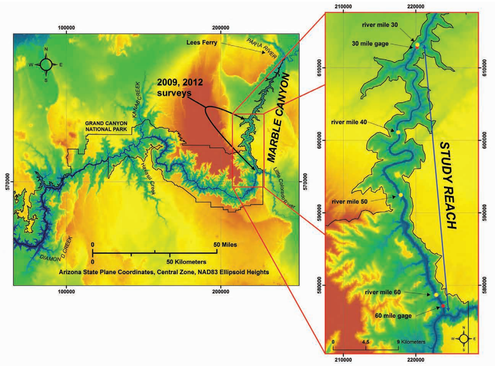
Constructing a Morphologic Sediment Budget, With Uncertainties, for a 50-km Segment of the Colorado River in Grand Canyon

Matt Kaplinski[1] (matt.kaplinski@nau.edu), Joseph E. Hazel[1], Jr., Dan Buscombe[2], Paul E. Grams[2], Dan Hadley[1], Keith Kohl[2]
Northern Arizona University, School of Earth Sciences and Environmental Sustainability, Flagstaff, AZ, 86011
Grand Canyon Monitoring and Research Center, U.S. Geological Survey, Flagstaff, AZ, 86001

ABSTRACT

Fluvial sediment budgets may be computed by measurement of sediment flux, measurement of channel morphologic change, or by a combination of both methods. Because the uncertainty associated with flux-based sediment budgets accumulates over time, it may be difficult or impossible to use this type of budget to predict or monitor long-term changes in sediment storage and channel morphology. Uncertainty in morphologically-based sediment budgets is not time-dependent and provides an attractive complement or alternative to sediment budgets based on measurements of flux. However, computation of a morphologically based sediment budget for long (~50 km) river segments does require thorough consideration of the suite of uncertainties (i.e. measurement error, interpolation error, and error associated with variability in bed surface texture, among others) that contribute to the sediment budget uncertainty. We report on repeat measurements of morphology and associated uncertainties for a 50- km segment of the Colorado River in Grand Canyon. Topographic (total station) surveys, bathymetric (multibeam and singlebeam) surveys, and underwater microscope grain-size measurements were conducted in 2009 and 2012 for the same river segment. Multibeam sonar surveys also incorporate backscatter information used to define the distribution of bed sediment. One meter DEM's of the study reach were interpolated from TIN models constructed from the combined topographic and bathymetric data and differenced to determine the sediment budget. Uncertainties were estimated for each dataset, as well as interpolation methods used to construct each DEM. This results in a spatially-variable 1-m model of surface uncertainty, which is used to determine the total uncertainty of the sediment budget calculated by DEM differencing. Sediment flux measurements are also measured for the study segment over the same time period. Together, these datasets provide a unique opportunity to compare sediment budgets derived from different methodologies for the same river segment.

I. Study Area

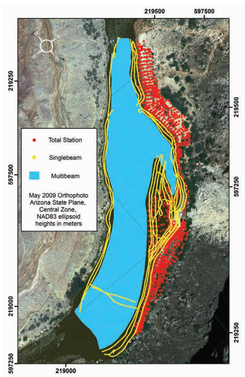


The study area is the Colorado River corridor within Marble Canyon in northern Arizona. Locations discussed in this report are referenced by the GCMRC river mile (RM) system, which is distance in miles along the channel centerline downstream from Lees Ferry, Arizona (U.S. Geological Survey, 2006). Lees Ferry (RM 0) is located 15.5 miles downstream from GCD, and 1 mile upstream from the mouth of the Paria River and the northeastern boundary of Grand Canyon National Park. Marble Canyon begins at Lees Ferry and the mouth of the Paria River and extends downstream to the Little Colorado River confluence.

All data were processed in the State Plane, Central Arizona (202) zone projection in meters using the NAD83 (2011) vertical datum. Elevations are reported as ellipsoid heights (EH) .

II. Survey Methods

Constructing a morphological sediment budget requires mapping as much of the study reach as possible. To accomplish this goal, a combination of remotely-sensed and ground-based data were collected in May 2009 and May 2012 on 18 day research river trips. All surveys are referenced to a geodetic control network developed by the GCMRC. Channel bathymetry was mapped by multibeam and singlebeam sonar and subaerial topography was mapped by total station.



