Monitoring Fine-Sediment Storage of the Colorado River Ecosystem below Glen Canyon Dam, Arizona

Sand Bar Studies Fact Sheet
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The distribution of fluvial sediment downstream of Glen Canyon Dam is of fundamental importance to the Colorado River ecosystem in Glen, Marble, and Grand Canyons. Sand deposited along the channel margins creates the foundation of the ecosystem by providing substrate and habitat for aquatic and terrestrial species. Sand bars deposited within eddies are also the primary campsites for rafting and hiking groups. Glen Canyon Dam has transformed the once sediment-laden Colorado River into a sediment-limited system. The only remaining sources of fine-sediment (sand and finer) input are tributaries, primarily the Paria and Little Colorado Rivers.

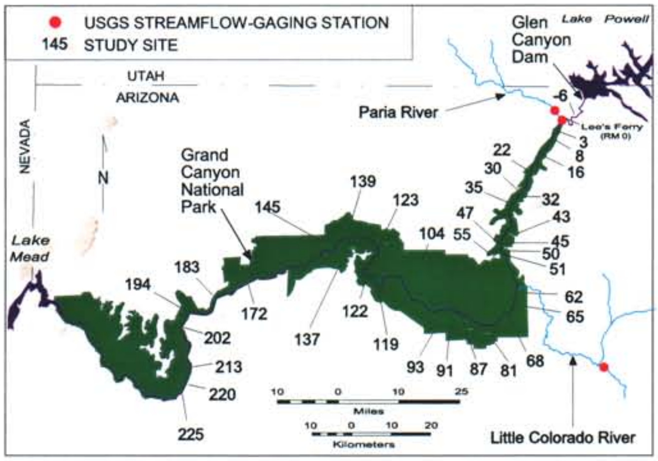


Figure 1. Location of NAU study sites and streamflow gaging stations. River miles after Stevens (1983).

In cooperation with the Glen Canyon Environmental Studies and the Grand Canyon Monitoring and Research Center, we have monitored the movement and accumulation of fine-sediment throughout the Colorado River ecosystem since 1990. Our approach is to conduct repeated topographic and hydrographic surveys at 35 long-term study sites and to use these data to estimate reach and system-wide responses of sediment to changing dam operations (Figure 1; see Kaplinski et al., 1995; 1998; or Hazel et al., 1999, for an extensive description of our methodology and study sites). In our analysis, we divide the river corridor into the Glen, Marble, and Grand Canyon reaches to describe sediment storage changes above and below the Little Colorado River. For each site, the volume of sediment stored within main channel, eddy, and sand bar environments are measured (Figure 2). These values are compared to previous surveys to determine site-specific changes, then averaged or summed over the entire reach to assess reach-scale effects. While these 35 sites are not wholly representative of the entire fluvial system, they provide the most accurate and complete time-series available to date for medium-term, volumetric and area changes in sediment storage. Furthermore, volumetric data from these monitoring sites, in conjunction with reach-scale aerial photogrammetric mapping (Schmidt et al., 1999a), flow modeling (Wiele et al., 1999), and suspended sediment sampling (Topping et al., 1999), is critical to the development of a Colorado River ecosystem sand budget (Schmidt, 1999; Hazel et al., in prep.). In this fact sheet, we briefly summarize our monitoring and stress the importance of tributary floods and controlled flood flows in conserving sediment and rebuilding eroded sand bars.

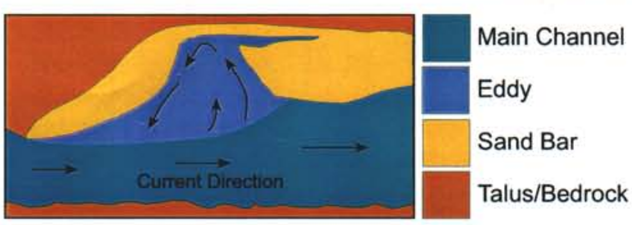


Figure 2. Cartoon map view of typical Colorado River sand bar showing areas where volumes are calculated.

