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

GCMRC Project 3 (now Project B)

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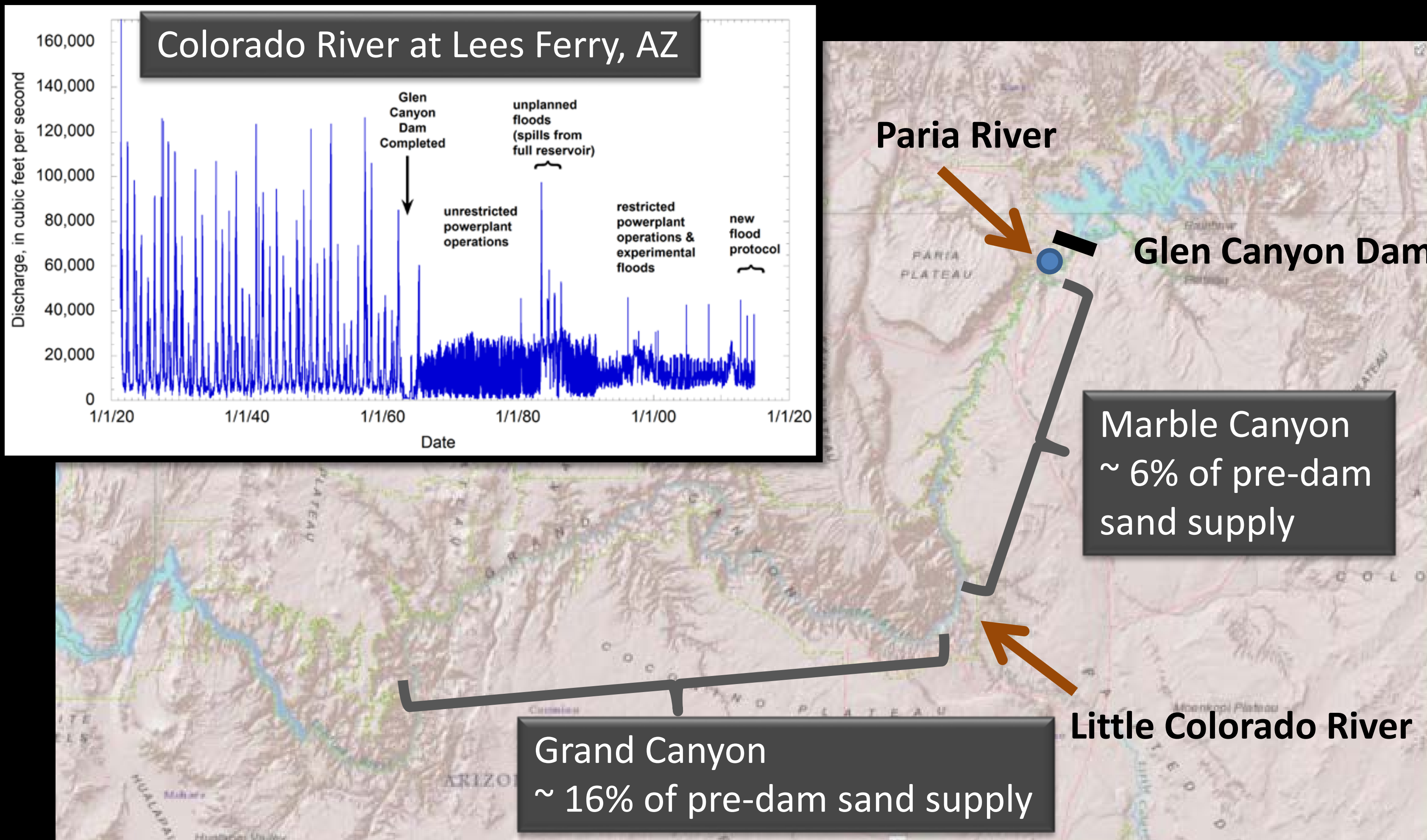
U.S. Department of Interior
U.S. Geological Survey

Overview

- Scientific background (geomorphology and sediment transport processes relevant to sandbars and HFE’s).
- Summary of FY 2015-2017 Project 3 Objectives and Accomplishments
- A bit more detail on:
  - Sandbar change and sand budget
  - Advances in remote sensing of the river bed
- Future work

The sand budget is affected by disruption of upstream sand supply (presence of Lake Powell) and change in flow regime (dam operations)



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

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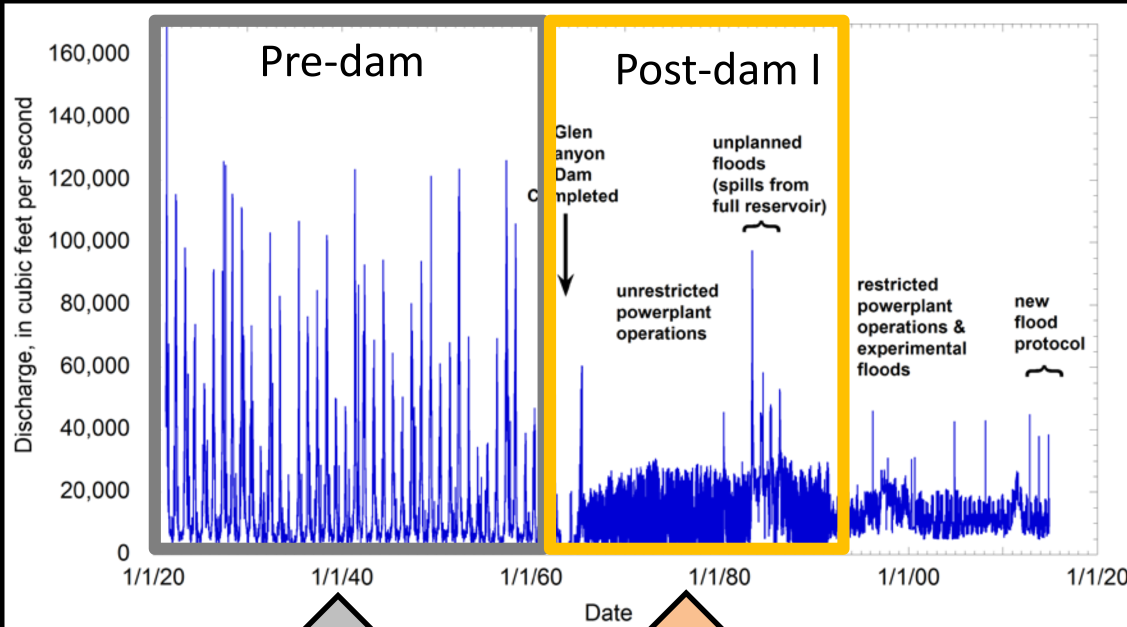
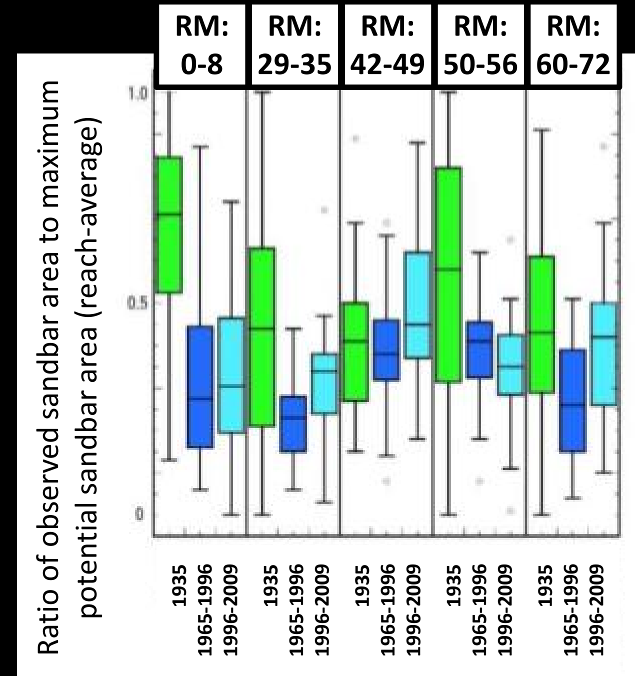
Topping et al. (2000)



Pre-dam:
- Annual floods
- Abundant sand supply
- Large sandbars

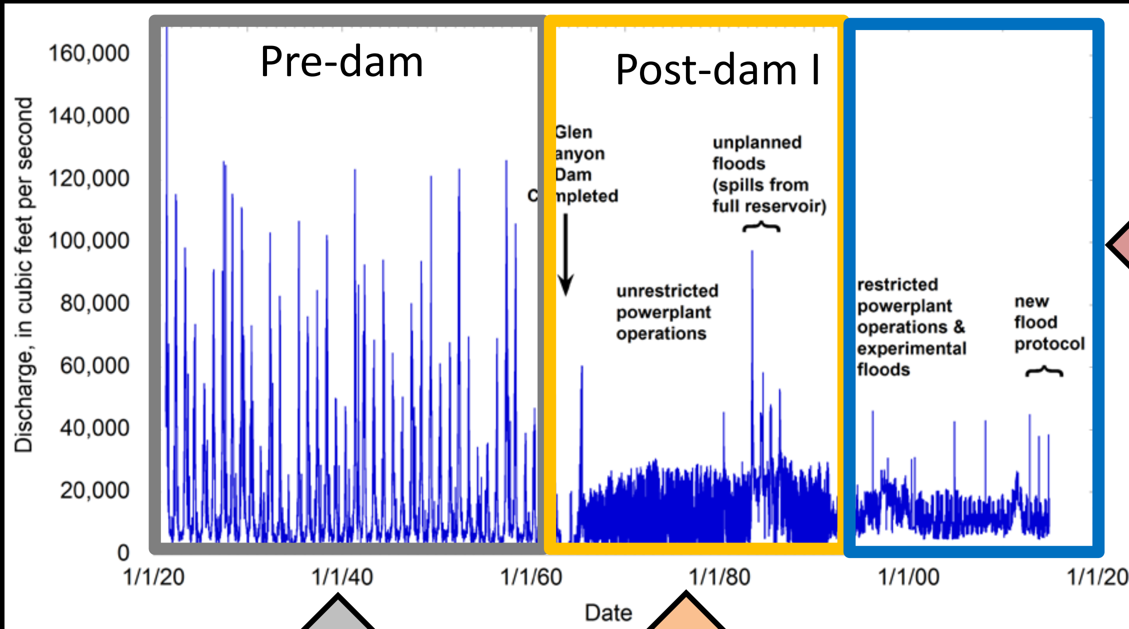
Post-dam I:
- Daily small floods
- Limited sand supply
- Eroding sandbars
- Unplanned floods (spills)



