NORTHERN ARIZONA UNIVERSITY

Department of Geology
Sand Bar Studies Fact Sheet

Colorado River Ecosystem Sand Bar Conditions in 2001: Results From 12 Years of Monitoring

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Monitoring fine-grained sediment (primarily sand) resources in Glen, Marble, and Grand Canyons, downstream from Glen Canyon Dam (GCD), is important for evaluation of management objectives and actions. Sand bars and deposits are valued components of the riverine ecosystem. They provide habitat for native and non-native fish, the substrate for riparian vegetation, erosion-protection for archeological sites, and campsites for river rafting trips. To maintain sand resources, interim operating criteria were implemented in 1991 and daily fluctuations were substantially reduced (U.S. Dept. of Interior, 1995). The 1996 Record of Decision (ROD) on the 1995 GCD Environmental Impact Statement (EIS) approved the Modified Low Fluctuating Flow Alternative (MLFF) as the base experiment of the GCD Adaptive Management Program (AMP). The MLFF restricted minimum and maximum flows to 141 and 708 m^3/s, and daily fluctuations to 227 m^3/s. An important management objective is to maintain the size of sand bars between the stages associated with dam releases of 227 and 1,274 m^3/s. A proposed baseline condition is the size that existed during EIS research flows conducted between June 1990 and July 1991.

Twelve years of survey data indicate that sand bars continued to erode during the MLFF. Net sand bar erosion has been greatest in the upstream portion of the ecosystem, in Marble Canyon. The only intentional GCD release that resulted in bar deposition lasting more than a few months exceeded powerplant-capacity. The pattern of change in sand bars may be the result of progressive erosion downsteam of GCD, and sand bars at some point further downstream in Grand Canyon, are being partially maintained by sand eroded from bars in Marble Canyon.

Water Release Patterns Between 1990 and 2002

GCD operations from 1990 to 2002 are summarized in Fig. 1. Following the 1990-1991 research flows, interim and MLFF flows reduced the daily range of GCD flows during the early 1990's. The latter 1990's were dominated by higher releases with lower release volumes returning in the early 2000's. The median discharge from GCD between 1991 and 2002 was approximately 385 m^3/s, ~70% higher than the median flow during the pre-dam gaging record (1921-1963). Despite flow restrictions, the MLFF have considerably more sand-transport capacity than the predam river when flows were dominately below 200-300 m^3/s from July through March (Topping et al., 2000a).

In addition to the MLFF experiment, four high flow tests occurred during the study period. Scheduled high releases within normal powerplant capacity (~892 m^3/s), and Beach/Habitat Building Flows (BHBFs) above this discharge, were included in the MLFF to maintain and create sand bars (Dept. of Interior, 1995). The only test of a BHBF occurred in spring 1996: a 7-day release of 1,274 m^3/s. Three shorter-duration releases of near powerplant-capacity (PPCap flows) occurred in November 1997, May 2000, and September 2000.

Tributary Sand Supply Between 1990 and 2002

The Paria River, ~25 km below GCD, and the Little Colorado River, ~125 km below GCD, are arid-region streams that intermittently supply most of the sand to the Colorado River (Fig. 2). Together, these two tributaries supplied 10 to 15% of the total sand load in the predam era (Topping et al., 2000a). During the 12-year period between 1990 and 2002, the Paria and Little Colorado Rivers supplied ~14.2 and ~9.7 million metric tons of sand, respectively (Fig. 1). This period was slightly below average for the Paria River with 44% of the sand load delivered between 1997 and 1999 (Hazel et al., 2000; Topping et al., 2000b). In contrast, most of the sand input by the Little Colorado River occurred in January-February, 1993, when large floods delivered ~6.4 million metric tons of sand and increased mainstem discharge to a peak of ~950 m^3/s (Fig. 1). Unfortunately, under most MLFF operations, tributary-supplied sand is tranported through Marble and Grand Canyons within several months to a year (Topping et al., 2000b). The MLFF was designed on the assumption that tributary supplied sand would

