Using remote sensing to determine sandbar area from 1935-2009 within select reaches, Marble and Grand Canyons, AZ

Robert P. Ross and Paul E. Grams
Grand Canyon Monitoring and Research Center, Southwest Biological Science Center,
Flagstaff, AZ 86001

ABSTRACT

Geomorphic maps created from April 1996 aerial imagery updated with shorelines from 2002, 2005, and 2009 indicate an overall decrease in total sand area from post-flood 1996 levels within defined eddy deposition zones in the Lees Ferry, North Canyon, Redwall Gorge, and Little Colorado River reaches. Total sand area slightly increases from post-flood 1996 levels in the Point Hansbrough and Granary View reaches. When these results area averaged for the post-flood 1996 periods and added to previously calculated post-dam average sand area, the data indicate a further declining trend in average post-dam deposits in the Lees Ferry reach, but indicate an increase in average depositional trend from April 1996 to 2009 in the North Canyon, Redwall Gorge, Point Hansbrough, Granary View, and Little Colorado River reaches.

PURPOSE AND SCOPE

Pre- and post-dam average values of reach-delineated area have been reported and analyzed by previous researchers (Schmidt and Leschin, 1995; Grams and Schmidt, 1999; Schmidt and others, 1999b; Sondossi, 2001; Schmidt and others, 2004). These reports establish a decline in sand area observed within common eddy boundaries from aerial photographs from October 1935 through April 1996. Each work analyzed a subset of the current selected reaches used for this report, with Schmidt (2004) synthesizing all previously reported reaches. Two reaches were previously mapped, but not analyzed for areal change (North Canyon and Granary View, reaches 3 and 6, respectively).

Between 1996 and 2009, three high-flow experiments (HFEs) were released from Glen Canyon Dam, as were two power-plant capacity releases (in August and September 2000). The HFEs comprised an upramp period of discharge to a maximum release value when bypass pipes from the dam were operating at peak discharge, a period of steady discharge at maximum flow, and a downramp period returning to regular operations. The purpose of these discharge events was to replenish sand supply downstream of the dam, and to rebuild sandbars and channel margin deposits. The 1996 flood was conducted in sediment-depleted conditions, and resulted in erosion and transport of existing sand deposits, due to transport capacity being proportionally greater than sediment supply. The experiments following the initial HFE of 1996 were done in sediment-enriched conditions, with mixed results. Individual eddy response was not consistent throughout reaches, indicating response based on specific site conditions.

While the previous works summarized by Schmidt and others (2004) establish a conservative comparison of areal change in the pre- and post-dam eras, the changes in sand deposit areas within the six study reaches have not been reported since those of 1996. Orthorectified aerial photography is now available for 2002, 2005, and 2009, and we updated the post-HFE 1996 (April) geomorphic maps to reflect the shorelines in each of those three years. Sand area within common eddy deposition zones for the six reaches is reported for 2002, 2005, and 2009, and pre- and post-dam average exposed sand area is reported and compared to those of Schmidt and others (2004).

Methods

Detailed geomorphic maps were created by tracing deposit contacts over aerial photographs for several fly-over dates. These maps contained sand deposits correlating to spatially and temporally distinct deposits from pre- and post-dam time periods. These deposit layers from April 1996 were unioned with previously existing eddy deposition zones, as well as the new shorelines derived from the 2002, 2005, and 2009 aerial photographs. All deposits corresponding to different sand levels were dissolved into one class of sand, which was then arranged into a pivot table based on the identification of the corresponding eddy deposition zone. Total sand areas from each eddy deposition zone for each year were tabulated into a spreadsheet. The same process was repeated for all dates prior to April 1996, but without the updated shorelines. The resulting table of information provides total sand area for each eddy deposition zone for each year, allowing a comparison across years.

