Glen Canyon Dam Adaptive Management Work Group
Agenda Item Information
August 8-9, 2013

Agenda Item
Update from 2014 Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting

Action Requested
Information item only

Presenters
Jack Schmidt, Chief, Grand Canyon Monitoring and Research Center
Scott VanderKooi, Deputy Chief, Grand Canyon Monitoring and Research Center

Previous Action Taken
N/A

Relevant Science
N/A

Background Information

The January 2014 Technical Work Group meeting was preceded by a 2-day Annual Reporting meeting during which GCMRC staff, cooperators and collaborators, and staff of sister federal agencies presented new findings and insights of management significance. Annual estimates of spring abundance of humpback chub in the Little Colorado River for fish >150 mm and >200 mm exceed 5,000 in each case, and trends remain stable or are increasing. The estimated total abundance of rainbow trout between Glen Canyon Dam and the Little Colorado River in January 2014 was approximately 600,000 fish, about half the estimated abundance in April 2012. Approximately 70 % of the population of rainbow trout occurs upstream from River Mile (RM) 20. New modeling tools to predict changes in fish populations in relation to possible changes in dam operations and environmental factors have been developed.

Sand bar resources are improving during the period of the High Flow Protocol implemented in July 2012. The linkage between sand bar condition and upslope flux of sand caused by wind redistribution processes was further demonstrated.

Grand Canyon Monitoring and Research Center

Fiscal Year 2013 Annual Project Report

for the

Glen Canyon Dam
Adaptive Management Program

Contents

Introduction

Following is the Grand Canyon Monitoring and Research Center's (GCMRC) Fiscal Year 2013 Annual Accomplishment Report. This report is prepared primarily for the Technical Work Group (TWG) of the Glen Canyon Dam Adaptive Management Program (GCDAMP). It includes a summary of accomplishments, shortcomings, and recommendations related to projects included in GCMRC's FY 2013 Work Plan for the GCDAMP.

Project and Title			
Project A: Sandbars and Sediment Storage Dynamics: Long-term Monitoring and Research at the Site, Reach, and Ecosystem Scales			
Program Manager (PM)	Paul Grams	**Principal Investigator(s)** (PI)	Paul Grams, USGS GCMRC, Phil David, USGS GCMRC, Barbara Ralston, USGS GCMRC, David Rubin, USGS, Joseph E. Hazel and Matthew Kaplinksi, NAU, Keith Kohl, USGS GCMRC
Email	pgrams@usgs.gov		
Telephone	(928) 556-7385		

SUMMARY

In 2013, scientists from Project A collected essential data on sandbars and in-channel sediment storage during two project-specific river trips and one joint Project A-Project B river trip. Findings published or presented in the past year describe the condition of sandbars and document the dynamics of local and reach-scale changes in sediment storage on the river bed. We expect that these advances coupled with advances in modeling capabilities will lead to a better understanding of processes governing sandbar deposition and erosion and an improved capacity for predicting sandbar response. Specific accomplishments in each project element are summarized briefly below.

A.1.1 Sandbar monitoring – In October 2012, 1-year after the 2011 equalization flows and 4-years after the previous high flow, the median size of sandbar monitoring sites in Marble Canyon was as low as any time since 1990. Topographic surveys and images from remote cameras indicate that the fall 2012 and 2013 HFEs resulted in increases in sandbar size in both Marble Canyon and Grand Canyon.

A.1.2 Sandbars from Remote sensing – We have analyzed 2002 and 2009 images for sandbar area in select reaches for comparison with previous data. This analysis suggests no measureable change in sandbar area in Marble Canyon between 1996 and 2009. We are in the final stages of analyzing the 2002 and 2009 images for changes in sandbar area at all large sand storage locations in Marble Canyon and Grand Canyon. An aerial overflight was conducted in May 2013 that included the collection of a new set of 4-band imagery between Glen Canyon Dam and Lake Mead.

A.1.3 Campsites – We have used vegetation maps made from the 2002 and 2009 images to map vegetation in campsites. Vegetation cover within campsite area boundaries has expanded by at least 10% between 2002 and 2009. Analysis will be extended to evaluate how campsites have been affected by changes in other geomorphic attributes. Monitoring of campable area and collection of repeat photographs has continued.

A.1.4 Sandbar Change, 1984-1990 – We have created digital terrain models from 1984 air photos for comparison with sandbar area and volume from sandbar monitoring sites. The 4 sites that have been analyzed thus far were 10 to 70% larger in 1984 than in 1990 when monitoring by topographic survey began.

A.2.1 & A.2.2 Sand Storage Monitoring – Repeat mapping of the river channel has demonstrated that changes in storage are highly variable from one storage location (eddy) to the next. Processing is now complete for the first repeat mapping of a long river segment (the segment between river mile 30 and river mile 61). Analysis is underway and preliminary results will be presented at the January 2014 reporting meeting. Completion of this comparison requires methods to map the bed texture (to distinguish sand from other substrate). We have made substantial progress in developing new methods to automate this using acoustic backscatter.

A.3 Sandbar Modeling – Advances in numerical modeling of flow in recirculation zones demonstrate that there are important processes controlling the transport, deposition, and erosion of sand in eddies that are not captured in simplified modeling approaches. In the next year, we will attempt to apply these new models of flow to model sandbar building in eddies.

A.4 Flow-Sediment Interactions – We completed joint measurements of suspended-sediment concentration, bed-sediment grain size, water velocity (to estimate bed shear stress), and bathymetry to investigate the relative contributions to the large (several order-of-magnitude) range in observed suspended sand concentrations for a given water discharge. We published a journal article on the relation between bed-sand coverage and suspended-sand transport that can be implemented in future modeling efforts.

A.5 Sediment Fingerprinting – Preliminary results from geochemical analysis of sand deposited during the Nov 2012 HFE indicate that the deposits consisted of up to 17% relic Colorado River sediment (in the 63-250 μm sand fraction). However, the results also indicate that sediment delivered to the Colorado River during winter 2012 may have been mobilized from a part of the Paria watershed that has not yet been characterized by this study. Collection and analysis of additional samples is required to reduce the uncertainty in these results.

A.6 Control Network and Survey Support – We improved the geodetic control network and provided survey support for Project A, Project B, Project J, and the May 2013 canyon-wide overflight.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
USGS report	Report on near-shore water temperatures observed during the near-shore ecology project: *Nearshore thermal gradients of the Colorado River near the Little Colorado River confluence, Grand Canyon National Park, Arizona, 2010*		Mar. 2013		Ross, R., and Grams, P.E. (2013): U.S. Geological Survey Open-File Report 2013–1013, 65 p. http://pubs.usgs.gov/of/2013/1013/.
USGSFact sheet	Summary of findings regarding near-shore water temperatures: *Nearshore Temperature Findings for the Colorado River in Grand Canyon, Arizona—Possible Implications for Native Fish*		Nov. 2013		Ross, R.P., and Vernieu, W.S. (2013): U.S. Geological Survey Fact Sheet 2013-3104, 4 p., *http://dx.doi.org/10.3133/fs20133104.*
data	Data from long-term sandbar monitoring sites	Annual		Jan. 2014	To be presented at Jan. 2014 reporting meeting.
photos	Images from daily remote camera monitoring of sandbars	Annual	Dec. 2012 &Dec. 2013		Photos uploaded to website following each HFE.
Article	To Re-photograph or Not, That is the Question: The Adopt-A-Beach Program Marches On	Annual	Dec. 2013		Zeke Lauck (2013), Boatman's Quaterly Review, Winter 2013-2014, 26, 4, p. 21-23, http://www.gcrg.org/bqr.php.
data	Map, showing extent of sandbars in selected reaches for 1988	Year 1			This was not completed. See project A.1.2.
data	Map, showing extent of sandbars throughout CRE in 2013	Year 2		Jan. 2015	
report	Report on system-wide sandbar monitoring, 1988-2013	Year 2		Jan. 2015	
report	Report on the geomorphic attributes of camping beaches	Year 2		Jan. 2015	
report	Report on the extended sandbar monitoring time series (1984 to present) based on use of old air photos	Year 2		Jan. 2015	
Journal Article	Report on changes in sediment storage, RM 30 to RM 61, titled: *Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design*	Year 1	Feb. 2013	Mar. 2014	Grams P. E., D. J. Topping, J. C. Schmidt, J. E. Hazel Jr., and M. Kaplinski (2013), J. Geophys. Res. Earth Surf., 118, 361–381, doi:10.1002/jgrf.20050. http://onlinelibrary.wiley.com/doi/10.1002/jgrf.20050/full Additional analysis and results to be presented at Jan. 2014 reporting meeting. Additional report by Mar. 2014.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal Article	Report describing the influence of bed-sand coverage in controlling suspended-sand transport *Transport of fine sediment over a coarse, immobile river bed*		Jan. 2014		Grams, P.E. and Wilcock, P.R., J. Geophys. Res. Earth Surf., 118, 361–381, doi: 10.1002 /2013JF002925, http:// http://onlinelibrary.wiley.com/doi/10.1002/2013JF002925/abstract
USGS Fact sheet	*A sand budget for Marble Canyon, Arizona--implications for long-term monitoring of sand storage change*		Aug. 2013		Grams P. E. (2013) U.S. Geological Survey Fact Sheet 2013–3074. *http://pubs.usgs.gov/fs/2013/3074/* .
data	Data from sediment storage monitoring, RM 30 to RM 61	Year 1		Jan. 2014	To be presented at Jan. 2014 reporting meeting.
data	Data from sediment storage monitoring for long reach mapped in 2013	Year 2		Jan. 2015	
data	Data from sediment storage monitoring for long reach mapped in 2014	After Year 2		Jan. 2016	
data	Maps of bed texture for each of the long reaches mapped in the sediment storage monitoring project	Year 2		Jan. 2015	
report	Report on bed material characterization	Year 2		Jan. 2015	
report	Report on eddy sandbar variability(eddy modeling)	Year 2		Jan. 2015	

Project A Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$576,937	$9,600	$52,900	$337,400	$75,600	$82,564	**$1,135,001**
Actual Spent	$483,065	$9,290	$98,263	$351,174	$137,125	$77,446	**$1,156,362**
(Over)/Under Budget	**$93,872**	**$310**	**($45,363)**	**($13,774)**	**($61,525)**	**$5,118**	**($21,361)**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel. Purchased equipment that we had been renting. Sent funds to WI Water Science Center's (CIDA) to help development of the realtime sediment budget web tool.

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

SUMMARY

The Streamflow, Water Quality, and Sediment Transport Core Monitoring Project is focused on high-resolution monitoring of stage, discharge, water temperature, specific conductance, dissolved oxygen, turbidity, and suspended-sediment concentration and particle size at a number of mainstem and tributary sites located throughout the Colorado River Ecosystem (CRE). These data are collected to address GCDAMP GOAL 7 and are used to inform managers on the physical status of the Colorado River in the CRE and how this physical status is affected by dam operations in near realtime. The high-resolution suspended-sediment data collected under this project are used to construct the mass-balance sediment budgets used by managers to plan dam releases (including triggering controlled floods, ie., HFEs). Details of this project (including descriptions of the data-collection locations) are provided in the GCMRC Annual Work Plan.

Outcome:

In summary, this project coordinated the collection of stage, discharge, water-quality, and sediment-transport monitoring data at 7 mainstem locations and 8 major tributary locations and 8 lesser tributary locations during FY 2013 (suspended sediment is monitored at a subset of 5 mainstem and 16 tributary locations). At all sites, acoustic instrument calibrations have been finalized and are being verified, with out-of-sample errors calculated. This work has resulted in the ability in FY 2013 to serve data at a new web site and update it on a monthly or more frequent basis. The two urls to use to access this new website are: http://www.gcmrc.gov/discharge_qw_sediment/
or http://cida.usgs.gov/gcmrc/discharge_qw_sediment/.
The second url provides backup access to the website in case the local web servers in Flagstaff go down.

Specifically, progress was made on many fronts within the Streamflow, Water Quality, and Sediment Transport Project:

1) The single most significant accomplishment this year was the completion of the new web site. This web site provides access to all of the data collected by the Streamflow, Water Quality, and Sediment Transport Project. In addition, this new web site allows user interactive sand budgets to be constructed for ultimately 6 reaches of the Colorado River in the CRE. Currently, sand budgets are available for the three reaches between Lees Ferry and the Grand Canyon gaging station at river mile 87 near Phantom Ranch, and the reach downstream from Diamond Creek. My March 2014, sand budgets for the two remaining reaches between the Grand Canyon gaging station and Diamond Creek. These user-interactive sand budgets allow the user to modify the contribution of bedload and to modify the uncertainties in the data. This ability allows managers to evaluate "how well the sand budgets need to be known" in their decision-making process. The servers supplying data to this new website have been moved to the USGS EROS Data Center in South Dakota for greater security and IT service (meaning the websites will be less likely to go down or experience catastrophic loss of data).

2) All monitoring data required by this project were collected. Processing of all data is complete except for laboratory analyses of some of the suspended-sediment data from the Paria River and Little Colorado Rivers (this will be completed by the end of March 2014 as is the usual schedule for this project).

3) Discharge measurements and suspended-sediment samples were collected during the November 2013 HFE by personnel stationed at two sites on the Colorado River. Automatic suspended-sediment samples were collected during this controlled flood at three additional sites on the Colorado River. The discharge measurements have been processed with stage-discharge ratings verified or adjusted as necessary; the suspended-sediment samples have begun to be processed through the GCMRC sediment laboratory (to be completed by late spring 2013).

4) 15-minute stage, discharge, and water temperature data (updated in realtime) and other QW data from the 9 gaging stations maintained by the USGS Arizona and Utah Water Science Centers under this project are available

at http://www.gcmrc.gov/discharge_qw_sediment/, http://cida.usgs.gov/gcmrc/discharge_qw_sediment/, or http://waterdata.usgs.gov/nwis.

5) An indirect discharge measurement was completed by the USGS Arizona Water Science Center for the peak of the largest Paria River flood of the year. This measurement will result in a roughly 25% decrease in the currently served peak discharge of the September 11, 2013, flood. This will, by extension, result in a downward revision of the Paria River sand supply during September 2013. These revisions will propagate through the sand budgets on the web site in March 2014 (the usual time for these types of revisions to occur).

6) 15-minute stage, discharge, water temperature, specific-conductance, turbidity, dissolved oxygen and suspended-sediment-concentration and grain-size data from the stations maintained by GCMRC under this project have been processed and are now served at our new web site at http://www.gcmrc.gov/discharge_qw_sediment/ or http://cida.usgs.gov/gcmrc/discharge_qw_sediment/. These data are updated as frequently as every month, depending on data-collection location.

7) Three major peer-reviewed reports (a journal article published in the Journal of Geophysical Research-Earth Surface, a USGS Scientific Investigations Report and a USGS Open-File Report) were published on normal core-monitoring tasks. These reports are listed below.

8) One major peer-reviewed report (a USGS Scientific Investigations Report) on turbidity was reviewed, revised, and submitted for USGS approval (report to be published during 2014). Title of report is "Extending the turbidity record: Making additional use of continuous data from turbidity, acoustic-Doppler, and laser diffraction instruments, and suspended-sediment samples in the Colorado River in Grand Canyon."

9) Four abstracts were published and presented at the 2013 Fall Meeting of the American Geophysical Union.

10) Annual water-data reports for the data collected during 2012 were published by the Arizona and Utah Water Science Centers.

11) Substantial progress was also made on completing the delivery of the historical periods of record for unit-value stage and discharge for USGS gaging stations with QW and sediment data relevant to the CRE. As of December 2013, the following historical periods of record have been processed and are available at http://www.gcmrc.gov/discharge_qw_sediment/ or http://cida.usgs.gov/gcmrc/discharge_qw_sediment/.

09380000 Colorado River at Lees Ferry, AZ Entire 1921-present period of station record processed and on website.
09381500 Paria River near Cannonville, UT Entire 1951-1956, 2001-2006 period of station record processed and on website.
09401000 Little Colorado River at Grand Falls Entire 1926-1960, 1994-1995 period of station record processed on website.
09401250 Moenkopi Wash near Moenkopi, AZ Entire 1974-1976 period of station record processed and available on website.
09401260 Moenkopi Wash at Moenkopi, AZ Entire 1976-present period of station record processed and available on website.
09401400 Moenkopi Wash near Tuba City, AZ 1949-1954, 1965-1977 available online. Other years remaining to be processed during 2014.
09401500 Moenkopi Wash near Cameron, AZ Entire 1954-1965 period of station record processed and available on website.
09402000 Little Colorado River near Cameron, AZ Entire 1947-present period of station record processed on website.
09402500 Colorado River near Grand Canyon, AZ Entire 1923-present period of station record processed on website.
09403000 Bright Angel Creek near Grand Canyon, AZ 1924-1974, 1991-1993 Entire period of station record processed on website
09403780 Kanab Creek near Fredonia, AZ 1964-1977 on website. 1978-1980 remaining to be processed.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
GCDAMP presentations	6-month updates made to TWG and AMWG on the state of sediment and QW in the CRE.				
Online database and web-based applications	Discharge, sediment transport, water-quality, and sand-budget data are served through the GCMRC web site. A web-based application has been implemented to provide stakeholders and interested public with the ability to perform interactive online data visualization and analysis, including the on-demand construction of sand budgets.	ongoing	updated every month	updated every month	http://www.gcmrc.gov/discharge_qw_sediment/ http://cida.usgs.gov/gcmrc/discharge_qw_sediment/
Online 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 in realtime	n/a	hourly	n/a	*http://waterdata.usgs.gov/nwis*
Abstracts	American Geophysical Union abstract for 2013 Fall Meeting entitled "Accurate sediment budgets in rivers require high-resolution discharge-independent measurements of suspended-sediment concentration." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Topping, D.J., Griffiths, R.E., Dean, D.J., Wright, S.A., Rubin, D.M., Garner, B.D., Sibley, D.M., and Reinke, T.A., 2013, Accurate sediment budgets in rivers require high-resolution discharge-independent measurements of suspended-sediment concentration: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Measurements of sediments loads in small, ungaged, basins may be required to accurately close sediment budgets: An example from a monitoring network on the southern Colorado Plateau." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Griffiths, R.E., and Topping, D.J, 2013, Measurements of sediments loads in small, ungaged, basins may be required to accurately close sediment budgets: An example from a monitoring network on the southern Colorado Plateau: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Reconciliation of Flux-based and Morphologic-based Sediment Budgets." Presentation made at AGU in December 2013.	FY 2013	August 2013	August 2013	Grams, P.E., Buscombe, D., Hazel, J.E., Kaplinski, M.A., and Topping, D.J, 2013, Reconciliation of Flux-based and Morphologic-based Sediment Budgets: EOS, Transactions, American Geophysical Union.
	American Geophysical Union abstract for 2013 Fall Meeting entitled "Warm Season Storms, Floods, and Tributary Sand Inputs below Glen Canyon Dam: Investigating Salience to Adaptive Management in the Context of a 10-	FY 2013	August 2013	August 2013	Jain, S., Melis, T.S., Topping, D.J, Pulwarty, R.S., and Eischeid, J., 2013, Warm Season Storms, Floods, and Tributary Sand Inputs below Glen Canyon Dam: Investigating Salience to Adaptive Management in the Context of a 10-Year Long Controlled

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
	Year Long Controlled Flooding Experiment in Grand Canyon National Park, AZ, USA." Presentation made at AGU in December 2013.				Flooding Experiment in Grand Canyon National Park, AZ, USA: EOS, Transactions, American Geophysical Union.
Journal articles and other major pubs.	Journal of Geophysical Research article entitled "Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design"	FY 2013	February 2013	February 2013	Grams, P.E., Topping, D.J., Schmidt, J.C., Hazel, J.E., Jr., and Kaplinski, M., 2013, Linking morphodynamic response with sediment mass balance on the Colorado River in Marble Canyon: Issues of scale, geomorphic setting, and sampling design: Journal of Geophysical Research: Earth Surface, v. 118, 18p., doi:10.1002/jgrf.20050, http://onlinelibrary.wiley.com/doi/10.1002/jgrf.20050/pdf.
	USGS Scientific Investigations Report entitled "Evaluation of intake efficiencies and associated sediment-concentration errors in US D-77 bag-type and US D-96-type depth-integrating suspended-sediment samplers"	FY 2013	Sept. 2013	Sept. 2013	Sabol, T.A., and Topping, D.J., 2013, Evaluation of intake efficiencies and associated sediment-concentration errors in US D-77 bag-type and US D-96-type depth-integrating suspended-sediment samplers: U.S. Geological Survey Scientific Investigations Report 2012–5208, 88 p., http://dx.doi.org/10.3133/sir20125208, http://pubs.er.usgs.gov/publication/sir20125208
	USGS Open-File Report entitled "Transient simulation of groundwater levels within a sandbar of the Colorado River, Marble Canyon, Arizona, 2004"	FY 2013	Sept. 2013	Sept. 2013	Sabol, T.A., and Springer, A.E., 2013, Transient simulation of groundwater levels within a sandbar of the Colorado River, Marble Canyon, Arizona, 2004: U.S. Geological Survey Open-File Report 2013-1277, 22 p., http://dx.doi.org/10.3133/ofr20131277
Reports	2012 Annual USGS Water-Data Reports	2-28-2013	2-28-2013	2-28-2013	*http://wdr.water.usgs.gov/wy2012pdfs/09380000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09381800.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09382000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09402000.2012.pdf* *http://wdr.water.usgs.gov/wy2012/pdfs/09402300.2012.pdf* http://wdr.water.usgs.gov/wy2012/pdfs/09402500.2012.pdf http://wdr.water.usgs.gov/wy2012/pdfs/09403850.2012.pdf *http://wdr.water.usgs.gov/wy2012/pdfs/09404115.2012.pdf*

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
					http://wdr.water.usgs.gov/wy2012/pdfs/09404200.2012.pdf

Project B Budget	**Salaries**	**Travel & Training**	**Operating Expenses**	**Cooperative Agreements**	**To other USGS Centers**	**Burden 11.329%**	**Total**
Budgeted Amount	$531,600	$0	$50,000	$0	$515,000	$65,889	**$1,162,489**
Actual Spent	$556,089	$4,702	$61,830	$0	$439,398	$70,537	**$1,132,556**
(Over)/Under Budget	**($24,489)**	**($4,702)**	**($11,830)**	**$0**	**$75,602**	**($4,648)**	**$29,933**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Underestimated salary, travel & training, and operating expenses in work plan. Database development work paid for from FY12 carryover.

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

Project and Title			
Project C: Water-Quality Monitoring of Lake Powell and Glen Canyon Dam Releases			
Program Manager (PM)	William Vernieu	**Principal Investigator(s)** (PI)	William Vernieu, USGS GCMRC
Email	bvernieu@usgs.gov		
Telephone	(928) 556-7051		

SUMMARY

Hydrology

Lake Powell received 5.12 maf (47% of average) of unregulated inflow in WY2013, placing 2013 as the fourth driest year on record since the closing of Glen Canyon Dam in 1963. Water years 2002, 1977, and 2012 were drier, receiving 2.64 maf, 3.53 maf, and 4.91 maf, respectively. Reservoir levels reached a peak of 3,602.2 ft on June 18, 2013, down from previous peaks of 3,637 ft in 2012 and 3,661 ft in 2011. At the end of the water year, Lake Powell's surface elevation was 3,591.25 ft, or 45% capacity. Releases for WY2013 totaled 8.232 maf, with Lake Powell operating under the Upper Elevation Balancing Tier. A High-Flow Experiment (HFE) was conducted in November 2013, in which 34,100 cfs was released for a 96-hour period and Lake Powell's surface elevation decreased by approximately 2.5 ft.

Operations for WY2014 will fall under the Mid-Elevation Release Tier with a total annual release volume or 7.48 maf scheduled. As of December 11, 2013, Lake Powell is projected to reach a minimum surface elevation of 3,576.19 at the end of March 2014, approximately 21 ft above the minimum surface elevation that was reached in 2005. The surface elevation at the end of WY2014 is projected to be 3,603.39.

