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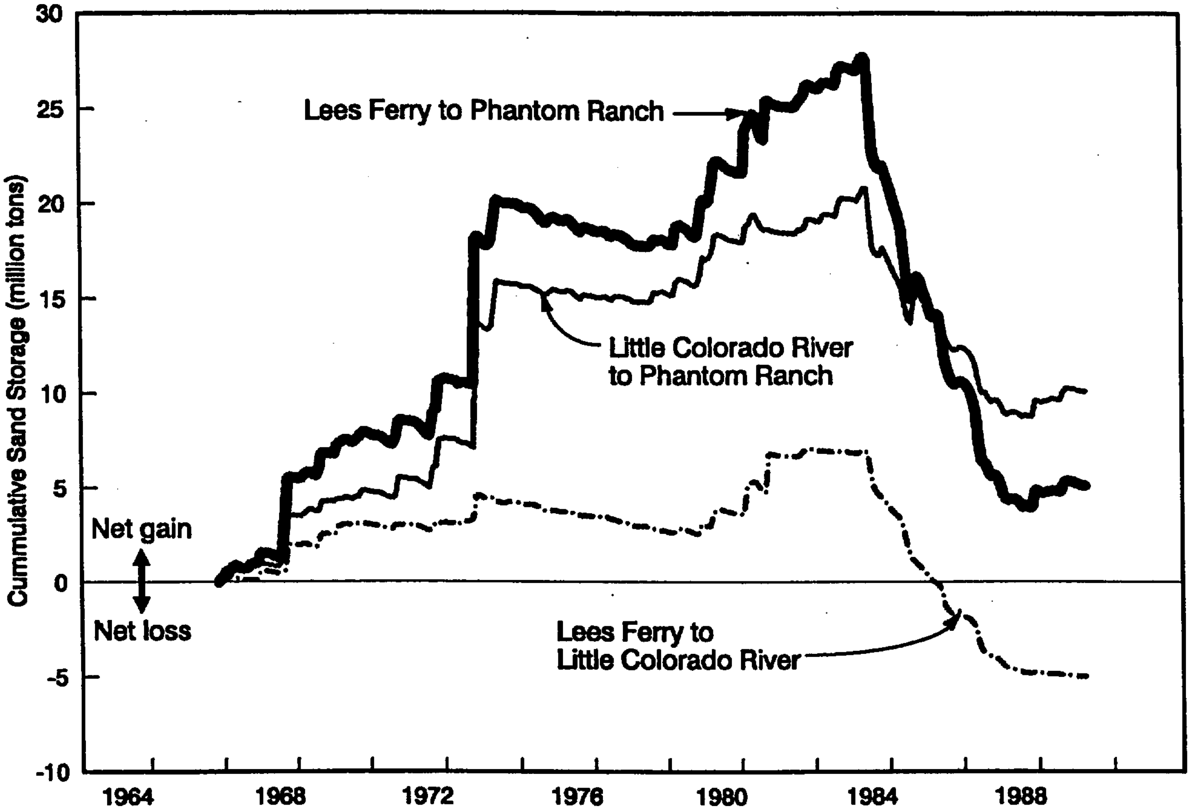


Figure III-15.—Cumulative sand storage between Lees Ferry and Phantom Ranch. Sand accumulated in the river during the relatively low releases while Lake Powell was filling, coupled with large sand contributions from the Paria and Little Colorado Rivers in 1972, 1979, and 1980. Sand was eroded from the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

so degradation stops. This process, called armoring, has happened in the Glen Canyon reach (Pemberton, 1976).

If the supply of sand is sufficient, the amount transported by the river is exponentially proportional to the riverflow (i.e., the rate of increase in sand load is much greater than the rate of increase in flow). Fluctuating flows, therefore, will transport more sediment than steady flows of the same volume because the fluctuating flows are higher than steady flows during part of each day. As the wave shape changes downstream (see WATER in this chapter), sediment transport capacity is reduced.

Computed sand loads at the gauge above the LCR for steady and fluctuating water releases of the same volume for 1 day are compared in figure III-16. Computed sand loads are based on the river's transport capacity. Actual sand loads may be smaller than computed loads when the tributary supply is less than transport capacity. As the bed elevation continues to increase, the annual transport through Grand Canyon will approach the amount delivered annually by tributaries. The sand that accumulates during low release years may be available to build sandbars during periods of sufficiently high discharge.

