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October 18, 2006

MEMORANDUM

To: Technical Workgroup Members, Science Advisors and GCMRC's cooperating physical scientists who participated in the August PEP review meeting

From: Ted S. Melis, Deputy Chief

Subject: **Distribution of External Peer Review on Sediment Monitoring Protocols**

Attached, is the SEDS-PEP III panel's final report on 2000 through 2006 research and development results on long-term monitoring of sediment resources of the Colorado River ecosystem.

Again, I would like to take this opportunity to thank those of you who participated in the August 15-17, 2006 meeting in Flagstaff. I especially appreciate the fact that the review panel delivered the report three weeks ahead of the assigned October 31st due date.

I believe that this review is another milestone for the GCMRC's science program and provides many solid recommendations that should be carefully considered and discussed by the Technical Workgroup and the GCMRC staff as future science planning continues.

Please feel free to contact me at 928-556-7282, if you have questions regarding this report.

GRAND CANYON MONITORING AND RESEARCH CENTER

Protocols Evaluation Program (PEP-SEDS III)

Final Report of the Physical Resources Monitoring Peer Review Panel

October 6, 2006

U.S. Geological Survey Field Center
Flagstaff, AZ

PROCEEDINGS OF THE EXTERNAL PEER REVIEW WORKSHOP III ON LONG-TERM MONITORING OF WATER AND SEDIMENT RESOURCES OF THE COLORADO RIVER ECOSYSTEM

WORKSHOP-III DATES: August 15-17, 2006

MEETING LOCATION: USGS Field Center, Bldg. #3, 2255 N. Gemini Dr., Flagstaff, AZ

PHYSICAL SCIENCE PEER REVIEW PANEL:

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I. OVERVIEW

The Grand Canyon of the Colorado River is one of the nation's premier national parks and one of the most visited natural sites on Earth. As the centerpiece of a heavily visited landscape, the riverine corridor attracts attention from diverse stakeholders that include numerous government agencies, user groups, scientists, and the general public. Management of natural resources and human activities within the Colorado River ecosystem is likely to remain the focus of intense scrutiny by these diverse stakeholders for decades to come.

Increasing concern over human effects on the Colorado River ecosystem led to the establishment of the Glen Canyon Environmental Studies (GCES) Program in 1982, which eventually gave rise to the present Glen Canyon Dam Adaptive Management Program (AMP). This latter program includes the Grand Canyon Monitoring and Research Center (GCMRC) as its science component. The Protocols Evaluation Panel convened in Flagstaff during August 2006, and is part of ongoing peer review of monitoring and research efforts carried out by the GCMRC. The August 2006 panel forms the third such review carried out by the Physical Resources Program thus far (earlier panels were convened in 1998 and 1999). The panel was charged with evaluating current recommendations on research and long-term monitoring of physical resources below Glen Canyon Dam, and was asked to respond to six review elements focused on monitoring protocols (Appendix 1) based on the Strategic Science Questions developed at the Knowledge Assessment Workshops in 2005 (Appendix 2). This report summarizes the recommendations of the panel with respect to the six review elements and to broader issues that the panel considers vital to the success of the GCMRC in administering a program of physical resources monitoring and research.

Design of the monitoring program

As has been the case during previous peer reviews, the 2006 panel is generally impressed with the direction of the GCMRC physical resources monitoring program as it is presently designed and operated. Largely as a result of research and monitoring guided and facilitated by the GCMRC, our collective understanding of the Colorado River ecosystem is remarkably detailed and comprehensive. The results of decades of study on the Colorado River ecosystem represent a unique and exemplary knowledge to guide river management and restoration on the Colorado and other rivers. The panel commends the individual scientists and the program administrators on the degree of communication and collaboration among research teams. Biennial science symposia attended by all participating scientists undoubtedly foster this communication and collaboration, but these symposia would be insufficient if individual scientists did not make the effort to work closely together that is reflected in group efforts such as FIST (Fine-grained Integrated Sediment Team) or the collaboration between David Topping and David Rubin.

Further efforts are necessary, however, to more fully integrate core monitoring and research efforts. The coarse sediment monitoring (Webb and others) seems to be better integrated with experiments and field work than the fine sediment modeling (Wiele and others), for example, but the projects focused on coarse sediment and fine sediment are not well integrated. Similarly, the scientists engaged primarily in modeling efforts could make more rapid progress in model development and application to specific management needs if these scientists worked more closely with the research teams focusing primarily on collection and analysis of field data. The clear articulation of a guiding framework that serves as a reference point for the role of individual studies and for integration of individual studies would strengthen collaborations among project scientists, facilitate effective communication between the three core monitoring programs of the GCMRC, and enhance the ability of outside reviewers to comment on the physical resources program.

The panel commends the attention given by participating scientists to the management implications of their monitoring and research activities. Numerous examples of using specific research results to inform management decisions were provided during the presentations given by participating scientists as part of the August 2006 meeting. Peter Wilcock, for example, discussed the potential to use the fine sediment model to understand the effect of daily flow fluctuations on sand retention following sand inputs from the Paria River, and David Topping noted that variability in some aspects of the flow regime post-dam exceeds pre-dam variability, which has implications for the height and frequency of fluvial re-working of terrace deposits and the erosion or protection of archeological sites. It is critical to the adaptive management process and to comprehensive, ecosystem-scale modeling that this consideration of management implications continues during design and implementation of future monitoring activities.

The panel also commends the program director and individual scientists for the progress made in addressing monitoring and research needs identified by the previous review panel during the 1999 meeting. This level of responsiveness helps to move the program toward meeting the needs of adaptive management, and gives the program a level of credibility that keeps participating scientists and stakeholders positively engaged in the adaptive management process.

At the broadest level, the effectiveness of the GCMRC to inform and promote adaptive management could be further improved by better integration among the three core monitoring and research programs of physical resources, biological resources, and sociocultural resources. Such integration is best achieved from bottom-up collaborations of scientists rather than top-down management edicts. Formulation of scientific questions and studies that bridge the three programs is one way to accomplish this. The programs appear to be starting such formulations, and the panel encourages continuation and expansion of these collaborations.

