Prepared in cooperation with the Glen Canyon Dam Adaptive Management Program

Draft Report to the Technical Work Group of the Glen Canyon Dam Adaptive Management Program: Recommended Protocols for Core Monitoring of Sediment within the Colorado River Ecosystem Below Glen Canyon Dam

Part IV – Developing a Scientifically Based Long-Term Monitoring Plan for the GCDAMP

By David J. Topping, Scott A. Wright, David M. Rubin, and Theodore S. Melis

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Executive Summary

This report was prepared by the U.S. Geological Survey's (USGS) Grand Canyon Monitoring and Research Center (GCMRC) in cooperation with its sediment research cooperators to provide specific recommendations to the Technical Work Group of the Glen Canyon Dam Adaptive Management Program on long-term monitoring of sediment resources below Glen Canyon Dam. As described in the 2007–11 Monitoring and Research Plan, these recommendations represent the final step in a four-part process for developing an integrated long-term monitoring plan for the Colorado River ecosystem below Glen Canyon Dam. As such, this report provides a brief summary of the research findings from two science projects that were funded between 2000 and 2007 specifically to test and evaluate new and existing methods for measuring suspended-sediment transport and sand storage within the Colorado River ecosystem below the dam. The ecosystem is a complex river system that extends through Glen Canyon National Recreation Area and Grand Canyon National Park, a distance of some 400 kilometers. The report also includes key findings from the ongoing external peer-review process for sediment monitoring, a three-part review that began in 1998 and was concluded in August 2006.

The recommendations contained in this report are based on a combination of previous and ongoing sediment transport research, information needs identified by stakeholders, guidance from three external peer-review panels, a recent National Research Council (NRC) report on USGS river science[1], as well as logistical and programmatic constraints. While only a small amount of the published scientific information is recounted in this report, the entire body of findings has been carefully considered as the basis for specific recommendations contained herein. In addition to the guidance provided by previous research, stakeholder information needs, and peer-review panels (all described for Goals 7 and 8 in Parts 1 and 2 of this report, respectively), we have also taken into consideration the recent recommendations provided by the NRC with respect to sediment transport science and monitoring in rivers, as follows:

- "The USGS should increase its efforts to improve the understanding of sediment transport and river geomorphology in the nation's rivers. Activities should include advancing basic research on sediment-transport processes, developing new technologies for measuring fluxes of bedload, suspended load, and washload, and monitoring flow velocity and water temperature associated with such sediment transport conditions. Through these activities, the USGS can provide key information and tools to predict channel morphodynamics, develop methods to mitigate future problems arising from sediment movement, and play a

[1] Committee on River Science at the U.S. Geological Survey, National Research Council, 2007. River science at the U.S. Geological Survey: Washington, D.C., National Academies Press, 194 p.

guiding role in multi-agency efforts to deal with the increasingly important national sediment challenges.”

- “Leveraging the infrastructure of the stream gaging network, the USGS should greatly expand sediment monitoring of the nation’s rivers. To meet the growing needs for sediment data, the USGS should take the lead in developing a comprehensive national sediment monitoring program.”

- “An index reach monitoring approach would help address many data needs for USGS river science priorities. The USGS should begin efforts to design and implement sampling plans on reach scales to integrate monitoring of physical, chemical, and biological condition for river science investigations.”

While it is clear that a monitoring program for a single river ecosystem cannot completely satisfy these broad recommendations, we feel that the monitoring program outlined herein at least partly addresses each recommendation, and can serve as an example that may be followed in the future for rivers with similar sediment transport issues as the Colorado River below Glen Canyon Dam. Finally, we have necessarily taken into consideration some broad logistical and programmatic constraints in developing these recommendations. For example, one approach would be to recommend monitoring of all tributaries that have been identified to deliver sediment to the Colorado River in the reach of interest; however, since there are nearly 800 of these tributaries, this approach would not be logistically or financially feasible. Thus, we have used knowledge of the system gained from previous research (e.g., the relative importance of the various tributaries with respect to sediment inputs) in combination with the stakeholder information needs and management objectives, to develop monitoring recommendations that balance the need for information with the logistical and programmatic constraints. In the end, the level of monitoring must be sufficient to evaluate the state of the resource of interest over the long-term: logistical and programmatic constraints cannot be allowed to compromise this evaluation. We believe that the monitoring program outlined herein will meet this objective.

The basic recommendations for long-term monitoring of sediment below the dam consist of a combination of annual to less frequent tasks aimed at: (1) continuously monitoring the flow and suspended-sediment flux (including grain size) between the dam and upper Lake Mead using a variety of conventional and sediment surrogate methods as part of Goal 7 (Quality of Water); (2) quantifying sediment storage throughout the system as part of Goal 8 (Sediment). Quantify sediment storage throughout the system requires annually measuring a subset of higher elevation sand deposits (with emphasis on sandbars used as campsites) in support of Goal 9 (Recreation); repeating inventories of all exposed mid- to higher elevation sand areas systemwide as derived from remote sensing imagery captured above 8,000 cfs stage elevation in support of Goals 6 (Riparian Vegetation), 9 (Recreation), 11 (Cultural) and Goal 2 (DASA); and repeating annually to biennially topographic channel mapping of continuous reaches between the separate suspended-sediment flux monitoring stations with emphasis on topography and grain size data below 8,000 cfs stage elevation as the third component of Goal 8 (Sediment) monitoring.

In addition, as part of Goal 8 (Sediment), the recommendations also include the continuation of an appropriate level of long-term monitoring of coarse sediment impacts to the main channel from tributary floods and debris flows using field methods that have been previously described in the ecosystem in combination with imagery from overflights (above 8,000 cfs stage elevation).

While these recommendations are forwarded to managers for their consideration, the sediment researchers continue to evaluate existing data collected during past research. As with any planning process, the GCMRC anticipates that continued discussions between scientists and managers will result in a core monitoring strategy for sediment that meets the needs of the Glen Canyon Dam Adaptive Management Program.

PART 1. Quality of Water [fine sediment] - Recommended Protocols for Monitoring Suspended-Sediment Flux Throughout the Colorado River Ecosystem

In support of GCDAMP Goal 7: Establish water temperature, quality and flow dynamics to achieve GCDAMP ecosystem goals (downstream sediment component only)

Project Title

Long-term monitoring for the "mass balance" of fine sediment (defined here as sand-sized and smaller particles) in multiple reaches of the CRE based on suspended-sediment flux measurements (short title: Mass Balance)

Geographic Scope

The mass balance project is primarily focused on a sub-reach of the main channel of the Colorado River ecosystem (CRE) from Lees Ferry (river mile 0) to upper Lake Mead (as measured at the gage upstream of Diamond Creek (river mile 226) (fig. 1.1). In addition, this project uses a combination of monitoring and modeling of tributary sediment inputs such that fine sediment and flow monitoring activities are also carried out in various tributary watersheds.

Justification for Long-Term Monitoring Effort

The primary linkage between dam operations and the response of the physical, biological, and cultural resources in the Colorado River ecosystem between Glen Canyon Dam and Lake Mead is through the discharge and quality of water in the Colorado River (U.S. Department of the Interior, 1995; National Research Council, 1996). Releases from Glen Canyon Dam provide the principal control on the discharge of water in the Colorado River between Glen Canyon Dam and Lake Mead. Only during periods of large tributary floods do tributaries exert any substantial control on the discharge of the Colorado River in the CRE. Fine sediment is an important water-quality parameter in the CRE because it comprises side-channel deposits that are important to multiple biological, cultural, and recreational resources (Rubin and others, 2002; Wright and others, 2005), and, when suspended in the water column, influences the aquatic ecology of the river.

Systematic measurements of the discharge of water and the quality of water (including suspended-sediment concentration) in the CRE began with the installation of the Lees Ferry gaging station by the U.S. Geological Survey (USGS) 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 in the CRE. 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 emphasis on measurements and modeling of water quality in the early 1980s (National Research Council, 1996). The results of these studies have been published in numerous USGS reports and journal articles. Research during and following the 1996 controlled-flood release (also referred to as a test of the beach/habitat-building flow concept or BHBF) from Glen Canyon Dam indicated that because sand transport was not regulated solely by the discharge of water (Rubin and others, 1998, 2002; Topping and others, 1999, 2000a, 2000b, 2005, in press a; Rubin and Topping, 2001; Wright and others, 2005), a return to a daily measurement program was required to track the status of the sediment budget in the CRE. This resulted in reinstituting quasi-daily suspended-sediment measurements at three gaging stations in the CRE in August 1999. Because substantial large discharge-independent changes in suspended-sediment concentration occur over timescales that could not be captured by this quasi-daily program, and this quasi-daily program proved to be cost prohibitive, laser diffraction and acoustic technologies for measuring suspended-sediment concentration and grain size were developed and tested in the CRE beginning in 2001 (Melis and others, 2003; Topping and others, 2004, 2006b, in press b). These tests have been successful and have been published in numerous reports in the peer-reviewed scientific literature. Where and when possible, predictive models have been developed and tested for stage, discharge, and sediment-transport.

Computing fine-sediment budgets for various reaches is required for evaluating the effects of dam operations, including controlled floods. The most recent of three sediment protocol evaluation panels, SEDS-PEP III (Wohl and others, 2006), recognized this need and stated the following:

> "The second approach for monitoring sediment is to track inputs, storage, and outputs for a sediment mass balance. This provides the ability to quantify a trigger for beach habitat building flows (BHBFs). Continuing key uncertainties in using the mass balance approach include inputs from the Paria and the LCR [Little Colorado River], how much sediment remains stored in the main channel, and how much sediment has moved through the river system. Further quantifying the mass balance will provide insight into these unknowns for future controlled floods. A minimal level of mass balance would be based on considering only inputs. A more robust mass balance would also include outputs and overall mass balance. The panel believes that it is critical to have the more robust mass balance because our understanding of the system is insufficient at this point to make recommendations about controlled floods."

