manipulation of river corridor vegetation needs to be systematically tracked and mapped, and specific activities and locations of vegetation manipulation should be clearly documented in readily accessible reports, so that cause-and-effect relationships between flow management and vegetation response can be accurately assessed in the future.

7) Whether HFEs have been a factor in the recent expansion of riparian vegetation is currently unknown and will require careful, real-time monitoring of vegetation following HFEs or retrospective analyses examining the age structure of encroaching vegetation. The seasonal timing of HFEs also warrants further study as timing of high flows could preferentially shift the structure and composition of riparian vegetation.

Next steps

In FY17, using carry-over funds from FY16, we will complete the species-specific analysis using repeat photographs, and will continue to match and analyze additional photographs from the 1923 expedition. In 2017, in collaboration with Dr. Scott, we will report the results of this analysis in a peer-reviewed journal article. This article will expand upon the initial conclusions reached from analyzing a sample of the Stanton photographs and will focus in more detail on the changes in abundance and distribution of each of the species identified in the FY15 workshop, so as to provide a more comprehensive assessment of the changes in the distribution and abundance of culturally-valued riparian species along the Colorado River corridor.

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Scott M.L., Webb R.H., Johnson R.R., Turner R.M., Friedman J.M., and Fairley H.C. In review. Evaluating Riparian Vegetation Change in Canyon-bound Reaches of the Colorado River Using Spatially Extensive Matched Photo Sets. Chapter 18. *In:* Johnson R.R., Carothers S.W., Finch, D.M., and Kingsley, K.J., 20XX. *Riparian Ecology: Past, Present, Future.* Gen. Tech. Rep. RMRS-GTR-XXXX. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

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	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Dam-induced changes to riparian ecosystems and associated traditional cultural values downstream of Glen Canyon Dam, Arizona: a progress report on a pilot study integrating science and traditional ecological knowledge.		10/8/15		Fairley, H.C., 2015, Dam-induced changes to riparian ecosystems and associated traditional cultural values 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.
Chapter in edited volume	Evaluating Riparian Vegetation Change in Canyon-bound Reaches of the Colorado River Using Spatially Extensive Matched Photo Sets		9/15/16		Scott M.L., Webb R.L., Johnson R.R., Turner R.M., Friedman J.M., and Fairley H.C. In review. Evaluating Riparian Vegetation Change in Canyon-bound Reaches of the Colorado River Using Spatially Extensive Matched Photo Sets. Chapter 18. In: Johnson R.R., Carothers S.W., Finch, D.M., and Kingsley, K.J., 20XX. Riparian Ecology: Past, Present, Future. Gen. Tech. Rep. RMRS-GTR-XXXX. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Project 12	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$20,000	$2,500	$5,500	$45,000	$0	$4,705	**$77,705**
Actual Spent	$19,542	$2,278	$12,529	$0	$0	$4,116	**$38,464**
(Over)/Under Budget	**$458**	**$222**	**($7,029)**	**$45,000**	**$0**	**$589**	**$39,241**

FY15 Carryover	**$21,917**		**CPI Decrease**	**($3,934)**		**FY16 Carryover**	**$57,224**

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

- Operating expenses increased due to a contract to organize and upgrade the database associated with the Desert Laboratory repeat photo collection.
- Cooperative agreements decreased due to a decision by tribal participants to not be cooperators in Phase II of this project. Unspent funds will be used to support additional work on the photo collection, travel, salary and river logistics associated with completing the photo matching component of this project in 2017.

Project 13: Socioeconomic Monitoring and Research

Program Manager (PM)	Lucas Bair	**Investigator(s)** (I)	Lucas Bair, USGS, GCMRC Charles Yackulic, USGS, GCMRC John Duffield, Univ. Of Montana Chris Neher, Univ. Of Montana David Patterson, Univ. Of Montana Michael Springborn, UC Davis Craig Bond, Pardee RAND Mathew Reimer, UA Anchorage
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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 preferences and values are influenced by Glen Canyon Dam (GCD) operations. In addition, Project 13 is integrating 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 tools for scenario analysis to 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 preferences for, and values of, downstream resources as impacted by GCD operations; and (13.3) development of scenario analysis methods and tools, using economic metrics, to inform management actions and prioritize monitoring and research on resources downstream of GCD.