Glen Canyon Dam Release Temperature

Glen Canyon Dam release temperatures from 2003-2010 have been above normal because of low reservoir elevations resulting from extended drought conditions in the Upper Colorado River Basin. In 2012 and 2013, release temperatures were representative of long-term average temperatures observed from 1990-2002, because of relatively higher reservoir elevations and low inflow volumes. However, with continued reservoir drawdown, release temperatures can be expected to return to above-average levels during the summer and fall of 2014.

Lake Powell Limnology

A winter underflow density current was observed, arriving in the hypolimnion at Glen Canyon Dam in February 2013. This caused a significant freshening of hypolimnetic dissolved oxygen concentrations, which had gradually diminished from the lack of a similar process during the previous year. Because of gradual encroachment of sediment deltas, the locations at which inflow tributaries met the reservoir were farther downstream than recorded in 2005, despite the fact that reservoir elevations were approximately 40 ft higher than in 2005. Because of localized monsoon storms in September 2013, an unusual event occurred in which releases from Glen Canyon Dam became turbid for several days and required a short-term study to determine the source of the turbidity. No significant changes to downstream release patterns or stratification within Lake Powell from the November 2013 HFE. The National Park Service detected larval quagga mussels in Lake Powell in the fall of 2012, and adult quagga mussels were discovered in Lake Powell marina areas in early 2013. The spatial and size distribution of the adult mussels does not yet indicate a large reproducing population in the reservoir and a strong prevention program remains in place.

Program Support

A five-year agreement for continued support of the Lake Powell water-quality monitoring program was developed with Reclamation in 2013 and provides funding for staff, supplies and maintenance of the Uniflite vessel and other equipment, and sample analysis. A contract for analysis of backlogged plankton samples is expected to be completed in the spring of 2014. Dale Robertson, of the USGS Wisconsin Science Center continues to collaborate on this project, assisting with data interpretation and development of an interpretive synthesis of the published data.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Reports	Vernieu, W.S., and Anderson, C.R., 2013, Water temperatures in select nearshore environments of the Colorado River in Grand Canyon, Arizona, during the Low Steady Summer Flow experiment of 2000	FY2013	2/22/2013		U.S. Geological Survey Open-File Report 2013–1066, 44 p. (Available at http://pubs.usgs.gov/of/2013/1066/.)
Reports	Vernieu, W.S., 2013, Historical physical and chemical data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1964–2012	FY2013	11/12/2013		U.S. Geological Survey Data Series 471, 23 p., http://pubs.usgs.gov/ds/471/.
Fact Sheet	Ross, R.P., and Vernieu, W.S., 2013, Nearshore Temperature Findings for the Colorado River in Grand Canyon, Arizona—Possible Implications for Native Fish	FY2013	11/25/2013		U.S. Geological Survey Fact Sheet 2013–3104, 4 p., http://dx.doi.org/10.3133/fs20133104.
Presentations	Data Management for Long-Term Water-Quality Monitoring in Lake Powell, Utah-Arizona, 1964–2011		11/7/2012		North American Lake Management Society 32nd International Symposium, Madison, WI
Presentations	Historic Deltaic Sedimentation Patterns in Lake Powell, Utah-Arizona, 1998-2011		11/8/2012		North American Lake Management Society 32nd International Symposium, Madison, WI
Presentations	Effects of Reservoir Drawdown on Lake Powell and Glen Canyon Dam Releases		7/10/2013		Museum of Northern Arizona Science Café Lecture Series, Flagstaff, AZ
Presentations	Organized and led special symposium, "Lake Powell after 50 Years – Patterns, Processes, and Predictions" with seven speakers		9/18/2013		12th Biennial Conference of Science and Management on the Colorado Plateau, Northern Arizona University, Flagstaff, AZ
Presentations	Historic Deltaic Sedimentation Patterns in Lake Powell, Utah-Arizona, 1998-2011		9/19/2013		Arizona Hydrological Society Annual Symposium, Tucson, AZ
Presentations	Lake Powell and Glen Canyon Dam – Storing Water in Times of Drought		9/30/2013		Presentations to three high school and middle school classes for Flagstaff Festival of Science in-school program
Other	Floods turn Powell Discharge Murky - Interview with Arizona Daily Sun reported Eric Betz		9/20/2013		http://azdailysun.com/floods-turn-powell-discharge-murky/article_cfd87d70-2285-11e3-9c56-001a4bcf887a.html

Project C Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$179,700	$7,200	$33,800	$0	$0	$25,003	**$245,703**
Actual Spent	$114,751	$6,834	$15,064	$0	$23,081	$15,481	**$175,211**
(Over)/Under Budget	**$64,949**	**$366**	**$18,736**	**$0**	**($23,081)**	**$9,522**	**$70,492**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel. Sent Dale Robertson's salary to the WI Water Science Center rather than him charging salary directly. No major boat repairs/maintenance.

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

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

SUMMARY

Mainstem Colorado River humpback chub (*Gila cypha*) aggregations were sampled during July and September, 2013 using hoop nets and trammel nets. Chub (n = 116) were captured at all aggregations, and they were also captured (n = 44) at locations not associated with aggregations. Synthesis of existing data and use of pooled capture probabilities to estimate abundance did not meet necessary assumptions of closed population estimators and was considered invalid by peer reviewers. Relative abundance as estimated by catch per unit effort (CPUE) indices provide the best estimate of status and trends of mainstem aggregations. Relative abundance of adult chub as estimated by catch per unit effort has increased or remained stable at all aggregations since sampling began in the 1990's.

Humback chub translocated to Shinumo Creek and to Havasu Creek from 2009-2011 contributed to the mainstem aggregations at those tributary mouths. Efforts to estimate abundance at the Shinumo Creek aggregation using two pass mark-recapture methods were not successful, likely because sampling events were too close together in time.

Use of trammel nets was discontinued at most aggregations due to concerns about overhandling fish and large amounts of debris from tributary flooding. Trammel netting was also discontinued when water temperatures exceeded 16° C.

We were not able to collect young-of-the-year humpback chub for Project element D.2.1, 'Natal origins of humpback chub at aggregations by otolith microchemistry'. We will collect water samples and surrogate species such as speckled dace to confirm that fish resident in Havasu Creek can be distinguished from Little Colorado River fish and provide samples to a Cooperator for otolith extraction and analysis.

Project D.2.2, 'Egg maturation studies using Ultrasonic Imaging and Ovaprim®' demonstrated that ultrasonic imaging can be used to detect eggs in female hatchery fish, and egg development in humpback chub was documented for fish collected in the mainstem Colorado River and in Havasu Creek.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Oral Presentation	Colorado River fish monitoring in Grand Canyon, Arizona: 2002-2012 humpback chub, Gila cypha, aggregations Persons, William*1, Vanhaverbeke, David R.2 (1-USGS Grand Canyon Monitoring and Research Center, 2-U.S. Fish and Wildlife Service).		11/21/13		Presentation to Desert Fishes Council, November 21, 2013.
Oral Presentation	Use of ultrasonic imaging and Ovaprim® to evaluate egg maturation of humpback chub, Gila cypha Brizendine, Morgan E.*1, Ward, David L.2, Bonar, Scott A.1 (1-University of Arizona, Arizona Cooperative Fish and Wildlife Research Unit, 2-U.S. Geological Survey, Grand Canyon Monitoring and Research Center).		11/21/13		Presentation to Desert Fishes Council, November 21, 2013.
Open File Report	Colorado River fish monitoring in Grand Canyon, Arizona: 2002-2012 humpback chub, Gila cypha, aggregations Persons, William*1, Vanhaverbeke, David R.2 (1-USGS Grand Canyon Monitoring and Research Center, 2-U.S. Fish and Wildlife Service).		6/22/13	3/1/14	Submitted for external peer review, undergoing revision to include data from 1993-2013.

Project D Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$63,900	$1,000	$19,500	$180,000	$0	$14,962	**$279,362**
Actual Spent	$72,581	$0	$22,805	$145,889	$42,646	$15,183	**$299,104**
(Over)/Under Budget	**($8,681)**	**$1,000**	**($3,305)**	**$34,111**	**($42,646)**	**($221)**	**($19,742)**

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

Additional staffing for field work.
Funds were suballocated to the USGS Cooperative Research Unit rather than the University as a Coop.

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

Project and Title			
Project E: Humpback Chub Early Life History in and Around the Little Colorado River			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Charles Yackulic, USGS GCMRC; Theodore Kennedy, USGS GCMRC; Colden Baxter, USU; Bill Pine, UF; Dennis Stone, USFWS; Craig Stricker, USGS; D.R. VanHaverbeke USFWS; David Walters, USGS; Rich Wanty, USGS; Mike Yard, USGS GCMRC
Email	svanderkooi@usgs.gov		
Telephone	(928) 556-7376		

SUMMARY

The main foci of activities in FY13 were collecting new data in the Little Colorado River, managing humpback chub data collected through the Natal Origins / Juvenile Chub Monitoring project and analyzing existing data to better understand humpback chub population dynamics. In FY 13, we undertook the first early-July, system-wide marking of juvenile humpback chub in the Little Colorado River (Project Element E.1). We also completed fish diet studies and initiated other food base studies (E.2). Substantial progress was also made in understanding and modelling humpback chub population dynamics in and around the Little Colorado River, including work to support the LTEMP EIS process.

In July of FY13, three teams completed two passes of the Little Colorado River over a 12-day period using multiple gears. Over 2000 juvenile chub (40 – 99 mm) were marked with visual elastomer tags (VIE) as part of this effort. Juvenile chub were found throughout the sampled area, but were less common in the upper portion of the sample river (i.e., Salt camp). The majority of the marked fish were between 40 and 60 mm. While we are still analyzing data, a preliminary analysis based on recaptures by the Natal Origins / Juvenile Chub Monitoring and Fish and Wildlife Service monitoring in the Little Colorado River suggests lower rates of outmigration to the Colorado River between July and September than was previously estimated using recapture data for fish marked at Boulder's Camp alone from 2009-2011.

In FY13, cooperators from Idaho State University completed fish diet studies for the entire fish assemblage in the LCR. Fish diet sampling occurred seasonally and in conjunction with several natal origins river trip, which provided logistical and field support. Diet sampling encompassed the most common species present in the LCR (i.e., humpback chub, bluehead and flannelmouth suckers). Approximately half of the >400 fish diet samples have been processed.

In FY13 we initiated studies on food quality in the LCR. Specifically, in June 2013 samples of invertebrates and organic matter were collected from throughout the mainstem Colorado River, the Little Colorado River and other tributaries in Grand Canyon (i.e., Nankoweep Creek, Kanab Creek, Havasu Creek). These samples will be processed for metal concentrations and other trace elements. Data will be compared among reaches, and relative to EPA standards for wildlife health. These data will be used to evaluate whether a key aspect of resource quality, metal concentrations, limits the quality of resources available to support fish populations throughout Grand Canyon.

We also initiated studies on the invertebrate assemblage throughout the LCR in FY13. Specifically, sticky traps and light traps used to catch adult aquatic insects were deployed throughout the LCR in July by personnel working on the juvenile chub marking study. These data indicate densities of adult aquatic insects decline along a downstream gradient in the LCR from Salt Camp to Boulders Camp; however, full implementation of the FY13 workplan, including assessing the potential for food limitation, was delayed because of inadequate staffing. A post-doctoral researcher was hired to assist with Project E in May 2013, and we are well positioned to conduct these food limitation studies in FY14.

In FY13 we completed one study of population dynamics in the Little Colorado River aggregation focusing on gross differences in survival and growth between the Colorado River and the Little Colorado River over the period 2009 – 2012, as well as movement patterns between these areas. This analysis was synthesized data collected by Fish and Wildlife Monitoring efforts in the LCR, the Near shore ecology project and data collected in 2012 by the Natal Origins / Juvenile Chub monitoring project. We also initiated an analysis of spatial and temporal variation in abundance, survival, and growth of age – 1 fish in the Little Colorado River using data collected by Fish and Wildlife monitoring efforts. Lastly, we initiated and effort that modified the general model of population dynamics in the LCR aggregation in order to link growth and survival in the Colorado River to temperature and estimates of trout abundance. Estimates from this model were compared to historical trends and used to develop a simulation model to support the LTEMP EIS process.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Peer-reviewed Journal Article	A quantitative life history of endangered humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival			Early 2014	Yackulic, C.B., Yard, M.D., Korman, J., and Van Haverbeke, D.R. (2014) A quantitative life history of endangered humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival *Ecology and Evolution.*
Presentation	A quantitative life history of humpback chub that spawn in the Little Colorado River: variation in movement, growth and survival		Nov. 2013		Presented by Yackulic at Desert Fishes Council.
Presentation	Variation in vital rates in a partial migratory system in a modified river network: Humpback chub in the lower Colorado River		May 2013		Presented by Yackulic at Euring Analytical Conference (Mark-recapture conference)
Presentation	Disentangling residency and migration in a partial migratory system where detection is much less than one		August 2013		Presented by Yackulic at Ecological Society of America meeting.
Presentation	Assessing variation through space and time in the vital rates of humpback chub in the Little Colorado River		Nov. 2013		Presented by Dzul at Desert Fishes Council.

Project E Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$225,600	$5,700	$25,000	$35,000	$75,000	$30,086	**$396,386**
Actual Spent	$188,792	$9,298	$29,921	$0	$97,754	$25,831	**$351,596**
(Over)/Under Budget	**$36,808**	**($3,598)**	**($4,921)**	**$35,000**	**($22,754)**	**$4,255**	**$44,790**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel. Funds were suballocated to the USGS Cooperative Research Unit rather than the University as a Coop.

Project and Title			
Project F: Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and the Lower Little Colorado River			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	William Persons, USGS GCMRC; Charles Yackulic, USGS GCMRC; Dave Rogowski, AZGFD; Luke Avery, USGS GCMRC; Josh Korman, Ecometric; Matt Kaplinski, NAU; D.R VanHaverbeke, USFWS; Dana Winkelman, CSU; Brian Healy, GCNP; Steve Martell, Uni. British Columbia
Email	svanderkooi@usgs.gov		
Telephone	(928) 556-7376		

SUMMARY

Project F, “Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and the lower Little Colorado River” is comprised of 15 elements and encompasses monitoring of fish, anglers, aquatic invertebrates, benthic algae and primary productivity. Project F also includes stock assessment and estimating humpback chub abundance, detecting rainbow trout movement, and sampling fish stomach contents and invertebrate drift. During 2013 there were four collaborative fish monitoring river trips and four natal origins/juvenile humpback chub monitoring trips. There were four Little Colorado River monitoring trips and one translocation trip.

Sampling was conducted from Glen Canyon Dam to the inflow of Lake Mead, including the lower 16 km of the Little Colorado River (LCR). System wide electrofishing of the Colorado River between Glen Canyon Dam and Lake Mead was conducted by Arizona Game and Fish Department following standard methods in place since 2000. During 2013 mean rainbow trout catch per unit effort (CPUE) increased from that observed in 2012 in Marble Canyon, but declined in the 20-mile reach immediately upstream of the Little Colorado River (LCR). Rainbow trout catch rates remained relatively low in the reach immediately downstream of the LCR while brown trout catch rates increased slightly from 2012. Electrofishing catch rates of flannelmouth and bluehead sucker in 2013 remained high and were similar to catch rates in 2012. Of note, two razorback suckers were captured during sampling downstream of Diamond Creek. Ten adult striped bass were captured (nine near river mile 213) during 2013 and four adult gizzard shad were captured in western Grand Canyon.

Mean CPUE of rainbow trout in the Lees Ferry reach declined from those observed in 2011 and 2012, driven largely by a decrease in abundance of small (< 152 mm) rainbow trout. It appears that the abundant 2009 and 2011 rainbow trout cohorts are still present and are now 250 – 300 mm total length (TL). Lees Ferry anglers experienced high success rate and angler satisfaction. Average catch rates were very good (approximately 2 fish/hour for boat anglers) and most anglers continued to practice catch-and-release. Of note, several young-of-the-year (< 100 mm TL) brown trout were captured in the Lees Ferry reach during 2013. The number of rainbow trout redds created in winter 2012-2013 was notably higher than the 9-year mean, but the November 2013 estimate of juvenile fish was similar to previous years. Sampling for rare nonnative fish captured three large walleye and two smallmouth bass at the base of Glen Canyon Dam near the spillways.

U.S. Fish and Wildlife Service sampled the Little Colorado River using standardized methods and the estimated spring abundance of adult humpback chub ≥ 150 mm TL was 8,549 fish. The mean spring point estimate for sub-adult chub in the 150 – 199 mm size class was 1,583. Although delayed by the government shutdown, 303 humpback chub were translocated to above Chute Falls and another 341 juvenile humpback chub, to be used for 2014 Havasu and Shinumo translocations, were transferred to the Southwestern Native Aquatic Resources and Recovery Center.

Two PIT tag antenna arrays in the Little Colorado River were operational for most of 2013, although high flows in the spring and fall damaged some antennas. Equipment was replaced and repaired in April and November. Kristen Pearson, Colorado State University conducted detection probability experiments in May. Antennas detected more than 3,000 unique humpback chub during 2013, including two fish that were translocated to Shinumo Creek in 2009 and 2010.

Data for rainbow trout tagged and recovered as part of the rainbow trout movement and natal origins project indicated that there was minimal movement among individual fish (< 20 km), but there was also evidence for population level downstream dispersal among study reaches.

Sampling initiated in the Near Shore Ecology project and continued in the Juvenile Chub Monitoring project allows us to model humpback chub populations in ways that were not possible prior to 2009. In particular, we can now account for large

variation in biological processes (i.e., survival, growth, etc.) between the Colorado River and Little Colorado River, and better model heterogeneity in capture probability using a multistate framework (where states are defined in terms of size and location). In contrast, these factors cannot be easily accounted for in the Age Structured Mark Recapture (ASMR) model, and failure to account for them may explain known biases such as the "retrospective bias," as well as potentially bias population size estimates. For these reasons, we are currently using the multistate models developed in Project E.3 to estimate population size and vital rates.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Report	Status of the Lees Ferry rainbow trout fishery 2013 annual report. Draft report in preparation.	FY 14		FY14	Rogowski, David L., R.J. Osterhoudt, P.N. Wolters, M.C. Anderson and A.J. Bunch. 2014. Status of the Lees Ferry rainbow trout fishery 2013 annual report. Draft report in preparation.
Report	Mark-Recapture and Fish Monitoring Activities in the Little Colorado River in Grand Canyon from 2000 to 2013	FY14		FY14	Van Haverbeke, David R., K. Young, D. M. Stone and M. J. Pillow. 2014. Mark-Recapture and Fish Monitoring Activities in the Little Colorado River in Grand Canyon from 2000 to 2013. Draft report submitted to GCMRC for review.
Report	Colorado River fish monitoring in Grand Canyon, Arizona – 2013 annual report	FY14		FY14	Wolters, P.N., D.L. Rogowski, and R.J. Osterhoudt. 2014. Colorado River fish monitoring in Grand Canyon, Arizona – 2013 annual report. Draft report in preparation
Journal	Long term monitoring of an endangered desert fish and factors influencing population dynamics	FY13	FY13		Van Haverbeke, D.R., L.G. Coggins Jr., D.M. Stone and M.J. Pillow. 2013. Long term monitoring of an endangered desert fish and factors influencing population dynamics. Journal of Fish and Wildlife Management 4(1):163-177. http://www.fwspubs.org/doi/abs/10.3996/082012-JFWM-071

Project F Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$334,000	$8,700	$99,300	$1,062,000	$0	$81,934	**$1,585,934**
Actual Spent	$318,945	$10,767	$121,348	$811,195	$39,917	$75,436	**$1,377,608**
(Over)/Under Budget	**$15,055**	**($2,067)**	**($22,048)**	**$250,805**	**($39,917)**	**$6,498**	**$208,326**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel. Purchased additional electrofishing and PIT tag equipment. Cooperative Agreement to Ecometric was delayed, but has been awarded in FY14. Funds were suballocated to the USGS Cooperative Research Unit rather than the University as a Coop.

Project and Title			
Project G: Interactions Between Native Fish and Nonnative Trout			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	David Ward, USGS GCMRC; Mike Yard, USGS GCMRC; Scott VanderKooi, USGS GCMRC; Brian Healy, NPS; Clay Nelson, NPS; Emily Omana, NPS; Melissa Trammel, Intermountain Region; David Speas, BOR
Email	svanderkooi@usgs.gov		
Telephone	(928) 556-7376		

SUMMARY

In 2013 two separate laboratory experiments were conducted to evaluate interactions between humpback chub and nonnative trout. Each laboratory experiment was designed to isolate and quantify how environmental variables affect competition and predation relationships of humpback chub and trout. In 2013, laboratory experiments focused primarily the effects of water temperature and fish size on predation and competition. The first laboratory experiment evaluated the relative effect that water temperature has on predation vulnerability of juvenile humpback chub. Hatchery-reared chub (50 – 90 mm in length) were exposed to predation by wild rainbow trout and brown trout in replicated overnight trials at three different water temperatures (10, 15, and 20°C). For each 1° C increase in water temperature, there was a corresponding 5% decrease in predation vulnerability to rainbow trout. Brown trout predation was much higher than for rainbows at all temperatures and was not significantly influenced by water temperature. The second laboratory experiment evaluated the effects of competition between rainbow trout and chub. Chub were maintained in replicate experimental tanks either with or without rainbow trout at fixed feed rations and densities. Changes in weight were measured over a 30-day period for both chubs and trout. Juvenile humpback chub (114 mm mean TL) lost 4% of their body weight when held in systems with adult rainbow trout (247 mm mean TL) whereas juvenile chub in tanks without trout increased in body weight by 18 %. This experiment was repeated with size-matched adult chub and adult rainbow trout. Again chub lost weight in tanks with trout (4.2%) while chub alone gained weight (1.3%). (See project element G.1 for more specific abstracts of laboratory results).

In collaboration with the National Park Service, mechanical removal of brown trout occurred within Bright Angel Creek and in the 8.4 km section of the mainstem Colorado River surrounding Bright Angel Creek. This removal effort is a pilot study to evaluate the feasibility and efficacy of mechanical removal of brown trout as a means to improve conditions for native fishes in Grand Canyon. Over a 10-day period in November, 1,370 rainbow trout and 336 brown trout were removed from the mainstem Colorado River surrounding Bright Angel Creek. Data entry and analysis for this effort is currently not complete. (See project element G.2 for more specific information on brown trout removal efforts).

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Peer reviewed publication	Effects of temperature and turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout			Dec 2014	On schedule
Peer reviewed publication	An Experimental evaluation of competition between rainbow trout *Oncorhnchus mykiss* and humpback chub *Gila cypha*			Dec 2014	On Schedule
USGS Annual Report	Efficacy and feasibility of brown trout mechanical removal in the mainstem Colorado River near Bright Angel Creek	March2014			Data entry and analysis in progress

Project G Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$139,900	$3,800	$23,000	$0	$0	$18,885	**$185,585**
Actual Spent	$105,961	$1,414	$21,241	$0	$0	$14,571	**$143,187**
(Over)/Under Budget	**$33,939**	**$2,386**	**$1,759**	**$0**	**$0**	**$4,314**	**$42,398**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel and reduced travel.

Project and Title			
Project H: Understanding the Factors Limiting the Growth of Large Rainbow Trout in Glen and Marble Canyons			
Program Manager (PM)	Scott VanderKooi	**Principal Investigator(s)** (PI)	Theodore Kennedy, USGS GCMRC; Charles Yackulic, USGS GCMRC; Mike Yard, USGS GCMRC; Mike Anderson, AGFD; Luke Avery, USGS GCMRC; Robert Hall, Uni WY; Josh Korman, Ecometric; Scott Wright, USGS Cal. Water. Science Center; William Persons, USGS GCMRC
Email	svanderkooi@usgs.gov		
Telephone	(928) 556-7376		

SUMMARY

The main focus of activities in FY13 was acquiring new data needed to identify the factors that limit the growth of large rainbow trout. In FY13, laboratory growth experiments with different genetic strains of rainbow trout were initiated (Project H.1), several synoptic drift sampling experiments were conducted (Project H.2.2), rates of algae production among reaches were quantified (Project H.2.1), existing trout bioenergetics models were tailored to conditions in Glen Canyon (Project H.3) and a large database of physical and biological data from 56 different tailwaters was assembled (Project H.4).

