Grand Canyon Monitoring and Research Center

Fiscal Year 2017 Annual Project Report

for the
Glen Canyon Dam
Adaptive Management Program

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Introduction

Following is the Grand Canyon Monitoring and Research Center's (GCMRC) Fiscal Year (FY) 2017 Annual Accomplishment Report. This report is prepared primarily for the Bureau of Reclamation to account for work conducted and products delivered in FY 2017 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, alterations, results, and recommendations related to projects included in GCMRC's FY 2015-2017 Triennial 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 include funds carried forward from FY 2016, shortfalls in funding due to lower than projected Consumer Price Index values, and funds that were carried forward to FY 2018.

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

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
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SUMMARY

The Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem 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 High-Flow Experiments (HFEs) under the 2012–2020 High-Flow Protocol and the Long-Term Experimental and Management Plan. Details of this ongoing project (including descriptions of the data-collection locations) are provided in the GCMRC FY 2015–17 Triennial work plan.

Science Question Addressed:

The Streamflow, Water Quality, and Sediment Transport in the CRE 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 FY 2015-17, this question was addressed through:

1) All monitoring data required by this project, including those required to trigger, design, and evaluate the November 2014 and November 2016 HFEs, were collected and posted to the web. 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 2018, as is the usual schedule for this project).
2) Maintenance and continued 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 during this triennial work plan).
3) Publication of 10 peer-reviewed interpretive papers since FY 2015. See product/report list below.
4) Completion of three other journal articles that are still in journal review and should be published before the January Annual Reporting Meeting. These three articles have the following working titles and authorship: "Hydrologic change on two large ephemeral rivers: Impacts of climate, humans, and

hydrogeomorphic feedbacks on streamflow of the Little Colorado River and Moenkopi Wash" by David J. Dean and David J. Topping, submitted to the Journal of Hydrology; "How many measurements are required to construct an accurate sediment budget? Insights gained from analyses of signal and noise in a well-sampled large river" by Paul E. Grams, Daniel Buscombe, David J. Topping, Matt Kaplinski, and Joseph E. Hazel, Jr., submitted to Earth Surface Processes and Landforms; and "False low turbidity readings during high suspended-sediment concentrations" by Nicholas Voichick, David J. Topping, and Ronald E. Griffiths, submitted to Hydrology and Earth System Sciences.

	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 2014 Fall Meeting entitled "The role of sediment budgets in the implementation and evaluation of controlled floods to restore sandbars along the Colorado River in Grand Canyon, Arizona." Presentation made at AGU in December 2014.	FY 2015	Dec. 2014	Dec. 2014	Grams, P.E., Schmidt, J.C., and Topping, D.J, 2014, The role of sediment budgets in the implementation and evaluation of controlled floods to restore sandbars along the Colorado River in Grand Canyon, Arizona: Abstract EP32A-06 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec.
	American Geophysical Union abstract for 2014 Fall Meeting entitled "Deciphering Paria and Little Colorado River flood regimes and their significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon." Presentation made at AGU in December 2014.	FY 2015	Dec. 2014	Dec. 2014	Jain, S., Topping, D.J, and Melis, T.S, 2014, Deciphering Paria and Little Colorado River flood regimes and their significance in multi-objective adaptive management strategies for Colorado River resources in Grand Canyon: Abstract H51J-0743 presented at 2014 Fall Meeting, AGU, San Francisco, Calif., 15-19 Dec.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	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.	FY 2016	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.
Abstracts presented at professional meetings (continued)	American Geophysical Union abstract for 2015 Fall Meeting entitled "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.	FY 2016	Dec. 2015	Dec. 2015	Grams. P.E., Buscombe, D., Hazel, J.E., Kaplinksi, M.A., and 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.	FY 2016	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.	FY 2016	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 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.
	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	FY 2016	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

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Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	stations on five rivers." Presentation made in July 2016.				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.
Abstracts presented at professional meetings (continued)	10th Symposium on River, Coastal and Estuarine Morphodynamics abstract entitled "Sand pulses and sand patches on the Colorado River in Grand Canyon." Presentation made in September 2017.	FY 2017	Sep. 2017	Sep. 2017	Grams, P.E., Buscombe, D., Topping, D.J., and Mueller, E.R., Sand pulses and sand patches on the Colorado River in Grand Canyon, 2017, *in* Lanzoni, S., Redolfi, M., and Zolezzi, G., eds., RCEM2017 10th Symposium on River, Coastal and Estuarine Morphodynamics, Trento–Padova 15-22 September 2017, p. 183, *http://events.unitn.it/sites/events.unitn.it/files/download/rcem17/rcem-bookofabstract-ebook_0.pdf.*
	American Geophysical Union abstract for 2015 Fall Meeting entitled "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.	FY 2016	Dec. 2015	Dec. 2015	Grams. P.E., Buscombe, D., Hazel, J.E., Kaplinksi, M.A., and 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.	FY 2016	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.
Journal articles and other major pubs.	Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Physically based method for measuring suspended-sediment concentration and grain size	FY 2015	April 2015	April 2015	Topping, D.J., Wright, S.A., Griffiths, R.E., and Dean, D.J., 2015, Physically based method for measuring suspended-

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Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	using multi-frequency arrays of single-frequency acoustic-Doppler profilers"				sediment concentration and grain size using multi-frequency arrays of single-frequency acoustic-Doppler profilers: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, pp. 834-846, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf.
Journal articles and other major pubs. (continued)	Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Reconciliation of flux-based and morphologic-based sediment budgets"	FY 2015	April 2015	April 2015	Grams, P.E., Buscombe, D., Topping, D.J., Hazel, J.E., Jr., and Kaplinski, M., 2015, Reconciliation of flux-based and morphologic-based sediment budgets: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 1144-1155, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf.
	EOS, Transactions of the American Geophysical Union journal article entitled "Building sandbars in the Grand Canyon"	FY 2015	June 2015	June 2015	Grams, P.E., Schmidt, J.C., Wright, S.A., Topping, D.J., Melis, T.S., and Rubin, D.M., 2015, Building sandbars in the Grand Canyon, EOS, Transactions of the American Geophysical Union, v. 96, n. 11, p. 12–16, https://eos.org/features/building-sandbars-in-the-grand-canyon
	Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "Inaccuracies in sediment budgets arising from estimations of tributary sediment inputs: An example from a monitoring network on the southern Colorado Plateau"	FY 2015	April 2015	April 2015	Griffiths, R.E., and Topping, D.J., 2015, Inaccuracies in sediment budgets arising from estimations of tributary sediment inputs: An example from a monitoring network on the southern Colorado Plateau: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 583-594, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf.

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Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	Federal Interagency Conference on Sedimentation and Hydrologic Modeling proceedings paper entitled "User-interactive sediment budgets in a browser: A web application for river science and management"	FY 2015	April 2015	April 2015	Sibley, D., Topping, D.J., Hines, M., and Garner, B., 2015, User-interactive sediment budgets in a browser: A web application for river science and management: Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling, April 19-23, Reno, Nevada, USA, p. 595-605, http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf.
Journal articles and other major pubs. (continued)	Journal article entitled "Turbidity, light, temperature, and hydropeaking control primary productivity in the Colorado River, Grand Canyon"	FY 2015	January 2015	January 2015	Hall, R.O. Jr., Yackulic, C.B., Kennedy, T.A., Yard, M.D., Rosi-Marshall, E.J., Voichick, N., & Behn, K.E., 2015, Turbidity, light, temperature, and hydropeaking control primary productivity in the Colorado River, Grand Canyon: Limnology and Oceanography, v. 60, n. 2, p. 512-526, doi: 10.1002/lno.10031, *http://onlinelibrary.wiley.com/doi/10.1002/lno.10031/abstract.*
	U.S. Geological Survey Professional Paper entitled "Long-term continuous acoustical suspended-sediment measurements in rivers—Theory, application, bias, and error."	FY 2016	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 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."	FY 2016	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, CD-ROM Proceedings of the International Conference on Fluvial Hydraulics, St. Louis, Missouri, USA, July

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					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."	FY 2016	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.
Journal articles and other major pubs. (continued)	Journal article entitled "Importance of measuring discharge and sediment transport in lesser tributaries when closing sediment budgets"	FY 2017	Nov. 2017	Nov. 2017	Griffiths, R.E., and Topping, D.J., 2017, Importance of measuring discharge and sediment transport in lesser tributaries when closing sediment budgets: Geomorphology, v. 296, p. 59-73, doi: 10.1016/j.geomorph.2017.08.037, *https://doi.org/10.1016/j.geomorph.2017.08.037.*

Project 2	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$671,000	$5,000	$53,000	$0	$512,000	$88,019	**$1,329,019**
Actual Spent	$550,423	$4,492	$242,967	$0	$436,100	$96,336	**$1,330,319**
(Over)/Under Budget	**$120,577**	**$508**	**($189,967)**	**$0**	**$75,900**	**($8,317)**	**($1,300)**
FY16 Carryover	**$60,503**		**CPI Adjust**	**($9,856)**		**FY17 Carryover**	**$49,348**

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 and purchasing additional equipment.
- Suballocations to other USGS cost centers decreased due to sending less funds to other USGS collaborators.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	Paul Grams	**Principal Investigator(s)** (PI)	Paul Grams, USGS, GCMRC Dan Buscombe, NAU Erich Mueller, Uni. Of WY. Joel Sankey, USGS, GCMRC Joseph Wheaton, USU Brandon McElroy, Uni. Of WY. Joe Hazel, NAU Matt Kaplinski, NAU Keith Kohl, USGS, GCMRC
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SUMMARY

Sandbar Monitoring and Research

The objectives of these project elements are to measure 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 the effectiveness of the HFE protocol and Long-term Experimental and Management Plan Environmental Impact Statement (LTEMP EIS) with respect to sandbar condition.

Sandbar and Campsite Monitoring (3.1.1.)

Annual changes in sandbars and campsites were measured by repeat topographic surveys at 47 long-term monitoring sites in September/October 2016 and September/October 2017. The total volume of sand within sandbar monitoring sites decreased between October 2014 and October 2016, a period which included one HFE (November 2014). Despite this decrease, sandbar size remained greater than was measured in 2011 and 2012, before the start of the HFE protocol. 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 (Mueller and others, 2018). Campsite area is strongly affected by sandbar erosion and deposition and by changes in vegetation (Hadley and others, 2018). While HFEs cause temporary increases in sandbar size and campsite area, vegetation expansion causes progressive declines in campsite area. Data from the 2017 monitoring trip are currently being processed and will be presented at the January 2018 Annual Reporting meeting.

Remote camera systems currently monitor 43 sandbars in Grand and Marble Canyons by providing five or more oblique images per day per site. Qualitative analysis of images indicated that the November 2016 HFE resulted in substantial deposition at 56% of the monitoring sites and substantial erosion 12% of the sites. Three months following the HFE, only 15% of the bars were still larger than the pre-HFE condition (Grams and others, *in press*; Tusso and others, 2015). By October 2017, eleven months after the HFE, 9% remained larger than before the 2016 HFE and 16% of the sites were smaller. The remaining sites were approximately the same size as they were before the 2016 HFE.

In order to use the remote camera network as cost-effective sandbar area and volume monitoring tools, we have focused on developing methods for quantifying sub-annual changes to sandbar topography. This has included the development of methods for spatially rectifying and registering the images, and a supervised segmentation

procedure that involves an interactive graphical program (Grams and others, *in press*). Using this program, a sandbar may be segmented (isolated from everything in the image that is not part of the sandbar) by an experienced operator in 1-2 minutes. Given the size of the remote camera image database, currently at many hundreds of thousands of individual images, long-term monitoring requires the development of an automated method for sandbar segmentation, which has been the focus of more recent efforts. A working program has been developed, using an artificial neural network approach to identifying regions of pixels associated with categories such as sand, water, rocks and vegetation. Initial results are promising and current work involves refining and quantifying error. A workflow is being tested on the images from the 30-mile site, to register, segment, rectify, compute sand areas, and finally, to generate a high-resolution (~monthly) time-series of sandbar areas. In addition, a workflow to use the waterlines in multiple photographs as stage elevation changes, to estimate slope of the sandbar front, and sand volume (by stacking contour lines to create a digital elevation model) is being evaluated. This workflow will be expanded to more sites and images from multiple years, to generate time-series of sandbar face slopes and volumes in addition to time-series of sand areas.

Sandbar Remote Sensing (3.1.2.)

The purpose of the remote sensing component of the sandbar monitoring project is to evaluate changes in sandbars caused by erosion, deposition, and change in vegetation cover throughout the Colorado River Ecosystem (CRE). This project has involved the creation of a geomorphic map that defines the depositional setting for all sand deposits between Glen Canyon Dam and Pearce Ferry (Ross and others, 2015; Ross and others, *in prep*.). Changes between 2002 and 2013 have been evaluated based on classifications of vegetation and sand on imagery acquired in 2002, 2009, and 2013. We estimate the sand classification has an accuracy of 95%, based on 187 field-checked validation points. We also quantified the uncertainty of the sand classification for each year as a function of variability in river flow during the respective overflight. We also estimated the uncertainty associated with unsteady discharge during image acquisition as less than 3%. The total area of mapped sand changed by less than 3% between 2002 and 2009. Between 2009 and 2012, the total area of mapped sand increased by 15%. The maps of sand and vegetation cover will be used with the geomorphic base map, to describe the spatial distribution of changes in sand area between 2009 and 2013 as functions of river flow, geomorphology, and riparian vegetation (Rossi and others, *in prep*.).

Sandbar Surveys with Digital Cameras (3.1.3.)

The SfM (structure-from-motion) photogrammetry method allows “surveying” sandbar topography with ordinary digital cameras. We evaluated the operational feasibility and accuracy of this method for sandbar monitoring. The method provides high-resolution data over bare and unvegetated portions of sandbars with accuracy similar to that obtained by conventional survey. The method was not practical for densely vegetated areas and does not work to measure submerged sand. Although the images for SfM photogrammetry can be collected by a single person, surveys are still required for geo-referencing and post-processing the images is time-consuming. Thus, SfM may be a useful tool for specific applications where high-resolution data of bare surfaces are required, but is not a practical method for the annual topographic measurements at the long-term sandbar monitoring sites. These findings are reported in presentations (Rossi and others, 2016), an MS thesis (Rossi, 2017), and scientific publication (Rossi and others, *in prep*.).

Historical Sandbar Topography (3.1.4.)

The purpose of this project element is to reconstruct sandbar topography from October 1984 photographs for comparison with current measurements at long-term monitoring sites. During FY 2017, we refined the methods, using a new digital terrain extraction module for extraction of 3-dimensional surfaces from the photogrammetrically-derived data. A total of eight long-term monitoring sites were processed in FY 2017 using these new methods, which allow more operator control to customize settings for each site. A paper describing methods and results, including horizontal and vertical accuracies, for sites processed through FY 2017 is in preparation (Hazel and others, *in prep*.).

Sand Storage Monitoring and Research (3.2.)

The goal of the sediment storage project is to measure 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 and LTEMP EIS. 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 FY 2015–17 work plan were to map the river channel in Glen Canyon (FY 2015), upper Marble Canyon (FY 2016), and west-central Grand Canyon (FY 2017). 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 are completed and a report is in preparation. In May 2016, we mapped the river bed and banks in Upper Marble Canyon (River Mile 0 to 32). These data have been processed and we expect to have preliminary results and comparisons with measurements made in 2013 in early 2018. In April 2017, we mapped west central Grand Canyon (River Mile 166 to 225). These data are currently being processed and we expect to produce completed maps in late 2018. The repeat bed measurements that have been analyzed in in lower Marble Canyon and eastern Grand Canyon have demonstrated 1) high spatial variability in erosion and deposition magnitudes, 2) the sand eroded during the 2011 reservoir equalization flows was derived from a relatively small fraction of the channel (~12%), 3) most changes in sand storage occur in the low-elevation parts of eddies and the channel adjacent to eddies, and 4) changes in exposed sandbars comprise a small fraction of net changes in sand storage (Grams and others, 2015; *in review*).

An important aspect of sand-storage monitoring is classification of bed sediment. Bed sediment classification maps completed using data collected during surveys of lower Marble Canyon in 2009 and 2012 have been disseminated (Kaplinski and others, 2017) and have recently been used and incorporated into studies of sediment budgets (Grams and others, 2015; *in review*), sediment connectivity (Kasprak and others, *in review*), bedform scaling and sand pulse dynamics in that reach. A new and improved technique for acoustic sediment classification has been developed and disseminated (Buscombe and Grams, 2016; Buscombe and others, 2017a; 2017b). This new classification approach builds on previous bed sediment classification techniques with:

1) improved signal filtering,
2) a new probabilistic classification procedure,
3) inclusion of submerged aquatic vegetation in the classification, and
4) validation in settings with a greater range of sedimentological characteristics, including aquatic vegetation, than previous work.

Sediment classification accuracies ranged between 52 and 100%, with a mean of 92, based on categorization of all backscatter into 8 substrate types (4 unvegetated types downstream of the Paria River and 4 partially vegetated types upstream in Glen Canyon). It was found that the new acoustical sediment classification method is precise enough to reliably detect actual changes in substrate composition over time that are greater than about 3%.

This new classification method has been applied to all data collected in Glen Canyon (2014), upper Marble Canyon (2013 and 2016), and eastern Grand Canyon (2011 and 2014), thereby developing 5 new high-resolution (25 centimeter [cm] grid) sediment classification maps. Methods were also developed to classify bed texture based on data from low-cost side-scan sonar (Buscombe, 2017; Hamill, 2017; Hamill and others, *in review*).

These automated methods can be applied to develop spatially distributed bed texture classifications for monitoring aquatic habitat.

Current and continuing work includes:

1) developing sediment classification maps for the 95-km reach in west central Grand Canyon mapped in spring 2017;
2) modifying the acoustic sediment classification approach for use with data collected using the Norbit iWMBS multibeam system, towards a goal of developing sediment classification maps for those shallower areas in Grand Canyon mapped using that system;
3) exploring the utility of multispectral acoustic backscatter for sediment classification, in particular for improved discrimination between vegetated and unvegetated substrates in Glen Canyon, towards an aim of improved longer term aquatic vegetation monitoring in that reach; and
4) exploring data fusion and machine learning approaches to accurately predicting substrate type in areas not mapped using multibeam sonar.

Our predictive understanding of sandbar change, sand transport, and changes in sand on the riverbed is limited by our present lack of information on the thickness and volume of sand stored within the channel and eddies. In conjunction with the map of the river bed for west central Grand Canyon made in April 2017, over 2,000 cross sections of sand thickness were collected using variable frequency Compressed High Intensity Radiated Pulse (CHIRP) sonar. From the perspective of the canyon-wide sediment budget, this is an important river segment, because it is often in sediment surplus and sandbar volumes are relatively stable in time. The measured cross sections, combined with the sonar-derived bathymetric and sediment class maps, provide the data necessary to construct sand thickness maps and estimate the volume of sand stored within the river's pools in the reach surveyed. Sand thickness at individual locations varies from a few cm to over 8.5 meters (m), while sand thickness averaged over entire pools ranges from 0.5 to 1.5 m (Platt and others, 2017). Based on these preliminary results, pool-average sand thickness is not constant and is not positively correlated with pool size (area), which suggests that pool size is not the only control on sand volume. Other possible controls on sand storage volume include gradient and pool depth. Understanding the spatial distribution of sand storage and the controls on storage volumes can help us understand how fluvially transported sand migrates through the Grand Canyon, as well as improve our understanding of the replenishment potential of riverbed stored sand for future HFEs.

Sandbar Modeling (3.3.)

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. 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 can 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. These results have been published in Sedimentary Geology (Mueller and others, 2018). In FY 2017, we extended this work and developed a preliminary model for sandbar response that is driven by the monitoring data and uses information from the sandbar groupings and numerical modeling (Alvarez and others, 2017). A journal article on this model is in preparation (Mueller and others, *in prep*.), although continued sandbar modeling work was not included in the final FY 2018-20 budget.

Sand Bedload Transport (3.4.)

Bedload flux is difficult to measure directly, and is potentially one of the largest sources of persistent bias in the computation of sand budgets. This work aims to provide a method for estimating bedload flux from routinely-measured suspended sediment variables. Repeat bathymetric surveys of dune migration were collected over seven days in March 2015 and November 2016 adjacent to the Diamond Creek sediment monitoring station in order to obtain direct estimates of bedload flux. These data were used to calibrate a statistical model that utilizes coupled changes in suspended sand concentration, grain size, and water discharge to track changes in bedload flux driven by the complex interaction between flow, dune roughness, and evolving bed grain size. Bedload flux is simulated over the full record at the Diamond Creek gage, which reveals systematic trends in the ratio of bedload to suspended load driven by flow strength and sediment supply-limitation. Currently, bedload flux is estimated as a constant 5% of suspended load; we show that this method tends to underestimate bedload flux at low discharges and overestimate bedload flux at high discharges (Ashley and others, 2017; *in prep*.). This method is extendable to other locations.

Control Network and Survey Support (3.5.)

The geodetic control network that is managed by GCMRC is used to ensure that geospatial data collected for research and monitoring are repeatable and have well-defined accuracy. The network currently includes more than 12,000 geodetic measurements collected throughout the CRE by conventional survey and global navigation satellite system (e.g. GPS). Absolute accuracies of less than 5 cm are available at most long-term monitoring sites and relative accuracy between stations is known to better than 3 cm at 95% confidence. In FY 2017, data were collected to improve mapping accuracies within Glen Canyon and between National Canyon and Diamond Creek. A report presenting methods, results, and error analyses for the control network is in preparation (Kohl and others, *in prep*.).

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
USGS Data	Project 3.1.1: Data from long-term sandbar monitoring sites	Annual	Jan. 2016; 2017; 2018		To be presented at annual reporting meeting and www.gcmrc.gov/sandbar
USGS Photos	Project 3.1.1: Images from remote camera monitoring of sandbars	Annual	Jan. 2016; 2017; 2018		Website: www.gcmrc.gov/sandbar
USGS Scientific Investigations Report	Project 3.1.1: Report on causes of campsite area change	FY 2015	Dec. 2017		Hadley, D.R., Grams, P.E., Kaplinski, M.A., Hazel, J.E., and Parnell, R.A., *in press*, Geomorphology and vegetation change at Colorado River campsites, Marble and Grand Canyons, Arizona, U.S. Geological Survey Scientific Investigations Report 2017-x.
USGS Open-File Report and Conference Proceedings	Project 3.1.1: Methods for measuring sandbar areas and volumes from remote camera images	FY 2016	Dec. 2017		Grams, P.E., Tusso, R., and Buscombe, D., *in press*, Automated remote cameras for monitoring alluvial sandbars on the Colorado River in Grand Canyon, Arizona, U.S. Geological Survey Open-File Report 2018-x. AND Tusso, R.B., Buscombe, D., and Grams, P.E., 2015, Using oblique digital photography for alluvial sandbar monitoring and low-cost change detection, *in* Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, p. 79–85, Reno, Nev. http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf
USGS Report and Conference Proceedings	Project 3.1.2: Sand area from remote sensing	FY 2017		Feb. 2018	Ross, R.P., and Grams, P.E., 2015, Long-term monitoring of sandbars on the Colorado River in Grand Canyon using remote sensing, *in* Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 86–96, Reno, Nev. http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf AND Kasprak, A., Buscombe, D., Caster, J., Grams, P.E., and Sankey, J.B., *in review*, The individual and additive effects of

					hydrologic alteration and vegetation encroachment on sediment connectivity in Grand Canyon: Progress in Physical Geography, submitted Sept. 2017. AND Ross, R., and others, *planned submission for Jan. 2018*, Alluvial deposits of the Colorado River in Glen Canyon, Marble Canyon, and Grand Canyon, Arizona, 2002 to 2013, U.S. Geological Survey Open-file Report.
Thesis and Conference presentation	Project 3.1.3: On SfM sampling protocol and extensions	FY 2017	Dec. 2017		Rossi, R.K., 2017, Evaluation of `structure-from-motion' from a pole-mounted camera for monitoring geomorphic change: Logan, Utah State University, unpublished MS thesis, 200 p. AND 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.
Thesis and Journal article	Project 3.1.3: SfM application	FY 2017	Dec. 2017	Jan. 2018	Completed MS thesis [above]; AND Rossi, R., and others, *planned submission for Jan. 2018*, Evaluation of `structure-from-motion' from a pole-mounted camera for monitoring geomorphic change, intended for Journal of Geophysical Research.
USGS Professional Paper	Project 3.1.4 (and 3.1.1): long-term trends at the sandbar monitoring sites	FY 2017	Dec. 2017		Hazel, J.E., and others, *planned submission for Jan. 2018 (*Methods revised and new analysis completed, report *in prep.*), Sandbar monitoring at selected sites, Colorado River in Glen, Marble and Grand Canyons, Arizona, 1990-2016, U.S. Geological Survey Professional Paper 2018-x.
USGS Maps	Project 3.2: Maps for upper Marble Canyon	FY 2017		May 2018	Data processing complete. Final maps to be published in 2018
USGS Report	Project 3.2: Geomorphic changes in upper Marble Canyon	FY 2017		Jun. 2018	Analysis is in progress.
Conference Proceedings and Journal article	Project 3.2: Geomorphic changes in lower Marble Canyon	FY 2015	FY 2015		Grams, P.E., Buscombe, D., Topping, D.J., Hazel, J.E., and Kaplinski, M., 2015, Use of flux and morphologic sediment

					budgets for sandbar monitoring on the Colorado River in Marble Canyon, Arizona, *in* Proceedings of the 5th Federal Interagency Hydrologic Modeling Conference and the 10th Federal Interagency Sedimentation Conference, pp. 1144–1155, Reno, Nev. http://acwi.gov/sos/pubs/3rdJFIC/Proceedings.pdf AND Grams, P.E., Buscombe, D., Topping, D.J., Hazel, J.E., Jr., Kaplinski, M., *in review*, Signal and noise in large-scale fluvial sediment budgets. Earth Surface Processes and Landforms, revised and resubmitted Nov 2017.
Conference Proceedings	Project 3.2: Use of low-frequency sonars for sand thickness	FY 2017	Dec. 2017	Jun. 2018	Platt, A.S., Buscombe, D., Porter, R.C., & Grams, P., 2017, Estimating sediment thickness from riverbed to bedrock within the Colorado River in the Grand Canyon: Abstract (232738) presented at 2017 AGU Fall Meeting, New Orleans, LA, 11-15 Dec. Publication expected in 2018.
Journal articles, USGS Data Release and thesis	Project 3.2: Reports on classification of river-bed substrate and submerged aquatic vegetation	FY 2017	2017		Buscombe, D., 2017, Shallow water benthic imaging and substrate characterization using recreational-grade sidescan-sonar: Environmental Modelling and Software, v. 89, p. 1–18, doi: 10.1016/j.envsoft.2016.12.003. AND Buscombe, D., Grams, P. E., & Kaplinski, M. A., 2017, Compositional signatures in acoustic backscatter over vegetated and unvegetated mixed sand-gravel riverbeds. Journal of Geophysical Research: Earth Surface, 122, 1771–1793, DOI: 10.1002/2017JF004302. AND Buscombe, D., Grams, P.E., & Kaplinski, M.A., 2017, Acoustic backscatter—Data and Python code: U.S. Geological Survey data release, https://doi.org/10.5066/F7B56HM0 AND Hamill, D., 2017, Quantifying riverbed sediment using recreational-grade side scan sonar: Logan, Utah State University, unpublished MS thesis, 71 p,

					https://digitalcommons.usu.edu/etd/6635/. AND Hamill, D., Buscombe, D., and Wheaton, J.M., *in review*, Substrate mapping by automated texture segmentation of recreational-grade side scan sonar imagery: River Research and Applications, submitted Nov 2017.
Journal articles	Project 3.3: Statistical sandbar model	FY 2017	Nov. 2017	Jun. 2018	Mueller, E.R., Grams, P.E., Hazel, J.E., and Schmidt, J.C., 2018, Variability in eddy sandbar dynamics during two decades of controlled flooding of the Colorado River in the Grand Canyon: Sedimentary Geology, v. 363, p. 181–199, doi: 10.1016/j.sedgeo.2017.11.007 AND Mueller, E.R., Grams, P.E., and Schmeeckle, M.A., *planned submission for Jun. 2018*, Modeling sandbar response to sub-daily changes in flow and sand concentration downstream from a large dam, intended for Journal of Geophysical Research.
PhD dissertation and Journal article	Project 3.3: LES model	FY 2017	Jan. 2017		Alvarez, L.V., 2015, Turbulence, sediment transport, erosion, and sandbar beach failure processes in Grand Canyon: Tempe, Arizona State University, Ph.D. dissertation, 176 p. http://repository.asu.edu/items/30069. AND Alvarez, L.V., Schmeeckle, M.W., and Grams, P.E., 2017, A detached eddy simulation model for the study of lateral separation zones along a large canyon-bound river: Journal of Geophysical Research: Earth Surface, v. 122, p. 25–49, doi: 10.1002/2016JF003895.
Journal article and Conference Proceedings	Project 3.4: Sand bedload transport	FY 2017		Jan. 2018	Ashley, T., McElroy, B., Buscombe, D., Grams, P., Kaplinsky, M., *planned submission for Jan. 2018*, Modeling bedload flux at sediment monitoring stations on supply-limited sand-bed rivers, intended for Water Resources Research. AND Ashley, T., McElroy, B., Buscombe, D., Grams, P.,

					Kaplinsky, M., 2017, Modeling bedload flux at sediment monitoring stations on supply-limited sand-bed rivers: Calgary, International Conference on Fluvial Sedimentology, Jul 2017.
USGS Scientific Investigations Report	Project 3.5: Report on control network and datum changes	FY 2017		Jan. 2018	Kohl, K., and others, *planned submission for Jan. 2018*, Geodetic control for monitoring geomorphic change detection along Grand Canyon's Colorado River corridor, U.S. Geological Survey Scientific Investigations Report.

Project 3	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$603,700	$5,900	$46,000	$449,000	$20,000	$92,627	**$1,217,227**
Actual Spent	$516,313	$11,519	$58,534	$490,908	$0	$85,525	**$1,162,799**
(Over)/Under Budget	**$87,387**	**($5,619)**	**($12,534)**	**($41,908)**	**$20,000**	**$7,102**	**$54,428**
FY16 Carryover	**($25,790)**		**CPI Adjust**	**($9,246)**		**FY17 Carryover**	**$19,393**

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

- Salary costs decreased due to receiving non-AMP funds and shifting funds to university cooperator.
- Operating Expenses increased due to Purchase of software & sensor for sonar and navigation system.
- Cooperative Agreement Expenses increased due to increased involvement by cooperators.
- Suballocations to other USGS cost centers decreased due to not needing to send funds to CIDA this FY.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program

Project Lead	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

Overview

Dam-released flows affect the deposition and retention of sand bars that serve as sources for other sediment 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 redistribution of river-derived sand by wind 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.

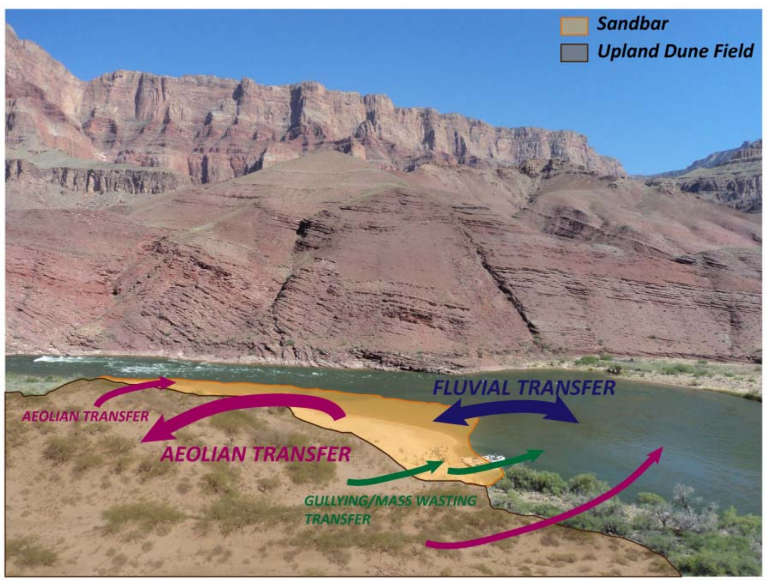

Figure 1. Conceptual overview of geomorphic processes that are important for sediment connectivity

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 quantify connectivity between the active river channel and higher elevation areas (above the 45,000 ft^3/s stage) at several spatiotemporal scales.

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 FY 2015-17 Triennial Work Plan (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 FY 2016 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" (East and others, 2016) which is based on work completed during Project 4 of the FY 2015-17 TWP, Project J of the FY 2013/14 Biennial Work Plan (BWP), and by the cultural resource monitoring research and development project conducted during the preceding decade.

Key findings presented in the professional paper are that, under current dam operations, elevated baseflows and infrequent High-Flow Experiments (HFEs) without large sediment-rich floods (i.e., greater than 45,000 ft^3/s) promote the expansion of riparian vegetation onto bare sand (Sankey and others, 2015) and limit the duration of time that sand is subaerially exposed and therefore available for aeolian transport (East and others, 2016). 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 (East and others, 2016). We also determined that many archaeological sites exist in source-bordering aeolian dunefields that are demonstrably coupled with upwind river sand (sandbars) at present (East and others, 2016).

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 coupled via wind to the active river channel was not answered in the professional paper by East and others (2016), but is very important for understanding the impacts of the HFE protocol on sandy landscapes throughout the river corridor. Thus during FY 2015-17 we initiated a study of new and archived data to understand the effect of HFEs on source-bordering aeolian dunefields. In FY 2017 we completed two companion manuscripts on this topic that are currently in review (Sankey and others, a and b*, in review*).

