Mainstem flow
Mainstem flow and sediment
Tributary flow and sediment
Sediment budget reach
RM 0-30 – upper Marble Canyon
RM 30-61 – lower Marble Canyon
RM 61-87 – eastern Grand Canyon
RM 87-166 – central Grand Canyon
RM 166-225 – western Grand Canyon

Between July 1 and November 17, 2012, ...

617,000 – 769,000 metric tons entered Colorado River from the Paria River

91,000 – 101,000 metric tons were transported past the RM 30 gage

Little to no fine sediment accumulated in lower Marble Canyon

Between 551,000 and 782,000 metric tons accumulated in upper Marble Canyon

Mass balance prior to 2004 and 2008 HFEs
July 1 to November 2004: 275,000 – 491,000 metric tons
December 2004 – March 2008: 567,000 – 1,823,000 metric tons

2. HFER Protocol implementation
Cumulative sand delivery to the Colorado River

Paria River at Lees Ferry

- Water
- Cumulative sand delivery to the Colorado River
- 769,000
- 617,000
Cumulative amount of sand transported out of upper Marble Canyon (past RM30 gage)

Cumulative amount of sand available for transport in upper Marble Canyon
Sand transport past RM30

Sand mass balance in upper Marble Canyon

Water
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
Deposition rates of sand in eddies are primarily determined by the concentration of sand transported by the river. Concentrations change with time.
Suspended-Sand Concentration on Day One of Flood

(after Topping and others, USGS OFR 2010-1128, 2010)
Bed-sand median grain size

Bed-sand area (amount)
Suspended-sand median grain size

(after Topping and others, USGS OFR 2010-1128, 2010)
Sand-concentration ranking of controlled floods

<table>
<thead>
<tr>
<th>RM 0</th>
<th>RM 30</th>
<th>RM 61</th>
<th>RM 87</th>
<th>RM 166</th>
<th>RM 225</th>
</tr>
</thead>
</table>

- 75% of sand-concentration rankings agree with bed-sand area (amount) analysis
- Only 40% of sand-concentration rankings agree with bed-sand grain-size analysis
- Mass-balance sand budgets should teach us more...
# Sand mass-balance context

Shown are changes in sand mass (metric tons)

<table>
<thead>
<tr>
<th>Period of budget</th>
<th>Upper Marble Canyon</th>
<th>Lower Marble Canyon</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 2002 - pre2004 flood</td>
<td>$330,000 \pm 194,000$</td>
<td>$-280,000 \pm 110,000$</td>
</tr>
<tr>
<td>pre2004 flood – pre2008 flood</td>
<td>$900,000 \pm 640,000$</td>
<td>$290,000 \pm 350,000$</td>
</tr>
<tr>
<td>pre2008 flood – pre2012 flood</td>
<td>$-1,500,000 \pm 620,000$ (mostly during May-August 2011)</td>
<td>$-12,000 \pm 430,000$</td>
</tr>
<tr>
<td>July 2012 – pre2012 flood</td>
<td>$670,000 \pm 120,000$</td>
<td>$18,000 \pm 15,000$</td>
</tr>
<tr>
<td>during 2012 flood</td>
<td>$-320,000 \pm 13,000$</td>
<td>$-78,000 \pm 36,000$</td>
</tr>
</tbody>
</table>
# Relations between sand mass balance and sand concentrations during controlled floods

<table>
<thead>
<tr>
<th>Year</th>
<th>Upper Marble Canyon</th>
<th>Lower Marble Canyon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004 flood</td>
<td>Cumulative post-July 2002 sand mass before flood (metric tons)</td>
<td>% of sand concentration during 2004 flood</td>
</tr>
<tr>
<td>2004 flood</td>
<td>330,000</td>
<td>100%</td>
</tr>
<tr>
<td>2008 flood</td>
<td>1,230,000</td>
<td>140%</td>
</tr>
<tr>
<td>2012 flood</td>
<td>-270,000</td>
<td>68%</td>
</tr>
<tr>
<td>post 2012 flood</td>
<td>-590,000</td>
<td></td>
</tr>
</tbody>
</table>
• Spatial decrease in “flow” leads to deposition

• Spatial increase in bed-sand grain size leads to deposition

• Spatial decrease in bed-sand area (amount) leads to deposition

• Greatest deposition rates occur in eddies when greatest flow “deceleration” occurs between channel and eddy, and sand in upstream channel is as fine as possible and amount on upstream channel bed is relatively large
Substantial Gain (18 sites)
Grand Canyon River Guides
Adopt-a-Beach Site

Shinumo
Wash Camp
RM 29.4 L

Apr 2008
Oct 2010
Dec 2012
No Substantial Change (12 sites)
Substantial Loss (3 sites)

RM 51 L

11/17/2012
0
11/28/2012
-1
Sandbar Response to 2012 HFE based on Analysis of Images from Remote Cameras

• **Summary of evaluations at 33 sites for 2012 HFE response**
  - Substantial Gain (deposition): 18 sandbars (55% of sites)
  - No substantial change: 12 sandbars (36% of sites)
  - Substantial Loss (erosion): 3 sandbars (9% of sites)

• **Downstream trends**
  - All sites between RM 0 and RM 32 increased
  - Downstream from RM 32, split between sites of noticeable gain and no change, with a few showing noticeable loss

- **15 sites with cameras present during all 4 events**
  - In each year, a few sites did better, a few not as well, nothing stands out, too few sites to make any general conclusions

- **26 sites with cameras present in 2008 and 2012**
  - Sandbar larger in 2012: 4 sites, 3 above RM 32
  - Sandbar smaller in 2012: 7 sites
  - Sandbar about the same in 2012: 15 sites
Sandbars in Marble Canyon before 2012 Controlled Flood

- Some increase between October 2011 and October 2012
- Both 2011 and 2012 are low relative to early 1990’s and post-flood surveys
What is the effect of changing the hydrograph of the high flow?
• 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
Conclusions

• 2012 flood resulted in sandbar building, as observed in previous controlled floods

• Bar building not as widespread as 2008
  – But likely stronger than 2008 in upper Marble Canyon

• Effect of slower rate of flood recession
  – Not a dramatically different response
  – May have resulted in bars that are less steep in a few locations
  – Need more observations, numerical modeling, and probably controlled laboratory experiments to better understand the effect of hydrograph shape
Long-term average size of sand deposits along the channel margin depends on how much deposition occurs during each flood, how much erosion occurs between each flood, and how frequently the floods occur.
These are all hypothetical trajectories of long-term sandbar change. We are hoping for the best, which can be accomplished by any scenario where the aggregate amount to sand deposited by floods exceeds the aggregate amount of erosion that occurs in the intervening times.