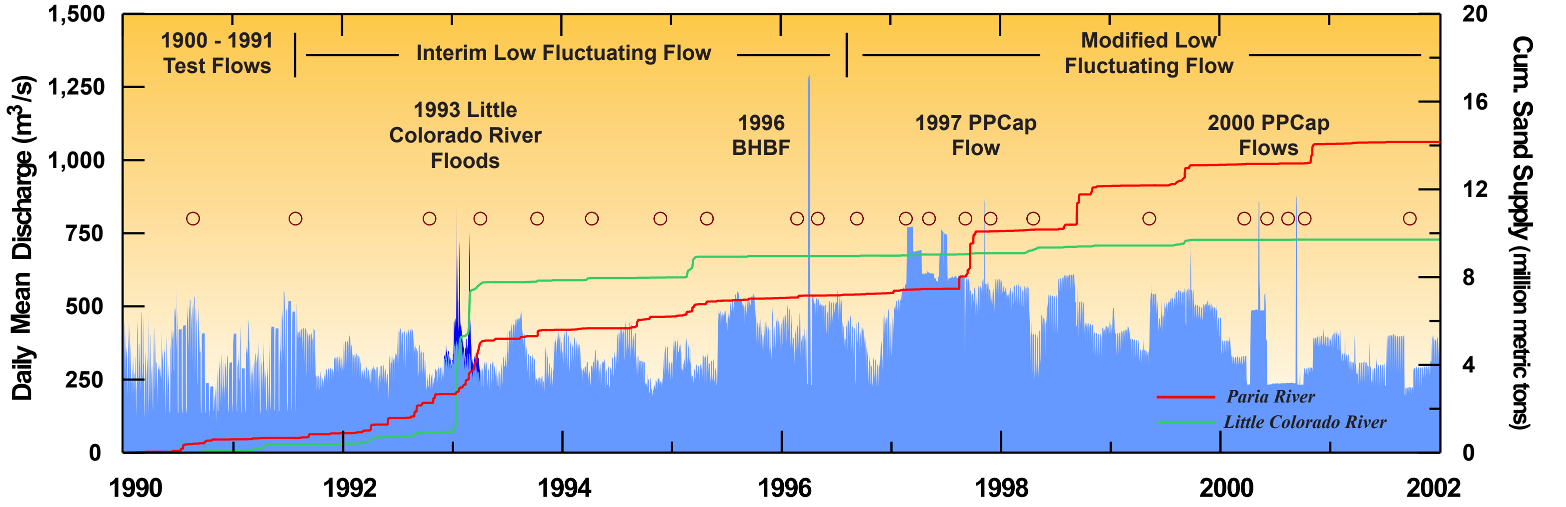

Figure 1. Daily mean discharge at USGS streamflow-gaging station Colorado River at Lees Ferry, Arizona, 1990-2002. Shown are the periods of interim flows, the MLFF, and experimental high flows. Cumulative tributary sand inputs from the Paria and Little Colorado Rivers are depicted by red and green lines. The 2-month period of increased mainstem flow during the 1993 Little Colorado River floods is shown in dark blue. Estimated sand loads were computed after the method of Topping (1997) with 20% uncertainties (D. Topping, USGS, pers com., 2002). The open symbols indicate timing of bar surveys.

Discussion and Conclusions

The results of this 12-yr monitoring project indicate that management goals for bar maintenance and sand conservation in the Colorado River ecosystem are not being met. Many factors are contributing to long-term sand bar erosion, including 1) erosion from flows with low mainstem sediment concentrations, 2) sand resupply from major tributaries does not occur in all years, 3) the median flow during normal MLFFs reduces the potential for multi-year accumulation and storage within the main channel, and 4) wind deflation. In Fig. 5, photographs illustrate this pattern of change. Comparisons of change induced by the BHBF and PPCap experiments indicate that flows greater than powerplant-capacity are required to rebuild eroded sand bars. Bar deposition needs to be at least a meter above the water surface reached by the MLFF for bar longevity and effective sand conservation.