The manuscripts focus on: 1) developing a methodological framework for quantifying the response of source-bordering dunefields to sediment supply changes, and 2) implementing that methodological framework to quantify the response of source bordering dunefields in Grand Canyon to the 2012, 2013, 2014, and 2016 HFEs. Key findings of the work are that: 1) there are 117 large (> 1000 m^2), source-bordering dunefields and aeolian-dominated sand areas along the Colorado River in Grand Canyon (Figure 2); 2) of these 117 large dunefields, at least 53 are downwind of adjacent, contemporary sandbar deposits and thus likely have a modern fluvial sediment supply (e.g., were supplied with fluvially-sourced aeolian sediment during the HFE protocol); 3) from the measured response of four dunefields to the 2012, 2013, 2014, and 2016 HFEs, we infer that controlled floods resupply sediment to dunefields with a frequency analogous to that observed for sandbars, in that sediment resupply was estimated to have occurred for roughly half of the instances of the controlled flooding at dunefields (via aeolian transport of fluvial sediment monitored in this study) and also at sandbars (monitored in the long-term sandbar monitoring element of TWP Project 3) (Sankey and others, a and b, *in review*).

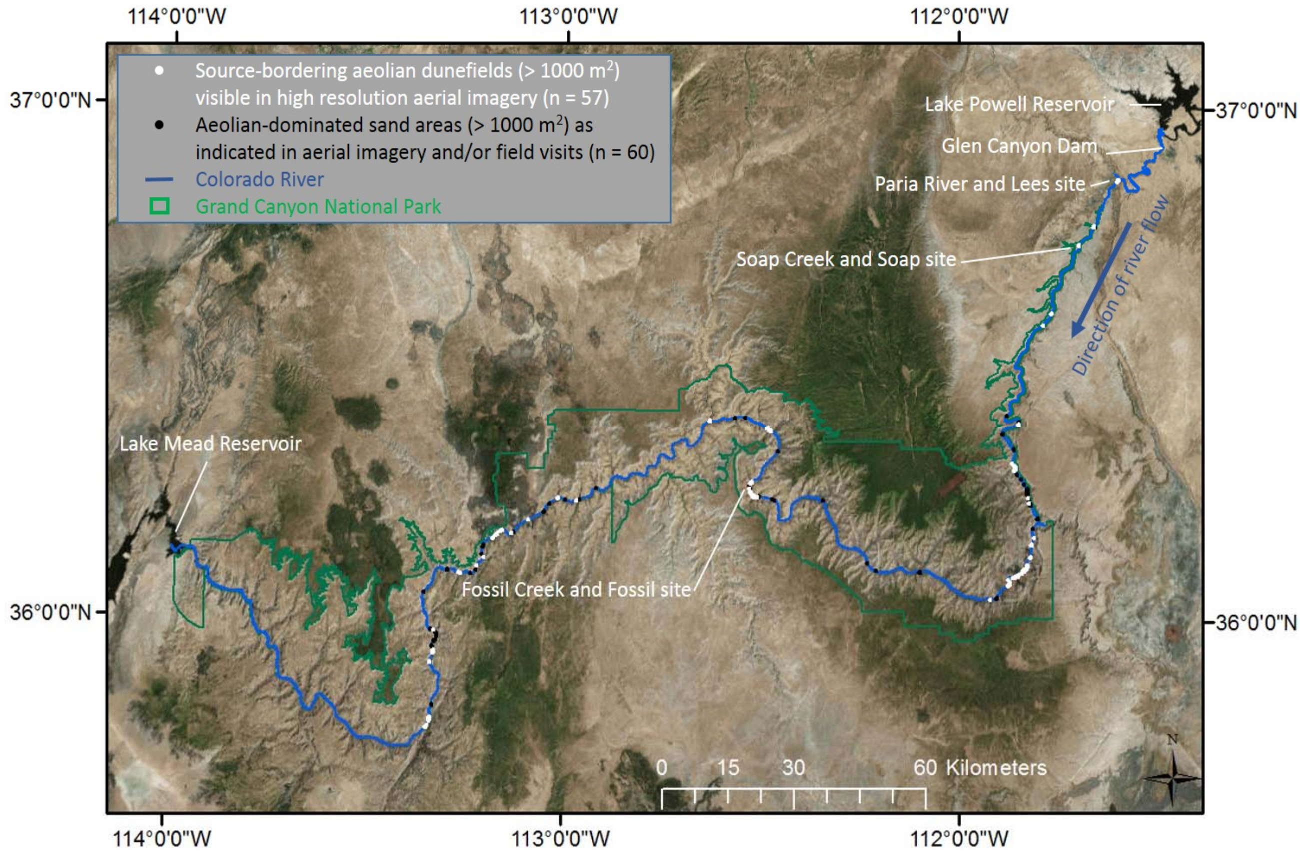

Figure 2. Map (From Sankey and others, *in review* a and b) showing locations of all large source-bordering aeolian dunefield (SBDs) as well as all other large aeolian-dominated sand areas (ADAs) along the Colorado River downstream of Glen Canyon Dam in the Grand Canyon region, Arizona, USA. There are currently at least 57 SBDs along the Colorado River in Grand Canyon that are large (spatially contiguous areas of unvegetated sand > 1000 m^2) and have dune morphology that is visible in high resolution aerial imagery. There are another at least 60 ADAs at which aeolian processes are a primary geomorphic process and dune morphology is not visible in aerial imagery but other indicators of aeolian sand transport such as sand shadows in the lee of shrubs, boulders, or arroyo channels have either been identified in the field (East and others, 2016) or are visible in aerial imagery. The Fossil Creek and Soap Creek sites are shown in historical oblique photos and modern matches in Figure 3.

The wealth of topographic data collected during the FY 2015–17 TWP, FY 2013–14 BWP, and previous research and monitoring efforts along the Colorado River over the past decade 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. Thus in FY 2015-17, we developed a robust, reproducible, and automated approach for analyzing these large volumes of archived topographic data in the form of original software. These novel tools were published in an article entitled “Geomorphic Process from Topographic Form: Automating the Interpretation of Repeat Survey Data in River Valleys” (Kasprak and others, 2016). In this paper, we developed and disseminated an open-source software utility for automatically interpreting the mechanisms driving geomorphic change as detected in repeat elevation data, such as the annual terrestrial laser scanning (e.g., lidar) datasets collected as part of Project 4. One of the major bottlenecks in Project 4 dataset analyses (and in the analysis of topographic data within the broader geomorphic community) has been the time-consuming and subjective nature of interpreting the processes driving changes in landscape form (i.e., fluvial, aeolian, or alluvial sediment transport, or mass failure). The software developed in this paper is capable of objectively quantifying the relative contributions of these transport mechanisms to geomorphic change at the site scale within minutes, whereas such analyses may have previously taken weeks, if not longer. The software were used in Project 4 research and monitoring to determine the changes in geomorphic condition at source-bordering dunefields and archeological sites during the current HFE protocol.

In FY 2015-17 we also focused 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. In FY 2017 we completed a remote-sensing analysis of the role of Colorado River flow and land cover change in reducing the areal extent of bare sand between river kilometers 71 and 97 (Kasprak and others, *in review*). By integrating spatial and time-series data from Projects A, B, and C, we quantified the reduction in bare sand extent from 1922 to 2017 resulting from:

(a) increased baseflows from Glen Canyon Dam and

(b) encroachment of riparian vegetation onto previously bare sand areas.

This work, currently under review as a manuscript at *Progress in Physical Geography*, found that hydrologic alteration has reduced bare sand area by 9% when comparing the pre- and post-dam periods, vegetation encroachment has reduced bare sand area by 45%, and the net effect of these two processes has been a 49% reduction in bare sand area between the pre- and post-dam periods (Kasprak and others, *in review*). Over the next 20 years under the Record of Decision (ROD) for the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP), we predict that bare sand area will decline by an additional 12%. (Kasprak and others, *in review*). Ongoing work seeks to extend this initial proof-of-concept study from the initial 26 kilometer study reach continuously over the 103 mile reach from Glen Canyon Dam to the Bright Angel Creek inflow. This work is important for pinpointing those archeological sites that are particularly susceptible to loss of connectivity and sediment supply, along with quantifying and mitigating the relative influence of flow alteration and vegetation encroachment in reducing sediment transport along the fluvial-aeolian-hillslope continuum.

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 > 30 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 dunefields with concentrations of cultural sites. The current state of cultural sites and aeolian landscapes are being similarly assessed based on more recent site photos as well as recent site surveys. One anticipated outcome of this analysis will be an estimate of the proportion of cultural sites for which the potential influence of aeolian sand inputs has changed from pre-dam to recent post-dam time, relative to changes in environmental characteristics including vegetation and biologic crusts.

In FY 2017, we continued to match historical images from the Colorado River, with an emphasis placed on matching panoramic images taken by Eugene C. La Rue during the 1923 Birdseye expedition. During the May 2017 monitoring river trip, we obtained high resolution digital matches of 46 historical images. An additional 45 matches were obtained in August-September 2017 in conjunction with the Project C (riparian vegetation monitoring) river trip. While this is still a work in progress, the analyses completed to date confirm that aeolian source areas along the Colorado River have diminished significantly during the past century 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 the 1990s as a result of modified dam operations (see discussion under Project 12 for further information on this topic). Several matched images from the 2017 field work serve as illustrations in a new Project 4 publication (Figure 3; from Sankey and others, *in review* a).

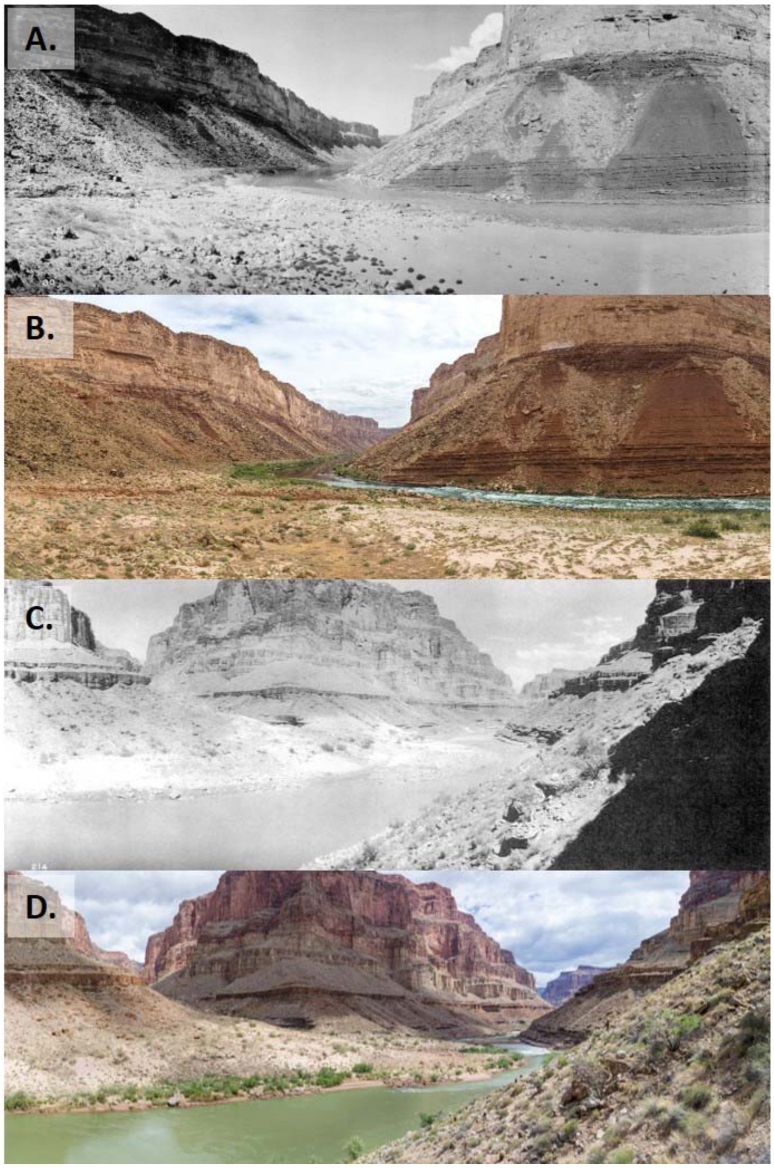

Figure 3. Photos showing approximately half (downwind portion) of the source-bordering dunefield at Soap Creek in A) 1923 and B) May 2017 (Photo Credits: A. H. Fairley, May 2017; E.C. La Rue, 1923). Most of the area covered by the Soap Creek dunefield was probably inundated by the largest floods (up to 210,000 CFS; Magirl and others, 2008) of the Colorado River prior to regulation (pre-1963), whereas the largest post-regulation floods during the early 1980s (up to 97,000 CFS) inundated roughly half of the area of the current SBD, and the largest floods since then (e.g., HFEs up to 45,000 CFS) have not inundated it. C) and D) show the source-bordering dunefield at Fossil Creek in 1923 and May 2017, respectively (Photo Credits: A. H. Fairley, May 2017; E.C. La Rue, 1923). Note the increase in riparian vegetation along the sandy river shorelines that are the sediment source areas for the dunefield between C and D.

Project Element 4.2. Monitoring Plan Development and Implementation

The primary objective for Project Element 4.2 in FY 2015-17 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 monitoring plan was to provide a protocol for collecting information relevant to the GCDAMP goal of documenting how dam operations, and changes in those operations, affect cultural resource site conditions. Another goal was to provide information useful in supporting Reclamation's commitment to maintain archaeological site integrity and National Historic Preservation Act (NHPA) compliance under the LTEMP. The monitoring plan, which was drafted and reviewed in FY 2015 and implemented in FY 2016, was designed to address specific target points outlined by BOR and NPS that were summarized in the Project 4 proposal of the FY 2015-17 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). While NPS archaeologists and tribal representatives monitor cultural characteristics important for maintaining cultural resource site integrity, the GCMRC plan focuses on strategies for providing objective, quantitative assessments of effects of geomorphic processes associated with dam operations on archaeological site conditions. 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 site 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. In FY 2017, we completed the processing and summary of geomorphic change at all of the FY 2016 lidar survey sites by using the new software that we developed as part of project element 4.1 (described above; Kasprak and others, 2016).

In May 2017, another monitoring trip was completed during which we revisited several of the sites surveyed in 2016 and also surveyed several new sites as well. We also completed drainage classifications for the remaining sites that had yet to be classified. These monitoring survey data have been processed completely and monitoring reports have been drafted for sites monitored in Grand Canyon National Park and Glen Canyon National Recreation Area during the TWP.

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. Stations collected measurements of rainfall, wind speed and direction, temperature, barometric pressure, and relative humidity at 4-minute timesteps.
- At three sites, stationary cameras took photographs once per day to record qualitative information about the timing and nature of landscape change.

In February 2016, the Project 4 team also worked in Glen Canyon with NPS Archaeology staff to visit and classify all river corridor archeological sites using both the aeolian and drainage classification systems. In FY 2017, a USGS Scientific Investigations report was published by the Project 4 team on the results of this work (East and others, 2017). The classification and report 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 (East and others, 2016).

References (Unless listed below, all other references cited in the text above are provided in the Products/Reports table)

Sankey, J.B., Ralston, B.E., Grams, P.E., Schmidt, J.C., and Cagney, L.E., 2015, Riparian vegetation, Colorado River, and climate—Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation: Journal of Geophysical Research—Biogeosciences, v. 120, no. 8, p. 1532-1547, http://dx.doi.org/10.1002/2015JG002991.

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Journal article	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Sankey, J.B., Kasprak, A., Caster, J.C., East, A.E., Fairley, H.C., *in review* a, The response of source-bordering aeolian dunefields to sediment-supply changes 1: Effects of wind variability and river-valley morphodynamics: Aeolian Research.			2018	In review
Journal article	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Sankey, J.B., Kasprak, A., Caster, J.C., East, A.E., Fairley, H.C., *in review* b, The response of source-bordering aeolian dunefields to sediment-supply changes 2: Controlled floods of the Colorado River in Grand Canyon, Arizona, USA: Aeolian Research.			2018	In review
Journal article	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Sankey, J.B., Buscombe, D., Caster, J.C., East, A.E., Grams, P.E., *in review,* Quantifying and forecasting the response of river valley sediment connectivity to altered hydrology and land cover: Progress in Physical Geography.			2018	In review
Journal article	Beyond compliance: Designing a monitoring program to document downstream dam effects at archaeological sites in Glen and Grand Canyons, Arizona.			2018	In revision with USGS

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Journal article	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Caster, J., Bangen, S., Sankey, J., 2017, Geomorphic process from topographic form: Automating the interpretation of repeat survey data in river valleys: Earth Surface Processes and Landforms, v. 42, no. 12, p. 1872-1883, DOI: 10.1002/esp.4143, https://doi.org/10.1002/esp.4143		2017		Published
USGS Scientific Investigations Report	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** East, A.E., Sankey, J.B., Fairley, H.C., Caster, J.J., and Kasprak, A., 2017, Modern landscape processes affecting archaeological sites along the Colorado River corridor downstream of Glen Canyon Dam, Glen Canyon National Recreation Area, Arizona: U.S. Geological Survey Scientific Investigations Report 2017–5082, 22 p., https://doi.org/10.3133/sir20175082.		2017		Published
USGS Professional Paper	East, A.E., Collins, B.D., Sankey, J.B., Corbett, S.C., Fairley, H.C., and Caster, J.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		May 2016		Published
Journal article	Collins, B.D., Bedford, D.R., Corbett, S.C., Cronkite-Ratcliff, C., and Fairley, H., 2016, Relations between rainfall-runoff-induced erosion and aeolian deposition at archaeological sites in a semi-arid dam-controlled river corridor: Earth Surface Processes and Landforms, v. 41, no. 7, p. 899-917, http://dx.doi.org/10.1002/esp.3874.		May 2016		Published
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

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
USGS Scientific Investigations Report	Caster, J.J., and 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, 38 p., https://pubs.er.usgs.gov/publication/sir20165012.		Feb 2016		Published
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		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
USGS Dataset	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Caster, J., Sankey, J., and Bangen, S., 2017, Geomorphic process topographic form, Colorado River, Grand Canyon—Data & models: U.S. Geological Survey Data Release, https://doi.org/10.5066/F73776X6.		2017		Published
USGS Dataset	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Sankey, J.B., Buscombe, D., Caster, J.C., East, A.E., Grams, P.E., *in review*, Quantifying and forecasting the response of river valley sediment connectivity to altered hydrology and land cover: Spatial Data and Model Scripts, U.S. Geological Survey Data Release.			2018	In review
Conference Presentation	Fairley, H.C., Sankey, J.B. and Caster, J., 2015, 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		

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Caster, J., Kasprak, A., and Sankey J.B., 2016, 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		
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** 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., 2016, 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	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Caster, J., Kasprak, A., and Sankey J.B., 2016, 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		
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** 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		

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** 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		
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Sankey, J.B., Kasprak, A., Caster, J., 2017, Riparian vegetation management for sand and cultural resource conservation in the Grand Canyon: Flagstaff, AZ, 14th Biennial Conference of Science and Management on the Colorado Plateau, September 11-14, 2017.		Sept 2017		
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Buscombe, D., Caster, J., East, A.E., Grams, P.E., Sankey, J., 2017, Linking fluvial and aeolian sediment transport in the Grand Canyon: Flagstaff, AZ, 14th Biennial Conference of Science and Management on the Colorado Plateau, September 11-14, 2017.		Sept 2017		
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Bangen, S., Buscombe, D., Caster, J., Grams, P.E., Sankey, J., 2017, Linking fluvial and aeolian morphodynamics in the Grand Canyon, USA: Padova, Italy, 10th Symposium on River, Coastal, and Estuarine Morphodynamics, September 18-22, 2017.		Sept 2017		

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Conference Presentation	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Sankey, J., Kasprak, A., Caster, J., East, A. and Fairley, H., 2017, Sediment connectivity at source-bordering aeolian dunefields along the Colorado River in the Grand Canyon, USA: Vienna, Austria, *in* EGU General Assembly Conference Abstracts, v. 19, p. 11104, April 23-28, 2017.		Apr 2017		
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		
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	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Caster, J., Sankey, J.B., East, A., Fairley, H., and Kasprak, A., 2016, Refining our understanding of sand distribution along the fluvial-aeolian-hillslope continuum: Preliminary results of Project 4 FY 2015 GIS analysis, GCDAMP annual reporting meeting, Phoenix, AZ.		Jan 2016		
Presentation at the 2017 Annual Reporting Meeting	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Kasprak, A., Buscombe, D., Caster, J., Grams, P.E., Sankey, J.B., 2016, The individual and additive effects of vegetation encroachment and hydrologic alteration on sediment connectivity in Grand Canyon: Phoenix, AZ, 2017 USGS GCMRC Annual Reporting Meeting, January 2017.		Jan. 2017		

	PRODUCTS/REPORTS				
Type	**Title/Citation**	**Due Date**	**Date Delivered**	**Date Expected**	**Comments**
Presentation at the 2017 Annual Reporting Meeting	**NOTE: KASPRAK NOT FUNDED BY THE GCDAMP.** Sankey, J.B., Kasprak, A., Caster, J., Fairley, H., East, A., 2017, Fluvial-aeolian sediment connectivity during the current HFE protocol: Effects for dunefields and archaeological sites: Phoenix, AZ, 2017 USGS GCMRC Annual Reporting Meeting, January 2017.		Jan. 2017		
Presentation at the 2017 Annual Reporting Meeting	Fairley, H.C., Sankey, J.B., Caster, J.J., East, A.E., 2017, Beyond compliance: Evolution and design of a program to monitor downstream effects of a large dam on archaeological sites in Glen and Grand Canyons, Arizona: Poster presentation at 2017 Annual Reporting Meeting, January 24, 2017.		Jan. 2017		

Project 4	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$317,200	$14,000	$34,000	$0	$87,300	$44,094	**$496,594**
Actual Spent	$361,925	$17,926	$69,072	$0	$34,884	$54,203	**$538,010**
(Over)/Under Budget	**($44,725)**	**($3,926)**	**($35,072)**	**$0**	**$52,416**	**($10,109)**	**($41,416)**
FY16 Carryover	**$72,807**		**CPI Adjust**	**($3,701)**		**FY17 Carryover**	**$27,690**

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

- Salary costs increased to retain staff using carryover funds to meet project objectives.
- Operating expenses increased to fund student services contract to conduct analysis of remotely sensed imagery of the Colorado River ecosystem.
- Funds to other USGS cost centers decreased due to reduced need from USGS collaborator.

Project 5: Foodbase Monitoring and Research

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program

Project Lead	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 Mike Yard, USGS, GCMRC
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SUMMARY

Overview

Our group's main focus this year was on data collection, the principal goals of which were threefold:

1) to continue our long-term citizen science light trapping and Lees Ferry monitoring activities in order to understand status and trends of the aquatic food base in a multi-year context,
2) to collect new data that will allow us to quantify food base responses to proposed Macroinvertebrate Production Flows (referred to here as bug flows) throughout Glen, Marble, and Grand Canyons, and
3) to collect new data on the aquatic food base in reaches where novel humpback chub populations appear to be growing (see Project 6 and 7).

We also collected data to understand the food web effects of trout removal in Bright Angel Creek, carried out pilot sampling to quantify the extent of quagga mussel (*Dreissena bugensis*) expansion into Marble and Grand Canyons, and organized expert elicitation, workshops, and syntheses on the status and trends of brown trout (*Salmo trutta*) in Glen Canyon.

Accomplishments

In FY 2017 our group launched two Grand Canyon river trips, one in spring and one in fall. The objectives of these trips were to sample invertebrate drift approximately every two miles throughout Glen, Marble, and Grand Canyons to describe spatial patterns in the aquatic food base and identify whether the periodicity in adult midge abundance that was evident in citizen science light trapping (Kennedy and others, 2016, *BioScience*) is also evident using more traditional, in-water invertebrate sampling methods. Additionally, if "bug flows" are implemented in FY 2018-20, both of these monitoring datasets (i.e., drift and citizen science light trapping) will provide valuable baseline information that we will use to determine ecosystem response to this flow experiment. For example, overall midge abundance is expected to increase with "bug flows", and the troughs in midge abundance related to the downstream propagation of the load-following waves are expected to flatten out under "bug flows". Both of the predictions (i.e., higher overall baseline midge abundance, flattening out of spatial periodicity) can be definitively tested with the drift samples collected on these twice annual river trips that began in 2016, and the citizen science light traps that we have collected since 2012. These river trips ultimately yielded 242 drift samples, which we expect to finish processing in summer 2018. Citizen science yielded 864 light trap samples in 2017, and we anticipate completion of processing in spring 2018.

Related to preparing baseline data in the event bug flows or other flow alternatives are implemented, our group also continued long-term monitoring of the aquatic food base with monthly drift and sticky trap sampling in from Glen Canyon Dam to Badger Rapid. This Lees Ferry monthly monitoring yielded 1388 sticky trap samples and 103 drift samples, for which processing is ongoing and sample enumeration from prior years is nearly completed. As part of our monthly sampling in Lees Ferry, we also re-calibrated and serviced dissolved oxygen monitoring instruments, which provide data used in modeling primary production in the Colorado River (Payn and others, 2017). Collectively, all of these data collection efforts allow us to assess the status and trends of the aquatic food base across a variety of sampling methods and on robust spatial and temporal scales.

Our group also provided support staff on rainbow trout Natal Origins (NO) / Juvenile Chub Monitoring (JCM) trips in FY 2017. We collected invertebrate drift samples to characterize the aquatic food base in new sampling reaches where chub populations appear to be expanding, and also at the LCR reach where chub population status continues to be of high management importance. These efforts yielded 73 drift samples, which we expect to finish processing in mid-2018.

In response to manager concerns, our group designed and implemented studies in FY 2017 aimed at documenting the range expansion of quagga mussels into Grand Canyon, and also to explore potential food web shifts in Bright Angel Creek due to ongoing trout mechanical removal efforts. Kennedy's 2007 *Dreissena* risk assessment (Kennedy, 2007) predicted that quagga mussels would do poorly in Marble and Grand Canyons due to suspended sediment turbidity that inhibited adult filter feeding and turbulence from rapids that kills larval veligers; our data collection here addressed the extent to which these predictions were correct. Specifically, we deployed 15 artificial quagga mussel colonization substrates throughout Glen, Marble, and Grand Canyons on our spring river trip, which were recovered six months later on our fall river trip in order to address whether quagga mussels were actively colonizing habitats in Grand Canyon. We also collected 32 samples with plankton nets to monitor for quagga mussel veligers throughout these reaches during our spring river trip to evaluate the potential for quagga mussels to colonize various points downstream of Glen Canyon Dam. Sample processing is ongoing, but to date no quagga mussels have been found in either of these sample sets, indicating quagga mussel colonization of Marble Canyon and Grand Canyon is relatively low compared to Glen Canyon, which is consistent with the predictions of Kennedy's risk assessment.

In Bright Angel Creek, we initiated sampling that broadly followed the design used by Whiting and others (2014, *Freshwater Science*) when they collected aquatic invertebrate data in Bright Angel Creek prior to trout removal. In total, we collected 58 benthic and 45 drift samples seasonally in the 1600-m reach upstream from the mouth of Bright Angel Creek. Benthic sample processing is completed and indicates that trout removal has shifted the structure of food web webs in Bright Angel Creek. Consistent with ecological theory, the removal of trout top predators appears to be initiating a "trophic cascade", allowing population growth of middle predators such as dragonflies and dobsonflies that would otherwise be suppressed by trout, which in turn leads to decreases in invertebrate herbivores such as certain taxa of mayflies (see Figure 1). Drift sample processing is ongoing.

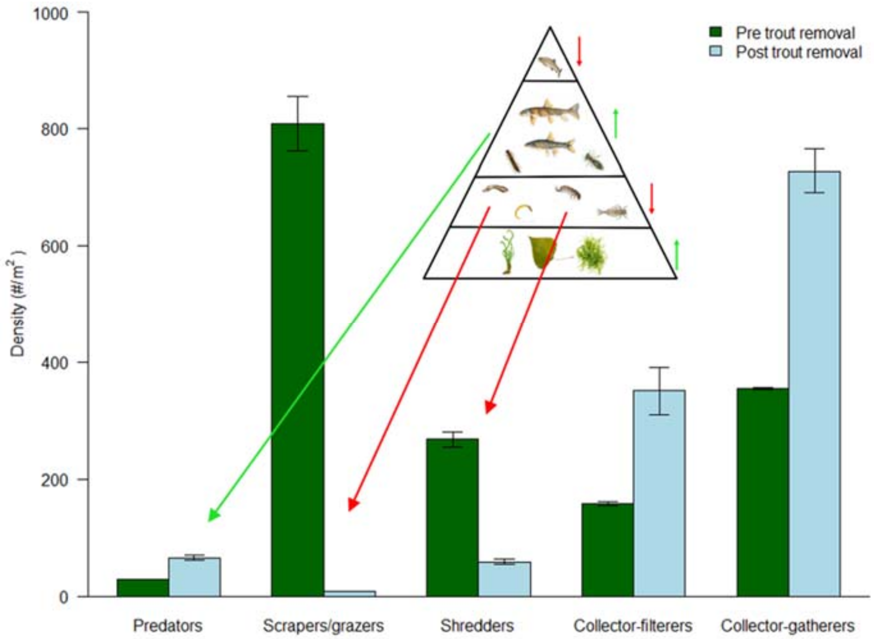

Figure 1. Benthic invertebrate results from Bright Angel Creek indicating differences in aquatic food web components pre- vs. post-trout removal. The arrows in the food web pyramid in the center of the figure indicates predictions if a trophic cascade occurs due to removal of top (trout) predators, which is broadly consistent with these results.

Our group also designed, organized, and carried out multiple expert elicitations and a workshop aimed at determining the root causes and viability of alternatives for managing recent growth in brown trout populations in Lees Ferry. These efforts included two expert elicitation surveys distributed to ~40 fisheries biologists and other individuals affiliated with fisheries research in Grand Canyon in the winter of 2016. Results of these expert elicitation surveys were presented at the Annual Reporting Meeting in January 2017. Discussions concerning root causes of brown trout increases were re-started in July 2017 and our group conducted several additional rounds of expert elicitation focused on root causes underlying increases in brown trout in support of these efforts. Results of these latest efforts were reported in a white paper and in a presentation at the Brown Trout workshop on September 21-22nd.

Finally, our group also worked with a panel of stakeholders in completing the knowledge assessment matrix for the food base resource. Over the course of four conference calls and in-person meetings, the group developed a set of food base metrics derived from our monitoring data. Across multiple metrics and sites, the condition of the aquatic food base has been deteriorating since at least 2013 (see Figure 2). Significantly, declines in the condition/plumpness of humpback chub near the LCR confluence and rainbow trout in the Lees Ferry reach are strongly correlated with the deteriorating food base. Owing to the system-wide deterioration of the food base and concomitant declines in the condition of multiple fish species, the working group rated the current status and trends of the Food Base as being of Significant Concern.

While the knowledge assessment groups were asked to evaluate numerous potential management actions, the food base working group felt that bug flows had the greatest potential for increasing the overall baseline abundance and diversity of the food base. In light of the multiple years of food base deterioration and associated declines in condition of desired fish species, the timing may be ripe for experimentation with bug flows to potentially improve this condition.

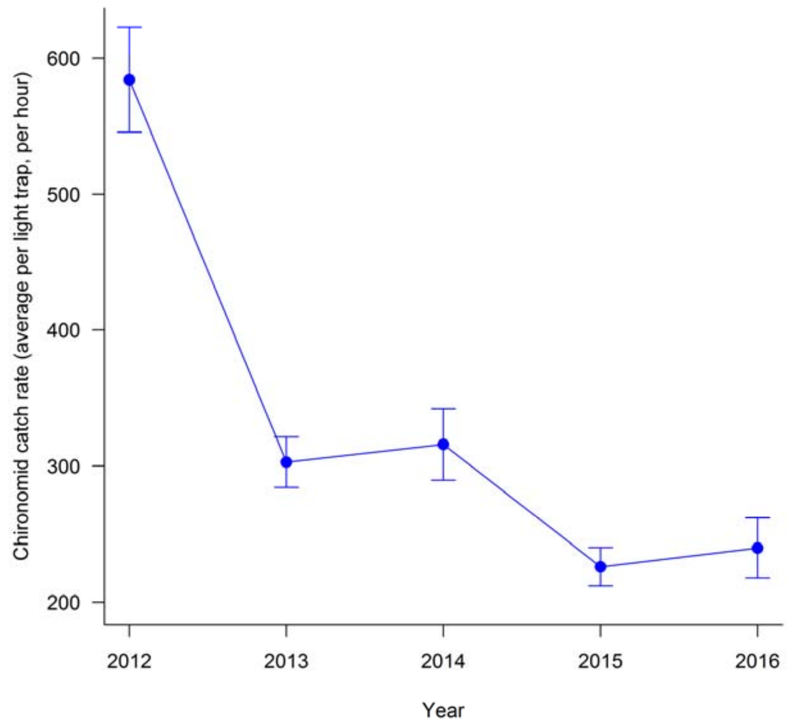

Figure 2. Line graph showing the long-term decline in abundance of adult midges (Chironomids) captured in citizen science light traps throughout Marble and Grand Canyon (points represent the average catch +/- one standard error). Adult midges are a key prey item for humpback chub, rainbow trout, and other desired fishes. After emergence from the Colorado River, adult midges are also a key prey item for terrestrial wildlife populations including birds, bats, and lizards. Testing of bug flows is predicted to increase the abundance of both aquatic and terrestrial life-stages of midges throughout Glen, Marble, and Grand Canyon.