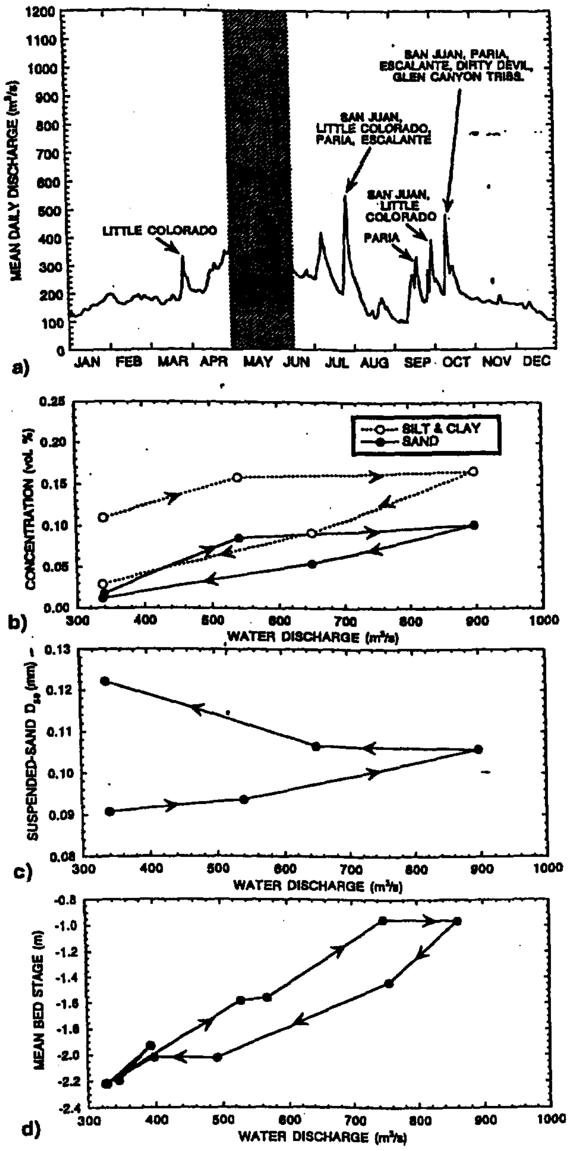


Figure 2. (Opposite) (a) The 1954 mean-daily discharge record from the Grand Canyon gage showing the seasonal separation between tributary sediment-input events and the annual snowmelt flood. Tributary rivers that contributed to the observed discharge peaks are indicated. Cross-hatched region indicates 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.