Laboratory studies (Project H.1) to evaluate whether the genetic strain of rainbow trout in Glen Canyon limits their growth were initiated in FY13. The start of these experiments was delayed somewhat because state regulations designed to prevent the spread of whirling disease also prevented us from collecting juvenile rainbow trout from Lees Ferry to use in these experiments. Instead, trout eggs were collected from Lees Ferry and hatched and reared in the laboratory. Juvenile rainbow trout from two other genetic strains were obtained from hatcheries, and all fish are being held in common outdoor ponds in Flagstaff to evaluate growth differences among genetic strains.

New data collections and modeling were initiated to describe the links among dam operations, environmental conditions, and the foodbase (Project H.2). In FY13, daily rates of algae production were quantified using a database of continuous dissolved oxygen measurements from Glen Canyon and Diamond Creek that runs from 2008-present (Project H.2.1). In FY14, these daily estimates of algae production will be used to develop mechanistic models of algae production for both reaches. Mechanistic models of algae production will allow us to identify cause and effect relationships between environmental conditions (i.e., suspended sediment turbidity and flow management) and algae production.

Two comprehensive invertebrate drift sampling experiments were done in Glen Canyon in FY13 (Project H.2.2). In October 2012, invertebrate drift concentrations were quantified at 25 locations throughout the 25 kilometer long Glen Canyon tailwater. Sampling was conducted on four consecutive days while discharge was a constant 8,000 ft3/s. Sampling direction varied among days (i.e., upstream to downstream, downstream to upstream) so spatial and temporal variation in drift concentrations could be separated. Drift sampling was repeated again in late May 2013 on two consecutive days while discharge was also constant 8,000 ft3/s associated with the quadrennial overflight. During the May data collection, water velocity profiles used to estimate shear stress were also collected at each station, and benthic invertebrate density was quantified at each sampling location. All samples have been processed and preliminary findings will be reported at the January 2014 meeting. These analyses will allow us to identify hotspots of invertebrate drift in Glen Canyon and whether these hotspots are associated with areas of high benthic invertebrate density, high bed shear stress, or both.

Invertebrate drift and benthic sampling was also conducted at 3 locations (Glen Canyon, Little Colorado River confluence area, and Diamond Creek) during the November 2012 High Flow Experiment to evaluate how large dam releases affect invertebrate drift (Project H.2.2). Drift sampling was done 5 times each day before, during, and after the HFE (35 different sampling bouts at each of three locations). Drift concentrations were characterized at 5 equally spaced locations across the channel at each sampling reach, yielding over 400 total drift samples among all locations. Laboratory processing of all Glen Canyon HFE samples was completed in November 2013. These data will be used to characterize how invertebrate drift concentrations among reaches vary across a large range of discharges.

Invertebrate drift samples and rainbow trout diet samples were also collected in conjunction with 4 natal origins river trips

in FY2013, yielding 1000 total samples (500 drift and 500 diet). These data will allow us to characterize how drift concentrations and trout feeding habits vary in response to suspended sediment turbidity, trout density, and other environmental variables (Project H.2.2). Processing of these samples is ongoing.

In FY13, existing trout foraging and bioenergetics models were modified based on the specific flow conditions, prey availability, and rainbow trout growth that have been observed in Glen Canyon. In FY14, these models will be used to estimate rainbow trout growth potential under different scenarios that include different patterns of flow, prey availability, and trout density.

Throughout spring and summer 2013 we contacted state, federal, non-governmental, and tribal organizations in charge of collecting fishery monitoring data in tailwater systems across the West. We acquired biological, environmental, and physical data from 56 tailwaters in 34 rivers in Arizona, Colorado, Utah, New Mexico, Idaho, Montana, Nevada, California, Oregon, and Wyoming. Fishery biologists provided data including fish length, weight, condition factor, and population size (CPUE or population estimates) for salmonids (e.g., rainbow, brown, cutthroat, brook trout, etc.) and other native and introduced fish species (e.g., flannelmouth suckers, mountain whitefish, carp, catfish, speckled dace, etc.). In total, we have data for 1.1 million fish captured from the early 1950s to 2013. The longest continuously collected fishery dataset spanned 35 years, while the shortest just 1 year.

In addition to fishery data, we collected information on the invertebrate food base from several data sources, including state fishery biologists, invertebrate biologists, and state and federal databases. Food base data ranged from 1-18 years in duration and was collected in 31 of the 56 tailwaters (although the year in which fish and invertebrate data was collected does not always match up). We acquired discharge and reservoir data from most tailwaters using state and federal databases—we have sub-daily discharge data from 49/56 tailwaters, which will be useful in determining the effects of hydropeaking on adult salmonid growth. We also have water quality, temperature, and angler pressure/harvest data from a subset of these systems. We have compiled all of the data and are in the process of analyzing and modeling the data to identify the factors that best explain the variation in trout size observed among tailwaters.

The 56 tailwaters that are represented in this database are:

1. Colorado River, Glen Canyon Dam (AZ)
2. Gunnison River, Aspinall Unit (CO)
3. Arkansas River, Pueblo Dam (CO)
4. Blue River, Dillon Dam (CO)
5. Blue River, Green Mountain Dam (CO)
6. Fryingpan River, Ruedi Dam (CO)
7. Taylor River, Taylor Park Dam (CO)
8. South Platte River, Spinney Mountain (CO)
9. South Platte River, Cheesman Dam (CO)
10. South Platte River, Elevenmile Dam (CO)
11. South Platte River, Strontia Springs (CO)
12. Big Thompson River, Olympus Dam (CO)
13. Delores River, McPhee Dam (CO)
14. Yampa River, Stagecoach Dam (CO)
15. Cimarron River, Silver Jack Dam (CO)
16. Colorado River, Windy Gap Dam (CO)
17. North Fork of Colorado, Shadow Mountain Dam (CO)
18. North Fork of Colorado, Granby Dam (CO)
19. Williams Fork of Colorado, Williams Fork Dam (CO)
20. Florida River, Lemon Dam (CO)
21. Muddy Creek, Ritschard Dam (CO)
22. Pine River (Los Pinos), Vallecito Dam (CO)
23. Uncompahgre River, Ridgway Dam (CO)
24. Williams Creek, Williams Creek Dam (CO)
25. Kings River, Pine Flat Dam (CA)
26. Henry's Fork of Snake, Island Park Dam (ID)
27. South Fork of Snake, Palisades Dam (ID)
28. Big Lost River, MacKay Dam (ID)
29. South Fork of Boise, Anderson Ranch (ID)
30. Madison River, Hebgen Dam (MT)
31. Madison River, Ennis Dam (MT)
32. Bighorn River, Yellowtail Dam (MT)
33. Beaverhead River, Clark Canyon Dam (MT)

34. Ruby River, Ruby Dam (MT)
35. Kootenai River, Libby Dam (MT)
36. Missouri River, Holter Dam (MT)
37. Missouri River, Hauser Dam (MT)
38. Milk River, Fresno Dam (MT)
39. Beaver Creek, Bear Paw Dam (MT)
40. Beaver Creek, Beaver Creek Dam (MT)
41. Tongue River, Tongue Dam (MT)
42. Flathead River, Kerr Dam (MT)
43. San Juan River, Navajo Dam (NM)
44. Colorado River, Davis Dam (NV)
45. Owyhee River, Owyhee Dam (OR)
46. Crooked River, Bowman Dam (OR)
47. Green River, Flaming Gorge Dam (UT)
48. Strawberry River, Soldier Creek Dam (UT)
49. Strawberry River, Starvation Dam (UT)
50. Lower Provo River, Deer Creek Dam (UT)
51. Middle Provo River, Jordanelle Dam (UT)
52. Buffalo Bill, Shoshone River (WY)
53. North Platte River, Grey Reef Dam (WY)
54. North Platte River, Kortes Dam (WY)
55. Wind River, Boysen Dam (WY)
56. Green River, Fontenelle Dam (WY)

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Peer-reviewed Journal Article	The relation between invertebrate drift and two primary controls, discharge and benthic densities, in a large regulated river.		December 2013		Kennedy, T.A., C.B. Yackulic, W.F. Cross, P.E. Grams, M.D. Yard, and A.J. Copp, 2014. The relation between invertebrate drift and two primary controls, discharge and benthic densities, in a large regulated river. *Freshwater Biology* doi:10.1111/fwb.12285
Peer-reviewed Journal Article	Food-web dynamics in a large river discontinuum.		July 2013		Cross, W.F., C.V. Baxter, E.J. Rosi-Marshall, R.O. Hall Jr., T.A. Kennedy, K.C. Donner, H.A. Wellard-Kelly, S.E.Z. Seegert, K.E. Behn, and M.D. Yard, 2013. Food-web dynamics in a large river discontinuum. *Ecological Monographs* **83**: 311-337.
Peer-reviewed Journal Article	Macroinvertebrate diets reflect longitudinal and turbidity-driven changes in food availability in the Colorado River downstream of Glen Canyon Dam.		April 2013		H.A. Wellard Kelly, E.J. Rosi-Marshall, T.A. Kennedy, R.O. Hall Jr., W.F. Cross, and C.V. Baxter, 2013. Macroinvertebrate diets reflect longitudinal and turbidity-driven changes in food availability in the Colorado River downstream of Glen Canyon Dam. *Freshwater Science* **32**: 397-411.
Fact Sheet	Native and nonnative fish populations of the Colorado River are food limited—evidence from new food web analyses		July 2013		**Kennedy, T.A.**, Cross, W.F., Hall, R.O., Jr., Baxter, C.V., and Rosi-Marshall, E.J., 2013, Native and nonnative fish populations of the Colorado River are food limited—evidence from new food web analyses: U.S. Geological Survey Fact Sheet 2013–3039, 4 p., http://pubs.usgs.gov/fs/2013/3039/.
Scientific Investigations Report	Identification of key scientific uncertainties related to fish and aquatic resources in the Colorado River, Grand Canyon: summary and interpretation of an expert elicitation questionnaire.		April 2013		Kennedy, T.A, 2013. Identification of key scientific uncertainties related to fish and aquatic resources in the Colorado River, Grand Canyon: summary and interpretation of an expert elicitation questionnaire. USGS Scientific Investigations Report 2013-5027. 42pp. [http://pubs.usgs.gov/sir/2013/5027/]

Project H Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$321,100	$24,700	$54,000	$20,000	$0	$45,893	**$465,693**
Actual Spent	$283,885	$9,519	$45,703	$0	$21,600	$38,417	**$399,124**
(Over)/Under Budget	**$37,215**	**$15,181**	**$8,297**	**$20,000**	**($21,600)**	**$7,476**	**$66,569**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel and reduced travel. Funds were suballocated to the USGS CA Water Science Center rather than as a Coop.

Project and Title			
Project I: Riparian Vegetation Studies: Response Guilds as a Monitoring Approach, and Describing the Effects of Tamarisk Defoliation on the Riparian Community Downstream of Glen Canyon Dam			
Program Manager (PM)	Barbara Ralston	**Principal Investigator(s)** (PI)	Barbara Ralston, USGS GCMRC; Phil Davis, USGS GCMRC; Joel Sankey, USGS GCMRC; Todd Chaudhury, NPS; Lori Makarick, NPS; David Merritt, USFWS; Dustin Perkins, NPS
Email	bralston@usgs.gov		
Telephone	(928) 556-7389		

SUMMARY

Each of the three elements of Project I advanced substantially in FY 13 and each is on track to meet FY14 goals. The three elements of Project I are: 1.1) Monitoring vegetation and channel response using vegetation response guilds and landscape scale vegetation analysis 1.2) State and transition model develop using response guilds and 1.3) Periodic landscape scale vegetation mapping and change analysis using remotely sensed data. In FY13, two 17-day river trips were completed in association with element 1.1. The field work consisted of sampling 1 m^2 plots within three zones of inundation: the active channel (<25k ft^3/s stage elevation), the active floodplain (<45k ft^3/s stage elevation), and the inactive floodplain (≥45k ft^3/s stage elevation). Sampling occurred at randomized and fixed sites along the river, including sites downstream of Diamond Creek. A total of 52 sites (>1,800 plots) were sampled on the first trip that occur in late August, and 44 sites (>1,500 plots) were sampled in a late September trip. Data entry for the second trip is complete, while data from the first trip are still being entered. A species list from these trips can be provided to stakeholders. Collaborations in this project include riparian scientists from the Forest Service, the U.S. Geological Survey in Fort Collins, the National Park Services' Inventory and Monitoring Network and Grand Canyon National Park. Subsequent analysis will include evaluating changes in dominant species within each inundation zone and among geomorphic features, changes in cover and changes in species richness and abundance, and relating these changes to response guilds. A response-guild manuscript is still in development. The hiring of a post-doc and technician for this project in FY14 ensures that planned integrated physical and biological analysis will proceed. The frame-based modeling approach for riparian vegetation response to operations, element 1.2 of project I, moved forward in FY13 with a workshop in October 2013 attended by ecologists from Grand Canyon National Park, the Hopi Tribe, and Argonne Labs. Submodel expansion occurred following input from the participants. Submodels now consist of upper and lower bars models for reattachment bars, separation bars, and channel margins. A draft Open-File report that explains model parameters is in review with publication expected in FY14. Advances made in the final element of project I, 1.3 include system-wide analysis of gross vegetation change from 1965 to 2009. Analysis, lead by Joel Sankey (USGS/GCMRC), at this scale indicates system-wide increases in vegetated area across all geomorphic features (e.g., sandbars, channel margins, and debris fans). Vegetation expansion is dependent on mean flood discharge. As the mean flood discharge has decreased, woody riparian vegetation has advanced shoreward to meet this boundary. Products associated with this work include a draft manuscript for a peer-reviewed journal, and presentations at the AMWG meeting, the 13th Biennial Conference of Science and Management on the Colorado Plateau, and the American Geophysical Union Fall Meeting. The 2013 imagery is being processed and will be used to update this data series. Segments of the imagery are being used for a master's project to assess tamarisk (*Tamarix* spp.) mortality associated with the tamarisk leaf-beetle that entered the Colorado River system downstream of Glen Canyon Dam in 2009. In general, each element is on track and deliverables anticipated for FY14 are achievable at this time.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
USGS - OFR	State and transition prototype model of marsh and riparian vegetation for alternative flow testing of the Colorado River downstream of Glen Canyon Dam	10/2013	In peer-review	March 2014	On schedule -- anticipate a journal article out of this as well.
Peer-review journal	Colorado River, vegetation, and climate: five decades of spatio-temporal dynamics in the Grand Canyon in response to river regulation	10/2014		Submitted to journal in Jan/Feb 2014	Ahead of schedule

Project I Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$133,300	$3,800	$4,000	$28,000	$0	$16,825	**$185,925**
Actual Spent	$0	$335	$1,143	$53,422	$0	$1,770	**$56,670**
(Over)/Under Budget	**$133,300**	**$3,465**	**$2,857**	**($25,422)**	**$0**	**$15,055**	**$129,255**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel and reduced travel. Funded PhD Student to conduct remote sensing analysis through a Coop. with the Park Service.

Project and Title			
Project J: Monitoring of Cultural Resources at a Small Scale and Defining the Large-Scale Geomorphic Context of those Processes			
Program Manager (PM)	Helen Fairley	**Principal Investigator(s)** (PI)	Helen Fairley, USGS GCMCRC; Amy Draut, USGS PCMSC; Brian Collins, USGS; Sky Corbett, USGS; David Bedford, USGS; Phil Davis, USGS GCMRC; Joel Sankey, USGS GCMRC
Email	hfairley@usgs.gov		
Telephone	(928) 556-7285		

SUMMARY

Project J is a new research initiative that is designed to evaluate the issue of small-scale archaeological site stability and erosion in a larger landscape-scale geomorphic context. The project includes three components designated J1, J2, and J3. Components J1 and J2 focus on measuring local conditions and topographic changes at specific archaeological sites in two contrasting settings: the Glen Canyon reach (J1), which lacks significant sediment inputs, and 4 specific sites in Grand Canyon that are situated in settings with relatively high potential to benefit from sand bar rebuilding and aeolian sand redistribution from past and future high flows (J2). J3, the third component, evaluates the role of aeolian sand in affecting gully erosion through landscape-scale mapping and measurements using remotely-sensed data supplemented with site-specific fieldwork. The two main working hypotheses of Project J are that gullies will be smaller and less developed in areas where aeolian movement of sand is active and relatively high and that the amount and type of erosion will differ between the Glen Canyon and Grand Canyon sites due to differences in sediment replenishment at each set of sites.

JI and J2 both involve collecting repeat lidar scans at eight specific archaeological sites (4 in Glen Canyon and 4 in Grand Canyon) and comparing the measured results against modeled results to determine whether these sites are eroding more rapidly or differently than would be expected given local substrate conditions, slope, catchment size, and historical precipitation patterns. All of the sites that are the focus of research in Project J1 and J2 were previously surveyed with terrestrial lidar as part of the 2006-2012 Cultural Monitoring R&D project, and the previous surveys provide the baseline measurements for the current work in Project J. In addition, this project is exploring the costs and benefits of employing airborne lidar for documenting topographic change on a landscape scale. At the same time, we are using airborne lidar to create a landscape context for evaluating the changes documented at an individual site level in the Glen Canyon reach.

In FY2013, we completed all fieldwork originally planned for FY2013. This included collecting field measurements in Glen Canyon during February 27-28, 2013, completing a 18-day river trip through Grand Canyon (April 27-May 14, 2013), and successfully completing an airborne lidar mission in Glen Canyon between miles -6 and -14.5 on July 9-10, 2013. Prior to initiating any field work, on February 25, 2013, Collins, Corbett and Fairley met with Glen Canyon staff in Page, AZ to review preliminary results of the September 2012 work in Glen Canyon (we collected terrestrial lidar survey data at four sites in Glen Canyon -- AZ C:2: 32, 35, 75 and 77 – in September 2012) and to go over the work plan for FY2013. The next day (February 26), Collins, Corbett, Draut, Bedford, Sankey and Fairley met with Grand Canyon staff to review the plan for FY2013 work in Grand Canyon.

The February 2013 fieldwork focused on the following three tasks: 1) verifying remotely sensed data developed by J. Sankey for establishing gully locations and sizes (areas) based on DEMs and aerial imagery collected during the 2009 system-wide overflight, 2) mapping active vs. inactive aeolian areas, and 3) gathering soil infiltration and shear strength data from multiple locations. The April-May 2013 Grand Canyon river trip focused on the same three activities described above, and in addition, we collected lidar scans at 4 sites in Grand Canyon (AZ C:5:31, AZ C:13:321. AZ B:10:225, and AZ G:3:72), activated 4 weather stations near these same sites, and visited another 76 sites to categorize them in terms of their potential to benefit (i.e., to acquire new sand) from past and future floods and redistribution of flood sediment by wind. In mid-June, Fairley and T. Andrews installed a new weather station near Lees Ferry, and in late June, Sankey and other GCMRC staff members visited Glen Canyon again to lay down panels ("targets") and survey their positions for the planned airborne lidar mission in early July. Following the successful completion of the airborne mission, the survey data were thoroughly reviewed by Collins, Corbett and Sankey and found to meet all contract specifications.

Between field sessions, Project J staff processed lidar data, analyzed other types of field data, and wrote journal articles and reports. In addition, Bedford initiated two different types of modeling activities in FY2013. One employed a high-resolution rainfall-runoff model to determine which kind of observed rainfall events were most likely to have caused erosion at sites where change has been detected in the past. The second modeling activity used a landscape evolution model (LEM) to better understand the larger dynamics driving gully formation. Some of the initial modeling results were incorporated

into a journal article by Collins and others (see descriptions of publications below) and other parts of this modeling work will be incorporated into future publications planned for FY2014 and 2015.

Two publications related to various aspects of Project J were submitted to journals in 2013. Collins, Corbett, Bedford, and Fairley completed and submitted an article to the *Journal of Geophysical Research* that had been under development for more than a year (Collins and others, in review). This article summarizes and synthesizes the key results of the previous Cultural Monitoring Research and Development study, the results of which form a foundation for the current work in Project J. This article concludes that individual storm events exceeding a specific intensity threshold cause most of the recent erosion measured at sites in Grand Canyon, that these events are common in Grand Canyon, and that the current amount of aeolian-redistributed sand appears insufficient to counter the erosional effects of storm run-off at the 13 sites monitored with repeat lidar surveys to date. Collins and others are now in the process of completing a new USGS Scientific Investigations Report that focuses on geomorphological analyses of the four sites monitored in Glen Canyon. This report will also compare and evaluate the resolution of topographic data collected by three different methods (terrestrial lidar, airborne lidar, and photogrammetric digital surface models) at the four Glen Canyon sites. Meanwhile, Sankey and Draut completed an article and submitted it to the journal *Geomorphology* (Sankey and Draut, in review.) This article summarizes the analysis of remotely-sensed gully locations and sizes in relation to active and inactive aeolian areas in both Glen and Grand Canyon. The data demonstrate that gullies are more prevalent in inactive aeolian sand areas than in active aeolian sand, supporting the hypothesis that active aeolian conditions help to anneal incipient gullies and prevent them from becoming progressively larger over time.

More details about each element of Project J can be found in the appendices at the end of this report.

Collins, B. D., Bedford, D.R., Corbett, S.C., Cronkite-Ratcliff, C. and Fairley, H.C., Meteorologic and anthropogenic effects on archeological site change in Grand Canyon, Arizona: fluvial-aeolian interactions within a dam-controlled river corridor. *Journal of Geophysical Research*, in review

Coulthard, T.J., Hancock, G.R., and Lowry, J.B.C., 2012, Modelling soil erosion with a downscaled landscape evolution model: Earth Surface Processes and Landforms, v. 37, no. 10, p. 1046-1055.

Sankey, J.B., and Draut, A.E., Gully annealing by aeolian sediment: field and remote-sensing investigation of aeolian-hillslope-fluvial interactions, Colorado River corridor, Arizona, USA: *Geomorphology*, in review.

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expected**	**Citations/Comments**
Journal	Meteorologic and anthropogenic effects on archeological site change in Grand Canyon, Arizona: fluvial-aeolian interactions within a dam-controlled river corridor				Collins, B.D., Bedford, D., Corbett, S.C.,Cronkite-Ratcliff, C, and Fairley, H.C., *in review*, Meteorologic and anthropogenic effects on archeological site change in Grand Canyon, Arizona: fluvial-aeolian interactions within a dam-controlled river corridor.
SIR	High resolution topography and geomorphology of select archeological sites in Glen Canyon National Recreation Area, Arizona				Collins, B.D., Corbett, S.C., Sankey, J.B., and Fairley, H.C., in preparation, High resolution topography and geomorphology of select archeological sites in Glen Canyon National Recreation Area, Arizona: U.S. Geological Survey

	PRODUCTS/REPORTS				
Type	**Title**	**Due Date**	**Date Delivered**	**Date Expect ed**	**Citations/Comments**
					Scientific Investigations Report, 80p.
Journal	Gully annealing by aeolian sediment: Field and remote-sensing investigation of aeolian-hillslope fluvial interactions, Colorado River corridor, Arizona, USA				Sankey, JB, Draut, AE, *in review.* Gully annealing by aeolian sediment: Field and remote-sensing investigation of aeolian-hillslope fluvial interactions, Colorado River corridor, Arizona, USA

Project J Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$78,400	$23,100	$63,000	$8,000	$261,900	$18,876	**$453,276**
Actual Spent	$4,896	$6,896	$10,885	$15,445	$378,999	$3,032	**$420,153**
(Over)/Under Budget	**$73,504**	**$16,204**	**$52,115**	**($7,445)**	**($117,099)**	**$15,844**	**$33,123**

COMMENTS *(Discuss anomalies in the budget; expected changes; anticipated carryover; etc.)*
Sequestration caused delays hiring personnel and reduced travel. LIDAR overflight in Glen Canyon funds were sent to the Rolla, MO USGS cost center rather than contracted out.

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

Project and Title			
Project K: GCMRC Economist And Support			
Program Manager (PM)	John C. Schmidt	**Principal Investigator(s)** (PI)	Lucas Bair, USGS GCMRC
Email	jcschmidt@usgs.gov		
Telephone	(928) 556-7364		

SUMMARY

The Grand Canyon Monitoring and Research Center hired Lucas Bair in FY 2013. The funding that was received in FY 13/14 supported the newly acquired salary, as well as travel and training for Lucas. Based on guidance from the AMWG, TWG, GCDAMP, work activities will be given throughout the years.