Next Steps

The main conclusion from our 2016 *BioScience* synthesis was that it might be possible to mitigate the negative effects that load-following flows are having on the aquatic food base by stabilizing flows every weekend during periods of peak insect activity. Thus, a logical next step in the adaptive management process is testing bug flows during the FY 2018-20 Triennial Work Plan (TWP). Project F in the FY 2018-20 TWP describes specific predictions concerning effects of bug flows on invertebrate populations, including taxa that are likely to respond, timeframe of predicted responses, and locations of greatest increase. If bug flows are tested in FY 2018-20, we will develop a study plan that elaborates on these predictions and describes how monitoring data will be used to test them. Regardless of whether or not bug flows are implemented in FY 2018-20, we propose continued research and monitoring of the invertebrate prey base supporting humpback chub, rainbow trout, and native fish populations.

In anticipation of testing bug flows in the immediate future, our lab has been expanding our expertise in sensitive mayfly, caddisfly, and stonefly (referred to here as EPT) taxonomic identifications and streamlining all aspects of our workflow, from sample collection in the field to laboratory processing and sample archiving. In FY 2017 we hired a new laboratory manager, Morgan Ford, who has considerable expertise and experience in identification and archiving of all EPT life stages (e.g., see Walters, Ford, and Zuellig, 2017 in products). This expertise will be critical should EPT taxa begin to appear in monitoring samples following testing of bug flows. Also late in FY

2017 we hired new part time technicians to speed processing of sample backlogs; we anticipate being completely up-to-date with key monitoring data sources (e.g. light traps and Lees Ferry drift) by spring 2018. Moving forward (by FY 2019), our goal is to process and post for AMP viewing key graphs depicting food base data (drift, sticky, and light traps) within months of their collection. To facilitate rapid reporting of verified data, Jeff Muehlbauer has completely redesigned our Access database and added error-checking at each step in the workflow for each different type of sample (e.g., light traps vs. drift), which will automatically flag suspect samples for further inspection. On the data processing front, Jeff Muehlbauer and Mike Dodrill are collaborating to develop statistical packages for automatically updating key graphs once new data are available from the database. In summary, our lab is well-positioned to make timely reporting on food base response to testing of bug flows in FY 2018-20.

Reference

Kennedy, T.A., 2007, A *Dreissena* risk assessment for the Colorado River ecosystem: U.S. Geological Survey Open-File Report 2007-1085, 24 p., http://pubs.usgs.gov/of/2007/1085/.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Phosphorous releases from a large dam are a lever on primary production and higher trophic levels up to 120 kilometers downstream.				Deemer, B.R., Yackulic, C.B., Hall, R.O., Kennedy, T.A. Muehlbauer, J.D., 2017, Phosphorous releases from a large dam are a lever on primary production and higher trophic levels up to 120 kilometers downstream: Society for Freshwater Science Annual Meeting.
Presentation	The Colorado River Basin: Aquatic insect diversity and distribution in a fragmented riverscape.				Metcalfe, A.N., Kennedy, T.A., Muehlbauer, J.D. & Marks, J.C., 2017), The Colorado River Basin: Aquatic insect diversity and distribution in a fragmented riverscape: Society for Freshwater Science Annual Meeting.
Poster	Aquatic invertebrate community structure downstream of hydropeaking dams in the Colorado River Basin				Abernethy, E.F., Kennedy, T.A., Muehlbauer, J.D., Van Driesche, R.P. & Lytle, D.A., 2017, Aquatic invertebrate community structure downstream of hydropeaking dams in the Colorado River Basin: Poster at the Society for Freshwater Science Annual Meeting.
Poster	Aquatic invertebrate response to trout removal in Bright Angel Creek, Grand Canyon, AZ				Daubert, M.E., Muehlbauer, J.D., Kennedy, T.A. & Healy, B.D., 2017, Aquatic invertebrate response to trout removal in Bright Angel Creek, Grand Canyon, AZ: Poster at the Society for Freshwater Science Annual Meeting.
Presentation	Dammed and adrift in the Colorado River Basin				Muehlbauer, J.D., 2017, Dammed and adrift in the Colorado River Basin: USGS Southwest Biological Science Center All-Hands Meeting.
Presentation	Brown trout in Glen Canyon: Insights from an expert elicitation survey.				Muehlbauer, J.D. & Bair, L., 2017, Brown trout in Glen Canyon: Insights from an expert elicitation survey: Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting.
Presentation	Fluvial aquatic ecology of the Colorado River				Muehlbauer, J.D., 2017, Fluvial aquatic ecology of the Colorado River: Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting.
Presentation	Floods, flows, and the aquatic foodbase.				Kennedy, T.A., Dodrill, M.J., Yackulic, C.B. & Muehlbauer, J.D., 2017, Floods, flows, and the aquatic foodbase: Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting.
Presentation	Use of alternative invertebrate sampling techniques can move the science of flow-ecology forward: Case studies from the Colorado River.				Kennedy, T.A., 2017, Use of alternative invertebrate sampling techniques can move the science of flow-ecology forward: Case studies from the Colorado River: Society for Freshwater Science Annual Meeting.
Poster	Aquatic invertebrate response to brown trout removal in Bright Angel Creek: Study design and preliminary results				Daubert, M.E., Ingram, A.E., Muehlbauer, J.D. & Kennedy, T.A., 2017, Aquatic invertebrate response to brown trout removal in Bright Angel

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					Creek: Study design and preliminary results: Poster at the Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting.
Poster	Lake Powell nutrient dynamics are a lever on food webs near the LCR.				Deemer, B.R., Yackulic, C.B., Hall, R.O., Kennedy, T.A. & Muehlbauer, J.D., 2017, Lake Powell nutrient dynamics are a lever on food webs near the LCR: Poster at the Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting.
Presentation	Brown trout expert elicitation survey results.				Muehlbauer, J.D. & Bair, L., 2016, Brown trout expert elicitation survey results: Grand Canyon Fish Cooperators Meeting.
Presentation	Root causes for the increase of brown trout in the Lees Ferry reach				Kennedy, T.A., and 9 others, 2017, Root causes for the increase of brown trout in the Lees Ferry reach: Brown Trout Workshop, Tempe, AZ.
Section from white paper	Root causes for the increase of brown trout in the Lees Ferry reach				Kennedy, T.A., and 9 others, 2017, Root causes for the increase of brown trout in the Lees Ferry reach, *in* Brown trout below Glen Canyon Dam: A preliminary analysis of risks and options, p. 21-34, white paper.
Presentation	Little Colorado River foodbase research: 3 years on.				Muehlbauer, J.D., Kortenhoeven, E.K., Kennedy, T.A. & Yackulic, C.B., 2016, Little Colorado River foodbase research: 3 years on: Grand Canyon Fish Cooperators Meeting.
Journal article	A coupled metabolic-hydraulic model and calibration scheme for estimating whole-river metabolism during dynamic flow conditions.				Payn, R.A., Hall Jr., R.O., Kennedy, T.A., Poole, G.C., and Marshall, L.A., 2017, A coupled metabolic-hydraulic model and calibration scheme for estimating of whole-river metabolism during dynamic flow conditions: Limnology and Oceanography: Methods, v.15, no.10, p. 847-866, http://dx.doi.org/10.1002/lom3.10204.
Journal article	A digital reference collection for aquatic macroinvertebrates of North America				**NOTE: THIS PRODUCT WAS NOT FUNDED BY THE GCDAMP.** Walters, D.M., Ford, M.A., and Zuellig, R.E., 2017, A digital reference collection for aquatic macroinvertebrates of North America: Freshwater Science, v. 36, no. 4, p. 693-697, https://doi.org/10.1086/694539.

Project 5	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$384,900	$11,800	$24,700	$8,600	$10,000	$51,138	**$491,138**
Actual Spent	$362,157	$18,615	$52,550	$25,086	$0	$53,072	**$511,479**
(Over)/Under Budget	**$22,743**	**($6,815)**	**($27,850)**	**($16,486)**	**$10,000**	**($1,934)**	**($20,341)**

FY16 Carryover	**$18,398**		**CPI Adjust**	**($3,681)**		**FY17 Carryover**	**($5,624)**

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.
- Travel & Training increased due to additional conference and meeting attendance.
- Operating expenses increased due to greater participation in citizen science program than expected.
- Cooperative Agreements increased due to increased participation by University collaborator.

Project 6: Mainstem Colorado River Humpback Chub Aggregations and Fish Community Dynamics

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	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 19 August-6 September 2017, a river trip was conducted to monitor mainstem Colorado River humpback chub aggregations with hoop nets. From 2015-2017, the aggregation trips have also deployed portable antennas to detect fish marked with passive integrated transponder (PIT) tags (see Project Element 6.3 below). The 2017 trip sampled fish within the boundaries of several known historic aggregations of humpback chub (i.e., 30-Mile (river kilometer [RKM] 48), Lower Colorado River (LCR; RKM 91), Lava-Chuar-Hance (RKM 125), Bright Angel (RKM 148), Shinumo (RKM 177), Stephen Aisle (RKM 184), Middle Granite Gorge (RKM 201), Havasu (RKM 251), and Pumpkin (342)), 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 35, and at several sites in western Grand Canyon where an increase in humpback chub densities have been detected).

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 Biological Opinion conservation measures. A major long-term finding of this study has been that since 2006 there have been significant increases in CPUE of humpback chub at most aggregation localities, as well as at non-aggregation sites. Additionally, we have detected increases in the relative abundances of humpback chub at translocation sites in Shinumo and Havasu Creeks, and have detected either new aggregations/populations of humpback chub (e.g., river mile 35, western Grand Canyon), or detected expansion of previously known aggregations (e.g. Shinumo, Havasu, Pumpkin). In 2017, we captured an unprecedented number of humpback chub in western Grand Canyon (Fig 1) that included humpback chub from the juvenile to the adult size classes. Finally, these trips gather information on other members of the fish community.

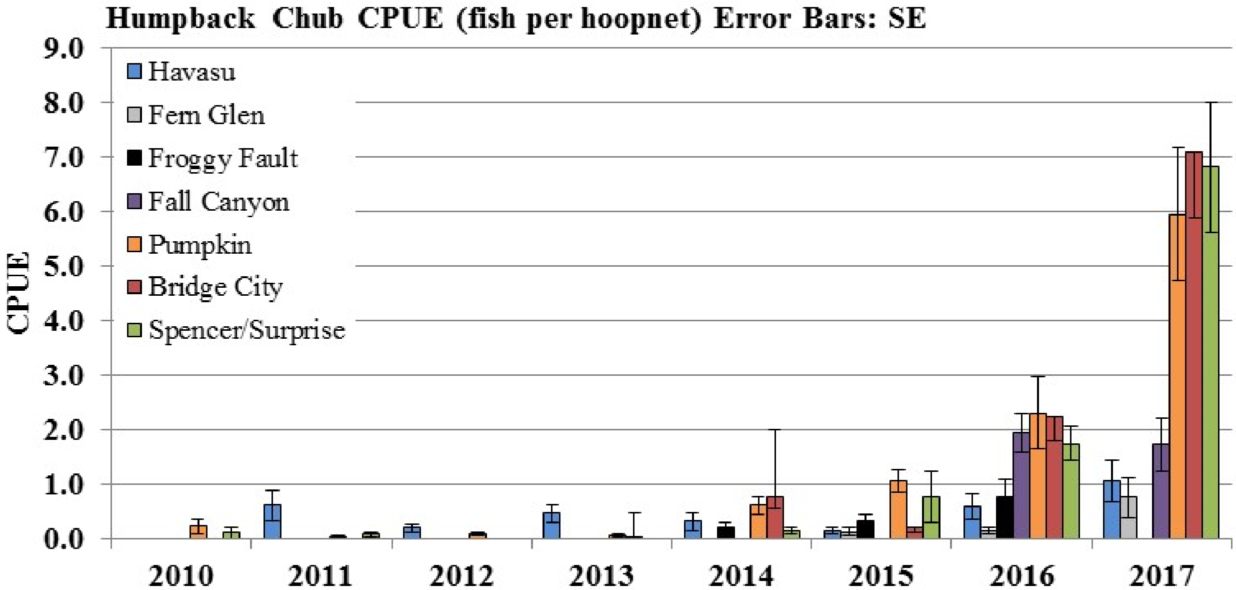

Figure 1. Catch per unit effort (CPUE) index of humpback chub captured in overnight hoop net sets from 2010-2017 at select sampling locations in western Grand Canyon. Havasu (RKM 251), Fern Glen (RKM), Froggy Fault (RKM 315), Pumpkin (RKM 342), Bridge City (RKM 383), Spencer/Surprise (RKM 396).

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. Although we did not deliberately kill any humpback chub for otolith microchemistry, a limited number of incidental mortalities were available from collections by various agencies (USGS, USFWS, AZGFD). From these samples, otoliths were dissected, cleaned, sectioned, and polished. We examined suites of trace elemental concentrations across transects made with laser ablation inductively coupled plasma mass spectrometry (LA-ICPMS) at the SUNY College of Environmental Science and Forestry. Additionally, water chemistry transects were made in four expeditions from 2014-2016, and an expanded suite of trace elements and isotopes extended the results from an earlier study (Nearshore Ecology Study).

Water chemistry continues to show variability, although the mainstem Colorado River continues to be more similar than most of the studied tributaries. This is more characteristic of element-to-calcium ratios than the stable isotopic ratios of C and O. There is evidence that small humpback chub collected in Grand Canyon have different otolith chemistry and thus provenance. Among the readily analyzed trace elements, barium in ratio to calcium shows promise to help identify the area(s) where humpback chub originate. Analyses of the core regions of the otoliths show greatest heterogeneity, whereas outer portions show the least. Given that all wild-caught individuals analyzed for this project were captured in the mainstem Colorado River, it is not surprising that their values begin to converge with respect to barium. The variability in Sr:Ca may suggest the influence of some tributaries or possibly even physiology.

Two manuscripts are in preparation: one focused on the provenance of small humpback chub in recent years, to test the hypothesis that chub are now reproducing in parts of Grand Canyon other than the Little Colorado River; and a second paper testing for interspecies differences in otolith chemistry. These manuscripts build on the final report submitted to GCMRC in July of 2017.

Project Element 6.3. Monitoring Mainstem Humpback Chub Aggregations Using PIT-tag Antenna Technology

We deployed up to 8 portable PIT-tag antennas within 15 sampling reaches during a September 2017 trip to monitor humpback chub and other tagged fish, including flannelmouth sucker and bluehead sucker within or between known humpback chub aggregation localities. These antennas detect many PIT-tagged fish that would otherwise go undetected using hoop nets alone. For example in 2017, 254 humpback chub and 272 flannelmouth suckers were detected only with antennas, representing 17% and 7% of the unique catches for these species 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 a US Fish and Wildlife Service geneticist. 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 gear 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, passive integrated transponder (PIT)-tag antennas and with both gear types during the 2017 mainstem aggregation trip.

		Unique PIT Tag Contacts/Captures by Gear									
Species		BHS	BNT	CRP	FBH*	FMS	FRH**	HBC	RBT	UNK	Total
Hoop Net Only	Captures (n)	9	0	1	0	3,494	3	1,160	2	0	4,669
	% of Total	*100%*	--	*20%*	--	*90%*	*100%*	*77%*	*100%*	--	*84%*
Antenna Only	Captures (n)	0	0	4	1	272	0	254	0	141	672
	% of Total	*0%*	--	*80%*	*100%*	*7%*	--	*17%*	--	*100%*	*12%*
Antenna and Hoopnet	Captures (n)	0	0	0	0	109	0	87	0	0	196
	% of Total	*0%*	--	--	--	*3%*	--	*6%*	--	--	*4%*
Total (n)		9	0	5	1	3,875	3	1,501	2	141	5,537

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 Monitoring

Goals and Objectives

The primary goal of the system wide monitoring program is to monitor the status and trends of native and nonnative fishes that occur in the Colorado River ecosystem from Lees Ferry, AZ 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. Boat electrofishing as well as baited hoop nets are utilized in this monitoring program. In addition, we use angling to sample for catfish each evening at camp once the trip is downstream of the Little Colorado River inflow.

Summary of Progress

We completed three mainstem sampling trips in 2017. A stratified random sampling approach was used to obtain a representative sample of the Colorado River fish community that was susceptible to electrofishing or baited hoop nets. A total of 560 sites were electrofished during the two spring/summer system-wide trips, but only 469 provided usable data because high turbidity (> 160 Nephelometric Turbidity Unit) during the April trip reduced electrofishing efficiency on 5 nights. A total of 3,562 fish were captured with electrofishing during spring/summer monitoring. During the fall sampling trip from Diamond Creek to Pearce Ferry Rapid, we captured 1,328 fish from 72 sites over three nights of electrofishing. We captured 4,443 fish in 460 hoop nets set over 4 nights at 58 sites. Flannelmouth sucker dominated the catch for both electrofishing and hoop nets, with 54 and 62 percent of the fish captured, respectively. We captured 553 humpback chub in baited hoop nets set from Lees Ferry to Pearce Ferry Rapid (Figure 2).

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

- Spring trip I: 1-17 April 2017
- Spring trip II: 25 May – 9 June 2017
- Diamond Down trip: 6-10 October 2017

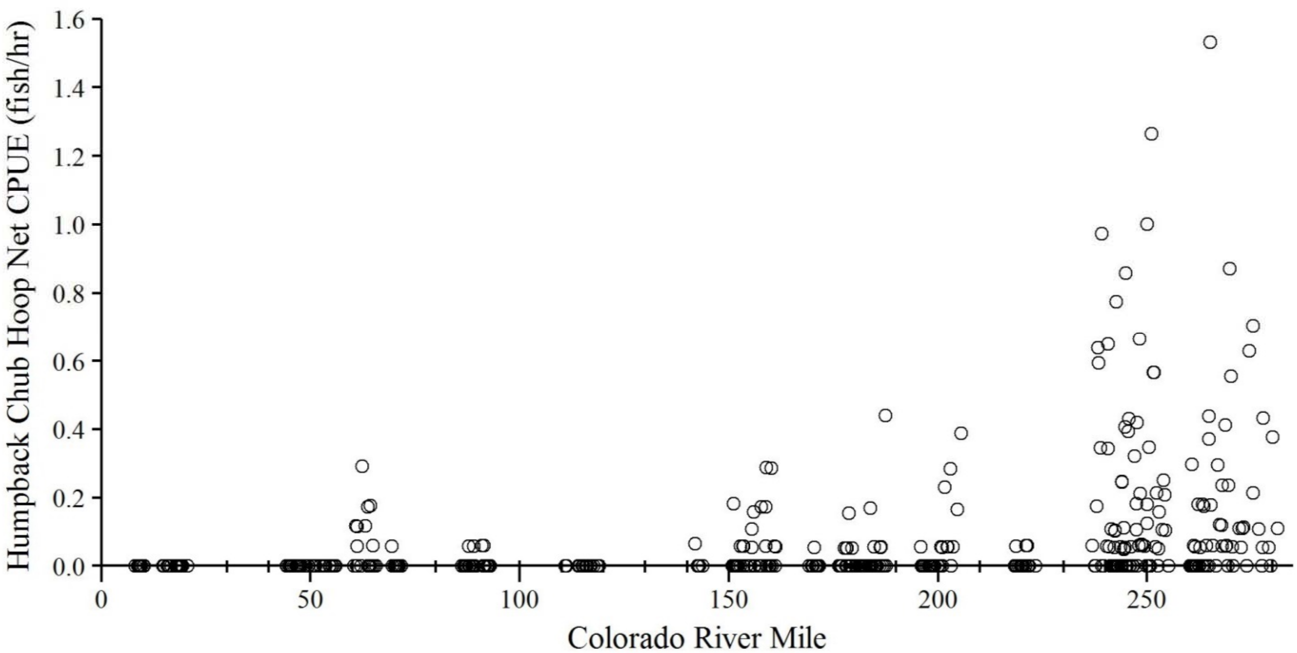

Figure 2. Catch per unit effort (CPUE; fish/hour) of humpback chub captured via baited hoop nets (n = 460) in 2017 by river mile (RM) from Arizona Game and Fish Department system wide sampling of the Colorado River from Lees Ferry (RM 0 to Pearce Ferry rapid RM 281.4)

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 Little Colorado River confluence. During the past five years, electrofishing CPUE throughout the river increased for flannelmouth sucker and decreased for brown trout and common carp. We did not detect any statistically significant trends in system-wide CPUE for bluehead sucker, speckled dace, or rainbow trout. Hoop net catch in 2017 corroborated our 2016 results showing that humpback chub are relatively abundant in the western Grand Canyon, particularly between Diamond Creek (river mile 226) and Pearce Ferry Rapid (RM 281.4).

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 (CPUE), population structure (size composition), distribution, reproductive success, growth rate, relative condition 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 2017, sampling 122 standard sites and capturing 4,285 fish (excluding the nonnative sampling). During our rare nonnative sampling monitoring in July of 2017, we captured one brown trout, and 32 common carp. Other rare nonnatives captured during our normal monitoring were: one bluegill, two green sunfish, seven common carp, and 68 brown trout.

Monitoring activities funded (boat electrofishing trips):

- Spring trip: 14-17 March 2017, 41 standard sample sites
- Summer trip: 17-21 July 2017, 41 standard sample sites, plus an additional 13 sites for nonnatives
- Autumn trip: 12-15 September 2017, 40 standard sample sites

Summary of Trends

Rainbow trout continue to dominate the fish community within the Lees Ferry reach, comprising 97.7 % of the catch (standard electrofishing), with brown trout comprising 1.58 % of the catch. This is a decline in relative abundance of brown trout compared to 2016 when brown trout comprised 3.3% of the catch at Lees Ferry.

Rainbow trout have maintained a self-sustaining population since the mid-1990s. Relative abundance, as measured by electrofishing CPUE, has fluctuated greatly since Arizona Game and Fish Department began standardized sampling in 1991. Rainbow trout CPUE was the highest ever recorded in 2011–2012, but declined from 2012 to 2016. Rainbow trout CPUE in 2017 has rebounded to double that observed in 2016 (3.55 vs. 1.65 fish/minute), with most of the increase attributable to young of the year (YOY) rainbow trout (< 152 mm). The percent YOY in the fall catch was relatively high (84 %), as was the CPUE of YOY at 2.95 fish/hour, the highest value observed since 2011 and 2012 (5.02. and 3.79, respectively).

The percent of large rainbow trout in the system has declined as has the median size of reproductively active fish. 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 for rainbow trout reached a record low (~ 0.8) in fall of 2014, and has been increasing since then, concurrent with the decrease in relative numbers of rainbow trout. Condition of rainbow trout in 2017 has been very good with the average condition at one or greater for all age classes for each sampling period (spring, summer, and autumn).

Project Element 6.5. Brown Trout Natal Origins through Body Pigmentation Patterns in the Colorado River

This project was not funded in the FY 2015-17 triennial work plan.

Project Element 6.6. Mainstem Translocation of Humpback Chub

Fish are scheduled to be stocked into the Mainstem Colorado river in Feb of 2018.

Project Element 6.7. Rainbow Trout Early Life Stage Surveys (RTELSS)

Goals and Objectives

The primary objective of the RTELSS study is to monitor the response of the age-0 (fish born within the last year, or less than one year old) 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 RTELSS in 2017 consisted of redd (spawning nest) surveys for estimation of spawning magnitude, and electrofishing sampling for estimation of population dynamics. Surveys were scheduled monthly over historic peak spawning times to best capture changes in redd abundance and distribution. Electrofishing sampling was conducted monthly in June, July, August, September, and November/December.

Summary of Trends

Redd Surveys

Four redd surveys were conducted from February 2017 through May 2017. We observed 5,456 redds and generated an overall estimate of 6,593 redds created for the season. Although only four redd surveys were conducted, observed numbers of redds remained consistently high throughout the surveys, leading to an exceptionally large estimate of seasonal redd production. With fewer surveys, we lose some precision in determining the timing and magnitude of the spawn, however, data indicate that spawning occurred earlier and with a greater abundance of redds than in previous years, with observed numbers of redds decreasing to within previously observed numbers by May (Table 1).

Table 1. Dates of the four redd surveys conducted in 2017 and the number of redds observed for each of those surveys.

Redd Surveys for 2017

Date of Survey	Number of Redds Observed
2/15/2017	1243
3/29/2017	2265
4/18/2017	1508
5/242017	440

In most years the “zero” count (count low enough to be considered the end of the spawn) for the tail end of the distribution does not extend into the month of June. Resources were allocated to electrofishing efforts in June and not additional redd surveys in 2017 because of logistical constraints.

Electrofishing Surveys

Four electrofishing surveys were conducted in 2017. Age-0 population estimates for June, July, August, and September are 276,000 (59,000 Lower Confidence Interval (LCI); 62,000 Upper Confidence Interval (UCI)), 471,000 (101,000 LCI; 113,000 UCI), 459,000 (101,000 LCI, 127,000 UCI)), and 478,000 (125,000 (LCI); 129,000 (UCI)) respectively. No survey was conducted in November because of logistic constraints. Population estimates for each month remained consistently higher than normal, with the largest estimate for age-o trout seen in any September survey. These results correlate well with the large estimated red production for 2017.

Project Element 6.8. Lees Ferry Creel (Angler) Survey

Goals and Objectives

The cold tailwater downstream of Glen Canyon Dam is an important rainbow trout recreational fishery. 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

Catch data from anglers is collected annually. As of this report, we have collected angler data through October 2017. Data for November through December 2017 will be analyzed and included in our annual report, to be submitted in 2018. Sampling days were stratified by month (6 days) and by weekday (2 days) and weekend (4 days). As of the end of October 2017, we have conducted angler surveys on 60 days, and interviewed 1,115 anglers, remarkably similar to the 1,106 anglers interviewed during the same time period in 2016. Since June 2015 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 October 2017, rainbow trout CPUE levels for boat anglers (n=876) has remained about the same (0.718 fish/hour) compared to 2016 (0.668 fish/hour). Average angler CPUE for rainbow trout to for the walk-in area was 0.291 fish/hour (n=236). As of October 2017, 73.5% of the interviewed boat anglers were from Arizona and the rest from out of state (or country). Of the boat anglers interviewed, 46.2% utilized a guide.

For calendar year 2016, we conservatively estimated 6,112 relative 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 an overall significant decline in relative angler use of the fishery since 2002 using standardized creek sampling methods. Based on a preliminary analysis of our game camera data (n=56 days), we are underestimating boat angler use by 22% on weekdays and 18% on weekends. Based on the game camera data, the boat angler use estimate would increase from 4908 [95% CI=4470, 5346] to 5988 [95% CI=5453, 6522].

Fishing satisfaction declined for both boaters and walk-in anglers: 3.5 and 3.2 on a scale of 1 – 5, respectively compared to 2015 (4.0 for boat anglers and 3.42 for walk-in anglers). There has been a declining trend in angler satisfaction over the last five years for both boat (r^2 =0.870, F1, 3 = 27.87, p = 0.0133) and walk-in anglers (r^2 = 0.866, F1, 3 = 26.96, p = 0.014).

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Report	Colorado River Fish Monitoring in Grand Canyon, Arizona – 2016 Annual Report.		May 2017		Rogowski, D.L., Osterhoudt, R.J, and Boyer, J.K., 2017, Colorado River Fish Monitoring in Grand Canyon, Arizona: 2016 GCMRC Annual Report
Report	Status of the Lees Ferry Rainbow Trout Fishery 2016 Annual Report		May 2017		Rogowski, D.L., Wolters, P.N., Manuell, K.M., and Boyer, J.K., 2017, Status of the Lees Ferry Rainbow Trout Fishery: 2016 GCMRC Annual Report
Journal Article	Use of ultrasonic imaging to evaluate egg maturation of humpback chub *Gila cypha* in Grand Canyon			April 2018	Brizendine, M.E., 2015, Use of ultrasonic imaging to evaluate egg maturation of humpback chub *Gila cypha*: submitted to Transactions of the American Fisheries Society
Journal Article	Viability of Razorback-Flannelmouth sucker hybrids			Feb 2018	**NOTE: THIS PRODUCT WAS NOT FUNDED BY THE GCDAMP.** Wolters, P.N., Rogowski, D.L. D.L., Ward, D.L., and Gibb, A.C.: submitted to Southwest Naturalist
Report	Monitoring of Mainstem Humpback Chub Aggregations 2017	Jan 2018		Jan 2018	Pillow, M.J., Van Haverbeke, D.R., Young, K.L., Dodrill, M.J., Monitoring of Mainstem Humpback Chub Aggregations 2017
Journal Article	Population Expansion of Humpback Chub in Western Grand Canyon and Hypothesized Mechanisms.		Accepted Nov 20 2017		Van Haverbeke, D.R., Stone, D.M., Dodrill, M.J., Young, K.L., Pillow, M.J., Population Expansion of Humpback Chub in Western Grand Canyon and Hypothesized Mechanisms: Southwest Naturalist
Report	Grand Canyon, Colorado River, Otolith Natal Origin Signal Study		July 2017		Limburg, K.E., and Evans, T.M., 2017, Grand Canyon, Colorado River, Otolith Natal Origin Signal Study: Final Report

Project 6	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$163,800	$5,200	$22,800	$340,000	$0	$33,358	**$565,158**
Actual Spent	$232,504	$667	$2,983	$344,960	$0	$38,862	**$619,976**
(Over)/Under Budget	**($68,704)**	**$4,533**	**$19,817**	**($4,960)**	**$0**	**($5,504)**	**($54,818)**

FY16 Carryover	**$80,209**		**CPI Adjust**	**($4,799)**		**FY17 Carryover**	**$20,591**

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

- Salary costs increased to retain staff using carryover funds to meet project objectives.
- Operating expenses decreased due to reduced need for supplies & materials.
- Cooperative agreements increased to offset cost of living increases.

Project 7: Population Ecology of Humpback Chub in and around the Little Colorado River

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	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

The goals of this project during the FY 2015 – 17 Triennial work plan were to:

1) Monitor humpback chub in the lower 13.6 km of the Lower Colorado River (LCR) and Colorado River reference or juvenile chub monitoring (JCM) reach (127.1 – 129.6 km downstream of Glen Canyon Dam).
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.
4) Undertake targeted, cost-effective research to understand mechanisms underlying observed population processes, including the roles of high carbon dioxide (CO_2) at base flow and parasites.
5) Continue to develop models that integrate findings from the above projects.

In 2017, biologists from US Fish and Wildlife Service (USFWS), US Geological Survey (USGS), and Arizona Game and Fish Department (AGFD) conducted numerous sampling trips to monitor humpback chub in the JCM reach and the lower 13.6 kilometers of the LCR. Sampling in the LCR included four USFWS trips (two in spring, two in fall). One additional USGS-led trip to the LCR occurred in June 2017 to mark age-0 (<100 mm total length; TL) humpback chub in this tributary before the onset of the summer monsoon season. Also, there were three trips that visited the JCM site in April, July, and September 2017. The mark-recapture studies conducted during these trips allows biologists to estimate seasonal survival rates, abundances, growth, and movement rates. In particular, the timing of the JCM and LCR trips helps biologists estimate the number of age-0 humpback chub produced in the LCR each year and the proportion that migrate from the LCR to the JCM site during the summer monsoon season. Lastly, USFWS translocated humpback chub from the lower 13.6 km of the LCR to upstream of Chute Falls (located 14.2 km upstream of the CR confluence) as part of the October 2017 trip. USFWS also monitored humpback chub above Chute Falls as part of their June 2017 sampling trip.

In addition to standard monitoring in both the LCR and JCM site this year, we initiated a pilot study aimed at developing a monitoring design for humpback chub in western Grand Canyon (hereafter JCM-west). We considered three possible sites for JCM-west and are in the process of analyzing data to choose a site for

monitoring trips scheduled in 2018. Based on catch data, particularly during the fall trip, we are optimistic that JCM-west sampling will allow us to estimate abundances and survival rates of various size classes in this population.

Various field efforts have been incorporating remote technologies for detecting PIT tags into their sampling effort. These efforts include a cross-channel array of antennas to detect PIT tags in the LCR (LCR array), a network of six shore-based single antennas (LCR network), USFWS supplemental antenna detections, and JCM/JCM-west supplemental antenna detections. The LCR array and LCR network both detect tags continuously and are placed near the LCR confluence in order to evaluate movement of fishes between the LCR and Colorado Rivers. In contrast, antenna used for supplemental detections are typically deployed only during sampling trips in order to increase capture probabilities of fish during mark-recapture sampling trips. These supplemental detections have shown to be highly effective because they often detect as many or more fish than are sampled using other methods (e.g., hoop nets, electrofishing).

Specific Findings from Monitoring and Research Projects

Remote Technologies

The LCR array detected 7782 unique PIT tags in FY 2017 (Oct 1, 2016 – Sep 30, 2017). Of these unique detections, most occurred in April (3570), followed by May (2701) and June (1808). For comparison, the USFWS encountered 2347 tagged fish in April 2017 and 1884 tagged fish in June 2017. Spring months are typically the time when humpback chub migrate into the LCR from the Colorado River to spawn, and accordingly this is the period when the number of LCR array detections is high. Dzul and others (2018) used data from Project Elements 7.4 and 9.2 to fit a model and estimate abundance of rainbow trout in the LCR in the winter of 2013-2014. Ongoing work is focusing on integrating these data into a multistate population model to improve our understanding of how environmental factors (e.g., flow, temperature) influence survival and movement of humpback chub.

In addition the continuing to maintain the LCR array, USGS and USFWS began testing the use of a network of shore-based individual antennas in the LCR for detecting movements of spawning native fishes. The reasons for deploying this new network design are twofold: 1) The LCR array shows signs of malfunction and the equipment it relies on s no longer supported by the manufacturer, and 2) we believe we can improve upon the design of the LCR array using a more cost-effective approach. The shore-based network design is still being developed and evaluated for its ability to maximize detection probability, and if results are favorable, this new design will replace the LCR array during the FY 2018-20 Triennial Work Plan.

