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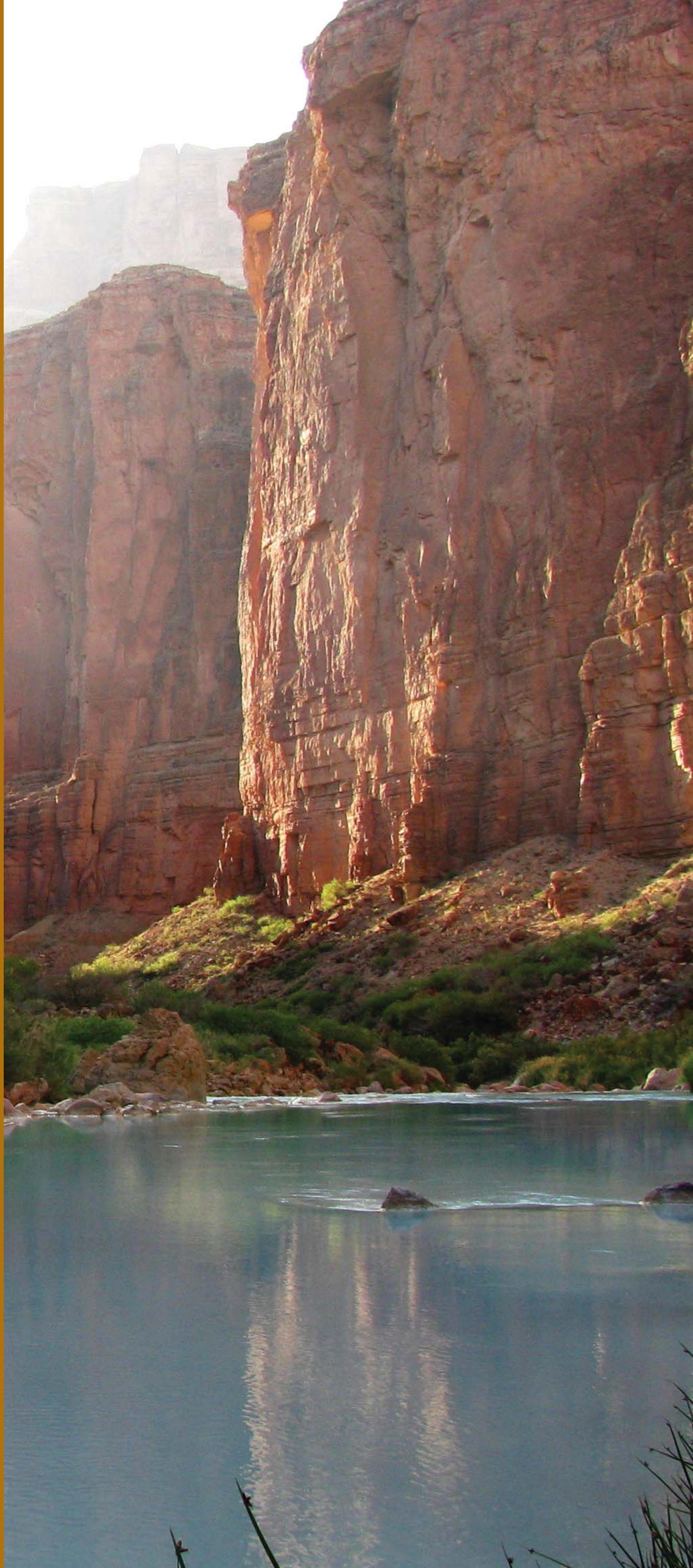
RECLAMATION
Managing Water in the West

Prepared in cooperation with the Glen Canyon Dam Adaptive Management Program

Glen Canyon Dam Adaptive Management Program Biennial Budget and Work Plan—Fiscal Years 2013–14

Prepared by
Bureau of Reclamation
Upper Colorado Regional Office
and
U.S. Geological Survey
Grand Canyon Monitoring and Research Center



Planning Document

U.S. Department of the Interior
U.S. Geological Survey

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Prepared by

Bureau of Reclamation
Upper Colorado Regional Office
Salt Lake City, Utah

and

U.S. Geological Survey
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Flagstaff, Arizona

Final—Approved by the Secretary of the Interior
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U.S. Department of the Interior
U.S. Geological Survey

Contents

Chapter 1. Bureau of Reclamation, Upper Colorado Region, Biennial Budget and Work Plan—Fiscal Year 2013/14

Introduction

The Glen Canyon Dam Adaptive Management Program (GCDAMP) is a science-based process for continually improving management practices related to the operation of Glen Canyon Dam (GCD) by emphasizing learning through monitoring, research, and experimentation. The Bureau of Reclamation's (Reclamation) Upper Colorado Region (BRUC) is responsible for administering funds for the GCDAMP and providing those funds for monitoring, research, and stakeholder involvement. The majority of program funding is derived from hydropower revenues; however, supplemental funding is provided by various Department of the Interior (DoI) agencies that receive appropriations. These agencies include Reclamation, the U.S. Geological Survey (USGS), the National Park Service (NPS), the U.S. Fish and Wildlife Service (USFWS), and the Bureau of Indian Affairs (BIA).

The budget and work plan for fiscal years 2013 and 2014 (FY13/14) was developed based on previous budgets and work plans, the GCDAMP Biennial Budget and Work Process approved by the AMWG on May 6, 2010, the Streamlined GCMRC Biennial Work Planning Process, version April 3, 2011, and GCDAMP priorities identified in a memo from Secretary's Designee Anne Castle on Grand Canyon Monitoring and Research Center (GCMRC) science planning. Additional consideration was given to meeting the commitments outlined in the following compliance documents(1) the *2007 USFWS Biological Opinion for the Proposed Adoption of Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (2007 Opinion); (2) the *2011 Reclamation Environmental Assessment* (EA) and *2012 Finding of No Significant Impact* (FoNSI) *for Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam, Arizona, 2011 through 2020* (HFE Protocol); (3) the *2011 Reclamation EA and 2012 FoNSI for Non-native Fish Control Downstream from Glen Canyon Dam* (NNFC EA and FoNSI); and the *2011 USFWS Final Biological Opinion on the Operation of Glen Canyon Dam including High Flow Experiments and Non-Native Fish Control* (2011 Opinion).

The process used to arrive at the FY 13/14 budget and work plan was adopted by the AMWG in 2004 and revised in 2010 and 2011 to a 2-year fixed budget. In summary, the Budget Ad Hoc Group (BAHG) of the Technical Work Group (TWG), with input from the Cultural Resources Ad Hoc Group (CRAHG), works with the BRUC and the GCMRC to develop a proposal for the TWG. The TWG then reviews the proposed budget and work plan and develops a recommendation to the AMWG (this document).

The FY 13/14 budget and work plan was also prepared in consideration of the projected hydrograph for Lake Powell release for water year (WY) 2013, which is based on forecasted inflows to Lake Powell reservoir and GCD releases determined by the 1996 Record of Decision on the operation of Glen Canyon Dam, the 2007 Record of Decision on interim guidelines for coordinated operation of Lake Mead and Lake Powell, and the 2008 FoNSI on the EA of experimental releases for the period 2008–12, and with the consideration of the FY12 BWP approved by the Secretary of the Interior on December 7, 2011. It also observes commitments made in the 2007 and 2011 biological opinions. The projected hydrograph is based on best estimates available from Reclamation's 24-month study released in May 2010; however, the forecast is subject to change as further data become available.

This document consists of two chapters: Chapter 1, the BRUC budget and work plan, and Chapter 2, the GCMRC budget and work plan. The FY13/14 BWP is organized differently from the BWPs of past years. The FY13/14 BWP includes fewer projects, and each project is organized around larger monitoring and research themes. For example, there were 12 projects concerning fish and other aquatic resources in the FY11/12 BWP, and there are 5 projects in the FY13/14 BWP. The monitoring and research themes identified in the FY13/14 BWP are those common to (1) the 5 priority questions and the 12 program goals developed by the AMWG in 2004, (2) the monitoring and research plan prepared by GCMRC, approved by AMWG in August 2007 and amended and approved in April 2009 (U.S. Geological Survey, 2007a), (3) the strategic science plan prepared by GCMRC in March 2007 and amended in April 2009 (U. S. Geological Survey, 2007b), (4) the draft Core Monitoring Plan (U. S. Geological Survey, 2011), (5) the General Science Plan appended to the Environmental Assessment for the Development and Implementation of a Protocol for High-flow Experimental Releases from Glen Canyon Dam (Bureau of Reclamation, 2011a, appendix B), (6) the Research and Monitoring Plan for the Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam (Bureau of Reclamation, 2011b, appendix B), (7) the March 31, 2011 memorandum from Secretary's Designee Anne Castle on GCMRC Science Planning; and (8) the 2011 report of the Desired Future Conditions Ad Hoc Group of the AMWG.

A comprehensive budget spreadsheet is provided in Appendix A-1.

A.1. Adaptive Management Work Group Costs

This budget represents Reclamation staff costs to perform the daily activities required to support the Adaptive Management Work Group (AMWG), the GCDAMP Federal Advisory Committee Act (FACA) committee. The work includes completing assignments resulting from AMWG meetings, consulting with stakeholders on a variety of GCDAMP issues relating to the operation of GCD, disseminating pertinent information to the AMWG, preparing and tracking budget expenses, and updating Reclamation's Web page. Reclamation also responds to regular requests from the General Services Administration (GSA) to complete FACA reports and incorporate meeting and member information into the FACA database. Reclamation is now required to complete all stakeholder travel, activities that range from preparing travel authorizations to completing travel vouchers. Additionally, BRUC staff must provide documentation related to litigation involving the Department of the Interior's operation of Glen Canyon Dam to various solicitors; these efforts often require many hours of work not programmed into the fiscal year budget(s).

The primary goal is to perform all work associated with the AMWG in a timely and efficient manner, while using the funds available as prudently as possible. Secondary goals include increasing each stakeholder's awareness of significant budget and legislative issues related to the GCDAMP, improving working relationships with the AMWG members/alternates, finding constructive ways to resolve differences, and addressing individual concerns in an open and accepting forum of discussion.

Reclamation will work to ensure that personnel costs will not exceed what has been proposed in the budget unless Federal employee salaries are increased above the consumer price index (CPI). Reclamation staff will provide budget information to the AMWG on a regular basis. Completed work products will be of high quality and promptly distributed to AMWG members/alternates and interested parties. Budget reports will be presented in a format conducive to AMWG needs.

Budget

FY13 = $190,391
FY14 = $196,103

Reclamation Project - Personnel Costs—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	123,223	132,892	131,165	134,443	136,846	141,030	145,261
Subtotal	123,223	132,892	131,165	134,443	136,846	141,030	145,261
DOI Overhead (35%)	35,735	43,855	43,284	44,367	47,923	49,361	50,842
Project total	158,958	176,747	174,449	178,810	184,846	190,391	196,103
Total outsourced (%)							

A.2. AMWG Member Travel Reimbursement

This budget covers the costs to reimburse AMWG members or alternates to attend regularly scheduled AMWG meetings.

Reimbursing AMWG members or alternates for travel expenses is done to encourage their attendance at all meetings. Many members live outside of Phoenix, Arizona, where meetings are typically held. As a result, many members must incur travel costs. By providing such reimbursement to AMWG members or alternates for air travel or mileage for the use of private vehicles, as well as other related travel costs such as hotel, per diem, and rental car, Reclamation can increase opportunities for members to participate in a variety of AMWG assignments. Because Reclamation can purchase airline tickets at the Federal Government rate, there are additional cost savings to the program.

The GCDAMP benefits from having all AMWG members participating in regularly scheduled meetings. As a collective body, they address and resolve concerns associated with the operation of GCD and make recommendations to the Secretary of the Interior for continued science efforts performed below the GCD.

Budget

FY13 = $15,199
FY14 = $15,655

Reclamation Project - AMWG Travel Reimbursement—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	16,651	17,467	17,240	17,671	14,756	15,199	15,655
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	16,651	17,467	17,240	17,671	14,756	15,199	15,655
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	16,651	17,467	17,240	17,671	14,756	15,199	15,655
Total outsourced (%)	—	—	—	—	—	—	—

A.3. AMWG Reclamation Travel

This budget supports travel expenses Reclamation staff incur to attend AMWG and ad hoc group meetings. In order to work on AMWG/ad hoc assignments, the meetings are typically held in Phoenix, Arizona. As such, Reclamation staff must make additional trips throughout the year in completion of those assignments.

The primary goal is for Reclamation staff to be able to travel to meetings and participate in completing AMWG/TWG assignments. By doing so, the program benefits from greater interaction among its members as well as continued improvement and commitment to operating GCD in the best manner possible and obtaining the results from science being conducted in the study area.

Reclamation staff will be involved with AMWG/TWG members in completing work assignments and resolving issues that affect the GCDAMP. They will develop better working relationships with all involved and work toward consensus on a variety of sensitive issues.

Budget

FY13 = $15,595
FY14 = $16,062

Reclamation Project - Reclamation Travel—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	13,765	14,439	13,994	14,344	15,140	15,595	16,062
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	13,765	14,178	13,994	14,344	15,140	15,595	16,062
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	13,765	14,178	13,994	14,344	15,140	15,595	16,062
Total outsourced (%)	—	—	—	—	—	—	—

A.4. AMWG Facilitation Contract

This budget supports a facilitator who is under contract to Reclamation to provide facilitation services for AMWG meetings. This person may also assist AMWG ad hoc groups in completing assignments.

The facilitator's primary responsibility is to keep the AMWG meetings organized and help the members reach consensus on important issues. The facilitator creates a setting that allows all members and the public to express their views.

Budget

FY13 = $41,747
FY14 = $43,000

Reclamation Project - Facilitation Contract—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	25,700	26,959	26,609	27,274	40,531	41,747	43,000
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	25,700	26,959	26,609	27,274	40,531	41,747	43,000
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	25,700	26,959	26,609	27,274	40,531	41,747	43,000
Total outsourced (%)	—	—	—	—	—	—	—

A.5. Public Outreach

This budget covers the expenses for Reclamation staff and the Public Outreach Ad Hoc Group (POAHG) to develop materials for the GCDAMP public outreach efforts.

Reclamation public affairs staff and the POAHG will work jointly in developing materials to inform and educate the public on the goals and administration of the GCDAMP. They will keep other GCDAMP members advised of progress and expenditures.

Products will include fact sheets, Web site information, tribal outreach materials, video B-roll, special events, conference participation, and other pertinent means of advising the public and program members on the achievements of the GCDAMP. The POAHG will maintain accurate records of payments made against the contracts and will keep Reclamation staff informed of discrepancies or concerns.

Budget

FY13 = $59,305
FY14 = $61,084

Reclamation Project - Public Outreach—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training		2,000	2,000	2,000	2,000	2,000	2,000
Operations/supplies	—	—	2,500	2,500	2,500	2,500	2,500
Reclamation salaries	41,040	38,846	36,714	37,744	39,430	45,247	46,605
Subtotal	41,040	40,846	41,214	2,244	43,930	45,247	46,605
DOI Overhead (35%)	11,902	13,684	13,600	13,940	15,375	15,837	16,312
Project total	52,942	55,536	54,814	56,184	59,305	61,084	62,917
Total outsourced (%)	—	—	—	—		—	

A.6. Other

This budget represents some of the other "miscellaneous" expenses incurred in operation of the AMWG, including the following expenses:

- Overnight mailings of AMWG meeting packets
- Copying of reports
- Purchasing meeting materials (cassette tapes, markers, paper, software upgrades for GCDAMP Web site posting, etc.)
- Purchasing equipment (audio recording/transcribing machines)

In addition to the expenses noted above, training courses are often required for staff to keep current on environmental issues, FACA changes, computer technology improvements, etc. Also included in this category are monetary awards given to Reclamation staff who have contributed significantly to the success of the GCDAMP.

The primary goal is to limit spending on "other" items as much as possible. By doing so, more money can be applied to science and research.

Other expenses will be kept to a minimum in an effort to reduce the administrative portion of the GCDAMP budget.

Budget

FY13 = $8,765
FY14 = $9,028

Reclamation Project - Other—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	5,597	5,969	5,865	6,062	6,509	6,765	7,028
Operations/supplies	2,000	2,000	2,000	2,000	2,000	2,000	2,000
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	7,597	7,969	7,865	8,062	8,509	8,765	9,028
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	7,597	7,969	7,865	8,062	8,509	8,765	9,028
Total outsourced (%)	—	—	—	—	—	—	—

B.1. TWG Personnel Costs

This budget represents Reclamation staff costs to perform the daily activities required to support the TWG, a subgroup of the AMWG. The work includes completing assignments resulting from TWG meetings, consulting with stakeholders on a variety of GCDAMP issues relating to the operation of GCD, disseminating pertinent information to TWG members, preparing and tracking budget expenses, and updating the Web pages Reclamation maintains for the program. Reclamation also completes all stakeholder travel activities, which range from preparing travel authorizations to completing travel vouchers.

Personnel costs will not exceed what has been proposed in the budget unless Federal employee salaries are increased above the CPI. Reclamation staff will provide budget information to the TWG on a regular basis. Completed work products will be promptly distributed to TWG members/alternates and interested parties.

Budget

FY13 = $92,045
FY14 = $97,651

Reclamation Project - Personnel Costs—Funding History

Activity	2008	2009	2010	2011	2012	2011	2012
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	56,306	64,808	63,965	65,565	68,181	70,227	72,334
Subtotal	56,306	64,808	63,965	65,565	68,181	70,227	72,334
DOI Overhead (35%)	16,329	21,387	21,109	21,636	23,864	24,579	25,317
Project total	72,635	86,195	85,074	87,201	92,045	94,806	97,651
Total outsourced (%)	—	—	—	—	—	—	—

B.2. TWG Member Travel Reimbursement

This budget provides funds to reimburse TWG members or alternates for expenses incurred to attend regularly scheduled TWG meetings.

Reimbursing TWG members or alternates for travel expenses is done to encourage their attendance at all meetings. Many members live outside of Phoenix, Arizona, where meetings are typically held. As a result, many members must incur travel costs. Having Reclamation provide reimbursement to TWG members or alternates for air travel or mileage for the use of private vehicles, as well as other related travel costs such as hotel, per diem, and rental car increases opportunities for members to participate in a variety of TWG assignments. Because Reclamation can purchase airline tickets at the Federal Government rate, there are additional cost savings to the program.

The GCDAMP will benefit from having all the TWG members participate in regularly scheduled meetings. As a collective body, TWG members address and resolve concerns associated with the operation of GCD and make recommendations to the AMWG for continued research.

Budget

FY13 = $22,331
FY14 = $23,001

Reclamation Project - TWG Member Travel Reimbursement—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	22,833	23,952	23,641	24,232	21,861	22,331	23,001
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	22,833	23,952	23,641	24,232	21,861	22,331	23,001
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	22,833	23,952	23,641	24,232	21,861	22,331	23,001
Total outsourced (%)	—	—	—	—	—	—	—

B.3. Reclamation Travel

This budget covers travel expenses that Reclamation staff will incur to prepare for and attend TWG meetings and ad hoc group meetings resulting from AMWG/TWG assignments. Meetings needed to advance AMWG/TWG efforts are typically held in Phoenix, Arizona, because it is centrally located to those entities/States represented on the AMWG/TWG. As a result, Reclamation staff members who are not located in Phoenix are required to make additional trips throughout the year in completion of AMWG/TWG assignments.

The primary goal is for Reclamation staff to be able to travel to meetings and participate in completing AMWG/TWG assignments. By doing so the program benefits from greater interaction among its members as well as continued improvement and commitment to operating GCD in the best manner possible and for obtaining the necessary results from science being conducted in the study area.

Reclamation staff will continue to be involved in meeting with AMWG/TWG members to complete work assignments and resolve issues that affect the operation of GCD. They will develop better working relationships with all involved and work toward consensus on a variety of GCDAMP issues.

Budget

FY13 = $15,407
FY14 = $15,869

Reclamation Project - Reclamation Travel—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	16,834	17,658	17,428	17,864	14,958	15,407	15,869
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	16,834	17,658	17,428	17,864	14,958	15,407	15,869
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	16,834	17,658	17,428	17,864	14,958	15,407	15,869
Total outsourced (%)	—	—	—	—	—	—	—

B.4. TWG Chair Reimbursement/Facilitation

This budget supports a person who is under contract to Reclamation to serve as the chairperson of the TWG. This person may also assist AMWG/TWG ad hoc groups in completing assignments. In the event that the TWG chair salary is covered through funding outside the GCDAMP, these funds can be used by Reclamation for administrative purposes or to cover professional facilitation of TWG issues.

The chairperson's primary responsibility is to conduct regularly scheduled TWG meetings. The chairperson also participates in ad hoc group assignments and works closely with Reclamation and GCMRC staff in setting meeting agendas. The chairperson follows up on TWG and ad hoc group assignments and ensures that information is shared with the members and alternates in a timely manner.

The chairperson creates an atmosphere in which the members and other participants at TWG meetings feel comfortable expressing their individual viewpoints. The chairperson will bring the TWG members to consensus on sensitive issues with the ultimate goal of making recommendations to the AMWG that incorporate the best scientific information available to the GCDAMP. The chairperson will follow up on action items and make assignments as necessary to accomplish TWG objectives.

Budget

FY13 = $31,049
FY14 = $31,980

Reclamation Project - TWG Chair Reimbursement—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	23,474	24,625	24,305	24,913	30,145	31,049	31,980
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	23,474	24,625	24,305	24,913	30,145	31,049	31,980
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	23,474	24,625	24,305	24,913	30,145	31,049	31,980
Total outsourced (%)	—	—	—	—	—	—	—

B.5. Other

This budget represents some of the other “miscellaneous” expenses incurred in support of the TWG, including the following expenses:

- Overnight mailings of TWG meeting packets
- Copying of reports
- Purchasing meeting materials (cassette tapes, markers, paper, etc.)
- Purchasing equipment (audio recording/transcribing machines)

The primary goal is to limit spending on “other” items as much as possible. By doing so, more money can be spent on science and research.

Other expenses will be kept to a minimum in an effort to keep within the GCDAMP budget.

Budget

FY13 = $2,504
FY14 = $2,579

Reclamation Project - Other—Funding History							
Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	2,171	2,277	2,247	2,303	2,431	2,504	2,579
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	2,171	2,277	2,247	2,303	2,431	2,504	2,579
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	2,171	2,277	2,247	2,303	2,431	2,504	2,579
Total outsourced (%)	—	—	—	—	—	—	—

C.1. Compliance Documents

This budget covers the costs for preparing documents for GCDAMP-proposed actions required to comply with the Endangered Species Act (ESA), National Environmental Policy Act (NEPA), and National Historic Preservation Act (NHPA). Reclamation staff will keep informed on changes to the ESA, NEPA, and NHPA and will consult with AMWG stakeholders to ensure appropriate compliance is undertaken for actions taken in support of the GCDAMP. Reclamation staff will be involved in all compliance issues related to the GCDAMP, using travel expenses to meet with the GCDAMP stakeholders to resolve any differences.

Because the primary compliance need for FY2013-14 will be the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS), and all personnel costs associated with the LTEMP will be paid through Reclamation appropriations, no funding is programmed for this project in FY13/14.

Budget

FY13 = $0
FY14 = $0

Reclamation Project - Compliance Documents—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	210,080	37,594	37,105	300,701	195,300		
Subtotal	60,923	37,594	37,105	300,701	195,300		
DOI Overhead (35%)		12,406	12,245	99,232	64,450		
Project total	271,003	50,000	49,350	399,933	259,750	0	0
Total outsourced (%)	—	—	—	—	—	—	—

C.2. Administrative Support for NPS Permitting

This budget provides funding to support the Grand Canyon National Park permitting of research and monitoring projects conducted under the GCDAMP. Grand Canyon National Park employs a permitting specialist and staff who review all proposals for projects to be completed in the park under the auspices of the GCDAMP. The program provides these funds to offset the park's administrative burden in providing these services.

The primary goal is to ensure that projects conducted under the GCDAMP are reviewed and permitted by the NPS.

Projects conducted under the GCDAMP will receive permits from the NPS in a timely manner.

Budget

FY13 = $126,242
FY14 = $130,029

Reclamation Project - Administrative Support for NPS Permitting—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	113,300	118,852	117,307	120,240	121,882	126,242	130,029
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	113,300	118,852	117,307	120,240	121,882	126,242	130,029
Total outsourced (%)	—	—	—	—	—	—	—

C.3. Contract Administration

This budget covers the expenses for Reclamation staff to prepare and monitor contracts associated with the GCDAMP. These contracts include AMWG facilitation and TWG chairperson reimbursement.

Reclamation contract specialists will accurately apply funds spent on individual contracts to ensure costs do not exceed contract limits. They will keep other Reclamation staff informed as to those charges so accurate reporting can be made to both AMWG and TWG members.

Contract specialists will ensure that individual contractors are fulfilling the requirements of their contracts. They will maintain accurate records of payments made against the contracts and will keep Reclamation staff informed of discrepancies or concerns. Work will be completed on time and within the limits of the contract.

Budget

FY13 = $43,945
FY14 = $45,264

Reclamation Project - Contract Administration—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	25,830	30,040	29,650	30,391	31,604	32,552	33,529
Subtotal	25,830	30,040	29,650	30,391	31,604	32,552	33,529
DOI Overhead (35%)	7,491	9,913	9,784	10,029	11,061	11,393	11,735
Project total	33,321	39,953	39,434	40,420	42,665	43,945	45,264
Total outsourced (%)	—	—	—	—	—	—	—

C.4. Experimental Carryover Funds

This budget item reserves funds for conducting experiments under the GCDAMP. The funds will be available to conduct experiments when conditions are appropriate. If the funds are not needed in a given year, they will be transferred to the Native Fish Conservation Carryover Fund.

Budget

FY13 = $515,000
FY14 = $515,000

Reclamation Project - Experimental Carryover Funds—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—		—		—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	500,000	500,000	493,500	505,838	521,013	515,000	515,000
DOI Overhead (35%)	—	—	—	—	—		—
Project total	500,000	500,000	493,500	505,838	521,013	515,000	515,000
Total outsourced (%)	—	—	—	—	—	—	—

C.5. Integrated Tribal Resources Monitoring

This budget item provides funds to identify traditional cultural properties (TCPs) and implement Native American monitoring protocols that were developed in FY07 and recommended by the TWG as part of efforts to develop a core-monitoring program.

In addition, the five GCDAMP Tribes (Hopi Tribe, Hualapai Tribe, Kaibab-Paiute Tribe, Pueblo of Zuni, and Navajo Nation) will work with Reclamation and the NPS to implement monitoring of historic properties in Glen and Grand Canyons. This will be accomplished by adding an additional 3 days to the annual GCDAMP monitoring trips.

The primary goal of this activity is to evaluate the effects of dam operations and other actions under the authority of the Secretary of the Interior on resources of value to Native American Tribes. A secondary goal is to conduct condition monitoring of historic properties to assist Reclamation in compliance with Section 106 of the National Historic Preservation Act.

Annual reports will be prepared detailing activities, findings, and monitoring data that result from implementing core-monitoring protocols for historic properties. Condition monitoring data will be provided to Reclamation to assist in prioritization of historic properties for treatment in subsequent years. In addition, monitoring data will be used to update NPS databases.

Budget

FY13 = $157,160
FY14 = $161,875

Reclamation Project - Integrated Tribal Resources Monitoring—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal (power revenues)	136,210	142,884	141,027	144,553	148,889	157,160	161,875
DOI Overhead (35%)	—	—	—	—	—	—	—
Appropriated Funds	—	—	75,000	75,000	—	—	—
Project total	136,210	142,884	216,027	219,553	148,889	157,160	161,875
Total outsourced (%)	—	—	—	—	—	—	—

C.6. Native Fish Conservation Contingency Fund

This budget item establishes a native fish conservation fund. This is a fund consisting of GCDAMP carryover funds from prior years, and serves to ensure that funds are available for the control of nonnative fish should the need arise. This includes implementation of non-native fish control actions as defined in the 2007 and 2011 Opinions, and the NNFC EA and F0NSI. Efforts to control nonnative fish, particularly warm water species that reproduce rapidly, may also be required to protect native fish populations more expeditiously than can be accommodated by the standard biennial budget process. Should excess funds become available beyond those needed for non-native fish control, these funds could be expended on other research, monitoring, and management actions that help conserve native fish. This fund will be incrementally increased with future carryover dollars when available.

Budget

FY13 = $782,660
FY14 = $1,321,139

Reclamation Project – Native Fish Conservation Contingency Fund—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	—	48,483	47,853	49,049	50,521	782,660	1,321,139
DOI Overhead (35%)	—	—	—	—	—	—	—
Project total	—	48,483	47,853	49,049	50,521	782,660	1,321,139
Total outsourced (%)	—	—	—	—	—	—	—

D.1. Cultural Resources Program Administrative Costs

This budget funds the salary and travel expenses of Reclamation staff to administer the NHPA compliance for the GCDAMP. This includes the 1994 PA for Glen Canyon Dam Operations, the 2012 Memoranda of Agreement (MOA) documents for Non-native Fish Control and the HFE Protocol, and general needs of tribal consultation for the GCDAMP. This also includes Reclamation staff administration costs associated with maintaining the grants for tribal participation in the GCDAMP and five tribal sole source contracts from power revenues to implement Native American monitoring protocols.

Project Goals and Objectives:

- Management of five tribal sole source contracts from appropriated funds for participation in the GCDAMP and management of five tribal sole source contracts from power revenues to implement Native American monitoring protocols.
- Management of the monitoring and data recovery of at-risk historic properties and other related projects associated with implementation of NHPA compliance agreements for the operation of Glen Canyon Dam.
- Attending TWG and AMWG meetings, Cultural Ad Hoc Group meetings, and conducting meetings required by the 1994 PA and 2012 MOAs.

Compliance with the National Historic Preservation Act, Section 106 is the primary outcome of this project, which also ensures accountability for the tribal grants and contracts and appropriate use of both appropriated dollars and power revenues.

Budget

FY13 = $127,839
FY14 = $131,310

Reclamation Project - Cultural Resources Program Administrative Costs—Funding History

Activity	2008	2009	2010	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	3,000	3,000	3,000	3,000	9,000	9,000
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	57,354	42,236	41,633	42,302	44,575	85,696	88,267
Subtotal	57,354	45,236	44,633	45,302	47,575	94,696	97,267
DOI Overhead (35%)	—	14,928	14,729	14,950	16,651	33,143	34,043
Project total	57,354	60,164	59,362	60,252	64,226	127,839	131,310
Total outsourced (%)	—	—	—	—	—	—	—

D.2. Cultural Resources Program Implementation

Introduction

The 1994 Programmatic Agreement (PA) has resulted in determinations of eligibility and 18 years of monitoring data, but given new efforts currently underway, it is appropriate to revisit and review our approach to a number of cultural resource issues. This project will provide for mitigation, treatment, and changes to monitoring of resources through the 1994 PA or the newly executed HFE Protocol and NNFC MOAs.

As the LTEMP EIS moves forward, Reclamation and NPS will be evaluating the necessary steps for compliance with the National Historic Preservation Act and 36 CFR 800 with respect to any undertaking or undertakings adopted as part of that new Federal action. Reclamation will be evaluating whether to amend and update the 1994 PA or to follow 36 CFR 800 for any undertakings identified in the EIS. This project will also provide a placeholder for potential planning and implementation actions that may be needed for LTEMP EIS NHPA compliance.

Reclamation's intent is to involve the American Indian tribes who participate in the GCDAMP during the development of the FY13/14 budget. Reclamation will seek tribal input through tribal consultation in addition to tribal input received in the GCDAMP biennial budget process.

The following is Reclamation's FY13/14 work plan prepared to be consistent with these NHPA compliance needs.

1. *Implementation of HFE Protocol MOA.* Consultation on the National Historic Preservation Act for the HFE Protocol resulted in a signed MOA in compliance with the NHPA and 36 CFR 800.6. The undertaking was considered to have an adverse effect on 19 historic properties, because the undertaking (multiple HFEs) might diminish the integrity of the property's setting, materials, feeling, or association. Reclamation and NPS consulted with the Arizona State Historic Preservation Office and the Advisory Council on Historic Preservation for these 19 sites. Stipulations to resolve the adverse effect included monitoring for multiple HFEs, and according to Stipulation I of the MOA, within 120 days after execution of the MOA, Reclamation must consult with the parties to the MOA to develop a program to resolve adverse effects of HFEs. Reclamation will have this meeting during FY12 to discuss potential monitoring, treatment and mitigation efforts related to the HFE Protocol (this will be funded with FY12 power revenues).

   In preparation for this meeting, Reclamation analyzed the 19 sites and has determined that four prehistoric sites within the Area of Potential Effect have not been mitigated and could be adversely affected by multiple HFEs. These sites are: AZ C:2:35, AZ C:2:75, AZ C:2:77, and AZ C:13:9. The first three sites are in Glen Canyon National Recreation Area, and the last site is in Grand Canyon National Park. Site C:2:75 was tested by the NPS in 1999 and NPS recommended no further work; however, a site condition assessment by Navajo Nation Archeology Department (NNAD) in 2007 recommended additional work. Likewise, C:2:77 was tested by NPS in 2000 and no further work was recommended, but the NNAD site condition assessment in 2007 recommended additional excavation to retrieve information important in prehistory (National Register Criterion d).

During the FY12 meeting, Reclamation will consult with all MOA signatories to seek agreement on mitigation of adverse effects of the undertaking on all or some of these four sites based on agreed upon field assessments and information provided by monitoring as well as tribal input. Proposed mitigation would include mitigation for loss of tribal associative values under National Register Criteria a and b (including consideration of traditional ecological knowledge (TEK), if applicable). If consultation results in agreement on resolution of effects, an MOA would be prepared and a contract would be awarded in FY13 for the first three sites, and FY14 for the fourth site to implement a treatment plan. The FY12 meeting may result in the identification of other resources requiring monitoring, treatment or mitigation. The proposed scope and budget (below) can be modified after the FY12 meeting to accommodate any changes.

Proposed budget: FY13 $66,000, FY14 implementation of treatment plan for one site in Grand Canyon $50,000.

2. *Documentation of Associative Values*. In FY13, Reclamation will consult with the tribes to see if they agree that there should be additional documentation. If so, Reclamation will convene a workshop to develop and implement a strategy for documenting associative values. Such a strategy might include developing a scope of work with the tribes for a contract for an ethnographer or ethnohistorian to document tribal associations with their eligible historic properties; i.e., the five historic properties determined eligible in the HFE Protocol and NNFC MOAs. The resulting documentation could include information that can be shared for purposes of educating tribal children on their heritage and association with the canyons. The documentation would also serve to mitigate for loss of associative values or integrity under the NPS's policies (see National Register Bulletin 15). If consultation during FY13 results in agreement among Reclamation and the tribes, then the contract would be awarded by the end of FY13.

Proposed budget: FY13 $100,000; FY14 $30,000.

3. *Non-native Fish Control Consultation*. Under the non-native fish control MOA, there are stipulations for consultation with tribes before and after any proposed removal actions and also stipulations for tribes to participate in non-native fish control efforts. This funding will facilitate tribal participation. During consultation, Reclamation will discuss any potential to include TEK into this project.

Proposed budget: FY13 $10,000; FY14 $10,000.

4. *GCMRC monitoring support*. GCMRC is developing a proposal to better understand aeolian transport and gully incision that will help identify dam operation effects on archaeological sites. This will fund most of GCMRC's Project Element J.3. As this project is developed, tribes will be consulted.

Proposed budget: FY13 $161,929; FY14 $156,129.

5. At the last TWG meeting, GCMRC presented information on TEK as it has been used for other projects. Using some of this data as the base, this line item would support the development of a pilot TEK project with the tribes for monitoring and/or treatment in the canyons. This will be a project that is developed with the tribes and may involve an existing monitoring or treatment program.

Proposed budget: FY13 develop this project with the tribes $15,000; FY14 implement the pilot project $50,000.

6. LTEMP Planning and Implementation. At this time, we can expect some recommendations to come out of LTEMP for the cultural resources program. This is a place holder.

Proposed budget: FY13 $10,000; FY14 implement any recommendations $40,000.

Reclamation Cultural Program Budget Table, FY13-14.

Fiscal Year	Treatment	Associative Values	NNMOA Consult	GCMRC Support	Tribal TEK Project	LTEMP Planning/ Implementation	Total
FY13	$ 66,000	$ 100,000	$10,000	$161,129	$15,000	$10,000	$362,129
FY14	$50,000	$30,000	$10,000	$156,129	$50,000	$40,000	$336,129

Budget

FY13 = $440,620
FY14 = $406,419

Reclamation Project – Cultural Resources Program Implementation—Funding History

Activity	2008	2009	2010*	2011	2012	2013	2014
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	300,000	500,000	493,500	205,838	519,500		
Subtotal (less GCMRC Sup.)						207,030	185,400
DOI Overhead (35%)	—	—	—	—	—	72,461	64,890
GCMRC Support						161,129	156,129
Project total	300,000	500,000	493,500	205,838	519,500	440,620	406,419
Total outsourced (%)	—	100%	100%	100%	100%	100%	100%

*Note that CPI and DOI Overhead are not applied to the funds for GCMRC Support because these figures include CPI and GCMRC Overhead.

D.3. Appropriated Funding

Tribal Participation in the GCDAMP: Sole-Source Reimbursable Contracts with Tribes

As a result of this project, participation in GCDAMP meetings, resource monitoring, and government-to-government consultation will be accomplished in concert with the five GCDAMP Tribes (Hopi Tribe, Hualapai Tribe, Kaibab Paiute Tribe, Pueblo of Zuni, Navajo Nation) and five DOI agencies (U.S. Geological Survey, National Park Service, Reclamation, U.S. Fish and Wildlife Service, and Bureau of Indian Affairs), with Reclamation serving as lead agency.

The purpose of funding of tribal contracts is to ensure tribal viewpoints are integrated into continuing GCDAMP dialogs, votes, and in the final recommendations made to the Secretary of the Interior.

The most important product is the incorporation of tribal perspectives into the recommendations forwarded to the Secretary. In addition, the Tribes prepare annual reports on activities funded under these contracts. Continued funding of government-to-government consultation through the agreements ensures enhanced communication and understanding of the GCDAMP issues and concerns.

Budget

FY13 = $475,000
FY14 = $475,000

Reclamation Project E. Tribal Participation in the GCDAMP: Sole-Source Reimbursable Contracts with Tribes—Funding History

Activity	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Outside Reclamation science/labor	—	—	—	—	—	—	—
Logistics field support	—	—	—	—	—	—	—
Project-related travel/training	—	—	—	—	—	—	—
Operations/supplies	—	—	—	—	—	—	—
Reclamation salaries	—	—	—	—	—	—	—
Subtotal	475,000	475,000	475,000	475,000	475,000	475,000	475,000
DOI Overhead (35%)							
Project total	475,000	475,000	475,000	475,000	475,000	475,000	475,000
Total outsourced (%)	100%	100%	100%	100%	100%	100%	100%

Appendix 1-A. FY 2013-14 Preliminary Draft Budget for the Bureau of Reclamation

Glen Canyon Dam Adaptive Management Program

FY 2013-14 Preliminary Draft Budget for the Bureau of Reclamation

Updated: 5/24/12

	Description				FY12 w/3.9% CPI	FY13 w/3.0% CPI	FY14 w/3.0% CPI
AMWG							
	Personnel Costs - Labor & Burden				184,846	190,391	196,103
	AMWG Member Travel Reimb				14,756	15,199	15,655
	AMWG Reclamation Travel Reimb.				15,140	15,595	16,062
	Facilitation Contract				40,531	41,747	43,000
	POAHG Expenses - Labor, Burden, & Travel				59,305	61,084	62,917
	Other				8,509	8,765	9,028
	Subtotal				**$323,087**	**$332,781**	**$342,765**
TWG							
	Personnel Costs - Labor				92,045	94,806	97,651
	TWG Member Travel Reimb.				21,681	22,331	23,001
	Reclamation Travel				14,958	15,407	15,869
	TWG Chair / Facilitation				30,145	31,049	31,980
	Other				2,431	2,504	2,579
	Subtotal				**$161,260**	**$166,097**	**$171,080**
OTHER							
	Compliance Documents				259,750	0	0
	Admin Support NPS Permitting				121,882	126,242	130,029
	Contract Administration - Labor, Burden, Travel				42,665	43,945	45,264
	Experimental Funds				507,679	515,000	515,000
	Integrated Tribal Resource Monitoring				152,583	157,160	161,875
	Native Fish Conservation Carryover Fund				0	782,660	1,321,139
	Subtotal				**$1,084,559**	**$1,625,007**	**$2,173,308**
CULTURAL PROGRAM							
	Cultural Resources Program Administrative Costs				64,226	127,839	131,310
	Cultural Resources Program Implementation				519,500	440,620	406,419
	Subtotal				**$583,726**	**$568,459**	**$537,729**
	Reclamation Power Revenue Costs Total				**$2,152,632**	**$2,692,344**	**$3,224,882**

	Reclamation Power Revenue Costs w/o Carryover				**$2,152,632**	**$1,909,684**	**$1,903,742**

Glen Canyon Dam Adaptive Management Program
FY 2013-14 Preliminary Draft Budget for the Bureau of Reclamation — **Updated: 5/24/12**

	Description				FY12 w/3.9% CPI	FY13 w/3.0% CPI	FY14 w/3.0% CPI
OTHER APPROPRIATED FUNDS							
	NPS Cultural Resources Monitoring FY12		91,000				
TRIBAL CONTRACTS (Appropriated Funds)							
	Hopi Tribe			95,000			
	Hualapai Tribe			95,000			
	Navajo Nation			95,000			
	Pueblo of Zuni			95,000			
	Kaibab Band of Paiute Indians			95,000			
	DOI Agency Appropriated Funds Total		**$91,000**	**$475,000**			
	Total		**$91,000**	**$475,000**	**$2,152,632**	**$2,705,038**	**$3,270,290**
	Total w/o Carryover				**$2,152,632**	**$1,909,684**	**$1,903,742**

Chapter 2. U.S. Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center Biennial Budget and Work Plan—Fiscal Years 2013/14

Introduction

The Glen Canyon Dam Adaptive Management Program (GCDAMP) is an advisory process wherein protection and management of Colorado River resources downstream from Glen Canyon Dam are considered in planning dam operations. The Grand Canyon Protection Act of 1992 directed the Secretary of the Interior to establish and implement long-term monitoring programs to ensure that Glen Canyon Dam is operated "… in such a manner as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established…." The Final Environmental Impact Statement (EIS) for Operation of Glen Canyon Dam (U.S. Department of the Interior, 1995) recommended creation of a federal advisory committee to advise the Secretary on implementation of an adaptive management program for operations of the dam. The Record of Decision for the EIS that was signed in October 1996 created this federal advisory committee, and the charter of the Adaptive Management Work Group (AMWG) that implements the GCDAMP was signed in January 1997.

The GCDAMP budget is administered by the Bureau of Reclamation (Reclamation). One part of the GCDAMP budget supports Reclamation's project administration and staff travel, provides reimbursements to AMWG members and members of other GCDAMP committees and subcommittees, provides meeting facilitation and public outreach, and supports compliance activities. Reclamation funding, with supplemental support from 4 other agencies of the Department of the Interior, also supports Native American tribal participation in many aspects of the program. These aspects of the program are described in Chapter 1.

A large proportion of the GCDAMP annual budget supports the monitoring and research work of the USGS Grand Canyon Monitoring and Research Center (GCMRC). The GCMRC is the primary science provider for the GCDAMP and undertakes monitoring activities about the status and trends of natural, cultural, and recreational resources of the Colorado River between Glen Canyon Dam and Lake Mead reservoir, as well as additional measurements of water quality in Lake Powell reservoir. The GCMRC also undertakes research activities to resolve critical uncertainties about how dam operations affect downstream river resources.

Purpose

This Biennial Work Plan (BWP) describes the monitoring and research activities that will be undertaken by GCMRC and its cooperators in fiscal years 2013 and 2014 (FY13/14). These fiscal years occur between October 1, 2013, and September 30, 2014.

Overview of the FY13/14 GCMRC Monitoring and Research Program

The FY13/14 BWP is organized differently from the BWPs of past years. The FY13/14 BWP includes fewer projects, and each project is organized around larger monitoring and research themes. For example, there were 12 projects concerning fish and other aquatic resources in the FY11/12 BWP, and there are 5 projects in the FY13/14 BWP. The monitoring and research themes identified in the FY13/14 BWP are those common to

(1) the 5 priority questions and the 12 program goals developed by the AMWG in 2004;
(2) the monitoring and research plan prepared by GCMRC, approved by AMWG in August 2007 and amended and approved in April 2009 (U.S. Geological Survey, 2007a);
(3) the strategic science plan prepared by GCMRC in March 2007 and amended in April 2009 (U. S. Geological Survey, 2007b);
(4) the draft Core Monitoring Plan (U. S. Geological Survey, 2011);
(5) Assistant Secretary Castle's March 31, 2011, memo establishing priorities in GCMRC science planning;
(6) the General Science Plan appended to the Environmental Assessment for the Development and Implementation of a Protocol for High-flow Experimental Releases from Glen Canyon Dam (Bureau of Reclamation, 2011a, appendix B);
(7) the Research and Monitoring Plan for the Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam (Bureau of Reclamation, 2011b, appendix B); and,
(8) the 2011 report of the Desired Future Conditions Ad Hoc Group of the AMWG.

The monitoring and research themes described in the various GCDAMP documents and agreements written during the past decade concern (1) maintenance of the predam physical template, especially regarding fine sediment, upon which the native ecosystem developed; (2) recovery of the endangered humpback chub (*Gila cypha*) and maintenance of populations of other native fish; (3) maintenance of the food base on which the native fish community depends; (4) maintenance of the native riparian vegetation community; and, (5) maintenance of culturally important sites, including those that are of archaeological and historical significance. The various goals, questions, information needs, and desired future conditions developed by the various GCDAMP committees also recognize the importance of the nonnative rainbow trout (*Oncorhynchus mykiss*) fish population in Glen Canyon and the role played by nonnative riparian vegetation in providing habitat for some desired fauna. In addition to these resource considerations, delivery of water in accordance with the Law of the River and generation of renewable hydroelectricity are essential to the economic well-being of the Southwest. Thus, economic analysis of the various recommendations of the GCDAMP is another critical part of the GCDAMP.

Overview of the FY13/14 Projects

In response to the monitoring and research themes described above, the FY13/14 work plan is organized into ten major projects. Three of these projects are in the fields of geomorphology, sediment transport, stream flow measurement, and water quality monitoring. Five projects are in the field of fish ecology, and one project is focused in riparian ecology. An additional project is focused in the field of cultural resources and includes project elements concerning small-scale monitoring of landscape change at archaeological sites and a project element concerning the larger scale geomorphic processes that affect archaeological sites.

Geomorphology, sediment transport, and water quality projects

Three projects are in the physical sciences. Project A concerns the geomorphology of fine sediment deposits in and near the Colorado River. Fine sediment is sand (0.0625 – 2 mm) and mud; in turn, mud is silt (0.0039-0.0625 mm) and clay (<0.0039 mm). These deposits are the substrate of the campsite resource, substrate in which the riparian ecosystem has developed, the architecture of native fish habitat including backwater nursery habitat for humpback chub, and is the substrate in and on which archaeological sites occur. The existence of Glen Canyon Dam and Lake Powell causes the deposition of all of the fine sediment supplied from the Upper Colorado River basin in the reservoir. Releases of reservoir water at the dam are free of sediment, and there is no significant fine sediment supply to Glen Canyon. The Paria River enters the Colorado River at Lees Ferry and delivers approximately 3.3 x 10^6 tons/yr of fine sediment (Topping et al., 2000), although the amount supplied from year to year varies greatly. The postdam fine sediment supply to the upstream end of Marble Canyon has been decreased by 95%, in relation to the predam fine sediment supply rate of 62.8 x 10^6 tons/yr that was supplied from the Upper Colorado River basin (Topping et al., 2000). Thus, the postdam Colorado River has excess mechanical energy available to transport fine sediment, and large amounts of fine sediment on the river bed and in eddies has been eroded and transported downstream towards Lake Mead.

The remaining fine sediment deposits that are of greatest interest to river managers are primarily composed of sand and occur in eddies. Eddies typically occur downstream from the rapids that make Marble and Grand Canyons a famous recreational whitewater river. Since the 1970s, river scientists have struggled to understand the dynamics of the postdam Colorado River and its adjustment to a greatly reduced fine sediment supply (Laursen and others, 1976, Howard and Dolan, 1981, Schmidt and Grams, 2011). It is inevitable that postdam fine sediment deposits will be smaller and more sparsely distributed than predam deposits, and significant river management questions concerning the Colorado River downstream from Glen Canyon Dam are: ***What is the largest, sustainable amount of fine sediment that can occur along the banks of the Colorado River, especially as eddy sandbars? What flow regime, in relation to the natural supply of fine sediment from the Paria and Little Colorado Rivers, results in the most widespread distribution of fine sediment along the channel banks and in eddies?***

Project B describes continued monitoring of the rate and quantity of the Colorado River's stream flow, as well as the inflow that occurs from tributaries. Additionally, Project B concerns measurement of the fine sediment that enters the Colorado River from tributaries and measurement of the quality of the Colorado River's water. Project C concerns continued monitoring of the quality of Lake Powell, because that water determines the quality of water in the Colorado River downstream.

Projects A and B are essential components to implementation of the Protocol for High-flow Experimental Releases, because the protocol calls for high flow releases from Glen Canyon Dam whenever a specified minimum amount of fine sediment delivered from the Paria River is exceeded. Project B is this measurement program, as well as the measurements that describe the fate of that fine sediment once it enters the Colorado River. Project A supports the direct measurements of the volume of fine sediment, especially sand, that is stored on the bed of the Colorado River, in its eddies, or at higher elevation along the river's banks. For the first time, the program for measurement of campsites is integrated with this fine sediment measurement program.

Projects in Fish Ecology

Projects D, E, F, G, and H concern the fishes of the Colorado River, its tributaries, and the food base on which those fish depend. Project F includes all of the long-term monitoring projects funded by the GCDAMP during the past few years. Projects D and E are research projects intended to resolve critical uncertainties about humpback chub, their distribution in the Colorado River ecosystem (CRe), and their life history in the Little Colorado River and elsewhere. Project H concerns the rainbow trout fishery of Glen Canyon, and Project G concerns understanding the competitive and predatory relationships between trout and native fish.

The goals in developing the aquatic ecology and fisheries portions of the FY13/14 BWP were to maintain long-term monitoring programs of key aquatic resources in the CRe while also addressing persistent scientific uncertainties that have plagued management of the aquatic ecosystem. Because nonnative rainbow and brown trout (*Salmo trutta*) compete and prey on native fish, including humpback chub, significant management questions focus on

What management strategies should to be employed to maintain a high quality rainbow trout fishery in Glen Canyon while protecting, and potentially recovering, the endangered humpback fish community in Marble and Grand Canyons?

New or expanded research projects are intended to provide information in areas where the greatest uncertainty remains. Most of the monitoring needs in the FY13/14 BWP were identified in the Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam and its associated Biological Opinion. These documents also identified areas of uncertainty where more research was needed. These uncertainties, as well as others identified during several workshops held as part of GCMRC's second Knowledge Assessment, formed the foundation of the projects for new and expanded research presented in the BWP. Consideration was also given to past recommendations and guidance that were part of the development of Strategic Science Questions, Research Information Needs, Core Monitoring Information Needs, and Desired Future Conditions.

The emphasis of research proposed in these projects is primarily on native fish, especially the humpback chub. Although much has been learned about the distribution, habitat use, life history, population dynamics, and other aspects of the biology and ecology of this species, key uncertainties remain. Two areas of uncertainty believed to be among the most critical include the dynamics and ecology of the mainstem population aggregations of humpback chub known as (Project D) and the variability in survival, growth, and emigration rates of early life history stages of humpback chub in the Little Colorado River. Additionally, little is known about biological drivers of this variation (Project E). Interactions between native and nonnative fish, particularly between humpback chub and trout, are still an area of concern given several remaining uncertainties. A research approach that includes laboratory experimentation and field study is needed to better understand the predation and competition effects of nonnative fish on native species and to determine to what extent these interactions are affected by environmental conditions (Project G).

Maintaining the rainbow trout fishery in Glen Canyon has been a longstanding management priority. While our understanding of some of the drivers of this population has improved, a number of unknowns remain. A combination of laboratory and field studies, modeling, and comparison to similar systems will help clarify the drivers of rainbow trout population status and trends, size composition, and downstream migration (Project H), thus allowing for more effective management of this important fishery.

Monitoring of key aquatic resources in the CRe remains a critical component of the FY13/14 BWP (Project F). In fact, the majority of work proposed for this biennium is monitoring to be conducted by GCMRC and its cooperators. These projects generate data that can be used to provide a baseline for observing status and trends in resources of interest, to assess the effectiveness of various management actions, and to inform managers as to the need to conduct management actions or the attainment of identified goals. Surveys of humpback chub and other fishes are proposed to continue in the Little Colorado River. This will include both physical captures of fish in the spring and fall and continuous electronic monitoring to detect individuals previously tagged with passive integrated transponders. Mainstem surveys will also continue annually in the fall as part of Project D and quarterly near the mouth of the Little Colorado River. These surveys provide critical information on the relative abundance of humpback chub populations and also provide data used in generating survival estimates as well as abundance estimates with the Age-Structured Mark Recapture model. Annual surveys of other native fish as well as nonnative species will also continue in Glen, Marble, and Grand Canyons. This work includes monitoring of trout spawning, early life stages, and adult populations in Glen Canyon, trout abundance and emigration in Marble Canyon, and the distributions and relative abundance of all native and nonnative fishes in Glen, Marble, and Grand Canyons. These efforts will help keep scientists and managers informed on the status and trends of fish throughout the CRe and will provide a mechanism of surveillance and early detection of invasive fish species. Although study of the aquatic food base has been integrated into several research proposals, monitoring of this important resource will also continue or be expanded. Information to be collected includes production of algae and invertebrates, organic matter biomass, and drift of invertebrates and organic matter. Understanding the aquatic food base and its dynamics are essential to understanding the distribution, condition, and abundance of fish populations in the CRe.

Project in Riparian Ecology

Results of on-going monitoring, and presentations made at the second Knowledge Assessment Workshop demonstrated that riparian vegetation is increasing greatly in the CRe, has significant impact on campsite availability, and has significant implications to the aquatic and terrestrial ecosystem. The expansion in the distribution of the tamarisk beetle (*Diorhabda spp.*) significantly affects the riparian ecosystem, and potentially provides the opportunity to river managers to create a new distribution of native and nonnative vegetation downstream from the dam, because the distribution of tamarisk (*Tamarix spp.*) is likely to greatly decrease. Project I is a revision and expansion of the present monitoring program for riparian vegetation. The revisions have been made to make the CRe work complementary to that underway in the Upper Colorado River basin, as conducted by the National Park Service's Northern Colorado Plateau Information and Monitoring Network. The effort here is to develop data sets that can be compared across larger spatial scale in different geomorphic settings and different dam operation scenarios. The field monitoring in riparian ecology is complemented by remote sensing work and an applied research project focused on assessing the implications of tamarisk beetle expansion.

Cultural Resources Monitoring and Research Project

In relation to past BWPs, the monitoring and research program in cultural resources is substantially revised. The project work in FY13/14 is divided into a monitoring phase and a research phase. The monitoring phase will partly take place in Glen Canyon where new airborne lidar protocols will be evaluated. In Glen, Marble, and Grand Canyons, existing ground-based lidar protocols will be applied at a range of sites dominated by different styles of geomorphic processes. A new applied research program will be initiated in FY13/14 that focuses on placing the various site-scale measurements into a larger context. The focus of this project element is to understand (1) the geographic extent of the influence of Glen Canyon Dam on those geomorphic processes that affect archaeological resources, (2) evaluate whether gully erosion is progressive in the CRe and the conditions under which windblown sand reverses gullying, and (3) how changes in sand bar area result in significant changes in erosional processes that threaten archaeological resources. This large-scale overview of geomorphic processes in the Colorado River valley will provide a critical context for the small-scale measurements made at monitoring sites.

Other Project Components

The FY13/14 program also supports the work of a yet-to-be-hired economist at GCMRC. Funding includes support for project work as well as the salary and benefits for this individual. The program of study that will be undertaken by this individual has not yet been comprehensively described. The program of the economist will involve consultation with the AMWG, the Technical Work Group (TWG), and ad hoc committees that are focused on economic issues.

Independent review of the work of the GCMRC, the work of GCMRC's associated scientists in sister agencies, consulting firms, and universities, and the decisions and programs of the AMWG and TWG are critical aspects of the GCDAMP. In FY13/14, the budgets allocated for specific independent reviews and for the work of the Science Advisors have been reduced, consistent with reduced expectations about the number of papers and proposals that are expected to require review. Nevertheless, funding supports the full suite of activities critical to the mission of the GCDAMP, especially by the Science Advisors.

GCMRC Project Administration

Administration of the GCMRCs work is funded in two ways – as direct costs associated with the salaries and travel expenses of key leadership and administrative personnel and as indirect costs (called "burden" in the USGS) that support the USGS Southwest Biological Science Center (SBSC). Part of the indirect costs are assessed at a 14% burden rate on all work conducted by GCMRC staff and partly by a direct $1 million allocation by the USGS to the SBSC.

Relation between FY13/14 Biennial Work Plan and Administrative Guidance

The FY13/14 BWP simplified and consolidated into larger projects focused on significant natural and socio-economic resource questions and resource conditions. There are ten projects (Project A – Project J) in the fields of physical and biological sciences. One of those projects addresses issues relevant to cultural resources. Funds are reserved for the hiring of a GCMRC staff economist. Other funds support independent reviews, administration of the GCMRC, and funds necessary to conduct a remote sensing overflight in 2013.

In developing the BWP, GCMRC explicitly considered the recently adopted Desired Future Conditions report and the direction on science priorities provided by Assistant Secretary Castle in her memo of March 31, 2011. Additionally, the BWP addresses commitments associated with GCMRC's role in implementing two recent Environmental Assessments. Most importantly, the GCMRC BWP is consistent with the various GCDAMP science planning documents. Each BWP Project describes how work in FY13/14 addresses strategic science questions and information needs previously addressed by the GCDAMP.

Desired Future Conditions

Desired Future Conditions (DFCs) for the Colorado River ecosystem were proposed by the Desired Future Conditions Ad Hoc Committee of the Adaptive Management Work Group (AMWG), and their report was presented to the AMWG in February 2012. By consensus, the AMWG commended to the Secretary of the Interior this report. On April 30, 2012, the Secretary of the Interior directed "the AMWG to utilize these DFCs to inform and guide the AMWG's future considerations, including advice and recommendations … concerning operations of Glen Canyon Dam and other related actions." Thus, these desired future conditions are an essential foundation for decision-making in the Glen Canyon Dam Adaptive Management Program. The DFCs are divided into four categories: the Colorado River ecosystem (CRe), power, cultural resources, and recreation.

As described in a following section, Assistant Secretary Castle had provided guidance about science planning in March 2011 that anticipated that these DFCs would be adopted. At that time, Assistant Secretary Castle directed GCMRC to focus most of its attention of those DFCs that concern sediment and fish, and the FY13/14 BWP follows that guidance. Here, the relation of the BWP to all DFCs is discussed.

Colorado River ecosystem

The CRe DFCs "address the natural resource values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established. As such, the CRe DFCs recognize that native and nonnative species are to be managed in accord with Federal regulations, policies, and guidelines. There are four attributes of the CRe specifically addressed by the DFCs: sediment-related resources, water quality, the aquatic domain, and the riparian domain.

The FY13/14 Biennial Work Plan (BWP) is organized to directly link with the organization of the CRe DFCs. Project A addresses monitoring and research topics related to the sediment-related resources of the CRe DFCs – primarily the characteristics of nearshore habitats for native fish, the substrate characteristics and landforms associated with marsh and riparian habitat for fish, and camping beaches. Project J addresses the linkage between fine-sediment deposits and cultural resource preservation.

Project B addresses the issues raised by the Water Quality CRe DFC, that calls for measurement of dissolved oxygen, nutrient concentrations and cycling, turbidity, temperature, and hydro-physical conditions such as discharge and sediment transport. Project C focuses on measurement of water quality attributes of Lake Powell reservoir.

The CRe DFC for the aquatic domain focuses on desired attributes of native species, rainbow trout, extirpated species, and nonfish biotic communities. Projects D, E, and F are focused on native fish species, especially the humpback chub, a federally-listed endangered species. Monitoring and research activities in Projects D and F address scientific issues associated with the desired recovery of humpback chub throughout its former range in the CRe. Project E is focused on scientific issues associated with the largest aggregation of humpback chub that occurs in and near the Little Colorado River.

Project H is focused on rainbow trout in Glen and Marble Canyons, and Project G is focused on the interactions between trout and native fish throughout the CRe.

There are no proposed projects that focus on the re-establishment of extirpated fish species in the CRe, despite the stated DFC on this topic. There are also no proposed projects focused on nonnative non-fish species such as the Northern Leopard Frog, although Projects F and H do include characterization of the invertebrate community that is a key part of the food base for native and nonnative fish.

Project I is focused on the CRe riparian domain. This project is primarily a vegetation monitoring project, because the distribution of vegetation communities, characterized as vegetation response guilds, and the distribution of fine-sediment substrates constitutes the various riparian habitats that are of interest in the DFCs.

The CRe DFCs explicitly propose four metrics by which achievement of the DFCs can be measured:

Percentage of critical habitat lost or gained
Condition of species variability
Carrying capacity thresholds
Population estimates

The FY13/14 BWP explicitly ensures that population estimates for humpback chub and rainbow trout are provided to the GCDAMP, and status and trend monitoring of other native and nonnative species are also determined. Additionally, the longitudinal distribution of humpback chub and trout are determined by studies of humpback chub aggregations and the distribution of rainbow trout throughout Marble Canyon. Other aspects Project F provide estimates of the distribution of other native and nonnative fish species. Changes in critical habitat are provided for the area and abundance of backwater habitat (Project A) and by mapping of riparian vegetation (Project I).

Power

The FY13/14 BWP does not include any specific projects focused on the DFCs for power, although these topics might be addressed once a GCMRC staff economist is hired.

Cultural Resources

Cultural resources in the CRe include prehistoric archaeological sites, historic sites, and Traditional Cultural Properties (TCPs). The DFC for prehistoric archaeological sites and for historic sites is "to the extent feasible, maintain significance and integrity through preservation in place." The focus of the DFCs for TCPs is that the attributes and integrity of TCPs is maintained. Thus, the DFC for cultural resources recognizes that many natural processes and attributes of the CRe affect cultural resources. These processes include those related to stream flow, sediment transport, geomorphology, and riparian vegetation. Cultural resources are also affected by recreation activity. The DFC specifically proposes that achievement of the goals for cultural resources be measured by:

Erosion or deposition rates of substrates in which cultural sites occur
Impacts at sites that affect eligibility to the National Register of Historic Places

The FY13/14 BWP is responsive to these DFCs and their proposed metrics. Project I involves a system-wide monitoring of riparian vegetation. Project J.3 initiates a system-wide, comprehensive study of geomorphic processes and geomorphic attributes that affect prehistoric and historic sites. Such a project has never been previously undertaken as part of the GCDAMP-funded GCMRC program. The goal of this project is to establish the linkage between the area and abundance of river sand bars (Project A) that are directly affected by dam operations and the redistribution of fine sediment upslope to areas that contain prehistoric and historic sites. Additionally, Project J.3 evaluates the degree to which gullies in the CRe grow or are eliminated by changing geomorphic conditions in the river channel itself. Project elements J.1 and J.3 explore detailed measurement protocols in Glen, Marble, and Grand Canyons that might be used to precisely measure topographic changes at the local scale. The challenge of Project J is to provide scientific guidance as to how large-scale and local-scale measurements and observations can be linked.

The cultural resource DFCs also propose metrics for assessing the condition of resources not eligible for the National Register of Historic Places. Because "only members of that culture can assess the status or health of the resources" important to each Native American Tribe, this monitoring activities are not part of the GCMRC program. Tribes are funded directly for their monitoring efforts, as described in Chapter 1.

Recreation

There are four categories for the recreation DFCs:

River recreation in Grand Canyon National Park (GCNP)
River recreation in Glen Canyon National Recreation Area (GCNRA)
Blue ribbon trout fishery in Glen Canyon National Recreation Area
River corridor stewardship

There are a number of specific conditions listed for each category of DFC, and there are a number of metrics by which achievement of these DFCs can be evaluated:

Socio-economic value of river recreation in GCNP
Socio-economic value of river corridor visitation in GCNP
Socio-economic value of "the Grand Canyon itself"
Economic effects of Grand Canyon tourism
Factors that make up the wilderness character of the CRe
Number and size of campable beaches
Socio-economic value of river recreation in GCNRA
Socio-economic value of the river corridor of GCNRA
Socio-economic value of the fishery of GCNRA
Effect of trout on the CRe in GCNP and the costs of mitigation undesirable populations of trout there
Characteristics most valued in the GCNRA fishery
River running visitation metrics
Water quality variables
River running safety

Many of these metrics are the subject of on-going discussion among the Socio-economic Ad Hoc Group of the TWG and the leadership of the on-going LTEMP EIS.

The FY13/14 BWP will provide monitoring data concerning the distribution and size of campable beaches (Project A). Additionally, Project G will provide research and monitoring data concerning the interactions between trout and native fish and Project H will directly inform management of the Glen Canyon fishery. A creel survey (Project F.2.3) will also provide data concerning angler success and experience in GCNRA.

A few of the economic aspects of the recreation DFC may be pursued by the yet-to-be-hired GCMRC economist. Other metrics are likely to be measured by the LTEMP process.

Science Planning to Implement the Environmental Assessment for a Protocol for High-Flow Experimental Releases

This Environmental Assessment (EA) was released by Reclamation on December 30, 2011, and this EA includes a General Science Plan that describes scientific activities needed to implement the High-Flow Experiment Protocol.

This Science Plan describes eight tasks that would be undertaken by GCMRC. The primary work activity is Task 1: Monitoring within-channel and high-elevation sediment storage, and these same activities are described in more detail in Project A.1 and A.2 of this BWP. Task 2 of the Science Plan is described as Project B of this BWP. Task 3 concerns monitoring archaeological site conditions, and these activities are described in Project J of the BWP. The work described in Project J represents advancements in thinking about how to monitoring and understand changes at archaeological sites, and thus differs in detail from what is briefly described in the Science Plan. Task 4 concerns monitoring the aquatic food base and this work is described in Project F.7 and Project H.2.2. Riparian vegetation monitoring that is described in Task 5 of the Science Plan is described in a more comprehensive way in Project I of the FY13/14 BWP. Task 6 concerns monitoring of the Kanab ambersnail. GCMRC does not propose to conduct any monitoring of these populations in FY13/14 because new information needs were not identified and delisting of the Grand Canyon populations are anticipated. Task 7 of the Science Plan concerns water quality monitoring in Lake Powell and in Glen Canyon and these measurements will be undertaken as parts of Projects B and C of the BWP. Task 8 concerns the evaluation of the effects on hydropower production, and this work will not be conducted as part of the GCMRC BWP.