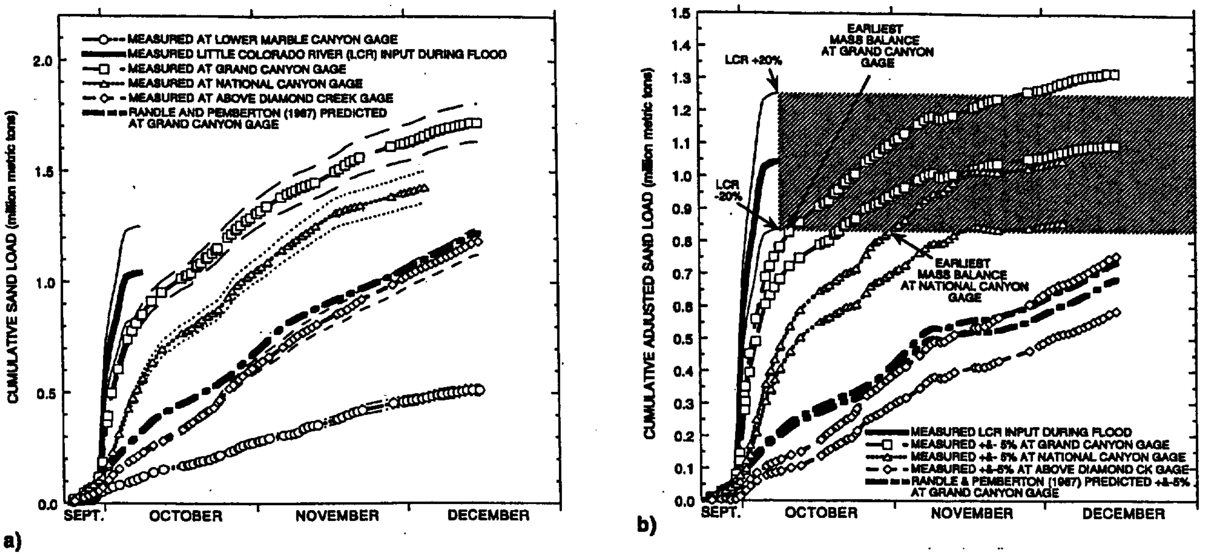
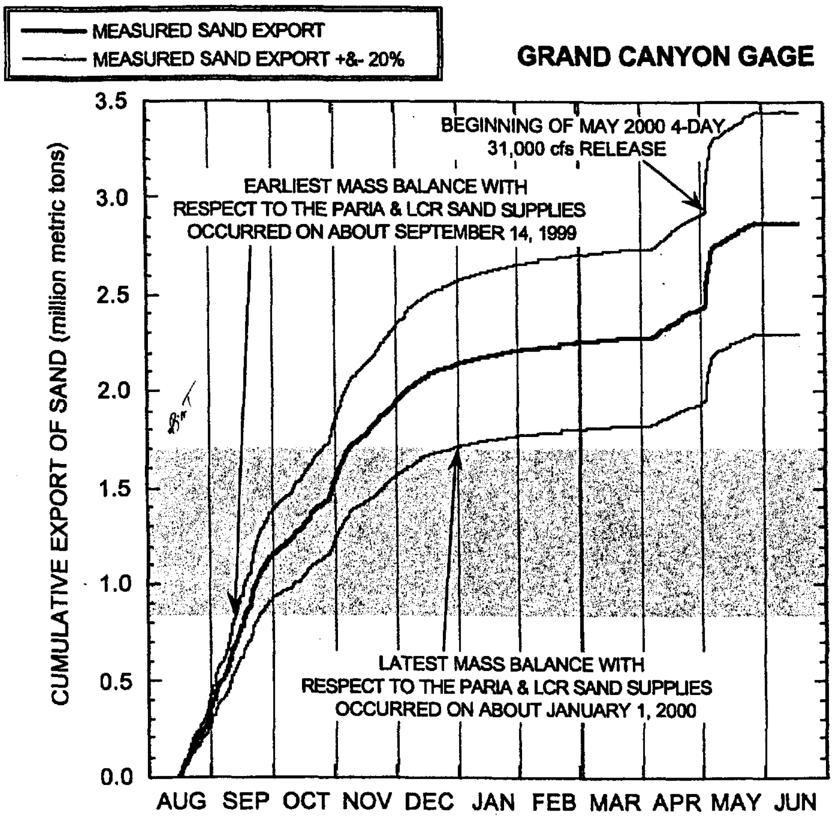


Figure 11. (a) Cumulative measured sand loads of the Colorado River at the Lower Marble Canyon gage and at the three gages downstream from the mouth of the Little Colorado River (LCR) and the cumulative measured sand load of the LCR at the highway 89 bridge at Cameron for the period after the beginning 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.



*GRAY SHADED REGION IS LIKELY RANGE OF THE COMBINED PARIA AND LCR SAND SUPPLIES DURING THIS PERIOD

*BETWEEN ABOUT 0.3 & 2.1 MILLION METRIC TONS OF SAND IN ADDITION TO THAT SUPPLIED BY THE PARIA RIVER AND LCR WERE EXPORTED FROM MARBLE AND UPPER GRAND CANYONS BETWEEN MID-AUGUST 1999 AND BEFORE THE MAY 2000 31,000 cfs RELEASE

*ONLY ABOUT 0.2 MILLION METRIC TONS OF THIS ADDITIONAL SAND EXPORT LIKELY CAME FROM THE OTHER TRIBUTARIES IN MARBLE AND UPPER GRAND CANYONS;
THE REST WAS PROBABLY ERODED FROM THE COLORADO RIVER IN MARBLE AND UPPER GRAND CANYONS

Figure 1b: Sand mass balance plot for the 141-km long reach from Lees Ferry to the Grand Canyon gage for August 1999-June 2000. The sand budget becomes for this period becomes negative (indicating net erosion of sand from the canyon) when the export curves exceed the gray box by more than about 0.2 million metric tons (the likely contribution of sand from the smaller tributaries).

