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

GCMRC Project 3

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photo : Michael Collier

Outline

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)

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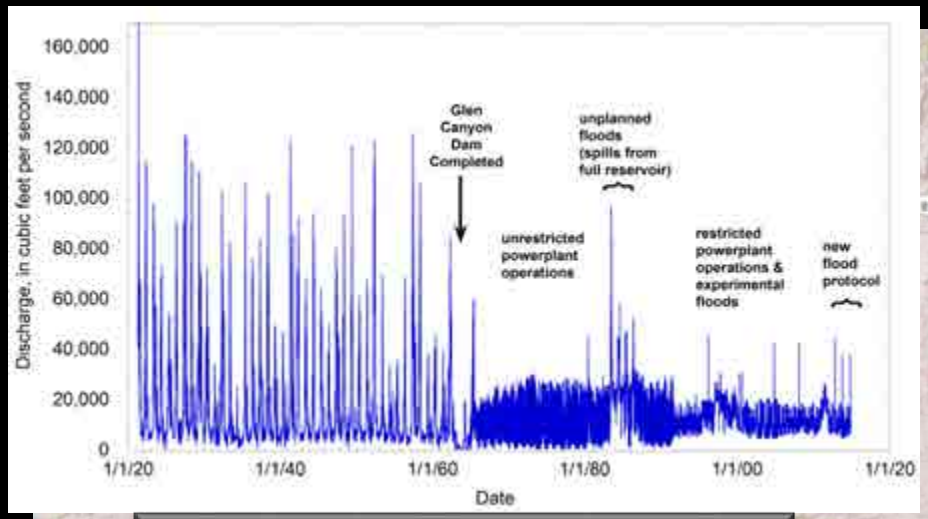
photo : Michael Collier

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



Colorado River at Lees Ferry, AZ

Paria River

Glen Canyon Dam

Marble Canyon
~ 6% of pre-dam sand supply

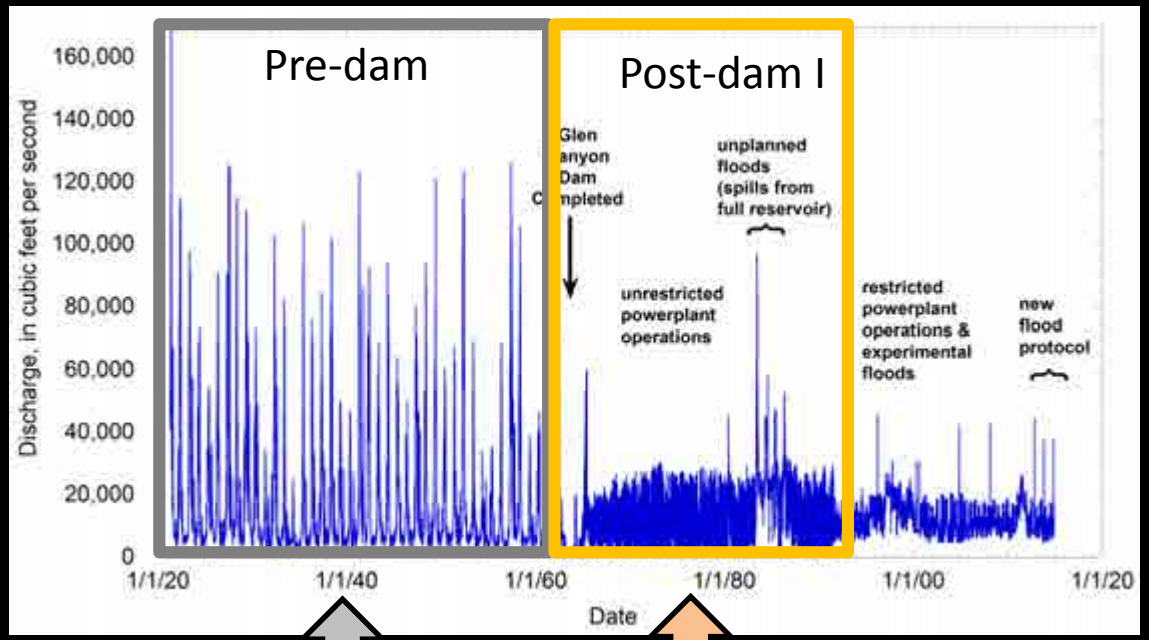
Little Colorado River

Grand Canyon
~ 16% of pre-dam sand supply

85 to 95% reduction in supply coupled with ~20% reduction in mean annual flow → sediment deficit

Topping et al. (2000)

USGS

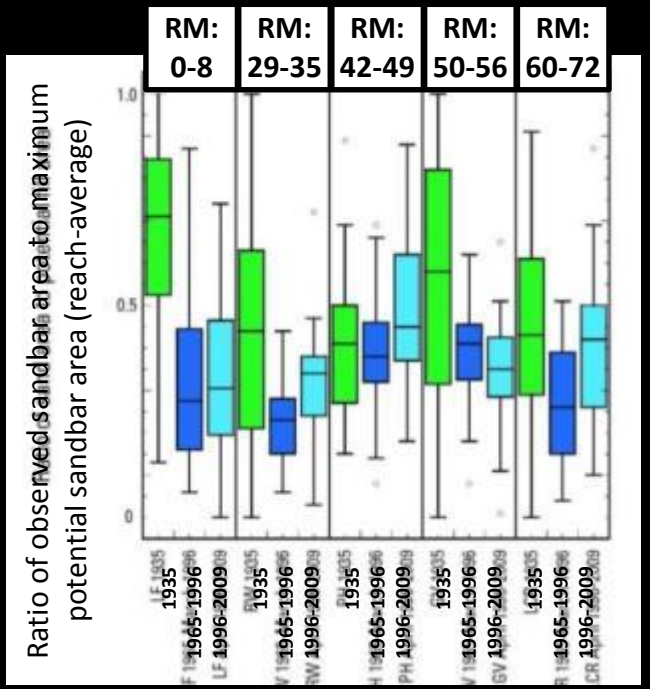


Pre dam:

- 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)

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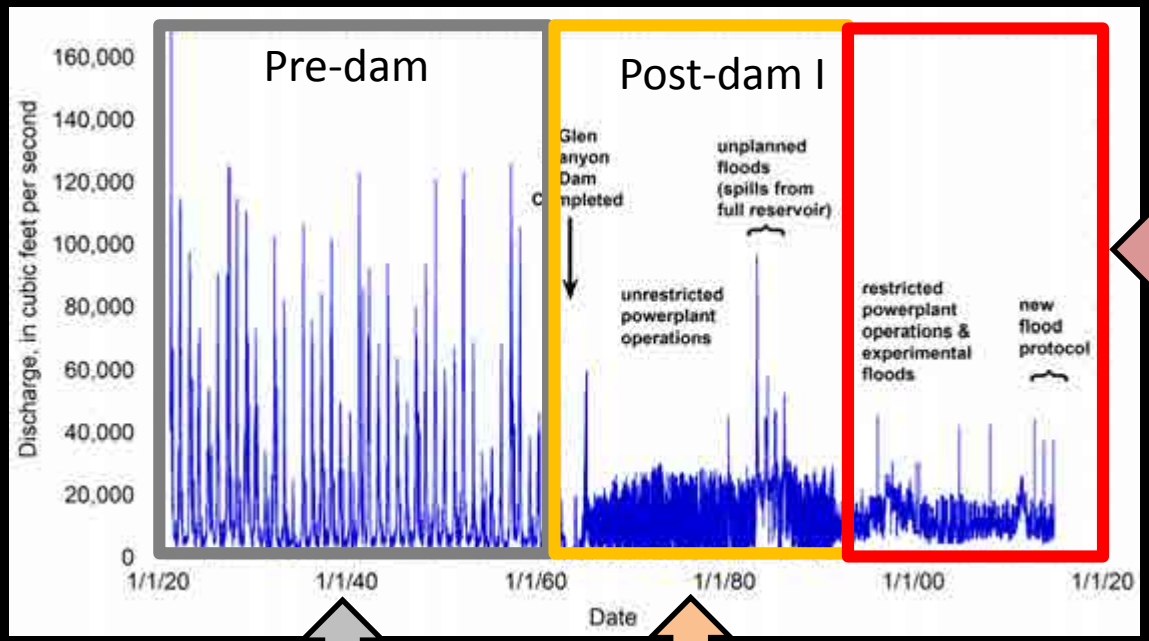

Post dam II:
- Restricted hydropower operations
- controlled floods triggered by sand supply

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?

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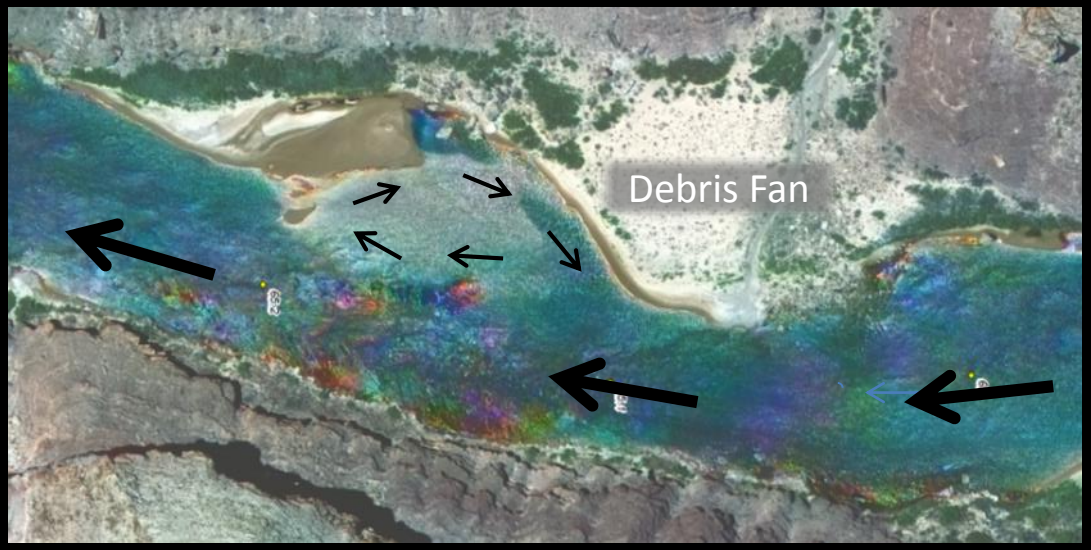
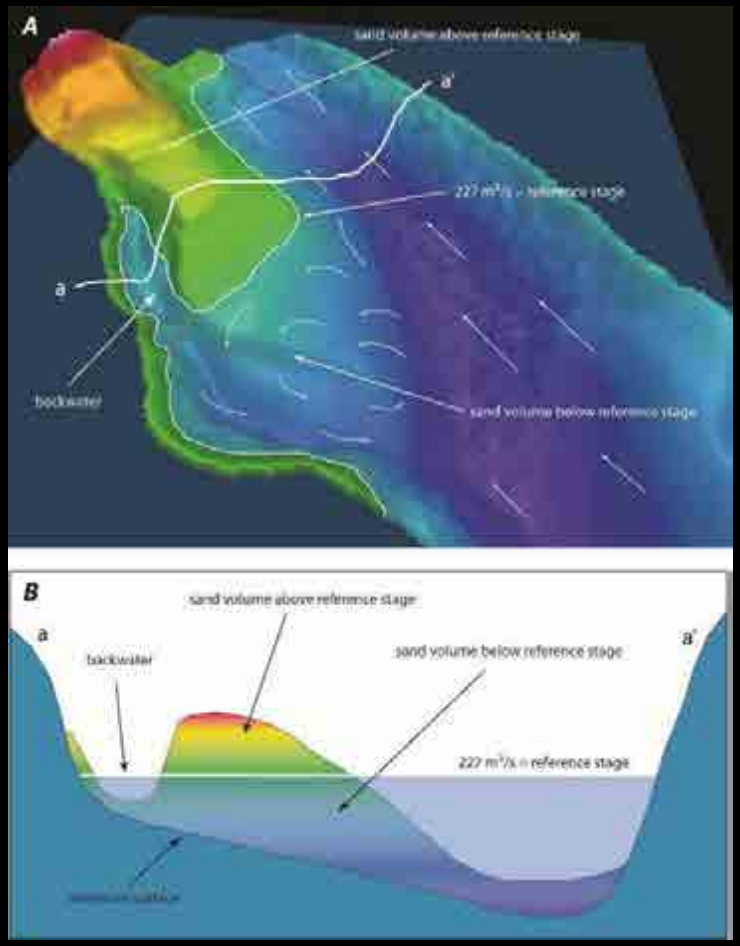
Eddy-deposited sandbars in Grand Canyon

- 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?