Science Planning to Implement the Environmental Assessment for Non-Native Fish Control

This Environmental Assessment (EA) and an associated Biological Opinion were released by Reclamation on December 30, 2011. The EA includes a General Science Plan that describes scientific activities needed to implement non-native fish control downstream from Glen Canyon Dam. The Biological Opinion also identifies research and monitoring activities needed for implementation of this EA.

The science plan in support of this EA identifies five objectives to be addressed by GCMRC. The first objective is to understand the relative roles of the Little Colorado River (LCR) and the mainstem Colorado River in juvenile humpback chub survival rates and recruitment into the adult humpback chub population which will be addressed by activities described in Projects D, E, F.3, F.4.1. F.4.2, F4.4, and F.5. To address objective two, determine the linkage between nonnative fish abundance and juvenile humpback chub abundance and survival rates in the LCR reach and elsewhere in Grand Canyon, we will undertake the tasks described in Projects F.3, F.6, and G. Determine the natal origins of rainbow trout found in Marble Canyon (river miles 8 to 56) and the LCR reach is the third objective and will be resolved by research and monitoring conducted as part of Projects F.1 and F.6. Objective four is to assess the efficacy of nonnative fish removal in the Paria Riffle-Badger Rapid reach for rainbow trout and Upper Granite Gorge for brown trout which will be addressed by activities described for Projects F.1, F.6, and G.2. The final objective, assess the efficacy of flow manipulations to manage trout populations in the mainstem Colorado River from Lees Ferry to the LCR reach, will be monitored through tasks described for Projects F.1, F.2.1, F.2.2, F.2.3, F.3, F.4, F.6, and H.5.

The Biological opinion mandates monitoring the status and trends of adult humpback chub in the LCR (see Projects F.4.1, F.4.2, and F.5), in the mainstem Colorado River (see Projects D.1 and F.1), and at areas where humpback chub have been translocated (see Projects D.1, F.1, and F.4.3). The Biological Opinion also defines triggers to determine when nonnative fish control will take place near the LCR. Triggers are related to the abundance of adult and juvenile humpback chub which are addressed in Projects D, F.3, F.4.1. F.4.2, F4.4, and F.5, survival rates of juvenile humpback chub as determined in Projects E, F.3, and F.4.3, abundance of rainbow trout and brown trout as determined in Projects F.1, F.3, F.6, and G.2, and river temperature monitored as part of Project B.

Research and Monitoring Priorities Provided by Assistant Secretary Castle

On March 31, 2011, Assistant Secretary Anne Castle provided direction to GCMRC regarding science planning; this direction was provided in the form of a memo to Kate Kitchell, Mark Sogge, and Ted Melis. Assistant Secretary Castle directed GCMRC to primarily focus on the DFCs that were, at the time, still in draft form. Within that context, the Assistant Secretary urged that GCMRC more narrowly focus its interest on a few of the DFCs, "because the DFCs are very comprehensive" and it was assumed that insufficient funds existed to focus on every DFC. The priorities provided in this memo are that GCMRC should "concentrate its resources" on

> "… compliance with the Endangered Species Act, which means focus on the native fish and particularly the humpback chub";
>
> "… focus on sediment, which was an instigating factor for the Grand Canyon Protection Act and continues to be an issue with resources downstream of the dam. That includes being able to respond if the high flow protocol goes forward"; and,
>
> "… science on both non-native fish control and the recreational trout fishery."

Assistant Secretary Castle also observed that "while cultural resources remain a very high priority, it is not clear that there are significant science questions involving those resources, or the [Temperature Control Device], that require attention at this time." Castle also indicated that core monitoring activities in other resource areas should continue. The overall objective of her guidance was "to enable GCMRC to better direct its limited resources and resist the Christmas tree approach to science planning."

GCMRC's FY13/14 BWP primarily focuses on the key priorities established by the Assistant Secretary, namely humpback chub (Projects D and E), native and nonnative fish

(Project F), recreational trout (Project H), and the interactions between trout and native fish (Project G). Projects A and B monitor the flux and distribution of fine sediment, which is also a priority described in the memo. Project B is also fundamental to implementation of the High Flow Experiment Protocol, and Project A is fundamental to evaluating the effectiveness of the Protocol. Projects I and J address monitoring and research needs in vegetation and cultural resources that are not explicitly described in the memo, but that have widespread stakeholder interest.

General Core Monitoring Plan

A final draft plan was prepared by GCMRC on February 18, 2011, and was submitted to the TWG. This plan is organized around the eleven GCDAMP Program Goals that concern natural resources. Previous BWP documents of the GCMRC were also organized around these Program Goals. However, in the reorganization of the BWP represented in the FY13/14 document, the various goals associated with the aquatic domain (Goals 1, 2, 3, and 4) were reorganized into Projects D, E, F, G, and H. Program Goal 5 concerns the Kanab ambersnail, and there are no activities proposed in FY13/14 on this topic. Program Goal 6 is the focus of Project I in the FY13/14 BWP. Goal 7 is the focus of Projects B and C, and Goal 8 is the focus of Project A. Goals 9 and 10 and not explicitly evaluated in the BWP, except as concerning camping beaches. Project J represents an expanded focus on Goal 11.

The monitoring methods described in the FY13/14 BWP represent a substantial scientific advancement in developing formalized protocols for regular measurement of key river resources. In the case of protocols for measuring sand bars (Project A), sediment transport and water quality (Project B), humpback chub and rainbow trout populations and status and trends of other fish species (Projects D, E, F, H), and monitoring vegetation communities, GCMRC has worked with sister agencies and collaborators to develop efficient protocols that take advantage of large bodies of historical data, address issues of how to extrapolate site scale measurements to the entire CRe, and how to estimate temporal trends in key resources.

The next step in the formalization of monitoring protocols will be to take the advancements described in the BWP and incorporate these into a revised General Core Monitoring Plan.

Monitoring and Research Plan

The most recent plan was amended and approved in April 2009. This plan describes various Strategic Science Questions (SSQs). Subsequent planning documents have identified Core Monitoring Information Needs (CMINs) and Research Information Needs (RINs). Each of the GCMRC projects of the FY13/14 BWP describes the administrative and management context for each specific proposal and describes the relevant SSQs, CMINs, and RINs. Each project description also discusses the current status of knowledge on the various scientific topics and the role of work in FY13/14 in answering key questions of the GCDAMP.

Allocation of the FY13/14 Budget

The total proposed budget of GCMRC in FY2013 is $10,440,500 of which $8,632,700 is from GCDAMP funds. An additional $825,900 is from FY12 GCMRC carryover funds, $413,500 from other regular Reclamation funding, and $568,400 from Reclamation carryover funds. The Reclamation carryover funds have a two-year duration and will fund specific applied research projects in fish ecology for the FY13/14 BWP.

Of the projected $10.4 million budget, 39% is to be allocated to monitoring and research work in fish ecology and 29% is to be allocated to the projects in geomorphology, stream flow monitoring, sediment transport, and water quality (Fig. 1). Direct administrative costs are 15% of the budget. The combined work in riparian ecology, cultural resources, economics, and independent reviews is a small part of the proposed work. The budget for the GCMRC part of the FY13/14 BWP is described at the end of each project description, and is summarized in various appendices at the end of this document.

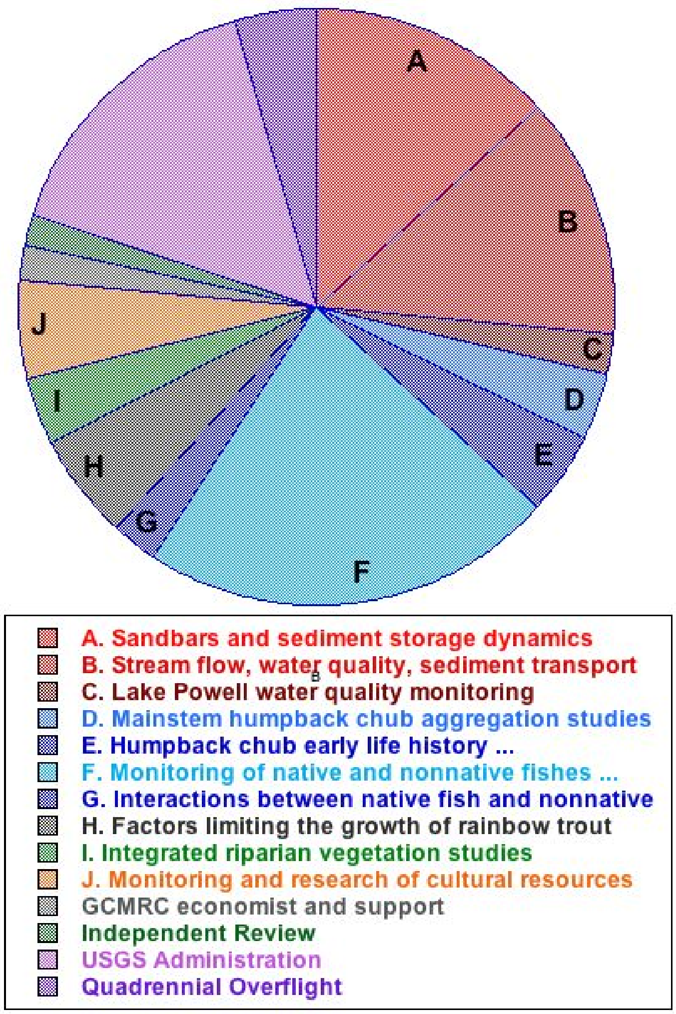

Figure 1. Allocations for the proposed FY13 GCMRC budget, including some projects for which funding has not yet been identified.

The proposed budget for FY14 is $10,518,400, of which $8,914,900 would be from GCDAMP funds, $421,100 from other Reclamation funding sources, $573,100 from Reclamation carryover sources, and $609,400 is from FY12 GCMRC carryover funds.

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

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2. Project Summary

This ongoing project consists of a set of integrated monitoring and research studies conducted at different spatial and temporal scales. Collectively, these studies are designed to track the results of individual High-Flow Experiments (HFEs) and to monitor the cumulative effect of these HFEs and of intervening operations. Additionally, the goal of this work is to advance understanding of sediment transport and eddy sandbar dynamics to improve capacity for predicting the effects of future dam operations.

One of the primary management goals for the Colorado River downstream from Glen Canyon Dam (GCD) is to maintain an abundant distribution of large eddy sandbars using only the limited supply of fine sediment (defined as sand and mud) delivered by the Paria River and other tributaries. This goal, and related goals, objectives, and information needs are described in section 3.2.

The key uncertainty about management of sandbars downstream from GCD articulated in the recently completed *Environmental Assessment for Development and Implementation of a Protocol for High-Flow Experimental Releases from Glen Canyon Dam* (HFE EA), is, "Can sandbar building during HFEs exceed sandbar erosion during periods between HFEs, such that sandbar size can be increased and maintained over several years?" This question can be answered through continued monitoring of sand deposits over a multi-year timeframe of repeated controlled flood experiments.

Management of GCD is not solely focused on achieving fine sediment goals, however, and achieving other goals that concern the aquatic or riparian ecosystem, or achieving water supply or hydropower objectives, sometimes requires reservoir releases that are not optimum for achieving fine sediment management goals. Thus, it is critical to develop and enhance modeling tools with which future fine sediment conditions can be predicted, because it is inevitable that reservoir operating rules that balance multiple resource objectives will be considered in the future. It is also critical that efficient and robust monitoring protocols be implemented to evaluate eddy sand bar conditions. Lastly, it is critical to evaluate fine sediment storage conditions that trigger implementation of the HFE protocol.

Monitoring conducted in Project A includes daily and annual observations of long-term sandbar monitoring sites by remote camera and conventional topographic survey, respectively. These observations add to an existing long-term dataset and will be available following each HFE as an initial assessment of resource condition that could be used to adjust the HFE implementation strategy on a semi-annual basis, if necessary. Because detailed monitoring sites represent only a small proportion of the total number of sandbars in Marble and Grand Canyons, Project A also includes the analysis of system-wide airborne remote-sensing data to monitor a much larger set of sandbars every four years to assess sandbar size and abundance in the entire Colorado River ecosystem (CRe).

The continued success of HFEs in maintaining an abundant distribution of large sandbars depends on maintaining an adequate supply of sand in and near the Colorado River. If there is a decline in sand storage, it is unlikely that HFEs alone can maintain sandbars. While the sandbar monitoring studies provide needed information on resource condition, they do not provide any measure of the total amount of sand in storage in and near the river, because a very small fraction of the sand in storage is in the monitoring sites. To provide the critical information about sand storage and to evaluate whether dam operations, including HFEs, are likely to result in sandbar maintenance or eventual decline, fine sediment storage will be monitored by repeat channel-wide surveys of river segments on a rotating basis of approximately every 3 to 10 years. Other components of this project are designed to integrate findings across longer spatial and temporal scales, investigate how specific changes in sandbar morphology affect campsite quality, link sandbar deposition dynamics with the distribution of riparian vegetation along shorelines, provide habitat and riverbed substrate information to biological studies, and improve understanding of the variability of sandbar response to dam operations. Collectively, these studies contribute to improved capacity to predict the effects of future controlled floods.

3. Background

One of the goals of the Glen Canyon Dam Adaptive Management Program (GCDAMP) is to “maintain or attain levels of sediment storage within the main channel and along shorelines” (U.S. Geological Survey, 2006). This overarching goal encompasses many linkages between sediment storage and ecosystem goals including: maintenance of sandbars used by recreationists, creation of sandbar-associated backwater habitats used by native fish, and maintenance of exposed bare sand surfaces that are available for redistribution to upland areas by wind. Research and monitoring work that supports these objectives also provides knowledge of the relative proportions and spatial distributions of fine and coarse sediment on the bed of the river, because those characteristics control transport of suspended fine sediment and affect primary production and aquatic habitat. Because many of these objectives concern sandbars, the focus of this project is on sand. We use the term “sediment” to refer to alluvium of all sizes, “fine sediment” to refer to sand, silt, and clay (all sediment < 2 mm), and “sand” to refer to sand-sized sediment only (0.0625 – 2 mm). Mud refers to silt and clay. This project addresses management objectives through monitoring components designed to track the trends in sandbars and fine sediment storage and research components designed to improve understanding of processes that affect fine-sediment related resources.

Conditions of fine sediment deficit and changes in flow regime brought about by completion of GCD have resulted in a decline in the number and size of sandbars in Grand Canyon National Park (Schmidt and others, 2004; Wright and others, 2005). Sandbars are used as camping beaches, form aquatic habitat, and are a source of eolian sand for the upland ecosystem (see Project J). Schmidt and others (2004) estimated that there has been about a 25% decrease in the area of exposed sandbars in Marble Canyon and eastern Grand Canyon based on comparison of pre-dam and post-dam aerial photographs. Monitoring of sandbars between 1990 and 2011 has shown that controlled floods cause widespread increases in the size of sandbars exposed at typical base flows and that these bars decrease in size between controlled floods (Schmidt and others, 1999; Hazel and others, 1999; Topping and others, 2006; Hazel and others, 2010; Schmidt and Grams, 2011). These findings demonstrate that fine sediment supplied by tributaries can be effectively redistributed from the bed of the river to higher elevations along the channel margins by high flows. Although we currently have very limited knowledge of the absolute amount of fine sediment stored on the bed of the river, we do know that there is a delicate balance between the amount of fine sediment exported from Marble Canyon and that supplied by the Paria River and small tributaries. Under some flow regimes and flood conditions on the Paria, fine sediment accumulates in Marble Canyon. Under other conditions, more fine sediment is exported than is supplied to Marble Canyon (D.J. Topping, US Geological Survey, unpublished data). Thus, the net long-term effect of dam operations, including controlled floods, remains unknown. The long term management goal is to achieve a stable fine-sediment budget and avoid prolonged periods when fine sediment is mined from storage (Fig. 1). If a quasi-stable sediment budget can be achieved, then controlled floods will continue to be an effective tool for building sandbars. However, a downward trending sediment budget would indicate a decreasing capacity to rebuild sandbars using clear-water floods alone (Rubin and others, 2002; Wright and others, 2008; Schmidt and Grams, 2011).

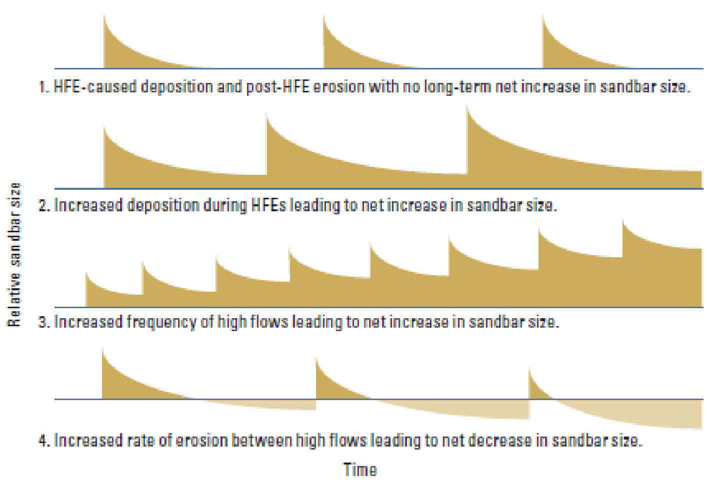

Figure 1. Conceptual diagram illustrating the dependency of net sandbar size on potential variations in the amount of deposition that occurs during a High-Flow Experiment (HFE), the frequency of HFEs, and the rate of post-HFE erosion (figured adapted from Schmidt and Grams, 2011). The case shown in 1 shows a hypothetical amount of HFE deposition followed by an equal amount of erosion. Cases two and three result in net increases in sandbar size by increasing the amount of deposition during HFEs and increasing the frequency of HFEs, respectively. In case 4, the rate of erosion following HFEs is greater than the HFE deposit such that there are net decreases in sandbar size.

The recently completed HFE EA outlines a program for conducting many controlled floods during the next 10 years. The sandbar and sediment storage monitoring and research described in Project A consists of a set of integrated studies designed to track the response of sand bars and sediment storage to HFEs. The time frames of interest to Project A include both individual HFEs and the cumulative effect of multiple HFEs and intervening operations. Project A also includes studies to advance understanding of sediment and eddy sandbar dynamics so as to increase the efficiency of specific HFEs in creating large and abundant sandbars.

3.1. Scientific Background

Closure of Glen Canyon Dam caused at least a 90% reduction in fine sediment supply to the Colorado River in Marble and Grand Canyons (Topping and others, 2000). In response to this reduction in sand supply and the alteration of the natural hydrograph by dam operations, sandbars in Marble Canyon and the upstream part of Grand Canyon have substantially decreased in size (Schmidt and others, 2004). Although there have been temporary increases during floods, bars erode during normal power plant operations (Wright and others, 2005; Schmidt and Grams, 2011). The long term effects of three HFEs have been mixed. In upper Marble Canyon and eastern Grand Canyon (Fig. 2), only about one-third of the long-term monitoring sites were larger in October 2008, 6 months after the most recent controlled flood, than they were immediately before the first controlled flood in 1996 (Schmidt and Grams, 2011). In all other reaches, 80% or more of the sandbars at monitoring sites increased in size.

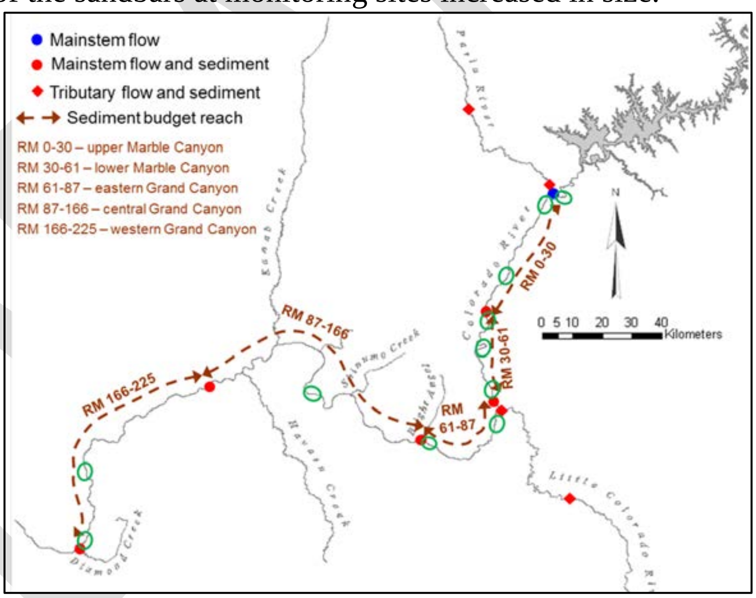

Figure 2. Map showing the Colorado River between Glen Canyon Dam and Diamond Creek. The stations for suspended sediment transport monitoring (Project B) are shown by the red circles. The short reaches where sediment storage was mapped in 2000 to 2005 are shown by the green ovals. The current sediment storage monitoring plan calls for mapping 50 to 80% of the channel in the segments between the sediment monitoring stations. In 2009 and 2012, most of the long sediment budgeting reach between RM 30 and RM 61 was mapped. In 2011, most of the sediment budgeting reach between RM 61 and RM 87 was mapped.

Findings about the effects of HFEs depend on a robust sandbar monitoring program. Growing concern about the effects of the operations of Glen Canyon Dam led to the initiation of systematic measurements of sandbars in the 1970s (Dolan and others, 1974; Howard, 1975; Howard and Dolan, 1981). This sandbar-monitoring program was reestablished in the 1980s

(Schmidt and Graf, 1990; Beus and others, 1992) and led to the sandbar-monitoring program now conducted by Northern Arizona University (NAU) (Hazel and others, 1999; Schmidt and others, 2004). A synthesis of these studies (Schmidt and others, 2004) indicated that the observations of change made at a small number of sandbar monitoring sites were not necessarily representative of changes in fine-sediment mass balance over the much longer sediment budgeting reaches[1] defined by sediment transport measurement stations (Project B). Survey programs have traditionally caused only a relatively small proportion of the total number and area of sandbars, and the variability of response among sites is typically large.

A parallel monitoring effort designed to document trends in fine-sediment storage on the channel bed involved repeat measurements at numerous channel cross-sections between 1992 and 1997 (Flynn and Hornewer, 2003). These data indicated bed degradation in some locations, but also showed high variability from place to place. This indication of sediment depletion coupled with the inability to detect significant trends owing to variability led to the recognition that there was a need for a more comprehensive and systematic measurement program. These findings resulted in the initiation in 1999 of (1) a suspended sediment sampling program to enable the calculation of sand budgets for long sediment budgeting reaches (Project B) and (2) a sediment storage monitoring program based on making repeat measurements over short reaches, 3 to 5 km in length. Here, we focus on the findings resulting from the pilot sediment storage monitoring that was conducted between 2000 and 2004. We refer to this effort as the "short-reach" monitoring program.

These monitoring programs were based around the concept of a sediment mass balance or sediment budget. The sediment budget is simply the accounting by mass, or volume, of all sediment entering and exiting a specified river segment. The budget may be expressed in mathematical terms as

$$I - O = \Delta S, \qquad (1)$$

which states that the sum of all sediment inputs, I, minus the sum of all outputs, O, is equal to the net change in sediment storage, ΔS, within the designated segment. In the case that inputs exceed outputs, ΔS is positive and indicates sediment accumulation. To provide greater resolution and the opportunity to monitor different mechanisms and resources, sand storage can be divided into sand stored at lower elevations that are typically underwater and sand stored at high elevations that are only inundated occasionally,

$$\Delta S = \Delta S_{low} + \Delta S_{high}. \qquad (2)$$

We use "low" to refer to sediment below the typical baseflow stage of 8,000 ft^3/s and "high" to refer to sediment above the 8,000 ft^3/s stage. The low-elevation sediment is underwater except during the trough of some flow fluctuations. The high-elevation fine sediment is alternately inundated and exposed, depending on the flow regime. The high-elevation sediment is most relevant to camping beaches, riparian vegetation, and other upland resources and the low-elevation sediment is relevant to aquatic habitat and, in the case of sandbars in eddies, is the foundation for the high-elevation sediment. The purpose of the measurements of suspended sediment initiated in 1999 (Project B) was to measure sediment inputs and outputs for each segment between measurement stations, i.e. the sediment budgeting reaches. This ongoing

[1] In this proposal, we refer to observations and study areas that span a variety of spatial scales. We use "monitoring site" to refer to monitoring locations that are at the scale of individual sandbars, 100's of meters in length. We use "short reach" to refer to study reaches that include many sites and are on the order of 2 to 5 km in length. We use "long reach" or "sediment budgeting reach" to refer to segments of the river that encompass the entire channel between fine-sediment monitoring gages; these reaches are 50 to 130 km in length.

measurement program tracks the accumulation and fate of tributary inputs and provides the information needed to plan high flow events. The purpose of the short-reach monitoring program was to measure changes in sediment storage and the locations where those changes in storage occurred.

The short-reach monitoring program, conducted from 2000 to 2004, was accomplished by repeat measurements of the river bed using sonar and repeat measurements of exposed deposits by airborne lidar, aerial photogrammetry, and conventional topographic survey. Eleven short reaches were selected, although repeat measurements were only made at seven of these reaches between RM 0 and RM 87 (Fig. 2). The methods are described by Hazel and others (2008) and Kaplinski and others (2009). This monitoring program was a substantial advancement beyond earlier monitoring programs, because nearly all of the channel in each short reach was mapped, in contrast to previous efforts which made measurements at widely-spaced cross-sections or isolated sandbars.

Results from this monitoring program demonstrated that 90% or more of the fine sediment in the post-dam river is stored below the elevation of typical base flows in low-elevation locations (Hazel and others, 2006). Thus, the fine sediment that is generally of greatest management interest is stored at higher elevation and comprises only about 10% of the fine sediment in the system. Research also demonstrated that change in low-elevation sediment storage computed from repeat measurements of erosion and deposition in short reaches is not consistent with the change in storage computed from the difference in sediment transport over longer sediment budgeting reaches (Topping and others, 2006; Grams and others, 2011). In other words, the measurement of ΔS over short reaches and extrapolation of the results to the longer reaches does not yield the same answer as the computation of ΔS from equation (1). This discrepancy does not result from an inability to measure changes with sufficient precision but from the inaccuracy of extrapolating measurements from the short reaches to longer reaches.

Extrapolation is made difficult for at least two major reasons: changes in storage are highly localized and changes in storage are variable from place to place. Schmidt and others (2004) showed that large changes in sediment storage are concentrated in eddies and in main channel pools. Adjacent eddy/channel storage locations in the same short reach do not necessarily behave consistently—scour in one eddy may be offset by an equal or larger magnitude of deposition immediately downstream. The magnitude of change in storage at each site can be large relative to the net change over a long reach. The net ΔS over a long reach is the sum of many individual ΔS terms, some positive, some negative, and nearly all of them large relative to the total sum. Thus, without better knowledge of the distribution, size, and behavior of these storage locations, it is not currently possible to extrapolate measurements from short reaches to longer segments (Grams and others, 2011). These findings indicate that in order to determine whether sediment storage as a whole–at low and high elevations and in the channel and eddy storage sites–is increasing, decreasing, or stable requires repeat measurements of sand storage throughout the long sediment budgeting reaches. Fortunately, advances in monitoring techniques now allow measurement of changes in topography at the scale of the sediment budgeting reaches. The proposed fine-sediment monitoring includes measurements of channel and eddy sand storage at the scale of the long river segments.

The variability observed in the short-reach monitoring program and the variability observed in the monitoring of individual sandbars are related. Grams and others (2011) showed how the volume of sand at many of the individual monitoring sites is correlated with the flow of the river during the preceding month. This means that, for a given flow regime and sediment supply condition, some sites tend to accumulate large sandbars while other sites tend to lose sand, and these differences depend on the flow regime. This insight was made possible, because we now have a long monitoring record at more than 30 individual sandbars that can be compared with discharge measurements made in Project B. Although we have identified that sandbar response is highly variable (Hazel and others, 1999; Schmidt and others, 1999; Schmidt and others, 2004; Hazel and others, 2010; Grams and others, 2011), we have yet to discover how to categorize eddies such that we can predict sandbar variability outside of the long-term monitoring sites where these relations are now determined empirically. It is likely that specific site characteristics, such as channel geometry, control the flow patterns in eddies and affect sandbar response. If the specific characteristics that determine patterns of erosion and deposition can be discovered, it would be possible to predict sandbar response at many other sites than the limited number where we have empirical observations.

Better understanding of the physical controls on eddy dynamics will also contribute to improved predictive capability through modeling. Documented and well-verified models have been developed to predict mainstem streamflow throughout Marble and Grand Canyons (Randle and Pemberton, 1987; Wiele and Smith, 1996; Wiele and Griffin, 1997; Magirl and others, 2008) and sediment flux at approximately 50-km increments between RM 0 and RM 87 (Wright and others, 2010). These models can be used to predict sediment availability for planning reservoir releases (Wright and Grams, 2010) but do not allow prediction of sandbar response. Wiele and others (2007) made an effort to couple canyon-scale flow models with detailed eddy models in order to provide better predictions of bar building response. This approach assumed all eddies behave similarly, with the magnitude of erosion and deposition scaled by eddy size. As described above, we now know that a predictive canyon-scale model for eddy response will have to incorporate the observed site-to-site variability in erosion and deposition. In FY13/14, we will conduct an empirical study that investigates the causes of this variability in our effort towards improving capacity to predict individual sandbar response.

Another one of the challenges that is faced in developing physically-based predictive models for sediment transport and eddy sandbar deposition is the linkage between the size and distribution of the fine sediment on the bed and the fine sediment in transport. The strong correlation between bed sediment grain size and the rate and grain size of fine sediment in transport was demonstrated for the Colorado River by Topping and others (1999). Grams and Wilcock (2007) used laboratory experiments to establish a relation between the areal extent of sand cover and sand entrainment rate. Both of these relations were used by Topping and others (2010) to infer bed composition and coverage from suspended sediment measures for the three controlled floods. This is a potentially useful monitoring technique, because it would allow the use of the continuous record of suspended sediment concentration to track the amount of sand on the bed. However, implementation will require a better understanding of the spatial scale at which the correlation between bed condition and suspended sediment concentration can be demonstrated.

3.2. Management Background

This project is organized around seven research questions (see section 3.2, below) that have evolved from the goals, strategic science questions, information needs, and desired future conditions developed in cooperation with stakeholders of the GCDAMP. The primary GCDAMP goal addressed is “Goal 8: Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve Adaptive Management ecosystem goals.” The articulation of this goal is somewhat refined in the strategic science questions: “Is there a “flow only” operation (that is, a strategy for dam releases, including releases responding to large tributary inputs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal timescales?” and “What is the rate of change in eddy storage (erosion) during time intervals between high flows?” To address these questions, the 2007 Monitoring and Research Plan identified a series of core monitoring information needs which specify the need to monitor fine sediment in the channel and eddies at both low and high elevations.

Further guidance on monitoring needs is provided by the HFE EA. The overarching sandbar-related question identified in the HFE EA is, "Can sandbar building during HFEs exceed sandbar erosion during periods between HFEs, such that sandbar size can be increased and maintained over several years?" This document also contains specific science questions related to sandbars and camping beaches: (1) Will multiple high flows conducted over a period of 10 years result in net increases in sandbar area and volume?; (2) With the available sand supply (i.e. tributary inputs), is the approach of using repeated floods to build sandbars sustainable?; and, (3) Will multiple high flows conducted over a period of 10 years result in net increases in campable area along the Colorado River?

The proposed project directly supports achievement of other GCDAMP goals, as well:

- Goal 9: Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem within the framework of GCDAMP ecosystem goals. The monitoring provides information on the size and abundance of sandbars, which are resources that affect the recreational experiences of Colorado River users.
- Goal 11: Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations. The project includes monitoring sandbars that provide a source of sediment, through aeolian transport, to high-elevation sand deposits that contain archaeological resources.

Because sediment monitoring addresses the physical framework of the ecosystem, which underlies many biological resource objectives, Project A also indirectly supports achievement:

- Goal 1: Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels. The proposed monitoring supports this goal by providing information on the size and distribution of channel substrate.
- Goal 2: Maintain or attain a viable population of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats. The proposed sandbar and sediment storage monitoring supports this goal by providing information on sandbars which create backwaters, a habitat used by native fish.
- Goal 6: Protect or improve the biotic riparian and spring communities within the Colorado River ecosystem, including threatened and endangered species and their critical habitat. The sediment storage and sandbar monitoring tracks the status of the fine sediment deposits which provide the substrate for riparian vegetation and marsh communities.

The 2003 GCDAMP Strategic Plan identified Core Monitoring Information Needs (CMINs) related to sediment storage. The CMINs that are addressed in Project A are listed below. For each, the prioritization ranking applied by the GCDAMP Science Planning Group (SPG) in 2006 is also included. In addition, several Strategic Science Questions (SSQs) were identified by scientists and managers during the knowledge assessment workshop conducted in summer 2005 (Melis and others, 2006).

- **CMIN 8.1.1.** Determine and track the biennial sandbar area and fine-sediment volume and grain-size changes within eddies below 5,000 cfs stage, by reach. ***Addressed in project A.2.***
- **CMIN 8.2.1.** Track, as appropriate, the biennial or annual sandbar area, volume. and grain-size changes within and outside of eddies between 5,000 and 25,000 ft^3/s stage, by reach. ***Addressed in projects A.1 and A.2.***
- **CMIN 8.5.1.** Track, as appropriate, the biennial sandbar area, volume, and grain-size changes above 25,000 ft^3/s stage, by reach. ***Addressed in projects A.1 and A.2.***
- **CMIN 8.6.1.** Track, as appropriate, changes in coarse sediment (> 2 mm) abundance and distribution. ***Addressed in project A.2.***
- **CMIN 9.3.1.** Determine and track the size, quality, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons. ***Addressed in project A.1.***
- **SSQ 4-1.** Is there a "flow only" operation (that is, a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal timescales? ***Addressed in all project components.***

3.2. Key Monitoring and Research Questions Addressed in this project

The goals, science questions, and information needs discussed above are incorporated in the following list of specific questions addressed in this project:

1. What is the long-term net effect of dam operations, including high flows, on changes in high-elevation sandbar area and sand storage (i.e. the sand above the 8,000 ft^3/s stage)? These changes are relevant to camping beaches, riparian vegetation, backwater habitat, and control the supply of bare sand that is redistributed by wind.
2. What is the long-term net effect of dam operations, including high flows, on changes in low-elevation sand storage and bed sediment texture (the sand below the 8,000 ft^3/s stage)? These changes are relevant to backwaters and other aquatic habitat, the foundation of eddy sandbars, and as the source of fine sediment that fuels transport and determines whether the use of high flows is sustainable.
3. What are the relative proportions of pre-dam fine sediment (sediment that entered the Colorado River before dam completion) and post-dam fine sediment (sediment from tributaries that has entered the Colorado River following dam completion) present in deposits formed by dam operations, including HFEs? Do the proportions of pre- and post-dam fine sediment indicate depletion of non-renewable pre-dam fine sediment from storage or accumulation of tributary-derived post-dam fine sediment? This question is relevant to determining whether the use of HFEs is sustainable.

4. What are the causes of variability in sandbar response to controlled floods and other dam operations (i.e. why do sandbars respond differently from place to place to the same flow and sediment supply conditions?), and how does vegetation affect sandbar response? This builds on sandbar monitoring (Question 1) to support prediction of sandbar response.
5. What is the spatial distribution of bed sediment texture, and how does it affect primary production, fish habitat, and sediment transport modeling? This builds on low elevation sand monitoring (Question 2) to support fine sediment transport and biological prediction.
6. Can we relate changes in the spatial distribution of bed sediment texture to observed changes in suspended sand concentration and grain size? This would enable use of the continuous record of suspended sediment to infer changes in bed sediment composition for use in modeling of sediment transport and primary production.
7. How have changes in sandbar size, sandbar characteristics (e.g., slope, roughness), and vegetation cover affected the Marble and Grand Canyon camping beach resource? This builds on sandbar monitoring (Question 1) to address the recreation resource.

4. Proposed Work

4.1. Project Elements

This project is divided into five major monitoring and research elements and one additional support element. The first two project elements are monitoring projects, each with some research aspects. The last three elements are research projects that contribute to improving the monitoring program and improving predictive capacity. Research element A.3 will investigate the relations among flow, vegetation, and geomorphology to determine the physical controls on sandbar deposition. This information will contribute to improved sampling design and the capacity to predict high flow response for specific locations. Element A.4 is an attempt to quantify relations among three bed sediment properties (grain size, total areal coverage with sand, and shear stress of the sites covered by sand). It is important to understand these effects, both to understand the data collected at the sediment gaging stations, and also so that we can ultimately use suspended sediment to understand distribution of bed sediment (which would give higher-frequency data at lower cost). Element A.4 is an attempt to use sediment geochemistry to distinguish mainstem Colorado River sediment (i.e., predam sediment) from Paria River sediment (post-dam sediment). If successful, this work will tell us whether sediment that is building new bars comes from a sustainable source (Paria River) or comes from a source that cannot be replaced (pre-dam sediment). The control network and survey project element support the other project elements, as well as other FY13/14 projects.

The ultimate measure of whether or not fine sediment is conserved in and near the Colorado River is the increase or decrease in volume and area of fine sediment deposits. Thus, monitoring elements involve repeat measurements of topography such that changes in the volume of sand deposits can be calculated. Because the management focus is on fine sediment, it is necessary to discriminate sand and finer sediment from gravel, cobbles, and boulders. In order to more effectively detect change in different resources of importance, it is necessary to monitor change in sand storage at both high and low elevations. This requires a mix of direct field measurement, remote sensing, and extrapolation throughout the 255 miles of the Colorado River between Glen Canyon Dam and River Mile 240, which is the upstream end of Lake Mead reservoir.

Data collection efforts occur across a wide range of spatial and temporal scales (Table 1) in order to detect change in a very large system in which significant change is often local and episodic. At a select set of long-term monitoring sites, sandbar monitoring is conducted at a daily (using remote cameras) and annual (by conventional survey) interval in order to track local response to individual events in the context of a long-term record. A larger collection of sandbars are also monitored every four years using remote sensing, in order to provide a synoptic view of the entire Colorado River

Table 1. Summary of sandbar and sediment storage monitoring efforts.

Project Element	**Spatial Focus**	**Method**	**Measurement Frequency**	**Information Needs Met**
A.1	Selected high-elevation sandbars (~50)	Conventional topographic surveys (volume and area)	Yearly	Annual status check on sandbar and camping beach condition
A.1	Selected high-elevation sandbars (~30)	Remotely deployed digital camera (approximate size)	Daily	Status check on sandbar condition at ~6-month intervals
A.1	High-elevation sandbars systemwide (>1000 sites)	Remote sensing (area)	Every 4 years	Long-term trend of sandbar condition
A.2	Low-elevation fine sediment storage in 30 to 80-mile segments.	Combined bathymetric and topographic surveys (area and volume)	Every 3 to 10 years, depending on reach.	Long-term trend in fine sediment storage

Monitoring of fine sediment deposits is also conducted at multiple scales using a variety of methods. Fine sediment inputs and outputs (the I and O terms in equation 1) are monitored at a daily scale in 30-mile or longer sediment budgeting reaches (Project B). In this project, we monitor changes in sediment storage directly (the ΔS term in equation 1) at approximately 3- to 10-year time intervals and with high precision. These monitoring strategies are complementary. The mass balance measurements of high temporal resolution can be used to track tributary inputs and to schedule high flows. Fine sediment storage monitoring provides a direct measurement of changes in storage for all storage environments over the entire monitoring period, whether a few years or several decades. The geochemical signature project element provides an additional indirect method to evaluate the fine sediment budget that is based on estimating the age of the sand deposits.

Project Element A.1. Sandbar and Camping Beach Monitoring ($261,900)

The main purpose of the sandbar monitoring element of the project is to track trends in the status of sandbars that are emergent above the water surface at 8,000 ft^3/s throughout Marble and Grand Canyons. This work is to be accomplished by a continuation of established monitoring activities and research. Monitoring is to be conducted at multiple spatial and temporal scales, in order to track detailed changes at a subset of monitoring sites and general changes at a larger number of sites. Work at the two scales is justified, because we would lack understanding of the causes of sandbar changes without higher frequency measures made at fewer sites, but, we would lack the ability to track sandbars beyond the area of the long-term monitoring sites without system-wide data.

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

A subset of sandbars and campsites located throughout the Colorado River will be monitored annually using conventional ground-based surveying methods. This dataset is commonly referred to as the “long term sandbar time series” and is the most temporally rich dataset describing the state of sandbars currently available. The monitoring program was initiated in 1990. These surveys of approximately 50 sites include measurements of sandbar area and sandbar volume above the stage associated with 8,000 ft^3/s. In addition, campable area is measured at 37 of these sites. Methods for these surveys are described by Hazel and others (2008, 2010), and Kaplinski and others (2009). These annual surveys are supplemented by daily photographs of about 30 sites using remote digital cameras. These images make it possible to record the effects of changes in flow regime that cannot be resolved by the annual measurements. The number of sites monitored by digital camera will be increased by adding 2 to 5 cameras each year.

The sites monitored in this project were selected because of their lengthy historical record. Although the sites were not selected randomly, preliminary analyses have indicated that the sites adequately represent the behavior of bars above 8,000 ft^3/s stage in Marble Canyon. We will continue to investigate the degree to which the long-term monitoring sites represent sandbar response system-wide in the remote sensing project A.1.2, described below.

This project will result in an annual report on the status of sandbars based on monitoring from the previous year. The sandbar monitoring surveys and photographs will also be made available on the GCMRC website.

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

Because only a subset of sandbars are surveyed in the field, we will use remote sensing to track the area of exposed sand above the elevation of the 8,000 ft^3/s stage (high-elevation sand) of more than 1000 large eddies along the Colorado River every 4 years. The canyon-wide remote sensing data that will be used in this effort consists of (1) four-band, orthorectified digital imagery (blue, green, red, and near-infrared bands) acquired in 2002, 2005, and 2009, and will be in acquired in 2013; (2) Digital Surface (elevation) Models (DSM) derived from the 4-band imagery mentioned above; (3) Color-InfraRed (CIR), stereo imagery acquired in 1988; and (4) DSM that will be derived from the 1988 stereo imagery. The annual ground surveys and quadrennial remote-sensing data are complementary. The ground-survey data, which provide detailed topographic and land-cover information for specific sites will be used to calibrate the DSM data and to "train" canyon-wide image analysis. These products will, in turn, be used to improve understanding of the degree to which changes observed based on long-term monitoring of sites in the field are representative of the entire system. Changes in area and volume observed from periodic remote-sensing data will be compared to the changes observed in the ground survey data to determine the degree to which and the scale at which the ground sites correspond to changes at larger scales.

The remote sensing effort will involve a landscape delineation of four units: water, vegetation, sand, and other bare ground (e.g. pre-dam alluvial deposits, talus, and bedrock). This landscape database is currently being produced for image data sets collected in 2002, 2005, and 2009. In the course of this project, new image data will be collected in 2013 and analyzed in 2014, which will allow an 11-year, quantitative examination of the changes in sand and vegetation surface area and how these changes compare to dam operations. For each image set, the water surface is mapped using interactive computer algorithms. Vegetation is mapped using the Spectral Angle Mapper (SAM) technique that determines the n-dimensional vector angle between the wavelength-band values of an image pixel and a user-supplied vegetation spectrum (Kruse and others, 1993). The smaller the vector angle for a particular image pixel, the more likely the pixel represents vegetation. A maximum SAM angle for vegetation is determined by visual comparison of the SAM image with its corresponding 4-band or CIR image on a regional basis and that maximum value is used to produce a thematic image of vegetation.

Following the classification of water and vegetation, areas of sand will be mapped at more than 1000 eddies. These sites are not the entire population of sand deposits, but comprise a very large sample that includes nearly every eddy that has ever contained a sandbar larger than about 250 m^2 and nearly every location that has had a camping beach in any campsite inventory since 1975. Sand surfaces are characterized by a set of relative spectral properties and a very low surface texture or roughness. Water and vegetated areas within each Area of Interest (AoI) will be removed from the image data, and a textural (roughness) analysis will be performed on the remaining image data. The surface texture analysis will be designed to (1) minimize confusion along roughness or cliff-shadow transition borders, (2) include damp or shadowed, lower reflectance sand areas, and (3) exclude bedrock with similar spectral and texture properties. The application of the sand-surface mapping will proceed similar to that for vegetation, in that the spectral and textural image properties of sand surfaces will be visually examined at a river-length interval to apply the optimum spectral and textural ranges to accurately map sand surfaces. In addition, surface slope (a factor for camping beaches) and sandbar volume change will also be examined using the digital surface models from the 2002, 2009, and 2013 data sets. The landscape maps for 2002, 2005, and 2009 will be completed before October 2012; the landscape maps for 2013 will be completed by September 2014 following collection and calibration of the 2013 image data.

Once the accuracy of the 2002-2009 databases are acceptable, the same landscape analysis will be performed on "historic" aerial photographic data. The 1988 photographs are the best images that approximately coincide with the beginning of sandbar monitoring by topographic survey and with the implementation of the Interim Operating Critera that limited the daily range of flow fluctuations in 1991. Before such analysis, the photographs that cover the AoI's will be orthorectified, which will first be attempted using one of our more recent DSM data sets, using fiducial points within the 2002 and 2009 image data as horizontal control points and their corresponding DSM values as vertical control points. Fiducial points are identifiable points whose location and elevation have not changed among different periods of observation. If an AoI does not have sufficient fiducial points for rectification or the DSM rectification does not produce accurate image results for an AoI (due to changes in an AoI's perimeter topography), then a DSM will be produced for the AoI using the 1988 CIR stereo images that cover the AoI, but this will require the acquisition of more accurate fiducial ground control by survey crew. Regardless, DSM data will be generated for sandbars within selected reaches in order to determine subaerial sandbar volume and to exam changes in volume, as well as area, throughout the time series. Stereo photogrammetry (which derives topography from stereo, point-perspective images) is time consuming and expensive and, therefore, "historic" volume change will only be estimated for a few reaches (see Project 1d).

This project will result in maps that depict the location and size of sandbars present in the 2013 images (for all of Marble and Grand Canyons) and the 1988 images (for selected reaches). The methods and findings will be documented in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article.

Project Element A.1.3. Geomorphic attributes of camping beaches

Paul Grams, Research Hydrologist, USGS/GCMRC
Graduate Student

Among the difficulties that have been encountered when interpreting the sandbar and campsite data is the imprecise relation between the monitoring metrics and the attributes of bars most relevant to camping. Current monitoring emphasizes sandbar area and volume (e.g. Hazel and others, 2010) as the primary metrics of sandbar change. The other metric currently in use is "campable area," which has been monitored since 1998 (Kaplinski and others, 2010). While this measure provides some indication of camping beach size, the metric lumps together important attributes, such as the extent and density of vegetation, slope, surface roughness, and others, thus providing an incomplete assessment of trends in camping beach characteristics. This currently results in an inability to specify the causes for change in "campable area" over time. Many factors such as the spatial distribution of sand and other geomorphic units, the slope of the sandbar, and the distribution and density of vegetation affect the degree to which a sandbar is desirable as a camping beach.

Many of the above factors can be examined by performing analyses on currently available data. Topographic characteristics of the camping beaches will be extracted from the dataset of sandbar surveys. The distribution of vegetation, substrate type, and other site characteristics will be interpreted from aerial photographs, the catalog of site photographs collected by remote cameras, and the site photographs. We will analyze these and other datasets to develop new metrics that can be used to track trends in specific camping beach attributes over time and in response to changes in flow regime. These new analytical tools will help managers understand whether or not management actions, such as controlled floods, are having the desired outcome of enhancing the camping beach resource in addition to causing sandbar deposition.

A second component of this project will be an analysis of the data collected by the Grand Canyon River Guides "Adopt-a-Beach" (AAB) program since 1996. These data, which include annual observations and photographs for approximately 40 of the most popular recreational camping beaches between Lees Ferry and Diamond Creek, are not currently utilized in assessments of sandbar or camping beach condition that are reported to the GCDAMP. Although the AAB observations do not provide absolute measures of sandbar size (area and/or volume), the data have the potential to provide valuable insight about camping beach condition from a river user perspective. We will work with the Grand Canyon River Guides in an analysis of the dataset either as an independent assessment of camping beach condition or as complementary observations to the sandbar monitoring conducted in project A.1.1. Funding to continue to support the Grand Canyon River Guides for collection of the AAB photographs and observations and involvement of in the analysis and interpretation of the data is included in this project.

The results from project A.1.3 will be described in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article.

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

Our understanding of the trends in sandbar size and abundance is limited by the extent of the monitoring period. Many perceptions regarding the current condition of sandbars is based on limited observations of sandbars following the floods of 1983-86 (Schmidt and Grams, 2011). However, those observations are based largely on imprecise photo comparisons and are not quantitatively tied to the current sandbar monitoring program. The purpose of this research activity is to extend the length of the monitoring record back in time for the long-term sandbar monitoring sites (Project A.1.1.) by incorporating data from air photos taken before 1990. Pilot studies (Blank, 2000; O'Brien and others, 2000) investigated the feasibility of applying digital photogrammetric methods to 1984 stereo photography to derive sandbar topography for comparison with modern surveys. Although these studies found that the photogrammetric surfaces did not agree perfectly with ground-based surveys, the elevations for sand areas were generally within 25 cm of surveyed elevations, which is sufficient for detecting significant change in sandbar elevation. Our proposed task will apply a similar, but more sophisticated, approach to derive topography for selected sandbar study sites in order to extend the sandbar monitoring record back in time. This project will produce digital elevation models using digitally scanned 1984 stereo photographs. In FY13, representative sites will be selected and various techniques and approaches will be tested to determine the method that produces the best results. If acceptable results are obtained from the 2013 effort, additional sites will be incorporated in 2014.

The results from this project will be described in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article.

Project Element A.2. Sediment Storage Monitoring ($597,600)

Project Element A.2.1. Bathymetric and topographic mapping

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

The purpose of the fine sediment storage monitoring element of this project is to track long-term trends in sand storage to provide a robust measure of whether or not management objectives for fine sediment conservation are being met. In other words, this project provides the direct measure of ΔS in equation (1) over the time scale of 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 (equation 2). The greatest challenge in developing an appropriate monitoring program is the scale of the area of management interest, which includes the entire CRe from Glen Canyon Dam to Lake Mead. As described above, previous efforts have demonstrated that measurements of fine sediment storage change made in short reaches cannot be extrapolated to determine sediment storage throughout the CRe. The large local variability in response requires sampling a large proportion of the river channel.

Using the repeat maps made for the short reaches between 2000 and 2004, we investigated potential sampling strategies. This was accomplished by artificially subsampling the maps of topographic change that cover an entire 5-km short reach, using three different sampling strategies: (1) regularly spaced channel cross-sections; (2) randomly located channel cross-sections; and, (3) subsampling of major eddy storage locations. This analysis indicates that all of these sampling strategies result in error that is greater than 50% of the actual change in storage unless sampling intervals are sufficiently small such that the level of effort is essentially equivalent to comprehensively mapping approximately 80% of the entire reach. To estimate storage change with an uncertainty of 50% of the observed value would require average cross-section spacing of 300 m or less, regardless of whether the spacing is regular or locations are selected randomly. To achieve a similar level of accuracy by sampling eddy storage locations would require sampling more than 75% of those locations. In response to these findings, and to reduce the need for extrapolation, the monitoring program in FY13/14 will consist of repeat mapping of most of the bed of the river. This strategy will result in the production of a high-resolution map of 50 to 80% of the bed of the Colorado River in Marble and Grand Canyons. Repeat maps will provide robust estimates of bed sediment storage change for each mass balance reach.

Because we currently lack a map of the bed of the river and our understanding of the distribution of important sediment storage locations is very limited, we believe that the mapping approach described here is the only strategy that we can implement that will provide robust long-term estimates of sediment storage change. However, these maps will also be used to evaluate the spatial distribution of the largest and most dynamic fine sediment storage locations. We anticipate that with this information we will eventually be able to develop a sampling design that requires repeat mapping of a smaller proportion of the river channel.

It is not logistically feasible to map the entire river corridor in every segment in each year. The goal of this work is, therefore, to map approximately 80% of each monitoring segment between the dam and RM 87 and approximately 50% of each segment between RM 87 and RM 225. Although it is not possible to identify all the important sediment storage locations prior to mapping, the effort is expected to result in mapping more than 90% of the large eddy storage locations upstream from RM 87 and at least 75% of those storage locations downstream from RM 87. We place greater emphasis on monitoring the three upstream reaches, because the most upstream reaches have greater sediment deficit and are, therefore, at greater risk for long term sand depletion. We further expect that because these reaches have larger sediment deficit that storage changes are likely to be more variable, requiring monitoring a greater proportion of each monitoring segment. Each year, one of the five sediment monitoring segments that are between 26 and 80 miles in length will be mapped such that each segment will be mapped twice in 10 years. This monitoring strategy was first described in the draft sediment core monitoring plan (Topping and others, 2007).

Table 2. Long sediment budgeting reaches for long-term monitoring of sediment storage.

Segment	River Miles	Existing or planned surveys	Short reaches*	Cross-sections**	Estimated proportion of reach mapping will cover	Repeat Interval
1	-15 to 0	2012-2014	1	20	80%	~ 10 yr
2	0 to 30	2013	2	41	80%	5 to 10 yr
3	30 to 61	2009, 2012	3	17	80%	3 to 5 yr
4	61 to 87	2011	2	39	80%	3 to 5 yr
5	87 to 166	2015	1	20	50%	~ 10 yr
6	166 to 225	2014	2	8	50%	5 to 10 yr
7	225 to 240	2013	--	--	***	~ 10 yr

* The number of short reaches 2 to 5 km in length that were mapped at least once between 2000 and 2005 (Kaplinski and others, 2009).
** The number of cross-sections that were measured at least once between 1992 and 1999 (Flynn and Hornewer, 2003).
*** The method that will be used for mapping this reach has not been determined.

Because about 90% of the sand and finer sediment that is available for redistribution by dam operations is below the water surface (Hazel and others, 2006), the monitoring method must include measurements of the bed of the river in eddies and pools. Data collection will combine multibeam and singlebeam sonar coupled with conventional surveys for areas above the water surface. These methods have been described by Hazel and others (2008), Kaplinski and others (2009) and were used extensively in monitoring the 2008 HFE (Hazel and others, 2010). Similar methods are used to monitor channel changes on other large rivers, including the Missouri River (Jacobson and others, 2009). The data will result in a high resolution digital elevation model of the mapped segments for each mapping effort. Upon completion of a repeat map of a segment, the DEMs will be compared to compute the net change in the volume of sediment within the segment. These computations will distinguish between fine and coarse sediment (see project element A.3.), between sediment stored in the channel and eddies, and between sediment at high- and low-elevation. The computations will also incorporate estimates of uncertainty (e.g. Wheaton and others, 2010). In addition to making comparisons between years for which the entire segments are mapped, comparisons will also be made to older data where available. This will include comparisons to data collected in short reaches in 2000 to 2005 and data collected at monumented channel cross-sections (Table 2).

The current approach differs from that outlined in the draft sediment core monitoring plan (Topping and others, 2007) in two ways. First, the core monitoring plan suggested a simple rotation beginning with upstream segments and working downstream. Our revised plan is to map in a sequence based on scientific and management priorities, balancing the need to map all segments with the need to provide repeat maps and preliminary results. The long reach from RM 30 to RM 61 was the first mapped in 2009. That segment is of high priority, because Marble Canyon has been identified as the segment most at risk for long-term erosion. Within Marble

Canyon, the downstream half was selected, because it includes the largest area where data were collected from 2000 to 2004. The second long reach mapped was the reach from RM 61 to RM 87 that was mapped in 2011. This long reach was chosen, because it contains areas that are of interest for habitat characterization. In spring 2012, we repeated the RM 30 to 61 long reach to evaluate the efficacy of demonstrating the methods described here and to show the sand storage response to the summer 2011 sustained high flows. Long reaches selected for data collection in 2013 and 2014 will depend on circumstances, but we currently plan to map the long reach from RM 0 to RM 30 in 2013 and the long reach from RM 166 to RM 225 in 2014. The other difference between this and the original monitoring plan is that the draft monitoring plan recommended against collecting data in years with HFEs. The current plan includes data collection each year, regardless of operating regime or if HFE's occur. We propose this change, because the current protocol for implementing future high flows involves a trigger that makes planning for data collection difficult, and because we believe that the repeat channel mapping will be most informative if data are collected annually.

This project will result in digital elevation models of the segment mapped in each year of the project. Those data will be made available on the GCMRC website. The results describing changes in sediment storage based on the repeat mapping of the RM 30-61 reach mapped in 2012 will be described in a U.S. Geological Survey interpretative report or peer-reviewed journal article.

Project Element A.2.2. Bed-material characterization

Paul Grams, Research Hydrologist, USGS/GCMRC
Matt Kaplinski, Research Associate, Northern Arizona University
Bob Tusso, Research Hydrologist, USGS/GCMRC
Postdoc

A necessary component of the effort to monitor fine sediment storage is the identification of the bed surface texture as well as the bed surface elevation. Currently, we rely on a categorization of the bed that does not do a good job of discriminating sand from gravel in those places where the bed topography has little relief. We propose to improve the method used to characterize bed texture using the backscattering data from the multibeam sonar surveys to identify and map bed material. The backscatter data collected by sonar will be calibrated and validated against observations of bed material characteristics made by underwater video camera, which are collected and processed using the methods of Rubin and others (2007) and Buscombe and others (2010). We expect that this technique will enable more robust discrimination among sand, gravel, cobbles, and boulders. This work will include testing of existing processing algorithms, comparing results for selected reaches to evaluate technology, and developing new algorithms, if necessary.

More specifically, research will be conducted into developing computational algorithms which will classify substrates based on multibeam backscatter properties. Bed texture refers to both the sediment grain size (sand, cobble, boulder, etc) and the micro-topography (for example, silt, sand, and gravel can be rippled or support dunes, and bare bedrock is often not smooth but has an undulating rough surface). Raw acoustic backscatter varies not only with particle size distribution, but also with incidence angles, bed slope, and bedforms/micro-topography (related to the grazing angle of the acoustic signal, or the acoustic footprint), as well as water properties such as depth and concentration of suspended and dissolved material (related to acoustic attenuation losses which reduce signal-to-noise ratios). Therefore, the problem is not trivial.

However, because the same area of bed is sensed by hundreds of individual acoustic beams, multibeam data have a wealth of information to exploit and research progress has been swift in the past decade (Brown and Blondel, 2009). Sediment classification from acoustic backscatter is a relatively new field, and in recent years, there have emerged two approaches to the problem, termed 'geoacoustic' and 'feature-based' approaches.

Feature-based approaches use image processing techniques to characterize the texture of images of areas of gridded backscatter data. Image intensity is related to the amount of acoustic energy backscattered. Techniques used to date include methods based on basic and higher statistical moments, including histograms, fractal dimensions, and power spectra; and methods based on texture models, such as Gray-Level Co-occurrence Matrices (GLCMs). The aim of the latter is to produce textural descriptors or 'indices' which are a set of statistical measures of the GLCMs unique to a particular texture. For example, one index is 'entropy' which quantifies the lack of spatial organization and will be higher for relatively rough surfaces such as rocks and lower for relatively organized textural variations such as ripples. These techniques have been shown to work well for relatively broad discriminations between sediment and different rock types (e.g. Blondel and Gomez Sichi, 2009), however, it remains to be seen whether such an approach alone can distinguish among sediment types. There is no widely accepted agreement on the best method or combination of methods (Brown and others, 2011).

Geoacoustic approaches analyze the shape and statistical properties of the backscattered waveform (backscatter intensity versus grazing angle, also known as the 'angular response') and try to relate these properties to specific bed textures. The average angular response is compared to mathematical models (Jackson and others, 1986) that link acoustic backscatter observations to seafloor properties (Fonesca and others, 2009; Lamarche and others, 2011). Such geoacoustic approaches, unlike feature-based approaches, have the potential to uncover information on the subsurface as well as surface sediment type, but this could also be a limitation if these influences are not robustly theorized.

In shallow water where the quality of the multibeam sonar data degrades due to low grazing angles, available backscatter data from sidescan sonar systems (which have higher along-track resolutions and lower-grazing angles than multibeam sonar data systems) will be merged and co-registered with the multibeam sonar data. It will be possible to validate/test these techniques using co-located data from towed video cameras and bed-sediment video microscopes (e.g. Rubin and others, 2007). Such data, collected over several years, are already being analysed for grain size and other attributes using the method of Buscombe and others (2010) and Buscombe and Rubin (2012). These techniques use advanced spectral analysis to derive grain size directly from the images of sediment by quantifying energy associated with grain-scale wavelengths of image intensity. Similar principles will be useful in the present problem, where the dominant wavelengths of intensity might be quickly estimated in images comprised of a mosaic of acoustic swaths.

Sediment classification techniques will have to be equally applicable to the full spectrum of scenarios from the relatively simple situation of uniform sediments, to more difficult scenarios such as where fine sediments are located among cobbles and boulders (i.e. in acoustic shadows); where fine sediments form shallow blankets over gravels and cobbles (where the challenge will be determining what particle size is surficial and what is subsurface); and, where the river bathymetry is very complicated. In addition, the techniques developed in this project will have to be applicable to multibeam data collected with different systems and at different spatial resolutions and precisions. It is anticipated that the techniques themselves will be sufficiently general to apply to other rivers and water bodies, thus of benefit to the wider scientific community.

Knowledge of bed texture is a specific requirement for modeling primary productivity, because algal growth varies depending on substrate type and affects benthic biomass, because invertebrate density varies by substrate type. Thus, improved maps of bed texture will help improve the estimates of reach-scale productivity that will be conducted in project H.2.1 (Developing a Mechanistic Model of Primary Productivity) and will inform foodbase monitoring (project F.7.4 Benthic Algae and Invertebrate Biomass). Bed texture and changes in bed texture are also of specific interest to biologists studying native fish. Maps of bed material texture will help fisheries biologists understand the spatial abundance of specific habitat types, such as sand, cobble, bedrock, or talus, and the degree to which those habitats are stable or dynamic.

The project will result in maps and other data formats of the bed texture/grain size for each segment of river mapped in each year of the project, and will be made available through the GCRMC website. The computational algorithms will be published in both a USGS interpretive report and a peer-reviewed journal article for review and use by the wider scientific community. The widespread geomorphological and ecological implications of such data will be disseminated at conferences and further peer-reviewed journal articles intended for a broad cross-disciplinary audience.

Project Element A.3. Investigating Eddy Sandbar Variability and the Interactions among Flow, Vegetation, and Geomorphology ($103,500)

Paul Grams, Research Hydrologist, USGS/GCMRC
Barbara Ralston, Biologist, USGS/GCMRC
Postdoc and Researcher

The large body of work that has been conducted on sediment transport on the Colorado River, coupled with the monitoring of sandbar response to high flows, has resulted in the observation that even when there is a large supply of sand on the river bed, as was the case in 2008, sandbar response is highly variable from place to place. The analysis of the long-term sandbar monitoring data by Grams and others (2011) showed that there are systematic differences in eddy behavior. Some eddies tend to accumulate sediment during relatively high flows (e.g. the high end of the range of powerplant operations and HFEs), while other eddies tend to accumulate fine sediment at relatively low flows (the low end of the range of powerplant operations). The purpose of this project is to systematically study the hydraulic characteristics of eddies that are representative of these different styles of behavior to discover what controls these differences. Improved understanding of eddy behavior will benefit monitoring efforts, because this study could provide a basis for developing a more targeted stratified sampling design. In addition, this knowledge could lead to better capacity to predict the sandbar-building response to HFEs and other dam operations to specific sites, or groups of similar sites.

There are many possible causes for variable sandbar-building response among eddies. In general, it is likely that the structure of the channel causes variability in time-scale hydraulics, and, thereby, variability in patterns of deposition and erosion. However, it is unknown which aspects of channel geometry are most important in controlling this variability. A related hypothesis is that the amount and spatial distribution of established vegetation affects patterns of deposition. Riparian vegetation affects sediment transport and deposition by stabilizing portions of eddy sandbars and by introducing added roughness that affects sediment deposition dynamics.

Thus, while vegetation may stabilize existing deposits, those stabilized areas may prevent or hinder the creation of new deposits.

We propose to investigate these dynamics with (1) an empirical analysis of existing data and (2) a numerical modeling study. In the empirical study, we will couple our large existing dataset of eddy sandbar behavior with metrics that describe site geometric and hydrodynamic characteristics. In other words, we will look for statistical relations between observed eddy behavior and site characteristics. We will use the analysis of Grams and others (2011) who categorized eddies by flow regime response as an initial basis for metrics to anticipate eddy behavior. We will characterize physical attributes by extracting metrics of channel geometry from topographic/bathymetric maps for each site. An exhaustive list of potential site characteristics is not included here, but will involve the identification of metrics for spatial changes in flow strength, such as changes in relative channel width, flow depth, and roughness. Other site characteristics, such as the extent, location, density, and maturity of vegetation will also be incorporated.

The expected result of this analysis is the discovery of specific site characteristics and vegetation patterns that most strongly affect the amount and pattern of sandbar deposition. Once we are able to identify characteristics that influence response, we will apply the efforts to additional sites to test these hypotheses. If we are able to discover site characteristics that are truly correlated with depositional patterns, we will have a powerful tool for predicting sandbar response to given flow events. The research is expected to result in a simple categorization of eddy sandbars into predicted styles of response to different flow regimes. For example, we predict for a given flow regime, such as a 45,000 ft^3/s controlled flood, which sites would be predicted to have large sandbars, small sandbars, or no sandbars.

For the modeling component of the study, we will select two sites that have very different behavior, as identified by Grams and others (2011). For each site, we will construct a 3-dimensional numerical model. Models for sandbar deposition have not yet performed well without "tuning" (Logan and others, 2010). Therefore, we recognize that these models will require calibration by adjusting the input suspended sediment concentration to produce modeled sandbars that match observations. Thus, these models will not be truly predictive, but should be useful for testing how variation in site characteristics affects sandbar building response. Once calibrated models are developed for each of the two sites, such that they adequately portray observed sandbar behavior across a range of flows (with constant sediment supply), they will be used to investigate how changes in site characteristics affect deposition patterns. This will be done by incrementally changing model boundary conditions such as roughness and channel geometry, testing any hypotheses generated based on the empirical analysis.

The expected outcome of this effort is a much improved understanding of the physical controls on sandbar behavior. This understanding will contribute to improved sampling design and possibly flow recommendations that are more specifically targeted towards building sandbars in either specific locations or specific segments of the river. This research project will result in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article that describes the methods and results of the study.

Project Element A.4. Quantifying the correlation between bed and transport grain size ($149,900)

Dave Rubin, Research Geologist, USGS

A strong correlation between bed sediment grain size and the rate and grain size of sediment in transport has been demonstrated for the CRe. This correlation has been used to infer bed composition and coverage from suspended sediment measurements. This is a potentially useful monitoring technique, but implementation will require a better understanding of the spatial scale at which the correlation can be demonstrated.