Additionally, JCM and JCM-west trips are supplementing mark-recapture data with remote detections by using submersible antennas. Unfortunately, there were issues with some of the batteries on these units that prevented them from being used on all JCM trips in 2017; however, the batteries have been replaced and the manufacturer believes the issues have been resolved. Initial results from submersible antennas (from both USFWS and USGS efforts) indicate these technologies are very effective at detecting PIT-tagged humpback chub, particularly larger fish that have low capture probabilities in hoop nets and with electrofishing. Specifically, data from the April 2017 USFWS trip report show that 46% of tagged humpback chub at Boulders reach were detected only with submersible antennas, 24% were both detected on antennas and captured in hoop nets, and 30% were captured in hoop nets but not detected on antenna. Accordingly, remote antennas have proven to provide valuable supplementary information to mark-recapture efforts.

Long Term Monitoring in the LCR

In 2017, four monitoring trips were conducted in April, June, September, and October by USFWS, Arizona Game and Fish, and volunteers. The goal of these trips is to monitor the population status of humpback chub in the LCR during spring and fall. It was estimated that there were 9,490 (Standard Error [SE] = 665) humpback chub ≥150 mm and 6,410 (SE = 531) ≥200 mm in the LCR in spring. It appears that the 2017 spring LCR abundances of humpback chub in these size classes are similar to those estimated in 2014. It was estimated that there were 3,532 (SE=243) humpback chub ≥150 mm and 1,921 (SE = 129) humpback chub ≥200 mm in the LCR in the fall. Additionally, the September and October trips captured 955 age-0 humpback chub (<100 mm TL). Finally 315 juvenile humpback chub <135 mm were translocated to above Chute Falls during the October trip.

Juvenile Chub Monitoring in the Colorado River Research Site

In 2017, there were three JCM trips (occurring in April, July, and September). After monitoring the JCM reach, each trip floated downstream to a different location in western Grand Canyon to sample humpback chub using the same methods. For both JCM and JCM-west sites, two methods (slow-shock electrofishing and hoopnets) were used to capture fish. All humpback chub > 79 millimeter (mm) total length (TL) were marked with PIT tags, and all humpback chub between 40-79 mm TL were marked using visual implant elastomer (VIE) in the JCM site (all 2017 trips) and in the JCM-west site (September 2017 only).

In total, all JCM trips captured 936 humpback chub > 99 mm TL and 731 chub between 40-99 mm TL. Catch of humpback chub>99 mm TL was 196 in April, 314 in July, and 426 in September. In addition, catch of humpback chub between 40-99 mm TL was 248 in April, 218 in July, and 265 in September. Furthermore, there were 7 humpback chub that were marked in the LCR in July and recaptured in the Colorado River JCM site in September. These data will be incorporated into a multi-state mark-recapture model to evaluate outmigration from the LCR to the JCM site in 2017.

The pilot studies in western Grand Canyon were aimed mainly at selecting a good sampling reach for standardized monitoring in the future. The three candidate sampling site locations were near Parashant Canyon (River Mile [RM] 198-201.5 sampled in April 2017), below Havasu Creek (RM 161.5-165 sampled in July 2017), and near Fall Canyon (RM 210-213.5 sampled in September 2017). Catch of humpback chub>99 mm TL by trip was 30 in April, 79 in July, and 289 in September. In addition, catch of humpback chub between 40-99 mm TL was 126 in April, 23 in July, and 167 in September.

Lastly, there were two publications submitted in FY 2017 that use these data to inform fish management in the Colorado River. One publication, Yackulic and others (*in review*; see Products/Reports Table), used JCM data to evaluate the effects of temperature and rainbow trout densities on juvenile humpback chub survival, and one publication, Bair and others (*in review*; see Products/Reports Table), evaluates the cost effectiveness of rainbow trout management strategies.

Pre-Monsoon Juvenile Chub Sampling in the LCR

In 2017, monitoring occurred from June 22 to July 3, 2017. As in previous years, three teams completed two passes of the LCR using hoop nets, seines, and dip nets. One change that occurred in 2017 is that all native fish > 100 mm TL captured during the afternoon haul using hoop nets were not processed (i.e., they were released immediately without scanning for a tag or obtaining measurements). This change occurred as a result of concerns that the high afternoon temperatures could stress larger fish. During this trip, 1186 humpback chub (40-79 mm TL) were marked with VIE. Catch was greatest in the middle reaches, and catch was particularly low in Boulders reach this year. Estimated abundances of age-0 fish in the LCR was greater in 2017 (N=8239) than 2016 (N=4658), but was low compared to 2013 and 2015 (N=19697 & 27847, respectively).

Effects of High CO_2 on Chub Early Life History

CO_2 concentrations in the LCR were measured at base flow from River Kilometer (RKM) 30 to the confluence with the Colorado River using titration methods as well as continuously using an Oxyguard portable CO_2 meter. Electronic probes yielded overall lower CO_2 concentrations than titration methods. CO_2 concentrations upstream of Blue Springs (RKM 20.8) are low enough for fish that get washed downstream during flood events to survive, but then increase to levels lethal for fish at Blue Springs and remain high until RKM 16. CO_2 levels decrease from this point downstream with large drops in CO_2 occurring at travertine dam complexes. As part of this project element, laboratory studies evaluated native and nonnative fish tolerance to high CO_2 levels for both juvenile and adult fish. Rainbow trout and brown trout had the lowest CO_2 tolerances (90 and 100 milligram per liter (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 CO_2 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 CO_2 concentration. CO_2 tolerance of all of fishes tested are much higher than CO_2 levels naturally found within the lower 16 km of the LCR, indicating CO_2 dynamics are unlikely to control fish populations inhabiting this portion of the LCR.

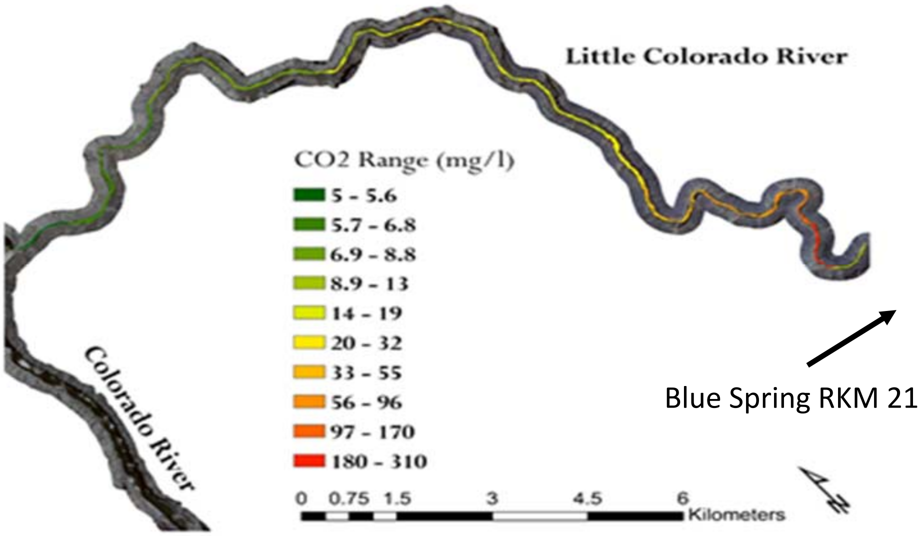

Figure 1. CO_2 levels in the Little Colorado River at base flow. Concentrations were measured with an Oxyguard portable CO_2 analyzer.

Asian Tapeworm Monitoring

No asian tapeworm monitoring was conducted in 2017 because of a Department of Interior helicopter contract dispute, which prevented helicopter support. Asian tapeworm monitoring was conducted in the LCR in May of 2015 and 2016 and is scheduled to occur again in 2018 along with additional monitoring of tapeworm infestation in humpback chub in the mainstem Colorado River. Although we do not have data for 2017, infestation rate Asian tapeworm in humpback chub in the LCR in 2015 and 2016 appears to be much lower than during 2005 to 2007. Both the proportion of humpback chub with tapeworms and number of tapeworms per fish appear highly variable from year to year and are likely linked to flooding within the Little Colorado River.

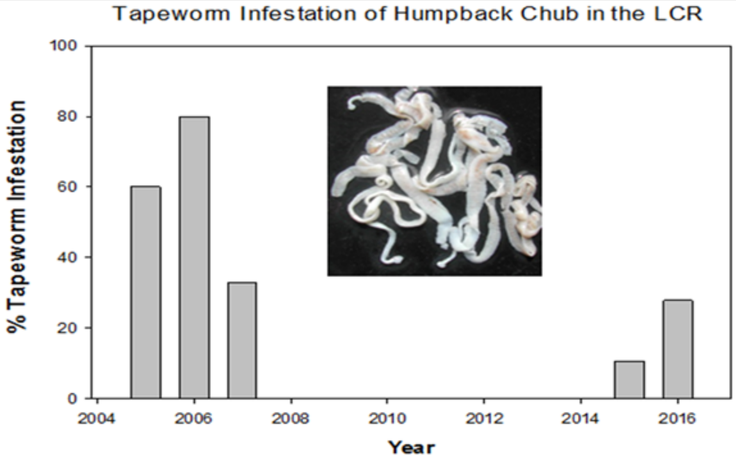

Figure 2. Proportion of humpback chub in the Little Colorado River infested with Asian tapeworm

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Inferring species interactions through joint mark-recapture analysis.			2018	Yackulic, C.B., Korman, J., Yard, M., Dzul, M.C., *in review*.
Journal Article	Identifying cost-effective invasive species control to enhance endangered species abundance in the Grand Canyon, USA.			2018	Bair, L.S., Yackulic, C.B., Springborn, M.R., Reimer, M.N., Bond, C.A., Coggins, L.G., *in review*.
Thesis	The trophic ecology of a desert river fish assemblage: Influence of season and hydrologic variability.		2017		Behn, K.E., 2017, M.S. Thesis, Idaho State University.
Journal Article	Estimating disperser abundance using open population models that incorporate data from continuous detection PIT arrays.		2017		Dzul, M.C., Yackulic, C.B., and Korman, J., 2017, Estimating disperser abundance using open population models that incorporate data from continuous detection PIT arrays: Canadian Journal of Fisheries and Aquatic Sciences, early view, https://doi.org/10.1139/cjfas-2017-0304.
Journal Article	Does bioelectrical impedance analysis accurately estimate the condition of threatened and endangered desert fish species?		2017		Dibble, K.L., Yard, M.D., Ward, D.L., and Yackulic, C.B., 2017, Does bioelectrical impedance analysis accurately estimate the physiological condition of threatened and endangered desert fish species?: Transactions of the American Fisheries Society, v. 146, no. 5, p. 888-902, http://dx.doi.org/10.1080/00028487.2017.1302993.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Effects of elevated carbon dioxide on fish populations within the Little Colorado River in Grand Canyon.			2018	Ward, D.L., Vaage, B., Sheehan, K., *in prep.*
Journal Article	Translating population viability analysis into a dynamic programing framework to facilitate economic intuition and adaptive management.			2019	Donovan, P., Springborn, M.R., Bair, L.S., Yackulic, C.B., *in prep*.
Trip Report	Spring 2017 monitoring of humpback chub *(Gila cypha)* and other fishes in the lower 13.57 km of the Little Colorado River, Arizona.	July 2017	July 2017		Pillow, M.J., 2017.
Trip Report	Fall 2017 monitoring of humpback chub *(Gila cypha)* and other fishes in the lower 13.57 km of the Little Colorado River, Arizona, trip report: 19-28 Sept and 17-26 Oct 2017.	Nov 2017		Nov 2017	Stone, D.M., 2017.
Annual Report	Mark recapture and fish monitoring activities in the Little Colorado River in Grand Canyon from 2000 to 2017.	Jan 2018		Jan 2018	Van Haverbeke, D.R., Young, K., Stone, D.M., Pillow, M.J., *in prep*.
Conference presentation	Combining continuous remote detections with traditional sampling to estimate the migratory flux of fish		Aug 2017		Dzul, M.C., Yackulic, C.B., Korman, J., 2017, Ecological Society of America, Portland, OR.
Conference presentation	Combining continuous remote detections with traditional sampling to estimate the migratory flux of fish.		Sep 2017		Dzul, M.C., Yackulic, C.B., Korman, J., 2017, 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region. Flagstaff, AZ.
Conference presentation	Modelling the joint dynamics of interacting species using occupancy or mark-recapture data.		July 2017		Yackulic, C.B., 2017, Euring Analytical Conference, Barcelona, Spain.
Conference presentation	Modelling the joint dynamics of interacting species.		Aug 2017		Yackulic, C.B., 2017, Invited presentation, Ecological Society of America, Portland, OR.
Conference presentation	Multi-state models applied to species interactions to inform endangered species management.		Sep 2017		Yackulic, C.B., 2017, Invited presentation, The Wildlife Society, Albuquerque, NM.
Conference presentation	Inferring species interactions to inform endangered species management in the Grand Canyon.		Sep 2017		Yackulic, C.B., 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region. Flagstaff, AZ. Organized.
Conference presentation	Identifying cost-effective invasive species control strategies in the Grand Canyon to enhance		April 6, 2017		Bair, L., Yackulic, C., Springborn, M., Reimer, M., Bond, C., Coggins, L.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	endangered species population viability.				Department of Interior Economics Workshop, Washington, D.C.
Conference presentation	Enhancing endangered species population abundance via cost-effective invasive species control strategies: Adaptive management in the Grand Canyon.		September 14, 2017		Bair, L., Yackulic, C., Springborn, M., Reimer, M., Bond, C., Coggins, L. 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region. Flagstaff, AZ. Organized.
Conference presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition and adaptive management.		September 25, 2017		Donovan, P., 2017, Presentation for Natural Resource Policy Lab, Davis, CA.
Conference presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition and adaptive management.		October 1, 2017		Springborn, M., 2017, Canadian Resource and Environmental Economists Study Group at Western University, London, Ontario.
Conference presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition.		October 1, 2017		Donovan, P., 2017, Heartland Environmental and Resource Economics Workshop at Illinois, Urbana-Champaign, IL.

Project 7	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$508,300	$11,500	$39,300	$430,000	$0	$80,406	**$1,069,506**
Actual Spent	$577,837	$24,219	$69,638	$440,223	$0	$94,307	**$1,206,224**
(Over)/Under Budget	**($69,537)**	**($12,719)**	**($30,338)**	**($10,223)**	**$0**	**($13,901)**	**($136,718)**
FY16 Carryover	**$125,639**		**CPI Adjust**	**($8,753)**		**FY17 Carryover**	**($19,832)**

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

- Salary costs increased to retain staff using carryover funds to meet project objectives.
- Travel & Training increased due to additional conference and meeting attendance.
- Operating expenses increased due to increased need for field equipment (PIT Tag Antennas), supplies & materials.
- Cooperative agreements increased due to sending funds to a university through a research work order.
- 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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	David Ward	**Principal Investigator(s) (PI)**	David Ward, USGS, GCMRC Brian Healy, NPS Clay Nelson, NPS Emily Omana, NPS Kirk Young, USFWS Dennis Stone, USFWS Randy VanHaverbeke, USFWS David Rogowski, AZGFD Scott VanderKooi, USGS, GCMRC
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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 2016 with a report from the panel delivered in December 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 occurred in the mainstem Colorado River near the confluence with Bright Angel Creek from 2013 to 2016. Removals did not occur in 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 November of 2013, 5 depletion passes were conducted over approximately 9 kilometer (km) (Zoroaster to Horn Creek). In February 2015, 10 depletion efforts were focused on the 4-km section from Bright Angel Creek inflow to Horn Creek (where the majority of fish were captured during the previous year's sampling). In February of 2016, efforts were further reduced to 5 depletion passes between the Bright Angel Creek inflow and Horn Creek with turbid conditions present for the majority of each sampling event. Ongoing trout removal efforts conducted by the Park Service within Bright Angel Creek have been conducted annually.

Trout catches decreased from 1,709 trout in 2013 to only 25 trout in 2016. In contrast, native fish catches increased over this same period, with 294 native fish captured in 2016 up from 132 in 2013 (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. 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 may 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
Nov 2013	332	1377	90	40	1	1	18	1	1	1
Feb 2015	84	391	270	120	0	0	8	0	0	0
Feb 2016	9	16	204	88	2	0	5	0	0	0
Nov 2017	Sampling did not occur because of highly turbid river conditions									

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 LCR, and is intended to increase growth rates and survivorship, expand the range, and ultimately augment the LCR humpback chub population 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 3,421 juvenile (~80-130 millimeter [mm] total length [TL]) humpback chub have been translocated upstream of Chute Falls (Figure 1). Of these, 315 humpback chub were released above Chute Falls (at RKM 16.2) on October 27, 2017.

This 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, 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 and Chute Falls reaches of the LCR. During these trips, capture probability data was obtained. From 2010–2017, this set of capture probability data was used to annually estimate the abundance of humpback chub upstream of RKM 13.6 in the two reaches (Figures 1 and 2). During a trip in June 2017, we estimated there were 267 humpback chub ≥100 mm (SE = 59) in the Chute Falls reach.

Of these it was estimated that 166 (Standard Error [SE] = 32) were adults ≥200 mm (Figure 1). In the Atomizer reach, it was estimated that there were 346 humpback chub ≥100 mm (SE = 64). Of these it was estimated that 281 (SE = 95) were adults ≥200 mm (Figure 2). Results have also indicated unusually rapid growth of translocated fish, and high apparent survival.

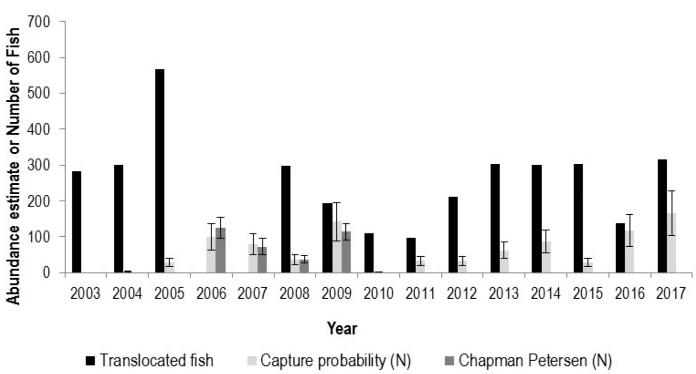

Figure 1. Numbers of juvenile humpback chub that have been translocated upstream of Chute Falls since 2003 (black bars), and abundances (±95% CI) of adult humpback chub (≥200 mm) estimated using capture probability data and with Chapman Petersen mark recapture methods upstream of Chute Falls (river km [rkm] 14.1 to 17.7).

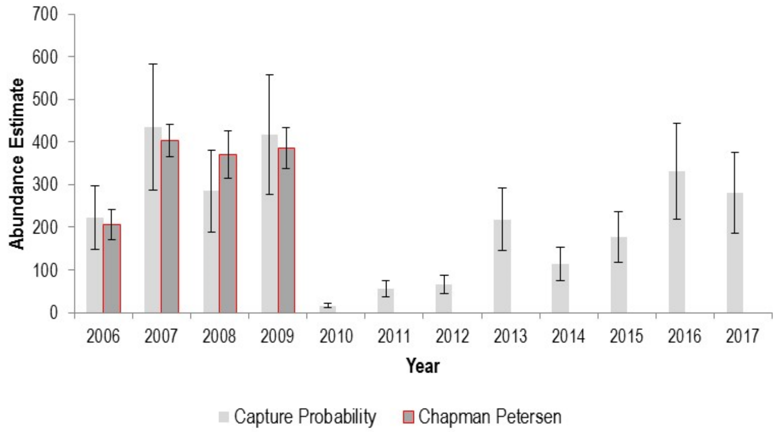

Figure 2. Abundances (±95% CI) of adult humpback chub (≥200 mm) estimated using capture probability data and with Chapman Petersen mark recapture methods in Atomizer Reach immediately below Chute Falls (river kilometer [rkm] 13.6 – 14.1) since summer 2006.

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, USGS 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 Flagstaff Science Campus and at Lees Ferry, AZ. The final report with recommendations from the panelists was delivered to GCMRC in December of 2016.

Project Element 8.4. Little Colorado River Invasive Aquatic Species Surveillance

US Fish and Wildlife Service staff surveyed 11 sites in the Little Colorado watershed to identify sources and potential pathways for colonization of new Aquatic Invasive Species into areas occupied by humpback chub. Nine common nonnative species were documented including, black bullhead, channel catfish, common carp, fathead minnow, plains killifish, green sunfish, white crappie, red shiner and smallmouth bass as well as three nonnative species which are new to the watershed including gizzard shad, smallmouth buffalo, and bigscale log perch. A final report detailing the effort is under preparation.

Project Element 8.5. Genetic Monitoring of Humpback Chub in Grand Canyon
Humpback chub fin clip samples were collected and preserved in ethyl alcohol during fish surveys in Grand Canyon. In excess of 300 samples were collected, preserved, and sent to Southwest Native Aquatic Resource and Recovery Center in Dexter, New Mexico. Initial genotyping of 2015 samples have been completed and QA/QC and analysis will commence Spring 2018.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Trip Report	Spring 2017 monitoring of humpback chub *(Gila cypha)* and other fishes above Lower Atomizer Falls in the Little Colorado River, Arizona, Trip report 9-15 June 2017.	July 2017	July 2017		Stone, D.M., 2017, Spring 2017 monitoring of humpback chub *(Gila cypha)* and other fishes above Lower Atomizer Falls in the Little Colorado River, Arizona, Trip report 9-15 June 2017.
Trip Report	Fall 2017 monitoring of humpback chub (*Gila cypha*) and other fishes in the lower 13.57 km of the Little Colorado River, Arizona, Trip Report 19-28 Sept and 17-26 Oct 2017.	Nov 2017	Nov 2017		Stone, D.M., 2017, Fall 2017 monitoring of humpback chub (*Gila cypha*) and other fishes in the lower 13.57 km of the Little Colorado River, Arizona, Trip Report 19-28 Sept and 17-26 Oct 2017.
Annual Report	Mark recapture and fish monitoring activities in the Little Colorado River in Grand Canyon from 2000 to 2017	Jan 2018		Jan 2018	Van Haverbeke, D.R., Young, K., Stone, D.M., and Pillow, M.J., *in prep*, Mark recapture and fish monitoring activities in the Little Colorado River in Grand Canyon from 2000 to 2017.
USGS Report	Glen Canyon Dam Adaptive Management Program Protocols Evaluation Panel: Fisheries Program Review		Dec 2016		Casper, A., Jackson, D., Gido, K., Peterson, J., and Rahel, F., 2016, Glen Canyon Dam Adaptive Management Program Protocols Evaluation Panel: Fisheries Program Review, December 27, 2016
Park Service Report	Bright Angel Creek Comprehensive Brown Trout Control Project		Aug 2017		**NOTE: THIS PRODUCT WAS NOT FUNDED BY THE GCDAMP.** Schelly, R.C., Omana Smith, E., Koller, R., and Healy, B., 2017, Bright Angel Creek comprehensive brown trout control project season report--October 18, 2016-February 7, 2017: Grand Canyon, Ariz., National Park Service, Grand Canyon National Park, Interagency agreement number 09-AA-40-2890, 11 p.

Project 8	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$69,400	$0	$6,300	$138,200	$0	$13,286	**$227,186**
Actual Spent	$75,788	$0	$1,940	$152,853	$0	$13,971	**$244,553**
(Over)/Under Budget	**($6,388)**	**$0**	**$4,360**	**($14,653)**	**$0**	**($685)**	**($17,367)**

FY16 Carryover	**$63,020**		**CPI Adjust**	**($1,937)**		**FY17 Carryover**	**$43,716**

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

- Salary costs increased to retain staff using carryover funds to meet project objectives.
- Operating expenses decreased due to reduced need for supplies & materials.
- Cooperative agreements increased to offset cost of living increases.

Project 9: Understanding the Factors Determining Recruitment, Population Size, Growth, and Movement of Rainbow Trout in Glen and Marble Canyons

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program

Project Lead	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 Modeling and Future Monitoring

A protocol evaluation panel (PEP; see Project Element 8.3) was convened in the fall of 2016 to review the GCMRC fisheries monitoring program. Consequent to the final PEP panel review, recommendations deemed technically appropriate were then responded to by cooperators (US Fish and Wildlife Service, National Park Service, Arizona Game and Fish Department, and Ecometric, Inc.), and modifications were then made to existing and proposed monitoring, and future research projects. These technical modifications are reflected in the Triennial Budget and Work Plan (TWP)—Fiscal Years 2018-20.

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

As originally conceived, a large-scale mark–recapture study called the Natal Origin (NO) project (2011-2016) was used to quantify rainbow trout population dynamics, this project was discontinued at the end of 2016. Findings from this research study were insightful and provided Glen Canyon Dam Adaptive Management Plan (GCDAMP) with new data collecting and analytical approaches for estimating rainbow trout abundance, survival, recruitment, and capture probabilities; and a better understanding of factors controlling trout movement and abundance near the Little Colorado River confluence where endangered humpback chub rear. The primary objectives of this research project were to quantify the extent of trout movement from Lees Ferry into Marble Canyon and the Little Colorado River (LCR) confluence area and to determine the physical and biological factors responsible for trout movement (density, food, growth, turbidity, High-Flow Experiments [HFEs], etc.). Since the NO project was discontinued two years through the FY 2015-17 TWP, concerns were raised at the 2016 Annual Reporting meeting that the resulting data-gap leads to unintended problems about the status and trends of trout, particularly in light of the recent expansion of brown trout, along with the substantial decline in the rainbow trout population at the Lees Ferry sport fishery. In response to the stakeholder's input and PEP findings, GCMRC made modifications to the NO sampling design to serve as a stop gap measure until the new FY 2018-20 workplan was fully developed and approved. Toward that goal, GCMRC has continued with some of the same sampling and analytical methods developed in the NO project for estimating trout abundance, survival, recruitment and capture probability. We report on this year's preliminary findings.

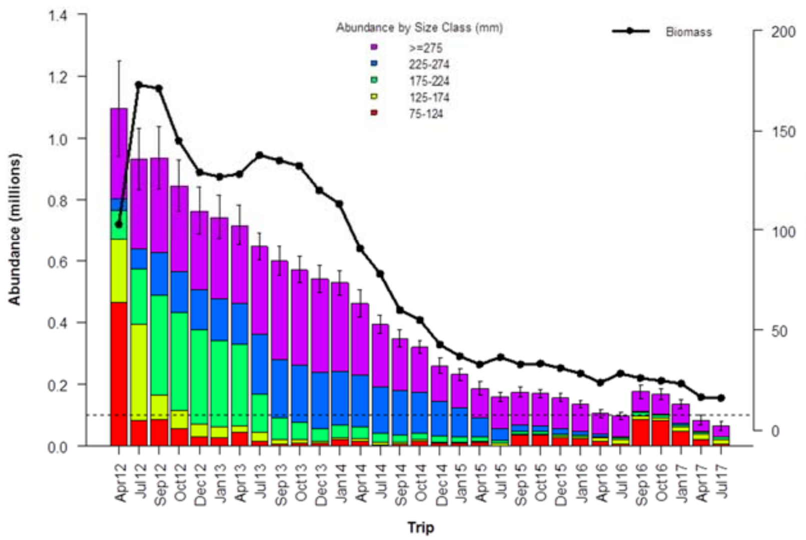

Figure 1. Rainbow trout abundance estimates for the Lees Ferry sport fishery by size class across all sampling trips conducted between April 2012 to July 2017.

In 2017, a total of four mark-recapture trips were conducted at Lees Ferry (Reach I, -15.6 to 0.0 RM) (Fig. 1, updated monitoring estimates). To help reduce the unplanned costs, separate data collection efforts were conducted in concert with the Juvenile Chub Monitoring (JCM) trips (Project 8) and using GCMRC staff. Findings from this data collection effort indicate that 2017 was another large trout recruitment year, and was similar to 2016 in the production of age-0 rainbow trout (RBT; fork length [FL] <125 mm). By late June, 77% of the total electrofishing catch (from two electrofishing passes, n ≈ 4,500) at Lees Ferry consisted of the age-0 cohort (modal size, 46-55 FL), and by September this cohort continued to have high survival and represented 78% of total catch (n ≈ 7,200). Previously, the NO study has reported on trout movement from Lees Ferry into Marble Canyon and the LCR confluence area. Past findings indicated that there was limited outmigration of age-0 rainbow trout from Lees Ferry into Marble Canyon (Korman and others, 2015), with the exception of the 2011 and 2016 cohorts. Unlike other NO study reaches the Houserock Reach (Reach II, 17.2-20.7 RM) is considered less suitable for spawning, and hence an ideal location to monitor for the presence of age-0 rainbow trout dispersing from Lees Ferry into Marble Canyon. For this reason, a single electrofishing pass was conducted over one night at the Houserock Reach on both the late-June and late-September JCM trips. Results indicated that by late-June total electrofishing catch (n ≈ 800) at Houserock Reach consisted of 47% age-0 trout (modal size, 66-75 FL), and by late-September this cohort had increased to 71% of total electrofishing catch (n ≈ 2,300).

Past NO findings have shown that although trout densities are lower in Marble Canyon than in Lees Ferry, the respective growth rates are higher. For comparison, the age-0 cohort in September was substantially smaller in the Lees Ferry Reach (modal size, 66-75 FL), which is in sharp contrast to the Houserock Reach (modal size, 86-95 FL). These findings further support the previous inference that dispersal was likely due to density- and growth-dependent factors. Although the overall catch for both rainbow trout and brown trout in the JCM LCR Reach (IVb, (62.8-65.8 RM) has remained low in comparison to past years (Coggins and others, 2011), the current trout catch appears to be increasing again in this critical reach where humpback chub reside. For example, total rainbow trout (RBT) catch in September 2016 was low (n = 12 RBT, age-0 = 58% [no brown trout]), which is in contrast to the observed catch on the September 2017 trip (n = 74 RBT, age-0 = 74%, and n = 3 brown trout [BNT]). These findings suggest that rainbow trout densities are increasing in Marble Canyon, and this is likely due to a number of sequential years (2016 and 2017) where age-0 RBT recruitment was good, followed by downstream dispersal from Lees Ferry, as well as possible local reproduction throughout Marble Canyon. Unfortunately, the current sampling design can no longer discern whether or not the other locations found downstream in Marble Canyon are increasing in age-0 trout due to downstream dispersal or from local reproduction. Low rainbow trout densities are not likely to persist in the JCM LCR Reach in the future if high recruitment years and downstream dispersal continue.

Fish that are highly piscivorous, like brown trout, are often uncommon and difficult to catch. For this reason, brown trout continue to remain a significant concern with management agencies tasked with: 1) preventing establishment of undesirable fish species, particularly in the Lees Ferry sport fishery; and 2) reducing risks attributed to downstream dispersal of brown trout to the JCM LCR Reach (62.8-65.8 RM), and by extension its potential threat to native fish including the endangered humpback chub. In 2017, a total of 735 brown trout were caught in the Lees Ferry Reach. Catches in January, April, and July had year-over-year increases continuing the trend observed since 2013. In contrast, brown trout catches in September and October dropped sharply from 2016 values (Fig. 2). On the late October trip, over 50% of brown trout captured were smaller than 125 mm FL (modal size, 91-95 FL) indicating that this species was successful in reproducing a strong cohort in Glen Canyon in 2017. It remains uncertain if this 2017 year class will survive to recruit into the adult population; however, based on size distributions for the October catch there is some indication that the previous 2016 cohort (modal size, 226-235 FL) was successful in recruiting to the adult brown trout population. Although these catch data suggest relatively large increases in brown trout in recent years, this inference is fraught with some degree of uncertainty due to our limited knowledge of catchability (i.e., capture probabilities), a problem that can only be resolved by applying an effective mark-recapture study or until such time that a CPUE indexing approach is more reliable because this species has become more abundant.

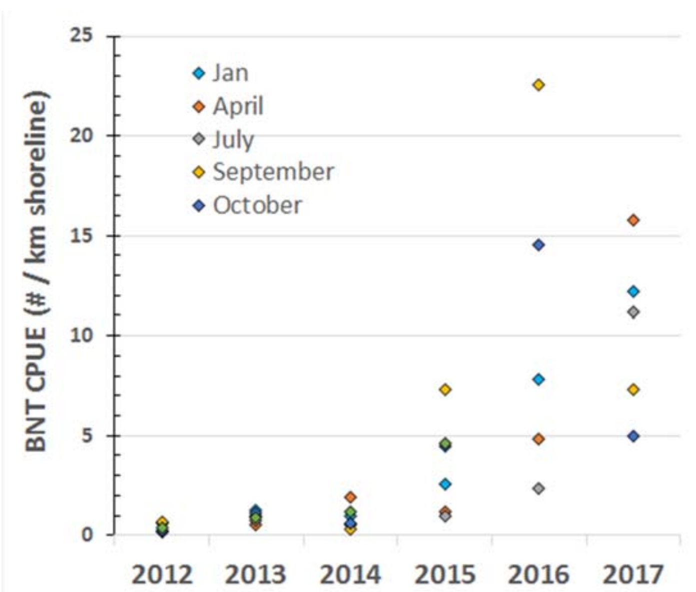

Figure 2. Brown trout electrofishing CPUE index (#BNT / kilometer) of linear shoreline at Lees Ferry sport fishery.

The data collected in 2017 are to be used in updating existing models (Korman and Yard, 2017) to estimate rainbow trout abundance, growth, survival, and recruitment in the Lees Ferry sport fishery. For additional information regarding Natal Origin Project refer to published citations (Korman and Yard 2016; Yard, and others, 2016; Korman and Yard, 2017, and Korman and others, 2017).

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 is 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. In FY 2015 we sampled approximately 100 rainbow trout and 25 brown trout during trips associated with the Natal Origins Project (9.2), during which we excised muscle, liver, and hindgut tissue from each fish in the field. In FY 2016 we processed all samples in the laboratory by extracting lipids from each tissue using gravimetric techniques, then conducted a preliminary analysis of the data.

In FY 2017 we compiled all lipid, tissue, and species data into a database, QA/QC the data, and built on a preliminary analysis from FY 2016. We will finish a more rigorous analysis of the data and submit one manuscript to a peer-reviewed journal in FY 2018.

