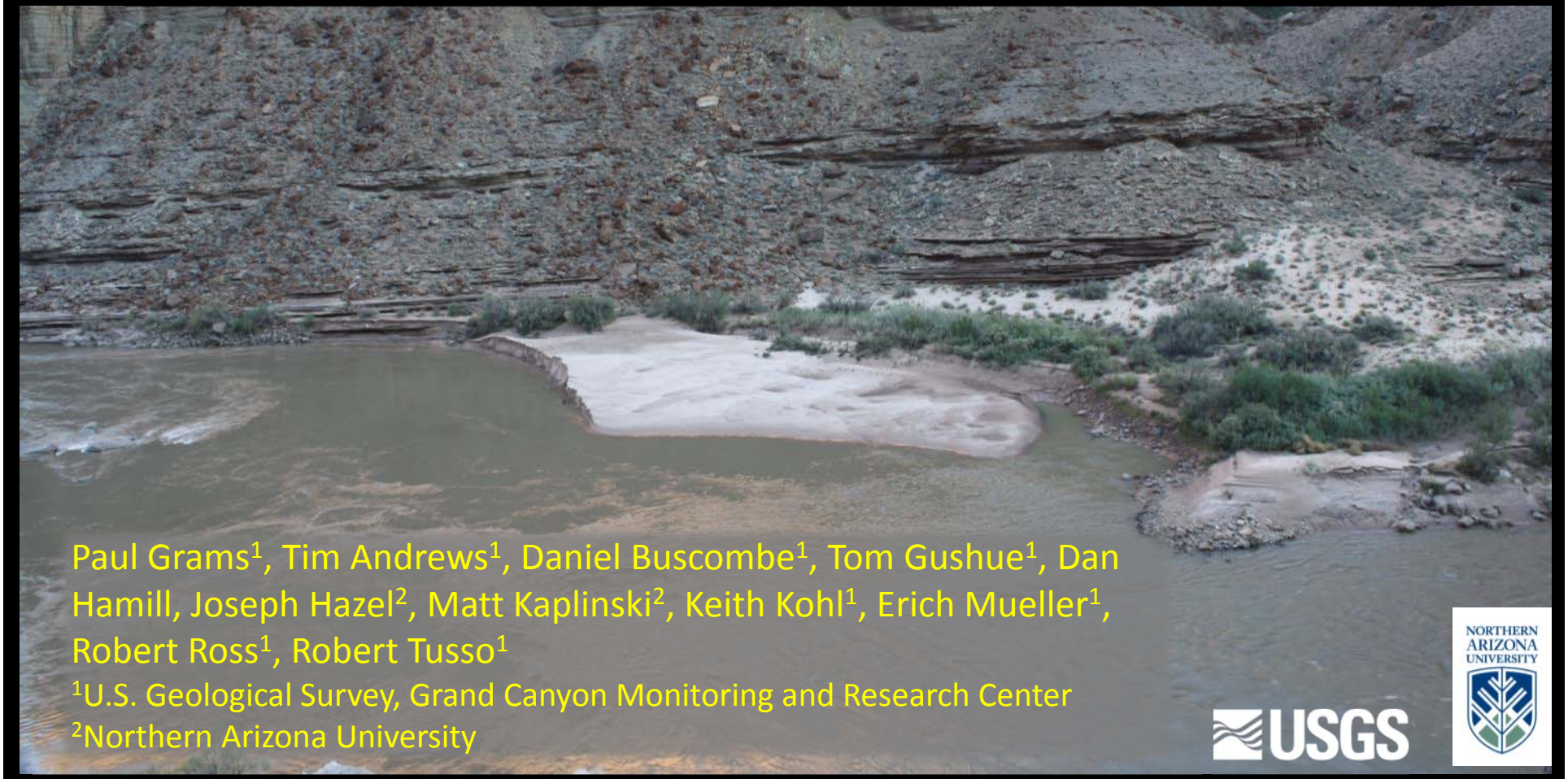
Sandbars and Sediment Storage in Marble and Grand Canyons: Response to Recent High-flow Experiments and Long-term Trends

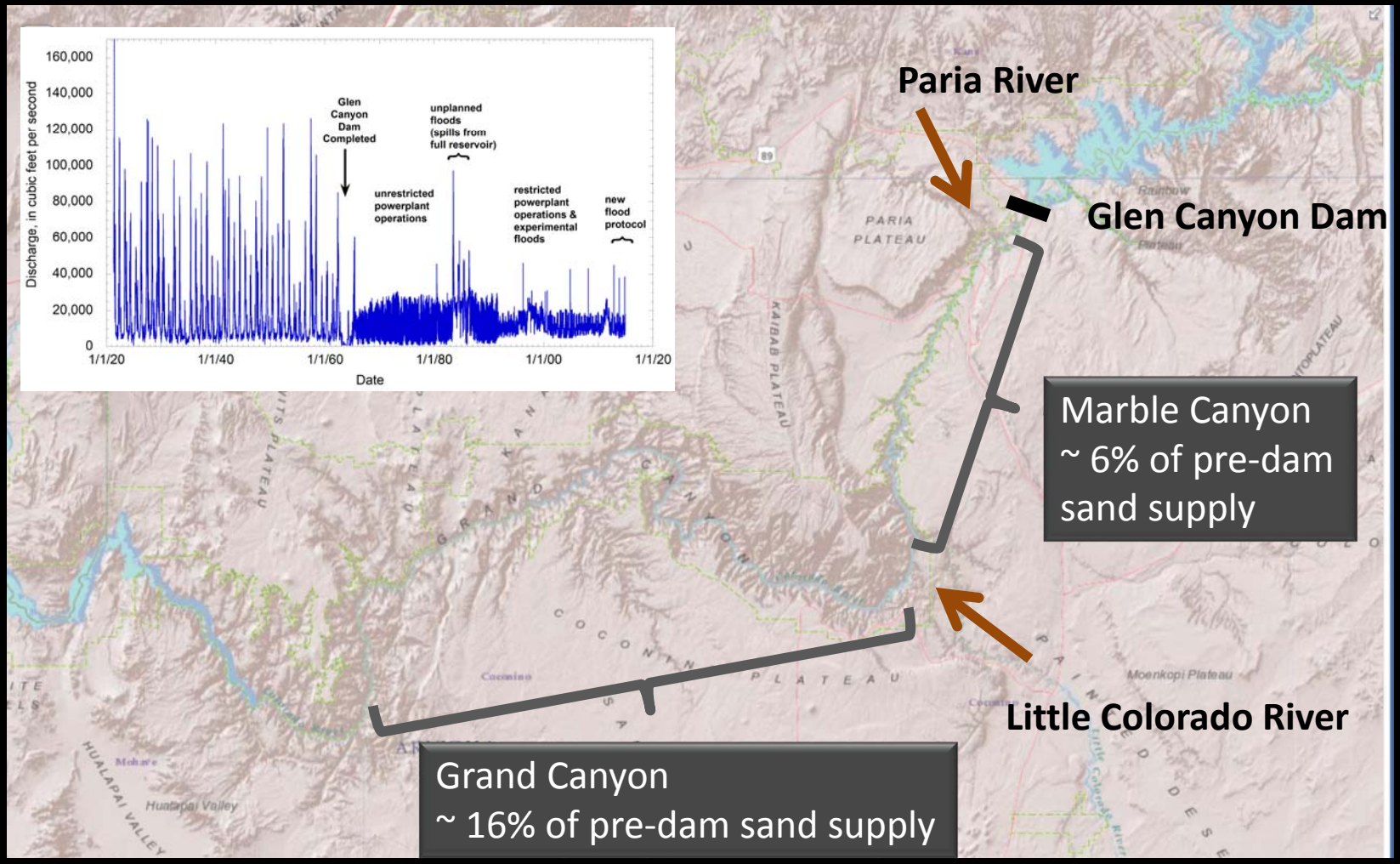


Paul Grams[1], Tim Andrews[1], Daniel Buscombe[1], Tom Gushue[1], Dan Hamill, Joseph Hazel[2], Matt Kaplinski[2], Keith Kohl[1], Erich Mueller[1], Robert Ross[1], Robert Tusso[1]