About 25% reduction in sandbar area in Marble Canyon

Schmidt et al. (2004); Ross and Grams (2015)

USGS



Post-dam II:
- Restricted hydropower operations
- **High Flow Experiments (HFEs)**
  - triggered by sand supply from Paria River

Pre-dam:
- Annual floods
- Abundant sand supply
- Large sandbars

Post-dam I:
- Daily small floods
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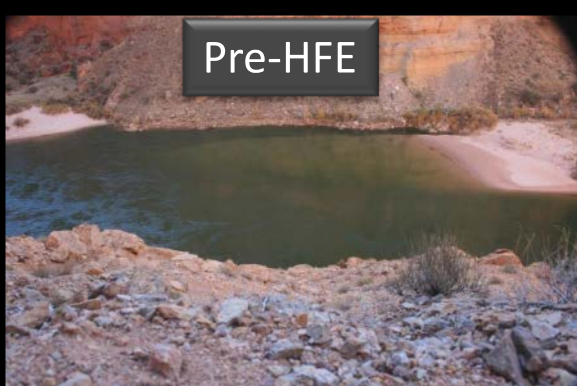

Science and Management Questions:
- With frequent HFEs, will sandbars increase in size and abundance?
- Will frequent HFEs cause sand supply in channel to decrease and exacerbate sediment deficit?

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Sandbars

- Geomorphic Framework – active sandbars part of natural river system
- Recreational Campsites
- Aquatic Habitats – nursery habitats for native fish
- Terrestrial Habitat – substrate for riparian vegetation
- Archaeological Site Preservation – most archaeological sites buried in sand/silt

sand dunes
(archeological sites)

campsites

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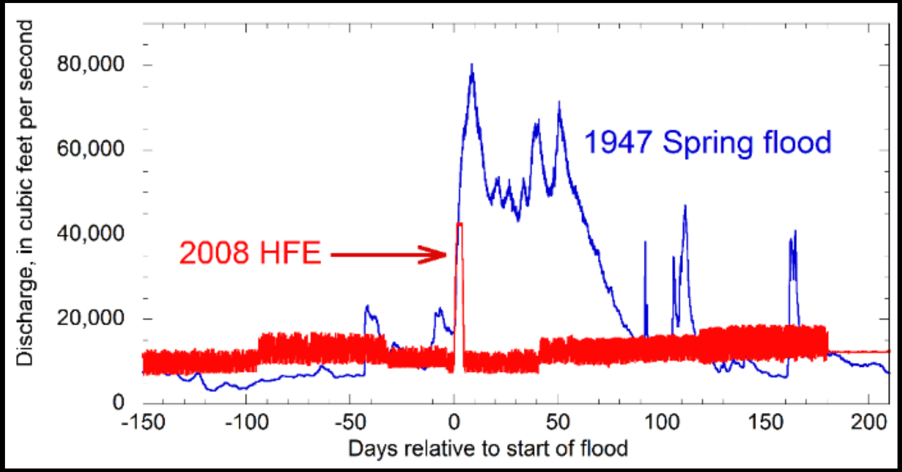
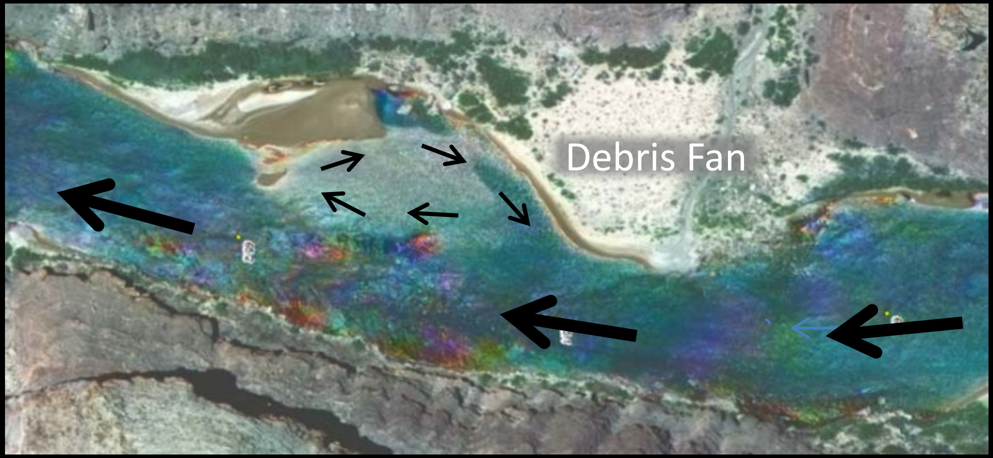
Building sandbars with HFEs





HFEs transfer sand from channel and low-elevation parts of eddies to sandbars along channel margins

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Project 3 – Overview

- 8 Project elements involving sandbar and sand storage monitoring and research
- 28 peer-reviewed publications (2015-2017)
  - 13 Journal articles
  - 7 Proceedings papers
  - 4 MS or PhD theses
  - 4 USGS Reports
  - 2 USGS data releases
- At least 6 additional articles or reports in preparation
- Sandbar photographs and data on GCMRC website (www.gcmrc.gov/sandbar)

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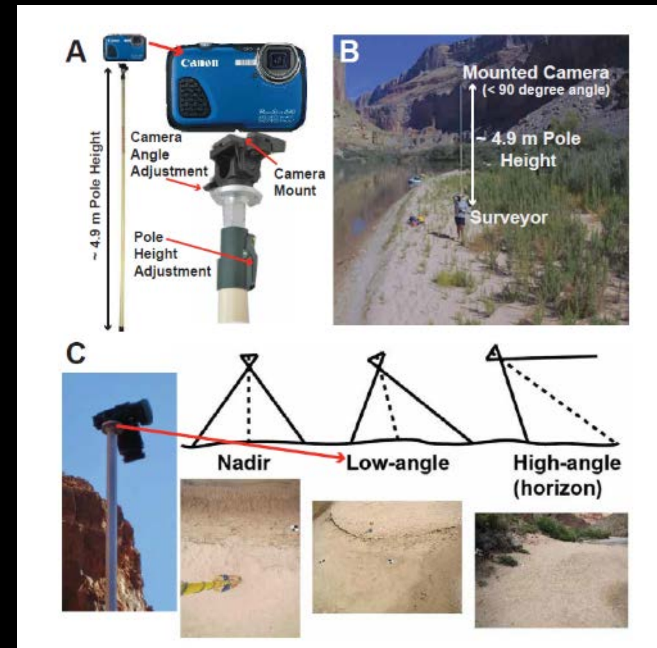
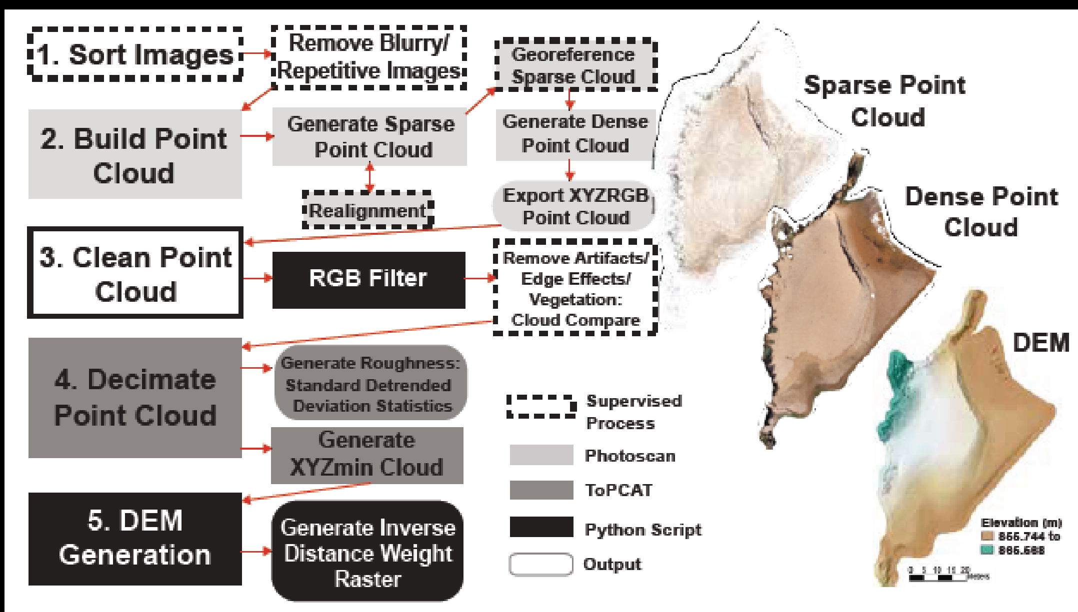
Sandbar surveys with digital cameras

- Objective:
  - Evaluate SfM (structure-from-motion) photogrammetry for “surveying” sandbars