Summary of Activities Completed and Relevant Accomplishments

Project Element 13.1

Angler interviews were initiated at Lees Ferry in Glen Canyon National Recreation Area during the spring of 2015 in cooperation with the Arizona Game and Fish Department. Anglers were intercepted on the river to obtain creel, name, and mailing address information. Interviews continued into early Fall 2016.

Grand Canyon National Park private whitewater floater name and address information was collected from the National Park Service in October, 2015. The sample included 1,425 individuals who participated in whitewater trips in Grand Canyon between September 2014 and August 2015.

Office of Management and Budget clearance was received for the study. In-depth surveys were mailed to anglers and whitewater floaters early in FY16. Data entry and analysis occurred in the spring of FY16. The final report detailing the study results was submitted to the Bureau of Reclamation.

Highlights from the data collection include:

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

Project Element 13.2

Project 13.2 is scheduled to be implemented in FY17. Meetings to discuss details of Project 13.2 with Tribal representatives to the GCDAMP and Tribal staff occurred in FY16:

- Lucas Bair from GCMRC participated in Project 13.2 discussions at the Hopi Cultural Preservation office on February 8, 2016, at a Zuni Cultural Resources Advisory Team meeting on March 3, 2016 and with Navajo Adaptive Management and Technical Work Group representatives on April 20, 2016.

Project Element 13.3

A bioeconomic model was developed to identify the economically preferred management strategy for established nonnative fish to achieve humpback chub survival targets. The model was completed and the manuscript stemming from this work will be submitted in December 2016. In FY17 the model will be expanded to include the following: 1) evaluating parameter uncertainty to aid in the identification and prioritization of monitoring and research of native and non-native fish; and 2) assisting in the experimental design of future management experiments in the Glen Canyon Dam Long-Term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS) (e.g. trout management flows).

Summary of Reports and Products

Project Element 13.1

The results of the angler and whitewater floater surveys identified regional expenditures in local counties (Coconino, Mohave and Navajo Counties, AZ, Kane, San Juan and Washington Counties, UT; and Clark County, NV) and net economic value (NEV) per trip of each recreational activity over a range of average Colorado River flows (cfs) (Duffield et al. 2016).

Regional Expenditures

- Guided anglers on average spent $1,101 per trip with $861 of these expenditures spent locally.
- Non-guided anglers on average spent $369 per trip with $268 of these expenditures spent locally.
- Private whitewater floaters on average spent $1,634 per trip with $969 of these expenditures spent locally.

Net Economic Value

NEV is the amount of money recreationists would be willing to spend in additional to what they already spent on their trip.

- For anglers, NEV ranges from $87 - $432 per trip, depending on average Colorado River flow (cfs). Ranking of flow scenario NEV is consistent with Bishop et al. 1987 (Figure 1).

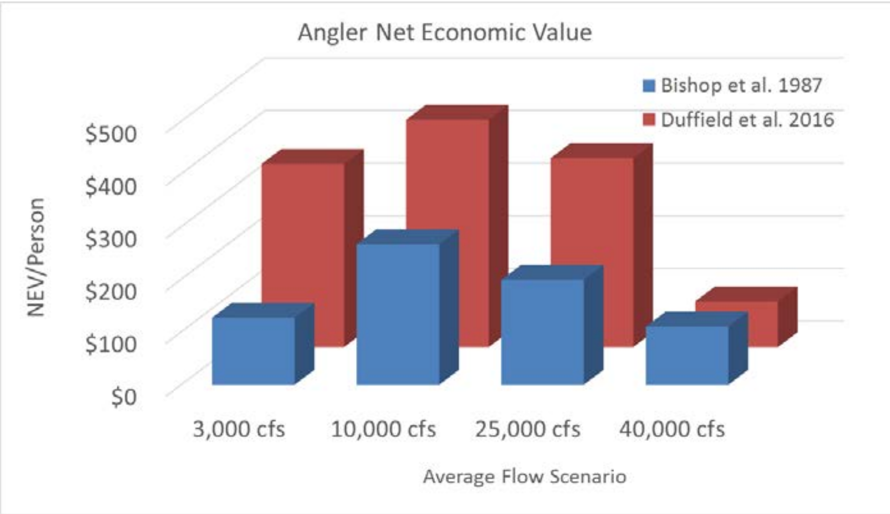

Figure 1 Angler net economic values across a range of average Colorado River flows. The data was generated from two surveys conducted in Glen Canyon National Recreation Area.