Project Element 9.4. Comparative Study on the Feeding Morphology of Drift Feeding Fish: NOT FUNDED

Project Element 9.5. Meta-Analysis, and the Development of Reactive Distance Relationships for Encounter Rate Model

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.

Understanding mechanisms by which abundance and growth rates of fish populations are regulated is fundamental in determining carrying-capacity levels, particularly when population dynamics of one species negatively affects an endangered species like the humpback chub. Although food is often one of the most limiting resources in aquatic ecosystems, visual sight feeders like rainbow trout may have encounter rates that are periodically reduced, in essence the number of invertebrates encountered daily, thereby effecting growth rates. This occurs especially when fish are exposed to frequent and varying turbidity levels as found in the Colorado River Ecosystem (CRE). Consequently, trout densities and growth rates may be mediated by various factors, including frequency and magnitude of tributary supply, and flow operations at Glen Canyon Dam.

Underwater light intensity is one of the more influential factors affecting reactive distance (predator visually perceives and reacts to a prey item). Two elements of underwater perception are important to visual sight feeders; (i) visual acuity – ability of a predator to discern small prey under high contrast, and (ii) apparent contrast – where predators are able to discern large prey under low contrast from an illuminated background.

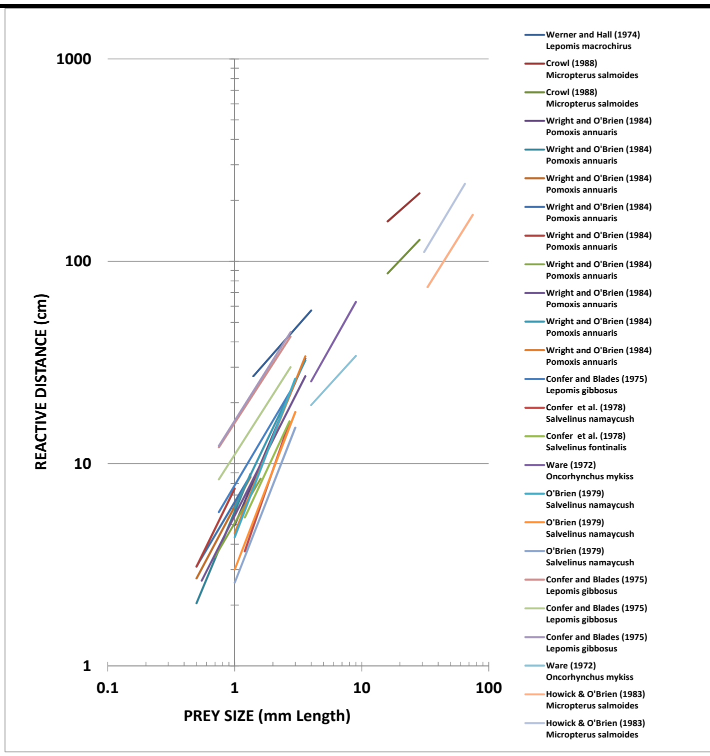

Figure 3. The corresponding relationship between published reactive distance regression slopes and prey size that exists among different marine and freshwater fish species.

To date, we have conducted an extensive literature search on all known published data on fish reactive distances. We have quantitatively summarized regression slopes obtained from either published relationships or through extraction of data from graphs and tables (Fig 3). We are currently performing an extensive meta-analysis on these data. Through this meta-analysis we are going to refine the predictive capabilities associated these reactive distance relationships so that they can be more broadly applied to more realistic environmental conditions (see Project Element 9.7). Once these analyses are complete we will prepare a manuscript, which will be submitted to a peer-reviewed journal sometime by the end of FY 2018.

Project Element 9.6. Evaluation of Turbidity (in terms of Total Suspended Solids) 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 utilized to manage rainbow trout populations downstream of the Paria River.

We conducted laboratory experiments in four recirculating artificial stream systems located at the U.S. Forest Service Rocky Mountain Research Station in Flagstaff, Arizona. Passive integrated transponders- (PIT) tagged rainbow trout were collected from Lees Ferry, acclimated to laboratory conditions, and placed into the artificial streams with abundant live amphipods for 30-days. Two stream systems were maintained with a turbidity of 100 Formazin Nephelometric Units (FNU) and two stream systems held clear water. Rainbow trout in turbid tanks gained an average of 9.6 grams over the 30-day trial while trout maintained in non-turbid tanks lost an average of 23 grams over the same time period. From a laboratory perspective, it does appear that relatively low levels of turbidity (100 FNU) disadvantage trout in as little as 30 days. To link laboratory results to field observations we used USGS gauge data to evaluate turbidity events that persisted for multiple weeks in the Colorado River downstream of the confluence with the Paria River and matched those data to rainbow trout condition during the same time period (Fig 4). Rainbow trout condition in this reach of the Colorado River does varies highly within a given year and preliminary analysis indicate low rainbow trout condition following periods of extended duration turbidity.

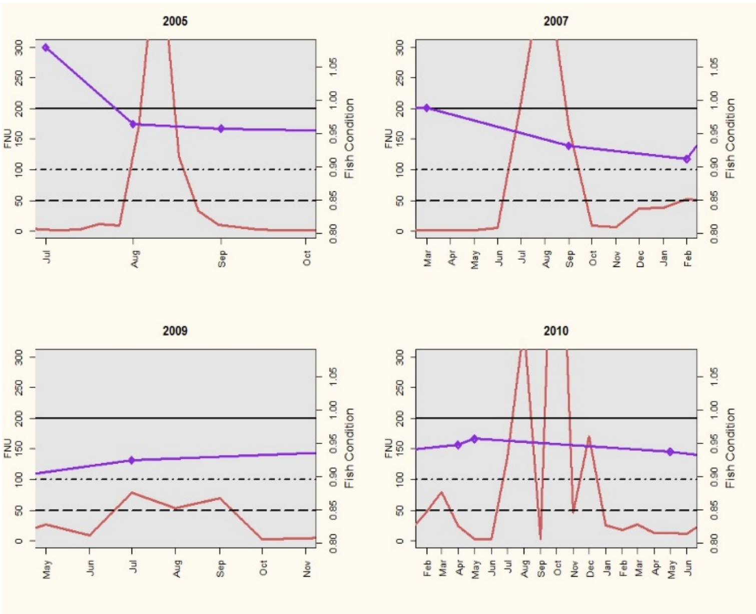

Figure 4. Rainbow trout condition (purple line) following periods of extended turbidity (red line) in the Colorado River downstream of the confluence with the Paria River.

Project Element 9.7. Application of a Bioenergetics Model in a Seasonally Turbid River

Drift-foraging bioenergetics approaches have been applied to rainbow trout at Lees Ferry, illustrating the importance of invertebrate prey to rainbow trout growth. This project element looks to expand this work and explore how other factors including turbidity influence conditions for trout growth. Turbidity influences how rainbow trout detect and react to drifting invertebrate prey, potentially influencing what types of prey are consumed, and can have large implications for energy intake and ultimately growth. We continue to refine these process-oriented models in order to improve our ability to predict how rainbow trout may respond to changing physical and biological conditions.

We have used information collected during Natal Origins (Project 9) trips on invertebrate drift rates (Project Element 5.2.2) and rainbow trout diets to assess prey selectivity of rainbow trout. This is accomplished using a discrete choice model, fit within a Bayesian modeling framework. This approach allows us to quantify how rainbow trout choose prey based on prey type and prey size. These finding are reported in a manuscript (Dodrill and others, *in prep.*) which is to be submitted to Canadian Journal of Fisheries and Aquatic Sciences. Additionally, we quantify how turbidity influences rainbow trout gut fullness and invertebrate prey selection. These findings are detailed in a manuscript (Dodrill and others, *in prep.*) to be submitted to Ecology of Freshwater Fish. Understanding how turbidity influences gut fullness patterns will help to calibrate drift-foraging bioenergetics models, improving predictive accuracy of these approaches. Knowledge of prey selection patterns can also be incorporated into drift-foraging bioenergetics models. 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 is 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 FY 2015 (funded in the FY 2013-14 work plan), which examined the influence of physical and biological variables such as flow and fish density 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 and air temperature warms. Therefore, in FY 2016 and FY 2017 we built on the body of knowledge gained from our first synthesis in two ways.

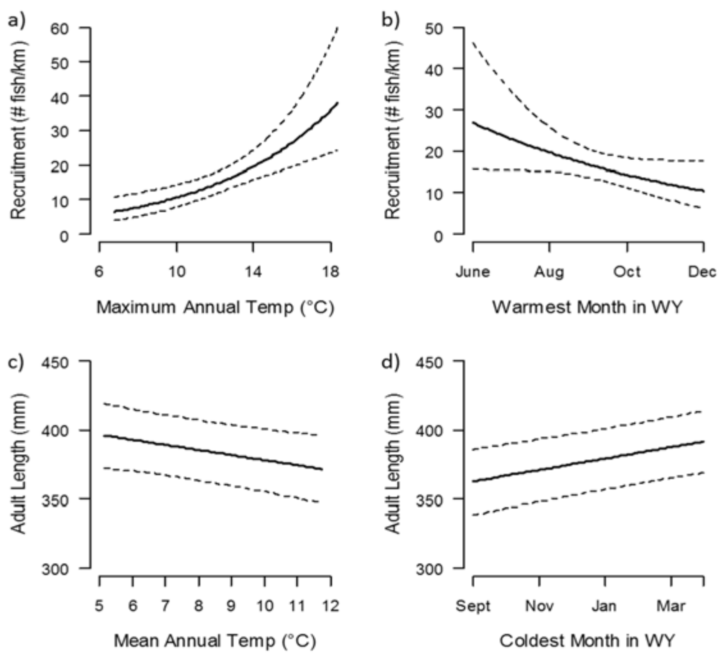

Figure 5. Relationship between a) rainbow trout recruitment (# of subadult fish per kilometer) and maximum annual temperature (°C); b) rainbow trout recruitment and the timing of the warmest month in each WY; c) adult rainbow trout length and mean annual temperature (°C); and d) adult rainbow trout length and the timing of the coldest month in each WY. The solid black line represents the curve for the best-fitting relationship between each response and predictor, with 95% confidence intervals in black dashed lines.

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 warming conditions. We found that summer water temperatures were inversely related to reservoir water level, with warm temperatures associated with reduced storage (e.g., drought) and with dams operated as run-of-river units. Variation in rainbow trout recruitment was linked to water temperature variation, with a fivefold increase in recruitment occurring at peak summer temperatures (18 ºC vs. 7 ºC) and a 2.5-fold increase in recruitment when peak temperatures occurred in summer rather than fall (Figs 5a-b). Conversely, adult trout size was only moderately related to water temperature. Rainbow and brown trout size decreased by ~2.5 centimeters and 1.9 centimeters, respectively, as mean annual and peak summer temperatures increased (Figs 5c, and 6). Further, rainbow trout size decreased by ~2.5 centimeters with an earlier onset of cold winter temperatures (Fig. 5d). These results suggest that warming water temperatures and shifts in seasonality resulting from climate change may increase trout recruitment but only moderately decrease adult size in western North American tailwaters. In FY 2017, we submitted this work to a peer-reviewed journal, submitted revisions based on reviewer comments, and are currently awaiting a decision on its publication. In addition, we prepared the data package associated with this product for publication in USGS ScienceBase.

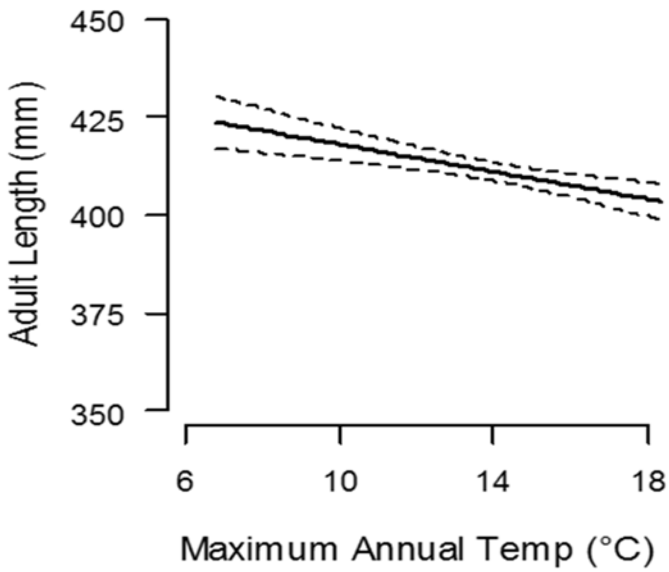

Figure 6. Relationship between adult brown trout length and maximum annual temperature (°C). The solid black line represents the curve for the best-fitting relationship between each response and predictor, with 95% confidence intervals in black dashed lines.

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. Such warmer waters may benefit native species, but thermal barriers to non-native fish invasion from the upper basin may be reduced or eliminated, threatening the recovery of endangered fish populations in Grand Canyon. We prepared a manuscript associated with these data in FY 2017, which will be submitted to a peer-reviewed journal in FY 2018.

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

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. This type of information has management implications, particularly downstream of 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. Based on trout recaptures (PIT-tagged fish) there is no indication that fish moved or were displaced by any of the four HFEs conducted from 2012 to

2016. If there is a flow effect related to HFEs, we hypothesize that the likely mechanism acts directly on the benthic invertebrate community; and secondarily, on trout by reducing the invertebrate prey available following the flow disturbance.

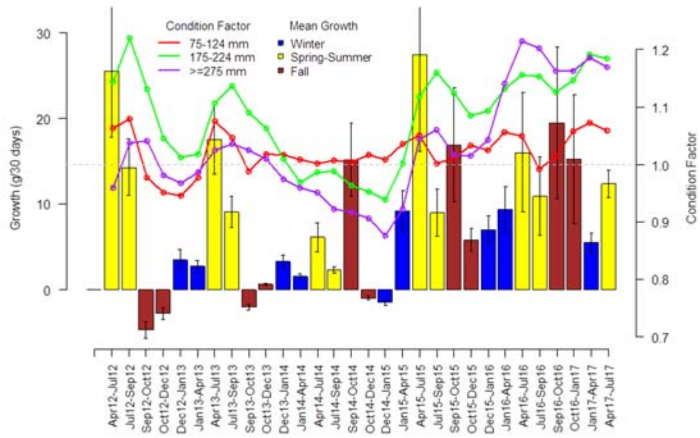

Figure 7. Bar-graph represents the average rainbow trout growth in weight per 30 days (g/ 30 da) based on a fish of 83.5 g, which is the expected weight for a 200 mm fish using the length-weight relationship over the entire period of this study. Error bars show 80% credible interval (lower 10th and upper 90th percentiles), and color denotes seasons: winter (blue), spring-summer (yellow), and fall (brown). Line graph represents condition factor (CF, 2nd-axis) that is estimated for three different size classes based on fork length, 75-124 mm FL (red), 175-224 mm (green), and ≥ 275 mm (purple).

Preliminary findings reported on in FY 2016 suggested 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 between pre- and post-flood periods and between years with and without HFEs (Fig 7, bar graph). Last year, we reported that poor fall-winter growth was observed in three consecutive HFE years (2012-2014). However poor growth in September-October 2012 occurred before the first fall HFE was implemented, suggesting that other factors (low P or high trout density) might be depressing growth over the fall-winter period (similar conditions were repeated in 2013 and 2014). In fall of 2014, the occurrence of high growth before HFE and low growth immediately after HFE in the winter of 2015 does suggest a potential HFE effect in that year.

This low growth period was particularly harsh on the trout population (note the dip in condition factor [CF line graph]), which led to high mortality of larger fish, poor reproduction in spring of 2015, and very poor recruitment from 2014 cohort. This suggest that even if HFEs do not have an effect in every year, their negative effects in occasional years can be important if it occurs in a year where trout are energetically compromised. There was good growth in fall-winter of 2015 when there was no HFE; however, good growth occurred in September-October 2015, a growth interval that preceded the HFE. Good growth in occurred in the fall 2016 before HFE and good growth occurred after the HFE, with no apparent negative HFE effect in this year. Unlike previous years when a HFE occurred, these data suggest that there was positive trout growth rather than negative growth during the October-January interval for the fall 2016 HFE.

There are numerous independent factors that are likely confounding these growth and condition factor results. Therefore, additional replication across a number of years, with and without HFEs, is further required to determine if fall-HFEs limit trout growth. Because of stakeholder concerns additional data is further required to make informed inferences on HFEs; and for that reason, the new FY 2018-20 Triennial Work Plan will continue to monitor trout dynamics in Lees Ferry in response to flow periods with and without HFEs. These data collection and analyses will occur as part of the new research project called Trout Recruitment and Growth Dynamics (TRGD).

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 HFE on the physiological condition of age-0 rainbow trout in Glen Canyon. Specifically, we assessed the influence of experimental floods on the daily growth rate, lipid storage dynamics, and growth and condition recovery rates of trout downriver of Glen Canyon Dam. We collected fish samples in fall during two flood years (FY 2013, FY 2014) that differed in magnitude and duration and compared samples to those collected during fall when an HFE did not occur (FY 2015).

In FY 2016 we extracted sagittal otoliths from post-flood fish samples and prepared them for microstructural analysis by embedding otoliths on slides, sectioning and polishing each otolith, and using a compound microscope attached to an image analysis system to measure the width between daily growth increments before, during, and after each flood. Since lipid acquisition and recovery plays an important role in the ability of fish to cope with environmental stressors (e.g., HFEs) and influences their long-term survival and recruitment processes, we partnered with the Wake Forest School of Medicine, Lipoprotein Analysis Laboratory to measure sensitive biochemical indicators of fish condition (triglyceride, cholesterol, phospholipid, total lipid) in pre-flood, post-flood, and control samples. We received the results of that analysis in late FY 2016 and conducted a preliminary review of the data in collaboration with the laboratory in FY 2017. A more rigorous analysis of these data will be conducted and a manuscript submitted to a peer-reviewed journal in FY 2018.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Trends in rainbow trout recruitment abundance survival and growth during a boom and bust cycle in a tailwater fishery.		Apr. 2017		Korman, J., Yard, M.D., and Kennedy, T.A., 2017, Trends in rainbow trout recruitment, abundance, survival, and growth during a boom-and-bust cycle in a tailwater fishery: Transactions of the American Fisheries Society, v. 146, no. 5, p. 1043-1057, http://dx.doi.org/10.1080/00028487.2017.1317663.
Journal Article	Supplement: Trend in rainbow trout recruitment, abundance, survival, and growth during a boom-and-bust cycle in a tailwater fishery--Description of multistate Jolly–Seber open-population model		Apr. 2017		Korman, J., Yard, M.D., and Kennedy, T.A., 2017, Trend in rainbow trout recruitment, abundance, survival, and growth during a boom-and-bust cycle in a tailwater fishery Description of multistate Jolly–Seber open-population model: Transactions of the American Fisheries Society, vo. 146, no. 5, p. 1043-1057, https://doi.org/10.1080/00028487.2017.1317663.
Journal Article	Effects of environmental covariates and density on the catchability of fish populations and interpretation of catch per unit effort trends		Jan. 2017		Korman, J., and Yard, M.D., 2017, Effects of environmental covariates and density on the catchability of fish populations and interpretation of catch per unit effort trends: Fisheries Research, v. 189, p. 18-34, https://doi.org/10.1016/j.fishres.2017.01.005.
Journal Article	*To be determined*		May. 2018		*In prep* - Korman, J., and M.D. Yard, M.D., Yackulic, C.B., Kennedy, T.A., and Wright, S.
Journal Article	Prey consumption: Linking bioenergetics and foraging models to estimate invertebrate production from rainbow trout dynamics.		May. 2018		*In prep* - Yard, M.D., Korman, J., Walters, C., Dodrill, M.J., and Yackulic, C.B.
Journal Article	Warm water temperatures and shifts in seasonality increase trout recruitment but only moderately decrease adult size in western North American tailwaters.		Dec. 2017		Dibble, K.L., Yackulic, C.B., and Kennedy, T.A., 2017, E*nvironmental Biology of Fishes*, *in review,* resubmitted to journal Dec 2017.
Data Release	The influence of water temperature on salmonid recruitment and adult size in tailwaters across western North America—Data: U.S. Geological Survey Data Release.		Dec. 2017		Dibble, K.L., Yackulic, C.B., and Kennedy, T.A., 2017, *in review*.
Journal Article	Drought facilitates longitudinal recovery of thermal regimes across regulated river networks but removes barriers to non-native fish invasion.		Sept. 2018		Dibble, K.L., Yackulic, C.B., Kennedy, T.A., Bestgen, K.R., and Schmidt, J.C.: BioScience.
Journal Article	Prey selection by rainbow trout in a large river ecosystem: Importance of prey type and size.		Sept. 2018		Dodrill, M.J., Yackulic, C.B. Kennedy, T.A. and Yard, M.D.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	The effects of turbidity on rainbow trout invertebrate prey selection and gut fullness.		Sept. 2018		Dodrill, M.J., Kennedy, T.A., and Yackulic, C.B.
Journal Article	Are hatchery reared trout effective predators on native fish?			Sept. 2018	**NOTE: THIS PRODUCT WAS NOT FUNDED BY THE GCDAMP.** Ward, D.L., Morton-Starner, R., and Vaage, B., Are hatchery reared trout effective predators on native fish?, 2018, *in review*, North American Journal of Fisheries Management.
Journal Article	Turbidity as a tool for management of Rainbow Trout in the Colorado River in Grand Canyon			Sept. 2018	Sheehan, K., Ward, D., and Vaage, B., Turbidity as a tool for management of rainbow trout in the Colorado River in Grand Canyon, *in prep.,* North American Journal of Fisheries Management.
Presentation	Drought may facilitate the recovery of natural temperature regimes downriver of dams across the western US, but such changes may not favor native fish species.		Sept. 2017		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 14th Biennial Conference of Science and Management on the Colorado Plateau and Southwest Region. Flagstaff, AZ. 9/12/2017.
Presentation	Drought facilitates longitudinal recovery of thermal regimes in regulated rivers but may remove barriers to warm-water fish invasion.		Aug. 2017		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 147th Annual Meeting of the American Fisheries Society. Symposium: What can we expect from non-natives and climate change? Tampa, FL. 8/23/2017.
Presentation	Effects of drought and climate change on trout fisheries and temperatures in tailwaters.		Dec. 2016		Dibble, K.L., C.B. Yackulic, and T.A. Kennedy. 2016 Annual Colorado River Fish Cooperator's Meeting. Flagstaff, AZ. 12/12/2016.

Project 9	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$228,900	$0	$79,700	$50,000	$0	$38,760	**$397,360**
Actual Spent	$436,857	$7,129	$38,325	$62,000	$0	$60,094	**$604,405**
(Over)/Under Budget	**($207,957)**	**($7,129)**	**$41,375**	**($12,000)**	**$0**	**($21,334)**	**($207,045)**

FY16 Carryover	**$69,000**		**CPI Adjust**	**($3,741)**		**FY17 Carryover**	**($141,786)**

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

- Salary costs increased due to TWG recommended continuation of trout monitoring that began as part of the Rainbow Trout Natal Origins study.
- Operating expenses decreased due to reduced need for supplies & materials.
- Cooperative agreement costs increased to support analysis of data from continued trout monitoring.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program

Project Lead	Mike Yard	**Investigator(s)** (I)	Dan Buscombe, USGS, GCMRC Mike Yard, USGS, GCMRC Josh Korman, EcoMetric Research Paul Grams, USGS, GCMRC Tom Gushue, USGS, GCMRC
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SUMMARY

The goal of Project 10 was to promote collaborative efforts between physical and biological scientists using an interdisciplinary approach. This project was intended to help inform resource managers on the Glen Canyon Dam Adaptive Management Program (GCDAMP) in the development of the Long Term Experimental Management Plan Environmental Impact Statement (LTEMP) for Glen Canyon Dam operations. The main purpose of this study was to better understand how specific dam operations influence the river's bed-sediment type and the 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 is also important for native fish conservation in Grand Canyon. The original primary researcher, Ted Melis, Physical Scientist, responsible for leading and completing Project 10 has been promoted to Deputy Director of USGS Southwest Biological Science Center. As a result, a revised proposal was submitted that identifies how the stated study objectives and deliverables are to be met after this change (see: http://www.usbr.gov/uc/rm/amp/amwg/mtgs/14aug27/Attach_06d.pdf).

The revised proposal provides 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.

Project Element 10.1. Imaging Channel-Bed, Bed-Texture, and Change Detection

The purpose of Project Element 10.1 was to complete sidescan sonar mapping/imaging methods. An additional purpose is to finalize a protocol for sidescan data collection. This monitoring involves collection and analysis of data and development of algorithms for determining changes in the areal extents of sand and gravel bed surface sediment types in areas where drifting benthic organisms and spawning trout are monitored in Glen and Marble Canyons.

The methods for sidescan data processing previously developed (Buscombe and others, 2015) are now implemented 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, 2017; Buscombe and others, 2017; Hamill, 2017; Hamill and others 2016; *in review*). These methods are suitable for providing relatively low-cost, automated and objective quantification of riverbed composition at temporal and spatial scales that are consistent with fish sampling programs.

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

The purpose of Project Element 10.2 was to conduct slope analyses to identify proportions 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, are 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 areas characterized as low- and high-angle. These data will then be overlaid 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

The purpose of Project Element 10.3 was to integrate physical data collected in elements 10.1 and 10.2 (segment-scale channel geometry, changes in areal bed surface sand coverage, and variations in flow patterns, total suspended sediment flux and water temperature) with biological data (the aquatic food base, in terms of invertebrate drift) and analyze these in terms of rainbow trout responses. Data from the first two project elements are on schedule and findings will be available for analyses soon. 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 (NO)". Data from this element is now available since fieldwork concluded at the end of FY 2016. The purpose of this study was to better understand the effects of sediment input on rainbow trout production between Glen Canyon Dam and the Paria River where effects of seasonal inputs of fine sediment are relatively modest compared to downstream of the Paria. However, over the course of the NO project, we have seen strong gradients in fish density, growth, abundance, and size structure within Glen Canyon. Better growth and higher densities have been observed in the upper half of the Glen Canyon reach and these trends may be caused by higher flow gradient and coarser grain sizes. The available physical and biological data were originally to be integrated, analyzed and synthesized into a number of manuscripts and prepared for publication by FY 2017 or FY 2018. The three topics to be covered were: 1) direct and indirect effects of high flow experiments (HFEs) on the rainbow trout fishery, and 2) spatial patterns in growth, condition, survival, and abundance of rainbow trout in Lees Ferry, and 3) a white paper describing optimal levels for trout management flows.

The analyses required for addressing topic 1 indicated that there are numerous independent factors that confound the results of the effects of HFEs (refer to Project 9.9). Owing to concerns strongly voiced by stakeholders, additional data is further required to make better informed management regarding HFEs; and for that reason, the new FY 2018-20 work plan will continue to monitor trout dynamics in Lees Ferry in response to flow periods with and without HFEs. These data collection and analyses will occur as part of the new research project called Trout Recruitment and Growth Dynamics (Project H).

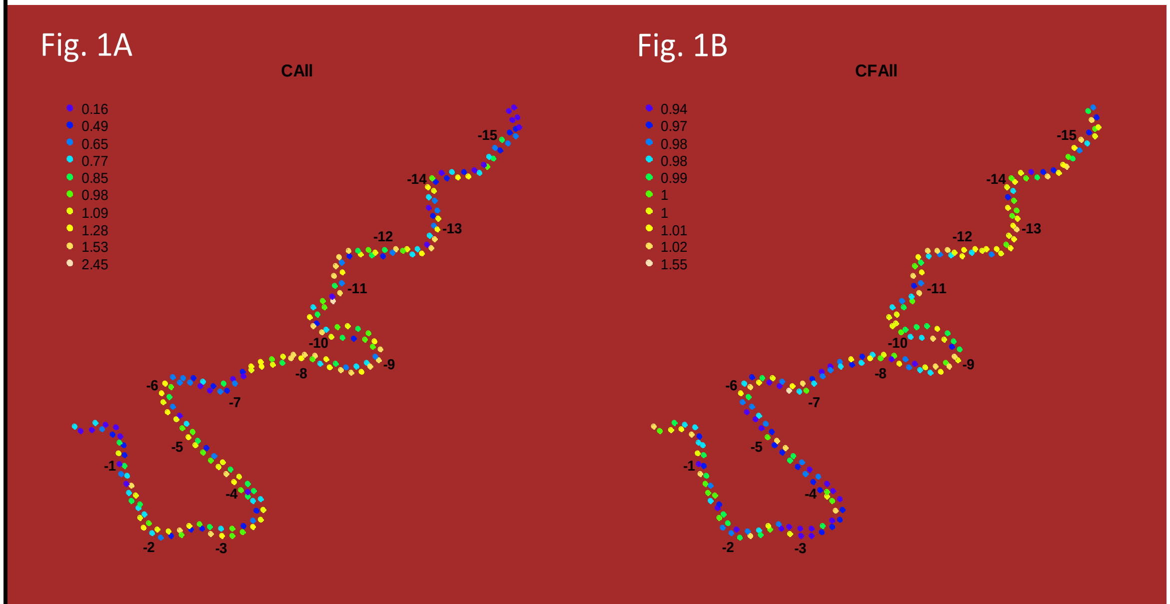

Figure 1. Shows the relative differences observed in rainbow trout total catch (Fig.1A; C-All) and condition factor (Fig 1B; CF-All) by sampling site (250 m in length) in the Lees Ferry sport fishery. These spatially distributed data have been integrated across all sampling trips conducted in late-October (2012-2016). Sampling sites are spatially denoted by river miles (RM) from Glen Canyon Dam (-15.6 RM) to Lees Ferry (0 RM). (The relative value in total catch is the ration between total catch at each site averaged across all sites and then average across all trips.)

The analysis required for addressing topic 2 are almost complete; however, development of the manuscript is just beginning. Tentative timeframe for the manuscript completion and submittal is projected for some time in FY 2018. Preliminary findings indicate that there are substantial spatial differences in the Lees Ferry sport fishery for rainbow trout (RBT) total catch (Fig. 1A) and condition factor (Fig. 1B). Typically, the relative difference in RBT total catch for sampling sites (250 m shoreline length) are highest near outside channel meanders. These types of high-catch sites are associated with a relatively well-defined thalweg (maximum channel depth along a series of successive cross sections) and are often located adjacent to shorelines consisting of high angle talus slopes. There is a higher occurrence of talus slopes along these outside bends, locations that often contain boulders, moderate velocities, and relatively deep water. These high total catch sites are typically found just downstream of a point bar or debris fan. Rainbow trout condition factor is spatially variable and often higher in the upper half of Glen Canyon (above river mile -8.0). Due to differences in hydraulic slope there is a higher frequency of sites containing RBT with elevated condition factors associated with environments having higher flow velocities. Abrupt changes in the channel morphology and decreased average flow velocities begins to occur at around river mile -8.0 (Fig. 1B). These downstream sites have lower RBT condition factor and are often associated with backwater areas, low velocity, and depositional zones.

The analyses required for addressing topic 3 has been slightly delayed because the hydrodynamic model requires a combination of GIS coverage data including shoreline slope and hydroacoustic data for Glen Canyon from Project Element 10.2, which are not complete. The types of analyses needed include evaluating hypsometric characteristics of shorelines in relation to changes in dam releases from 5,000 to ~25,000 ft^3/s by using an existing hydraulic flow model. These analyses will identify locations and areal extent of shorelines associated having low-angle (less than 11 degree slope) channel margins most sensitive to changes in dam operations on the basis of modelled shorelines over a range of 5,000 to 25,000 ft^3/s within lower Glen Canyon. These analyses are expected to be completed by January 2018, and will be used by Project Element H.1 (Experimental flow assessment of trout recruitment) identified in FY 2018-20 work plan to help develop a conceptual/quantitative model to estimate the optimal flow characteristics to use for stranding juvenile rainbow trout and brown trout. Also proposed with this research project is using a combination of analytical methods and field observations to address some of the LTEMP questions (section 2.2.1 Alternative D; LTEMP).

Questions that need to be addressed are:

1) What is the duration of high flows needed to lure YOY rainbow trout into near-shore, habitats?,
2) What is the magnitude of the high flow that will be more effective in luring YOY trout to near-shore habitats?,
3) Is it necessary to move to high flows first to reduce YOY trout numbers (as opposed to simply dropping rapidly from normal flows to minimum flows)?,
4) What is preferred timing of TMF cycles during the May–August period of trout emergence?, and
5) What is the number of cycles necessary to effectively limit trout recruitment?

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Shallow water benthic imaging and substrate characterization using recreational-grade sidescan-sonar				Buscombe, D., 2017, Shallow water benthic imaging and substrate characterization using recreational-grade sidescan-sonar: Environmental Modelling & Software, v. 89, p. 1-18, http://dx.doi.org/10.1016/j.envsoft.2016.12.003.
Journal Article	Compositional signatures in acoustic backscatter over vegetated and unvegetated mixed sand-gravel riverbeds				Buscombe, D., Grams, P.E., and Kaplinski, M.A., 2017, Compositional signatures in acoustic backscatter over vegetated and unvegetated mixed sand-gravel riverbeds: Journal of Geophysical Research: Earth Surface, v. 122, no. 10, p. 1771-1793, http://dx.doi.org/10.1002/2017JF004302.
Journal Article	Automated riverbed sediment classification using low-cost sidescan sonar				Buscombe, D., Grams, P.E., and Smith, S.M.C., 2015, Automated riverbed sediment classification using low-cost sidescan sonar: Journal of Hydraulic Engineering, v. 142, no. 2, online at http://dx.doi.org/10.1061/(ASCE)HY.1943-7900.0001079.
Thesis	Quantifying riverbed sediment using recreational-grade side scan sonar				Hamill, D., 2017, Quantifying riverbed sediment using recreational-grade side scan sonar, Utah State University, Logan, Utah, unpublished MS thesis, 71 p, https://digitalcommons.usu.edu/etd/6635
Journal Article	Substrate mapping by automated texture segmentation of recreational-grade side scan sonar imagery				Hamill, D., Buscombe, D., and Wheaton, J.M., *in review*, Substrate mapping by automated texture segmentation of recreational-grade side scan sonar imagery: River Research and Applications, submitted Nov 2017
Extended Abstract	Bed texture mapping in large rivers using recreational-grade sidescan sonar				Hamill, D., Wheaton, J.M., Buscombe, D., and Melis, T.S., 2016, Bed texture mapping in large rivers using recreational-grade sidescan sonar, in Constantinescu, G., Garcia, M., and Hanes, D., eds., River Flow 2016--Eighth International Conference on Fluvial Hydraulics, St. Louis, Mo., July 12-15, 2016: Boca Raton, Fla., Taylor and Francis Group, CRC Press, doi: 10.1201/9781315644479-

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					51, p. 306-312, http://www.crcnetbase.com/doi/10.1201/9781315644479-51.
Journal Article	Spatial patterns in growth, condition, survival, and abundance of rainbow trout in Lees Ferry			FY 2018	Korman, J., Wright, S., Yard, M.D., Kennedy, T.A., Muehlbauer, J.D., and Buscombe, D.

