A Report From the Technical Work Group Ad-hoc Committee on Sediment: Summary of Recent Findings and Recommendations for Future Actions

Introduction

The Technical Work Group (TWG) sediment ad-hoc group was formed at the November 8, 2001, TWG meeting to "work with the GCMRC to develop a white paper on the current understanding of sediment storage and transport and what that means to the AMP." (November 8, 2000 minutes). This group, herein referred to as "the ad-hoc", was formed in response to a memorandum, dated August 29, 2000, from GCMRC cooperating scientists to the GCMRC chief, which outlined important research findings and their relationship to Glen Canyon Dam (GCD) operations (Rubin et al., 2000). The sediment ad-hoc convened two meetings (February 20, 2001 and March 13, 2001) that included ad-hoc committee members and GCMRC cooperating scientists to discuss the recent findings and their implications. This report discusses the recent research and monitoring results and their implications to the Glen Canyon Dam Adaptive Management Program.

Background

Prior to Phase I of the Glen Canyon Environmental Studies (early 1970's), managers at Grand Canyon National Park initiated studies on the possible impacts of Glen Canyon Dam operations on sediment resources below the dam. As a result of those studies, Laursen et al. (1976) predicted long-term patterns of erosion below the dam, on the basis of remaining sediment input characteristics and projected hydropower release patterns that elevated the minimum discharge of the river and decreased flood frequency. In contrast to that initial view of downstream fine-sediment storage and transport, a major paradigm introduced in the Operations of Glen Canyon Dam – Final Environmental Impact Statement (EIS; DOI 1995) was that sand would accumulate within the ecosystem over multiple years if the dam was operated under several of the evaluated alternatives. This idea was derived from the results of several independent studies (Randle et al.,1993, Smillie et al., 1993, Bennett, 1993). These investigators relied on sediment transport relationships at the streamflow gaging stations developed by Randle and Pemberton

(1987) and Andrews (unpublished sand transport equation, 1992). These approaches utilized stable sediment rating curves for the Colorado River gaging stations at Lees Ferry, Above the Little Colorado River, and Phantom Ranch, and tributary stations on the Paria River at Lees Ferry and the Little Colorado River near Cameron. A stable sediment-rating curve is derived by generating a best-fit line through the cloud of suspended-sediment measurements made over a range of discharges. This best-fit line defines the sediment transported at a given discharge. The Randle et al. (1993) mass-balance model used the simple equation:

> *riverbed sand change = tributary sand supply + upstream reach sand supply – downstream sediment transport.*

Estimates of tributary sand input and mainstem transport were computed using the stable rating curve developed for each USGS streamflow gaging-station. Results from this modeling suggested that most operational alternatives, except for the no-action, maximum powerplant capacity, and high fluctuating flow alternatives would likely result in a net increase in riverbed sand when the tributary contributions of sand from the Paria and Little Colorado Rivers was average (Figure 1; Figure 6 from Randle et al. 1993, and Figure III-15, DOI 1995). A reasonable corollary followed that this accumulated sediment could be moved from the channel bed to higher elevation storage location (i.e. sand bars) through the release of Beach Habitat-Building Flows (BHBFs), or flows above peak power-plant capacity

The Rubin et al. (2000) memorandum challenges the EIS paradigm that substantial fine sediment can accumulate on the channel bed over multiple years, while generally supporting the earlier conclusions of Laursen et al (1976). Rubin et al. (2000) ~~uses~~ several lines of evidence to support their conclusions, the most important being the work of Topping (1999) and Topping et al. (2000a, 2000b). The recent work of Topping and others conclusively shows that sediment rating curves are not stable in a bedrock canyon river with infrequent sediment supply and that the stable rating curve approach underestimates the amount of sediment transport. Based on the analysis of pre- and post-dam sediment transport measurements, Rubin et al. (1998) and Topping et al. (2000a, 2000b) identified a coupled hysteresis in the suspended-sediment concentrations, grain-size, and bed elevation (Figure 2 – Figure 2a from Topping et al. 2000a). The hysteresis indicates that as the upstream sediment supply decreases, the suspended sediment concentrations coarsen and the bed begins to scour. Sediment transport, therefore, is greater when the bed grain size is finer, such as following a tributary input. Thus, the Randle et al. (1993) model underestimated the amount of sediment transport following tributary inputs, which resulted in a projected surplus of sediment under the preferred alternative, known as the "Modified Low-Fluctuating Flow" alternative. Much of this new information was unknown until testing of the controlled flood concept occurred in spring 1996 (Rubin et al., 1998).