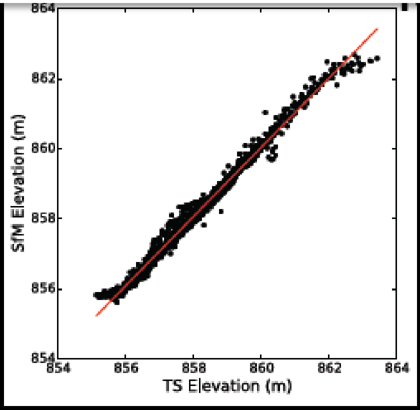




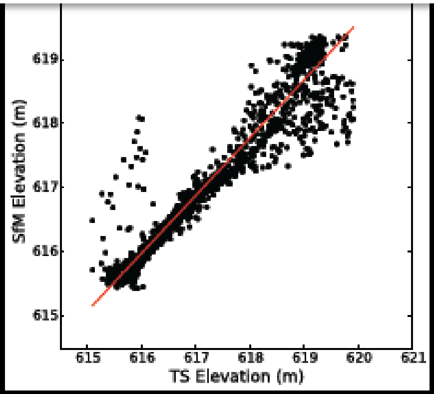
Sandbar surveys with digital cameras

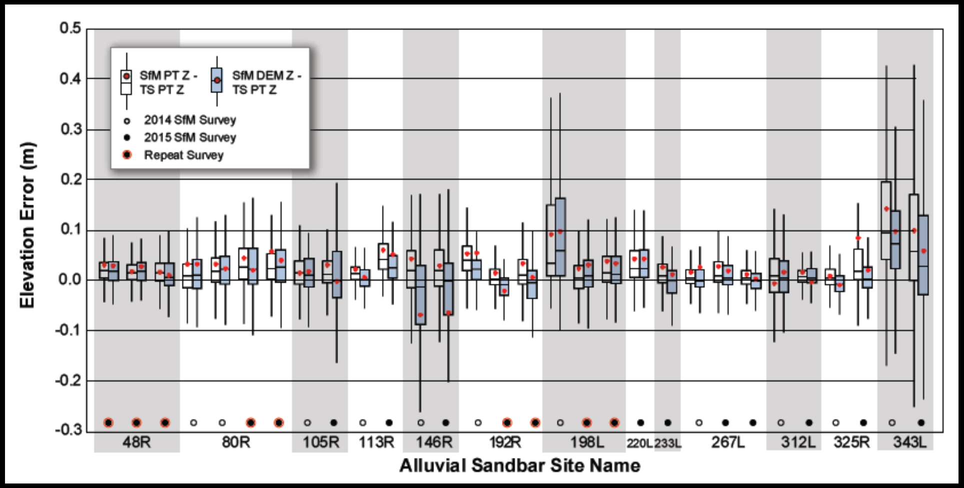
- Results:
  - Method yields accurate, high-resolution topographic data, suitable for detailed investigations
  - But, no substantial time or cost savings over conventional survey methods
  - *MS Thesis completed, journal article in preparation*
- Management implications
  - We have a tested method for high-resolution surveys.
  - Would be most efficient if data were collected with drones

Bare sand bar = Very good agreement with conventional survey



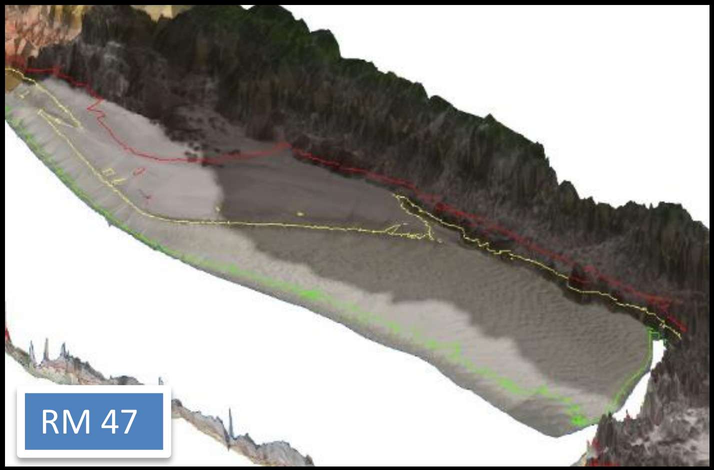
Sandbar with dense vegetation = greater uncertainty compared with conventional survey

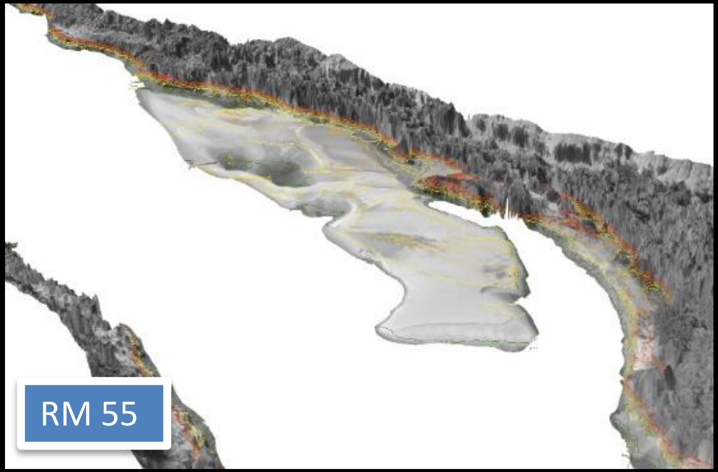




Historical Sandbar Topography

Sandbars reconstructed from 1984 images





- Objective:
  - Reconstruct sandbar topography from 1984 aerial photographs for long-term monitoring sites
- Results:
  - Developed workflow for accurate reconstructions
  - Applied method to 6 sites
  - Additional 4 sites to be completed this year
  - *Report in preparation*
- Management implications
  - We have a working method for precise reconstructions of topography from old (1984) air photos.
  - Provides perspective for sandbar size produced by HFEs compared to size that was produced by larger floods.

Preliminary results, do not cite

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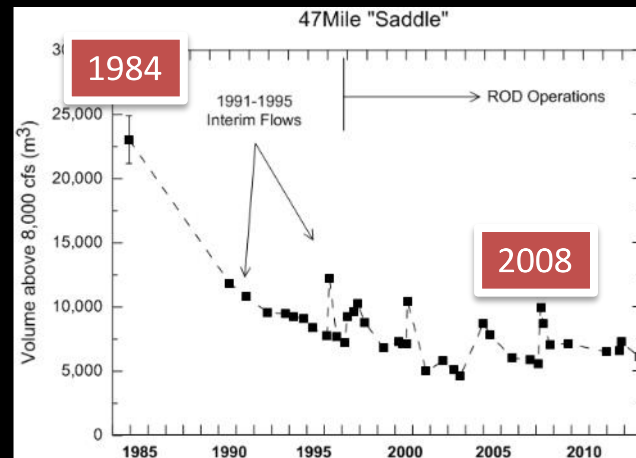
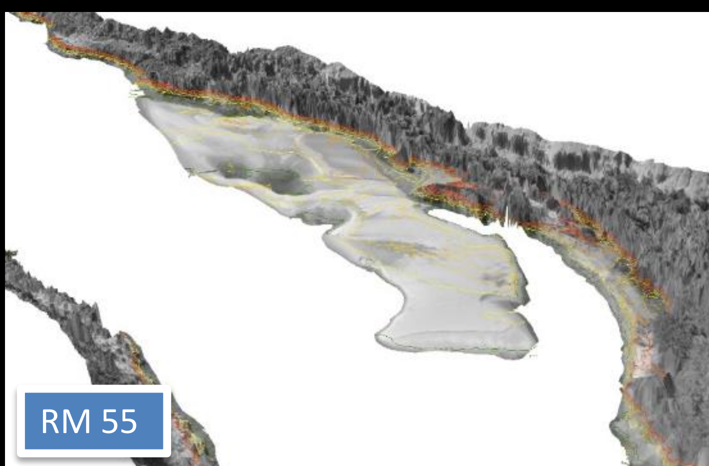
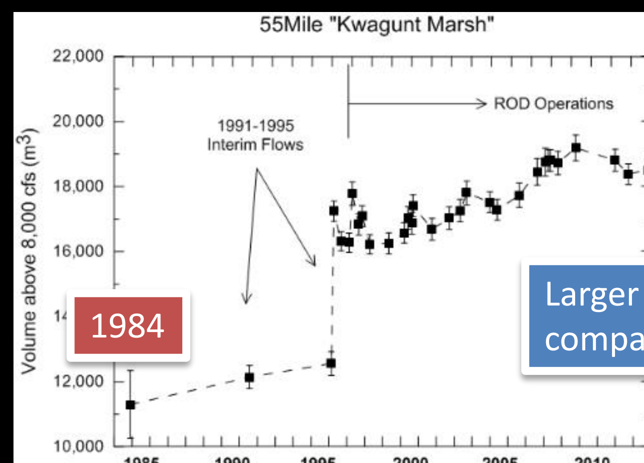
Historical Sandbar Topography