Herein we outline the "more robust" mass balance as recommended by the SEDS-PEP III (PEP). The PEP also recommended monitoring of the size and distribution of sandy deposits; this recommendation is addressed in the section on Goal 8 of the draft core monitoring report. Finally, the PEP panel reviewed the downstream quality-of-water project (which includes mass balance) annual work plan (Topping and others, 2006a) and stated:

> "In summary, the review panel commends the physical resources program director and contributing scientists for the progress made with respect to core monitoring and analysis since the 1999 program review. Although the panel believes that many specific improvements can be made within the physical resources program and in cross-program linkages within GCMRC, we think that the physical resources program is proceeding in a manner that will be effective in addressing core monitoring information needs and strategic science questions."

AMWG Goal(s) Addressed

The mass balance project directly supports achievement of the following AMP goals:

Goal 7 – Establish water temperature, quality, and flow dynamics to achieve AMP ecosystem goals.

Goal 8 – Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve AMP ecosystem goals.

Because the project addresses the physical framework of the ecosystem, which underlies many biological, cultural, and recreational resource objectives, it indirectly supports achievement of almost all other AMP goals, as follows:

Goal 1 – Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels. The mass balance project supports this goal by providing information on flows and turbidity that aids in food base 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. The mass balance project supports this goal by providing sediment concentration data that is used to adjust for catch efficiency in population models, flow and stage data that is important to understanding the effects of nearshore habitat disruption caused by fluctuating flows, and information on sandbars which create backwater habitats that are thought to be important for 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 mass balance project tracks the transport and fate of fine sediment which provides the substrate for riparian vegetation and marsh communities.

Goal 9 – Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem within the framework of AMP ecosystem goals. The mass balance project provides information to understand flow dynamics and 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 mass balance project collects information on sandbars that provide a source of sediment, through aeolian transport, to high elevation sand deposits that contain archaeological resources.

Key Science Questions and Managers' Information Needs Addressed

Several strategic science questions (SSQ) were identified by scientists and managers during the Knowledge Assessment Workshop conducted in the summer of 2005 (Melis and others, 2006). The mass balance monitoring project provides valuable information to help answer several of the questions related to sediment conservation, and in particular the primary sediment question: "Is there a 'Flow-Only' operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?"

The 2003 AMP Strategic Plan identified Core Monitoring Information Needs (CMINs) related to flow and water quality (Goal 7) and sediment storage (Goal 8). Because fine sediment is a water-quality parameter as well as a component of sediment storage, the fine sediment mass balance project addresses CMINs falling under Goals 7 and 8. The CMINS that are addressed by the mass balance project are listed below. For each, the prioritization ranking applied by the AMP Science Planning Group in 2006 is also included.

CMIN 7.4.1 – Determine and track releases from Glen Canyon Dam under all operating conditions. #1 ranked Goal 7 CMIN.

CMIN 7.4.2 – Determine and track flow releases from Glen Canyon Dam, particularly related to flow duration, upramp, and downramp conditions. #1 ranked Goal 7 CMIN (essentially the same as 7.4.1).

CMIN 7.2.1 – Determine the seasonal and yearly trends in turbidity, water temperature, conductivity, DO, and pH, (decide below whether selenium is important) changes in the mainstem throughout the Colorado River ecosystem. #3 ranked Goal 7 CMIN.

CMIN 7.1.2 – Determine and track LCR discharge near mouth (below springs). #4 ranked Goal 7 CMIN.

CMIN 8.1.3 – Track, as appropriate, the monthly sand and silt/clay -input volumes and grain-size characteristics, by reach, as measured or estimated at the Paria and Little Colorado River stations, other major tributaries like Kanab and Havasu creeks, and "lesser" tributaries. #1 ranked Goal 8 CMIN.

CMIN 8.1.2 – What are the monthly sand and silt/clay -export volumes and grain-size characteristics, by reach, as measured at Lees Ferry, Lower Marble Canyon, Grand Canyon, and Diamond Creek Stations? #2 ranked Goal 8 CMIN.

Developing and testing monitoring protocols for these CMINs was the primary focus of research and development conducted during fiscal years (FY) 1998–2006, as reviewed by SEDS-PEP III.

Project Goals, Tasks, and Schedule by Task

The overarching goal of the mass balance project is to provide information to the management group that meets their information needs, such that they can manage the system in a way that addresses their management goals (as outlined in the previous section). The primary tasks associated with meeting this objective are as follows:

- Collection of high-resolution time series of suspended-sediment flux at multiple mainstem locations and major tributaries (methods outlined in the following section).
- Collection of high-resolution stage (discharge is computed based on results from a multidimensional flow model) and episodic suspended-sediment data on key lesser tributaries in Glen, Marble, and Grand Canyons.
- Processing and analysis of the suspended-sediment flux data in order to construct sediment budgets for multiple reaches of the river through Marble and Grand Canyons.
- Publication of the results in peer-reviewed outlets (USGS reports, journal articles) and presentation of the results at AMP management and scientific meetings.

The schedule of the mass balance core monitoring project is on a continuing basis. Data are collected essentially continuously, with results published annually (USGS report) and presentations given at Glen Canyon Dam Adaptive Management meetings on a biannual basis.

Recommended Long-Term Monitoring Protocols

Surface water measurements (i.e., stage and discharge) would be made through this project, using standard USGS methods (described in *Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Section A*), at the following sites (see fig. 1.1): Colorado River at Lees Ferry, AZ (09380000), Colorado River near river mile 30 (new), Colorado River above the Little Colorado River near Desert View, AZ (09383100, currently discontinued), Colorado River near Grand Canyon, AZ (09402500), Colorado River above National Canyon near Supai, AZ (09404120, currently discontinued), Colorado River above Diamond Creek near Peach Springs, AZ (09404200), Paria River near Kanab, UT (09381800), Paria River at Lees Ferry, AZ (09382000), Little Colorado River near Cameron, AZ (09402000), Little Colorado River above mouth near Desert View, AZ (09402300), Moenkopi Wash Wash near Cameron, AZ (09401500, currently discontinued), Havasu Creek above mouth near Supai, AZ (09404115), and Kanab Creek above mouth near Supai, AZ (09403850, currently discontinued) (see fig. 1.1). At most sites, 15-minute data will be available approximately real-time (every four hours) through the USGS NWIS database (http://waterdata.usgs.gov/usa/nwis/rt). The surface water gages would be maintained and operated by the USGS Water Resources Discipline (WRD) Arizona and Utah Water Science Centers.

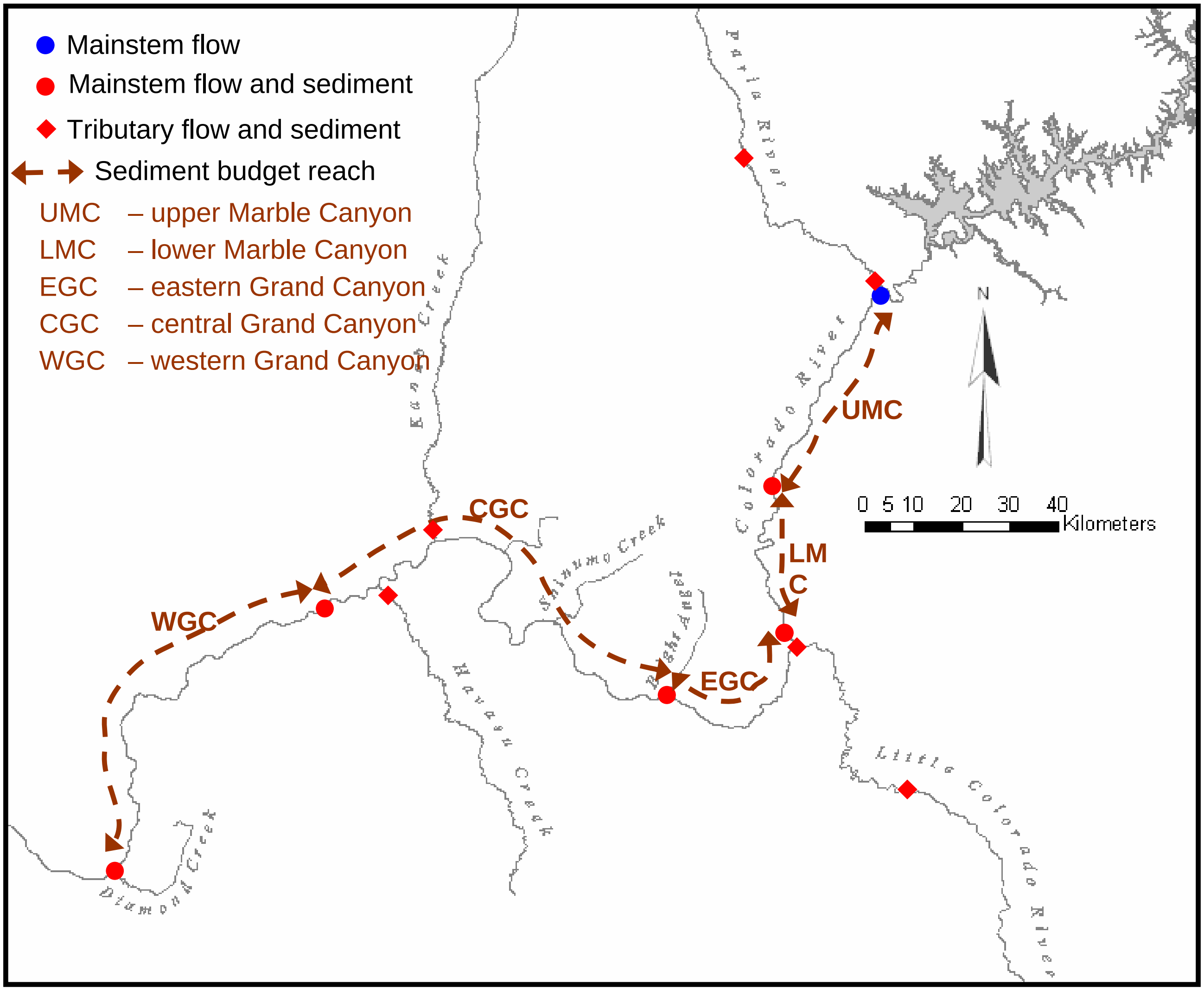
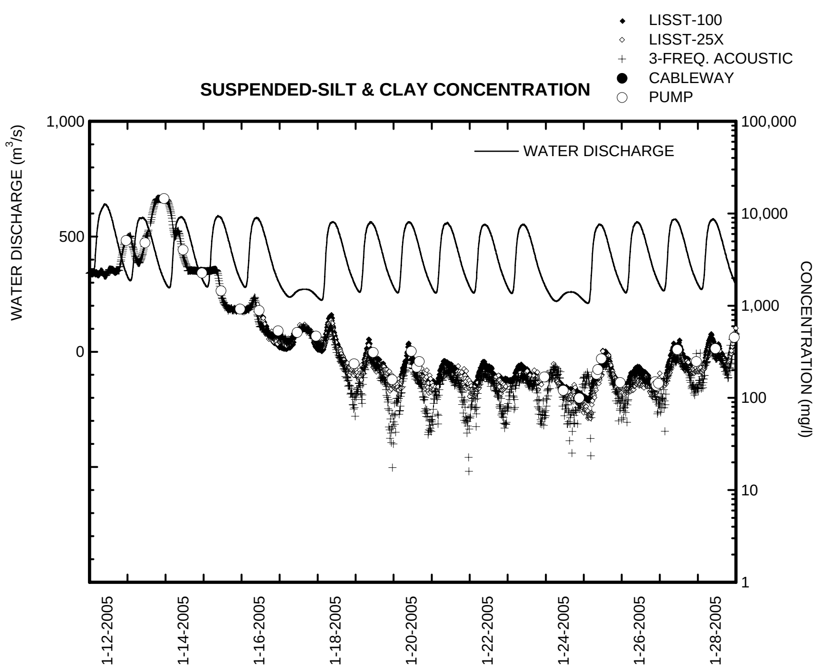