- For whitewater floaters, NEV ranges from $603 - $1,237 per trip, depending on average Colorado River flow measured in cubic feet per second (cfs). The whitewater floaters highest NEV is at 22,000 cfs. Ranking and magnitude of flow scenario NEV is consistent with Bishop et al. 1987 (Figure 2).

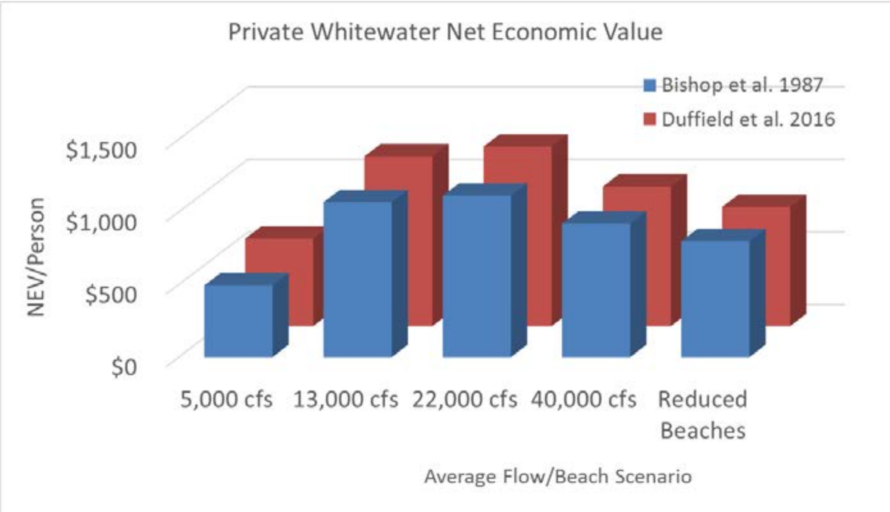

Figure 2 Private whitewater floater net economic values across a range of average Colorado River flows. The data was generated from two surveys conducted in Grand Canyon National Park.

Project Element 13.3

The modeling objective is to identify the least-cost management strategy that reduces downstream rainbow trout (trout) abundance to achieve mainstem annual juvenile humpback chub (chub) survival targets, which are set to meet chub population recovery goals. The model integrates an abridged version of the LTEMP EIS chub and trout population models, where trout populations in the Juvenile Chub Monitoring (JCM) reach trigger the number of removal trips in a year. The model captures uncertainty over annual trout recruitment in the tailwater of GCD.

Preliminary results indicate that the least-cost management strategy to achieve juvenile chub survival goals requires trout removal over a limited range of trout abundance.[2] For example, under this strategy, trout removals would not be conducted when the numbers of trout in the JCM reach are below 1,238 or above 2,622. Instead, removals would be performed 4-6 times per year, with the number of removals increasing with increasing trout abundance in the JCM reach (Figure 3).

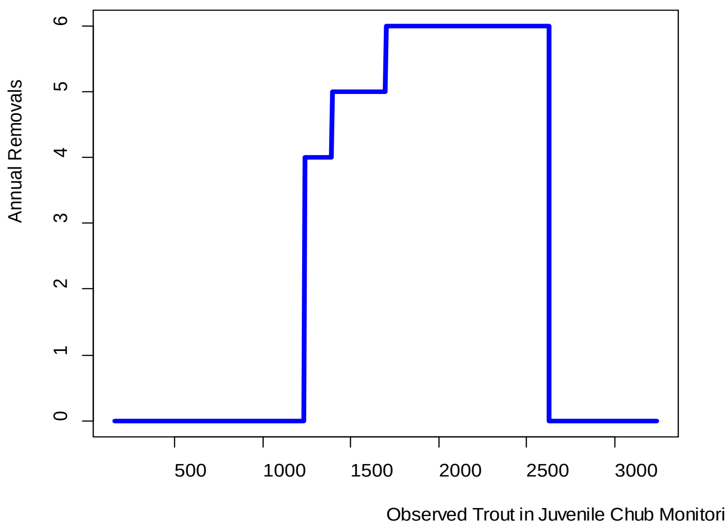

Figure 3 Least-cost trout removal strategy to achieve juvenile chub survival goals.