The current adaptive management process, in which AMWG (Adaptive Management Work Group) and TWG (Technical Work Group) prioritize core monitoring information needs based on group consensus, is cumbersome and likely inhibits setting clear, prioritized goals and making decisions. Jacobson defines adaptive management as “a cyclic, learning-oriented approach to the management of complex environmental systems that are characterized by high levels of uncertainty about system processes and the potential ecological, social and economic impacts of different management options. As a generic approach, adaptive management is characterized by management that monitors the results of policies and/or management actions, and integrates this new learning, adapting policy and management actions as necessary." Advances in understanding and improvements in management require that the adaptive management concept be better implemented. The gap between experimental floods, for example, should be less than eight years. Under the current adaptive management process, the identification of goals and approaches by AMWG and TWG takes the form of lists of priorities and needs considered mostly in isolation from each other and lacks a strong rationale for prioritization.

II. SPECIFIC CHARGES TO THE PHYSICAL RESOURCES MONITORING PEER REVIEW PANEL (Appendix 1)

Draft statements of work for FY 2007

1. *Integrated quality-of-water core monitoring, with emphasis on sediment elements (Topping and others).*

The panel considers the sediment statement of work (SOW) to be reasonable. This SOW effectively documents the role that the measurements play in overall sediment and water quality monitoring and in supplying data for modeling efforts. It is clear that most of the measurements and budgeted effort are related to background measurements and would be relatively unaffected by the occurrence (or not) of an experimental flow. The proposed activities seem to be important to creating a realistic sediment budget and water-quality assessment. The panel supports funding to continue the work by David Topping and others, and recommends that Topping be fully funded. Other staffing requests in the SOW are appropriate.

The statement of work gives more attention to what has already been done than to proposed work for 2007, with the exception of installing a LISST infinity at the Paria River gage. Specific suggestions from the panel include

- Greater attention to prioritization of proposed activities and associated budgeted items.
- The SOW does not identify what fraction of the budget is support for any experimental flows that might occur during the budget period. Does the budget reflect the anticipation of an experimental flow, or would supplementary funds be required for such an event?
- The level of effort and analysis provided seems to warrant a full-time effort by the project chief, rather than 75% of his time.
- The scope and sophistication of sediment and water quality measurements have undergone dramatic increase during the past 3-5 years. Although the document clearly identifies the techniques, protocols, and schedules to be used, there is less sense of the place of the work plan in the long-term evolution of sediment and water quality monitoring. For example, which of the activities are baseline monitoring that would be expected to occur many years into the future, and which

are relatively short-term measurements primarily to be used for model calibration and then discontinued?

- The monitoring could be strengthened in two ways to reflect the scientific findings of the past few years. Two important discoveries are that bed sediment size and tributary (mainly Paria) sediment inputs exert first-order control on sediment transport in the Colorado downstream of Glen Canyon Dam. In light of this, the panel recommends more focus on 1) bed sediment grain size (and its temporal and spatial variations) and 2) Paria inputs. For grain size, we recommend that the bed sediment camera be added as a routine component of the monitoring during field trips. Some effort should be expended to explore the feasibility of a remotely operating bed sediment camera that could be used for "continuous" monitoring. With regard to the Paria river, a variety of sensors should be installed upstream of the Colorado River junction in order to obtain more accurate measurements of discharge, stage, suspended sediment flux, bed sediment grain size, and bedload sediment flux. The proposed LISST-infinity is a great start, but there should be even more emphasis on obtaining better data in the Paria, in order to more accurately constrain the sediment input to the Colorado. This is a significant request that requires either increased resources or cuts elsewhere. If program cuts are required, the panel recommends reducing work downstream of the Grand Canyon gage.
- *Instrumentation issues:* A USGS series report thoroughly documenting instrument calibration and development of time series of cross-sectionally averaged velocity weighted suspended sediment concentrations (silt/clay and sand) should be written. A comparison of the D-77 bag sampler used on this project with the currently recommended D-96 sampler should be provided to document that the project sampler is acceptable. The review panel understands the difficulty and limitations of the D-96 sampler, but the performance of the D-77 bag sampler needs to be documented through direct comparison or standard isokinetic laboratory tests. A comparison of pumped and sampler collected water samples should be provided to document that pumping samples is acceptable. Suspended-sediment load is determined with the Equal Width Increment (EWI) method using five stations in a cross section, whereas the rule of thumb is twenty stations. An evaluation of whether the EWI method with five stations is sufficient should be provided. A subset of this report should be published in the peer reviewed literature. If possible, validation should also be presented.
- The project should consider the cost of maintaining redundant systems as calibration and intercomparisons of data measurement techniques become sufficient. The LISSTs appear to be the instrument that requires the most maintenance and with fully operational acoustics could be considered for elimination to reduce long-term maintenance costs. If the data provided by the LISST continue to be important, the project should consider the LISST infinity which, although having a larger initial cost, will likely reduce long-term maintenance

- The project should evaluate servicing frequency because several instrument malfunctions developed during the preceding six-month servicing interval, necessitating difficult and inefficient return trips by foot. Perhaps a four-month servicing interval would actually save the project money and allow for more efficient use of staff time.
- When instruments are not operating, the shifting rating curves presented by Scott Wright appear to be a potential method to fill data gaps, and the project should continue to investigate this method. It is important that these data be appropriately flagged in the database, however, as being estimated.
- Does the proposed SOW include funding to WRD to maintain and develop the water discharge side of the data?
- Although Topping's approach to characterizing the tributaries is the least expensive approach available, the accuracy of the siphon samplers is uncertain.
- The techniques developed and used in the Grand Canyon to monitor suspended sediments should be fully developed and tested in other environments. The validation of these methods in other environments will provide added validation to the data collected in the Grand Canyon and will likely make these methods standard techniques rather than special, research-oriented techniques. This could be important in any court challenges to the scientific data produced.
- The management information needs are for monthly data, but continuous data are still needed because of the ephemeral nature of flows, especially from tributaries, and the daily variation of discharge.
- *Data reports*: Given that the water-quality data collection is evolving from a research activity to a monitoring activity, an annual USGS open-file report summarizing suspended-sediment concentration data should be written or the data should be included in Arizona's Annual Data Report.
- *Error estimates*: The project personnel are commended for their recognition and concern for the errors associated with the field measurements and the effects on long-term system response and prediction. The error analysis reported to the panel, however, was based purely on a composite unsigned error. The project should better determine the components of the error associated with random uncertainty and bias. It is recommended that someone with statistical expertise in quantifying long-term errors be consulted, and that a better representation of the prediction errors be determined.