Project 10	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$96,800	$7,000	$0	$0	$0	$12,533	**$116,333**
Actual Spent	$5,810	$0	$0	$81,000	$55,677	$3,131	**$145,617**
(Over)/Under Budget	**$90,990**	**$7,000**	**$0**	**($81,000)**	**($55,677)**	**$9,402**	**($29,284)**
FY16 Carryover	**$28,271**		**CPI Adjust**	**$812**		**FY17 Carryover**	**($202)**

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

- Salary and Travel & Training 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.
- Sent funds to CA WSC for research scientist participation in project.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	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 FY 2015–17

Riparian vegetation is an important part of the Colorado River Ecosystem (CRE) in that it influences sediment deposition and retention, is key habitat for wildlife, can reduce camping 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.
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, 2016, and 2017 in both Glen Canyon National Recreation Area and Grand Canyon National Park (GRCA). In 2017, data was collected at 88 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 2017 are currently being entered and error checked. Data from 2012 – 2016 are available for use. Summaries from 2014 - 2016 data indicate that vegetation cover remained relatively unchanged. Total foliar cover tends to be highest in western Grand Canyon and approximately the same in Marble Canyon and eastern Grand Canyon (Figure 1) The increase in total foliar cover in western Grand Canyon is primarily due to an increase in herbaceous vegetation. Woody cover is notably high in Glen Canyon, on sandbars in Marble Canyon, and channel margins in Eastern GRCA (Figure 2). Glen Canyon (river miles -15.5 to 0) has the overall highest total foliar cover, as well as the highest overall percent woody plant cover (Figures 1, 2). Vegetation on long-term monitoring sandbars is primarily composed of shrubs and grasses, but forbs and trees (largely tamarisk) also contribute. Sedges and rushes are a very small part of the sandbar vegetation, despite a history of well-developed marshes. A species list and summary of the 2017 data will be available at the annual reporting meeting in January 2018.

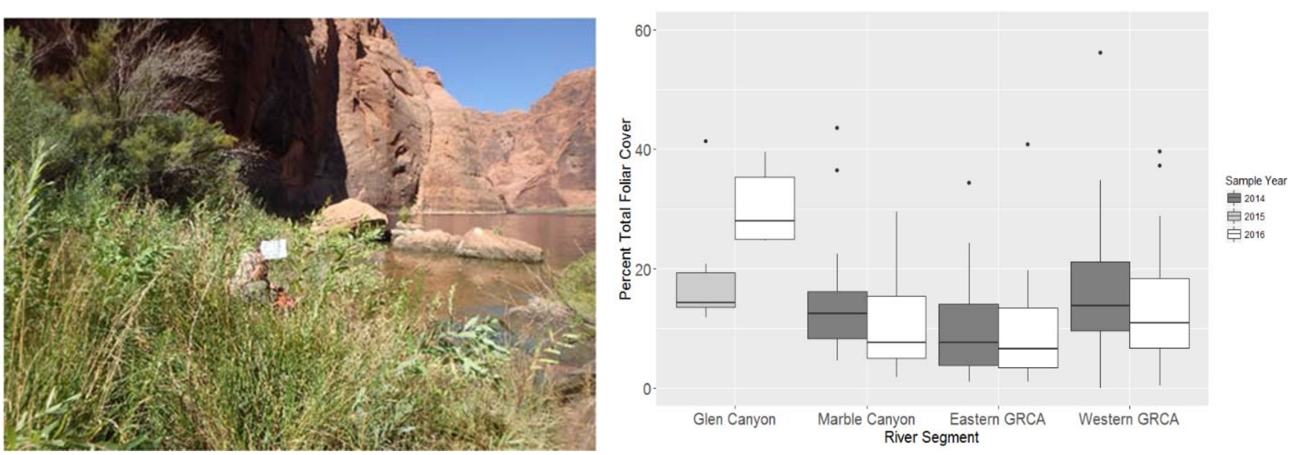

Figure 1. Total foliar cover and woody vegetation cover is highest in Glen Canyon. Dense vegetation shown at a debris fan at river mile -6.8L on 8/9/2017 on the left. The graph on the right describes percent total foliar cover for each river segment for the years 2014 through 2016. For each box plot, median is indicated by the horizontal bar, the 25th and 75th percentiles are indicated by the box, and whiskers extend to the most extreme data point that is not more than 1.5x the interquartile range).

A series of publications in the last year identified key attributes of riparian vegetation in the CRE that contribute to understanding of how dam operations may have differing affects along the corridor. Two publications by McCoy-Sulentic and others (2017a, 2017b) investigated patterns of plant functional traits across hydrologic gradients. These studies indicate that trait patterns are different between herbaceous and woody species, traits differ from wet to dry habitats, and plant species growing in frequently inundated zones exhibit different life strategies than those growing in areas only flooded by High-Flow Experiments (HFEs). Frequent flooding appears to reduce vegetation cover through limitations on establishment and growth. Reductions in flow releases would increase the cover of drought tolerant, upland plant species.

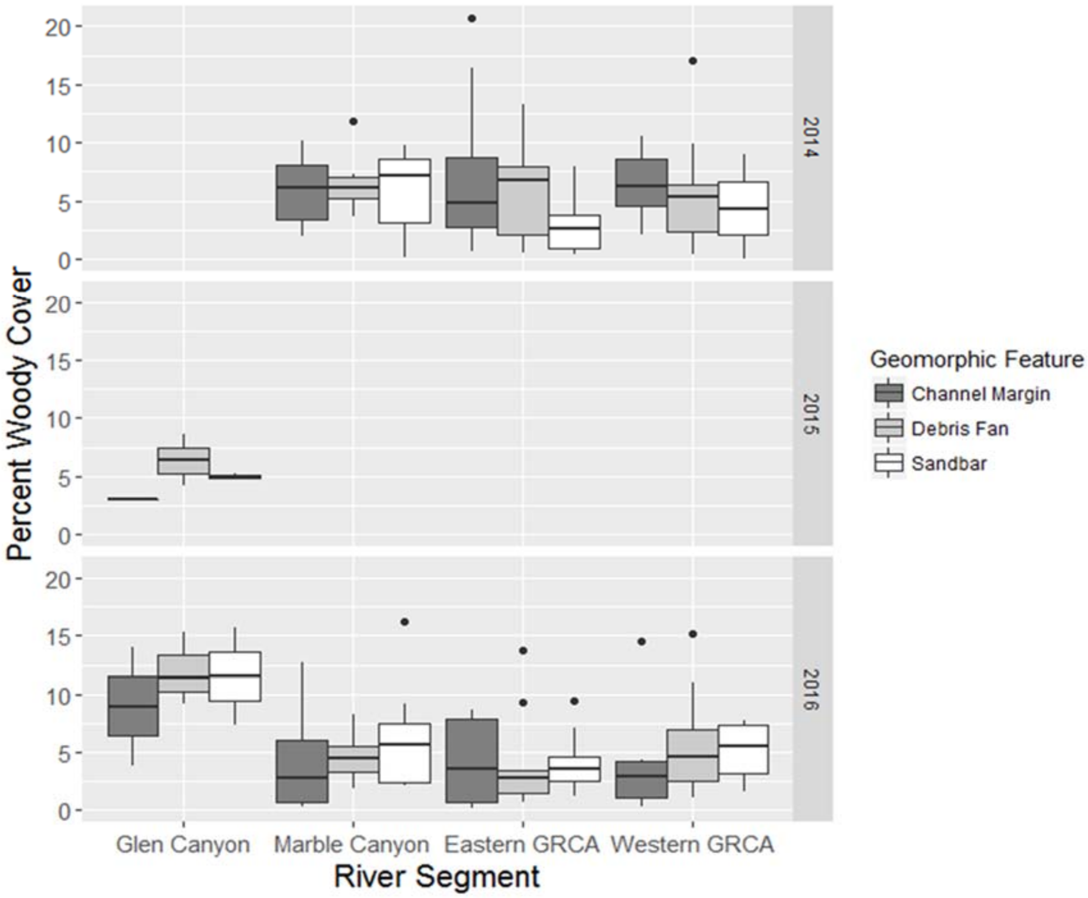

Figure 2. Woody cover in each river segment by year and by geomorphic feature at randomly sampled sites. Marble Canyon = river mile (rm) 0 – 61, Eastern GRCA = rm 61 – 161, Western GRCA = rm 161 – 240.

Palmquist and others (2017b) quantitatively show that there is a significant change in riparian plant communities with distance downstream. These riparian plant communities differ in composition, richness, and functional groups, possibly resulting in differing dependent communities and responses to hydrologic change. Future studies will have to account for these different floristic groups, such that plant response to dam operations is not masked by differential responses among the groups.

Data sets accompanying the above mentioned publications were published on ScienceBase and are freely available to the public. Additionally, Palmquist and others (2017a) published a note and associated data set which makes plant trait data used for analyses in the CRE available for other researchers or the interested public to use in their own studies. Since trait data is largely unavailable elsewhere for many southwestern riparian plant species, this work benefits the greater plant ecology community in addition to understanding the CRE.

Fine-tuning the long-term monitoring methods for riparian vegetation continues. A Techniques and Methods document describing, in depth, the monitoring protocol used in the CRE has been reviewed, revised, and is currently at SPN for editing. This document is designed to be make our data collection procedures repeatable and transparent. While intended to be consistent over time, procedures for making minor and major changes to protocol are included in the document. As an outgrowth of reviewer comments, a comparison of two competing vegetation sampling methods was conducted in June 2016. A manuscript about the results of this comparison are in preparation and will be published as a journal article.

In the next year, we will be finalizing the riparian vegetation monitoring protocol, submitting the methods comparison manuscript for review, and beginning work on the next Triennial Work Plan (TWP). Included in the TWP is continued annual monitoring of both random sample sites and long-term monitoring sandbars in August – October of each year.

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 riparian 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.

In this project element, the overflight imagery acquired in May 2013 were processed, mosaicked, assessed for accuracy, and then published (made publicly available) as a USGS data series report (Durning and others, 2016a) and dataset (Durning and others, 2016b). The imagery were then classified to produce and publish maps of total riparian vegetation (Durning and others, 2017a) and water in the low flow (~8,000 ft^3/s) river channel (Durning and others, 2017b). A species level classification of the 2013 imagery is currently in progress (Durning and others, 2017c), and has been completed and cross-walked with the response guilds, to date, through Glen, Marble, and Eastern Grand Canyon. Once the species level classification is also completed for western Grand Canyon, the entire map dataset will be published in 2018.

The overflight imagery were also used successfully to map all of the tamarisk vegetation in the 2009 and 2013 imagery and tamarisk beetle impacts in the 2013 imagery throughout the 412 km river corridor from Glen Canyon Dam to Lake Mead. The maps were published (made publicly available) as a USGS dataset (Bedford and others, 2017a), the work was published in an M.S. thesis (Bedford, 2016) and two journal articles (Sankey and others, 2016; Bedford and others, *in review*), and has been presented at conferences (Bedford and others, 2017b; Sankey and others, 2017). Long-term changes in vegetation from 1965-2009 were analyzed with change detection of remote sensing imagery, summarized as a function of Colorado River hydrology (dam operations) and climate (precipitation and drought), and published as a USGS dataset (Sankey and others, 2015b) and a journal article (Sankey and others, 2015a). The long-term change detection and analysis work was subsequently updated to include analysis of overflight imagery acquired in 2013 and the updated results were presented at Annual Reporting and AMWG (Adaptive Management Work Group) meetings that occurred during the FY 2015-17 workplan (Sankey and others, 2016a, b).

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 ft^3/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 ft^3/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?

Vegetation survey data from 20 sandbars collected in 2012-2016 have been used to develop ecological niche models that quantify riparian plant species responses to various aspects of hydrology and climate throughout the CRE. Species-specific models have been developed for the 17 most common woody, and 58 most common herbaceous, species and have been scaled-up to estimate vegetation-level sensitivity to hydrological variation within each sandbar. These models are currently being used in two ways. First, they are being used to assess how closely riparian vegetation is tied to hydrological variation within and across the active channel, active floodplain and inactive floodplain, and how these relationships vary longitudinally along the river corridor as a function of spatial variation in climate. A manuscript detailing these results and their implications for vegetation management is near completion.

Second, these models have been used to spatially project predicted suitable habitat for each species across the full extent of each sand bar, both for the most recent surveys as well as at every point through time in which those sandbars have been surveyed. These models will allow us to associate changes in the elevation of any point on a sandbar through time with the predicted vegetation, and to scale up these associations to changes in the extent and complexity of entire sandbars. Initial results indicate strong ties between particular species and the aggradation and erosion of sand. Analyses are ongoing.

Historic vegetation data collected by Kearsley and others in the late 1990s and early 2000s have been gathered, and data digitization is ongoing. These data will be used to assess the accuracy of the suitable habitat projections based on the ecological niche models developed from contemporary data, both as a check on the predictive ability of current models under past flow regimes, as well as to assess fundamental changes in plant-hydrology linkages under different flow regimes.

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. In FY 2017, research toward this project element was focused on two specific projects: 1) The PhD dissertation research of Arizona State University student Christina Lupoli, funded in part by GCMRC and in part by ASU, and 2) a study of the terrestrial arthropod community in the Lees Ferry reach lead by Jeff Muehlbauer.

Lupoli's PhD research is titled "Hydropower and the aquatic-terrestrial dynamic along the Colorado River" and focuses on what factors influence the interaction between aquatic and terrestrial food webs; specifically, the objectives of this project are:

1) To determine the contribution of emergent aquatic insects to the diet of riparian consumers between Glen Canyon and Hoover Dams.

2) To determine whether this contribution varies based on consumer taxa.

3) To determine whether this contribution varies based on hydropeaking, due to its effects on midge abundance.

These objectives will be achieved through stable isotope analysis and population surveys of riparian communities between Glen Canyon and Hoover dams. Preliminary findings indicate that riparian consumers do use the river as a food source, though the degree to which does depend on taxa, season, and abundance of midges. In areas of high midge abundance, consumers appear to be more aquatic in their stable isotopic signature, indicating a higher dependence on the river as a food source. However, final results are not expected until Lupoli completes her dissertation, on or around May 2022.

The GCMRC study in Lees Ferry employed pitfall traps approximately monthly over 1 year throughout this 15-mile reach (24 km), with the intent of collecting terrestrial arthropod predators that feed discriminately on either aquatic or terrestrial prey, or both. The goal of this study was to use stable isotope analysis to describe the extent to which these terrestrial predators are capitalizing on aquatic vs. terrestrial prey items, and to explore the riverine and riparian conditions (such as daily shoreline inundation, vegetation cover, and local river flow velocities) that affect these feeding interactions. A subset of traps have been processed to date and preliminary results indicate that terrestrial arthropods might be concentrated on low-angle shorelines where daily inundation due to hydropower flows has the largest spatial extent; however, results are still subject to change as the majority of samples are still being processed.

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 USGS Open-File Report of the extended abstracts from the riparian restoration workshop was published in July 2017. 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**
Journal article	Functional traits and ecological affinities of riparian plants along the Colorado River in Grand Canyon		Feb 2017		Palmquist, E.C., Ralston, B.R., Sarr, D., Merritt D.M., Shafroth, P.B., and Scott, J.A., 2017a, Functional traits and ecological affinities of riparian plants along the Colorado River in Grand Canyon: Western North American Naturalist, v. 77, no. 1, p. 22--30, http://scholarsarchive.byu.edu/wnan/vol77/iss1/3.
Dataset	Southwestern riparian plant trait matrix, Colorado River, Grand Canyon, 2014 to 2016-Data.		Aug 2016		Palmquist, E.C., Ralston, B.E., Sarr, D., Merritt, D., Shafroth, P.B., and Scott, J.A., 2016, Southwestern riparian plant trait matrix, Colorado River, Grand Canyon, 2014 to 2016-Data: U.S. Geological Survey data release, http://dx.doi.org/10.5066/F7QV3JN1.
Journal article	Variation in species-level plant functional traits over wetland indicator status categories		Apr. 2017		**NOTE: MCCOY-SULENTIC NOT FUNDED BY THE GCDAMP.** McCoy-Sulentic, M.E., Kolb, T.E., Merritt, D.M., Palmquist, E.C., Ralston, B.E., and Sarr, D.A., 2017a, Variation in species-level plant functional traits over wetland indicator status categories: Ecology and Evolution, v. 7, no. 11, p. 3732--3744, https://doi.org/10.1002/ece3.2975.
Dataset	Plant functional traits, Colorado River, Grand Canyon, 2012-2014—Data		Apr. 2017		**NOTE: MCCOY-SULENTIC NOT FUNDED BY THE GCDAMP.** McCoy-Sulentic, M.E., Kolb, T.E., and Palmquist, E.C., 2017b, Plant functional traits, Colorado River, Grand Canyon, 2012-2014—Data: U.S. Geological Survey data release, https://doi.org/10.5066/F7BV7DTQ.
Journal article	Changes in community-level riparian plant traits over inundation gradients, Colorado River, Grand Canyon		Mar 2017		**NOTE: MCCOY-SULENTIC NOT FUNDED BY THE GCDAMP.** McCoy-Sulentic, M.E., Kolb, T.E., Merritt, D.M., Palmquist, E., Ralston, B.E., Sarr, D.A., and Shafroth, P.B., 2017, Changes in community-level riparian plant traits over inundation gradients, Colorado River, Grand Canyon: Wetlands, v. 37, no. 4, p. 635--646, https://doi.org/10.1007/s13157-017-0895-3.
Dataset	Community-level riparian plant traits, Colorado River, Grand Canyon, 2013-2015—Data		Mar 2017		**NOTE: MCCOY-SULENTIC NOT FUNDED BY THE GCDAMP.** Palmquist, E.C, McCoy-Sulentic, M.E., and Kolb, T.E., 2017, Community-level riparian plant traits, Colorado River, Grand Canyon, 2013-2015—Data: U.S. Geological Survey data release, https://doi.org/10.5066/F73R0R24
USGS Open-File Report	Case studies of riparian and w atershed restoration in the southwestern United States—Principles, challenges, and successes		Jul 2017		**NOTE: THIS OFR WAS NOT FUNDED BY THE GCDAMP.** Ralston, B.E., and Sarr, D.A., 2017, Case studies of riparian and watershed restoration in the southwestern United States—Principles, challenges, and successes: U.S. Geological Survey Open-File Report 2017-1091, 116 p., https://pubs.er.usgs.gov/publication/ofr20171091.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal	Landscape-scale processes influence riparian plant composition along a regulated river		Oct 2017		Palmquist, E.C., Ralston, B.E., Merritt, D.M., and Shafroth, P.B., 2017b, Landscape-scale processes influence riparian plant composition along a regulated river: Journal of Arid Environments, doi: 10.1016/j.jaridenv.2017.10.001, early view, https://doi.org/10.1016/j.jaridenv.2017.10.001.
Dataset	Riparian vegetation and environmental variables, Colorado River, 2014—Data		Oct 2017		Palmquist, E.C, 2017, Riparian vegetation and environmental variables, Colorado River, 2014—Data: U.S. Geological Survey data release, https://doi.org/10.5066/F7V986X3.
Oral Presentations	Landscape-scale processes influence riparian plant composition along a regulated river		June 2017, Sept 2017		Palmquist, E.C., Ralston, B.E., Merritt, D.M., and Shafroth, P.B., 2017, Landscape-scale processes influence riparian plant composition along a regulated river, Botany Conference, Fort Worth, TX. AND Palmquist, E.C., Ralston, B.E., Merritt, D.M., and Shafroth, P.B., 2017, Landscape-scale processes influence riparian plant composition along a regulated river, Biennial Conference of Science & Management on the Colorado Plateau, Flagstaff, AZ.
Poster Presentation	Comparison of vegetation cover survey methods in a riparian ecosystem		June 2017		Sterner, S.A., Palmquist, E.C., and Ralston, B.E., 2017, Botany Conference, Fort Worth, TX.
Techniques and Methods	Monitoring riparian vegetation composition and cover along the Colorado River downstream of Glen Canyon Dam			Jan 2018	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
Journal	A comparison of riparian vegetation sampling methods along a large, regulated river.			Oct 2018	Palmquist, E.C., Sterner, S., Durning, L.E., and Ralston, B.E., *in prep*, A comparison of riparian vegetation sampling methods along a large, regulated river: To be submitted to River Research and Applications.
Journal	Hydrology and climate interactively shape riparian vegetation composition along the Colorado River, Grand Canyon			Oct 2018	Butterfield, B.J., Palmquist, E.C., and Ralston, B.E., *in prep*, Hydrology and climate interactively shape riparian vegetation composition along the Colorado River, Grand Canyon: To be submitted to Applied Vegetation Science.
Journal	Riparian flow-response guilds for a large regulated river in the arid southwest			May 2018	Unexpected loss of lead author, currently being completed by collaborators. 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.
Journal	Riparian flow-response guilds: A management tool to predict vegetation change along a regulated river.			Dec 2018	Merritt, D.M., Scott, J.A., Palmquist, E.C., Shafroth, P.B., and B.E. Ralston, *in prep,* Riparian flow-response guilds: A management tool to predict vegetation change along a regulated river.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Data Series Report	Four-band image mosaic of the Colorado River corridor downstream of Glen Canyon Dam in Arizona, derived from the May 2013 airborne image acquisition		2017		Durning, L.E., Sankey, J.B., Davis, P.A., and Sankey, T.T., 2016a, 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 1027, https://doi.org/10.3133/ds1027.
Dataset	Four band image mosaic of the Colorado River Corridor in Arizona—2013, including Accuracy Assessment Data		2017		Durning, L.E., Sankey, J.B., Davis, P.A., and Sankey, T.T., 2016b, 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/F7TX3CHS.
Thesis	Remote sensing of tamarisk (*Tamarix* spp.) defoliation by the tamarisk leaf beetle *(Diorhabda carinulata)* along the Colorado River in Arizona		May 2016		**NOTE: BEDFORD NOT FUNDED BY THE GCDAMP.** Bedford, A., 2016, Remote sensing of tamarisk (*Tamarix* spp.) defoliation by the tamarisk leaf beetle *(Diorhabda carinulata)* along the Colorado River in Arizona, M.S. thesis: Flagstaff, Northern Arizona University. Advised by E. Scheifer, T. Sankey, J. Sankey, and B. Ralston
Journal Article	Remote sensing of tamarisk beetle *(Diorhabda carinulata)* impacts along 412 km of the Colorado River in the Grand Canyon, Arizona, USA.			Dec 2017	**NOTE: BEDFORD NOT FUNDED BY THE GCDAMP.** Bedford, A., Sankey, T.T., Sankey, J.B., Durning, L.E., and Ralston, B.E., *in review*, Remote sensing of tamarisk beetle impacts along 400 km of the Colorado River between Lake Powell and Lake Mead in the Grand Canyon, Arizona, USA: Remote Sensing of Environment.
Dataset	Remote sensing derived maps of tamarisk (2009) and beetle impacts (2013) along 412 km of the Colorado River in the Grand Canyon, Arizona, USA		2017		Bedford, A., Sankey, T.T., Sankey, J.B., Durning, L.E. and Ralston, B.E., 2017a, Remote sensing derived maps of tamarisk (2009) and beetle impacts (2013) along 412 km of the Colorado River in the Grand Canyon, Arizona, USA: U.S. Geological Survey data release, https://doi.org/10.5066/F72B8X71.
Journal Article	Remote sensing of tamarisk biomass, insect herbivory, and defoliation: novel methods and applications in the Grand Canyon region, Arizona, USA.		Aug 2016		Sankey, T.T., Sankey, J.B., Horne, R., and Bedford, A., 2016, Remote sensing of tamarisk biomass, insect herbivory, and defoliation--Novel methods in the Grand Canyon region, Arizona: Photogrammetric Engineering and Remote Sensing, v. 82, no. 8, https://doi.org/10.14358/PERS.82.8.645.,
Journal Article	Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation		June 2015		Sankey, J.B., Ralston, B.E., Grams, P.E., Schmidt, J.C., and Cagney, L.E., 2015, Riparian vegetation, Colorado River, and climate--Five decades of spatiotemporal dynamics in the Grand Canyon with river regulation: Journal of Geophysical Research--Biogeosciences, v. 120, no. 8, p. 1532-1547, http://dx.doi.org/10.1002/2015JG002991.
Dataset	Riparian vegetation, Colorado River, and climate: Five decades of spatiotemporal		June 2015		Sankey, J.B., Ralston, B.E., Grams, P.E., Schmidt, J.C., and Cagney, L.E. 2015. Riparian vegetation, Colorado River, and climate: Five

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	dynamics in the Grand Canyon with river regulation - Data				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.
Dataset	Riparian vegetation classification of the Colorado River Corridor, Grand Canyon, Arizona, 2013—Data		2017		Durning, L.E., Sankey, J.B., Chain, G.R., and Sankey, T.T., 2017a, Riparian vegetation classification of the Colorado River Corridor, Grand Canyon, Arizona, 2013—Data: U.S. Geological Survey data release, https://doi.org/10.5066/F7K64GJF.
Dataset	Water classification of the Colorado River Corridor, Grand Canyon, Arizona, 2013—Data		2017		Durning, L.E., Sankey, J.B., Chain, G.R., and Sankey, T.T., 2017b, Water classification of the Colorado River Corridor, Grand Canyon, Arizona, 2013—Data: U.S. Geological Survey data release, https://doi.org/10.5066/F7PZ5799.
Presentation	Riparian vegetation monitoring with remote sensing.		2016		Sankey and others, 2016b, Riparian vegetation monitoring with remote sensing: AMWG meeting, August 2016.
Presentation	Riparian vegetation monitoring with remote sensing.		2016		Sankey and others, 2016c, Riparian vegetation monitoring with remote sensing: Annual Reporting Meeting, January 2016
Presentation	Riparian species classification map derived from May 2013 high resolution multi-spectral imagery within Grand Canyon, Arizona.		2017		Durning, L.E., Sankey, J.B., Bedford, A., Sankey, T.T., 2017c, Riparian species classification map derived from May 2013 high resolution multi-spectral imagery within Grand Canyon, Arizona: 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region September 11–14, 2017, Flagstaff, Arizona.
Presentation	Remote sensing of tamarisk beetle *(Diorhabda carinulata)* impacts along 400 km of the Colorado River in the Grand Canyon, Arizona, USA.		2017		Bedford, A., Sankey, T.T., Sankey, J.B., Durning, L.E., Ralston, B.E., 2017b, Remote sensing of tamarisk beetle *(Diorhabda carinulata)* impacts along 400 km of the Colorado River in the Grand Canyon, Arizona, USA: 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region September 11–14, 2017, Flagstaff, Arizona.
Presentation	Remote sensing of tamarisk biomass, insect herbivory, and defoliation: Lidar and multispectral image fusion in the Grand Canyon, AZ.		2017		Sankey, TT, Sankey, J.B., Bedford, A., Durning, L.E., 2017. Remote sensing of tamarisk biomass, insect herbivory, and defoliation: Lidar and multispectral image fusion in the Grand Canyon, AZ: 14th Biennial Conference of Science and Management for the Colorado Plateau and Southwest Region September 11–14, 2017, Flagstaff, Arizona.
Book Chapter	Variables affecting resource subsidies from streams and rivers to land and their susceptibility to global change stressors.			Jan. 2019	Muehlbauer and others, *in review*, Variables affecting resource subsidies from streams and rivers to land and their susceptibility to global change stressors.
Ph.D. Thesis	Hydropower and the aquatic-terrestrial dynamic along the Colorado River.			May 2022	Lupoli, C.A., Sabo, J.L., Kennedy, T.A., Muehlbauer, J.D., and Yackulic, C.B., Hydropower and the aquatic-terrestrial dynamic along the Colorado River: Tempe, Arizona State

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					University, School of Life Sciences. Advisers include C. Yackulic, J. Muehlbauer, and T. Kennedy.
Oral Presentation	Hydropower and the aquatic-terrestrial dynamic along the Colorado River.		Aug. 2017		Lupoli, C.A., Sabo, J.L., Kennedy, T.A., Muehlbauer, J.D., and Yackulic, C.B., 2017, Hydropower and the aquatic-terrestrial dynamic along the Colorado River: Biennial Conference of Science & Management on the Colorado Plateau, Flagstaff, AZ.
Invited Oral Presentation	Can we relate terrestrial-aquatic linkages to hydropower flows downstream of a large dam?		Jun. 2017		Muehlbauer, J.D., Quigley, T.J., and Kennedy, T.A., 2017, Can we relate terrestrial-aquatic linkages to hydropower flows downstream of a large dam?: Society for Freshwater Science Annual Meeting, Raleigh, NC.
Poster Presentation	Terrestrial-aquatic linkages in the Grand Canyon.		Jun. 2017		Lupoli, C.A., Sabo, J.L., Kennedy, T.A., Muehlbauer, J.D., Yackulic, C.B., 2017, Terrestrial-aquatic linkages in the Grand Canyon: Society for Freshwater Science Annual Meeting, Raleigh, NC.

Project 11	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$217,100	$8,000	$6,700	$125,500	$3,500	$31,753	**$392,553**
Actual Spent	$156,590	$6,787	$24,391	$233,309	$8,752	$29,670	**$459,499**
(Over)/Under Budget	**$60,510**	**$1,213**	**($17,691)**	**($107,809)**	**($5,252)**	**$2,083**	**($66,946)**
FY16 Carryover	**$85,932**		**CPI Adjust**	**($3,209)**		**FY17 Carryover**	**$15,777**

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

- Salary costs reduced due to vacancy.
- Operating expenses increased to fund student services contract to conduct vegetation mapping analysis.
- Cooperative agreement expenses increased to fund PHD student and University Research Scientist in lieu of filling USGS position.
- Costs to other USGS cost centers increased to fund additional work by USGS Collaborator.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program

Project Lead	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, two-part 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 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.

Following the initiation of the project in FY 2015, there was a significant turn-over in tribal personnel, and several tribes that were formerly supportive of this project subsequently decided that they no longer wished to participate. In addition, the lack of a full time riparian ecologist at GCMRC after August of 2015 further hampered our ability to complete the project as originally envisioned. This project now focuses primarily on completing Phase 1 objectives #2 and #3 and is anticipated to be completed in FY 2018.

Previous 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 FY 2016, Fairley continued the work started in FY 2015 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 FY 2015 and continuing in FY 2016, 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 USGS Desert Laboratory Repeat Photography collection, high-resolution digital scans of several hundred photographs from the 1923 USGS Birdseye expedition were obtained in November 2015 from the USGS library archives in Denver, CO.

FY 2017 Accomplishments

In 2017, work effort was primarily focused on acquiring more high resolution matched images of historical photographs, with an emphasis placed on matching panoramic images taken by Eugene C. La Rue during the 1923 USGS dam site survey in Grand Canyon. A total of 91 additional photographic matches were obtained in 2017 over the course of two separate river trips. One trip occurred in May, 2017, in conjunction with Project 4 Light Detection and Ranging (LIDAR) survey work, and the second trip took place in August-September 2017, in conjunction with Project 11 vegetation monitoring. In both cases, the river trips were primarily designed to accomplish the work of these other projects, and therefore, the photographic matching effort had to be worked in around other trip priorities. Nevertheless, the Project 12 team obtained a total of 46 matches during the May trip and another 45 matches in August-September, 2017.

In FY 2017, as in FY 2016, we were greatly aided in this effort by volunteer photographer, Alan Fairley, who contributed many volunteer hours not only towards obtaining accurate matches, but also to processing the imagery after the field work ended (using commercial software to merge multiple images in order to recreate each panoramic image) and organizing voluminous metadata associated with each matched image. In August 2017, we were joined in the field by another volunteer, retired USGS riparian ecologist Dr. Michael Scott, who was a great asset in relocating photo stations and in identifying the riparian species encountered in the new and old high water zones captured in each matched image.

Including the matches obtained in FY 2016, we have now successfully matched a total of 119 individual images along the Colorado River. All matches show marked increases in woody and herbaceous riparian vegetation within the former flood scour zone of the pre-dam Colorado River.