The range of dates selected for this analysis was based on the need for common analysis between all reaches. The only pre-dam year available for all six reaches was 1935. The other years selected are 1965, 1973, 1984, 1990, March and April 1996, 2002, 2005, and 2009. Only eddy deposition zones larger than 1000 m^2 are considered, and this sub-selection is further narrowed by only using eddy deposition zones that were consistently mapped throughout all years. This selection is smaller for 1935-2009 than the range selected for 1990-2009, since mapping was more complete in recent years.

Area of sand in years mapped prior to 1996 were also corrected to reflect discharge at time of imagery. This was done by taking the total area of sand within a given reach, and plotting this total against the discharge. The resulting equation was then applied to the area calculations, resulting in a better approximation of sand area above the 226 m^2/s discharge level. The resulting sub-sets were graphed as total sand area for each date as a time-series, and were then processed into a series of fill ratios, where the total exposed sand area is divided by the total area of the eddy deposition zone. This normalized metric indicates the proportion of the potential fill area with sand deposits at any given time.

REFERENCES

Grams, P. E. and Schmidt, J. C. 1999. Integration of photographic and topographic data to develop temporally and spatially rich records of sand bar change in the Point Hansbrough and Little Colorado River confluence study reaches. Final Report to the Grand Canyon Monitoring and Research Center.

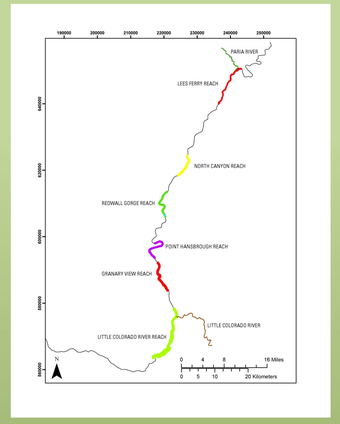
Schmidt, J. C., Grams, P. E., and Leschin, M. F. 1999b. Variation in the magnitude and style of deposition and erosion in three long (8-12 km) reaches as determined by photographic analysis, in Webb, R. H., Schmidt, J. C., Marzolf, G. R., and Valdez, R. A., eds., The 1996 Controlled Flood in Grand Canyon. Washington, D. C., American Geophysical Union, Geophysical Monograph 110: 185-203.

Schmidt, J. C. and Leschin, M. F. 1995. Geomorphology of post-Glen Canyon Dam fine-grained alluvial deposits of the Colorado River in Point Hansbrough and Little Colorado River confluence study reaches in Grand Canyon National Park, Arizona: final draft report for the U. S. Bureau of Reclamation, Glen Canyon Environmental Studies.

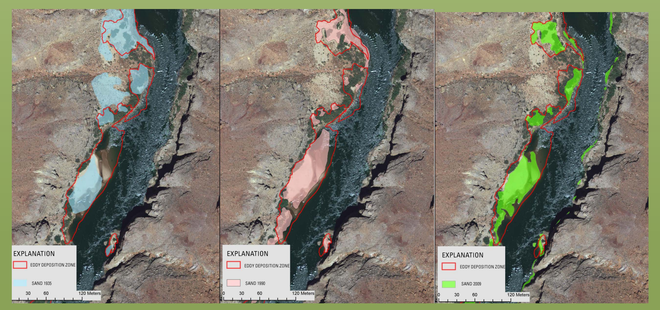
Schmidt, J. C., Topping, D. J., Grams, P. E., and Hazel, J. E. 2004. System-wide changes in the distribution of fine sediment in the Colorado River corridor between Glen Canyon Dam and Bright Angel Creek, Arizona: Final report submitted to Grand Canyon Monitoring and Research Center.

Sondossi, H. A. 2001 Historical analysis of the geomorphology of sand bars along the Colorado River in Upper Marble Canyon, Arizona. Unpublished master's thesis, Utah State University, 138 p.