[1]U.S. Geological Survey, Grand Canyon Monitoring and Research Center

[2]Northern Arizona University

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



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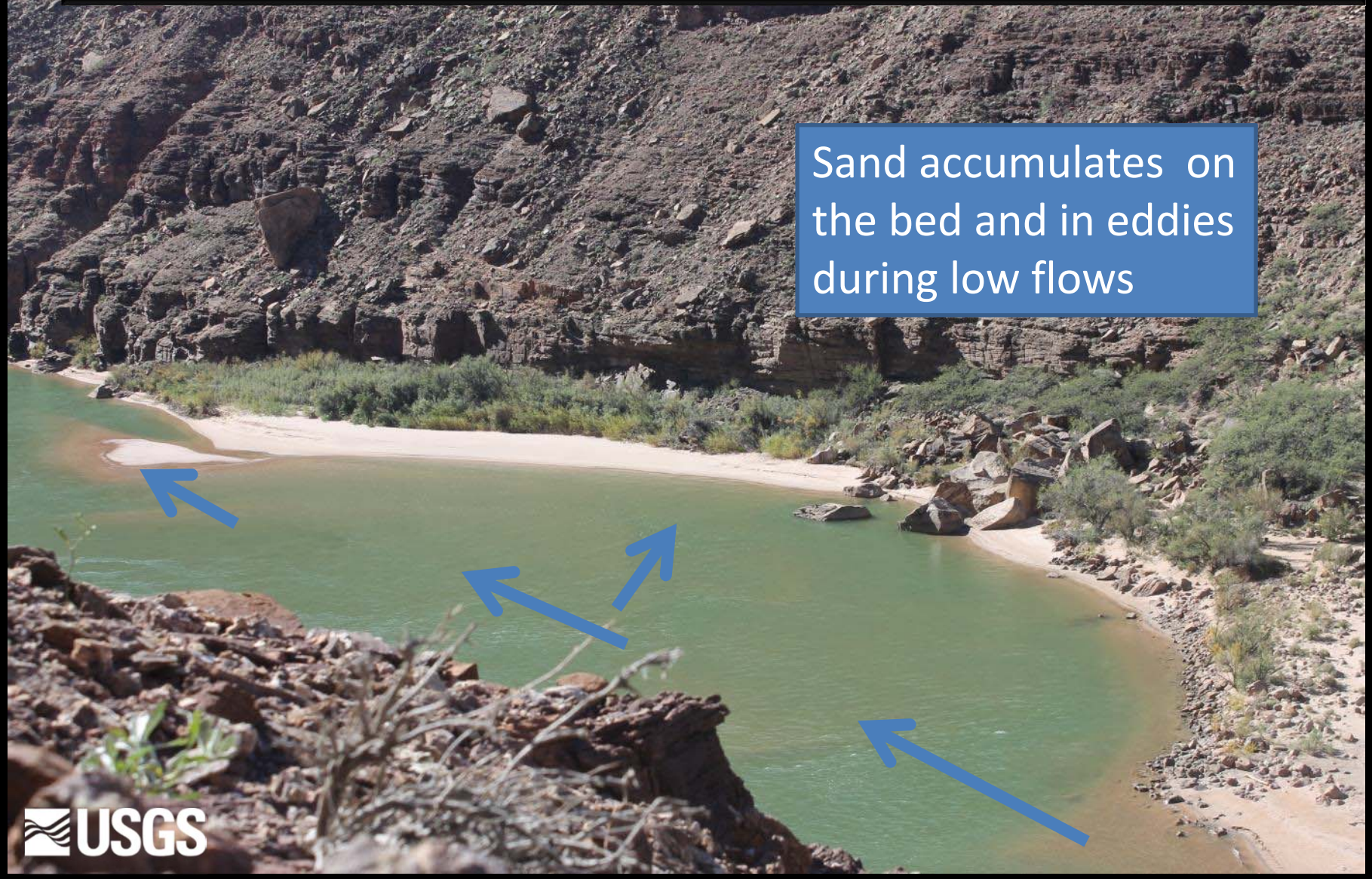
(UGSG gage 09383000: http://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09383000)

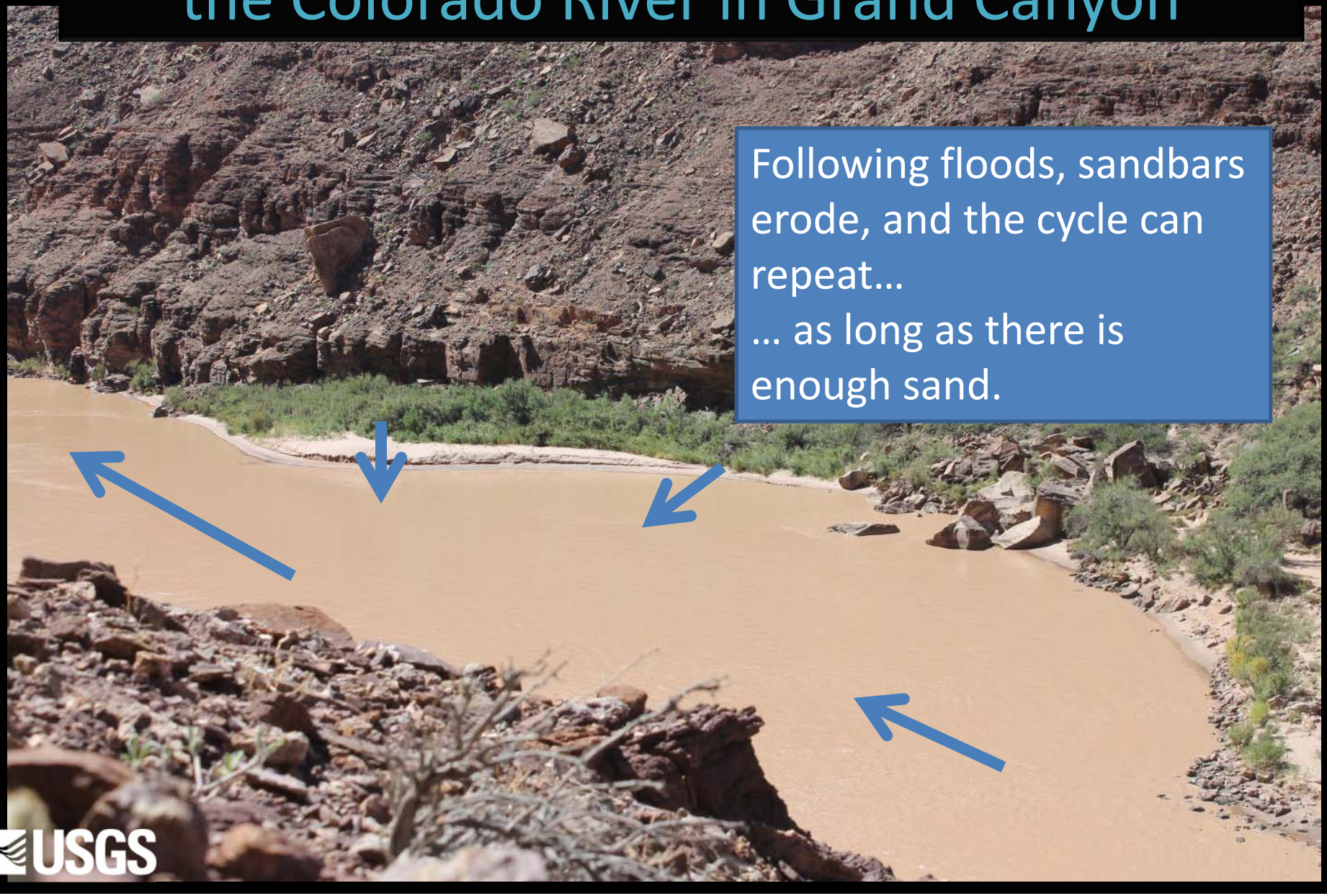
Sandbars and the sand mass balance on the Colorado River in Grand Canyon



