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

Project B: Effects of dam releases on in-channel sediment storage and sandbar dynamics

GCDAMP Annual Reporting Meeting
Phoenix, Arizona
January 13, 2020

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Project B: Sandbar and Sediment Storage Monitoring and Research

- Project Elements
  - B.1 Sandbar Monitoring
  - B.2 Bathymetric and topographic mapping for monitoring long-term trends in sediment storage
  - B.3 Control Network and Survey Support
- Project Objectives
  - track the effects of individual High Flow Experiments (HFEs) on sandbars
  - monitor the cumulative effect of successive HFEs and intervening operations on sandbars and sand conservation
  - investigate the interactions between dam operations, sand transport, and eddy sandbar dynamics
- GCDAMP FY2019 Funding: $1,100,000
- Cooperators: Northern Arizona University

Project B: Sandbar and Sediment Storage Monitoring and Research, cont.

- Data Products FY19
  - Sandbar monitoring photographs
    - www.gcmrc.gov/sandbar OR www.usgs.gov/apps/sandbar
  - Sandbar monitoring data
    - www.gcmrc.gov/sandbar OR www.usgs.gov/apps/sandbar
- Data collection FY19
  - April: Bathymetric and topographic mapping of Lower Marble Canyon and Eastern Grand Canyon (River Mile 29 to 87)
    - Data are currently being edited and processed
    - Expect to report results that will show 10-year trends in sandbars and sand storage for these reaches by next January
  - October: Sandbar and campsite surveys
    - Data are ~50% processed
    - Results in next (Hazel and Kaplinski) presentation
    - Remaining sites will be processed and data on website by end of February

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Project B: Publications (2018-2019)

- Buscombe, D., 2019, SediNet—A configurable deep learning model for mixed qualitative and quantitative optical granulometry: Earth Surface Processes and Landforms, https://doi.org/10.1002/esp.4760.
- Grams, P.E., 2019, Sandbar deposition caused by high-flow experiments on the Colorado River downstream from Glen Canyon Dam--November 2012-November 2018, in High-flow experiments assessment extended abstracts--Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting Presentations, March 12-13, 2019, Phoenix, Ariz.: U.S. Geological Survey, Grand Canyon Monitoring and Research Center, p. 12-22, https://www.usbr.gov/uc/progact/amp/amwg/2019-03-06-amwg-meeting/20190301-HFE_Extended_Abstracts-Combined_FINAL.pdf.
- Leary, K.C.P., and Buscombe, D., 2019, Estimating sand bedload in rivers by tracking dunes--A comparison of methods based on bed elevation time-series--preprint discussion paper: Earth Surface Dynamics, https://doi.org/10.5194/esurf-2019-38.
- Topping, D.J., Grams, P.E., Griffiths, R.E., Hazel, J.E., Kaplinski, M.A., Dean, D.J., Voichick, N., Unema, J.A., and Sabol, T.A., 2019, Optimal timing of high-flow experiments for sandbar deposition, in High-flow experiments assessment extended abstracts--Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting presentations, March 12-13, 2019, Phoenix, Ariz.: U.S. Geological Survey, Grand Canyon Monitoring and Research Center, p. 3-9, https://www.usbr.gov/uc/progact/amp/amwg/2019-03-06-amwg-meeting/20190301-HFE_Extended_Abstracts-Combined_FINAL.pdf.
- Grams, P.E., Buscombe, D., Topping, D.J., Kaplinski, M.A., and Hazel, J.E., Jr., 2019, How many measurements are required to construct an accurate sand budget in a large river? Insights from analyses of signal and noise: Earth Surface Processes and Landforms, online, https://doi.org/10.1002/esp.4489
- Buscombe, D., and Ritchie, A.C., 2018, Landscape classification with deep neural networks: Geosciences, v. 8, no. 7, article 244, https://doi.org/10.3390/geosciences8070244
- Buscombe, D., and Grams, P.E., 2018, Probabilistic substrate classification with multispectral acoustic backscatter--A comparison of discriminative and generative models: Geosciences, v. 8, no. 11, article 395, https://doi.org/10.3390/geosciences8110395
- Buscombe, D., Grams, P.E., & Kaplinski, M., 2018, Probabilistic models of seafloor composition using multispectral acoustic backscatter: GeoHab 2018 International Symposium, R2Sonic Multispectral Backscatter competition entry. Download using online form at: https://www.r2sonic.com/geohab2018/
- Grams, P.E., Tusso, R.B., and 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, 50 p., https://doi.org/10.3133/ofr20181019.
- Hamill, D., Buscombe, D., and Wheaton, J.M., 2018, Alluvial substrate mapping by automated texture segmentation of recreational-grade side scan sonar imagery: PLOS One, v. 13, no. 3 (e0194373), p. 1-28, https://doi.org/10.1371/journal.pone.0194373.
- Hadley, D.R., Grams, P.E., and Kaplinski, M.A., 2018, Quantifying geomorphic and vegetation change at sandbar campsites in response to flow regulation and controlled floods, Grand Canyon National Park, Arizona: River Research and Applications, online, https://doi.org/10.1002/rra.3349
- Hadley, D. R., Grams, P. E., Kaplinski, M. A., Hazel, J.E., J., & Parnell, R. A., 2018, Geomorphology and vegetation change at Colorado River campsites, Marble and Grand Canyons, Arizona: U.S. Geological Survey Scientific Investigations Report 2017–5096, 64 p., https://doi.org/10.3133/sir20175096
- Kasprak, A., Sankey, J.B., Buscombe, D., Caster, J., East, A.E., and Grams, P.E., 2018, Quantifying and forecasting changes in the areal extent of river valley sediment in response to altered hydrology and land cover: Progress in Physical Geography: Earth and Environment, online, https://doi.org/10.1177/0309133318795846.
- Mueller, E.R., Grams, P.E., Hazel, J.E., Jr., and 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, v. 363, p. 181-199, https://doi.org/10.1016/j.sedgeo.2017.11.007.