Next Steps

Project Element 13.1

- Next steps may include updating and expanding on the Glen Canyon and Grand Canyon Recreation Economic Utility that was developed for the LTEMP EIS (Interior 2016). This would provide a tool for the GCDAMP to conduct scenario analysis to assess the impacts of GCD operation on recreation in Glen and Grand Canyons, with up-to-date recreation economic data.

Project Element 13.2

- Project 13.2 is scheduled to be implemented in FY17.

Project Element 13.3

- Identify the importance of parameter uncertainty on the sensitivity of cost-effective outcomes in the bioeconomic model. Evaluating parameter uncertainty will aid in the identification and prioritization of monitoring and research of native and non-native fish.
- Incorporate additional non-native fish management actions and associated costs in the bioeconomic model, such as trout management flows at GCD, to identify the most cost-effective management alternatives to achieve juvenile chub survival targets under various future scenarios. This inform on future native and non-native fish management and other LTEMP EIS experiments.

[2] This information is preliminary. Final results will be present pending updated juvenile humpback chub field data collected during the summer of 2016.

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	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Bioeconomic Model of Rainbow Trout (Oncorhynchus mykiss) and Humpback Chub (Gila cypha) Management in the Grand Canyon.	NA	June 2016	NA	Bair, L., C. Yackulic, M. Springborn, M. Reimer, and C. Bond. Presentation at Association for the Sciences of Limnology and Oceanography. Santa Fe, NM.
Presentation	Bioeconomic Model of Rainbow Trout (Oncorhynchus mykiss) and Humpback Chub (Gila cypha) Management in the Grand Canyon.	NA	June 2016	NA	Bair, L., C. Yackulic, M. Springborn, M. Reimer, and C. Bond. Presentation at World Conference on Natural Resource Modeling. Flagstaff, AZ. June 16, 2016.
Report	Economic Analysis of Glen Canyon Angler and Grand Canyon Whitewater Visitor Surveys	FY 16	September 2016	FY 16	Duffield, J., C. Neher, and D. Patterson. University of Montana.
Journal manuscript	Economic Value of Angling on the Colorado River at Lees Ferry: Using Secondary Data to Estimate the Influence of Seasonality	Extra product no date	Published September 2016	FY 16	Bair, L., D. Rogowski, and C. Neher. This is a manuscript that is an outgrowth of Project 13.1.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal manuscript	Enhancing native species population viability via cost-effective invasive species control in the Grand Canyon, USA	FY 15-17	Anticipated submission December 2016	FY 16-17	Bair, L., C. Yackulic, M. Springborn, M. Reimer, and C. Bond. In preparation.

Project 13	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$124,900	$10,000	$800	$54,000	$0	$17,881	**$207,581**
Actual Spent	$126,087	$5,235	$22,628	$36,000	$0	$19,528	**$209,479**
(Over)/Under Budget	**($1,187)**	**$4,765**	**($21,828)**	**$18,000**	**$0**	**($1,647)**	**($1,898)**

FY15 Carryover	**$9,296**		**CPI Decrease**	**($10,510)**		**FY16 Carryover**	**($3,111)**

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

- Operating expenses increased and cooperative agreement expenses decreased due to contracting with one "Cooperator" rather than entering into a cooperative agreement.
- Shortfall will be made up with Project 15 carryover.