2. *Modeling support linked to integrated quality-of-water core monitoring (Wright and others).*

The goals of the modeling effort, as outlined in the statement of work, are appropriate and reasonable. The statement of work appears to place the modeling effort within GCMRC, which the panel endorses. The proposed effort appears reasonable and very dependent on Scott Wright's involvement. He has been working on the project for over two years, is knowledgeable of the system, appears to work well with other team members, and has the necessary sediment transport and modeling background. Although he recently moved to Sacramento, GCMRC should endeavor to maintain his involvement in the modeling effort. Steps should be taken to ensure that the modeling program is properly integrated with the core monitoring program of Topping and others. Where appropriate and possible these two programs should benefit from mutual feedback, because they share similar objectives. Participation of Scott Wright in both programs is regarded as a positive step in this direction.

Additional specific comments from the panel (see Appendix 3 for written suggestions or recommendations provided by scientists):

- The statement that the model will be used to fill data gaps where instrument problems have occurred must be implemented carefully. Model simulations are not observed data and need to be clearly identified and represented as simulations.
- The 1-d temperature model seems appropriate, but the combination of separate FORTRAN codes that must be operated in sequence is awkward. Hopefully the interface will automate and hide all of this from the operational user.
- Although the integration of tributary sediment input into the Colorado River sediment transport model is important, the panel is not convinced that the Colorado River model is currently adequate. Also, the budget for the proposed integration seems low, irrespective of the adequacy of the mainstem model.
- It is unfortunate that the proposal does not address improvements to the current mainstem model. Presentations during the PEP by Peter Wilcock clearly showed the type of long-term results desired from the model, but the model is not currently capable of producing those results. The only task in the current proposal for addressing this deficiency is further investigation of beta. Given that the model did not accurately replicate the erosion of sand from eddies, more research is needed to parameterize the eddy contributions to sediment management in the model.
- A long-term sediment transport model is desperately needed to demonstrate to stakeholders the potential results of various operational scenarios. This capability unfortunately does not exist at present, and the proposed work does not convincingly demonstrate that the current situation will be significantly improved. There was insufficient time to get into the detailed problems associated with the current model during the PEP, but the panel remains concerned about the condition of the model. The panel recommends that the current one-dimensional Colorado River model be critically reviewed by a small group that will be tasked with making recommendations to guide further development or re-development of the model.
- No detailed statements of work corresponding to that provided for the Topping et al. effort detail the efforts of Rubin and Wright.
- Although the document covers the new near-shore temperature monitoring (and modeling?) effort, it is not clear who will be responsible for this program.
- The largest single line item in the budget is "Outside USGS Contract Science Labor (17% Burden Rate)" at $325K, but the dispersal of these funds is largely unexplained.

Does this cover the beach monitoring activities of the NAU group and/or the coarse sediment monitoring and research efforts or river trip logistics?

Effectiveness of current or proposed sediment core monitoring in meeting identified core information needs and answering strategic science questions

Need for a comprehensive structured approach. At the most fundamental level, the panel notes the lack of a comprehensive structured approach that can be used to prioritize information needs, to define the flow of information that will get program scientists to a desired endpoint of understanding, and to specify the level of detail, such as the spatial and temporal resolution needed to address driving questions. It was not clear during the review panel meeting whether an integrative adaptive management model remains an envisioned endpoint of the GCMRC activities, because such a model was not used as a framework to guide discussion of physical science research projects.

As an example of the questions that arise in the absence of a structured approach, the panel remains uncertain how the efforts to model fine sediment dynamics (Steve Wiele and others) integrate with the efforts to model coarse sediment dynamics (Robert Webb and others). A structured approach defining how the different research components within the physical resources program fit together would promote understanding of program activities by peer reviewers and stakeholders, and would facilitate integration among individual scientists and research efforts. At present, such an understanding seems to be implicit in the minds of many individual researchers, but not clearly articulated in a framework on which all program scientists agree. A comprehensive structured approach would improve program effectiveness by allowing (i) identification of gaps in existing monitoring and research efforts, (ii) identification of gaps in the current state-of-the-knowledge of the overall system, (iii) evaluation of whether the balance among the effort distribution in monitoring, applied studies, and modeling is appropriate, (iv) evaluation of the cost versus benefit for specific lines of research (all of the existing studies represent good work, but it remains unclear whether extending some of the projects is beneficial to achieving long-term goals; the sediment mass balance, for example, is fairly mature at this point, whereas the fine sediment modeling is fairly immature), and (v) clear identification of, and agreement on, the integrated goals and objectives of the physical resources program. A structured approach would also provide a framework for integration of the physical program with the biological and cultural programs and for the adaptive management cycle of experimentation, monitoring, evaluation, and implementation.

Fine sediment modeling. The panel believes that more effective communication is required between scientists involved primarily in modeling (Steve Wiele and others) and scientists focusing on data collection and analysis. Modeling must be a component of the mass balance, FIST, and coarse sediment projects, rather than a stand-alone exercise. This relationship requires that individual scientists work to ensure that they are making the best possible use of the data and understanding of other GCMRC scientists. The current collaboration between David Topping and David Rubin provides a good example of an effective partnership, whereas the apparent lack of collaboration between David Topping and Steve Wiele reduces the effectiveness of the GCMRC physical resources program.

Scientists engaged in data collection and analysis should help guide model development by prioritizing the critical questions to be addressed in simulations, as well as identifying the appropriate spatial and temporal scope and resolution. A longitudinal, system-wide model of water and sediment movement within the river ecosystem is essential, for example, but this can only be developed if Wiele's group puts forth an effort comparable to Topping's group, and is more integrated into the physical resources program than at present. The panel feels that the development of the fine sediment model thus far is below what could reasonably be expected. Modelers need to better assess the most important aspects of model unknowns and pursue these systematically. The existing model could also be substantially improved by strengthening the treatment of hydraulics within eddies, given the importance of this portion of the river system for sediment dynamics. Evaluation of different management scenarios requires a 2-3 eddy-length multidimensional model that can be tested during experimental flow releases.

The model contains many simplifications, among which reach averaging, equilibrium, and one-dimensionality are the most significant. Given these simplifications, there is no reason to expect that theoretical coefficients would produce optimal results. Thus, the model must be calibrated. In addition, the equilibrium assumption is not applicable to experimental floods that are the primary application of the model, so the assumption should be removed from the model. For example, simulation of the 2004 experimental flood featured too much sediment arriving too soon at mile 30. This could result from the assumption of equilibrium, or from a settling velocity that is too small for the well-mixed cross section. At mile 87 the results were better, which is unusual because errors normally propagate downstream. The assumption of equilibrium would get better with distance downstream, so it is likely that the equilibrium assumption is the primary cause of the poor results at mile 30. Part of the problem is that the model remains at the stage of preliminary testing. Proposed calibration of the model using existing 2007 funds will presumably lead to future improvements.