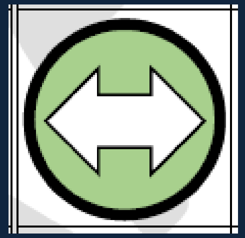
Project B Presentations at Annual Reporting Meeting

- Talks:
  - In-channel sand storage (this talk)
  - Sandbar changes (Joe Hazel, next talk)
  - Relation between riparian vegetation and sandbar deposition (Brad Butterfield, tomorrow AM)
- Posters:
  - Estimates of sand thickness and total sand storage for west-central Grand Canyon (Daniel Buscombe and Matt Kaplinski)
  - Tracing the origin of sandbar deposits in the Grand Canyon of the Colorado River using XRF signatures and Bayesian mixing models (Katie Chapman)

Project B: Key findings with respect to LTEMP Goals and Knowledge Assessment

- LTEMP goal:
  - "Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes."
- Assessment:
  - Although specific targets are not defined, each HFE has resulted in deposition and the general objective of retaining and/or increasing sand volume above the 8000 cfs stage has been achieved in the HFE Protocol period (2012-2019).
- Prognosis:
  - Deposition at sandbars is likely stage-limited (bars not likely to get larger without larger HFEs)
  - Since 2011, dam releases have been relatively low and sand inputs from Paria River generally high. Changes in either of these conditions could cause trend to reverse.

OR



Status: unknown, because targets not defined; or good, because sand volume and area are not currently decreasing

Trend: unchanging because HFEs result in deposition, but bars are not progressively expanding

Confidence: high, because the monitoring is robust.

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Project B: AMP goals addressed and information provided

- LTEMP goal:
  - "Increase and retain fine sediment volume, area, and distribution in the Glen, Marble, and Grand Canyon reaches above the elevation of the average base flow for ecological, cultural, and recreational purposes."
- Question from HFE Protocol:
  - "Can sandbar building during HFEs exceed sandbar erosion during periods between HFEs, such that sandbar size can be increased and maintained over several years?"
- Project B address these questions by two related monitoring efforts:
  - Annual sandbar and campsite monitoring (sandbar surveys and daily photographs)
    - Critical information provided: Annual assessment of the effects of HFEs and other dam operations on selected sandbars and campsites.
  - Periodic channel mapping (Combined topographic and bathymetric mapping)
    - Critical information provided: Periodic assessment of long-term trends at large sample of sandbars and trends in sand storage on the river bed.