High elevation bar erosion in response to the MLFF was anticipated in the EIS (Dept. of Interior, 1995). However, the reduced fluctuations and stage change were also expected to reduce the zone affected by daily GCD releases (active width) and result in more stable bars than other proposed alternatives. Instead, cutbank retreat and lowering of the bar surface results in substantial volume loss. Sand is transferred to lower elevations or transported downstream. Assuming our results represent the system-wide condition, net erosion has been greatest in Marble Canyon, whereas in Grand Canyon, the rates of erosion have been considerably less. Downstream from the Little Colorado River, it has been hypothesized that sand additions are sufficient to maintain a balance between erosion and deposition (Webb, 1996). However, following the 1993 Little Colorado River floods, the cumulative inputs have been substantially less than that of the Paria River (Fig. 1). Net erosion may eventually progress further downstream from this tributary.

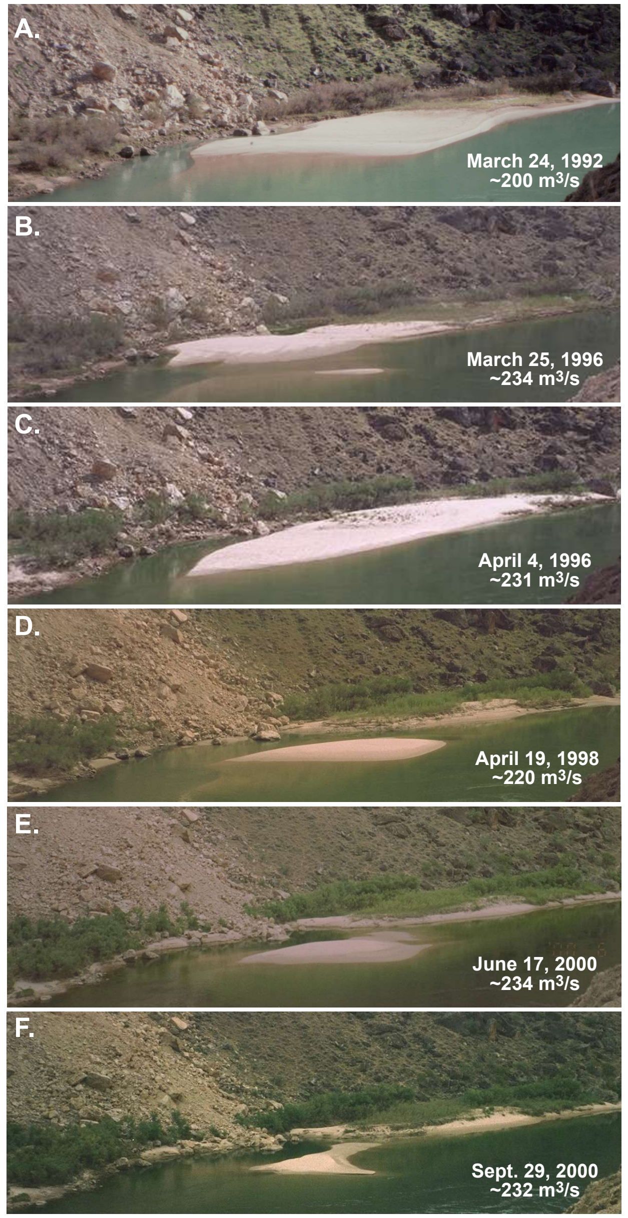

Figure 5. Selected photographs from a study site located in Marble Canyon (river mile 45). A. Interim flows. B. Pre-1996 BHBF. C. Post-1996 BHBF. D. 5-months post-1997 PPCap flow. E. Post-May 2000 PPCap flow. F. Post-Sept. 2000 PPCap flow. Flow in main channel is from left to right.