The panel believes that the fine sediment model needs to have the capability to (i) simulate a range of flow scenarios, (ii) account for eddy storage dynamics to at least a first-order approximation, and (iii) better address reach-scale processes. Essentially, the model needs to provide first-order estimates of the effects of different management scenarios, although in order to do this it may be necessary to run 2d or 3d models of specific processes such as eddy dynamics, for which field-based hydraulic measurements will be needed. The initial, one-dimensional theoretical model without calibration has been used to assess general model trends, and this approach indicates that the model has promise. The model now needs further refinement and calibration and the panel suggests that the modeling team develop shorter time-step, more detailed simulations that are used to parameterize longer model runs that can then be applied to scenario testing as a management tool (for e.g., evaluating relative sediment input, sediment retention, and sediment output). The lack of detailed measurements during periods of change limits modeling efforts. Measurements of hourly to daily changes over a time period of days on a reach basis, for example, are necessary for the fine sediment model to be useful for management.

The modelers first need to demonstrate that the model works on a simplified, theoretical or laboratory-type example, however, and this has not yet been shown by Wiele’s group. At this point, the existing model needs further work to make it applicable to evaluating different management scenarios, and this in turn requires much closer collaboration between modelers and field-based researchers. One way to facilitate this closer collaboration and to ensure that the fine sediment model meets the needs of the mass balance and FIST groups would be for GCMRC rather than other USGS offices to lead the modeling program. The FY2007 statement of work for modeling appears to accomplish this. One of the primary reasons that the earlier panel recommended concentrating on several reaches for the FIST monitoring effort was to provide the three-dimensional geometry and temporal history of fine sediment storage that could be used in a two-stage approach of using Wiele’s 2+d model to calibrate the one-dimensional model. The FIST reaches do not appear to have been utilized in this way.

A weakness of the present modeling efforts resides in the lack of quality control of the model and its solution. There are recommended practices that should be followed by any general modeling program, and those have not been followed here. These practices have been standardized across disciplines by the AIAA (American Institute of Aeronautics and Astronautics), the ASME (American Society of Mechanical Engineering) and the ASCE (American Society of Civil Engineering), which publish those standards in manuals and other practice recommendation documents. Wiele and coworkers are referred to those documents and encouraged to follow them in future work.

Assessing thresholds. Another issue relevant to data collection and modeling is how well physical resources scientists need to know the parameters and trends that they study. This issue can be paraphrased by asking, “Where is the elbow curve in a data set?” In other words, rather than focusing on detailed resolution, it may be most effective for project scientists to understand trends and thresholds within the river ecosystem. Given that the level of effort needs to be commensurate with the set of objectives identified, scientists involved in modeling and monitoring need to consider how to assess, for example, whether they’ve reached an 80% level of understanding of the system. Individual physical resources scientists are constantly assessing their level of accuracy, which is admirable, and the panel commends this as a strength of the program. However, there may be unnecessary overlap in current measurement programs, such as using both LISST and multifrequency acoustics. The LISST appears to provide valuable data, but requires an extraordinary amount of maintenance. Is the added value worth the cost? Could the system be monitored to an acceptable level with only multifrequency acoustics? If the LISST is needed, it is likely that the initial cost of installing LISST Infinities would be recovered in reduced maintenance costs. An analysis of this and associated costs should be developed. Project scientists should carefully consider what would be the minimal instrumentation needs to derive a trigger for an experimental flow release. The monitoring requirements to identify a trigger may be different than the monitoring requirements to track the short-term and long-term response to the triggered release. (An example might be discharge and sediment using acoustics and event-driven sampling at the Paria, LCR (Little Colorado River), and Diamond Creek, with 20% accuracy in the associated rating curve.)

Core monitoring and analysis. Monitoring, applied studies, and modeling form the three basic components of the physical resources program of GCMRC. Monitoring activities feed directly into the identified CMIN (core monitoring information needs), applied studies address key uncertainties, and modeling ties all three components together and provides a framework for the physical resources program and for scenario evaluation. The panel suggests that all three of these components be collectively referred to as *core monitoring and analysis* because effective monitoring requires interpretation, as provided by applied studies and modeling, that can inform adaptive management.

Experimental flows. Experimental flow releases remain critical to the core monitoring and analysis program. These flows form an integral part of monitoring because they create episodic changes in the river ecosystem that can be planned for and measured, and thus provide a platform for calibrating conceptual and numerical models, and testing model predictions. The November 2004 flood provides a good example of adaptive management. The experimental release that created this flood was triggered by a naturally occurring flood on the Paria River. The November 2004 flood reversed much of the recent erosion on sand bars, but did not restore bars to pre-1990 condition. The flood also demonstrated the existence of “hot spots” where most of the change in sediment storage occurs.

Because experimental flows remain critical to achieving understanding of the Colorado River ecosystem, these flows must continue. One of the largest constraints on the ability of the physical resources program to learn is the lack of experimental flows. Scientists in the physical resource program have not yet evaluated the ability of annual or biannual experimental flows to build sustainable beach habitat and have not addressed the question of how to manage flows in order to conserve sand bars following experimental releases, for example. Scientists will probably need further experimental releases in order to address these critical questions. Experimental flows are necessary to adaptive management, and may result in operational flexibility that is not yet recognized as being possible. The use of scenarios modeled by an appropriately developed model could help provide justification to the AMWG that the costs of experimental floods are justified. The model may need to be revised as data collected during these floods are analyzed, but that is the heart of the adaptive management process. The lack of a model to show potential results may be hindering the project from moving forward.

Sediment monitoring strategies. Lacking specific metrics to guide monitoring, at least three complementary but potentially redundant approaches exist with respect to sediment monitoring in the Colorado River ecosystem. The first approach is to detect the trend of change in sand bar area and volume. This is only a first-order determination, yet is one of the more difficult to accomplish. In this context, the panel commends the works of the NAMDOR team in producing ground-based survey data that are critical to evaluating bar changes. The minimalist monitoring to accomplish detection of trends in sand bar area and volume is repeat surveys of existing, established sites on a regular basis, such as once a year, using ground-based techniques. This would provide the ability to detect long-term trends through time, but would not provide any insight into cause and effect or into impacts of changing flow regime. Adding event-based surveys to the annual surveys would increase the ability to detect the influence of controlled floods or fluctuating flow regime. The most effective monitoring will be sufficiently flexible and responsive to utilize unexpected events, such as sediment inputs from the Paria or LCR, as well as planned events such as controlled floods on the main channel.