Review of Figure 2 (Figure 11 from Topping et al., 2000b), shows the results of sediment-transport measurements collected in 1983, compared with the predictions of Randle and Pemberton (1987). Using this information, Topping et al. (2000a, 2000b) conclude that most newly input sediment is not stored in the channel for long periods of time, perhaps with the exception of the coarser fraction. Preliminary Analysis of suspended-sediment data from August 1999-April 2000 supports this conclusion and indicates that at least as much sand was transported through Grand Canyon as was supplied by the upstream tributaries (D. Topping, USGS, written communication-attachment B). In summary, most fine sediment coming into the system is being transported rapidly through the ecosystem, and recent intensive sediment-transport data indicate a negative sand mass balance under most operations above 8,000 to 10,000 ft^3/s. These recent data support the earlier conclusions of Laursen et al. (1976), about long-term erosion, despite the implementation of reduced fluctuations and limited ramping rates since 1991. A significant result of flow regulation by Glen Canyon Dam has been to promote sand transport by eliminating the period of low flows between August and April that used to allow sediment to accumulate in the pre-dam river.

These recent findings are based on sound research and have important implications for operation of Glen Canyon Dam. However, we raise the question, if most of the fine-sediment coming into the system is being transported out, then where is the sand being stored that can potentially be utilized to rebuild eroded bars? Site specific and reach-scale mapping of sediment deposits and photographic analyses show that most sand bars at high elevations (above 20,000 ft^3/s stage elevation) were substantially aggraded during high flows from 1983 to 1986 (Beus et al., 1985; Kearsley et al., 1994; Schmidt and Graf, 1990), and during the 1996 Beach/Habitat Building flood (1996 BHBF) (Hazel et al., 1999; Schmidt et al, 1999; Schmidt, 1999). Based on these and other studies the three most important sand storage locations are: 1) eddy systems below maximum powerplant operations, 2) shoreline areas, including eddy and channel margin locations, above normal powerplant operations, and 3) the main channel.

Sand within Eddy Systems

The eddy complexes have the greatest volume potential for long-term sand storage. Eddies are efficient traps for fine sediment at any discharge. In general, during the 1996 BHBF, high elevation bars in eddies were aggraded at high elevation, while the lower elevations scoured (Schmidt, 1999; and Hazel et al., 1999). Schmidt (1999) and Hazel et al. (1999) concluded that low elevation storage within eddies supplies a substantial amount of sand for bar building during a clear water flood (Figure 3 from Hazel et al., 1999). Thus, the amount of sand in eddies and the rate of its renewal are important factor for in determining the feasibility of conducting future BHBFs.

Coarse Sand along the Main Channel

The distribution of sand along the main channel is not continuous, and is interspersed with pebbles, cobble and bedrock. Surveys of the main channel at long-term monitoring sites showed that sand-sized sediment and possibly gravel was scoured from the bed during the 1996 BHBF. Differential scouring and greater retention of coarser fractions was indicated by the coarsening of sediment in transport during the same flow event and by inversely graded sand bar deposits following the event (Rubin et al. 1998, Topping et al. 2000a, 2000 b).

The majority of the fine sand that can be transported to higher elevations in eddies and along the banks is not stored in the main channel but is stored in the lower elevations of eddies. This interpretation is based on dredge samples from both storage environments and surveys of sand deposits (Hazel et al., unpublished. manuscript). Thus, when tributaries supply sand, the finer size fractions (0.25 mm or less) are more easily transported into eddies where they can be stored for long periods (on the order of years) and have a short residence time in the main channel, on the order of weeks to months (Topping et al. 2000b). Sand bars in this ecosystem are predominately composed of sand less than 0.25 mm in diameter, whereas, sand sampled in the main channel is typically coarser.

Ad-hoc Committee Conclusions

Main Channel Deposits

The ad-hoc concurs with the conclusions of the memorandum (Rubin et al., 2000) regarding the rapid transport of the sand and finer fractions added by tributary sediment inputs. Under ROD operations, the sand that is left in the main channel over inter-annual time scales is presumably the coarsest fraction of each input. Depending on the nature of tributary inputs (gaged and ungaged) and debris flows, the ad-hoc hypothesize that there could be multi-year accumulation of sediment on the main channel, but it would be coarser, and therefore more difficult to redeposit using controlled floods, than assumed in the final EIS. Coarser sand retained in the ecosystem limits the potential deposition for any range of BHBF flow magnitude; meaning that higher magnitude flows are needed of longer duration to achieve bar building. It is also important to note that this coarse fraction is a small percentage of Paria River inputs, perhaps only 10 percent (D. Topping, personal communication). Thus, unless some additional management action is taken to preserve a greater percentage of these inputs, the long-term sediment budget for the Grand Canyon will likely be negative, as originally concluded by Laursen et al. (1976).

