Sandbars and Sediment Storage in Marble and Grand Canyons: Response to Recent High-flow Experiments and Long-term Trends

GCMRC Project 3
Paul Grams¹, Daniel Buscombe¹, Tom Gushue¹, Dan Hamill, Joseph Hazel², Matt Kaplinski², Keith Kohl¹, Erich Mueller¹, Robert Ross¹, Robert Tusso¹
¹U.S. Geological Survey, Grand Canyon Monitoring and Research Center
²Northern Arizona University
Project 3

3.1 Sandbar Monitoring and Research
   3.1.1 Annual Sandbar Monitoring (this talk)
   3.1.2 Sandbar Monitoring by Remote Sensing (Sankey talk)
   3.1.3 Use of Structure-from-motion Photogrammetry (poster)
   3.1.4 Analysis of Historical Photographs (not covered)

3.2 Long-term Sediment Storage Monitoring and Research (this talk and poster)

3.3 Sandbar Modeling (this talk)

3.4 Bedload Sand Transport (poster)

3.5 Control Network and Survey Support (not covered)
Sediment budget affected by disruption of sand supply and change in flow regime

85 to 95% reduction in supply coupled with ~20% reduction in mean annual flow \(\rightarrow\) sediment deficit

Topping et al. (2000)
Pre-dam:
• Annual floods
• Abundant sand supply
• Large sandbars

Post-dam I:
• Daily small floods
• Limited sand supply
• Eroding sandbars
• Unplanned floods (spills)

About 25% reduction in sandbar area in Marble Canyon (Schmidt et al., 2004; Ross and Grams, 2015)
Pre-dam:
• Annual floods
• Abundant sand supply
• Large sandbars

Post-dam I:
• Daily small floods
• Limited sand supply
• Eroding sandbars
• Unplanned floods (spills)

Overarching Questions:
• With frequent floods, will sandbars increase in size and abundance?
• What will happen to sand storage with frequent floods?

Post dam II:
• Restricted hydropower operations
• controlled floods triggered by sand supply
Eddy-deposited sandbars in Grand Canyon

- Campsites
- Habitat
- Source of sand for upland areas
- At least about 1400 eddies that may contain large sandbars between Lees Ferry and Diamond Creek (based on inspection of air photos)
- 569 sandbars that may form backwater habitat based on inventories done in 2008
3.1.1 Sandbar Monitoring

- What is effect of individual HFES?
- What is cumulative effect of HFES and dam operations?

- Topographic Surveys

- Photographs from automated remote cameras.
Major Components of Sandbar and Sediment Storage Monitoring

- **Sandbar monitoring**
  - Annual topographic surveys at 47 sites
  - Daily photographs (42 sites)
  - High-elevation sand only (above 8,000 ft³/s stage)
  - Long-term record back to 1990
  - Denser network of sites in Marble Canyon than Grand Canyon
Annual Sandbar Monitoring

Period of HFE Protocol
- Blue arrows/lines show each HFE
- Surveys are ~11 months after most recent HFE

preliminary data, do not cite
Annual Sandbar Monitoring

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- Largest increase is during 2012 HFE

*preliminary data, do not cite*
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- Bars largest in October 2014

preliminary data, do not cite
Annual Sandbar Monitoring

Period of HFE Protocol
- Blue arrows/lines show each HFE
- Surveys are ~11 months after most recent HFE

- Largest increase is during 2012 HFE
- Bars largest in October 2014
- “Balancing” flows peaking at 20,000 cfs likely caused more erosion than previous years.
- Consistently larger than “average” for period without regular HFE’s

preliminary data, do not cite
November 2016 High-flow Experiment Sandbar Deposition

River Mile (RM) 119 R

HFE Deposition →

11/07/2016

11/13/2016

River Mile (RM) 122R

HFE Deposition →

11/07/2016

11/13/2016
November 2016 High-flow Experiment Sandbar Deposition

- Post 2016 HFE images available from 14 out 45 monitoring sites.
  - Net deposition at 9 sites
  - Erosion at 2 sites
  - No net change at 3 sites
- Images from remaining sites will be collected in February

*preliminary data, do not cite*
Sandbar Research, Data Processing, and Online Access

• 25 years of data to manage
  – Web tool for data storage and viewing
  – Scripted data processing tools
  – New database for centralized storage and data management

Photos at www.gcmrc.gov
Sandbar data at www.gcmrc.gov/sandbar/
Project 3.2: In-channel Sand Supply: Research and Long-term monitoring

- Periodic repeat mapping to measure trends in sand storage
  - Will dam operations (including HFEs) cause increase, decrease, or stable sand supply?
  - If changes occur, where do they occur?
- What is “total” supply of sand in channel?
- What are the relative proportions of “recent” sand from the Paria River and “old” sand in HFE-deposited sandbars? *(see Katie Chapman’s poster)*

View is looking upstream
Black dots are 0.1 mi intervals
Results: closed sand budget for Lower Marble Canyon: May 2009 to May 2012

- Both budgets have large uncertainty
- Good agreement between methods

Sand loss during equalization flows
- Over short (3-year) period have similar uncertainty to flux measurements
- Over long (10-20 year) period have much less uncertainty than flux measurements

Grams et al. (2015)
Small changes at most locations, but large changes at some locations

Grams et al. (2015)
Better Estimates of “Absolute” sand storage

• Based on:
  – Measured topography/bathymetry
  – Bed composition
  – Dune heights in channel
  – Assumptions for sand thickness*

→ 5 to 13 million m³ (7 to 21 million metric tons) sand in eddies and channel in Lower Marble Canyon.
1 million metric tons is about the amount of sand delivered by the Paria in a good input season (like 2016).