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, 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. The more robust mass balance should include monitoring of bed sediment grain size and density of coverage based on research results to date, although it remains unclear whether bed sediment size is causal or correlative with supply and transport history.

The third approach for monitoring sediment is to continue a full FIST approach to identify changes in the spatial distribution of sediment on the bank and bars in long reaches of the river. This approach would include detailed, event-based measurements of hydrodynamics and sediment transport in multiple eddies. The approach would provide the largest spatial distribution of data, but may be limited in accuracy because of the uncertainty associated with remote sensing data and surficial bathymetric surveys that cannot quantify the depth and composition of the bed material.

It is unlikely that approaches 1 and 3 could provide the level of detail needed to trigger BHBFs or to develop and validate a sediment transport model of the system. Approach 2 can only provide information on how much sediment is stored or eroded, but not on where the storage or erosion is occurring in the system. A combination of approaches is therefore required, and all approaches need to be part of a unified and integrated work plan. Until the final results of the remote sensing data are completed, its usefulness compared with cost cannot be determined. There is always value in long-term data sets and for this reason the repeated ground surveys of the NAU sites should be continued. Based on the results of the remote-sensing data, it may be beneficial to reduce the number of NAU sites while expanding the spatial distribution with remote-sensing data. This determination will have to be made by the project staff once the processing and analysis of the remote sensing data are complete.

It will be the task of managers, as guided by recommendations from program scientists and peer reviewers, to choose among the alternate approaches for sediment monitoring. This panel recommends employing the first two approaches by continuing both annual and event-based ground monitoring of sand bars, and continuing development of the sediment mass balance for the river ecosystem. The panel also emphasizes that it is essential that funding for all existing research efforts continue for a sufficient period of time to allow the scientists to analyze their data in order to recoup the GCMRC's existing investment.

Potential for integration of sediment core monitoring protocols with other related program activities and objectives

The degree of integration among the three core programs of the GCMRC has improved since 1999, but the programs are not yet effectively integrated. The panel recommends the following actions as means to foster integration among the programs:

- Establish common frames of reference that facilitate discussion of effects of changing flow and sediment regimes among scientists in the three programs. Stage in relation to discharge provides an example of such a frame of reference; discussing various flow scenarios with respect to stage would facilitate quantification of parameters such as fish habitat or camping area on bars, which are of particular concern to the biological and sociocultural programs, respectively.
- Evaluate trade-offs among different resources as a function of differing flow regimes. For example, how does a specific flow scenario affect survival of humpback chubs versus camping space versus preservation of archeological sites? Scientists in the physical resources program need to consider not just bar building, but also what comes after with respect to the continuing effects of different flow scenarios. The concept of trade-off space represents a higher objective for the monitoring program that would facilitate comparison of trade-offs among the multiple objectives articulated by stakeholders in the adaptive management process.
- Identification by scientists in other programs of physical parameters which are central to their understanding of the river ecosystem. Scientists in the physical resources program have impressive measurement capabilities for many parameters that are likely to be important to scientists in other programs, but integration is limited if the physical scientists are not informed of these parameters, and of the spatial and temporal resolution of measurements most useful to scientists in other programs. What level of detail do biologists want for quantifying aquatic and riparian habitat, for example, with respect to area, volume, or substrate type? What other types of measurements (e.g. water temperature, dissolved oxygen) could be emplaced at existing flow and sediment measurement sites that would be useful to biologists?
- Joint annual research symposia and river trips by scientists in the three core monitoring and research programs that are organized specifically to identify common frames of reference and to evaluate trade-offs among resources under differing management scenarios would foster collaboration and integration, and should ultimately facilitate use of an ecosystem-level adaptive management model.
- As noted earlier in this report, many of the 1999 recommendations of the PEP SEDS panel have been implemented by the GCMRC staff and scientists. It is not clear to the panel that this type of follow-through occurs as consistently in other programs. Serious attention to external review and implementation of review recommendations by other programs within GCMRC would provide important impetus to these programs and would facilitate integration among programs. Many of the recommendations from the most

recent panel review for the sociocultural program are directly related to sediment issues, for example, as are many of the objectives of both the biological and sociocultural programs, albeit on different time scales.

Responses to specific questions and recommendations from scientists in the physical resources program

- The FIST data would need to be fully evaluated in relation to the mass balance and NAU data before the panel could recommend continuation of one versus the other. The physical resources program lacks consistent cross-comparison of different approaches within the same frame of reference, which hinders recommendations for prioritizing ongoing data collection efforts. True evaluation of the effectiveness of different approaches requires more integrated, comprehensive analysis of results and comparison between methods. FIST has not yet facilitated calibration and validation of Wiele's 2d model, which was part of the original intent of implementing FIST. The original intent of FIST was to inform detailed models, which would then inform bin-based models. The FIST group collected the type of data intended, but these data have not been utilized by modelers.
- At this point, the panel does not consider it necessary to add further monitoring sites downstream from Phantom Ranch, but this may need to be revisited (presumably by stakeholders) in the future.
- The fact that much remains to be learned about where bars will be built or reduced as a function of flow magnitude, duration, and timing with respect to tributary sediment inputs argues for development of a robust sediment mass balance that includes the transport and export of sediment. As part of this, the panel endorses the goal of reducing error in the sediment mass balance by obtaining better data (particularly high flow data) from the Paria River.
- Work to date on LiDAR is very impressive and is useful for monitoring changes in beach area and vegetation cover. The panel recommends continued use of LiDAR, although this may not be necessary every year or with continuous coverage of the Colorado River ecosystem. LiDAR surveys should be carefully designed to provide information to all three GCMRC programs. LiDAR may be more effective as a targeted tool that is used in combination with ground-based surveys. Evaluations of different techniques would be facilitated by detailed comparisons such as ground-based versus LiDAR bar cross sections, or changes in volume, area, or vegetation cover of bars; fish finder versus NAU bathymetric surveys; or NAU versus FIST surveys for trend analysis of bars. Evaluations within individual data sets would also help to address questions such as whether fewer than 45 sections can be used for NAU surveys. The panel suggests that project scientists consider using the Kruskal-Wallis rank test or a similar statistical test to address this question.
- Topping and Rubin have already done a tremendous amount of work, but the panel questions their ability to make substantial additional progress without more clearly articulated goals within the overall sediment program. At present, they can provide a sand budget for the river ecosystem, the NAU group and Jack Schmidt can provide bar

area, and Rubin and Roberto Anima can provide bed composition. All of these elements can now be tied together. Wiele’s 1d sediment transport modeling is a good start at tying these different data sets together, but work is needed on model calibration rather than on further model development.