Sandbars reconstructed from 1984 images



Much smaller sandbar following recent HFEs compared to 1983-84 floods





Larger sandbar now compared to 1983-84 floods

Preliminary results, do not cite

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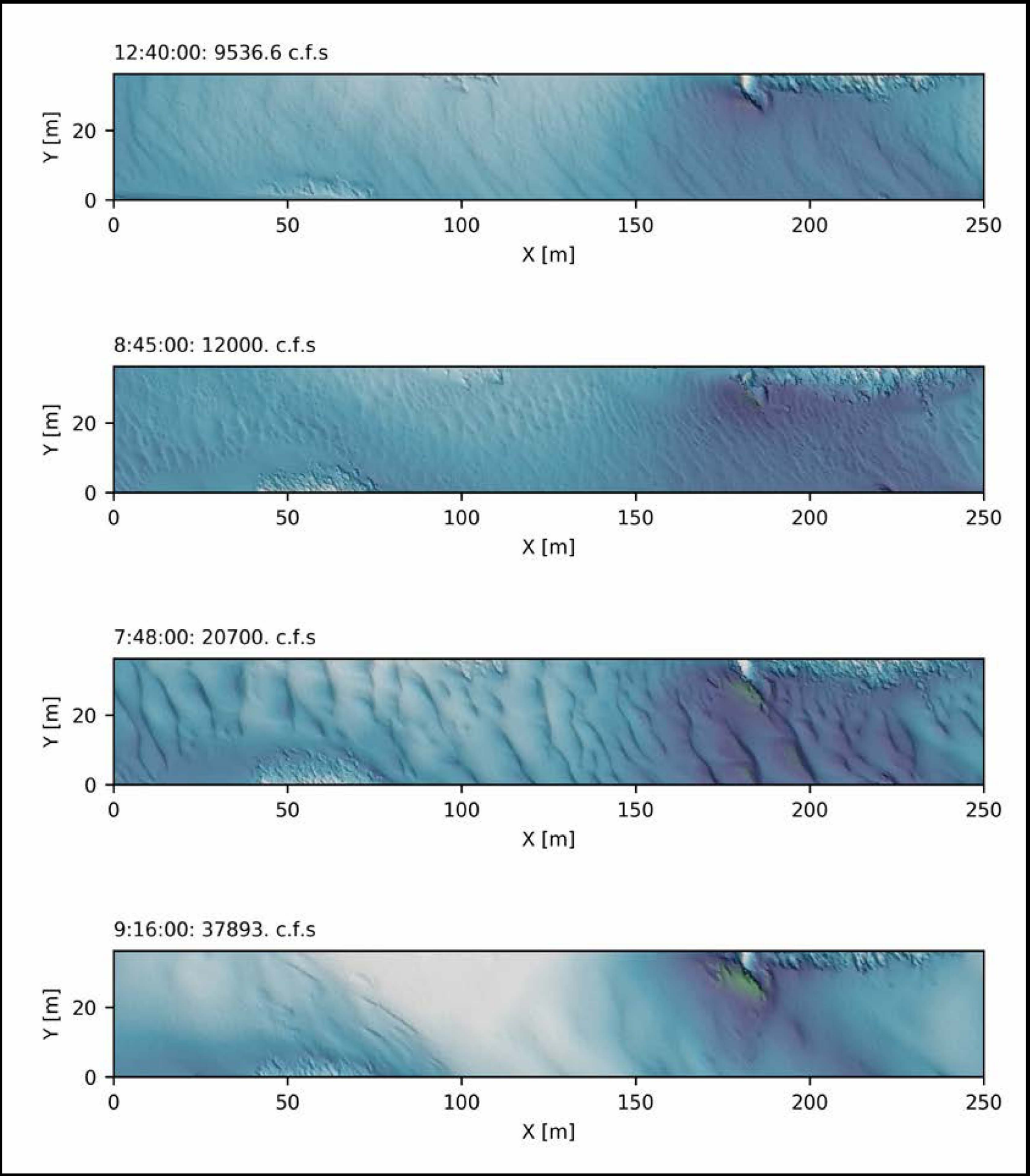
Sand Bedload Transport



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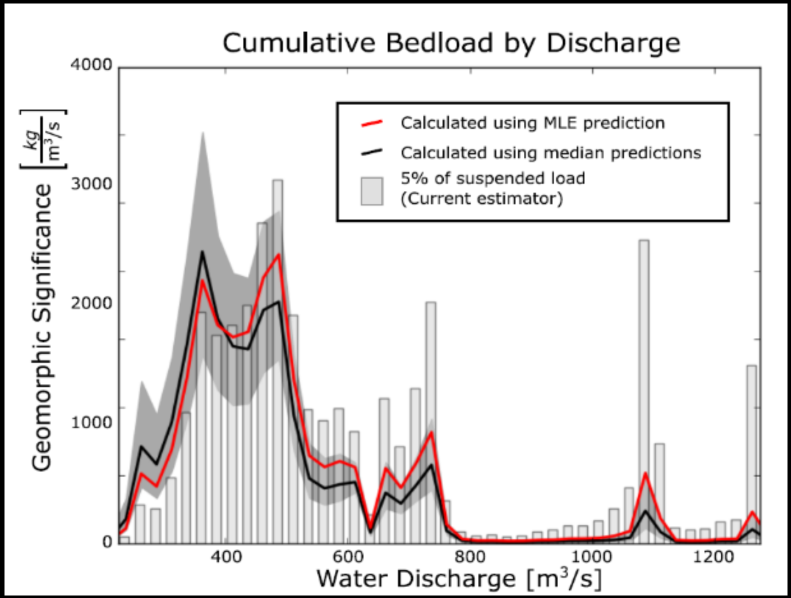
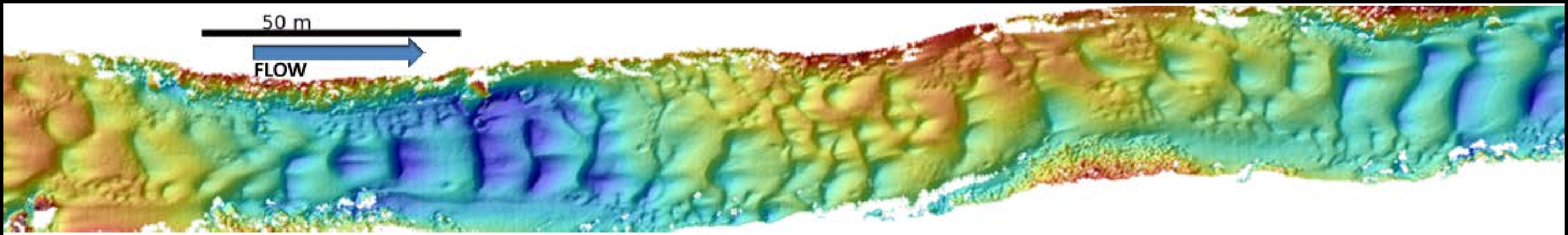
Sand Bedload Transport

- Objective:
  - Improve our estimates of sand transport by better inclusion of bedload transport
- Results:
  - Made repeat measurements of bed topography at different flows to measure sand dune migration
  - Used data to estimate transport and develop model for general application
  - *Journal article in preparation*
- Management implications:
  - Less uncertainty in estimates of sand transport and better model predictions for sand transport

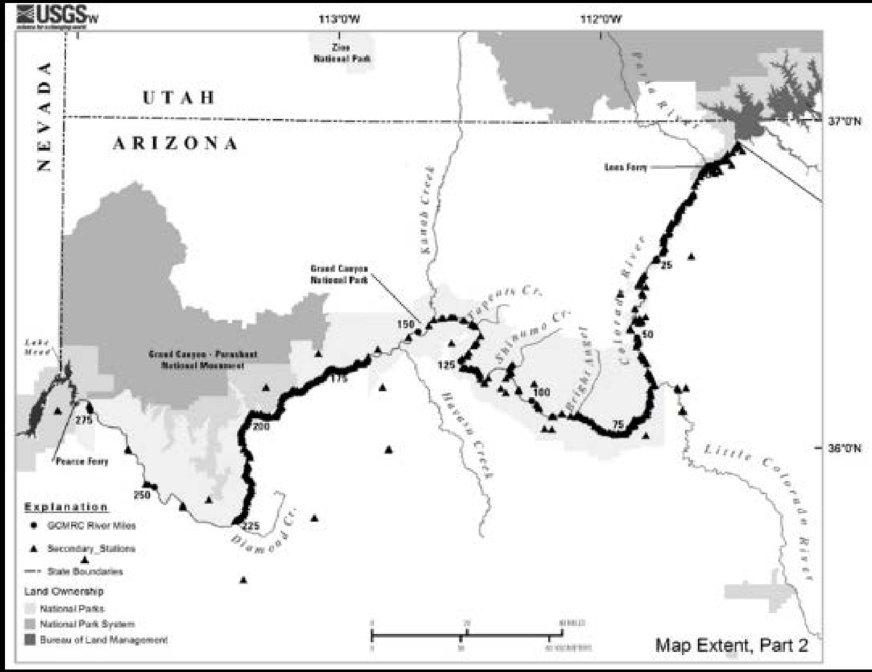




Tom Ashley, PhD Thesis

Control network and survey support

- Objective:
  - Establish and maintain network of control points (bench marks) throughout Grand Canyon
- Results:
  - Network involves over 12,000 measurements made by conventional survey and GNSS (GPS)
  - Both absolute and relative accuracy of are well-constrained (~ 3 cm relative accuracy at 95% confidence)
  - Points are “blue-booked” (published with National Geodetic Survey) and in GCMRC control database
- Management implications
  - Network provides stable reference for long-term monitoring.



Control network (3.5)

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Sandbar monitoring and modeling

- Objective:
  - Track results of HFEs and long-term trends in sandbars and sandbar campsites
  - Improve capacity for predictive modeling
- Results:
  - HFEs cause increases in sandbar size at a majority of long-term monitoring sites
  - Sandbars consistently larger than periods without HFEs
  - Developed new framework for classifying sandbars (Mueller et al., 2018)
  - Developed new predictive model for sandbar response (Mueller et al., in prep.)
  - Developing improved methods for monitoring sandbars at higher frequency
- Management implications
  - HFEs continue to be effective in building sandbars
  - Sandbars continue to erode following HFEs (continued HFEs required to maintain sandbar size)
  - Not seeing substantial cumulative increase in sandbar size