Project K Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$150,000	$23,700	$25,000	$0	$0	$22,511	**$221,211**
Actual Spent	$18,160	$1,083	$1,799	$0	$0	$2,384	**$23,426**
(Over)/Under Budget	**$131,840**	**$22,617**	**$23,201**	**$0**	**$0**	**$20,127**	**$197,785**

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

Sequestration caused delays hiring personnel and reduced travel.

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

Project and Title			
Project M: USGS Administration			
Program Manager (PM)	John C. Schmidt	**Principal Investigator(s)** (PI)	Jack Schmidt, USGS GCMRC Scott VanderKooi, USGS GCMRC
Email	jcschmidt@usgs.gov		
Telephone	(928) 556-7364		

SUMMARY

During the Fiscal Year 2013, this budget covered the salaries for the communications coordinator, librarian, and budget analyst, as well as monetary awards for GCMRC personnel. The vehicle section covers the GSA vehicles that all of GCMRC use for travel and field work. The money was used for the monthly lease fee, mileage cost, and any costs for accidents and damages. This project also helps pay leadership personnel, some travel and training for the Chief, Deputy Chief, and two program managers. This section also covers the costs of IT equipment for GCMRC. Logistics base cost covers salaries and travel/training.

Project M Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$687,800	$51,900	$265,800	$71,500	$0	$116,058	**$1,193,058**
Actual Spent	$738,547	$14,063	$240,313	$65,529	$291,912	$114,454	**$1,464,818**
(Over)/Under Budget	**($50,747)**	**$37,837**	**$25,487**	**$5,971**	**($291,912)**	**$1,604**	**($271,760)**

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

Obligated the majority of the GCMRC Chief's FY14 salary to Utah State University.
Sequestration reduced travel.
Used FY12 carryover to fund AZ and WI Water Science Center's (CIDA) development of the realtime sediment budget web tool.

Logistics Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$244,000	$14,300	$1,002,000	$0	$0	$142,779	**$1,403,079**
Actual Spent	$232,776	$1,483	$1,113,248	$16,000	$0	$153,139	**$1,516,646**
(Over)/Under Budget	**$11,224**	**$12,817**	**($111,248)**	**($16,000)**	**$0**	**($10,360)**	**($113,567)**

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

Sequestration limited overtime and travel.
Conducted additional river trips and higher helicopter rates due to BOR helicopter major maintenance.
Cooperative agreement to BOR to cover pilot's travel and miscellaneous expenses.
Contributed extra funds to working capital fund for future purchase(s) of boats and/or vehicles.

Logistics Operating Expenses	
Satellite Communications	$13,000
Helicopter	$90,000
Log Spt Contracts (HS Spt, Mango, River Cans Cleaned	$543,000
Other Services	$12,000
Maintenance	$39,000
Misc. Supplies	$16,000
Food	$116,000
Vehicle Parts/Supplies	$50,000
Fuel	$38,000
Boats/Motors	$34,000
Other Equipment	$82,000
WCF Deposit	$80,000
Total	**$1,113,000**

FY 2013 Project Report for the Glen Canyon Dam Adaptive Management Program

Project and Title			
Project N: Incremental Allocations in Support of Quadrennial Overflights			
Program Manager (PM)	John C. Schmidt	**Principal Investigator(s)** (PI)	Phil Davis, USGS GCMRC Joel Sankey, USGS GCMRC
Email	jcschmidt@usgs.gov		
Telephone	(928) 556-7364		

SUMMARY

GCMRC successfully conducted the quadrennial overflight of 296 miles of the Colorado River between Glen Canyon Dam and Lake Mead over the course of one week that began May 25, 2013. Digital multispectral imagery and topographic data were collected at high resolution (20 cm pixels) from fixed-wing aircraft while river discharge was steady at 8,000 cubic feet per second. The digital data were delivered to GCMRC in December, 2013. The data will be used to further GCMRC's research and monitoring efforts to examine changes to important resources that include sandbars, riparian vegetation, cultural sites, and the effects of dam operations for these resources.

GIS Budget	Salaries	Travel & Training	Operating Expenses	Cooperative Agreements	To other USGS Centers	Burden 11.329%	Total
Budgeted Amount	$605,786	$10,015	$542,014	$0	$92,184	$131,169	**$1,381,168**
Actual Spent	$509,500	$2,993	$487,286	$149,991	$0	$117,765	**$1,267,535**
(Over)/Under Budget	**$96,286**	**$7,022**	**$54,728**	**($149,991)**	**$92,184**	**$13,404**	**$113,633**

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

Received additional funds from DOD for Phil Davis' salary.
Sequestration reduced travel.
Overflight was cheaper than anticipated.
Sent funds to NAU for Photogrammetry and Tech Support for Joint Research as a Cooperative Agreement rather than to other USGS Centers.

Appendix

The following appendix focuses on each project element for all the main projects. This allows a more detailed report of each project element in regards to how many trips were taken, data collected, methods, and outcomes.

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

Paul Grams, Research Hydrologist, USGS, Grand Canyon Monitoring and Research Center
Phil Davis, Research Geologist, USGS, Grand Canyon Monitoring and Research Center
Barbara Ralston, Biologist, USGS, Grand Canyon Monitoring and Research Center
David Rubin, Research Geologist, USGS, Coastal and Marine Geology
Joseph E. Hazel, Jr. and Matt Kaplinski, Research Associates, Northern Arizona University School of Earth Science and Environmental Sustainability
Keith Kohl, Surveyor, USGS, Grand Canyon Monitoring and Research Center
Daniel Buscombe, Research Geologist, USGS, Grand Canyon Monitoring and Research Center
Daniel Hadley, Northern Arizona University, School of Earth Science and Environmental Sustainability

Project Element A.1.1. Monitoring sandbars using topographic surveys and remote cameras

Joseph Hazel and Matt Kaplinski, Research Associates, Northern Arizona University
Bob Tusso, Hydrologist, USGS/GCMRC

In October 2012 and September/October 2013, we collected repeat surveys of the topography and campsite area at the long-term sandbar monitoring sites located in Marble and Grand Canyons. We collected supplemental surveys at 6 sites immediately following the 2012 High Flow Experiment (HFE). All 2012 data have been processed into final topographic surfaces. The September/October, 2013 surveys have been processed for survey quality, errors, and blunders. Thirty-four of the 45 sites are fully processed into topographic surfaces.

Preliminary findings from the data collected in 2012 (including the surveys made following the 2012 HFE) were presented at the January 2012 reporting meeting. Between 2011 and 2012, the sandbars located in Marble Canyon had continued to erode following the 2008 HFE. Most sites were smaller than when first measured in 1990. In contrast, most sandbars located in Grand Canyon were larger in 2012 than in 1990. Some of these changes were attributed to erosion or deposition during the summer 2011 equalization flows. Preliminary results from the data collected in September 2013 suggest considerable bar building as a result of the 2012 HFE. Despite bar erosion during the intervening 10 months between the November 2012 HFE and the September 2013 survey, 26 out of 34 sandbars (~76%) were greater in size compared to the 2012 measurements. These results will be presented at the January 2014 reporting meeting.

We are in the process of completing a comprehensive report on the long-term sandbar monitoring data (Hazel and others, in prep) that is expected to be in review by January 31, 2014.

Sandbars are also monitored by remote cameras. In 2013, GCMRC installed 6 additional cameras and now maintains a network of 46 remote cameras along the Colorado River in Grand Canyon. These provide high-resolution images of sandbars and other important features five times daily at each site. A photographic record at some of the sites exists as far back as the early 1990s. Using the photos, qualitative analyses of sandbar size can be made more quickly, frequently, and inexpensively than ground-based field surveys. The imagery is particularly valuable for rapid analysis of geomorphic events such as controlled high flows or tributary flash floods. Before and after images from the 2012 HFE (http://www.gcmrc.gov/gis/sandbartour2012/index.html) and the 2013 HFE (http://www.gcmrc.gov/gis/sandbartour2013/index.html) were posted to the web for public viewing within weeks of the water receding. The images following the 2012 HFE were supplemented with images showing post-HFE sandbar erosion. Analysis of the images following the 2012 HFE indicated sandbar building comparable with previous HFEs, as reported at the January 2013 reporting meeting. Analysis of the images collected following the 2013 HFE is in progress and will be presented at the January 2014 reporting meeting.

We are currently exploring techniques for rectifying the images and extracting sandbar area and volume calculations. Development and implementation of methods to quantify sandbar changes from the remote cameras is a possible project for the FY 2015-16 work plan.

Project Element A.1.2. Monitoring sandbars by remote sensing

Phil Davis, Research Geologist, USGS/GCMRC
Rob Ross, Hydrologist, USGS/GCMRC
Paul Grams, Research Hydrologist, USGS/GCMRC

The 2013 Image Overflight

The 2013 overflight involved the collection of digital, four-band images and three stereo panchromatic images with 20-cm resolution for the entire river corridor between Glen Canyon Dam and Lake Mead in May, 2013. The four-band imagery allows mapping of relevant physical and biologic resources; the stereo images are used to produce a digital surface model (elevations) of the corridor. The data collection required 6 days to complete, starting on May 25. The weather was clear throughout the collection, but wind turbulence (that can produce image smearing) required recollection of certain flight lines on subsequent days.

The four-band imagery and the digital surface model images were delivered by the contractor in November; the four-band imagery are now being processed at GCMRC to prepare for image mosaicking into USGS map tile format. This initial image processing has progressed half way through the river corridor and will be completed by the end of January 2014. Observations thus far find the image data to have the same high quality as the data collected in 2009.

Analysis of 2002 and 2009 Four-Band Image Data

Water in the mainstem and tributaries and all vegetation in non-shadow areas were mapped in the 2002 and 2009 images by the end of 2012. In 2013, we completed the vegetation mapping within shadowed areas of the corridor in order to provide the botanists a complete picture of changes between 2002 and 2009. The 2005 images are of poorer quality and are more difficult to map accurately. Therefore, we only completed vegetation mapping using this data at selected sites where vegetation was mapped previously from pre-dam photographs and a time series with greater temporal resolution was most valuable.

We also began the process of mapping exposed sand within the corridor, concentrating on 1368 sites that include most large sandbar deposition zones and camp sites throughout the river corridor. We are currently mapping bedrock, boulders, cobbles, and sand surfaces, as well as less-defined smooth and rough surfaces that are not included in these four specific categories. The image analysis proceeded in two phases, and each phase consists of seven steps. We are currently at the final step in phase 2, which involves manual editing of the autonomous classification results produced by the previous steps. The autonomous classification results in more numerous errors in sand detection than were expected, requiring more manual editing that was planned. By mid-January we will have completed manual editing for the first 100 river miles for both 2002 and 2009 image data. We will present preliminary results from this effort at the January 2014 reporting meeting. We expect to complete manual editing of the second 100 miles by the end of February, and the final 66 river miles by the end of March 2014. We will not perform this analysis on the 2005 images, because the autonomous classification performs even more poorly on those data. Mapping the exposed sand on the 2002 and 2009 images required more effort than anticipated. Because of this, we were unable to map sand area from the 1988 air photos, as originally planned in the 2013 work plan.

Analysis of Sandbar Area in Select Reaches, 1935-2009

While working on the identification of sandbars throughout the river corridor, described above, we have also been working on and are nearly completed with a different analysis of sandbar area from the same 2002 and 2009 photos for selected reaches between Lees Ferry (river mile 0) and Big Bend (river mile 68). Maps of sand deposits created by Utah State University have been reanalyzed for dates common to the selection of reaches (1935, 1965, 1973, 1984, 1990, March and April 1996), and the maps from April 1996 have been updated to coincide with shorelines derived from the 2002, 2005, and 2009 image sets.

Areas of exposed sand for each year within common eddy deposition zones have been calculated. Preliminary analysis of these data indicate that the number and size of sandbars exposed above the 8,000 cfs stage elevation in these reaches was similar in the 2002-2009 period compared to the 1990-1996 period. Comparisons between these data and the topographic surveys conducted since 1990 as part of the Northern Arizona University sandbar monitoring program are underway to determine the relation between changes in area of exposed sand and changes in sandbar volume.

This project element will produce at least 2 reports in the next year. The first report, on the select reaches previously studied by USU, is anticipated to be in review in early 2014. Depending on the progress made in developing the canyon-wide classification system, the second report should be ready for review by late spring 2014.

Project Element A.1.3. Geomorphic attributes of camping beaches

Dan Hadley, Northern Arizona University
Paul Grams, Research Hydrologist, USGS/GCMRC

Vegetation change between 2002 and 2009 has been calculated within the boundaries of campsites as depicted in the GCMRC/NPS campsite atlas. This consists of 504 campsites within Glen Canyon, Marble Canyon, and Grand Canyon, and includes the 37 campsites monitored by project A.1.1. The analysis includes vegetation change at campsites within reaches, including the Glen Canyon reach, the non-critical reaches and critical reaches within Marble and Grand Canyons, and the reach past Diamond Creek. Every reach has shown vegetation expansion within campsite boundaries. Between 2002 and 2009, 11% of the total area within the 504 campsite boundaries became vegetated. Vegetation change will also be calculated within the total extent of campable areas mapped at each of the 37 NAU monitored sites. This will give a better estimation of the direct loss of campable area due to vegetation expansion.

Erosion, gullying, and deposition during HFE's also affect the amount of campable area available at sandbars. An analysis of sandbar morphology between 2002 and 2009 is currently being conducted to determine how different types of morphologic changes contribute to campsite area change. DEMs derived from sandbar topographic data are being utilized to determine areas of erosion, deposition, and slope changes within campsite change areas. This will be combined with the vegetation analysis, with the goal to determine what proportion of morphologic change versus vegetation change determines gains and loss in campable area.

We continued to monitor campsite condition in cooperation with the Grand Canyon River Guides through their "Adopt-a-Beach" program. In 2013, GCRG collected repeat photographs at 43 different camping beaches with contributions from at least 34 river guides. This collection of photographs provides a record since 1996 of the conditions at many of the most popular and heavily used camping beaches from the perspective of river guides. The 2013 efforts are summarized in the Winter 2013-2014 issue of Boatman's Quarterly Review.

IPads equipped with a GIS application are also being evaluated as another way to measure campable area at sandbars. During the Fall 2013 sandbar monitoring trip, campable areas were measured at 26 out of the 37 NAU monitored campsites. The IPads were shown to work reliably in the field; however, IPad surveys will be compared to the total station surveys to determine accuracy of the IPad monitoring method.

Project Element A.1.4. Analysis of historical images at selected monitoring sites

Joe Hazel, Research Associate, NAU
Phil Davis, Research Geologist, USGS/GCMRC
Tom Gushue, Information Technology Specialist, USGS/GCMRC

The goal of this project element is to apply digital photogrammetric techniques to pre-1990 photographs for sandbar monitoring sites. The objective of this work is to create digital terrain models (DTMs) from these data and thereby compare the size (area and volume) of sandbars from the old photographs with conditions since monitoring began in 1990. In FY2013, 1984 air photographs were processed for seven sandbar monitoring sites based on procedures and criteria established during a pilot project conducted for one site in 2012. For each site we have rectified the 1984 photographs to create orthophotographs, extracted elevations to create a DTM, and made error assessments. The procedure resulted in good quality DTMs for 6 of the 7 sites. We were unable to create a usable DTM from the remaining site (RM 16) because it was not possible to collect a sufficient number of ground control points.

We have estimated that the DTMs created from the 1984 air photos have a surface uncertainty of 25 cm or less. This level of uncertainty allows us to use the DTMs to determine sandbar volume and area for comparison with the ground-based measurements made since 1990. These comparisons have been made at 4 of the 7 sites. Initial findings indicate that sandbar volume and area was much greater in 1984 compared to 1990. The largest difference was observed for the sandbar located at river mile 47 (Saddle Canyon), which was 70% greater in area and volume in 1984; whereas the others were 10 to 50% greater in size. Once completed for additional sites, we expect that this project will provide a means to compare the sandbars built by recent high flows with those built by the 1983 and 1984 floods. We plan to complete the analysis for 6 additional sites in FY 2014.

Project Element A.2.1. Bathymetric and topographic mapping

Matt Kaplinski, Research Associate, NAU
Paul Grams, Research Hydrologist, USGS/GCMRC

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

Data Collection: In 2013, we mapped the river channel from Lees Ferry (RM 0) to South Canyon (RM 32). Collection of these data involved 47 multibeam sonar surveys, 52 singlebeam sonar surveys, and 88 total station surveys. We also collected 4416 subaqueous and 225 subaerial images for grain size analysis. On this trip we also surveyed high-water marks for use in flow modeling, placed emplaced photogrammetric panels for the 2013 overflight, and examined stratigraphy of sandbars deposited by the 2012 HFE at 11 sites.

Data Processing: Final processing and generation of digital elevation models for data collected in 2009 and 2012 for the reach between RM 30 and the Little Colorado River (RM 61) is complete. The data collected in 2013 are currently being processed and we anticipate that DEMs of the entire river segment will be completed by March 2014.

Results and Analysis: To facilitate analysis of the channel mapping data, we developed a geomorphic base map for the reach between RM 30 and RM 61. This map serves as the template for analyzing the changes in sediment storage. We are currently analyzing the changes in storage between 2009 and 2012 in context with the geomorphic base map and the results from bed texture mapping (see A.2.2, below). The results from this project depict, for the first time, changes in sediment storage comprehensively for an entire 30-mi segment of Marble Canyon. We expect to report preliminary results at the January 2014 reporting meeting.

Project Element A.2.2. Bed-material characterization

Dan Buscombe, USGS/GCMRC
Bob Tusso, Research Hydrologist, USGS/GCMRC

The following progress has been made towards the development of an automated process for the classification of river bed material texture from the multibeam sonar data. Once developed, the procedure will be used in the computation of reach-scale sand budgets and in the characterization of aquatic habitat. Specific accomplishments this year include:

1. Additional grain-size data were collected in May and August 2013 in order to properly validate a sediment classification algorithm from multibeam echosounder backscatter.
2. A workflow has been developed to extract raw echosounding levels and other required information from raw binary multibeam file formats.
3. Methods have been developed and tested to correct raw echosoundings to acoustic backscatter amplitudes based on solving an acoustic budget. The software has been written to allow for more sophisticated or alternative methods to be adopted in the future.
4. An algorithm has been developed to classify sediments based on corrected backscatter from the current Reson 7125 system (2011 - present). This has been developed and tested using high-density observations of sediment type from both eyeball and video sled systems.
5. The next stage is to use this classification to provide rough estimates of bed sediment type (sand versus gravel and rock) for the 30-60 mile reach mapped in 2012. This will be completed by mid-January and results will be presented at the annual reporting meeting.
6. Further work is required to improve and test the algorithm and provide estimates of uncertainties in sediment type estimates.
7. Further work is required to be able to distinguish between relative proportions of sand and gravel over small patches ("mixtures" of sediment types). Controlled laboratory experiments might be necessary to do this.
8. Further work is required to develop a workflow for the multibeam data collected with different systems (2009 and earlier).
9. This work will be published in a technical article that outlines the approaches currently being taken to classifying sediments using acoustic backscatter.

Project A.3. Investigating Eddy Sandbar Variability and the Interactions among Flow, Vegetation, and Geomorphology

Mark Schmeeckle and Laura Alvarez, Arizona State University
Paul Grams, Research Hydrologist, USGS/GCMRC
Barbara Ralston, Biologist, USGS/GCMRC

Work on this project component in 2013 has focused on development of improved models for hydrodynamics in areas of recirculating flow (eddies) on the Colorado River in Grand Canyon. Previously we have developed a parallelized, three dimensional, turbulence-resolving model of flow in lateral separation eddies. Recently we have focused on validating the model. Using the detached eddy simulation (DES) technique, which is a hybrid between LES and RANS techniques, we simulated the High Flood Experiment of 2008 (HFE 2008) for 1.4 km of river transect along the Eminence and Willie Taylor fan-eddy complexes. The forecasting-capabilities of the three-dimensional DES flow model were assessed using a point-to-point verification method. Thus, the simulated velocities were compared against observed velocity data at 4920 collocated points along transects that correspond to the transect lines of ADCP field surveys. The accuracy of the model was evaluated using four absolute error metrics (MAE, MFE, RMSE, Pearson correlation coefficient R) and two relative error metrics (MAPE, MdAPE). The error in velocity magnitude was found to be less than 17% (accordingly to MdAPE) and 0.29m/s absolute error (MAE). The mean deviation of the direction of velocity with respect to the measured velocity was found to be 20 degrees. Furthermore, the thee-dimensional DES model was compared against a more conventional two-dimensional depth-averaged flow model developed in OpenFOAM. This comparison demonstrates the capability of the DES-3D model at reproducing the size and position of the primary and secondary eddies in lateral recirculation zones at EM and WT. In contrast, the two-dimensional turbulence-closure model captures a strong recirculation zone predominated by one steady primary eddy cell and fails to predict the secondary recirculation zones and return channels currents at both fan eddy complexes. The results demonstrate short-term temporal changes in the direction of the velocity vectors. There is a convergence of the near-bed velocity vectors in the eddy eye relative to the surface velocity vectors. In terms of vorticity, large scale turbulence structures with vorticity predominantly in the vertical direction are produced at the shear layer between the main channel and the separation zone. Nonetheless, these structures rapidly become three-dimensional with no preferred orientation of vorticity. A suspended sediment model utilizing the DES velocity vectors reveals that the temporal variability and different orientation of near-bed velocity vectors relative to the water surface vectors are key factors in the export of sediment from lateral separation eddies. **These findings demonstrate that there are important processes controlling the transport, deposition, and erosion of sand in eddies that are not captured in simplified modeling approaches. We believe that these advances in our capability to model the hydrodynamics of eddies on the Colorado River will lead to improved models for sediment transport and sandbar morphodynamics.**

Project A.4. Quantifying the correlation between bed and transport grain size

David Rubin, University of California, Santa Cruz
Dan Buscombe, USGS/GCMRC
Paul Grams, Research Hydrologist, USGS/GCMRC

This research project aims to address the question: "what are the relative contributions to the large (several order-of-magnitude) range in observed suspended sand concentrations for a given water discharge?" Addressing this question requires joint measurements of suspended-sediment concentration, bed-sediment grain size, water velocity (to estimate bed shear stress), and bathymetry. In summer 2013, we made these measurements at each of the 5 mainstem discharge/sediment transport gages (see Project B). These sites span a range of hydraulic and sediment supply conditions. The surveys included multibeam sonar, bed-sediment grain size (eyeball) and water velocity (using ADCP) at each of the sites. A sampling protocol for velocity ADCP was developed based on analysis of errors in increasing numbers of cross-channel transects. Specific tasks accomplished include:

1. Maps of sediment type at discrete points have been compiled for the 30 and 60 mile site based on the eyeball measurements.
2. Maps of continuous sediment type ('sand areal coverage') estimates have been produced for the 30 and 60 mile sites using a newly developed algorithm for sediment classification based on acoustic backscatter.
3. ADCP data have been worked up for the 30, 60 and 90 mile sites into discrete 2D slices with some quality control.
4. Digital Elevation Models have been constructed for the 30 and 60 mile sites.
5. Analysis of suspended sediment variability at daily timescales in relation to suspended sediment grain size over multi-year periods. This forms the basis of the data set we are trying to explain.
6. Publication of journal article on the relation between bed-sand coverage and suspended-sand transport. This report presents a modeling approach that can be implemented in future efforts to model suspended sand transport on the Colorado River in Grand Canyon.

Outstanding data processing tasks include:

1. Producing maps of sediment type from eyeball data at the 90, 166 and 225 mile sites
2. Producing maps of continuous sediment type ('sand areal coverage') for the 90 and 166 and 225 mile sites. It may not be possible to do this at the latter two sites owing to poor backscatter records due to very high suspended sediment concentrations.
3. Analyzing all eyeball images of sand for grain size (at all sites)
4. Production of Digital Elevation Models for the 90, 166 and 225 mile sites.
5. Further processing of ADCP data to derive shear stress estimates.
6. Using these shear stress estimates to drive a 2D numerical flow model for a spatially continuous estimate of shear stress at each site.