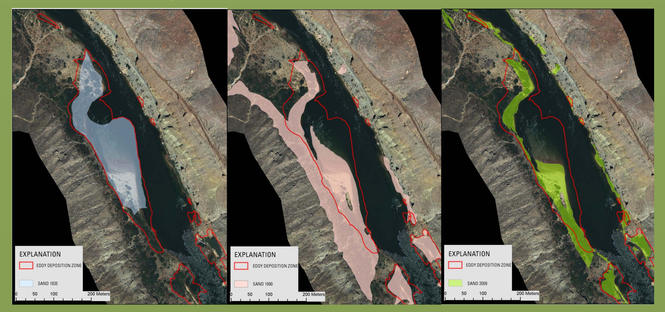
STUDY AREA



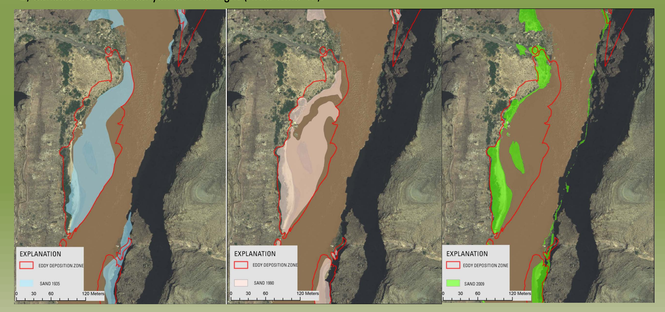
Location of reaches used in this study. Total length of river corridor mapped is 38.3 miles, representing 52% of the total length of the section of river from upstream of Lees Ferry to the downstream end of the LCR reach.



A) 30-Mile Sandbar on river right.



B) Sandbar at Saddle Canyon on river right (River Mile 47).

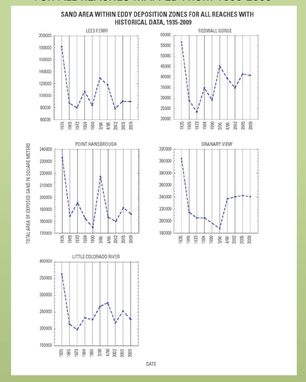


C) Sandbar at Carbon Canyon on river right (River Mile 65).

Sand area mapped at (A) 30-Mile, (B) Saddle Canyon, and (C) Carbon. Blue polygon is 1935, pink is 1990, and green is 2009. Flow direction is from top to bottom of screen for all photos. (A) shows a small increase from 1935 to 1990, followed by a small decrease in 2009. (B) shows a continuing decrease in area from 1935 to 2009. (C) shows no significant change from 1935 to 1990, followed by a significant decrease from 1990 to 2009.

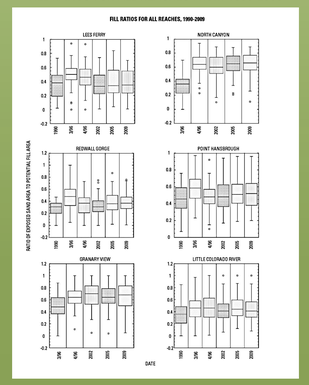
Provisional Data – do not cite

TOTAL SAND AREA WITHIN EDDY DEPOSITION ZONES FOR ALL REACHES MAPPED FROM 1935-2009



The total area of sand was between 105 and 226 percent greater in 1935 compared to the post-dam years (1965-2009). The area in 1935 was between 122 and 213 percent greater than the average values of the post-dam years. The North Canyon reach was not included because of shadow in the 1935 photos.

FILL RATIOS FOR ALL REACHES FROM 1990-2009

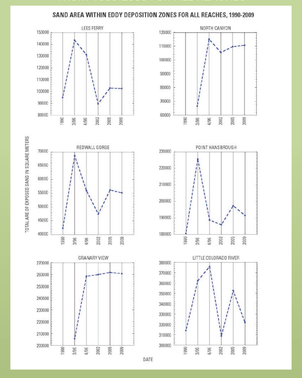


The "fill ratio" is the ratio of sand observed at the time the indicated photograph taken to the maximum extent of sand observed in each eddy. Thus, the magnitude of the fill ratio is an measure of bar size relative to the size of the eddy deposition zone. A fill ratio of one would indicate that the eddy is "full" of sand. The small variations in fill ratios shown above indicate that changes in bar area are small relative to the size of the eddy deposition zone. An exception is North Canyon, where there was a larger increase after the 1996 flood. 1990 data were incomplete or missing for North Canyon and Granary View; the first fill ratio for each of these reaches is from March 1996.