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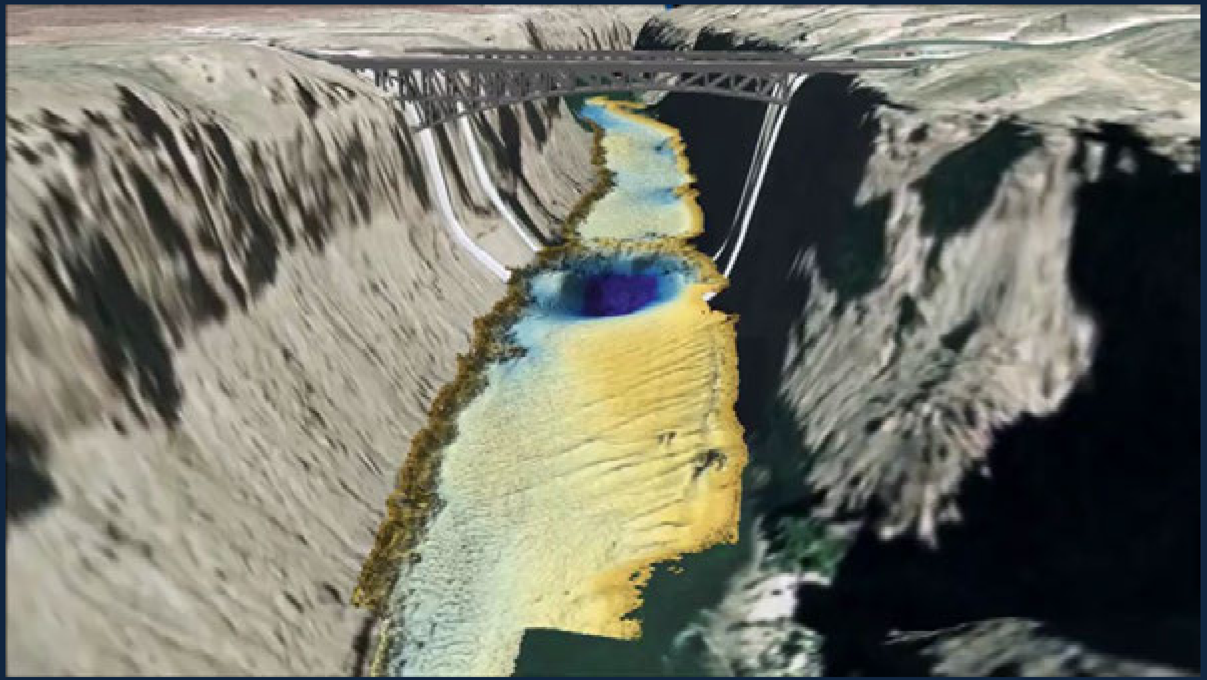
Why measure sand storage by mapping the riverbed?

- Sandbar replenishment controlled by:
  - Flow (need high flows to build large bars)
  - Sand supply (if supply in the channel is low, a net loss from eddy sandbars is risked)
- Sand supply is controlled by:
  - Dam releases (annual volume and release pattern)
  - Inputs from tributaries



- The sand that builds sandbars is stored on the bed of the river and understanding the sand supply is critical to understanding and predicting sandbar response