Figure 1.1 Location map showing streamflow and suspended-sediment transport data collection sites and fine sediment budget reaches. Locations of lesser tributary monitoring stations are not shown.

The supply of fine sediment to the Colorado River from tributaries downstream from Glen Canyon Dam is computed using a combination of physically based models and measurements. On a near real-time basis, the concentration and grain-size distribution of the sand and finer material supplied by the major tributaries (Paria and Little Colorado Rivers) are computed using the real-time discharge data along with a geomorphically coupled flow and sediment-transport model (Topping, 1997). Sediment-transport measurements are collected on these two major tributaries by conventional and pump methodologies by the USGS WRD Arizona and Utah Water Science Centers and provided to our laboratory. Because of the uncertainties associated with measurements of discharge and suspended-sediment concentration on the Paria River, additional sediment-transport data may be collected on the Colorado River downstream from the mouth of the Paria River as an additional constraint on the fine-sediment supply to Marble Canyon during periods of flooding on the Paria River. As sediment transport data become available from the GCMRC's sediment laboratory, the predictions from the models are verified (to within the error in the measurements) and adjusted if necessary. Inputs of suspended sediment from Kanab and Havasu Creeks and Moenkopi Wash will be estimated on an event basis using measurements of flow and suspended-sediment concentration and grain-size using standard USGS methods (*Techniques of Water-Resources Investigations of the U.S. Geological Survey, Book 3, Section C*). Inputs of suspended sand (with grain size) and suspended silt and clay from the lesser tributaries are computed based on stage and sediment data collected in a network established beginning in 2000; this network now covers 55% of the formerly ungaged tributary area between Glen Canyon Dam and the Little Colorado River.

Mainstem suspended-sediment concentration and grain size are monitored every 15 minutes using laser-acoustic technologies at the following sites: 30-mile, 61-mile, 87-mile (near Grand Canyon gage), 166-mile, and 226-mile (above Diamond Creek gage, see figs. 1.1 and 1.2). The methodologies associated with the laser-acoustic technologies are described in Melis and others (2003), and Topping and others (2004, 2006b, and in press b). Conventional pump and cross-sectionally integrated samples are also collected at these sites for calibration and validation of the laser-acoustic technologies. At the sites that are not monitored for stage and discharge by the Arizona Water Science Center (30-mile, 61-mile, 166-mile), stage is measured with the acoustic instrumentation and stage-discharge rating curves have been developed based on discharge measurements during the November 2004 controlled flood/BHBF test and during subsequent river trips. The discharge time series allow for computation of suspended-sediment flux, by grain size, at all sites.



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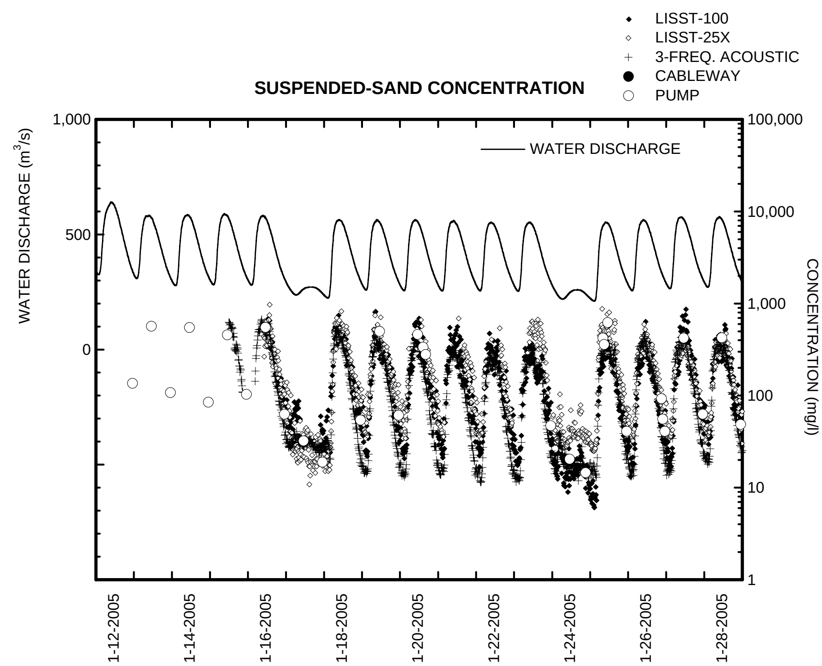

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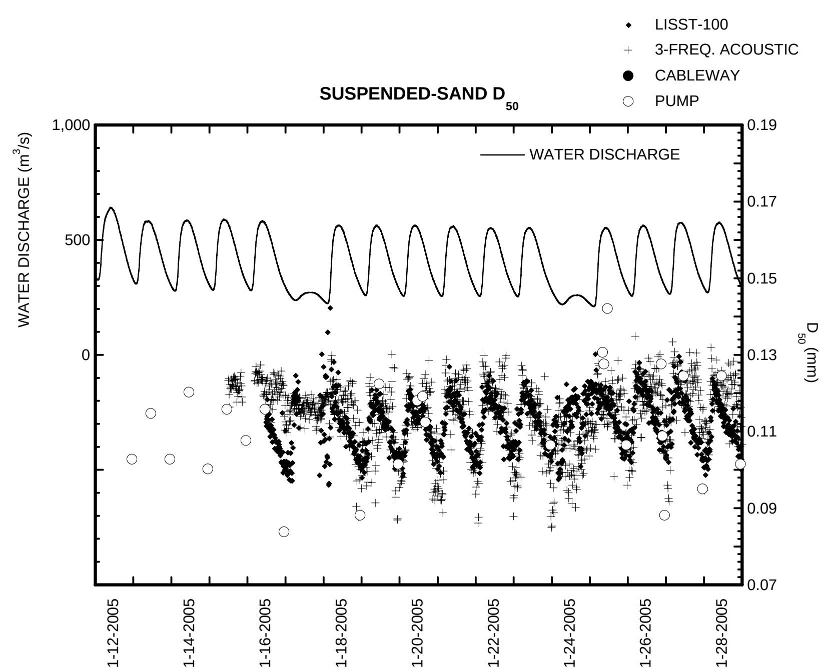
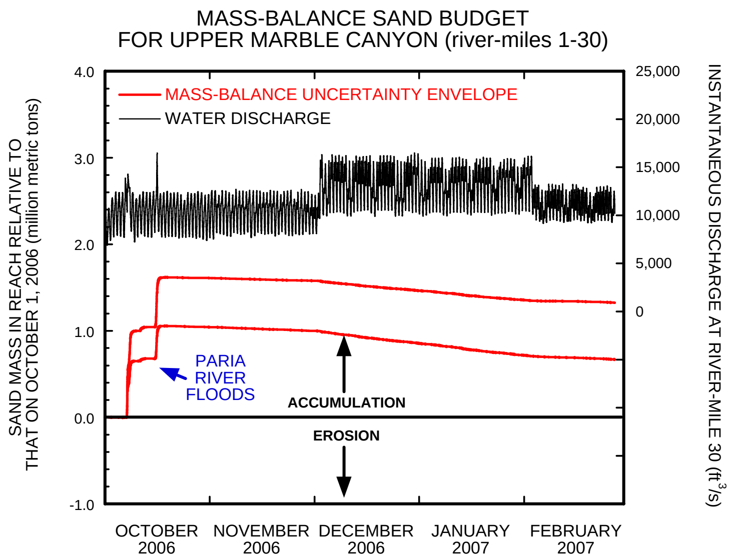


(c)

Figure 1.2 Examples of the high-resolution laser-acoustic suspended-sediment data from the Grand Canyon gaging station beyond the period of calibration. No EDI measurements were made from the cableway during this 17-day period. Silt and clay concentrations were too high during the first 3 1/2 days of this period to get LISST or acoustic measurements of suspended-sand concentration or median grain size. (a) Silt and clay concentration (preceding page), (b) Sand concentration, (c) Suspended-sand median grain size (D_{50}).