Sandbars and the sand mass balance on the Colorado River in Grand Canyon

USGS

Sandbars and the sand mass balance on the Colorado River in Grand Canyon

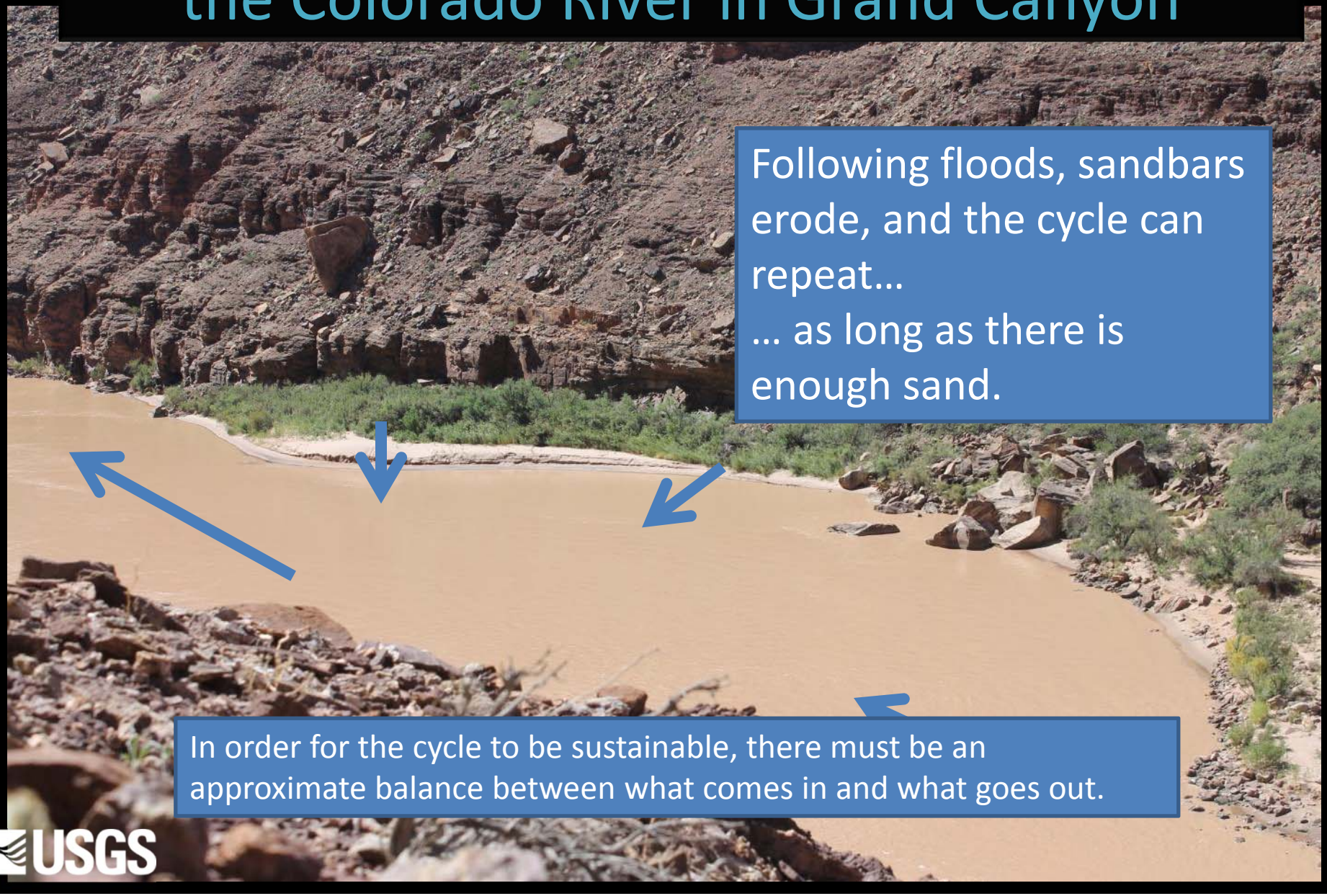


Following floods, sandbars erode, and the cycle can repeat…

… as long as there is enough sand.

USGS

Sandbars and the sand mass balance on the Colorado River in Grand Canyon



Following floods, sandbars erode, and the cycle can repeat…
… as long as there is enough sand.

In order for the cycle to be sustainable, there must be an approximate balance between what comes in and what goes out.

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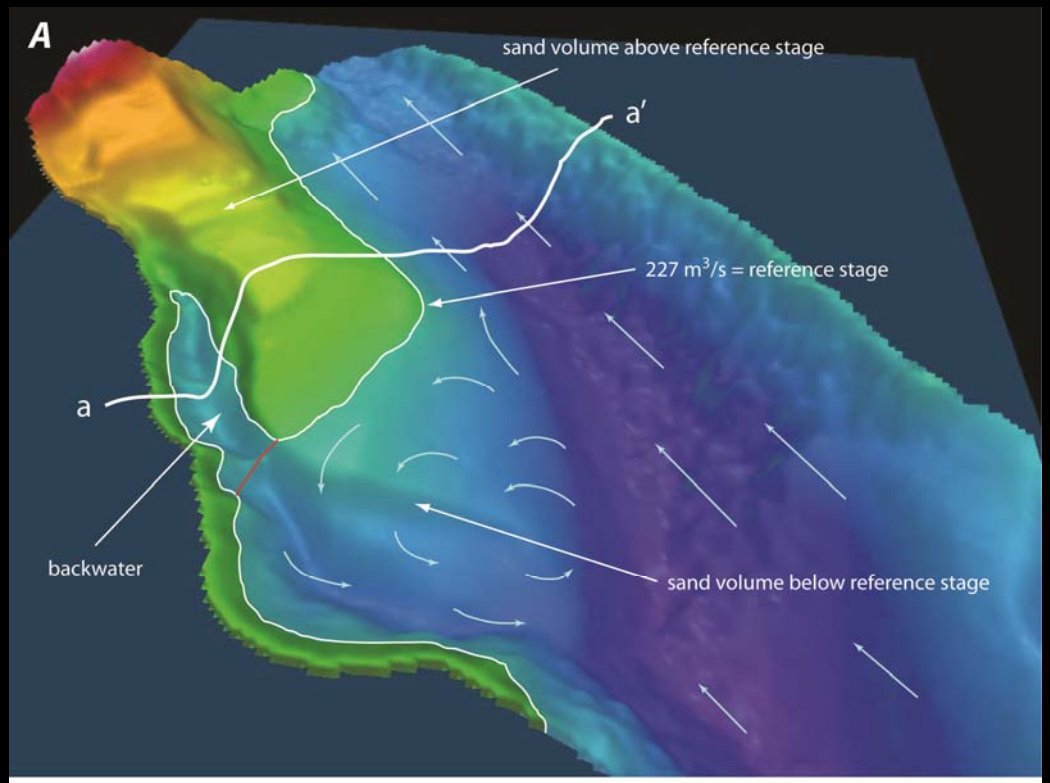
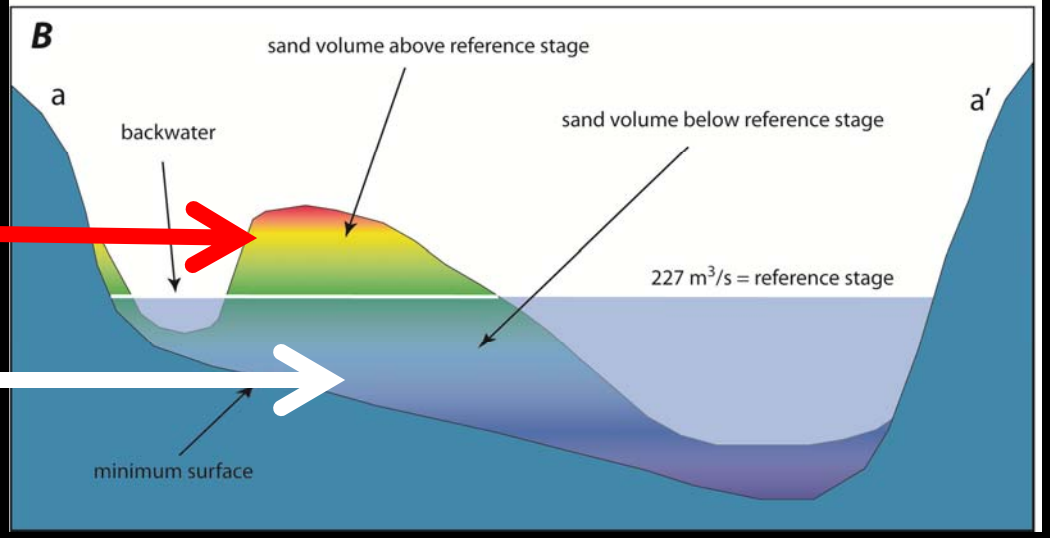
Sandbar Deposition

- Sand Supply
  - More sand → 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)

USGS

Grams and others (2010)

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)