* Will refine these assumptions using measurements of sand thickness made in 2016

Preliminary results, do not cite
Eastern Grand Canyon
1-1-2011 through 1-1-2017

Change in Sand Mass
Zero Bias Value: -2,100,000 Metric Tons
Upper Uncertainty Bound: -690,000 Metric Tons
Lower Uncertainty Bound: -3,600,000 Metric Tons

USGS (2017)
Most of the net sand evacuation for the first 3 years of this period was from pools in the upper Granite Gorge.

Most of the erosion is not from sandbars on the channel margins, but from the deep parts of eddies and the center of the channel.

*Preliminary results, do not cite*
Project 3.2: In-channel Sand Supply: Research and Long-term monitoring

- Validation and context for flux-based sand mass balance (project 2)
  - Measurements are independent of the acoustical measurements of concentration
  - Measurements reveal locations of change in sand storage
  - Only method to allow estimates of the absolute sand storage

- Advances on methods for bed classification using a range of acoustic methods (high-end to inexpensive) – See Dan Hamill poster

- Provides data used for a range of applications:
  - Bed composition for aquatics and fish habitat
  - Channel bathymetry/topography for new and improved flow models

- Better estimates of sand transport as bedload – See Tom Ashley poster

- May lead to refining expectations for sand supply and sandbar response in different segments of the canyon
3.3 Sandbar Modeling

- What is relation between channel shape and sandbar characteristics?
- What is relative importance of site characteristics, streamflow, and sediment supply in determining sandbar response to HFEs?

We know what the monitoring sites are doing, less confident extrapolating to “all sandbars”

Mean changes in normalized bar volume at same sites
- Error bars are standard error
- Larger uncertainty, owing to variability among sites

Sum of changes in sand volume at all long term monitoring sites (“NAU sites”)
- Error bars are measurement uncertainty
- Small, because measurements are accurate and precise
Grouping sites of similar behavior and structure

Observations of similar behavior among sites with similar vegetation cover

- Abundance of perennial vegetation is one of the characteristics that distinguishes site behavior
- Vegetation and channel shape have stronger influence on bar response than distance downstream
  → Progress towards a process-based model for sandbar response

Preliminary results, do not cite

Mueller et al. (in review)
What is the effect of changing the hydrograph of the high flow?
Surveys before and after 2012 HFE at 3 large reattachment bars

- Bar volume largest in 1996 (highest discharge and longest duration), area above 8,000 cfs stage largest in 2012 (gradual downramp)
- Slope from bar crest to 8,000 cfs level less steep than other floods

Preliminary data subject to revision – do not cite.
Objectives for pilot project:

- Can we make a physically realistic recirculation zone (eddy)?
- Describe flow and morphology for comparison with numerical model and validation.

Ultimate objective:

- Develop predictive relations for bar shape based on channel characteristics, streamflow, and sediment conditions.
With a few modifications

~ 1:50 geometric scaling of channel

Froude scaling of flow

\[
\frac{v_1}{\sqrt{gd_1}} = \frac{v_2}{\sqrt{gd_2}}
\]

16.5 m

2.74 m
## Experimental Runs and Measurements

<table>
<thead>
<tr>
<th>Run</th>
<th>Flow (l/s)</th>
<th>Froude Number</th>
<th>Duration (hr)</th>
<th>Measurements</th>
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<tbody>
<tr>
<td>1a</td>
<td>90</td>
<td>~0.6</td>
<td>24</td>
<td>Bed topography, PIV</td>
</tr>
<tr>
<td>1b</td>
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<td></td>
<td>Bed regraded to flat</td>
</tr>
<tr>
<td>2</td>
<td>165</td>
<td>~0.5</td>
<td>17</td>
<td>Bed topography</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bed regraded to flat, moved constriction</td>
</tr>
<tr>
<td>3</td>
<td>165</td>
<td>~0.5</td>
<td>4</td>
<td>Bed topography</td>
</tr>
</tbody>
</table>
Run 1 – ~90 l/s

- No deposition in constriction
- Rapid initial development of scour hole
- Slow lengthening of scour hole
- Slow downstream migration of mid-channel dune
- Deposition of bar in recirculation zone upstream from reattachment point

Preliminary results, do not cite
Recirculating flow characteristics in lab, model, and field

Field-scale LES  PIV in flume

Mean velocities in flume about 1/10 field scale, but different distribution tail (PIV vs model?).

Images for PIV (playing ~ 0.4 x actual speed)

Detached eddy simulation model at flume scale

Preliminary results, do not cite
Rate and Pattern of Morphological Development

Using downstream dune as index: morphological development is function of time, discharge, and constriction shape/position

Preliminary results, do not cite