The tributary and mainstem suspended-sediment flux data are then used to compute sediment budgets, by summing the inputs and subtracting the export, for the following reaches of the CRE (fig. 1.1): river miles 0 to 30 (upper Marble Canyon, UMC), river miles 30 to 62 (lower Marble Canyon, LMC), river miles 62 to 88 (eastern Grand Canyon, EGC), river miles 87 to 166 (central Grand Canyon, CGC), and river miles 166 to 226 (western Grand Canyon, WGC). These sediment budgets indicate whether sediment is accumulating or eroding, within the error associated with the measurements, from the given reach over the time period analyzed (figs. 1.3 and 1.4).



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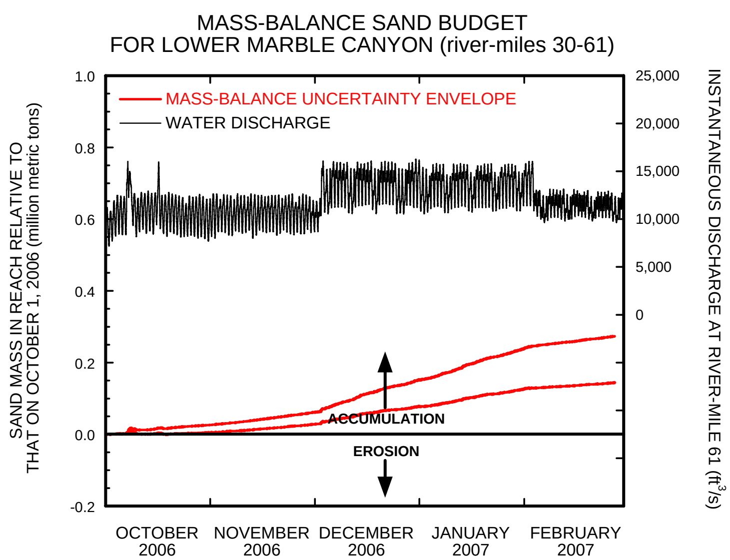

(b)

Figure 1.3 Examples of mass-balance sand budgets for two reaches in the CRE during October 2006–February 2007: (a) upper Marble Canyon and (b) lower Marble Canyon.

Linkage to Other Resources, Processes and Models

The mass balance core monitoring project provides data that is essential to the development and testing of numerical predictive models of discharge, stage, sediment transport, sandbar morphology, and other water-quality parameters (such as temperature, because these models require discharge and stage data/models). These predictive models can be used to evaluate a wide range of resource responses, such as the fate of sandbar habitats, to various dam release scenarios, such as controlled floods, steady flows, fluctuating flows, etc.

The mass balance project provides the sediment data required for triggering future BHBF tests and management actions.

The mass balance project also supports new research focused on the food web of the river ecosystem by providing continuous data on surface flow in the main channel and major tributaries, as well as suspended-sediment concentrations and grain size for suspended particles in transport. The mass balance and food web research project currently share personnel and sampling resources in order to document the organic content of suspended material.

Finally, the mass balance project supports science activities in the fisheries program by providing flow and quality-of-water data that may be used by the fisheries biologist in evaluating their fish catch data, as well as growth, movement and habitat use information. In particular, suspended fines (silt and clay) data are currently being used to evaluate the catchability of nonnative fishes via electrofishing.

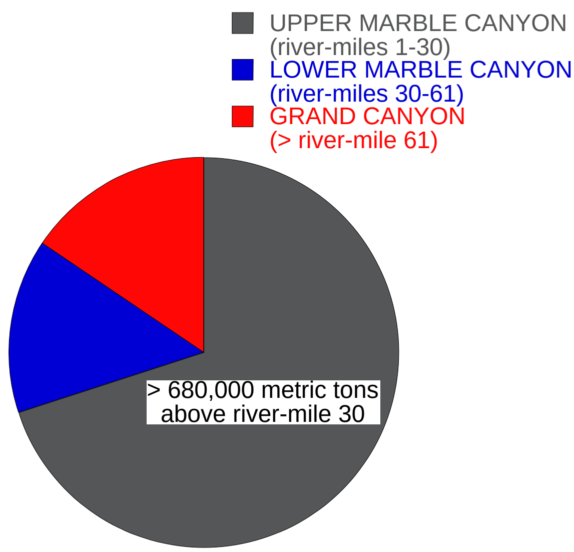

Figure 1.4. Example of a mass-balance pie chart indicating the March 1, 2007, location of large sand inputs supplied to the CRE by the Paria River in October 2006.

Expected Outcomes

The expected outcomes are detailed throughout this report, summarized as follows:

- Streamflow (discharge and stage), and suspended-sediment concentration and grain-size time series at multiple mainstem sites and at the mouths of major tributaries (fig. 1.1).

- Sediment budgets for five reaches of the CRE: upper Marble Canyon, lower Marble Canyon, eastern Grand Canyon, central Grand Canyon, and western Grand Canyon (figs.1.1–1.4).
- Annual peer-reviewed USGS report documenting results of the monitoring project.
- Contribution to other research-related peer-reviewed publications (such as models).
- Biannual presentations at GCDAMP meetings.

Estimated proposed annual funding for core monitoring program

Out of a total gross budget projected for FY 2008 downstream quality of water monitoring project of $883,024, the GCMRC estimated that approximately $700,000 of this amount is required to support monitoring of surface water and suspended-sediment data for the fine sediment mass balance (flux) monitoring currently described in the FY 2008 annual work plan. The estimated additional cost for all flow and suspended-sediment data required to fully implement the recommendations described herein is $345,000, resulting in a total funding need of $1,045,000.

GOAL 7 - Sediment Monitoring References

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PART 2. Recommended Protocols for Monitoring Changes in Sand Storage Throughout the Colorado River Ecosystem

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

Project Title

Long-term monitoring for the sediment budget and sandbar status throughout the CRE utilizing direct topographic/bathymetric measurements and remote sensing (short title: SED TREND)

Geographic Scope

The SED TREND monitoring is focused on detecting long-term (i.e., 4-year to multi-decadal) trends in the CRE (fig. 1.1) sediment budget for both fine (sand and finer material) and coarse sediment. In addition, this project utilizes a combination of direct topographic measurement and remote sensing to monitor the status of high-elevation (> the stage associated with a discharge of 8,000 ft^3/s) sandbars on an annual to 4-year basis. The geographic extent of this monitoring is from Glen Canyon Dam to the upper end of Lake Mead (near Separation Canyon).

Justification for Long-Term Monitoring Effort

Sediment forms the physical template for the Colorado River ecosystem downstream from Glen Canyon Dam (U.S. Department of the Interior, 1995; National Research Council, 1996). The endangered and threatened native fishes evolved in a highly turbid river (Gloss and Coggins, 2005), with turbidity predominantly due to suspended silt and clay, and to a lesser degree suspended sand. Prior to the closure of Glen Canyon Dam, 60% of upstream sediment supply from the Colorado River in Glen Canyon was silt and clay (Topping and others, 2000). Closure of Glen Canyon Dam reduced the supply of silt and clay by about 96% at the upstream boundary of Grand Canyon National Park, with the Paria River now the major supplier of silt and clay at this location (Topping and others 2000). The postdam Colorado River in Marble and Grand Canyons is much less turbid (with clearer-water conditions than ever occurred naturally) and, because the in-channel storage of sand, silt, and clay in the postdam Colorado River is greatly reduced from predam conditions, the Colorado River in the CRE is only now turbid during periods of tributary activity downstream from the dam.

Sandbars and other sandy deposits in and along the Colorado River in Grand Canyon National Park were an integral part of the natural riverscape, and are important for riparian habitat, native fish habitat, protection of archeological sites, and recreation (Rubin and others, 2002; Wright and others, 2005). Recent work has shown that the low-elevation parts of these sandbars (< the stage associated with a discharge of 8,000 ft^3/s) in lateral recirculation eddies contain the bulk of the sand, silt, and clay in storage (Hazel and others, 2006), and the surface grain size of these sandbars is the dominant regulator of sand transport over multiyear timescales (Topping and others, 2005). Thus, the low-elevation parts of sandbars and the channel (as will be shown below) comprise the long-term "bank account" for sediment in the CRE. These deposits have eroded substantially following the 1963 closure of Glen Canyon Dam that reduced the supply of sand at the upstream boundary of Grand Canyon National Park by about 94% (Topping and others, 2000). In response to this reduction in sand supply and the alteration of the natural hydrograph by dam operations (Topping and others, 2003), sandbars in Marble Canyon and the upstream part of Grand Canyon have substantially decreased in size since closure of the dam (Schmidt and others, 2004) and are still in decline under normal powerplant operations at the dam (Wright and others, 2005).

Growing concern about the effects of the operations of Glen Canyon Dam on the CRE 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 revisited in the 1980s (Schmidt and Graf, 1990), and eventually led to the sandbar-monitoring program conducted by Northern Arizona University (NAU) during the 1990s (Hazel and others, 1999; Schmidt and others, 2004). Evaluation begun in the 1990s and finalized in the geomorphic synthesis of Schmidt and others (2004) indicated that the observations of change made during these site-based programs were not necessarily representative of changes in the fine-sediment resource over longer reaches of the Colorado River because these programs utilized surveys of relatively small areas and the variability between sites was large. Moreover, the fact that substantial positive changes in sediment volume were observed in these site-based programs during periods when no sediment entered the system, called into question the value of sediment budgeting based on monitoring of small sites (Hazel and others, 2006). In contrast to the large variability within the site-based NAU data, analysis of cross-section data collected by the USGS indicated near-universal scour of sediment from the CRE during the 1990s (Flynn and Hornewer, 2003). These observations led to the development of the flux-based "mass-balance" sediment budgeting conducted under the downstream integrated quality-of-water (IQW) core-monitoring project (Goal 7) in 1999, and led to the development of the more comprehensive reach-based Fine Grained Integrated Sediment Team (FIST) monitoring project in 2001.