USGS

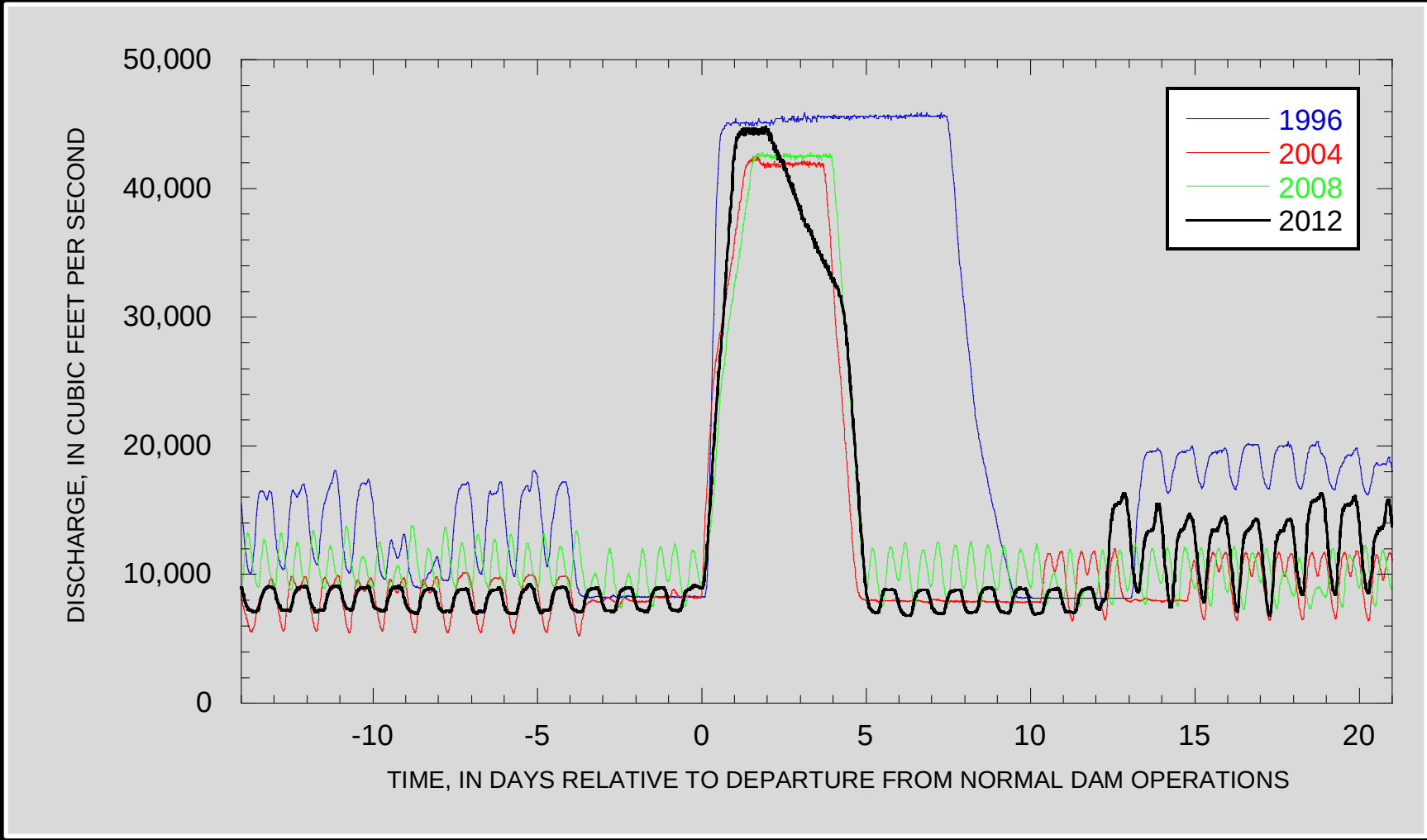
Photos at www.gcmrc.gov/sandbar/

RM 35L, Nautiloid Camp

USGS

Photos at www.gcmrc.gov/sandbar/

2012 Controlled Flood

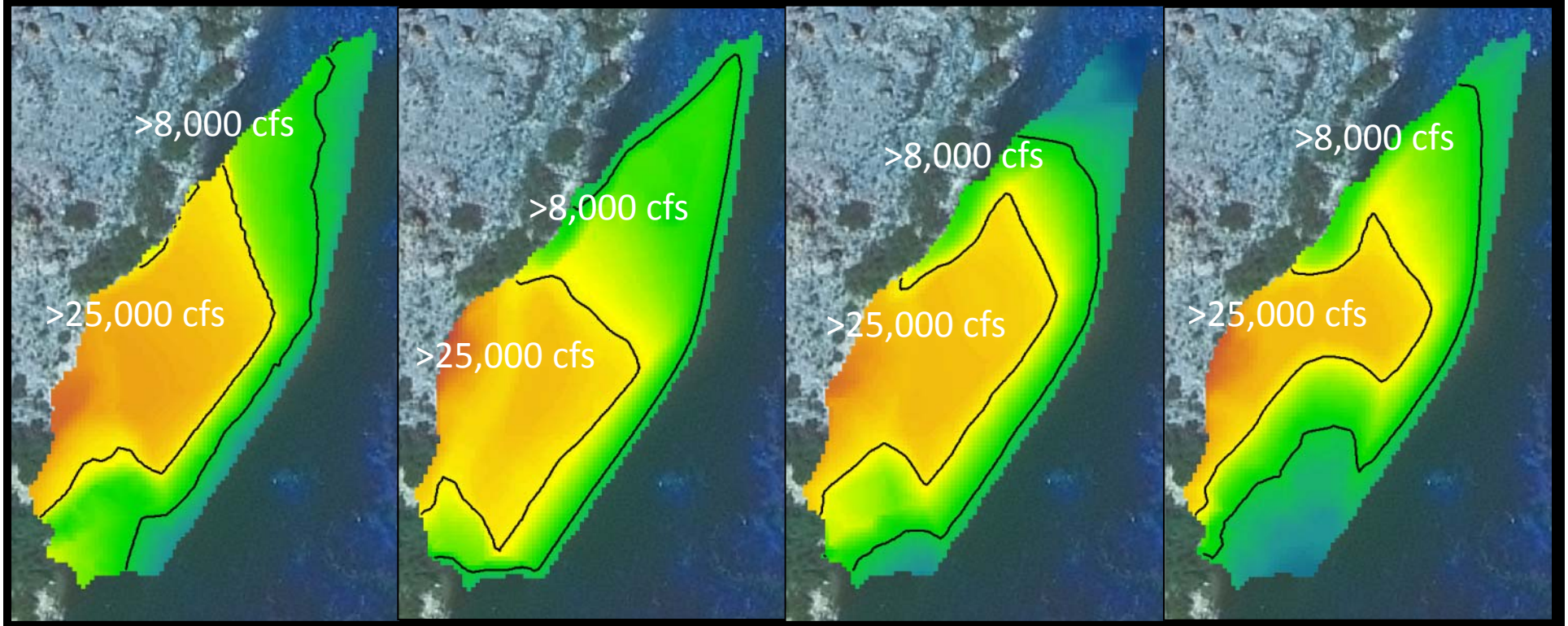


- 24 hr. upramp from 7,000 to 43,400 ft^3/s
- 24 hr. peak at 43,400 ft^3/s
- 53 hr. downramp from 43,400 to 31,200 ft^3/s
- 24 hr. downramp from 31,200 to 7,000 ft^3/s

USGS

(UGSG gage 09383000: http://www.gcmrc.gov/discharge_qw_sediment/station/GCDAMP/09383000)