RESULTS

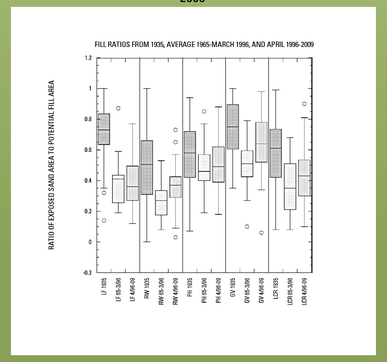
- The area of sand deposits decreased from 1935 to post-dam values for all reaches.
- The highest level of sand area in the post-dam period was observed bracketing the 1996 flood. In three cases, the high point is in April 1996 (post-flood), but in three of the six reaches, the high point is in March 1996 (pre-flood).
- In all cases except the Point Hansbrough and Little Colorado River reaches, sand area is not noted to significantly change from 2002-2009, which is similar to the trend shown for sandbar volume relative to 2002 from Northern Arizona University long-term monitoring sites (right).
- Fill ratios for all reaches from 1990-2009 indicate small fluctuations in sand area within the eddy deposition zones, with the only significant overall increase being seen in North Canyon. When average fill ratios from 1965-March 1996 are compared to average fill ratios from April 1996 to 2009, it appears that in all reaches except Lees Ferry, the post-flood 1996 average will increase the overall post-dam average values.
- It appears that sand area in the post-flood period displays a lower magnitude change in area than the period from 1965-1990, generally half or less.
- The next step in this analysis is to compare data from the NAU/GCMRC long-term monitoring sites to the data gleaned from the aerial photos, both as error analysis, and to determine if current monitoring sites address reach-scale dynamics, as well as to compare area and volume, and determine if area can be used as a proxy for volumetric change. Other work is expanding the approach of this study to a canyon-wide data series for 2002, 2005, and 2009. Currently, almost 1400 regions where significant sand area has been noted in the past are being classified based on the presence of sand, vegetation, and water.

TOTAL SAND AREA WITHIN EDDY DEPOSITION ZONES FROM 1990-2009 FOR ALL REACHES

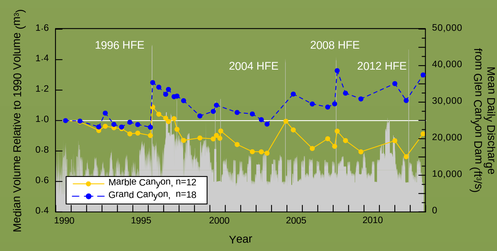


Total sand area increased between 1990 and 2009 in most reaches. 1990 data are incomplete or missing for North Canyon and Granary View.

FILL RATIOS FOR 1935 COMPARED TO AVERAGE FILL RATIOS FROM 1965-MARCH 1996 AND AVERAGE FILL RATIOS FROM APRIL 1996-2009



Fill ratios from 1935, the average fill ratio from 1965-March 1996, and the average fill ratio from April 1996-2009. In all cases, post-dam values area significantly lower than the 1935 values. In Lees Ferry, the average value from April 1996 to 2009 is lower than for the 1965-1996 period. In all other reaches, the average from April 1996-2009 is larger than the 1965 to 1996 period.



Median sand volume relative to 1990 levels for NAU/GCMRC long-term monitoring sites. The volume trend agrees with the trends in areal change from this study. Further work will evaluate the possibility of inferring volumetric change from areal change. Figure courtesy of Joseph Hazel, Northern Arizona University.