An alternative hypothesis is that net erosion decreases in a downstream direction, not because of the addition of sand from the Little Colorado River and lesser tributaries, but rather from upstream erosion of bars in Marble Canyon. If this hypothesis is correct, despite near average sand contribution from the Paria River (Fig. 1), sand bars in Grand Canyon are at least partially being maintained by sand supplied from background storage in Marble Canyon. This hypothesis is supported by sediment transport data collected by the USGS in Marble and Grand Canyons from 1997 through 2001 (Topping et al., 2000b, D. Topping, pers. com., 2002). These data show that suspended sand concentrations were approximately the same in both Marble and Grand Canyons during the MLFF, the PPCap flows, and during and following large Paria floods. Thus, sand entering Grand Canyon was more likely being eroded from Marble Canyon rather than being supplied by the Little Colorado River.

Sand bar maintenance may not be possible in the Colorado River ecosystem without changes in GCD operations (Rubin et al., in press). High flows can potentially rebuild eroded bars but the lower elevations of sand bars are a primary source of sand when there is limited sediment supply (Schmidt, 1999). Since high flows will always export more sand from the system than is deposited on bars, management actions for sand resources should consider scheduling flows greater than powerplant-capacity closely with newly input, tributary supplied sand, or restricting GCD flows to levels that permit sand accumulation until such a high flow can be implemented.

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- Joe Hazel, Matt Kaplinski, Rod Parnell and Mark Manone

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For more information, please contact us at:
Northern Arizona University, Department of Geology
Box 4099, Flagstaff, AZ 86011-4099
http://vishnu.glg.nau.edu/gcmrc/index.html

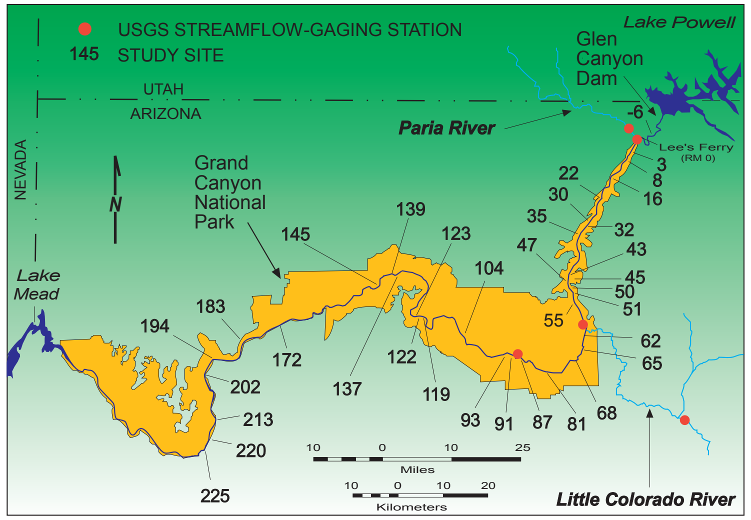

Figure 2. Locations of study area, major sand supplying tributaries, USGS streamflow-gaging stations, and sand bar monitoring sites (site reference numbers use river mile location).

accumulate in the channel if peak discharges were less than 566 m^3/s (Dept. of Interior, 1995). However, the approach used in the EIS underpredicted the capacity of the MLFF to transport sand supplied by tributaries (Topping et al., 2000a).

The Northern Arizona University Sand Bar Monitoring Project

Concerns for campsite loss and vegetation encroachment led the National Park Service in 1974 to initiate a study of sand bars at 20 sites (Howard, 1975). In 1990, a project at Northern Arizona University began a resurvey of the original sites using different methods and expanded the sample size to 33 sand bars. Since then, the study sites have been monitored annually and before and after flood events. Survey accuracy and precision was discussed by Hazel et al. (1999). The sites are representative of the different types of eddy sand bars and are spatially distributed throughout the Colorado River ecosystem (Fig. 2). However, at the time the sites were selected, little was known about the variability of site response to change in flow regime. Recent analysis of site-to-site variability and system behavior indicates that at least in Marble Canyon, the sample set is representative of the response style of the entire population (Schmidt et al., 2002).

We calculate the area and volume of sand stored in two distinct topographic levels of each sand bar: the fluctuating zone, the area inundated by flows of 227 to 708 m^3/s; and the high elevation bar above the 708 m^3/s stage elevation. This upper topographic level was chosen to define high elevation because this discharge is the highest operating limit for GCD under the MLLF. Areas below the 708 m^3/s discharge are regularly inundated and reworked by dam releases and typically are not available for camping or colonization by plants.