Sandbar Shape – RM 30

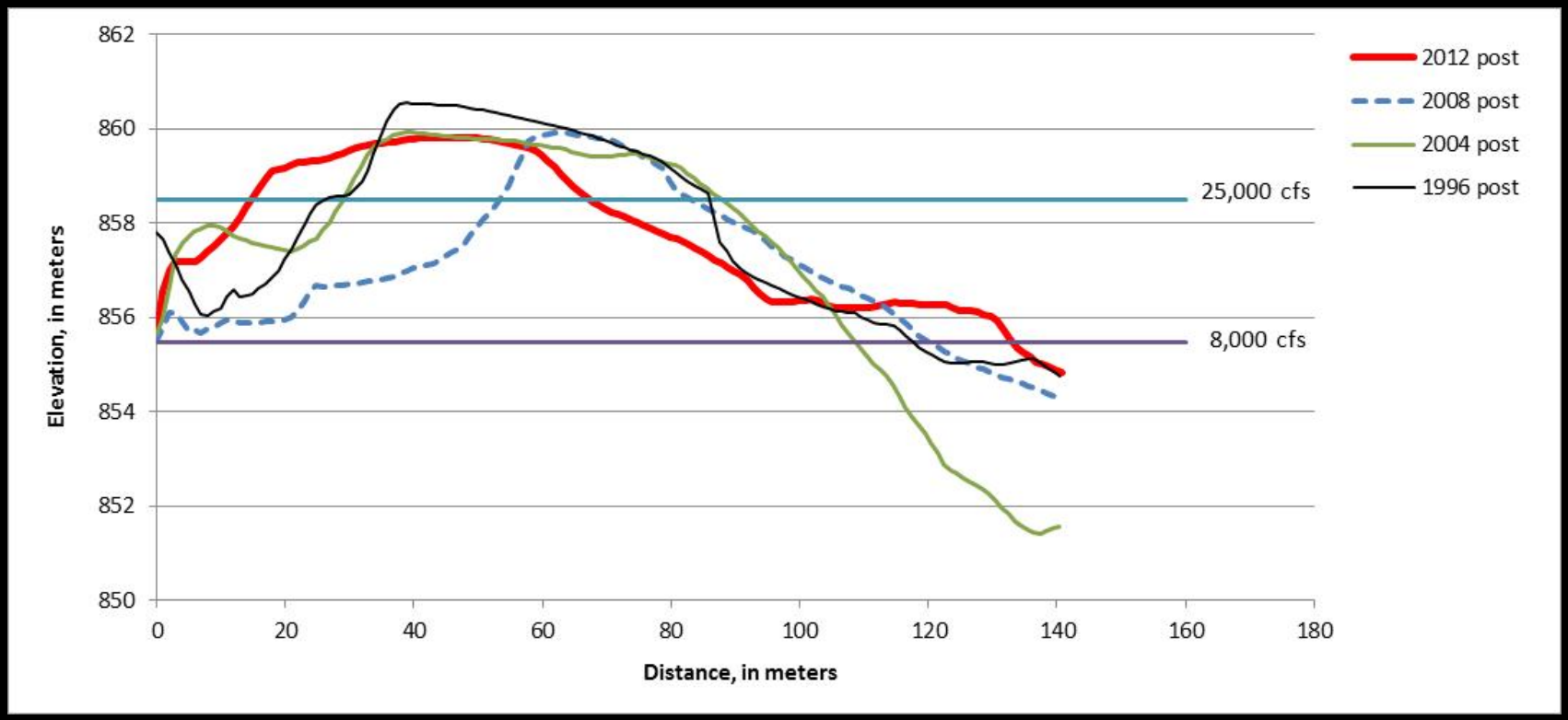


1996 post-HFE 2012 post-HFE 2004 post-HFE 2008 post-HFE

- *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

USGS

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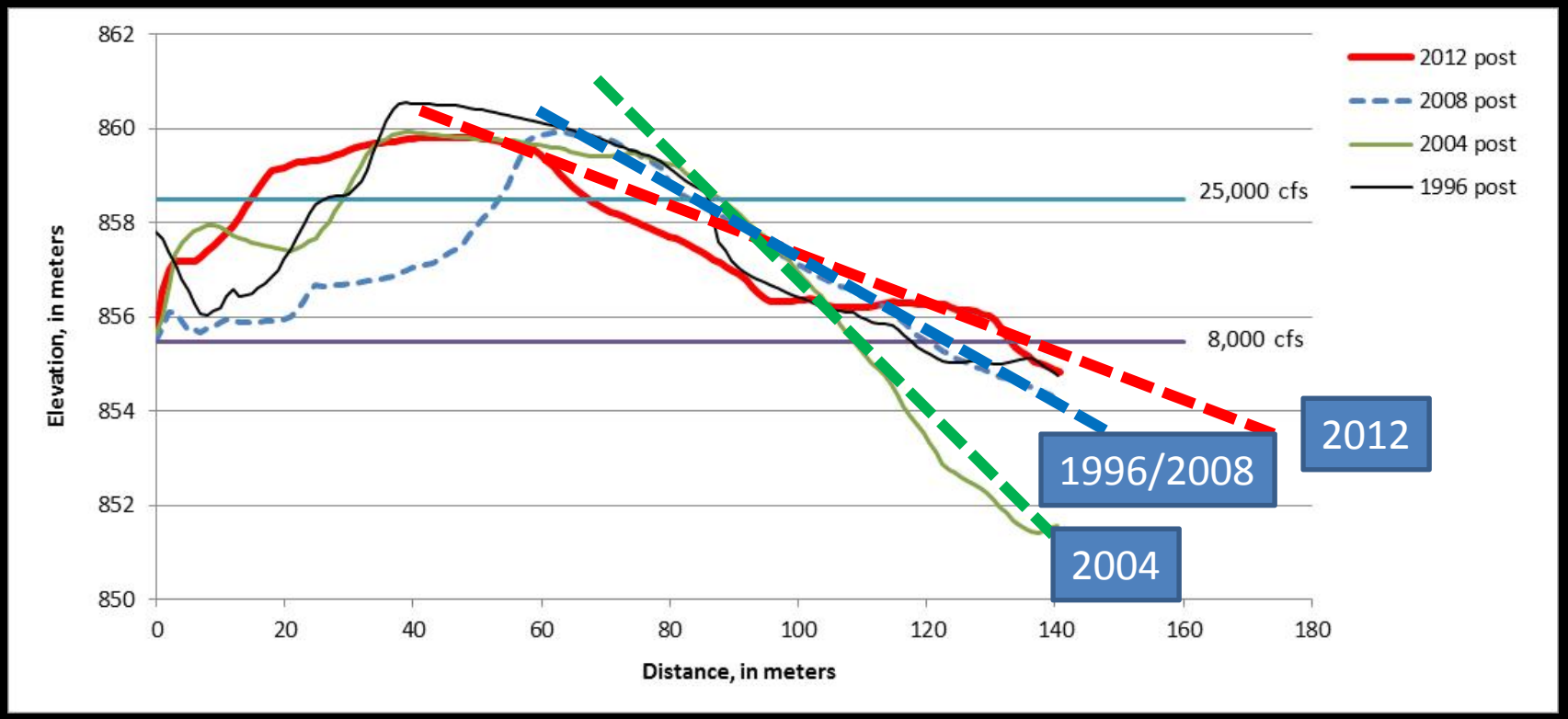
Sandbar Shape – RM 30



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USGS

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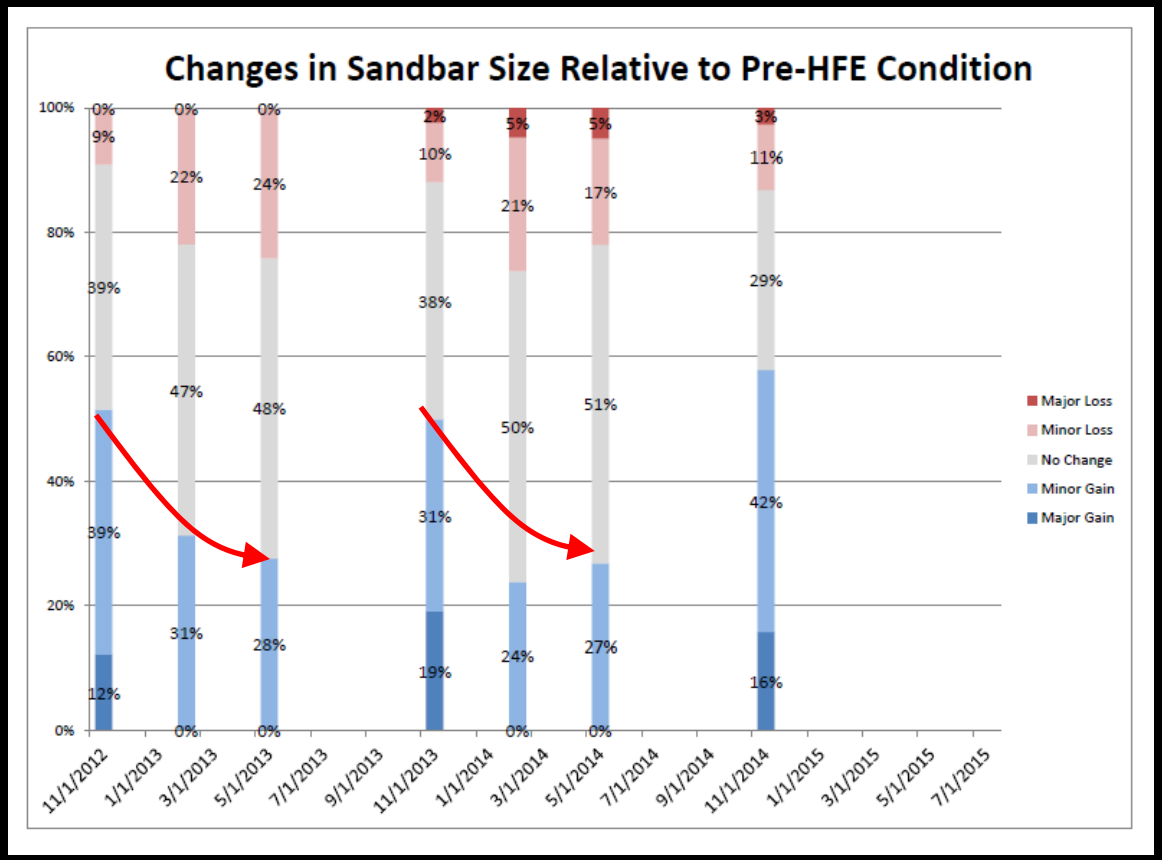
2014 HFE

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

Photos at www.gcmrc.gov/sandbar/

USGS

Response to HFE Protocol



2012 HFE 2013 HFE 2014 HFE

- 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/

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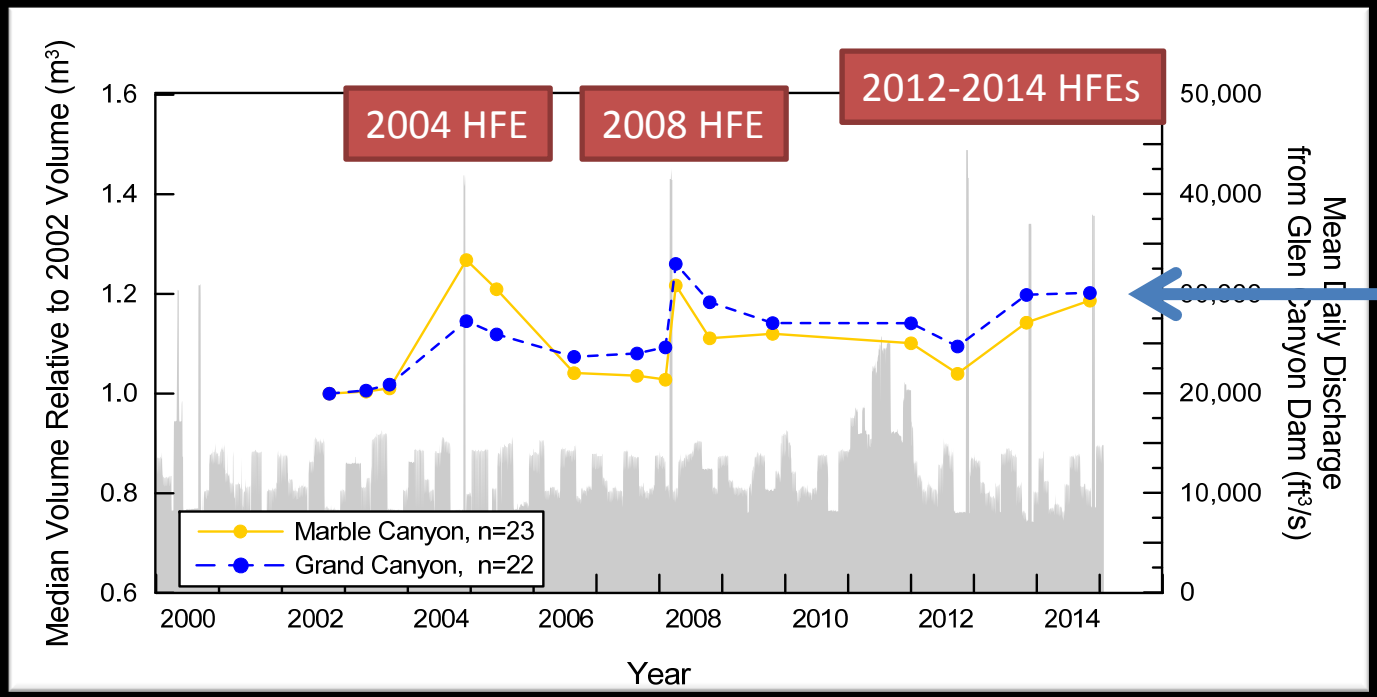
Preliminary results, subject to review and revision – do not cite

Sandbars: 2002-present



~10 months after HFEs, bars still larger than before start of protocol

- 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.