Discharge data shown in Figure 3a summarizes the pattern for Glen Canyon Dam operations from 1991-1999. Interim flows, released during completion of the Glen Canyon Dam EIS (DOI, 1995), occurred from 1991 through 1996, and were intended to minimize sand bar erosion and export of sand, as well as to maximize potential fine-sediment storage in the river channel. Despite the reduced peak daily flows,

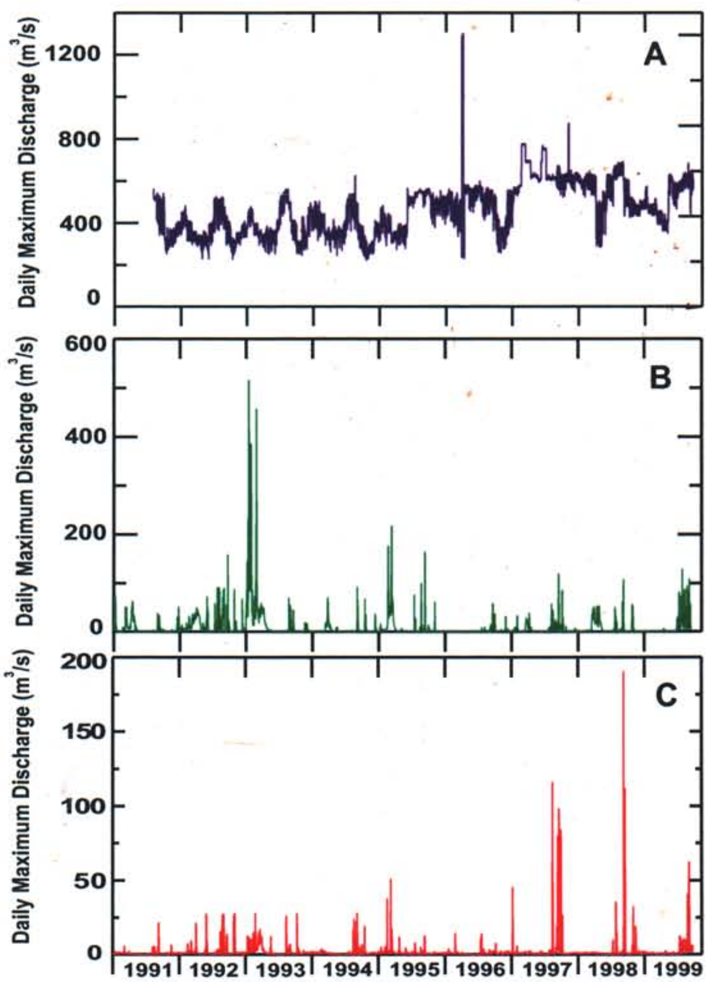


Figure 3. Daily maximum discharge hydrographs from U.S.G.S. gaging stations. A) Colorado River near Lee's Ferry (09380000), B) Little Colorado River near Cameron (094020000), C) Paria River near Lee's Ferry (9382000).

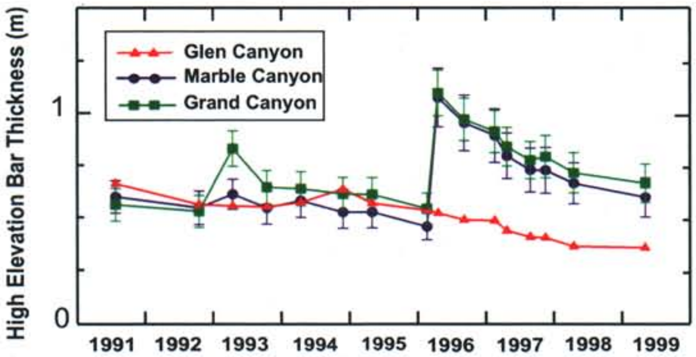


Figure 4. Average sand thickness of high-elevation sand bars in Glen, Marble, and Grand Canyons.

limited hourly ramping rates, and fluctuation range characteristic of interim flows, high-elevation (above the 556 m^3/s [20,000 ft^3/s] stage elevation) sandbars were progressively eroded (Figure 4).