Eddy Deposits

The major questions remaining to be answered concerning the fine-sediment budget are directed at the behavior and size of the eddy deposits. The ad-hoc thinks there is a possibility that eddy deposits might be manipulated under ROD operations to provide fine sand for beaches without unduly exacerbating the loss of fine sediment from the system. This strategy is dependent on eddies being efficient fine sediment traps and the amount of fine sand trapped in eddies being sufficient to build beaches at elevations largely protected from the effects of ROD operations. The total amount of sand in storage in Marble and Grand Canyons is still an unknown quantity but current monitoring and research projects are addressing this question.

Sand Deposits Inundated by High Flow Events

Prior to the closure of the dam, much higher sediment concentrations than at present contributed to the creation of numerous fine sand deposits at elevations exceeding the 100,000 ft^3/s level. In addition, many high elevation (above 31,000 ft^3/s level) fine-sand deposits were created in the post-dam era, both within eddies and channel margin settings. One of the concerns of both sediment researchers and the ad-hoc is that these deposits are being "mined" during high flow events. It is the opinion of the ad-hoc group that additional research (possibly provided by GCMRC-contracted work currently under review) should focus on the changes to these deposits. Expected impacts to these deposits should play a major role in determining the nature of future high flow events.

Response to Rubin et al.(2000) recommendations

The ad-hoc responded to each recommendation contained in the Rubin et al. memo and offered two additional alternatives. The ad-hoc recommendations were forwarded to the TWG experimental flow ad-hoc group for inclusion into the suite of experimental flows being developed. These recommendations are summarized in Table 1. The Rubin et al. (2000) memo suggests three approaches for restoring or retaining sand resources in the Colorado River Ecosystem below GCD.

1) **Implement releases above power-plant capacity discharge immediately after substantial inputs of fine-sediment from tributaries.**

TWG Response: The implementation of high flow events immediately following substantial tributary inputs is likely the most efficient mechanism for increasing the percentage of new fine-sediment inputs conserved within the ecosystem. However, since Paria River tributary inputs most frequently occur in the fall, it is not currently possible to schedule releases above powerplant capacity in the months of August through December. This situation is tied to the hydrologic triggering criteria, which attempts to meet the requirements of both the spill avoidance provisions of the 1968 Colorado River Basin Project Act and the resource protection mandate of the 1992 Grand Canyon Protection Act. The ad-hoc believes that this first recommendation cannot be implemented at this time, but that it might eventually need to be tested experimentally if other alternatives fail. The ad-hoc group also believes that other dam release options exist that might promote potential eddy storage in ways that better conserve tributary inputs. Two of these options are to implement releases at power plant capacity or load following releases with fluctuations and magnitude greater than ROD restrictions immediately after substantial inputs of fine sediments. These release alternatives would be first order priorities in testing sediment conservation release patterns. However, if testing of such alternative flow actions fail to achieve program goals, recommendation #1 should be considered as the next possible experimental action.

2) Maintain low flows following fine-sediment inputs until releases above peak power-plant discharge can be implemented.

TWG Response: The recommendation to maintain low flows between the onset of tributary sand inputs and the release of BHBF's is based on the premise that flows below about 8,000 to 10,000 ft^3/s will not rapidly transport fine sediment out of the ecosystem, but allow new sand, and even finer sediment (silt and clay) to accumulate throughout the main channel. Ensuing BHBF's could then suspend this stored sediment for deposition as high elevation bars. The ad-hoc believes that this option has technical merit and should be considered by the experimental flow ad-hoc in their deliberations on flows to meet the intent of the experimental flow provisions of the 1995 Biological Opinion.

3) Add sediment downstream from the dam.