Project 14: Geographic Information Systems (GIS) Services and Support

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SUMMARY

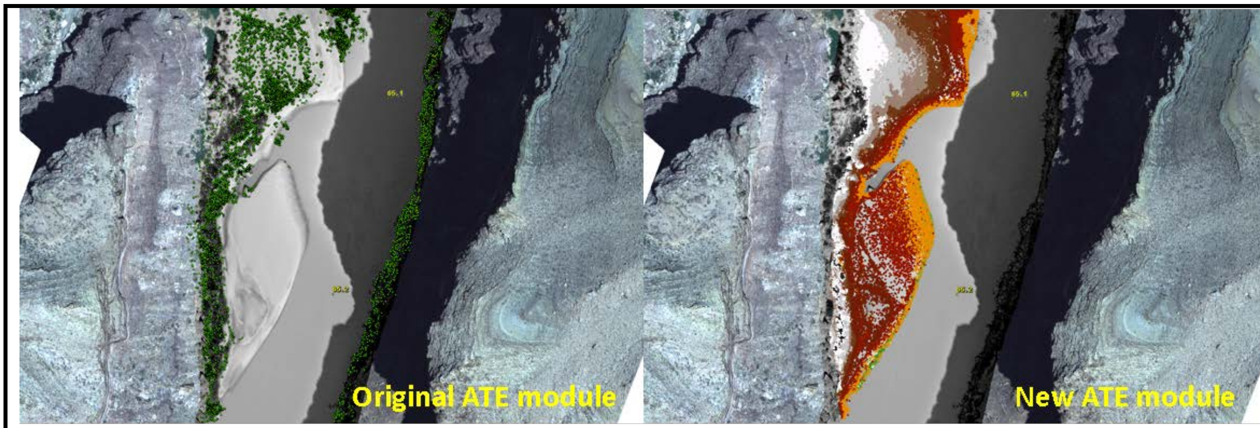
Geographic Information Systems (GIS) continues to play a critical role in nearly all of GCMRC's science efforts and is prevalent in many of the projects proposed in the FY15–17 Triennial Work Plan (TWP). It is used across disciplines and is a powerful tool for integrating geospatial data collected by 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. . This annual report affords us a chance to clearly define the work performed in each of these elements, accomplishments made over the past year, and how this work relates to both individual science projects and the GCMRC's overall mission.

14.1. Geospatial Data Analysis: Support to Science Projects

The GIS Project continued to support other science projects through geospatial data processing and analysis in FY15. As described in the Triennial Work Project, this element of the GIS Project has defined linkages to other projects where a high level of GIS support would be required. Most GCMRC projects usually require some level of GIS support, and this usually 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 science projects.

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 that are extracted photogrammetrically from 1984 historical aerial photography. Using the new DTM extraction software module from ERDAS (Auto DTM), a new workflow has been created to more accurately process the orthophotos into 3-dimensional data sets used for determining change in sandbar volume. This new module includes more robust algorithms for finding similarities between stereo pair photographic frames contained within a photogrammetric block. Four long-term monitoring sites have been processed using this new software module and results are showing denser point clouds than previously generated with better accuracies being reported at each site. This will allow us to more accurately compare sandbar volumes between 1984 and when ground surveys began in the 1990s. (See Project 3, 3.1.4).



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

GIS staff analyzed the tabular data and fixed 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 continued the work of migrating survey control network database out of Microsoft Access and into ESRI Geodatabase format. This will serve as a staging repository before migrating to a relational database for storing, analyzing, and serving Grand Canyon survey control network data. A new enterprise application now exists in beta format that is designed to take survey control network data out of Trimble Geomatics Office (TGO), perform quality control tasks, calculate or relate additional information to each survey control point, and populate a new SQL database. This new database will allow for both easier updates to the survey control network in Grand Canyon every year and for enabling access to the survey control network database through a web-based interface.

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

The GIS project also worked with GMCRC'S Socio-Economic scientist on analyzing Lees Ferry angler survey data to detect spatial and temporal patterns in fisheries use data for Glen Canyon. This work involved processing tabular data in meaningful aggregations and building summarized spatial data sets representing different attributes of site visits by fishermen. These attributes including zip code information, number of trips, average cost of each trip, and when the trips occurred (season). From these outputs, we created a series of maps driven by this analysis that show spatial and temporal use patterns of the Lees Ferry fishery.

14.2 Geospatial Data Management

During FY16 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.

For GCMRC's enterprise spatial database system, user-schema geodatabases in Oracle have been upgraded to version 10.3.1 (current ArcGIS version deployed on most machines in USGS). Also during this past fiscal year, the GIS project was able to expand on the scope of geospatial data hosted by the Oracle Spatial Database. Large, regional data sets now available through the database now include the May 2013 4-band overflight data, a new Glen Canyon 2013 1-meter DEM , and an updated Lake Powell 5-meter DEM and hillshade representing pre-dam topography.