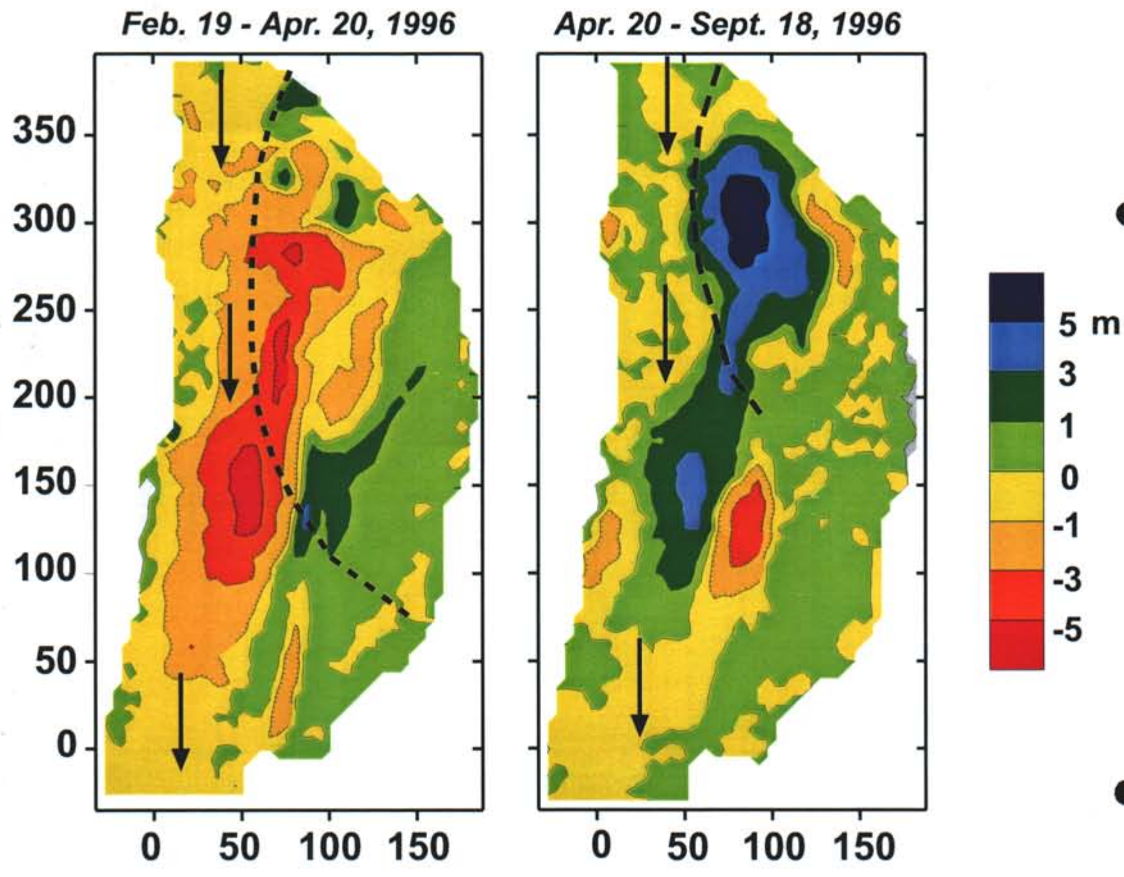
Sand bars aggraded during tributary flood events from the Paria and Little Colorado Rivers in 1993 and 1995. Floods from the Little Colorado River during the winter of 1993 raised mainstem flows to over 950 m^3/s (33,000 ft^3/s) (Figure 3b). Following these floods, we measured a substantial increase in high-elevation sand bar thickness downstream of the Little Colorado River confluence. The observed bar building demonstrated that flows in excess of power plant capacity were a viable mechanism to aggrade high elevation sand bars.

In the final EIS, it was hypothesized that controlled flooding could transfer sediment from the channel bed to the channel banks and re-build eroded sand bars (Schmidt et al. 1999b). Aggraded sandbars would potentially provide more area for riparian habitat development, camping, and prolong the residence time of sediment within the system by removing it from direct downstream transport. A controlled flood would also re-introduce a "disturbance" to the ecosystem; much like controlled burns are used in forest ecosystems. Short-duration dam-released floods, in excess of powerplant capacity, were included as an integral part of the preferred alternative in the final EIS on operations of Glen Canyon Dam (DOI, 1995) and the Record-of-Decision (DOI, 1996).

The 1996 controlled flood, released on March 26, 1996, was designed to test these hypotheses (Figure 3a). The hydrograph consisted of a seven day, sustained high discharge of 1,274 m^3/s (45,000 ft^3/s), preceded and followed by three days of a constant low discharge of 227 m^3/s (8,000 ft^3/s). The data summarized by Webb et al. (1999) indicate that the 1996 controlled flood achieved many of the intended goals. The high-elevation parts of sand bars accumulated a significant volume of sand (Figures 4 & 5). Even the site in Glen Canyon was aggraded, where sand supply is thought to be most limited. Hazel et al. (1999) correlated the magnitude of deposition to space available for deposition and stressed the importance of antecedent conditions in the prediction of future floods intended to aggrade sand bars. In contrast to high-elevation deposition, sediment was scoured from low-elevation storage areas in the main channel and large eddies (Figure 5 & 6). Significant scouring of sand from the low-elevation parts of large eddies suggests that eddy systems can store as much, or more sand than the adjacent main channel pool. The 1996 experiment demonstrated that controlled flooding could transfer fine-sediment from the bed to the channel margin.