- The panel recommends that Topping and other physical resources program scientists consult with experts on error and uncertainty, such as Tim Cohen of the U.S. Geological Survey, Office of Surface Water, in Reston, Virginia.
- The panel recommends careful consideration of cost-benefit ratios for all monitoring and analysis techniques used in the physical resources program.
- The panel and GCMRC need a better-coordinated scheme for identifying the type of information now critical to modeling efforts in order to prioritize funding for continued monitoring and research efforts versus new directions.
- The qualities of “sustainable” or “attainable” conditions in resources need to be more precisely defined to guide monitoring.
- The panel feels that David Topping plays an essential role in this program. He does very high quality work and has many skills that cannot be replicated by other scientists involved in the program. The innovative nature of the sediment mass balance that he has developed is admirable. The panel views his participation in the physical resources program as essential, and recommends that anything that would facilitate his continued participation should be endorsed because he plays such a unique role. Program success likely would considerably diminish without his presence at GCMRC and institutional knowledge, and his progress over the last decade has been phenomenal.

III. SUMMARY

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.

The panel stresses the need for more experimental releases in order to assess the adequacy of any model that program scientists use to predict changes in bar distribution and size. Continued experimental flows are critical to resolving the complex uncertainties of bar dynamics in terms of how variations in flow magnitude, duration, and timing influence sand transport and storage. The lack of experimental flows constrains the ability of scientists and managers to learn and predict because experimental flows are not solely research tools, but also function as monitoring and management tools that reflect the outcome of alternative strategies of dam management. Monitoring of system responses to experimental flows will allow identification of flexibility within the river ecosystem with respect to parameters such as ramping rates and daily fluctuations. Experimental flows may provide a better, faster, and cheaper alternative than using a sediment pipeline to restore declining sand bars within the Colorado River ecosystem. Because scientists studying this ecosystem are not yet able to specify the characteristics of experimental floods necessary to preserve or restore sand bars, experimental flows remain critical to monitoring how the system responds to high flows. The crux of adaptive management is to experiment, monitor, design management, and experiment again until the desired state is achieved and, in the Colorado River ecosystem, this process requires experimental flow releases.

The panel believes that the greatest opportunities for learning presently lie in addressing issues such as (i) plausibly simulating a multi-eddy, multi-bar system and linking this to management scenarios, (ii) better understanding the spatial organization of the Colorado River ecosystem, and (iii) developing a better sense of trajectories in the system following different release schedules (existing sediment research, for example, seems to support the idea of relaxing restrictions on daily flow fluctuations). One type of data collection is necessary for understanding a complex system, and this is now largely complete for the physical resources component of the Colorado River ecosystem. Another type of data collection is necessary for monitoring the system, and this should be the continuing focus of the GCMRC physical resources program.

As noted in the final report of the 1999 physical resources program review panel, excellent progress continues to be made in developing an understanding of the physical behavior of the Colorado River in Grand Canyon. The physical resources program is well managed and integrated. The quality of the overall research and monitoring effort is exceptionally high. The effectiveness of the physical resources program, and the GCMRC as a whole, can be improved by attention to the issues highlighted in this report, which include:

- clear articulation of a structured approach that guides core monitoring and analysis efforts in each research project and in all GCMRC programs
- closer integration within the physical resources program between efforts aimed primarily at monitoring and applied studies, and efforts to develop integrated models of hydraulics and sediment dynamics within the river ecosystem
- integration of frequent experimental releases into core monitoring and analysis
- development of a common frame of reference and discussion of trade-offs among differing resources under varying flow regimes by scientists in all three GCMRC programs
- consideration by physical resources scientists of issues of resolution versus trends and thresholds in the parameters being measured or modeled with respect to a context of adaptive management
- development of a monitoring plan based on a structured approach and including details of techniques to be used, desired spatial and temporal resolution of data collection and modeling, and data storage and retrieval

Appendix 1. Review Elements

1. Please comment on any long-term sediment monitoring protocols identified or recommended by the GCMRC staff during the SEDS-PEP III meeting for FY 2008 and beyond.
2. Please review and evaluate all written suggestions or recommendations for future long-term sediment monitoring and modeling provided by other cooperating scientists during the August 15-17, 2006 meeting.
3. Please review and provide comments on draft statements of work proposed for FY 2007 (a) integrated quality-of-water core monitoring – with emphasis on sediment elements (Topping and others), and (b) proposal for modeling support linked to integrated quality-of-water core monitoring (Wright and others).
4. Please provide evaluations of how effectively the panel thinks the sediment scientists' monitoring recommendations will be in meeting the identified core monitoring information needs for sediment goals and management objectives.
5. Please comment on how effective the current or proposed sediment core monitoring (presumably, in combination with sediment flow experiments and modeling activities) will be in answering the strategic science questions that have been recently identified for sediment resources (sustainable sand bar restoration through implementation of BHBF and possible optimization).
6. Please comment on potential for integration of the sediment core monitoring protocols with other related program activities and objectives.

Appendix 2. Strategic Science Questions

Strategic Science Questions developed cooperatively by scientists and managers as a result of the Knowledge Assessment Workshops in 2005

4.1 Physical Resources

4.1.1 Is there a "Flow-Only" (non sediment augmentation) operation that will restore and maintain sandbar habitats over decadal time scales?
4.1.2 Is there an optimal strategy for BHBF implementation to manage tributary inputs on an annual to inter-annual time scale?
4.1.3 What are the short-term responses of sandbars to BHBFs?
4.1.4 What is the rate of change in eddy storage (erosion) during time intervals between BHBFs?
4.1.5 How does the grain-size distribution of the deposits affect sandbar stability? Main channel turbidity?
4.1.6 What are the effects of ramping rates on sediment transport and sandbar stability?
4.1.7 Can we develop a relationship between suspended sediment concentration and turbidity to support fisheries research?

Appendix 3. Suggestions or recommendations for future long-term sediment monitoring

and modeling provided by project scientists

Set 1. Future Sand Modeling Activities
Peter Wilcock and Stephen Wiele

We have demonstrated the viability of the reach-averaged approach to modeling sand routing and its application to the Colorado River in Grand Canyon. An uncalibrated model provides a good fit to the 2004 flow and transport conditions. We will develop example applications to management questions and collaborate on delivery of a Graphical User Interface with Josh Korman, completing work on the first version of sand routing model.