Project A.5. Geochemical Signatures of Pre-Dam Sediment

Renee Takesue, USGC Coastal and Marine Geology
David Rubin, University of California, Santa Cruz

In May 2013, 15 sandbars produced by the November 2012 high flow event were sampled in Marble Canyon from the Paria River mouth to River Mile 61. Geochemical compositions were determined on the 63–250 µm sand fraction from five or six stratigraphic layers of the 9-Mile, 16-Mile, 22-Mile, and 31-Mile bars plus near-surface samples of the 55-Mile and 61-Mile bars.

Aluminum (Al)-normalized contents of the elements potassium (K), sodium (Na), and rubidium (Rb), which are indicative of alkali feldspars and micas, are the best geochemical discriminants between Paria and relic Colorado River 63-250 µm sand. Based on these tracers, 63-250 µm sand in sandbars from the Nov 2012 HFE had geochemical compositions that were Paria-like, but that in some instances exceeded the current Paria end member composition. This suggests that sediment delivered to the Colorado River during winter 2012 may have been mobilized from a part of the Paria watershed that has not yet been characterized by this study. Although the Paria end member composition could change with future sampling, geochemical mixing ratios between Paria and relic Colorado end members were calculated for sandbars created by the Nov 2012 HFE. These calculations show that the 63-250 µm sand fraction consisted of up to 17 ± 2% (1s) relic Colorado River sediment in sandbars at RM 22, 55, and 61.

<u>Next steps:</u> Two approaches will be taken in FY14 to improve understanding and accuracy of geochemical sediment discrimination in the upper Colorado River. First, more extensive sampling of the Paria watershed and possibly smaller tributaries will be conducted to improve the characterization of end member values. Second, because sandbars have grain size distributions that coarsen upward, the grain size distributions of select sandbars created by the Nov 2012 HFE will be determined, and these results used to guide further geochemical characterization of sediment size classes such as the silt and clay fractions. Elemental contents of sediments increase as grain size decreases, and end member characteristics may be more pronounced in finer particles, allowing for greater sensitivity of the tracers to small mixing differences.

Project A.6. Control Network and Survey Support

Keith Kohl, Surveyor, USGS/GCMRC
Paul Grams, Research Hydrologist, USGS/GCMRC

An accurate geodetic control network is required to support nearly every aspect of this project as well as other GCMRC monitoring projects. The purpose of the control network is to ensure that spatial data acquired on all projects are collected with accurate and repeatable spatial reference. We are in the process of documenting the GCMRC control network in a report which will describe the purpose, collection methods, reference systems, coordinates resulting from least-squares adjustment procedures, and estimated errors of rim, primary, secondary, and tertiary levels of geodetic control. The report is expected to be in final review before May 2013. Specific control network and survey support activates in 2013 are summarized below:

1) Project A was supported by preparing all equipment, software, control and survey files. Over 100 survey files and nearly 500 control shots were collected in April alone. All were added into the control network and adjusted with least-squares principles.
2) The 2013 digital imagery overflight was supported by preparing 24 GNSS receivers and training 17 operators for occupations, download, and data delivery. 43 control stations were occupied during the overflight with dual frequency GNSS receivers. Data was edited, processed, and adjusted for publishing. 200 ground control panels were placed on stations positioned using static GNSS and terrestrially derived, optical measurements.
3) Survey support was provided for several additional projects including:
    - Project A received shoreline, control coordinates, recovery photographs, stakeout, and cross section files for data collection.
    - 2013 Aerial imagery overflight was supported with GNSS equipment, operators, training, panel deployment, panel coordinates, rim control coordinates, and contractor coordination.
    - Suspended sediment monitoring reference at all gages along the Colorado River
    - Tributary flow modeling at Water Holes, North Canyon, Little Colorado River, Shinumo Creek
    - Equipment and processing support for ground-based Lidar of archeological sites in Glen, Marble and Grand Canyon
    - Multibeam sonar surveys of Lees Ferry, 30-Mile, 60-Mile, Grand Canyon, National and Diamond Creek gage reaches.
    - Photo-identifiable control points were surveyed for orthorectification of 1984 aerial images
    - Multibeam boat was surveyed for offsets in reference to the new Inertial Motion Unit
    - Multibeam tracking systems accuracies were compared to monumented level line to determine errors of site positioning system.
    - Over 100 historical USGS cross sections were positioned and compiled for integration of past channel profiles. Data referenced to these cross sections in Glen Canyon have been translated and rotated to the NAD83 (2011) reference frame
    - Surveys were performed at Lake Mary to position and calibrate multibeam and singlebeam sonar data collection.

Project C Elements. Water-Quality Monitoring of Lake Powell and Glen Canyon Dam Releases

William S. Vernieu, Hydrologist, USGS, Grand Canyon Monitoring and Research Center

Project Element C.1. Revisions to Existing Program

William Vernieu, USGS GCMRC

In 2013, an evaluation of paired chlorophyll samples collected from two reservoir surveys was made, comparing two methods of sample preservation, dessication and freezing. After this evaluation, freezing was reinstated as the primary method of preservation and involves storage and shipment of the samples on dry ice. Because of continued reservoir drawdown in 2013, selection of a suitable site for deployment of inflow water-quality monitoring equipment was not possible. The installation of weather stations at remote pumpout stations did not occur, pending procurement of instrumentation and coordination with National Park Service. Both projects are expected to be performed in 2014. Progress has been made on developing longitudinal sediment delta profiles, including the discovery of two significant post-dam landslide deposits in the Escalante River arm which have significant effects to water quality in that area. Delta profile data were presented to the North American Lake Management Society, Arizona Hydrological Society, and at the Colorado Plateau Biennial Conference. A proposal for additional USGS Data Rescue Project funding, submitted in early 2013, was declined. Further development of the project will continue in 2014.

Project Element C.2. Details of Current Program

William Vernieu, USGS GCMRC

During WY2013, ten reservoir forebay surveys were conducted at approximate monthly intervals. Three complete reservoir surveys were conducted in December 2012 and March and July 2013. A proposed early October 2013 survey was cancelled because of the government shutdown. The Seabird SBE-19plusV2 CTD instrument, acquired in 2010, continued to perform well as the primary profiling instrument for the reservoir surveys, except for a failure of the dissolved oxygen sensor which was repaired in the summer of 2013. Monitoring and sample collection in the Glen Canyon Dam forebay and tailwaters has been maintained. Water-quality data collection from the Glen Canyon Dam releases has been consistent and the remote telemetry system continues to provide current, reliable data. Continuous monitoring of Lees Ferry water quality was transferred to the downstream water-quality program in 2011. Maintenance has continued on the Uniflite limnology vessel. No major repairs were required in 2013. In addition to regular monitoring activities, logistics support was provided for a Southwest Biological Science Center/Arizona Game & Fish amphibian survey and a research project on sediment oxygen demand with Brigham Young University.

Project Element C.3. Reservoir Modeling

William Vernieu, USGS GCMRC

Simulation modeling of Lake Powell water quality and hydrodynamic patterns is currently being conducted by Nick Williams of Reclamation's Upper Colorado Regional Office using the Army Corps of Engineers CE-QUAL-W2 model. GCMRC continues to provide monitoring data to the modeling effort for calibration and verification. In addition, a thermistor string deployed near the chain line upstream of the dam is providing continuous temperature data at discrete elevations to aid in the modeling effort. Output from the model is being used to make predictions of release temperature and other water-quality parameters under various operational scenarios and provides valuable information to fisheries studies and the LTEMP program.

Project D Elements. Mainstem Humpback Chub Aggregation Studies and Metapopulation Dynamics

William Persons, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
David L. Ward, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
D.R. VanHaverbeke, Fishery Biologist, U.S. Fish and Wildlife Services
Scott Bonar, Fishery Biologist, USGS, University of Arizona
Karin Limburg, Professor, State University of New York, College of Environmental Science and Forestry

Project Element D.1. Improve aggregation sampling to develop more rigorous approaches to monitor aggregations (includes ongoing monitoring).

D.R. VanHaverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
William Persons, Fishery Biologist, USGS/GCMRC
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park

Two mainstem trips during July and September 2013 sampled fish by hoop net and trammel net. We fish approximately 236 overnight hoopnet sets and 58 two-hour trammel net sets during the two trips. Trammel nets were not fished during 2013 at the Little Colorado River, Stephen Aisle, Havasu Creek and Pumpkin Spring aggregations. Grand Canyon National Park crews (Brian Healy) sampled the Shinumo aggregation during June 13-18 and during September 7-13, 2013. Humpback chub were collected at locations not previously sampled, including approximately 25 adult chub near River Mile 35. There was little movement between aggregations and adult humpback chub demonstrated high site fidelity, with most fish recaptured at the same location they were originally tagged. Not including NPS captures, eight of ten humpback chub captured in 2013 near Shinumo Creek and 84% of humpback chub captured near and in Havasu Creek had been previously translocated. Translocations appear to be augmenting mainstem aggregations of humpback chub.

Project Element D.2.1. Natal origins of humpback chub at aggregations by otolith microchemistry

Karin Limburg, Professor, State University of New York, College of Environmental Science and Forestry
William Persons, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
D.R. VanHaverbeke, Fishery Biologist, U.S. Fish and Wildlife Services
Biran Healy, Fishery Biologist, NPS, Grand Canyon National Park

Project Element D.2.2. Egg maturation studies using Ultrasonic Imaging and Ovaprim ®

Karin Limburg, Professor, State University of New York, College of Environmental Science and Forestry
William Persons, Fishery Biologist, USGS-GCMRC
D.R. Van Haverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park

Although nine known aggregations of humpback chub, *Gila cypha*, currently exist in the main stem Colorado River, little is known about their reproduction. It has been hypothesized that water temperatures of the main stem Colorado River below Glen Canyon Dam are too low for female humpback chub to develop eggs for spawning due to hypolimnetic dam releases. In this study, we will evaluate use of ultrasonic imaging and Ovaprim® to identify egg development in female humpback chub. In addition, we will document locations of female chub with developing eggs in the Colorado River drainage, especially the main stem below Glen Canyon Dam. Based on our initial results, we conclude that ultrasonic imaging is an effective method for identifying egg development in female humpback chub.

Project E Elements. Humpback Chub Early Life History in and Around the Little Colorado River

Charles Yackulic, Research Statistician, USGS, Grand Canyon Monitoring and Research Center
Theodore Kennedy, Research Aquatic Biologist, USGS, Grand Canyon Monitoring and Research Center
Colden Baxter, Associate Professor, Idaho State University
Bill Pine, Associate Professor, University of Florida
Dennis Stone, Fishery Biologist, U.S. Fish and Wildlife Service
Craig Stricker, Research Biologist, USGS—Fort Collins Science Center
Randy VanHaverbeke, Fishery Biologist, US Fish and Wildlife Service
David Walters, Research Ecologist, USGS—Fort Collins Science Center
Rich Wanty, Research Chemist, USGS—Fort Collins Science Center
Mike Yard, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center

Project Element E.1 July Little Colorado Marking

Charles Yackulic, Research Statistician, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS/GCMRC

During the July 2013 LCR trip, fish were sampled in the lower 13.6 km of the Little Colorado River (LCR) from June 28, 2013 to July 8, 2013. The lower 13.6 km of the LCR was divided into three camps (also referred to as 'reaches'): Boulders (the most downstream reach), Coyote (the middle reach), and Salt (the most upstream reach). Each reach spanned a 4.5km distance and was divided into five equal subreaches (each 0.9 km in length). There was one team, consisting of four people, stationed at each of the three camps, and each team sampled one subreach per day. Thus, each subreach was sampled twice during the entire ten-day sampling period. Fish were captured using hoop nets, seines, and dip nets.

Over 4500 humpback chub were captured, including ~2300 age-0 fish. Most humpback chub were captured using hoop nets (~1600), followed by dip nets (~400) and seines (~300). Catch of age- 0 humpback chub was similar in Boulders and Coyote reaches and lower in Salt reach. Fish marked in July were recaptured during both fall sampling trips by FWS in the LCR and during the September Natal Origins – Juvenile Chub Marking trip, however analyses of these data are ongoing. The July 2013 LCR trip was successful in catching and marking age0 humpback chub. We will continue this project in 2014 to help improve our understanding of what factors affect survival, growth and outmigration of this critical age class and how these rates vary between years.

Project Element E.2. Describing food web structure and the potential for food limitation within the LCR ($260,600)

Theodore Kennedy, Research Biologist, USGS/GCMRC
Colden Baxter, Associate Professor, Idaho State University
David Walters , Research Ecologist, USGS - Fort Collins Science Center

Dennis Stone, Fishery Biologist, U.S. Fish and Wildlife Service-Flagstaff
Craig Stricker, Research Biologist, USGS-Fort Collins Science Center
Richard Wanty, Research Chemist, USGS- Crustal Geophysics and Geochemistry Science Center
Randy VanHaverbeke Fishery Biologist, U.S. Fish and Wildlife Service-Flagstaff

Full implementation of Project E2 did not occur in FY13 because of inadequate staffing. A post-doctoral researcher was hired to assist with Project E in May 2013, and we are well positioned to implement E2 in FY14.

In FY13, cooperators from Idaho State University completed fish diet studies for the entire fish assemblage in the LCR. Fish diet sampling occurred seasonally (July 2012, September 2012, January 2013, March 2013) and in conjunction with several natal origins river trip, which provided logistical and field support. Diet sampling encompassed the entire LCR fish assemblage (i.e., humpback chub, bluehead and flannelmouth suckers, speckled dace, channel catfish, red shiner, fathead minnow, common carp, plains killifish, rainbow and brown trout). To date, approximately half of the 367 fish diet samples have been processed.

In FY13 we initiated studies on food quality in the LCR. Specifically, in June 2013 samples of invertebrates and organic matter were collected from throughout the mainstem Colorado River, the Little Colorado River and other tributaries in Grand Canyon (i.e., Nankoweep Creek, Kanab Creek, Havasu Creek). These samples will be processed for metal concentrations and other trace elements by collaborators at USGS Fort Collins Science Center. Data will be compared among reaches, and relative to EPA standards for wildlife health. These data will be used to evaluate whether a key aspect of resource quality, metal concentrations, limits the quality of resources available to support fish populations throughout Grand Canyon.

We also initiated studies on the invertebrate assemblage throughout the LCR in FY13. Specifically, sticky traps and light traps used to catch adult aquatic insects were deployed throughout the LCR in July by personnel working on the juvenile chub marking study. These data indicate densities of adult aquatic insects decline along a downstream gradient in the LCR from Salt Camp to Boulders Camp.

Project Element E.3 Population modeling

Charles Yackulic, Research Statistician, USGS/GCMRC
Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Bill Pine, Associate Professor, University of Florida

In FY 2013, we completed one study of population dynamics in the Little Colorado River aggregation focusing on differences in survival and growth between the Colorado River and the Little Colorado River over the period 2009 – 2012, as well as movement patterns between these areas. Major findings include evidence of large differences in growth and survival between the portions of the river system, quantification of rates of skip spawning in smaller and larger humpback chub adults, evidence for a resident LCR population, and initial estimates of the rate of outmigration by age 0 fish into the Colorado River. This analysis synthesized data collected by Fish and Wildlife Monitoring efforts in the LCR, the Near shore ecology project and data collected in 2012 by the Natal Origins / Juvenile Chub monitoring project.

In FY 2013, we also initiated an analysis of spatial and temporal variation in abundance, survival, and growth of age – 1 fish in the Little Colorado River using data collected by Fish and Wildlife monitoring efforts. While this analysis is ongoing, preliminary results suggests strong year to year variation in survival, growth and movement of age 1 fish, potentially linked to density. Our goal is to submit a manuscript based on this work to a peer-reviewed journal in FY 2014.

Lastly, we initiated an effort that modified the general model of population dynamics in the LCR aggregation described in the first paragraph, in order to link growth and survival in the Colorado River to temperature and estimates of trout abundance. This modeling suggests a role for both temperature and trout in explaining variation in growth and survival of humpback chub. Estimates from this model were compared to historical trends and used to develop a simulation model to support the LTEMP EIS process. We intend to submit a manuscript based on this work to a peer-reviewed journal in FY 2014.

Project F Elements. Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and the lower Little Colorado River

William Persons, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Charles Yackulic, Research Statistician, USGS, Grand Canyon Monitoring and Research Center
David Rogowski, Fishery Biologist, Arizona Game and Fish Department
Luke Avery, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Josh Korman, President, Ecometric Research, Inc.
Matt Kaplinski, Research Assistant, Northern Arizona University
David VanHaverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
Dana Winkelman, Professor, Colorado State University
Brian Healy, Fishery Biologist, Grand Canyon National Park
Steve Martell, Professor, University of British Columbia

Project Element F.1. System Wide Electrofishing

David Rowgowski, Fishery Biologist, AZGFD
William Persons, Fishery Biologist, USGS GCMRC

The primary goal of the System Wide Electrofishing project is to provide baseline status and trend information on native and nonnative fish in the Colorado River from Lees Ferry to Lake Mead. Annual monitoring has been occurring since 2000. In 2013 we conducted two spring trips (4-15 April, 25 May to 7 June) sampling from Lees Ferry to Diamond Creek, and one fall trip (28 October to 1 November) sampling from Diamond Creek to Lake Mead. For the spring trips, 232 and 224 sites were sampled respectively, with 68 sites sampled in the fall trip. In total 8,200 fish were captured, with native fish comprising 21% of the catch (Table F.1-1). Rainbow trout continue to dominate the catch in Marble Canyon with native species increasing downstream of the Little Colorado River. For the spring trips nonnative species accounted for 83% of the total catch, while for the October trip native species accounted for 89% of the total catch. Catch rates for both flannelmouth and bluehead suckers remain at relatively high levels .Of note were two razorback suckers captured on the October trip, one of these had not been tagged previously (PIT: passive integrative transponder), the other was a recapture (e.g. previously tagged with a sonic and a PIT tag).This is a welcome change as prior to these two razorback suckers only one other sucker was captured in 2012, the first in 20 years.

Table F.1-1. Species composition from system wide boat electrofishing Colorado River from Lees Ferry to Lake Mead, Arizona Game and Fish Department.

Species	LF-DC	DC-LM	Sum	Percent of total catch
Native				
Bluehead sucker	134	20	154	1.88
Flannelmouth sucker	1084	210	1294	15.78
Humpback chub	12	0	12	0.15
Speckled dace	110	143	253	3.09
Razorback sucker	0	2	2	0.02
Total	1340	375	1715	20.91
Nonnative				
Channel catfish	0	1	1	0.01
Black bullhead	3	0	3	0.04
Brown trout	380	0	380	4.63
Common carp	165	9	174	2.12
Fathead minnow	14	1	15	0.18
Gizzard shad	1	3	4	0.05
Rainbow trout	5865	4	5869	71.57
Striped bass	10	0	10	0.12
Plains killifish	0	1	1	0.01
Red shiner	0	27	27	0.33
Walleye	0	1	1	0.01
Total	6438	47	6485	79.09

LF = Lees Ferry; DC = Diamond Creek; LM = Lake Mead

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

David Rowgoski, Fishery Biologist, AZGFD
Michael Anderson, Fishery Biologist, AZGFD
William Persons, Fishery Biologist, USGS/GCMRC

In 2013 we conducted three standard electrofishing sampling trips: spring, summer, and fall; sampling 144 sites in total, with 49, 47, 48 sites sampled respectively. Rainbow trout dominated the fish community comprising 99.4% of fish captured (Table 1). Rainbow trout catch per unit effort (CPUE) overall was 4.21 fish/minute (Figure F.2.1-1). During the fall sampling average length of rainbow trout captured was 209 mm and approximately 25% of the trout collected were below 152 mm (8 inches) indicating a good cohort of fish recruited this year. Mean fall length has been trending upwards since 2010. Overall rainbow trout condition (all samples) was 1.08 (SE=9.2), with one being the value of an average fish. One night in July was dedicated to sampling for other non-native fish. Near the dam two smallmouth bass and three walleyes were captured with an additional two walleyes observed. At the slough (R-Km 5.6) 75 carp were captured along with seven flannelmouth suckers. Carp continue to dominate the fish community in the slough, and this year 40% were recaptures (previously marked).

Table F.2.1-1. Species composition in Glen Canyon during 2013 standard monitoring (boat electrofishing) by Arizona Game and Fish Department.

Species	spring	summer	fall	Total	Percent
Rainbow trout	1385	2092	1422	4899	99.37
Brown trout	7	7	4	18	0.37
Carp	3	0	0	3	0.06
Flannelmouth sucker	1	7	1	9	0.18
Green sunfish	1	0	0	1	0.02

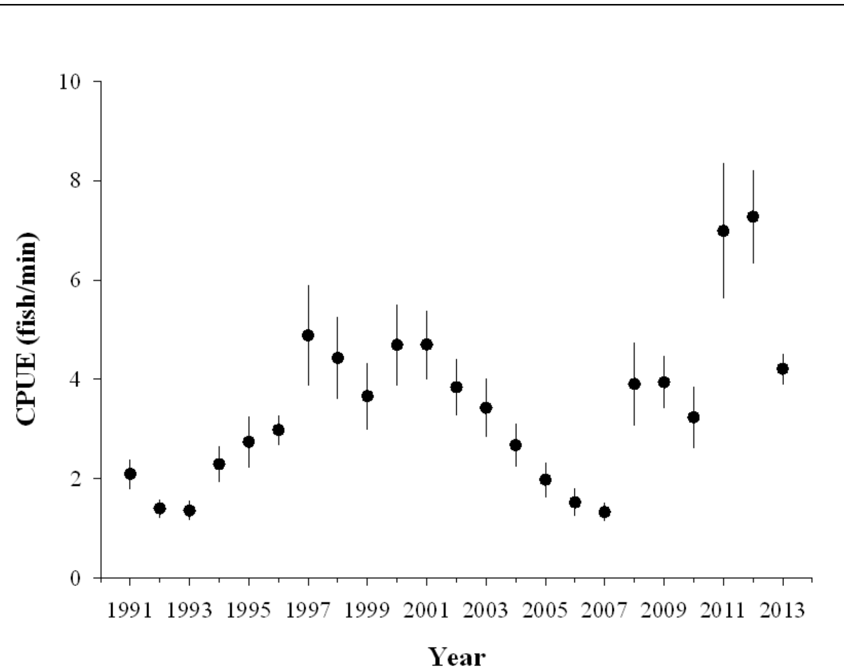


Figure F2.1-1. Overall mean CPUE for rainbow trout among years from all samples combined (by year) from the Lees Ferry reach of the Colorado River, error bars represent 95% confidence intervals.

Project Element F.2.2. Rainbow Trout Early Life Stage Studies

Luke Avery, Fishery Biologist, USGS/GCMRC
G.D. Foster, Logistic Support, USGS/GCMRC
Josh Korman, President, Ecometric Research, Inc.
Matt Kaplinksi, Research Associate, NAU

Nine redd surveys were conducted for the 2013 season of the rainbow trout early life stage survey, with the first occurring on December 13, 2012 and the last occurring on June 4, 2013. The estimated number of redds created in 2013 was 2669, which is notably higher than the 9 year mean (2004, 2006-2013) of 1805. This higher than normal redd estimate may be a response to the 2012 November high flow event (HFE), though direct observations of response of early life stages of rainbow trout to fall HFE's are currently limited to this one occurrence and no definitive conclusions can be drawn.

Four larval and juvenile fish surveys were conducted in 2013 during July, August, September, and November. The November survey occurred on the 5th through the 7th, prior to the November 2013 HFE. The July population estimate was 293,000 fish for the entire Lees Ferry reach, with lower and upper confidence intervals of 199,000 and 408,000, respectively. This was a little higher than may have been expected and may be a response to the 2012 fall HFE, but again observations on response to fall HFE's are limited. The November population estimate was 39,000 fish for the entire Lees Ferry reach, with lower and upper confidence intervals of 29,000 and 52,000, respectively. This estimate is similar to previous years.