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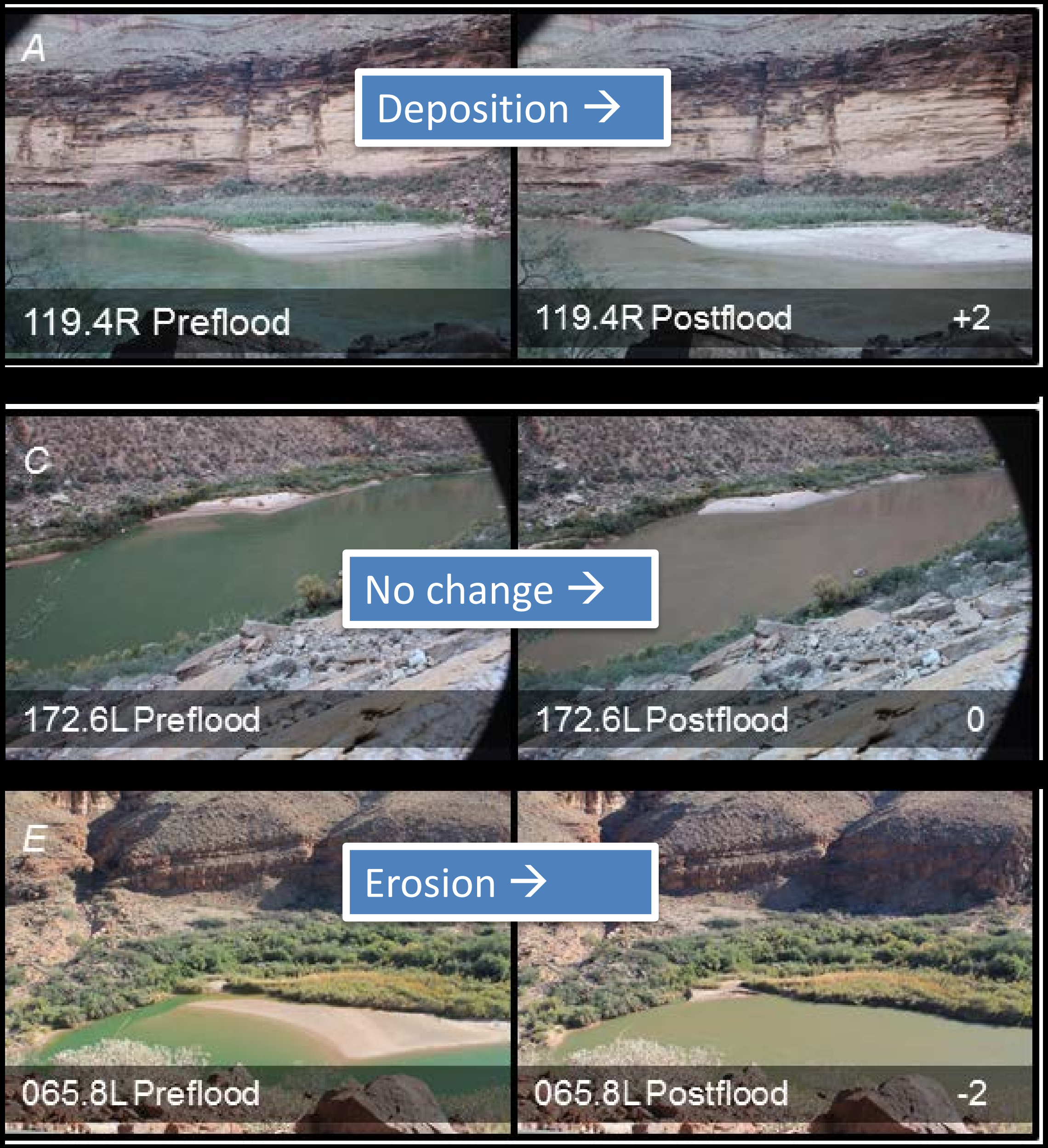
Types of sandbar response to HFEs



~ 50-60% of sites

~ 30-40% of sites

~ 10% of sites

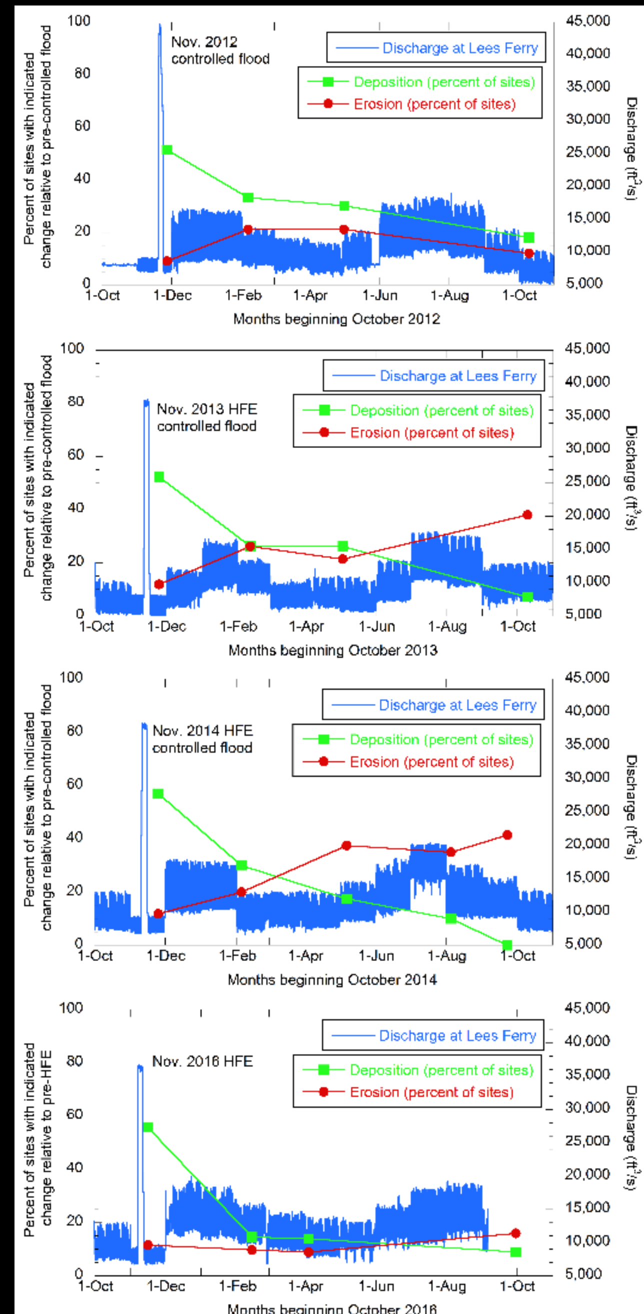
Grams et al. (2018)

USGS

Erosion of HFE deposit

Most sandbars erode near pre-HFE size within 6 to 12 months.

HFE Response: 2012 to 2017



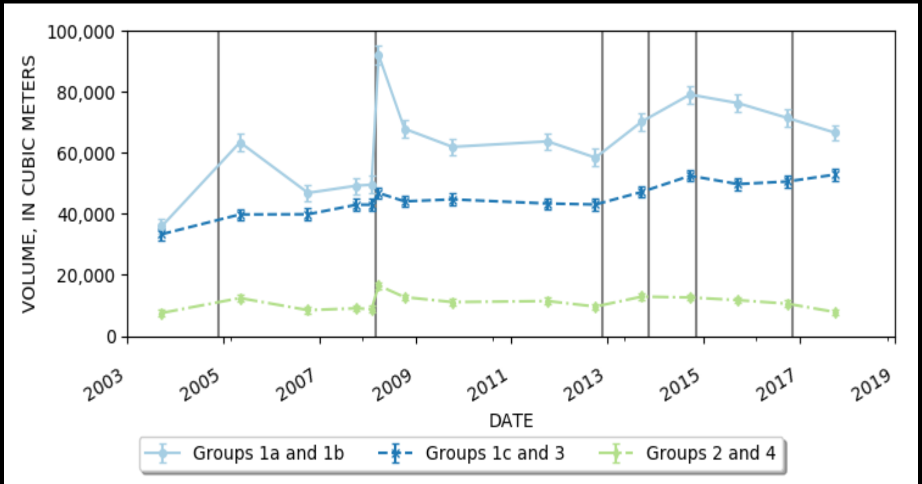
Grams et al. (2018)

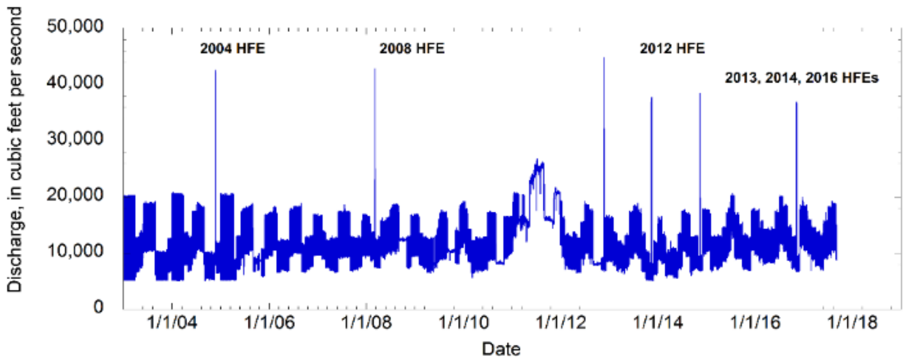
USGS

Sandbar monitoring

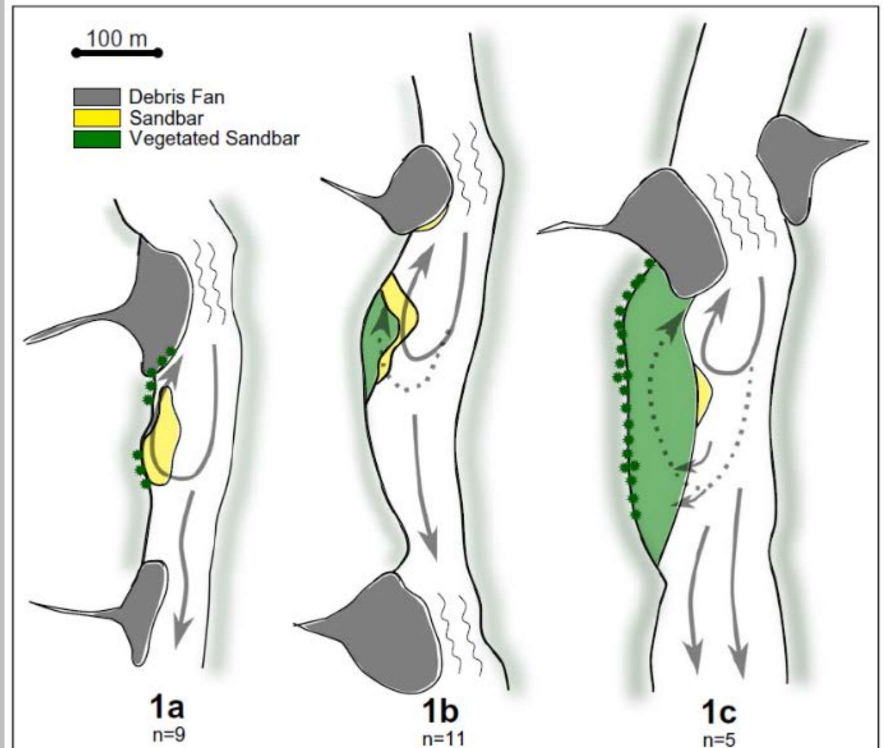
New analysis of sandbar trends based on grouping of bars by morphology and average response

- Groups 1a and 1b:
  - relatively large and mostly open bare sandbars
  - Strongest response to HFEs
- Groups 1c and 3:
  - heavily vegetated bars
  - Less dynamic around HFEs, tend to accumulate over time
- Groups 2 and 4:
  - Mostly smaller bars adjacent to debris fans (don't project into eddy)
  - Tend to be most stable
  - HFEs still improve condition by filling gullies and burying/removing debris