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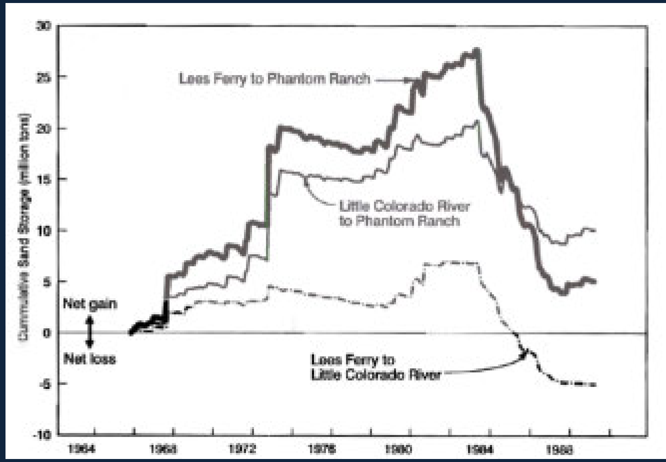
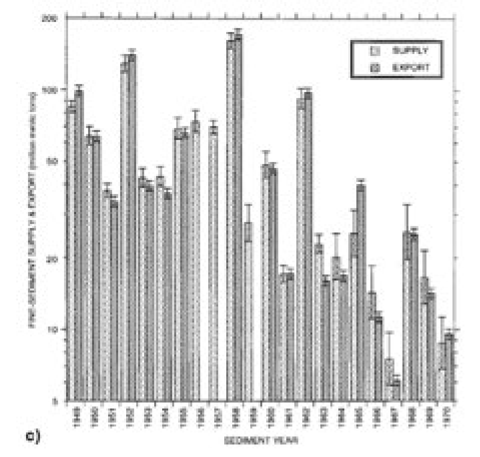
Three decades of Sand Budgets in Grand Canyon have been incorrect or ambiguous because of inadequate measurements or because of measurement uncertainty

1990's



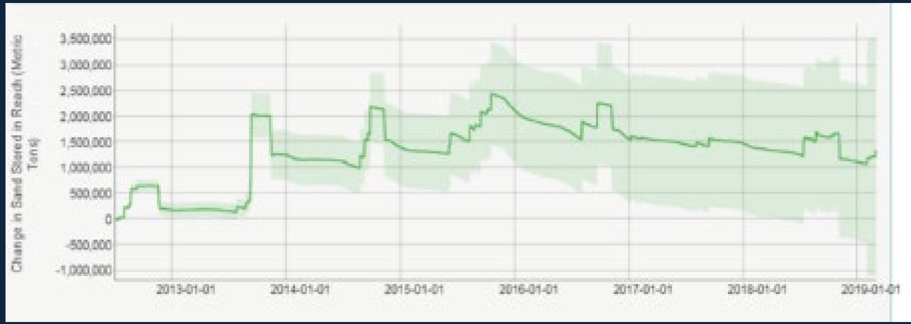
Stable rating curves → **sand accumulation**
(Glen Canyon Dam Environmental Impact Statement, 1990)

2000's



Analysis of historical data → **no accumulation**
(Topping et al., 2000)

2010's



Continuous measurements of flux → **accumulation and evacuation with large uncertainty**