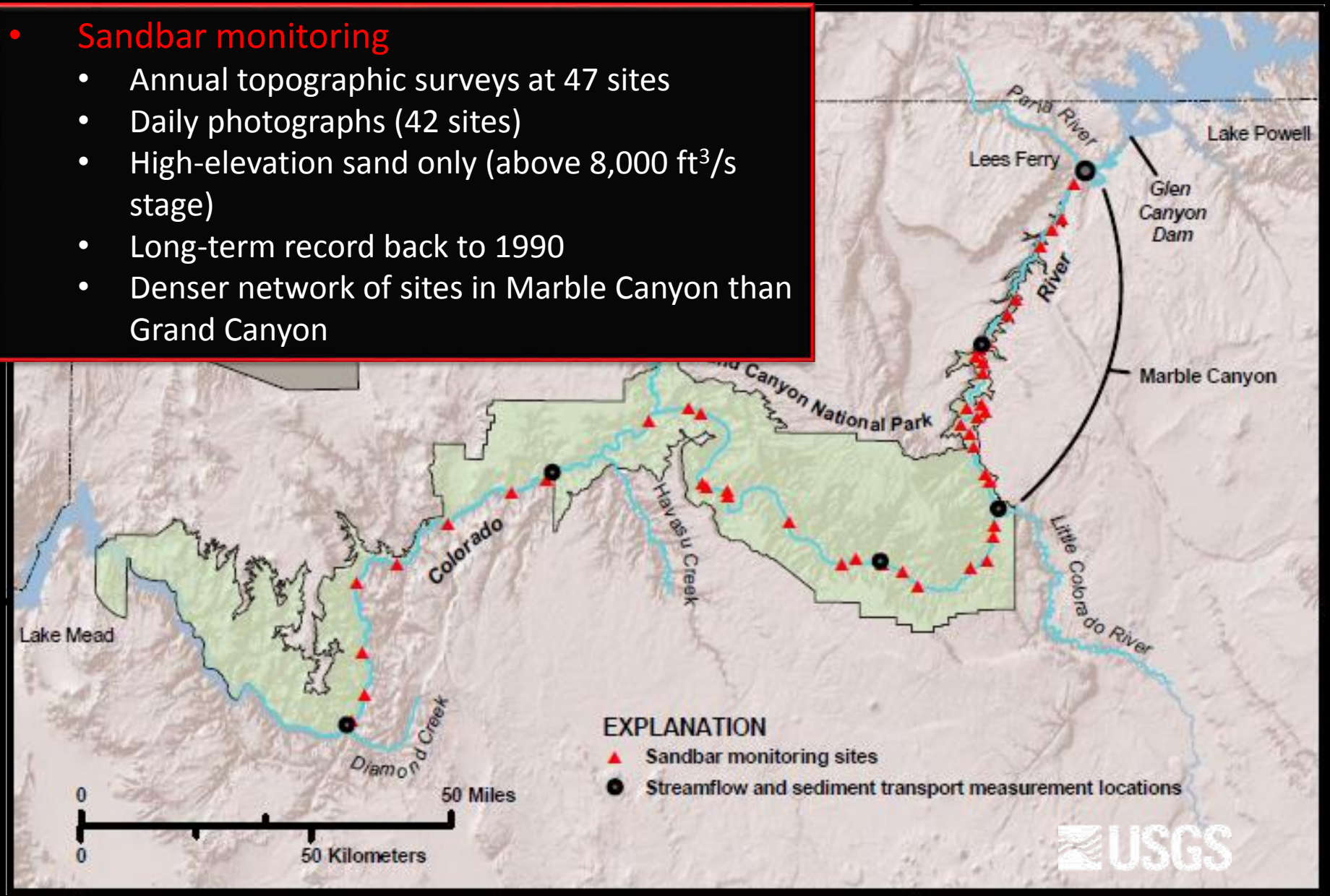


- Topographic Surveys

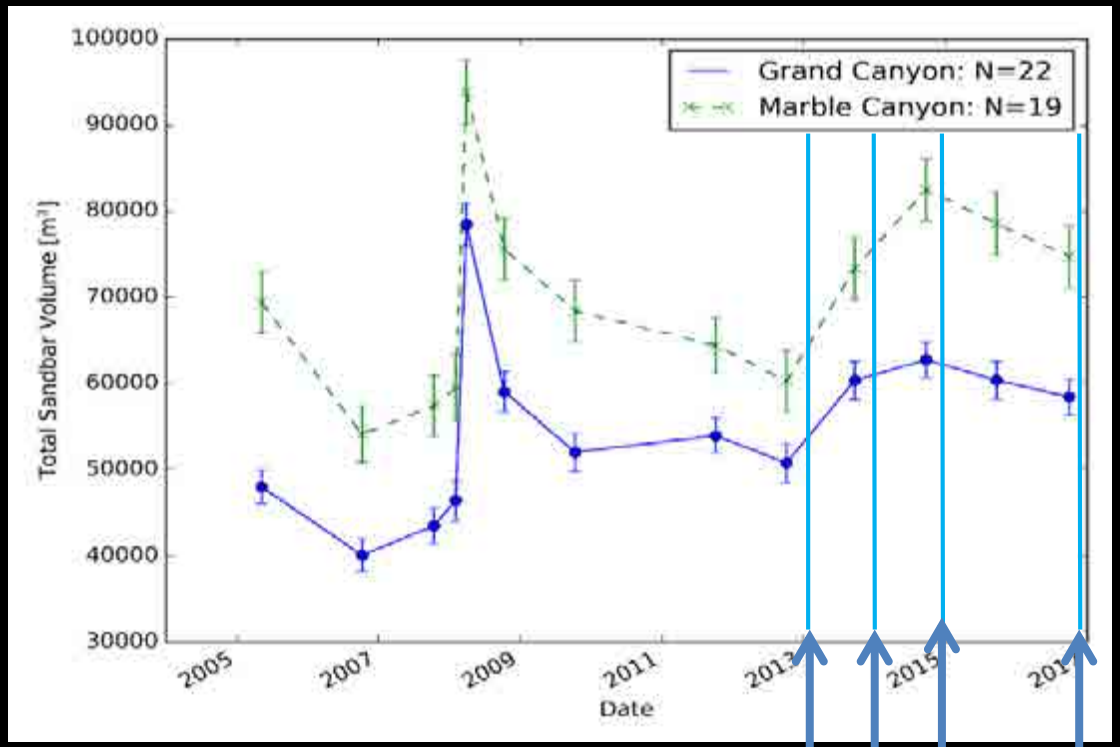
- Photographs from automated remote cameras.

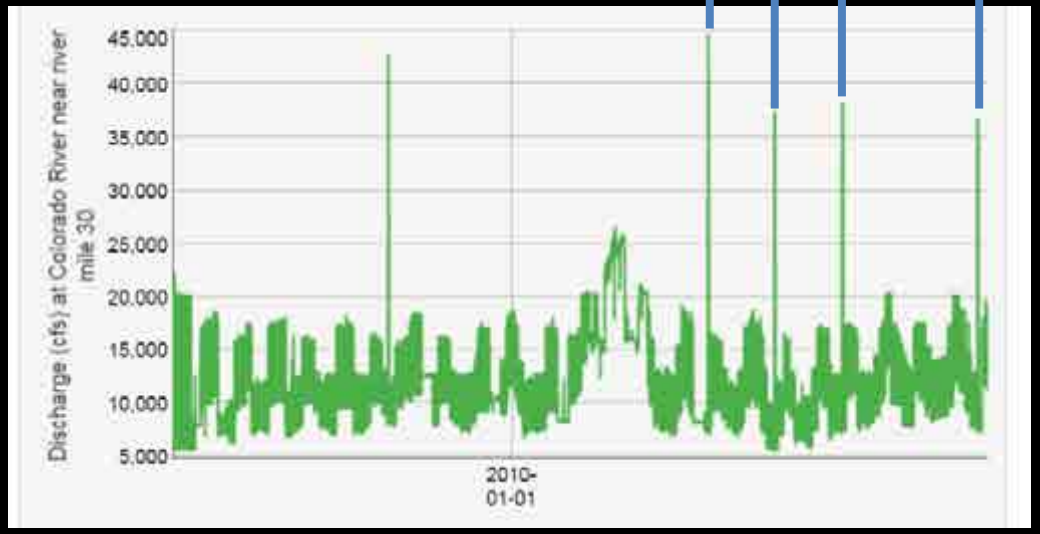
Major Components of Sandbar and Sediment Storage Monitoring

- Sandbar monitoring
  - Annual topographic surveys at 47 sites
  - Daily photographs (42 sites)
  - High-elevation sand only (above 8,000 ft^3/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