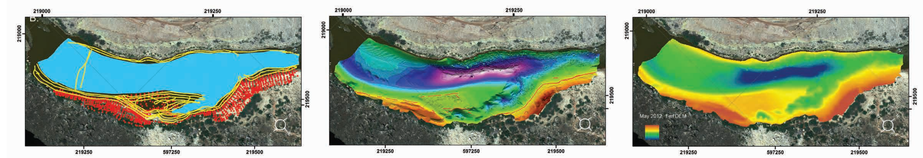
Total Station Topographic Surveys & Spatial Referencing

Total stations were used to collect topographic data, place temporary benchmarks for bathymetric navigation stations and complete a line-of-site traverse of the control network benchmarks throughout the entire study reach, and to spatially reference subaerial and subaqueous sample sites (e.g., scour chains, digital microscopes, and video cameras).

Multibeam and Singlebeam Bathymetric Surveys

Bathymetric data covered the largest portion of the study reaches and comprise approximately 74% of the total DEM area. The bathymetric data collection system used a robotic total station, or shore station established on benchmarks to provide line-of-sight navigation data. Multibeam surveys were utilized in the deeper parts of the channel and eddies within the study site and singlebeam surveys were collected along shallow shoreline areas. Multibeam soundings were reduced by calculating the median elevation of soundings within 0.25m and 1.0m grid cells. The 1m sorted data were used to construct the bathymetry portion of the DEMs and the 0.25m sorted data were used for bed texture analysis. The number of soundings per 1 m grid cell varies from 1 to 3,000, with an average of approximately 200 soundings per cell.

III. DEM CONSTRUCTION

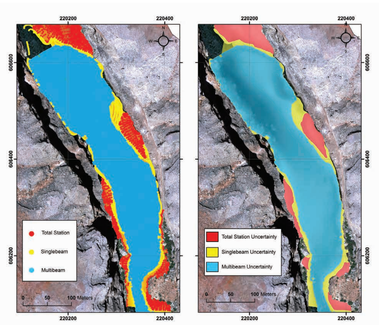


Total Station & Bathymetry points → TIN Model with breaklines → 1 meter DEM

The combined point data were used to construct DEMs of the channel bed and banks for each reach and each monitoring period using ESRI's ArcGIS. The general approach was to create a TIN model from the input datasets, then generate a 1-m raster DEM from the TIN model. Breaklines were incorporated into the TIN models to ensure the model best represented the ground surface at the time of the surveys. When generating the 1m DEM from the TIN model it is important to generate DEMs that are co-registered and concurrent, so that each grid cell from different surveys overlays exactly.

IV. DEM UNCERTAINTY

We estimate the vertical component of uncertainty for each data type (total station, multibeam and singlebeam surveys). This method results in spatially distributed uncertainty estimates that depend upon the specific survey method. The uncertainty results are tabulated in a raster surface, concurrent with the DEM, that contains uncertainty values for each survey date.



The Uncertainty for each survey method can be estimated as:

$$TU_Z = \sqrt{(SU_Z)^2 + (IU_Z)^2}$$

where, TU_z is the total uncertainty for a given survey method (total station, singlebeam, multibeam), SU_z is the survey component of uncertainty, and IU_z is the uncertainty associated with interpolating the topographic surface from the data points

Total Station

Survey uncertainty of total station data was estimated by repeat control point observations. Interpolation Uncertainty was estimated by comparing TIN models with checkpoints (Hazel and others, in prep).

$TU_z = 0.032$ m $SU_z = 0.024$ m $IU_z = 0.015$ m

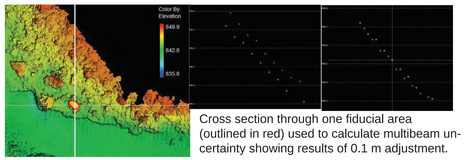
Singlebeam

Survey uncertainty of singlebeam data was estimated by cross line analysis (comparing the difference in elevation of crossing points). Interpolation uncertainty was estimated by a bootstrapping technique that compared the elevation of DEMs with test points (Kaplinski and others, in review).