https://www.gcmrc.gov/discharge_qw_sediment/reaches/GCDAMP

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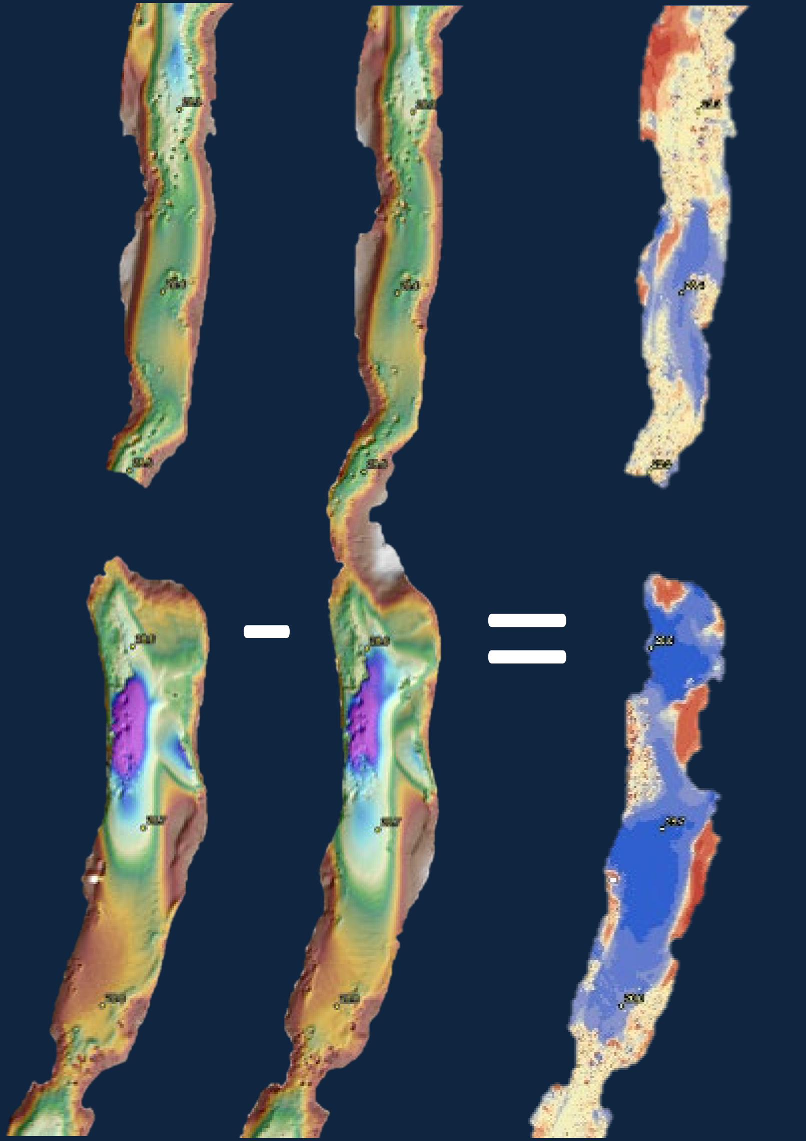
How we measure sand storage on the bed

- Repeat topographic and bathymetric measurements
  - Multibeam sonar
  - Singlebeam sonar
  - Total station
- Referenced to geodetic control network
- Use backscatter to classify sand/gravel/rock
- High spatial resolution
- Uncertainty accumulates spatially – not over time



May 2016 May 2013 Difference

Blue = deposition
Red = erosion

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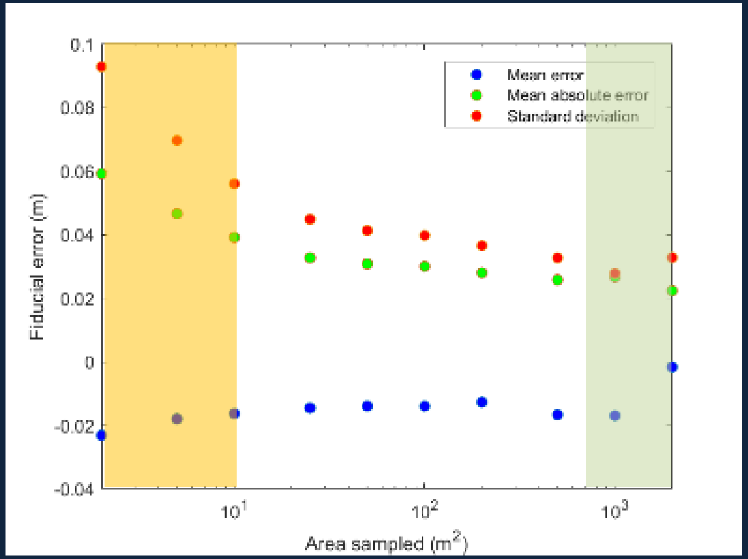
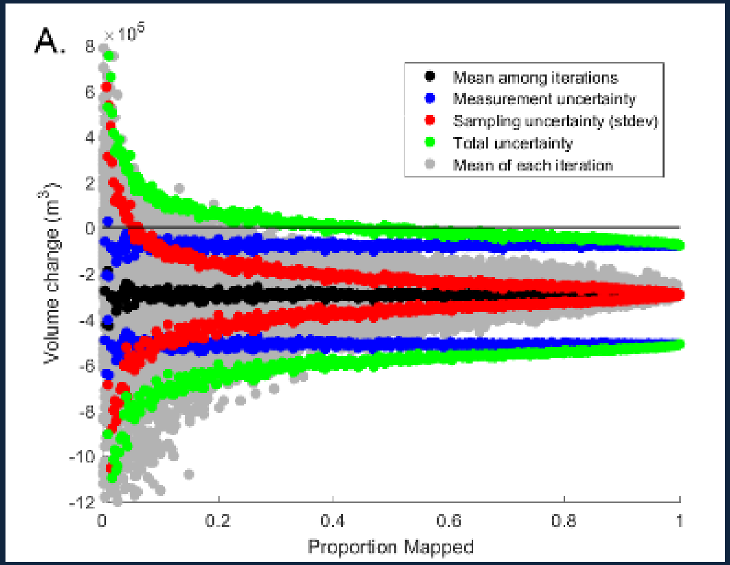
Uncertainty in measurements of sand storage