A draft report for the 2012 and earlier rainbow trout early life stage surveys was completed and submitted to various reviewers using the Department of the Interior internal publishing process. A manuscript for submission in an external peer reviewed journal concerning specifically the effects of the 2011 equalization flows is currently in the works.

Project Element F.2.3. Lees Ferry Angler Surveys

Michael Anderson, Fishery Biologist, AZGFD
David Rowgoski, Fishery Biologist, AZGFD
William Persons, Fishery Biologist, USGS/GCMRC

Creel (angler) surveys are an important tool to gather information on fishing effort and harvest. Arizona Game and Fish Department has been conducting creel surveys at Lees Ferry off and on since about 1977 with various changes to the methods. Since 2011 we have been following a standard protocol. Angler surveys were conducted on 52 days for the period of 1 January- 20 November 2013 (surveys still in progress). Anglers are divided into two categories, those going upriver using boats and those that access the fishery on foot, walk-in anglers. During these surveys a total of 1083 anglers were interviewed, 840 from upriver (boaters) and 243 utilizing the walk-in section. In the upriver section, anglers interviewed reported a total of 12,583 fish being caught with an average catch rate of 1.97 fish/hr. Harvest rates in the upriver section continue to be extremely low with only 2.4% of the total catch of rainbow trout harvested. In the walk-in section of the fishery 660 fish were caught by anglers interviewed resulting in an average catch rate of 0.75 fish/hr. Harvest rates in the walk in section were 13.7% of total catch. Overall angler success remains high with 95.2% and 53.9 % of the anglers in the upriver section and walk-in section respectively, catching at least one fish. Angler satisfaction on a scale of one to five remains high for both boaters and walk-in anglers averaging 4.84 and 4.52 respectively. Results from our angler preference question revealed that there was no statistical difference in preference of catching ten 16" fish, over the alternative of catching two 20" fish (Fisher's exact test: p=0.39).

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

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

The primary goal of this project is to collect data for use in estimating state variables (abundance and occupancy) and vital rates (survival, growth, immigration and emigration) of juvenile humpback chub (*Gila cypha*) near the LCR confluence area (63.4 to 64.9 RM). Sampling in the Colorado River was restricted to a ~3 km section of the river downstream of the confluence. Vital rates and abundances of smaller size classes provide a leading indicator of future adult population size. These data are also used in a multi-state framework combining data from seasonal sampling in the LCR (April-May, September-October; Project F.4.1; and July Project E.1) (Yackulic et al. *in press*). Upon capture, HBC are measured and marked following visual examination or electronically scanned for prior marks from either visual elastomer (VIE, < 100 mm total length) of passive integrated transponders (PIT ≥ 100 mm TL). In 2013, four mark-recapture trips were conducted (January, April, July, and September; 9 da/trip) concurrent with Natal Origin trip (Project Element F.6.) using multiple passes and a combination of gear types that include hoop nets (8-passes) and electrofishing (3-passes). In 2013, a total of 2,502 native fish were caught consisting of 205 bluehead sucker (*Catostomus discobolus*), 263 flannelmouth sucker (*Catostomus latipinnis*), 2,034 humpback chub (HBC), and speckled dace (*Rhinichthys osculus*); and 2,065 nonnative fish were caught consisting of 49 brown trout (*Salmo trutta*), 13 carp (*Cyprinus carpio*), 253 fathead minnow (*Pimephales promelas*), 9 plains killifish (*Fundulus zebrinus*), 1,705 rainbow trout (*Onchorhynchus mykiss*), 28 red shiner (*Cyprinella lutrensis*), 5 black bullhead (*Ameiurus melas*), and 3 striped bass (*Morone saxatilis*). For HBC, a total of 1,448 new VIE tags (fish <100 mm TL) and 269 PIT-tags (fish ≥ 100 mm TL) were administered as new marks. Additionally, 17 HBC were recaptured that had originally been marked in the LCR. Future work will focus on exploring annual variation in vital rates, and movement and growth among the two river systems.

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

D.R. VanHaverbeke, Fishery Biologist, USFWS
William Persons, Fishery Biologist, USGS/GCMRC

Since 2000, a series of two-pass, closed mark-recapture efforts have been conducted in the spring and in the fall in the Little Colorado River to track the abundance of humpback chub, *Gila cypha*. During spring 2013 the estimated abundance of humpback chub ≥150 mm in the lower 13.57 km of the Little Colorado River was 8,549 (SE = 757). Of these fish, it was estimated that 5,734 (SE = 512) were ≥200 mm. These numbers indicate that the spring spawning abundances of humpback chub have remained relatively stable or have continued to increase since experiencing significant post-2006 increases. A similar post-2006 pattern for humpback chub has been seen during the fall. During fall 2013 the estimated abundance of humpback chub ≥150 mm

in the lower 13.57 km of the Little Colorado River was 4,946 (SE = 1,141). Of these fish, it was estimated that 3,022 (SE = 1,240) were ≥200 mm.
In addition, bluehead sucker, *Catostomus discobolus*, and flannelmouth sucker, *C. latipinnis*, underwent significant post-2006 increases in relative abundance during the spring season, but have since declined. These results suggest that sometime during the mid-2000s, conditions were favorable for all three large bodied native fishes in Grand Canyon. These favorable conditions are thought to be related to warmer water temperatures experienced in the Colorado River because of drought and a system-wide decline of non-native salmonids in the Colorado River. In addition, it is thought that benefit has accrued to humpback chub because of translocation efforts within the Little Colorado River.

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

David Rogowski, Fishery Biologist, AZGFD
William Persons, Fishery Biologist, USGS/GCMRC

Hoop net monitoring of fishes in the lower 1,200 meters (m) of the Little Colorado River (LCR) in the Grand Canyon began in 1987 to assess population status and trends of the endangered humpback chub (*Gila cypha*) during annual spring spawning migrations. In addition to humpback chub, other native fish common in this community include flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*Catostomus discobolus*), and speckled dace (*Rhinichthys osculus*). The LCR represents the primary spawning and production site in the Grand Canyon for many of these species. Sampling occurred from 4 April to 12 May 2013, with 13 hoop nets set every evening (295 net sets in total). A total of 2,214 fish representing 10 species were captured during 2013 spring monitoring (Table 4.2-1), with humpback chub comprising 35% of total catch. Native fishes have dominated total catch (97.6% in 2013) since 1987 with the exception of 1997 when fathead minnows were the majority of total catch. Mean catch-per-unit-effort (CPUE; fish/24 hrs) for subadult to adult humpback chub (considered > 150 mm total length [TL]) dropped significantly since 1987-1988, but has shown a general increasing trend since 2006. Mean CPUE of humpback chub < 150 mm TL has increased steadily from 2010 -2013. Seasonal timing of sampling, flood events, and changes in hydrology of the mainstem Colorado River may have influenced CPUEs over the last few years.
Table 4.2-1. Species composition and catch per unit effort (CPUE) for native fishes in the lower 1200 m of the Little Colorado River in 2013, Arizona Game and Fish Department.

Species	Count	Length category (mm)	CPUE (95% CI)
Native fishes			
		<150	1.42 (±0.269)
Humpback chub	769	≥ 150	1.23 (±0.211)
		≥ 200	1.01 (±0.19)
Bluehead sucker	439	≥ 150	1.24 (±0.270)
Flannelmouth sucker	488	≥ 150	1.55 (±0.230)
Speckled dace	465	all	1.60 (±0.399)
Nonnative fishes			
Black bullhead	7	-	-
Channel catfish	9	-	-
Fathead minnow	18	-	-
Plains killifish	6	-	-
Rainbow trout	3	-	-
Red shiner	13	-	-

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

D.R. VanHaverbeke, Fishery Biologist, USFWS
Brian Healy, Fishery Biologist, Grand Canyon National Park
William Persons, Fishery Biologist, USGS/GCMRC

During 14-24 May 2013, a monitoring trip was conducted in the Chute Falls reaches of the Little Colorado River (LCR) to estimate the abundance of humpback chub. Gear type used was hoop nets (50-60 cm in diameter, 100 cm long, a single 10 cm throat, 6 mm nylon mesh netting) baited near their cod ends with nylon mesh bags (30 x 30 cm, 6 mm mesh) filled with ~160 g AquaMaxTM Grower 600 for Carnivorous Species (Purina Mills Inc., Brentwood, MO). During this trip, crews sampled the lower reach below Chute Falls (13.57-14.1 km) with 17 nets and the upper reach above Chute Falls (14.1-17.6 km) with 33 nets, deployed for three consecutive ~24 h hauls. Population was estimated using capture probability data. We estimated that there were 99 (SE = 22) humpback chub ≥100 mm above Chute Falls, and that 62 (SE = 12) of these fish were ≥200 mm. In addition, we estimated that there were 280 (SE = 52) humpback chub ≥100 mm in the lower reach below Chute Falls, and that 218 (SE = 38) of these fish were ≥200 mm. These numbers indicate that since summer of 2010, numbers of humpback chub have again been steadily increasing in the two Chute Falls monitoring reaches. Recall that during summer 2010, numbers of humpback chub in both Chute Falls reaches precipitously declined after a prolonged 2010 spring flood deposited large amounts of sediment in the deep pool habitat of the Chute Falls reaches, evidently displacing humpback chub that were in the Chute Falls reaches downriver in the LCR.

<u>2013 Translocations</u> – The 2013 translocations occurred during three separate efforts. First, during 14-24 May 2013, USFWS removed 73 larval humpback chub from the LCR and transported them to the Southwestern Native Aquatic Resources and Recovery Center (SNARRC) in Dexter, New Mexico. Our objective was to investigate collecting humpback chub at the larval stage for future translocation activities outside of the LCR (e.g., Shinumo and Havasu translocations). These larval fish were collected from Boulders reach.

Second, a translocation trip was conducted from July 8-12, 2013, with the objectives of 1) capturing 300 juvenile humpback chub (80-130 mm) and translocating them to above Chute Falls, and 2) capturing and transporting 500 juvenile chub (<80 mm) to SNARRC. The 500 chub destined for SNARRC included 200 and 300 chub to be translocated into Shinumo and Havasu Creeks, respectively, within Grand Canyon National Park during 2014. However, because of a large flood that occurred in the LCR during collection activities, our objectives were only partially met. No fish were collected for the Chute Falls translocation and only 90 humpback chub made the transport to SNAARC. These 90 humpback chub were collected from Coyote reach.

Third, as a result of the above, another translocation trip was conducted by USFWS and Grand Canyon National Park from 29 October to 7 November 2013. During this trip, 341 humpback chub <80 mm were successfully transported to SNAARC. Hence, including the 73 larval fish collected in May, our objective of transporting 500 chub to SNAARC for 2014 Shinumo and Havasu translocations was easily met. Finally, during the Oct/Nov collection trip, 305 humpback chub (80-130 mm) were successfully translocated to above Chute Falls. All chub collected during this trip were from the Coyote reach.
The above 2013 Chute Falls monitoring and translocation activities are summarized in the following two trip reports submitted to Grand Canyon Monitoring and Research Center:

Dennis M. Stone. 2013. Summer 2013 Monitoring and Translocation of Humpback Chub (*Gila cypha*) above Lower Atomizer Falls in the Little Colorado River, Arizona. Trip Report for May 14-24, 2013 Monitoring Trip and July 8-12, 2013 Translocation Trip in the Little Colorado River, Arizona. Prepared for U.S. Geological Survey Grand Canyon Monitoring and Research Center, Flagstaff, AZ. U.S. Fish and Wildlife Service, Arizona Fish and Wildlife Conservation Office, Flagstaff, AZ. USFWS Document No. USFWS-AZFWCO-FL-13-003. 13 pp.

Dennis M. Stone and M. J. Pillow. 2013. Fall 2013 Monitoring of Humpback Chub (*Gila cypha*) and other Fishes in the Lower 13.57 km of the Little Colorado River, Arizona. Trip Report: Little Colorado River Sep. 13-19 and Oct. 29-Nov. 07, 2013. Prepared for U.S. Geological Survey Grand Canyon Monitoring and Research Center, Flagstaff, AZ U.S. Fish and Wildlife Service, Flagstaff, AZ. USFWS Document No. USFWS-AZFWCO-FL-14-001. 14 pp.

Project Element F.4.4. PIT Tag Antenna Monitoring

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

Two PIT tag antenna arrays deployed in the Little Colorado River were monitored during 2012-13. The upstream array was operational through most of the year although flooding during July and September disconnected two of the five antennas. The downstream array operated well through most of 2012, but flooding disconnected several antenna cables. Cables were repaired and replaced in November, 2013. As of December 24, 2013 nine of twelve antennas were operational. During 2013 antennas detected 3,069 unique humpback chub, 1,783 unique bluehead suckers and 1,229 unique flannelmouth suckers. Antenna data were used in an analysis and presentation on spawning probability of humpback chub at the 2013 Desert Fishes Council meeting by Kristen Pearson, Colorado State University.

Project Element F.5. Stock Assessment and Age Structured Mark Recapture Model Humpback Chub Abundance Estimates

Charles Yackulic, Research Statistician, USGS/GCMRC
Steve Martell, Professor, Uni. Of British Colombia

Better sampling in the Colorado River, pioneered in the Near Shore Ecology project and continued in the Juvenile Chub Monitoring project, now allows us to make better inferences about population vital rates (growth, survival, etc.) than was possible prior to 2009. For example, it is now possible to fit models that estimate survival and growth independently for the Little Colorado River and Colorado River and this has revealed systematic spatial variation in these rates. As a consequence, chub that rear entirely in the Colorado River may not grow to over 250 mm until they are 8-9 years old, whereas chub rearing in the Little Colorado River reach this size in roughly half this time. Prior modelling efforts were forced to assume that fish grew at the same rates regardless of their environment (N.B. Coggins et al. 2006 attempted to fit spatial models to pre-2006 data and the research statistician has tried using pre-2009 data, however there is simply not enough information, partially due to the lack of systematic sampling in this era.)

Another issue with ASMR, and more recently SSMR, is the way they model the capture process, given our understanding of chub biology and the timing of sampling. In particular, these analyses assumed an annual time step and lumped together various sampling efforts covering different spatial extents, but assumed all chub of a given size had equal capture probability. This assumption is likely to be grossly violated, and heterogeneity in capture probability is well known to lead to biased estimates of abundance (and may also explain the so-called retrospective bias reported for ASMR). To illustrate the extent of this bias, consider the single largest contributor of data to ASMR and SSMR, monitoring data in the Little Colorado River collected by FWS. Many chub are caught during the two spring trips and these captures include some adult chub that only recently migrated to spawn and will soon leave, as well as some adults that are likely to remain through the fall (and perhaps the next spring) and will thus be exposed to two more capture events. In addition, there is a proportion of the adult population that will not enter the LCR at all during the year, but may have been present the year before (so-called skip spawners). As such some adults have a higher capture probability (chub exposed to both fall and spring sampling), others have a lower capture probability (chub exposed only to spring sampling) and other have a capture probability of zero (adults that don't spawn).

Given the arguments above and improvements in sampling, ASMR is no longer the best available model for estimating population size and associated vital rates and this project element was combined with population modeling project E.3. Accordingly, the research statistician will report demographic parameters as estimated within a multistate framework (see Project E.3). The multistate approach has already yielded key insights into key management questions including the relative roles of trout and temperature in determining recruitment to the adult population. Over time this framework will evolve as more data becomes available, key assumptions are tested, and additional hypotheses are investigated. For example, there may be additional strong sources of heterogeneity in the systems either with regards to the capture process or vital rates (including movement parameters) that have not yet been considered in any modelling framework. Moreover, current efforts to tie covariates to vital rates must necessarily take a fixed effects approach because only four years of data are available, however, random effect should yield more realistic estimates of uncertainty when data becomes available.

Project Element F.6. Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam/Natal Origins

Josh Korman, President, Ecometic Research, Inc.
Michael Yard, Fishery Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
David Rowgoski, Fishery Biologist, AZGFD

In response to FWS Biological Opinion (2012) the primary goal of this project is to estimate abundance, movement, growth, and mortality of age-0 and older rainbow trout between Glen Canyon Dam and LCR confluence area. Research and monitoring objectives are to determine the physical and/or biological factors responsible for trout movement (density, food, growth, turbidity, HFEs, etc.) and to quantify the extent of trout movement originating from Lees Ferry into Marble Canyon and LCR confluence area. In 2013 four seasonal mark and recovery trips (January, April, July, and September; 9 da/trip) were conducted at Lees Ferry (-5.5 to -2.1 RM), House Rock (17.2 to 20.6 RM), Buckfarm (38.2 to 41.6 RM), Above LCR (60.2 to 61.2 RM) and Below LCR (63.4 to 64.9 RM). An additional fall trip (10 da/trip) was conducted throughout Glen Canyon (-15.5 to 0.0 RM) to mark new age-0 recruits, juvenile and adults (2013). This overall project began in the fall of 2011 and has resulted in a total combined catch of 161,125 trout (fall of 2011, 2012-2013), which includes 53,510 PIT-tagged trout and 4,543 recaptured trout. Capture probabilities estimated for within (0.05-0.21) and across trips (0.02-0.10) are negatively correlated to trout density (300-17,000/km), such that capture probabilities are low when trout abundance is high, which limits reliability of trout index sampling. Currently, recapture data indicates that trout residency is high with minimal movement among individuals (99.3% of across trip recaptures have an absolute movement distance less than 20 km). However at a population level, metrics for both abundance and length frequency suggest there is evidence for downstream dispersal among study reaches showing declining trends in abundance in the upper three reaches and an increasing trend in the lower two reaches. Reach estimates of age structure distributions and survival rates suggest that the quantity of young recruits into the LCR inflow area are insufficient in numbers to maintain overall population levels without additional immigration from older /larger fish. Abundance estimates below the LCR (Reach IVb) indicate that trout numbers have exceeded the threshold level specified in Biological Opinion for three of four sampling periods in 2013. Also, there is some evidence that the very large trout cohort of 2011 immigrated (episodic dispersal) from Glen Canyon into the downstream reaches of Marble Canyon prior to the initiation of this study. Recapture data indicates that trout growth rates are highest in the spring for all downstream reaches in Marble Canyon with the lowest growth occurring in Lees Ferry and below the LCR. Growth overall decreases during summer (July-Sept.) due to turbidity (exception Lees Ferry), whereas growth in the fall and winter remain low for all study reaches, which is likely due to food limitations.

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

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

Invertebrate drift and rainbow trout diet samples were collected on each of 4 Natal Origins river trips in FY13 (i.e., January, April, June, and September 2013). At each of 5 Natal Origins sampling reaches, 20 invertebrate drift samples and 20 rainbow trout diet samples were collected, for a total of 500 drift and 500 diet samples in FY13. Similar sampling was conducted in FY12 during the 3 Natal Origins river trips that were conducted in FY12. To date, drift and diet samples from the first year of the Natal Origins project have been processed in the laboratory (i.e., the 500 drift and 500 diet samples collected in April, June, and September of 2012, and January of 2013, have been completed). These data will allow us to determine how the availability of drifting invertebrate prey varies through space and time, and whether rainbow trout feeding habits track the availability of prey in the drift. These data on prey availability and trout feeding habits among locations will also aid interpretation of rainbow trout densities and movements among Natal Origins sampling locations.

Project Element F.7.2. Citizen Science Monitoring of Emergent Aquatic Insects

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Adam Copp, Ecologist, USGS/GCMRC
Colden Baxter, Idaho State University

In FY13 we collaborated with fifteen different commercial river guides to acquire emergent insect samples from throughout Marble and Grand Canyon. 562 emergent insect samples were collected by these citizen scientists between April and mid-November of 2013. Laboratory processing of all 562 samples, which contained over 1 million insects, was completed in December 2013. Preliminary results, including comparison with the 2012 emergence data, will be presented at the January reporting meeting.

Project Element F.7.3. Primary Production Monitoring

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

In collaboration with the GCMRC water quality monitoring program, we have been continuously monitoring dissolved oxygen concentrations in Glen Canyon, river mile 30, river mile 61, river mile 87, river mile 166, and river mile 225. Continuous dissolved oxygen monitoring in Glen Canyon was started in 2008, at river mile 225 continuous monitoring started in 2009, and for other locations monitoring of dissolved oxygen started in 2011.

In FY13, dissolved oxygen data from Glen Canyon were analyzed by cooperators at University of Wyoming and Montana State University and used to estimate primary production for the Colorado River from 2008-2011; processing of data from 2011-present is ongoing. Processing of dissolved oxygen data from 2009-2012 from river mile 225 was also completed by cooperators at University of Wyoming. Processing of dissolved oxygen data from other sites will occur in FY14. These data will be used to characterize how primary production, which represents the base of the Colorado River food web, varies seasonally and spatially. These data will also be used to parameterize mechanistic models of primary production that are described in Project H.

Project Element F.7.4. Benthic Algae and Invertebrate Biomass

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

Benthic algae and invertebrate biomass were characterized in conjunction with four Natal Origins river trips in FY13. Benthic algae and invertebrate biomass were collected at each of five Natal Origins sampling sites. Processing of these samples is ongoing.

Project G Elements. Interactions between Native Fish and Nonnative Trout

David Ward, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Mike Yard, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Scott VanderKooi, Supervisory Biologist, USGS, Grand Canyon Monitoring and Research Center
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park
Clay Nelson, Fishery Biologist, NPS, Grand Canyon National Park
Emily Omana, Fishery Biologist, NPS, Grand Canyon National Park
Melissa Trammel, Fishery Biologist, Intermountain Region
David Speas, Fishery Biologist, Bureau of Reclamation

Project Element G.1. Laboratory studies to assess the effects of trout predation and competition on Humpback chub

David Ward, Fishery Biologist, USGS/GCMRC

Effects of water temperature and turbidity on predation vulnerability of juvenile humpback chub to rainbow trout and brown trout

Predation of juvenile native fish by introduced rainbow trout *Oncorhynchus mykiss* and brown trout *Salmo trutta* is considered a significant threat to the persistence of endangered humpback chub *Gila cypha* and other native fishes in Grand Canyon. Diet studies of rainbow trout and brown trout in Grand Canyon indicate that these species do eat native fish, but population level impacts are difficult to assess because predation vulnerability changes with turbidity, fish size, and water temperature. We conducted laboratory experiments to evaluate how short term predation vulnerability of humpback chub changes in response to each of these factors. Hatchery-reared, juvenile humpback chub 50 to 90 mm TL were exposed to rainbow and brown trout at 10, 15, and 20 °C and at turbidities ranging from 0 to 1000 formazin nephelometric units (FNU). Brown trout were highly piscivorous at all sizes and water temperatures. A 1° C increase in water temperature decreased short term predation vulnerability of humpback chub to rainbow trout by about 5%. Increases in turbidity reduced predation vulnerability above 50 FNU. Relatively low turbidities 50-100 FNU appear to be sufficient to significantly reduce predation vulnerability of humpback chub to rainbow trout, but additional trials are needed to quantify this relationship. This will be the focus of research conducted in 2014.

An Experimental evaluation of competition between rainbow trout *Oncorhnchus mykiss* and humpback chub *Gila cypha*

Introduced rainbow trout *Oncorhynchus mykiss* inhabit many of the same environments as endangered humpback chub *Gila cypha* in Colorado River in Grand Canyon. Competition for limited food resources between these two fish species may play an important role in humpback chub population dynamics. We evaluated competitive interactions between humpback chub and rainbow trout in 30-day laboratory trials at 16 °C using 12 replicate artificial stream systems. PIT tagged fish were fed a maintenance ration of 2 percent body weight per day and monitored for changes in weight. Small humpback chub (114 mm mean TL) lost weight (4 %) when held in systems with adult rainbow trout (247 mm mean TL) whereas humpback chub (110 mm mean TL) in tanks without trout increased their body weight by 18 % over the same time period. Size matched roundtail chub *Gila robusta* (236 mm mean TL) (as a surrogate for humpback chub) and rainbow trout (259 mm mean TL) showed a similar pattern, but results were less pronounced with chub alone gaining 1.3 % body weight and chub with trout loosing 4.2% of their body weight during the 30-day trial. These data suggest humpback chub in Grand Canyon could be adversely impacted by competitive interactions with adult rainbow trout although these relationships may change with water temperature.