TWG Response: The recommendation of sediment augmentation has merit if the AMP believes that it is important to restore the natural sediment storage characteristics of the pre-dam river. The ad-hoc sees numerous difficulties with this approach, including cost, engineering feasibility, environmental compliance, and the impact to Lake Mead storage, and we believe that other dam release alternatives should be formally evaluated first. The ad-hoc agreed that this option is currently untenable. However, should the research and monitoring results from the suggested program of fine-sediment focused experimental flows determine that there is no other option, sediment augmentation should be seriously evaluated by stakeholders as the only option for sediment-resource sustainability.

Summary

The ad-hoc believes that the sediment researchers have provided important new information about the fine-sediment resources of the Colorado River ecosystem below Glen Canyon Dam. It is important to the success of the AMP to address this information as dam operations and other management actions are considered to protect resources downstream of the Glen Canyon Dam. It is also important to increase the communication between the TWG and the researchers to improve understanding of both technical advancements and resource management decision-making. Towards this goal, the ad-hoc recommends that the sediment group be maintained on an ongoing basis to continue its role of incorporating results from the sediment research program into the adaptive management process.

Two categories of implications to the AMP are evident from the revised fine-sediment paradigm. First, if dam operations as identified under the preferred alternative in the EIS and Record of Decision (ROD) will not allow for the accumulation of fine-sediment and the periodic building of sand bars, the challenge of meeting existing AMP goals will be increased. Fine sediments are important to river runners as camping beaches and also for their effects on reproduction and growth of riparian vegetation (Johnson 1991, Kearsley and Ayers 1999), and their role in formation of seasonally warm native fish rearing habitats in the otherwise cold Colorado River (Arizona Game and Fish Department 1996, Brouder et al. 1999).

The second implication to the AMP is for the largely untested process of integration of new scientific findings into adaptive management. The revised fine-sediment paradigm is the first major shift in thinking since the EIS and ROD were completed. As such it represents a challenge to communication and coordination by scientists and managers to ensure that the program experimentally tests new hypotheses, incorporates new knowledge, and applies that knowledge correctly to management decisions that may greatly affect the future of the Colorado River ecosystem.

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Table 1. Summary of Recommendations to TWG experimental flow ad-hoc committee

#	Recommendation	From Whom	Action	Priority*
1	Implement releases above power plant capacity discharge immediately after substantial inputs of fine sediment.	Rubin et al. (2000)	Forward to ex-flow ad-hoc	Level 2
1a	Implement releases at power plant capacity discharge immediately after substantial inputs of fine sediment.	TWG Ad-hoc	Forward to ex-flow ad-hoc	Level 1
1b	Implement load following releases with fluctuations and magnitude greater than ROD restrictions immediately after substantial inputs of fine sediment	TWG Ad-hoc	Forward to ex-flow ad-hoc	Level 1
2	Maintain low flows following fine sediment inputs until releases above power plant discharge can be implemented	Rubin et al. (2000)	Forward to ex-flow ad-hoc	Level 1
3	Add sediment downstream of Glen Canyon Dam	Rubin et al. (2000)	Forward to ex-flow ad-hoc	Level 3

* Level 1: consider implementation immediately in suite of experimental flows
Level 2: consider implementation only after trying level 1 options
Level 3: untenable option at this time. However, this may need to be considered if levels 1 & 2 don't work.