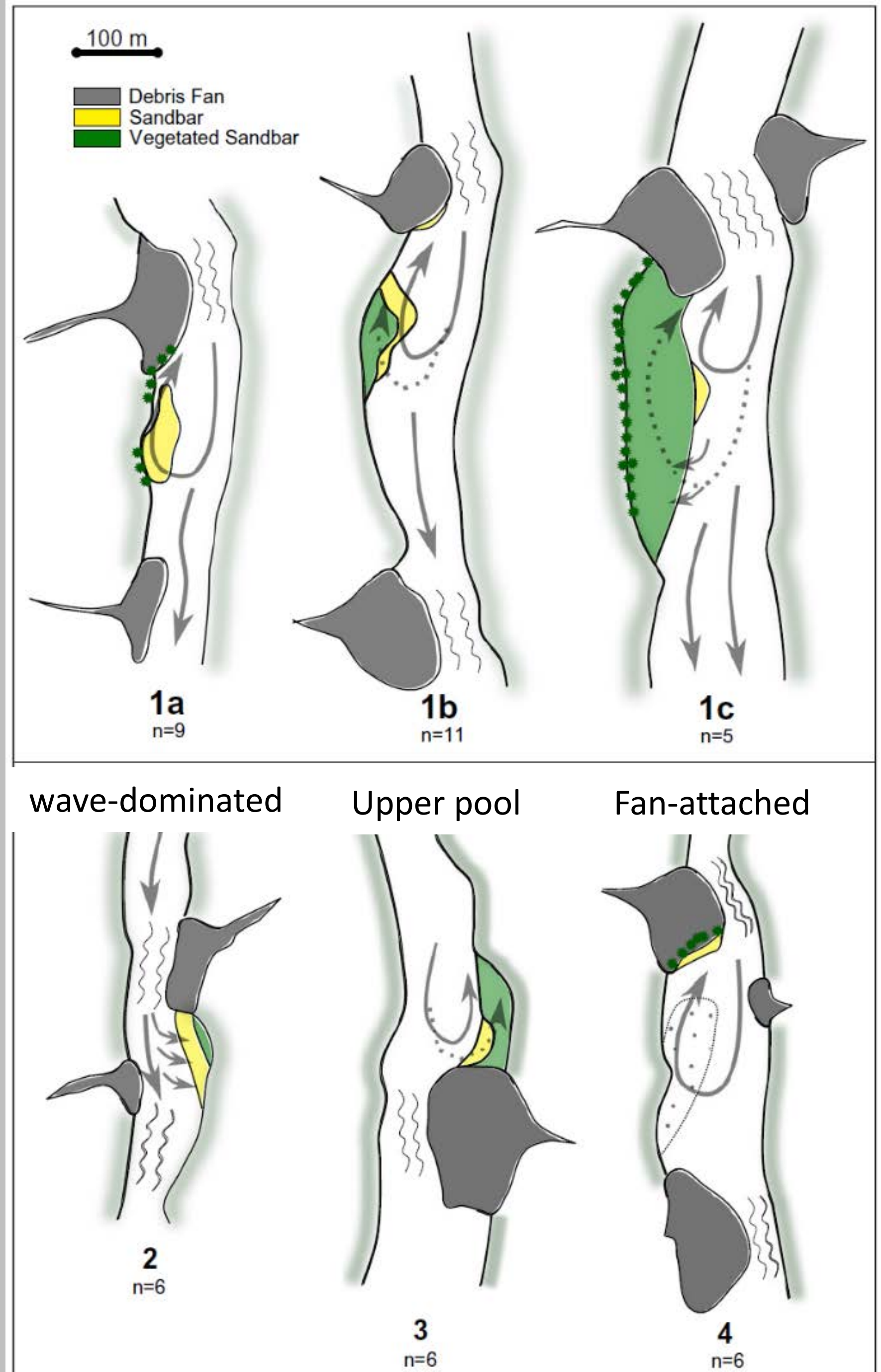
Mueller et al. (2018); unpublished data, do not cite



Sandbar Groupings

More than half of the long-term monitoring sites contain "typical" reattachment bars with varying degrees of vegetation encroachment

Mueller et al. (2018)



Sandbar Groupings

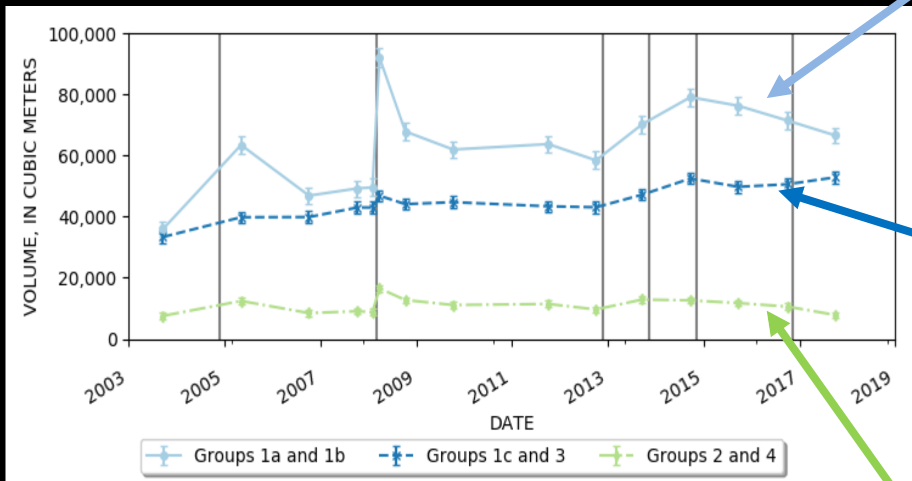
More than half of the long-term monitoring sites contain "typical" reattachment bars with varying degrees of vegetation encroachment

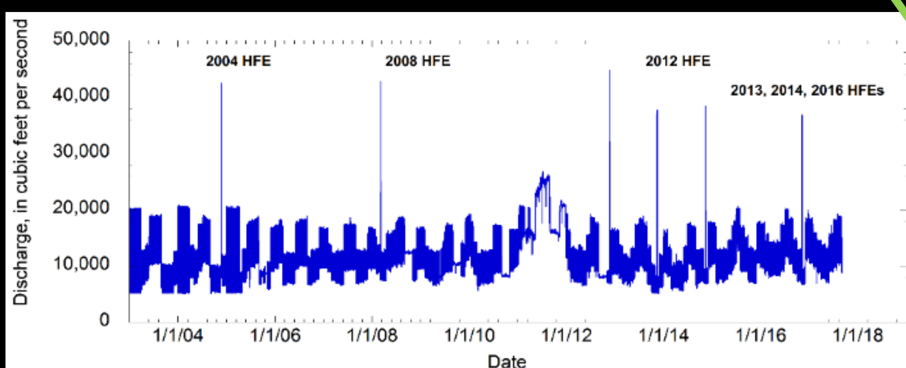
Additional common sandbar types

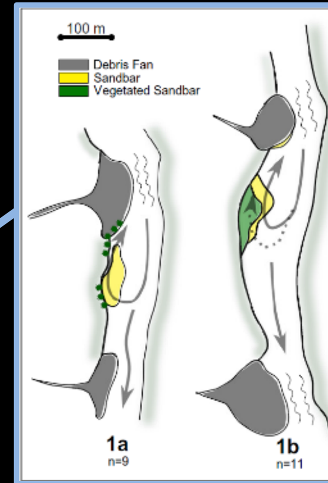
Mueller et al. (2018)