Perhaps more important than the deposition during the 1996 controlled flood was the longevity of the newly aggraded bars. Subsequent monitoring from 1996 to 1999, showed that sand bars eroded rapidly during the first six months of "normal" dam operations following

Figure 5. Topographic changes at the 51 mile study site. Areas of deposition are shown in greens and blues, and areas of erosion are shown in yellows and reds. Arrows indicate the direction of the main current. A) Changes from before and after the 1996 controlled flood. Approximate location of the eddy fence at a discharge of 1,274 m^3/s is shown by the dashed line. Note the low-elevation scour within the eddy and main channel, and high-elevation deposition along the sand bar. B) Changes six months after the 1996 controlled flood. Approximate location of the eddy fence at 556 m^3/s eddy fence is shown by the dashed line. Note the low-elevation deposition within the eddy and the main channel, and high-elevation erosion of the downstream end of the sand bar exposed to direct downstream current.



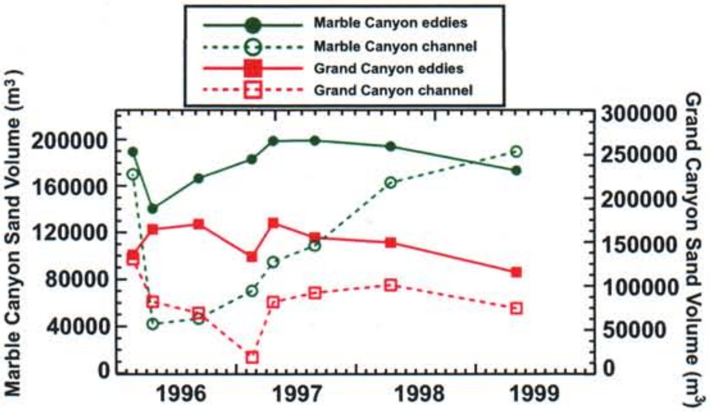


Figure 6. Total cumulative eddy and channel sand volume in Marble and Grand canyons.

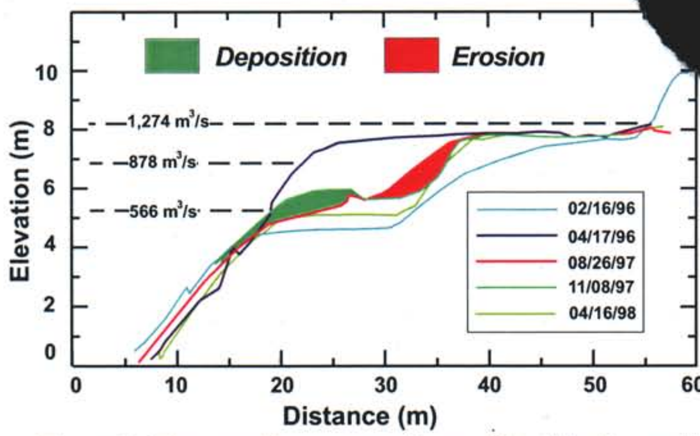


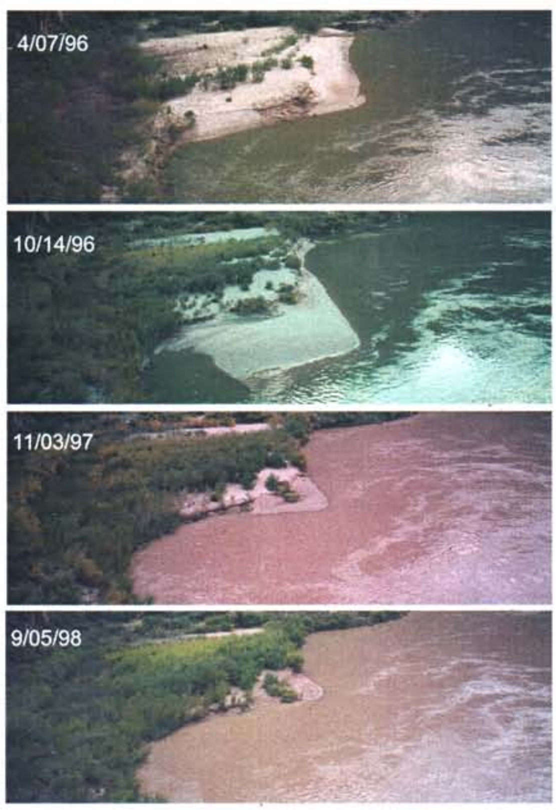
Figure 7. Topographic cross-sections of the 30 mile sand bar in upper Marble Canyon. Flow stage elevations for thehigh-elevation volume calculations (556 m³/s, 20,000 ft³/s), the 1996 controlled flood (1,274 m³/s, 45,000 ft³/s),and 1997 test flow (878 m³/s, 31,000 ft³/s) are shown.