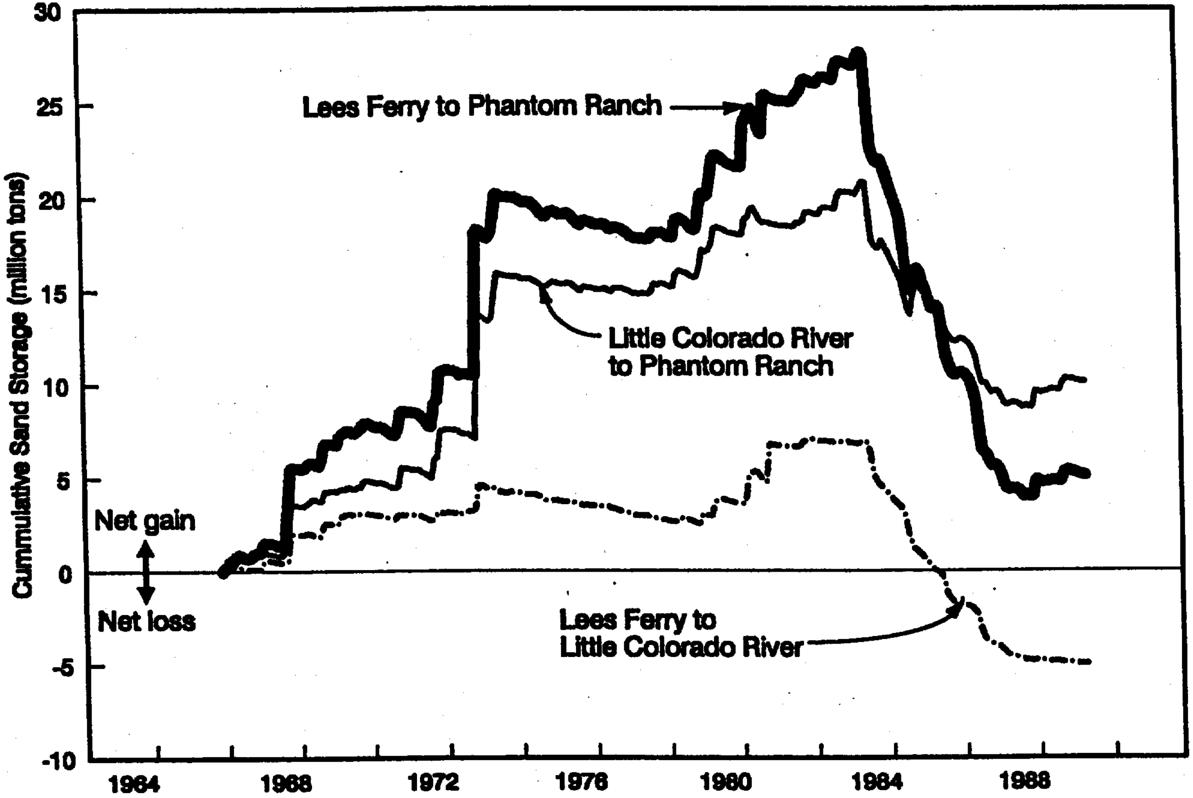

Figure III-15.—Cumulative sand storage between Lees Ferry and Phantom Ranch. Sand accumulated in the river during the relatively low releases while Lake Powell was filling, coupled with large sand contributions from the Paria and Little Colorado Rivers in 1972, 1979, and 1980. Sand was eroded from the channel during the 1983-86 high water years. Computation method is described in text.

Figure 1. Sediment mass-balance model results used in the GCDEIS (DOI, 1995).