During FY16, the GIS project was also involved with implementing 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 USGS data management protocols now require that the data used for peer-reviewed publications also go through a standardized review process, and be published concurrently with any publication.

14.3.1 Access to Geospatial Data Holdings – The Geospatial Portal

The GIS Project continued to advance the Center's ability to host and share geospatial and other scientific data through web-based applications. This work involved testing and troubleshooting 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. Upgrading these systems to the latest versions has provided 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.

Improvements to the GCMRC Map and Data Portal page ***https://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
https://grandcanyon.usgs.gov/gisapps/hfephotoviewer/hfe_2014.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). Additional HFE applications for past events (1996, 2004, 2008, 2012, and 2014) as well as for the most recent HFE in November 2016.

NEW Sandbar Time-Series Photo application

https://grandcanyon.usgs.gov/gisapps/sandbarphotoviewer/RemoteCameraTimeSeries.html

It is also now possible to view remote camera photographs that have been subsetted to one image per day for the entire length of record at each site. It is strongly recommended to use the date filtering tool under Options in the application prior to attempting to view these photo collections as there are close to 90,000 photos available through this app.

UPDATED Grand Canyon GIS Portal application ***https://grandcanyon.usgs.gov/portal***

There has been further development of the GCMRC GIS Portal to include more items, organized all web content on Portal into descriptive groups such as by resource type (physical, biological, socio-economic) and by data types (imagery, topography, base may layers, publication maps, river maps, etc.). This is a great platform for view basic geospatial items such as Grand Canyon map layers, river miles, imagery from past overflights, and topographic data sets.

UPDATED Geospatial Services page ***https://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 downloading a link (*.lyr) file of any service. They can also be accessed in web applications developed by users outside the GCMRC, or added into to a Google Earth session as a layer.

14.3.2. Access to Geospatial Data Holdings – ESRI's ArcGIS Online

http://usgs.maps.arcgis.com/home/search.html?q=GCMRC&t=content

We have expanded on the data made available to the public through this service. Data and services added or updated to ArcGIS Online include the May 2013 Colorado River Imagery, the Grand Canyon Aquatic Ecology Web Application, the Predicted Shorelines for High Flows application, Lake Powell Water Quality Station Map Service and Application, the Lake Powell Nutrient Sampling Map Service and Web Application, 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.

Because of the advances made in this project over the last few years, it became apparent that the lead in this project (GIS Coordinator) would take the initiative to begin leverage online cloud resources for delivering information to stakeholders and the public more efficiently in the future. This work has involved considerable collaboration with other IT staff in the Southwest Biological Science Center as well as with other USGS Science Centers.

Project 14	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$172,900	$6,000	$16,000	$0	$0	$23,355	**$218,255**
Actual Spent	$144,331	$2,430	$32,403	$0	$0	$21,469	**$200,634**
(Over)/Under Budget	**$28,569**	**$3,570**	**($16,403)**	**$0**	**$0**	**$1,886**	**$17,621**

FY15 Carryover	**$11,090**	**CPI Decrease**	**($11,099)**	**FY16 Carryover**	**$17,612**

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

- Salary costs decreased due to vacancies.
- Operating expenses increased due to buying software.
- Carryover will be used to offset FY17 shortage.

Project 15: Administration

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SUMMARY

During the Fiscal Year 2016, this budget covered the salaries for the communications coordinator, librarian, and 80% of a 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, and part of the salary of one program manager. 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 11.983%	Total
Budgeted Amount	$563,200	$32,000	$118,500	$81,500	$0	$87,968	**$883,168**
Actual Spent	$367,175	$32,112	$114,221	$91,539	$0	$64,280	**$669,327**
(Over)/Under Budget	**$196,025**	**($112)**	**$4,279**	**($10,039)**	**$0**	**$23,688**	**$213,841**

FY15 Carryover	**$414,395**	**CPI Decrease**	**($44,714)**	**FY16 Carryover**	**$583,521**

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

- Salary costs decreased due to GCMRC Deputy Chief and Physical Scientist vacancies.
- Cooperative agreements increased due to additional funds to NAU for support staff.
- Carryover will be used to offset FY17 shortage.