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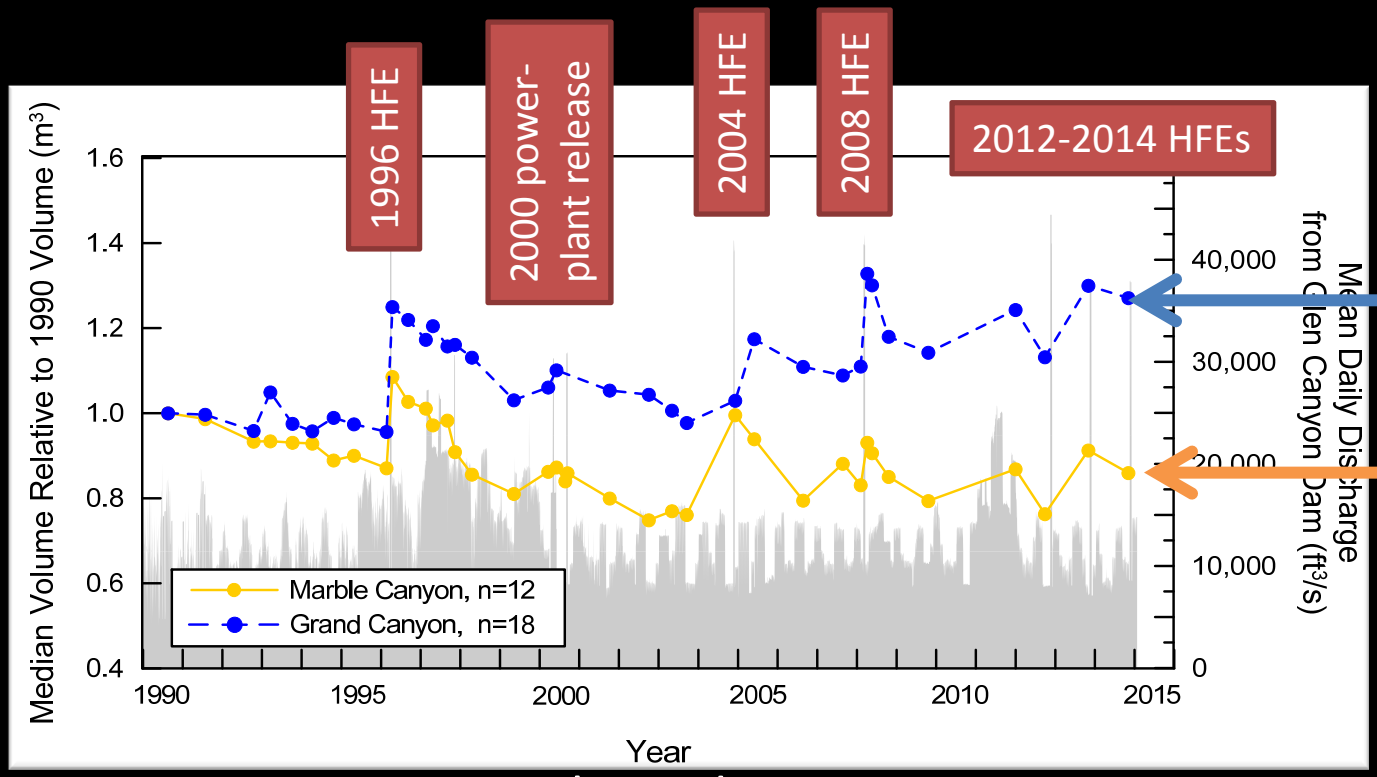
Sandbars: 1990-present



Grand Canyon: bars about as large as ever measured

Marble Canyon: bars larger than low point; smaller than early 1990's

- 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

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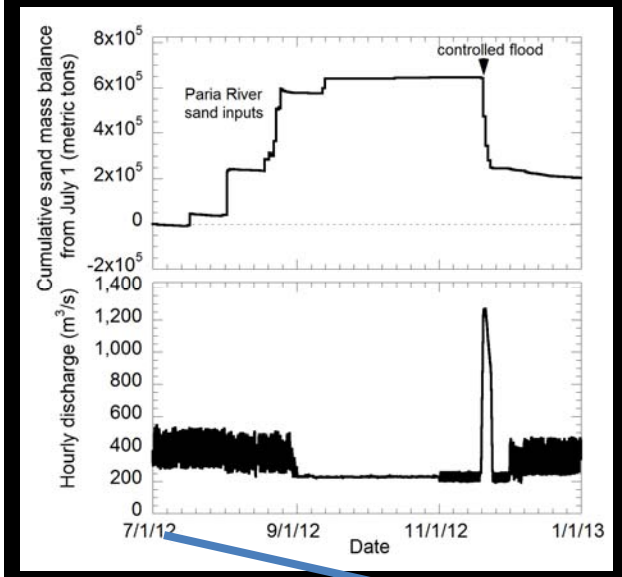
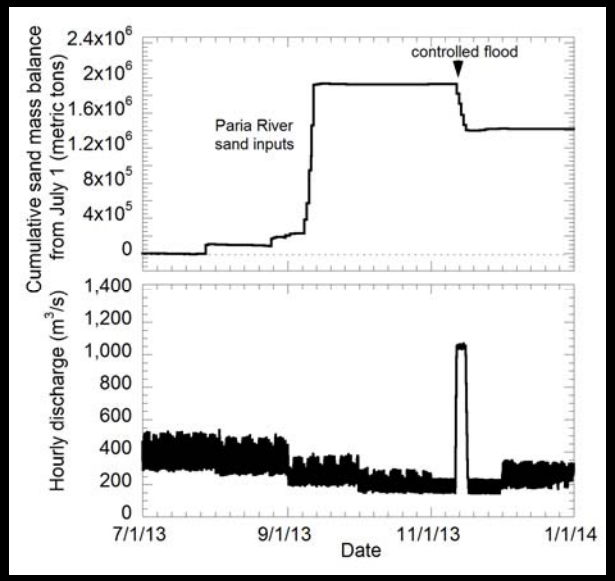
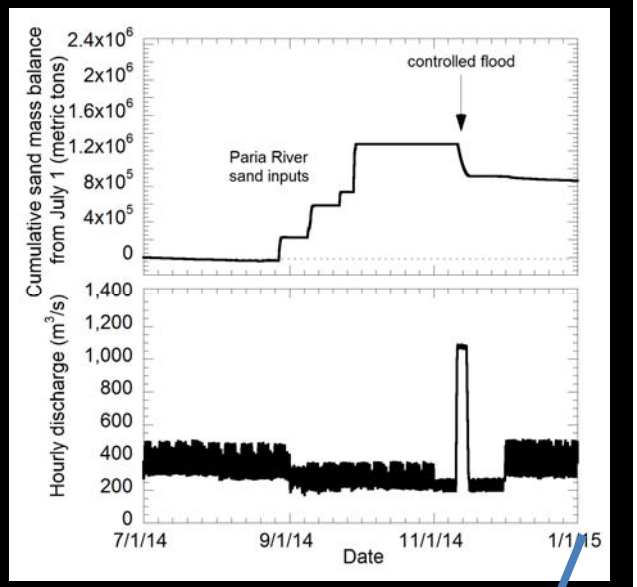
Sand Storage in Marble Canyon During HFE Protocol



2012 HFE

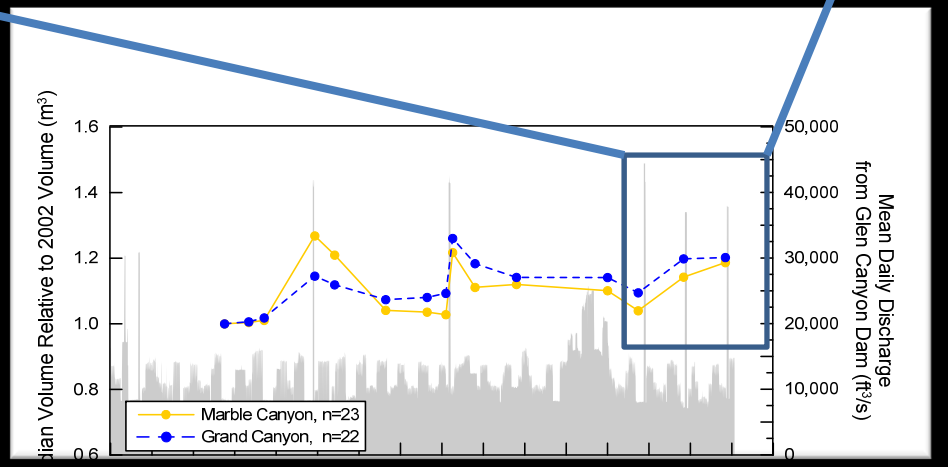


2013 HFE



2014 HFE

- 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



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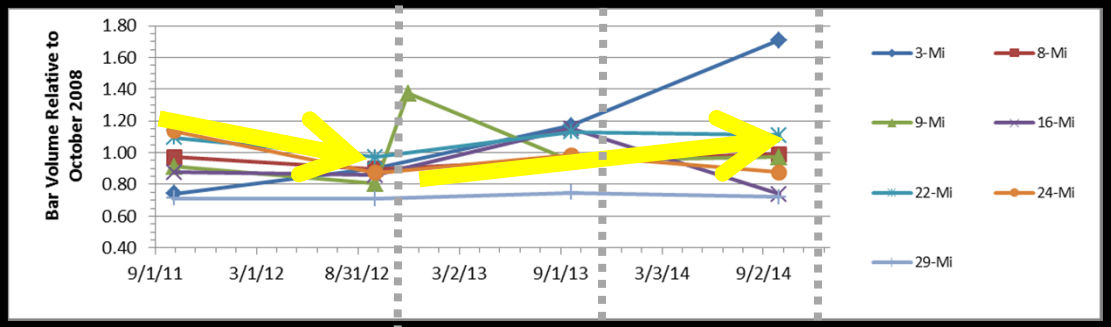
Sandbars 10 months following 2012 and 2013 HFEs