The FIST project conducted reach-based fieldwork in 2002, 2004, and before and after the November 2004 BHBF test, and completed sandbar/campsite surveys in 2001, 2002, 2003, 2004, and 2005. Data from these field efforts have been processed, finalized, and delivered to DASA. Results from the FIST project have been presented at the following professional scientific meetings: 2003 Geological Society of America Annual Meeting (published abstract); 2005 Geological Society of America Annual Meeting (published abstract); 2004 American Geophysical Union Fall Meeting (2 published abstracts); 2005 American Geophysical Union Fall Meeting (3 published abstracts); 8th Federal Inter-Agency Sedimentation Conference, Reno, Nevada, April 2-6, 2006 (published proceedings article). The project is now in its final stages with articles being prepared for publication.

Key results from the FIST project include the following:

1. More than 90% of the fine sediment stored in the CRE occurs in the lower-elevation parts of eddy sandbars and in the channel (below the stage associated with a discharge of 8,000 ft3/s). This low-elevation sediment-storage environment is herein referred to as the fine-sediment "bank account." Of the amount of fine sediment stored in eddies, approximately 90% is stored below the stage associated with a discharge of 8,000 ft3/s (Hazel and others, 1999, 2006).
2. Analyses indicate that sediment budgets constructed using FIST and mass-balance data track (meaning that they have the same sign) only in parts of the CRE (e.g., in upper and lower Marble Canyons, but not in the part of Grand Canyon between the Little Colorado River and river mile 88). Furthermore, in river segments where the FIST and mass-balance sediment

budgets do track (have the same sign; e.g., lower Marble Canyon), too much of the change in sand volume detected by the mass-balance approach occurs in the subset of this river segment in the FIST reaches (fig. 2.1). Thus, as was the case with the earlier NAU sandbar- monitoring program (which also do not always track (have the same sign) with the mass-balance sediment budgets), the extent of the river covered by the FIST reaches is still too small of an area to be representative of changes in the fine-sediment resource over longer reaches of the CRE. This result suggests that extrapolation of reach-based results (as in the FIST project) to longer segments of the CRE is extremely problematic, if not impossible. Therefore, in the future, extrapolation cannot be used and monitoring changes in the fine-sediment “bank account” at low elevations must be done over reaches that are much longer and ideally equate with the longer reaches used in the mass-balance project (fig. 2.2).

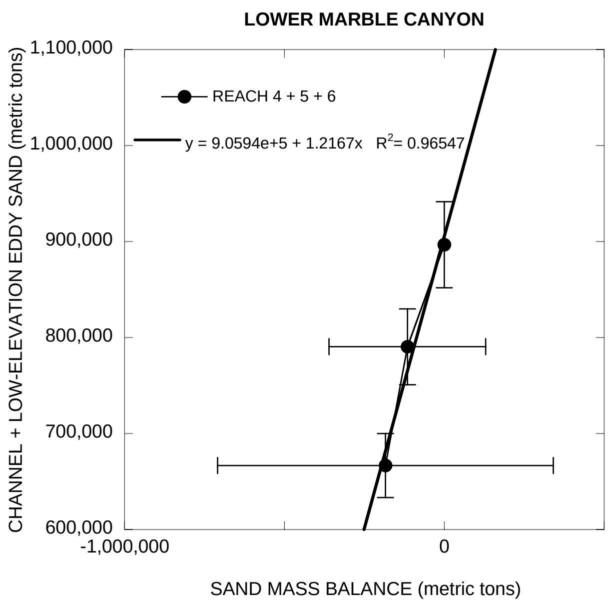


Figure 2.1 Relation between the volume of sand measured by the mass-balance project between river miles 30 and 61 and the volume of sand in combined FIST reaches 4 (river miles 29-32), 5 (river miles 42-46), and 6 (river miles 54-56). Note that although the relation is quite good (with an R^2 value of 0.97), approximately 120% of the change in sand volume between river miles 30 and 61 occurred in only the 9 miles surveyed by the FIST project. Thus, the net change in the other un-surveyed 22 miles of the CRE between river miles 30 and 61, must have undergone changes in sand volume that opposed those surveyed by FIST. Therefore, FIST sediment-budget results cannot be extrapolated to longer reaches of the CRE with any confidence.

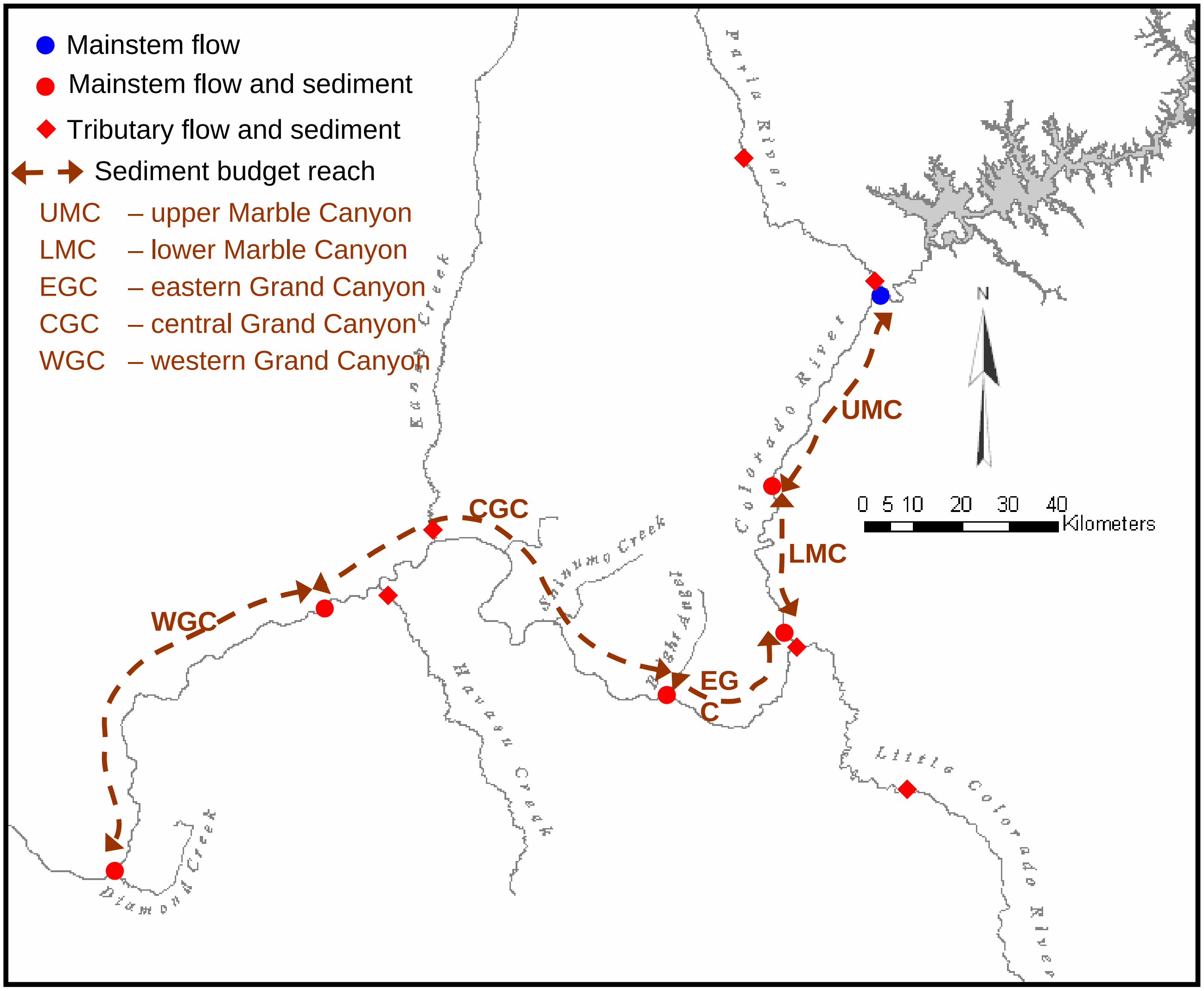
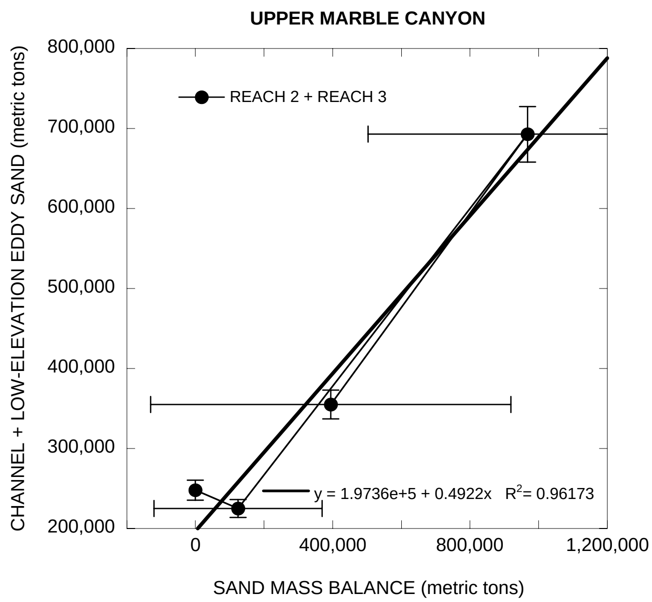
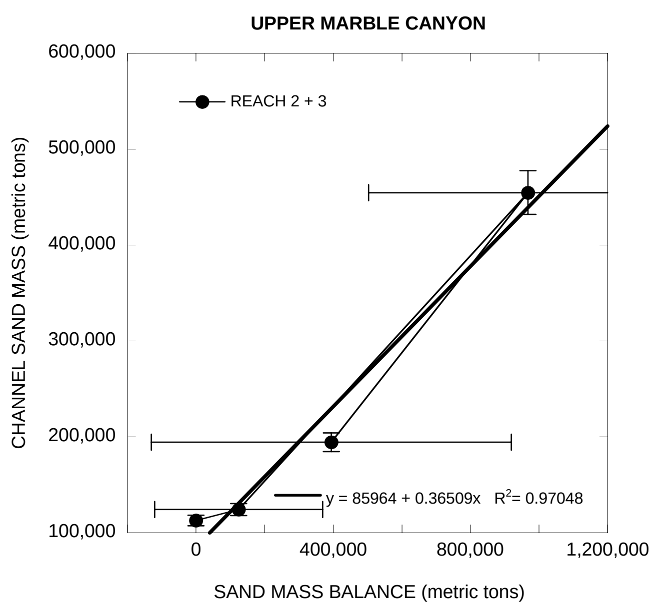