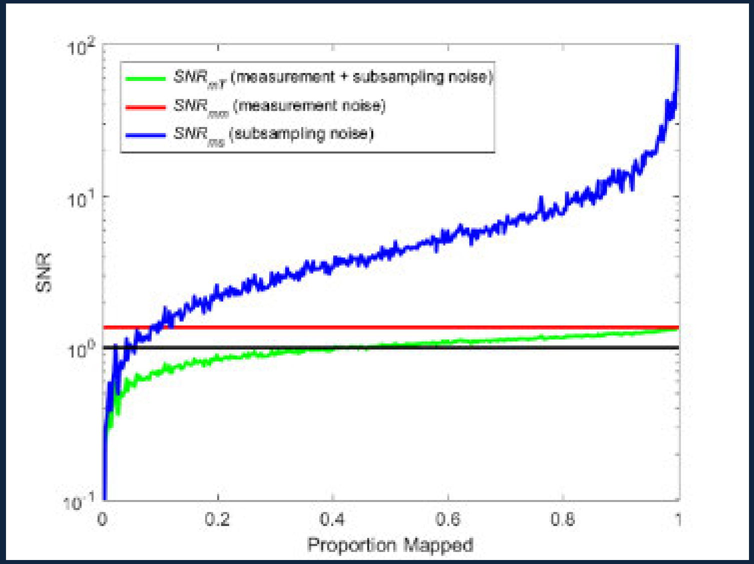
- Measurement uncertainty
  - Caused by instrument and/or position errors
  - Estimated by analysis of stable rock and gravel
- Sampling uncertainty
  - Caused by gaps in data coverage and large spatial variability of erosion and deposition
  - Estimated by bootstrap analysis for over the area we mapped



Error is less when computing changes in mean elevation over large areas
And is less than 0.03 m when averaging over areas more than 500 m^2



Random sampling from among mapped segments shows the decrease in uncertainty as a function of sample size



Must map at least 50 to 60% of the reach to detect direction of change (SNR > 1).

Grams et al. (2019)

