USGS AZ WSC sampling near the PARIA RIVER AT LEES FERRY, AZ gage during a flood on the Paria River

US D-74 sampler suspended from fixed reel on bridge

ISCO 6712 automatic pump sampler

INTAKE location for the ISCO 6712 pump sampler
Between July 1 and November 17, 2012, ...

- **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

**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**

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

**Little to no fine sediment accumulated in lower 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
- 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

91,000
101,000
551,000
782,000

water
Sand transport past RM30

Sand mass balance in upper Marble Canyon
Review from last year’s knowledge assessment

From scale analysis of Exner equation, sandbar deposition rates depend on spatial changes in sand flux (depth-integrated product of flow and concentration) into eddies, which in turn depend on

• flow conditions
• bed-sand grain size
• bed-sand area (amount)
\[
\frac{\Delta \eta}{\Delta t} \propto - \frac{\Delta \left( u_*^{4.5} h A_b D_b^{-2.5} \right)}{\Delta x}
\]

- 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
In the previous slide, there is no distinction made between new tributary supplied sand and background sand storage, both are combined in $D_b$ and $A_b$.

Thus, if background sand storage in a reach of the Colorado River decreases in volume or coarsens over time, then similar magnitudes of tributary sand inputs will result in progressively lower eddy-sandbar deposition rates over a series of artificial floods released from Glen Canyon Dam.

Conversely, if background sand storage remains constant over time, then similar magnitudes of tributary sand inputs will result in similar eddy-sandbar deposition rates over a series of artificial floods released from Glen Canyon Dam.

And, if background sand storage in a reach of the Colorado River increases in volume or fines over time, then similar magnitudes of tributary sand inputs will result in progressively higher eddy-sandbar deposition rates over a series of artificial floods released from Glen Canyon Dam.
Suspended-sand concentration

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

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

(after Topping and others, USGS OFR 2010-1128, 2010)
Bed-sand area (amount)

(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></th>
<th>Upper Marble Canyon</th>
<th>Lower Marble Canyon</th>
</tr>
</thead>
<tbody>
<tr>
<td></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>
Intervening dam operations greatly affect sand concentrations and therefore sandbar deposition rates during controlled floods...

Should sand accounting be reset to zero every July?

- Twice as much sand accumulated in upper Marble Canyon during the months preceding the 2012 flood than during the months preceding the 2004 flood.

- But sand concentrations at RM30 during the 2012 flood were only ~68% of those during the 2004 flood.

This apparent paradox was the result of the scour of >1 million metric tons of sand from upper Marble Canyon during the high equalization flows of May-August 2011.
New tools for this year

• Sand budgets on web by April 2013

• Station discharge, QW, and sediment data on web at selected stations now at

  http://www.gcmrc.gov/discharge_qw_sediment/