the controlled flood, but erosion rates then decreased with time (Figure 4). In contrast, low elevation eddy and main channel environments aggraded (Figures 5 & 6). Sand eroded from high-elevation bars was gradually transferred back to low elevation storage environments in eddies and the main channel (Figures 4 & 6).

Beginning in 1995, and continuing into 1999, dam releases were generally high to prevent spills from Lake Powell (Figure 3a). In 1997, four closely-spaced floods from the Paria River in August and September 1997, delivered an estimated 770,000 m³of sand to the Colorado River (Figure 3c). Following these inputs, the Glen Canyon Dam adaptive management program recommended that a short-duration, powerplant capacity test flow be released in Fall 1997. The 1997 test consisted of a constant flow of 878 m³/s (31,000 ft³/s) for 48 hours. The 1997 test flow examined the hypothesis that a shorter-duration, lower magnitude dam release could mimic the results of the 1996 controlled flood and transfer Paria-supplied sediment from the channel bed onto channel margin sandbars before the sand was transported downstream from Marble Canyon.

Our monitoring shows that the 1997 test flow only temporarily and partially achieved this objective. The 1997 test flow did not reverse the trend of high elevation erosion following the 1996 controlled flood (Figure 4). Net high-elevation sand bar thickness did not increase because deposition of sand on the bar was offset by erosion of the deposit above the stage elevation reached by the 878 m³/s (31,000 ft³/s) flow (Figure 7). These results suggest that the stage elevations reached by the 1997 test flow were not high enough to result in deposits that could escape rapid erosion by the dam releases that followed.

Our latest monitoring data show that, as of April 1999, fine-sediment has accumulated within the channel and eddies and eroded from the sand bars to levels at, or near those measured before the 1996 flood (Figures 4 & 5). In 1998 and 1999, the Paria River continued to input a significant amount of sediment into the Colorado River (Figure 3c). Our monitoring does not indicate that these inputs increased storage at our sites, but the inputs may have been retained elsewhere in the ecosystem (Figure 5). This suggests that low-elevation storage areas scoured by the 1996 controlled flood had filled with sand eroded from the channel margin and from the 1997 tributary inputs. These results support the conclusion of Topping et al. (in press) that the amount of sand storage is limited in the Colorado River, and that when eddy and main channel environments are full, new sediment inputs are rapidly transported downstream because Record-of-Decision flows are relatively higher, on average, than pre-dam flows, and little space is available for deposition. Our latest measurements in April 1999, indicate that, at our monitoring sites, space is available for high elevation deposition and low elevation sediment is available for redistribution. In general, these data imply that a controlled flood, at the present time, will likely result in high-elevation deposition.



Selected Photographs from the 194 mile study site. Main channel flow is from bottom to top. Note the colonization of the 1996 controlled flood deposit by riparian plants.

Topographic surveys determine the amount of sediment stored on sand bars.

Hydrographic surveys determine the amount of sand stored in the channel.

Conclusions

As of April 1999, sand storage levels measured at our study sites are near those measured before the 1996 controlled flood. High- elevation sand bars have eroded to levels slightly higher than pre-flood measurements. Low elevation storage environments in eddies and in the main channel have recovered to approximately equal to pre-flood measurements.

The 1996 controlled flood resulted in widespread high-elevation sand bar deposition.

The 1997 test flow resulted in some high-elevation deposition of sand, however most of these sand deposits were rapidly eroded under high dam releases by April 1998.

In addition to sediment availability, the volume of sand occupying depositional sites prior to flooding is an important factor in determining the magnitude and persistence of flood related deposition.

The most efficient way to conserve fine sediment in the system is to release controlled floods that redistribute sand to higher elevations along the channel margins where it will remain in storage for relatively long periods.

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Sand bars built by flood flows and used as campsites are continually being eroded by flows from Glen Canyon Dam.

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