As designed, the sand routing model addresses questions of sand routing and storage corresponding to management actions and tributary events over a time frame of days to months. The model can be used to evaluate dam release scenarios for conserving tributary sand supplies prior to high flow releases. The model is intended to assist in determining the most effective dam operations for conserving tributary sand inputs.

Broader questions arise regarding the long-term sand balance. Can sand conservation flows and BHBFs maintain or increase the amount of sand stored in the system? Is sand augmentation necessary to increase the amount of stored sand and, if so, in what quantities? The completed sand routing model can be used to evaluate dam releases, tributary supplies, and sand augmentation in terms of optimizing storage of introduced sediment, but the long term balance depends also on the rate at which sand is lost from eddies over long time periods between high flow events. To complete our ability to model the long-term effects of management actions on the sand resource, the short-term sand routing model will need to be coupled with a long-term eddy sand loss model. The long-term model will need to be developed in close coordination with long-term field monitoring of changes in eddy sand volume in order to constrain model error accumulated over long computational periods. This will require a focused research effort that includes (1) monitoring of sand loss over long periods with no high flows and different initial conditions of sand storage and (2) a model framework combining the relevant mechanisms with long-term constraints based on observations of eddy sand loss.

Set 2. Downstream Integrated Quality-of-Water Monitoring (below Glen Canyon Dam)
David Topping, Scott Wright, and David Rubin

The downstream IQW project focuses mostly on monitoring, but can also support implementation of flow research related to stable flow testing, evaluation of alternative fluctuating flows, tests of BHBFs and ongoing development and evaluation of numerical modeling. In some instances, it is difficult to separate these elements from experimental elements because they support each other. For example, monitoring the suspended sediment budget may be considered core monitoring, but it is also required to assess a trigger for a BHBF such that it could be considered experimental research support. In the section on project goals/tasks, the individual project elements are described along with the associated category(s). This project is intended to provide core-monitoring information to meet the information needs of the GCD AMP related to Goals #7 and #8 under an ongoing schedule during FY 2007 and beyond.

Geographic Scope:

The downstream IQW project is primarily focused on the main channel of the Colorado River from just below Glen Canyon Dam (mile -15) downstream to Diamond Creek (mile 226). However, an important component of the project is a combination of monitoring and modeling of tributary sediment inputs such that sediment and flow monitoring activities are also carried out in various tributary watersheds, such as the Paria and Little Colorado Rivers.

Project Goals/Tasks:

The downstream IQW monitoring project is focused primarily on measurements of surface flow throughout the river ecosystem, as well as quality-of-water parameters such as temperature, specific conductivity, dissolved oxygen, and suspended-sediment transport. The monitoring project directly supports achievement of the following GCD AMP goals:

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

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

Because this monitoring 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 GCD AMP goals, as described below:

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

The downstream IQW project supports this goal by providing information on flows, water temperature, 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 downstream IQW project also supports the native fish program by providing near-shore water temperature data for the assessment of growth rates, 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 near-shore habitat disruption caused by fluctuating flows, and information on sandbars which create backwater habitats that are thought to be important 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. The downstream IQW project also monitors dam release and Glen Canyon quality-of-water, which proved critically important in fall 2004 when dissolved oxygen levels were low requiring modifications to release patterns in order to raise oxygen levels.

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 downstream IQW project also 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 GCD AMP ecosystem goals. The downstream IQW project also produces monitoring data and supports experimental and modeling research to understand flow dynamics and the size and abundance of sandbars, which are resources that affect the recreational experiences of Colorado River users such as rafters and fishermen.
Goal 11: Preserve, protect, manage, and treat cultural resources for the inspiration and benefit of past, present, and future generations. The downstream IQW project also provides monitoring data related to riverine sand bars that provide a source of sediment, through aeolian transport, to high elevation sand deposits that contain archaeological
resources. In addition, the downstream IQW project has also developed stage modeling capabilities that allow for the assessment of the flow level that inundates a given cultural site. In August 2004, the AMWG reviewed these goals and identified priority questions. The top five priority questions are as follows:
Priority 1: Why are the humpback chub (HBC) 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 Traditional Cultural Properties (TCPs), are within the Area of Potential Effect (APE), which should we treat, and how do we best protect them? What are 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 Temperature Control Device (TCD) is tested or implement? How should it be operated? Are safeguards needed for management?
As with the AMP goals, the IQW monitoring directly supports some priorities while indirectly supporting others. For example, monitoring and research on flows, sediment transport, and water temperature clearly directly support priorities 3, 4, and 5, while also indirectly supporting priorities 1 and 2 by providing information on the general physical framework of the riverine environment.
There are several project related tasks that occur within the downstream IQW project:
• Flow and stage monitoring: Continued monitoring of flow and stage at established mainstem locations and major tributaries (-15-mile, 0-mile, 30- mile, 61-mile, 87-mile, 226-mile, Paria, and Little Colorado Rivers).
Category(s): Core Monitoring. Schedule: Ongoing.
• Quality-of-Water monitoring: Continued monitoring of water temperature at established mainstem locations and major tributaries (-15-mile, 0-mile, 30-mile, 61-mile, 87-mile, 166-mile, 226-mile, 246-mile, Paria and Little Colorado Rivers, Kanab, Havasu). Implement of a new nearshore/backwater temperature monitoring program. Continued
monitoring of conductivity at established stations (-15-mile, 0-mile, 30-mile, 61-mile, 87-mile, 226-mile). Continued monitoring of turbidity at established stations (30-mile, 61-mile, 226-mile).Category(s): Core Monitoring. Schedule: Ongoing for mainstem temperature, conductivity, and turbidity monitoring; implementation of nearshore/backwater monitoring program in FY07, then ongoing; monitoring data supports completion of downstream thermal model development during FY07, applications ongoing.
• Suspended-sediment flux monitoring: Continued monitoring of suspended-sediment flux at

established mainstem locations and major tributaries (30-mile, 61-mile, 87-mile, 226-mile, Paria and Little Colorado Rivers). Because BHBF triggers are based on sediment retention within the mainstem, it is insufficient to monitor tributary inputs only.
Category(s): Core Monitoring. Schedule: Ongoing.

• Collaboration with and support of aquatic food base program: Integrated research studies with the aquatic food base program, including submerged aquatic vegetation and bed texture classification with acoustics, monitoring algal drift with acoustics, and quantification of tributary inputs of organic material. Category(s): support for Research and Development. Schedule: Ongoing.

• Coordination with other resource areas: Regular meetings and interaction with other resource area personnel, particularly at the Program Manager level, in order to facilitate an ecosystem approach to our scientific studies and ensure that the IQW is providing useful information regarding the physical environment to the other resource areas. Category(s): Program Management. Schedule: Ongoing.