Project Element G.2. Efficacy and ecological impacts of brown trout removal at Bright Angel Creek

David Ward, Fishery Biologist, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS/GCMRC
Scott VanderKooi, Supervisory Biologist, USGS/GCMRC
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park
Emily Omana, Fishery Biologist, NPS, Grand Canyon National Park
Melissa Trammel, Fishery Biologist, Intermountain Region
David Speas, Fishery Biologist, Bureau of Reclamation

Introduced brown trout are known to prey upon juvenile native fish in Grand Canyon and may adversely impact recruitment of juvenile humpback chub that disperse downstream from the Little Colorado River. A multi-year, brown trout removal treatment using electrofishing is currently being conducted in collaboration with the National Park Service to evaluate the efficacy and feasibility of using mechanical removal to reduce brown trout populations in this area. In 2013, mechanical removal of brown trout occurred in both Bright Angel Creek and in the 8.45 km section of the mainstem Colorado River surrounding Bright Angel Creek. Mainstem removal efforts took place from Nov 19-Dec 1, 2013. Researchers conducted a 5-pass depletion over the entire sampling area using two 16’ sport boats and removed 1,370 rainbow trout and 336 brown trout during this 10-day effort. All fish were processed for human consumption. Turbid water, and low flow conditions occurring during the sampling period impeded electrofishing efforts. Population estimates and estimates of removal efficiency are not yet known as data entry and analysis are not yet complete.

Project H Elements. Understanding the Factors Limiting the Growth of Rainbow Trout in Glen and Marble Canyons

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS, USGS/GCMRC
Mike Anderson, Fishery Biologist, Arizona Game and Fish Department
Luke Avery, Biologist, USGS/GCMRC
Robert Hall, Biologist, University of Wyoming
Josh Korman, President, Ecometric Research Inc.
Scott Wright, Research Hydrologist, USGS, California Water Science Center
William Persons, Fishery Biologist, USGS/GCMRC

Project Element H.1. Laboratory Feeding Studies

Luke Avery, Fishery Biologist, USGS/GCMRC

This project aims to evaluate the growth potential of Lees Ferry rainbow trout relative to three other strains of rainbow trout by rearing them in captivity. Forty rainbow trout, from each of four different strains, were placed into two outdoor ponds located at the Rocky Mountain Research Station in Flagstaff, AZ during the spring and summer of 2013. The four strains of rainbow trout used were: Lees Ferry, Bell Aire, Hoefer (whirling disease resistant) and Fish Lake (triploid). All fish were tagged with Passive Integrated Transponder tags (PIT) to allow individual assessment of growth rates. Permitting restrictions would not allow rainbow trout from Lees Ferry, that could be infected with whirling disease, to be transported and held in outdoor ponds in Flagstaff, so gametes were taken from spawning rainbow trout and reared in the laboratory until they were of adequate size to be PIT tagged. This additional step has added a year to the length of time it will take to achieve results for this study, because very small sizes fish had to be acquired for each strain to prevent predation. Fish are fed a combination of live red wigglers *Eisenia fetida* and amphipods *Gammarus lacustris* during the growing season. Ponds will be harvested in spring of 2014 to assess initial growth rates and then returned to the ponds for further grow out.

Project Element H.2.1. Developing a Mechanistic Model of Primary Productivity

Mike Yard, Fishery Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Bob Hall, Biologist, University of Wyoming

The objective of this project element is to develop a mechanistic model of primary production that can be used to make predictions about the effects of dam operations and environmental conditions (i.e., turbidity, water quality from Lake Powell) on a key food web component—algae. The current model being developed uses photosynthetic-irradiant curves where photosynthetic rates vary with underwater irradiance, temperature, and algal biomass (Yard

2003). The study location used in this model is important because most of the primary production in this system occurs in Glen Canyon. The initial model uses a specific reach (-6 to 0 RM) found in Glen Canyon because of empirical data collected from past and present studies as part of the aquatic foodbase monitoring (project F.7.4 Benthic Algae and Invertebrate Biomass;) and possible biotic linkages with other research studies assessing higher trophic levels (Project Element H.2.2. Characterizing Invertebrate Drift Element; and Project F.6. Detection of Rainbow Trout Movement). Physical data required as part of this project include: solar incidence, light extinction coefficients, channel geometry, water velocity, temperature, unsteady flow routing, and algal biomass. Incoming solar incidence reaching the surface of the water is affected strongly by topographic obstructions. The topographic complexity in Glen Canyon generates a mosaic (spatial and temporal) of varying solar incidence available to the aquatic ecosystem, and the optical properties of water (light extinction coefficients, K m^{-1}) then determine the quantity of light (instantaneous photosynthetic photon flux density PPFD: µmol m^{-2} s^{-1})used by algae found at given channel depths. These data are generated from past and current optical measurements made and an existing solar incidence model (Yard et al. 2005). Channel geometry and stage discharge relationships (Randle and Pemberton 1987) are used for estimating depth intervals over a range of daily flow variation using hypsometric analysis. The unsteady flow model (Wiele and Griffin 1997) provides a method for varying algal depth exposed to different underwater light regimes or to desiccation affects from atmospheric exposure and resultant loss in algal biomass (Benenati et al. 1998). Surface area for the channel-bed is determined by multiplying stream length between cross-sections and then summing across all channel segments along the longitudinal axis of the river. The potential productive areas of the channel are determined using estimated proportions of hard (> 25 cm) substrate and fine sediment on the bed and its vertical distribution within the channel. Using photosynthetic-irradiant curves (Yard 2003) are used to estimate primary production at specific depths by varying PPFD, temperature, and algal biomass over small time intervals. All of these secondary models and predictive relationships are currently being programmed as subroutines for this mechanistic primary production model.

Project Element H.2.2. Characterizing Invertebrate Drift

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS/GCMRC

Humpback chub and rainbow trout are the two focal fish species that drive many of the management actions undertaken by the Glen Canyon Dam Adaptive Management Program. Both species are 'drift feeders', which means they consume invertebrate prey that are drifting through the water column. Further, previous food base research documented that populations of both species are limited by the availability of high quality invertebrate prey (Cross and others 2013, Kennedy and others 2013). The objective of this project element is to describe how invertebrate drift concentrations (i.e., prey availability) for humpback chub and rainbow trout varies through space and time.

To characterize spatial variation in invertebrate drift in Glen Canyon, we conducted two comprehensive invertebrate drift sampling experiments in FY13. In October 2012, invertebrate drift concentrations were quantified at 25 locations throughout the 25 kilometer long Glen Canyon tailwater. Sampling was conducted on four consecutive days while discharge was a constant 8,000 ft3/s. Sampling direction varied among days (i.e., upstream to downstream, downstream to upstream) so spatial and temporal variation in drift concentrations could be separated. Drift sampling was repeated again in late May 2013 on two consecutive days while discharge was also constant 8,000 ft3/s associated with the quadrennial overflight. During the May data collection, water velocity profiles used to estimate shear stress were also collected at each station, and benthic invertebrate density was quantified at each sampling location. These data identify hotspots of invertebrate drift in Glen Canyon, and statistical analyses will determine whether these hotspots are associated with areas of high benthic invertebrate density, high bed shear stress, or both.

Invertebrate drift and benthic sampling was also conducted at 3 locations (Glen Canyon, Little Colorado River confluence area, and Diamond Creek) during the November 2012 High Flow Experiment to evaluate how large dam releases affect invertebrate drift. Drift sampling was done 5 times each day before, during, and after the HFE (35 different sampling bouts at each of three locations). Drift concentrations were characterized at 5 equally spaced locations across the channel at each sampling reach, yielding over 400 total drift samples among all locations. Laboratory processing of all Glen Canyon HFE samples was completed in November 2013. Sample processing for other locations is ongoing. These data will be used to characterize how invertebrate drift concentrations among reaches vary across a large range of discharges.

An additional 400 invertebrate drift samples were collected in FY13 in conjunction with the Natal Origins of Rainbow Trout project. 20 Samples were collected at each of the 5 Natal Origins sampling reaches, and sampling occurred during each of the 4 Natal Origins trips in FY13. At each sampling reach, samples were collected at a single location during midday (6 samples per site and date) and again at the same location during late afternoon/evening just prior to when rainbow trout gut contents were collected (14 samples per site and date). To date, all 300 drift samples collected in FY12 have been processed, as well as 100 of the samples collected in FY13 (from January 2013 trip). Sample processing for the other three trips conducted in FY13 is ongoing.

Project Element H.3. Developing a Bioenergetics Model for Large Rainbow Trout

Charles Yackulic, Research Statistician, USGS/GCMRC
Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS/GCMRC
Scott Wright, Research Hydrologist, USGS, California Water Science Center
Mike Anderson, Biologist, Arizona Game and Fish Department
Josh Korman, President, Ecometric Research Inc.

In FY13, an existing trout foraging and bioenergetics models was recoded in an open source software (R statistical program), which will enable us to modify this model to better environmental conditions in Lees Ferry. Using data collected from other studies in the work plan, we are beginning to use this model to investigate how growth varies under different scenarios. Initial modelling suggests the important role that size of maturation may play in determining how rainbow trout grow as they age. We are currently working to scale measurements of prey weight (measured in dry weight) to measurements of rainbow trout weight (measured in wet weights). In FY 2014, we will continue to develop this model and determine the degree to which the growth of large rainbow trout can be explained by bioenergetics constraints, including allocation of resources to reproduction and the lack of larger prey items in the Lees Ferry tailwater.

Project Element H.4. Learning from other Tailwaters—a Synthesis of Tailwaters in the United States

Theodore Kennedy, Research Aquatic Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
Bill Persons, Fishery Biologist, USGS/GCMRC
Mike Yard, Fishery Biologist, USGS/GCMRC
Josh Korman, President, Ecometric Research Inc.

The objective of this project is to describe the effects of dam operations on the size structure of rainbow and brown trout populations in tailwaters across the Western United States. It is anticipated that by learning how flow regimes influence salmonid population dynamics in other regulated rivers, this project will inform fishery management in the Glen Canyon Dam by providing insights into those flow management strategies that are mostly likely to benefit the rainbow trout fishery.

Dr. Kimberly Dibble, post-doctoral researcher, was hired in January 2013 to spearhead this project. This project is being conducted in several phases, the first of which involved the acquisition and compilation of biological (fish, foodbase), environmental (flow, reservoir volume, water quality, temperature), and physical (stream size) data from state, federal, non-governmental, and Tribal organizations. Throughout spring and summer of 2013, Dibble acquired data from 56 tailwaters in 34 different rivers spanning Arizona, Colorado, Utah, New Mexico, Idaho, Montana, Nevada, California, Oregon, and Wyoming.

Data synthesis and analysis represents the second phase of this project. At present, Dibble and her advisors (Drs. Charles Yackulic, Ted Kennedy, Phaedra Budy) have conducted an initial analysis of the data using 'mixed-effects models' (http://en.wikipedia.org/wiki/Mixed_model). Mixed effects models are being used to identify the functional relations between trout population metrics (i.e., average adult size and overall size structure of the population) and predictors such as reservoir storage capacity, reservoir age, the degree of hydropeaking, seasonal flow patterns, inter-annual variability in discharge, trout stocking rate, presence/absence of fish diseases, invertebrate prey richness, and rainbow and brown trout densities. A manuscript that describes results from these analyses will be submitted for peer-review in FY14.

Phase three of this project will include more focused analyses in data-rich tailwaters in the Colorado River Basin (e.g., Navajo, Flaming Gorge, etc.). The purpose of these analyses is to identify the precise mechanisms underlying differences in salmonid growth rates among tailwaters. Because many mechanisms underlying trout growth rate differences might be indirect and involve several causal steps (e.g., dam operations→prey base→trout growth), phase three analyses will use a statistical technique known as 'path analysis' (http://en.wikipedia.org/wiki/Path_analysis_(statistics)). Results of this analysis will be presented in a peer-reviewed journal article that will be submitted in early FY15.

We also expect to produce at least one additional synthetic journal publication as part of this project given the richness of the accumulated datasets, however, the exact nature of this publication will depend on results from the first two analyses. Additionally, all information will be condensed and presented in a USGS Fact Sheet. Information products will be provided to the GCDAMP and other natural resource managers and fishery biologists throughout the West, including those that provided data in support of the synthesis.

Project Element H.5. Contingency Planning for High Experimental Flows and Subsequent Rainbow Trout Population Movement

Mike Yard, Fishery Biologist, USGS/GCMRC
Josh Korman, President, Ecometric Research, Inc.

The objective of this project element is to determine the effects of fall HFEs and other potential management actions on rainbow trout populations in the Glen Canyon sport fishery. It is possible that fall HFEs may lead to further population fluctuations and dispersal of rainbow trout downstream that might necessitate further management response(s); furthermore these fall HFE may also directly impact juvenile and adult rainbow trout (RBT) abundance for the Glen Canyon sport fishery. For this reason an additional fall mark-recapture trip is conducted in December post HFE to estimate trout abundance, survival, and movement of RBT throughout the entire length of Glen Canyon (-15.5 to 0.0 RM). The sampling design for this study incorporates other sampling efforts that are conducted as part of the Natal Origin marking trip (Project Element F.6). The Natal Origin marking trip is annually conducted in the fall (October) prior to any scheduled flow event. A total of 195 sites (250 m in shoreline length) are sampled over a 10 day period. This sampling effort is then followed by an additional late fall trip that recaptures previously marked fish as well as marks new age-0 recruits, juvenile and adult RBT. Prior to the HFE in 2013, the total electrofishing catch for RBT from the initial fall marking trip conducted between 10/22 and 11/01/2013 had a catch of 10,981 fish that comprised of 2,610 fish <75 mm total length (TL), 2,849 between 75-150 mm TL, and 5,522 fish >150 mm TL. The total number of fish marked with PIT-tags was 5,838 fish. The post HFE trip conducted between 12/08 and 12/17/2013 had a catch of 7,943 RBT that comprised of 816 fish <75 mm TL, 2,304 between 75-150 mm TL, and 4,823 fish >150 mm TL. The total number of fish marked with PIT-tags was 5,536 fish. The total number of across trip recaptures (i.e., that also includes additional marks from other Natal Origin trips) for the December post HFE trip was 422 RBT. Currently, estimates of across trip differences in the abundance, and rates of survival, growth, and movement for RBT has not been determined.

Project I Elements. Riparian Vegetation Studies: Response Guilds as a Monitoring and Modeling Approach with Landscape Scale Vegetation Mapping for Change Detection

Barbara Ralston, Biologist, USGS, Grand Canyon Monitoring and Research Center
Phil Davis, Research Geologist, USGS, Grand Canyon Monitoring and Research Center
Joel Sankey, Research Physical Scientist, USGS, Grand Canyon Monitoring and Research Center
Todd Chaudhry, Restoration Ecologist, Grand Canyon National Park, NPS
Lori Makarick, Vegetation Program Manager, Grand Canyon National Park, NPS
Dustin W. Perkins, Program Manager, Northern Colorado Plateau Inventory and Monitoring Program, NPS
Anthony M. Starfield, Modeling consultant, Dallas, Texas

Project Element I 1.1. Monitoring vegetation and channel response using vegetation response guilds and landscape scale vegetation analysis

Barbara Ralston, Biologist, USGS/GCMRC
Todd Chaudhry, Restoration Ecologist, Grand Canyon National Park, NPS
Lori Makarick, Vegetation Program Manager, Grand Canyon National Park, NPS
Dustin W. Perkins, Program Manager, Northern Colorado Plateau Inventory and Monitoring Program, NPS
Post-doc, USGS/GCMRC
Technician, USGS/GCMRC

Riparian vegetation monitoring in FY13 consisted of sampling fixed sites that are coincident with Project A 1.1 (Monitoring sandbars using topographic surveys and remote cameras) and conducting the first trip of sampling random sites in coordination with the National Park Service's Northern Plateau Inventory and Monitoring Network's Big Rivers Protocol. Entering data and analysis of the previous October 2012, fixed site sampling trip also occurred. Sampling consisted of recording plant species and estimating cover of those species occurring within 1-m^2 plots placed within three zones of potential inundation associated with dam operations. These zones and the range of discharge that define each zone's boundaries are as follows:

- the active channel (8k ft^3/s to 25k ft^3/s, daily inundation within this range of discharge)
- the active floodplain (25k ft^3/s to 45k ft^3/s, potentially yearly inundation dependent on sediment input volumes and reservoir elevations)
- the inactive floodplain ($\geq$ 45k ft^3/s, low potential of inundation, dependent on reservoir elevations, last inundation occurred in the late 1980's)

The boundaries are related to the current record of decision flows (Department of Interior, 1996) which define release volumes from Glen Canyon Dam at which fluctuations change to steady releases (25k ft^3/s), and the upper boundary associated with high flow experimental releases, to date (45k ft^3/s). The inactive floodplain is that area that last inundated by dam operations in the 1980's. Plots in this last zone were limited to 6 m above the 45k ft^3/s boundary.

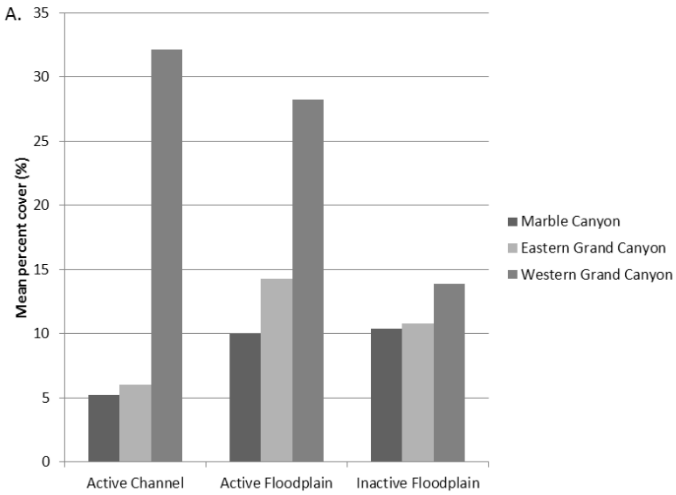
The 2012 October trip resulted in 22 sites, 847 plots sampled, and 115 plant species encountered. Overall, the number of plant species encountered declined with distance downstream among three river segments: Marble Canyon (n=73 species encountered in plots), Eastern Grand Canyon (n=50 species encountered) and Western Grand Canyon (n=44 species encountered). This pattern of decline occurred in the active channel (fig. 1) for mean species richness. In contrast, richness was greater in the active floodplain in Eastern Grand Canyon and Western Grand Canyon compared with Marble Canyon, while richness in the inactive floodplain was similar across segments (fig. 1).

Table 1. Species richness, evenness and diversity for river segments by hydrologic zones for 2012 samples

River Segment	Hydrologic zone	Species richness	Species evenness	Simpson's diversity index
Marble Canyon	Active Channel	3.4	0.51	0.71
	Active Floodplain	1.5	0.24	0.32
	Inactive Floodplain	2.3	0.72	0.69
Eastern Grand Canyon	Active Channel	0.5	0.17	0.13
	Active Floodplain	2.5	0.67	0.76
	Inactive Floodplain	2.6	0.74	0.82
Western Grand Canyon	Active Channel	0.5	0.14	0.09
	Active Floodplain	2.4	0.8	0.82
	Inactive Floodplain	2.8	0.86	0.92

Mean herbaceous plant cover was greatest in Western Grand Canyon across all hydrologic zones (figure 1A), while mean woody vegetation was lowest in the active channel for the Eastern Grand Canyon and Western Grand Canyon river segment (Figure 1B). The percent cover of woody vegetation in the active channel of Marble Canyon was similar to those in other hydrologic zones and among other river segments (figure 1B). Among herbaceous species, *Phragmites australis* (common reed) was the most frequently encountered species in the active channel (Table 2). *Pluchea sericea* (arrowweed) and *Tamarix* spp (tamarisk) were the most frequently encountered woody species (Table 2). The low vegetative cover may be a result of scour associated with the equalization flows that occurred in the summer of 2011. Data from 2013 may show increases vegetative cover for the river segments of Marble Canyon and Eastern Grand Canyon.

Figure 1. Mean herbaceous (A) and woody (B) vegetation cover for plot from three river segments and across three hydrologic zones.



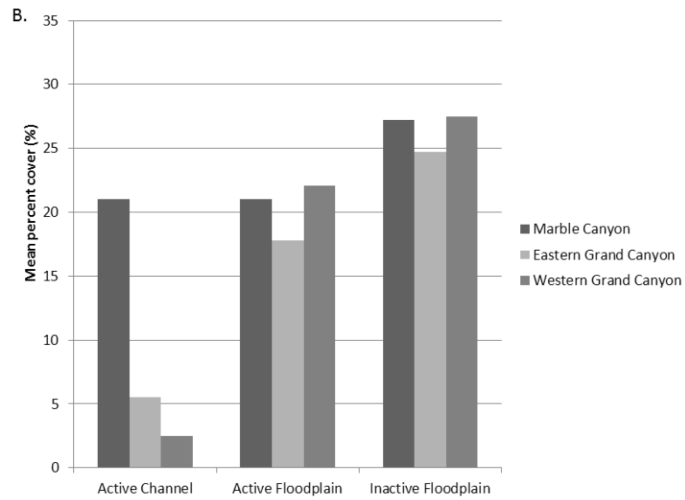


Table 2. Dominant herbaceous and woody plant species for plot from three river segments and across three hydrologic zones.

River Segment	Hydrologic zone	Dominant herbaceous species of plots	Dominant woody species of plots
Marble Canyon	Active Channel	*Phragmites australis*	*Pluchea sericea / Tamarix* spp.
	Active Floodplain	*Phragmites australis / Carex* sp.	*Pluchea sericea / Tamarix* spp.
	Inactive Floodplain	*Lepidium latifolium / Bromus rubens*	*Pluchea sericea / Tamarix / Prosopis* glandulosa
Eastern Grand Canyon	Active Channel	*Cynodon dactylon*	*Tamarix* spp.
	Active Floodplain	*Equisetum* sp.	*Tamarix* spp.
	Inactive Floodplain	*Bromus rubens / Sporobolus* sp.	*Acacia greggii*
Western Grand Canyon	Active Channel	*Phragmites australis*	*Pluchea sericea*
	Active Floodplain	*Phragmites australis / Cynodon dactylon*	*Baccharis / Pluchea sericea*
	Inactive Floodplain	*Bromus* rubens	*Baccharis / Tamarix* sp./ *Prosopis glandulosa*

Analysis in FY14 will used vegetation plot data collected in 2012 and 2013 to identify the response guilds found along the river corridor and to compare percent cover values, species richness, evenness, and species diversity between years, among river segments, and among hydrologic zones. The information will form the content for annual vegetation monitoring reports and a manuscript describing response guilds found within Grand Canyon.

Project Element I 1.2. State and transition model develop for riparian vegetation

Barbara Ralston, Biologist, USGS/GCMRC
Anthony M. Starfield, Modeling Consultant, Dallas, Texas
Colorado River Riparian Ecologists (TBD)

Frame-based models, used successfully in grassland systems, provide an opportunity for stakeholders concerned with riparian systems to evaluate riparian vegetation responses to alternative flows. In FY13, frame-based, state and transition models of riparian vegetation for reattachment bars (Figure 1a), separation bars (Figure 1b) and the channel margin (Figure 1c) found downstream from Glen Canyon Dam were constructed using information from the literature. The models are spreadsheet models that include seven states (Table 1) and five operations (default, sustained high flows, sustained low flows, experimental high flows, and spill control flows) that cause transitions between states. Each model divides operations into the growing (April to September) and non-growing seasons (October to March) and incorporates an upper and lower bar submodels. The inputs (operations) can be used by stakeholders to evaluate flows that may promote dynamic riparian vegetation states, or identify those flow scenarios that may promote less desirable states (for example the state of Tamarisk (*Tamarix* sp.) temporarily flooded shrubland). This prototype model, though simple, can still elicit discussion about operational options and vegetation response. A manuscript of this model is in review and to be published as an Open-File Report.