The influence of bed sediment on suspended sediment is complicated, because bed sediment influences suspended sediment concentration and grain size in at least three ways. First, finer sediment on the bed is hypothesized to cause higher suspended-sediment concentrations and finer suspended sediment (where other forcing and boundary conditions are constant), as modeled and observed by Rubin and Topping (2001). Second, greater areal coverage is hypothesized to produce higher concentrations, but no change in grain size, as observed in experiments (Grams and Wilcock, 2007). Finally, distribution of bed sediment in areas with greater than average shear stress is hypothesized to produce higher concentrations of suspended sediment, with coarser grain size (again, for constant water discharge, mean grain size on the bed, and areal coverage of sand). The aim of this work is to quantify these three effects and derive the mathematical relation among these three properties of bed sediment and the resulting concentration and grain size in suspension.

The proposed work will use both field measurements and modeling to partition these three effects, in order to provide a more reliable link between bed and transport grain size. Modeling will use work of Grams and Wilcock (2007) to quantify the effect of areal sand coverage and the approach of Rubin and Topping to quantify the effects of local shear stress and grain size, which previously have been quantified at a reach average. We will use dense field measurements of bed topography and bed texture extending 2 to 4 km upstream from one or more gages. We don't know for certain that this is the optimum measurement distance, but we suspect that reaches extending only hundreds of meters upstream from the gages will be insufficient to capture the important average bed properties (because grains settle too slowly), and that regions extending tens of km upstream are unnecessarily long (because pools within these long reaches will trap sediment) and logistically impossible or too expensive to survey. These measurements will be repeated at approximately 2-month intervals for a 6-month period beginning in early 2013. The measurements will either be made in a reach that is accessible without requiring additional river trips (e.g. near Diamond Creek), or the measurements will be made in conjunction with other trips; no additional river trips dedicated to this project are proposed. Additional possible technological approaches include deploying a recording bed camera to measure a time series of grain size at a single point, or deploying rotating sonar to develop a time series of areal coverage of sand on the bed.

This work will improve our understanding of the linkages between suspended-sediment observations and bed-sediment texture, which will provide greater understanding of the upstream extent of river that determines concentration and grain size at sediment gaging stations. Findings from this work will be used to improve models for suspended sediment transport and may provide improved methods for tracking the abundance of sand on the river bed using the suspended sediment monitoring network. For example, Topping and others (2010) used the measurements of suspended sand concentration during the 1996, 2004, and 2008 HFEs to estimate the proportion of the bed covered by sand and the grain size of that sand. Those calculations suggested that, in some reaches, there was likely more sand on the bed in 1996 than in 1998, although of coarser grain size. Results from this project would improve our ability to use measurements of sand in suspension to infer the condition of the bed.

The specific hypotheses that will be investigated by this component of the project are:

1. Observed variability in sand flux (as much as 1000-fold differences in flux for a given water discharge) is caused by—and can be mathematically described as a function of—changes in bed sediment (grain size, areal coverage, and specific spatial distribution).
2. Observations of suspended-sediment concentration and grain size can be used to calculate these three properties of bed sediment.
3. Application of the relations between bed-sediment and flux and observations of bed-sediment boundary conditions can be used to improve or optimize bar-building flows (greatest bar-building for a given amount of sediment and water used during artificial floods.

Better understanding of temporal changes in bed texture will also be used to improve our ability to model and predict aquatic primary productivity. Bed sediment texture, the spatial distribution of bed sediment, and bed topography all affect the rate of primary production. These characteristics affect the amount of light that reaches a given portion of the bed and the substrate that algae and invertebrates occupy. For example, coarse bed material, such as cobbles and boulders, is associated with different benthic species and population densities than sand and finer substrate. This project will be conducted in cooperation with studies of the aquatic foodbase (Project H) to advance understanding of these issues and improve models for primary production.

This research project will result in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article that describes the methods and results of the study.

Project Element A.5. Geochemical Signatures of Pre-Dam Sediment ($50,900)

Renee Takesue, Geologist, USGS/Pacific Science Center

In the post-dam era, the Paria River is the dominant supplier of sand to the Colorado River in Marble Canyon between Lees Ferry and the Little Colorado River confluence. Prior to dam completion, the Paria provided less than 10% of the sand supplied to Marble Canyon. This dramatic shift in sediment source creates an opportunity to distinguish sand deposits based on chemical properties. Provided that sediment from the Paria and Colorado Rivers have distinct geochemical signatures, these end member signatures can be used to determine proportions of material from the two sources that comprise downstream sediment deposits. Such information would be particularly valuable for evaluating long-term trends and individual event-scale changes in sand bar composition arising from (HFEs). For example, this approach would allow testing of the following basic hypothesis: *sand bar composition has changed from Colorado River-sourced sand to Paria-sourced sand.* The alternative hypothesis is that sand-bar composition is generally invariant over time, being predominantly composed of either Colorado-sourced sand or alternatively Paria-sourced sand. In particular, some changes may indicate whether or not recent bar-building flows are sustainable. For example, if deposits of individual high-flows are composed entirely of Paria-sourced sand, bar-building may be sustainable. On the other hand, a shift in source from Paria River to pre-dam Colorado River sand during high flows, may suggest an unsustainable sediment supply exists.

Exploratory work during the past two years has shown that in the .25-0.0625 mm size fraction, which is representative of the material in suspension during HFEs, Paria and Colorado Rivers sediment can be distinguished based on their sodium (Na), potassium (K), and rubidium (Rb) contents. These elements are likely hosted in sand-sized alkali feldspars. We propose to begin applying this geochemical source-discrimination technique to new and archived material from HFEs. Hypotheses about temporal changes in sediment composition can be tested using archives of suspended sediment from past HFEs and/or new samples from a HFE in 2013 or 2014. Budget requests include about two months of annual salary and benefits for R. Takesue, analysis costs of about 60 sediment samples, funds for field work if a HFE occurs during the funding period, and costs of information dissemination in a USGS report or scientific journal and at a scientific meeting.

If successful, this approach will give scientists and managers an additional measure to evaluate long-term trends of sediment abundance in Marble Canyon and the ability to detect mined pre-dam sediment in future high flows. This approach for investigating the sediment budget is independent from measurements of sediment inputs, outputs, and topographic change, and, unlike other methods, does not require subtraction of one number from another, such as in equation (1). Rather, the method relies on estimating the proportion of sediments within a deposit that pre- or post-date dam completion. *This research addresses some of the most important questions regarding sediment in the ecosystem: Is pre-dam sand still being excavated and exported downriver under present operations of the dam? Is the rate constant, or has the amount of pre-dam sand changed during the past half century? If the rate is constant, is it because pre-*dam sand is stable and protected, or is it because most pre-dam sand has already been removed?

This research project will result in at least one U.S. Geological Survey interpretative report or peer-reviewed journal article that describes the methods and results of the study.

Project Element A.6. Control Network and Survey Support ($56,300)

Keith Kohl, Surveyor, USGS/GCMRC

An accurate geodetic control network is required to support nearly every aspect of this project as well as other GCDAMP monitoring projects. The purpose of the control network is to ensure that spatial data acquired on all projects are collected with accurate and repeatable spatial reference. The control network is essential to enable comparison among data sets collected by different methods and ensure that spatially referenced observations are repeatable and that all data are archived appropriately. Projects that are directly dependent on the control network include this project, all other projects that use system-wide airborne remote sensing, archeological site monitoring, and vegetation monitoring. The remote sensing work is particularly dependent on accurate control operations, without which image data could not be compared accurately with ground-based measurements.

The control network is the set of monumented and documented reference points (benchmarks) that exist along the river corridor and on the rim together with the collection of observations that determine the relative and absolute positions of those points. Those points serve as the basis for referencing all ground- and air-based monitoring observations. Currently, the control network includes more than 7,000 GPS observations and more than 2,000 optical observations that determine the precise location of 1,303 benchmarks in the river corridor and on the canyon rim. This project includes work in three broad categories: (1) building the control network, (2) direct support of research and monitoring activities, and (3) storage and archival of the control database.

Building the Control Network

The primary task of building the control network involves making GPS observations at new and existing benchmarks. This effort is nearing completion, and most segments of the river corridor now have a sufficient number of control points to support monitoring activities. In 2013 and 2014, field work will be required to complete this task in Glen Canyon (between the dam and Lees Ferry), RM 81 to RM 91, RM 98 to RM 119, RM 144 to RM 166, and RM 225 to 277. Building the control network also requires addressing the difference that exists between ellipsoid height, which is provided by the GPS observations that GCMRC makes, and orthometric elevation (i.e. NAVD88), which can be obtained only by gravity measurements or precise leveling. The deviation between ellipsoid height and orthometric height can be as large as 10 cm over a distance of 1 km. This problem exists everywhere and is a major focus of work by the National Geodetic Survey (NGS). The problem has not been resolved in Marble and Grand Canyons because of the remote location, low population, and difficult access. We are working on this problem by incorporating existing leveling measurements into the control network and encouraging the NGS to conduct a campaign of gravity measurements for the Grand Canyon region.

Support of Research and Monitoring Projects

The two major project elements that require survey support in 2013 and 2014 are concerning sandbars (A.1.) and sediment storage (A.2.). The sandbar and sediment storage project elements described here utilize the control network and the expertise of the survey staff in data collection efforts. Geodetic control work supports the remote sensing data collection effort by panel placement and recovery, collecting reference base station data for overflights, and processing the data to publish GNSS results for the stations within the NGS database. Other projects that receive survey support include the Streamflow, Water Quality, and Sediment Transport project (Project B), and the Vegetation Monitoring project (Project I).

Storage, Archival, and Documentation of the Control Network Database

The control network data are stored in a Microsoft Access database that is linked with the GCMRC GIS database. The survey staff works with GIS staff to maintain and update the database as needed.

This project will result in updates to the National Geodetic Survey Integrated Database (NGSIDB) of all available Height Modernization and Benchmark stations. This project will also result in at least one U.S. Geological Survey report or peer-reviewed journal article on the accuracy and uncertainty in topographic change detection associated with measurement instrumentation, geodetic projections, or a related topic.

4.2 Personnel and Collaborations

The project lead is Paul Grams. Phil Davis is the remote sensing expert. Keith Kohl is the control network specialist and surveyor. Support is provided by Rob Ross and Bob Tusso who are term hydrologists. One term post-doctoral fellow will be hired to work on the bed material characterization project (Project A.2.2.), a second post-doctoral research fellow will be hired to work on the eddy sandbar variability project (Element A.3.), and an MS level graduate student will work on the geomorphic attributes of camping beaches (Project A.1.3.). The GCMRC staff have management responsibility for the entire project and share responsibility for data collection, analysis, and reporting. David Rubin and Renee Takesue at the USGS, Costal and Marine Geology, Joseph E. Hazel, Jr, and Matt Kaplinski from Northern Arizona University.

4.3 Deliverables

Products from this project will include annual reports to the GCDAMP, presentations at TWG and AMWG meetings, presentations at scientific meetings, and reports. All of the products listed as reports will be peer-reviewed USGS interpretive reports or peer-reviewed scientific journal articles. Updates of the status of sandbars based on annual surveys and the remote cameras will be made available at the January annual reporting meeting of each year to support the HFE EA science plan. Specific products are listed below:

Product	Project Element*	Lead Responsibility	Time of Completion
Data from long-term sandbar monitoring sites	A.1.1./HFE	NAU	Annual
Images from daily remote camera monitoring of sandbars	A.1.1./HFE	GCMRC	Annual
Map, showing extent of sandbars in selected reaches for 1988	A.1.2.	GCMRC	Year 1
Map, showing extent of sandbars throughout CRE in 2013	A.1.2./HFE	GCMRC	Year 2
Report on system-wide sandbar monitoring, 1988-2013	A.1.2./HFE	GCMRC	Year 2
Report on the geomorphic attributes of camping beaches	A.1.3.	GCMRC/NAU	Year 2
Report on the extended sandbar monitoring time series (1984 to present) based on use of old air photos	A.1.4.	NAU	Year 2
Report on changes in sediment storage, RM 30 to RM 61	A.2.1./HFE	GCMRC	Year 1
Data from sediment storage monitoring, RM 30 to RM 61	A.2.1./HFE	NAU	Year 1
Data from sediment storage monitoring for long reach mapped in 2013	A.2.1./HFE	NAU	Year 2
Data from sediment storage monitoring for long reach mapped in 2014	A.2.1./HFE	NAU	After Year 2
Maps of bed texture for each of the long reaches mapped in the sediment storage monitoring project	A.2.2.	GCMRC	Year 2
Report on bed material characterization	A.2.2.	GCMRC	Year 2
Report on eddy sandbar variability	A.3.	GCMRC	Year 2
Report on interaction between bed sediment and suspended sediment	A.4.	CMG	Year 2
Report on geochemical signature of pre-dam sediment	A.5.	CMG	Year 2

* HFE indicates products that also support the HFE science plan.

5. Productivity from Past Work

During FY11/12, the following products were either delivered to the GCDAMP prior to April 1, 2012, or are on track to be delivered by September 30, 2012.

5.1. Data Products

Sandbar monitoring database. Digital elevation models of sandbar surveys 1990-2011 in ArcGIS geodatabase format. To be made available at http://www.gcmrc.gov pending website improvements. Currently available at ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/physical/sandbar or by request.
Channel mapping database. Maps and digital elevation models of channel mapping surveys. To be made available at http://www.gcmrc.gov pending website improvements. Data currently available at ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/physical/cm_data and maps available at ftp://ftpext.usgs.gov/pub/wr/az/flagstaff/physical/cm_maps or by request.

Survey control database. Microsoft Access database containing all geodetic control, over 1600 reference marks, in Glen Canyon, Marble Canyon, and Grand Canyon. Available upon request.

Geomorphic change detection software. Software to compute changes in sediment storage between successive surveys. Developed in collaboration with Utah State University and ESSA Technologies. Software is available at http://gcd.joewheaton.org/

5.2. Completed Publications

Alvarez, L. and Schmeeckle, M., 2012, Erosion of sandbars by diurnal stage fluctuations in the Colorado River in Marble and Grand Canyon--full-scale laboratory experiments: River Research and Applications, online at, http://onlinelibrary.wiley.com/doi/10.1002/rra.2576/abstract.

Schmidt, J.C., and Grams, P.E., 2011a, The high flows--physical science results, *in* Melis, T.S., ed., Effects of three high-flow experiments on the Colorado River ecosystem downstream from Glen Canyon Dam, Arizona: U.S. Geological Survey Circular 1366, 53-91 p., accessed on June 28, 2011, at http://pubs.usgs.gov/circ/1366/.

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Melis, T.S., Grams, P.E., Kennedy, T.A., Ralston, B.E., Robinson, C.T., Schmidt, J.C., Schmit, L.M., Valdez, R.A., and Wright, S.A., 2011, Three experimental high-flow releases from Glen Canyon Dam, Arizona—Effects on the downstream Colorado River ecosystem: U.S. Geological Survey Fact Sheet 2011-3012, 4 p.

5.3. Publications in progress

Polino, M., Grams, P.E., and Kennedy, T.A., in review, A General Classification of Bed Texture for Select Reaches of the Colorado River in Grand Canyon, Arizona, U.S. Geological Survey Open-file report, 20xx-xxxx, xx p.

Ross, R. and Grams, P.E., in revision, Near-shore Thermal Gradients of the Colorado River Near the Little Colorado River Confluence, Grand Canyon National Park, Arizona, U.S. Geological Survey Open-file report, 20xx-xxxx, xx p.

Grams, P.E., and others, in preparation, Linking Morphodynamic Response with Sediment Mass Balance: Issues of Scale, Geomorphic Setting, and Sampling Design, to be submitted for review to Sedimentary Geology by June 30, 2012.

Czarnomski, N., Wheaton, J.M., Grams, P.E., Hazel, J.E., Kaplinski, M.A., Schmidt, J.C., in preparation, Untangling Geomorphic Processes in the Grand Canyon with Topographic Time Series from Hybrid Surveys, to be submitted for review to journal by September 30, 2012.

Hazel, J.E., Jr., Kaplinski, M., Schott, N., Parnell, R., Grams, P., and Ross, R., in progress, Sand Storage Measured at Selected Sites in Colorado River in Marble and Grand Canyons, Arizona, 1990-2009: U.S. Geological Survey Scientific Investigations Report, to be submitted for review by June 30, 2012.

Kaplinski, M., Grams, P., Hazel, J.E., Gushue, T., Tusso, R., Kohl, K., Shott, N., in progress, Monitoring Fine-Sediment Volume in the Colorado River Ecosystem, Arizona: Construction and Analysis of Digital Elevation Models, U.S. Geological Survey Scientific Investigations Report, to be submitted for review by June 30, 2012.

Wheaton and others, in preparation, Documentation and users guide for geomorphic change detection software, to be submitted for review by September 30, 2012.

Kohl, K., and others, in preparation, Establishing a Spatial Infrastructure for Long Term Monitoring in Grand Canyon, Arizona: Robust Geodetic Control in Support of Scientific Research and Resource Management, to be submitted for review by July 30, 2012.

5.4. Presentations at GCDAMP meetings

1. Presentations at TWG and AMWG meetings. Presentations are available at http://www.usbr.gov/uc/rm/amp/
2. Presentations at January 2011 GCMRC Annual Reporting Meeting.
3. Multiple presentations at July 2011 Knowledge Assessment workshop for physical sciences.
4. Presentation at October 2011 Knowledge Assessment workshop.
5. Presentations at January 2012 Knowledge Assessment workshop and annual reporting meeting.

5.5. Presentations at professional meetings

Grams, P.E., Topping, D.J., Schmidt, J.C., Kaplinski, M.A., Hazel, J.E., 2011, Linking Morphodynamic Response with Sediment Mass Balance: Issues of Scale, Geomorphic Setting, and Sampling Design, Abstract EP31F-04 presented at 2011 Fall Meeting, American Geophysical Union San Francisco, CA, 5-9 Dec.

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Schmidt, J.C., Grams, P.E., Hazel, J.E., Kaplinski, M.A., 2010, Topographic Analyses of Reaches of the Colorado River in Grand Canyon Reveal Focused Locations of Fine-Sediment Accumulation and Evacuation, Abstract EP31C-0756 presented at 2010 Fall Meeting, American Geophysical Union San Francisco, CA, 13-17 Dec.

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7. Budget

FY 2013					
Project Element A.1. Sandbar and Camping beach monitoring		Project Element A.2. Sediment storage monitoring		Project Element A.3. Investigating eddy sandbar variability and the interaction among flow, vegetation, and geomorphology	
Salaries	$103,100	Salaries	$252,900	Salaries	$86,800
Traveling and Training	$2,300	Traveling and Training	$2,700	Traveling and Training	$1,900
Operating Expenses	$10,600	Operating Expenses	$36,000	Operating Expenses	$2,100
Logistics	$22,300	Logistics	$68,200	Logistics	$0
GIS/RS/Electronics support (includes burden)	N/A*	GIS/RS/Electronics support (includes burden)	N/A*	GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$101,200	Cooperators (non-USGS)	$168,700	Cooperators (non-USGS)	$0
USGS cooperators	0	USGS cooperators	$13,700	USGS cooperators	$0
USGS Burden	$22,400	USGS Burden	$55,400	USGS Burden	$12,700
Total	$261,900	***Total***	$597,600	***Total***	$103,500
Project Element A.4.Quantifying the correlation between bed and transport grain size		Project Element A.5. Geochemical signatures of pre-dam sediment		Project Element A.6. Control network and surveying support	
Salaries	$41,900	Salaries	$6,300	Salaries	$17,100
Traveling and Training	$2,100	Traveling and Training	$0	Traveling and Training	$600
Operating Expenses	$1,000	Operating Expenses	$0	Operating Expenses	$3,200
Logistics	$9,500	Logistics	$0	Logistics	$28,500
GIS/RS/Electronics support (includes burden)	N/A*	GIS/RS/Electronics support (includes burden)	N/A*	GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$67,500	Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0
USGS cooperators	$18,200	USGS cooperators	$43,700	USGS cooperators	$0
USGS Burden	$9,700	USGS Burden	$900	USGS Burden	$6,900
Total	$149,900	***Total***	$50,900	***Total***	$56,300

* GIS support and image processing costs are shared among multiple individual projects. Only the gross portion shared by the sandbar and sediment storage project is shown here.

GIS/RS/Electronics Support (includes burden): $180,600

FY 2013 Project A. Gross Total: $1,400,700

FY 2014

Project Element A.1. Sandbar and Camping beach monitoring	
Salaries	$107,900
Traveling and Training	$2,300
Operating Expenses	$10,600
Logistics	$22,300
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$104,100
USGS cooperators	$0
USGS Burden	$23,200
Total	$270,400

Project Element A.2. Sediment storage monitoring	
Salaries	$263,100
Traveling and Training	$2,700
Operating Expenses	$36,000
Logistics	$71,500
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$173,600
USGS cooperators	$13,700
USGS Burden	$57,500
Total	$618,100

Project Element A.3. Investigating eddy sandbar variability and the interaction among flow,	
Salaries	$91,100
Traveling and Training	$1,900
Operating Expenses	$2,100
Logistics	$0
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$0
USGS cooperators	$0
USGS Burden	$13,300
Total	$108,400

Project Element A.4.Quantifying the correlation between bed and transport grain size	
Salaries	$43,500
Traveling and Training	$2,100
Operating Expenses	$1,100
Logistics	$9,500
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$69,400
USGS cooperators	$76,600
USGS Burden	$9,900
Total	$212,100

Project Element A.5. Geochemical signatures of pre-dam sediment	
Salaries	$6,500
Traveling and Training	$0
Operating Expenses	$0
Logistics	$0
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$0
USGS cooperators	$47,400
USGS Burden	$900
Total	$54,800

Project Element A.6. Control network and surveying support	
Salaries	$18,000
Traveling and Training	$600
Operating Expenses	$3,200
Logistics	$28,500
GIS/RS/Electronics support (includes burden)	N/A*
Cooperators (non-USGS)	$0
USGS cooperators	$0
USGS Burden	$7,000
Total	$57,300

* GIS support and image processing costs are shared among multiple individual projects. Only the gross portion shared by the sandbar and sediment storage project is shown here.

GIS/RS/Electronics Support (includes burden): $189,600

FY 2014 Project A. Gross Total: $1,510,700

Project B.
Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem

1. Investigator

David Topping, Research Hydrologist, USGS, Grand Canyon Monitoring and Research Center

2. Project Summary

This proposal is to fund the ongoing measurement of stage, discharge, water quality (water temperature, specific conductance, turbidity, and dissolved oxygen), suspended sediment, and bed sediment at gaging stations in the Colorado River ecosystem (CRe) downstream from Glen Canyon Dam in Glen Canyon National Recreation Area and Grand Canyon National Park. The data collected by this project provide the fundamental stream flow, sediment transport, temperature, and water quality data that are used by other physical, ecological, and socio-cultural resource studies. Thus, this project directly links dam operations to the physical, biological, and sociocultural resources of the CRe. This project also funds interpretation of these data, specifically examining how stream flow and its related attributes affect resources of the CRe.

3. Background

3.1. Scientific Background

The primary linkage between dam operations and the response of the physical, biological, and cultural resources in the CRe between Glen Canyon Dam and Lake Mead reservoir is through the stage, discharge, water quality, and sediment transport of the Colorado River (U.S. Department of the Interior, 1995; National Research Council, 1996). Releases from Glen Canyon Dam provide the principal control on these attributes of the Colorado River downstream from the dam. Only during periods of large tributary floods do tributaries exert any substantial control on stage, discharge, water quality, or sediment transport.

Sediment on the bed and banks forms the physical template for the CRe (U.S. Department of the Interior, 1995; National Research Council, 1996). Suspended sediment is an important water quality parameter, because it regulates the eddy sandbars and channel-margin deposits that are important to many biological, cultural, and recreational resources (Rubin and others, 2002, Wright and others, 2005). Suspended sediment also controls turbidity and therefore influences the aquatic ecology of the river. The endangered and threatened native fishes evolved in a highly turbid river (Gloss and Coggins, 2005). Turbidity is predominantly determined by the concentration of suspended silt and clay and, to a lesser degree, suspended sand. Prior to the closure of Glen Canyon Dam, 60% of the upstream sediment supply to the Colorado River in Glen Canyon was silt and clay (Topping and others, 2000a). Closure of Glen Canyon Dam reduced the supply of sand, silt, and clay by about 95% at Lees Ferry, and the Paria River is now the major supplier of sediment to Marble Canyon (Topping and others, 2000). The post-dam Colorado River in Marble and Grand Canyons is much less turbid with clearer-water conditions than ever occurred naturally. Because the in-channel storage of sand, silt, and clay in the post-dam Colorado River is greatly reduced from pre-dam conditions, the Colorado River in the study area is only now turbid during periods of tributary inflow.

Systematic measurements of stream flow and the quality of water, including suspended-sediment concentration, in the CRe began with the installation of the Lees Ferry gaging station in May 1921 (Topping and others, 2003; Howard, 1947). During much of the 20th century, daily measurements of suspended-sediment concentration and temperature, and episodic measurements of other water-quality parameters, were made by the USGS at multiple sites. This intensive period of measurements ended in the early 1970s (Topping and others, 2000a). Concern over the effects of the operations of Glen Canyon Dam on the CRe resulted in a new scientific emphasis on measurements and modeling of water quality and sediment transport beginning in the early 1980s (National Research Council, 1996). The results of these studies have been published in numerous USGS reports and journal articles and ultimately resulted in the current form of this project.

Recent research on the Colorado and other rivers has shown that, to be meaningful, measurements of stage, discharge, water quality, and suspended fine sediment must be made directly, and not through proxies at temporal resolutions higher than those over which these parameters vary. In the specific case of suspended fine sediment, substantial changes in suspended-sand concentration and suspended-silt-and-clay concentration are driven by changes in the upstream supply of sediment. These changes occur over timescales < 1 hour (Topping and others, 2000b). Furthermore, Rubin and Topping (2001, 2008) showed that, in the case of the dam-regulated Colorado River, suspended-sand transport is equally regulated by changes in discharge and changes in the size of sand available for transport that is driven by changes in the upstream supply of sand. The former control is largely determined by changes in dam operations, and the latter control is largely determined by changes in tributary sediment supply interacting with changes in dam operations. The major flaw that invalidated key aspects of the 1995 Environmental Impact Statement (EIS) (U.S. Department of the Interior, 1995) was that, in the 1995 EIS, suspended-sand transport was thought to be only regulated by changes in discharge (Rubin and others, 2002). ***Thus, this project is designed to provide measurements of stage, discharge, water quality, and suspended sediment at sufficiently high temporal resolutions (~15-minute) to allow accurate determination of suspended sediment loads, as well as other water quality parameters.*** To allow the construction of this comprehensive and cost-effective monitoring network, this project has conducted pioneering, cutting-edge research on using new laser-diffraction and acoustic technologies to measure water quality and sediment.

3.2. Key Monitoring and Research Questions Addressed in this project

This project also directly addresses the following Strategic Science Questions (SSQs), Core Monitoring Information Needs (CMINs), and Research Information Needs (RINs) previously identified by the Glen Canyon Dam Adaptive Management Program (GCDAMP).

- **SSQ 4-1.** Is there a “Flow-Only” operation that will restore and maintain sandbar habitats over decadal timescales?
- **SSQ 5-1.** How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and nearshore water temperatures throughout the CRe?

- **CMIN 7.4.2.** Determine and track flow releases from Glen Canyon Dam, under all operating conditions, particularly related to flow duration, upramp, and downramp conditions.
- **CMIN 7.1.2.** Determine and track LCR discharge and temperature near the mouth.
- **CMIN 7.1.1.** Determine the water temperature dynamics in the mainstem, tributaries, backwaters, and near shore areas throughout the Colorado River ecosystem.
- **CMIN 8.1.3.** Track, as appropriate, the monthly sand and silt/clay volumes and grain-size characteristics, by reach, as measured or estimated at the Paria and LCR, other major tributaries like Kanab and Havasu Creeks, and "lesser" tributaries.
- **CMIN 8.1.2.** What are the monthly sand and silt/clay export volumes and grain-size characteristics, by reach, as measured or estimated at Lees Ferry, Lower Marble Canyon, Grand Canyon, and Diamond Creek Stations?

- **RIN 7.4.1.** What is the desired range of seasonal and annual flow dynamics associated with powerplant operations, BHBFs, and habitat maintenance flows, or other flows that meet GCDAMP goals and objectives?
- **RIN 7.3.1.** Develop simulation models for Lake Powell and the Colorado River to predict water-quality conditions under various operating scenarios, supplants monitoring efforts, and elucidate understanding of the effects of dam operations, climate, and basin hydrology on Colorado River water quality.
- **RIN 8.5.1.** What elements of RoD operations are most/least critical to conserving new fine sediment inputs, and stabilizing sediment deposits above the 25,000 ft^3/s stage?

3.3. Management Background

This project funds ongoing monitoring and research activities associated with the measurement of stream flow, sediment transport, and associated water quality attributes. This project began as fundamental research in the late 1990s and became a GCDAMP-approved core-monitoring project in 2007, designed to fully address the monitoring needs of GCDAMP Goal 7 and partially address the monitoring needs of GCDAMP Goal 8.

- **Goal 7:** Establish water temperature, quality, and flow dynamics to achieve GCDAMP ecosystem goals.
- **Goal 8:** Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.

The primary objectives of this project are to measure water stage and discharge as well as the water-quality parameters of water temperature, specific conductance, turbidity, dissolved oxygen, suspended-sediment concentration, and suspended-sediment grain size. These data are basic to other physical science, biology, and sociocultural projects funded by the GCDAMP. In essence, the data collected by this project are those that directly link dam operations to most of the other resources of the CRe. Although the focus of this project is on monitoring, the project also supports research related to evaluation of alternative flow regimes, as well as implementation of the High-Flow Experiment protocol (U.S. Department of the Interior, 2011). Thus, data collected by this project constitute core monitoring, administrative support for agency actions such as the High-Flow Experiment protocol EA and fundamental support for understanding ecosystem processes. Additionally, these data are used to monitor compliance with the 1996 RoD, to support research about flow experiments and are critical to development of numerical models concerning river processes.

In addition to supporting GCDAMP Goals 7 and 8 (above), this project also supports Goals 1, 2, 4, 6, 9, and 11.

- **Goal 1:** Protect or improve the aquatic foodbase so that it will support viable populations of desired species at higher trophic levels.

This project supports Goal 1 by providing information on flows, water temperature, turbidity, and dissolved oxygen that aids in foodbase studies, such as the assessment of primary productivity and allochthonous inputs.

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

This project supports Goal 2 by providing water-temperature data for the assessment of fish growth rates, turbidity data that are used to adjust for catch efficiency in population models, flow and stage data that are important to understanding the effects of nearshore habitat disruption caused by fluctuating flows, and data on sandbars and resulting backwater habitats that are helpful in understanding the importance of sandbars for native fish.

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

This project supports Goal 4 through monitoring of dam releases, water temperature, specific conductance, turbidity, and dissolved oxygen levels in Glen Canyon.

- **Goal 6:** Protect or improve the biotic riparian and spring communities within the CRe, including threatened and endangered species and their critical habitat.

This project supports Goal 6 by monitoring the transport and fate of sand, silt, and clay, which provides the substrate for riparian vegetation and marsh communities.

- **Goal 9**: Maintain or improve the quality of recreational experiences for users of the CRe within the framework of GCDAMP ecosystem goals.

This project supports Goal 9 by collecting the monitoring data used in experimental and modeling research relating flow and sediment-transport dynamics to the size and abundance of sandbars used as campsites.

- **Goal 11:** Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations.

This project supports Goal 11 by collecting the stage, flow, and sediment data used to assess effects of dam operations on cultural sites.

In August 2004, the GCDAMP Adaptive Management Work Group reviewed these goals and identified priority questions. The top five priority questions are as follows:

- **Priority 1**: Why are humpback chub not thriving, and what can we do about it? How many humpback chub are there and how are they doing?
- **Priority 2:** Which cultural resources, including TCPs, are within the Area of Potential Effect (APE), which should we treat, and how do we best protect them? What is the status and trends of cultural resources and what are the agents of deterioration?
- **Priority 3:** What is the best flow regime?
- **Priority 4:** What is the impact of sediment loss and what should we do about it?

- **Priority 5:** What will happen when a TCD is tested or implemented? How should it be operated? Are safeguards needed for management?

This project provides direct support to some of the priority questions, while indirectly supporting others. Monitoring of stage, flows, sediment transport, water temperature (and other water quality parameters) supports priority questions 3, 4, and 5 directly and indirectly supports priority questions 1 and 2 by providing information on the general physical framework of the river environment.

4. Proposed work

4.1. Project Element ($1,276,400)

Much of the proposed work in this project consists of high-resolution (typically 15-minute) measurements of: stage, discharge, water temperature, specific conductance, turbidity, dissolved oxygen, suspended-sediment concentration, and suspended-sediment grain-size distribution. In addition, episodic measurements of bed sediment are made. These parameters are measured at USGS stream-flow gaging stations located on the Colorado River in Marble and Grand Canyons at river miles 0, 30, 61, 87, 166, and 225. Selection of these gaging-station locations was largely based on the need to resolve longitudinal differences in sediment storage in key reaches of the CRe, to bracket major tributaries, to support other GCDAMP-funded projects, and to reoccupy former USGS stream-flow gaging stations. In addition, high-resolution stage, discharge, water temperature, suspended-sediment concentration, and suspended-sediment grain-size distribution are measured in all of the major tributaries to the Colorado River and in a representative subset of the smaller, and formerly ungaged, tributaries. Some of the gaging stations on the Colorado River and its tributaries receive substantial amounts of funding from non-GCDAMP sources, thus their locations are partially dictated by non-GCDAMP goals. All measurements of stage, discharge, water quality, and physical measurements of suspended- and bed sediment are made using standard, approved USGS techniques. The laser diffraction and acoustic measurements of suspended sediment are made using techniques described in Melis and others (2003), Topping and others (2004, 2006b, 2007b), and Wright and others (2010c). To augment the limited number of physical measurements of the bed-sediment grain-size distribution, the methods of Rubin and Topping (2001, 2008) are used to back-calculate changes in reach-averaged bed-sediment grain size from the suspended-sediment data.

In addition to the collection of these basic stream-flow, water-quality, and sediment-transport data, time is spent in this project interpreting the data and reporting on the results and interpretations in peer-reviewed articles in the areas of hydrology, water quality, and sediment transport. These papers are designed to answer key questions relevant to river management, especially to GCDAMP managers in the. The data collected in this project form the basis of the collaborations listed in the next section. All of the projects funded in the areas of physical science, biology, and socioeconomics require the data collected by this project.

One of the major products of this project has been the mass-balance sand budgets (e.g., Topping and others, 2010) used to trigger controlled floods and to evaluate the effects of all dam operations on the CRe. To make all of the data collected by this project—and especially these sediment budgets—more available to both GCDAMP stakeholders and the general public, a major emphasis is being placed on the development of user-interactive web tools for downloading and visualizing these data through collaboration with the USGS Center for

Integrated Data Analytics (CIDA). CIDA is the leader within the USGS in database and web programming. Collaboration with the CIDA will therefore result in a major leap forward in serving data in a user friendly and interactive way, something that has proven problematic for GCMRC to do on its own in previous funding cycles. The tools developed in collaboration with CIDA will allow anyone to plot the data, construct mass-balance sediment budgets, and plot changes in reach-averaged bed-sediment grain size for any time period in any reach of the CRe on demand. In addition, these tools will allow different user-chosen methods for error propagation through these sediment budgets. Because sandbar response during artificial floods depends on both the amount and grain-size distribution of the sand stored in each reach (Topping and others, 2010), these tools will be essential in the planning of controlled floods under the HFE EA (U.S. Department of the Interior, 2011) and in the upcoming Long-Term Environmental Management Plant (LTEMP) EIS that is now being produced. Much of the proposed increase in the budget for this project above previous funding levels is for this effort to make the data collected by this project more available, more usable, and therefore more relevant, to the decision makers in the GCDAMP.

It is also proposed to continue the development and application of a one-dimensional sand routing model (Wright and others, 2010a). One task for this modeling component will be to extend the existing model, whose downstream boundary is river mile 87, through the central and western part of Grand Canyon to river mile 225. Downstream extension of the model is dependent on discharge and sand concentration/flux data for the central and western parts of the canyon and major tributaries, because it is a simplified yet physically-based model that requires calibration with field data. Sufficient data from this monitoring program (for example, river mile 166 station, Kanab and Havasu Creek gaging stations) is now available to make this model extension possible. Another task of the modeling component will be to make more comparisons between the model and the measurements, particularly with respect to suspended-sand concentration and grain size. Previous comparisons have focused primarily on the total sand flux at a gaging station, because this is of importance for sand mass balance accounting. However, further comparisons between the model and measurements are necessary to better understand where the model performs well and where the modeling assumptions cause deviation between predictions and measurements. The final project element will be to continue to update the model predictions through the present as new boundary condition data become available from the monitoring program.

4.2. Personnel and Collaborations

The major collaborations funded through this project are with four cooperators in the U.S. Geological Survey: the Arizona Water Science Center, the Utah Water Science Center, the California Water Science Center, and the Center for Integrated Data Analytics. Together, these four cooperators will receive about 39% of the total project funding given to this project (as described below). Collaborations also exist between this project and other physical-sciences and biology projects at the GCMRC, mostly in a supporting role, and with researchers in academia. In previous years, academic collaborations have existed between this project and researchers at the University of Colorado, College of William and Mary, Arizona State University, Utah State University, and Northern Arizona University. Additional collaborations within the USGS during 2013-14 are planned with research scientists in Western Coastal and Marine Geology and the National Research Program.

The staff of this project at the GCMRC consists of four full-time, permanent USGS employees, one full-time, term USGS employee, and one student laboratory technician. The leader of the project is David J. Topping, a Research Hydrologist at the USGS, whose research expertise is in the areas of sediment transport and sedimentology. Support staff on this project are: Nicholas Voichick (emphasis on non-sediment water quality), Thomas Sabol (emphasis on Colorado River stage, discharge, and suspended sediment), Ronald Griffiths (emphasis on CRe tributary sediment supply, modeling, and monitoring network maintenance), Karen Vanaman (laboratory manager and emphasis on CRe tributary stage and discharge), and Jason Fobair (student laboratory technician). Topping, Voichick, Sabol, and Griffiths regularly interface with cooperating USGS employees funded by this project in the Arizona, Utah, and California Water Science Centers and in the CIDA. Topping, Sabol, and Griffiths receive parts of their salaries from non-GCDAMP funds. Additional employees at the GCMRC that are partially funded by this project are Glenn Bennett (Oracle database support and collaborator with CIDA) and Timothy Andrews (electronics support). Karen Vanaman oversees work in the GCMRC sediment laboratory, where all sediment samples collected by all GCDAMP-funded projects are processed. The GCMRC sediment laboratory participates in the USGS Branch of Quality Systems Sediment Laboratory QA/QC Project, where it repeatedly performs as one of the best (most accurate) sediment laboratories in the country. This project conducts two river trips per year to perform maintenance on the monitoring network in the CRe and to collect suspended-sediment samples used to calibrate and/or verify the 15-minute resolution acoustic suspended-sediment data.

4.3 Deliverables

Products from this project are as follows:

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

5. Productivity from Past Work

During FY11/12, the following products were either delivered to the GCDAMP prior to April 1, 2012, or are still on track to be delivered to the GCDAMP by September 30, 2012.

5.1. Data Products

1. 15-minute stage, discharge, and water temperature data (updated every 1-4 hours 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://waterdata.usgs.gov/nwis and http://www.gcmrc.gov.
2. 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 are available at http://www.gcmrc.gov. These data are updated as frequently as every month, depending on data-collection location.
3. Annual water-data reports for stage, discharge, and water quality data collected during 2010 and 2011 were published by the Arizona and Utah Water Science Centers. These reports are at:

   http://wdr.water.usgs.gov/wy2010/pdfs/09380000.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09381800.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09382000.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09402000.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09402300.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09402500.2010.pdf

   http://wdr.water.usgs.gov/wy2010/pdfs/09404200.2010.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09380000.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09381800.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09382000.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09402000.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09402300.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09402500.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09403850.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09404115.2011.pdf

   http://wdr.water.usgs.gov/wy2011/pdfs/09404200.2011.pdf

Topping, D.J., Rubin, D.M., Wright, S.A., and Melis, T.S., 2011, Field evaluation of the error arising from inadequate time averaging in the standard use of depth-integrating suspended-sediment samplers: U.S. Geological Survey Professional Paper 1774, 95 p. [http://pubs.usgs.gov/pp/1774/]

5.2. Publications in progress

Griffiths, R.E., Topping, D.J., Andrews, T., Bennett, G.E., Sabol T.A., and Melis, T.S., in press, Design and maintenance of a network for collecting high-resolution suspended-sediment data at remote locations on rivers, with examples from the Colorado River: U.S. Geological Survey Techniques and Methods 2–A__, __p.

Sabol, T.A., and Topping, D.J., in press, 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-__, __p.

The following USGS Professional Paper by Topping, Wright, Rubin, and others entitled "Evaluation of using multi-frequency acoustics, laser diffraction, and automatic samplers to measure the concentration and grain-size distribution of suspended sediment at high temporal resolution over multi-year durations" is on track to be in USGS peer review before September 30, 2012.

5.3. Presentations at professional meetings

Grams, P.E., Topping, D.J., Schmidt, J.C., Kaplinksi, M.A., and Hazel, J.E., 2011, Linking Morphodynamic Response with Sediment Mass Balance: Issues of Scale, Geomorphic Setting, and Sampling Design: Abstract EP31F-04 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec.

Sabol, T.A., Topping, D.J., and Griffiths, R.E., 2011, 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: Abstract EP43B-0689 presented at 2011 Fall Meeting, AGU, San Francisco, Calif., 5-9 Dec.

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. All historical data from these stations should be available online by 2013. As of April 2012, the following historical periods of record have been processed and are available at http://www.gcmrc.gov.

09380000 Colorado River at Lees Ferry, AZ 1921-1986...Entire period of station record processed and online.

09381500 Paria River near Cannonville, UT 1951-1956...Entire period of station record processed and online.

09401000 Little Colorado River at Grand Falls 1926-1960, 1994-1995...Entire period of station record processed and online.

09401250 Moenkopi Wash near Moenkopi, AZ 1974-1976...Entire period of station record processed and online.

09401260 Moenkopi Wash at Moenkopi, AZ 1976-1988...Entire period of station record processed and online.

09401400 Moenkopi Wash near Tuba City, AZ 1949-1954, 1965-1977...Other years remaining to be processed.

09401500 Moenkopi Wash near Cameron, AZ 1954-1965...Entire period of station record processed and online.

09402000 Little Colorado River near Cameron, AZ 1947-1990...Entire period of station record processed and online.

09402500 Colorado River near Grand Canyon, AZ 1923-1986...Entire period of station record processed and online.

09403000 Bright Angel Creek near Grand Canyon, AZ 1933-1936, 1943-1974, 1991-1993...Other years remaining to be processed.

09403780 Kanab Creek near Fredonia, AZ 1964-1970, 1974-1977...Other years remaining to be processed.

Sediment and QW updates for the CRe were provided to the GCDAMP Adaptive Management Work Group at 6-month intervals.

The annual report for FY11 was delivered to the GCDAMP on time (January 2012) and the annual report for FY12 will be delivered to the GCDAMP on time (January 2013).

Although progress was made on developing user-interactive web tools to make the collected by this project (including the mass-balance sediment budgets) more useful for stakeholders, managers, and the general public, it was determined that GCMRC and SBSC lacked the expertise to finish this work. Therefore collaboration with CIDA was initiated so that this work can be completed within FY13/14.

5.4. Productivity prior to 2011

Akahori, R., Schmeeckle, M.W., Topping, D.J., and Melis, T.S., 2008, Erosion properties of cohesive sediments in the Colorado River in Grand Canyon*: River Research and Applications*, v. 24, p. 1160-1174, doi: 10.1002/rra.1122.

Barnhardt, W., Kayen, R., Rubin, D., and Minasian, D., 2001, The internal structure of sand bars on the Colorado River, Grand Canyon, as determined by ground-penetrating radar: *U.S. Geological Survey Open-File Report* 01–425.

Draut, A.E., Rubin, D.M., Dierker, J.L., Fairley, H.C., Griffiths, R.E., Hazel, J.E., Jr., Hunter, R.E., Kohl, K., Leap, L.M., Nials, F.L., Topping, D.J., and Yeatts, M., 2005, Sedimentology and stratigraphy of the Palisades, Lower Comanche, and Arroyo Grande areas of the Colorado River corridor, Grand Canyon, Arizona: *U.S. Geological Survey Scientific Investigations Report* 2005-5072, 68 p.

Draut, A. E., Rubin, D. M., Dierker, J. L., Fairley, H. C., Griffiths, R. E., Hazel, J. E. Jr., Hunter, R. E., Kohl, K., Leap, L. M., Nials, F. L., Topping, D. J., and Yeatts, M., 2008, Application of sedimentary-structure interpretation to geoarchaeology in the Colorado River corridor, Grand Canyon, Arizona, USA: *Geomorphology*, v. 101, n. 3, p. 497-509, doi: 10.1016/j.geomorph.2007.04.032.

Draut, A.E., Topping, D.J., Rubin, D.M., Wright, S.A., and Schmidt, J.C., 2010, Grain-size evolution in suspended sediment and deposits from the 2004 and 2008 controlled-flood experiments in Marble and Grand Canyons, Arizona: *Proceedings of the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling*, June 27- July 1, 2010, Riviera Hotel, Las Vegas, Nevada, http://acwi.gov/sos/pubs/2ndJFIC/Contents/P_DRAUT_GRANDCYN_FINAL.pdf.

Flynn, M.E., and Hornewer, N.J., 2003, Variations in sand storage measured at monumented cross sections in the Colorado River between Glen Canyon Dam and Lava Falls Rapid, Northern Arizona, 1992–1999: *U.S. Geological Survey Open-File Report* 03–4104, 39 p.

Grams, P.E., Schmidt, J.C., and Topping, D.J., 2007, The rate and pattern of bed incision and bank adjustment on the Colorado River in Glen Canyon downstream from Glen Canyon Dam: *Geological Society of America Bulletin*, v. 119, p. 556-575, doi: 10.1130/B25969.1, with additional supporting material in the Geological Society of America Data Repository.

Grams, P.E., Hazel, J.E., Schmidt, J.C., Kaplinski, M., Wright, S.A., Topping, D.J., and Melis, T.S., 2010, Geomorphic response of sandbars to the March 2008 high-flow experiment on the Colorado River downstream from Glen Canyon Dam: *Proceedings of the Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling*, June 27- July 1, 2010, Riviera Hotel, Las Vegas, Nevada, http://acwi.gov/sos/pubs/2ndJFIC/Contents/5D_Grams.pdf.

Gray, J.R., Gooding, Melis, T.S., Topping, D.J., and Rasmussen, P.P., 2003, U.S. Geological Survey suspended-sediment surrogate research, Part II: Optic technologies: *Proceedings of the Virginia Water Research Symposium 2003, Water Resource Management for the Commonwealth*, Virginia Polytechnic Institute and State University, Blacksburg, October 8-10, 2003, pp. 58-64.

Gray, J.R., Melis, T.S, Patiño, Eduardo, Larsen, M.C., Topping, D.J., Rasmussen, P.P., and Figueroa-Alama, Carlos, 2003, U.S. Geological Survey research on surrogate measurements for suspended sediment, *in* Renard, K.G., McElroy, S.A., Gburek, W.J., Canfield, H.E., and Scott, R.L., eds., *Proceedings of the 1st Interagency Conference on Research in Watersheds*: U.S. Department of Agriculture, Agricultural Research Service, October 27-30, 2003, Benson, Arizona, pp. 95-100.

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7. Budget

FY 2013	
Project B: Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem	
Salaries	$524,000
Traveling and Training	$0
Operating Expenses	$50,000
Logistics	$57,000
GIS/RS/Electronics support (includes burden)	$55,000
Cooperators (non-USGS)	$0
USGS cooperators	$502,000
USGS Burden	$88,400
Total	$1,276,400

(contingency) HFE gage maintenance and measurements	
Salaries	$7,600
Logistics	$42,800
USGS Cooperators	$13,000
Burden	$7,000
Total	$70,400

FY 2013 Project B. Gross Total: $1,276,400

FY 2013 Project B. Gross Total (with HFE gage maintenance and measurements): $1,346,800

FY 2014	
Project B: Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem	
Salaries	$539,700
Traveling and Training	$0
Operating Expenses	$51,500
Logistics	$61,800
GIS/RS/Electronics support (includes burden)	$56,700
Cooperators (non-USGS)	$0
USGS cooperators	$517,100
USGS Burden	$90,600
Total	$1,317,400
FY 2014 Project B. Gross Total: $1,317,400	

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

1. Investigator

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

2. Project Summary

The data collected by this project describe the current quality of Glen Canyon Dam releases to the downstream ecosystem, as well as describe the current water-quality conditions and hydrologic processes in Lake Powell, which can be used to predict the quality of future releases from the dam. The current long-term monitoring program will continue at the current level, with possible minor revisions to the number of sites monitored or parameters collected. In an effort to improve the predictive capabilities of the CE-QUAL-W2 simulation model, it is proposed that one or more inflow monitoring stations be reestablished to provide input data on inflow temperature and salinity. It is also proposed to establish one or more weather stations at remote pumpout stations in the upper part of the reservoir to improve inputs to the model. In addition to the ongoing monitoring program, efforts are currently being made to analyze sonar chart paper data to develop longitudinal profiles of the sediment deltas of the three major tributaries to evaluate rates and patterns of deposition under varying hydrologic regimes and reservoir levels. These profiles have been collected in conjunction with most quarterly reservoir surveys since 2001. This project conducts water-quality monitoring on Lake Powell and the Glen Canyon Dam tailwaters. The water-quality monitoring program consists of monthly surveys of the reservoir forebay and tailwater, as well as quarterly surveys of the entire reservoir, including the Colorado, San Juan, and Escalante arms. It also includes continuous monitoring of dam releases. The entire funding for this project is provided directly by the Bureau of Reclamation (Reclamation). No Adaptive Management Program funds are used for this project.

3. Background

The Grand Canyon Monitoring and Research Center (GCMRC) will be continuing its long-term water-quality monitoring program of Lake Powell reservoir. This program has been in existence since 1965. USGS has conducted the monitoring program since 1996. The monitoring program measures water-quality conditions in the forebay of the reservoir on a monthly basis and throughout the reservoir on a quarterly basis. Water temperature, specific conductance, dissolved oxygen, pH, redox potential, and turbidity are measured throughout the water column at 30 sites (fig. 1), with samples for major ionic constituents, nutrients, dissolved organic carbon, chlorophyll, phytoplankton, and zooplankton being collected at selected sites. Physical and chemical information from this program was published as USGS Data Series Report DS-471 (Vernieu, 2009). An updated revision to this report is currently in review. Biological data are contained in a separate data series report, also in review. All information from this program is stored in the WQDB database.

Data from this monitoring program describe current status and trends of water quality in the reservoir, the movement and fate of advective currents flowing through the reservoir, and the quality of releases from Glen Canyon Dam (GCD) to the Colorado River ecosystem (CRe) in Grand Canyon as they relate to various patterns of dam operation, hydrology, and climatologic patterns.

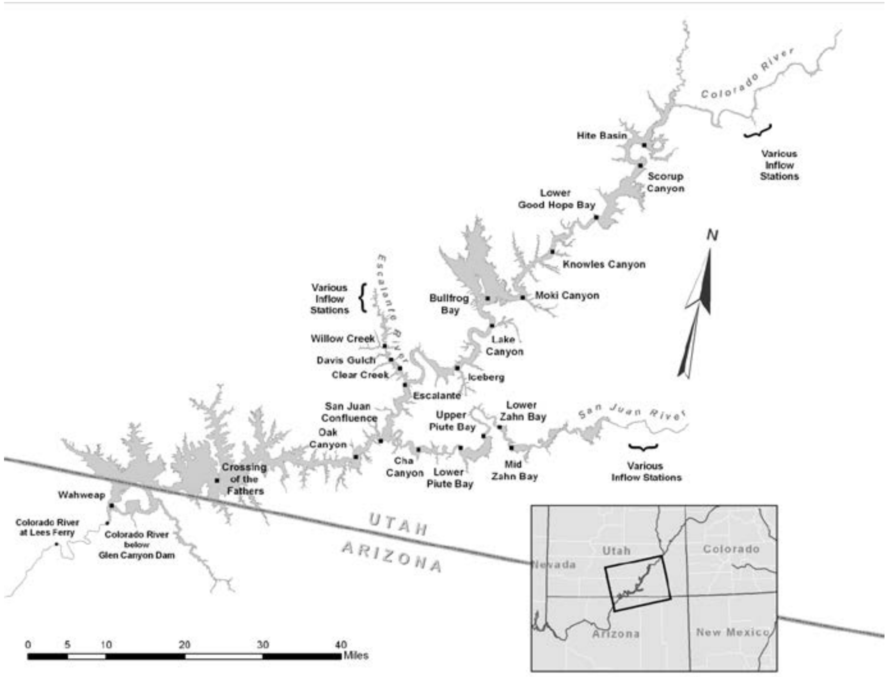

Figure 1. Lake Powell water-quality monitoring locations.

Reclamation initiated a water-quality monitoring program in 1965, consisting of sampling at 8 sites on Lake Powell for major ionic chemical constituents. This program was augmented in 1990 and conducted by Reclamation's Glen Canyon Environmental Studies office to include sampling at an increased number of sites with a more precise vertical resolution and the addition of nutrient, chlorophyll, and plankton samples. Further enhancements to the monitoring program design have been incorporated by GCMRC. The current program reflects a suite of sampling sites, monitoring frequencies, and methodologies to meet the scientific objectives of the program, listed in the following section, at a reasonable cost on a sustainable basis. Specific details of site selection, frequency, and methodology are listed in USGS Data Series Report DS-471 (Vernieu, 2009).

An assessment conducted in 1996 by GCMRC determined that various aspects of dam operations, such as daily fluctuations, high sustained releases, and operation of alternate withdrawal structures have a measureable effect on the quality of reservoir water and dam releases (Hueftle and Vernieu, 1998). Various concerns were raised by the Glen Canyon Dam Adaptive Management Program (GCDAMP) stakeholders as to whether it was appropriate to fund studies conducted upstream from GCD even though the program measured the effects of the dam on water flowing into the CRe downstream from GCD. Reclamation agreed to fund the monitoring program directly from operating and maintenance funds. Therefore, while funding for the monitoring program was not provided by the GCDAMP, it was agreed that the program was an integral part of the GCDAMP, while meeting Reclamation's internal reservoir-monitoring needs.

A protocol evaluation panel was conducted in 2000 to evaluate the scientific basis for the monitoring program and provide comments for integration with other aspects of the GCDAMP (Jones and others, 2001). The panel recommended a gradual shift in emphasis from Lake Powell to downstream, the employment of water-quality/ecosystems models to link GCD operations with downstream responses, integration with other GCMRC programs, and the development of a long-range water-quality monitoring strategy to evaluate current and future management actions at GCD. Subsequent to the panel's report, downstream temperature monitoring has been moved to the GCMRC physical sciences program, and aquatic foodbase monitoring work has developed and conducts additional downstream monitoring. Additionally, Reclamation has employed and maintained the CE-Qual-W2 reservoir model to provide projections of release temperature and other parameters. A Seabird oceanographic profiler has been acquired that automates reservoir profiling procedures and includes the ability to obtain vertical profiles of chlorophyll concentration.

The program is currently funded as part of a three-year agreement with Reclamation, which will be evaluated for renewal in FY13.

3.1. Scientific Background

The objectives of this monitoring program have changed since 1965, reflecting changes in scientific interest as the reservoir filled, responsibilities of Reclamation for maintaining salinity levels in the Colorado River, and the monitoring status of Upper Colorado River basin reservoirs;. Objectives have also been responsive to more recent environmental concerns related to the Grand Canyon Protection Act, the GCD Environmental Impact Statement and subsequent Record of Decision, and the establishment of the GCDAMP.

Objectives of this long-term monitoring program include:

1. Determination of water-quality status and trends in Lake Powell and GCD releases;
2. Documentation of the historical record of Lake Powell water quality during various climatological and hydrological conditions;
3. Documentation of the effects of the structure and operation of GCD on the quality of water in Lake Powell and GCD releases;
4. Integration with GCDAMP information needs and downstream monitoring programs;
5. Documentation of the density structure of the water column in the GCD forebay and other locations in the reservoir to determine the quality of water available for release from GCD;
6. Assessment of the distribution and patterns of major ionic constituents;
7. Assessment of the distribution and patterns of nutrient constituents; and,
8. Assessment of the structure, status, and trends of the plankton community and its effect on primary and secondary production.

3.2. Monitoring Background

Since 1965, Lake Powell's water quality has been monitored in order to gather information describing water-quality conditions and to observe changes in water quality as the reservoir filled and matured. There have been four distinct phases of monitoring activity (table 1). Phase 1, 1965-71, consisted of monthly forebay surveys and quarterly reservoir-wide surveys at 8 locations, the collection of major ion samples at 50-ft depth intervals, shipboard temperature measurements, and Winkler titrations for dissolved oxygen concentration in the samples collected. In Phase 2, 1972-81, monthly reservoir-wide surveys were conducted and electrometric determinations of temperature and dissolved oxygen concentrations were added. In Phase 3, 1982-90, a multi-parameter profiling device was employed which measured temperature, specific conductance, dissolved oxygen concentrations, pH, and oxidation-reduction potential at various depths in the water column. However, the frequency of monitoring was decreased through that period from quarterly to yearly reservoir-wide surveys, because of decreased needs of the Colorado River Salinity Control Program. At the beginning of Phase 4, 1990-present, monitoring was conducted by Reclamation's Glen Canyon Environmental Studies office. At this time, the current schedule of monthly forebay surveys and quarterly reservoir-wide surveys was initiated, sampling for nutrient concentrations was added, and the depth interval of sampling was changed to represent major strata within the reservoir, rather than sampling at 50-ft depth intervals. Quantitative sampling for chlorophyll, phytoplankton, and zooplankton began and continuous monitoring of the GCD tailwater, immediately downstream from the dam and at Lees Ferry, was initiated. Monitoring activities were transferred to GCMRC (USGS) in 1996.

	Phase 1 1965–71	Phase 2 1972–81	Phase 3 1982–90	Phase 4 1990–Present
Frequency: forebay reservoir	 monthly quarterly	 monthly monthly	 quarterly to yearly quarterly to yearly	 monthly quarterly
Number of stations	8	8	8–10	23–30
Physicochemical parameters	Temperature DO (Winkler titration), occasional SC & pH	Temperature DO (electrometric)	Multiparameter profiling (T, SC, DO, pH, ORP)	Multiparameter profiling with datalogger (T, SC, DO, pH, ORP, turbidity). Seabird CTD in use since 2010.
Chemical Sampling	Major Ions	Major Ions	Major Ions (Field processing initiated)	Major Ions Nutrients
Sampling interval	50 ft	50 ft	50 ft	Variable, representative of stratification
Biological sampling	none	none	Qualitative zooplankton sampling	chlorophyll phytoplankton zooplankton
Inflow monitoring	none	none	selected sites depending on reservoir level	selected sites depending on reservoir level
Tailwater monitoring	none	none	below dam T, SC	below dam Lees Ferry T, SC, DO, pH

In September 2010, a Seabird SBE-19plusV2 oceanographic CTD profiler was purchased by Reclamation to replace the previously used Hydrolab H20/Surveyor 3 and profiling instrument. This instrument continuously collects data every 0.25 seconds while lowered and raised through the water column. It also provides for the collection of depth profiles at a more precise vertical resolution in a shorter time period.

Studies related to Lake Powell were conducted in the 1970s by university consortiums and Federal and State agencies on topics that include sedimentation, circulation patterns, trace-element chemistry, remote sensing, and public-health issues (Potter and Drake, 1989). Various agencies and institutions have conducted additional research and monitoring on water quality and sedimentation during Lake Powell's recent history (Ferrari, 1988; Wurtsbaugh and others, 1992; Hart and Sherman, 1996; Marzolf, 1998; Hart and others, 2005; Majeski, 2009; Pratson and others, 2009; Wildman and others, 2011; Wildman and Hering, 2011).

3.3. Reservoir Conditions

Based on existing data, the limnology of Lake Powell is dominated by penstock withdrawal from the reservoir at an elevation of 3,470 ft and advective inflow currents flowing through the reservoir at different depths throughout the year. During the summer months, inflow from snowmelt runoff in the upper Colorado River basin consists of warm dilute water of low density relative to the receiving waters of the reservoir. This inflow enters the reservoir as an overflow density current and flows along the surface of the reservoir, usually appearing near the dam in late summer/early fall. During winter months, inflows are colder, more saline, are usually denser than the receiving waters of the reservoir, and tend to flow along the bottom of the reservoir. Depending on the density of the water in the deepest portions of the reservoir, these inflows either (1) continue to flow along the bottom of the reservoir, or (2) encounter deeper water of higher density and flow through the reservoir at an intermediate depth. In the former case, the winter inflows appear near the dam in the months from April to May and displace the deep water upwards to be gradually entrained in dam releases. This refreshes the deeper portions of the reservoir with oxygenated water and serves to mix the reservoir from below. In the latter case, the inflows do not disturb this deep body of water and tend to contribute more directly into dam releases. In this case, the deeper portions of the reservoir stagnate and dissolved oxygen concentrations decrease over time.

In the winter months, convective cooling mixes the epilimnion, or surface layer, of the reservoir to increasingly greater depths. As convective mixing progresses, release temperatures gradually warm until the depth of mixing reaches that of the penstock withdrawal zone, usually between November and December. At this point, dam releases are being drawn from the mixed epilimnion, which contains the warmest water in the reservoir at that time, and release temperatures reach an annual maximum. As the epilimnion continues to cool, release temperatures drop correspondingly to reach an annual minimum temperature in February and March.

Through most of the past decade, the Colorado River basin has experienced drought conditions, which resulted in the drawdown of the reservoir to a minimum of 3,555 ft in 2005. This resulted in warmer surface layers being drawn down nearer to the penstock withdrawal elevation, and release temperatures increased to a maximum of 16^{0}C in October 2005, more than 6^{0}C above normal for that period. Release temperatures were above normal from 2003 through 2010 as the reservoir remained at elevations below 3,640 ft. In 2011, Lake Powell received 15.97 maf (147% of average) of unregulated inflow, increasing reservoir levels to over 3,660 ft. This resulted in increased releases from GCD to meet equalization criteria for Lake Mead. These increased releases began in January and continued through 2011. The increased releases from the penstock withdrawal zone, situated below the thermocline of the reservoir, resulted in a large volume of cold water (8-9^{0}C) being released during the months of February through May 2011. This depleted much of the cold water from the deeper portions of the reservoir near the penstock withdrawal zone, which was replaced with warmer water from surface layers and reservoir inflows, essentially lowering the thermocline much the same way that low reservoir levels in 2005 brought warmer water nearer to the withdrawal zone.. Release temperatures began to increase sharply in June 2011 and the warmest release temperatures since 2005 occurred, reaching 15.2^{0}C on November 12, 2011, in spite of higher reservoir elevations.

Associated with the drought-induced reservoir drawdown, sediment deltas in the inflow tributaries became exposed and the continued head cutting of the tributaries through these sediments resulted in the re-suspension of large quantities of delta sediment, causing a severe oxygen demand to the reservoir inflows. This process resulted in reduced dissolved oxygen concentrations to a minimum of 3.3 mg/L in October 2005.

4. Proposed Work

4.1. Project Elements ($251,600)

Project Element C.1. Revisions to Existing Program

Evaluations will be mad, of current chlorophyll preservations methods, involving preservation by desiccation, compared to conventional methods of freezing. In an effort to improve the predictive capabilities of the current simulation modeling, one or more inflow monitoring stations will be reestablished to provide input data on inflow temperature and salinity. One or more weather stations will be established at remote pumpout stations in the upper part of the reservoir. In addition to the ongoing monitoring program, efforts are currently being made to construct historical longitudinal profiles of the sediment deltas of the three major tributaries to evaluate rates and patterns of deposition under varying hydrologic regimes and reservoir levels. These profiles have been collected in conjunction with most quarterly reservoir surveys since 2001 and currently exist as sonar chart paper records. They will be compared to other work done by Ferrari (1988), Majeski (2009), and Pratson (2009) to provide a more precise temporal record of sedimentation in Lake Powell.

Project Element C.2. Details of Current Program

The ongoing Lake Powell water-quality monitoring program consists of monthly surveys of the reservoir forebay and tailwater and quarterly surveys of the entire reservoir, including the Colorado, San Juan, and Escalante arms of the reservoir to the inflow areas. The GCD forebay station is located approximately 2.4 km upstream from GCD. Two tailwater sites are located immediately downstream from the dam and at Lees Ferry, approximately 25km downstream. Depending on reservoir elevation, 25-30 established sites, including the forebay and tailwater stations, are sampled on a quarterly basis and extend up the three major tributary arms (Colorado, San Juan, and Escalante) to the inflow areas.

At each site, initial surface observations (for example, bottom depth, Secchi depth, weather observations) are recorded, after which a depth profile of temperature, specific conductance, dissolved oxygen, pH, redox potential, turbidity, and chlorophyll florescence is collected, using the Seabird SBE19plusV2 instrument. These data are downloaded immediately after collection and viewed in the field to determine stratification patterns. Based on stratification patterns, chemical samples for major ionic constituents and nutrient concentrations are collected in the major strata at selected sites. Dissolved organic carbon samples are collected at the forebay, tailwater, and tributary inflow sites. Biological samples for chlorophyll concentration, phytoplankton, and zooplankton are also collected at selected sites. Samples are filtered and preserved in the field for subsequent laboratory analysis.

Analysis for major ionic constituent, nutrient, and chlorophyll concentrations are performed by Reclamation's Lower Colorado Regional Laboratory in Boulder City, NV. Phytoplankton and zooplankton samples are analyzed under contract by BSA Environmental, Inc.

Data processing of the Seabird profile data is performed in the office shortly after the field survey. All field and analytical data are entered into the WQDB database for statistical and graphical analysis and long-term storage.

Details of the monitoring program, a description of the WQDB database, and physicochemical data from 1965 to 2008 are available as a USGS Data Series report at http://pubs.usgs.gov/ds/471/ (Vernieu, 2009). A revision of this report, including data through 2011, is currently in review. Biological data from the monitoring program will be published in a separate data series report, currently in peer review with an expected publication date of 2013.

Project Element C.3. Reservoir Modeling

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. The CE-QUAL-W2 model is a two-dimensional (longitudinal and vertical), laterally averaged, finite-difference water-quality and hydrodynamic model for rivers, estuaries, lakes, reservoirs and river basin systems. The model was originally known as LARM (Laterally Averaged Reservoir Model), developed by Edinger and Buchak (1975). In its early stages, the LARM model was applied to Lakes Powell and Mead, (Edinger and Buchak, 1982; Edinger and others, 1984). Current model release enhancements have been developed under research contracts between the Army Corps of Engineers and Portland State University under supervision of Dr. Scott Wells (2000). Williams (2007) applied the CE-QUAL-W2 model to Lake Powell and developed an initial dissolved oxygen calibration for the model.