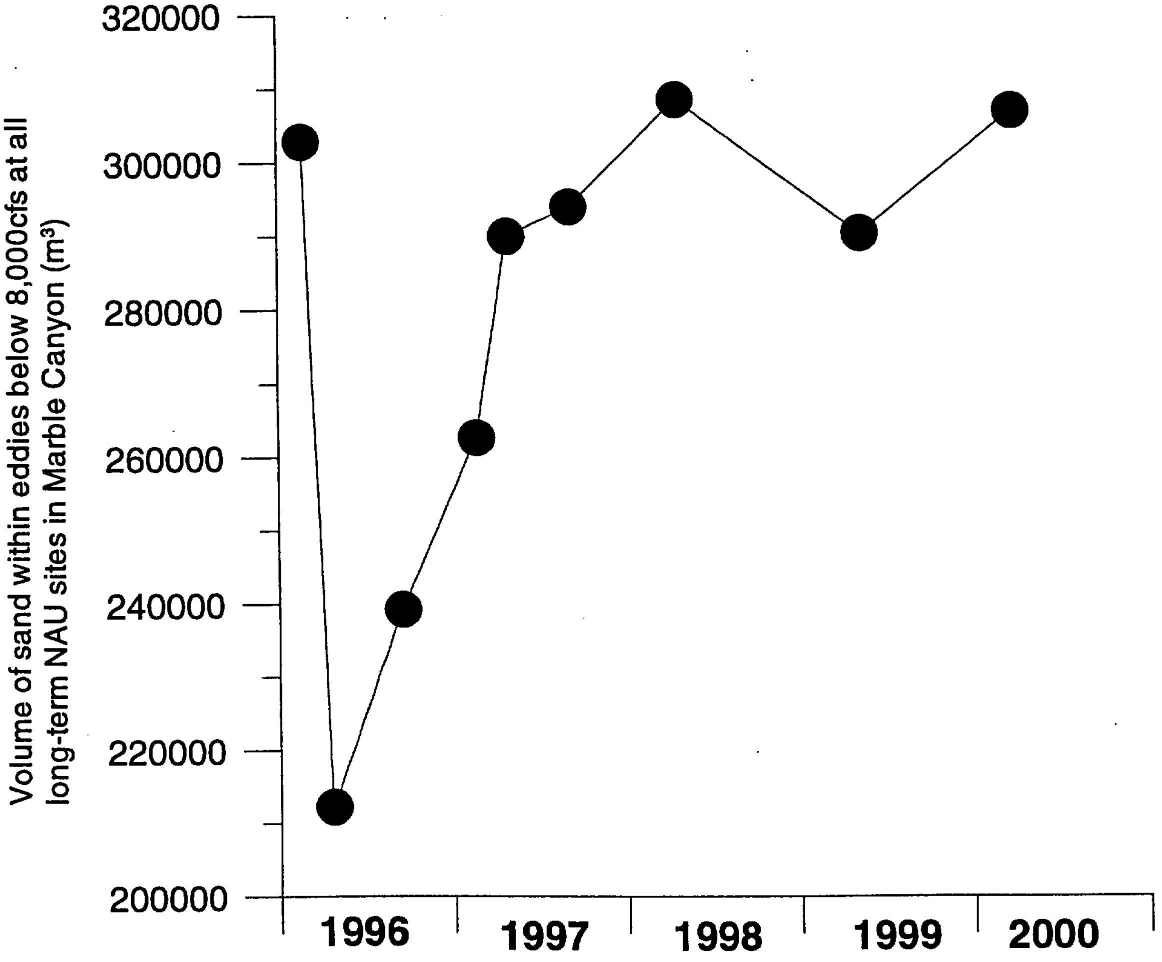


Figure 4. Changes in low-elevation eddy sand volume at all long-term NAU study sites in Marble Canyon (unpublished NAU data).