Need for the Project:

Information on flow, water quality, and suspended-sediment transport is critical to understanding the physical environment upon which biological and socio-cultural resources depend (see details in Section 1 of this project description). In order to understand responses of these resources to dam operations, we must first understand the effects of dam operations on the physical environment. The goal of the downstream IQW project is to provide this information and link dam operations to changes in the physical environment.

Strategic Science Questions:

The downstream IQW monitoring project is designed with the goal of providing data that supports answering the two primary physical resources questions identified during the Knowledge Assessment Workshop conducted in the summer of 2005, as follows:

• Is there a “Flow-Only” operation (i.e. a strategy for dam releases, including managing tributary inputs with BHBFs, without sediment augmentation) that will restore and maintain sandbar habitats over decadal time scales?

• How do dam release temperatures, flows (average and fluctuating component), meteorology, canyon orientation and geometry, and reach morphology interact to determine mainstem and near shore water temperatures throughout the CRE?

Also, as detailed throughout this project description, the IQW project provides information on the physical environment that is critical to other resource areas and will thus contribute indirectly to answering a variety of other science questions related to other resources.

Links/Relationship to Other Projects:

Aquatic Food Web Research: The downstream IQW project 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 related quality-of-water data, such as water temperature, specific conductivity, dissolved oxygen and suspendedsediment concentrations and grain size for suspended particles in transport.

Fisheries Monitoring and Research – the IQW also 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.

Information Needs Addressed:

The downstream IQW project directly addresses several of the core monitoring and research information needs (CMINs and RINs) related to AMP Goals 7 and 8. A selection of the information needs that are addressed by IQW are listed below. The IQW addresses many more CMINS, but the ones listed below are considered most relevant to answering the science questions outlined above.

• CMIN 7.4.1 Determine and track flow releases from Glen Canyon Dam under all operating conditions.

• CMIN 7.1.2 Determine and track LCR discharge and temperature near the mouth (below springs).

• 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 –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?

• 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?

The monitoring data from IQW not only fulfill the CMINs listed above, but are also intended to feed new information directly into modeling efforts (see Project PHY 07.R1.07) that will allow sediment-transport modelers the opportunity to address research information needs (RINs) related to AMP Goals 7 and 8.

• RIN 7.4.1: What is the desired range of seasonal and annual flow dynamics associated with power plant operations, BHBFs, and habitat maintenance flows, or other flows that meet AMP 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, supplant 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 Record of Decision operations (upramp, downramp, maximum and minimum flow, MLFF, HMF, and BHBF) are most/least critical to conserving new fine-sediment inputs, and stabilizing sediment deposits above the 25,000 cfs stage?

General Methods:

Flow, stage, water temperature, conductivity, turbidity and suspended-sediment data are collected using standard USGS protocols with QA/QC. Suspended-sediment sampling is supplemented through the use of emerging technologies, including acoustics and laser diffraction. Stage, water temperature, conductivity, turbidity, and suspended-sediment surrogates (i.e. acoustics and laser-diffraction) are monitored with in-situ instrumentation recording at 15-minute intervals. River flow is measured periodically and used to develop a stage-discharge rating curve, providing 15-minute flow records. Similarly, suspended-sediment concentration is measured periodically and used to calibrate and acoustic and laser diffraction instrumentation, providing 15-minute records of concentration (sand, silt/clay, and sand grain-size).

Products/Reports:

The following products/reports are expected on an annual basis:
• Streamflow, stage, and tributary sediment data published in annual Arizona Water Resources Data reports and served through the GCMRC webpage.
• Biennial Data Report summarizing mainstem sediment transport and water quality data; data also served through the GCMRC webpage.
• 2 – 4 conference abstracts and proceedings articles
• 1 – 3 journal articles
• Frequent presentations at stakeholder meetings.

Set 3. Bar Monitoring
David Rubin and FIST participants
Bar surface area:
Should have higher priority than bar volume because area is how the resource is used (real estate lots are sold by area--rather than volume--for a reason). Also, area (such as area above 8000 cfs) can be measured at lower cost and with lower error than volume. Could be measured by surveyors on the ground at edge of water, from air photos, or lidar--whichever has the best balance of coverage and accuracy to cost. Frequency of measurements could be every year for selected bars and campsite areas, every few years or pre- and/or post-flood for longer reaches or more bars, and every 5-10 years for a larger region (entire river corridor).

Bar volume:
Should have lower priority than measuring area because of greater cost and lower benefit. Too early to decide what is the best surveying technology, sampling strategy, or recommended time interval.

Grain size:
Reasons for mapping grain size:
(1) Monitoring requested by managers
(2) Learn how to design more effective monitoring plans for the future (compare results with beta-calculations and shifting rating curves)
(3) Learn how the river works, where fine sediment is stored, how long it resides in different locations
(4) Extremely inexpensive (compared to bathymetric mapping and mass-balance monitoring)

Recommended near-term plan:
(1) Map grain size using eyeball in cooperation with other bathymetric surveying trips, preferably before and/or after each flood, a minimum of once each year
(2) Recent surveys have collected in excess of 5000 images per trip (approximately 1000 locations with 5 images per location). The estimated error (95% confidence) in the mean for such large samples with the observed standard deviation is only 10% of the grain size. Because the estimated error in the mean scales with the square root of the number of samples, we could get by with fewer samples, provided we don't sacrifice spatial coverage. We therefore recommend streamlining the operation by collecting and processing fewer images per location (rather than fewer locations).

(3) In our existing data-processing scheme, the most time-consuming step is frame-grabbing of images from the digital video tapes collected in the field. Our existing digital recorder has a slot for inserting a memory card for still-image capture. We recommend using this feature to grab frames in the field (and collect the digital tape primarily as a back-up, or for replacement of any defective images grabbed in the field).
(4) We recommend using whatever navigation system is most compatible with other simultaneous field operations: (a) using a combination of monumented cross-sections (for longitudinal location) and pressure transducer on the eyeball housing or markings on the eyeball cable (for depth and therefore transverse location using surveyed depths for that cross-section), (b) gps, or (c) tracking by laser surveyor.

Set 4. Sand Bar Monitoring
Matt Kaplinski and Joe Hazel

1) Measuring bar volume and topography/bathymetry provides additional information not included in measurements of area alone.
2) Errors arise if bar area is mapped while water discharge is changing
3) Measuring area at low, steady discharge might not save money.