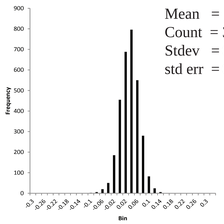
$TU_z = 0.09$ m $SU_z = 0.01$ m $IU_z = 0.09$ m

Multibeam

Multibeam uncertainty was estimated by comparing elevation differences between 1-m DEMs within 8 fiducial areas that did not change (flat rocks, bedrock ledges, or gravel bars) during the study period. These areas are typically flat rock outcrops or gravel bars. A systematic offset was discovered between the 2009 and 2012 data. Three fiducial areas were used to calculate an offset of 0.1 m between the datasets. The 2009 data were adjusted and the results of all 8 fiducial areas show a TU_z = 0.03 m (mean absolute difference).



Cross section through one fiducial area (outlined in red) used to calculate multibeam uncertainty showing results of 0.1 m adjustment.

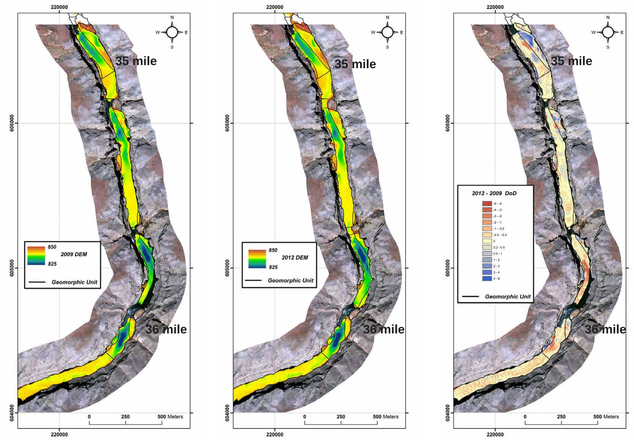


Mean = 0.02 m
Count = 3152
Stdev = 0.02 m
std err = 0.001 m

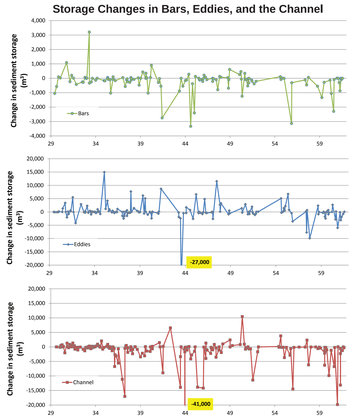
Elevation difference between 2009 and 2012 multibeam bathymetry within 8 fiducial areas.

V. DEM COMPARISON

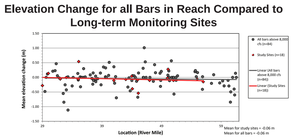
The quantity and location of fine-grained sediment storage changes within the study reach is shown by the difference between the 2009 and 2012 DEMs. Maps below show a portion of the study reach between river mile 35 and river mile 36.5 mile.



Preliminary Results

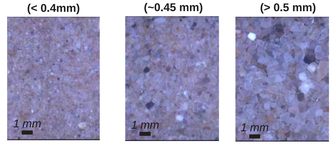


Storage change in the bars and in the channel was negative while storage change in the eddies was positive. Changes in the bars and eddies consist mainly of sand transported in suspension and monitored at the stream gages. Changes in the channel include coarse sand and gravel transported as bed load.



Changes in 84 sandbars above the 8,000 cfs stage elevation from May 2009 to May 2012 is very similar to changes at the 18 Long-term monitoring sites (NAU sites) in the same reach for the October 2009 to October 2012 period.

Bars (< 0.4mm)	Eddies (~0.45 mm)	Channel (> 0.5 mm)



Conclusions

- Changes in sediment storage vary greatly throughout the 30-mile reach.
  - ~7% of gross storage change in exposed bars
  - ~38% of gross storage change in eddies
  - ~55% of gross storage change in channel
- The channel and eddies have the same sign of change in some reaches and have opposing sign in some reaches.
- The net storage change is negative in bars, positive in eddies, and negative in the channel.
- A large proportion of entire budget can occur within one pool (for example, changes in channel near mile 36 and changes in the eddy and channel near mile 44).

Preliminary Data and Results: Do Not Cite