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

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Review of Problem: Sediment budget affected by disruption of sand supply and change in flow regime

- **Grand Canyon**: ~16% of pre-dam sand supply
- **Marble Canyon**: ~6% of pre-dam sand supply
- **Paria River**: Disruption of sand supply
- **Little Colorado River**: Change in flow regime

(UGSG gage 09383000: http://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09383000)
Sandbars and the sand mass balance on the Colorado River in Grand Canyon

Sand accumulates on the bed and in eddies during low flows.
Sandbars and the sand mass balance on the Colorado River in Grand Canyon

Floods build sandbars and export sand downstream
Following floods, sandbars erode, and the cycle can repeat... ... as long as there is enough sand.
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In order for the cycle to be sustainable, there must be an approximate balance between what comes in and what goes out.
Sandbar Deposition

• Sand Supply
  – More sand $\rightarrow$ larger bars

The high-elevation sand is ~10 to 15% of the sand. As little as 2% of changes in sand storage involve high-elevation sand.

Total Sand Budget

High-elevation sand (the beaches)

Low-elevation sand (most of the sand)
RM 22: 2013 HFE – pre-flood

Photos at www.gcmrc.gov/sandbar/
RM 22: 2013 HFE – post-flood

Photos at www.gcmrc.gov/sandbar/
RM 22: 2013 HFE – 3 months post-flood

Photos at www.gcmrc.gov/sandbar/
RM 22 R – Returned to pre-HFE size by February (about same response as 2012)

Photos at www.gcmrc.gov/sandbar/
RM 35L, Nautiloid Camp

Photos at www.gcmrc.gov/sandbar/
2012 Controlled Flood

- 24 hr. upramp from 7,000 to 43,400 ft³/s
- 24 hr. peak at 43,400 ft³/s
- 53 hr. downramp from 43,400 to 31,200 ft³/s
- 24 hr. downramp from 31,200 to 7,000 ft³/s

(UGSG gage 09383000: http://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09383000)
Sandbar Shape – RM 30

- Bar volume largest in 1996, area above 8,000 cfs stage largest in 2012

Preliminary results, subject to review and revision – do not cite
Sandbar Shape – RM 30

- Slope from bar crest to 8,000 cfs level less steep than other floods
- For 3 sites with post-flood surveys and large reattachment bars, the area of newly deposited bar above the 8,000 cfs stage with slope less than 8 deg. was larger in 2012 than previous floods

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*Preliminary results, subject to review and revision – do not cite*
2014 HFE

- 22 sites (58%) larger
- 11 sites (29%) no change
- 5 sites (13%) smaller

Photos at www.gcmrc.gov/sandbar/
Response to HFE Protocol

- Each of the HFEs in the past 3 years has resulted in sandbar deposition
  - They continue to erode in following 6 to 12 months

Photos at www.gcmrc.gov/sandbar/

Preliminary results, subject to review and revision – do not cite
Sandbars: 2002-present

- Increase in volume in both Marble Canyon and Grand Canyon at long-term monitoring sites
  - Deposition by HFEs
  - Bars erode following HFEs, but not quite to pre-flood size
- Frequent HFEs = consistently larger bars
- Cumulative effect? No evidence yet that bars will get progressively larger.
- 2013 and 2014 HFEs were smaller than 2012 and earlier.

\[\text{Mean Daily Discharge from Glen Canyon Dam (ft}^3/\text{s})\]

\[\text{Median Volume Relative to 2002 Volume (m}^3)\]

\[\text{Year}\]

Preliminary results, subject to review and revision – do not cite
• 30 monitoring sites have data to 1990
  – 12 in Marble Canyon
  – 18 in Grand Canyon
• Increase in sandbar volume at sites in Grand Canyon
• Marble Canyon bars still less volume than 1990, but larger than low point of 2001-2003

Preliminary results, subject to review and revision – do not cite
Since 2012, each year has had enough sand accumulation to have a controlled flood and have sand accumulation.

Accumulation has more than replaced “evacuation” that occurred in 2011.
Sandbars 10 months following 2012 and 2013 HFEs

Upper Marble Canyon (RM 0-29)
5 of 7 sites larger than Oct. 2011
2 of 7 sites larger than Oct. 2008

Lower Marble Canyon (RM 30-62)
9 of 16 sites larger than Oct. 2011
13 of 16 sites larger than Oct. 2008

Eastern Grand Canyon (RM 62-87)
3 of 7 sites larger than Oct. 2011
4 of 7 sites larger than Oct. 2008

Preliminary results, subject to review and revision – do not cite
Sandbars 10 months following 2012 and 2013 HFEs

- **Upper Marble Canyon (RM 0-29)**
  - 5 of 7 sites larger than Oct. 2011
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- **Lower Marble Canyon (RM 30-62)**
  - 9 of 16 sites larger than Oct. 2011
  - 13 of 16 sites larger than Oct. 2008

- **Eastern Grand Canyon (RM 62-87)**
  - 3 of 7 sites larger than Oct. 2011
  - 4 of 7 sites larger than Oct. 2008

Preliminary results, subject to review and revision – do not cite
Sandbars 10 months following 2012 and 2013 HFEs

E. Central Grand Canyon (RM 88-166)
5 of 9 sites larger than Oct. 2011
8 of 9 sites larger than Oct. 2008

W. Central Grand Canyon (RM 166-225)
8 of 8 sites larger than Oct. 2011
7 of 8 sites larger than Oct. 2008

Preliminary results, subject to review and revision – do not cite
Sandbars 10 months following 2012 and 2013 HFEs

**E. Central Grand Canyon (RM 88-166)**
- 5 of 9 sites larger than Oct. 2011
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**W. Central Grand Canyon (RM 166-225)**
- 8 of 8 sites larger than Oct. 2011
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Sandbar Monitoring Sites Compared to all Sandbars in 6 Short Reaches

Monitoring sites are representative of sandbar response above the 8,000 cfs stage when averaged over long reaches in Marble Canyon.

Preliminary results, subject to review and revision – do not cite
In Lower Marble Canyon, long-term monitoring sites are representative of large sample of bars.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Mean Change</th>
<th>Maximum Deposition</th>
<th>Maximum Erosion</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 Monitoring Sites</td>
<td>-0.06 m</td>
<td>0.54 m</td>
<td>-0.54 m</td>
<td>0.23 m</td>
</tr>
<tr>
<td>84 Bars above 8,000 ft³/s elevation</td>
<td>-0.06 m</td>
<td>1.01 m</td>
<td>-1.12 m</td>
<td>0.35 m</td>
</tr>
</tbody>
</table>

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Summary

• Each HFE has resulted in sandbar deposition
• Bars continue to erode between HFEs
• No strong evidence for “progressive” increases in sandbar size
• Limited evidence that gradual downramp may result in bars that are less steep
• First three years of HFE protocol has been a period of low annual release volumes and good tributary sand supply
  – Bar deposition without depleting sand from storage
  – Sand has accumulated in Marble Canyon, replenishing sand evacuated during 2011 equalization
• Trends in sandbar volume 2012 to 2014
  – 65% of monitoring sites in Marble Canyon Larger than at start of HFE Protocol
  – 79% of monitoring sites in Grand Canyon Larger than at start of HFE Protocol