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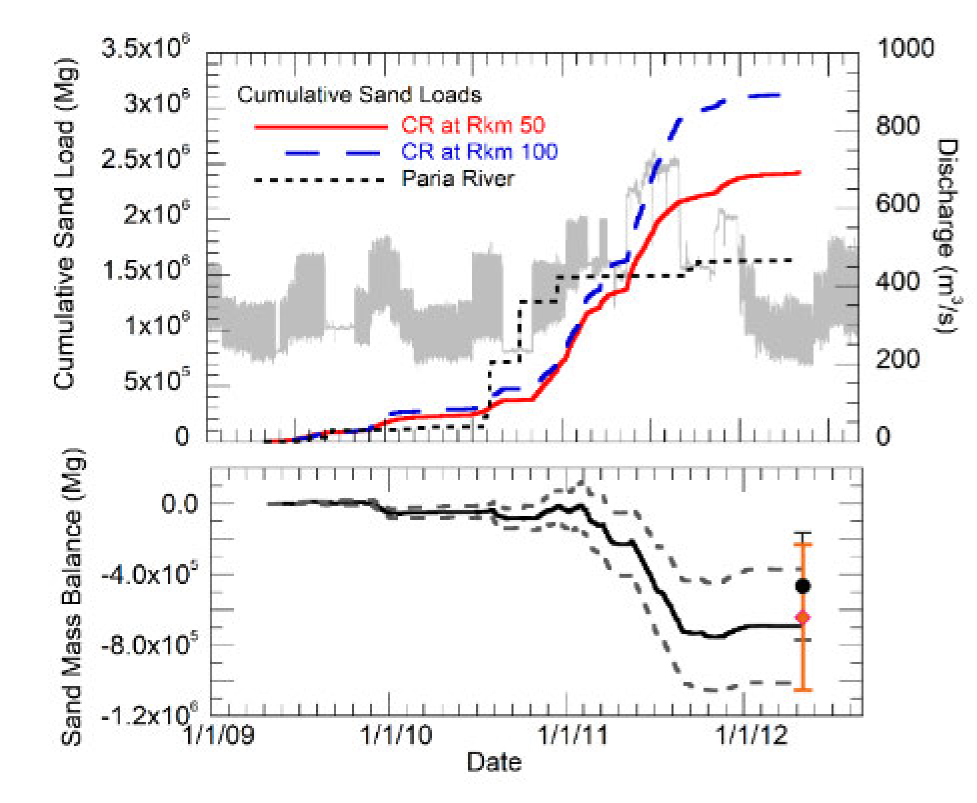
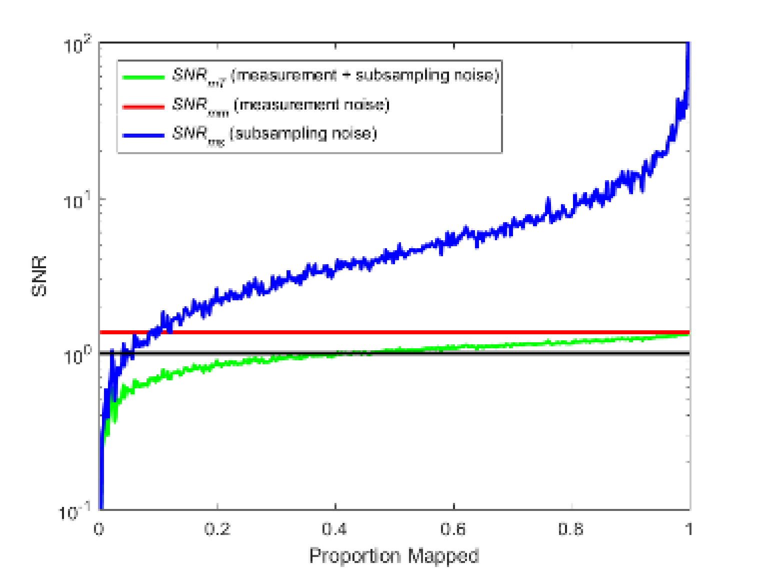
Channel mapping results: Lower Marble Canyon, 2009-2012

50-km reach (50-100 km downstream from Paria River)





Must map at least 50 to 60% of the reach to detect direction of change (SNR > 1).

Lower Marble Canyon, 2009-2012

- No controlled floods
- Includes 2011 equalization flows
- Flux budget: -700,000 ± 317,000 Mg
- Morphological budget: - 466,700 ± 303,300 Mg

Grams et al. (2019)