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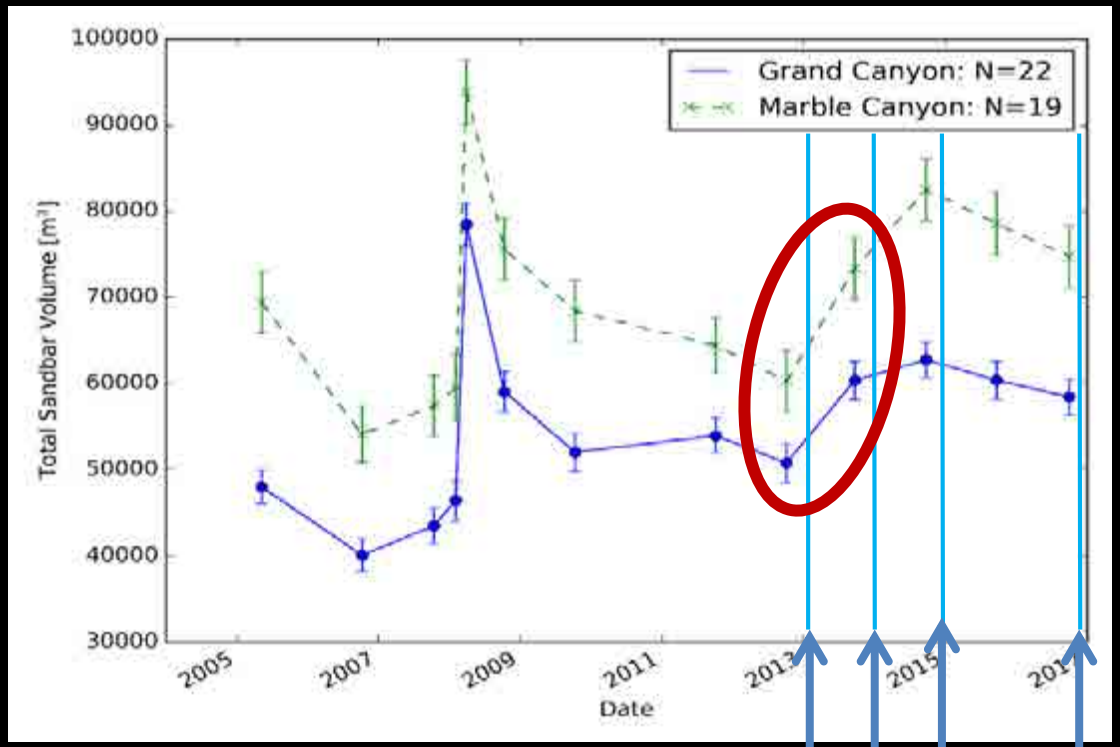
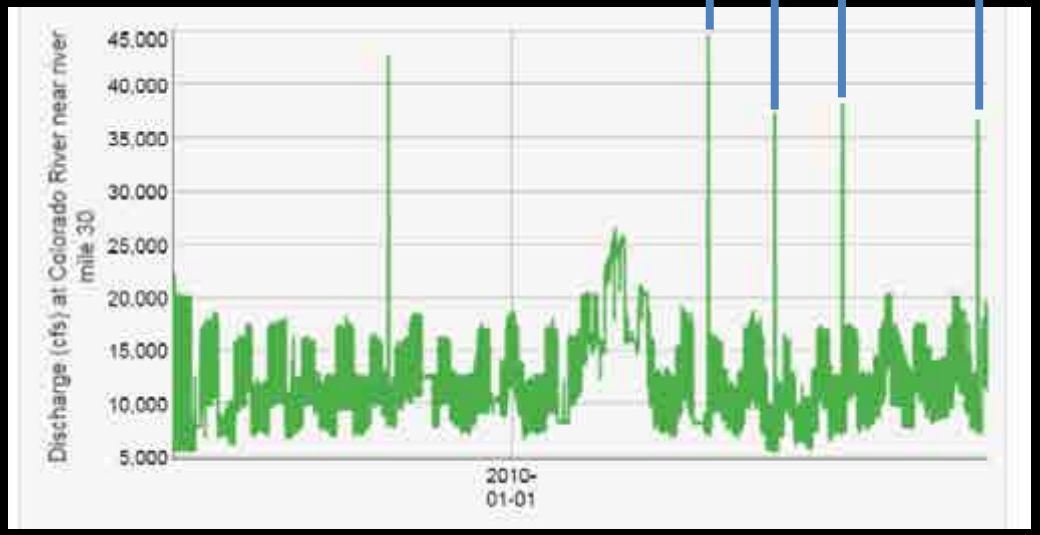
preliminary data, do not cite

Annual Sandbar Monitoring





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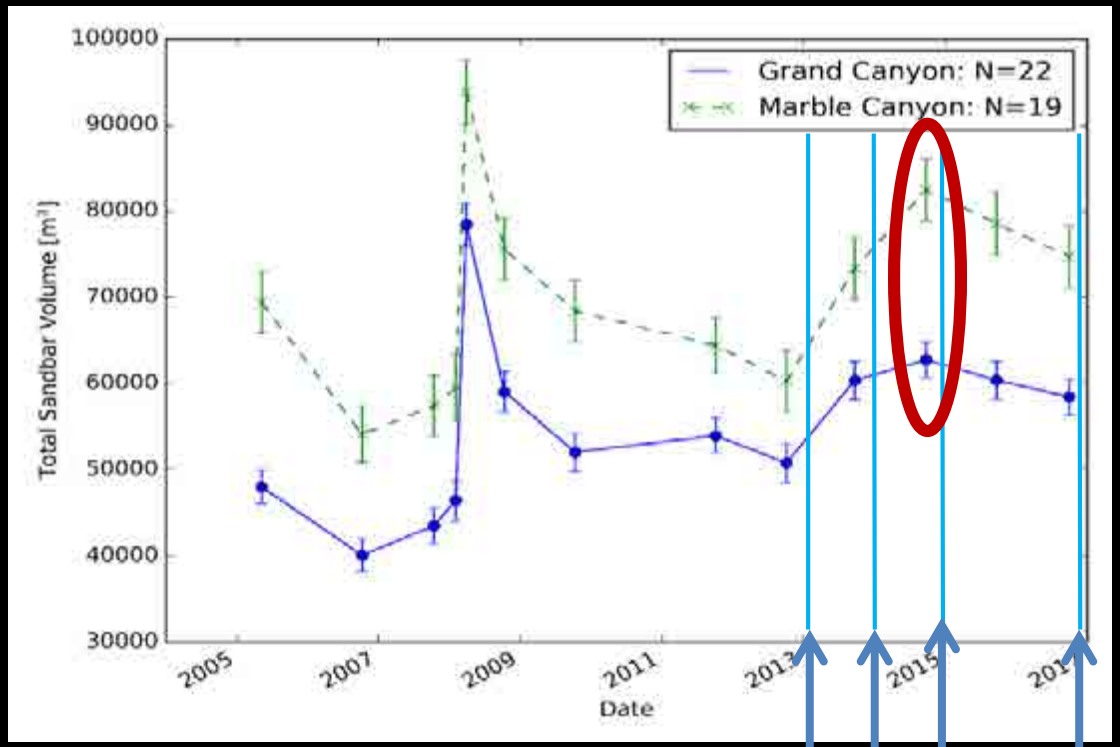
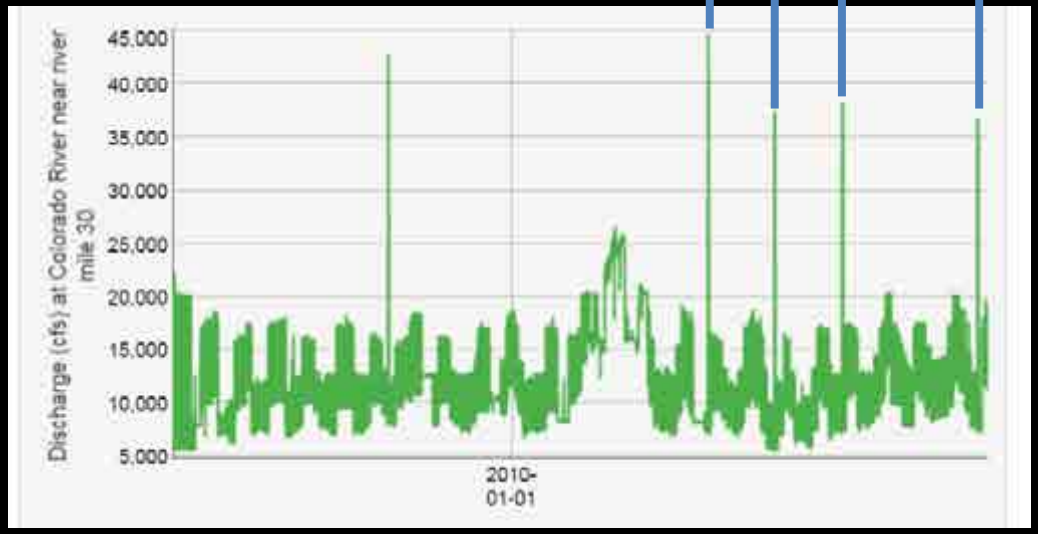
- Largest increase is during 2012 HFE

USGS

preliminary data, do not cite

Annual Sandbar Monitoring





Period of HFE Protocol

- Blue arrows/lines show each HFE
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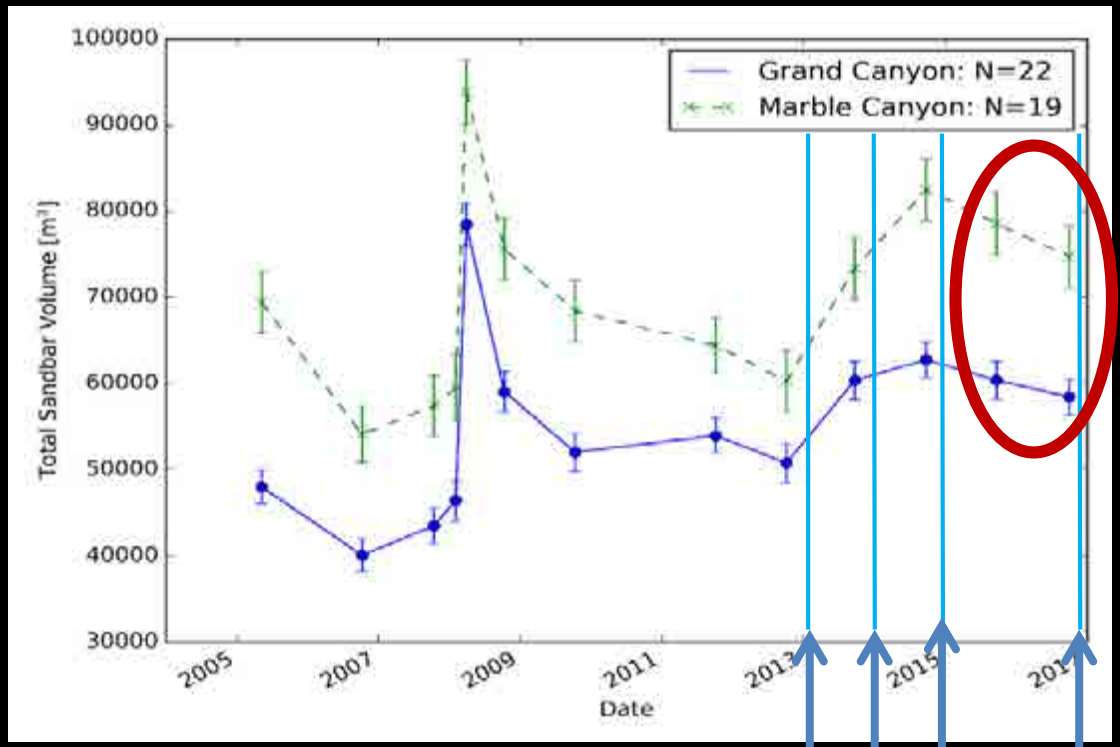
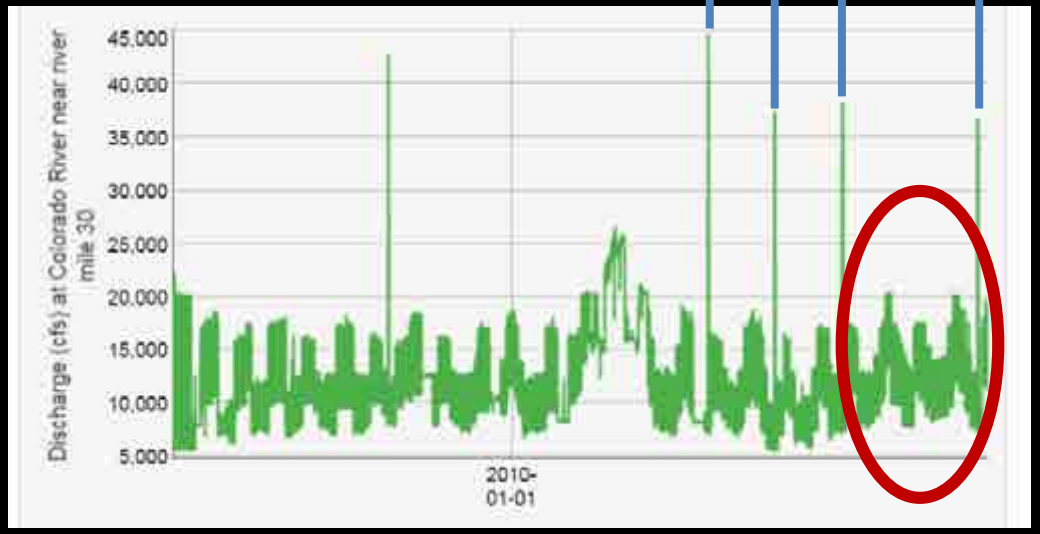
- Largest increase is during 2012 HFE
- Bars largest in October 2014