Figure 2.2 Location map showing sediment budget reaches for Goals 7 and 8 core monitoring activities. FIST reaches 2 and 3 are located within UMC and FIST reaches 4–6 are located within LMC.

3. Analysis of sediment budgets constructed using FIST and mass-balance data indicate that, (a) in reaches immediately downstream from major tributaries, the main channel is the most important fine-sediment storage environment (fig. 2.3), and (b) in reaches farther downstream, that is in the bulk of the CRE, eddies below the stage associated with a discharge of 8,000 ft^3/s are the most important fine-sediment storage environment (fig. 2.4). Therefore, monitoring the status of the fine-sediment "bank account" over decadal timescales requires monitoring changes in fine-sediment volume in both the main channel and the low-elevation (i.e., less than the stage associated with 8,000 ft^3/s) parts of eddies.

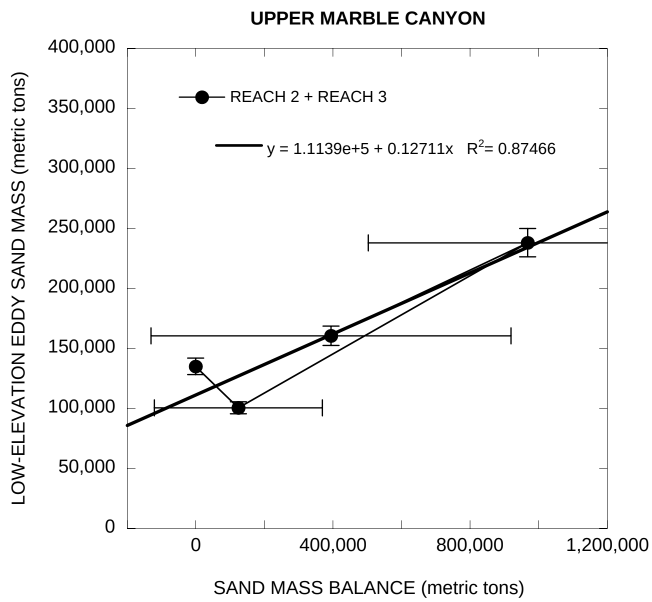


(a)



(b)

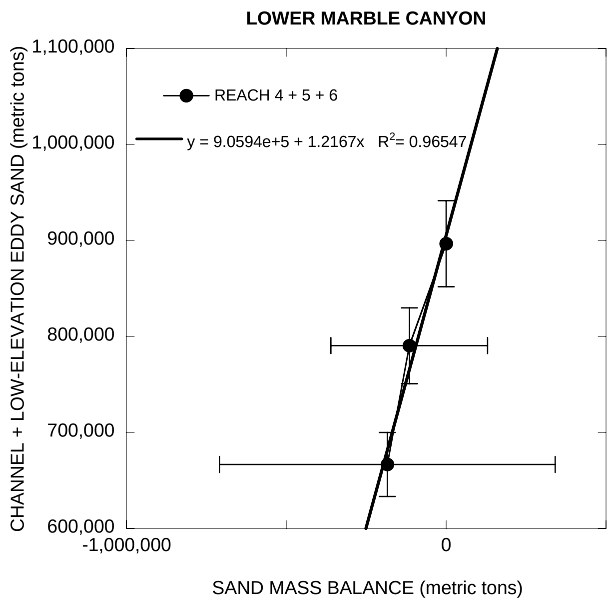
Figure 2.3 (part 1)



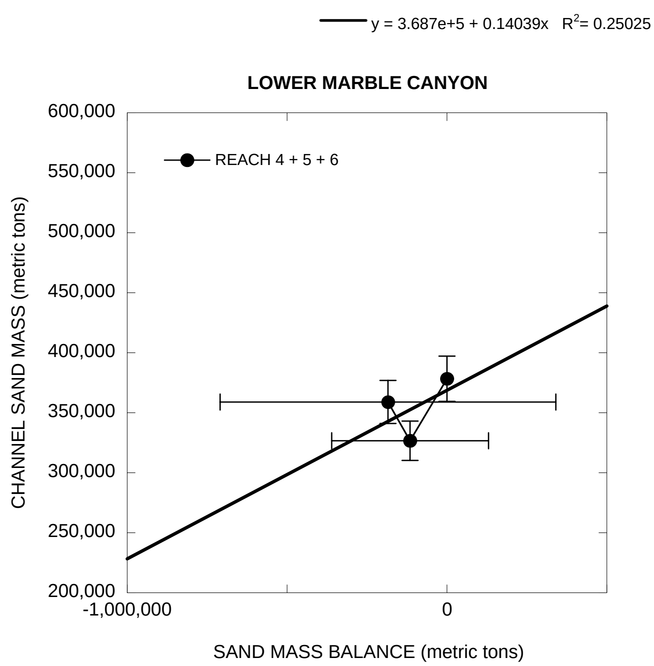
(c)

Figure 2.3 Relation between the volume of sand measured by the mass-balance project between river miles 1 and 30 and the volume of sand in (a) the low-elevation (<8,000 ft^3/s) eddies and channel in combined FIST reaches 2 (river miles 1–3) and 3 (river miles 21–23), (b) only the channel in combined FIST reaches 2 and 3, and (c) only the low-elevation eddies in combined FIST reaches 2 and 3. Note that in this segment of the CRE the channel is the more important fine-sediment storage environment.

4. Data collection on the geometries of backwaters (i.e., eddy return-current channels) requires topographic data collection below the stage associated with a discharge of 8,000 ft^3/s.
5. The sediment budget and the amount of sand at higher elevations (above the stage associated with a discharge of 8,000 ft^3/s) commonly varied inversely (did not have the same sign). This is because less than 10% of the fine-sediment in the CRE occurs at these higher elevations. Although it does not necessarily provide information on the status of the sediment budget, monitoring the fine sediment in these high-elevation environments is however required to evaluate the effectiveness of dam operations for rebuilding and maintaining the high-elevation parts of sandbars critical for GCDAMP Goals 6, 8, 9, and 11.

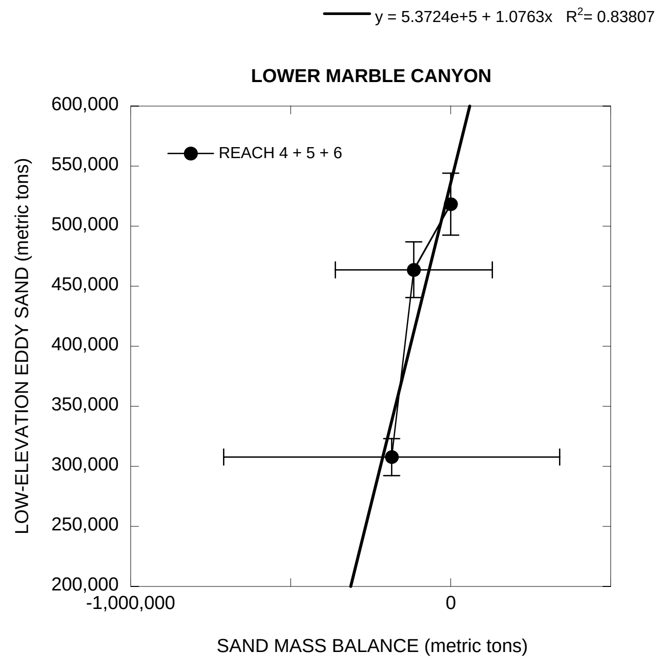


(a)



(b)

Figure 2.4 (part 1)



(c)

Figure 2.4 Relation between the volume of sand measured by the mass-balance project between river miles 30 and 61 and the volume of sand in (a) the low-elevation (<8,000 ft^3/s) eddies and channel in combined FIST reaches 4 (river miles 29–32), 5 (river miles 42–46), and 6 (river miles 54–56), (b) only the channel in combined FIST reaches 4, 5, and 6, and (c) only the low-elevation eddies in combined FIST reaches 4, 5, and 6. Note that in this segment of the CRE the low-elevation eddy is the dominant fine-sediment storage environment.