Trends in Sand Bar Erosion and Deposition

Our approach is to divide the sample population into sites in Marble Canyon (the reach between the Paria and Little Colorado Rivers) and those in Grand Canyon (downstream from the Little Colorado River). To remove the effects of site size, net area and volume changes between successive surveys are expressed as a percentage of the maximum area or volume observed at each site during the entire monitoring period. This method allows smaller sites located in narrow reaches to be compared with larger ones located in wide reaches. Temporal comparison of bar size in the fluctuating zone is subject to some uncertainty because of short-term erosion or deposition, whereas high elevation bars are less variable because they are rarely inundated. However, the 12 yr period of observation is sufficient to show that erosion has exceeded deposition by a wide margin.

The relationship between sand bar area and volume change and the daily mean discharge is illustrated in Fig. 3 for which sufficient data were available. Large positive values at discharges of 1,274 m^3/s and 950 m^3/s indicate that only two events resulted in net high elevation deposition during the study period: the 1996 BHBF and the 1993 Little Colorado River flood. In contrast, the changes for discharges around 890 m^3/s are not significantly different than 0, suggesting that PPCap flows are stage-limited. That is, the bars were not inundated to sufficient depth that mobilized sand was deposited on the upper bar. Rather, these flows erode the high elevation deposit and leave a vertical cutbank. The natural 1993 flood of only slightly higher magnitude than PPCap increased the size of bars because of a greatly increased sand supply. At discharges between about 320 m^3/s and 708 m^3/s, the changes are negative or near 0, indicating that net erosion mostly occurs during these discharges. At discharges below ~320 m^3/s, the values are equal to 0 which indicates that high elevation bars are relatively stable at low discharges.

The relationship between area and volume change and daily mean discharge in the fluctuating zone is more variable than that at high elevation but several trends are apparent (Fig. 3). At nearly all discharges between 227 m^3/s and 708 m^3/s the values are positive, negative or 0. However, while the data show that both erosion and deposition occurs within this discharge range, the negative values are greater than the positive values and occur with greater frequency. Values for PPCap flows (~890 m^3/s) are either positive or not much different than 0, indicating that net deposition or little change occurs at this discharge. In contrast, the higher discharge 1996 BHBF is represented by large negative area values and large positive volume values, suggesting that net deposition was accompanied by area loss due to bar narrowing.