USGS

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

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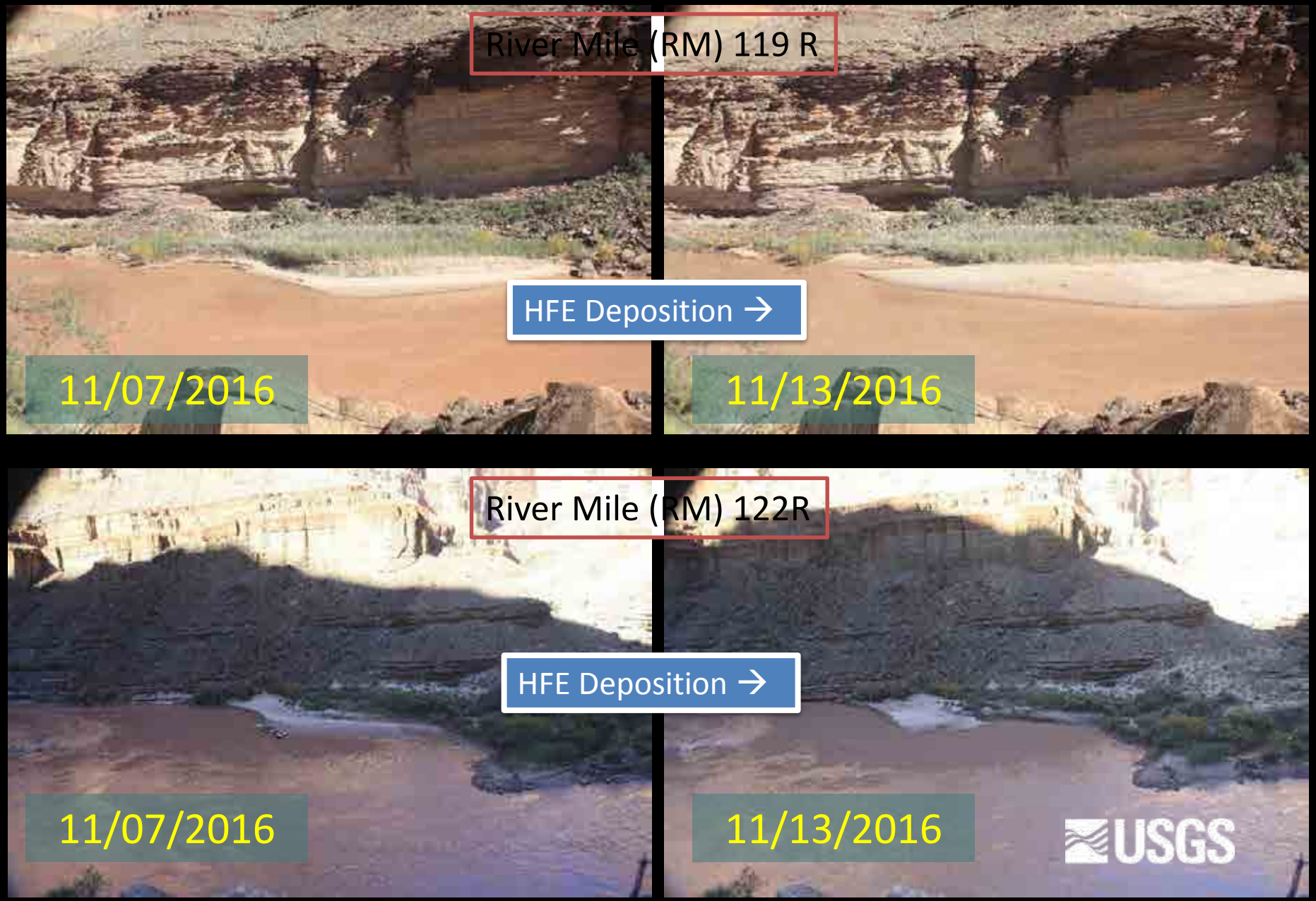
November 2016 High-flow Experiment Sandbar Deposition



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

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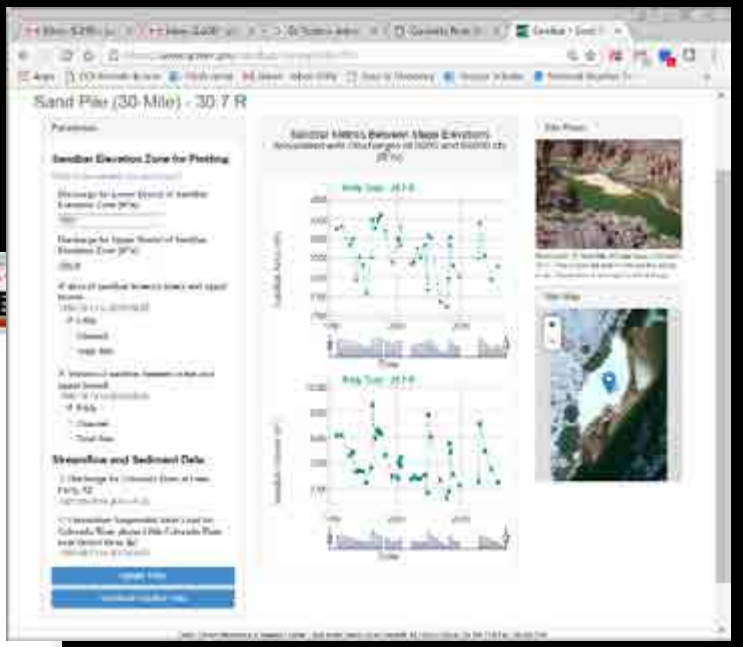
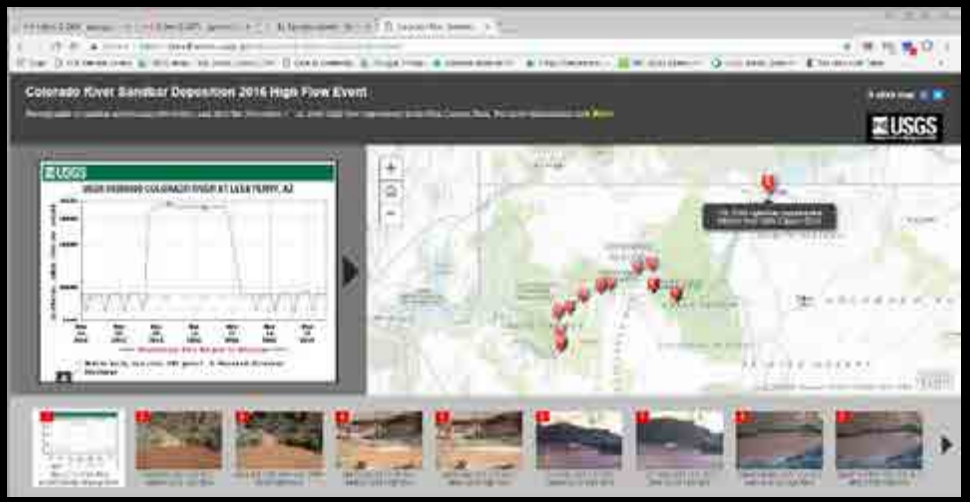
preliminary data, do not cite

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/

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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