6. The sandbars monitored as part of the NAU time series are sufficient to detect trends in the area of sand at stages above the stage associated with a discharge of 8,000 ft^3/s (Schmidt and others, 2004).
7. There is not a unique relation between fine-sediment volume and area (owing to changes in deposit convexity/concavity in cross-section). This observation requires that both area and volume of fine sediment be monitored.
8. Both bed grain size and bed sand area are important for regulating suspended-sand transport in the CRE (Rubin and Topping, 2001), although bed grain size dominates over bed sand area (Topping and others, in press). The dominant regulator of sand transport in the CRE over decadal timescales is the grain size of underwater sandbar surfaces (Topping and others, 2005). Furthermore, the grain size of exposed sandbar surfaces is an important regulator of aeolian sand transport upslope into areas containing archeological resources (Draut and Rubin, 2005, 2006, in press; Draut and others, 2005). Thus, some aspect of any core-monitoring program must include surficial grain-size data. Monitoring of grain size can be accomplished through use of the on-shore and underwater versions of the underwater microscope developed by Chezar and Rubin (2004), Rubin and others (2006, in press) and algorithm developed by Rubin (2004).

A major outstanding question is whether frequent BHBFs conducted under sediment-enriched conditions (such as those that existed during the 2004 BHBF test) can result in the rebuilding and maintenance of sandbars throughout the CRE. Scour of the low-elevation eddy and channel pool environments during sand-depleted BHBF tests, such as the 1996 Controlled Flood, is not subsequently offset by deposition of new sand under normal powerplant releases (Schmidt and others, 2004; Topping and others, 2006). Analysis of surveys conducted one to four times per year during the 1990s indicates that sandbars in Marble Canyon and the upstream part of Grand Canyon contained ~25% less sand at lower elevations in 2000 than in 1991, and that the lower-elevation parts of these sandbars and the adjacent channel bed never fully recovered in sand volume after scouring during the 1996 flood. This net decrease in low-elevation fine-sediment volume occurred despite that fact tributary inputs of sand during this period were well above average. Thus, controlled floods conducted under sediment-depleted conditions, such as those that existed in 1996, cannot be used to sustain sandbar area and volume. In addition, the dominant response (downstream from the upstream half of Marble Canyon) during the 2004 BHBF test was that eddies lost sand (although less than was gained in upper Marble Canyon). By definition, if BHBFs are to be a successful tool for the rebuilding and maintenance of sandbars in the CRE, then the volume of fine sediment stored at lower elevations (i.e., in the long-term fine-sediment "bank account") must not decrease over longer timescales as a result of the occurrence of the BHBFs.

Computing fine-sediment budgets for various reaches in the CRE (fig. 2) over long (i.e, decadal or longer) timescales is required for evaluating the effects of dam operations, including BHBFs. Over shorter timescales (up to perhaps several years), this is best done by the "mass balance" approach described in the section on Goal 7 of the Draft Core Monitoring Report. However, because of the increasing uncertainties over time associated with the "mass balance" approach, another approach is needed to track the fine-sediment budget for the CRE over longer timescales. This other complimentary approach (described herein) is required to evaluate whether future dam releases (including BHBFs) continue to mine the sediment "bank account" or whether this bank account (stored largely at elevations less than the stage associated with a discharge of 8,000 ft^3/s) remains stable or increases under future dam releases. If the amount of sediment in this "bank account" continues to decrease, then dam operations will ultimately not be able to sustain the fine-sediment resources at higher elevations. In addition to this other approach for long-term sediment budgeting, additional monitoring is required to evaluate the effectiveness of future dam releases (including BHBFs) in rebuilding and maintaining the higher-elevation parts of sandbars. Both of these integrated monitoring programs are described as part of the SED TREND monitoring outline below.

All of the aspects of sediment monitoring that comprise the SED TREND monitoring have been reviewed by three PEP panels convened in 1998, 1999, and 2006 (the final panel). The final PEP panel recommended that, over shorter timescales (months to years), monitoring of the sediment resource in the CRE is most accurately accomplished using the "mass-balance" approach described in the section on Goal 7 of the Draft Core Monitoring Report. In addition, this panel recommended that the annual protocol established by the USBR Glen Canyon Environmental Studies to monitor trends in the high-elevations parts of sandbars be continued. Furthermore, depending on the outcome of analyses that are now complete and cost, this panel recommended that longer reaches of the river could be surveyed at some frequency to track the fine-sediment budget over longer timescales. Finally, all three PEP panels recommended that continued monitoring of coarse sediment was also needed (Wohl and others, 2006). Coarse sediment (gravel) supplied to the CRE during tributary floods and debris flows provides the geomorphic framework that controls the location and influences the size of eddy sandbars. Additionally coarse sediment provides an important substrate for the aquatic food base and for trout spawning.

AMWG Goal(s) Addressed

The SED TREND monitoring directly supports achievement of the following AMP goals:

Goal 8 – Maintain or attain levels of sediment storage within the main channel and along shorelines to achieve AMP ecosystem goals.

Goal 9 – Maintain or improve the quality of recreational experiences for users of the Colorado River ecosystem within the framework of AMP ecosystem goals. The SED TREND 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 SED TREND monitoring collects information on the sandbars that provide a source of sediment, through aeolian transport, to a number of high-elevation sand deposits that contain archaeological resources.

Because the SED TREND monitoring addresses the physical framework of the ecosystem, which underlies many biological resource objectives, it also indirectly supports achievement of the following four AMP goals:

Goal 1 – Protect or improve the aquatic food base so that it will support viable populations of desired species at higher trophic levels. The SED TREND monitoring supports this goal by providing information on coarse sediment inputs which provide the substrate for parts of the aquatic food base.

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 SED TREND monitoring supports this goal by providing information on sandbars which create backwater habitats that are thought to be important for 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 SED TREND monitoring monitors the status of the fine-sediment deposits which provides the substrate for riparian vegetation and marsh communities.

Key Science Questions and Managers' Information Needs Addressed

Several strategic science questions (SSQ) were identified by scientists and managers during the Knowledge Assessment Workshop conducted in the summer of 2005 (Melis and others, 2006). The SED TREND monitoring project provides valuable information to help answer several of the questions related to sediment conservation, and in particular the primary sediment question: "Is there a 'Flow-Only' operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will rebuild and maintain sandbar habitats over decadal time scales?"

As mentioned above, the SED TREND monitoring tracks the status of sandbar habitats and is the project that monitors the long-term status of the fine-sediment "bank account" stored at lower elevations. Both of these types of data are required to answer this SSQ.

The 2003 AMP Strategic Plan identified Core Monitoring Information Needs (CMINs) related to sediment storage (Goal 8). The CMINS that are addressed by the SED TREND monitoring are listed below. For each, the prioritization ranking applied by the AMP Science Planning Group in 2006 is also included. The SED TREND monitoring directly addresses three of the top five Goal 8 CMIN priorities; the other two of these five are addressed by the mass balance project described under Goal 7.

CMIN 8.1.1 – Determine and track the biennial fine-sediment volume and grain-size changes in the main channel below 5,000 cfs stage, by reach. **#3 ranked Goal 8 CMIN.**

CMIN 8.4.1 – Track, as appropriate, the biennial or annual sandbar area, volume and grain-size changes within eddies between 5,000 and 25,000 cfs stage, by reach. . **#4 ranked Goal 8 CMIN.**

CMIN 8.5.1 –Track, as appropriate, the biennial sandbar area, volume and grain-size changes above 25,000 cfs stage, by reach. **#5 ranked Goal 8 CMIN.**

The SED TREND monitoring also addresses these unranked Goal 8 CMINs.

CMIN 8.2.1 – Track, as appropriate, the biennial or annual sandbar area, volume and grain-size changes outside of eddies between 5,000 and 25,000 cfs stage, by reach.

CMIN 8.3.1 – Track, as appropriate, the biennial or annual sandbar area, volume and grain-size changes within eddies below 5,000 cfs stage, by reach.

CMIN 8.6.1 – Track, as appropriate, changes in coarse sediment (> 2 mm) abundance and distribution.

The SED TREND monitoring also directly addresses this top-ranked Goal 9 CMIN priority.

CMIN 9.3.1 – Determine and track the size frequency, and distribution of camping beaches by reach and stage level in Glen and Grand Canyons. **#1 ranked Goal 9 CMIN**

Developing and testing monitoring protocols for these CMINs was the primary focus of research and development conducted during FY 1998-2006, as reviewed by SEDS-PEP III.

Finally, at the 2004 AMWG priority-setting workshop, questions relating specifically to sediment (and monitored by the herein described SED TREND monitoring) were identified under three of the top five priorities of the AMP. These priorities were, in decreasing order of relevance to sediment, AMWG Priority 4: What is the impact of sediment loss and what should we do about it?, AMWG Priority 3: What is the best flow regime?, and AMWG Priority 2: Which cultural resources, including Traditional Cultural Properties (TCP), are within the Area of Potential Effect, 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?

Project Goals, Tasks, and Schedule by Task

Goals

The primary goal of the Goal 8 SED TREND core monitoring project is to determine magnitudes and trends in fine-sediment storage throughout the CRE in the main channel and eddies at all elevations, specifically broken down into bins below the stage associated with a discharge of 8,000 ft^3/s (where over 90% of the fine sediment in the CRE is typically stored), between the stages associated with discharges of 8,000 and 25,000 ft^3/s, and above the stage associated with a discharge of 25,000 ft^3/s.

The secondary goals of this project are to determine magnitudes and trends in campsite area and distribution (this supports Goal 9), backwater geometry (area plus depths) and distribution (this supports Goal 2), and the availability of open dry sand on sandbars that can be transported by the wind upslope into archeological sites thereby helping preserve these resources (this supports Goal 11).