GCMRC has provided data and collaboration in the development of the model, its calibration, and its verification. The model has been calibrated and verified to simulate historical patterns of temperature and salinity in GCD releases. Dissolved oxygen is also being simulated; however, some additional effort is needed for final calibration and verification. This model can be used to synthesize data for periods in which regular monitoring was not conducted and to simulate the effects of various hypothetical operational, hydrological, and climatological scenarios on historical patterns. It is also used to provide predictions of future temperature and dissolved oxygen patterns in GCD releases. One major shortcoming of the model's predictive capabilities is the lack of adequate input data for inflow water quality and meteorological conditions in the upstream portion of the reservoir. The error in predictive capability decreases substantially with the input of data from reservoir monitoring in the early summer.

4.2 Personnel and Collaborations

Funding for the Lake Powell water-quality monitoring program is provided directly by Reclamation; no Adaptive Management funds are used for this project. In addition to funding, Reclamation also provides field support staff for quarterly reservoir surveys, provides chemical sample analysis through its Lower Colorado Regional Laboratory and plankton analysis through contract, and recently purchased the Seabird SBE19plusV2 profiling instrument. The National Park Service provides a 0.5 FTE field technician, also funded by Reclamation. GCMRC participates in the Lake Powell Cooperators Group, a group of federal, state, and academic researchers, tribal representatives, concessionaires, recreational organizations, and members of the general public with interests in scientific activities conduction on Lake Powell. The National Park Service hosts annual meetings of the Lake Powell Cooperators Group to present and discuss current monitoring activities and findings, and coordinate future activities.

Dale Robertson, of the USGS Wisconsin Science Center, has been collaborating with the Lake Powell program to assist with data interpretation and modeling and develop an interpretive synthesis of the published data. This synthesis will describe the physical, chemical, and biological characteristics of Lake Powell and GCD releases, compared to climatological factors and various aspects of GCD operations. Available meteorological, hydrological, and limnological data will be used to improve, document, and verify the existing CE-QUAL-W2 model for Lake Powell, in collaboration with Reclamation scientists. The model will then be used to better understand the changes that have occurred in Lake Powell, predict future changes in response to climate change, and verify interpretive hypotheses.

Efforts are underway by Dr. Robertson to feature a special Lake Powell symposium at the 2013 meeting of the North American Lake Management Society in November 2013. In addition to serving as the annual meeting for the Lake Powell cooperators group, this symposium will also bring together researchers from academic, government, and private organizations with interest in Lake Powell, Lake Mead, and similar reservoirs. The proceedings of this symposium will be published in a special issue of Lake and Reservoir Management.

In recent years, GCMRC has worked closely with Richard A. Wildman, currently serving as postdoctoral fellow and Harvard University Center for the Environment. GCMRC has provided field assistance, data availability, and review for publications related to phosphorus release and sediment transport related to reservoir drawdown (Wildman and others, 2011; Wildman and Hering, 2011.)

4.3 Deliverables

During the FY13/14 period, an interpretive data synthesis report will be developed to build on the monitoring data and provided insights into how climatological, meteorological, and hydrodynamic processes, as well as the operation of GCD, affect inflow routing and stratification in the reservoir and the quality of releases from GCD. A website will be developed during this period to provide current conditions and historical data to the public. Other reports will be developed in future years describing water-quality changes in response to climatological factors, model development and verification, and application of modeling results to downstream resources.

5. Productivity from Past Work

Products from the Lake Powell monitoring program include published reports, listed in the following section, the WQDB database, available on-line, presentations at scientific meetings, presentations to the general public, and presentations or supporting data to the AMWG and TWG. Preliminary data from monitoring surveys are provided to Reclamation within one month of collection.

5.1. Completed Publications

Vernieu, W.S., 2012, Biological data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1991-2008: U.S. Geological Survey Data Series xxx (in development).

Vernieu, W.S., 2012, Water temperatures in select nearshore environments of the Colorado River in Grand Canyon, Arizona, during the low summer steady flow experiment of 2000. (Final review completed, in publication.)

Vernieu, W.S., 2010, Effects of the 2008 high-flow experiment on water quality in Lake Powell and Glen Canyon Dam releases, Utah-Arizona: U.S. Geological Survey Open-File Report 2010–1159, 51 p.

Vernieu, W.S., 2009, Physical and chemical data for water in Lake Powell and from Glen Canyon Dam releases, Utah-Arizona, 1964–2008: U.S. Geological Survey Data Series 471, 23 p. and database. (an updated revision of this report, presenting data collected through 2011, is currently in review.)

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Wildman, R.A. and Hering, J.G., 2011, Potential for release of sediment phosphorus to Lake Powell (Utah and Arizona) due to sediment resuspension during low water level: Lake and Reservoir Management, v. 27, no. 4, p. 365-375, http://dx.doi.org/10.1080/07438141.2011.632705.

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7. Budget

FY 2013	
Project C: Lake Powell	
Salaries	$179,700
Traveling and Training	$7,200
Operating Expenses	$33,800
Logistics	$0
GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$0
USGS cooperators	$0
USGS Burden	$30,900
Total	$251,600
FY 2013 Project C. Grand Total: $251,600	

FY 2014	
Project C: Lake Powell Water Quality Monitoring	
Salaries	$185,100
Traveling and Training	$7,400
Operating Expenses	$34,800
Logistics	$0
GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$0
USGS cooperators	$0
USGS Burden	$31,800
Total	$259,100
FY 2014 Project C. Grand Total: $259,100	

Project D.
Mainstem Humpback Chub Aggregation Studies and Metapopulation Dynamics

1. Introduction

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2. Project Summary

Sampling mainstem humpback chub (*Gila cypha*) aggregations has been conducted periodically over the last decade including in 2002 through 2004, 2006, 2010, and 2011. Fish were sampled by hoop and trammel nets at aggregations first described by Valdez and Ryel (1995). These monitoring efforts provide catch per unit effort indices, but abundance estimates were infrequently made. This project proposes to increase sampling during FY13/14, following on the results of a pilot study in FY12. The purpose of this work is to improve monitoring techniques and provide estimates of humpback chub abundance in several mainstem aggregations. Continued monitoring of aggregations is required as part of the Non-Native Fish Control Environmental Assessment and associated Biological Opinion. Additionally, this project will improve our understanding of the impact of translocation efforts in humpback chub metapopulation dynamics. Basic information on status and trends of humpback chub outside of the Little Colorado River (LCR) aggregation is also desired by managers to assess impacts of operations of Glen Canyon Dam and other management actions on mainstem Colorado River humpback chub aggregations.

Although recent catch rate information indicates aggregations might be growing, absolute numbers of humpback chub at aggregations remain low relative to the aggregation that occurs at the confluence with the Little Colorado River (hereafter referred to as the LCR aggregation). We will also evaluate the growth potential of humpback chub at aggregations by quantifying the availability of food resources and measuring feeding habits. These data will be compared with similar data collected near the LCR (Project E: Humpback Chub (*Gila cypha)* Early Life History in and around the Little Colorado River). Given the importance of understanding the status and trends of these population segments, we believe an experimental approach is needed to develop a more quantitative method for monitoring these fish. We also propose research on otolith microchemistry of juvenile humpback chub captured at aggregations or of areas such as during backwater seining to assess whether these aggregations are supported by emigration of juvenile fish from the LCR or local spawning and recruitment. ***Collectively, the proposed research will yield a more rigorous aggregation monitoring program and will increase our understanding of the ecology of aggregations, including whether downstream reaches in Grand Canyon are capable of supporting self-sustaining populations of humpback chub.***

3. Background

3.1 Scientific Background

Currently, the only known reproducing and self-sustaining population of humpback chub within Grand Canyon is in the LCR and in the mainstem Colorado River near its confluence with the LCR (Valdez and Ryel, 1995; Gloss and Coggins, 2005; Coggins and others, 2006). Because these fish appear to rely exclusively on the LCR for reproduction, these fish are at increased risk of catastrophic loss (U.S. Fish and Wildlife Service, 2008; Bureau of Reclamation, 2011).

Eight other aggregations of humpback chub were described in the mainstem Colorado River (Valdez and Ryel, 1995), and closed population model abundance estimates were generated for six of those aggregations (table 1). An aggregation was defined as “a consistent and disjunct group of fish with no significant exchange of individuals with other aggregations, as indicated by recapture of Passive Integrated Transponder (PIT) tagged juveniles and adults and movement of radio-tagged adults” (Valdez and Ryel, 1995). Recent data collected at aggregations and throughout the Colorado River, suggest that there is substantial movement among some of the originally identified aggregations, and they may not all meet the original definition of an aggregation.

Table 1. Locations of nine mainstem aggregations, adult (> 200 mm) humpback chub abundance (N) and 95% confidence interval (CI) estimated in 1993 by (Valdez and Ryel, 1995).

Aggregation	River Miles	N	95% CI
30-Mile	29.8 - 31.3	52	24-136
Little Colorado River Inflow	57.0 - 65.4	3,482	2,682-4,281
Lava Chuar to Hance[1]	65.7 - 76.3		
Bright Angel Creek Inflow	83.8 - 92.2		
Shinumo Creek Inflow	108.1 - 108.6	57	31-149
Stephen Aisle	114.9 - 120.1		
Middle Granite Gorge	126.1 - 129.0	98	74-153
Havasu Creek Inflow	155.8 - 156.7	13	5-70
Pumpkin Spring	212.5 - 213.2	5	4-16

[1]Recent examination of PIT tag recaptures indicated that humpback chub in the Lava Chuar to Hance aggregation mix with humpback chub in the LCR aggregation, and thus the two locations could be considered the same aggregation.

Only the LCR aggregation is known to successfully reproduce and recruit into the spawning population (Coggins and others, 2006). This aggregation has been sampled extensively with regular reporting of its status and trends (Coggins and others, 2006; Coggins and Walters, 2009). The remaining eight aggregations were sampled during 1990-93, again in 2002-04, and in 2006 (Valdez and Ryel, 1995; Ackerman, 2008). In 2010 and 2011, the U.S. Fish and Wildlife Service conducted surveys to assess their status and trends (VanHaverbeke and Persons, 2012, unpublished). The abundance of humpback chub at aggregations appears to be increasing, but current monitoring methods only provide catch rate indices that have a high degree of uncertainty. Recent synthesis of data suggests that capture probability estimates pooled over all aggregations may be used to derive a relatively unbiased estimate of overall (summed over aggregations) humpback chub abundance (C. Walters, pers. comm.)

Annual humpback chub mainstem aggregation monitoring was specified in the 2011 Environmental Assessment for Non-native Fish Control Downstream from Glen Canyon Dam (Bureau of Reclamation, 2011) and was funded in FY10 and FY11/12 (Bureau of Reclamation and U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2010). However, a long-term monitoring program has not been developed for the project, and a thorough synthesis of existing aggregation data has not been completed or published. We will produce a long-term monitoring plan for sampling humpback chub aggregations by the end of FY14.

The metapopulation dynamics, including movement among aggregations, of chub in the LCR inflow aggregation and the rest of the mainstem Colorado River are poorly understood. Adult humpback chub generally have high site fidelity, i.e., PIT tagged adults are usually recaptured in the same aggregation where they were tagged (table 2), (Paukert and others, 2006; Coggins, 2007, 2008; Coggins and Walters, 2009). However, dispersal of juvenile and subadult (age 1-4) humpback chub is poorly understood. The natal origins of humpback chub at downstream aggregations are uncertain. Fish at aggregations may be dispersing from the LCR as juveniles or subadults (ages 1-3). Alternatively, humpback chub at aggregations may be derived from local spawning and recruitment. Humpback chub have been reported to initiate spawning at about 16° C (Hamman, 1982). Mainstem water temperatures vary depending on release temperature from Glen Canyon Dam, and water can warm to 16°C at River Mile 65 during some years (Wright and others, 2008). Understanding if the mainstem Colorado River can support self-sustaining populations of humpback chub will help inform future experimentation conducted as part of the adaptive management process. However, the ability of humpback chub females to produce viable gametes in the mainstem Colorado River at mainstem aggregations is unknown.

Table 2. Nights of sampling, sampling location, and gear (T=trammel net, H=baited hoop net) at fixed sites (aggregations) and at stratified random sites (outside of aggregations), spring and fall, FY13 and FY14.

		Spring Trip: Fixed site and stratified random CPUE sampling		Fall Trip: Fixed site mark-recapture and CPUE sampling		Total	
Aggregation	Gear	FY13	FY14	FY13	FY14	FY13	FY14
Outside of aggregations	T,H	14	14	4	4	18	18
30-Mile	T,H		1	2	1	2	2
Little Colorado River Inflow	H	1	1	2	2	3	3
Bright Angel Creek Inflow	T,H	1	1	1	1	2	2
Shinumo Creek Inflow	H	1	1	2	2	3	3
Stephen Aisle	T,H	1		1	2	2	2
Middle Granite Gorge	T,H	1	1	2	1	3	2
Havasu Creek Inflow	T,H	1	1	2	2	3	3
Pumpkin Spring	T,H	1	1	1	2	2	3
Total nights		21	21	17	17	38	38

3.2. Key Monitoring and Research Questions Addressed in this project

This project directly addresses the following Strategic Science Questions (SSQs), Core Monitoring Information Needs (CMINs), and Research Information Needs (RINs) previously identified by the Glen Canyon Dam Adaptive Management Program (GCDAMP).

Primary SSQ addressed:

- **SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?
- **SSQ 1-2.** Does a decrease in the abundance of rainbow trout and other cold- and warm water nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?

The GCDAMP Science Advisors articulated the following summary science questions addressed by this project:

- **SA 1.** What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young of year and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?
- **SA 2.** What are the most probably positive and negative impacts of warming the Colorado River on humpback chub adults and juveniles?

Information Needs Addressed

- **CMIN 2.1.2.** Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the Colorado River.
- **CMIN 2.4.1.** Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River.
- **CMIN 2.6.1.** Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.
- **RIN 2.4.2.** Determine if suppression of nonnative predators and competitors increases native fish populations.
- **RIN 2.4.3.** To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish through predation or competition?
- **RIN 2.4.4.** What are the target population levels, body size, and age structure for nonnative fish in the Colorado River ecosystem that limit their levels to those commensurate with the viability of native fish populations?

3.3 Key management goals and objectives addressed in this project

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

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

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

4. Proposed Work

4.1. Project Elements

Project Element D.1. Improve aggregation sampling to develop more rigorous approaches to monitor aggregations (includes ongoing monitoring) ($199,500)

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

We propose increasing our sampling effort at a subset of aggregations in both FY13 and FY14. This additional effort may be needed to estimate population sizes of humpback chub at several aggregations in order to estimate capture probability. A second sampling trip will be conducted in July to assess humpback chub relative abundance in areas of the river outside of the defined aggregations. Information from this study will allow us to evaluate the use of catch per unit effort indices as a tool to monitor relative abundance of fish in aggregations and to determine if humpback chub distribution has increased. Preliminary work synthesizing existing aggregation data as well as initial mark-recapture efforts at the aggregations is already underway and is funded in FY12. In addition, recent synthesis of data suggests that we may be able to pool capture probability estimates over all aggregations, and use the pooled capture probability to derive a relatively unbiased estimate of overall (summed over aggregations) humpback chub abundance.

We will investigate use of mark-recapture methods during FY12 at the Shinumo Inflow aggregation (table 1) and will include sampling at translocation tributary inflow aggregations Havasu and Shinumo Creeks during FY13/14 (table 3). Shinumo Inflow aggregation sampling will be conducted twice in September, 2012: the initial "marking" sampling event will be conducted by the National Park Service/Bureau of Reclamation during the September Shinumo Creek translocation monitoring trip with the potential for sampling over 3-5 nights (number of net sets to be determined), and the recapture sampling effort will be conducted during the U.S. Fish and Wildlife Service/GCMRC aggregation monitoring trip. No trammel nets will be used during this effort to investigate whether baited hoop nets can be used to collect sufficient capture-recapture data to infer abundance and capture probabilities. In addition to improving abundance estimates, work at these sites will improve our understanding of the role of translocations in humpback chub metapopulation dynamics. For example, coordinated humpback chub sampling in the mainstem and in Shinumo Creek in the future may allow for improved estimates of survival of translocated fish, as well as PIT tag antenna detection efficiency estimates through a multistate capture-recapture model (Horton and others, 2011) if translocations of humpback chub into Shinumo Creek continue.

During FY13 and FY14, three or four of the aggregations, exclusive of the LCR, will be sampled on two successive nights to attempt closed population estimates using mark-recapture methods; these efforts will also yield a more precise estimate of capture probabilities. The current approach to monitoring, which involves one or two nights of sampling at each aggregation, only provides catch rate indices (i.e., fish captured per hour). Because of the large uncertainty in capture probabilities (the probability of catching an individual fish), the inferences that can be drawn from the current monitoring program are very limited.

Because of concerns about potential impacts of increased sampling on aggregations, we propose sampling different aggregations in FY13 than in FY14. Thus, all aggregations will be sampled during the two year budget period. Sampling will be reduced in later years. With a better understanding of capture probabilities and associated variation at aggregations, long-term monitoring in later years should involve one or two nights of sampling at each aggregation to make absolute abundance estimates based on pooled capture probabilities.

A stratified random sampling design will be used for the second sampling trips in FY13 and FY14 to assess humpback chub relative abundance in other areas of the river (table 3). It is likely that as humpback chub abundance in the mainstem Colorado River increases, the species may not merely increase in abundance at specific locations, but may colonize new habitats in the river. Baited hoop nets and trammel nets will be fished in sections of the river not associated with known aggregations.

To address concerns about over handling humpback chub, trammel nets will be discontinued in areas where hoop nets can be fished effectively. Trammel nets will be checked every two hours, they will not be fished in water warmer than 16° C, and they will not be fished in the same location for more than one night in a row.

This project will result in the following products:

- FY13 and FY14: Capture probability estimates to allow inferences about abundance estimates to be drawn from a long-term monitoring program of catch-per-unit.
- FY13: Catch per unit effort estimates at four aggregations (30 mile, LCR, Shinumo Creek, and Havasu Creek).
- FY14: Catch per unit effort estimates at four aggregations (Shinumo Creek, Havasu Creek, Middle Granite Gorge, Pumpkin Springs)
- FY13 and FY14: Estimates of humpback chub abundance at mainstem aggregations exclusive of the LCR aggregation.
- FY14. Long-term monitoring plan and protocols to guide future, cost-effective monitoring program published in the peer reviewed literature.
- One Administrative report
- One article submitted to a peer review journal

Table 3. Tag and recapture location for humpback chub recaptured more than 13.9 days after tagging, LCR and mainstem Colorado River, 1991 – 2011. Numbers in bold and italic represent fish recaptured in the same reach as they were tagged in. Numbers above the diagonal indicate downstream movement whereas numbers below the diagonal indicate upstream movement. Numbers do not represent individual fish because some fish were recaptured more than once. Does not include fish translocated to Shinumo Creek. 30M = 30 Mile aggregation, LCR = Little Colorado River, LCR reach = Little Colorado River mainstem aggregation, LCH = Lava Chuar to Hance aggregation, BAC = Bright Angel Creek aggregation, SHI = Shinumo Creek aggregation, STE = Stephen Aisle aggregation, MGG = Middle Granite Gorge aggregation, HAV = Havasu Creek aggregation, PUM = Pumpkin Spring aggregation.

	Location Recaptured (rkm)										
Location Tagged (rkm)	74 - 77.3 (30M)	LCR	117.7 - 131.4 (LCR reach)	131.4 - 151.5 (LCH)	160.9 - 174.4 (BAC)	199.5 - 203 (SHI)	210.9 - 220.4 (STE)	227.2 - 233.6 (MGG)	276.7 - 279 (HAV)	368 - 372.2 (PUM)	Total
74 - 77.3 (30M)	***34***	1	2	-	-	-	-	-	-	-	37
LCR	2	***28,730***	1,659	60	2	1	-	4	2	-	30,460
117.7 - 131.4 (LCR reach)	1	1,438	***460***	8	1	-	-	1	2	-	1,911
131.4 - 151.5 (LCH)	-	39	10	***8***	-	-	-	-	-	-	57
160.9 - 174.4 (BAC)	-	1	-	-	-	-	-	-	-	-	1
199.5 - 203 (SHI)	-	-	-	-	-	***9***	1	2	-	-	12
210.9 - 220.4 (STE)	-	-	1	-	-	-	***1***	2	-	-	4
227.2 - 233.6 (MGG)	-	-	1	-	-	-	1	***86***	1	-	89
276.7 - 279 (HAV)	-	4	-	-	-	-	-	-	***6***	-	10
368 - 372.2 (PUM)	-	-	-	-	-	-	-	-	-	***2***	2
Total	37	30,213	2,133	76	3	10	3	95	11	2	32,583

Project Element D.2. Natal origins of Humpback Chub, adult condition and reproductive potential ($167,400)

We do not know if the mainstem Colorado River under current dam operations can support self-sustaining populations of humpback chub. This knowledge gap makes it very difficult to plan management actions and future dam operations aimed at conservation of humpback chub. The first step in determining if the mainstem Colorado River provides the necessary elements for humpback chub to complete their life cycle is to evaluate if existing mainstem water temperatures are warm enough for successful gamete development. Fish reproductive cycles are separated into the growth (gametogenesis) and maturation phase (oocyte maturation and spermiation), both of which are influenced by water temperature (Mylonas, 2010). Disruptions in male and female reproductive cycles because of cold water have been documented for other species (Rideout and others, 2000), and stenothermic environments that lack seasonal variation have been shown to interrupt egg production in some fish (Robinson and others, 2011). Mainstem water temperatures vary from year to year depending on release temperature from Glen Canyon Dam (Project C:Water-Quality Monitoring of Lake Powell and Glen Canyon Dam Releases), and water can warm to 16° C at River Mile 65 during some years (Wright and others, 2008). Humpback chub have been reported to initiate spawning at about 16° C (Hamman, 1982). However, the ability of humpback chub females to produce viable gametes in the mainstem Colorado River at mainstem aggregations is unknown.

If water temperatures are adequate for female humpback chub to mature gametes yet no viable gametes are found, it would indicate other factors such as nutritional requirements are not being met (Toucher, 2010). If female humpback chub are meeting thermal and nutritional requirements to produce and mature gametes in the various mainstem aggregations, then the next step is to determine if those eggs hatch and if the larval humpback chub survive. By systematically examining each life stage of humpback chub development in the mainstem Colorado River, we can isolate factors that may be limiting mainstem survival and recruitment and focus management actions on those limiting life stages.

This study will require additional handling of humpback chub, but efforts will be made to minimize any harmful effects of handling. Hoop nets will be used instead of trammel nets whenever possible, and trammel nets will not be used if mainstem water temperatures are above 16° C to minimize capture related mortality (Hunt and others, 2012). Procedures that require additional manipulation of captured fish will not be conducted at the same aggregation more than once per year, and captured fish will be maintained in oxygenated coolers at salinity of 3.0 ppt to minimize capture/handling related stress.

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-GCMRC
D.R. Van Haverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park

Pilot work done by Limburg and Hayden in 2010 revealed that carbon stable isotopic ratios can be used to differentiate water samples from the mainstem Colorado River and many tributaries to the Colorado River. Sixteen humpback chub otoliths were also analyzed using Secondary Ion Mass Spectroscopy (SIMS) (K. Limburg, pers. comm). Results from this pilot work revealed that carbon and oxygen isotopic ratios in the otoliths can be used to discriminate where the fish were located at various life stages. Determining the natal origin of fish that inhabit the aggregations has important implications for management of humpback chub. Positively linking natal origin of fish to either the LCR, or the mainstem, or other Grand Canyon tributaries will help to inform management actions. If all of the fish in the downstream aggregations are from the LCR, then management actions aimed at increasing survival of downstream dispersing individuals may be beneficial to the humpback chub population in Grand Canyon. If certain age classes show signs of mainstem origin then we may be able to link dam operations and water temperatures to times when mainstem recruitment occurred.

We propose to capture 30-40 young-of-the-year humpback chub annually from up to 3 downstream aggregations and from locations not associated with aggregations, as well as from the LCR and Havasu Creek and sacrifice them for otolith microchemistry evaluation. Surrogate species will be tested in FY12 to confirm that fish resident in Havasu Creek can be distinguished from LCR fish. Specimens will be preserved in the field and provided to a Cooperator for otolith extraction and analysis. A PhD. Student will be supported for two years with a Cooperative Agreement with SUNY.

This project will result in a final report and recommendation for use of techniques as part of long term monitoring of mainstem Colorado River humpback chub recruitment dynamics (FY14). A dissertation with a chapter as a peer review publication detailing use of techniques to identify natal origins of humpback chub from the mainstem Colorado River downstream of the LCR (FY14).

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

David L. Ward, Fishery Biologist, USGS-GCMRC
Scott Bonar, Fishery Biologist, USGS and University of Arizona (MS student project)
D.R. Van Haverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
Brian Healy, Fishery Biologist, NPS, Grand Canyon National Park

Ultrasonic images have been used in fisheries research to non-lethally determine sex and maturational status of many fishes (Evans and others, 2004). Use of ultrasonic imagery may help resolve questions about stage of maturity of adult humpback chub in mainstem aggregations. We will collect ultrasound images of captive reared fish at fish hatcheries to refine methods and techniques. Ultrasound images will then be collected from a small sample of adult fish from the LCR, and at mainstem aggregations to evaluate the ability of female humpback chub to produce viable gametes in mainstem aggregations.

Following development and testing of ultrasonic methods at hatcheries and in the LCR, a small number of adult humpback chub (<30 fish) will be captured at up to three mainstem aggregations, exclusive of the LCR inflow, using hoopnets. Fish will be non-lethally scanned with ultrasound to evaluate the status of gamete development. If females with developed eggs are encountered, a subset of these individuals (<10 fish) will be injected with Ovaprim®, a synthetic hormone used to artificially induce spawning in fish. If the females have eggs that are close to being mature, Ovaprim® will allow those eggs to be manually extruded within 2 days. If females do not have eggs that are close to maturation, it will have no effect on the fish. Ultrasound and Ovaprim® methods will be developed and tested in the LCR in FY13, and if proven useful, will be used on humpback chub from mainstem aggregations in FY14. Fish will be held in the river in holding pens following hormone injection and subsequently released. In a survey of 40,000 fish of 25 different species (mostly cyprinids), mortality after handling and injection with Ovaprim® was 1.3% (Hill and others, 2009). These hormone injections on fish known to possess eggs using ultrasound will be conducted on less than 10 adult fish per year from 2-3 mainstem aggregations. If eggs are expelled from any females, they will be incubated in the laboratory to evaluate hatching success. Use of ultrasound combined with Ovaprim® injections at different times of year over the space of 2-3 years, will allow researchers to assesses if the mainstem Colorado River conditions are adequate for females to mature and ripen eggs.

This project will produce a Final report/MS thesis chapter suitable for publication presenting results of Ultrasound and Ovaprim studies (FY14).

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7. Budget

FY 2013				
Project Element D.1. Aggregation Sampling			Project Element D.2. Natal Origins of Humpback Chub, adult condition, and reproductive potential	
Salaries	$21,900		Salaries	$42,000
Traveling and Training	$0		Traveling and Training	$1,000
Operating Expenses	$6,000		Operating Expenses	$13,500
Logistics	$74,800		Logistics	$0
GIS/RS/Electronics support	$0		GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$80,000		Cooperators (non-USGS)	$100,000
USGS cooperators	$0		USGS cooperators	$0
USGS Burden	$16,800		USGS Burden	$10,900
Total	$199,500		***Total***	$167,400

FY 2013 Project D. Gross Total: $366,900

FY 2014				
Project Element D.1. Aggregation Sampling			Project Element D.2. Natal Origins of Humpback Chub, adult condition, and reproductive potential	
Salaries	$22,500		Salaries	$35,200
Traveling and Training	$0		Traveling and Training	$1,000
Operating Expenses	$6,200		Operating Expenses	$6,900
Logistics	$77,000		Logistics	$0
GIS/RS/Electronics support	$0		GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$82,400		Cooperators (non-USGS)	$103,000
USGS cooperators	$0		USGS cooperators	$0
USGS Burden	$17,800		USGS Burden	$9,200
Total	$205,900		***Total***	$155,300

FY 2014 Project D. Gross Total: $361,200

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

1. Investigators

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2. Project Summary

In FY13/14, we will: (a) estimate growth, survival, and movement of juvenile humpback chub in the Little Colorado River (LCR) by marking young-of-year humpback chub (*Gila* cypha) each year in the LCR in July, (b) describe food web structure and assess the potential for food limitation within the LCR, and (c) conduct data analysis and modeling that will integrate findings from the above efforts and ongoing standardized monitoring to determine the relative roles of LCR hydrology, intraspecific and interspecific interactions, and mainstem conditions in humpback chub juvenile life history and adult recruitment. These new research efforts will address a suite of questions that have arisen based on insights gained from standardized monitoring conducted since 2000 and new findings from the mainstem monitoring of native and nonnative fishes near the LCR confluence-Juvenile Chub Monitoring (Project Element F.3.):

1. To what extent do survival and growth in the LCR aggregation vary annually and spatially (i.e., mainstem vs. LCR downstream of Chute Falls vs. LCR upstream of Chute Falls)?
2. What are the drivers of observed variation in survival and growth? Specifically, to what extent are endogenous (e.g., intraspecific predation and competition for food) versus exogenous factors (e.g., interspecific competition and predation, mainstem conditions—including dam operations—and variation in LCR hydrology, etc.) responsible for temporal and spatial variation in survival and growth?
3. To what extent does outmigration of humpback chub from the LCR vary over time?

Prior to the Near Shore Ecology (NSE) project (2009-2011), our understanding of variation in humpback chub early life history was limited to back-calculations of cohort strength (# of fish surviving to adulthood from a given birth year) derived from abundance estimates of four year-old fish (Coggins and others, 2006; Coggins and Walters, 2009). The life history parameters (i.e., direct estimates of survival and growth for juvenile humpback chub rearing in specific locations) provided by NSE-style sampling are more germane to evaluating ongoing adaptive management experimentation because population dynamics of many fish species are driven by changes in growth or survival at early life stages (Walters and Martell, 2004). Furthermore, direct estimates of survival and growth for juvenile humpback chub are more sensitive to yearly changes in, for example, dam operations or LCR hydrology, than the indirect estimates of survival and growth derived from back-calculations in the Age-Structured Mark Recapture (ASMR) model (Coggins and Walters, 2009).

The survival rate estimates for juvenile humpback chub in the mainstem measured by the NSE project were higher than most scientists anticipated (Knowledge Assessment, 2011; 2012). However, the NSE project occurred during a period when water temperatures, rainbow trout (*Oncorhynchus mykiss*) abundances, and LCR conditions were all favorable to native fish and fairly consistent among years. Continuation of NSE sampling in FY12 and beyond will allow scientists to determine the impacts of increasing rainbow trout abundances and decreasing water temperature, which are anticipated in FY12, on juvenile humpback chub survival and growth in the mainstem. However, even these estimates of juvenile humpback chub survival and growth in the mainstem under a new set of conditions will be partially confounded by un-described variation in LCR conditions unless additional primary research studies in the LCR are initiated. The NSE project also found that growth rates for juvenile humpback chub were higher in the LCR relative to the mainstem during summer months. However, the opposite was true in the fall—growth rates were higher in the mainstem than in the LCR. This finding—that growth rates in the mainstem were at times higher than in the LCR—also came as a surprise to many scientists. Yet, interpretation of these differences in growth rates is not straightforward, because densities in one habitat—the LCR—may be dependent on conditions there (e.g., density of adult humpback chub and other native species, food availability, etc.), but juvenile abundance in the LCR might also be a function of conditions in the mainstem (i.e., warm water, low non-native abundances, etc.).

Humpback chub translocations upstream of Chute Falls have also yielded insights about early life history parameters. Growth rates for juvenile humpback chub rearing upstream of Chute Falls are two times higher than growth rates of juvenile humpback chub rearing in the LCR downstream of Chute Falls. It is worth noting that these differences in juvenile humpback chub growth within the LCR (upstream vs. downstream of Chute Falls) are actually *larger* than the differences in juvenile humpback chub growth between the downstream part of the LCR and the mainstem (Knowledge Assessment, 2011; 2012).

Standardized monitoring indicates that fall juvenile abundances in the LCR vary strongly among years (VanHaverbeke and others, 2012; Knowledge Assessment presentations, 2011; 2012). During the NSE project, fall LCR juvenile abundances were consistently high, but there have been years in the recent past (i.e., 2002 and 2006) when LCR juvenile abundances in the fall were very low. These years—2002 and 2006—may correspond to either higher or lower juvenile abundances in the mainstem, depending on whether variation in juvenile survival in the LCR *or* outmigration from the LCR is the primary lever affecting fall LCR juvenile abundances. Put another way, low fall abundances in the LCR might be a leading indicator of a failed birth year because of poor juvenile survival in the LCR, or low fall abundances may simply reflect decreased use of the LCR by juveniles because of forced (LCR flooding) or purposeful migration into the mainstem Colorado River. Additional primary research studies in the LCR are needed to resolve these new questions and associated uncertainties.

3. Background

Population dynamics for many fish species are driven by changes in survival at early life stages (Walters and Martell, 2004); survival of adult fish is less affected by changes in environmental conditions than is the survival of small juveniles, because adult fish have larger energy reserves that can be used to survive occasional periods of unfavorable environmental conditions. Larger, adult fish are also less vulnerable to predation than juveniles. Differences in survival of juvenile humpback chub among years are likely responsible for long-term trends in adult humpback chub abundances, because adult survival rates over the last 20 years have been high and stable through time (Coggins and Walters, 2009). This is why previous and ongoing adaptive management experimentation has been directed towards improving the rearing environment for juveniles (i.e., mechanical removal of rainbow trout, fall steady flow experiments, high-flow experiments that create backwaters, etc.). Estimating humpback chub cohort strength and juvenile survival annually is critical to evaluation of ongoing adaptive management experimentation.

Prior to the NSE study, our understanding of humpback chub early life history was limited to back-calculations of cohort strength and juvenile survival derived from the abundance of approximately four-year old fish (Coggins and others, 2006; Coggins and Walters, 2009). Humpback chub are considered adults, and therefore capable of reproduction, when they reach approximately 200 mm in total length (Kaeding and Zimmerman, 1983), and it takes humpback chub around four years to attain this size. By calculating the number of new adult (that is, 200 mm long) humpback chub added to the population each year, scientists were able to back-calculate four years and estimate juvenile survival rates for specific birth years (i.e., survival for the 2002 birth year, based on the number of new adult fish in 2006). Estimates of survival and cohort strength for specific years were then analyzed in relation to environmental conditions in the mainstem (i.e., rainbow trout abundance, water temperatures, etc.) in an attempt to evaluate the effectiveness of ongoing adaptive management experimentation (Coggins and Walters 2009). Unfortunately, these back-calculated estimates of cohort strength and survival are imprecise, because there are large differences in growth rates for juveniles rearing in the LCR versus the mainstem. Differences in growth rates (and hence length) among individuals that are the same age but using different habitats leads to inaccurate age assignments, and by extension, inaccurate estimates of back-calculated survival for specific birth years (e.g., the 2002 birth year started recruiting to the adult population in 2006, but slower growing individuals were not considered adults until 2007 or later and get assigned to subsequent birth years). Further, there are large differences in the timing and amount of juvenile humpback chub outmigration from the LCR, which may itself be a function of conditions in both the LCR and the mainstem.

To overcome some of the limitations inherent in back-calculating juvenile survival, the NSE project (2009-2011) directly measured survival of juvenile humpback chub by batch marking small humpback chub using Visual Implant Elastomer (VIE) tags. Fish can be marked with VIE tags at a smaller size than the Passive Integrated Transponder (PIT) tags that are used to mark larger fish (>100 mm) as part of regular monitoring. Recaptures of these batch-marked humpback chub has substantially increased our understanding of juvenile humpback chub life history parameters, even though recaptures of batch-marked fish do not yield as much information as recaptures of PIT-tagged fish, which are an individual mark similar to a social security number. Specifically, the survival rate estimates for juvenile humpback chub in the mainstem were higher than most scientists anticipated.

US Fish and Wildlife Service (USFWS) standardized sampling and translocations of juvenile humpback chub within the LCR have also yielded insights about early life history parameters (VanHaverbeke and others, 2012). Standardized sampling demonstrates that there is large year-to-year variation in the fall abundances of juvenile humpback chub in the LCR (VanHaverbeke and others, 2012). Large differences in fall abundances in the LCR among years could be a result of differences in juvenile survival among years. Alternatively, differences in fall abundance estimates in the LCR could be unrelated to survival *per se* and instead reflective of higher migration out of the LCR due to, for example, relatively favorable rearing conditions in the mainstem. Growth rates for juvenile humpback chub translocated and rearing upstream of Chute Falls are two times higher than growth rates for juvenile humpback chub rearing in the LCR downstream of Chute Falls. It is worth noting that the differences in juvenile humpback chub growth rates within the LCR (upstream vs. downstream of Chute Falls) are actually *larger* than the differences in growth rates between the downstream end of the LCR and the mainstem. In light of these new findings, three key uncertainties relevant to the early life history of humpback chub are:

1. To what extent do survival and growth in the LCR aggregation vary temporally (i.e., among years) and spatially (i.e., mainstem vs. LCR upstream of Chute Falls vs. LCR downstream of Chute Falls)?
2. What are the drivers of observed variation in survival and growth? Specifically, to what extent are endogenous (e.g., intraspecific predation and competition for food) versus exogenous factors (e.g., interspecific competition and predation, dam operations, variation in LCR hydrology, etc.) responsible for temporal and spatial variation in juvenile survival and growth?
3. To what extent does outmigration of humpback chub from the LCR vary from year to year?

3.1. Scientific Background

Standardized sampling in the LCR over the last decade has revealed substantial variation in fall juvenile abundances from year to year (VanHaverbeke and others, 2012). In particular, abundances in 2002 and 2006 were markedly lower than other years (Knowledge Assessment, 2012) and occurred in the same years as the two lowest snowmelt runoff floods in the LCR over the same span, suggesting an important and unresolved link between LCR hydrology and humpback chub population dynamics. There are at least four hypotheses to explain this linkage, each of which has different implications for the significance of the observation—low juvenile fall abundance in the LCR—to humpback chub population dynamics and adult recruitment. These hypotheses also have different implications for the relative roles of conditions in the mainstem Colorado versus the LCR in determining adult humpback chub population dynamics and adult recruitment. Low juvenile abundance in the fall could be a leading indicator of a failed birth year caused by: (Hypothesis-(H1) poor egg survival in the LCR, (H2) poor juvenile survival in the LCR the preceding summer associated with low prey production, (H3) low juvenile survival in the LCR the preceding summer due to predation by conspecifics, or (H4) unrelated to juvenile survival and instead a result of outmigration from the LCR due to displacement from monsoon floods or relatively favorable rearing conditions in the mainstem Colorado River.

Under Hypothesis 1 (**H1**) *Survival of humpback chub eggs in the LCR is limited in years when snowmelt flooding is negligible or small because of poor spawning substrate conditions*. The rationale for this spawning limitation hypothesis is that the LCR is a travertine system, and marl deposition in the lower LCR is extremely rapid (Robinson and others, 1996). Without moderate/large snowmelt floods that deliver clean gravels, substrates in the downstream part of the LCR during the spawning season will likely be cemented together with marl and will lack the interstitial spaces necessary for egg survival. Under this hypothesis, we would expect lowered numbers of juveniles in both the LCR and in the mainstem near the LCR confluence during years without large LCR snowmelt floods. Further, if this hypothesis is true, it suggests that the continued success of the LCR population may be predicated on climatic conditions in the LCR basin and are best in years of moderate/large snowmelt floods.

Under *Hypothesis 2* ***(H2)*** *Large snowmelt floods in the LCR stimulate production of the prey base through improvements in both the quantity and quality of food resources consumed by humpback chub, which leads to high juvenile humpback chub survival and low outmigration.* (**H2)** is somewhat related to H1 in that it also posits a link between LCR hydrology and juvenile abundance in the fall, but the mechanism underlying H2 is different. In years with small snowmelt floods, the foodbase in the LCR is depauperate and unproductive (see Fisher and others, 1982; Cross and others, 2011), which in turn leads to low survival and/or high out-migration of juvenile humpback chub. Under this hypothesis, the population of juvenile humpback chub (both yearlings and young-of-year) in the mainstem could remain the same, or even increase, if juveniles choose to outmigrate in response to low food densities in the LCR in years without substantial snowmelt flooding. If this hypothesis is true, and there is earlier and higher outmigration in response to negligible/small snowmelt floods in the LCR, it suggests that mainstem conditions may be especially important as a greater proportion of the juvenile population will be rearing in the mainstem.

Hypothesis 3 ***(H3)*** focuses on the role of intraspecific interactions, especially predation and cannibalism by yearlings on young-of-the-year, and can take two non-mutually exclusive forms. The first variety of this hypothesis ***(H3a)*** *posits that in years without large LCR snowmelt floods, more yearlings remain in the system and there are higher levels of cannibalism and competition than in years with large LCR snowmelt floods.* The second version **(H3b)** posits that, independent of the reason for decreases in fall abundances in 2002 and 2006, *the lack of yearlings in the LCR in the following spawning season (2003 and 2007) led to especially large cohorts of young-of-year in those birth years because of reduced cannibalism and competition*.

It is also possible that snowmelt floods are not an important factor affecting humpback chub dynamics and, instead, the intensity of summer/fall monsoon floods is the primary driver of fall abundances of juvenile humpback chub; that is, low LCR fall abundances are *not* a leading indicator of a failed birth year. In both 2002 and 2006, LCR discharge during the snowmelt season was negligible, but there were relatively large monsoon floods in the fall. This observation leads to *Hypothesis 4* ***(H4),*** *which argues that outmigration rates of juvenile humpback chub from the LCR are directly linked to the intensity of monsoon flooding in the summer and fall.* Under this hypothesis, we would expect increased migration from the LCR to the mainstem during years of large monsoon flooding in the LCR, and we would expect most migration to occur during the monsoon season—from July to September. VIE marking as part of both USFWS and NSE sampling between 2009 and 2011 has provided hints of movement between the LCR and the mainstem over these time scales; however, interpretation of these data has been hampered by the relatively low number of juveniles marked between the spawning season and before fall monsoons. Specifically, the last scheduled spring marking event in the LCR occurs in May, and young-of -year humpback chub are rarely large enough to mark with VIE tags (>40 mm total length). The next scheduled marking occurs in September, and monsoon floods that displace young-of- year may have already occurred.

Survival rates for juvenile fish are highly correlated with individual growth rates; a juvenile population that grows rapidly will generally experience higher survival relative to a population of juveniles that is growing slowly (Walters and Martell, 2004). Understanding the causes of variation in juvenile humpback chub growth rates among habitats will therefore aid interpretation of any estimates of juvenile survival among habitats. *One hypothesis to explain the observed variation in humpback chub growth rates among locations and times is that growth rates are mainly driven by concomitant changes in water temperature* **(H5)**. This hypothesis has clear implications for dam operations. Another hypothesis **(H6)** *states that humpback chub growth among locations and times is mainly driven by differences in the quantity and quality of prey available to juvenile humpback chub*. This hypothesis also has implications for dam operations, but the types of operational changes that might be evaluated to mitigate low prey production in the mainstem are very different from the types of operations that might be evaluated to mitigate water temperature effects related to (**H5)**. Lastly, *interspecific and intraspecific competition for food resources is the main driver of humpback chub growth rates among locations and times* **(H7)**. These hypotheses (**H5**-**H7**) are obviously not mutually exclusive. **H6** and **H7**, in particular, are linked because food limitation (**H6**) is a necessary condition for resource competition (**H7**). We feel the distinction is important, however, because LCR hydrology may have strong effects on resource availability (H6) independent of fish abundance (H7). Thus, there may be some years when one factor ultimately limits or constrains humpback chub growth, and other years when a different factor limits growth.

It is improbable that a two-year study could fully resolve all of these hypotheses, in part because our ability to distinguish among certain hypotheses is dependent on LCR hydrology. However, irrespective of LCR hydrology, the new activities we will conduct in FY13/14 will allow us to evaluate the strength of evidence for at least some of the above hypotheses and address key uncertainties surrounding the population dynamics of humpback chub. This new research will be integrated with ongoing USFWS monitoring in the LCR and NSE-style sampling in the mainstem, which will help minimize handling of juvenile humpback chub. Integration of this new research effort into ongoing monitoring will also build upon these long-term efforts in a way that allows us to ask new questions.

4. Proposed Work

4.1. Project Elements

Project Element E.1. July Little Colorado Marking ($129,400)

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

The objective of this project element is to determine the extent of juvenile humpback chub outmigration and the role that summer monsoon floods play in augmented outmigration.

We will use hoop net and seining at each of the 3 camps used by USFWS in July to capture juvenile humpback chub. Fish between 40-100 mm will be given VIE batch marks, and fish larger than 100 mm will be scanned for PIT tags. Recaptures of these marked individuals will occur as part of ongoing monitoring projects (i.e., USFWS sampling, NSE sampling).

The additional marking trip in July is primarily motivated by a trend emerging from the NSE study. A proportion of the small number of fish marked in the LCR by NSE researchers during July are captured in the Colorado River in later sampling periods. However, relatively few of the fish marked by the USFWS in the fall are subsequently found in the Colorado River. This suggests that large numbers of juveniles may be moving out of the LCR between July and the fall, consistent with **H3**.

Whether juveniles out-migrate or die is unimportant for determining the causes of year-to-year variation in LCR juvenile abundances, but crucially important for determining the long-term impacts of such variation on humpback chub population dynamics. Juvenile humpback chub survival has been higher than anticipated under the Colorado River conditions of the last few years. Nevertheless, given the novelty of this study, we do not know how these rates compare to rates under different environmental conditions (*e.g.*, with different nonnative fish abundance or different dam operations, including changes in water temperature). Estimating juvenile humpback chub growth and survival under a new set of conditions in the Colorado River (i.e., higher nonnative abundance, colder water) than those observed during the NSE sampling era will hopefully provide the contrast needed to resolve whether water temperatures or nonnative abundance are master variables affecting humpback chub population dynamics. Resolving this uncertainty will require both continued NSE sampling and LCR sampling, an additional LCR marking event in July, followed by statistical analyses and modeling to integrate these data. Lastly, if many juveniles are moving from the LCR between July and September, then VIE marking in July will allow us to more definitively link dynamics in the LCR to dynamics in other aggregations, particularly as sampling in these aggregations becomes more rigorous (Project D: Mainstem Humpback Chub Aggregation Studies and Metapopulation Dynamics).

Project Element E.2. Describing food web structure and the potential for food limitation within the LCR ($257,200)

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

The objective of this project is using quantitative food webs and trophic basis of production estimates to identify mechanisms underlying differences in juvenile humpback chub growth rates among sites and seasons. For this project, we will develop quantitative food webs for two segments of the LCR—the reach upstream of Chute Falls and the reach downstream of Chute Falls—using methods described in Cross and others (2011). Quantitative food webs developed for the mainstem Colorado River near the LCR confluence from 2006-2009 will also be updated. Quantitative food webs will be used to estimate both the flux of energy (that is, carbon) along food web pathways, and also the flux of contaminants (i.e., arsenic, lead, selenium, etc.) along these same food web pathways. In this way, trophic pathways that are important to fish growth or contribute to elevated contaminant burdens among sites can be identified.

Spatial and temporal variation in the prey base may play an important role in determining patterns of juvenile humpback chub growth and survival (e.g., **H2**, **H6**). After habitat, food is the resource that most often limits animal populations (Krebs, 1994). To understand whether differences in the quantity or quality of food resources is an important driver underlying differences in humpback chub growth or movement among habitats, it is necessary to place estimates of juvenile humpback chub growth and survival in the context of the LCR and mainstem food webs as a whole. A food web context is critical because humpback chub are one of several species of fish (i.e., flannelmouth sucker [*Catostomis latipinnis*] and bluehead sucker [*Catostomis discobolus*]) that rely heavily on the LCR for spawning and rearing (VanHaverbeke and others, 2012; Walters and others, 2012). Indeed, the spawning season abundance estimates for bluehead sucker in the LCR from 2007-2009 ranged from 40,000-70,000, or nearly ten times higher than spawning season abundance estimates for humpback chub (VanHaverbeke and others, 2012). Although suckers and humpback chub have different feeding modes—suckers are bottom feeders whereas chub are drift feeders—the sheer numbers of bluehead suckers present in the LCR during spawning season in these years suggests interspecific competition for food could be an important factor affecting humpback chub juvenile growth at times. Recent foodbase research efforts indicate fish production in the mainstem near the LCR may even be limited by the availability of high quality invertebrate prey (Donner, 2011); however, food web structure and the potential for food limitation of humpback chub in the LCR itself have not been studied.

During the 1990s, several investigators documented low invertebrate abundance and biomass in the LCR downstream of Chute Falls relative to both the mainstem Colorado River and also the reach upstream of Chute Falls (Robinson and others, 1996; Haden, unpublished data). Robinson and others (1996) went a step further and also translocated juvenile and yearling humpback chub and yearling bluehead sucker to the reach upstream of Chute Falls to assess whether water quality upstream of Chute Falls represented an acute stress for fish other than speckled dace—dace are common upstream of Chute Falls. These short-term cage experiments (3 days in duration) revealed significantly higher mortality rates for juvenile humpback chub near Blue Springs (at river kilometer 20) relative to other locations (river kilometers 17.5 and 15 and a control reach downstream of Chute Falls at river kilometer 10; Chute Falls is at river kilometer 14.1). There was no difference in mortality rates for yearling humpback chub or bluehead sucker among locations. These authors concluded that food resources and water chemistry were not restricting the distribution of humpback chub and bluehead sucker within the LCR to the segment downstream of Chute Falls. They went on to suggest, “Translocations of fish to the reach [upstream] of Chute Falls, or breaching that barrier, may be feasible management actions to increase available habitat for the endangered humpback chub and other native fishes in the LCR” (Robinson and others, 1996).

The USFWS began translocating juvenile humpback chub to the reach upstream of Chute Falls in 2003. Growth rates for these translocated fish are two times higher than juveniles rearing in the LCR downstream of Chute Falls (Knowledge Assessment, 2012). Since 2003, 1848 juvenile humpback chub have been translocated upstream of Chute Falls, but total abundance in 2011for the translocation segment was only 133. Thus, humpback chub are apparently moving downstream of Chute Falls even though conditions there are extremely favorable for growth.

Patterns of juvenile humpback chub growth rates among habitats could be due to differences in either the quantity or quality of food resources, among other things. Algae biomass and production in the lower LCR segment is low and appears to be limited by rapid marl deposition and low water clarity (Robinson and others, 1996). Indeed, there is a negative feedback between algae growth and marl deposition in carbonate-rich systems like the LCR (Spiro and Pentecost, 1991). Algae uptake of CO_2, which is required for photosynthesis, drives the dissolved inorganic carbon budget for travertine streams out of balance and actually causes precipitation of marl on spatial scales ranging from the microscopic scale (individual algae cells become smothered in marl) to the segment (i.e., lower LCR downstream of Chute Falls; Robinson and others, 1996). Floods that scour the LCR and remove marl may temporarily increase the production of high-quality algae biomass, which then fuels production of the fast growing invertebrate taxa that are the preferred prey items of humpback chub (see Fisher and others, 1982; Cross and others, 2011 for examples of floods stimulating production of fast growing invertebrate taxa). Algae are probably an important component of the LCR food web, but it may not be the only basal resource that fuels production of higher trophic levels. The LCR food web is almost certainly based in part on detritus inputs that are delivered with large floods, as has been observed in the mainstem (Wellard Kelly and others, *in review*; Donner, 2011). The environment for decomposition in the LCR appears favorable (warm temperatures, deep pools that will retain detritus), particularly in relation to mainstem conditions. Large snowmelt floods might deliver large amounts of detrital organic matter that then fuels production of fast growing invertebrate prey.

The quality of food resources could also be affecting humpback chub growth in the LCR. Concentrations of metals and other toxins in food resources, in particular, could be an important determinant of resource quality for chub. High fluxes of selenium have been measured along a primary food web pathway in the mainstem for 4 different segments (river mile 62, 127, 165, and 225) downstream of the LCR (suspended organic matter→filter feeding black flies→ fish; Walters and others, *in prep*). The elevated concentrations of selenium in rainbow trout and speckled dace downstream of the LCR are actually cause for concern because they exceeded the U.S. Environmental Protection Agency (EPA) wildlife warning threshold of 3 μg Se per gram dry weight (EPA, 2004). If inputs of water, sediment, or detritus from the LCR are capable of driving selenium concentrations in the mainstem food web above wildlife warning thresholds, it begs the question of whether selenium or other metals are playing a major role in fish growth, condition, and survival within the LCR? Andrews and others (1995) documented elevated concentrations for a suite of toxic metals (arsenic, copper, mercury, lead, selenium, and zinc) in fish collected from segments of the LCR that are well upstream of the perennial reach in Grand Canyon. Ecotoxicology of the LCR food web clearly warrants further study.

Developing quantitative food webs requires estimates of production (or supply) for each trophic level (i.e., algae production, detritus inputs during floods, invertebrate production, fish production), and also information on feeding habitats of higher trophic levels (that is, invertebrates and fish). Algae production will be estimated by constructing dissolved oxygen budgets, using the methods of Hall and others (2010). Detritus inputs will be estimated by sampling organic matter fluxes during LCR floods. Measurement of organic matter standing stock in both segments will be used to track the fate of new detritus inputs. These measurements of inputs and standing stock will be complemented by decomposition experiments in both locations and across seasons to assess the potential for detritus inputs to be incorporated into the food web. Benthic invertebrate production will be estimated using either the instantaneous growth method or size-frequency method, depending on taxa (Cross and others, 2011). Invertebrate drift rates will also be quantified as an independent estimate of food availability to humpback chub, which are generally considered drift feeders. We will sample the diets of all common species of fish in the LCR on a seasonal basis. Diets of humpback chub will be assessed using non-lethal gastric lavage (Baker and Fraser, 1976). Gastric lavage is not feasible with the native suckers (mortality is extremely high because suckers have a thin-walled digestive tract) or small-bodied fishes (speckled dace and fathead minnow) that are common in the LCR, so we will humanely euthanize up to 30 individuals of each species per site and season to assess feeding habits of other fish species. Estimates of population size for the entire fish assemblage from multiple years of monitoring will be coupled with information on age structure and size-age-weight relationships to estimate fish production using the instantaneous growth rate method (Hayes and others, 2007).

There are two methods for calculating the trophic basis of production for fish—quantitative gut content analysis (Benke and Wallace, 1980) and stable isotope analysis (McCutchan and Lewis, 2002). Trophic basis of production is the proportional contribution of each food resource to fish production. In the case of gut content analysis, assimilation efficiencies of each food resource are used to estimate the relative importance of each food resource in the diet of the fish, thereby accounting for differences in quality/digestibility among different food resources (Cummins, 1973). Algae production, detritus inputs/supply, and invertebrate production estimates are then incorporated to calculate flows from food resources to fish. These calculations yield a rate ($g\ m^{-2}\ y^{-1}$), which represents the flow of carbon from food resources to consumers and is taxon and resource specific. We will extend these flux estimates to include contaminants by measuring contaminant concentrations in food web compartments. Evaluation of contaminants in fish requires muscle plugs, which can be taken from fish without sacrificing the animal, but collecting even a small muscle plug obviously represents a major stressor to individual fish. In FY13, we will assess contaminant levels in all food web compartments including common native fish *other than* humpback chub (i.e., suckers and speckled dace). If contaminant levels in these fish are elevated, we will submit an amendment to our USFWS permit and seek permission to take muscle plugs from humpback chub in FY14 to assess contaminant levels.

Stable isotope analysis can also be used to estimate the trophic basis of production for fish (McCutchan and Lewis, 2002), so long as potential food sources are sufficiently separate in isotope space—that is, food resources have stable isotope signatures that are unique and can be distinguished. Isotope analysis of the food web in the mainstem Colorado River has documented high variability within specific food web compartments (e.g., the carbon isotope signature for algae varies spatially; Shannon and others, 2001) and a general lack of separation among potential carbon sources, making trophic basis of production estimates for fish using stable isotopes infeasible (Shannon and others, 2001; Rosi-Marshall, *unpublished data*). However, we believe stable isotopes may be a useful tool for trophic basis of production calculations within the LCR because of strong gradients in dissolved inorganic carbon within the LCR (Robinson and others 1996). As ground water discharged from springs in the LCR equilibrates with atmospheric conditions, the concentration of dissolved CO_2 decreases (CO_2 is a major component of dissolved inorganic carbon in all streams; Robinson and others, 1996). Algae production, by taking up dissolved CO_2 from the water, also speeds the process of dissolved CO_2 equilibration and decline. Likewise, geomorphic features like Chute Falls, which increase rates of air-water gas exchange (Hall and others, 2012), will also speed the process of CO_2

equilibration. Strong and predictable downstream gradients in dissolved inorganic carbon will cause strong and predictable gradients in algal carbon stable isotope values (Finlay and Kendall, 2007; Kennedy and others, 2005). Kennedy and others (2005) were able to capitalize on similar downstream gradients in algal carbon stable isotope values in a spring-fed stream in Nevada to resolve trophic pathways linking basal resources to two species of endangered fish.

We will take fin clips from humpback chub and other fish in FY13/14, along with collections of food resources (i.e., algae, terrestrial detritus, and invertebrates) and analyze stable isotope ratios of carbon, nitrogen, and sulfur. We will follow the methods of McCutchan and Lewis (2002) to incorporate stable isotope information into our trophic-basis of production calculations. We will update the quantitative food webs developed for the mainstem during the foodbase project (2006-2009; project F:Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and Lower 13.6 km of the LCR, element F.7. Foodbase Monitoring) to describe conditions there; however, updating the mainstem food web will mainly involve new estimates of invertebrate production and invertebrate drift whereas the feeding habits of fishes in the mainstem will not be reassessed. Bioenergetics models will be used to integrate these data and assess the potential for food limitation in both the LCR and the mainstem.

We will measure trace metals (e.g., Cu, Cd, Zn, etc.) as well as Hg and Se in water, organic matter, and organisms in the LCR food web. These data, in combination with the trophic basis of production data will allow us to 1) characterize the extent and magnitude of metal contamination in the LCR; 2) identify those metals posing the greatest risk to LCR fishes; 3) calculate rates ($\mu g\ m^{-2}\ y^{-1}$) of metal flux from food resources to consumers that are taxon and resource specific. This will allow us to quantify important pathways of metal exposure to species of concern like humpback chub. In addition, we will analyze samples for isotopic ratios of selected metals – Cu, Cd, and Zn. Based on previous studies (Cloquet et al., 2008) we expect to see significant fractionation of Zn isotopes between trophic levels, and by extension, perhaps greater fractionations in Cu isotopes, as Cu participates in fractionating redox reactions. Together with the other data gathered in this study, the isotopic fractionations and mass balances should yield insights into the mechanism of biological uptake and transfer among trophic levels.

This project will produce multiple peer-reviewed publications and a master's thesis.
Idaho State University is providing a graduate student stipend/salary in support of this Project Element.

Project Element E.3. Population modeling ($89,500)

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

This project's objectives are to develop integrated statistical models to estimate survival, growth and movement in the LCR and Colorado River portions of the LCR complex. This project will also develop models to test the roles of intraspecific interactions and hydrology in explaining observed juveniles abundance trends over the last decade.

We will use multistate mark-recapture models to estimate survival, growth, and movement within the LCR complex. Multistate mark-recapture models provide a flexible means for estimating transition rates between states which can be defined in many ways. In our model, states will be defined in terms of both location and size allowing us to estimate both movement and growth. Although multistate models are fairly standard in wildlife ecology (Williams and others, 2001), the model we will develop will require new developments to integrate batch (VIE marks) and individual marks (PIT tags) and share information across sampling events. Data collected through project element E.1. will be very important in allowing us to estimate juvenile movement between the LCR and the mainstem with an acceptable level of precision.

We will also develop deterministic models to evaluate the degree to which variation in juvenile abundances and sizes in the LCR can be attributed to LCR hydrology versus intraspecific or interspecific interactions. Our ability to evaluate hypotheses H1-H4 during FY13/14 will be somewhat dependent on LCR hydrology in 2012-2014, when better estimates of juvenile survival and movement between the LCR and NSE study area will be available; however, we will also be able to incorporate existing data into our analyses, particularly FWS and NSE data gathered in 2009-2011.

Prior to 2009, fish under 150 mm were not marked, limiting our ability to track individuals and make direct inferences about movement, growth, and survival. However, catch per unit effort data collected in the LCR over the last decade suggests that there is large variation in size distributions among seasons and years suggesting variable growth and survival and/or movement out of the LCR. Since 2009, fish between 100 mm and 150 mm have begun to be individually marked and fish between 40 mm and 100 mm have received batch marks. Batch marks were applied in all NSE trips and during fall FWS trips (at 1 of 3 camps in 2009 and all 3 camps in following years). NSE trips in July and August also applied a limited number of VIE marks in the lower parts of the LCR in 2009-2011. Extension of marking efforts to smaller fish and increased effort in the mainstem now provides us with the opportunity to better understand variation in early life history and the role that variation in mainstem and LCR conditions plays in early life history variation. The multistate model developed as part of the project element will help us estimate variation in life history parameters more accurately than separate analyses of LCR and mainstem data, while the deterministic model will, at the very least, help to clarify which hypotheses are unlikely and what observations would be needed to distinguish likely hypotheses.

This project will produce at least 2 peer reviewed articles.

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6. Budget

FY 2013

Project Element E.1. July LCR marking		Project Element E.2. Describing the food web structure and the potential for food limitation within the Little Colorado River	
Salaries	$58,600	Salaries	$103,300
Traveling and Training	$0	Traveling and Training	$1,900
Operating Expenses	$8,000	Operating Expenses	$15,000
Logistics	$17,000	Logistics	$17,000
GIS/RS/Electronics support	$34,100	GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$25,000
USGS cooperators	$0	USGS cooperators	$75,000
USGS Burden	$11,700	USGS Burden	$20,000
Total	$129,400	***Total***	$257,200

Project Element E.3. Population Modeling	
Salaries	$63,700
Traveling and Training	$3,800
Operating Expenses	$2,000
Logistics	$0
GIS/RS/Electronics support	0
Cooperators (non-USGS)	$10,000
USGS cooperators	$0
USGS Burden	$10,000
Total	$89,500

FY 2013 Project E. Gross Total: $476,100

FY 2014

Project Element E.1. July LCR marking		Project Element E.2. Describing the food web structure and the potential for food limitation within the Little Colorado River	
Salaries	$54,800	Salaries	$106,400
Traveling and Training	$0	Traveling and Training	$2,000
Operating Expenses	$8,200	Operating Expenses	$15,500
Logistics	$17,500	Logistics	$17,600
GIS/RS/Electronics support	$30,800	GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$25,800
USGS cooperators	$0	USGS cooperators	$77,200
USGS Burden	$15,700	USGS Burden	$23,000
Total	$127,000	***Total***	$267,500

Project Element E.3. Population Modeling	
Salaries	$65,700
Traveling and Training	$3,900
Operating Expenses	$2,100
Logistics	$0
GIS/RS/Electronics support	0
Cooperators (non-USGS)	$10,300
USGS cooperators	$0
USGS Burden	$10,400
Total	$92,400

FY 2014 Project E. Gross Total: $486,900

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

1. Investigators

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Steve Martell, Professor, University of British Columbia

2. Summary

Native fish populations in Grand Canyon are key resources of concern influencing decisions on both the operation of Glen Canyon Dam and non-flow actions. To inform these decisions, it is imperative that accurate and timely information on the status of fish populations, particularly the endangered humpback chub (*Gila cypha*), be available to managers. A suite of adaptive experimental management actions are being contemplated to better understand the mechanisms controlling the population dynamics of native fish and to identify policies that are consistent with the attainment of management goals. The assessments generated from this project provide a baseline from which to assess the effects of implemented experimental actions. This information is therefore crucial to (1) inform the program as to attainment of identified goals, (2) provide baseline status and trend information to be used as a backdrop to further understand mechanisms controlling native and nonnative fish population dynamics, and (3) evaluate the efficacy of particular management policies in attaining program goals. The results of this project are potentially useful in assessing changes to the Federal Endangered Species Act listing status of humpback chub in Grand Canyon.

This project will continue long-term monitoring of fishes and the aquatic foodbase in Glen and Grand Canyons as well as in the lower Little Colorado River. It will provide updated information on

- F1, status and trends of native and non-native fishes in Glen and Grand Canyon (Makinster and others, 2010),
- F2.1, status and trends of the rainbow trout population in the Lees Ferry reach (Makinster and others, 2011) as well as targeted sampling for other nonnative fishes in the Lees Ferry reach (Anderson and others, 2012),
- F2.2, status and trends, and initial response of early life stages of rainbow trout in the Lees Ferry reach (Korman and others, 2011)

- F.2.3, status and trends of angler use, catch rates and total catch of rainbow trout captured in the Lees Ferry recreational fishery (Anderson and others, 2012),
- F.3, estimates of juvenile humpback chub survival rates in the mainstem Colorado River near the confluence with the LCR,
- F.4.1, F.4.2, status and trends, and humpback chub abundance estimates in the LCR, (Coggins and others, 2006; Coggins and Walters, 2009; Clark and others, 2010; Van Haverbeke and others, 2011)
- F.4.3, status and trends of humpback chub abundance upstream of Chute Falls as well as information on humpback chub translocations within the LCR and other tributary streams (Van Haverbeke and others, 2012)
- F.6, information on downstream movement of rainbow trout from the Lees Ferry reach,
- F.7, status and trends of algae production, algae and organic matter biomass, invertebrate production, and invertebrate and organic drift.

3. Background

Long-term monitoring of fishes and aquatic resources in Glen and Grand Canyon is of interest to the Glen Canyon Dam Adaptive Management Program (GCDAMP), a federally authorized initiative to protect and mitigate adverse impacts to the resources downstream from Glen Canyon Dam (GCD). The U.S. Geological Survey's Grand Canyon Monitoring and Research Center (GCMRC) is responsible for long-term fish monitoring for the program, which is implemented in cooperation with the Arizona Game and Fish Department (AGFD), U.S. Fish and Wildlife Service (USFWS), and others. Long-term monitoring establishes a "baseline," through which response of resources to changing management policies or experiments can be interpreted and evaluated (Walters and Holling, 1990). For example, since 1996, a series of experimental high flows have been released from GCD as part of a strategy intended to restore sandbars in Grand Canyon (Melis and others, 2011); several stable-flow tests and localized removal of nonnative fish have been conducted to benefit native fishes (Coggins and others, 2011; Yard and others, 2011). In addition, drought induced warming of the Colorado River that occurred during 2004 and 2005 is thought to have benefitted native fishes (Coggins and others, 2011).

Two recent Environmental Assessments and an associated Biological Opinion, as well as the GCDAMP 2011-2012 Work plan and Budget (Bureau of Reclamation and U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2010; Bureau of Reclamation, 2011; U.S. Fish and Wildlife Service, 2011), mandate monitoring the status and trends of adult humpback chub in the Little Colorado River (LCR) near the confluence, in the mainstem Colorado River (see Mainstem Humpback Chub Aggregation, Project D), and at areas where humpback chub have been translocated. The Biological Opinion defines triggers to determine when nonnative fish control will take place near the LCR. Triggers are related to the abundance of adult and juvenile humpback chub, survival rates of juvenile humpback chub, abundance of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), and river temperature. The following monitoring projects contribute data and information required by the Environmental Assessments and Biological Opinion to determine if elements and conditions of the trigger are met.