In the course of working with the historical photo collections in FY 2016-17, we became aware of some previous attempts at matching 1923 images from the USGS dam survey expedition. One of these efforts was documented in a 1994 publication (Baars and others, 1994). Another attempt, however, was never completed or reported, due in part to the complexity of accurately matching La Rue's panoramic images (T. Melis, personal comm., 2016). Although the latter attempt at matching La Rue panoramas was only partially completed, numerous prints resulted from this earlier effort that are contained in the Desert Laboratory Repeat Photography collection currently housed at the Southwest Biological Science Center in Flagstaff, AZ. In FY 2017, we began exploring ways to incorporate these earlier matching efforts as part of Project 12 in order to provide a more complete diachronic picture of riparian vegetation change along the Colorado River downstream of Glen Canyon Dam. Volunteer A. Fairley worked on the technical aspects of creating matches from photographs taken in the late 1970s through mid-1990s, while H. Fairley focused on extracting information from these images. As in FY 2016, H. Fairley applied analytical methods previously developed by USGS hydrogeologist Robert H. Webb (Webb 1996; Webb and others, 2011) to evaluate post-dam vegetation changes by comparing the 1923 La Rue photos with replicates taken in 1975-1994 and then comparing these post-dam matches with the more recent duplicate images obtained in 2016 and 2017. This qualitative analysis began in late summer of 2017 and is ongoing. While still a work in progress, preliminary analysis reveals patterns and trends similar to those identified from a similar analysis conducted with Stanton photos (Scott and others, *in press*), i.e., while riparian vegetation clearly increased dramatically below the level of pre-dam spring flood elevations during the first 10-20 years following emplacement of Glen Canyon Dam, riparian vegetation has continued to increase in subsequent decades within the new high-water zone (Figures 1-2). Since initiation of interim and post-1996 EIS Record-of-Decision modified low fluctuating flows in the early-mid 1990s, most of the formerly open space between tamarisk trees has become infilled with other woody shrubs, primarily *Baccharis* sp., while the fluctuating flow zone below the 25,000 $ft^3/2$ stage elevation, which was only sparsely vegetated in the early 1990s, has become densely colonized with riparian wetland species such as *Phragmites australis, Equisetum* sp., *Juncus* sp., and other water-loving plants.

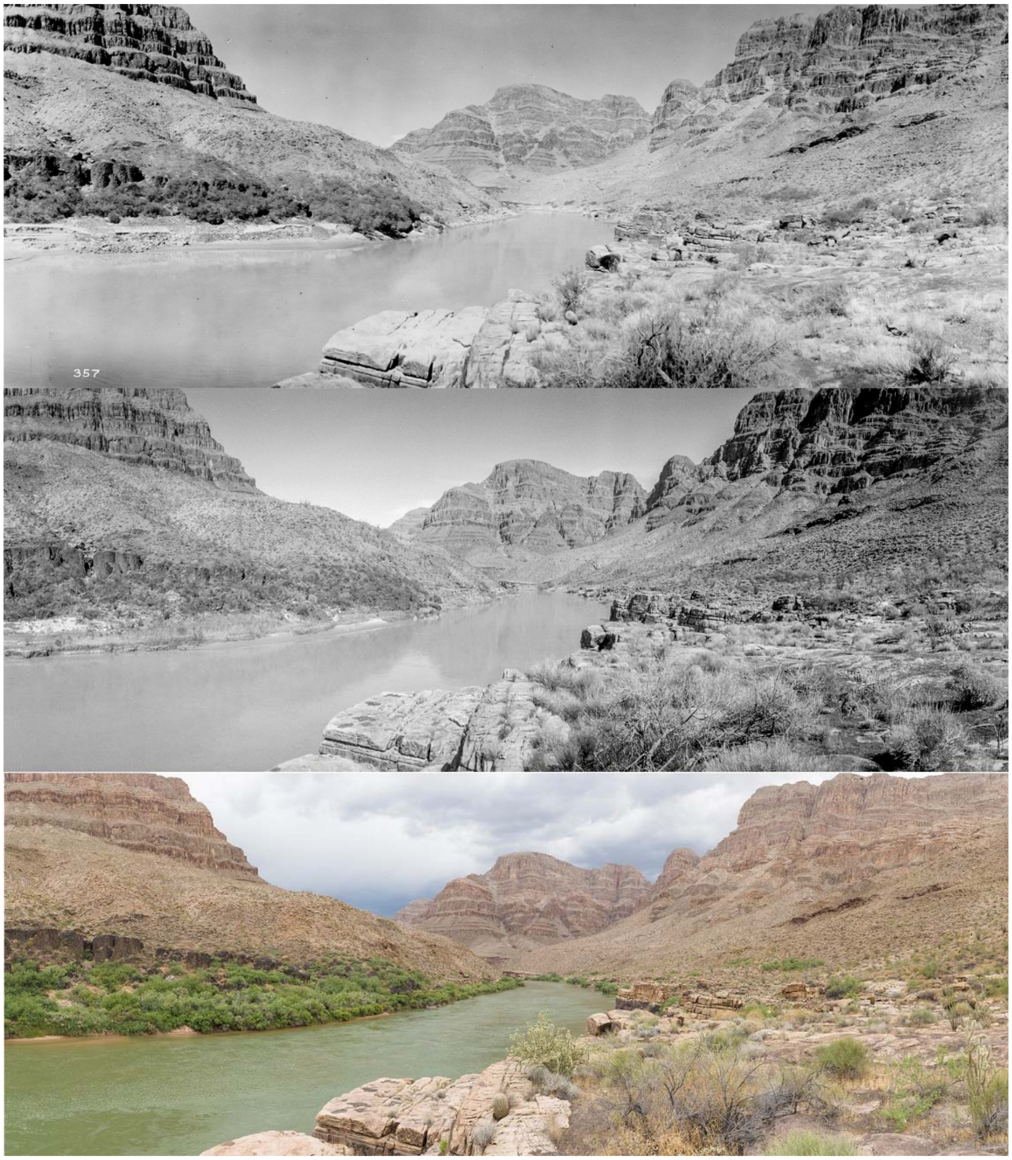

Figure 1. Matched view at river mile 215.7, left bank, looking upstream (Stake No. 701). Top photograph by E.C. La Rue, September 30, 1923. Middle photograph by Liz Hymans, March 13, 1993. Bottom photograph by A. H. Fairley, May 17, 2017. Note how 2017 riparian vegetation has filled in previously open sand areas since 1993, including the formerly exposed sandy strip at water's edge.

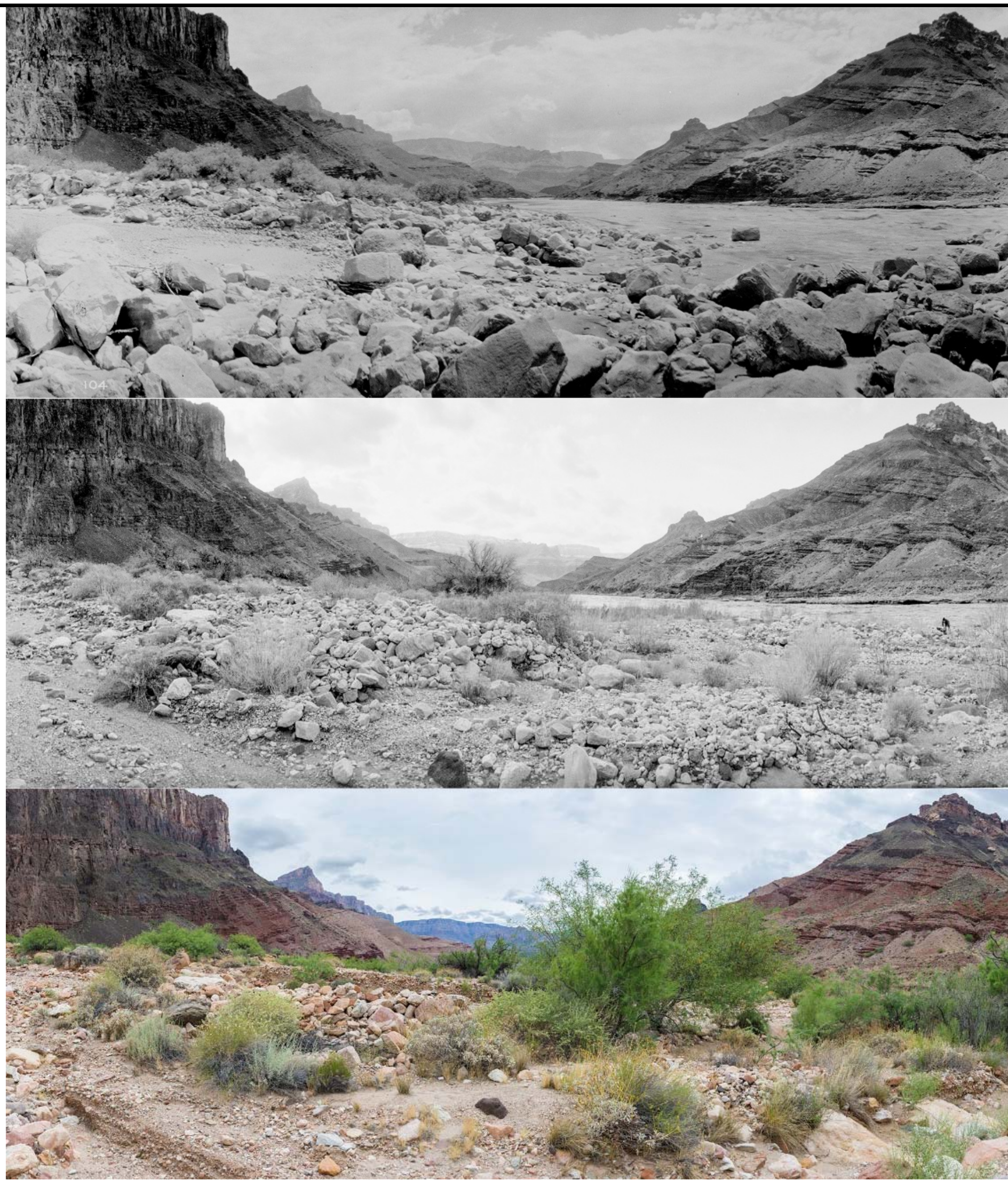

Figure 2. Matched view at river mile 65.95 (mouth of Palisades Creek), left bank, looking across and downstream (Stake No. 1707a). Top photograph by E.C. La Rue, August 14, 1923. Middle photograph by Liz Hymans, March? 1993. Bottom photograph by A. H. Fairley, May 10, 2017. Note how the growth of tamarisk and mesquite trees and increase in other riparian species such as *Pluchea sericea* obscures the view of the Colorado River in 2017.

Figure 3. Matched view at river mile 66.7, left bank, looking upstream (Stake No. 1436a). Top left photograph by R. B. Stanton, January 22, 1890. Top right photograph by R. H. Webb, January 24, 1990. Bottom left photo by J. Mortimer, September 20, 2010. Bottom right photo by A. H. Fairley, August 27, 2017. Note the relatively sparse riparian vegetation along the shoreline in the 1990 photo compared to the 2010 and 2017 matches. Also note the thinning of the tamarisk foliage in 2017 compared to 2010, presumably due to tamarisk beetle defoliation.

Next Steps

In FY 2018, we intend to continue collecting matches of 1923 USGS expedition photographs in conjunction with Project D field work and will complete the species-specific analysis using these repeat photographs. In collaboration with volunteers Michael Scott and A. Fairley, we intend to report the results of this project in a peer-reviewed USGS publication. This report will include numerous sets of the matched images and will expand upon the initial conclusions reached from analyzing a sample of the Stanton photographs in FY 2016 (Scott and others, *in press*), with emphasis placed on changes in abundance and distribution of each of the species identified in the FY 2015 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.

References

Baars, D.L., Buchanan, R.C. and Charlton, J.R., 1994, The canyon revisited: A rephotography of the Grand Canyon 1923/1991: Salt Lake City, University of Utah Press, 168 p.

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 9, *in* Johnson R.R., Carothers S.W., Finch, D.M., and Kingsley, K.J., 20XX. Riparian ecology: Past, present, future—General Technical Report RMRS-GTR-XXXX: Fort Collins, Colo.: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Webb, R.H., 1996, Grand Canyon: A century of change: Rephotography of the 1889-1890 Stanton Expedition: Tucson, University of Arizona Press, 290 p.

Webb, R.H., Belnap, J., Scott, M.L., and Esque, T.C., 2011, Long-term change in perennial vegetation along the Colorado River in Grand Canyon National Park (1889-2010). Park Science v. 28, no. 2, p. 83-87.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Historical changes to culturally-important riparian plants along the Colorado River: A progress report on a pilot study integrating science and traditional ecological knowledge		01/24/17		Fairley, H.C., 2017, Historical changes to culturally-important riparian plants along the Colorado River: A progress report on a pilot study integrating science and traditional ecological knowledge: Oral presentation at 2017 Annual Reporting Meeting Phoenix, Arizona January 24, 2017.
Poster	Documenting Glen Canyon Dam effects to culturally-valued riparian vegetation using repeat photography		09/12/17		Fairley, H.C, Fairley A.H., 2017, Documenting Glen Canyon Dam effects to culturally-valued riparian vegetation using repeat photography: Poster presentation at Colorado Plateau Biennial Conference, September 12, 2017.
Chapter in edited volume	Evaluating riparian vegetation change in canyon-bound reaches of the Colorado River using spatially extensive matched photo sets		09/15/16	2018	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 9, in Johnson R.R., Carothers S.W., Finch, D.M., and Kingsley, K.J., 20XX. Riparian ecology: Past, present, future—General Technical Report RMRS-GTR-XXXX: Fort Collins, Colo.: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

	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, Helen 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.
Presentation	Changes in the distribution and abundance of culturally-important plants in the Colorado River ecosystem: A pilot study to explore relationships between vegetation change and traditional cultural values.		2/18/15		Fairley, H.C., Bungart, P., Joe, T., and Yeatts, M., 2015, Changes in the distribution and abundance of culturally-important plants in the Colorado River ecosystem: A pilot study to explore relationships between vegetation change and traditional cultural values. Oral presentation at Project 12 Workshop, Flagstaff, Arizona, February 18, 2015.
Presentation	Changes in the distribution and abundance of culturally-important plants in the Colorado River ecosystem: A pilot study to explore relationships between vegetation change and traditional cultural values.		4/21/15		Fairley, H.C. 2015, Changes in the distribution and abundance of culturally-important plants in the Colorado River ecosystem: A pilot study to explore relationships between vegetation change and traditional cultural values. Oral presentation at Glen Canyon Dam Adaptive Management Program Technical Work Group meeting, Phoenix, Arizona, April 21, 2015.
Presentation	Dam-induced changes to riparian ecosystems and associated traditional cultural values downstream of 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.

Project 12	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$0	$0	$0	$0	$0	$0	**$0**
Actual Spent	$0	$3,923	$350	$0	$0	$516	**$4,790**
(Over)/Under Budget	**$0**	**($3,923)**	**($350)**	**$0**	**$0**	**($516)**	**($4,790)**

FY16 Carryover	**$57,224**		**CPI Adjust**	**$0**		**FY17 Carryover**	**$52,435**

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

- Funds were used to support continued field work to meet project objectives.

Project 13: Socioeconomic Monitoring and Research

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	Lucas Bair	**Investigators:** In alphabetical order	Lucas Bair, USGS, GCMRC Craig Bond, Pardee RAND Lewis Coggins, USFWS Pierce Donovan, Uni, of California John Duffield, Uni. Of Montana Chris Neher, Uni. Of Montana David Patterson, Uni. Of Montana Michael Springborn, Uni, of California Charles Yackulic, USGS, GCMRC
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SUMMARY

Summary of FY 2015–17 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 that 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 downstream from GCD, and whitewater boating in Grand Canyon National Park 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.

Project 13.1 concluded in FY 2016. Publications related to the research and surveys conducted in FY 2015-16 are ongoing and FY 2017 manuscripts are listed in the Products/Reports table.

Project Element 13.2.

Project 13.2 was initiated in FY 2017. The project has two goals: measuring market, nonmarket, and non-use values for Colorado River ecosystem resources valued by tribes and as affected by dam operations; and identifying socioeconomic impacts of GCD operations and experiments to tribal communities. The study was designed to fit within the framework of the AMWG's proposed GCDAMP Socioeconomic Program.

While the entire study (Workplan FY 2015-17 and Workplan FY 2018-20) consists of a set of eleven tasks within two broad phases (qualitative research and tribal population surveys), work to date has focused on the first 4 tasks of Phase 1 (qualitative research) of the study. This Phase 1 qualitative research component has included reviewing

relevant Tribal studies, meetings with Tribal representatives to the AMWG, and using approaches similar to focus groups for survey development.

Specific Phase 1 work undertaken includes:

- Task 1. Review of previous work.

This task entailed a literature review of relevant prior work and information relating to tribal socioeconomics for the five AMWG tribes. Between January and March, 2017 the investigators undertook a comprehensive review of the literature including examples, methods, and theory associated with economic valuation of Native American or Indigenous resources, activities, or preservation of cultural heritage. This review included examples of studies undertaken in North America as well as worldwide. The review was completed in March and references from the review will be included in the Draft and Final project reports.

- Task 2. Modification of National Park Service (NPS) passive use survey to include culturally relevant attributes as affected by dam operations.

The NPS Glen Canyon Passive Use Survey was modified and tailored for each of the five tribes included in the study design (Navajo, Southern Paiute, Hopi, Zuni, and Hualapai). Input was solicited from tribal representatives, and special attention was given to structuring the surveys and valuation questions from each tribe's perspective.

- Task 3. Kick-off Meetings with tribal representatives to the AMWG.

During the period May 1-4, 2017 the researchers (Duffield and Neher from University of Montana, and Bair from GCMRC) met with representatives of the Hualapai, Navajo, Hopi and Zuni to present the draft surveys, and get feedback on the surveys and the process for meeting with representative Tribal focus groups to administer the surveys.

- Task 4. Qualitative research including day-long stakeholder meetings with tribes in the GCDAMP.

Researchers met with a Hopi tribal focus group consisting of the Hopi Cultural Resources Advisory Task Team (CRATT) members on August 23, 2017. On the August 24, 2017 the researchers met with members of the Zuni Cultural Resources Advisory Team. In both of these meetings the researchers presented the draft survey instrument and solicited comments, responses, and suggestions for improvement. Planning was also discussed for follow-up meetings with both groups to present modified surveys. A second Hopi CRATT focus group meeting is tentatively scheduled for the week of December 11, 2017. The objective of this meeting will be to present a modified survey instrument and collect survey responses from the group participants. In addition to meetings with Hopi and Zuni focus groups, a comprehensive Institutional Review Board application package was prepared and submitted to the Navajo Nation, in anticipation of receiving permission to undertake surveys in 2018. This submission is currently under review.

Project Element 13.3.

Project 13.3 integrates economic information with data from long-term and ongoing physical and biological monitoring and research studies led by the GCMRC to develop tools for scenario analysis to improve the ability of the GCDAMP to evaluate and prioritize management actions, monitoring, and research. Specifically, this work provides an optimal removal strategy of nonnative rainbow trout (RBT) as a means of achieving an abundance goal of the endangered native humpback chub (HBC).

In the first phase of Project 13.3 a bioeconomic model was developed to identify the economically preferred management strategy for established nonnative fish to achieve HBC survival targets (Bair and others, *in review*). The model was completed and the manuscript stemming from this work is in review.

In FY 2017, building on initial modeling efforts, a dynamic decision-making model was developed to identify how a HBC population abundance goal can be met with a given level of confidence. This model was developed to evaluate parameter uncertainty to aid in the identification and prioritization of monitoring and research of native and nonnative fish. The model is an extension of a standard framework from natural resource economics called stochastic dynamic programming (SDP). This kind of model is used in various management contexts (fisheries, nonnative species control, etc.) when the decision problem is repeated over time (e.g., annually), decisions are dependent on the current state of the system (e.g., population levels) and a balance is sought in the tradeoff between immediate consequences (e.g., costs of control) and future outcomes (e.g., improved population levels). The model was calibrated so that population dynamics (e.g., response to removals) are in agreement with the existing bioeconomic model developed in project 13.3, which used Monte-Carlo simulation-based methods (Bair and others, *in review*; see Products/Reports table).

Summary of Reports and Products

Project Element 13.1.

Two journal articles were submitted in FY 2017 and are listed in the Products/Reports table. Results are consistent with the FY 2016 Project Report for the Glen Canyon Dam Adaptive Management Program.

Project Element 13.2.

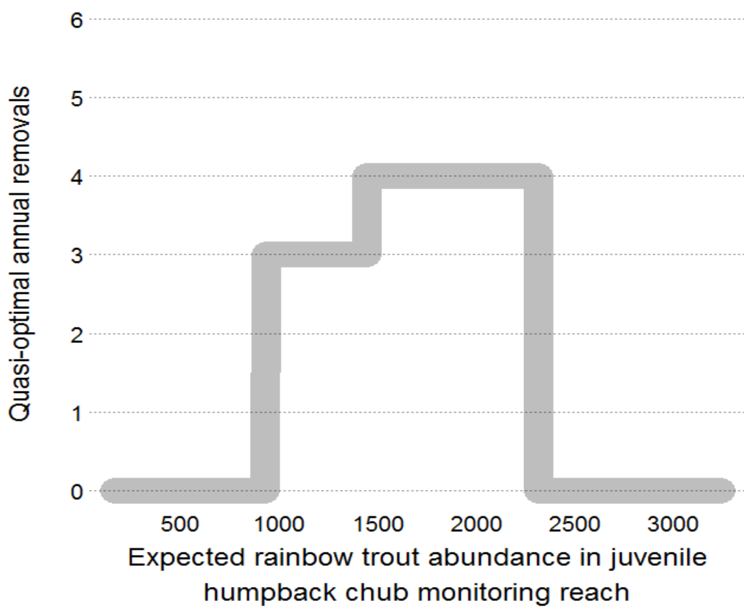
A summary of Phase 1 (qualitative research) results will be compiled following the conclusion of the focus group meetings with the individual tribes.

Project Element 13.3.

The overarching objective of Project 13.3 is to identify the least-cost management strategy that reduces downstream RBT abundance to achieve HBC recovery goals (e.g., 7000 adult HBC). As referenced in the FY 2016 Project Report, initial results indicate that the least-cost management strategy to achieve adult HBC goals requires RBT removal over a limited range of RBT abundance. For example, under this strategy, RBT removals would not be conducted when the numbers of RBT in the juvenile humpback chub monitoring (JCM) reach are below 925 or above 2300. Instead, removals would be performed 3-4 times per year, with the number of removals increasing with increasing RBT abundance in the JCM reach (Figure 1).

Expanding on these findings, the SDP model developed in this project derives an optimal policy as a function of both HBC and RBT abundance. The SDP approach developed here generates two advantages relative to commonly used simulation-based approach: (1) solutions are much faster, and (2) no functional form is imposed on the shape of the policy function mapping the current state into an action. This SDP model will also facilitate adaptive management modeling. The method readily scales to the ultimate state space that adaptive management requires in a computationally feasible way.

The HBC abundance goal can be described in three parts: (1) a minimum population level above which HBC are to be maintained, (2) a time horizon over which this minimum should not be breached, and (3) a confidence level with which elements 1 and 2 should be achieved. The objective is to find the least-cost management strategy that reduces RBT abundance to achieve this HBC abundance goal whenever it is feasible.



The solution to the SDP model provides the optimal policy and a distribution of likely HBC and RBT levels under the optimal policy. An additional output of the model is an estimate of the implicit cost of violating the specified population abundance threshold. This implicit cost is the monetary value that is just high enough to induce a decision maker to take the costly action needed to achieve the abundance goal. We also show how the implicit cost of violating the population threshold is increasingly "anticipated" by the decision maker as population levels fall, thereby incentivizing appropriate investment in control.

Figure 1. The policy function that identifies the least-cost rainbow trout removal strategy to achieve humpback chub abundance goals (Bair and others, *in review*).

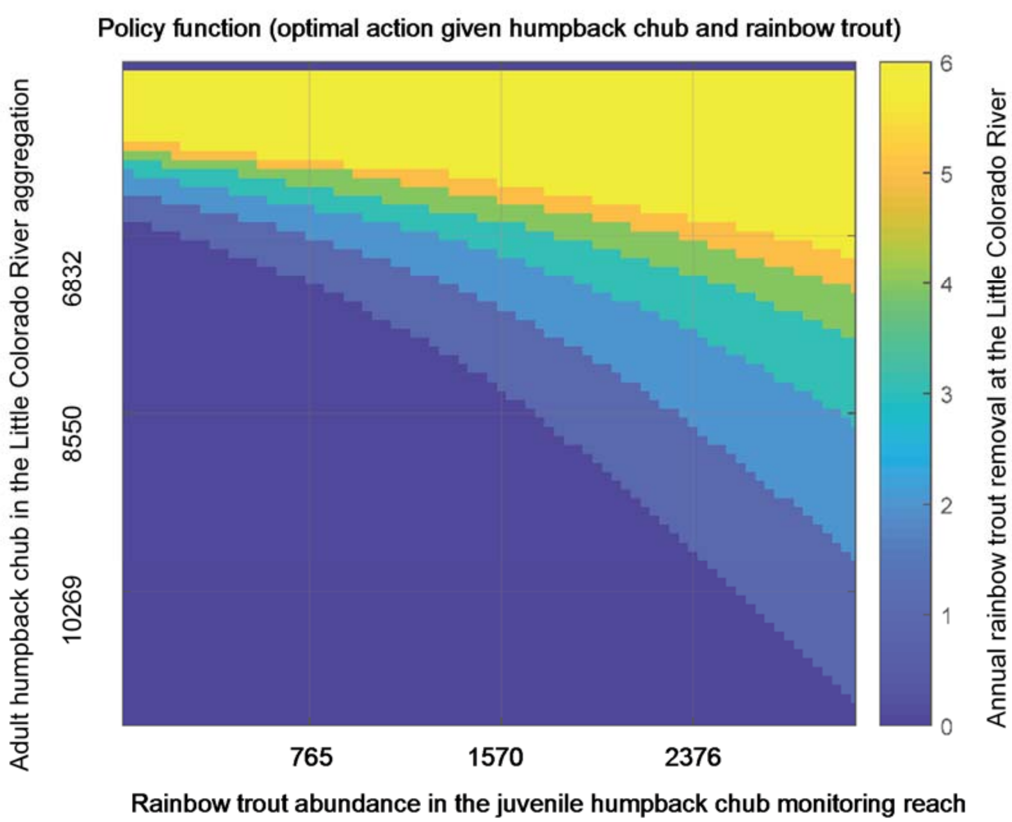


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Figure 2. The policy function shows how many mechanical removals of rainbow trout are optimal in a year given the current populations of rainbow trout (horizontal axis) and humpback chub (vertical axis) in the juvenile humpback chub monitoring reach. When we have more abundant humpback chub and/or less abundant rainbow trout (towards the bottom-left), the optimal policy dictates fewer removals. Here, we have a fine discretization over feasible population levels of 150 rainbow trout and HBC states each, for a total of 22,500 possible states.

The resulting policy function takes the form of a lookup table (Figure 2). Importantly, it prescribes moderate action for the area consistent with current populations. For example, if HBC levels are around a mean estimate of 7,600 individuals in the aggregation, the optimal policy suggests to 1-3 removals based on RBT estimates. Our finding that these conditions warrant a low level of control are consistent with existing research (Bair and others, *in review*).

Figure 3 shows the distribution or likelihood of HBC and RBT levels under the optimal policy. HBC levels are maintained safely away from the minimum threshold, which lies at the top edge of the figure. If HBC levels do decline, RBT levels also likely decline due to the optimal feedback policy of increasing the number of mechanical removals (Figure 2).

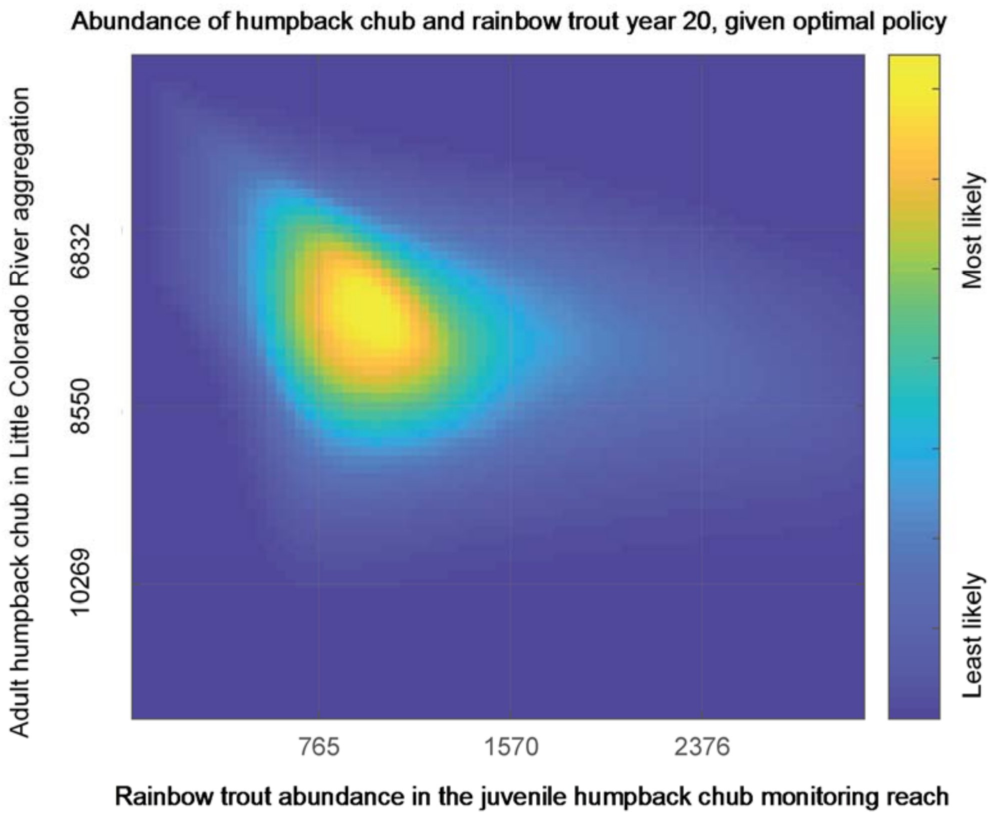

Figure 3. The density of HBC and RBT levels in the JCM reach after 20 years, under the optimal policy. Likely values lie safely above the specified critical threshold of 7,000 individuals in the aggregation.

Next Steps

Project Element 13.1.

- Continue to publish angling and whitewater related economic research based on available data and Project 13.1 survey results. Refining and further evaluating angler and whitewater preferences for Colorado River flow and other recreational attributes will provide insight into the timing of experiments at GCD and impacts to recreational groups.

Project Element 13.2.

- The proposed quantitative population-level tribal research (Phase 2) is the next step in Project 13.2. The project will be implemented in FY 2018, conditional on successful completion of Phase 1, and coordinated with other tribal related studies, including the Bureau of Reclamation's Tribal Associated Values Studies project.

Project Element 13.3.

- Further develop the SDP model by adding adaptive management to the model. This includes specifying the particular learning i.e., (adaptive management) mechanism of interest. For example, the uncertain impact of RBT on HBC in the JCM reach could be learned about via research generating a stream of information independent of the core model. Alternatively, the observation of a new HBC and RBT abundance given the previous abundance and intermediate removal action could be incorporated into a Bayesian learning process. Both of these methods relax the assumption that the effect of RBT abundance on HBC population is perfectly known, and instead acknowledge the presence of uncertainty which can, at least in part, be reduced over time.

- Incorporate additional non-native fish management actions and associated costs in the bioeconomic model, such as RBT management flows at GCD, to identify the most cost-effective management alternatives to achieve HBC abundance goals under various future scenarios. This will inform future native and nonnative fish management and other LTEMP EIS experiments. Future step also include hosting a RBT management flow workshop at GCMRC in January of 2017 and coordination with research in Project N of the GCDAMP Triennial Work Plan FY 2018-20.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Identifying cost-effective invasive species control strategies in the Grand Canyon to enhance endangered species population viability.	NA	April 6, 2017	NA	Bair, L., Yackulic, C.B., Springborn, M. Reimer, M., Bond, C., and Coggins, L., DOI Economics Workshop, Washington, D.C.
Presentation	Economic value of angling and whitewater boating on the Colorado River: Using revealed and stated preference methods to inform adaptive management.	NA	Sep. 12, 2017	NA	Bair, L., Neher, C., Duffield, J., Patterson, D., Neher, K., Presentation at 14th Biennial Conference, Flagstaff, AZ.
Presentation	Enhancing endangered species population abundance via cost-effective invasive species control strategies: Adaptive management in the Grand Canyon.	NA	Sep. 14, 2017	NA	Bair, L., Yackulic, C. Springborn, M. Reimer, M., Bond, C., and Coggins, L., Presentation at 14th Biennial Conference, Flagstaff, AZ.
Presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition and adaptive management	NA	Sep. 25, 2017	NA	Donovan, P., M. Springborn, L. Bair, and C. Yackulic. Natural Resource Policy Lab, Davis, CA.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition and adaptive management	NA	Oct. 1, 2017	NA	Springborn, M., Donovan, P., Bair, L., and Yackulic, C, Canadian Resource and Environmental Economists Study Group, London, Ontario.
Presentation	Translating population viability analysis into a dynamic programming framework to facilitate economic intuition	NA	Oct. 1, 2017	NA	Donovan, P., Springborn, M., Bair, L., and Yackulic, C., Heartland Environmental and Resource Economics Workshop, Urbana-Champaign, IL.
Journal manuscript	Testing the limits of temporal stability: Willingness to pay values among Grand Canyon whitewater boaters across decades	FY 2015-17	FY 2017, in press	FY 2018	Neher, C., J. Duffield, L. Bair, D. Patterson, and K. Neher, *in press*, Water Resources Research.
Journal manuscript	Convergent validity between willingness to pay elicitation methods: an application to Grand Canyon whitewater boaters	FY 2015-17	FY 2017, in review	FY 2018	Neher, C., J. Duffield, L. Bair, D. Patterson, and K. Neher, *in review*, Journal of Environmental Management and Planning.
Journal manuscript	Enhancing native species population viability via cost-effective invasive species control in the Grand Canyon, USA	FY 2015-17	FY 2017, in review	FY 2018	Bair, L., C. Yackulic, M. Springborn, M. Reimer, C. Bond, and L. Coggins, *in review*, Biological Conservation.
Journal manuscript	Translating population viability analysis into a dynamic programing framework to facilitate economic intuition and adaptive management.	FY 2015-17	In preparation	FY 2018	Donovan, P., M. Springborn, L. Bair, and C. Yackulic, *in prep.*

Project 13	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$127,400	$12,500	$1,000	$171,500	$0	$22,157	**$334,557**
Actual Spent	$117,544	$3,607	$85	$171,218	$0	$19,775	**$312,229**
(Over)/Under Budget	**$9,856**	**$8,893**	**$915**	**$282**	**$0**	**$2,382**	**$22,328**

FY16 Carryover	**$29,336**		**CPI Adjust**	**($2,335)**		**FY17 Carryover**	**$49,328**

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

- Salary expenses were lower than expected.
- Travel & Training and Operating expenses decreased due to less travel than anticipated.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	Tom Gushue	**Investigator(s)** (I)	Thomas Gushue, USGS, GCMRC Timothy Andrews, USGS, GCMRC James Hensleigh, USGS, GCMRC
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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 conducted over the last three fiscal years (FY 2015–17). The Triennial Work Plan (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.