USGS

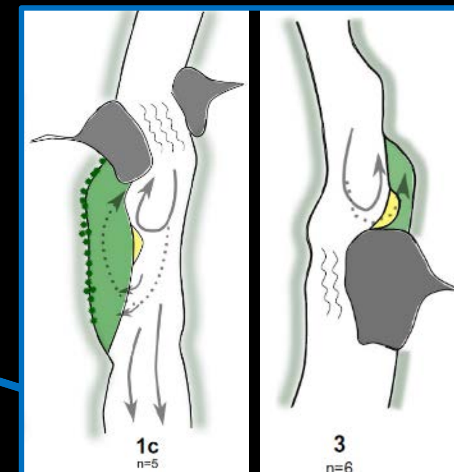
Sandbar monitoring



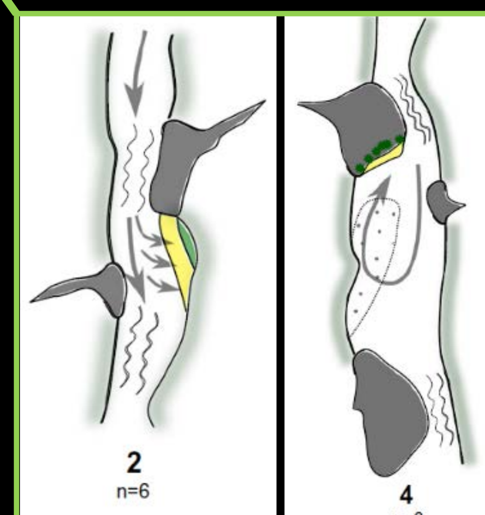




Large and open bars with strongest response to HFEs



Most heavily vegetated bars: aggrade

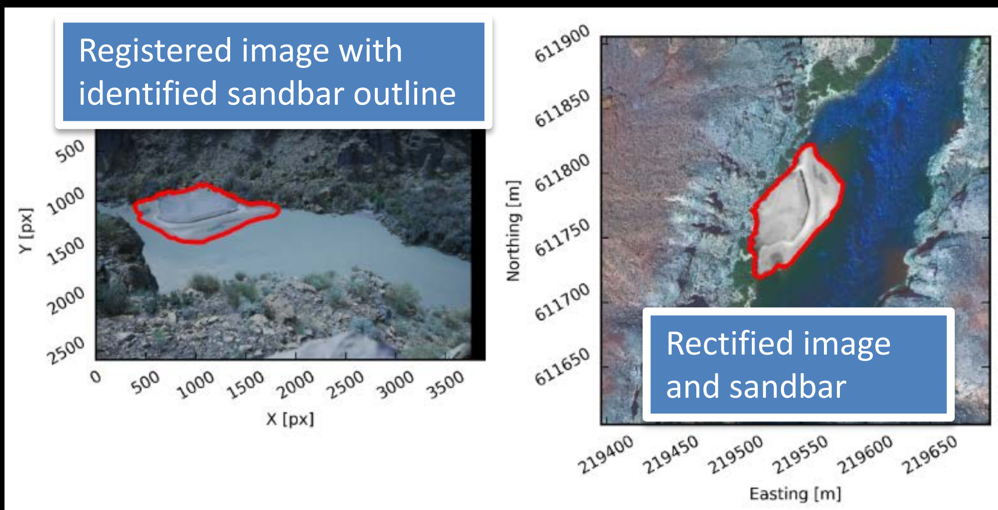


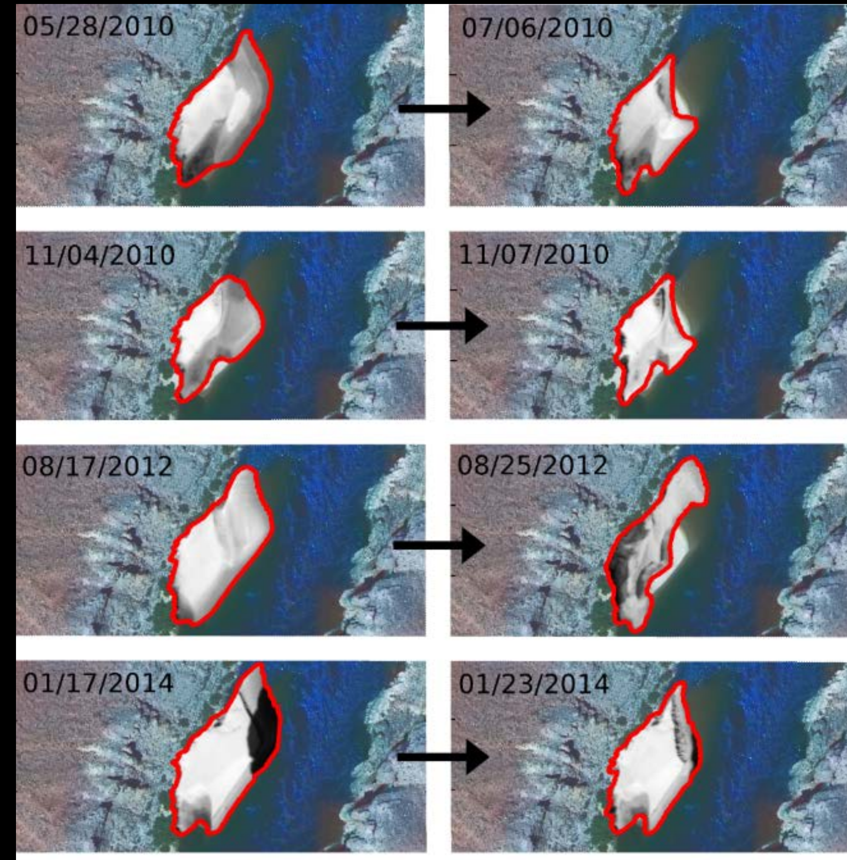
Smaller bars adjacent to fans: stable, HFE’s fill gullies and cover debris

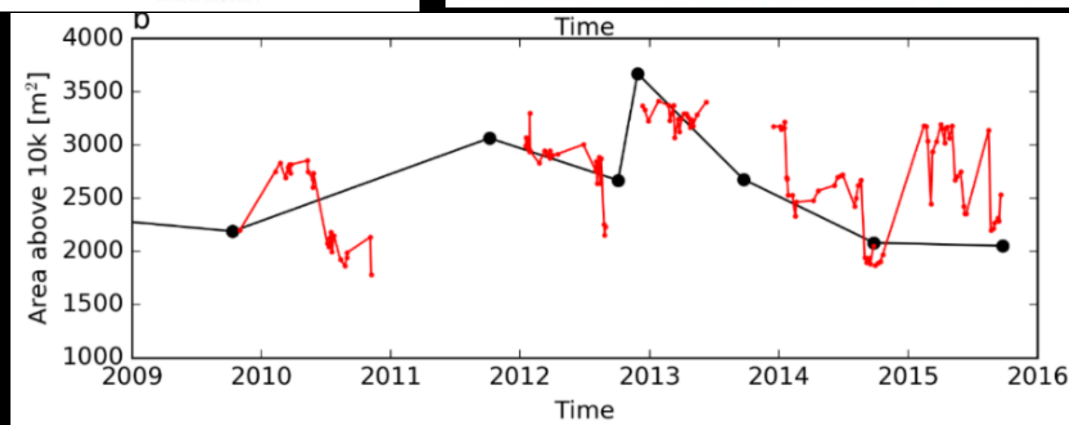
Mueller et al. (2018); unpublished data, do not cite

Large short-term changes in sandbar area

- Objective:
  - Quantitative measure of HFE response and post-HFE erosion rates







- Quantification of changes in sandbar area at short (daily/weekly/monthly) intervals
- Currently relies on semi-automatic delineation of sandbar from images

Grams et al. (2018)

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Completely automated sandbar segmentation

- Segmenting sandbars from imagery, by training artificial neural networks to reliably recognize features (sand, water, rocks, vegetation)
- Each image takes only a minute or two
- Thousands of images processed per day

“water”

“rock”

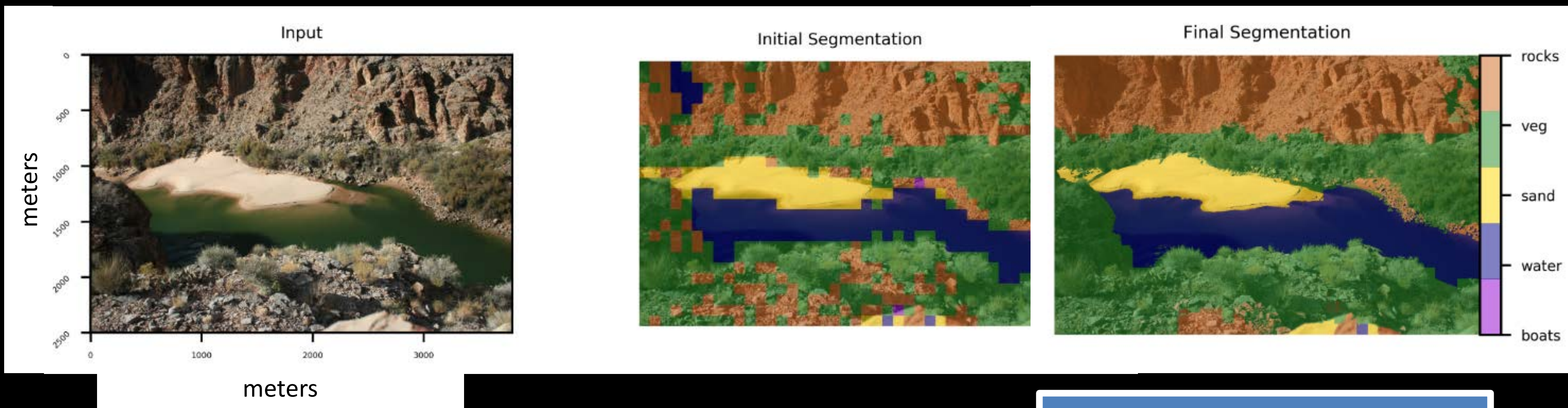
“sand”

“vegetation”

Create “library” of image parts for each class, the neural network “learns” to identify

USGS

Completely automated sandbar segmentation



Initial classification using image library and “deep neural network”

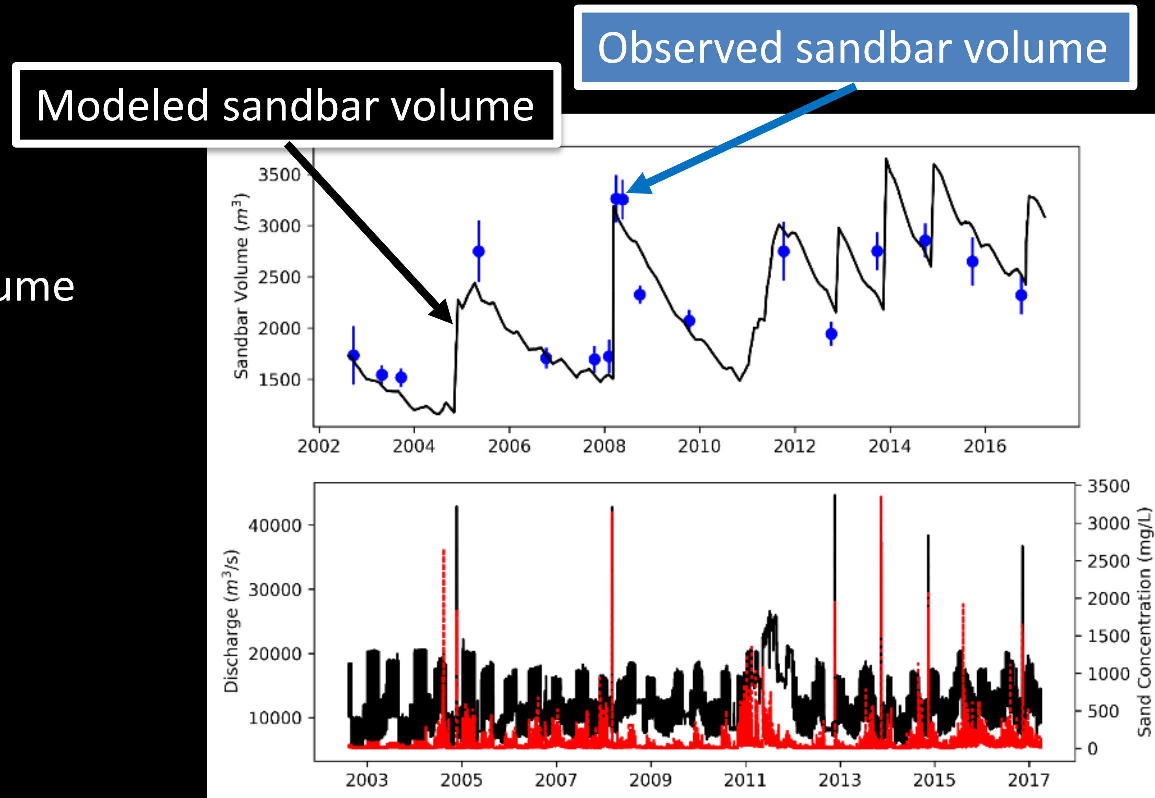
Final classification using “conditional random fields”