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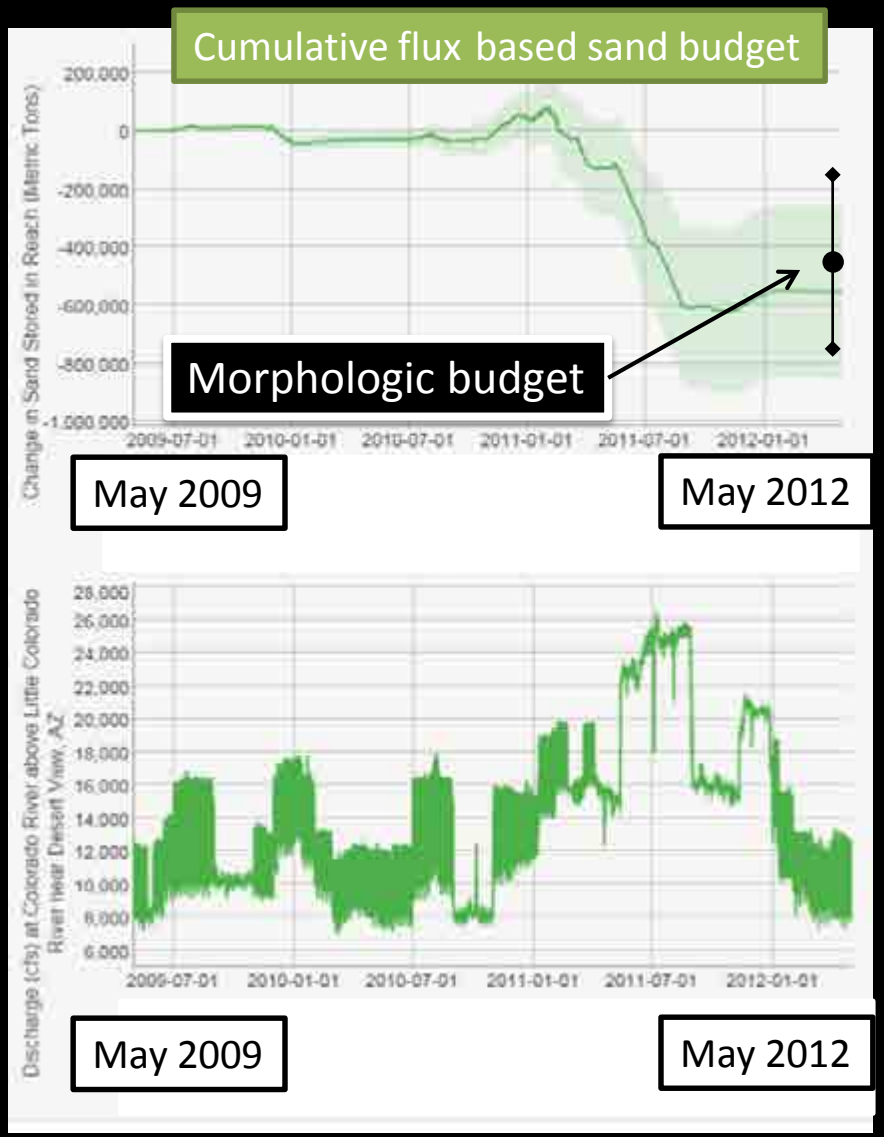
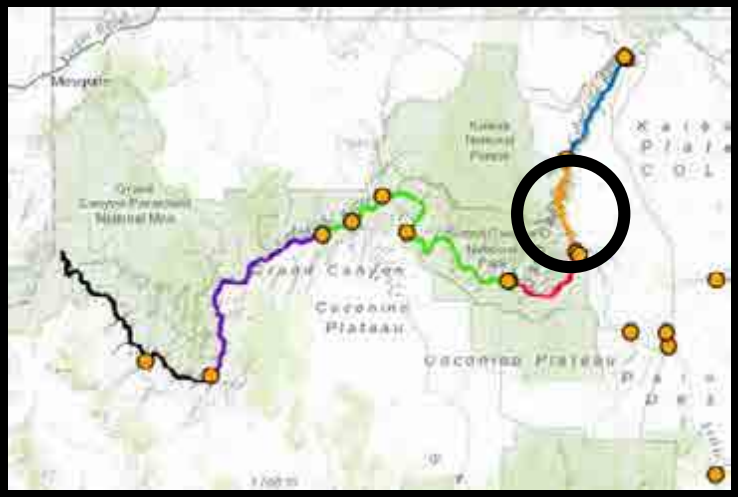
Results: closed sand budget for Lower Marble Canyon: May 2009 to May 2012

- *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





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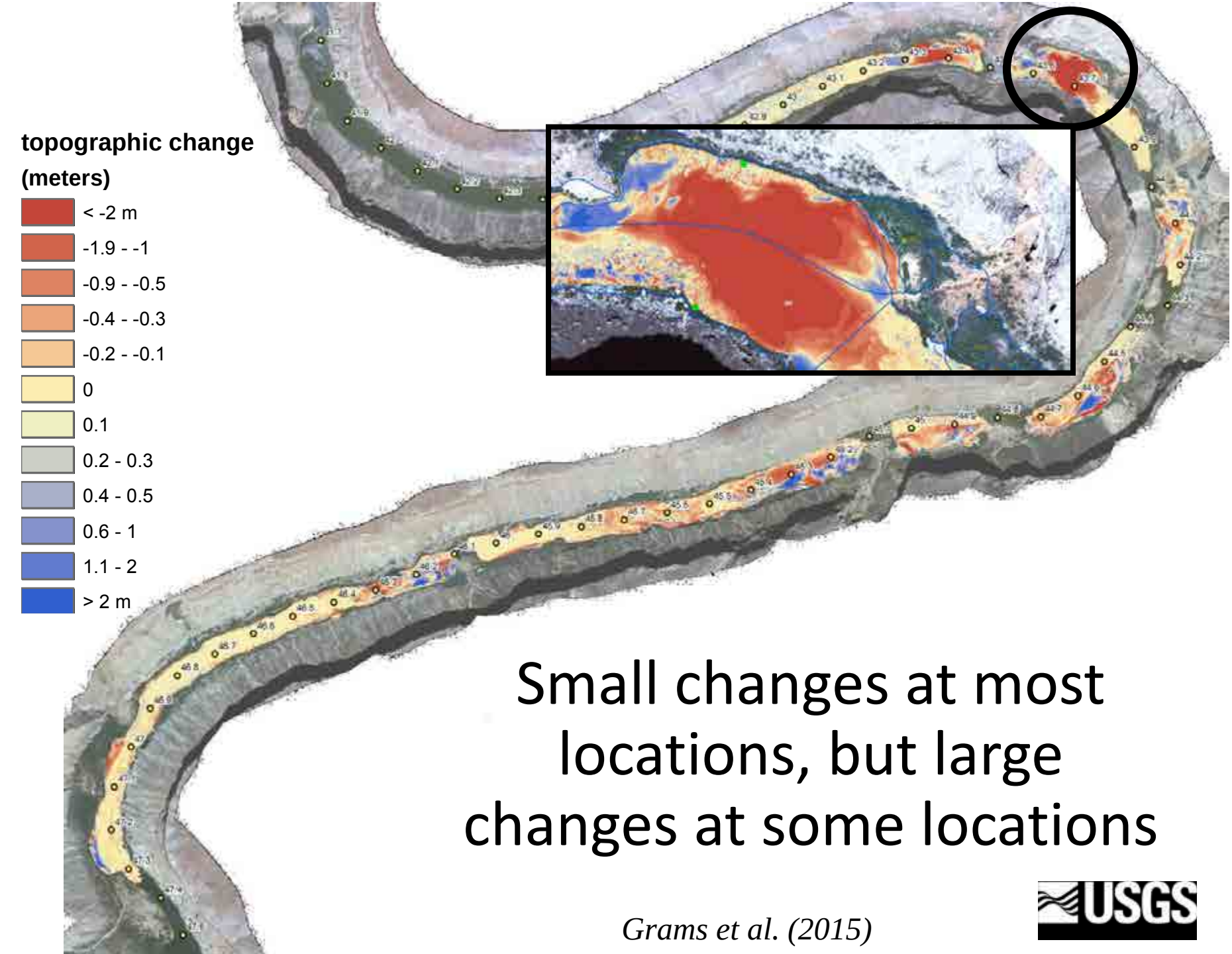
Grams et al. (2015)



Small changes at most locations, but large changes at some locations

Grams et al. (2015)

USGS

Better Estimates of "Absolute" sand storage

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

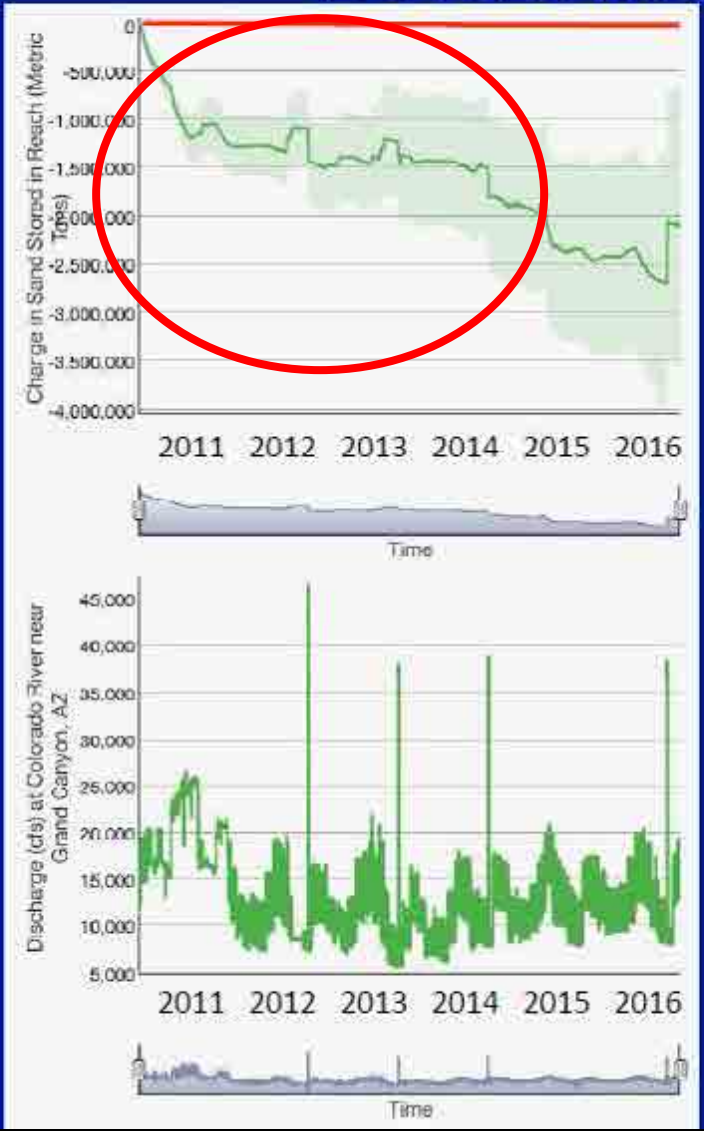
→ 5 to 13 million m^3 (7 to 21 million metric tons) sand in eddies and channel in Lower Marble Canyon.
1 million metric tons is about the amount of sand delivered by the Paria in a good input season (like 2016).