Long-term perspective is necessary when evaluating ecosystem change that results from management actions. Changes may take place over a period of years rather than abruptly, hence the critical importance of long-term baseline monitoring. The currently funded monitoring program (Bureau of Reclamation and U.S. Geological Survey Grand Canyon Monitoring and Research Center, 2010) includes two types of monitoring (Walters and others 2012).

1. "Core" monitoring provides annual estimates of net recruitment rates to the adult population of native and nonnative fishes along with basic information on changes in water quality parameters such as temperature and suspended sediment, and biomasses of aquatic foodbase organisms. This "core" program provides information on net recuritment of native and nonnative fishes within about 2-3 years after treatments. Some treatments may affect juvenile life stages, and "core" monitoring does not consider density dependent or environmental conditions outside of the treatment that may affect recruitment.
2. "Initial response" monitoring programs provide short term (seasonal) information on immediate effects of treatments on abundance and survival rates of juvenile fishes. The "initial response" monitoring provides information with which to interpret data gathered later through "core" monitoring and may provide more information concerning cause and effect mechanisms that influence survival and recruitment.

3.1. Scientific Background

Monitoring projects have been designed in anticipation of management actions such as high-flow experiments (HFEs), fall steady flows, and others. These plans are consistent with science plans described in the Science Plans of the Environmental Assessments (EAs) for nonnative fish control and HFEs. Typically, management actions or experimental treatments are considered as annual treatments and it is difficult to discern effects of single flow perturbations like HFEs on biological resources such as adult fish populations. In cases where we are interested in the effect of an HFE on a particular life stage of fish, such as juvenile rainbow trout in Glen Canyon, the Rainbow Trout Early Life Stage Study (RTELSS, F.2.2.) has sufficient resolution to estimate effects of such a high flow. In the case of RTELSS, extra field sampling can be conducted quickly around an HFE to assess short term impacts to juvenile rainbow trout. The Rainbow Trout Monitoring in Glen Canyon Project (Element F.2.1.) will also be able to assess impacts of an HFE to juvenile rainbow trout recruitment at an annual time scale. Responses of juvenile humpback chub in the mainstem Colorado River immediately downstream of the LCR confluence will be assessed by quarterly sampling during FY13/14 as part of Project Element F.4.

The Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam Project (Element F.6.) includes separate contingency plans for marking additional fish after a HFE if necessary. Other fish monitoring projects are assessing impacts on an annual or larger time step, and no additional field work is required. Foodbase Monitoring (Project Element F.7.) may need to add additional drift and benthos samples to bracket any HFE in an attempt to describe short term impacts of the experimental treatment on foodbase resources.

3.2. Management Background

This project directly addresses the following Strategic Science Questions (SSQs), Core Monitoring Information Needs (CMINs), and Research Information Needs (RINs) previously identified by the Glen Canyon Dam Adaptive Management Program (GCDAMP).

- **Goal 2:** Maintain or attain a viable population of existing native fish, remove jeopardy for humpback chub and razorback sucker, and prevent adverse modification to their critical habitats.
- **Goal 4:** Maintain a naturally reproducing population of rainbow trout above the Paria River, to the extent practicable and consistent with the maintenance of viable populations of native fish.

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

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

In March 2011, the Secretary's Designee, Assistant Secretary for Water and Science, identified that the first priority was compliance with the Endangered Species Act, followed by sediment, with the third priority being science on both non-native control and the recreational trout fishery. These monitoring projects contribute to improved understanding of humpback chub, rainbow trout, and their interactions.

3.3. Strategic Science Questions

Primary SSQ addressed:

- **SSQ 1-1.** To what extent are adult populations of native fish controlled by production of young fish from tributaries, spawning and incubation in the mainstem, survival of young-of-year and juvenile stages in the mainstem, or by changes in growth and maturation in the adult population as influenced by mainstem conditions?
- **SSQ 1-2.** Does a decrease in the abundance of rainbow trout and other cold- and warm water nonnatives in Marble and eastern Grand Canyons result in an improvement in the recruitment rate of juvenile humpback chub to the adult population?
- **SSQ 3-6.** What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?

Additional SSQs addressed:

- **SSQ 1-3.** Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and, if so, during what life stages? To what extent do Glen Canyon immigrants support the population in Marble and eastern Grand Canyon?
- **SSQ 5-6.** Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?

- **SSQ 1-4.** Can long-term decreases in abundance of rainbow trout in Marble and eastern Grand Canyons be sustained with a reduced level of effort of mechanical removal or will recolonization from tributaries and from downstream and upstream of the removal reach require that mechanical removal be an ongoing management action? This question also applies to future removal programs targeting other nonnative species.
- **SSQ 1-8.** How can native and nonnative fishes best be monitored while minimizing impacts from capture and handling or sampling?
- **SSQ 5-4.** What is the relative importance of increased water temperature, shoreline stability, and food availability on the survival and growth of YoY and juvenile native fish?
- **SSQ 5-6.** Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?

The GCDAMP Science Advisors articulated the following summary science questions addressed by this project:

- **SA 1.** What are the most limiting factors to successful humpback chub adult recruitment in the mainstem: spawning success, predation on young of year and juveniles, habitat (water, temperature), pathogens, adult maturation, food availability, competition?
- **SA 2.** What are the most probably positive and negative impacts of warming the Colorado River on humpback chub adults and juveniles?

Information Needs Addressed

- **CMIN 2.1.2.** Determine and track recruitment of all life stages, abundance, and distribution of humpback chub in the LCR.
- **CMIN 2.4.1.** Determine and track the abundance and distribution of nonnative predatory fish species in the Colorado River.
- **CMIN 2.6.1.** Determine and track the abundance and distribution of flannelmouth sucker, bluehead sucker, and speckled dace populations in the Colorado River ecosystem.
- **CMIN 4.1.1.** Determine annual population estimates for age 2+ rainbow trout in the Lees Ferry reach
- **CMIN 4.1.2.** Determine annual proportional stock density of rainbow trout in the Lees Ferry reach.
- **CMIN 4.1.4.** Determine annual growth rate, standard condition (Kn), and relative weight of rainbow trout in the Lees Ferry reach.
- **RIN 2.2.2.** Determine if a population dynamics model can effectively predict response of native fish under different flow regimes and environmental conditions.
- **RIN 2.2.8.** What combination of dam release patterns and nonnative fish control facilitates successful spawning and recruitment of humpback chub in the Colorado River ecosystem?
- **RIN 2.4.2.** Determine if suppression of nonnative predators and competitors increases native fish populations.
- **RIN 2.4.3.** To what degree, which species, and where in the system are exotic fish a detriment to the existence of native fish through predation or competition?

- **RIN 2.4.4.** What are the target population levels, body size, and age structure for nonnative fish in the Colorado River ecosystem that limit their levels to those commensurate with the viability of native fish populations?
- **RIN 4.1.1.** What is the target proportional stock density (that is, tradeoff between numbers and size) for rainbow trout in the Lees Ferry reach?
- **RIN 4.2.1.** What is the rate of emigration of rainbow trout from the Les Ferry reach?
- **RIN 4.2.2.** What is the most effective method to detect emigration of rainbow trout from the Lees Ferry reach?
- **RIN 4.2.3.** How is the rate of emigration of rainbow trout from the Lees Ferry reach to below the Paria River affected by abundance, hydrology, temperature, and other ecosystem processes?
- **RIN 4.2.5** To what extent is there overlap in the Colorado River ecosystem below the Paria River of RBT habitat and native fish habitat?
- **EIN 2.1.1** How does the abundance and distribution of all size classes of HBC in the LCR and mainstem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?
- **EIN 2.1.2** How does the year class strength of HBC (51–150 mm) in the LCR and mainstem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?
- **EIN 2.4.1** How does the abundance and distribution of nonnative predatory fish species and their impacts on native fish species in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?
- **EIN 2.6.1** How does the abundance, distribution, recruitment and mortality of flannelmouth sucker, bluehead sucker and speckled dace populations in the Colorado River ecosystem change in response to an experiment performed under the Record of Decision, unanticipated event, or other management action?

4. Proposed Work

The majority of the work proposed here has been described previously in documents already vetted by the GCDAMP. Rather than merely copy from these sources, we have instead provided brief summaries of ongoing projects and referenced the relevant sections of the original documents. For those projects where expanded or new work is being proposed, more detailed information in the form of background, rationale, and methods is provided as needed.

4.1. Project Elements

Project Element F.1. System Wide Electrofishing ($216,900)

Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department
William Persons, Fishery Biologist, USGS/GCMRC

Annual monitoring of native and nonnative fish in the main stem Colorado River has been ongoing since 2000 (Makinster and others, 2010). These efforts rely upon boat-operated electrofishing to provide information on status and trends of native and nonnative fish between Lees Ferry and Lake Mead. Sampling consisted of two annual spring electrofishing trips during

2002-2010, except during 2007 when a spring trip and a fall trip were conducted. During 2011 and 2012 a single annual spring trip was conducted. Adult humpback chub are generally not vulnerable to electrofishing; therefore they are sampled in Project D. Two annual springs trips are planned for 2013-14. Data collected from this project are used to provide trout relative abundance estimates which, in turn, may be used as part of the suite of triggers identifying when to implement mechanical removal of nonnative fish to protect humpback chub (Bureau of Reclamation, 2011). The project also uses catch per unit effort indices to track relative status and trends of most common native and nonnative fish. This project includes sampling downstream from Diamond Creek annually.

This project will produce trip and annual reports.

Project Element F.2. Glen Canyon Monitoring ($263,800)

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

Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department
Mike Anderson, Arizona Game and Fish Department
William Persons, Fishery Biologist, USGS/GCMRC

The importance of the Lees Ferry rainbow trout fishery as a valuable recreational resource is recognized by the GCDAMP. Monitoring the trout fishery and evaluating responses of the rainbow trout population in Glen Canyon to GCD operations is also critical to the Adaptive Management Program (AMP). The fishery is regulated by biotic and abiotic mechanisms that may in turn be affected by the operations of GCD. The monitoring of basic fish population elements, including relative abundance, size composition, distribution, and recruitment of native and nonnative fish, provides the information necessary to assess the status of these resources and to inform the GCDAMP.

Electrofishing has been used to sample the fish community in Glen Canyon since the early 1980s (Maddux and others, 1987). Standardized monitoring using electrofishing was initiated in 1991 and has been used since that time to provide data to evaluate the response of the rainbow trout population to GCD dam operations (McKinney and others, 2001; Makinster and others, 2011). The sampling program underwent refinements following protocol evaluation panels (PEPs) in 2000 and 2009 that provided independent, external scientific reviews of monitoring protocols (Anders and others, 2001; Bradford and others, 2009). The project, as described in the FY11/12 Work Plan (BIO 4.M2.11, 12), will conduct three trips in FY12 that each sample 36 random sites stratified longitudinally by river mile and by shoreline type. This design is planned to continue in FY13/14.

The 2009 PEP recommended that the Lees Ferry rainbow trout monitoring project be expanded to include an invasive fish surveillance and detection program at sites where nonnative fish are most likely to be captured, including the slough at RM -12, warm spring inputs, and immediately downstream of the dam. This project was initiated in 2010, and 15 sites were surveyed for warm water nonnative fish in Glen Canyon. The objective is to provide an early detection system for warmwater nonnative fish species that may pass through the GCD turbines or be otherwise introduced into the area.

During 2010 and 2011 surveys detected smallmouth bass (*Micropterus dolomieu*), walleye (*Sander vitreus*), and bluegill sunfish (*Lepomis macrochirus*) (Bunch and others, 2012, Hilwig and Foster, 2010). Sampling will be conducted as part of the Rainbow Trout Monitoring in Glen Canyon Project to save costs.

This project will produce annual stock assessment reports showing status and trends of rainbow trout relative abundance, size distribution, and condition factor, in the Lees Ferry reach by size class. Information on angler use, harvest, and attitudes is included in this report, as well as information on invasive fish surveillance and detection sampling.

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

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

This project was initiated to assess the response of early life stages of rainbow trout in the Lees Ferry tailwater to experimental nonnative fish suppression flows in years 2003-2005 (Korman, 2009). Continued sampling using the same methods described in the Monitoring Lees Ferry Fish project's (BIO 4.M2.11, 12) Early Life History Monitoring element in the FY11/12 Work Plan, has provided information on the effects of other flow manipulations, such as the high flow event of 2008 and the steady equalization flows of 2011 (Korman and others, 2011). Winter and early spring redd surveys provide information on the magnitude of spawn and the effects of flows on incubation mortality. Electrofishing of nearshore habitat in the summer and fall provides information on recruitment, survival, and growth of juvenile fish. Whereas the Rainbow Trout Monitoring in Glen Canyon Project (Project Element F.2.1.) monitors relative abundance of young-of-the-year rainbow trout in the fall, this project provides "initial response" information about survival rates of age-0 rainbow trout, and provides insight into how early rainbow trout life stages are affected by their density.

This project will produce Reports presenting annual results in context of previous results, and relating early rainbow trout survival to dam operations.

Project Element F.2.3. Lees Ferry Angler Surveys

Michael C. Anderson, Fishery Biologist, Arizona Game and Fish Department
Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department
William Persons, Fishery Biologist, USGS/GCMRC

Rainbow trout (*Oncorhynchus mykiss*) were initially stocked in the Colorado River below Glen Canyon Dam (GCD) in 1964. Operation of Glen Canyon Dam affects the ecology of rainbow trout and the aquatic food base in the Lees Ferry reach (McKinney and others, 1999, 2001). The Lees Ferry recreational fishery was recognized as a resource of concern in the Operation of Glen Canyon Dam Final Environmental Impact Statement (U.S. Department of the Interior (DOI), 1995), which concluded: "Glen Canyon Dam Adaptive Management Program (GCDAMP) goals for the trout fishery are to provide a recreational resource while maintaining and conserving native fish in Grand Canyon".

Angler surveys have been collected consistently at the Lees Ferry boat ramp since 1991. Survey methods are described in Anderson and others, 2012. Individual angler effort and catch are used to estimate annual angler use, catch rates and total angler catch and harvest at Lees

Ferry. A series of attitude questions will also be asked of anglers. This project will incorporate results into the annual report prepared as part of Project Element F2.1.

Project Element F.3. Mainstem Monitoring of Native and Nonnative Fishes Near the LCR Confluence; Juvenile Chub Monitoring ($464,000)

Mike Yard, Fishery Biologist, USGS/GCMRC
Josh Korman, President, Ecometric Research, Inc.
D.R. VanHaverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department

This project will estimate juvenile humpback chub survival rates, and will estimate rainbow trout and brown trout abundance near the confluence of the mainstem Colorado River and the LCR. Obtaining rainbow and brown trout abundance estimates between RM 63–64.5 were identified as necessary activities in the 2011 Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam and associated Biological Opinion (Bureau of Reclamation, 2011). The metrics are included in the suite of triggers identifying when to implement mechanical removal of nonnative fish to protect humpback chub. Continued annual assessments of juvenile humpback chub survival rates and abundance in the mainstem using methods developed in the Near Shore Ecology Study (B. Pine, *pers. Comm.;* see also Bio 2.R15.11, 12 in the FY11/12 Work Plan) will provide key metrics by which management actions such as rainbow trout removal will be evaluated.

This project will result in annual reports with juvenile humpback chub survival rates and recommendations for future sampling, and peer reviewed publication relating humpback chub survival rates and management activities.

Project Element F.4. Little Colorado River Monitoring ($811,200)

LCR monitoring consists of three primary elements that provide information on status and trends of native and nonnative fishes in the LCR. All LCR monitoring projects provide data for use in the Age-Structured-Mark-Recapture Model (ASMR) as well as information required in the 2011 Biological Opinion. These projects also include monitoring external parasites on native and non-native fishes.

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. Van Haverbeke, Fishery Biologist, U.S. Fish and Wildlife Service
William Persons, Fishery Biologist, USGS/GCMRC

Spring and fall closed population abundance estimates provide annual estimates of abundance of adult humpback chub ($\geq$ 150 mm and $\geq$ 200 mm total length(TL)), and during some years provides abundance estimates of other native fishes (Coggins and others, 2006; Coggins, 2007; Van Haverbeke, 2010). The project also marks juvenile humpback chub (< 100 mm TL) with Visible Implant Elastomer tags in the fall to assist the Natal Origins Project (Project Element D.1.1) This is an ongoing project since 2000 (see BIO 2.m.1.11, 12 in FY11/12 Work Plan) and the monitoring was identified as a necessary component in the 2011 Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam and associated Biological Opinion (Bureau of Reclamation, 2011). Sampling is conducted by nine biologists at three camps during four annual trips. Logistics costs include helicopter and food costs.

Reports expected from this project are annual reports provided to GCMRC with spring and fall abundance estimates of humpback chub in the lower 13.6 km of the LCR. In addition, a draft translocation plan for Grand Canyon has been developed by the U.S. Fish and Wildlife Service and Grand Canyon National Park (Translocation and Refuge Framework for Humpback Chub (*Gila cypha*) in Grand Canyon). The report is being reviewed by the two agencies and by GCMRC prior to further external peer review. We expect the report to be finalized by mid-2013.

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

Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department
William Persons, Fishery Biologist, USGS/GCMRC

This program, established by the Arizona Game and Fish Department in 1987, has operated continuously, except in 2000 and 2001 (Coggins and others, 2006); Arizona Game and Fish Department, unpub. data, 2011; see also BIO 2.M1.11, 12 in the FY11/12 Work Plan). The program produces annual assessments of the relative abundance (that is, catch-per-unit effort) of all size classes of humpback chub, flannelmouth suckers, bluehead suckers, speckled dace, and a host of nonnative fish in the lower 1,200 m of the LCR. Data are collected during a 30- to 40-day period in spring (April and May) using hoop nets set in standardized locations throughout the reach. Results of this monitoring provide independent comparisons to humpback chub abundance trends generated by the ASMR model and Project element 2.1. The statistical power of this portion of the monitoring program has not yet been assessed, but statistically significant differences in relative abundance are apparent in current data.

Reports to be expected from this project are annual reports with results of monitoring of the lower 1.2 km of the LCR.

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

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

Efforts to translocate humpback chub upstream of Chute Falls on the Little Colorado River and to monitor their status have been ongoing annually since 2003 (see BIO 2.M3.11, 12 in the FY11/12 Work Plan). Approximately 1,850 juvenile (80 – 130 mm TL) humpback chub have been translocated upstream of Chute Falls to date. Beginning in 2006, two-pass mark recapture population estimates of humpback chub were conducted upstream of Chute Falls and Lower Atomizer Falls at 13.57 km. Early results suggested rapid growth of translocated fish, although few adult humpback chub ($\geq$ 200 mm) have been caught upstream of Chute Falls since 2009. The project is identified as a Conservation Measure in the 2011 Biological Opinion. Translocations to Shinumo Creek and Havasu Creek and the continued maintenance of a refuge population of humpback chub at Dexter National Fish Hatchery and Technology Center are also prescribed in the Biological Opinion, but funding and work activities occur largely outside of GCMRC. There is a need to continue coordinating the various translocation efforts and to conduct an independent peer-review of results to guide future management activities.

A report describing results of translocation and monitoring activities is expected out of this project

Project Element F.4.4. PIT Tag antenna monitoring

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

This has been an ongoing effort since 2009 (see BIO 2.R13.11, 12 in the FY11/12 Work Plan), with lapses and equipment failures during parts of 2010 and 2011. The project has installed a PIT tag antenna system in the LCR approximately 2 km upstream from the confluence with the mainstem Colorado River. The antenna system reads PIT tags from fish as they pass the tag station, and data can be used within ASMR and to provide information on timing of movement and survival of PIT tagged native fishes. Between January 1, 2012 and April 27, 2012, 1,576 unique PIT tagged humpback chub were detected by the antenna. An agreement is in place with Dr. Dana Winkelman, Colorado State University, and a graduate student, Kristen Pearson, for FY12 and FY13 to:

1. Assemble all available capture, recapture, and remote PIT tag detections, and integrate them to estimate abundance, survival, and movement probabilities by life stage.
2. Estimate abundance, survival, and movement probabilities by life stage, ignoring detection data from the PIT tag arrays, and compare precision with the integrated data.
3. Estimate survival and movement probabilities by life stage, using just initial capture data with remote detections of tagged fish from the PIT tag arrays (i.e., ignoring physical recaptures), and compare precision and estimability of parameters with the integrated analysis.
4. Use simulation, based on the parameter estimates from the previous analyses, as well as cost information for capturing fish, to identify an optimal allocation of capture effort combined with PIT tag array detections.
5. Empirically evaluate detection probabilities of PIT tags in the LCR.

Expected Products for this project is a Master's thesis and at least one peer-reviewed publication.

Project Element F.5. Stock Assessment and Age Structured Mark Recapture Model humpback chub abundance estimates ($20,200)

Charles Yackulic, Research Statistician, USGS/GCMRC
Steve Martell, Professor, University of British Colombia

This project will provide essential updates of population size composition and capture rates of humpback chub and other Grand Canyon fish to the GCDAMP and other managers. This work was previously described in the FY11/12 Work Plan as part of two projects: Stock Assessment of Grand Canyon Native Fish (BIO 2.R7.11, 12) and Biometrics and General Analysis (BIO 2.R19.11, 12). Reporting will include periodic updates on the status and trends of populations of humpback chub and other native fishes in Grand Canyon and retrospective time series of native fish populations to allow for comparison with previous years' data. The assembled humpback chub data from the Grand Canyon fish monitoring projects will be incorporated into updates of the ASMR model approximately every 3 years. Providing ASMR estimates is called for in the Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam and associated Biological Opinion.

Products that will come from this project are a report with estimates of humpback chub abundance and description of ASMR or revised length-based model.

Project Element F.6. Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam/Natal Origins ($276,000)

Josh Korman, President, Ecometric Research Inc.
Mike Yard, Fishery Biologist, USGS/GCMRC
Charles Yackulic, Research Statistician, USGS/GCMRC
Aaron Bunch, Fishery Biologist, Arizona Game and Fish Department

This project as described in the FY11/12 Work Plan (BIO 2.E18.11, 12), has been modified and expanded. This study is an experimental research project to determine if Glen Canyon is the natal source of trout emigrating into the downstream reaches of Marble and Grand Canyons (Korman and others, 2011). Information from this project will help resolve some of the uncertainties about prescribing nonnative fish control activities in locations that are geographically distant to the area of concern (Little Colorado River confluence area). This project is based on existing information (Coggins, 2008; Coggins and others, in review) that concludes that rainbow trout reared in the Lees Ferry reach of the Colorado River (Glen Canyon Dam to Lees Ferry) move out of that reach under some conditions.

The central objectives of this research project are to (1) determine the natal origins of rainbow trout in the Marble Canyon/LCR confluence area via a large-scale mark and recovery effort, (2) to evaluate the linkage between trout populations in the Lees Ferry reach and Marble Canyon, and (3) assess the efficacy of Paria to Badger Reach removal efforts. Response of juvenile native fish to changes in trout density near the LCR area resulting from removal and experimental flow treatments will be studied.

This project also provides logistical and field support for Project H "*Identifying the main drivers of rainbow trout growth, population size, demographics and distribution in Glen and Marble Canyon*" (Study Elements: H.2., H.3., and H.5.), and project element F.3., Mainstem monitoring of native and nonnative fishes near the LCR confluence -Juvenile Chub Monitoring (as per Environmental Assessment 2011).

Reports expected from this project are annual and final reports and possible peer-reviewed publications.

Project Element F.7. Foodbase Monitoring ($271,800)

Monitoring of the aquatic foodbase in the Colorado River below Glen Canyon Dam is an ongoing project. The activities described in the FY11/12 Work Plan (BIO 1.M1.11, 12) and being conducted in FY12 include estimating algae production, algae and organic matter biomass, invertebrate production, and invertebrate and organic drift at two sites: Lees Ferry and Diamond Creek. This work will continue in FY13 and FY14 with the modifications and additions described below.

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

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

The two focal fish species for the Glen Canyon Dam Adaptive Management Program—humpback chub and rainbow trout—are both drift feeders. Invertebrate drift measurements are easy to collect relative to benthic invertebrate samples, and these data are much less variable than benthic invertebrate data. A key component of long-term foodbase monitoring will therefore involve characterizing spatial and temporal variation in invertebrate drift. Invertebrate monitoring programs typically involve benthic sampling, but benthic sampling in the Colorado River is extremely challenging because of swift currents and hydropeaking. Thus, the proposed approach to monitoring overcomes these challenges by focusing on a foodbase metric—invertebrate drift—that might actually be more meaningful to focal drift-feeding fish species relative to benthic invertebrate abundance. However, not all invertebrates that are drifting will be available to drift feeding fish. For example, turbidity combined with small overall invertebrate size may mean that only a small portion of the drift is available to humpback chub or rainbow trout. Understanding what spatial and temporal variation in drift rates means to food availability for fishes will therefore require simultaneous sampling of invertebrate drift and fish feeding habits (see Project H). Long-term monitoring of drift will occur at two accessible sites—Glen Canyon and Diamond Creek. Collections will occur in the thalweg. Drift nets will be vertically integrated throughout the water column for 5 minutes. Monitoring will include three midday drift collections and three collections after dark in order to characterize temporal variability in drift. Six samples will be collected every six weeks from each location.

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

There is a consistent relation between the production of benthic insects in a river reach and the total flux of insects that emerge from a river reach (Statzner and Resh, 1993; Gratton and VanderZanden, 2009). Thus, tracking the flux of emergent insects might represent a useful surrogate for traditional benthic invertebrate monitoring programs. However, insect emergence is temporally variable and characterized by pronounced 'hatches'. Given large spatial variation in water temperatures and resource quality across the 390 km of Colorado River, one might expect large temporal variation in the timing of these hatches. Further, midges and blackflies have multiple emergences per year. Spatial variation in emergence timing makes it unlikely that a single science river trip per year could adequately capture peak emergence among sites in Grand Canyon. We will overcome these challenges by using a previously untapped pool of citizen scientists—professional river guides. We will equip up to 10 guides with light traps to collect samples of flying insects from April through October. Light traps will catch both flying aquatic and terrestrial insects. Thus, light trap data might also be useful for long-term monitoring of terrestrial insect populations. Each guide will be equipped with two light traps. One will be deployed near the day's high water line and the second trap will be deployed near the 45,000 cfs stage elevation. Light traps will be deployed within an hour after sunset and will stay on for one hour. Samples will be preserved in ethanol. Interpretive materials and handouts will be provided to guides to facilitate outreach with the public. Guides will collect light trap samples in Glen Canyon during the evening prior to their launch downstream. Emergent aquatic insects represent an important subsidy that sustains animals populations in riparian zones adjacent to rivers (Sabo and Powers 2002; (Sabo and others, 2002; Gratton and Vander Zanden, 2009). These data can also be used to better understand the potential importance of aquatic-terrestrial linkages in the Colorado River below Glen Canyon Dam.

We will also sample emergent insects in Glen Canyon and Diamond Creek in association with regular monitoring trips to these accessible sites. Emergence monitoring at these sites will involve additional gear types. Specifically, we will use sticky traps, similar to fly paper, to characterize insect abundance over longer-time scales than is possible with lights traps. Plexiglass sheets (0.1 m^2) coated with Tangelfoot and suspended from a garden post temporarily placed along nearshore areas will be used to catch emergent insects. These traps will be deployed for up to a week. The timing of peak emergence is not known precisely, but conversations with river and fishing guides suggests that peak emergence occurs between March and June. Once we have a better idea of emergence timing, future emergence monitoring at Lees Ferry and Diamond Creek may be reduced and just focus on key months when emergence is high.

Samples of emergent insects are far easier and quicker to process than traditional benthic samples because there is little organic matter or debris on emergence samples and winged adults are easier to identify than aquatic larvae. This is an important consideration in the selection of monitoring metrics because a program that emphasizes samples that are quick and easy to process is more likely to provide timely information to decision makers relative to a program that emphasizes samples that are difficult and time-intensive to process.

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

Algae is the crank that turns the Colorado River food web in Glen Canyon and Grand Canyon. We will continuously monitor algae primary production at 5 locations (Glen Canyon, river mile 30, river mile 61, river mile 87, and river mile 225) using methods described in (Hall and others, 2010). Yard (2003) predicts large variation in algae growth among reaches, especially due to differences in canyon orientation, channel depth, and turbidity. Continuous estimates of primary production at these five sites will be used to evaluate the predictions of Yard (2003). These monitoring data will also be used to parameterize a mechanistic model of primary production that can be used to make predictions about algae growth response to dam operations.

Project Element F.7.4. Benthic Algae and Invertebrate Biomass

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

Traditional benthic sampling of invertebrates is another important part of our foodbase monitoring strategy because it will provide information on the non-insect taxa that tend to dominate production budgets, but do not emerge or drift, and would therefore be missed using just drift and emergence measurements (Cross and others, 2011). However, directly sampling benthic habitats in the Colorado River is extremely difficult and time intensive, which limits the utility of benthic biomass as a monitoring metric. For example, hydropeaking constrains benthic sampling to a brief window of low water that varies in timing throughout the canyon (i.e., low water at river mile 30 is typically in the late morning while low water at river mile 61, near the

LCR confluence, occurs in the middle of the night), which greatly limits the area of habitat that can be sampled in a day.

We will conduct traditional benthic sampling once per year. Further, we will conduct this annual synoptic monitoring at a time of year when discharge is low (i.e., spring) to maximize our ability to sample benthic habitats. One objective of annual benthic sampling is detecting new species of invertebrates that might become established in Grand Canyon in the future. As such, benthic habitats throughout Grand Canyon will be sampled using river trips. We will sample all habitat types, not just the most productive ones (i.e., cobble), in order to develop habitat-weighted estimates of algae and invertebrate abundance, biomass, and composition that can be compared among years. These data will provide a comprehensive snapshot of the benthic environment in Grand Canyon that can be repeated annually and will allow for detection of major trends such as the arrival of new invertebrate taxa, or changes in the diversity or richness of the invertebrate assemblage. A detailed benthic sampling design that incorporates randomly selected sites will be developed in consultation with GCMRCs research statistician to ensure the scope of inference for these samples is canyon-wide.

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6. Budget

FY 2013					
Project Element F.1. Mainstem spring/nonnative fish monitoring		Project Element F.2. Glen Canyon monitoring		Project Element F.3. Mainstem monitoring of native and nonnative fishes near the LCR confluence	
Salaries	$7,800	Salaries	$38,400	Salaries	$49,900
Traveling and Training	$1,900	Traveling and Training	$3,400	Traveling and Training	$0
Operating Expenses	$8,000	Operating Expenses	$4,300	Operating Expenses	$9,000
Logistics	$59,600	Logistics	$23,500	Logistics	$178,100
GIS/RS/Electronics support	$22,700	GIS/RS/Electronics support	$22,800	GIS/RS/Electronics support	$11,400
Cooperators (non-USGS)	$103,000	Cooperators (non-USGS)	$157,000	Cooperators (non-USGS)	$177,000
USGS cooperators	$0	USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$13,900	USGS Burden	$14,400	USGS Burden	$38,600
Total	$216,900	***Total***	$263,800	***Total***	$464,000
Project Element F.4. LCR monitoring		Project Element F.5. Stock assessment and structured mark recapture model humpback chub abundance estimates		Project Element F.6. Detection of rainbow trout movement from upper Colorado	
Salaries	$45,200	Salaries	$7,700	Salaries	$25,100
Traveling and Training	$0	Traveling and Training	$0	Traveling and Training	$0
Operating Expenses	$23,000	Operating Expenses	$0	Operating Expenses	$50,000
Logistics	$122,700	Logistics	$0	Logistics	$96,500
GIS/RS/Electronics support	$56,900	GIS/RS/Electronics support	$11,400	GIS/RS/Electronics support	$11,400
Cooperators (non-USGS)	$521,000	Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$67,000
USGS cooperators		USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$42,400	USGS Burden	$1,100	USGS Burden	$26,000
Total	$811,200	***Total***	$20,200	***Total***	$276,000
Project Element F.7. Foodbase monitoring					
Salaries	$159,900				
Traveling and Training	$3,400				
Operating Expenses	$5,000				
Logistics	$26,700				
GIS/RS/Electronics support	$11,400				
Cooperators (non-USGS)	$37,000				
USGS cooperators	$0				
USGS Burden	$28,400				
Total	$271,800				
FY 2013 Project F. Gross Total: $2,323,900					

FY 2014					
Project Element F.1. Mainstem spring/nonnative fish monitoring		Project Element F.2. Glen Canyon monitoring		Project Element F.3. Mainstem monitoring of native and nonnative fishes near the LCR confluence	
Salaries	$8,000	Salaries	$39,600	Salaries	$51,400
Traveling and Training	$2,000	Traveling and Training	$3,500	Traveling and Training	$0
Operating Expenses	$8,200	Operating Expenses	$4,400	Operating Expenses	$9,300
Logistics	$61,400	Logistics	$24,200	Logistics	$183,400
GIS/RS/Electronics support	$20,500	GIS/RS/Electronics support	$20,600	GIS/RS/Electronics support	$10,300
Cooperators (non-USGS)	$106,100	Cooperators (non-USGS)	$161,800	Cooperators (non-USGS)	$182,300
USGS cooperators	$0	USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$17,700	USGS Burden	$18,000	USGS Burden	$42,400
Total	$223,900	***Total***	$272,100	***Total***	$479,100
Project Element F.4. LCR monitoring		Project Element F.5. Stock assessment and structured mark recapture model humpback chub abundance estimates		Project Element F.6. Detection of rainbow trout movement from upper Colorado	
Salaries	$46,500	Salaries	$8,000	Salaries	$25,800
Traveling and Training	$0	Traveling and Training	$0	Traveling and Training	$0
Operating Expenses	$23,700	Operating Expenses	$0	Operating Expenses	$51,500
Logistics	$126,500	Logistics	$0	Logistics	$99,500
GIS/RS/Electronics support	$51,400	GIS/RS/Electronics support	$10,300	GIS/RS/Electronics support	$10,300
Cooperators (non-USGS)	$495,400	Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$69,000
USGS cooperators	$0	USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$50,400	USGS Burden	$2,500	USGS Burden	$29,000
Total	$793,900	***Total***	$20,800	***Total***	$285,100
Project Element F.7. Foodbase monitoring					
Salaries	$164,700				
Traveling and Training	$3,500				
Operating Expenses	$5,200				
Logistics	$27,500				
GIS/RS/Electronics support	$10,300				
Cooperators (non-USGS)	$38,100				
USGS cooperators	$0				
USGS Burden	$30,900				
Total	$280,200				
FY 2014 Project F. Gross Total: $2,355,100					

Project G.
Interactions between Native Fish and Nonnative Trout

1. Investigators

David Ward, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Mike Yard, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
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David Speas, Fishery Biologist, Bureau of Reclamation

2. Project Summary

This project will evaluate impacts of rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*) on humpback chub (*Gila cypha*) in both laboratory and field settings. Laboratory studies will be used to isolate confounding variables and quantify relative competition and predation impacts of rainbow and brown trout on humpback chub under varying environmental conditions. Results of laboratory tests will then be used in conjunction with data from long-term monitoring to model population level impacts of trout on humpback chub. The field study will remove brown trout by electrofishing in and around Bright Angel Creek and subsequently evaluate impacts of brown trout removal on native fish populations. Combining laboratory studies, field studies, monitoring efforts, and modeling will allow researchers to understand how predation and competition by rainbow and brown trout impact humpback chub at various life stages and at population level. This will allow managers to improve management actions designed to conserve Colorado River native fishes.

3. Background

Continued decline of native fish populations in the southwestern United States is largely attributed to interactions with invasive aquatic species (Minckley and Marsh, 2009; Tyus and Saunders, 2000). Repeated studies demonstrate the inability of native fishes to persist in environments where nonnative fish have become established (Marsh and Pacey, 2005). Diet studies of rainbow and brown trout collected from the confluence of the Little Colorado and Colorado Rivers, indicate these species do consume native fish (Yard and others, 2011), but population level impacts are difficult to assess because predation vulnerability is known to change with turbidity (Yard and others, 2011), fish size, and water temperature (Ward and others, 2002; Ward and Bonar, 2003; 2011 GCMRC knowledge assessment workshop presentations). Competitive interactions with introduced trout can also impact native fishes (Robinson and others, 2003), but the extent to which these interactions affect humpback chub populations in the Grand Canyon is unknown. Understanding the effects of predation and competition by trout on endangered humpback chub is critical in evaluating management options aimed at preservation of native fishes in Grand Canyon and was identified as a critical information need at recent Knowledge Assessment Workshops (GCMRC and Cooperator presentations, 2011-2012).

Many key questions related to native southwestern fishes' recruitment and survival remain unanswered because of the cost and difficulties of conducting field studies in remote environmental settings like Grand Canyon and in isolating confounding factors present in natural systems. This project introduces a new laboratory component to Grand Canyon fish research that augments existing Colorado River field based data collection capabilities. In this part of the project, researchers will conduct studies on stream dwelling organisms in a controlled laboratory setting. This new capability will allow researchers to quickly and cost-effectively quantify relative impacts of rainbow and brown trout competition and predation on humpback chub, which can then be extrapolated to population level responses using long-term monitoring data.

The second part of the project is to evaluate the effects of brown trout on native fish in a field setting. Brown trout are known to suppress growth and movement of other fish species (McHugh and Budy, 2006) and are much more piscivorous on juvenile native fishes in Grand Canyon than rainbow trout (Yard and others, 2011). The highest catch rates of brown trout in Grand Canyon are found in the Colorado River near the confluence of Bright Angel Creek (Makinster and others, 2010), and in Bright Angel Creek itself, with densities as high as 30 fish per 100 meters (National Park Service data). Large numbers of juvenile chub and suckers are known to exit the LCR each spring (Robinson and others, 1998), yet relatively few juvenile humpback chub are captured in the mainstem Colorado River downstream of Bright Angel Creek. Dispersal of juvenile humpback chub into downstream areas of Grand Canyon may be limited by brown trout inhabiting the area around Bright Angel Creek. If this is the case, then management efforts targeted to reduce brown trout predation near Bright Angel Creek may have positive benefits for downstream dispersal and recruitment of juvenile humpback chub. Following consultation with the tribes, we will apply an experimental treatment and remove brown trout from the area in and around Bright Angel Creek to evaluate this hypothesis. If effective, mechanical removal of brown trout from Bright Angel Creek and from the mainstem Colorado River surrounding Bright Angel Creek could be applied as a long-term management action to increase habitat for native fishes and reduce predation on these species.

3.1. Scientific Background

Endangered humpback chub, endemic to the Colorado River basin, have declined in both abundance and distribution due to the introduction of nonnative species and alternation of flow and temperature regimes (Minckley and Marsh, 2009). Introduced rainbow trout and brown trout are known to prey upon juvenile native fish in Grand Canyon (Yard and others, 2011) including humpback chub. Predation by these nonnative species may adversely impact native fish at a population level. To reduce potential predation on humpback chub, electrofishing was used to mechanically remove nonnative fish from the Colorado River, near the confluence with the LCR, from 2003-2006, and again in 2009 (Coggins and others, 2011). Humpback chub abundance increased following removal efforts, but system-wide decreases in rainbow trout and drought-induced increases in water temperature occurred during the same time period making it difficult to determine which factors were responsible for increased native fish abundance (Coggins and others, 2011). The interaction between water temperature, fish size, and trout presence has been shown to affect predation vulnerability in flannelmouth suckers in laboratory studies and likely all play a role in predation vulnerability of native fish in Grand Canyon (Ward and others, 2002; Ward and Bonar, 2003).

Brown trout are of particular concern given their highly piscivorous nature (Yard and others, 2011). The highest densities of brown trout in Grand Canyon occur in or near Bright Angel Creek (Makinster and others, 2010; NPS data). Large numbers of brown trout in this area may be limiting native fish abundance, including humpback chub, locally as well as downstream. This idea is based on the hypothesis that most of the humpback chub inhabiting western Grand Canyon are produced within the LCR and disperse downstream. If the bottleneck to dispersal and recruitment of humpback chub or other native fish species in western Grand Canyon is occurring near the confluence of Bright Angel Creek because of brown trout predation, then removing brown trout from this area could increase the number of native fish that inhabit downstream reaches.

3.2. Key Monitoring and Research Questions Addressed in this project

This work, along with ongoing National Park Service (NPS) brown trout removal from Bright Angel Creek, has been identified as a conservation measure in the December 2011 Biological Opinion for the Environmental Assessment for Non-Native Fish Control Downstream from Glen Canyon Dam. It also addresses AMWG priority Questions 1: Why are humpback chub not thriving; and Science Activity #1: What are the most limiting factors to successful humpback chub adult recruitment in the mainstem.

This project also specifically addresses the following Key Strategic Science Questions (SSQ's), Research Information Needs (RINs), and science advisors summary questions (SA) which were identified in the 2007 Grand Canyon Monitoring and Research Plan:

- SSQ RIN 1: What habitats and habitat characteristics, if any, will enhance survival, growth, and reproduction of native Grand Canyon fishes, especially humpback chub, in the mainstem Colorado River?
- SSQ RIN 2: What are the most effective strategies and control methods to limit nonnative fish predation on, and competition with, native fishes?
- SSQ RIN 3: What life stage(s) of rainbow trout pose the greatest threat to humpback chub and other native fishes in Grand Canyon?
- SA 1: What are the most limiting factors to successful humpback chub recruitment in the mainstem: spawning success, predation on young-of-year and juveniles, habitat (water temperature), pathoges, adult maturation, food availability, and competition?

This project will answer the follow key questions about impacts of nonnative fish on native fish within Grand Canyon:

1. What are the mechanisms by which nonnative trout impact humpback chub?
2. What is the relative predation risk for humpback chub to rainbow trout and brown trout under varying temperature, flow, and turbidity conditions?
3. What is the efficacy and feasibility of using electrofishing to control brown trout populations through a coordinated mainstem and tributary removal effort in and around Bright Angel Creek?
4. Does brown trout removal have a measurable positive effect on native fish abundance and distribution in the mainstem near Bright Angel Creek or within Bright Angel Creek?

4. Proposed Work

4.1. Project Elements

Project Element G.1. Laboratory Studies to Assess the Effects of Trout Predation and Competition on Humpback Chub ($93,400)

David Ward, Fishery Biologist, USGS/GCMRC

The first objective for this project element is to determine to what extent water temperature and turbidity influences vulnerability of humpback chub to predation by rainbow and brown trout. Laboratory experiments will allow evaluation of these variables prior to any changes in dam operations or implementation of expensive management options. We will evaluate the effects of water temperature food availability and turbidity on predation vulnerability of juvenile humpback chub, captive reared humpback chub larvae will be obtained from Dexter National Fish Hatchery and reared at the Rocky Mountain Research Station in Flagstaff, AZ, for six months until they are 50 to 100 mm total length (TL). Twelve replicate raceway tanks will be used to create artificial stream environments of varying temperature and turbidity from 0 to 500 Nephelometric Turbidity Units (NTU). Juvenile humpback chub 50 to100 mm TL will be exposed to rainbow and brown trout predators at varying sizes, temperatures and turbidities during overnight trials to assess predation vulnerability as a function of temperature and turbidity.

The second objective is to determine if rainbow and brown trout present more or less of a predation threat to juvenile chub than predation by adult chub. This assessment of potential impacts of predation by adult chub on juvenile chub gives context with which to evaluate predation by nonnative fishes and allows for an assessment of the relative impacts of predation by introduced fish on the overall humpback chub population. We will do this by determining if rainbow and brown trout present more or less of a predation threat to juvenile chub than cannibalism by adult chub. For this experiment, non-listed roundtail chub (*Gila robusta*) will be used as a surrogate for humpback chub. Roundtail chub are a good surrogate for humpback chub because they are closely related genetically (Douglas and Douglas, 2007), morphologically, and in habitat use (Kaeding and others, 1990; Karp and Tyus, 1990). Using a surrogate for humpback chub will greatly expedite our ability to conduct this study, because adult captive-reared humpback chub are not available at this time for laboratory research. Captive reared roundtail chub 50 to 70 mm TL obtained from Bubbling Ponds Native Fish Conservation Facility will be exposed to adult rainbow trout from Lees Ferry and similar sized adult roundtail chub collected from Fossil Creek, AZ. Relative predation vulnerability will be assessed in 12 replicate artificial streams at 15 - 20°C during overnight trials using 4 predators and 12 prey fish per tank.

And the third objective is to evaluate the effects that rainbow and brown trout competition have on condition and growth of similar sized humpback chub, using roundtail chub as a surrogate for humpback chub. Laboratory evaluations of competition require large numbers of adult humpback chub to be held in captivity. As stated above, these fish are not currently available which makes research using non-listed surrogates (roundtail chub) a good alternative. We will evaluate the effects that trout competition may have on condition and growth of humpback chub, we will use adult roundtail chub captured with hoop nets from Fossil Creek or the Verde River as surrogates for humpback chub. Rainbow trout and brown trout will be collected by electrofishing. Similar sized roundtail chub and rainbow and brown trout will be held jointly and separately at two densities in 12, 200-L artificial raceways at the Rocky Mountain Research Station in Flagstaff, AZ at 20°C. Fish will be fed a combination of amphipods and small fathead minnows every other day. Condition and growth of all fish will be monitored over a 6-month period. Remote video camera observations will be made to evaluate how competitive interactions alter chub behavior.

This research will result in three peer reviewed publications with the following titles:

- Effects of temperature and turbidity on predation vulnerability of juvenile humpback chub to rainbow and brown trout
- Relative predation vulnerability of juvenile chub to adult conspecifics (cannibalism) and to rainbow and brown trout
- Effects of competition between rainbow and brown trout and roundtail chub (as a surrogate for humpback chub).

Project Element G.2. Efficacy and Ecological Impacts of Brown Trout Removal at Bright Angel Creek ($181,900)

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

The objective for this project is to evaluate the feasibility and efficacy of brown trout removal in and around Bright Angel Creek using electrofishing, and assess the response of native fish to brown trout removal.

A multi-year, brown trout removal treatment using mechanical removal will be applied to both the mainstem Colorado River and Bright Angel Creek with the objective of significantly reducing brown trout abundance by 75–80%. Removal in the Colorado River mainstem will occur in a 8.45 km (5.25 mile) reach of Upper Granite Gorge (river miles 85 to 90) using electrofishing depletion methods similar to those used from 2003 to 2006 at the confluence of the LCR (Coggins and others, 2011). Electrofishing removals on the mainstem Colorado River will occur during the motor season in September and in April and will compliment ongoing NPS operation of a weir within Bright Angel Creek from October to March. Researchers will conduct 6 to 10-pass depletions with a single pass occurring over the entire study area in two nights (amount of effort based on calculated capture probabilities with a goal of 75% reduction in brown trout numbers). It has been estimated that each trip will consist of 10-20 nights of sampling. All electrofishing will be conducted at night using two 16' sport boats outfitted for electrofishing with a Coffelt® or equivalent CPS unit with one netter per boat. Large numbers of brown trout (> 2,000 fish) are likely to be removed. The beneficial use for these fish will be identified through the NPS's comprehensive fish management planning process and Section 106 consultation with Native American tribes. We estimate that as many as 500 fish could be removed on the first depletion pass with numbers diminishing thereafter. This estimate is based on 2010 and 2011 catch per unit effort data from fish captured in the Bright Angel reach during spring nonnative fish monitoring conducted by the Arizona Game and Fish Department (Bunch and others, 2010; 2011). Mechanical removal efforts in the Bright Angel Reach will be conducted simultaneously with additional native fish hoop net monitoring in the same area to assess whether or not a decrease in abundance of brown trout in the Bright Angel Reach is correlated with increased presence and abundance of native fish.

This effort will be conducted in consultation with Native American tribes and in collaboration with the NPS's ongoing removal efforts (fish weir and electrofishing) in Bright Angel Creek and with potential future efforts such as expanded electrofishing, chemical treatments, a rotary screw trap designed for capturing migrating juvenile fish, or other methods yet to be determined. To determine efficacy and ecological consequences of brown trout removal, capture probabilities for each study area will be estimated and used to develop a closed population model for estimating size-structured abundance of brown trout. Densities and conditions of native fishes in Bright Angel Creek and areas near its confluence will be monitored. Continued native fish monitoring, both within the removal area and in other areas downstream, are needed to assess if increased dispersal of native fish is occurring as a result of removal efforts (see Project D: Mainstem Humpback Chub Aggregation Studies and Metapopulation Dynamics and Project F: Monitoring of Native and Nonnative Fishes in the Mainstem Colorado River and Lower Little Colorado). In addition, primary productivity and invertebrate production will be monitored in Bright Angel Creek and the mainstem near its confluence to quantify any changes in availability of food for native fish. This project is proposed as an experimental research project to be conducted in FY13 with possible extension through FY16.

This research project will result in annual NPS data series and/or USGS open-file reports throughout the duration of the study, as well as trip reports for each electrofishing effort. A peer reviewed publication will be produced (co-authored USGS, NPS, and Reclamation biologists) on the efficacy of brown trout removal using electrofishing in and around Bright Angel Creek and the ecological impacts of brown trout removal. This publication will inform managers on the effectiveness of mechanical removal of brown trout as a tool to aid in native fish conservation in Grand Canyon.

5. Publications

5.1. Publications in progress

Ward, D.L., and Figiel, C.R., Jr., in review, Behaviors of four southwestern native fishes in response to catfish predators: The southwestern Naturalist.

Ward, D.L., Morton-Starner, R., and Hedwall, S., in review, An evaluation of liquid ammonia (Ammonim Hydroxide) as a candidate piscicide: Journal of Fish and Wildlife Management.

Ward, D.L., 2012, in press, Salinity of the Little Colorado River in Grand Canyon confers antiparasitic properties for native fish: Western North American Naturalist.

Hunt, T.A., Ward, D.L., Propper, C.R., and Gibb, A.C., in press, Effects of capture by trammel net on Colorado River native fishes: Journal of Fish and Wildlife Management.

5.2. Past Productivity

Ward, D.L., Childs, M.R., and Persons, W.R., 2008, PIT tag retention and tag induced mortality in juvenile bonytail and Gila chub: Fisheries Management and Ecology, v. 15, no. 2, http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2400.2008.00595.x/abstract.

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7. Budget

FY 2013			
Project Element G.1. Laboratory Studies		Project Element G.2. Efficacy Ecological Impacts of Brown Trout	
Salaries	$62,000	Salaries	$77,900
Traveling and Training	$1,900	Traveling and Training	$1,900
Operating Expenses	$18,000	Operating Expenses	$5,000
Logistics	$0	Logistics	$74,800
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0
USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$11,500	USGS Burden	$22,300
Total	$93,400	***Total***	$181,900

FY 2013 Project G. Gross Total: $275,300

FY 2014			
Project Element G.1. Laboratory Studies		Project Element G.2. Efficacy Ecological Impacts of Brown Trout	
Salaries	$67,900	Salaries	$84,300
Traveling and Training	$2,000	Traveling and Training	$2,000
Operating Expenses	$18,500	Operating Expenses	$5,200
Logistics	$0	Logistics	$77,000
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0
USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$12,400	USGS Burden	$24,200
Total	$100,800	***Total***	$192,700

FY 2014 Project G. Gross Total: $293,500

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

1. Investigators

Theodore Kennedy, Research Aquatic Biologist, USGS, Grand Canyon Monitoring and Research Center
Charles Yackulic, Research Statistician, USGS, Grand Canyon Monitoring and Research Center
Mike Yard, Fishery Biologist, USGS, Grand Canyon Monitoring and Research Center
Mike Anderson, Fishery Biologist, Arizona Game and Fish Department
Luke Avery, Biologist, USGS, Grand Canyon Monitoring and Research Center
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, Grand Canyon Monitoring and Research Center

2. Project Summary

This project will involve: (a) a simple laboratory experiment to determine if the strain of rainbow trout (*Oncorhynchus mykiss*) in Lees Ferry is capable of growing to large size; (b) data collection and model development to better understand factors controlling primary production and invertebrate drift; (c) collecting hydrodynamic and fish diet data, which will be used to develop a bioenergetics model of trout foraging; and (d) undertaking a synthesis of other tailwaters to better understand how dam operations affect the size distribution of salmonids in other settings. In addition, we present a contingency plan of work activities in case a fall high-flow experiment (HFE) occurs in Fiscal Year 2013 or 2014. Although we have a good understanding of food web response to the spring high-flow experiments conducted in 1996 and 2008, our understanding of food web response to the fall high-flow experiment in 2004 is more limited. Thus, we are poised to take advantage of learning opportunities presented by any high-flow experiments that occur during FY13 or FY14.

Over the last few decades, the rainbow trout fishery in Lees Ferry has been characterized by three undesirable properties: (1) population fluctuations characterized by decadal scale cycles in rainbow trout abundances (Makinster and others, 2011); (2) increasing potential for negative interactions between rainbow trout and native fishes caused by expansion of rainbow trout populations downstream (Yard and others, 2011); and (3) an absence of the large-sized rainbow trout that are highly valued by the angling community (Schmidt and others 1998). The causes of the long term population cycles are fairly well understood (Korman and others, *in* press; Cross and others, 2011), and the Natal Origins project (Project Element D.2.) was specifically designed to address uncertainties surrounding the downstream migration of rainbow trout. In this project we propose a suite of research activities designed to better understand the factors limiting the growth of large rainbow trout. These efforts will also provide information that can be used to

better the understand factors of population fluctuations and the potential for negative interactions between rainbow trout and native species.

3. Background

The history of rainbow trout in the Colorado River can be thought of as having two eras. During the "stocking era," which began in 1964, the fishery was sustained by annual stocking and recruitment was limited (McKinney and others, 2001). The size of stocked rainbow trout varied by year and ranged from 4 to 8 inches (10 to 20 cm). Adult rainbow trout routinely grew to 20 inches (50 cm), with occasional 30 inch plus fish (>75 cm), earning the fishery a reputation as blue ribbon (Schmidt and others, 1998). Rainbow trout were also found downstream in areas used by native fish (Valdez and Ryle, 1996). However, the extent of native and nonnative fish interactions during this period is not well understood, and is often presumed to have been limited in comparison to more recent years. Since 1991, the fishery has been increasingly sustained by natural recruitment and stocking was completely phased out by 1998 (McKinney and others, 2001). While limited recruitment was occurring prior to 1991 (Maddux and others, 1987), this transition to a "recruitment era" is often attributed to implementation of modified low fluctuating flows (MLFF; DOI, 1996). Demography of rainbow trout during the recruitment era is closely linked not only to implementation of MLFFs, but also to HFEs. High-flow experiments in 1996 and 2008 led to recruitment of large numbers of juvenile rainbow trout in the subsequent years (Korman and others, *in press*). Research surrounding the 2008 flood suggests that this recruitment, driven by increased juvenile survival and growth, was mainly attributable to increased food availability in the drift. In turn, this was linked to higher production of key drifting species of insects upon which rainbow trout rely heavily (blackflies and midges; Cross and others, 2011).

The rainbow trout fishery during the recruitment era has been characterized by three undesirable properties:

1. instability in population size, in which there are decadal cycles of large and small numbers,
2. increasing potential for negative interactions between rainbow trout and native fishes, especially humpback chub (*Gila cypha*), primarily due to rainbow trout population expansion downstream (Yard and others, 2011), and
3. an absence of the large rainbow trout that are highly valued by the angling community (Schmidt and others, 1998).

The degree to which dam operations and associated factors (i.e., population cycles) interact to affect the growth of large rainbow trout is the largest uncertainty associated with adaptive management of the fishery (McKinney and others, 2001; McKinney and Speas, 2001; Cross and others, 2011). The existence of this uncertainty has led to a plethora of hypotheses regarding the ultimate cause of diminished growth in large rainbow trout, which would take decades of manipulation and observation to sift through if we relied solely on field monitoring in Glen Canyon. In other words, while ongoing monitoring in association with adaptive management experimentation is important for documenting trends in population size, size distribution, and rainbow trout distribution, monitoring alone is an extremely inefficient way to determine the factors limiting the growth of large rainbow trout. With regard to the first and second undesirable properties (cyclic changes in population size and downstream expansion), we have a good understanding of the dynamics and drivers over the last decade (Korman and others, *in press*), but we still lack a cause-and-effect understanding that would allow us to confidently predict the impacts of dam operations outside the set of observed operations that occurred during the same time span (2000-2011).

To resolve these uncertainties, we propose complementing long-term rainbow trout monitoring with a suite of new research activities. We will pursue a multipronged approach to understanding these complex issues that involves:

1. laboratory studies of fish growth;
2. algal colonization and growth experiments, including an assessment of nutrient limitation of algae growth and targeted field sampling of algae biomass and invertebrate drift, to support development of predictive models of both primary production and invertebrate drift;
3. collection of hydrodynamic and rainbow trout diet data to help parameterize a bioenergetics model that explicitly incorporates information on water velocities (swimming costs) and drift delivery rates (concentrations and daily loads) in order to estimate net energy intake potential for rainbow trout; and,
4. a national synthesis of tailwaters to understand how dam operations affect salmonid populations dynamics in other systems.

Collectively, these studies will allow us to better understand the consequences of alternative dam operations on rainbow trout populations in both Glen and Marble Canyons. The proposed research activities will be integrated with the ongoing Foodbase Monitoring Program (Project Element F.7.), as well Detection of Rainbow Trout Movement from the Upper Reaches of the Colorado River below Glen Canyon Dam (Project F.6.) and Rainbow Trout Early Life Stage Survival project (Project Element F.2.2.) The foodbase monitoring program currently monitors drift and primary production at fixed locations in the Glen Canyon, Marble Canyon (river mile 30), near the LCR confluence (river mile 61), Phantom Ranch (river mile 87), and Diamond Creek (river mile 225). The natal origins project addresses uncertainties surrounding the amount of downstream rainbow trout dispersal; the potential dependence of dispersal on both population (density-dependence) and individual (size) properties; questions relevant to understanding population dynamics; distribution dynamics; and spatial variation in growth. The Rainbow Trout Early Life Stage Survival project (Project Element F.2.2) is critical in helping us understand the dynamics of young rainbow trout, which are both integral to population dynamics and may also limit growth of larger rainbow trout (see Hypotheses, below).

3.1. Scientific Background

The many hypotheses to explain the lack of trophy rainbow trout can be arranged by the degree to which these hypotheses attribute declining growth of large rainbow trout to changes in dam operations.

Hypothesis 1 (H1) *The strain of rainbow trout present in Glen Canyon is incapable of growing to large sizes (i.e., >20 inches)*. **H1** attributes the absence of large rainbow trout to a change in the strain of rainbow trout sometime after the 1970s. Thus, **H1** does not consider that rainbow trout conditions are affected by dam operations. Although exact strains stocked during the 1970s are unknown, records of fish larger than 30 in (76 cm) were not uncommon in the creel from 1977–1984 (Persons and others, personal communication). Since the mid 1980's, fish caught by angling or in electrofishing surveys have rarely been larger than 22 in (56 cm) (GCMRC and AGFD, unpublished data).

Hypothesis 2 (H2) *The current prey base, composed chiefly of midges and black flies, can support the growth of smaller rainbow trout, but does provide enough energy to allow for growth in large rainbow trout.* **H2** argues that there have been shifts in the foodbase that now leave it incapable of supporting larger rainbow trout. While dam operations can shift the foodbase to favor the recruitment and growth of small rainbow trout (Cross and others, 2011), growth and survival of large rainbow trout appears largely unaffected by dam operations. Possible causes of this shift in the foodbase include declining nutrient inputs from Lake Powell as the reservoir has aged (Stockner and others, 2000), introduction of invasive species (i.e., New Zealand mudsnail; Cross and others, 2010), and changes in substrates as the Glen Canyon reach has degraded over time (Grams and others, 2007). Changes in invertebrate composition could lead to changes in both the seasonal availability of drifting invertebrates (there is currently ~100-fold variation in drift rates among seasons; Kennedy unpublished data) and in the prevalence of high quality drift (i.e., large prey items such as *Gammarus*), both of which might strongly constrain growth of large rainbow trout while still allowing small rainbow trout to thrive. Support for this hypothesis comes from McKinney and Speas (2001), who observed size-related asymmetries in rainbow trout diet and energy intake that suggests larger sized trout are food-limited more often than smaller fish. Although the total amount of prey available to support rainbow trout populations may have increased during this time period (Angradi and Kubly 1993; Blinn and others, 1995; Benenati and others, 1998), juvenile trout appear to be the primary beneficiaries of any such change (McKinney and Speas, 2001). More recent research on the Glen Canyon food web (Cross and others, 2011) supports these observations.

A corollary to **H2** is that some combination of rainbow trout dispersal patterns, food availability, and declining prey detectability explains the declining abundances of rainbow trout at distances further downstream from Lees Ferry (Carothers and Brown, 1991; Makinster and others, 2011). Turbidity increases downriver, and since rainbow trout are visual feeders, it is more challenging for them to see food. However, the importance of this effect relative to declining food availability and dispersal rates is unknown (Barrett and others, 1992; Stuart-Smith and others, 2004; Yard and Coggins, *in review*).

Hypothesis 3 (H3) *The growth of large rainbow trout is limited by exploitative competition for limited prey items*. The diet composition of large and small rainbow trout overlap (i.e., their production is primarily supported by midges, black flies, and *Gammarus*; McKinney and Speas, 2001; Cross and others, 2011); however, smaller rainbow trout may be able to subsist on smaller prey items, and this may in turn affect food availability for larger rainbow trout. Many of the smaller prey items (small *Gammarus* and 1st instar larvae of midges and black flies) consumed by small rainbow trout represent early life stages of species that large fish would be better able to exploit if these prey items continued to mature. Since recruitment of smaller rainbow trout is tied to dam operations, **H3** posits an indirect and time lagged linkage to dam operations. While **H2** and **H1** predict no changes in large rainbow trout growth if small rainbow trout numbers are suppressed, **H3** predicts an increase in the growth of large rainbow trout if small rainbow trout are suppressed. **H3** can also be extended to argue that while high-flow experiments augment juvenile recruitment, the dynamics in the following years may be chiefly driven by intraspecific interactions between younger and older age-classes of trout, as opposed to physical factors (Schlosser 1985; Walters and Post, 1993).

Hypotheses 4 (H4) *Operational constraints that occurred in 1990 limit the growth of large rainbow trout.* **H4** directly links the lack of large rainbow trout to changes in dam operations. **H4** posits that the load-following dam operations that occurred during the stocking era created habitat that was more beneficial to large rainbow trout by favoring a fast-growing and high-quality early successional algal assemblage, creating daily surges in invertebrate drift (Perry and Perry, 1986). This also favored larger invertebrate prey items, all of which sustained the growth of larger rainbow trout (Barrett and others, 1992; Graf, 1995; Stuart-Smith and others, 2004). Growth studies on young-of-year rainbow trout have demonstrated that daily flow variation has significant effects on growth for early life stages (Korman and Campana, 2009). However, we lack a similar understanding of how daily variation in discharge affects growth of larger rainbow trout.

The motivation for this proposed research is to improve the recreational fishing experience for rainbow trout at Lees Ferry, while at the same time protecting and maintaining native fish populations downstream in Marble and Grand Canyons. Being able to distinguish among these four hypotheses will help inform the types of experiments the Adaptive Management Program might evaluate during the Long-Term Experimental and Management Plan (LTEMP) Environmental Impact Statement (EIS) to meet native and nonnative goals. If the research outlined below supports either **H1** or **H2**, then changes in dam operations alone are unlikely to provide the conditions necessary to support the large rainbow trout that are sought by anglers. If we find support for **H1**, this would suggest that the Adaptive Management Program might pursue stocking of alternative strains of rainbow trout, which are capable of growing to large size, into Glen Canyon. If the proposed research primarily supports **H2**, the Adaptive Management Program could consider introducing invertebrate species from other Colorado River Basin tailwaters (i.e., San Juan, Flaming Gorge, etc.), particularly larger taxa, and/or consider habitat modification (e.g., flows, large woody debris additions, or a temperature control device). If the proposed research primarily supports **H3** or **H4**, the Adaptive Management Program might consider alterations in dam operations. In recent years, dam operations designed to achieve goals for sediment and native fish (i.e., high-flow experiments and Low Summer Steady Flows) or meet equalization requirements (i.e, 2011), have created pulses of rainbow trout recruitment (Korman and others, *in press*). As a consequence, recreational catch rates in Glen Canyon have increased following these operations, yet the large rainbow trout that are sought by many anglers are absent. Further, these pulses of recruitment and subsequent downstream dispersal have led to costly and controversial rainbow trout removal efforts designed to reduce the threat that they pose to endangered humpback chub (Coggins and others, 2011). One specific management option available to the Adaptive Management Program is moving towards dam operations that will suppress juvenile recruitment. Suppressing juvenile rainbow trout recruitment could improve growth of larger rainbow trout either by lowering the degree of competition with smaller size classes (**H3**) or by creating more ideal habitat conditions (**H4**).

3.2. Key Monitoring and Research Questions Addressed in this Project

This project directly addresses the following Strategic Science Questions (SSQs), Core Monitoring Information Needs (CMINs), and Research Information Needs (RINs) previously identified by the Glen Canyon Dam Adaptive Management Program (GCDAMP).
Primary SSQ addressed:

- SSQ 1-3. Do rainbow trout immigrate from Glen to Marble and eastern Grand Canyons, and, if so, during what life stages? To what extent do Glen Canyon immigrants support the population in Marble and eastern Grand Canyon?
- SSQ 3-5. How is invertebrate flux affected by water quality (for example, temperature, nutrient concentrations, turbidity) and dam operations?
- SSQ 3-6. What GCD operations (ramping rates, daily flow range, etc.) maximize trout fishing opportunities and catchability?
- SSQ 5-6. Do the potential benefits of improved rearing habitat (warmer, more stable, more backwater and vegetated shorelines, more food) outweigh negative impacts due to increases in nonnative fish abundance?

Primary Core Monitoring Information Needs addressed:

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

Key Strategic Science Questions

AMWG Priority 1

- 5 What are the important pathways, and the rate of flux among them, that link lower trophic levels with fish and how will they link to dam operations? [FY06/09]

4. Proposed Work

4.1. Project Elements

Project Element H.1. Laboratory Feeding Studies ($37,700)

Luke Avery, Fishery Biologist, USGS/GCMRC

The objective of this project element is to evaluate growth potential of Glen Canyon rainbow trout by rearing fish in captivity to address **H1**.

Adult Glen Canyon rainbow trout will be collected by angling, transported to a facility yet to be determined, and fed *ad libitum* with high quality trout food for two years. Fish will be measured and PIT tagged when stocked, and will be measured throughout the study to estimate growth and condition. Tissue samples will be taken, which can be used to compare Glen Canyon trout to trout in the National Fish Strain Registry, and growth rates will be compared with growth of rainbow trout in other tailwaters as well as with wild populations (see Project Element H.5.).

Project Element H.2. Understanding the Links among Dam Operations, Environmental Conditions, and the Foodbase ($244,000)

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.