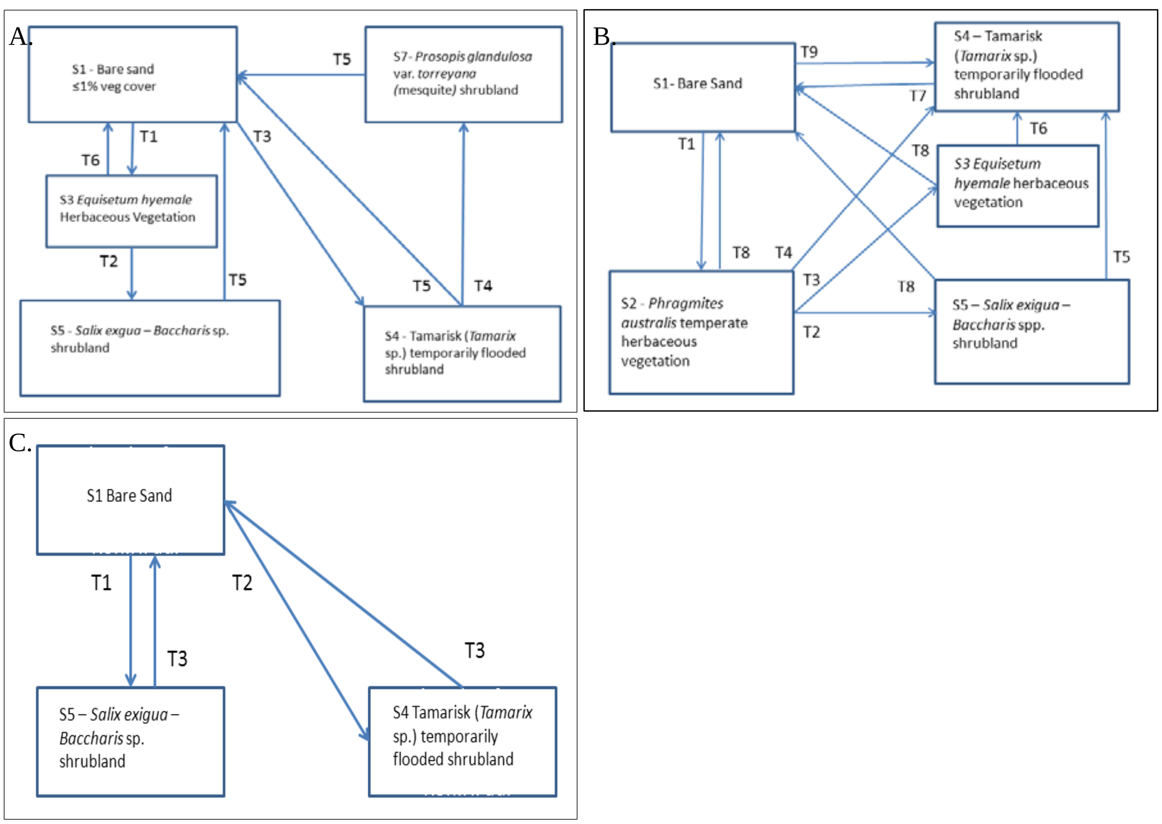


Figure 1. State and transition diagram for (A) a reattachment bar, (B) as separation bar, and (C) a channel margin. Transitions are numbered and are associated with the starting

state of a transition arrow pointing toward the end state, that are identified as plant associations.

Table 1. List of community states and plant associations

Community States	Plant Associations	Channel Association
S1 - Bare sand	<1 percent vegetation	All
S2 – *Phragmites australis* temperate herbaceous vegetation	Common reed (*Phragmites australis*), cattail (*Typha latifolia*), common tule (*Schoenoplectus acutus*), creeping bent grass (*Agrostis stolonifera*). Cover to 20 percent	Active channel
S3 – *Equisetum hyemale* herbaceous vegetation	Occurs in small patches around seeps, ponds, on streambanks, and within floodplains. Associated with forb species *Apocynum cannabinum* and *Helenium autumnale var. montanum*. Other forbs occur with low cover. Seedlings of *Populus deltoides ssp. wislizeni* are often present, as are the shrubs *Chrysothamnus* sp. and *Salix exigua*.	Active Channel to lower boundary of Active floodplain (<31k ft^3/s stage)
S4 – Tamarisk temporarily flooded shrubland	Tamarisk (*Tamarix* spp.). Dense woody cover	Active channel and throughout active floodplain
S5 – *Salix exigua* – *Baccharis* spp. shrubland	Seepwillow (*Baccharis* spp.,), Goodings willow (*Salix goodingii*), and Coyote willow. High, dense, woody cover.	Active channel, to 31k ft^3/s – active floodplain
S6 – *Pluchea sericea* seasonally flooded shrubland	Arrowweed (*Pluchea sericea*) in pure stands, or associated with *Baccharis* spp., Mesquite (*Prosopis glandulosa*), coyote willow. The latter species occurring in low cover.	Throughout active floodplain
S7 – *Prosopis glandulosa* var. *torreyana* shrubland	Mesquite dominant associated with *Baccharis* spp, *Pluchea sericea*.	Primarily ≥ 40k ft^3/s discharge. Found in inactive floodplain ≥50k ft^3/s

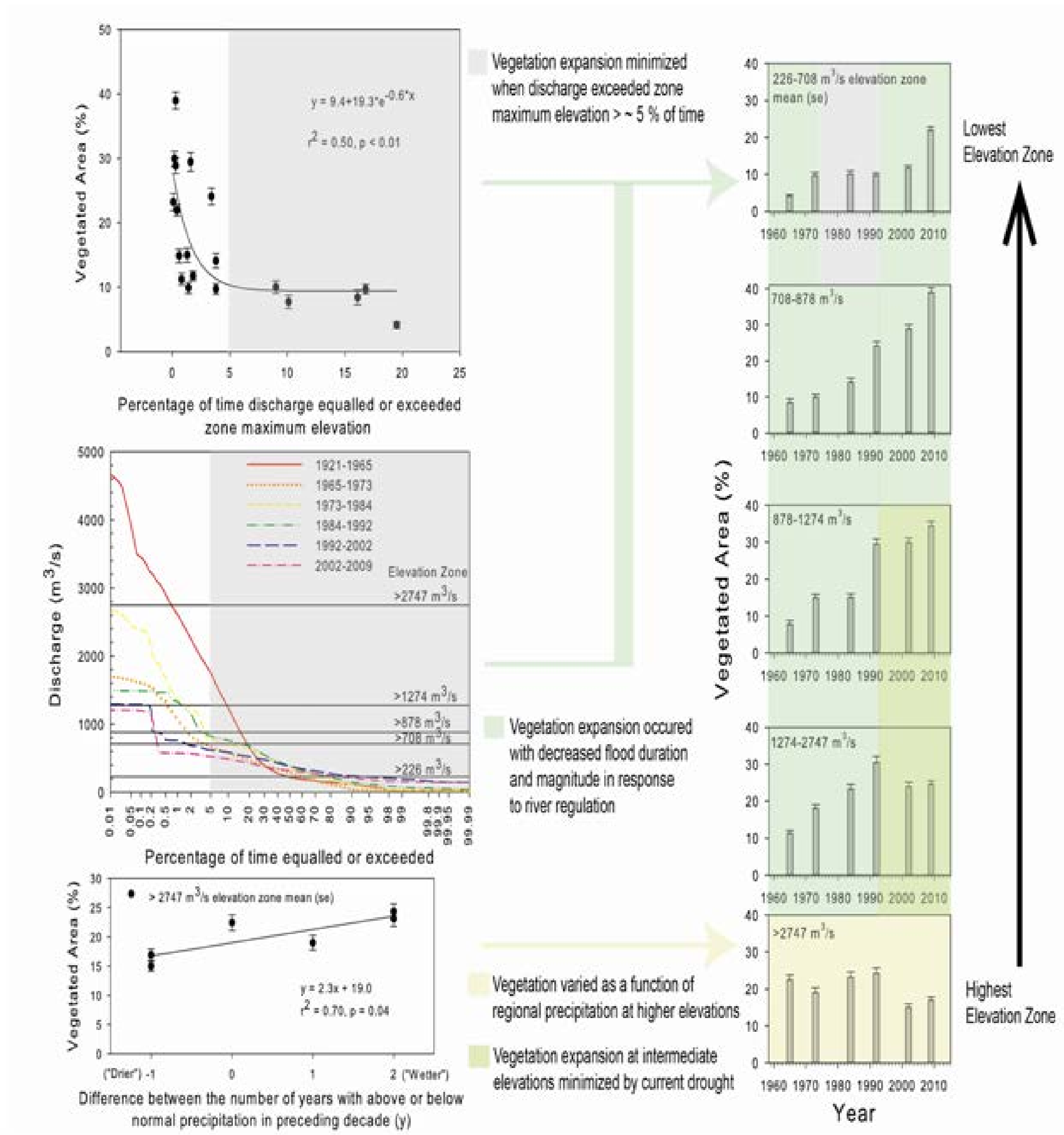
Table 2. Operations of Glen Canyon Dam and extent of potential inundation for three channel categories (active channel, active floodplain, and inactive floodplain).

Dam operation options	Active Channel (8k ft^3/s – 25k ft^3/s)	Active floodplain (25k ft^3/s - 45k ft^3/s)	Inactive floodplain/uplands (>45k ft^3/s)
Default operations	Daily fluctuating operations that vary by 8k ft^3/s daily, do not fluctuate above 25k ft^3/s stage	No inundation	No inundation
High flow Experiment	Steady flows for duration of operations that exceed default operations. Duration at peak up to 96 hours	High Flow in spring or fall can vary from 25k ft^3/s to 45k ft^3/s. Duration of inundation at peak is 96 hours.	No inundation
Sustained high flows	High steady flows 25k ft^3/s of duration >1 month.	Inundation between 25k - 45k ft^3/s stage.	No inundation
Sustained low flows	Low steady flows ≤ 10k ft^3/s Duration for 1 month to 3 months	No inundation	No inundation
Spill control flooding	Steady flows for the duration of the high flow	High magnitude flow in late spring/summer –≥45k ft^3/s	Inundation to 90k ft^3/s stage possible

Project Element I.1.3 Periodic landscape scale vegetation mapping and change analysis using remotely sensed data

Phil Davis, Research Geologist, USGS/GCMRC
Joel Sankey, Research Physical Scientist, USGS/GCMRC
Barbara Ralston, Biologist, USGS/GCMRC

We examined spatio-temporal changes, and persistence, in riparian vegetation for ~400 km of the Colorado River relative to dam and reservoir management and regional climate, over the 5-decade period from completion of the upstream Glen Canyon Dam in the mid-1960s to present. We employed archived maps that used aerial imagery from six dates between 1965 and 2009 coupled with flow regime data related to dam operations. Analysis confirmed a net increase in vegetated area occurred since the completion of the dam. Magnitude and timing of vegetation change were river stage-dependent. Vegetation expansion at lower elevations relative to the river was greater for decades with lower average discharges. At higher elevations, vegetated area reflected regional precipitation patterns, and coincided with significant wet and dry periods. A majority of elevation zones analyzed for riparian vegetation were decoupled from river hydrology in the current, early 21st-century drought. Dam operations intended to promote the resilience of riparian vegetation to future changes must contend with communities that have been subjected to decreased water availability and disconnected from river hydrology. These results are part of a manuscript to be submitted to a peer-reviewed journal in January/February of 2014 (Sankey and others, unpublished data).


Vegetated Area (%)
y = 9.4+19.3*e^-0.6*x
r2 = 0.50, p < 0.01
Percentage of time discharge equalled or exceeded zone maximum elevation
Discharge (m3/s)
1921-1965
1965-1973
1973-1984
1984-1992
1992-2002
2002-2009
Elevation Zone
>2747 m3/s
>1274 m3/s
>878 m3/s
>708 m3/s
>226 m3/s
Percentage of time equalled or exceeded
> 2747 m3/s elevation zone mean (se)
y = 2.3x + 19.0
r2 = 0.70, p = 0.04
("Drier") -1
2 ("Wetter")
Difference between the number of years with above or below normal precipitation in preceding decade (y)
Vegetation expansion minimized when discharge exceeded zone maximum elevation > ~ 5 % of time
Vegetation expansion occured with decreased flood duration and magnitude in response to river regulation
Vegetation varied as a function of regional precipitation at higher elevations
Vegetation expansion at intermediate elevations minimized by current drought
226-708 m3/s elevation zone mean (se)
708-878 m3/s
878-1274 m3/s
1274-2747 m3/s
>2747 m3/s
Year
Lowest Elevation Zone
Highest Elevation Zone

Project J Elements. Monitoring Cultural Resources at a Small Scale and Defining the Large-Scale Geomorphic Context of the Processes affecting Cultural Resources

Helen Fairley, Archaeologist and Cultural Program Manager, USGS/GCMRC
Amy Draut, Research Geologist, USGS Pacific Coastal and Marine Science Center
Brian Collins, Research Civil Engineer, Research Geologist, USGS Geology, Minerals, Energy and Geophysics Science Center
Skye Corbett, Geomorphologist, USGS Geology, Minerals, Energy and Geophysics Science Center
David Bedford, Research Geologist, USGS Geology, Minerals, Energy and Geophysics Science Center
Phil Davis and Joel Sankey, Research Physical Scientists, USGS/GCMRC

Project Element J.1. Cultural Site Monitoring in Glen

Helen Fairley, Archaeologist and Cultural Program manager, USGS/GCMRC
Brian Collins, Research Civil Engineer, USGS Geology, Minerals, Energy and Geophysics Science Center
Skye Corbett, Geomorphologist, USGS Geology, Minerals, Energy and Geophysics Science Center

In FY2013, we conducted field work, processed previously collected and new data sets, attended project and stakeholder meetings, and began preparation of reports. Field work consisted of site visits to four archaeological sites in Glen Canyon (AZ:C:02:0032, AZ:C:02:0035, AZ:C:02:0075, AZ:C:02:0077, all located between river mile -9 to river mile -12) during February 27-28, 2013, layout of survey panel targets on June 25-28, 2013 for overflight and airborne lidar data collection, and collection of airborne lidar from July 9-10, 2013 for approximately 8.5 river miles that overlapped the archaeological sites previously referenced. During the February 2013 field work, we made soil infiltration measurements, mapped areas of active and inactive aeolian sediment, and field-checked the location and size of gullies determined previously using remote sensing methods (i.e., terrestrial lidar and photogrammetric digital surface models - DSMs). During the June 2013 field work, we established 16 survey panel locations total on both sides of the river that were subsequently used for error checking of airborne lidar data collected in July 2013. For this effort, we contracted with Fugro Aerial and Airborne Mapping, Inc. to fly a low-altitude helicopter lidar mission from approximately river mile –6 to mile -14.5. The aerial lidar data were delivered by Fugro in August 2013, thoroughly reviewed by the Collins, Sankey and Corbett, and accepted as complete in September 2013. The data collection effort met specifications, capturing a point density of >50 points/m^2 per flight line and providing average vertical and horizontal accuracy within 7 and 10 cm (95% confidence), respectively, as specified in the data acquisition proposal. Processing work consisted of reprocessing our September 2012 terrestrial lidar data into the most recently updated coordinate system now being used at GCMRC (NAD82[NA2011]), conducting the error analysis of the airborne lidar data (found to be within specification), and integrating and analyzing the dual terrestrial-airborne lidar data sets for geomorphological analysis.

On February 25, 2013, we met with members of Glen Canyon National Recreational Area (GCNRA) at their Page, Arizona offices to share results from our September 2012 terrestrial lidar data collection work and to identify protocols and data formats for transfer of final products related to this data. We also attended several conference calls with fellow Project J staff and communicated our results with GCNRA staff via email and phone calls. Finally, we continued work on a now 60% complete USGS Scientific Investigations Report (SIR) that will become the final product for the delivery of the 2012 terrestrial and 2013 airborne lidar data sets and results, along with an integration of analyses using photogrammetric digital surface models (DSMs). This SIR had previously been slated for publication as a USGS Open File Report (OFR), but the timely data collection and integration of the airborne data has allowed us to make progress on a more substantial and interpretive SIR rather than a more simple data presentation OFR. The SIR report is expected to be published in 2014.

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

Helen Fairley, Cultural Program Manager, USGS/GCMRC
Brian Collins, Research Geologist, USGS Geology, Minerals, Energy and Geophysics Science Center
Skye Corbett, Research Geologist, USGS Geology, Minerals, Energy and Geophysics Science Center

This part of Project J aims to measure rates and processes of landscape change at 4 archaeological sites in Grand Canyon that are known to receive windblown sand from HFE (fluvial sandbar) deposits. Measurement of landscape change, and the weather events (wind and rainfall) to which landscape change can be attributed, depends on data collected at weather stations, from camera stations taking daily photographs, and from high-resolution terrestrial lidar surveys. During 2013 the investigators conducted fieldwork in Grand Canyon on a river trip lasting from 4/27/13 to 5/14/13. The work conducted on that trip supported both J.2 and J.3 components and is summarized here; full details are provided in the trip report that was sent to NPS (trip permit GRCA 3300-3181) at the end of May 2013.

During the Grand Canyon trip, terrestrial lidar surveys (high-resolution topographic surveys) were completed successfully at 24.8L, 70.4L, 125.6L, and 223.5R. (These 4 study sites had also been scanned by terrestrial lidar in 2006-2007 and 2010, providing a longer-term basis for assessing landscape change at those places). We established working weather stations at river-mile 24.8L, 70.4L, 125.6L, and 223.5R, and stationary cameras were set up at 24.8L, 70.4L, and 125.6L. No camera was deployed at 223.5R because no suitable camera location could be found that provided a satisfactory view of the study site. Cameras and weather stations were subsequently downloaded in August and September during a vegetation monitoring trip and were found to be working normally, with the exception of a camera malfunction at 125.6L and the discovery that NPS rangers had inadvertently removed the weather station at 223.5 R in July. (This station was replaced with the assistance of NPS rangers in December, 2013). Lidar data collected during the spring trip are currently being processed by Corbett in Menlo Park and are being compared with previous surveys at those study sites to analyze sediment volume gain or loss, and mechanisms of landscape change. Processing of weather data and stationary camera photos will begin in January, 2014, with the hiring of a project support technician.

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

Amy Draut, Research Geologist, USGS Santa Cruz
David Bedford, Research Geologist, USGS Menlo Park
Joel Sankey, Research Physical Scientist, GCMRC

This component of Project J evaluates the role of aeolian sand in the larger landscape context of limiting and annealing gully erosion, particularly erosion which may compromise archaeological sites. Active and inactive aeolian sand area was mapped during the spring 2013 river trip in the reaches specified in the project permit, having previously been completed in Glen Canyon from RM-6 to -13 during the February field work session described above under project component J.1. Specifically, Draut mapped sand area in RM 87–99, 116–130, and 207–210. The mapping captured not only sand areas showing geomorphic features of aeolian reworking (dunes, etc.) but all river-derived sand area; we mapped any river-derived sand as being either active or inactive with respect to aeolian transport to help answer one of the research questions driving Project J—to what extent does aeolian sand activity in Grand Canyon potentially limit gully development? After the fieldwork, these data were digitized by Draut into ArcGIS and compared with the occurrence of gully erosion, using remote-sensing data developed by Sankey from 2009 digital topography data, and 1984, 2002, 2009 imagery, previously acquired by the GCMRC remote sensing program. Results indicate that a wide range of variability in the relative aeolian activity of sediment deposits and abundance of gullies exists throughout Grand Canyon. Gully erosion was found to be more prevalent in sediment deposits that are inactive with respect to aeolian transport, which supports one of the study hypotheses. This and associated results have been written up in a journal manuscript by Sankey and Draut that is currently undergoing internal and external peer review (Sankey and Draut, in review). These results were also presented by Sankey at the fall meeting of the American Geophysical Union in San Francisco, CA.

Also during the spring 2013 fieldwork, we visited 76 archaeological sites (site numbers are listed in the trip report) to assess the role of river-derived sand in the geomorphic context of each, to determine local prevailing wind directions, and to assess whether the November 2012 HFE deposited new sediment upwind of those sites, and if so, whether any topographic or vegetation barrier was present that would limit windblown transport of HFE sand toward the archaeological site(s). We also used these site visits to collect information on the specific attributes of each site that contribute to their relative stability or actively deteriorating condition.

From those site visits, and with the help of Jennifer Dierker (NPS), we developed a classification system to identify whether HFE sand supply likely reaches each site through post-HFE windblown sediment transport. In this classification system, we assign sites to one of five types. Types 1–4 refer to sites where river-derived sand is an integral part of the geomorphic context, while Type 5 refers to sites where river derived sand is incidental to the geomorphic setting of the site or non-existent.

- Type 1 = sites with an adjacent, upwind HFE sand deposit (these receive HFE-derived aeolian sand supply)
- Type 2 = sites with an upwind HFE deposit but some kind of barrier separating the HFE deposit from the archaeological site:
- 2a = vegetation barrier between HFE deposit and archaeological site
- 2b = topographic barrier, such as a tributary channel or high cliff, separating the HFE sand from the archaeological site
- 2c = both vegetation and topographic barrier separating HFE deposit and archaeological site
- Type 3 = sites with a 45,000 cfs shoreline upwind, but no HFE sand having been deposited there
- Type 4 = sites with no 45,000 cfs shoreline upwind.
- Type 5 = sites where river-derived sand is absent or only incidental to site context.

This classification system ranks sites in order of their likelihood of receiving aeolian sand supply resulting from HFEs of 45,000 cfs or similar magnitude. Field observations of the site context, local prevailing wind direction, and 2012 HFE response were compared with archival photographs in the GCRMC library from the 1996 HFE to provide a more thorough evaluation of the overall number and proportion of river-corridor archaeological sites that (potentially) benefit from HFE flows of ~45,000 cfs. So far, we have classified 181 sites and we have approximately 212 additional sites to assess, including sites in Glen Canyon. Although this classification work and analysis are not yet complete, preliminary results show that there are more Type 3 sites and fewer Type 1 sites in 2013 compared to 1984 or 1996. These preliminary results will be discussed further at the January 2014 TWG reporting meeting.

Another component of J.3 involves the use of models to simulate landscape changes through time. In 2013, two modeling activities occurred. The first involved the use of a high-resolution rainfall-runoff model to determine which kind of observed rainfall events are likely to have caused erosion at sites where change has been detected in the past. The model requires high-resolution data to run, and can take several days for an event to be simulated (depending on the amount of runoff generated and the input topography resolution – typically 25x25 cm grid cells). The results have been used to identify thresholds for runoff-generating rainfall and likely erosion (Collins and others, in review). The results are also being used in Project J to generalize site characteristics that make them more or less likely for erosion (i.e. larger proportions of low-infiltration areas such as bedrock/colluvium or dense cryptobiotic crusts). The second modeling activity involves using a landscape evolution model (LEM) to better understand the larger dynamics driving gully formation. The LEM we are using, called CAESAR-lisflood (Coulthard and others, 2012), is capable of determining erosion and deposition over long time scales and can integrate river dynamics such as variable discharge (and thus base level). The model can use real or synthetic data at relatively coarse resolution. Currently we are running the LEM using the last 50 years of rainfall and river discharge to simulate erosion over ~1-2 mile-long river reaches, using a DEM that has had gullies "erased" (filled) as an initial condition. The model is run using observed river discharge, constant flow discharge, and a heightened (flashy) discharge to determine effects of river discharge on incision of gullies, and to better understand where gullies are initiated, assuming that aeolian processes anneal (fill) them.

Thus far, fieldwork and associated office work for this project have been informative and successful. We anticipate that additional valuable information will come from repeat lidar surveys planned for FY2014 and additional archaeological-site evaluations that will take place during the spring 2014 river trip.

References

Collins, B. D., Bedford, D.R., Corbett, S.C., Cronkite-Ratcliff, C. and Fairley, H.C., Meteorologic and anthropogenic effects on archeological site change in Grand Canyon, Arizona: fluvial-aeolian interactions within a dam-controlled river corridor. *Journal of Geophysical Research*, in review.

Coulthard, T.J., Hancock, G.R., and Lowry, J.B.C., 2012, Modelling soil erosion with a downscaled landscape evolution model: Earth Surface Processes and Landforms, v. 37, no. 10, p. 1046-1055.

Sankey, J.B., and Draut, A.E., Gully annealing by aeolian sediment: field and remote-sensing investigation of aeolian-hillslope-fluvial interactions, Colorado River corridor, Arizona, USA: *Geomorphology*, in review.