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

Preliminary results, do not cite

USGS

Eastern Grand Canyon
1-1-2011 through 1-1-2017



Change in Sand Mass

Zero Bias Value: **-2,100,000 Metric Tons**

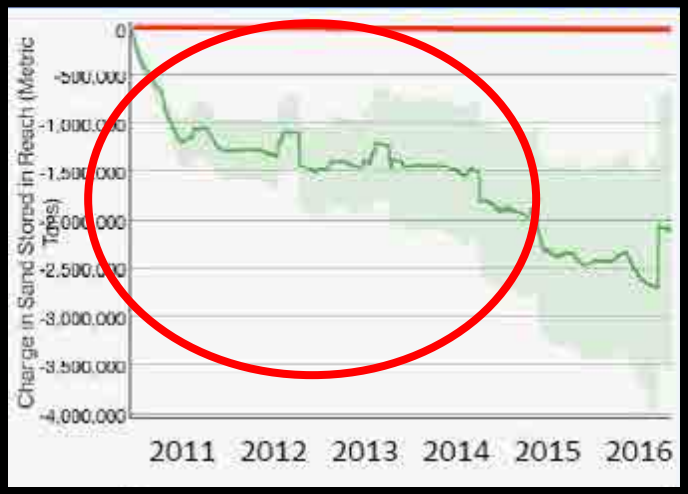
Upper Uncertainty Bound: -690,000 Metric Tons

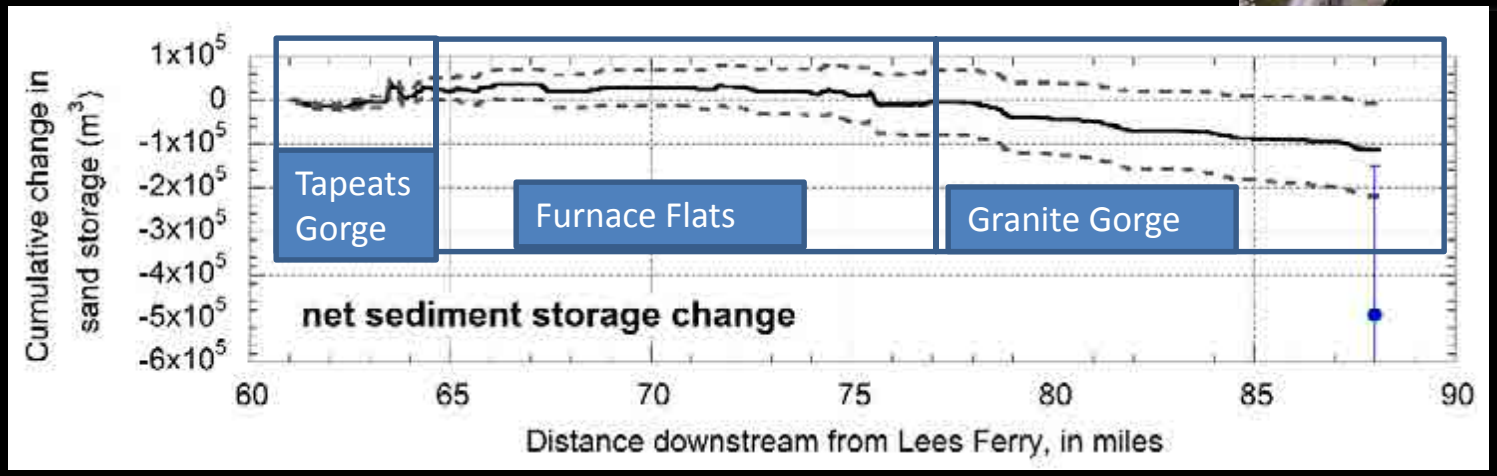
Lower Uncertainty Bound: -3,600,000 Metric Tons

USGS (2017)

USGS science for a changing world

Eastern Grand Canyon: 2011-2014





- 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.

USGS

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

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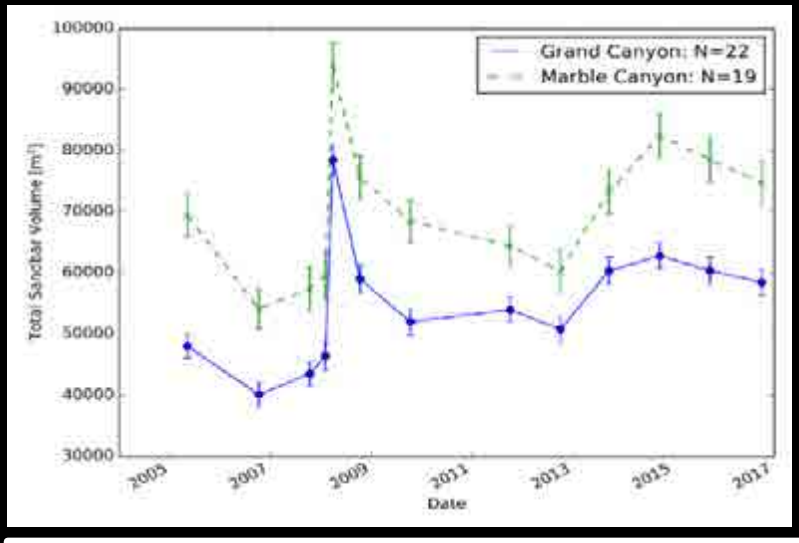
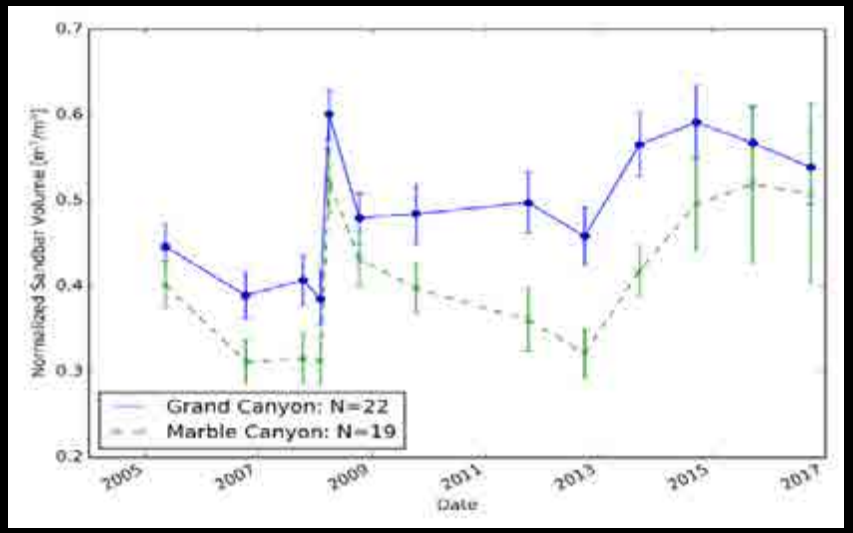
3.3 Sandbar Modeling

- 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”



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



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

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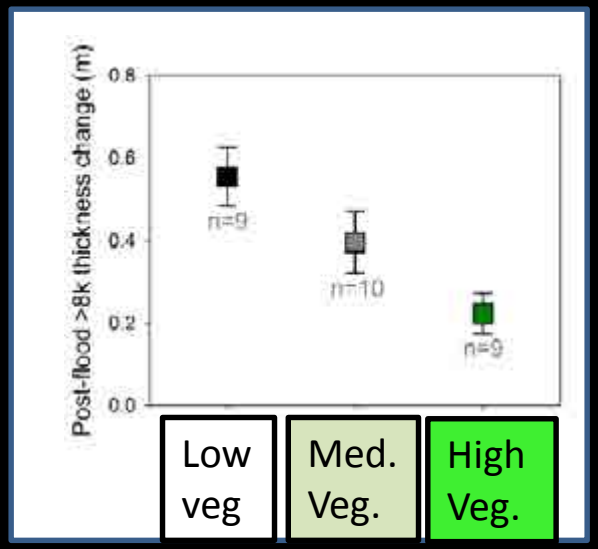
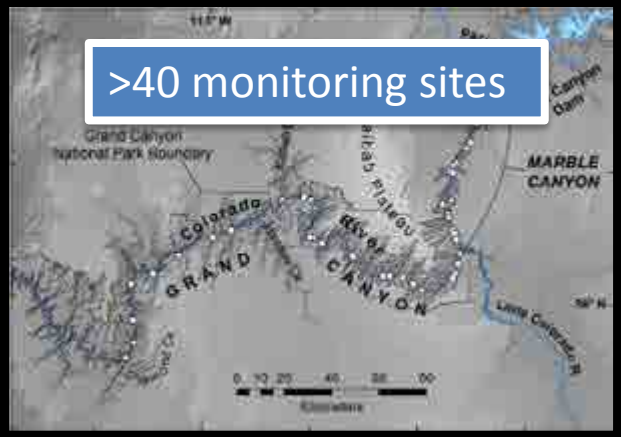
Preliminary results, do not cite

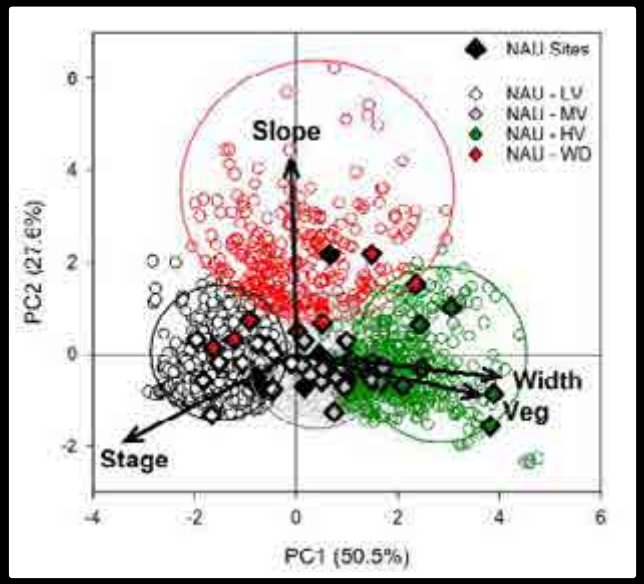
Grouping sites of similar behavior and structure



Observations of similar behavior among sites with similar vegetation cover



statistical classification (PCA + k means)



- 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)

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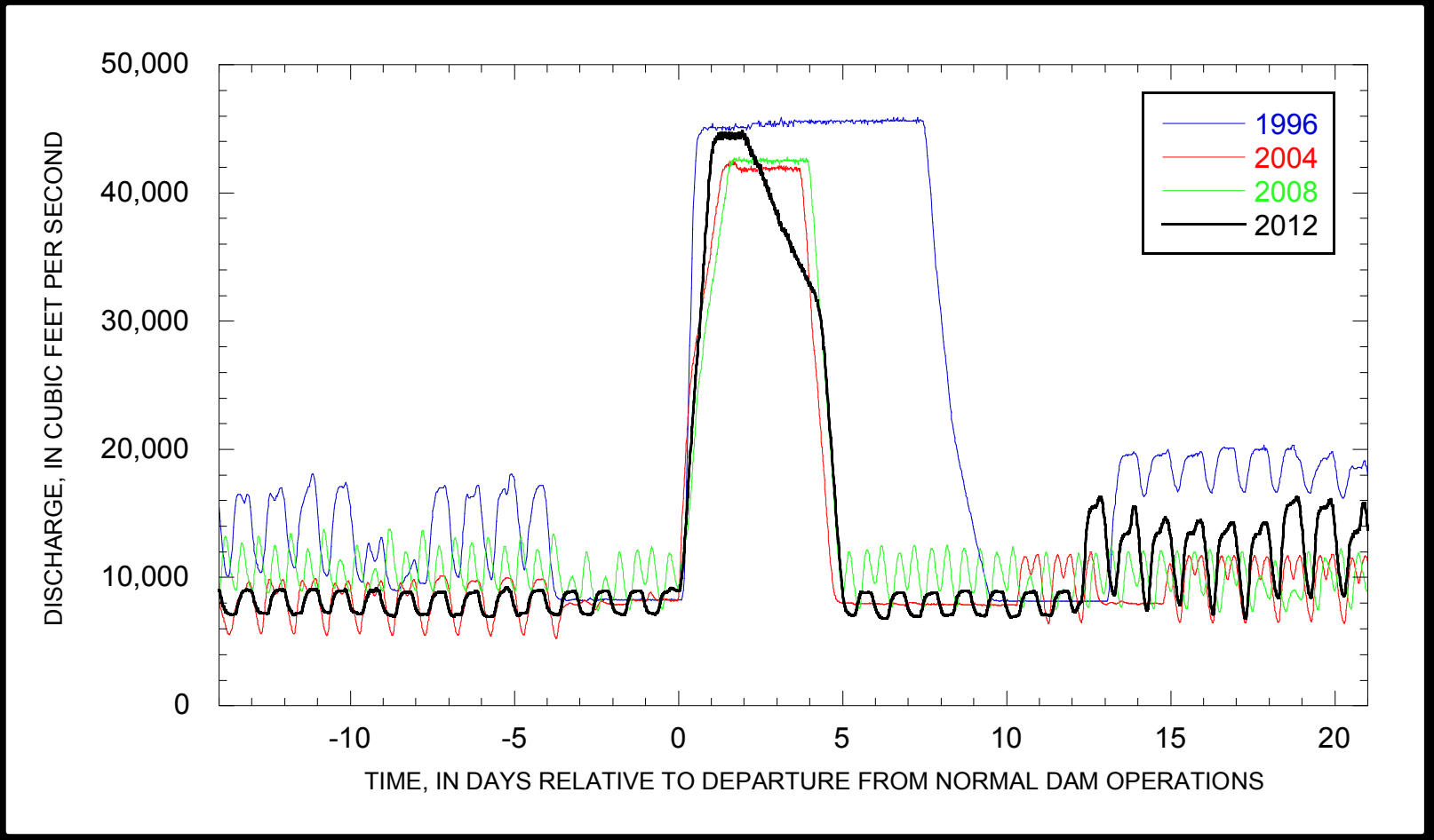
What is the effect of changing the hydrograph of the high flow?