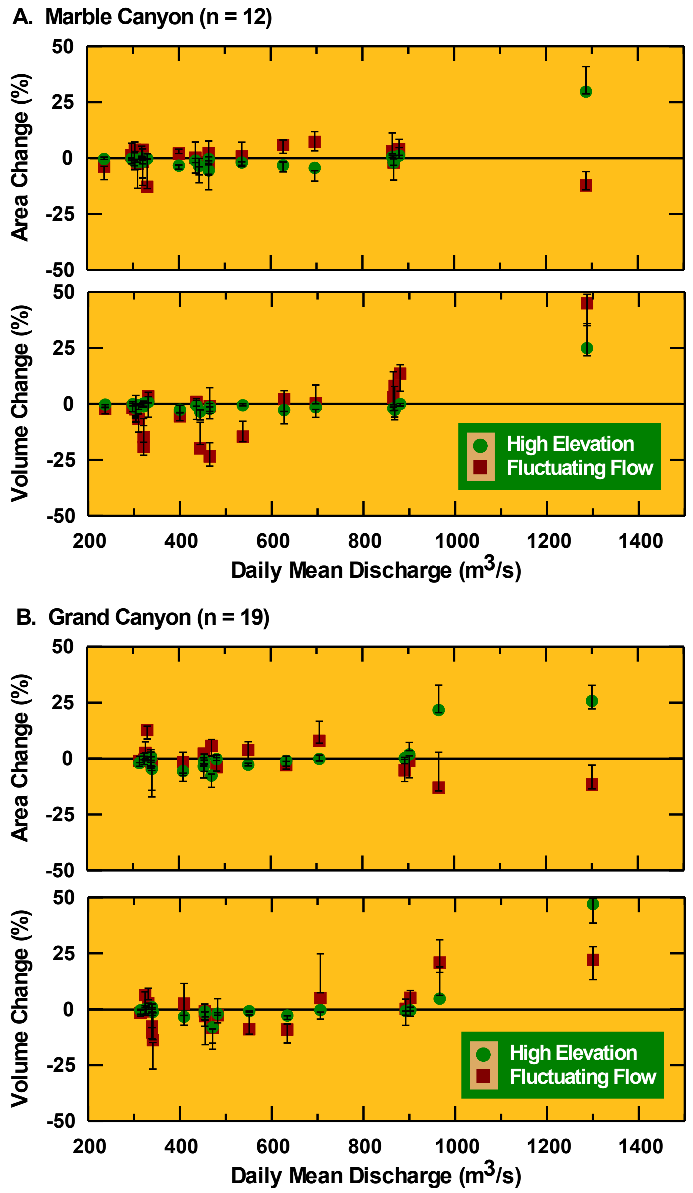

Figure 3. Median high elevation and fluctuating zone area and volume changes plotted as a function of the daily mean discharge. A. Marble Canyon. B. Grand Canyon. Error bars are standard errors about the mean.