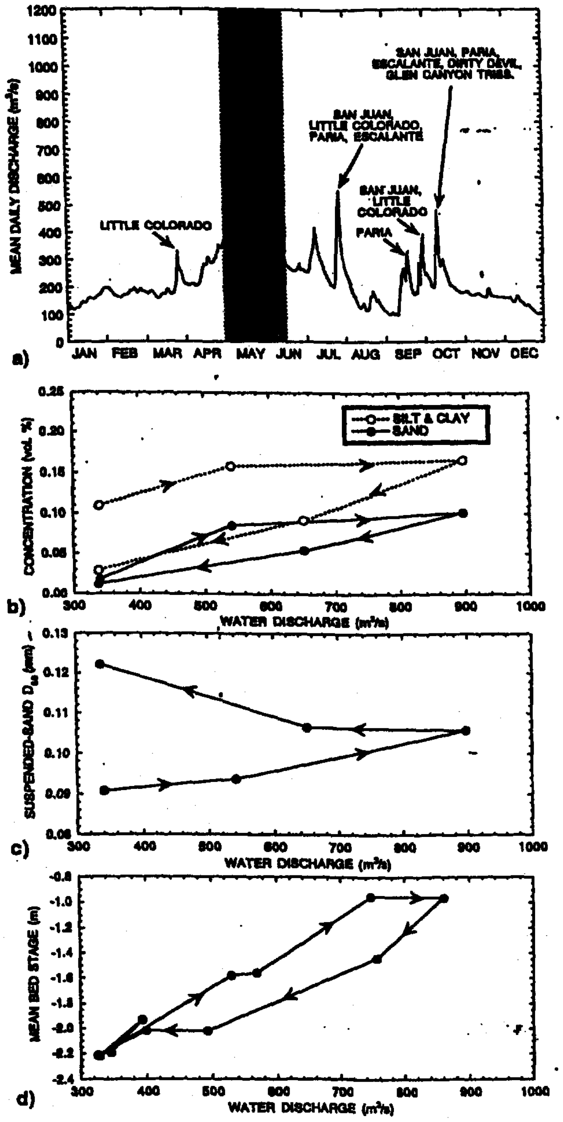

Figure 2. (Opposite) (a) The 1954 mean-daily discharge record from the Grand Canyon gage showing the seasonal separation between tributary sediment-input events and the annual snowmelt flood. Tributary rivers that contributed to the observed discharge peaks are indicated. Cross-hatched region indicates the period from April 28, 1954, through June 14, 1954, during which the data shown in Figures 2b–2d were collected. (b) Hysteresis in the concentration of suspended silt and clay and suspended sand; arrows indicate the sequence of measurements. Progressive depletion of the finer sediment caused the concentrations (for a given discharge) to be lower on the receding limb than on the rising limb. (c) Hysteresis in the median grain size of the suspended sand. The suspended sand was coarser (for a given discharge) on the receding limb than on the rising limb. (d) Hysteresis in mean bed elevation. Stage is relative to gage datum.

Figure 2. Coupled hysteresis in suspended sediment concentrations, grain-size, and bed elevation. Figure 2a from Topping et al (2000a).

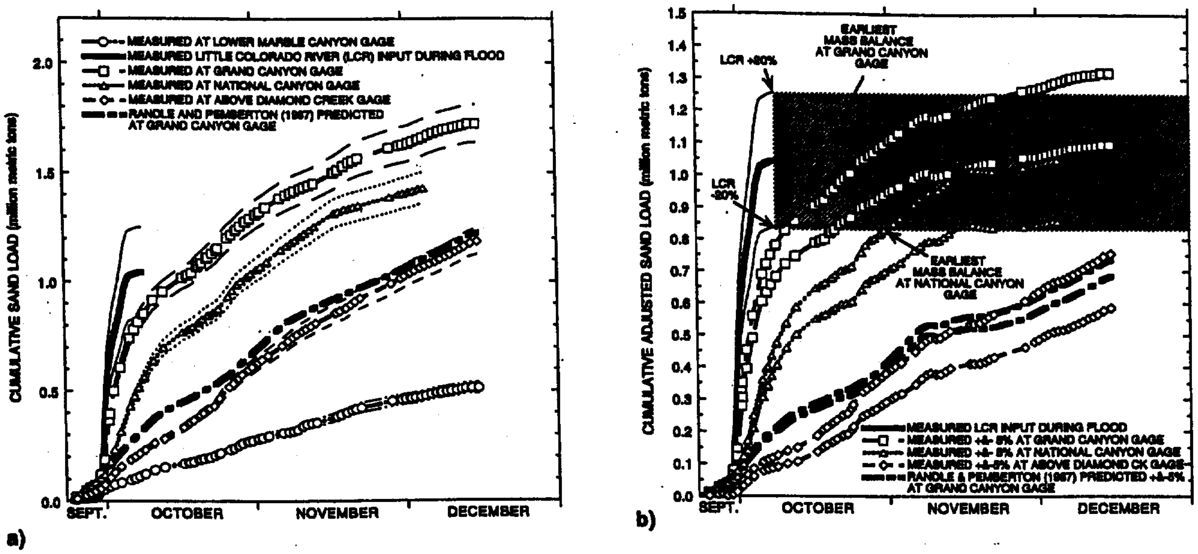

Figure 11. (a) Cumulative measured sand loads of the Colorado River at the Lower Marble Canyon gage and at the three gages downstream from the mouth of the Little Colorado River (LCR) and the cumulative measured sand load of the LCR at the highway 89 bridge at Cameron for the period after the beginning of the 1983 LCR flood. The lowest cumulative load was measured at the Lower Marble Canyon gage, because it is located on the Colorado River immediately upstream from the mouth of the LCR. The greatest cumulative sand load during early October was measured in the LCR. Downstream from the mouth of the LCR, progressively smaller loads were measured, since less of the LCR sand input passed each of these more distant sites during the sampling period. Uncertainties (thin dashed lines) of 5% were assigned to the measured sand loads of the Colorado River, and an uncertainty (thin solid lines) of 20% was assigned to the measured sand load of the LCR; see *Topping et al.* [this issue] for justification of these uncertainties. Also shown is the cumulative sand load predicted by *Randle and Pemberton* [1987] at the Grand Canyon gage. Because their approach was based on a fixed, coarsened grain-size distribution of bed sediment, *Randle and Pemberton* [1987] underpredict the sand load at the Grand Canyon gage during this period by about 30%. (b) Sand budget for the 1983 LCR flood constructed using the data in Figure 10a. Shown are (1) the cumulative measured sand load (with 20% uncertainties) during the LCR flood and (2) plus and minus 5% error envelopes for the adjusted cumulative measured and predicted sand loads at the gages on the Colorado River downstream from the mouth of the LCR. The cross-hatched region indicates the plus and minus 20% error envelope for the sand input during the LCR flood. The loads of the Colorado River downstream from the mouth of the LCR were adjusted by subtracting the measured load (with uncertainties) of the Colorado River at the Lower Marble Canyon gage. See text for further explanation.