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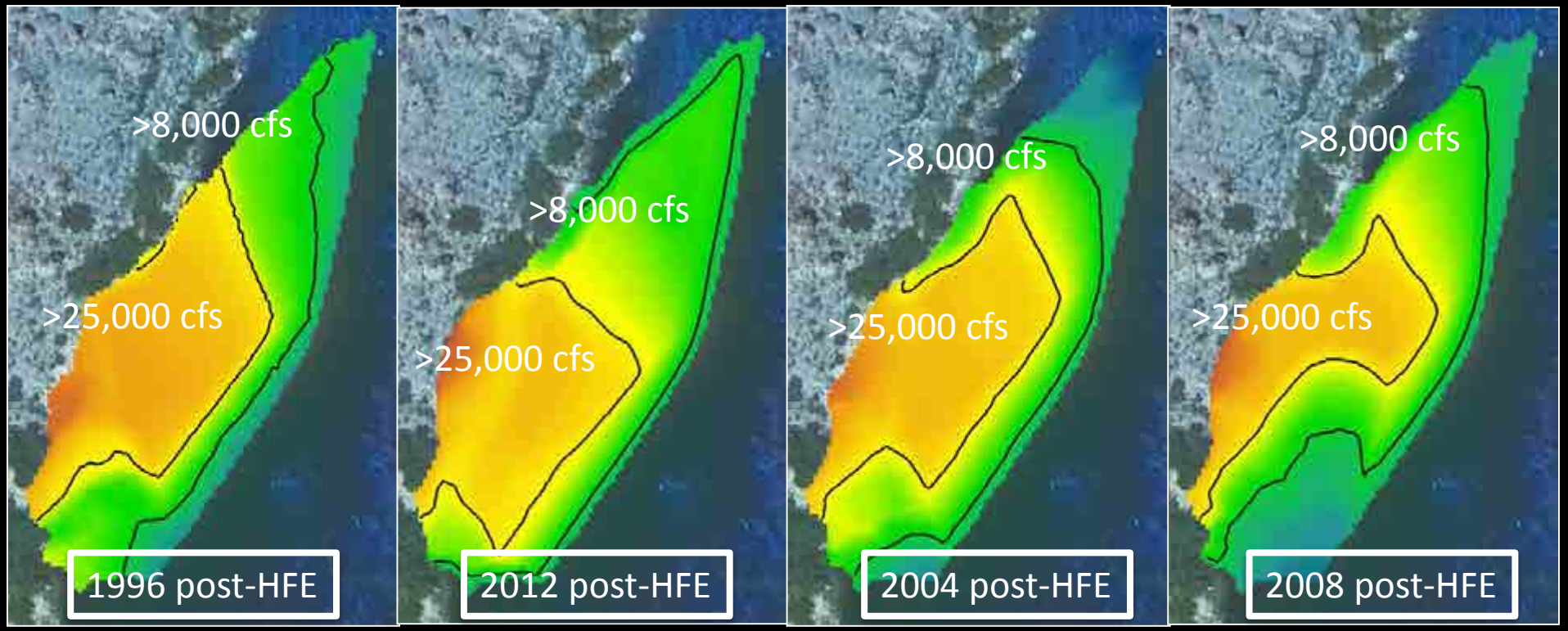
Post-HFE Sandbar Shape



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.

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Physical model for Grand Canyon sandbars: July 2016 Pilot Study

Colorado River in Grand Canyon

St. Anthony Falls Hydraulic Lab, University of Minnesota

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

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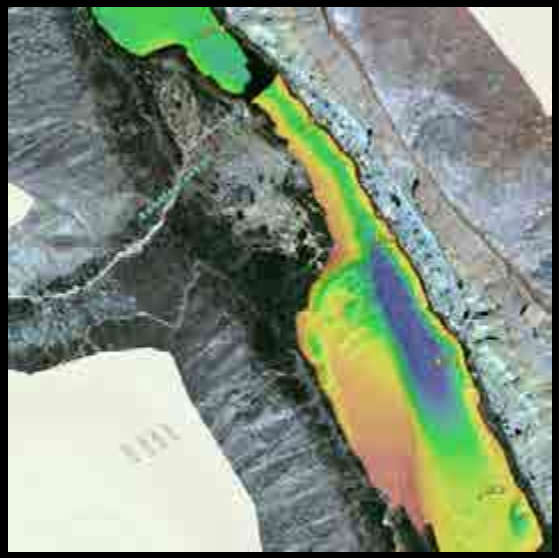
With a few modifications



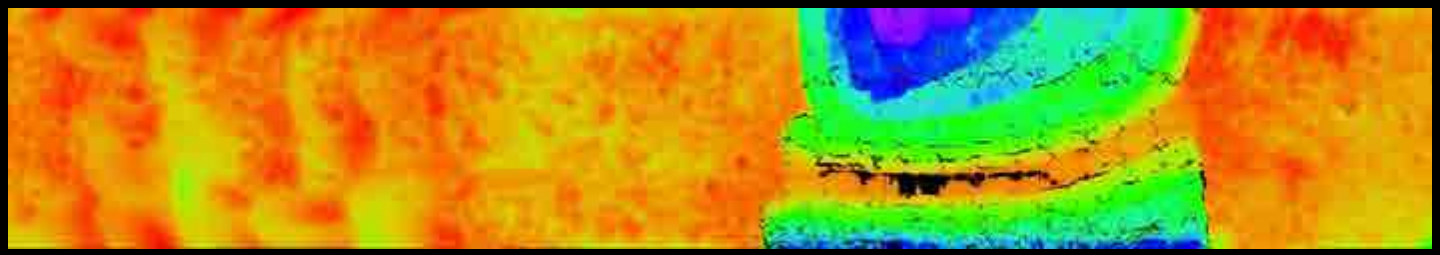
~ 1:50 geometric scaling of channel

Froude scaling of flow

$$\frac{v_1}{\sqrt{gd_1}} = \frac{v_2}{\sqrt{gd_2}}$$

16.5 m

2.74 m



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Experimental Runs and Measurements

Run	Flow (l/s)	Froude Number	Duration (hr)	Measurements
1a	90	~0.6	24	Bed topography, PIV
1b	90	~0.3	26	Bed topography, PIV, ADV
Bed regraded to flat				
2	165	~0.5	17	Bed topography
Bed regraded to flat, moved constriction				
3	165	~0.5	4	Bed topography

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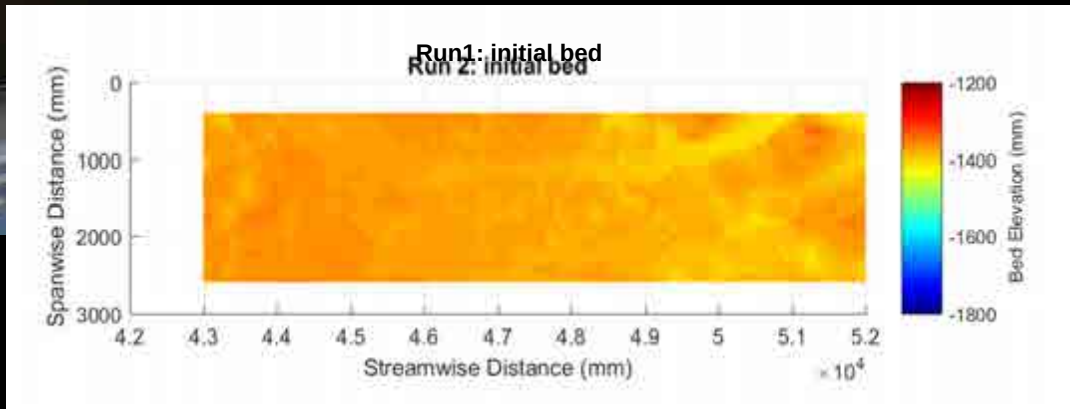
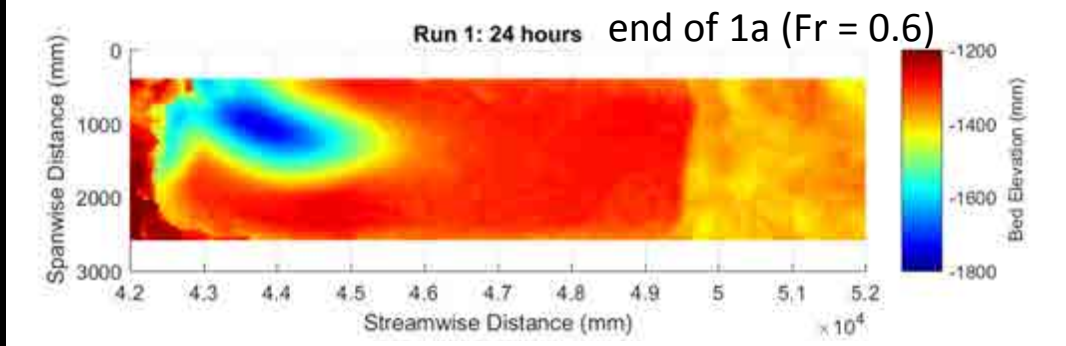
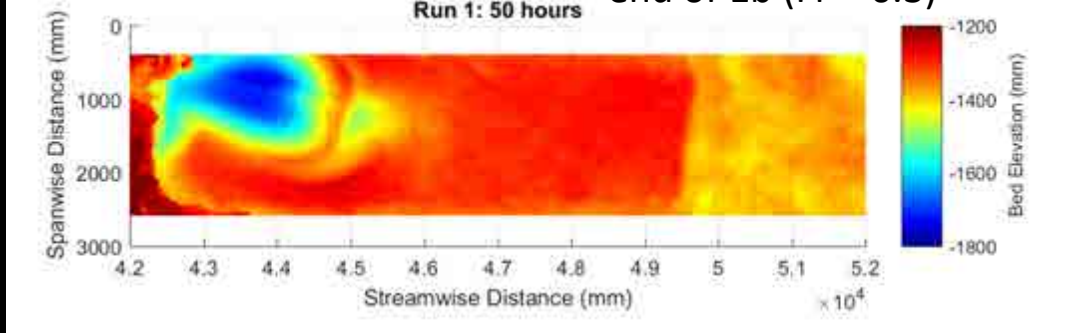
Run 1 – ~90 l/s