Contained within this annual report is a description of the accomplishments made over the past year, FY 2017, and where appropriate, links to the products and content that are a direct result of the work performed by members of this project. While the focus of this report is on FY 2017, it is important to note that many of the items discussed have been part of the previous two years, and in some cases, the root of these accomplishments extend much farther back in time. The way GIS is applied within GCMRC has evolved well beyond a simple support group, and functions as both a collaborative scientific force in data acquisition, processing and analysis, and as a comprehensive geospatial resource for the Center.

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 FY 2017. 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 is usually in the form of connecting to and accessing layers from GCMRC's spatial database, new GIS layer creation, GPS applications and use, and map outputs created for field use, presentations and publication purposes. Below are a few more in-depth descriptions of GIS support provided to other science projects.

Project 3.1.4. Geomorphology: Analysis of Historical Images at Select Monitoring Sites

During FY 2017, the historical sandbar area and volume project element continued to refine the existing methods for using the new Auto Digital Terrain Model (DTM) module, a component of the Earth Resource Development Assessment System (ERDAS) remote sensing software package, for extracting 3-dimensional surfaces out of photogrammetrically-derived aerial photography data dating back to October of 1984. Eight long-term monitoring sites were processed in FY 2017 using this new, more advanced module.

The Auto DTM module allows for more control on the processing for each site with 12 different settings that can be modified to better match the uniqueness of both the input data (Single-band, scanned film acquired in October 1984) and the geographic setting of sites (steep canyon environment in a remote location). These unique characteristics, and the interaction of those characteristics, require a fair amount of attention during the photogrammetry and DTM extraction process, as each site has its own, unique challenges to successfully processing the data.

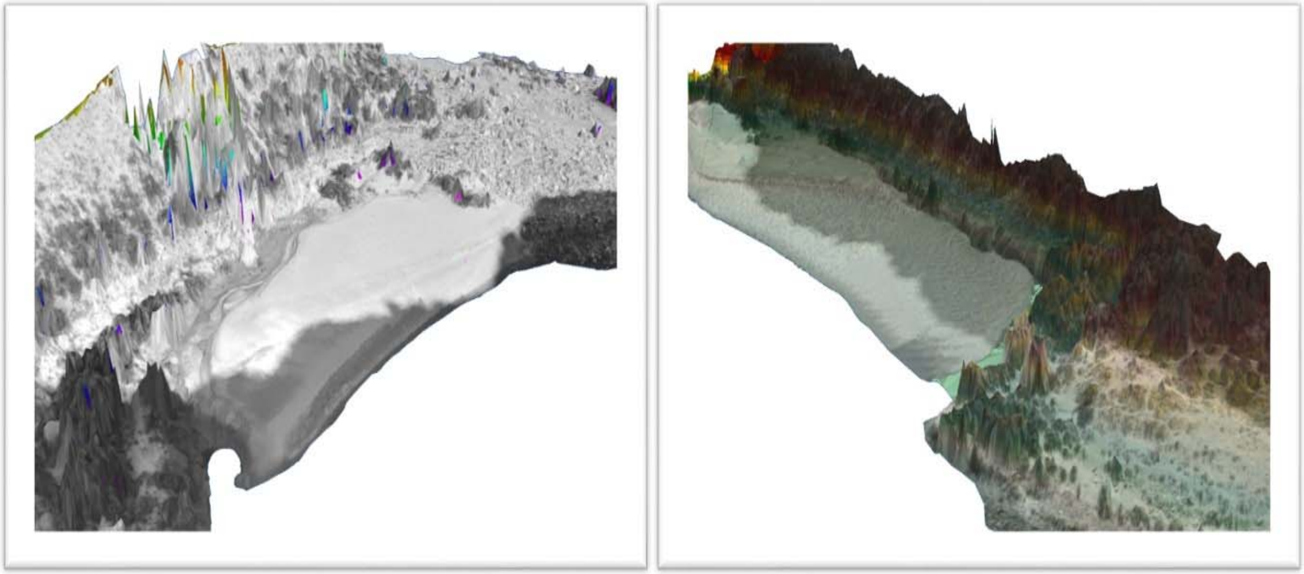

Figure 1. 3-Dimensional views of sandbars from October 1984 for two long-term monitoring sites: Anasazi Bridge at River Mile 43 (left), and Lower Saddle at River Mile 47 (right). In these images, the orthorectified, single-band image (black-and-white) is overlaid on top of the 3-D surface, represented as a Triangular Irregular Network (TIN), which has been extracted from the 1984 aerial imagery.

This important work has future management implications as the Glen Canyon Dam Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) is implemented because it is one of the few research efforts that addresses the desired future conditions of sediment resources – and more specifically sandbars that are part of the long-term monitoring project. A paper describing methods used and results achieved, including horizontal and vertical accuracies, for sites processed through FY 2017 is in preparation. (See Project 3, 3.1.4).

Project 3.5. Control Network and Survey Support: Database Development and Application Release

In FY 2017, GIS project staff and the Center's Survey-lead worked to develop a new Geodetic Control Database and Application which is now being actively used to store, manage, perform assessments on, and provide access to GCMRC's geodetic control network – a system that serves as the backbone for geospatial data collected and managed by the Center. This new Structured Query Language (SQL) Server relational database platform now simplifies the workflow for handling all geodetic control data collected through survey-grade Global Positioning Systems (GPS), total station terrestrial surveys, terrestrial Light Detection And Ranging (LIDAR) positional control and scans, and eventually, even multi-beam sonar scan data. This new database allows for both easier updates to the survey control network in Grand Canyon an annual basis and for enabling access to the survey control network database through an application interface.

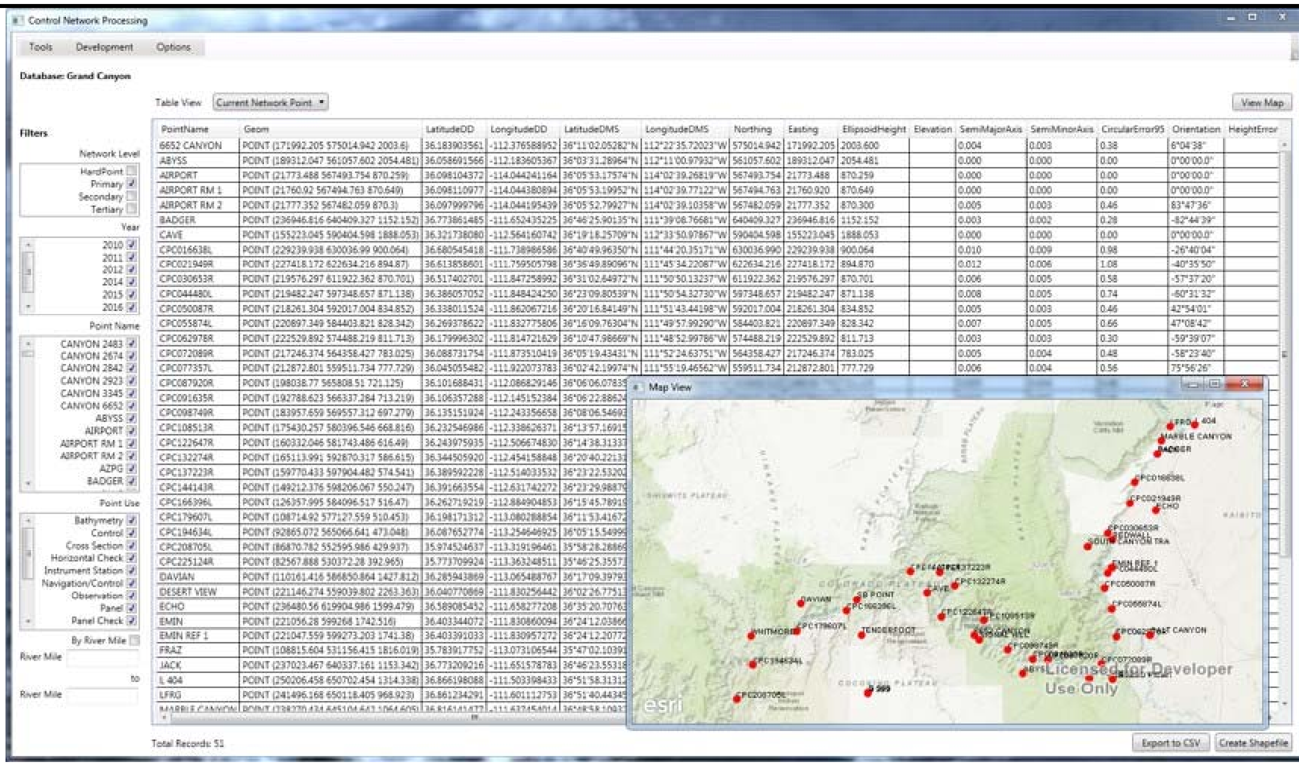

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Figure 2. An example display of the Geodetic Control Network Application showing some of the attributes contained in the survey control data, filtering tools available on the left panel of the application, and an interactive Map View window (inset) that corresponds to filter queries that have been applied in the application. All data exist in back-end relational database.

This application provides an interface to all geodetic control data and allows for advanced filtering of the data by the user. With this database and application, users can now import survey control network data from professional-grade survey software, such as Trimble Geomatics Office (TGO), perform quality control tasks, calculate or relate additional information to each survey control point, and populate or update the new relational database. Additionally, users can interact with the data more intuitively, with the ability to export data to ascii text file or ESRI shapefile and display query results of network control within the interactive Map View.

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

This project continued to provide dedicated support to the Natal Origins project as it transitioned from its experimental phase and into a monitoring effort in FY 2017. The work performed over the past year included continued support to scientists on refining the spatial aspects of the Natal Origin sampling, the modification of the existing Fish Sampling Unit system used to electroshocking to be repurposed for the Juvenile Chub Monitoring phase of this work, and the development of new subunits within and coincident to the electroshocking units that would be used to represent hoop net sampling efforts. This marks a new, concerted effort to better account for the spatial characteristics for sampling with hoop nets. Additionally, the project continued to support all fish monitoring efforts with custom river map books used to field data collection, instruction and oversight into the data entry phase for certain fish monitoring efforts, and the creation of other map products for publication and presentation purposes.

Project 11. Riparian Vegetation Monitoring and Analysis of Riparian Vegetation

The GIS team also provide various, and at times, high-level support to the vegetation monitoring project. This work included working with the vegetation team to automate computationally-intensive geoprocessing tasks involving the conversion of canyon-wide, continuous vegetation classification data into discreet vector-based data sets. Additionally, some of the completed data sets from this project were further processed in GIS and imported into the Oracle Spatial Database. This sets the stage for developing some interesting web mapping applications to be developed in the next fiscal year. Members from the GIS project also took the lead on designing a power supply box to be used to charge tablet field computers that will improve the efficiency of data collection on river trips.

14.2. Geospatial Data Management

During FY 2017 the GIS project continued to serve as the Center lead for geospatial data management. This work involved coordinating between GCMRC science staff and the Southwest Biological Science Center (SBSC) Information Technology (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.

During FY 2017, the GIS project staff continued to assist 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.

Adoption and Use of Source Control

This project has taken the lead within GCMRC to managed geoprocessing scripts, web application and other work involving programming through online source control and versioning platforms, such as USGS GitLab, USGS CHS GitLab, and USGS BitBucket spaces. This effort has led to greater efficiency in code development, geoprocessing task performance and faster development of new web applications than previously possible within the Center. By spearheading this shift to source/versioning control for the Center, the GIS team is able to better serve as technical advisors for other GCMRC scientists and technical staff, and will allow for greater collaboration with external entities to the Center.

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.

A great deal of the work involved in creating and deploying an Enterprise-level GIS platform happens in the background to normal, daily work functions for GIS staff. Incremental steps in system design, web server configuration, and network access troubleshooting and incorporating new geospatial data in the system happen continuously amid the other tasks required of GIS staff. The benefits, however, are much more immediate and have a much larger impact. One data set that is imported and maintained in this system can be accessed simultaneously by anyone with the Center through desktop applications and by the greater audience of potential users throughout web mapping services and web-based 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.

UPDATED 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. This was released towards the end of FY 2016, with updates and modifications made throughout FY 2017.

UPDATED HFE Sandbar Photo Tour:
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 High Flow Experiments (HFEs) from Glen Canyon Dam (2012–2014). HFE applications for past events (1996, 2004, 2008, 2012, and 2014) as well as for the most recent HFE in November 2016. New functionality has been added in F20Y17, and all components updated to conform to HTTPS protocol (a DOI requirement).

UPDATED Sandbar Time-Series Photo Application:
https://grandcanyon.usgs.gov/gisapps/sandbarphotoviewer/RemoteCameraTimeSeries.html

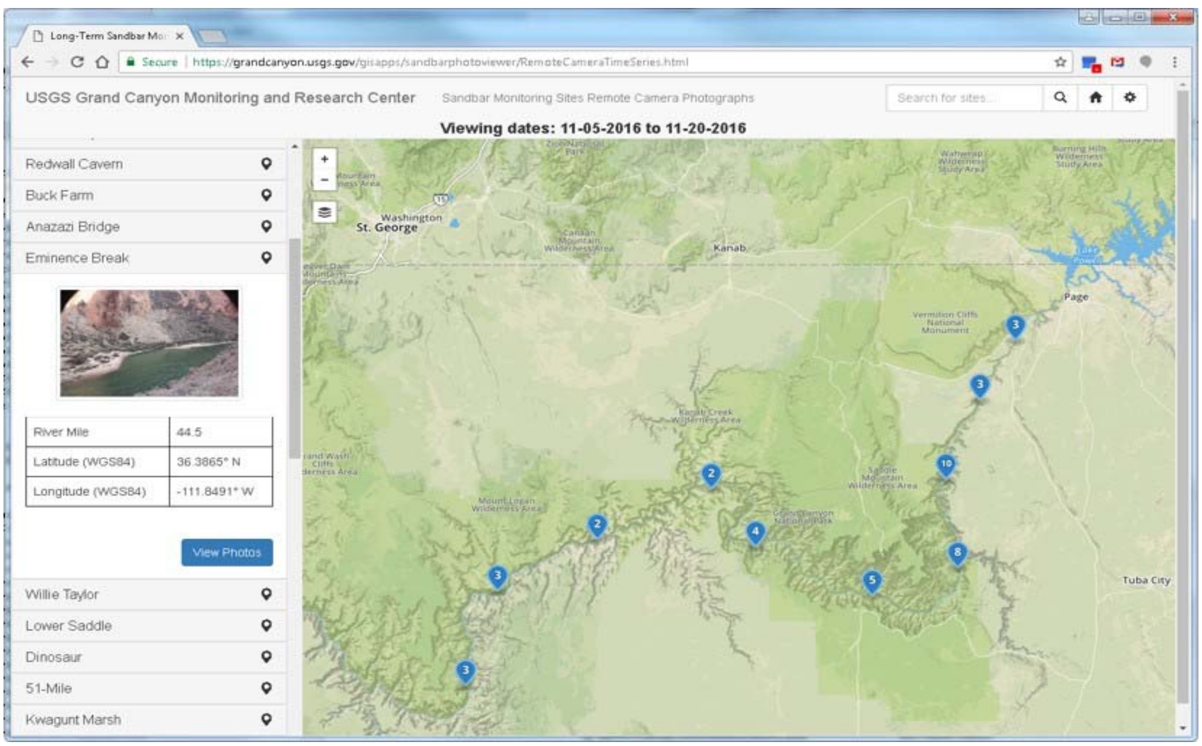

Figure 3. A view of the newly updated Sandbar Photo Viewer web application. Users can explore site photos through the list of sites on the left panel, or by using the interactive map.

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. Upon launching the application, a standard filter of the previous 365 days is applied, so that a user will see the most recent photographs available for each site. Under the Options Tab, pre-defined queries for the past High-Flow events allow a user to simply select the HFE of interest and return to viewing the sandbar photos. A custom date filtering tool also exists under Options in the application, allowing the user to specify a range of dates. This application grants access to tens of thousands of repeat, remote camera photographs used to track sandbar changes and response to experimental flows along the Colorado River. Additionally, by going to the "Dual Viewer" mode, users can view repeat photos from different dates side-by-side.

Figure 4. A view of the photograph viewing module with the Dual Viewer mode on. The photos shown here are for before and after the November 2016 HFE at Eminence Break site, River Mile 44.

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 map 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.

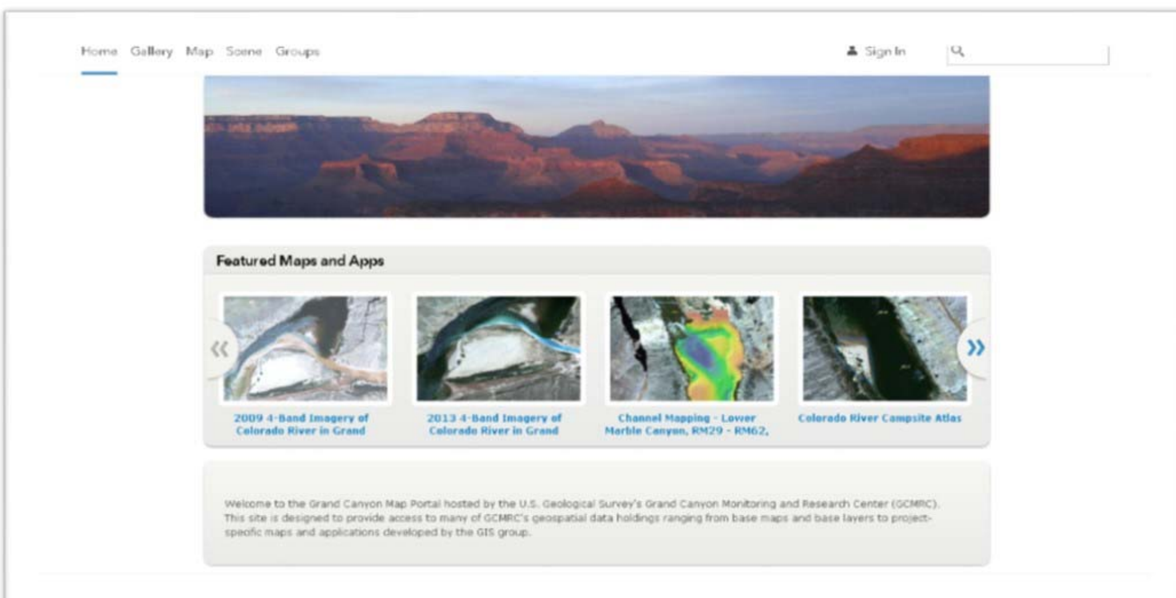

Figure 5. A view of the Grand Canyon Map Portal home page. The portal provides easy access to many of the Center's geospatial data sets without the need for specialized or proprietary software by leveraging server technologies and web-based map services.

UPDATED Geospatial Services page: https://www.gcmrc.gov/geospatial

The Geospatial Services page has been updated in FY 2017 to contain only 10.3.1 services. We continue to provide access to GCMRC's geospatial data sets through a web services directory page that organizes Representational State Transfer (REST) service endpoints by data set and resource type. Web services and applications built on the REST architectural style have standardized methods for interacting with the data content and are optimized to work best on the Web. 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 other programs, such Google Earth, as a layer on the map. The GIS team has expanded on the number of services available on this page over the past fiscal year, including the 2013 overflight imagery data set, a collective imagery service that contains multiple overflight imagery data sets (2002, 2005, 2009 and 2013), a new shaded relief base of the Grand Canyon region, and other updated thematic data services.

These services take advantage of new functionality that is available to geospatial data at this version, while still being backwards-compatible with 10.x versions of ESRI ArcGIS desktop software. Additionally, many of the geospatial services are being offered as Web Map Services (WMS) as defined by the Open-source Geospatial Consortium (OGC), which essentially means that many of GCMRC's geospatial data sets can be accessed by anyone through open-source software and custom-built applications. This increases both the importance of the Center's Enterprise GIS platform, and the visibility of the Center's work to a much wider audience.

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 SBSC as well as with other USGS Science Centers.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Online Data Set	GCMRC Centerline and River Mileage System	FY 2015		01/10/2018	To be published to USGS ScienceBase
Online Data Set	GCMRC Colorado River Map Book	FY 2016		01/10/2018	To be published to USGS ScienceBase
Online Data Set	GCMRC Colorado River Fish Sampling Cross Reference System	FY 2017		01/10/2018	To be published to USGS ScienceBase

Project 14	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$179,300	$4,000	$16,000	$0	$0	$24,063	**$223,363**
Actual Spent	$171,532	$2,883	$27,523	$0	$0	$24,382	**$226,320**
(Over)/Under Budget	**$7,768**	**$1,117**	**($11,523)**	**$0**	**$0**	**($319)**	**($2,957)**
FY16 Carryover	**$17,612**		**CPI Adjust**	**($1,559)**		**FY17 Carryover**	**$13,096**

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

- Salary costs decreased due to vacancies.
- Operating expenses increased due to buying software.

Project 15: Administration

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Project Lead	Scott VanderKooi, Chief	**Investigator(s)** (I)	Scott VanderKooi
Email	svanderkooi@usgs.gov		
Telephone	928-556-7376		

SUMMARY

During the Fiscal Year 2017, the budget for this project included the salaries for the communications coordinator, librarian, and 80% of a budget analyst. This budget also includes leadership personnel salaries, some travel and training for the Chief and Deputy Chief, and part of the salary of one project lead. The vehicle section covers the costs associated with Interior owned and GSA leased vehicles that GCMRC uses for travel and field work. Costs include fuel, maintenance and repairs for Interior owned vehicles and monthly lease fees, mileage costs, and any costs for accidents and damages for GSA leased vehicles. This project also includes the costs of IT equipment for GCMRC. Salaries, travel, and training for logistics staff are also included in this project's budget.

Project 15 (- Logistics)	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$578,100	$34,000	$226,000	$84,000	$0	$103,712	**$1,025,812**
Actual Spent	$503,626	$24,986	$230,701	$0	$0	$91,679	**$850,992**
(Over)/Under Budget	**$74,474**	**$9,014**	**($4,701)**	**$84,000**	**$0**	**$12,033**	**$174,820**

FY16 Carryover	**$400,994**		**CPI Adjust**	**($7,317)**		**FY17 Carryover**	**$577,750**

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 decreased due to departure of University Cooperator.

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

FY 2017 Project Report for the Glen Canyon Dam Adaptive Management Program			
Program Manager (PM)	Bridget Deemer	**Investigator(s)** (I)	Bridget Deemer Nick Voichick
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Telephone	928-556-7316		

SUMMARY

NOTE: PROJECT 1 WAS NOT FUNDED UNDER THE 2015-17 GCDAMP.

In fiscal year (FY) 2017, GCMRC collected physical, biological, and chemical data and samples from Lake Powell, Glen Canyon Dam, and Lees Ferry. While sampling frequency had been reduced in FY 2015 and FY 2016 relative to previous years, the addition of new funding in FY 2017 sparked renewed collaboration between GCMRC and Bureau of Reclamation (Reclamation) and more intensive sampling was conducted. In early FY 2018, GCMRC also conducted an independent review of the Lake Powell Water Quality Monitoring Program wherein a panel of scientific experts was convened to evaluate the water-quality work of the GCMRC in Lake Powell. This review was funded in the FY 2015-17 Triennial Work Plan (TWP).

Project Summary

GCMRC has conducted a long-term water-quality monitoring program of Lake Powell and Glen Canyon Dam (GCD) releases. The Lake Powell monitoring program was designed to: 1) determine status and trends of the water quality of Lake Powell and GCD releases, 2) determine the effect of climate patterns, hydrology, and dam operations on reservoir hydrodynamics and the water quality of GCD releases, and 3) provide predictions of future conditions.

Monitoring Activities

Water-quality monitoring was conducted by Reclamation from 1964 to 1996. Since 1997, the GCMRC and the Reclamation have continued water quality monitoring with assistance from the National Park Service under a cooperative agreement funded via the Water Quality group in the Upper Colorado Regional Office of the Reclamation. For most years since 1997, the sampling program has consisted of monthly sampling in the forebay area immediately upstream of GCD, in the GCD draft tubes, and in the GCD tailwater (at Lees Ferry), 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 field observations of weather conditions, Secchi depth measurements, and 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 ions, dissolved organic carbon, 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 FY2017, Reclamation conducted two complete reservoir-wide surveys and two abbreviated reservoir-wide survey with involvement from GCMRC. In addition, GCMRC conducted six complete forebay surveys and one partial survey of the GCD draft tubes and Lees Ferry to supplement the July quarterly survey. GCMRC also maintained instruments to monitor GCD releases and conducted several methods tests to compare historic and current filtration techniques for inlet water.

The beginning dates of the quarterly and monthly surveys are shown in Table 1 below.

Table 1. Dates and sampling activity for the Lake Powell water-quality monitoring for FY 2017.

Date	Sampling Activity
10/11/16	forebay, draft tubes, and lees ferry
11/07/16	abbreviated quarterly
12/01/17	abbreviated quarterly
01/31/17	forebay, draft tubes, and lees ferry
03/22/17	forebay, draft tubes, and lees ferry (no Seabird data)
05/19/17	quarterly survey
06/08/17	forebay, draft tubes, and lees ferry
07/17/17	quarterly survey
08/01/17	draft tubes and lees ferry
08/28/17	forebay, draft tubes, and lees ferry
09/19/17	forebay, draft tubes, and lees ferry

Laboratory analytical results are usually received within two months of collection. All data are entered into a Microsoft Access database. Progress continues to be made to serve data from this database to the public on the GCMRC website. Reclamation also uses a subset of the water quality data to run the CE-QUAL-W2 model and also to create cross-section time series visualizations of reservoir temperatures, dissolved oxygen, pH, and total dissolved solids.

Analysis Activities

Given hypothesized links between bioavailable phosphorus and food web dynamics in the Glen Canyon reach of the Colorado River, an effort has begun to analyze historical nutrient data from Lake Powell, Lees Ferry, and the three major gaged tributary sites to Lake Powell (Colorado River at Cisco, Green River at Green River, and San Juan River at Bluff). The goal of this analysis is to better understand the controls on phosphorus releases from GCD with the eventual goal of modeling/predicting these releases. Work is also ongoing to ensure that nutrient collection and analysis protocol are yielding the highest quality data possible, especially with regards to phosphorus species.

Water-Quality Review (Funded under AMP FY2015-17 Triennial Work Plan)

A review of the Lake Powell water-quality monitoring program was conducted in Page, AZ on October 24-26, 2017. The GCMRC periodically convenes independent review panels to assess the quality, comprehensiveness, and integrity of its science programs and to identify needs for future monitoring and research. The review was performed by a panel of 5 subject-matter experts including; Steven Hamilton, PhD – Michigan State University, Edward Stets, PhD – US Geological Survey, Kristin Strock, PhD – Dickinson College, Todd Tietjen, PhD – Southern Nevada Water Authority, and Chris Holdren, PhD – US Bureau of Reclamation (retired). Panelists heard presentations on all aspects of water-quality monitoring and research that has been, and currently is being, conducted in Lake Powell as well as in the Colorado River ecosystem. In addition to presentations, the review included field trips to observe data collection activities on Lake Powell and the Colorado River south of GCD and a tour of the Glen Canyon Dam facility including the power house and outlet works. The final report with recommendations from the panelists is expected to be delivered to GCMRC in February of 2018.

Current Conditions

Hydrology - Lake Powell received 11.9 million acre-feet (maf) (110% of the 1981-2010 average) of unregulated inflow in water year (WY) 2017, more than the inflow observed in WY 2015 or WY 2016 (94% and 89% of average, respectively). The reservoir elevation reached a peak of 3635.8 ft on July 10 2017, compared to a peak of 3621.5 ft in 2016. At the end of WY 2017, Lake Powell's surface elevation was 3628.4 ft with storage of 14.7 maf, or 54% of full capacity. This is up from the end of WY 2016 when surface elevation was 3,610.93 ft, and storage was 12.8 maf.

Releases for WY 2017 totaled 9.0 maf (the same as for WY 2015 and WY 2016) with operations under the Upper-Elevation Balancing Tier. Operations for WY 2018 will also fall under the Upper Elevation Balancing Tier, with a most probable inflow volume of 8.9 maf and a most probable release volume of 9 maf.

Glen Canyon Dam Release Temperature – Given somewhat higher water levels in WY 2017, Glen Canyon Dam release temperatures did not reach the highs that they have reached during lower reservoir elevation years. Thus, while GCD releases had reached nearly 14°C at the end of September 2016, they peaked at 12.9°C in September 2017. This is notable given that peak temperatures in GCD releases have exceeded 15°C in 2 of the 3 previous years.

Lake Powell Limnology – Similar to other years, an interflow plume of low dissolved oxygen water moved through Lake Powell and contributed to low (but not historically low) values of dissolved oxygen (DO) in the GCD tailwaters (minimum DO of 5.5 milligram per liter [mg/L] in October of 2017, compared to 4.7 mg/L in October 2015). 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 throughout the reservoir.

Program Support

Historically this project has been funded entirely by Reclamation from power revenues generated by GCD and receives no funding from the GCDAMP. In addition to direct funding of the program, Reclamation also provides support for laboratory analyses. A five-year agreement for support of the Lake Powell water-quality monitoring program was developed with Reclamation in 2013. Funding received under this agreement in 2014 supported all FY 2015 and FY 2016 activities. In FY 2017, additional funds were received from Reclamation and this allowed part-time funding of several scientists on this project through early FY 2019 (budget table). Support for GCMRC's participation beyond this date is uncertain.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Turbid releases from Glen Canyon Dam, Arizona, following rainfall-runoff events of September 2013	FY 2017	Mar 24, 2017		Wildman, R.A., Jr., and Vernieu, W.S., 2017, Turbid releases from Glen Canyon Dam, Arizona, following rainfall-runoff events of September 2013: Lake and Reservoir Management, v. 33, no. 3, p. 211-216, https://doi.org/10.1080/10402381.2017.1293756

Project 1 (non-AMP)	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount						$0	**$0**
Actual Spent	$11,834	$1,665	$2,053	$0	$0	$1,878	**$17,431**
(Over)/Under Budget	**($11,834)**	**($1,665)**	**($2,053)**	**$0**	**$0**	**($1,878)**	**($17,431)**
FY16 Carryover & FY17 Addition	**$258,108**		**CPI Adjust**	**$0**		**FY17 Carryover**	**$240,677**

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

- NOTE: THIS IS NON AMP FUNDING!!!
- Carried $12,199 over from previous FY.
- Received $245,909 in additional Non-AMP funds from Reclamation.
- Carried over $240,677.

Project 1.1 (AMP)	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 12.074%	Total
Budgeted Amount	$0	$0	$0	$0	$0	$0	**$0**
Actual Spent	$0	$0	$0	$0	$0	$0	**$0**
(Over)/Under Budget	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**
FY16 Carryover	**$20,600**		**CPI Adjust**	**$0**		**FY17 Carryover**	**$20,600**

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

- Carried over $20,600 of AMP Funds to FY18 (originally from FY15).
- Was used to fund the Lake Powell Protocol Evaluation Panel (PEP) in October 2017.

Budget Summary—AMP Total (without Lake Powell Agreement)

AMP Total (without Lake Powell Agreement)							
Total	**Salaries**	**Travel & Training**	**Operating Expenses**	**Cooperative Agreements**	**To other USGS Centers**	**Burden 12.074%**	**Total**
Budgeted Amount	$4,415,700	$124,900	$1,310,000	$1,796,800	$632,800	$760,305	**$9,040,505**
Actual Spent	$4,347,956	$130,098	$1,766,336	$2,014,725	$535,413	$814,389	**$9,608,917**
(Over)/Under Budget	**$67,744**	**($5,198)**	**($456,336)**	**($217,925)**	**$97,387**	**($54,084)**	**($568,412)**
FY16 Carryover	**$1,103,755**		**CPI Adjust**	**($61,480)**		**FY17 Carryover**	**$483,114**

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

- FY17 Carryover will be used to meet the shortfall identified in the FY18 budget as well as unanticipated costs including salary, equipment replacement and to support completion of outstanding tasks from the FY15-17 work plan.

Logistics Budget

Logistics	**Salaries**	**Travel & Training**	**Operating Expenses**	**Cooperative Agreements**	**To other USGS Centers**	**Burden 12.074%**	**Total**
Budgeted Amount	$269,800	$6,000	$754,500	$0	$0	$124,398	**$1,154,698**
Actual Spent	$279,049	$3,345	$947,277	$13,168	$0	$148,866	**$1,391,705**
(Over)/Under Budget	**($9,249)**	**$2,655**	**($192,777)**	**($13,168)**	**$0**	**($24,468)**	**($237,007)**
FY16 Carryover	**$0**		**CPI Adjust**	**($2,158)**		**FY17 Carryover**	**($239,165)**

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.