We will conduct small scale experiments of nutrient limitation and direct measurement of algae biomass at various depths using self-contained underwater breathing apparatus (SCUBA) to describe how algae growth is limited by nutrients and variation in light availability. Cliff habitats will be the focus of these measurements and experiments, because water velocities are often too high in other habitat types to safely SCUBA. Further, by doing this work at cliff habitats, we will be able to measure algae growth rates across a large range of depths and light availability. We will follow the methods of Tank and Dodds (2003) to assess nutrient limitation of algae growth. Nutrient diffusing substrates that include nitrogen, phosphorus, a combination of nitrogen and phosphorus, and a control will be deployed at multiple depths in several cliff habitats in Glen Canyon and near Diamond Creek. We will then develop a model that builds upon the work of Yard (2003) and Hall and others (2010) by linking our predictive understanding at small spatial scales to measurements at the reach-scale. Mechanistic models proposed here have a higher probability of making accurate predictions for conditions outside the set of observed conditions relative to more phenomenological models (Cale and others, 1989; Oreskes and others, 1994). New data collections will occur, and mechanistic models developed, in the Glen Canyon and Diamond Creek reaches because of the availability of long-term algae growth estimates (since 2008 and 2009, respectively). Reach scale estimates of algae growth will also continue at other reaches (i.e., RM 30, 61, and 87) but no additional data collections or mechanistic models are proposed for these reaches.

Algae is the crank that turns the Colorado River food web in Glen Canyon (Shannon and others, 1994; Angradi 1994; Cross and others, 2011) and in Marble and Grand Canyons (Stevens and others 1997; Cross and others *in prep*). Yard (2003) demonstrated how light, turbidity, and algae biomass interact to affect algae production using experiments in small chambers. Yard (2003) extrapolated from these small-scale measurements (meters) to demonstrate how algae growth at the scale of the reach (10s of river miles) would likely be affected by the interactive effects of turbidity and discharge, which affect river depth and therefore light availability at the scale of the reach. Yard (2003) predicted something that is somewhat counterintuitive—at downstream locations that are limited by light due to suspended sediment turbidity, reach-scale algae growth can actually decline as discharge increases. This is due to strong effects of light limitation on algae growth when river depth reaches a critical value that is dependent on reach geometry (width and depth) and turbidity.

Hall and others (2010) estimated algae production at the scale of the reach (10s of river miles) by developing detailed dissolved oxygen budgets that incorporate information on incident light (Yard and others, 2005) and air-water gas exchange rates (Hall and others, 2012). Initially, as a proof-of-concept, dissolved oxygen was monitored for 1.5 days at regular intervals as part of foodbase research (once per month at Diamond Creek and Glen Canyon, and quarterly at 4 sites in Grand Canyon during river trips). In collaboration with the Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem monitoring project (project B), continuous dissolved oxygen monitoring has been occurring in Glen Canyon since 2008, Diamond Creek (at river mile 225) since 2009, and at river miles 30, 61, and 87 since summer 2011 (see Project F.7.). Analysis of long-term algae production estimates from Glen Canyon reveals strong seasonal variation in primary production, and also links to operations. But as predicted by Yard (2003), the effect of operations on algae growth does not appear as pronounced as for downstream locations that are more limited by light availability caused by suspended sediment turbidity. Analysis of long-term algae production estimates from Diamond Creek reveals strong effects of turbidity and discharge on algae growth that are consistent with the predictions of Yard (2003), but there is also a strong interaction between turbidity and discharge (Hall and others, *in prep*). Interactions such as this complicate interpretation of main effects—turbidity and discharge. That is, because there is a strong interaction between the main effects, we are unable to completely disentangle the effects of turbidity from discharge and predict with confidence algae growth rates for dam operations that are outside of the set of observed conditions (i.e., Modified Low Fluctuating Flows). Further, we are unable to describe how the March 2008 HFE affected annual rates of algae growth in Glen Canyon near Diamond Creek, because continuous dissolved oxygen monitoring was initiated in Glen Canyon in February 2008, just weeks before the high-flow experiment occurred and at Diamond Creek in 2009. Algae biomass estimates from Glen Canyon that were also collected as part of foodbase research efforts indicate the March 2008 HFE scoured algae from habitats in Glen Canyon and that algae quickly regrew. However, these data cannot be used to make precise estimates of reach-scale effects over annual timescales because they were only collected from shallow nearshore habitats.

Evaluating **H2** and predicting algae response to environmental conditions will also require a better understanding of algae growth response to differing concentrations of dissolved nutrients. Nutrient loadings from Lake Powell are known to vary seasonally and in response to changing reservoir elevations (Vernieu and others, 2005). Further, large reservoirs such as Lake Powell undergo an aging process over timescales of decades, where nutrient concentrations of releases are initially high as a vast terrestrial landscape is flooded (Stockner and others, 2000). As nutrients from the inundated valley floor are leached and depleted, nutrient concentrations released to the downstream ecosystem progressively decline (Stockner and others, 2000). The nutritional quality of algae also declines over the scale of decades, which can ultimately affect the growth potential of downstream fish populations (Stockner and others, 2000). A small scale research project conducted in Glen Canyon as part of Foodbase monitoring (Project Element F.7.) revealed algae growth is jointly limited by dissolved nitrogen and phosphorus. The nutritional quality of the algae itself likely varied too, but this was not measured.

Predicting algae growth response to novel flow regimes that are outside of the set of observed conditions will be an important component of ongoing adaptive management experimentation. To address this need, we propose additional data collection and development of a mechanistic model of algae growth that can be used to predict algae response to dam operations and changing environmental conditions (i.e., turbidity and nutrient loading).

This research will result in a mechanistic model that can be used to predict algae growth response to dam operations and environmental conditions, as well as multiple peer-reviewed journal articles describing (a) nutrient limitation experiments, (b) time-series analysis of reach-scale primary production estimates, and (c) mechanistic model of algae growth.

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

The objective of this project element is to characterize spatial and temporal variation in the quantity and size distribution of invertebrate drift throughout Glen and Marble Canyon**.**

We will undertake additional sampling during the Natal Origins of Humpback Chub at Aggregations by Otolith Microchemistry Project (Project Element D.2.1.) river trips to characterize spatial variation in drift throughout Glen and Marble Canyons. Invertebrate drift will be quantified on two consecutive days at each of the four fixed sampling sites during the daytime. Drift samples will be collected from multiple depths in the thalweg. More intensive drift measurements beyond what we propose here are not possible in the context of the natal origins project because of the large electrofishing effort. Characterizing smaller spatial scale variation in drift rates will therefore only occur in Glen Canyon. As part of regular monitoring trips, we will sample drift at additional sites that span the full range of habitat types present there. Data on spatial and temporal variation in drift from both long-term monitoring and the research proposed here will be analyzed using standard statistical techniques and results will inform **H2** and **H3**. These drift data will also be used to parameterize a rainbow trout bioenergetics model (see Project Element H.3.).

Invertebrate drift monitoring under the Foodbase Monitoring project (Project Element F.7.) focuses on describing temporal variation in drift rates at a single fixed location—USGS cableways—in both Glen Canyon and near Diamond Creek. These monitoring data revealed that drift rates for key taxa—midges and blackflies—at Glen Canyon increased in the months following the March 2008 HFE (Cross and others, 2011), and this foodbase sustained the high juvenile rainbow trout growth and recruitment that was subsequently observed (Korman and others, 2011). The sites where drift monitoring occurs are ideal for long-term monitoring, because the hydrodynamics of these sites are conducive to measurement of sediment and invertebrate flux, and access to both locations is relatively easy. But the distribution of large rainbow trout varies spatially, with larger fish generally found proximate to highly productive cobble bars (AZGFD, unpublished data) that also have high water velocities, both of which lead to higher food delivery rates relative to other habitat types (Hayes and others, 2007). Here, we propose collecting additional data on invertebrate drift rates among various habitat types in Glen Canyon, and also in association with the natal origins project, to estimate net energy intake potential for small versus large rainbow trout (see Project Element H.3.).

Project Element H.3. Developing a Bioenergetics Model for Large Rainbow Trout ($138,300)

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.

The objective to this project element is to develop a bioenergetics model that allows us to quantify the effects of prey size, water velocity, and intra-specific competition on growth potential for rainbow trout.

We will develop an integrated invertebrate drift and trout foraging model building on the work of Paukert and Peterson (2007), Hayes and others (2007), and Rosenfeld and Taylor (2009). This model depends on outputs from Project Element H.2., as well as additional data collection. Specifically, in this project element, we propose quantifying how rainbow trout energy intake varies between small and large rainbow trout by analyzing stomach contents seasonally at the four Natal Origins project sample sites (Project Element D.2.1.). We will also collect detailed hydrodynamic data from these reaches. Stomach contents of 120 rainbow trout on each Natal Origins trip will be collected by Mike Yard and analyzed by Ted Kennedy; for each of the four Natal Origins sites that will be sampled seasonally, the stomach contents for 15 small (<15 cm) and 15 large (>15 cm) rainbow will be collected and analyzed. Scott Wright will use an acoustic Doppler current profiler to characterize water velocity profiles at multiple cross-sections throughout Glen and Marble Canyons at different flow levels. Charles Yackulic, Mike Yard, Josh Korman, and Mike Anderson will estimate size-specific growth rates for rainbow trout in Glen and Marble Canyons using various long-term data sources (i.e., Rainbow Trout Early Life Stage Survival Project Element F.2.2., annual Lees Ferry rainbow trout monitoring project element F.2.1., and Natal Origins Project Element D.2.1.). The bioenergetics model will be developed jointly by Charles Yackulic, Ted Kennedy, Mike Yard, and Scott Wright and will be used to evaluate both **H2** and **H3** by allowing us to determine how energy gains and losses vary at different discharge and prey density levels, and the degree to which intra-specific competition (by lowering prey densities) lowers the growth potential of large rainbow trout.

Drift feeding fish like rainbow trout are known to feed across gradients in water velocity, from a holding position in slow-moderate velocities into faster surrounding waters that have higher prey delivery rates (Hayes and others, 2007, and references therein). This strategy confers the highest net energy intake for drift feeding fish, because it optimizes the tradeoff between the need to acquire food with the energetic costs of swimming that must be expended while capturing prey (Hayes and others, 2007). The daily energy intake requirements for fish increase as fish grow in size, such that small fish are able to meet these requirements in habitats that have low prey delivery rates (e.g., shallow, low velocity nearshore habitats), but as fish grow they must begin occupying habitats that have higher prey delivery rates. But even here, large fish can balance this tradeoff between energy intake and swimming costs by either selecting habitats that have lower swimming costs (deep pools) or faster velocity habitats that have higher prey delivery rates (Rosenfeld and Taylor, 2009).

Benthic invertebrates are the ultimate source of the drifting invertebrates consumed by rainbow trout, and there are large differences in benthic invertebrate biomass across multiple spatial scales—from the reach scale (i.e., higher biomass in Glen Canyon and lower biomass at locations reaches; Stevens and others, 1997; Cross and others, 2011) to the patch scale (i.e., within a given reach, invertebrate biomass is highest on cobble bars relative to other habitat types; Stevens and others, 1997; Cross and others, 2011). Further, water velocities and geomorphology varies across these same spatial scales (Schmidt and Graf, 1990; Graf, 1995). Water velocities also vary strongly as a function of dam operations (Graf, 1995), and under the modified low fluctuating flow alternative, these differences in flow regimes tend to vary seasonally (large discharge volumes and high water velocities in summer and winter, lower discharge volumes and water velocities in spring and fall). Thus, invertebrate drift rates and hydrodynamic data across flow regimes, seasons, and from multiple spatial scales—from the reach to the patch—are needed to develop a cause-and-effect understanding of how net energy intake potential for rainbow trout populations in Glen and Marble Canyons vary in response to things such as HFEs (Cross and others, 2011), dam operations (i.e., 2011 equalization flows), and among segments (i.e., Glen Canyon versus Marble Canyon). Constraints on the net energy intake potential for large rainbow trout in Glen Canyon is a leading hypothesis explaining the absence of large rainbow trout from the Glen Canyon sport fishery (see **H2**). Differences in net energy intake potential among segments may also partially explain the recent finding that rainbow trout appear to migrate from Glen Canyon downstream late in their first year of life (Korman and others, *in press*). We propose addressing these uncertainties and testing **H2** by developing a bioenergetics model for rainbow trout that includes information on invertebrate drift rates, water velocities, and water temperatures. Previous bioenergetic models developed for Grand Canyon fish populations have focused on evaluating growth potential for humpback chub and rainbow trout as a function of water temperature (Peterson and Paukert, 2005; Paukert and Peterson, 2007). Our model will also include water temperature because this has a strong effect on fish metabolism and swimming performance (Peterson and Paukert, 2005; Hayes and others, 2007). We will also incorporate information on water velocities, because this information is critical for evaluating differences in net energy intake potential among segments (i.e., Glen Canyon versus Marble Canyon) and among seasons and flow regimes.

Project Element H.4. Learning from other Tailwaters—a Synthesis of Tailwaters in the United States ($146,500)

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 to this project element is to develop a broader understanding of the links between dam operations and salmonid population dynamics, including novel flow regimes that might be evaluated on Glen Canyon Dam, by synthesizing data from tailwaters throughout the nation.

While it is not possible to evaluate **H4** without major changes in Glen Canyon Dam operations, it is possible to evaluate **H4** by synthesizing data from other tailwaters that experience different flow regimes than Glen Canyon Dam. The tailwaters downstream from all the major Colorado River dams (e.g., Navajo Dam, Aspinall Units, Flaming Gorge) are intentionally managed for salmonid (i.e., rainbow trout brown trout [*Salmo trutta*]) populations, because the clear, cold-water conditions that exist are ideal for these species. Environmental flows, and in some cases temperature modification, have been implemented on many segments of the Colorado River in an attempt to restore ecosystem processes and benefit native fish species. For example, a program of environmental flows that includes artificial spring floods, summer minimum flows, and thermal modification using a selective withdrawal structure, has been implemented at Flaming Gorge Dam (Muth and others, 2000). Environmental flows have also been implemented for Glen Canyon Dam, but the focus has been on artificial floods only (Kennedy and Ralston, 2011; Schmidt and Grams, 2011). Thermal modification in Grand Canyon is not possible, because no selective withdrawal structure exists. However, the artificial flood conducted in 2008 strongly benefitted the population of rainbow trout in the dam's tailwaters (Cross and others, 2011; Korman, Kaplinski, and Melis, 2011). This led to a large cohort of juvenile rainbow trout, but significant increases in the abundance of large rainbow trout were not seen. Countless other examples of environmental flows—both with and without thermal modification—exist for various dams in the Colorado River basin, all of which are intended to benefit native fish populations, while still maintaining salmonid sport fisheries in the tailwaters. There are numerous tailwaters outside of the Colorado River basin that are also managed for salmonids, and we will learn about the links among flow regimes, water temperature regimes, and salmonid populations dynamics by incorporating information from these systems into our synthesis. We will hire a post-doctoral researcher to synthesize available monitoring and research data from tailwaters throughout the United States, with an emphasis on tailwaters in the Colorado River basin. The post-doctoral researcher will be charged with making connections with the scientists from state, federal, and academic organizations throughout the United States needed to acquire relevant data from other tailwaters (i.e., information on the foodbase and fish catch data). The synthesis will culminate with a symposium that the post-doctoral researcher organizes. By comparing long-term trends in salmonid populations across a range of tailwaters, we will develop a broader understanding of the links between dam operations and salmonid populations than could be achieved with monitoring and research in Glen Canyon alone.

Project Element H.5. Contingency Planning for High Experimental Flows and Subsequent Rainbow Trout Population Management ($44,500)

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

The objective to this project element is to determine the effects of fall HFEs and other potential management actions on rainbow trout populations in Glen Canyon. Spring floods are known to have a large impact on age-0 rainbow trout mortality and movement. However, the effects of fall floods are less well understood. It is possible that fall HFEs may lead to further population fluctuations and dispersal downstream necessitating management response(s). A fall HFE may also directly impact juvenile and adult trout in the system. Therefore, we propose that in the event of an HFE, there should be an additional trip shortly after to monitor trout responses. The Natal Origins marking trip will occur before a potential HFE and the next sampling would not be scheduled until January, making it difficult to parse out direct impacts of fall flooding (i.e. increased dispersal) on life history parameters from indirect impacts (e.g., through the foodbase), so the contingent marking trip would require additional pit tagging.

Any actions to manage rainbow trout populations in Glen Canyon would also require monitoring to determine their effectiveness. Potential actions may include flows or flow regimes that limit availability of suitable spawning or rearing habitat, reproduction, or survival of fertilized eggs, larvae, or juveniles. Ongoing monitoring projects including System Wide Electrofishing (Project F.1.), Rainbow Trout Monitoring in Glen Canyon (Project F.2.1.), Rainbow Trout Early Life Stage Studies (Project F.2.2.), and Natal Origins (Project F.6.) will provide information on the responses of rainbow trout in Glen Canyon to these actions. Additional monitoring, however, may also be necessary if, as described above for HFEs, the timing of management actions and planned monitoring activities makes it difficult to resolve the effects of any experimental actions. Supplemental monitoring may include electrofishing surveys to determine any changes in size composition, relative abundance or distribution of rainbow trout or additional tagging of fish to generate abundance estimates through mark-recapture.

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6. Budget

FY 2013					
Project Element H.1. Laboratory feeding studies		Project Element H.2. Understanding the links among dam operations, environmental conditions, and the foodbase		Project Element H.3. Developing a bioenergetics model for large rainbow trout	
Salaries	$17,100	Salaries	$116,100	Salaries	$68,900
Traveling and Training	$0	Traveling and Training	$7,700	Traveling and Training	$2,900
Operating Expenses	$16,000	Operating Expenses	$20,500	Operating Expenses	$1,500
Logistics	$0	Logistics	$0	Logistics	$0
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$79,500	GIS/RS/Electronics support	$34,100
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$20,000
USGS cooperators	$0	USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$4,600	USGS Burden	$20,200	USGS Burden	$10,900
Total	$37,700	***Total***	$244,000	***Total***	$138,300
Project Element H.4. Learning from other tailwaters--a synthesis of tailwaters in the U.S.		Project Element H.5. Contingency planning for High Flow Experiments and subsequent rainbow trout population management			
Salaries	$112,400	Salaries	$6,600		
Traveling and Training	$14,100	Traveling and Training	$0		
Operating Expenses	$2,000	Operating Expenses	$14,000		
Logistics	$0	Logistics	$18,400		
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$0		
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0		
USGS cooperators	$0	USGS cooperators	$0		
USGS Burden	$18,000	USGS Burden	$5,500		
Total	$146,500	***Total***	$44,500		
FY 2013 Project H. Gross Total: $611,000					

FY 2014					
Project Element H.1. Laboratory feeding studies		Project Element H.2. Understanding the links among dam operations, environmental conditions, and the foodbase		Project Element H.3. Developing a bioenergetics model for large rainbow trout	
Salaries	$17,600	Salaries	$119,500	Salaries	$70,900
Traveling and Training	$0	Traveling and Training	$7,800	Traveling and Training	$2,900
Operating Expenses	$16,500	Operating Expenses	$21,100	Operating Expenses	$1,500
Logistics	$0	Logistics	$0	Logistics	$0
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$71,800	GIS/RS/Electronics support	$30,800
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$20,600
USGS cooperators	$0	USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$4,800	USGS Burden	$30,900	USGS Burden	$15,500
Total	$38,900	***Total***	$251,100	***Total***	$142,200
Project Element H.4. Learning from other tailwaters--a synthesis of tailwaters in the U.S.		Project Element H.5. Contingency planning for High Flow Experiments and subsequent rainbow trout population management			
Salaries	$115,800	Salaries	$14,500		
Traveling and Training	$14,700	Traveling and Training	$0		
Operating Expenses	$2,100	Operating Expenses	$14,400		
Logistics	$0	Logistics	$19,000		
GIS/RS/Electronics support	$0	GIS/RS/Electronics support	$0		
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0		
USGS cooperators	$0	USGS cooperators	$0		
USGS Burden	$18,700	USGS Burden	$6,900		
Total	$151,300	***Total***	$54,800		
FY 2014 Project H. Gross Total: $638,300					

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

1. Investigators

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2. Project Summary

Riparian vegetation affects physical processes and biological interactions in the Colorado River ecosystem (CRe). The presence and expansion of riparian vegetation promotes bank stability and diminishes the magnitude of scour and fill during floods. Scour and fill is the process that maintains bare sandbars. This project is focused on monitoring riparian vegetation and its changes. Monitoring is centered on measure of response guilds, a relatively new concept in riparian ecology. Response guilds are groups of plant species not closely related, but respond similarly to flow variables. The presences of particular guilds are an indicator of the status of vegetation and other resources such as sandbar stability and campsite availability.

The effect of riparian vegetation on associated resources and the uncertain direction of the riparian community's response to dam operations and the tamarisk beetle (*Diorhabda* spp.) have garnered the attention of stakeholders within the Glen Canyon Dam Adaptive Management Program (GCDAMP). The stakeholders of the GCDAMP requested that a greater effort be made to understand riparian vegetation response to dam operations and the effect of riparian vegetation on other resources. This project will monitor vegetation using a response guild approach. Monitoring vegetation using response guilds is a strategy being applied across the Colorado River basin within the National Park system. Thus, the approach described here is complimentary to work elsewhere and permits comparison of vegetation response across the watershed and subject to different flow regimes. The sampling described here occurs within a hydro-geomorphic framework and allows interpretation of vegetation response as related to dam operations and geomorphic setting. The type of response guilds found downstream from Glen Canyon Dam can identify contracting or expanding areas of the river channel, as well as simplification of the riparian community.

3. Background

Substrate properties, channel geomorphology (e.g., width, depth, bed and bank material, slope, floodplain functionality), and flow regime affect the abundance, structure, and location of riparian plant communities (Auble and Scott 1998; Mahoney and Rood 1998; Auble and others, 2005; Naiman and others, 2005). Convergent adaptations by species that respond similarly to these geomorphic and hydrologic attributes create response guilds that cross genera and vary in habit and longevity (Grime, 1979; Lavorel and Garnie, 2002; Merritt and others, 2010). Alteration of the flow regime through dam regulation changes the disturbance regime for riparian species and leads to changes in the response guilds present within a riparian ecosystem. River regulation thus becomes a selective force on riparian community structure that has the potential to shift the dominant species and response guilds of the native ecosystem to an alternative state.

River regulation in the semi-arid West creates conditions that support both nonnative and native riparian plant species (Stromberg, 1998; Rood and others, 2009). The reduced flood frequency and magnitude and the increased base flow of regulated rivers permit vegetation to persist along the historic annual flood line and migrate downslope and shoreward. The altered hydrograph can promote successful colonization of nonnative species, particularly tamarisk (*Tamarix* spp.), on newly exposed bare substrates (Sher and others, 2000; Birken and Cooper, 2006; Mortenson and others, 2012). In the southwest, the riparian plant community is one in which nonnative tamarisk or Russian olive (*Eleaganus angustifolia*) dominate the landscape (Friedman and others, 2005). In Grand Canyon, tamarisk is a keystone species of the postdam riparian community, because the plant affects multiple biological interactions and processes. Tamarisk affects food availability and nesting preferences of birds, the composition of ground dwelling arthropods, plant diversity, litter quality and quantity, and other community interactions and functions (Bailey and others, 2001; Ellis and others, 2001; Sogge and others, 2003; Kennedy and Hobbie, 2004, Yard and others, 2004).

Selective forces, such as river regulation, that creates alternative riparian community states that support nonnative species can create feedback loops with geomorphic processes. Shoreward migration of vegetation that includes tamarisk colonization can result in channel narrowing and channel simplification (Allred and Schmidt 1999; Dean and Schmidt, 2011). These changes can affect the riparian community by changing the width, structure, and composition of riparian vegetation including reductions in vegetation diversity (Auble 2005; Graf 2006). The expectation for large river channels in the southwestern U.S. is that continued channel narrowing will occur, particularly due to reduced stream flow (Seager and others, 2007; Sabo and others, 2010). To reverse this undesired condition, natural resource managers seek to improve natural resources downstream of dams by exploring alternative dam operations that may promote biodiversity and healthy ecosystems.

Society is increasingly interested in restoring and maintaining diverse riparian communities (National Research Council, 2002; Shafroth and others, 2008). **Accordingly, the stakeholders of the GCDAMP identified a riparian habitat dominated by native species as the preferred desired future condition for the Colorado River downstream from the dam.** In other words, stakeholders are interested in identifying those selective forces that will permit riparian vegetation to switch from the present state of a tamarisk-dominated habitat to one dominated by native riparian species. Approaches available to changing the composition of the riparian community include physical removal of nonnative species, introducing biocontrol agents (for example, the tamarisk beetle), and/or changing the pattern of annual water delivery. Changes in the flow regime might include periodic flood pulses, altering daily and monthly flow volumes, and altering the daily pattern of releases (Poff and Zimmerman, 2010; Wright and Kennedy, 2011).

Shifting the riparian ecosystem from the present tamarisk-dominated condition to a native species-dominated condition is a significant scientific challenge. Because tamarisk is a keystone species along the Colorado River, its reduction may profoundly affect the riparian community's composition, structure, and general character, which merits monitoring and study. Further, because plants form guilds in response to hydrologic regimes (Merritt and others, 2010), and these guilds can affect channel response (Allred and Schmidt, 1999; Dean and Schmidt, 2011), it is necessary that vegetation data collection be set within a hydro-geomorphic framework. Without a hydro-geomorphic framework, the linked responses of channel morphology and the riparian community to drivers of change (e.g., altered hydrology, tamarisk beetle) will remain unknown. The result is that stakeholders will remain unable to understand how dam operations may or may not effectively shift the riparian community from the tamarisk-dominated state toward a native species-dominated state.

3.1. Scientific Background

The current hydrologic regime of Glen Canyon Dam promotes woody vegetation expansion (Stevens and others, 1995; Kennedy and Ralston, 2010), and it is unknown how the introduced tamarisk beetle, in combination with future flow regimes, will affect the riparian community downstream of the dam. Stakeholders of the GCDAMP recognized riparian communities as an important element of the Colorado River and developed a specific management goal [Goal 6: Protect or improve the biotic riparian and spring communities, including threatened and endangered species and their critical habitat]. Reduced flows in the summer can promote tamarisk recruitment if there is sufficient open substrate and persistent water for establishment (Porter, 2002; Birken and Cooper, 2006; Mortenson and others, 2012). Increased frequency of high flows of similar magnitude and duration in the spring or fall may reduce wetland and riparian plant diversity by selecting for a single type of response guild that is adapted to burial and that can expand through vegetative propagation (Ralston, 2010; Kennedy and Ralston, 2011). The effect of vegetation expansion can negatively affect the quality of other resources within the riparian zone. For example, available campable area can decline as vegetation expands (Kearsley and others, 1994). Additionally, though not well documented in Grand Canyon, increasing vegetation on sandbars likely confounds sediment conservation efforts by affecting sediment transport dynamics and eolian processes (Trimble 2004, Kean and Smith, 2004; Dean and others, 2011; Draut and Rubin, 2008). **Thus, the status of riparian vegetation and its relationship to other resources is a primary information need for the stakeholders to evaluate how dam operations are affecting downstream resources**.

This project is entirely focused on, (1) vegetation monitoring. There are three components of the monitoring (a) monitoring riparian vegetation response guilds to dam operations within a hydrogeomorphic framework, (b) developing a state and transition model for riparian vegetation change, and (c) periodic landscape scale vegetation mapping and change analysis using remotely sensed data. The work proposes:

1. *To use ecological and life-history traits of riparian plant species found along the Colorado River downstream from Glen Canyon Dam to define flow response guilds (sensu Merritt and others, 2010.) These guilds will be the basis to monitor directional*

responses of the riparian community and the river channel to dam operations. Directional responses revealed by monitoring might include a constricting or expanding riparian vegetation community, simplification of the riparian community, and narrowing of the river channel.

2. *To use traits of response guilds to identify ecological states for riparian vegetation and those conditions (flow scenarios) that cause states to switch.* This approach recognizes a multi-state pathway and multiple steady states as a way to describe riparian vegetation dynamics.
3. *To use remotely sensed imagery to quantify landscape scale changes in vegetation type and amount and to conduct change detection analysis of vegetation since 2002.*

These project components will provide stakeholders necessary information about riparian vegetation response to dam operations, and information about how changes in vegetation, be it expanded area, or community structure, may affect other resources such as campsite availability and quality, terrestrial and aquatic food webs, and sediment dynamics related to sediment transport.

3.2. Core Monitoring and Research Questions Addressed in this project

This project addresses the following Strategic Science Questions (SSQs), Core Monitoring Information Needs (CMINs), and Research Information Needs (RINs) previously identified by the GCDAMP.
Primary SSQs addressed are:

- **SSQ 2-1.** Do dam-controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites, and if so, how?
- **SSQ 5-7.** How do warmer releases affect viability and productivity of native/nonnative vegetation?

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

- Determine and track the abundance, composition, distribution, and area of terrestrial native and nonnative vegetation species in the CRe
- Determine parameters and metrics to be measured, and the information needs that address each element
- Determine how the abundance, composition, and distribution of the OHWZ, NHWZ, and sand beach community have changed since dam closure (1963), high flows (1984), interim flows (1991), and the implementation of ROD operations (RIN 6.2.1, 6.3.1, 6.4.1, 6.5.1, 6.5.2, 6.5.3)

3.3. Management Background

This project funds monitoring and associated research activities relating to the measurement of riparian vegetation attributes in response to dam operations to inform multiple stakeholder needs. Project I incorporates information gained from previous monitoring pilot efforts (Stevens and Ayers 1995; Kearsley and Ayers 1995; Kearsley and others, 2006) and recommendations from protocol review panels (Urquhart and others, 2000; Cooper and others, 2008).

The primary objectives of this project are to measure variables of plant response (cover, species presence, and abundance) as related to the geomorphic setting, stage elevation, and dam operations. These variables inform stakeholders about the status of vegetation and support analysis of vegetation's role in the physical and sociocultural responses to dam operations. The proposed methods in the Response Guild project also support research related to evaluation of alternative flow regimes, including implementation of the High-Flow Experiment protocol (U.S. Department of the Interior, 2011), because sampling is hydrologically and geomorphically based, and its annual sampling schedule in September generally brackets proposed high flow releases. The annual sampling at the end of each growing season provides an assessment of riparian vegetation. Thus, data collected by this project contribute to core monitoring, agency actions such as the High-Flow Experiment protocol or other dam operations, and fundamental support for understanding ecosystem processes within a regulated river.

In addition to supporting GCDAMP Goal 6, this project also supports Goals 8, 9, and 11.

- **Goal 8:** Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve GCDAMP ecosystem goals.

This project supports Goal 8 by collecting vegetation response data associated with sandbars and other geomorphic features that physical scientists can use to further understand mechanisms affecting sediment storage and transport.

- **Goal 9**: Maintain or improve the quality of recreational experiences for users of the CRe within the framework of GCDAMP ecosystem goals.

This project supports Goal 9 by collecting vegetation response data that may inform researchers about how vegetation cover and abundance affects recreational experiences.

- **Goal 11:** Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations.

This project supports Goal 11 by collecting vegetation cover data and an overall species list that may be used to inform other researchers about how the quantity of vegetation affects sediment transport and cultural site preservation, or how the loss or gain of plant species affect interpretations of ecosystem status.

4. Proposed Work

4.1. Project Elements

Project Element I.1.1. Monitor Vegetation and Channel Response using Response Guilds and Landscape Scale Vegetation Change Analysis ($376,500)

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Todd Chaudhry, Restoration Ecologist, Grand Canyon National Park, NPS
Lori Makarick, Vegetation Program Manager, Grand Canyon National Park, NPS
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Technician, USGS/GCMRC

Response guild development involves identifying groups of species that share traits related to life history, reproductive strategy, adaptation to fluvial disturbance, and inundation duration response (i.e., water availability) within a particular river geomorphic setting. For each guild, a probabilistic response to a flow variable is determined and projected (Fig. 1). The guilds can be used to indicate a directional response of the riparian community and the river channel to an implemented flow regime. For example, on the Yampa River, the presence of active channel plant species measured in monitored plots are used as an indicator of the responsiveness of the channel (Scott and others, 2011) . The response guild approach, which is a relatively new approach to riparian vegetation management (Merritt and others, 2010) provides managers an opportunity to evaluate trade-offs and risks associated with flow management strategies. Sampling that uses guilds as a monitoring approach can validate projected responses. The guilds downstream from Glen Canyon Dam would be metrics that identify contracting or expanding areas of riparian vegetation, simplification of the riparian community, and simplification or narrowing of the river channel. Because guilds have a probabilistic response to flows, we can project their trajectory and model faunal species responses to riparian changes.

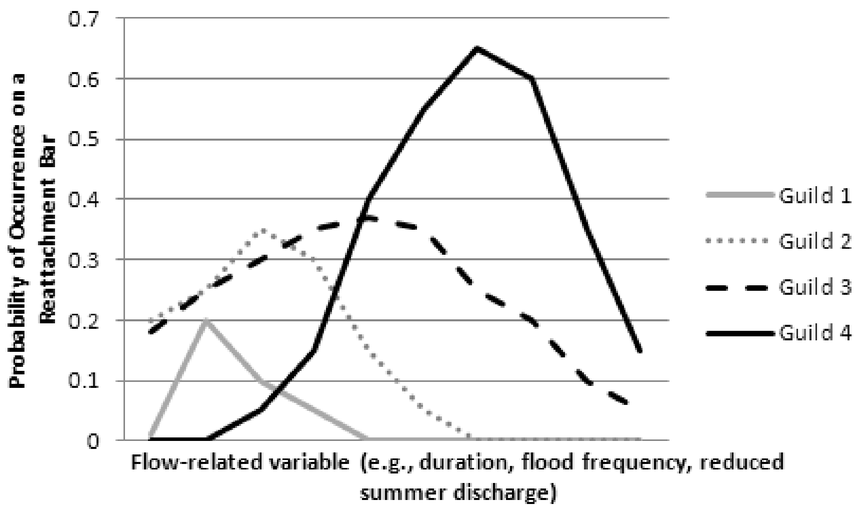

Figure 1. Hypothetical graph of probability of occurrence curves for 4 plant guilds subject to a flow scenario and associated with a typical reattachment bar in Grand Canyon. In this scenario, Guilds 4 and 3 are more responsive to greater variation in the flow variable as seen by the height and width of the curves, while Guilds 1 and 2 have narrower ranges of response and may be found in more specific sites or under more specific flow scenarios (adapted from Merritt and others, 2010).

Implementing a response guild approach for monitoring in Grand Canyon compliments riparian vegetation monitoring that is occurring in other National Parks bisected by the Colorado or Green Rivers (Scott and others, 2011). These monitoring efforts are occurring in association with the National Park Service's Northern Plateau Inventory and Monitoring Program, also known as the Big River Protocol (BRP). The BRP is hypothesis driven, which allows for articulation of system response and focuses monitoring efforts that are crucial for understanding resource response and management options in a scientific context. Further, because experimental releases are part of the Glen Canyon Dam adaptive management strategy, comparisons between changes observed in riparian vegetation in Grand Canyon with those observed in the upstream reaches of the Colorado River basin would be possible.

Measuring and reporting riparian vegetation changes in Grand Canyon has occurred for more than 70 years, but the data stream is not continuous. The discontinuous nature of data collection hampers understanding long-term vegetation responses, particularly vegetation changes due to dam operations. Data includes periodic floristic surveys conducted in the 1930s, 1970s, and 1980s (Clover and Jotter, 1944; Carothers and others, 1976; Phillips and others, 1977; Greene, 1980; Turner and Karpiscak, 1980). The use of repeat photography by Turner and Karpiscak (1980) documented the expansion of plants along the channel margins. Turner and Karpiscak (1980) noted the expansion of tamarisk within the river corridor. Clover and Jotter (1944) noted the presence of tamarisk along the river on their trip in 1938.

Event driven sampling of vegetation occurred in the mid-1980s and early 1990s in response to the large annual floods of 1983, 1984, 1985, and 1986. These years also had unusually large total runoff and only short periods of fluctuating flows. Research during this period was also associated with the Environmental Impact Statement for the operations of Glen Canyon Dam (Stevens and Waring, 1986; Stevens and others, 1995). Sampling measured the loss of vegetation following sustained flooding, and the expansion of woody vegetation following reductions in flows and changes in daily operations.

These results parallel other work on riparian ecology in Europe and the western United States (Nilsson and others, 1989, 1997; Stromberg, 1993; Nilsson and Jansson, 1995) in regulated and unregulated river systems. Ancillary to these efforts, Webb (1996) conducted another repeat photography effort that compared the 1889 Stanton expedition photos with images from the river for the period of 1989–1993. The latter effort provided qualitative information about the state of vegetation prior to implementation of interim flows and modified low fluctuating flow operations. **General conclusions from these studies were that 1) tamarisk colonization events occur following large-scale disturbance, or operations that expose bare substrate for colonization (Stevens and Waring, 1986; Mortenson and others, 2012); 2) that river regulation that reduces flood magnitude and frequency permits the development of marsh communities (Stevens and others, 1995); and, 3) that woody riparian vegetation, in general, would be expected to expand under Record of Decision (RoD) operations because of their greater drought tolerance compared with marsh vegetation that requires greater inundation duration (Stevens and others, 1995).**

The Record of Decision for Glen Canyon Dam operations (U.S. Department of Interior, 1996) included the establishment of the GCDAMP. Urquhart and others (2000) provided the first review of research and monitoring protocols for terrestrial ecosystems. The review was not limited to vegetation sampling and included recommendations for faunal elements (e.g., birds, arthropods, endangered snails). For riparian vegetation, the recommendation was to link sampling to the elevation of different characteristic discharges (e.g., stage) and to expand the number of sampling sites. An overall recommendation for terrestrial monitoring was to develop sampling approaches that integrated multiple biological resource responses to Glen Canyon Dam operations and to develop a vegetation map using remotely sensed data (Urquhart and others, 2000).

A subsequent sampling approach included testing a sample design wherein vegetation plots were rotated during different sample periods and plots at different stage elevations were sampled (e.g., 8,000 ft^3/s , 15,000 ft^3/s, etc. ; Kearsely and others, 2006). Total vegetated cover (%), species richness, and species diversity were determined from the 4 1-m^2 plots and were summed across 60 sampling sites for the river corridor for each stage. Indicator species analysis was conducted for each stage to determine if associated species changed significantly in cover from year to year. Indicator species analysis identifies species that are uniquely associated with a stage. The vegetation map that was created was based on 2002 imagery and identified 6 vegetation classes and determined vegetated area for each vegetation class by geomorphic segment following the geomorphic scheme of Schmidt and Graf (1990) (Ralston and others, 2008). **Conclusions associated with these data collection efforts were that vegetation up to 35,000 ft^3/s is affected by annual operations of Glen Canyon Dam (Kearsley and others, 2006). These results supported the work of Stevens and others (1995). Plant cover data collected in plots above power plant operations (>35,000 ft^3/s) provided information on plant response to the low dam releases that began in 2000.**

Review of this approach (Cooper and others, 2008) suggested that sampling design should incorporate hydrologic and geomorphic units to distinguish plant responses among these environments along the river corridor. Nesting river stage within hydrologic units is complementary with recent riparian response modeling efforts that group riparian plants into flow-related response guilds (Merrit and others, 2010). Cooper and others (2008) recommended retaining the larger scale vegetation mapping effort that estimates area change of vegetation at a landscape scale.

Long-term monitoring that incorporates these recommendations can inform stakeholders about how specific types of vegetation may respond in specific geomorphic settings. These geomorphic features are also associated with other resources of concern (e.g., sandbars that serve as camping beaches), and the information about vegetation response can contribute to the evaluation of these resource conditions. Analysis of total vegetated area monitors vegetation expansion across the river corridor and corroborates smaller scale change observed in ground-based monitoring. Incorporating compatible sampling strategies from other rivers (e.g., Green River, Colorado River in Utah; Scott and others, 2011) within the Colorado River basin provides comparable data and thus aids resource managers trying to determine if the responses in the Grand Canyon portion of the Colorado River are unique, or are typical of the entire basin. Though we cannot replicate the river as can be done in controlled experiments, we can use replicate response guilds to compare hydrologic treatments across the Colorado River basin.

The study area consists of four river segments whose limits are defined by the influence of tributaries and by floristic communities (Glen Canyon, Marble Canyon, eastern Grand Canyon, western Grand Canyon; fig. 2). The confluences of the Paria and Little Colorado Rivers and Kanab Creek with the Colorado River are points that divide the four segments. These river segment designations also overlap with suspended sediment sampling stations and work focused on sediment budgets that bracket Marble Canyon and eastern Grand Canyon (see Project B). Further, assessing response guilds within short river reaches can help stakeholders identify areas that may be more or less responsive to dam operations. Species lists obtained from plot sampling (described below) within these river segments can inform park management of areas where undesirable species occur in greater abundance and allow a more focused approach to controlling these species.

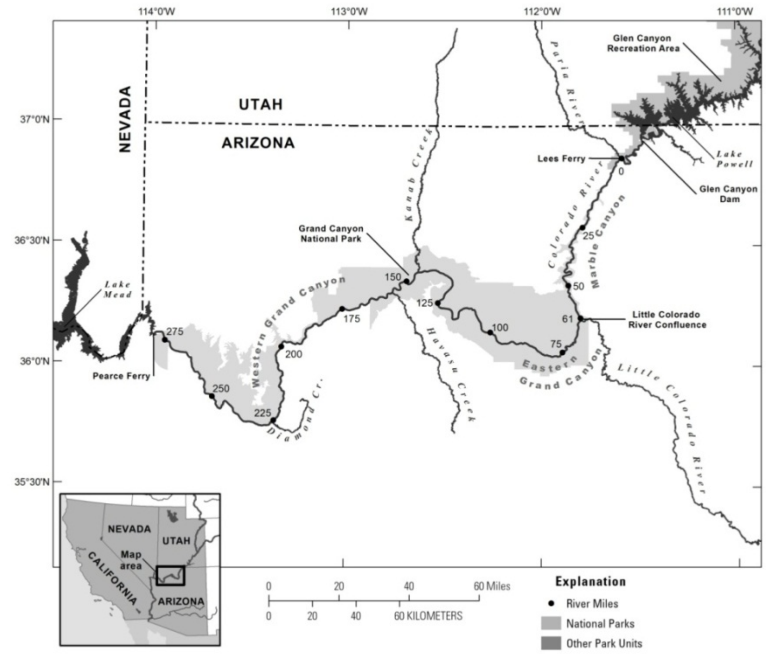

Figure 2. Four landscape-scale reaches used for stratification (Glen Canyon, Marble Canyon, Eastern Grand Canyon, and Western Grand Canyon. The confluence of the Paria, the Little Colorado Rivers Kanab Creek with the Colorado River separates the four reaches).

Ground-based sampling using Flow Response Guilds

Sampling in the BRP (Scott and others, 2011) includes fixed sites and randomly sampled plots that are matched to geomorphic features (e.g., reattachment bar, separation bar, debris fan, channel margins). Sampling downstream from Glen Canyon Dam will follow a similar approach. Fixed sites will be coincident with sandbar monitoring sites (Hazel and others, 2010) and channel mapping segments (USGS, 2011), see Project A. Random sites will be stratified and equal numbers of geomorphic features will be sampled within river segments. Response guild identification will be initiated in 2012 in collaboration with D. Merritt using species lists and data collected from 2001-2005 (Kearsley and others, 2006) and Stevens and others (1995) from 1991-1993.

Fixed site sampling

Sampling sites will be coincident with sandbar and channel monitoring sites. Among the potential sites that can be sampled (50 sandbars and the river channel data from RM 30 to 87), sandbar sites that are most and least responsive, as measured by changes in sand volume and area (Hazel and others, 2010; Schmidt and Grams, 2011) to high-flow events will be established as fixed sampling sites. Data from Hazel and others (2010) will be used to identify these sites. Because the 50 sites in Project A are surveyed and sandbar area and volume calculated, the relationship between vegetation plot locations, associated plant response guild (derived from plot samples) and stage elevation can be determined. Monitoring vegetation response guilds at sandbars that are measured for responses to HFEs and other dam operations can help address physical resource questions about causes of variability in sandbars response. Specifically, this co-located data collection effort can support the monitoring and research question 4 presented in Project A with respect to the role of vegetation and the type of vegetation present on a sandbar affecting sandbar response to HFEs.

Plots at fixed sites will consist of 1-m^2 quadrats that are stratified across geomorphic features within a debris-fan eddy complex (upper pool, debris fan, separation bar, reattachment bar). The number of quadrats sampled will be proportional to the area of each feature. For example, a reattachment bar may be half the size of a separation bar and would have 50% fewer plots sampled. Plots will be randomly placed within each geomorphic feature. Their location will be identified on aerial photos of the site. The 22-cm resolution of the 2009 imagery provides an ability to approximate plot location. Randomized plot points generated prior to sampling trips will ensure unbiased sampling. Because the sandbar sites are topographically surveyed annually (Project A), the topographic information can be used to determine river stage of the random plots. This reduces the time necessary to locate permanent plots and reduces the need to monument plots. The vegetation monitoring determines annual changes in response guilds to dam operations and informs managers about how these changes may affect geomorphic features. Data collected will include cover and species presence. Plot data will also provide species richness and diversity and distinguish between native and nonnative species (table 1).

Table 1. Proposed data collected at fixed sites

Objective	**Data**			**Inference Goal**	
	Raw	Summarized		Trend	Statistic(s) for status
Estimate temporal change in riparian and wetland plant communities	Herbaceous spp			Y*	$\bar{x}$ % cover/sp; p plots/sp
		spp richness		Y	$\bar{x}$ richness
		Total herbaceous		Y	$\bar{x}$ % cover
		PI		Y	$\bar{x}$ index value
	Woody spp			Y*	$\bar{x}$ % cover/sp; p plots/sp; $\bar{x}$ no./m^2
		Total woody		Y	$\bar{x}$ % cover; p plots; $\bar{x}$ no./m^2
	Exotic spp			Y*	$\bar{x}$ % cover/sp; p plots/sp
		spp richness		Y	$\bar{x}$ richness
		Total exotics		Y	$\bar{x}$ % cover; p plots
	Litter			Y	$\bar{x}$ % cover
	Bare ground			Y	$\bar{x}$ % cover

Random site sampling

The objective of random site sampling is to assess the % of the channel in each river segment that has response guilds that may indicate a directional response within each river segment. Plot sampling here is limited the area affected by annual dam operations including HFEs. Sampling will also include an equal number of sandbars, debris fans, and channel margins within each river segment. One-meter square quadrats will be used, and data collected will be on the presence and absence of indicator species of identified guilds and total vegetative cover. Selection of random sites will occur prior to the sampling trip to ensure the sites are logistically feasible. Quadrats will be located along transects that are perpendicular to the channel. Because the locations will be determined prior to launch of the trip, the height above river level to the 45,000 ft^3/s stage can be determined using established stage elevation relationships and flow routing models (Wiele and Griffin, 1998, Hazel and others, 2006). Having the known river discharge for a particular day and time of day can assist in determining distance upslope to reach the 45,000 ft^3/s stage. Successive plots along the transect line will be sampled. These results will be compared with the fixed sampling site results for an assessment of the river segment and total river corridor.

Data will be collected annually at the end of the growing season (September/October) to capture vegetation response to changes in annual flows that may include short-duration flood pulses. The timing for these sampling brackets any likely planned HFE (Wright and Kennedy, 2011). These sampling approaches will also capture non-river related interactions (e.g., tamarisk leaf beetle) that affect changes in community composition.

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

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

As a part of implementing a response-guild approach for monitoring, the development of a conceptual model that uses the identified guilds and their anticipated vegetation response to operations may help identify limitations that dam operations have in altering vegetation trajectories. A model may also identify other hypotheses about vegetation and channel response beyond those already identified in this project (see above). Alternatively, a model may narrow the hypothesis of vegetation response to a one-sided hypothesis (e.g., with x annual operations response guild Y will expand), rather than an either/or statement (e.g., with x annual operations response guild Y will expand or contract). Uncertainty about operational scenarios and vegetation response may also be reduced. A model may be a tool that allows managers to respond to undesired outcomes, or avoid them altogether by eliminating operational scenarios that result in unwanted vegetation responses.

Models can be extremely detailed, and data rich (e.g., ASMR model for Humpback chub population estimates (Coggins and others, 2008) or very simple (e.g., figs. 1, 3) depending on their purpose. A modeling approach commonly used in grassland ecosystems and more recently applied to riparian systems is the state and transition approach (Stringham and others, 2003; Bestelmeyer and others, 2006; Zweig and Kitchens, 2009). This approach recognizes a multi-state pathway and multiple steady states as a way to describe ecological dynamics. A state represents a persistent vegetative community and transitions between states are triggered by events that are natural or managed (Westoby and others, 1989). A hypothetical state and transition model for a reattachment bar is illustrated in figure 3 with five ecological states including an open sandbar with no vegetation. Dam operations would be those transitions that cause the open sandbar to switch to an alternative ecological state or response-guild. Current preliminary state and transition models exist for reattachment bars and separation bars (Ralston and Starfield, unpublished). These models would be refined following more formal response-guild identification.

To validate the preliminary model and expand on its utility, a workshop that brings together riparian research scientists that have worked in the Colorado River downstream of Glen Canyon Dam or other river systems in the southwest is proposed for Fall 2012. A smaller working group from this workshop would work on model components, as needed. The modeling effort is likely to benefit the Long-Term Experiment Management Plan Environmental

Management Plan process with respect to understanding riparian vegetation response to alternative flow scenarios.

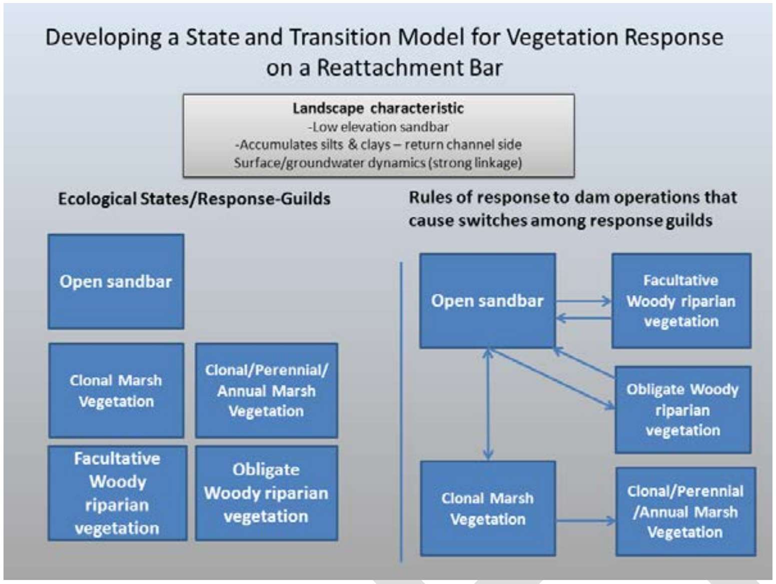

Figure 3. Hypothetical State and Transition Model for riparian vegetation found on a reattachment bar. The ecological states are potential response-guilds and arrows on the right side of the diagram, indicate directions that state can switch to depending on a suite of dam operations (operations causing transitions are not explicitly identified in this figure).

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

Landscape scale mapping of vegetation provides data that can inform stakeholders about the status of multiple resources of the CRe. Riparian vegetation affects camp site quality (Kearsley and others, 1994), eolian transport and archaeological site preservation (Draut and Rubin, 2008), and provides habitat to wildlife (Sogge and others, 1993). Knowing the area cover and the type of vegetation cover is one data source that contributes to the evaluation of the stakeholder's goals for recreation, cultural resources, and riparian communities. Further, data from landscape-scale mapping and change detection of vegetation can supplement and corroborate results obtained from ground-based vegetation sampling. For example, if the area of tamarisk expands in a segment of river as observed in the mapping effort, then ground based sampling should corroborate this finding. The objectives of this portion of the study are to complete a total vegetation database and vegetation class database for the 2009 imagery, and to conduct change detection analysis of vegetation between 2002 and 2009. In May 2013, another overflight will be conducted, and it is anticipated that ground-truthing will take place during this time. Accuracy assessment of the 2009 database will be combined with this field effort.

Corridor-wide Riparian Vegetation Database

This effort produces total vegetation and a vegetation class database with at least 6 vegetation classes for the entire river corridor up to the top of the Old High-Water Zone (at the 250,000 ft^3/s flow stage) using image processing of remotely sensed data. The first such database was generated for the river corridor using the 2002 image data. The approach used Normalized Difference Vegetation Index (NDVI) to determine total vegetation and then classified the result into vegetation classes.

Although NDVI is a commonly used method to segregate total vegetation in multispectral data, a more robust and accurate method is the Spectral Angle Mapper (SAM), which is proposed for mapping using the 2009 imagery. The SAM technique provides the vector angle between the wavelength-band values of an image pixel and user-supplied vegetation spectra. The smaller the vector angle, the more similar the image pixel is to user-designated vegetation. Both sunlit and shadowed vegetation spectra will be used in the SAM analysis in order to map all vegetation, even within shadows. If image band data are consistent throughout the corridor, then the range of SAM values for vegetation should also be consistent, or at least vary systematically throughout the canyon, allowing the vegetation to be mapped quickly. The range of SAM values for vegetation will be determined interactively using the SAM image and its corresponding color-infrared image. Initially, SAM ranges will be determined every 8-km of the corridor; if the derived SAM ranges are consistent or vary systematically, then the observed SAM range relation will be used to map the total vegetation throughout the canyon. The results for each of the 126 image tiles that cover the river corridor will be examined for accuracy and the SAM range adjusted when necessary. If the initial SAM ranges at 5-mile increments are random, then the SAM range for every image tile will be determined and applied interactively to provide an accurate total vegetation database. In order to segregate vegetation in the 2009 image data, the SAM ranges defined by the previous task will be used on the 2009 image data for all 126 image-mosaic tiles that cover the river corridor.

Once total vegetation is segregated in the 2009 image data set (anticipated by fall 2012), a most likely vegetation species will be assigned to each image pixel based on reflectance angle. Even though final mapping will probably occur at the alliance or association level (categories of classification within the National Vegetation Classification Standard (FGDC, 2008)), the spectral band quality of the 2009 imagery are very different in terms of dynamic range, consistency, and accuracy and, therefore, the level of the final vegetation map for this database will not be known until the species classification is completed. We do know that the 2009 image data are much better in all respects than the 2002 digital image data sets. Species classification will be accomplished using the following information, in order of preference: (1) ground observations that occurred near the period of image acquisition in 2009; (2) ground-truth site observations that occurred during other image acquisitions (2002), where it is obvious by visual examination of the periodic images that certain vegetation is the same in the image data being analyzed; and (3) our previously collected ground-reflectance database for the common vegetation species within the canyon. Image classification will proceed in 8-km increments progressing downstream in the river corridor from Glen Canyon Dam, because vegetation composition and the spectral properties of species gradually change downstream.

Image classification will be based mostly on the image-band signatures and canopy texture of representative vegetation species. The 2002 vegetation inventory was produced using an unsupervised (ISODATA) classifier, because we did not have an extensive ground-truth database at the time of analysis. Species classification using the 2009 image data will use a supervised classifier, such as Maximum Likelihood, SAM, or Neural Net. We will experiment with various classifiers to determine the classifier that is most robust and produces the highest map accuracies for most vegetation species. We will use the same canopy texture measures that were employed for the 2002 vegetation mapping, although the areal dimensions of the spatial tools may change due to the higher spatial resolutions of the 2009 image data compared to that of the 2002 image data.

Undoubtedly, there will be ambiguities in the final species classifications, because the spectral and textural characteristics of some species overlap. We will try to reduce the ambiguity using knowledge of dominant species within particular ecotones or river stages, although care will be exercised within the riparian zone not to exclude xeric species. The downslope migration of xeric species has been observed for several years. When the species classification process reaches the point of diminishing returns, a statistical accuracy assessment will be performed on the 2009 results, and a determination will be made as to the aggregation levels for their final vegetation databases. We will also incorporate approaches used in Grand Canyon National Park's vegetation-mapping project to develop compatible layers and classes of vegetation.

Vegetation change will compare changes in area among vegetation classes and total area between 2002 and 2009. Changes in vegetation classes occurring with the debris fan-eddy complexes will be compared with the response guilds identified for the ground-based monitoring component to assess changes in response guilds between 2002 and 2009. Historic aerial photographs from 1984 that are orthorectified and coincide with long-term sandbar studies will be incorporated for change analysis on a longer time scale.

4.2. Collaborations

Project collaborations include the Northern Colorado Plateau Inventory and Monitoring Network (D. Perkins), Grand Canyon National Park (L. Makarick, T. Chaudhry), and other riparian ecologists within the Colorado Plateau (e.g., riparian ecologists from USGS/Fort Collins, Colorado State, US Forest Service, Arizona State University) related to the modeling effort. These collaborations will ensure that data collection approaches implemented downstream from Glen Canyon Dam are compatible with those occurring on other river segments of the Colorado and Green Rivers in the Upper Basin. Data sharing across park management groups is anticipated to enable system-wide comparisons of vegetation response. Image processing, classification, and analysis will be done by researchers within GCMRC, including GIS technical support and a Ph.D. graduate student at the University of Arizona (T. Andrews (USGS), L. Cagney (USGS), P. Davis (USGS), B. Ralston (USGS), J. Sankey (USGS), and U. Nguyen (U of A).

4.3. Deliverables

FY13 Products from the Ground-based Riparian Monitoring and landscape scale vegetation mapping and change detection include:

- Manuscript describing the response guilds found within Grand Canyon (B. Ralston in collaboration with D. Merritt);
- Manuscript of State and transition model for the riparian vegetation for Colorado River and workshop outcome (B. Ralston lead with multiple authors/participants TBD);
- Total vegetated area extraction and quantification; quantification of vegetation within vegetation classes for 2009 imagery; manuscript of vegetation change analysis

between 2002 and 2009 (lead – P. Davis and J. Sankey); May 2013, coincident with the planned overflight, a ground-truthing trip will take place using FY2009 imagery. The ground-truthing will verify the 2009 vegetation data base

- Field data from the September 2013 vegetation monitoring trip will be entered within 30 days of the end of the trip and a trip report submitted to the NPS and Reclamation. Data from 2012 and 2013 will be used to establish base-line vegetation monitoring data report in a U.S. Geological Survey interpretive report or data series report.

For FY 14, products from the ground-based riparian monitoring will include:

- A draft manuscript relating the % and locations of response guilds within river segments of the Colorado River downstream from Glen Canyon Dam (lead B. Ralston), and a species list of plants found within geomorphic features including native and nonnative species (Lead – TBD GS-7 technician).
- For landscape scale vegetation mapping and change detection, products include a draft manuscript of Multi-scale and multi-temporal comparison of vegetation change along the Colorado River from 1984 to 2009 (co-authors P.Davis, J. Sankey, B. Ralston).

5. Productivity from Past Work

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5.2. Completed Publications

Ralston, B.E., Cobb, N.S., Brantley, S.L. and Higgins, J. River regulation increases ground-dwelling arthropod diversity along a semi-arid river. For submission to River Research and Applications.

Cobb, N.S., Ralston, B.E., Brantley, S.L. and Higgins, J. Inventory of ground dwelling arthropods found among three riparian habitats downstream from Glen Canyon Dam and evaluation for monitoring. For submission to Great Basin Naturalist.

5.2. Unpublished Reports

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7. Budget

FY 2013	
Project Element I.1. Monitor Vegetation and Channel Response using Response Guilds and Landscape Scale Vegetation Change Analysis	
Salaries	$133,300
Traveling and Training	$3,800
Operating Expenses	$4,000
Logistics	$43,700
GIS/RS/Electronics support (includes burden)	$137,000
Cooperators (non-USGS)	$28,000
USGS cooperators	$0
USGS Burden	$26,700
Total	**$376,500**
FY 2013 Project I. Gross Total: $376,500	

FY 2014	
Project Element I.1. Monitor Vegetation and Channel Response using Response Guilds and Landscape Scale Vegetation Change Analysis	
Salaries	$133,400
Traveling and Training	$3,800
Operating Expenses	$4,000
Logistics	$28,500
GIS/RS/Electronics support (includes burden)	$137,000
Cooperators (non-USGS)	$28,000
USGS cooperators	$0
USGS Burden	$24,600
Total	**$359,300**
FY 2014 Project I Gross Total: $359,300	

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

1. Principal Investigators

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2. Project Summary

This proposal is composed of three integrated elements that collectively comprise a single research and monitoring project, with the monitoring and research conducted at different spatial scales. In FY13/14, GCMRC will continue monitoring cultural sites in Glen Canyon, continue monitoring a few select sites in Marble and Grand Canyons, and begin a comprehensive Colorado River valley geomorphology research program that will inform current and future cultural site research and monitoring. The objective of the first two elements of this project are to implement a monitoring program to evaluate how our expectations for a suite of flow-related processes and responses at particular cultural resource sites in Glen, Marble, and Grand Canyons compare with actual observed and measured responses under varying flow and local environmental conditions, including expected responses of different groups of sites to the new High Flow Experimental Protocol. The third element of this project initiates a large-scale evaluation of the geomorphic processes which have created and maintain the Holocene deposits in and on which many archaeological sites occur. This element seeks to determine the long-term stability and erosional vulnerability of those deposits and relies on a combination of field measurements, remote sensing, and geomorphic modeling. The integration of small scale, site specific monitoring approaches (Project Elements J.1. and J.2.) with large scale landscape-level assessment approaches (Project Element J.3.) will allow individual site-specific monitoring results to be evaluated in a broader geomorphic context.

3. Background

Cultural resources along the Colorado River downstream from Glen Canyon Dam consist of the physical evidence of past human activities dating back at least 8,000 years before present, as well as places and natural resources of traditional cultural importance to present day communities. Many of the remnants of past human activity, commonly referred to as “archaeological sites” or “historic properties”, are buried by, embedded within, or situated on top of fine-grained sediment derived from the Colorado River. These historically and culturally significant places are susceptible to damage over time due to natural weathering and erosion processes, inundation by the river, and by a variety of visitor use-related impacts.

Grand Canyon is an iconic erosional landscape. Past geomorphic studies (Hereford and others, 1993, 1996; Lucchitta, 1991; Pederson and others, 2003, 2006; Draut and others, 2005; Collins and others, 2009) describe a dynamic landscape where erosion and deposition of boulders, gravel, sand, and mud frequently occur. Whereas some erosion of cultural resources is inevitable given the high intensity rainfall and seasonal winds of this region, past studies (e.g., Hereford and others, 1993) suggest that erosion of the Holocene-age sediment that forms the substrate of many cultural sites in the Colorado River ecosystem (CRe) may have increased during the past few decades. Several factors have been proposed to explain the apparent increase in erosion rates, including increased intensity and magnitude of rainfall during the late 1970s and early 1980s, reduction in the rate at which fine sediment is now supplied to the CRe, the ongoing depletion of fine sediment in sandbars, and secondary effects related to increased visitation and cumulative impacts from recreational use of the river corridor (Hereford and others, 1993; Thompson and others, 2000; Fairley, 2005).

During the past 15 years, two related hypotheses have been proposed to explain how dam operations affect cultural sites in the CRe. One hypothesis (Hereford and others, 1993) suggests that the system-wide decrease in fine sediment, especially at elevations typical of pre-dam floods, has caused gullies to incise and prograde upslope throughout their drainage networks. Hereford and others (1993) suggested that the mouths of most ephemeral tributaries in the pre-dam era were graded to alluvial terrace surfaces high above the elevation of typical base flows. Where tributaries had eroded to enter the Colorado River at lower elevations typical of base flows, high magnitude floods with relatively high suspended-sediment concentrations would have backfilled these gully mouths. In the modern, sediment-depleted conditions of the post-Glen Canyon Dam era, gully mouths are not regularly filled with flood alluvium, gullies have expanded in size, and erosion has propagated throughout the tributary watersheds. Although the hypothesized connection of gully evolution to changes in effective base level was in keeping with some gully evolution models (e.g., Schumm and others, 1984), the application of this hypothesis to management of archaeological sites in the river corridor was extensively criticized by Doelle (2000) in the Final Report of the Protocol Evaluation Panel that reviewed the Cultural Program of the GCMRC; nonetheless, Hereford and others’ (1993) conceptual model still significantly influences river corridor managers and is frequently referenced in administrative documents.

A second, closely-related hypothesis focuses on the role of wind-blown sand in affecting surface infiltration capacity and gully backfilling processes. This hypothesis posits that the reduction in numbers and area of high elevation sand bars (Hazel and others, 2010; Schmidt and others, 2004; Schmidt and Grams, 2011) has resulted in a reduction in the amount of sand transported inland towards archeological sites by wind, and this in turn, has changed the depth and surface characteristics of aeolian sand cover at many archaeological sites (Lucchitta, 1991; Thompson and others, 2000; Draut and Rubin, 2008; Draut, 2012). Because aeolian sand transport is able to counteract surface erosion to some degree by creating expanses of aeolian sand that can absorb rainfall and by filling in small gullies that form during rainfall-induced overland flow events, the post-dam decrease in large, unvegetated sandbars is hypothesized to have resulted in a consequent increase in the amount and intensity of surface erosion. Draut (2012) posits that this process is only significant in controlling gully erosion where there are large sand bars whose surfaces are available to be entrained by wind, and where those sand bars are appropriately positioned relative to the prevailing winds so that the sediment is transported from the bars towards upland areas. The proportion of Glen, Marble, and Grand Canyons that has this favorable combination of factors is currently unknown, but this project (Project Element J.3) will begin to address this information gap.

One objective of the recent Environmental Assessment for Development and Implementation of a Protocol for High-Flow Experimental Releases (HFEP EA) is to propose a protocol that results in redistribution of sand, silt, and clay to higher elevations and to increase the area of bare sand bars that provide potential sand sources for redistribution to higher elevations by wind. It is hypothesized that deposition of aeolian sand can bury and help to protect sites from future erosion. This process has been documented in at least one case by Collins and others (2009). The evaluation of the efficacy of this management technique partly depends on the ability to measure relatively small (<10 cm vertical) topographic changes associated with these processes of deposition or erosion at and near cultural sites, where effects are expected to be much smaller compared to changes in sand bar area and volume immediately adjacent to the river banks (Collins and others, 2009, 2012).

The Grand Canyon Protection Act and the work of the GCDAMP depends on monitoring and research to track and decipher the effects of dam operations and experimental management actions on the CRe and its associated resources. Stated goals of the GCDAMP include the need to track the status and trends of cultural resource condition, evaluate the role that dam operations play in influencing resource condition, and determine how best to mitigate effects due to dam operations (GCDAMP, 2003). A standardized monitoring protocol that can systematically track changes in resource condition tied to dam operations is essential for improving understanding of how dam operations affect cultural sites and also for helping managers understand how and why resource condition degrades (e.g., Wildesen, 1982; Wood and Johnson, 1978). In addition, a robust monitoring program can help managers select the most appropriate methods for preserving sites and can also be useful for evaluating how well the selected erosion control methods perform at decadal time scales. In FY13, Reclamation will implement the new HFEP that is designed to benefit sediment-dependent resources, including cultural resources. Although the effects of high flows on sand bars can be measured with well understood precision and accuracy using established methods (Project A), the degree to which high flows mitigate and influence erosion rates through backfilling tributary mouths or the degree to which changes in sand bar size affect aeolian deposition rates at archaeological sites is poorly known. Thus, an expectation of Project J is the refinement of an accurate and precise monitoring program to track the amount and rate of physical change occurring at cultural sites in the CRe and to determine whether and to what degree dam operations are responsible for that change.