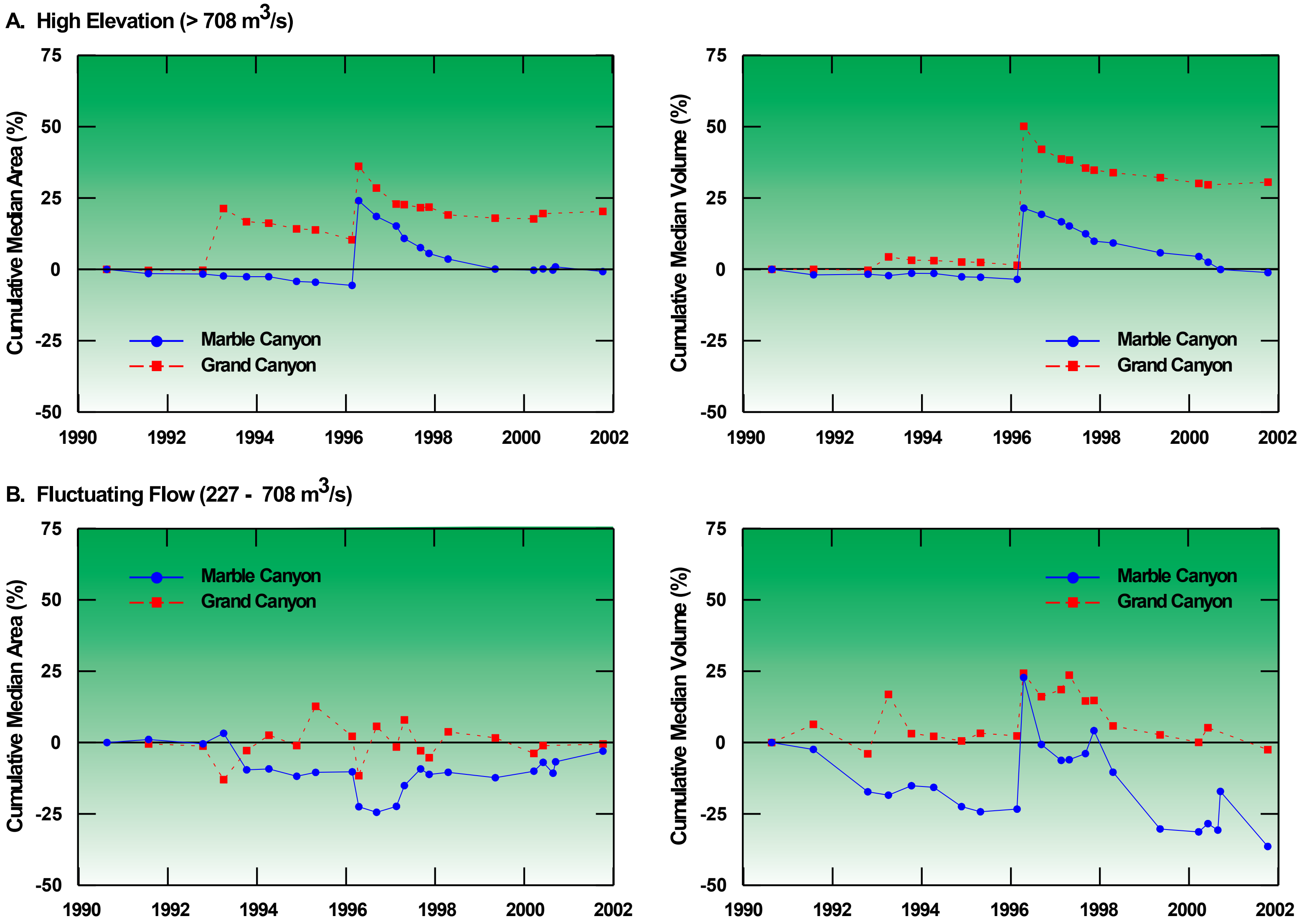

Figure 4. Cumulative median sand bar area and volume from September 1990 to October 2001. A. High Elevation. B. Fluctuating Zone. Shown are the values for Marble and Grand Canyons.

The results of Fig. 3 indicate that the MLFF mostly result in net bar erosion. Only at the lowest flows, as indicated by median values close to 0, are bars stable in both the fluctuating zone and high elevation areas. At higher MLFFs, however, area changes are more variable than volume changes. The variability reflects a pattern of high elevation erosion that increases the area available for inundation and reworking in the fluctuating zone, and as the average elevation of the bar surface is lowered, the bar volume decreases. Total bar area may change little or even increase in the fluctuating zone. At flows greater than powerplant capacity, such as the 1996 BHBF, the changes include net deposition but also bar narrowing caused by net erosion of bar area in the fluctuating zone. Thus, the source for much of the sand redistributed to high elevation during the 1996 BHBF probably came from the fluctating zone and lower elevation parts of bars (Schmidt, 1999).

The median values of change between successive surveys were combined to produce a time series of cumulative area and volume response between 1990 and 2002 (Fig. 4). The high elevation time series indicates that the sites in both Marble and Grand Canyons had a similar response to the MLFF and high flow experiments during the 12-yr monitoring period, but the magnitude of change varied greatly between the two reaches (Fig. 4a). Sand bar area and volume increase associated with the 1996 BHBF rebuilt bars in both reaches. The bars then eroded system-wide following this depositional event. Erosion rates decrease as the availability of erodible sediment decreases or when a stable slope is reached. However, while the decreases in high elevation area and volume were initially similar in Marble and Grand Canyons following the 1996 BHBF, after about August 1997, area and volume continued to decline in Marble Canyon, and by October 2001 had returned to 1990 levels. In contrast, there was little further bar erosion in Grand Canyon after 1997, and high elevation sand storage in October 2001 remained considerably enhanced compared to 1990 levels.

The fluctuating zone time series suggests a somewhat different pattern of bar response to the MLFF and high releases as that depicted at high elevation (Fig. 4b). While bar area in 2001 was relatively unchanged compared to 1990 levels, bar lowering during MLFF operations resulted in substantial volume loss. Erosion was greatest in Marble Canyon. Deposition from the 1996 BHBF persisted longer in Grand Canyon. In contrast, deposition from the 1997 and May 2000 PPCap flows was greatest in Marble Canyon; which suggests that because bar erosion in this reach was more extensive and topographic surfaces lower, bars were potentially inundated to greater depths, resulting in increased accomodation space available for deposition (Hazel et al., 1999; 2000). Nonetheless, PPCap-deposited sand only lasted a few months, whereas the 1996 BHBF deposits persisted a few years.