Figure 3. Results of sediment transport measurements compared with predictions of Randle and Pemberton (1987) model. Figure 11a from Topping et al., 2000b).

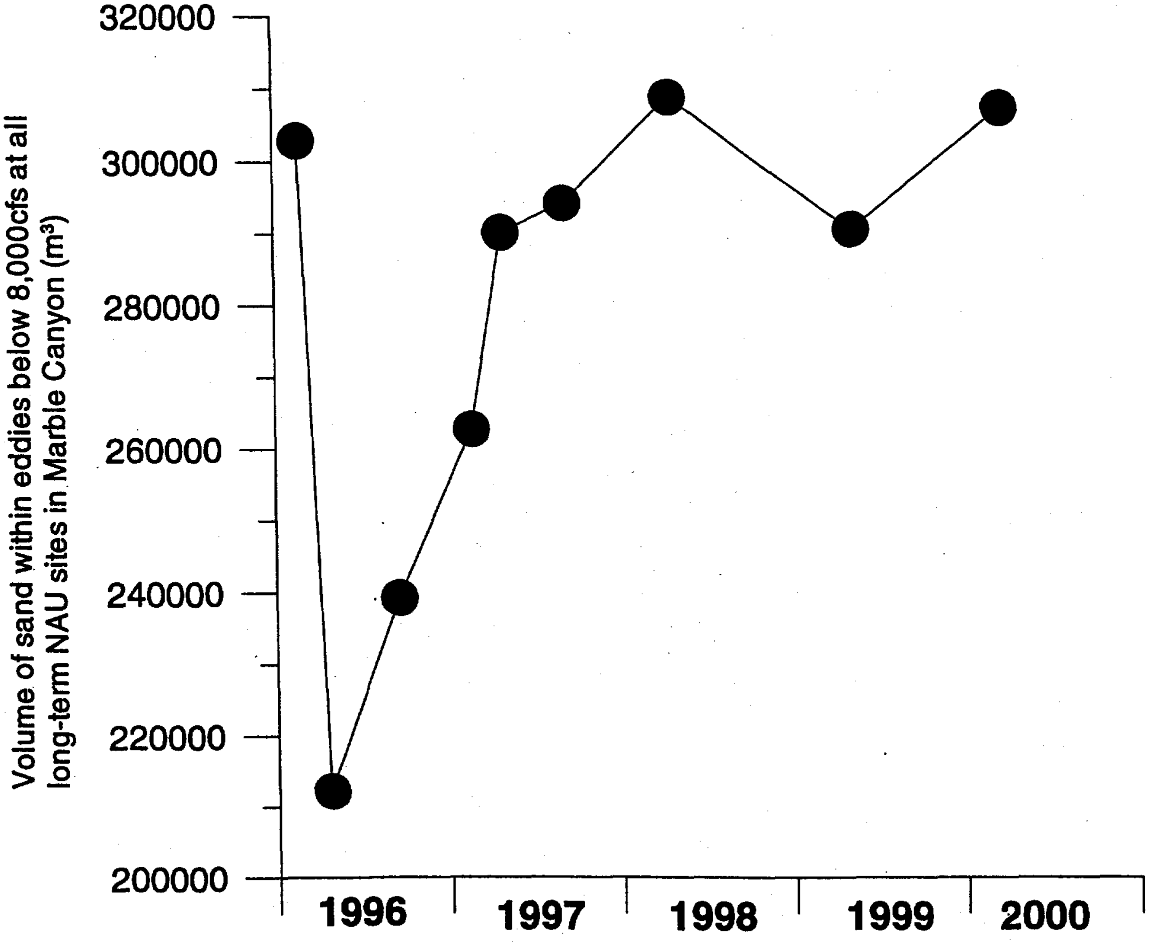

Figure 4. Changes in low-elevation eddy sand volume at all long-term NAU study sites in Marble Canyon (unpublished NAU data).