2012 HFE

2013 HFE

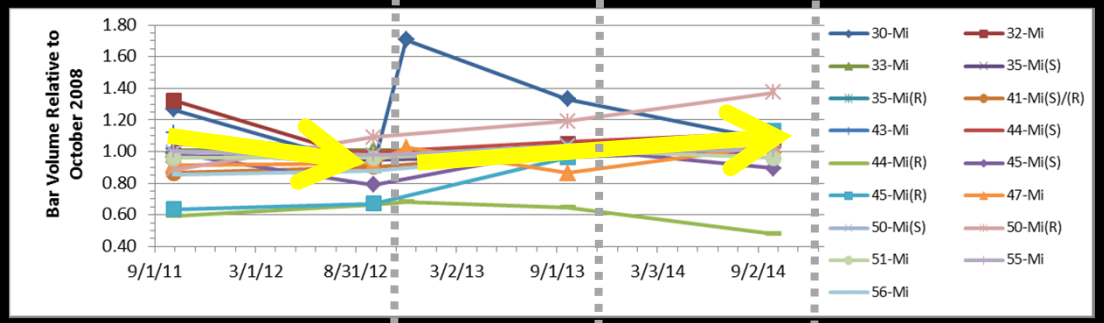
2014 HFE



Upper Marble Canyon (RM 0-29)

5 of 7 sites larger than Oct. 2011

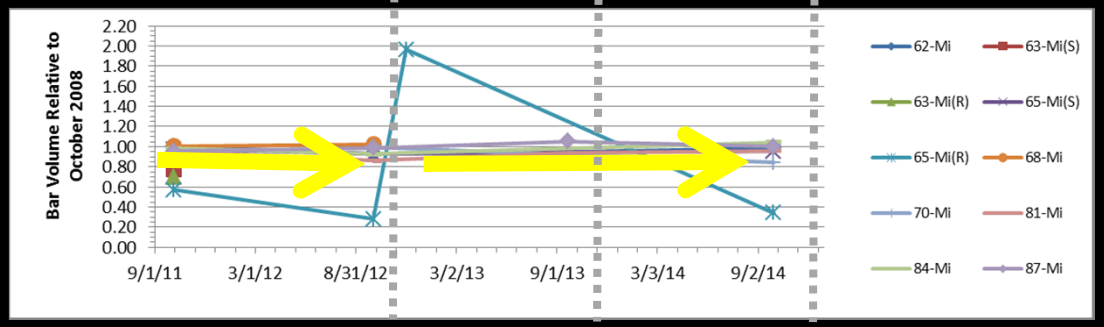
2 of 7 sites larger than Oct. 2008



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

USGS

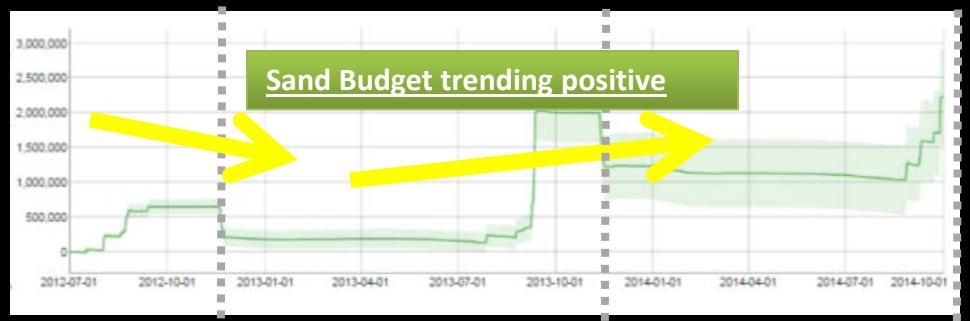
Preliminary results, subject to review and revision – do not cite

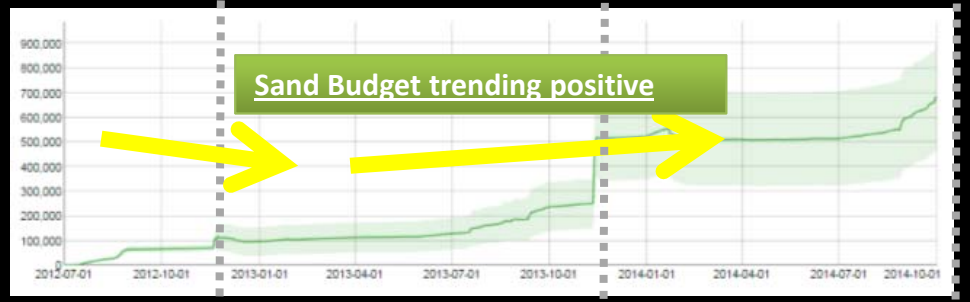
Sandbars 10 months following 2012 and 2013 HFEs

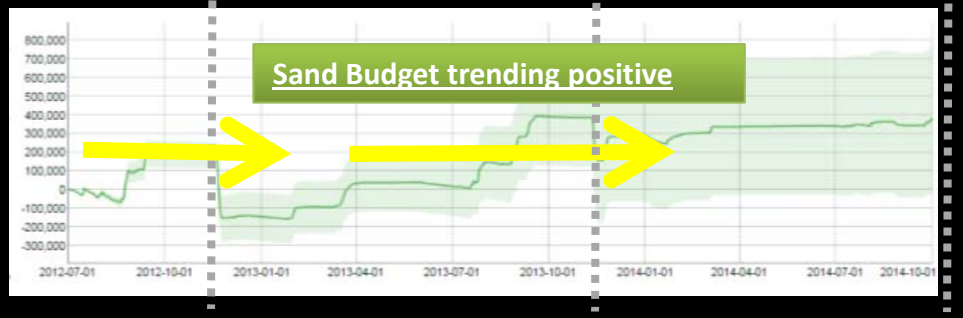
2012 HFE

2013 HFE

2014 HFE







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5 of 7 sites larger than Oct. 2011

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Lower Marble Canyon (RM 30-62)
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USGS

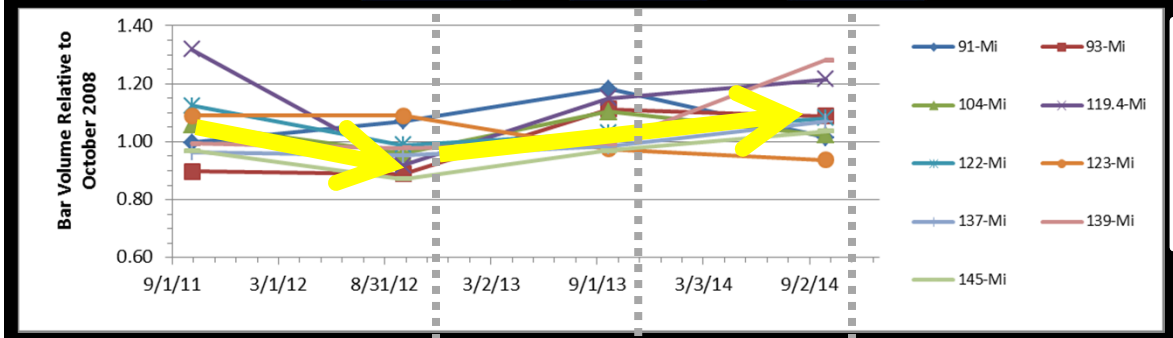
Preliminary results, subject to review and revision – do not cite

Sandbars 10 months following 2012 and 2013 HFEs

2012 HFE

2013 HFE

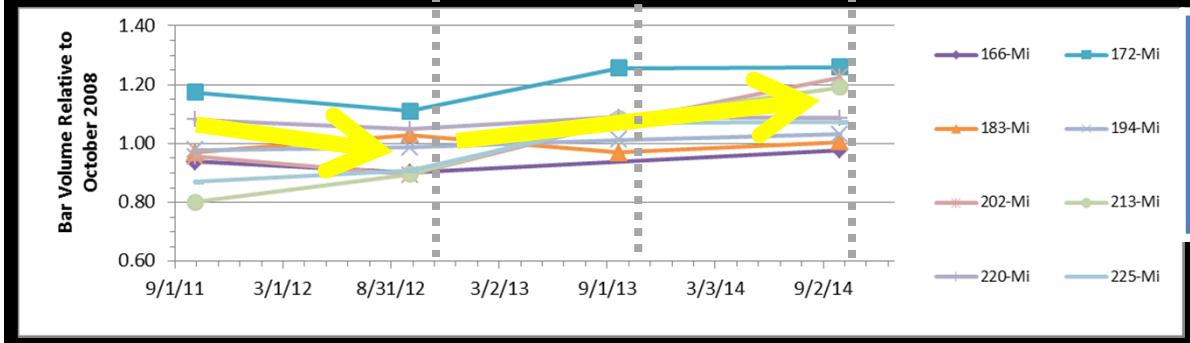
2014 HFE



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

USGS

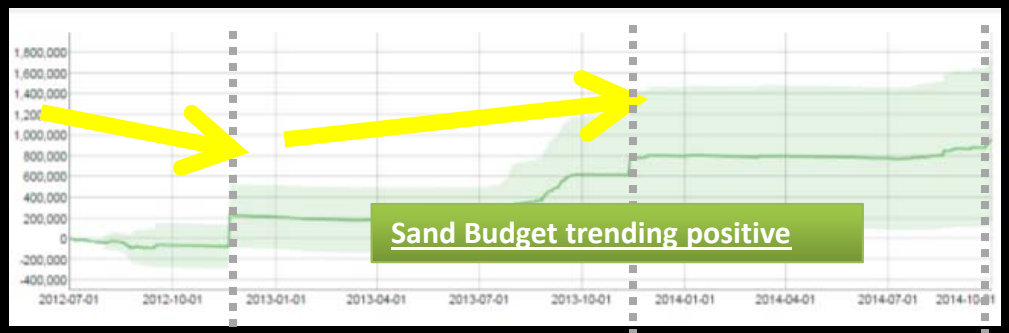
Preliminary results, subject to review and revision – do not cite