- 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





end of 1a (Fr = 0.6)



end of 1b (Fr = 0.3)

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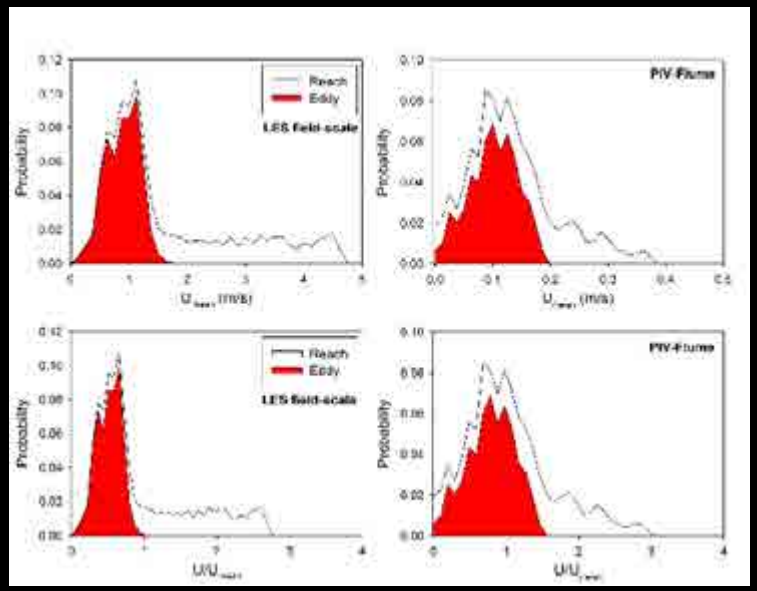
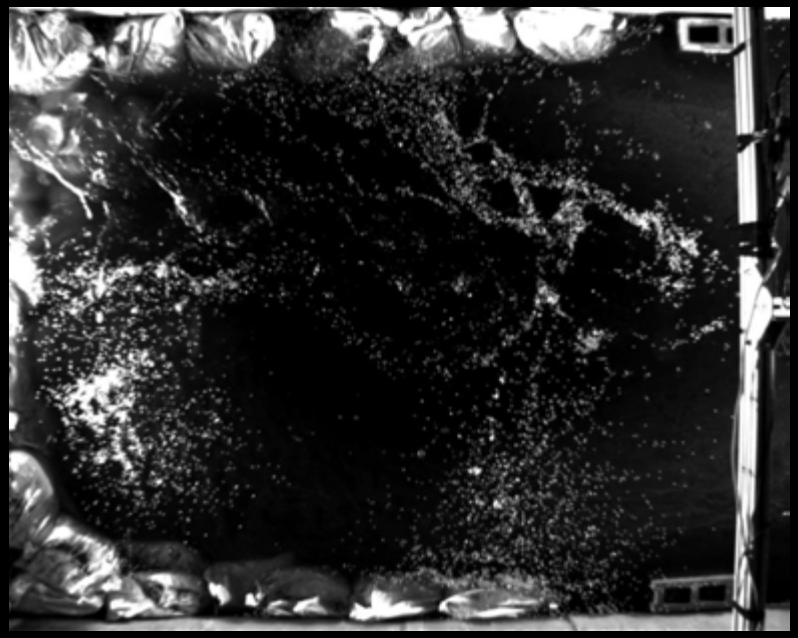
Preliminary results, do not cite

Recirculating flow characteristics in lab, model, and field

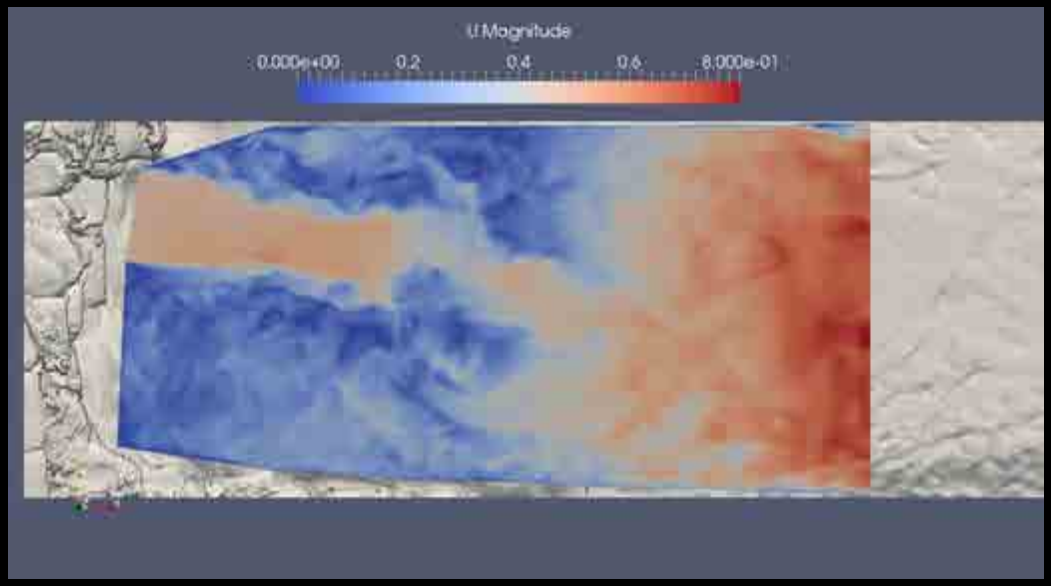


Field-scale LES PIV in flume

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

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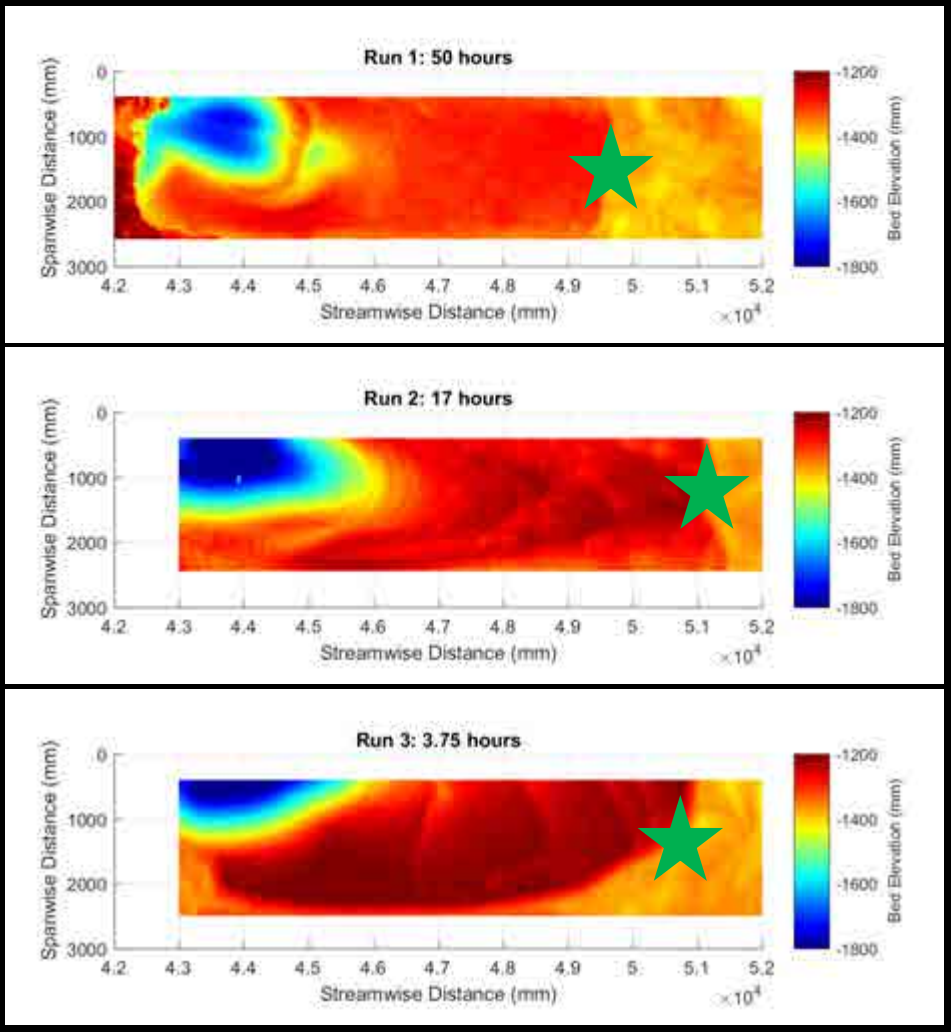
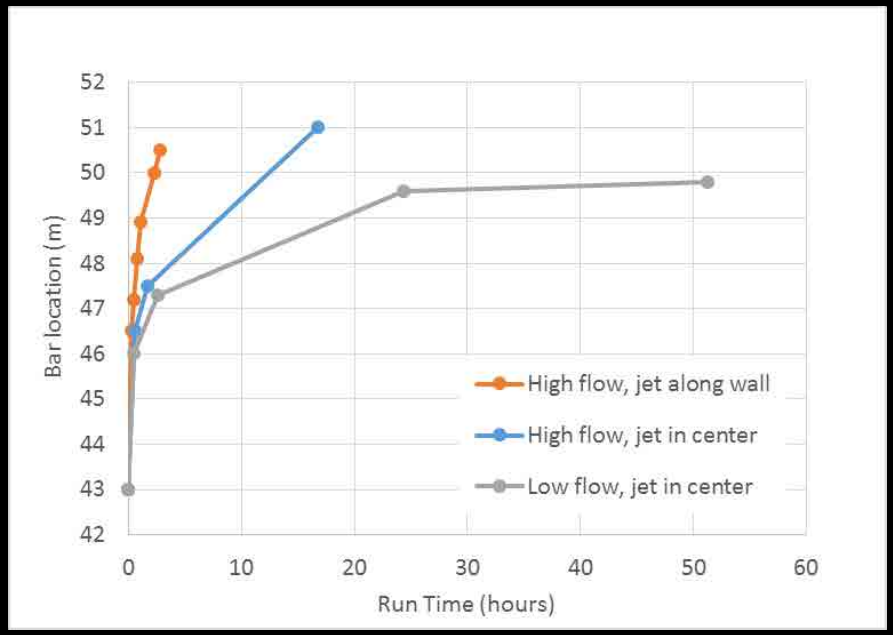
Preliminary results, do not cite

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

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