Logistics	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$264,500	$5,500	$793,200	$0	$0	$127,403	**$1,190,603**
Actual Spent	$267,490	$493	$908,270	$9,800	$0	$141,244	**$1,327,298**
(Over)/Under Budget	**($2,990)**	**$5,007**	**($115,070)**	**($9,800)**	**$0**	**($13,841)**	**($136,695)**

FY15 Carryover	**$0**	**CPI Decrease**	**($60,279)**	**FY16 Carryover**	**($196,974)**

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

- Operating expenses increased due to additional river trips and logistics expenses higher than budgeted.
- Cooperative agreements increased due to a coop. with Grand Canyon Youth.

Project 1: Lake Powell and Glen Canyon Dam Release Water-Quality Monitoring

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SUMMARY

In fiscal year 2016, we continued to collect physical, biological, and chemical data and samples from Lake Powell, Glen Canyon Dam, and Lees Ferry. However, similar to FY15, we sampled less frequently and in fewer locations than previously due to the decision by Reclamation to begin conducting Lake Powell monitoring internally.

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 receives no monetary support from the GCDAMP. In addition to direct funding of the program, Reclamation also provides support for laboratory analyses.

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

Monitoring Activities

Water-quality monitoring was conducted by Reclamation from 1965 to 1996, and then by GCMRC through 2015. For most years since 1997, the sampling program has consisted 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 have typically been conducted within a six-day time period. Monitoring has consisted 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 have been collected near the surface at selected stations. In FY16, Reclamation conducted two reservoir-wide surveys and GCMRC conducted four forebay surveys and maintained instruments monitoring GCD releases.

The beginning dates of the monthly GCMRC surveys are shown below. The surveys also included sample collection in Glen Canyon Dam and at Lees Ferry.

10/12/15	forebay
01/22/16	forebay
05/31/16	forebay
07/20/16	forebay

Monitoring activities included field observations of weather conditions, Secchi depth measurements, and vertical depth profiling of water quality parameters. In addition, chemical and biological samples were collected. Analyses of these samples are usually received within two months of collection. These data are all entered into a Microsoft Access database. Progress continues to be made to serve data from the Access database on the GCMRC website.

Current Conditions

Hydrology - Lake Powell received 9.62 maf (89% of average) of unregulated inflow in water year (WY) 2016, less than the inflow observed in 2015 and 2014 (94% and 96% of average, respectively), and significantly higher than inflows observed in 2012 and 2013 (45% and 47% of average, respectively). The reservoir elevation reached a peak of 3621.5 ft on July 9, 2016, compared to a peak of 3614.32 ft in 2015. At the end of WY2016, Lake Powell's surface elevation was 3,610.93 ft with storage of 12.8 maf, or 53% of full capacity. This is similar to the end of WY2015 when surface elevation was 3,606.01 ft, and storage was 12.3 maf.

Releases for FY16 totaled 9.0 maf (the same as for FY15) with operations under the Upper-Elevation Balancing Tier. Operations for FY17 will also fall under the Upper Elevation Balancing Tier, with a total projected annual release volume of 9.0 maf after an April 2017 adjustment.

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 elevation in 2016, combined with a relatively high inflow volume, also resulted in above-average release temperatures during the summer and fall of 2016, with release temperature nearly reaching 14°C at the end of September 2016.

Lake Powell Limnology – Similar to 2015, a winter underflow density current was not observed in spring 2016. These density currents 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. Funding was last received under this agreement in 2014 and all FY16 activities were conducted using funds carried forward from this last allocation. After an internal review, Reclamation decided to shift Lake Powell monitoring internally. GCMRC was asked to continue conducting forebay sampling and water quality monitoring of GCD releases with the remaining funds from the Lake Powell agreement. Reclamation has expressed interest in GCMRC continuing this part of the program in the near term and may provide additional funding in FY17.

Project 1	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.983%	Total
Budgeted Amount	$14,295	$462	$1,266			$1,920	**$17,943**
Actual Spent	$14,295	$462	$1,266	$0	$0	$1,920	**$17,943**
(Over)/Under Budget	**($0)**	**$0**	**($0)**	**$0**	**$0**	**$0**	**($0)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
- Carried $30,100 over from FY15 to FY16 and we did not receive any FY16 Funds non-AMP Lake Powell Funds. - Carried over $12,200 of non-AMP Lake Powell Funds. - Carried over $20,000 of AMP Lake Powell Funds.