Sandbars 10 months following 2012 and 2013 HFEs

2012 HFE

2013 HFE

2014 HFE



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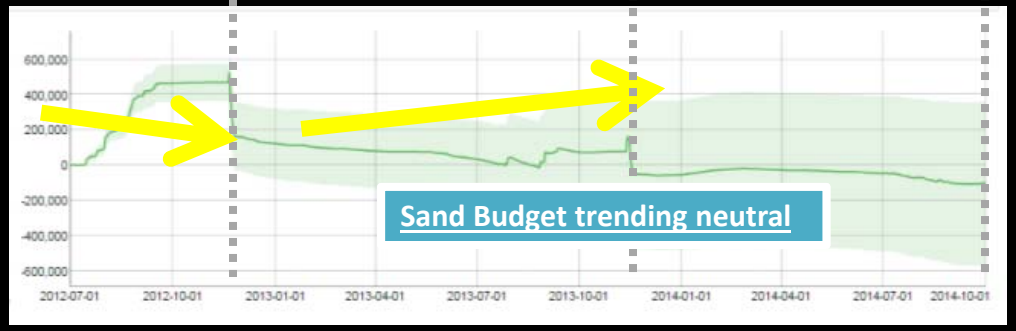

W. Central Grand Canyon (RM 166-225)

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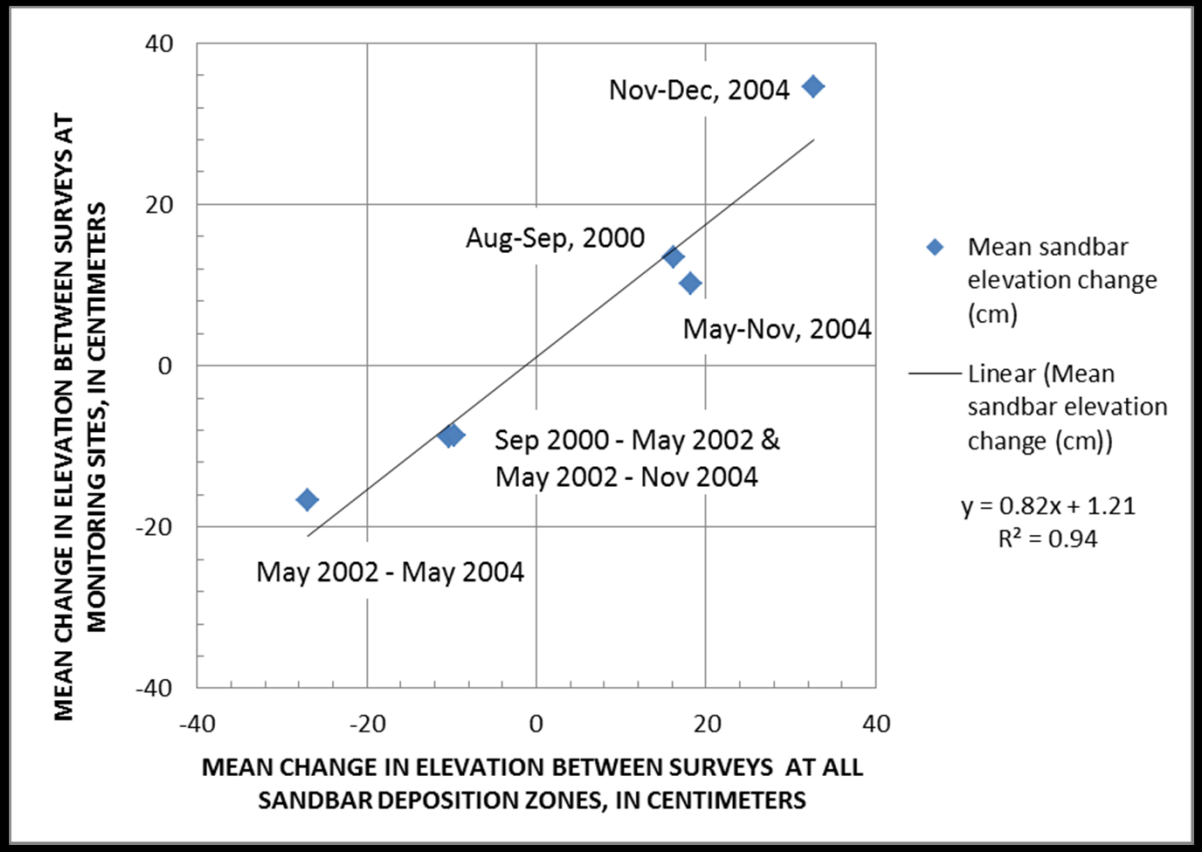
Sandbar Monitoring Sites Compared to all Sandbars in 6 Short Reaches

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

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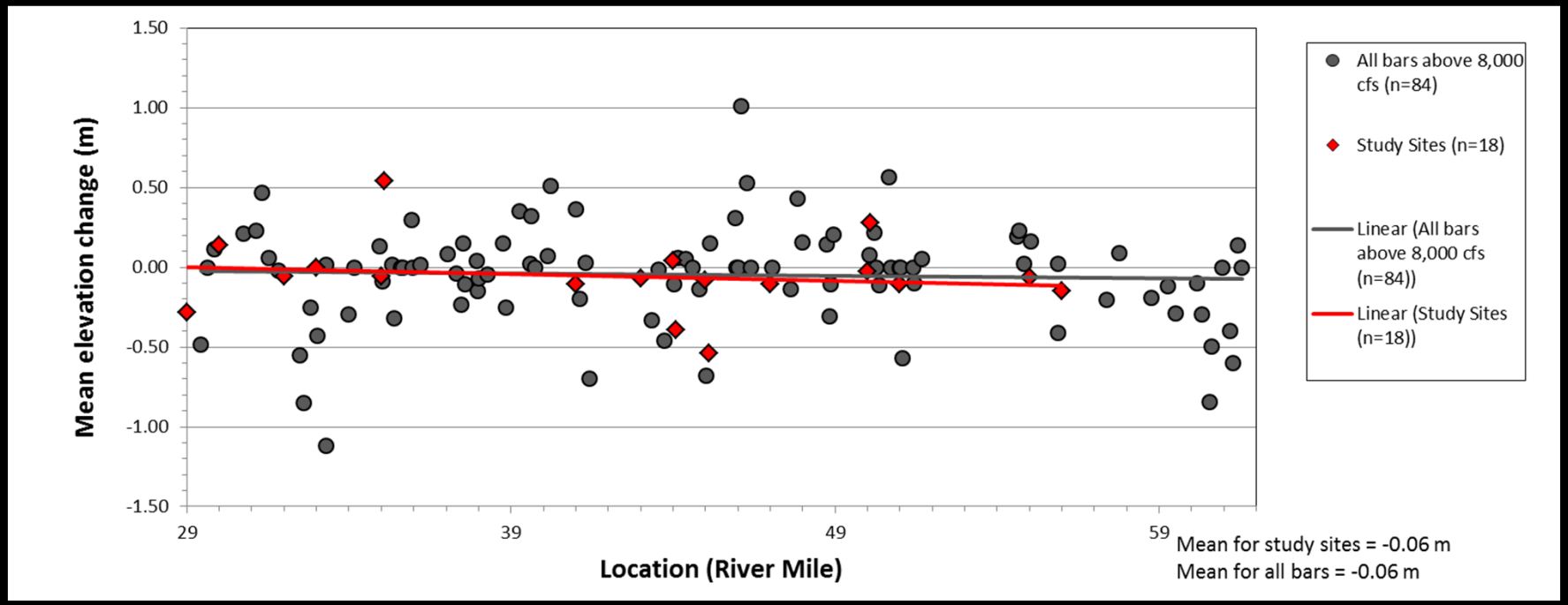
In Lower Marble Canyon, long-term monitoring sites are representative of large sample of bars



Sample	Mean Change	Maximum Deposition	Maximum Erosion	Standard Deviation
18 Monitoring Sites	-0.06 m	0.54 m	-0.54 m	0.23 m
84 Bars above 8,000 ft^3/s elevation	-0.06 m	1.01 m	-1.12 m	0.35 m

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

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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

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