Scientists struggle to understand whether measurement of small changes in aeolian deposition is necessary to describe the effects of dam-controlled flows, and especially the High-Flow Experimental Protocol, at cultural sites, or if large-scale, coarse resolution measurements are sufficient to measure these effects. Similarly, scientists debate the amount of erosional change that needs to be detected at cultural sites. Some archaeologists have argued that measurements must be to a scale of 10-15cm, because changes larger than this have the potential to irreversibly damage, or in some cases, completely obliterate, archaeological deposits and cultural features. Other scientists hypothesize that coarse resolution measurements are sufficient to monitor site status over the large spatial scale of the CRe. Project J aims to tackle these difficult questions through collection and interpretation of high resolution topographic data at a suite of archeological sites in the CRe (Project Elements J.1 and J.2), and through subsequent analysis of those measurements in the context of landscape-scale mapping and geomorphic modeling (Project Elements J.3).

As noted above, a critical objective of this project is to place the small scale, detailed measurements proposed in Project Elements J.1 and J.2 in the context of CRe-scale processes. This effort to provide large-scale, geomorphic context will be accomplished by an integrated suite of field-based and model-based approaches (Project Element J.3). Modeling is an important tool with which to describe the field situation in a relatively simple suite of processes and parameters. These modeling approaches will be used to inform our understanding of how dam operations potentially affect landscape geomorphic and vegetation processes that in turn affect site stability and erosion rates. The ultimate aim of this modeling effort is to identify those sites that are most vulnerable to the effects of weather, human visitation, and other factors.

3.1. Scientific Background

Native people have lived in and made use of the natural resources of the Glen, Marble, and Grand Canyons for thousands of years. Western scientists first became aware of this fact when John Wesley Powell observed and commented on the presence of ancestral Puebloan ruins located at several places along the banks of the Colorado River and encountered actively tended native gardens in western Grand Canyon (Powell, 1875). After Grand Canyon became a National Park, and especially after river running became a popular recreational past time, many additional archaeological sites were documented (Adams, 1960; Adams and others, 1961; Euler 1969, 1974; Fairley, 2003; Fairley and others, 1994). With the initiation of plans to build dams in Grand Canyon, the first professional efforts of archaeologists to inventory the river corridor were undertaken (Adams and others, 1961; Euler, 1967c; Taylor, 1958). This pioneering work, supplemented by subsequent studies by NPS archaeologists, eventually led to the documentation of over 130 prehistoric and historic archaeological sites in the river corridor (Fairley, 2003). Early efforts to document archaeological evidence in Glen, Marble, and Grand Canyons were not comprehensive in scope, nor did they consistently meet modern archaeological standards for documentation. Therefore, when the need for a thorough inventory of the river corridor was identified in the late 1980s, the Bureau of Reclamation sponsored a comprehensive archaeological survey as part of the Glen Canyon Environmental Studies, Phase II, program. Between August 1990 and April 1991, a team of NPS archaeologists documented 475 archaeological sites between Glen Canyon Dam and Separation Canyon, of which 336 were evaluated as having the potential to be directly or indirectly affected by future dam operations (Fairley and others, 1994). These sites ranged in age from several thousand years before present to the mid-20th century and included structures, artifact scatters, petroglyphs, roasting pits, constructed trails, and a variety of other physical remains representing the activities and detritus of past human occupation along the Colorado River. The 336 sites that were evaluated as being directly or indirectly affected by dam operations were situated in or on Holocene deposits derived from the Colorado River, within the area potentially affected by maximum controlled releases from Glen Canyon Dam, or on sediment derived from pre-dam flood events (Fairley and others, 1994; USDI 1995).

As previously noted, the environmental processes and factors that contribute to the current condition of cultural resources in the CRe are complex. Because the vast majority of archaeological sites in the CRe are situated well above the elevation reached by 25,000 ft^3/s (hereafter referred to as "stage") (Sondossi and Fairley, *in revision*), effects of dam operations on cultural sites are mainly indirect and manifest themselves through diffuse effects to the larger terrestrial ecosystem (Fairley and others, 1994; Fairley and Sondossi, 2010). The Glen Canyon segment of the Colorado River has no significant fine sediment supply (Topping and others, 2003), and the Paria River contributes around 5-10% of the pre-dam sand supply to Marble Canyon. Downstream from the Little Colorado River, about 15% of the pre dam sediment supply is available (Topping and others, 2003). In addition to these effects that are related to the existence of the dam, the post-dam flow regime has effectively eliminated low flows that formerly would have allowed sediment to accumulate in the channel and also the very high flows that formerly redistributed sediment to higher elevations (Topping and others, 2003), while the higher average daily volume of water released through the dam transports fine sediment out of the system on an essentially continuous basis (Wright and others, 2008).

These conditions of fine sediment deficit and changes in flow regime have resulted in a decline in the number, size, and volume of sandbars in Marble and Grand Canyons (Topping and others, 2003; Schmidt and others, 2004; Schmidt and Grams, 2011). Along with the decrease in bar volumes, daily fluctuating flows, in conjunction with expanding riparian vegetation (see Project I) have had the effect of limiting the amount of open, dry sand area available for redistribution by wind, resulting in the deflation of formerly active sand areas that covered and partially protected many cultural sites in the CRe (Draut and others, 2005, 2006; Draut and Rubin, 2008; Thompson and others, 2000).

The post-dam loss of high elevation sand has led to a situation where Marble and Grand Canyons have less active aeolian sand area than does the less regulated Cataract Canyon immediately upstream from Lake Powell reservoir (Draut, 2012). Thus, available evidence indicates that the existence of Glen Canyon Dam and its present flow regime have led to reduced aeolian sand supply and increased biological soil crust cover, which further reduces mobility of high-elevation sand deposits, with multiple interacting effects to surface erosion processes. However, rainfall-induced erosion is a natural process in Grand Canyon, and pre-dam floods inundated and eroded many cultural sites in the past. Thus, erosion of cultural sites is a natural and ongoing process that would be occurring whether or not Glen Canyon Dam existed (Hereford and others, 1993; Hereford and others, *in review*, Pederson and others, oral comm., 2011). ***Therefore, a key research question that needs to be resolved is not whether cultural sites are eroding or otherwise changing but whether they are eroding or changing faster or in a significantly different manner than they would if the dam was operated differently than it has been.***

Interest in the potential of dam operations to affect erosion rates at cultural resource sites in the CRe dates back to the early 1980s when NPS archaeologists first observed an increase in the amount and severity of gullying at archaeological sites (Hereford and others, 1991; Fairley, 2003). In 1989, a decision by the Department of Interior to undertake research on the downstream effects of Glen Canyon Dam initiated several studies focused on mapping the geomorphic context of archaeological resources and the geomorphic processes acting on those resources (Hereford and others, 1991, 1993, 1996; Lucchitta, 1991). This initial phase of research led to the publication of several detailed maps that emphasized the distribution of Holocene deposits in areas of high cultural resource density, plus several reports documenting changes in the post-dam environment (Hereford and others, 1993, 1996; Hereford, Burke and Thompson, 1998, 2000a, 2000b; Lucchitta, 1991).

One hypothesis that emerged from this initial research effort focused on the role that changes in the post-dam flood regime plays in affecting gully formation and erosion processes. Hereford and others (1993) hypothesized that, in the pre-dam era, archaeological sites were subject to the same fundamental geomorphic processes that they are today but that natural erosion processes were ameliorated to some degree by annual spring and monsoon-season floods of the Colorado River that periodically deposited a large volume of fine-grained sediment on terraces, in eddies, and along the channel margins. During large flood events, fluvial deposits backfilled the mouths of tributary drainages (McKee, 1938). Hereford and others (1993) hypothesized that these backfilling events had the effect of temporarily raising the *effective* base level of minor tributaries. Hereford and others (1993) observed that many tributary drainages are not integrated with the main stem of the Colorado but debouch onto alluvial terrace surfaces several meters above the level of the active river channel, forming small temporary ponds in the dune fields. Without periodic restorative floods, however, Hereford and others (1993) argued that many of these drainages eventually work their way out to the terrace edge and integrate with the mainstem Colorado River. Once this occurs, gullies rapidly erode headward, as the drainages re-grade their channels to the lower base level of the main channel.

Lucchitta (1991) added an important nuance to Hereford and others' (1993) hypothesis by focusing on the role of wind-blown sand in reducing the erosion potential of alluvial terraces and associated archaeological sites. Lucchitta (1991) hypothesized that in pre-dam times, barren sand bars and open sand areas were more prevalent, owing to both more frequent flood-related depositional events and more frequent low flows. Consequently, there was more sand available for redistribution by wind and more wind-blown sand covering the surfaces of terraces and archaeological sites. The aeolian sand cover helped to absorb rainfall and reduce the potential for rainfall-induced gullying. Furthermore, with more abundant sand available for redistribution by wind, the smaller gullies that did form on terrace surfaces were backfilled by sand prior to the next gullying event, thereby reducing the potential for gullies to erode further and become integrated with the mainstem.

Thompson and others (2000) built upon on this body of work and proposed a geomorphic model based on the familiar and widely-used Universal Soil Loss Equation. They measured gully catchment area, made imprecise slope measurements, and estimated vegetation cover and soil characteristics. They categorized approximately 100 sites in the CRe in terms of their susceptibility to future gully erosion. Although the model and study were subsequently criticized for failing to adequately account for the effects of hill slope processes (Doelle, 2000), this research made important contributions by exploring the influence of aeolian sand cover as a natural mitigation to erosion by comparing the condition of alluvial terraces and gully size in Cataract Canyon, where a less regulated river system still allows for high spring floods and associated high elevation sand deposition, to the condition of sites in Grand Canyon. Thompson and others (2000) also found that gullies were fewer and smaller in Cataract Canyon terrace deposits than in Grand Canyon.

Draut and Rubin (2005, 2006, 2008) further explored the role of aeolian sediment in preserving archaeological sites. As part of this research, anemometers, rain gages, and sand traps were installed at several locations within the river corridor, and information was collected on wind speed and direction, rainfall, and sand-transport rates near selected archaeological sites (Draut and Rubin, 2006, 2008). These instruments established large-scale wind regimes, an essential component of understanding whether and where fine sediment from sandbars deposited by controlled floods is transported onshore by wind toward threatened archaeological sites. Data from these instruments were used to document effects of the 2004 controlled-flood experiment, and demonstrated differences in sand-transport rates in various locations.

Concurrently with these research efforts, the NPS began experimenting with various techniques for monitoring erosion and topographic change at archeological sites in Grand Canyon. NPS monitoring methods underwent considerable modification throughout the 1990s, beginning initially with qualitative observations, and then progressed to repeat oblique photography and total station surveys (Leap and others, 2000). Use of total station surveys was abandoned, however, because it soon became apparent that total station survey methods could not measure small-scale topographic changes over large areas with sufficient precision and accuracy without causing extensive surface disturbance. Other remote sensing methods, such as oblique, ground-based photogrammetry, did not detect topographic changes over large site areas at a satisfactory level of resolution. Pederson and others (2003) argued that in order to detect erosion (especially the progression of nick points in gully thalwegs) before gullies incised to the point of irreversibly damaging archaeological features and deposits, it was important to be able to detect vertical changes on the order of 10-20 cm. Pederson and others (2003, 2006) explored low altitude semi-automated aerial photogrammetry as an alternative monitoring method in an attempt to refine the amount of topographic change that could be reliably detected within gullies. Based on experiments using very low altitude, helicopter-based imaging technology, Pederson and others (2003, 2006) concluded that changes less than 20 cm could not be reliably measured using that approach. Therefore, they measured gully thalweg incision rates using repeat, conventional total station survey methods.

Although measuring gully thalwegs using traditional total station survey methods is not without challenges (Pederson and others, 2003, 2006; Hazel and others, 2008), this method remains a reliable and efficient option for measuring rates of gully thalweg incision. However, if an objective of monitoring is to detect sediment deposition as well as erosion over entire site areas, then total station surveys are not the best or most appropriate tool.

Within the past decade, rapidly evolving lidar (light detection and ranging) technology has offered scientists an alternative option for obtaining precise measurements of topographic change over large areas. Collins and Kayen (2006) first demonstrated lidar's potential utility for documenting topographic and vegetation change in the CRe. Elsewhere, lidar has been widely used by archaeologists as an architectural documentation tool (Barber and others, 2006; Hough and Brennan, 2007; D. Jones, 2007; Korumaz and others, 2010) and for mapping sites in advance of excavation. Lidar has also been used to monitor millimeter-scale erosion of stone surfaces exhibiting prehistoric rock art (Barnett and others, 2005). While the concept of using lidar as a monitoring tool has been in use for several years, actual application of lidar for detecting and quantifying rates of topographic change across entire site areas had not previously been demonstrated prior to the initiation of GCMRC's cultural monitoring project in 2006. In recent years, however, the Bureau of Reclamation has initiated a monitoring project using airborne lidar as a primary tool for tracking erosion impacts at archaeological sites in the American Falls Archaeological District and is using terrestrial lidar to document baseline site conditions for long term monitoring of erosion and vandalism impacts at archaeological sites at the Cedar Bluff Reservoir in Kansas (Bureau of Reclamation, 2008.)

Project J is a direct outgrowth of the phased program of research and development that was undertaken in 2006-2010 towards implementation of a long-term core-monitoring program

(Fairley and others, 2007). The first phase of this project (Phase I) began in spring 2006 and initially focused on completing a comprehensive assessment of the geomorphic and archaeological attributes of 232 river corridor sites (O'Brien and Pederson, 2009a) to characterize the range of variability in the population of potentially affected archaeological sites and to aid in the selection of an appropriate sample for a future pilot monitoring program (Vance and Smiley, 2011). As described above, Phase I also involved testing a variety of survey techniques, in addition to terrestrial lidar, as potential tools for measuring change in resource condition (Collins and others, 2008).

The applicability and utility of monitoring archaeological sites using terrestrial lidar was subsequently demonstrated at 11 sites in Grand Canyon (e.g., Collins and others, 2008, 2009, 2012). Collins and others (2008) showed that terrestrial lidar technology could be used to collect data as accurate as or better than total station techniques for large areas while minimizing impacts to the sites being monitored. Collins and others (2009) showed that topographic changes greater than 8 cm in the vertical could be documented using a state-of-the-art terrestrial lidar instrument at 6 of 9 monitored sites. Since these initial field studies, advances in the technology have resulted in laser scanning devices with greater accuracy and new software with improved potential to measure small-scale (centimeter-level) topographic change (Collins and others, 2012). Incorporating these advances, Collins and others (2012) collected multiple comparable lidar data sets at 11 sites over a 5-year period. This effort demonstrated that (1) change could be reliably and accurately detected at less than 5 cm and (2) it is possible to link observed changes to specific geomorphic processes. Development of a network of solar-powered weather stations for monitoring local weather conditions throughout the river corridor was also a component of the initial research and monitoring effort (Fairley and others, 2007; Draut and others, 2009a, 2009b, 2010a, 2010b). These weather data are currently informing researchers about the conditions that drive surficial changes at archeological sites, such as those detected by Collins and others (2009, 2012).

3.2. Key Monitoring and Research Questions Addressed in this Project

Grand Canyon National Park (GCNP) archeologists began monitoring cultural sites in the river corridor during the late 1970s, and they continue to do so. Kintigh and others (2007) observed that the current NPS monitoring approach is designed to document the presence or absence of visitor use impacts and other types of threats and disturbances. These threats and disturbances include observation of the presence of gullies that potentially compromise the integrity of cultural sites. The NPS monitoring approach results in a general determination of site condition. Based on observed impacts, NPS archaeologists assign a rating of poor, fair, good, undisturbed, or destroyed to characterize overall site condition (See NPS Archaeological Site Information Management System Handbook and GCNP's Colorado River Management Plan Cultural Resource Monitoring Protocols for more information). Kintigh and others (2007) noted that past and present GCNP monitoring programs are not designed to distinguish or track dam effects from other processes.

The NPS monitoring approach relies on assigning sites by categorical monitoring criteria that are supplemented with repeat photographs of impacted areas. Maps are drawn to show locations of specific impacts. Monitoring is performed to meet the Park's compliance obligations under Section 110 of the National Historic Preservation Act (NHPA) and to demonstrate progress towards achieving federally-mandated goals for historic preservation under the Government Performance and Results Act. At the same time, the NPS monitoring program results in identification of sites that may require excavation or other forms of "treatment" to preserve their cultural, historic, and scientific values. The same approach is currently used by GCNP archaeologists to monitor impacts associated with implementing the Colorado River Management Plan and to monitor sites on the canyon rims (E. Brennan, oral communication, August 2011).

In 2000, a cultural Protocol Evaluation Panel (PEP) recommended redesigning the Bureau of Reclamation (Relamaction)'s 1994–2000 Programmatic Agreement (PA) monitoring program to focus more specifically on monitoring the effects of dam operations and evaluating the efficacy of erosion control efforts (Doelle, 2000). Specifically, the PEP recommended that the monitoring activities of the NPS and GCMRC should be integrated and refocused to: (1) evaluate the effectiveness of long-term management strategies (including treatments designed to control/minimize erosion) and (2) evaluate effects of different flow regimes on archaeological sites and other cultural resources such as Traditional Cultural Properties (TCPs). The PEP noted that "monitoring should be designed and organized to serve as the basis for periodic quantitative evaluations of the effect of dam operations, effectiveness of erosion control methods, and development of treatment plans."

Throughout the history of the GCDAMP, there has been ongoing discussion and considerable debate about the need for monitoring programs in general and what purpose(s) monitoring is supposed to serve. In general terms, monitoring can serve a broad variety of purposes (Hellawell, 1991):

- To assess the effectiveness of policy or legislation;
- To comply with regulatory requirements (performance or audit function); and,
- To detect incipient change ("early warning system").

Noon (2003) proposed an additional reason: to "assess the value and temporal (or spatial) trend of those indicators that characterize the state of an ecological system." In the GCDAMP generally, and in the cultural program arena specifically, all of these reasons have been cited as driving the need for monitoring (GCDAMP, 2003). Additionally, there is concern with meeting legal mandates, such as those identified in the Grand Canyon Protection Act (GCPA), which calls for "long term monitoring programs and activities that will ensure that Glen Canyon Dam is operated in a manner consistent with that of Section 1802." Section 1802 requires that the dam be operated in such a manner as to "protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established including, but not limited to natural and cultural resources and visitor use." In addition, there are legal obligations embedded within the National Historic Preservation Act (NHPA) that require federal agencies to consider effects of their actions on cultural resources (NHPA, Section 106) and also for the responsible land manager to identify, evaluate, and protect historic properties under their care (NHPA, Section 110). While monitoring is not specifically required for compliance with NHPA, monitoring is often implemented to assess effects or to evaluate the effectiveness of mitigation measures.

In the 2003 Strategic Plan (GCDAMP, 2003), GCDAMP stakeholders distinguished two monitoring categories: "Core Monitoring" and "Effects Monitoring". The GCDAMP developed the following definition of core monitoring:

Core monitoring consists of consistent, long-term, repeated measurements using set protocols and is designed to establish status and trends in meeting specific management objectives. Core monitoring is implemented on a fixed schedule regardless of variable factors or circumstances (e.g., water year, experimental flows, temperature control, stocking strategy, non-native control, etc.) affecting target species.

Effects monitoring, on the other hand, was defined as:

… the collection of data associated with an experiment performed under the Record of Decision, an unanticipated event, or other management action. Changes in resource conditions measured by effects monitoring generally will be short-term responses. The purpose of effects monitoring is to supplement the fixed schedule and variables collected under core monitoring. This will both increase the understanding of the resource status and trends and provide a research opportunity to discover the effect of the experiment or management action.

The project described here will implement monitoring protocols to address both "core monitoring information needs" (CMINs) and "effects information needs" (EINs) for cultural sites in Glen and Grand Canyons. The highest priority CMIN for historic properties,as revised by the Cultural Resource Ad Hoc Group (CRAHG) and adopted by the Science Planning Group (SPG) of the GCDAMP in the fall of 2005, is:

CMIN 11.1.1 (SPG revised**).** Determine the condition and integrity of prehistoric and historic sites in the CRe through tracking rates of erosion, visitor impacts, and other relevant variables. Determine the condition and integrity of TCPs in the CRe.

In 2007, an expert panel reviewed the previous PA monitoring protocols and existing NPS monitoring data and developed recommendations for potentially incorporating these "legacy" monitoring data into future monitoring programs for the GCDAMP (Kintigh and others, 2007). Among several recommendations, the panel recommended that the monitoring program be redesigned to "unpack" the concept of site condition and separate out the factors affecting site condition that are potentially dam related from those that are not (Wood and Johnson, 1978; Wildesen, 1982; Jones, 2007). In addition, the reviewers suggested exploring the use of lidar technology as a tool for measuring and tracking surface changes at archaeological sites that are potentially influenced by dam operations. At the same time, the panel recommended developing a model reflecting current understanding of how dam operations affect archaeological site condition, and to use the monitoring program to evaluate whether model predictions conform to monitoring results. The current proposal incorporates these recommendations.

As noted previously, this project is aimed at addressing the highest priority CMIN for historic properties (as revised by the CRAHG and SPG in fall 2005):

This project is also designed to address two primary Strategic Science Questions (SSQs) identified in the 2007 Monitoring and Research Plan (GCMRC, 2007):

- **SSQ 2-1.** Do dam-controlled flows affect (increase or decrease) rates of erosion and vegetation growth at archaeological sites and TCP sites in the CRE, and if so, how?
- **SSQ 2-4.** How effective are various treatments (e.g., experimental flows, check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term?

A high-quality monitoring program is also essential for determining whether management actions designed to stabilize or improve site conditions are working as intended. Therefore, this project also directly addresses EIN 11.1 (formerly CMIN 11.1.2 of the GCDAMP Strategic Plan, subsequently re-designated by CRAHG/SPG as EIN 11.1):

- **EIN 11.1.** Determine the efficacy of treatments for mitigation of adverse effects to historic properties.

Additionally, this project addresses a general GCDAMP research information need (formerly identified as CMIN 11.1.4 in the 2001 GCDAMP Strategic Plan):

How effective is monitoring, what are the appropriate strategies to capture change at an archaeological site—qualitative, quantitative?

More recently, AMP stakeholders have worked with DOI management agency personnel to craft descriptions of desired future conditions (DFCs) for resources in the CRe, which are intended to provide general targets for resource conditions to guide future monitoring and management projects, and the Department of Interior has accepted these DFCs as official program guidance (Salazar, 2012). The DFCs for archaeological sites identify preservation in place as the desired goal for archaeological sites and specify rates of erosion or deposition as one metric for assessing whether desired future conditions are being achieved. Other metrics for assessing cultural resource condition include the presence of other impacts that affect National Register eligibility of sites (such as evidence of artifact collecting and deliberate vandalism).

In summary, Project J has been designed to be responsive to the stated goals of the GCDAMP, the recommendations of the 2000 PEP (Doelle, 2000) and the 2007 Legacy Monitoring Data review panel (Kintigh and others, 2007), the needs of Reclamation and NPS related to compliance with Section 106 and Section 110 for assessing effects of normal dam operations and effectiveness of experimental management actions such as HFEs, as well as the effectiveness of other non-flow management actions that may be initiated in the future to achieve the management goals for *in situ* preservation of archaeological sites. The data collected by this project will also be relevant for addressing strategic science questions.

4. Proposed Work

At its most basic level, monitoring provides a means to assess either stability or change. As the sophistication of monitoring increases, then there is increasing potential to determine causes for stability or change. Within the context of archaeological sites in the CRe, site-specific topographic monitoring allows an assessment of site stability. Similarly, as the sophistication of monitoring increases, we are able to assess potential causes for instability. Since it is important to the NPS, as land manager, to have monitoring techniques that are cost efficient, replicable, and, most importantly, time sensitive to recognize the development of instabilities at archeological sites, any monitoring program must recognize and aim to address each of two fundamental goals: (1) to inform whether dam operations are, or are even capable of, affecting archeological sites, and (2) to identify when geomorphic changes (whether from dam operations or from other sources) are occurring at sites that might warrant future mitigation.

To achieve these goals, we must first determine what factors, be they climatic or anthropogenic have the potential to affect archeological site stability. This must then be coupled with a quantitative assessment of where these factors influence the landscape. Once quantified, we can then determine if the factors actually cause quantifiable change at the archeological sites that NPS manages. Generally speaking, research to date (e.g., Hereford and others, 1993; Leap and others, 2000; O'Brien and Pederson, 2009b; Collins and others, 2009, 2012; Draut, 2012) has identified the key factors potentially affecting archeological sites. What is needed is a follow up quantification of how these factors affect particular sites throughout the CRe. Then, concise, targeted monitoring can be proposed to assess if the expected processes are resulting in site change.

Project J is designed to make headway on each of these points. As such, we propose a quantitative assessment of geomorphic processes throughout the CRe, relying on the extensive work by O'Brien and Pederson (2009a) to guide both the determination of processes and their spatial distribution throughout the CRe. We propose to build on this effort by combining the GIS database of archeological sites in the CRe with the O'Brien and Pederson (2009a) database and with knowledge of regional prevailing wind patterns in the CRe so that we can extract and delineate process patterns by river segment. For example, identifying the number of archeological sites located in dynamic, erodible substrates provides a measureable expectation for the monitoring and/or mitigation necessary for managing these sites. Similarly, if we can determine the % age of sites in the CRe that are potentially affected by HFE effects (e.g., sites located downwind from sand bars), then we will be able to evaluate the overall expected potential effects from such HFEs. By quantifying the number and proportion of sites that not only are influenced by aeolian sand (based on the O'Brien and Pederson, 2009a database) but also have the potential to receive new sand supply from HFE sandbars (based on prevailing wind patterns and the locations of HFE-enlarged sandbars), we will be able to address the long-standing question of what number and what proportion of river-corridor archaeological sites could benefit potentially from renewed aeolian sand supply after a sandbar-building HFE. This will assist in quantifying management expectations for such experiments.

As another component of this work, we propose a targeted terrestrial-lidar-based monitoring effort focused on sites that can potentially receive new windblown sand from HFE sandbars as well as sites that have no prospect of being restored by windblown HFE sand. This effort builds upon previous work aimed at quantifying topographic changes at archaeological sites (Collins and others, 2009, 2012). We know that this type of monitoring (terrestrial-lidar) is applicable for certain types of sites, but not all, and that it will inform particular research questions regarding the effects of dam operations on archeological site stability. At other sites, changes related to dam operations may not be expected at all and qualitative assessments or repeat photography may suffice for assessing site condition. Thus, suites of monitoring strategies are likely to be appropriate in the CRe for assessing site stability. However, the main effort of this current proposal is not structured around implementing a full suite of strategies, as this can only be done after the processes and their spatial distribution have been quantified. Our current proposal is formulated around the concept that targeted archeological site monitoring can be used to inform the expectations of how sites respond to certain stressors. For example, where erosion is measured, monitoring should provide a means to assess whether erosion is progressive or is intermittently offset by depositional processes. In addition, monitoring provides the inputs to test models for both reconstructing measured site changes and projecting expected site behaviors. Again, in the context of archaeological sites in the CRe, quantitative monitoring data will feed geomorphic models capable of examining various cause and effect scenarios driving gullying erosion.

In addition to the proposed work that will quantify the spatial distribution of various processes affecting archeological sites throughout the CRe, Project J outlines and evaluates a monitoring strategy consisting of extensive and precise topographic measurements accompanied by weather data collection at eight archaeological sites, four in Glen Canyon and another four in Grand Canyon. Through the monitoring program, we will track rates and amounts of erosion and deposition, as well as areas of surface stability at this sample of sites. Whereas this proposal focuses on the collection of pertinent data necessary to continue to quantitatively assess short-term changes affecting site condition of archaeological sites in the CRe (and therefore complementing ongoing NPS efforts to monitor site condition using qualitative methods), the project work has also been structured to address several existing research questions of importance to site response from the potential effects of high flows and to longer-term expectations of site condition. The sites proposed for monitoring have been specifically selected on the basis that an understanding of their individual geomorphic and topographic behavior will provide either confirmation or contradiction to existing expected responses. Although specific sites are described here as the locations for our work, we will continue to consult with the NPS to identify other sites that may be appropriate to include in this initial monitoring effort, given the specific objectives of this project and the geomorphic criteria used to select these sites (see below).

One of the goals of this proposal is aimed at establishing quantifiable data that segregates CRe archeological sites from one another based on the expected process regimes affecting their condition and location within the river corridor. This will assist in answering such remaining unanswered questions as:

"What number and proportion of archeological sites have the potential to benefit from new aeolian sand supply from future HFE building sand deposits?"

With this established by the work described in this project, we will be in a more informed position to assess the potential for various monitoring strategies to inform managers about dam effects. In some cases, as described in the next sections, we have expectations for how some sites should behave. However, we require carefully collected data to properly assess our expectations. Monitoring has already shown that existing assumptions as to how the river system may behave under both natural and anthropogenic changes (i.e., HFEs) can be both confirmed or challenged based on what is recorded at the site- specific level. Thus, precise topographic measurements can help inform on both the individual and cumulative effects of small-scale incremental changes, as well as the effects from less frequent, but often more dramatically transformative, episodic events, such as exceptionally intense storms, high main stem flows, and tributary floods. The small-scale, site-specific measurements of Project Elements J.1 and J.2. will inform the larger-scale, landscape-process investigations that will be conducted under Project Element J.3.

In summary, the objective of the first two elements of this monitoring and research project are to monitor the physical condition of a small sample of archaeological sites that represent the settings and types of sites most likely to reflect flow-related impacts and to further assess expectations for a suite of dam-controlled flow effects, including HFE-related processes and responses, at particular types of archaeological resources in Glen, Marble, and Grand Canyons. The third element of this project initiates a large-scale evaluation of the geomorphic processes that have created and maintain the Holocene deposits in and on which archaeological sites occur. This third project element seeks to determine the long-term stability and erosional vulnerability of those deposits and relies on a combination of field measurements, remote sensing, and geomorphic modeling. The integration of small-scale (J.1. and J.2.) and large-scale (J.3.) approaches links the large-scale geomorphic context to the detailed measurements obtained from the sample of specific archaeological sites.

4.1. Project Elements

J.1. Cultural Site Monitoring in Glen Canyon ($161,700)

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As a starting point for determining whether current archeological site erosion rates exceed pre-dam rates, it is necessary to quantify and understand the context of current rates of erosion occurring at sites. For example, if, as hypothesized by Hereford and others (1993), tributary drainages crossing alluvial terraces cut down and retreat faster once they become integrated with the main drainage of the Colorado River, it is essential to have data documenting differences in rates of erosion between terrace-based and river-based tributaries. Additionally, if, as hypothesized by several researchers (e.g., Lucchitta, 1991; Thompson, 2000; Draut and Rubin, 2008; Draut, 2012), a reduction in aeolian transport to sites leads to changes in the depth and characteristics of surface cover, then we should expect that sites located in river reaches with little to no sediment input (i.e., Glen Canyon) should erode more quickly than those with at least some sediment input (i.e., Marble and Grand Canyons).

To address these hypotheses, we propose monitoring and analysis programs in both Glen Canyon (this project element) and Marble and Grand Canyons (Project Element J.2). Monitoring can provide a perspective on the cumulative effects of diverse processes acting on cultural sites. Such a program can also provide a site-specific perspective on how dam-related processes and impacts, weather, and other environmental factors interact to affect the physical stability and rates and amounts of erosion occurring at cultural sites. Although the monitoring approach described here is primarily designed to track and quantify trends in the amount and rates of erosion and deposition, and thereby provide a measure of site stability and current resource condition, the resulting data have the potential to shed light on the cumulative effects of diverse and diffuse geomorphic processes acting over time as well.

The project element described herein outlines and evaluates a monitoring strategy consisting of collection of precise topographic, site condition, and weather data at four archeological sites in Glen Canyon. In addition, the project proposes collection of high resolution topographic data over a large portion of Glen Canyon between Glen Canyon Dam and approximately 6 miles upstream from Lees Ferry. The purpose of the site-specific data collection is to quantify the existing state and rate of erosion at archeological sites and to use the data in geomorphic modeling analyses (see Project Element J.3). The collection of canyon-wide topographic data in Glen Canyon will also provide information on the state of erosion outside of archeological sites, in the upstream half of Glen Canyon. Thus, this project element is aimed at answering several key research questions including what the state of erosion is in and around archeological sites in Glen Canyon and whether erosion rates between terrace- and river-based tributaries differ. The sites selected for monitoring in Glen Canyon provide a variety of erosional features in various states of development that allow comparison and contrast of erosion rates with sites in Marble and Grand Canyons.

Proposed Monitoring and Site Locations

In FY13/14, the monitoring program for Glen Canyon will measure surface changes, track trends in condition, and measure weather data at four sites (AZ C:2:0032, AZ C:2:0035, AZ C:2:0075 and AZ C:2:0077). In addition, we will collect and analyze topographic data in the reach between Glen Canyon Dam and approximately river mile -6.0 using airborne lidar methods in order to identify and quantify a large suite of geomorphic features such as gullies and rills that might influence erosion rates at the archeological sites. In FY13, we will collect the airborne lidar data and use these data to: (1) calibrate the accuracy of the airborne data via comparison with the terrestrial data and (2) detect any topographic changes that may have occurred that are above the accuracy threshold determined by the calibration. In FY14, we propose to resume site-specific monitoring with terrestrial lidar; however, the decision to conduct monitoring in FY14 will be based in part on an assessment of recent flow and weather conditions. If there is no possibility that changes could have occurred in the intervening months, we will forego additional monitoring in FY14 and continue to analyze the airborne data and integrate these data with the geomorphic models developed in Project Element J.3.

Unlike the majority of sites in Glen Canyon, many of which are located on cliff faces unaffected by Glen Canyon Dam operations or on lands managed by the Navajo Nation, the four sites targeted for detailed monitoring in Glen Canyon are located on NPS lands within and on the surface of fine-grained alluvial terraces adjacent to the Colorado River. These sites are situated in the upstream half of Glen Canyon, where sediment inputs to the system are minimal, and where on-going erosion of cultural deposits is evident. The sites provide locations in which to measure erosion rates that might be expected to be at their maximum for the river corridor, thereby bracketing expectation at other sites further downriver. The four sites are clustered between River Miles (RM) -11.5 and -9.5 and are situated in and on interbedded mainstem alluvium and colluvium dating between 2000-8000 BP. The four buried sites are of corresponding age; two of the sites also exhibit evidence of more recent use during the ancestral Puebloan occupation of Glen Canyon (ca. 1200-800 BP). These sites include some of the oldest archaeological materials documented in the river corridor, with one site producing a calibrated 2-sigma C_{14} date on wood charcoal from a hearth of 7320–7070 BC (Anderson, 2006: Table 1).

All sites show signs of recent active erosion. In one place, the terrace cut bank shows evidence of recent slumping, where large blocks of fine sediment have dropped directly into or immediately adjacent to the Colorado River, threatening the integrity of two sites perched on the brink of these cut banks, and clearly indicating that processes other than gully incision may pose erosional threats to cultural sites. In another area farther upstream, the terraces and associated sites have been affected by post-dam floods. Previous work by Grams and others (2007) documented significant amounts of terrace erosion and cut-bank retreat in the vicinity of all four sites between 1956 and 2000 (see especially Figure 6 in Grams and others, 2007). The individual archaeological sites exhibit various forms and intensities of recent erosion, from relatively minor gullies incised into terrace scarps to large scale retreating terrace cut banks. At one site, an arroyo has cut down through >3 m of fine grained alluvium to Navajo sandstone bedrock, and the gully appears to be laterally expanding in multiple directions through cut bank and headcut retreat.

It is important to note that owing to their threatened and eroding condition, three of the four sites proposed for targeted monitoring in the Glen Canyon reach (AZ C:2:35, AZ C:2:75 and AZ C:2:77) have recently been identified by Reclamation as potential candidates for data recovery (archeological excavation) (see Reclamation's Cultural Resources Program Implementation Project, this volume). However, Reclamation's plans for mitigating dam effects are still conceptual, and site-specific consultations with Native American tribes have not yet occurred; therefore, we propose to move forward with the plan to monitor these four sites and conduct terrestrial vs. airborne trade-off analysis while details about future mitigation actions are being worked out. If Reclamation and NPS decide to conduct full site excavations in FY13, monitoring would be redirected towards other sites in 2014. Alternatively, if future mitigation activities are restricted to only small-scale excavations or non-invasive treatment methods, then monitoring of these sites in future years would continue. In either case, the topographic data that will have been collected through lidar monitoring will allow us to evaluate the potential of using airborne lidar in lieu of terrestrial lidar for monitoring future changes in the CRe, and the existing topographic data will provide highly detailed and accurate base maps for documenting excavations or other treatments that may occur in the future.

Research Questions

The primary goal of the Glen Canyon monitoring is to identify the current geomorphic state of the selected archeological sites and to establish whether these states are what should be expected given the historical weather patterns in this area. A secondary goal is to address whether the state of erosion in Glen Canyon is higher than river segments downstream from Lees Ferry in Marble and Grand Canyons where the availability of fine-grained sediment (the Paria River, Little Colorado River, and other tributaries) has the potential to influence site stability. The precise measurements performed using terrestrial lidar, combined with site-specific modeling to be undertaken in Project Element J.3, will address the first goal, whereas the airborne data collection and analysis will partially address the second goal.

The topographic data provided by site-specific terrestrial lidar data collection in FY12 will provide some of the required input to the geomorphic model to begin addressing the first goal outlined above. In addition, we intend to analyze weather data available from Page, Arizona (Station: PAGE, available from National Climatic Data Center since 1957) to determine if the number of erosive events from precipitation is likely to account for all of the erosion measured at these sites. This question will be explored using site-specific models that project erosion rates under varying precipitation regimes and environmental constraints (see Project element J.3). Unlike the previous work of Grams and others (2007) that examined the issue of channel erosion and narrowing in Glen Canyon using large scale, course grained approaches (i.e., by measuring changes in channel cross-sections and comparing aerial photos), Project Element J.1 focuses on documenting the state of erosion of the alluvial terrace surfaces and associated archaeological sites. The analysis work will begin with analysis of the Page weather data to synthesize a record of all storms during the post-dam time period that are of sufficient magnitude to have caused gullying at the study areas. The model will use these as cumulative inputs to generate an end scenario representing the expected gullying morphology resulting from this time period. Additionally, the air photo analysis proposed in Element J.3 will be used to guide the model results (i.e., if particular precipitation events appear to have caused gullying, we will try to verify these events with temporally-proximate air photos, if available). These results will then be compared to the actual gullied topography provided by the terrestrial lidar surveys. If the modeled erosion is more than what is likely to have occurred since 1963, when the dam cut off the sediment supply to Glen Canyon, then this would indicate that the erosion at these sites is a pre-dam feature. Although this would not necessarily discount that dam influences might still be causing increased erosion, answering this question and quantifying the erosion is a first step to understanding the recent (post-dam) geomorphologic history of the sites. Overall, we intend this analysis to provide general conclusions on a site-specific basis – these results will then be tied into the system wide analysis conducted by Element J.3 in order to put the site specific conclusions into context. For example, if several of the site's modeling results indicate that all gullying appears to have occurred in the post-dam time period, these will be compared to the likelihood that the aeolian character of these reaches might have changed during this time period.

The research second goal of Project Element J.1. focuses on answering the following research question:

Are archeological sites in Glen Canyon significantly more eroded (e.g. are gullies more incised) compared to those found downstream from Lee's Ferry where the fine-grained sediment supply is larger?

Through topographic and geomorphic analysis of the airborne lidar data collected in Glen Canyon, we plan to obtain an overall quantitative assessment of the state of erosion in the upper half of the Glen Canyon reach. These airborne results will be compared to similar data collected from select reaches downstream in Marble and Grand Canyons (Davis and others, 2004), as well as to the known state of erosion at specific sites in Marble and Grand Canyons from previous research and monitoring efforts (e.g., Hereford and others,1993; O'Brien and Pederson, 2009a; Collins and others, 2009, 2012) to provide a quantitative evaluation of this question. If weather conditions are comparable, and if it is found that the degree of erosion is higher in Glen Canyon, this would be indicative that fine-grained sediment inputs to Marble and Grand Canyons are likely having some positive effects on archeological site stability. Although this does not necessarily provide a conclusive answer, it would support the hypothesis that archeological sites are affected by sediment sources potentially influenced by dam operations (i.e., by both controlled flow regimes and blockage of fluvial sediment). If no difference is found between stretches above and below Lees Ferry, this would indicate that erosion is mainly controlled by effects other than sediment input (i.e., variable precipitation patterns). As part of this work, we will compare precipitation data between Page and Phantom Ranch, Arizona (Station: PHANTOM RANCH, available from National Climatic Data Center since 1966) to assess historical precipitation variability as a potential cause for erosional differences between Glen Canyon and Grand Canyon. We note that these long-term weather data can only be used to paint broad-brush assessments of the climate in the two parts of the canyon and can not necessarily be used to inform on smaller site-scale processes discussed in element J.2.

Methods

Topographic Data Methods

Using methods developed during a preceding phase of this project (Collins and others, 2008, 2009, 2012), we propose to collect topographic data in FY14 at the four sites where we collected data in FY12. In FY13, however, the main data collection effort in the Glen Canyon reach will be an airborne lidar survey covering the upper half of the segment, from Glen Canyon Dam to approximately river mile -6.0. This effort will capture not only the topography of the immediate site areas monitored by terrestrial methods in FY12, but also the topography of the terrain surrounding the sites. In addition to collecting information on the topographic context of each site, collection of airborne lidar in FY13 will serve as a basis for assessing the efficiency, costs, and data accuracy of both data collection methods. Further, the airborne dataset will provide a baseline topographic record for other sites not currently being monitored within the scanned area. We expect airborne lidar to produce slightly less accurate measurements of much larger areas at somewhat less cost per area. Airborne lidar will be collected and processed by an external contractor, then delivered to GCMRC for analysis. Data collection will also involve a ground survey effort (conducted by USGS personnel in conjunction with the external contractor) to establish control points for georeferencing the data. This will include total station and/or RTK GPS data collection.

Both terrestrial and airborne data will be edited and filtered to produce a “bare-earth” terrain model without reflections from vegetation canopy. Assuming that airborne and terrestrial lidar datasets are comparable surface maps of each site area from each time period will then be generated and compared with one another in order to document the amount, rate, and specific locations of erosion and deposition, as well as deterioration of built features (hearths, structures, etc.) that may become exposed at sites over time. Collins and others (2009, 2012) provide technical details of how surface change is calculated using terrestrial lidar measurements; nearly identical protocols are used to integrate airborne methods. An important focus will be the comparison of resolution and accuracy of the two lidar types, as well as the comparison of the relative capacity of terrain models produced from the lidar data types to quantify topographic variability with accuracy and precision sufficient to characterize and predict the relevant gullying and aeolian processes. The accuracy of the models is expected to be less than 2 cm in the case of terrestrial lidar and on the order of 10 cm in the case of airborne lidar. Precision at this scale allows identification of subtle topographic features that might allow prediction of future gully knick points, areas of aeolian dune growth or deflation, and rilling.

The resolution of the raw and filtered data is expected to differ for the two types of lidar collection, and this can initially be assessed by comparison of the point density between the two data types for the raw and filtered datasets. After filtering is performed to produce the bare-earth terrain models, the terrestrial lidar dataset can be compared to the airborne data set, and both lidar data types can be evaluated for elevation (vertical) and horizontal accuracy with a suite of methods and metrics previously developed and reported by Collins and others (e.g., Stewart and others, 2009; Stock and others, 2011; Zimmer and others, 2012). For example, to evaluate the elevation accuracy, the RMSE, bias, and dispersion of each lidar data type can be compared to ground points (e.g., control network or total station survey). The lidar data types can also be directly compared to one another using the same metrics. Relative horizontal accuracy of each lidar data type can be assessed by evaluating ability to characterize lateral dimensions of well-defined surfaces and erosional features. The horizontal accuracy assessment can be performed in reference to ground points from the total station control point survey as well as directly between the two lidar data types.

Analyses will include identifying gullies and other erosional features and measuring their geomorphic attributes (e.g., width, depth, length). This will be performed in a GIS environment. Field verification will be necessary to ensure data calibration and accuracy; this can be performed in conjunction with the weather station monitoring trips also proposed in this research element (see below). Additional analyses will include relative comparisons to data sets already available from Marble and Grand Canyon to determine the overall degree of erosion between Glen Canyon and Marble and Grand Canyons.

Supplementary Site Condition Monitoring

In addition to the collection of high-resolution topographic data, supplementary monitoring data will be collected at the same sites. Supplementary monitoring data will include repeat photography using automated digital cameras and observational data recorded during annual field visits. The automated repeat photography will record daily images of the sites to document physical changes with high temporal resolution. The supplementary observational data will provide data on characteristics that describe the cumulative state of erosion and on a short timestep basis that is useful in separating the various erosive agents from one another. Observational monitoring will emphasize condition factors that cannot be detected remotely, such as soil crust cover changes and human impacts such as soil compaction from trampling, graffiti, vandalism, artifact piling, and structural modifications. These data will be integrated with data derived from existing NPS monitoring protocols so that a combined site condition monitoring approach that serves both the needs of NPS archeologists to track overall site condition and USGS geomorphologists to track potential dam effects can be developed. We expect that close collaboration with NPS staff will be necessary for this work.

Meteorological Monitoring

Although previous studies have explored the relationship between weather and archaeological site condition to varying degrees (e.g., Hereford and others, 1993; Thompson and others, 2000; Draut and Rubin, 2008; Draut and others, 2010a, b; Hereford and others, *in revision*), the degree to which local weather variation affects archaeological site condition and erosion warrants further evaluation. Weather data are essential for evaluating the role of individual storm events in causing specific types and amount of overland flow and gullying and for evaluating the effectiveness of erosion control measures under varying weather conditions (Pederson and others, 2003; Draut and Rubin, 2008; Collins and others, 2012). Therefore, in addition to monitoring the condition of individual cultural sites and the overall historical patterns between two long-running weather stations (see previous discussion with respect to the Page and Phantom Ranch stations), two weather stations installed near the mouth of the Paria River and near the archaeological sites at approximately river mile -10.0 in FY12 will monitor a suite of weather parameters in FY13/14. These stations will allow us to better understand the range of local weather variability in this part of the river corridor. We will analyze these data and determine if the largest storm events are capable of causing erosion and/or deposition. This analysis will be tied closely to the modeling analyses proposed in Element J.3. Repeat surveys of the sites will then confirm whether the expected erosion and/or deposition actually occurred as a result. Our conclusions will aim to determine site-specific thresholds for geomorphic change to the sites. These data will also complement weather data proposed for collection downstream in

Marble and Grand Canyons. The monitored parameters include temperature, rainfall intensity and amount, wind speed and direction, barometric pressure, and humidity. In addition to the two weather stations, a single, unobtrusive rain gage installed in FY12 in the vicinity of AZ C:02:0075 will collect supplementary data on local precipitation rates.

The data collected from these weather stations will be managed in accordance with protocols developed and implemented during the previous Cultural Resource Monitoring Research and Development project (e.g., Draut and others 2009a, 2009b, 2010a.) See project J.2 methods section for additional description of the proposed management, analysis and use of these meteorological data.

Logistical Support

Logistical support for Project Element J.1 will require one low altitude (~100 m above ground surface) helicopter-based lidar data collection mission of 1-2 hrs duration in the winter of FY13, and a 5-day motorized boat-support mission to collect site specific data using terrestrial lidar in FY14. In both years, the main data collection mission will be supplemented with several single-day trips by motorized skiff to download and maintain the weather station at river mile -10 mile and the rain gage near RM -11.5. These latter, 1-day trips may be carried out in conjunction with other ongoing monitoring efforts conducted by the GCMRC biology program. In addition, two single-day motorized raft trips will be necessary prior to and immediately following the airborne overflight to install and remove GPS ground control instruments.

Research Expectations

The monitoring strategy provided herein is intended to provide the necessary data to assess the current site condition with respect to expected geomorphic change. In addition, the data should be sufficient to establish conclusive baseline levels for future research efforts. In addition, the data will allow researchers to consider and understand the effects of archaeological site change in an area of the river in which the sediment supply has been completely shut off. This can help establish a “control” data set to compare with expected changes further downriver in which the sediment supply is slightly higher and may be cumulatively increased as a result of high-flow experiments (HFEs).

Project Element J.2. Monitoring of Select Cultural Sites in Grand Canyon ($191,100)

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Proposed Monitoring and Site Locations

Similar to the monitoring program for Glen Canyon, in FY13/14, monitoring in Grand Canyon will focus on measuring geomorphic processes and land surface change at four cultural sites: AZ C:05:0031, AZ C:13:0321, AZ B:10:0225, and AZ G:03:0072. Based on surface evidence, three of these sites date to the Puebloan era (1200-800 BP); the other is primarily protohistoric in age (<700BP). These sites are all situated in areas mantled with aeolian sand; subsurface materials are primarily debris fan colluvium, coarse gravels, and sandy alluvium.

Unlike the sites being monitored in Glen Canyon, all of which are primarily threatened by progressive erosion, the four sites in Grand Canyon have been selected for long-term monitoring based on their geomorphic settings, surface characteristics, and specific locations in the river corridor landscape which place them in positions that are potentially conducive for aeolian deposition. These sites are situated downwind from sand sources that will be potentially enlarged by future high flows. These sites are distributed throughout the river corridor, in both narrow and wide reaches of the CRe, and all are associated with active or semi-active aeolian areas. In addition, the topography of each of these sites has been measured at least twice previously between 2007-2010 by Collins and others (2008, 2009, 2012), providing a foundation for extending long-term trend data at these sites. Monitoring thus far has identified important aspects of site change with respect to archaeological site stability. These include extensive gullying and subsequent gully infilling at AZ:B:10:0225 during 2007-2010 and continued site erosion at AZ:C:13:0321 despite a positive buildup of an upwind river-sandbar-derived sediment source.

In addition to the formally structured monitoring work described above, we will further analyze the geomorphic data collected by O'Brien and Pederson (2009a, 2009b), segregating sites into geomorphic categories and analyzing their distribution in the river corridor using GIS. We will use the qualitative geomorphic assessments of individual archaeological sites prepared by O'Brien and Pederson (2009a) to identify sites situated on sandy substrates, in coppice dunes, or in active aeolian areas that received an erosion ranking of 1 or 2 (stable or only slightly eroding), as well as sites situated in similar settings with erosion rankings of 4 or 5 (seriously or severely eroded), and select a non-random sample of these locations to investigate in the field. The purpose of these field visits will be to evaluate and discuss with colleagues the specific conditions that appear to contribute to site stability and severe erosion. These field visits will include the researchers involved in Project J and archaeological staff from GCNP. The data collected from these site visits will be incorporated into the interpretations of monitoring results for project element J.2 and syntheses of mapping and aerial image analysis (Project Element J.3).

Research Questions

Monitoring the four selected sites in Grand Canyon will allow us to track rates of deposition and erosion at sites optimally situated to benefit from future HFEs and to test the hypothesis that over time, individual sites situated near sand sources that are situated predominantly downwind from these sources, will be less prone to gullying and ultimately more stable than sites located in areas where sediment resupply via aeolian deposition does not routinely occur. For example, at sites AZ:C:05:0031 and AZ:C:13:0321, previous HFEs have provided an upwind sediment source (Draut and Rubin, 2006, 2008). However, whereas a river sandbar formed upwind of these sites in the 2008 HFE and some aeolian sediment was transported either near or directly to these sites, we nevertheless recorded an overall erosion signal during a six-month interval several years later. This leads to the following question:

> ***Is the magnitude of aeolian transport to and deposition at sites from river sand bars sufficient to offset erosion, and thereby protect archaeological resources?***

This question will be addressed at the site-scale in Element J.2 and will be expanded into a larger, reach-scale assessment in Element J.3 below. Monitoring the four sites proposed here in Element J.2 will provide evidence either that erosion is progressive or that occasional deposition reverses the effects of erosion. Past monitoring data at two sites (AZ:B:10:0225 and AZ:G:03:0072; see Collins and others, 2012) has demonstrated that large gullies can and do form in active aeolian areas (see also Draut and Rubin, 2006). In addition, these data also indicate that the processes responsible for obliterating evidence of these gullies may be more complex and less benign than simple infilling by wind-blown sand. For example, at one site near Fossil Canyon, previous monitoring documented a fresh, deep, vertical-walled gully that had formed during an intense rainstorm during September 2007. Three years later, this gully had been modified from a steep-walled arroyo with a V-shaped cross section, to a broader and shallower gully with an open U-shaped cross section. Topographic monitoring showed that this transformation involved large scale deposition on the floor of the former arroyo, accompanied by bank slumping and horizontal expansion of the gully perimeter (Collins and others, 2012). Much of the infilling appeared to be due to slumping of the arroyo side walls rather than aeolian infilling, although there was evidence of some aeolian infilling as well. Thus, although three years later the gully was shallower and less sharply defined than in 2007, the overall effect was a lateral expansion of the gully area accompanied by more than 100 m³ of net erosion. Over time, it is likely that the gully will eventually disappear, but the ground surface on either side of the former gully will be considerably lower and will result in significant (more than 15 cm) surface deflation, directly impacting the integrity of adjacent cultural deposits. Thus, although evidence of erosion may not be visible in future years, the cultural site and its associated deposits will have experienced a net loss of sediment. The meaning of these observations can be framed within the following research question:

In areas with active aeolian deposition, do sites that are subjected to significant gullying (i.e., >30cm downcutting) undergo net topographic lowering such that the physical and informational integrity of archaeological resources are impacted?

The monitoring of this site over time will allow us to evaluate whether these predictions are born out over time, and if not, what processes intervened to change the trajectory of the site's topographic evolution.

Systematic, measurement-based monitoring at these sites, along with the geomorphic modeling already initiated and expanded upon in Project Element J.3, below, will provide a means to quantitatively assess the relative components of site change.

Methods

Topographic Surveys

Topographic data will be collected using a combination of conventional total station mapping and RTK GPS for establishing survey controls and for pin-pointing knickpoint positions within gullies, along with ground-based lidar for capturing the topography of entire site areas and documenting surface changes through time. In addition, these data will be accompanied with automated digital photography (taken from the same position as the lidar scanner.) These complementary data provide both a realistic visual and interpolated digital topographic image of the site.

Ground-based lidar provides a remotely-sensed solution for obtaining high resolution, highly precise topographic surveys. The ability to measure changes at the sub-decimeter scale is necessary to identify topographic subtleties, such as knickpoints and dune deflation, that often govern site erosion patterns. Collins and others (2008, 2009, 2012) provide details and descriptions for the use of this technology in Grand Canyon.

Ground-based lidar surveys will be directed by either GCMRC personnel or cooperating USGS scientists following methods employed and refined in Phase I (Collins and others, 2008, 2009, 2012). Lidar data will be manually edited and filtered to produce a "bare-earth" terrain model without reflections from vegetation canopy. The terrain models will then be compared to existing datasets from each of these sites previously collected between 2006 and 2010. This will provide a short-term understanding of archaeological site change that will inform the geomorphic modeling work and aerial photographic analysis proposed under Project Element J.3.

Supplementary Site Condition Monitoring

In addition to the collection of high-resolution topographic data, supplementary monitoring data will be collected at the same sites where topographic surveys are performed. Supplementary monitoring data will include repeat photography using automated digital cameras and observational data recorded during annual field visits. In Grand Canyon, the automated repeat photography will record daily images of the sand bars that are the aeolian source deposits for specific sites, as well as the sites themselves to track changes in their overall size and level of inundation under varying flows. The supplementary observational data will provide data on characteristics that describe the overall state of site erosion in a cumulative sense and on a basis that tries to separate the various erosive agents from one another. One purpose of this latter effort is to assess the differences in the quality of site assessment information gained by detailed lidar measurements and simple qualitative assessment techniques. Observational monitoring will emphasize condition factors that cannot be detected remotely, such as soil crust cover changes and ground-disturbing human impacts such as trailing. This aspect of the project will be undertaken in cooperation with GCNP.

Although not dam-related, human visitation impacts at archaeological sites can have profound effects on site condition. While some human impacts are intentional and deliberately destructive, in National Park settings most visitor impacts are inadvertent, incremental, and cumulative. However, even unintentional impacts can have profound impacts on archaeological site integrity over time. For example, foot paths created by visitors can evolve over time into erosion channels, as precipitation run-off concentrates and flows along the shallow linear depression created by visitors repeatedly walking to and from sites. Likewise, trampled zones created by visitors milling about on sites can create compacted soil areas where rainfall pools, then overflows down trails, creating a more concentrated flow and more severe erosion than would otherwise occur if the soil had not been compacted. Although the full extent of human impacts at cultural sites in the CRe has not been systematically analyzed, we know from the monitoring reports of Native American tribes that visitor impacts are observed at many tribally-valued cultural sites. For example, in the 2010 report of the Zuni tribe, Dongoske (2011) reported that 34 of 61 monitored sites (56%) exhibited human impacts unrelated to Glen Canyon Dam. When human impacts are combined with system-wide decreases in sand bar areas and aeolian sediment replenishment, as is occurring downstream from Glen Canyon Dam effects to site condition may be more extreme than if human or dam effects were occurring separately. For this reason, human impacts to archaeological sites need to be monitored and considered along with potential effects of dam operations and climate factors in assessing changes to site condition in the CRe. We propose to do this using a combination of approaches, including documenting area of disturbed and undisturbed biological crust cover and tracking specific geomorphic changes and surface evidence linked to human activities. This work will be undertaken in cooperation with the staff of GCNP. Once quantified, we will use these data in a modeling framework to assess if human-induced site changes are expected to outpace natural causes such as aeolian or gully-induced erosion, thereby quantifying expected responses at a suite of sites.

Meteorological Monitoring

In conjunction with the site-based topographic monitoring, three existing weather stations located adjacent to three of the four sites are proposed for continued monitoring of rainfall, wind, and other weather characteristics. Detailed weather data has been collected from some of these stations since 2007, and continuing data collection at these sites will allowing a long term, high resolution weather record to be acquired for these sites that can be used to evaluate the role of climate and local weather events in affecting current site conditions. In addition, a new station is proposed to be installed near the fourth site (AZ B:10:0225) to constrain precipitation characteristics here that has previously led to high-intensity gully erosion events and to document when wind conditions conducive to aeolian transport and deposition occur. A distribution of stations throughout the river corridor will allow us to track the range of local weather variability and verify assumptions regarding the amount and intensity of rainfall and wind that drives gully erosion and infilling at sites. These data will directly drive modeling efforts proposed in Project Element J.3. The monitored parameters include temperature, rainfall intensity and amount, wind speed and direction, barometric pressure, and humidity. These data will complement similar weather data being collected in Glen Canyon and provide a generalized spatial understanding over a majority of the river corridor.

These weather data will be managed in accordance with protocols developed and implemented during the previous Cultural Resource Monitoring Research and Development project (e.g., Draut and others 2009a, 2009b, 2010a.) Data will be downloaded at 3-4 month intervals and examined for evidence of significant storms, periods with high rates and volumes of precipitation, and high wind events that could cause significant erosion or deposition at nearby sites. The weather data will be compared with photographic data (see below) to document and contrain the timing of significant erosional or depositional episodes. In the previous project, annual reports summarizing each year's weather data were produced, but in FY2013, as part of this project. we will develop a USGS data series report so that in the future, weather data can be served routinely via GCMRC's website following previously established protocols.

Site Visits to Assess Local Factors Contributing to Site Stability

In addition to the formally structured monitoring work described above, we propose to visit additional site locations where previous monitoring and assessment work has indicated either little or no evidence of active erosion or severe erosion. We will use the qualitative geomorphic assessments of individual archaeological sites prepared by O'Brien and Pederson (2009a) to identify sites situated on sandy substrates, in coppice dunes, or in active aeolian areas that received an erosion ranking of 1 or 2 (stable or only slightly eroding) and 4 to 5 (serious to severe erosion). The purpose of these field visits will be to evaluate and discuss with colleagues the specific conditions that appear to contribute to site stability and significant erosion. These field visits will include the researchers involved in Project J and archaeological staff from GCNP.

In addition, in order to quantify erosion potential, including the ability to model erosion (see Project element J.3), we will collect infiltration capacity and shear strength measurements of representative areas with which to quantify the susceptibility to water and wind erosion. Representative areas include talus slopes, eolian dunes (active and inactive), and terrace sands. Methods similar to those of O'Brien and Pederson (2009b) will be used. These methods are standard in soil hydrology field measurements and include use of automated mini-disk infiltrometers and vane-type shear strength tests. Mini-disk infiltrometers measure the rate of water infiltration into soil from a small (~3cm diameter) tube, which are often combined with data loggers to accurately determine the rate of water influx. Vane-type testers (e.g. Torvane) apply increasing shear to intact sediments until deformation occurs, which accurately determines the shear strength. Shear strength is an important characteristic, because it represents the amount of energy that must be applied to dislodge soil particles (i.e., to initiate erosion). These methods are time intensive but are minimally intrusive and give accurate measurements of soil properties. We will also test "proxy" measurements that can be made with less time-consuming methods such as Li and others (2010).

Logistical Support

A single river trip per year will collect the topographic data necessary for archaeological site change detection at the four sites. This trip will be coupled with the geomorphic data collection proposed in Project Element J.3. to both minimize costs and to ensure sufficient overlap between researchers working on different parts of this project. For example, it will be essential that relevant geomorphic information from Project Element J.3. be integrated with the observations made as a result of the monitoring and change detection proposed here. We proposed to utilize additional planned GCMRC river trips being conducted for other research purposes for data retrieval and maintenance of the weather stations. The effort to collect weather data is not expected to be a significant burden on any of these existing trips.

Research Expectations

We expect that the monitoring and research proposed herein will make direct contributions to understanding changes in archaeological site condition on several fronts. First, we will be able to track decadal scale trends in topographic change in order to gain confidence in tracking the effects of geomorphic processes on site condition. Second, we will quantify the processes leading to site change.

Project Element J.3. Defining the Extent and Relative Importance of Gully Formation and Annealing Processes in the Geomorphic Context of the Colorado River Ecosystem ($187,100)

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The balance of forces that cause gully incision in relation to those processes that cause gully annealing, or infilling, ultimately determines the eventual extent of erosion into Holocene sediment deposits and the archaeological sites associated with those deposits. Thus, a more thorough understanding of the interaction between gully incision and annealing processes as they operate today in Glen, Marble, and Grand Canyons is essential for evaluating the extent to which dam operations have altered the physical and cultural resources there. Analyzing gully erosion processes and the effectiveness of gully amelioration in the modern river corridor is also important for evaluating the possible future progression of erosion in sediment deposits above the modern high water line and the archaeological sites within and on those deposits. The proposed work to be undertaken for Element J.3 is a large-scale, process-based geomorphic study that will provide a more complete context for the site-scale processes measured and monitored by Elements J.1 and J.2. The reach-scale geomorphic study of Element J.3 is intended to evaluate to what extent the site-scale processes measured under J.1 and J.2, such as gully erosion and aeolian deposition or deflation, shape the overall landscape in upland aeolian dune fields containing cultural sites. The larger-scale evaluation of landscape processes in J.3 will inform GCDAMP managers as to what may be expected as aeolian landscapes continue to evolve in the future and may erode and expose archaeological sites that have not yet been exposed or documented, and so have never been subjected to site-based monitoring.

In addition to linking with measurements made in Elements J.1 and J.2, Element J.3 will build on related previous landscape investigations by researchers including Hereford and others (1993, 1996), Thompson and others (2000), Pederson and others (2006), Collins and others (2009, 2012), Draut and others (2008, 2010a), and Draut (2012). The work proposed in Element J.3 will be concentrated in segments encompassing approximately 100 river km in Glen, Marble, and Grand Canyons, though reference will be made to other locations as necessary, based on investigators' past experience working in other areas and on findings from the aerial photographic record. The investigators will seek to relate findings there to other areas of the Colorado River corridor that have either already been investigated or in which related work will be pursued under separate (non-GCDAMP) funding. The goal of this proposed work is to develop and refine quantitative and conceptual understanding of gully development and annealing in order to evaluate the effectiveness of management actions on a large scale (such as controlled flooding) and smaller scale (such as check dams and other site-scale erosion control measures) in reducing gully erosion of sediment deposits and associated archaeological sites.

Gully erosion of alluvial deposits occurs as a result of episodic rainfall forming overland flow runoff. Storms in Grand Canyon and the surrounding region occasionally produce sufficiently intense rainfall to exceed the infiltration capacity of terrace sand deposits, generating runoff that may have sufficient erosive power to form gullies. However, a more common occurrence in Marble and Grand Canyons is for rainfall runoff over nearly impermeable upland bedrock or talus surfaces to form overland flow that concentrates and localizes upslope of sand deposits and then incises into the sand deposits. Gullies that erode sand deposits in this way can terminate either at the Colorado River or on terrace surfaces at higher elevation than the river (Hereford and others, 1993). Factors contributing to the formation of gullies include the catchment or drainage-basin area, slope, permeability of the substrate in and upslope of the alluvial deposit, and rainfall intensity. As discussed above, natural processes counteracting gully incision would be infilling by large, sediment-rich floods, and windblown sand deposition. Infilling by deposition during large floods is consistent with long-standing field observations that spatially extensive unconsolidated, fine-sediment deposits in Grand Canyon are composed predominantly of flood-deposited material (for example, Lucchitta, 1991; Hereford and others, 1996; Draut and others, 2005, 2008; Anderson and Neff, 2011), including those with some of the largest and best-studied gully systems (such as Palisades and Arroyo Grande, at RM 66 and 208, respectively). Using topography from a digital elevation model (DEM), Magirl and others (2008) used hydrologic models to demonstrate that a flood of 170,000 ft^3/s, a level last attained in spring 1921, would be sufficient to submerge most of the area where alluvial and aeolian sediment occurs in the river corridor of Marble and Grand Canyons. A sediment-rich flood of this magnitude could fill areas that are presently gullied and would have deposited new sediment over widespread areas that have not received substantial fluvial or aeolian sediment supply since such a flood last occurred. According to a flood-frequency analysis by Topping and others (2003), a predam flood of such size (170,000 ft^3/s) would have had a recurrence interval of ~40 years. Smaller floods on the order of 120,000 ft^3/s occurred on ~8-year intervals (Topping and others, 2003), and such floods would also have backfilled many gullies and created high-elevation sand deposits that would have been reworked and redistributed by wind. In a natural, unregulated river environment, during the decades-long intervals between the large floods, the flood-deposited sediment would have been reworked by wind to form aeolian dunes, would have been colonized by plants and biologic soil crust (see conceptual model by Draut, 2012), and would have been incised by gullies during rainfall runoff events.

In the absence of such large, sediment-rich floods in the postdam river, the only remaining natural process for gully annealing is infilling by aeolian sand deposition, with probably intermittent contribution by slopewash (if runoff events are depositional on occasion rather than erosional). Filling of gullies by windblown sand has been observed in localized occurrences in Marble and Grand Canyons (for example, Draut and Rubin, 2008; Collins and others, *in review*) and has been called “one of the strongest restorative forces operating at [eroding] archaeological sites” (Neal and others, 2000), but it remains unknown exactly how effective aeolian deposition is overall today in the Colorado River corridor at counteracting erosion of sediment deposits and associated cultural sites. Aeolian deposition may be thought of as a “band-aid” hindering gully development, though gully erosion could only be entirely stopped (temporarily) by a sediment-rich flood much larger than any postdam flows have been. It is presently not known whether the “band-aid” of aeolian sedimentation prevents one tenth of the gully erosion that otherwise would occur in Marble–Grand Canyon, or one half, or some other proportion, or whether it has no detectable effect on the extent of gully erosion today.