- Promising method for processing the images from remote cameras
- Plan to start using for data analysis this year or next
- Evaluating extending the method to canyon-wide remote sensing images

Sandbar modeling

New physically-based model for sandbar response based on bar groupings

- Predicts changes in sandbar volume based on:
  - Discharge (observed)
  - Suspended sediment concentration (observed)
  - Sand grain size (observed)
  - Water depth
  - Sandbar and eddy size (measured)
  - Eddy exchange rate (estimated)
  - Sandbar erosion rate (estimated)



- Model can be applied to predict bar response over periods of many years with HFEs of different magnitude and frequency
- Can be improved with additional measurements of bar erosion from analysis of remote camera images

Mueller et al. (in prep.)

preliminary results, do not cite

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Sand-storage changes in Lower Marble Canyon and Eastern Grand Canyon (RM 30 – 87)

- Erosion in Lower Marble Canyon (2009-2012)
  - Sandbars: ~ 22 cm decrease in sand thickness (10% of vol. change)
  - Eddies: ~ 3 cm increase in sand thickness (7% of vol. change)
  - Channel: ~ 10 cm decrease in sand thickness (83% of vol. change)
- Erosion in Eastern Grand Canyon (2011-2014)
  - Sandbars: ~ 8 cm increase in sand thickness (3% of vol. change)
  - Eddies: ~ 9 cm decrease in sand thickness (12% of vol. change)
  - Channel: ~ 10 cm decrease in sand thickness (85% of vol. change)

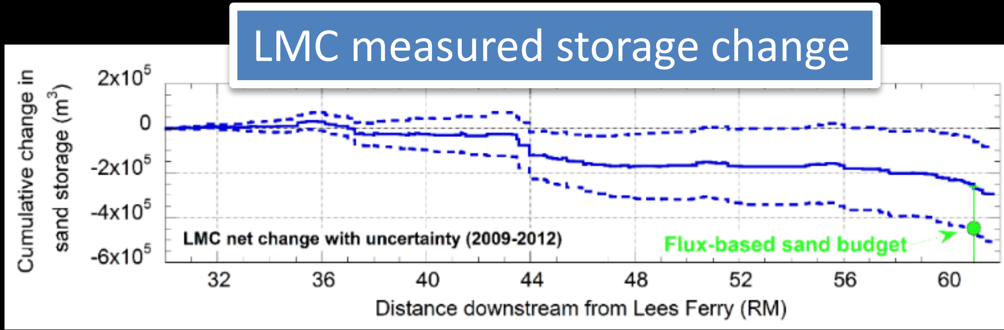
- Equalization without HFEs → erosion everywhere
- Equalization followed by HFEs → erosion in channel and eddies, but deposition on bars
- Sand patches decrease in thickness but are stable in area and location during evacuation

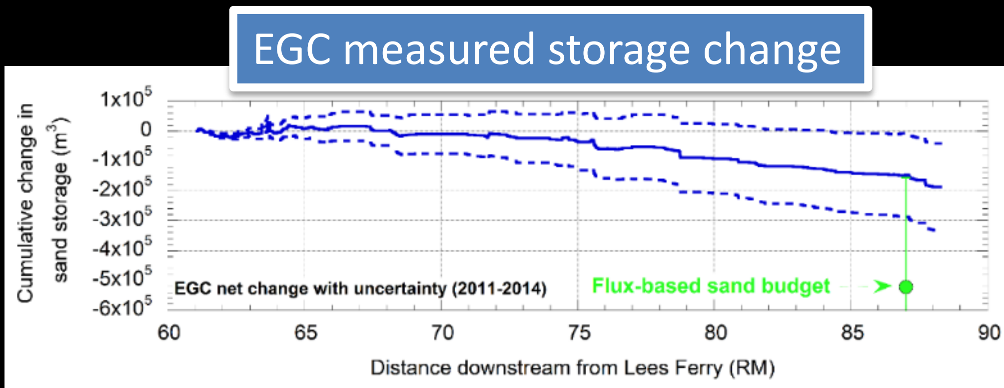
preliminary results, do not cite

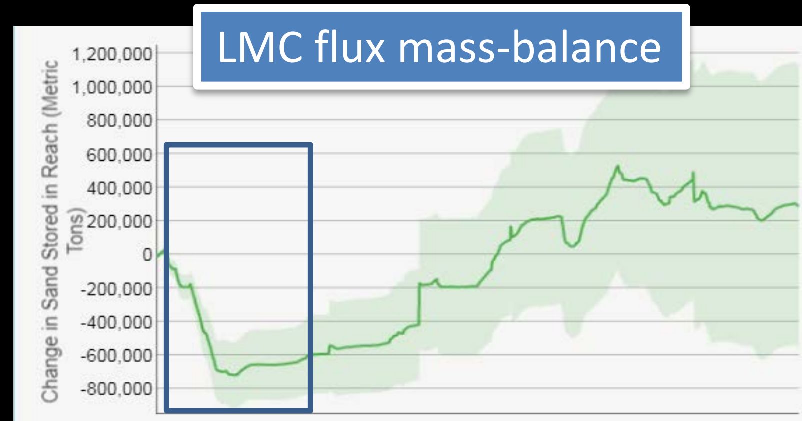
Maps of sand distribution, erosion and deposition, RM 30-87

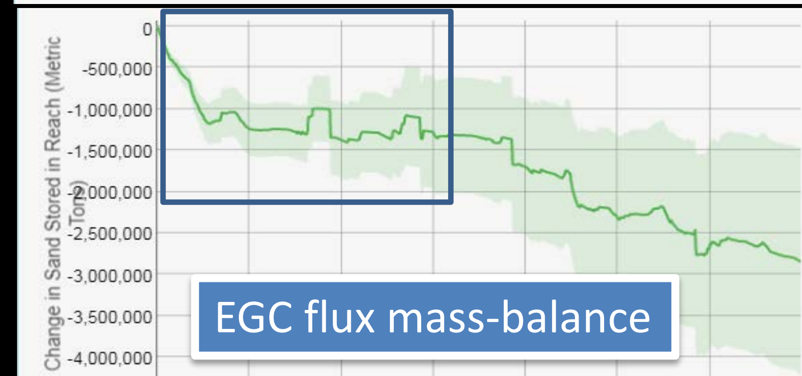
USGS

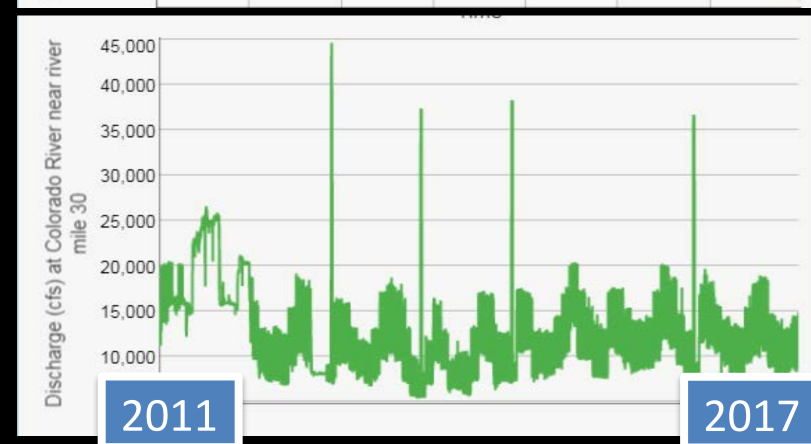
Sand-storage changes in Lower Marble Canyon and Eastern Grand Canyon (RM 30 – 87)











- Equalization flows in 2011 caused net erosion
- Net accumulation in Lower Marble Canyon
  - Consistent sand inputs from Paria River (5 out of 7 years)
  - Export during HFEs has been less than accumulation
- Net evacuation in Eastern Grand Canyon
  - Paria inputs either retained in Marble Canyon or transported through (to Lake Mead)
  - Period of low inputs from Little Colorado River

preliminary results, do not cite

USGS

Project B: FY 2018-20

- Sandbar monitoring and research
  - Continue annual monitoring
  - Maintain remote cameras for HFE response
  - Develop quantitative metrics for monitoring from remote camera images (see Ryan Lima poster)
  - Complete publications (modeling, analysis of 1984 images)

- Sand storage change
  - Complete processing of data collected in 2017
  - Work on control network in preparation for mapping between RM 87 and 166 in next work plan
  - Analysis and reporting on measurements of sand thickness (see Andrew Platt poster)
  - Mapping of Lower Marble Canyon and Eastern Grand Canyon in 2019
  - Publications and reporting on sand storage changes in Marble and Eastern Grand Canyon

Referenced cited:

Grams, P. E., Tusso, R. B., & Buscombe, D. (2018). Automated Remote Cameras for Monitoring Alluvial Sandbars on the Colorado River in Grand Canyon, Arizona. U.S. Geological Survey Open-File Report 2018-1019, 61. https://doi.org/10.3133/ofr20181019

Mueller, E. R., Grams, P. E., Hazel, J. E., & Schmidt, J. C. (2018). Variability in eddy sandbar dynamics during two decades of controlled flooding of the Colorado River in the Grand Canyon. Sedimentary Geology, 363, 181–199. https://doi.org/10.1016/j.sedgeo.2017.11.007

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Schmidt, J. C., Topping, D. J., Grams, P. E., & Hazel Jr., J. E. (2004). System-wide changes in the distribution of fine sediment in the Colorado River corridor between Glen Canyon Dam and Bright Angel Creek, Arizona. Flagstaff, Ariz.: U.S. Geological Survey, Grand Canyon Monitoring and Research Center. Retrieved from http://www.gcmrc.gov/library/reports/Physical/Fine_Sed/Schmidt2004.pdf