Tasks

These goals can be met through the following data collection efforts:

1. Annually, monitoring of the area and volume of fine sediment (as well as campsite area) above the stage associated with 8,000 ft3/s for subsets of sandbars and campsites throughout the CRE using ground-based surveys. This dataset is commonly referred to as the “NAU sandbar time series” and is the longest running dataset on the state of sandbars currently available (initiated in 1990). This task is conducted in coordination with Goal 9 core monitoring and will take place in the fall of each year.
2. Approximately every four years (but only in years without BHBFs, see “Schedule by task” section below for details), monitoring of systemwide area and volume of fine sediment (especially open sand) above the stage associated with a discharge of 8,000 ft3/s (i.e., approximately 10% of the fine sediment in the CRE) based on aerial overflight data (LiDAR and orthrectified hyperspectral aerial photography). These remote-sensing data can be used to monitor the magnitude and trends in potential campsite area, backwater area and distribution, the availability of open dry sand on sandbars, as well as for other resource areas such as riparian vegetation monitoring. These data will also be used to help quantify the inputs of new gravel from tributaries. These gravel inputs provide important substrate for the aquatic food web.
3. Annually (but only in years without BHBFs, see “Schedule by task” section for details), monitoring the area and volume of fine sediment at all elevations over long reaches using multi-beam bathymetric surveys, ground-based topographic surveys, underwater video transects, and limited underwater microscope data collection for bed grain size. Ideally, this task would be performed on a systemwide basis every 5-10 years in order to estimate fine sediment budgets over time scales for which the Goal 7 mass balance sediment budgets likely become inconclusive due to accumulating measurement errors. However, since it is currently logistically impossible to survey the bathymetry of the entire river in any given year, surveys

will be completed annually of 30–80 mile sections of the river with a different section surveyed each year on a rotating basis. The sections (or reaches) will correspond to the same reaches outlined in the Goal 7 mass balance core monitoring project (fig. 2.2), as follows: Reach 1 – RM0 to RM30 (upper Marble Canyon); Reach 2 – RM30 to RM61 (lower Marble Canyon); Reach 3 – RM61 to RM87 (eastern Grand Canyon); Reach 4 – RM87 to RM166 (central Grand Canyon); Reach 5 – RM166 to RM226 (western Grand Canyon, see fig. 2.1). These reach surveys will occur in the late spring and will only be completed in years without BHBFs (see "Schedule by task" section for details); thus, in the absence of BHBFs each reach would be surveyed every 5 years, or, if BHBFs occurred on average every other year, then each reach would be surveyed on average every 10 years. The 5-10 year interval is considered by sediment scientists to be sufficient to detect long-term trends in the fine sediment budget based on changes in topography and bathymetry. Finally, since some reaches are longer than others, it is possible that some reaches will be too long to survey completely in a single river trip (e.g., Reaches 4 and 5); for these reaches, available side-scan sonar data will be used to identify the portions of these reaches that are most likely to store fine sediment. It is also possible that continued technological advancements and improvements in methods will allow for complete surveys of these reaches in the future. In addition to providing key sediment budget information (i.e., the status of the fine-sediment "bank account"), these data will provide information on the location and geometries of backwaters thought to be important habitat for native fish. These data will also provide information on the accumulation of tributary-supplied gravel and the redistribution of this gravel (used as substrate by the aquatic food web) in the CRE.

Schedule by Task

The schedule for core monitoring under Goal 8 is complicated by the potential for BHBFs, except for Task 1 sandbar and campsite surveys which will occur annually in the fall whether or not a BHBF is scheduled. For Task 2 remote sensing missions and Task 3 reach surveys, it is advantageous to have these occur in years without BHBFs so that the monitoring data are not dominated by the effects of a single BHBF (BHBF monitoring is described under a separate science plan developed by the GCMRC in 2007). Rather, the remote sensing and reach survey monitoring should represent the integral response of the system to several years of dam operations and tributary inputs. Further, logistical constraints would make it difficult to conduct the remote sensing and reach survey core monitoring in addition to the BHBF monitoring. Thus, without knowing the exact frequency of BHBFs, it is impossible to outline the exact schedule for Goal 8 core monitoring.

It is possible, though, to outline potential schedules based on assumptions regarding BHBF frequency. Two possible 10-year schedules are outlined for illustrative purposes (table 2.1). The first is the schedule in the absence of BHBFs where the exact schedule can be delineated. The second schedule assumes that BHBFs occur every other year, which would be the approximate frequency under previous triggers based on tributary sediment supply. In reality, even if the frequency were every other year on average, there would likely be periods with successive years of BHBFs and successive years without BHBFs such that the core monitoring schedule for remote sensing and reach surveys must be flexible.

Table 2.1 Possible alternatives for implementing long-term sediment monitoring tasks with and without beach/habitat building flow tests

	Schedule without BHBFs			With BHBFs every other year		
Year	**Task 1: NAU sandbars**	**Task 2: Remote sensing**	**Task 3: Reach surveys**	**Task 1: NAU sandbars**	**Task 2: Remote sensing**	**Task 3: Reach surveys**
2008	X		X (R1)	X		X (R1)
2009 (BHBF)	X	X	X (R2)	X		
2010	X		X (R3)	X	X	X (R2)
2011 (BHBF)	X		X (R4)	X		
2012	X		X (R5)	X		X (R3)
2013 (BHBF)	X	X	X (R1)	X		
2014	X		X (R2)	X	X	X (R4)
2015 (BHBF)	X		X (R3)	X		
2016	X		X (R4)	X		X (R5)
2017 (BHBF)	X	X	X (R5)	X		

Recommended Long-Term Monitoring Protocols

Task 1 is conducted using standard ground-based surveying protocols described in Hazel and others (1999, 2000, in review). Task 2 is conducted using remote-sensing protocols described in Davis (2004) and LiDAR protocols (including error analyses) described in Davis and others (in review). Task 3 is conducted using standard ground-based surveying protocols and multibeam-sonar bathymetric surveying protocols (including error analyses) described in Kaplinski and others (2000, 2007, in review). The grain-size data collected under Task 3 (recommended by the final SEDS-PEP III panel, Wohl and others, 2006) are collected and processed using protocols described in Rubin and others (2006, in press) and Rubin (2004).

Linkage to other resources, processes and models

The SED TREND monitoring project provides data (i.e, the maps showing the topography and distribution of sediment types over ~30-mile reaches of the river) that is essential to the development and testing of numerical predictive models of discharge, stage, sediment transport, and sandbar morphology. These predictive models can be used to evaluate a wide range of resource responses, such as the fate of sandbar habitats, to various dam release scenarios, such as controlled floods, steady flows, fluctuating flows, etc.

The SED TREND monitoring provides the data used to evaluate the effectiveness of dam operations (including BHBFs) on rebuilding and maintaining sandbars in the CRE. Additionally, the SED TREND monitoring will provide the data showing whether dam operations continue to mine the long-term fine sediment “bank account” stored at elevations below the stage associated with a discharge of 8,000 ft^3/s (more than 90% of the fine sediment in the system is currently stored below this elevation). If the amount of sediment in this "bank account" continues to decreases, then operations will ultimately not be able to sustain the fine-sediment resources at higher elevations.

The SED TREND monitoring supports the campsite inventories conducted under Goal 9 by characterizing the status and trends of a sample of the sandbars used as campsites. The SED TREND monitoring supports Goal 11 by characterizing the status of fine-sediment at higher elevations in and around cultural sites, and by characterizing the amount of open dry sand available to be transported by the wind into some of these cultural sites (thereby helping to preserve these sites). The SED TREND monitoring also supports new research focused on the food web of the river ecosystem by providing data on the input of new gravel from tributaries, and the accumulation and redistribution of gravel used as a substrate by the aquatic food web. The SED TREND monitoring also provides information on the distribution of the fine-sediment deposits that form the substrate for the riparian ecology. Finally, the SED TREND monitoring supports science activities in the fisheries program by providing the data (as part of the long ~30-mile data collection effort described under Task 3) to characterize the locations and geometries of backwaters though to be important habitat for native fish. In addition, annual repeat inventories of nearshore backwater habitats have been collected periodically systemwide (and may continue), as measured each fall during fishery monitoring trips, as part of Goal 2 (Native Fish).

Expected Outcomes

The expected outcomes are detailed throughout this report, summarized as follows:

- Annual updates of the NAU sandbar time series showing trends in the area and volume of the high-elevation parts of sandbars. In addition to providing annual data showing the effectiveness of dam operations on rebuilding and maintaining sandbars, these data directly support the campsite monitoring conducted under Goal 9.
- Maps and analyses of the systemwide area and volume of fine sediment at high elevations as determined by digital aerial photography and LiDAR. These maps and analyses will be of great use in characterizing the status of fine-sediment in and around cultural sites and in quantifying the dry high-elevation sand potentially available to be transported by the wind into these sites.
- Topographic maps of the CRE in five long reaches: upper Marble Canyon, lower Marble Canyon, eastern Grand Canyon, central Grand Canyon, and western Grand Canyon. These maps will be produced 1-2 times per decade for each reach on average. These maps will characterize the geometries of the backwaters (thought to be important habitat for native fish) in each ~30-mile reach.
- Decadal timescale sediment budgets for these five reaches of the CRE. These data will provide managers information on the long-term status of the fine-sediment "bank account." These sediment budgets will be compared to the sediment budgets computed for these reaches under the complimentary mass balance project described under Goal 7. This comparison will help evaluate the uncertainties associated with the SED TREND monitoring and fine sediment mass balance approaches.
- Where possible, data collected in upper Marble Canyon in FY 2008 will be compared with earlier multibeam-sonar data collected in 2000, 2001 and as part of the 2002–04 FIST project to evaluate volume changes in the fine-sediment bank account (2000 vs. 2008).
- Annual peer-reviewed USGS data reports documenting results of the monitoring project.

- Contribution to other research-related peer-reviewed publications (such as models).
- Biannual presentations at GCDAMP meetings.

Estimated Proposed Annual Funding for SED TREND Core Monitoring Program

Task #1 ~$95,000 (see FY 2008 draft work plan description for Project REC 9.R1.07/PHYS 8.M2/07),

Task #2 (scope of analyses and cost are yet to be fully determined; refer to FY 2008 and 2009, DASA project descriptions for Goal #12, Remote Sensing and Analysis),

Task #3 ~$200,000 (as described above).

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