Determining the large-scale effectiveness of aeolian sediment at counteracting gully incision in Grand Canyon National Park, as Element J.3 of this work aims to do, will provide critical information concerning the effectiveness of GCDAMP management actions that intend, in part, to increase the aeolian sand supply in the Colorado River corridor by releasing controlled floods from Glen Canyon Dam. Although surveys have documented local instances of flood-deposited sand being reworked by wind and forming aeolian dunes that migrate inland in the months following a controlled flood (Draut and others, 2010a), this proposed work will place such observations into a larger context by quantifying the effect, if any, that such locally observed processes have had on the present state of upland (above the 41,000 ft^3/s water line) landscapes in various parts of the river corridor. The results of Element J.3 work will inform GCDAMP managers as to whether the effectiveness of aeolian sand transport at limiting gullies is sufficient to warrant planning future controlled floods such that the timing of greatest sandbar extent is maximized during spring, so that the typically dry, windy weather in that season can move the most possible sand from fluvial sandbars into upland regions. Such timing of controlled flooding occurred in spring 2008 and has been suggested in previous high-flow-experiment planning documents. Another factor to be evaluated concerns defining the duration over which sand bars remain sufficiently large to constitute significant sources of sand available for wind transport. A fall flood, for example, might create large bars in winter, but such bars must still be large in spring if they are to benefit upslope distribution of sand by wind.

If it is found that aeolian sand activity has, overall, had only negligible effect on gully incision and landscape development in the modern river corridor, then the seasonal timing of future controlled floods could be determined based solely on other resource needs without consideration for upland sediment and cultural resources. If Element J.3 findings support this latter situation, then this would imply that site-scale management actions such as checkdam construction or installing run-off diversion features, rather than increasing aeolian sand availability by controlled flooding to enlarge sandbars, may be the only means available to temporarily counteract erosion-driven loss of archaeological cultural material.

The proposed work for Element J.3 will combine field-based investigations, analysis of historical aerial photographs, and geomorphic modeling to quantify the extent of aeolian sediment activity in the river corridor and its effectiveness at counteracting gully incision in upland sediment deposits. This work will link to studies conducted under Project A and Project I in some of the study localities where the locations and enlargement of sandbars (Project A) is known to affect sand supply into modern-fluvial-sourced dune fields, and the effectiveness of this process depends in part upon the amount of riparian vegetation bordering the sandbars (Project I). Increases in area, density, and biomass of riparian vegetation assemblages have been documented over the past several decades for the Colorado River in general from Glen Canyon Dam through Grand Canyon National Park (e.g., Webb and others, 2011). The analysis of legacy aerial photographs conducted under Project J.3, in particular, will assist evaluation of how the integrated system of fluvial sandbars, riparian vegetation, nearby aeolian sediment deposits, and associated cultural sites have changed through time. It is clear from examination of aerial imagery, for instance, that any sandbar deposition from HFEs in the Furnace Flats area near river-mile 71–72 will be unlikely to reach the large aeolian dune fields on river left in this region even though the wind direction blows from the river into those dunes, because a large amount of riparian vegetation has grown in that area in post-dam time (Draut and others, 2009b, 2010b). However, the investigations in Project J include many sites and large areas where, because of the lack of postdam floods, the aeolian landscapes and cultural sites within them are disconnected from modern river sandbars and riparian vegetation (Draut, 2012); the (desert) vegetation assemblage in aeolian dunes above the postdam high water line is distinctly different from the riparian vegetation assemblage and does not have an apparent connection to dam-controlled flows (see vegetation study by Draut, 2011). Long term increases in abundance and size of individuals of desert perennial species have also been documented for the past century (Webb et al., 2011), suggesting a trend of further impediment for the potential for aeolian transport of relict and fluvial sourced sands to archaeological sites. For example, in many upland sediment deposits and associated archaeological sites (those that are in relict-fluvial-sourced dune fields; Draut, 2012) the prevailing wind direction does not supply sand from modern, HFE-deposited fluvial sandbars (such as at Palisades, RM 66), but rather the source of sediment in the dune field and protecting the cultural sites was left by predam floods larger than any postdam flows have been. Thus, some but not all of the sites and results investigated in Project J can link to results obtained under Projects A and I.

Research Questions and Methods

Part J.3 investigations will address the following three research problems in FY13/14:

Research Question 1: How does the relative abundance of active and inactive aeolian sediment vary in different regions of the Colorado River corridor?

Hypothesis: The proportion of active aeolian sand will be less in wide reaches of the river corridor and greater in narrower reaches of the river corridor.

As a first step in determining the effectiveness of aeolian sand transport at annealing gullies that erode sediment deposits and archaeological sites, it is necessary to identify the extent of active, mobile aeolian sand in the river corridor. It is likely that there is spatial variation in

Marble and Grand Canyons in the role that aeolian sand plays in gully development and cultural-site erosion, but the spatial prevalence (or lack) of these process has never been thoroughly defined. “Active” aeolian deposits and landscapes are defined as those having evidence for contemporary sand transport: wind-rippled surfaces and, locally, dune slipfaces at the angle of repose (Lancaster, 1994). Previous work has shown that in the highly flow-regulated and sediment-supply limited environment downstream of Glen Canyon Dam, the proportion of active, mobile aeolian sand is substantially lower (by a factor of 5) than in the much less regulated river corridor upstream of the dam in Cataract Canyon, Utah (Draut, 2012). This difference is attributed to the greater availability of sand from sandbars to act as a windblown sand supply in Cataract Canyon (Thompson and others, 2000; Draut, 2012). This finding was based upon a study in lower Marble Canyon (Eminence–LCR, RM 44–61) chosen specifically for comparison with geometrically and geomorphically similar Cataract Canyon. Because the spatially extensive environment of Grand Canyon includes a diverse range of river-corridor morphology (controlled by bedrock lithology and faulting), it is likely that the proportion of active and inactive aeolian sand, and therefore the potential for aeolian sand to mitigate erosion at cultural sites, varies considerably in different regions of the canyon system.

The hypothesis above was developed based on the possibility that modern aeolian sand activity may be, at least in part, a function of river-corridor width. Wide reaches commonly contain areally extensive predam fluvial sediment deposits that have not received new sediment supply in postdam time; aeolian dunes that depended on those predam flood deposits as a sediment source therefore also have not received substantial new sediment postdam. The last flood large enough to overtop and replenish sand deposits substantially in wide reaches of the river corridor occurred in 1921, as discussed above. Places of former (predam) sediment deposition that are sediment-starved in the modern, dammed era tend to develop extensive biologic soil crust cover and to have little aeolian sand transport, comprising sand deposits that are inactive with respect to wind transport of sediment. Therefore, the prevalence of ample accommodation space in wide reaches that formerly were loci of major predam flood deposition now may have led to an especially high proportion of inactive aeolian sediment there. Identifying spatial variation in active vs. inactive aeolian landscapes is important because of the connection between aeolian sand activity and annealing of small gullies, and also because the concentration of archaeological sites is greatest in wide reaches of the river corridor (Fairley and others, 1994; Damp and others, 2007; O’Brien and Pederson, 2009a). If inactive aeolian landscapes are most common in reaches of the river corridor where the archaeological record is also densest, then this could mean that the ability of aeolian sand transport to fill gullies and reduce erosion risk is least effective in those regions of the river corridor where the cultural record could most benefit from gully annealing and is at the greatest risk of loss by gully erosion.

To address this hypothesis, we will map active and inactive aeolian sand area in targeted reaches of the Colorado River corridor and to analyze the relative proportions of active and inactive sand by delineating their boundaries using ArcGIS. The river corridor in the Eminence–LCR reach, in which active and inactive aeolian sand have already been mapped, has a ratio of the river at predam flood stage vs. 8000 ft^3/s of 2.1 to 2.3. The proportion of active aeolian sand in that reach is 13.0% (Draut, 2012); the archaeological site density in this Eminence–LCR reach is 1.2 sites per mile, which is slightly less than the river-corridor average of 1.9 per mile (Fairley and others, 1994). Doing similar aeolian-sand mapping in other reaches would likely yield different results and thus would be very informative for analyzing the availability of active aeolian sand that could counteract gully incision in various regions of the river corridor. We hypothesize that in a wide reach (such as Furnace Flats, RM 66–72, where the flood:nonflood width is as great as 6 and the archaeological site density is the highest of any region in the river corridor; Fairley and others, 1994), the proportion of active sand would be less than in the Eminence-LCR reach. It will be valuable also to analyze narrower reaches such as Upper Granite Gorge where the flood:nonflood river width is less, between 1 and 2 (RM 87–99), and a reach with width similar to Eminence-LCR (ratio of 2.1 to 2.3) but in the western canyon where there is more sediment (e.g., Stevens/Conquistador Aisles, RM 116–130, where archaeological site density is above the river-corridor average; Fairley and others, 1994). We also will map active and inactive aeolian sand area in the same part of Glen Canyon where Element J.1., studies will be conducted. It would also be valuable to map active and inactive sand area in Granite Park (RM 207–210), an additional wide reach (flood:nonflood width ratio approaching 6) in the western canyon, if permitted by NPS and the Hualapai Tribe. Although this reach-based approach covers slightly more than one third of the river-corridor length in Grand Canyon National Park and not its entirety, evaluating how aeolian sand activity varies with river-corridor width could lead to the ability to characterize other areas' susceptibility to aeolian-sand influence on gully incision without the need to map at the same level of detail as in the study reaches. The proposed study reaches also focus on the areas of the canyon with the densest concentrations of archaeological sites (Fairley and others, 1994), in order to maximize the utility of the research results for application to cultural-resource preservation.

It is likely that valley width is not the only factor affecting active:inactive aeolian sand proportion in the river corridor, and that access to modern windblown sand supply having been blocked by recent growth of riparian vegetation (Projects A and I) is also a factor; this has been observed, for instance, at the Malgosa dune field in recent years (RM 57.9R, Draut and others, 2010b). Supply limitation by riparian vegetation will be evaluated both in the field and through aerial photographic analysis under Question 2 below; however, as mentioned above, many of the canyon's relict aeolian landscape processes now are unrelated to either sandbar formation, fluvial sandbar erosion, or riparian vegetation, because the wind direction is not conducive to bringing sand from modern sandbars into the relict dunes even if there were no riparian vegetation. For this reason, it is likely that the accommodation-space differences in a wide vs. a narrow river reach lead to differences in the ratio of active to inactive aeolian sand.

Mapping will be conducted by identifying in the field aeolian sand-deposit area in each of the proposed reaches and mapping active and inactive aeolian sand by drawing active sand boundaries on a set of printed aerial photographs using GCMRC's high-resolution 2009 imagery. This involves making short stops at every place in each reach where aeolian sand is present. (It became clear during the 2011 field work that field checking is necessary and that aeolian sand activity cannot be determined merely by identifying the lightest-colored sand areas on aerial photographs without field verification; areas of light colored gravel commonly look identical to active aeolian sand deposits on aerial photographs.) After the field work is complete, areas of active and inactive sand identified on the photographs will be digitized as polygons in ArcGIS and their area and relative proportions analyzed. In all of these study reaches, the GIS coverages of archaeological site localities will be compared with the spatial occurrence of active and inactive aeolian sand, as a means to more thoroughly assess the potential for aeolian sand activity to directly affect each cultural site (building on previous work by O'Brien and Pederson, 2009a; Collins and others, 2009, 2012).

Research Question 2: How does the degree of gully incision differ in sediment deposits that are active vs. inactive (with respect to aeolian sand transport)?
Hypothesis: Gullies will be larger and longer-lived in inactive aeolian sand deposits than in active aeolian sand deposits.

In the absence of large floods in postdam Marble and Grand Canyons, the geomorphic process most able to counteract the effects of gully incision and potentially reduce erosional damage to cultural sites is that of aeolian sand transport that can partially or entirely fill small gullies (on the order of tens of centimeters). This process has been observed in several instances in the modern river corridor, operating on time scales of months (e.g., Thompson and others, 2000; Draut and Rubin, 2008). Aeolian inflation of the land surface at one archaeological site was measured by Collins and others (2009) over a time span of just less than a year. The individual, short-term occurrences of aeolian deposition counteracting erosion that these examples illustrated, however, have not yet been expanded into a landscape-scale evaluation of how prevalent gully-annealing aeolian processes are over longer recent time scales (years to decades) within Marble and Grand Canyons.

Observations indicate that extensive evidence of gully incision is much more prevalent in sediment deposits with surfaces containing well developed biologic soil crust rather than active aeolian sand. Well-developed biologic crust and aeolian sand activity are essentially mutually exclusive, with evidence for contemporary sand transport (Lancaster, 1994) generally not observed on sand surfaces where biologic crust cover exceeds ~20% of the ground area (Draut, 2012). It is also known that biologic soil crust not only limits aeolian sand activity (by armoring surface sediment; Belnap and Lange, 2003) but also that biologic crust can affect the potential for gullying because of its influence on soil infiltration capacity. Therefore, it is likely that the extent of gully incision differs in active and inactive sedimentary landscapes. However, no systematic survey has yet been made of gully extent in active vs. inactive sediment deposits. If it is found that gullies are larger, deeper, and longer-lived in areas without substantial aeolian sand activity, this would support the supposition made by previous researchers that aeolian sand transport is an effective process counteracting gully incision and cultural-site erosion in the postdam Colorado River ecosystem. It is also important to discover whether or not there are examples in the available temporal record of gully networks entirely annealing by windblown dune activity, which would indicate that there can be larger spatial scale or longer temporal-scale healing of gullies by aeolian sand, in addition to the lesser spatial and temporal scales on which these processes have already been documented in the field.

To address this second research question, we propose to map gully extent (position and depth) in the field, using the same targeted reaches identified under Question 1 above. Field mapping will be conducted using aerial photographs and supplemented by RTK GPS measurement to assure positional accuracy. Gully extent has already been mapped for much of the Furnace Flats reach and will be entered into ArcGIS in summer 2012. During the 2012 fieldwork, it was observed that no part of the several hundred meters of mapped gully length was incised into active aeolian sediment. With the exception of one gully segment ~5 m long that was partially filled by an active aeolian dune along one side of the gully, all of the gullies observed in Furnace Flats (RM 65–71) reach to date affected sediment deposits that were inactive with respect to aeolian sand transport. The remaining study reaches proposed here have not yet been assessed. We propose to conduct measurements in Glen Canyon concurrently with fieldwork occurring for Element J.1 above, and in Marble and Grand Canyon by the use of one river trip, in combination with the work described above for Element J.2.

The above field-based approach targets spatial variation in gully extent in the modern river corridor. This research question will also be addressed by examination (led by Sankey) of temporal changes in gully extent using historical aerial photographs and other remote-sensing information from the GCMRC library archives. The goal of this effort is to examine links, if any, between the site-scale examples known of aeolian sand annealing gullies (those already measured by Collins and Pederson in previous studies, and those that may be measured during this study under Elements J.1 and J.2) and the impact that such processes may have on the larger landscape over annual to decadal time scales. The resolution and exposure of early photographs (particularly from the 1960s and earlier) might limit the quantitative information that can be gleaned regarding the condition of sediment deposits, so care must be taken regarding the potential for study bias. More-recent photographs have much greater resolution than earlier photographs (which allow the number and size of gullies to be identified more easily and in greater detail in later photographs), but older air photos may nevertheless provide some valuable temporal information about possible changes in gully extent over the past several decades. In addition to looking for direct evidence of the gully annealing processes, the image time series analysis will also permit the determination of rates of change (encroachment) of perennial vegetation. These change detection analyses are anticipated to provide evidence of the extent that increases in riparian or desert vegetation in the vicinity of historical gullies and associated aeolian sand sources might have posed impediments to the gully annealing processes.

Remote sensing methods such as aerial photography and topographic surface interpretation provide useful tools for quantifying changes in formation and development of gullies and interactions with other erosion and deposition processes (Vrieling, 2006; Marzolff and Poesen, 2009; Shruthi and others, 2011). For example, multispectral imagery has been used to identify important evidence of geomorphic change associated with interactions of aeolian-fluvial processes in desert regions, such as the encroachment of aeolian dunes into gullies (Farraj and Harvey, 2004). Time series of digital imagery, often in conjunction with digital terrain models, are used to monitor gully erosion processes like head cutting, collapse of sidewalls, and erosion of the gully floor (Aber and others, 2010). DEMs derived from remotely sensed imagery and data sources are particularly useful for large-scale geomorphic change detection through the construction of DEMs of difference (Wheaton and others, 2010; James and others, 2012). A limitation to this DEM-based approach for geomorphic change detection in Marble and Grand Canyons is that the available GCMRC data archive currently consists of digital surface models for the time frame of 2000 to present, but not earlier. Moreover, remote sensing detection and measurement of many gullies is also likely limited by the photogrammetric accuracy of the data relative to gully features that often only vary in horizontal and vertical extent on the order of 10s of centimeters. Nonetheless, contemporary larger gullies in Marble and Grand Canyons with width and depth on the order of 1s to 10s of meters have been identified and mapped in the field (for example, Hereford and others, 1993, 1996; Thompson and others, 2000; Pederson and others, 2006; Collins and others, 2009 in addition to Draut, observations in Furnace Flats from 2012 mentioned above). The presence of large gullies of this size can be visually identified in the range of historical image data types available from the GCMRC archives. The identification of gullies in the historical image data will initially require vegetation classification steps to segment the more protected, vegetated surfaces from erodible bare surfaces (Aber and others, 2010). Classification of vegetated surfaces for individual dates of imagery will permit the determination of rates of change in the density and extent of vegetation among the longer time series of imagery (Sankey and Germino, 2008). Methodology applicable to change detection for deciduous and non-deciduous perennial vegetation in dryland systems will be employed using the multispectral and black and white imagery and aerial photography (Sankey and Germino, 2008; Sankey, 2009).

We propose to identify large gullies in the historical imagery and then work progressively forward in time in the remote-sensing record to identify any evidence of sediment deposition or complete infill by aeolian processes. While the analysis will use a presence/absence approach to quantifying changes to gullies that are proximal to aeolian sediment sources over time, change analysis will also attempt to detect decreases in 2D area of gullies over time (Aber and others, 2010). A benefit of this approach to historical image analysis (looking for decrease, rather than increase in gully presence and extent) is that it potentially alleviates a bias problem of better image quality of modern relative to historical data. Evidence, or lack thereof, of decrease in the presence of historically identifiable gullies, or decreases in gully 2D area, over the 127 river km of the proposed study reaches will directly address the question of whether there are places in Glen, Marble, and Grand Canyons where aeolian sediment activity identifiably prevents or limits gully incision of river-corridor sediment deposits over larger spatial scales, and potentially longer temporal scales, than has already been observed in isolated cases in the field. Knowing whether such cases exist in the decadal-scale remote-sensing record will be highly informative in answering the question of whether the site-scale aeolian infilling processes already observed and measured in the field may extend over large enough spatial and temporal scales to provide substantial erosion prevention to cultural sites in the postdam river corridor.

Research Question 3: To what extent does aeolian sediment transport counteract gully erosion in Marble and Grand Canyon?

Hypothesis: Aeolian sediment substantially limits gully incision of river-corridor sediment deposits in Glen, Marble, and Grand Canyons such that the modeled extent of gully development will be greater than the actual extent.

This third research question is similar to the second but utilizes a modeling approach to evaluate potential vs. actual gully development in the proposed study reaches of the river corridor. Addressing this question will allow the entire research project to move from site-scale observations of gullies being annealed by aeolian sand (previous work and Elements J.2 of this proposal), through larger-scale field and remote-sensing observations of gully prevalence and annealing in active vs. inactive aeolian landscapes (Questions 1 and 2 of Element J.3), to a process-based evaluation of the effectiveness of aeolian sand at annealing gullies in the postdam environment of Glen, Marble, and Grand Canyons. To refer back to the “band-aid” analogy given in the introduction to Element J.3, this modeling investigation will provide insight into how extensively aeolian sediment movement prevents gully incision that would otherwise additionally erode sediment deposits and archaeological sites.

A suite of physically-based erosion modeling approaches can be used to better understand processes driving archaeological site stability. We will use two complementary approaches to modeling to better understand gully dynamics. We intend to extend existing modeling work begun by David Bedford in FY12 to better understand generation of runoff and subsequent erosion. We also propose to implement a landscape evolution model to test some of the hypotheses of gully formation, expansion, and healing.

Detailed modeling already underway (FY12) is aimed at determining rainfall intensity thresholds and quantifying runoff and erosion generation for areas around specific cultural sites where high-resolution topography exists. This modeling, at a site-specific level, can also be generalized towards more simple assessments of the kinds of sites that are susceptible to erosion. It is anticipated that some of this modeling, at lower resolution, will likely be necessary in order to define criteria for assessing vulnerability to site erosion.

Landscape evolution models (LEMs) can be used to better understand processes that sculpt the land. In cases where much is known about landscape processes and either initial, transient, or resulting conditions can be determined, LEMs can make significant contributions to understanding landscape change (Tucker, 2009). One of the benefits of using a LEM is that they can inform on changes both in hypothetical landscapes and real landscapes, but also allow initial or input conditions to be changed to understand effects of different scenarios.

We intend on implementing a LEM to better understand gully dynamics in the postdam environment of Glen, Marble, and Grand Canyons. We will likely implement one of three LEMs that have previously been used to model gully systems. The CHILD LEM (Tucker and others, 2001) has a long history of use and has been used to model gully systems (Istanbulluoglu and others, 2005). Two other similar models, SIBERIA and CAESAR have been used in gully environments and over shorter time frames appropriate for changes to sites along the CRE (Hancock and others, 2000, 2010, 2011). While each of these models has the potential to inform on changes affecting sediment deposits and associated archaeological sites, only initial implementations of the models will make clear which is the most effective model. We intend to use the LEM to test the formation of gullies and the effects of geomorphic processes that may exacerbate or counteract gully expansion. We will do this by modifying landscape evolution trajectories under various hypothesized drivers of gully incision (e.g., Simon and Rinaldi, 2006). Under this method, we assume that gullies will form as long as there is readily mobile sediment under high-intensity rainfall. Using the 2002 digital elevation and digital surface models with 1-m resolution (available from GCMRC), we will use these robust modeling capabilities to identify places within each of the proposed study reaches where gullies would be expected to form (and to what extent), and then will compare the model results with the current real state of those anticipated gullies. By comparing the predicted (modeled) state of gully development with the actual gully extent, we will then evaluate whether landscape processes evidently explain any differences between modeled and real conditions, i.e., are there places in the Colorado River corridor where robust models predict gully development, but where active aeolian dunes exist instead? If so, how extensive and how common are such examples? If modeling results are highly consistent with the actual sites and extent of gully presence today, and if thus no locations can be identified where aeolian dunes occur in place of model-predicted gullies, then this would support the notion that aeolian sand activity has not substantially inhibited gully development in the study reaches over a large spatial scale and on the 90-year time scale over which these sediment deposits have gone without major sediment resupply, even though (from prior observations and to be explored further in Element J.2 of this proposed project) aeolian sand may temporarily anneal small gullies or portions of gullies on smaller spatial and temporal scales.

Further modeling applications include the ability to simulate trajectories where gullies are allowed to form in the LEM but are periodically backfilled by flood or aeolian sand. LEMs can also be used to test how well CRE incised systems (gullies) fit into traditional views of incising systems (e.g. Schumm and others, 1984). The widely accepted framework for incised sytems by Schumm and others (1984) consists of five stages of channel evolution: 1) stable, 2) incised (degraded), 3) widening through bank failures, 4) aggrading, and 5) quasi-equilibrium channel connected to stable floodplain. If it is determined that CRE gully systems operate in this manner (or a new sequence of stages is determined) a large suite of channels can be identified for their current status and the need for mitigation efforts can be determined. Finally, we can test the "base level" hypotheses of Hereford and others (1993) by simulating gully formation and propagation on terraces with raised base level (i.e., those that would be replenished by periodic large flooding in an unregulated flow regime) but driven by 20th century climate, and then simulate observed low base level, also with 20th century climate. Such modeling investigations could provide new insights on the role of flood sediment deposition on base level of channels, thus evaluating some of the concepts proposed by Hereford and others (1993). Ultimately these modeling exercises can be used to guide the adoption or elimination of gully development hypotheses, move toward a better understanding of the conditions driving gully formation, and help lead investigators to locations on the actual landscape that warrant further study.

Overall, the large-spatial-scale change-detection and modeling effort of Element J.3 will utilize the site-scale change detection and modeling from Elements J.1 and J.2 to place the rates and processes of change (such as gully erosion and aeolian infilling) measured at individual sites into a geomorphic context for the river corridor, and evaluate the relative effectiveness of gully incision and aeolian sediment movement at shaping the upland landscapes that exist today after more than 90 years without a substantial flood. The expansion of landscape-process evaluation from site-scale to reach-scale also will provide NPS and other managers with information necessary to understand what possible future conditions to expect in upland sediment deposits—such as the overall area subject to long-lived gully degradation or aeolian dune movement—where archaeological sites likely exist but have not yet been discovered, and thus have never been monitored in detail.

We propose the above work as steps to be undertaken in FY13/14, from which further work could expand in subsequent years. Based upon the results obtained in the phases of work outlined above, additional work could expand upon these concepts for a further 2–5 years (or longer), to more fully analyze the question of whether sedimentary landscapes and associated archaeological sites are eroding more rapidly, and/or under different processes, in the modern postdam river corridor compared with a predam or unregulated environment (assuming comparable climatic conditions). Informative future work in subsequent phases of the study could include an investigation of short-term vs. long-term erosion rates, whereby short-term erosion rates quantified by Collins and others (2009, 2012, and proposed for additional study in Element J.2) would be compared to longer-term, decadal or centennial-scale erosion rates of sediment deposits in the river corridor. This might be conducted through the use of radionuclide or optically stimulated luminescence (OSL) studies in a vertical section of sediment exposed in a large gully or arroyo (e.g., building on work by Rittenour, 2008). It could also be possible to build on anticipated results of the modeling component outlined under Question 3 above, to identify places where gullies are predicted to occur but are currently absent. If such places were identified, it might be worthwhile to propose targeted trenching of sediment deposits to look for paleogullies that were infilled by sediment, and to examine any such areas for sedimentary structures consistent with aeolian deposition. Because such work would require more invasive techniques, such as disturbing sediment deposits and collecting samples for laboratory analysis that would need more involved permitting, we would propose such work only if the results of the currently proposed study indicated that such work could be especially informative to the research questions.

4.2 Personnel and Collaboration

This project builds upon several past research efforts, including the previous work of Draut and Rubin (2006, 2008), Draut and others (2005, 2009a, 2009b, 2010a, 2010b), Draut (2011, 2012), Pederson and others (2003, 2006) O'Brien and Pederson (2009a, 2009b), Damp and others (2007), Fairley and others (2007; Fairley and Sondossi 2010) and Collins and others, (2008, 2009, 2012). Specifically, it builds upon the work of Draut and others by extending the 2003-2010 weather monitoring record and measurements of aeolian sand transport at selected locations in the CRe and examines the role that changes in aeolian sediment distribution may play in affecting stability of cultural sites over time. It also expands information on gully erosion rates initiated by Utah State University (USU) in FY01/02 and continued in FY06/07, and it expands on the geomorphic baseline data set collected for the 151 site treatment plan (Damp and others, 2007). In addition, it directly builds upon the Phase I work of the Cultural Monitoring Research and Development Project by applying the knowledge gained through that effort (Collins and others, 2008, 2009, 2012; Draut and others 2009a, 2009b, 2010a, 2010b; O'Brien and Pederson 2009a, 2009b) to track and quantify dam-related topographic changes (i.e., amounts and rates of erosion and deposition from fluvial sand sources) occurring at cultural sites throughout the CRe.

This study complements Grand Canyon National Park's CRMP monitoring program. Monitoring protocols for assessing impacts of human visitation at archaeological sites are being developed independently by GRCA staff to serve the monitoring needs of the Park Service for evaluating effects of visitation at cultural sites. The quantitative approaches for monitoring change in archaeological site condition developed through the previous cultural monitoring R&D effort and proposed for implementation now as part of this project will supplement and enhance the qualitative, observational monitoring protocols and data being developed by NPS for CRMP compliance.

Other ongoing GCMRC monitoring projects that have benefited or could potentially benefit from the work being undertaken by this project includes:

- Project A: Sandbars and Sediment Storage Dynamics: Long-term Monitoring and Research at the Site, Reach, and Ecosystem Scales: measured data on volumes of sediment moved during storm events of documented intensity; in some locations, studies of cultural sites and aeolian landscapes will link to modern dam-controlled sandbar occurrence and monitored sand bars.
- Project B: Streamflow, Water Quality, and Sediment Transport in the Colorado River Ecosystem: temperature data from the weather stations to inform water temperature monitoring and modeling.
- Project I: Riparian Studies: Response Guilds as a Monitoring Approach, and Describing the Effects of Tamarisk Defoliation on the Riparian Community Downstream of Glen Canyon Dam: the full suite of weather data could be useful for interpreting observed changes in vegetation; in some locations, studies of cultural sites and aeolian landscapes will link to riparian vegetation growth history.

4.3 Logistics

One five-day motor-supported trip in FY12, plus several day-trips by motor boat will be needed to support Element J.1, during which related J.3 work in Glen Canyon will also be carried out. In addition, one low altitude helicopter mission of 1-2 hours duration will be required to collect airborne lidar data in FY13. One 14-day motor trip will be required each year to support Element J.2, and these trips will also support Element J.3 work in Grand Canyon. In addition, one or more researchers will accompany GCMRC trips permitted for other projects to maintain weather stations and collect additional field measurements.

4.4 Deliverables

With the exception of trip reports, weather data, and other administrative or data-type reports, all publications proposed for this project are intended to be collaborative efforts linking the data and analysis results from all three project elements. The goal of the publication effort is to synthesize the site specific and system-wide scales of analysis into coherent documents that explain the geomorphic history and future expectations for archeological sites in the CRe under current river flow conditions.

- Trips reports will be prepared after each field episode to fulfill NPS permit requirements.
- Weather data will be served annually via GCMRC's website. A USGS Data Series Report describing the technical aspects of the weather monitoring project will be prepared in FY13.
- An interim Open File report summarizing progress on development of a geomorphic model will be published in FY13. A final Scientific Investigations report, USGS Professional Paper, or peer-reviewed journal article documenting the entire modeling effort will be prepared in FY15.
- A USGS Scientific Investigations Report will be completed in FY15, summarizing the results of the first two years of the monitoring work and the implications of these results for interpreting erosion rates and dam-related effects to cultural sites in different segments of the river corridor. This report will form the basis for a shorter, professional journal article in FY16. A comprehensive report analyzing the monitoring project results over a five year period will be prepared at the conclusion of the five year period (FY17).
- Additional journal articles will be prepared in FY15 covering one or more of the following components of this project: airborne lidar as a landscape scale change detection tool for assessing impacts to cultural sites; use of historical analog imagery for detecting changes in pre and post-dam gully erosion patterns; the results of the active vs. inactive mapping and site condition analysis.
- Results will be presented at TWG and AMWG meetings as appropriate, as well as at major national scientific meetings such as the American Geophysical Union, to ensure that the findings from this significant research endeavor are shared with the scientific research community and may inform other, related river- and environmental-management programs.

5. Productivity from Past Work

Project J builds on research conducted and completed as part of the 2006-2011 Cultural Monitoring Research and Development Project (Fairley and others, 2007). Below is a summary of the products that resulted from this previous research and development initiative:

5.1. Data Products

During FY11/12, the following data sets were compiled, checked for accuracy, and delivered to the GCMRC Data Base Manager for posting on the GCMRC website:

1. 4-minute data from 11 weather stations spanning calendar years 2007-2010 for precipitation rate, precipitation volume, wind speed, wind direction, temperature, humidity, and barometric pressure.
2. Sand transport data from 12 sand traps through calendar year 2010.
3. Compiled weather data from 32 regional weather stations spanning the period 1893-2008.

5.2. Published Reports and Papers

Collins, B.D., Brown, K.B., and Fairley, H., 2008. Evaluation of Terrestrial LIDAR for Monitoring Geomorphic Change at Archaeological Sites in Grand Canyon National Park, Arizona: U.S. Geological Survey, Open File Report 2008-1384, 60 p. (Available at http://pubs.usgs.gov/of/2008/1384/.)

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

Collins, B.D. and Kayen, R., 2006. Applicability of Terrestrial LIDAR Scanning for Scientific Studies in Grand Canyon National Park, Arizona, U.S. Geological Survey, Open File Report 2006-1198, 27p, Menlo Park, California, (Available at http://pubs.usgs.gov/of/2006/1198/.)

Collins, B.D., Minasian, D., and Kayen, R., 2009. Topographic Change Detection at Select Archaeological Sites in Grand Canyon National Park, Arizona, 2006-2007: U.S. Geological Survey, Scientific Investigations Report 2009-5116, 97p. (Available at http://pubs.usgs.gov/sir/2009/5116/ .)

Draut, A.E., 2011, Vegetation and substrate properties of aeolian dune fields in the Colorado River corridor, Grand Canyon, Arizona: U.S. Geological Survey Open-File Report 2011-1195, 16 p. and 28 tables, at http://pubs.usgs.gov/of/2011/1195/.

Draut, A., 2012, Effects of river regulation on aeolian landscapes, Colorado River, southwestern USA: Journal of Geophysical Research – Earth Surface, v. 117, F2, doi:10.1029/2011JF002329.

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7. Budget

FY 2013				
Project Element J.1. Cultural Site Monitoring in Glen Canyon			Project Element J.2. Monitoring of Select Cultural Sites in Grand Canyon	
GCMRC Salaries	$35,000		GCMRC Salaries	$35,000
Traveling and Training	$1,900		Traveling and Training	$8,000
Operating Expenses	$5,000		Operating Expenses	$5,000
Logistics	$1,900		Logistics	$19,000
GIS/RS/Electronics support (includes burden)	$22,500		GIS/RS/Electronics support (includes burden)	$4,800
Contractors/Cooperators (non-USGS)	$53,000		Contractors/Cooperators (non-USGS)	$5,000
USGS cooperators	$29,200		USGS cooperators	$104,800
USGS Burden	$13,200		USGS Burden	$9,500
Total	$161,700		***Total***	$191,100

Project Element J.3. Defining the Extent and Relative Importance of Gully Formation and Annealing Processes in the Geomorphic Context of the Colorado River Ecosystem	
GCMRC Salaries	$8,400
Traveling and Training	$13,200
Operating Expenses	$3,000
Logistics	$0
GIS/RS/Electronics support (includes burden)	$31,200
Contractors/Cooperators (non-USGS)	$0
USGS cooperators	$127,900
USGS Burden	$3,400
Total	$187,100

FY 2013 Project J. Gross Total: $539,900

FY 2014				
Project Element J.1. Cultural Site Monitoring in Glen Canyon			Project Element J.2. Monitoring of Select Cultural Sites in Grand Canyon	
Salaries	$37,000		Salaries	$37,000
Traveling and Training	$9,500		Traveling and Training	$2,900
Operating Expenses	$5,000		Operating Expenses	$5,000
Logistics	$1,900		Logistics	$19,000
GIS/RS/Electronics support (includes burden)	$23,900		GIS/RS/Electronics support (includes burden)	$4,600
Cooperators (non-USGS)	$3,000		Cooperators (non-USGS)	$5,000
USGS cooperators	$92,000		USGS cooperators	$97,000
USGS Burden	$7,600		USGS Burden	$9,100
Total	$179,900		***Total***	$179,600
Project Element J.3. Defining the Extent and Relative Importance of Gully Formation and Annealing Processes in the Geomorphic Context of the Colorado River Ecosystem				
Salaries	$9,000			
Traveling and Training	$12,400			
Operating Expenses	$3,000			
Logistics	$0			
GIS/RS/Electronics support (includes burden)	$33,100			
Cooperators (non-USGS)	$0			
USGS cooperators	$136,000			
USGS Burden	$3,400			
Total	$196,900			
FY 2014 Project J. Gross Total: $556,400				

Project K.
GCMRC Economist and Support

The economist position within GCMRC is expected to be filled during FY12. Funding in FY13/14 will support the anticipated salary of this individual and associated travel and training. The work activities of this individual will be developed based on consultation with the AMWG, TWG, GCDAMP ad hoc committees, and guidance from agencies.

GCMRC Economist and Support	
Salaries	$150,000
Traveling and Training	$23,700
Operating Expenses	$25,000
Logistics	$0
GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$0
USGS cooperators	$0
Total	$198,700

FY 2013 Gross Total: $198,700

FY 2014 Gross Total: $204,700

Project L.
Independent Reviews and Science Advisors

Independent reviews are an essential part of the GCDAMP. There are two items in the independent review part of the GCDAMP budget. One part concerns independent reviews commissioned by GCMRC. The primary activity is the convening of Protocol Evaluation Panels (PEP) to review the state-of-the-science in critical areas of science and management and to consider development of formal protocols for monitoring different aspects of the CRe. In FY13/14, there are no new PEPs scheduled, and the work involved in these reviews is expected to decrease. Thus, the proposed budget for this activity from $36,000 in FY12 to $27,700 in FY13.

Careful consideration was given to providing appropriate support for the work of the Science Advisors. The work of the Science Advisors is coordinated by L. D. Garrett of M3 Research. Dr. Garrett was the first Chief of the GCMRC. Dr. Garrett provided a request to GCMRC describing proposed activities for FY13 in a memo dated May 3. After review of that request, the requested Science Advisor budget for report review and development was funded, the amount allocated to meeting attendance was significantly reduced, and LTEMP support was eliminated. Thus, the Science Advisors budget is proposed to be:

Reviews by 5 Science Advisors (total requested amount)	$50,000
Review support by additional specialists (total requested amount)	$8,500
New Cultural Resources Science Advisor	$10,000
GCMRC reviews and review development by L. D. Garrett (total requested amount)	$24,000
LTEMP support (0% of requested amount)	$0
Stipend and travel costs in service to GCDAMP meetings (31% of requested amount)	$19,000
Development of white papers and reports to Secretary's Designee, AMWG, TWG (total requested amount)	$20,000
Participation in phone calls and webinars (50% of requested amount)	$6250
Project administration (total requested amount)	$6,500
Total Science Advisors request	$144,300
USGS burden	$22,000
Total budget amount	$164,500

Independent Reviews	
Salaries	$0
Traveling and Training	$0
Operating Expenses	$0
Logistics	$0
GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	24,300
USGS cooperators	
USGS Burden	$3,400
Total	$27,700

FY 2013 Gross Total: $27,700

FY 2014 Gross Total: $28,500

Science Advisors	
Salaries	$0
Traveling and Training	$0
Operating Expenses	$0
Logistics	$0
GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$144,300
USGS cooperators	$0
USGS Burden	$22,000
Total	$164,500

FY 2013 Gross Total: $164,500

FY 2014 Gross Total: $169,400

Project M.
USGS Administration

The USGS Administration budget covers salaries for the communications coordinator, the librarian, and the budget analyst for GCMRC, in addition to monetary awards for all GCMRC personnel. The vehicle section covers GSA vehicle costs including monthly lease fee, mileage costs, and any costs for accidents and damage. DOI vehicles are also included in this section of the budget to pay for vehicle gas, maintenance, and replacements costs. Leadership personnel covers salary and some of the travel and training costs for the GCMRC Chief, Deputy Chief, and two program managers. AMWG/TWG travel covers the cost of GCMRC personnel to travel to the AMWG and TWG meetings. SBSC Information Technology (IT) overhead covers GCMRCs IT equipment costs. Logistics base costs covers salaries and travel/training. These base costs also include a $35,000 contribution to the equipment and vehicles working capital fund.

Budget Analyst, Communications Support, Library, Discretionary Awards		Vehicles	
Salaries	$253,400	Salaries	$0
Traveling and Training	$5,600	Traveling and Training	$0
Operating Expenses	$46,900	Operating Expenses	$111,400
Logistics	$0	Logistics	$0
GIS/RS/Electronics support (includes burden)	$0	GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$71,500	Cooperators (non-USGS)	$0
USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$45,000	USGS Burden	$15,600
Total	$422,400	***Total***	$127,000
Leadership Personnel		AMWG/TWG Travel	
Salaries	$434,400	Salaries	$0
Traveling and Training	$19,500	Traveling and Training	$26,800
Operating Expenses	$0	Operating Expenses	$0
Logistics	$0	Logistics	$0
GIS/RS/Electronics support (includes burden)	$0	GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0
USGS cooperators	$0	USGS cooperators	$0
USGS Burden	$63,600	USGS Burden	$3,800
Total	$517,500	***Total***	$30,600
SBSC IT Overhead		Logistics Base Costs	
Salaries	$0	Salaries	$244,000
Traveling and Training	$0	Traveling and Training	$14,300
Operating Expenses	$107,500	Operating Expenses	$0
Logistics	$0	Logistics	$0
GIS/RS/Electronics support (includes burden)	$0	GIS/RS/Electronics support (includes burden)	$0
Cooperators (non-USGS)	$0	Cooperators (non-USGS)	$0
USGS cooperators	$5,000	USGS cooperators	$0
USGS Burden	$15,000	USGS Burden	$36,100
Total	$127,500	***Total***	$294,400
FY 2013 Gross Total: $1,606,000			
FY 2014 Gross Total: $1,780,600			

Project N.
Incremental Allocations in Support of Quadrennial Overflights

Overflights, during which digital aerial photographs and remotely-sensed data are acquired, occur every 4 years as part of the regular monitoring program of the GCDAMP. These data are used by most of the projects described in the BWP. $475,000 will be needed to conduct the FY13 overflight. Of this amount, $390,000 is carryover from FY12 GCMRC budget and $84,000 is funded from the FY13 GCDAMP budget.

Appendices

Appendix 2-A summarizes the categories for the FY13 budget. A budget summary for each project element is described. The category for “non-USGS cooperators” includes universities, consulting firms, sister agencies of the federal government, and agencies of state government. The category for “USGS cooperators” includes various science centers of the USGS located in Arizona, California, and Wisconsin. Investigators and their affiliations are described in each project description.

Appendix 2-B summarizes the source of funding for each project element. Project elements for which no funding source has presently been identified are listed.

Appendix 2-C lists the total project amount for each project element for FY14 and lists the anticipated source of that funding.

Appendix 2-D lists all schedules river trips

Appendix 2-A. Fiscal Year 2013 Budget

	Fiscal Year 2013										
	Project Description	**Salaries**	**Travel & Training**	**Operating Expenses**	**Logistics**	**GIS / RS / electronics support (includes burden)**	**Contractors**	**Cooperators (non-USGS)**	**USGS Cooperators**	**USGS Burden**	**Total**
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
A	***Sandbars and sediment storage dynamics***										
	GIS and image processing costs for entire project (includes burden)					$180,600					$180,600
	A.1. Sandbar and camping beach monitoring	$103,100	$2,300	$10,600	$22,300			$101,200		$22,400	$261,900
	A.2. Sediment storage monitoring	$252,900	$2,700	$36,000	$68,200			$168,700	$13,700	$55,400	$597,600
	A.3. Investigating eddy sandbar variability and the interactions among flow, vegetation, and geomorphology	$86,800	$1,900	$2,100						$12,700	$103,500
	A.4. Quantifying the correlation between bed and transport grain size	$41,900	$2,100	$1,000	$9,500			$67,500	$18,200	$9,700	$149,800
	A.5. Geochemical signatures of pre-dam sediment	$6,300							$43,700	$900	$50,900
	A.6. Control network and surveying support	$17,100	$600	$3,200	$28,500					$6,900	$56,300
B	***Stream flow, water quality, and sediment transport***	$524,000		$50,000	$57,000	$55,000			$502,000	$88,300	$1,276,400
	(contingency) HFE gage maintenance and measurements	$7,600			$42,800				$13,000	$7,000	$70,400
C	***Lake Powell water quality monitoring***	$179,700	$7,200	$33,800						$30,900	$251,600

	Project Description	Salaries	Travel & Training	Operating Expenses	Logistics	GIS / RS / electronics support (includes burden)	Contractors	Cooperators (non-USGS)	USGS Cooperators	USGS Burden	Total
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
D	***Mainstem humpback chub aggregation studies***										
	D.1. Aggregation sampling	$21,900		$6,000	$74,800			$80,000		$16,800	$199,500
	D.2. Natal origins of humpback chub, adult condition, and reproductive potential	$42,000	$1,000	$13,500				$100,000		$10,900	$167,400
E	***Humpback chub early life history in and around the Little Colorado River***										
	E.1. July LCR marking	$58,600		$8,000	$17,000	$34,100				$11,700	$129,400
	E.2. Describing the food web structure and the potential for food limitation within the Little Colorado River	$103,300	$1,900	$15,000	$17,000			$25,000	$75,000	$20,000	$257,200
	E.3. Population modeling	$63,700	$3,800	$2,000				$10,000		$10,000	$89,500
F	***Monitoring of native and nonnative fishes in the mainstem Colorado River and the lower Little Colorado River***										
	F.1. System wide electrofishing	$7,800	$1,900	$8,000	$59,600	$22,700		$103,000		$13,900	$216,900
	F.2.1 Glen Canyon monitoring	$10,200		$3,000	$9,300	$11,400		$132,000		$7,100	$173,000
	F.2.2. Rainbow trout early life stage studies	$26,300	$3,400	$1,300	$14,200	$11,400				$6,300	$62,900
	F.2.3. Lees Ferry creel survey	$1,900						$25,000		$1,000	$27,900
	F.3. Mainstem monitoring of native and nonnative fishes near the LCR confluence	$49,900		$9,000	$178,100	$11,400		$177,000		$38,600	$464,000
	F.4.1. Annual spring and fall humpback chub abundance estimates in the downstream 13.6 km of the Little Colorado River	$15,500		$14,000	$66,600	$11,400		$364,000		$24,400	$495,900

	Project Description	Salaries	Travel & Training	Operating Expenses	Logistics	GIS / RS / electronics support (includes burden)	Contractors	Cooperators (non-USGS)	USGS Cooperators	USGS Burden	Total
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
	F.4.2 Monitoring native and nonnative fishes in the downstream 1.2 km of the Little Colorado River	$7,800		$3,000	$8,600	$11,400		$50,000		$4,200	$85,000
	F.4.3 Translocation and monitoring above Chute Falls	$3,900		$1,000	$37,700	$11,400		$67,000		$8,000	$129,000
	F.4.4 PIT tag antenna monitoring	$18,000		$5,000	$9,800	$22,700		$40,000		$5,800	$101,300
	F.5. Stock assessment and estimation of humback chub abundance using the age structured mark recapture model	$7,700				$11,400				$1,100	$20,200
	F.6. Detection of rainbow trout movement from Glen Canyon to Marble Canyon	$25,100		$50,000	$96,500	$11,400		$67,000		$26,000	$276,000
	F.7. Foodbase monitoring	$159,900	$3,400	$5,000	$26,700	$11,400		$37,000		$28,400	$271,800
G	***Interactions between native fish and nonnative trout***										
	G.1. Laboratory studies to assess the effects of trout predation and competition on humpback chub	$62,000	$1,900	$18,000						$11,500	$93,400
	G.2. Efficacy and ecological impacts of brown trout removal at Bright Angel Creek	$77,900	$1,900	$5,000	$74,800					$22,300	$181,900

	Project Description	Salaries	Travel & Training	Operating Expenses	Logistics	GIS / RS / electronics support (includes burden)	Contractors	Cooperators (non-USGS)	USGS Cooperators	USGS Burden	Total
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
H	***Understanding the factors limiting the growth of rainbow trout in Glen and Marble Canyons***										
	H.1. Laboratory feeding studies	$17,100		$16,000						$4,600	$37,700
	H.2.1. Developing a mechanistic model of primary productivity	$56,500	$4,800	$17,000		$34,100				$11,000	$123,400
	H.2.2. Characterizing invertebrate drift	$59,600	$2,900	$3,500		$45,400				$9,200	$120,600
	H.3. Developing a bioenergetics model for large rainbow trout	$68,900	$2,900	$1,500		$34,100		$20,000		$10,900	$138,300
	H.4. Learning from other tailwaters -- a synthesis of tailwaters in the United States	$112,400	$14,100	$2,000						$18,000	$146,500
	H.5. Contingency planning for High Flow Experiments and subsequent rainbow trout population management	$6,600		$14,000	$18,400					$5,500	$44,500
I	***Integrated riparian vegetation studies***										
	I.1.Monitor vegetation and channel response using response guilds and landscape-scale vegetaiton change analysis	$133,300	$3,800	$4,000	$43,700	$137,000		$28,000		$26,700	$376,500

	Project Description	Salaries	Travel & Training	Operating Expenses	Logistics	GIS / RS / electronics support (includes burden)	Contractors	Cooperators (non-USGS)	USGS Cooperators	USGS Burden	Total
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
J	***Monitoring of cultural resources at a small scale and defining the large-scale geomorphic context of those***										
	J.1. Monitoring the status of cultural resources in Glen Canyon National Recreation Area	$35,000	$1,900	$5,000	$1,900	$22,500	$50,000	$3,000	$29,200	$13,200	$161,700
	J.2. Monitoring strategies for the status of cultural resources in Grand Canyon National Park	$35,000	$8,000	$5,000	$19,000	$4,800		$5,000	$104,800	$9,500	$191,100
	J.3. Large-scale geomorphology of the Colorado River valley in Glen, Marble, and Grand Canyons	$8,400	$13,200	$3,000		$31,200			$127,900	$3,400	$187,100
K	**GCMRC economist and support**	$150,000	$23,700	$25,000							$198,700
L	**Independent Review**										
	Independent Reviewers						$24,300			$3,400	$27,700
	Science Advisors						$144,300			$20,200	$164,500
M	**USGS Administration**										
	Budget analyst, communications support, library, discretionary awards	$253,400	$5,600	$46,900				$71,500		$45,000	$422,400
	vehicles			$111,400						$15,600	$127,000
	leadership personnel	$434,400	$19,500							$63,600	$517,500
	AMWG/TWG travel		$26,800							$3,800	$30,600
	SBSC IT overhead			$107,500					$5,000	$15,000	$127,500
	Logistics base costs	$244,000	$14,300							$36,100	$294,400
	GIS/RS/electronics base costs										$86,600

	Project Description	Salaries	Travel & Training	Operating Expenses	Logistics	GIS / RS / electronics support (includes burden)	Contractors	Cooperators (non-USGS)	USGS Cooperators	USGS Burden	Total
	Total Amount in Category	$3,597,400	$177,500	$665,300	$1,002,000	$726,800	$218,600	$1,741,900	$932,500	$817,000	$10,440,600
N	**Quadrennial Overflight**										
	May 2013 flight										$475,000
	contribution to 2017 flight										
	* pending approval by Bureau of Reclamation										

Appendix 2-B. Fiscal Year 2013 Funding Source

	Fiscal Year 2013 funding sources				
	Project Description	**GCDAMP Funding**	**GCMRC FY12 Carryover Funding ***	**Other BOR Funding**	**BOR Funding from AMP Carryover Funds**
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
A	***Sandbars and sediment storage dynamics***				
	GIS and image processing costs for entire project (includes burden)	$180,600			
	A.1. Sandbar and camping beach monitoring	$261,900			
	A.2. Sediment storage monitoring	$597,600			
	A.3. Investigating eddy sandbar variability and the interactions among flow, vegetation, and geomorphology	$103,500			
	A.4. Quantifying the correlation between bed and transport grain size		$149,900		
	A.5. Geochemical signatures of pre-dam sediment	$50,900			
	A.6. Control network and surveying support	$56,300			
B	***Stream flow, water quality, and sediment transport***	$1,276,400			
	(contingency) HFE gage maintenance and measurements	$70,400			
C	***Lake Powell water quality monitoring***			$251,600	

	Project Description	GCDAMP Funding	GCMRC FY12 Carryover Funding *	Other BOR Funding	BOR Funding from AMP Carryover Funds
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
D	***Mainstem humpback chub aggregation studies***				
	D.1. Aggregation sampling		$199,500		
	D.2. Natal origins of humpback chub, adult condition, and reproductive potential				$167,400
E	***Humpback chub early life history in and around the Little Colorado River***				
	E.1. July LCR marking	$129,400			
	E.2. Describing the food web structure and the potential for food limitation within the Little Colorado River	$257,200			
	E.3. Population modeling	$89,500			
F	***Monitoring of native and nonnative fishes in the mainstem Colorado River and the lower Little Colorado River***				
	F.1. System wide electrofishing	$216,900			
	F.2.1 Glen Canyon monitoring	$173,000			
	F.2.2. Rainbow trout early life stage studies	$62,900			
	F.2.3. Lees Ferry creel survey	$27,900			
	F.3. Mainstem monitoring of native and nonnative fishes near the LCR confluence	$464,000			
	F.4.1. Annual spring and fall humpback chub abundance estimates in the downstream 13.6 km of the Little Colorado River	$495,900			

	Project Description	GCDAMP Funding	GCMRC FY12 Carryover Funding *	Other BOR Funding	BOR Funding from AMP Carryover Funds
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
	F.4.2 Monitoring native and nonnative fishes in the downstream 1.2 km of the Little Colorado River	$85,000			
	F.4.3 Translocation and monitoring above Chute Falls	$129,000			
	F.4.4 PIT tag antenna monitoring	$101,300			
	F.5. Stock assessment and estimation of humback chub abundance using the age structured mark recapture model	$20,200			
	F.6. Detection of rainbow trout movement from Glen Canyon to Marble Canyon	$276,000			
	F.7. Foodbase monitoring	$271,800			
G	***Interactions between native fish and nonnative trout***				
	G.1. Laboratory studies to assess the effects of trout predation and competition on humpback chub				$93,400
	G.2. Efficacy and ecological impacts of brown trout removal at Bright Angel Creek	$181,900			

	Project Description	GCDAMP Funding	GCMRC FY12 Carryover Funding *	Other BOR Funding	BOR Funding from AMP Carryover Funds
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
H	***Understanding the factors limiting the growth of rainbow trout in Glen and Marble Canyons***				
	H.1. Laboratory feeding studies				$37,700
	H.2.1. Developing a mechanistic model of primary productivity				$123,400
	H.2.2. Characterizing invertebrate drift	$120,600			
	H.3. Developing a bioenergetics model for large rainbow trout	$138,300			
	H.4. Learning from other tailwaters -- a synthesis of tailwaters in the United States				$146,500
	H.5. Contingency planning for High Flow Experiments and subsequent rainbow trout population management	$44,500			
I	***Integrated riparian vegetation studies***				
	I.1.Monitor vegetation and channel response using response guilds and landscape-scale vegetaiton change analysis	$376,500			

	Project Description	GCDAMP Funding	GCMRC FY12 Carryover Funding *	Other BOR Funding	BOR Funding from AMP Carryover Funds
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
J	***Monitoring of cultural resources at a small scale and defining the large-scale geomorphic context of those***				
	J.1. Monitoring the status of cultural resources in Glen Canyon National Recreation Area	$161,700			
	J.2. Monitoring strategies for the status of cultural resources in Grand Canyon National Park	$191,100			
	J.3. Large-scale geomorphology of the Colorado River valley in Glen, Marble, and Grand Canyons	$25,200		$161,900	
K	**GCMRC economist and support**	$198,700			
L	**Independent Review**				
	Independent Reviewers	$27,700			
	Science Advisors	$164,500			
M	**USGS Administration**				
	Budget analyst, communications support, library, discretionary awards	$422,400			
	vehicles	$127,000			
	leadership personnel	$517,500			
	AMWG/TWG travel	$30,600			
	SBSC IT overhead	$127,500			
	Logistics base costs	$294,400			
	GIS/RS/electronics base costs		$86,600		

	Project Description	GCDAMP Funding	GCMRC FY12 Carryover Funding *	Other BOR Funding	BOR Funding from AMP Carryover Funds
	Total Amount in Category	$8,632,700	$826,000	$413,500	$568,400
N	**Quadrennial Overflight**				
	May 2013 flight	$85,000	$390,000		
	contribution to 2017 flight				
	* pending approval by Bureau of Reclamation				

Appendix 2-C. Fiscal Year 2014 Funding Source

	Fiscal Year 2014 funding sources					
	Project Description	**total request**	**GCDAMP Funding**	**Other BOR funding**	**BOR Funding from AMP Carryover Funds**	**GCMRC FY12 Carryover Funding ***
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
A	***Sandbars and sediment storage dynamics***					
	GIS and image processing costs for entire project (includes burden)	$189,600	$189,600			
	A.1. Sandbar and camping beach monitoring	$270,400	$270,400			
	A.2. Sediment storage monitoring	$618,100	$618,100			
	A.3. Investigating eddy sandbar variability and the interactions among flow, vegetation, and geomorphology	$108,500				$108,500
	A.4. Quantifying the correlation between bed and transport grain size	$212,100				$212,100
	A.5. Geochemical signatures of pre-dam sediment	$54,800				$54,800
	A.6. Control network and surveying support	$57,300	$57,300			
B	***Stream flow, water quality, and sediment transport***	$1,314,700	$1,314,700			
	(contingency) HFE gage maintenance and measurements					
C	***Lake Powell water quality monitoring***	$259,100		$259,100		

	Project Description	total request	GCDAMP Funding	Other BOR funding	BOR Funding from AMP Carryover Funds	GCMRC FY12 Carryover Funding *
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
D	***Mainstem humpback chub aggregation studies***					
	D.1. Aggregation sampling	$205,900	$205,900			
	D.2. Natal origins of humpback chub, adult condition, and reproductive potential	$155,200			$155,200	
E	***Humpback chub early life history in and around the Little Colorado River***					
	E.1. July LCR marking	$127,100	$127,100			
	E.2. Describing the food web structure and the potential for food limitation within the Little Colorado River	$267,500	$267,500			
	E.3. Population modeling	$92,400	$92,400			
F	***Monitoring of native and nonnative fishes in the mainstem Colorado River and the lower Little Colorado River***					
	F.1. System wide electrofishing	$223,900	$223,900			
	F.2.1 Glen Canyon monitoring	$178,200	$178,200			
	F.2.2. Rainbow trout early life stage studies	$65,000	$65,000			
	F.2.3. Lees Ferry creel survey	$28,900	$28,900			
	F.3. Mainstem monitoring of native and nonnative fishes near the LCR confluence	$479,100	$479,100			
	F.4.1. Annual spring and fall humpback chub abundance estimates in the downstream 13.6 km of the Little Colorado River	$511,200	$511,200			

	Project Description	total request	GCDAMP Funding	Other BOR funding	BOR Funding from AMP Carryover Funds	GCMRC FY12 Carryover Funding *
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
	F.4.2 Monitoring native and nonnative fishes in the downstream 1.2 km of the Little Colorado River	$87,600	$87,600			
	F.4.3 Translocation and monitoring above Chute Falls	$133,100	$133,100			
	F.4.4 PIT tag antenna monitoring	$62,000	$62,000			
	F.5. Stock assessment and estimation of humback chub abundance using the age structured mark recapture model	$20,800	$20,800			
	F.6. Detection of rainbow trout movement from Glen Canyon to Marble Canyon	$285,100	$285,100			
	F.7. Foodbase monitoring	$280,100	$280,100			
G	***Interactions between native fish and nonnative trout***					
	G.1. Laboratory studies to assess the effects of trout predation and competition on humpback chub	$100,800			$100,800	
	G.2. Efficacy and ecological impacts of brown trout removal at Bright Angel Creek	$192,700	$192,700			

	Project Description	total request	GCDAMP Funding	Other BOR funding	BOR Funding from AMP Carryover Funds	GCMRC FY12 Carryover Funding *
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
H	***Understanding the factors limiting the growth of rainbow trout in Glen and Marble Canyons***					
	H.1. Laboratory feeding studies	$38,900			$38,900	
	H.2.1. Developing a mechanistic model of primary productivity	$126,900			$126,900	
	H.2.2. Characterizing invertebrate drift	$124,200	$124,200			
	H.3. Developing a bioenergetics model for large rainbow trout	$142,200	$142,200			
	H.4. Learning from other tailwaters -- a synthesis of tailwaters in the United States	$151,300			$151,300	
	H.5. Contingency planning for High Flow Experiments and subsequent rainbow trout population management	$54,800	$54,800			
I	***Integrated riparian vegetation studies***					
	I.1.Monitor vegetation and channel response using response guilds and landscape-scale vegetaiton change analysis	$359,300	$359,300			

	Project Description	total request	GCDAMP Funding	Other BOR funding	BOR Funding from AMP Carryover Funds	GCMRC FY12 Carryover Funding *
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
J	***Monitoring of cultural resources at a small scale and defining the large-scale geomorphic context of those***					
	J.1. Monitoring the status of cultural resources in Glen Canyon National Recreation Area	$179,900	$179,900			
	J.2. Monitoring strategies for the status of cultural resources in Grand Canyon National Park	$179,600	$179,600			
	J.3. Large-scale geomorphology of the Colorado River valley in Glen, Marble, and Grand Canyons	$196,900	$35,000	$161,900		
K	**GCMRC economist and support**	$204,700	$204,700			
L	**Independent Review**					
	Independent Reviewers	$28,500	$28,500			
	Science Advisors	$169,400	$169,400			
M	**USGS Administration**					
	Budget analyst, communications support, library, discretionary awards	$432,800	$432,800			
	vehicles	$130,800	$130,800			
	leadership personnel	$715,800	$715,800			
	AMWG/TWG travel	$31,500	$31,500			
	SBSC IT overhead	$131,300	$131,300			
	Logistics base costs	$304,400	$304,400			
	GIS/RS/electronics base costs	$34,000				$34,000

	Project Description	total request	GCDAMP Funding	Other BOR funding	BOR Funding from AMP Carryover Funds	GCMRC FY12 Carryover Funding *
	Total Amount in Category	$10,518,400	$8,914,900	$421,000	$573,100	$609,400
N	**Quadrennial Overflight**					
	May 2013 flight					
	contribution to 2017 flight	$200,000				$200,000
	* pending approval by Bureau of Reclamation					

Appendix 2-D Logistics of River Trips

Logistics Budget	general logistics description	logistics type	annual # trips	trip months	boats	#people	#days
$ 27,200.00	one river trip anually to survey established longterm set of monitoring sites. Non motorized trip consisting of 6-18' row boats occurs in October	river trip	1	October	6 row	12	18
$ 74,300.00	one river trip anually, motor supported trip occurs April/May to map channel in rotating reaches of river. In 2013,RM 0-30 will be surveyed.	river trip	1	May	2 support, 2-22' technical (multi-beam and "eye-ball"), 1-16' technical (single beam), 1-16' technical	20	19
	one river trip, motor supported trip to launch at Diamond Creek to survey river channel between Diamond Creek and Pierce Ferry	river trip (Diamond Creek launch)	1	Feb/March	1 support, 1-16' technical (singlebeam)	8	5
$ 36,900.00	sampling at existing gages on scheduled river trips or accesible gages (Diamond creek), on bi-monthly basis beginning on SSM trip in April/May	Diamond Creek access	6 (initial sampling occurs on May SSM trip and continues on Diamond Creek access trips bi-monthly	May, July, September, November, January, March	1-22' (multibeam	6	4
$ 5,700.00	support included on existing trips, external helicopter support including 2013 overflight support??	rim support, utilize scheduled river trips					

Logistics Budget	general logistics description	logistics type	annual # trips	trip months	boats	#people	#days
$ 21,900.00	food packs provided for quarterly Lake Powell monitorng trips, 4-6 people, 7 days, includes limited boat/motor maintence support	Lake Powell trip	4				
$ 100,000.00	two river trips anually, to support monitoring focused on identified HBC aggregations	river trip	2	July, September	2-support, 2-16' technical	10	18
$ 10,000.00	helicopter support for 3 LCR camps to monitor LCR HBC populations	helicopter support	1	July		6 (2/camp)	5
$ 55,000.00	two river trips anually, to electrofish sample entire river corridor,	river trip	2	April, May	2-support, 2-16' technical	10	14
$ 42,000.00	3 Glen Canyon trips to monitor RBT population, includes additional day on July trip for non-native fish detection	Glen Canyon	3	April, July, October	2-16' technical	4	4days, July trip 5 days

Logistics Budget	general logistics description	logistics type	annual # trips	trip months	boats	#people	#days
$ 15,000.00	8 winter/spring one day trips to survey Glen Canyon reach for RBT redds, and 4 sampling trips utilizing electrofishing and backpack shocking to monitor RBT early life stage	Glen Canyon	8 Redd, 4 RTLESS	Redd: Dec, Jan, Feb, March, April RTELSS: July, Aug, Sept, Nov	Cofelt, 2-16' technical	2	Redd: one day trips, RTELSS: 2-16' technical
$ 147,000.00	4 river trips anually to monitor Juvenile HBC survival in LCR confluence reach. (Logistics are combined with project F.3.)	river trip	4	May, July, September, January	2-support, 1-22' processing boat 3-16' technical	18	14 (total trip length is 20 days)
$ 86,000.00	helicopter support for 3 LCR camps, April/May and September/October, 9 people, 11 days per trip	helicopter support	4	April, May, September, October		9	11
$ 12,000.00	helicopter support, Boulders camp, 2 people 30 days	helicopter support	1	April/May		2	30-40
$ 37,000.00	3 helicopter supported trips for HBC mark/recap and translocation/capture	helicopter support	3	April/May, July			
$ 6,000.00	maintence of remote PIT tag array as needed	helicopter support	1			2	4
$ 87,000.00	Logistics are combined wit project F.3 (first six days of river trip) to electrofish sample for tagged RBT between Glen Canyon Dam and LCR confluence.	river trip	4	May, July, September, January	2-support, 1-22' Processing boat 3-16' technical	18	18
	november Glen Canyon marking trip	Glen Canyon	1	November	1-support, 1-22' processing boat, 2-16' technical, cofelt	10	9
$ 20,000.00	included in F.3./F.6. plus Lees Ferry and Diamond Creek monitoring	river trip, Glen Canyon, Diamond Creek,Citizen science					

Logistics Budget	general logistics description	logistics type	annual # trips	trip months	boats	#people	#days
$ 89,000.00	new project to colaborate with NPS to remove Brown trout in Bright Angel Creek confluence. Logistics could be coupled with F.3/F.6 project run-out.	river trip/Phantom Ranch base camp?	2	May, September	1-support, 2-16' technical	8	18
$ 1,200.00	Glen Canyon/Diamond Creek		2				
$ 1,200.00	Glen Canyon/Diamond Creek (included in NO/JCM trips)		2				
$ 23,000.00	1 additional RBT marking trip in Glen Canyon post HFE	Glen Canyon	2	Dec	1-support, 1-22' processing boat, 2-16' technical, cofelt	10	9
$ 30,000.00	one river trip to monitor riparian vegetation	river trip	1	September	4 row	14	16
$ 6,000.00	this project is currently unfunded	Glen Canyon					
$ 2,000.00	panel deployment for overflight	Glen Canyon	1	Nov/Dec	cofelt	2	4
$ 19,000.00	one river trip to monitor designated sites and maintain weather stations, additional logistics for weater station maintenace will be covered on existing scheduled trips (GCY, FCS, NO/JCM)	river trip	1	May	1-support, 1-22'	10	13
$ 1,014,400.00							