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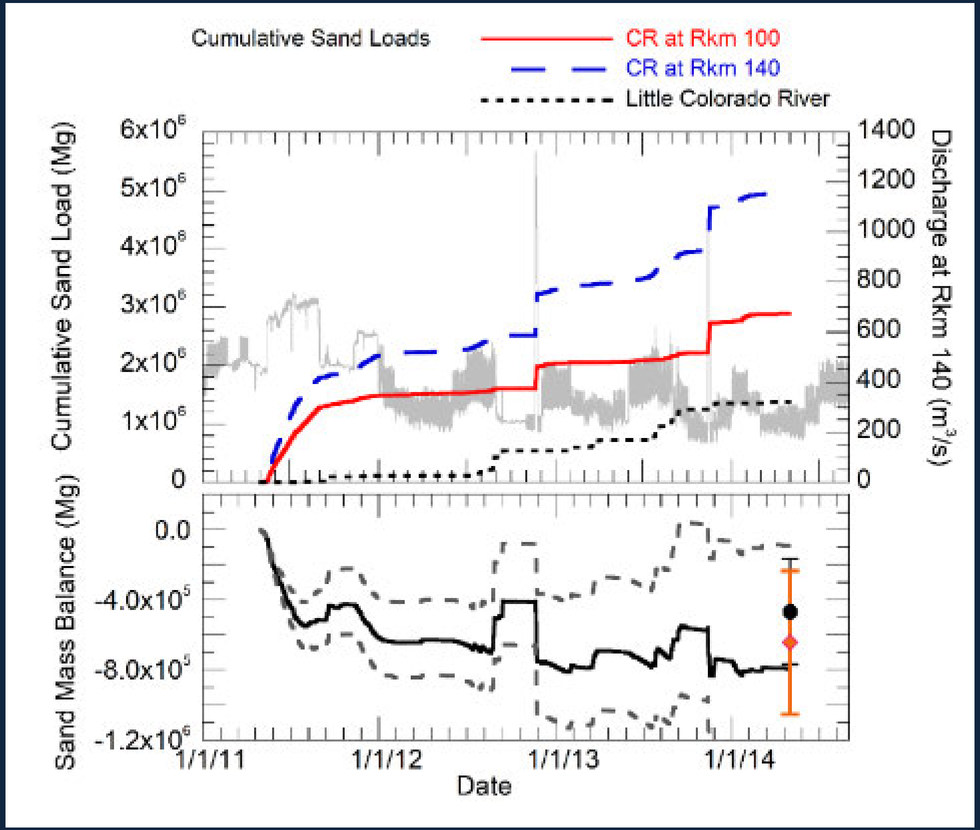
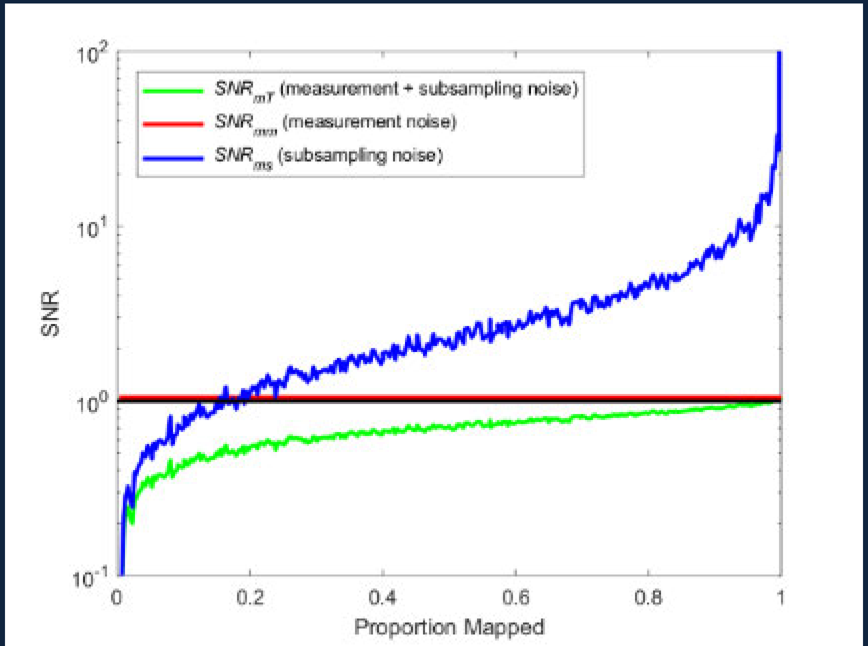
Channel mapping results: Eastern Grand Canyon, 2011-2014

40-km reach (100-140 km downstream from Paria River)





SNR never > 1; must map everything!

Eastern Grand Canyon, 2011-2014

- Includes 2 controlled floods
- Includes 2011 equalization flows
- Flux budget: -690,000 ± 580,000 Mg
- Morphological budget: -297,300 ± 231,800 Mg

- Average inputs coupled with high flow volumes → moderate erosional signal that can be detected only by mapping a majority of the reach

Preliminary data, do not cite

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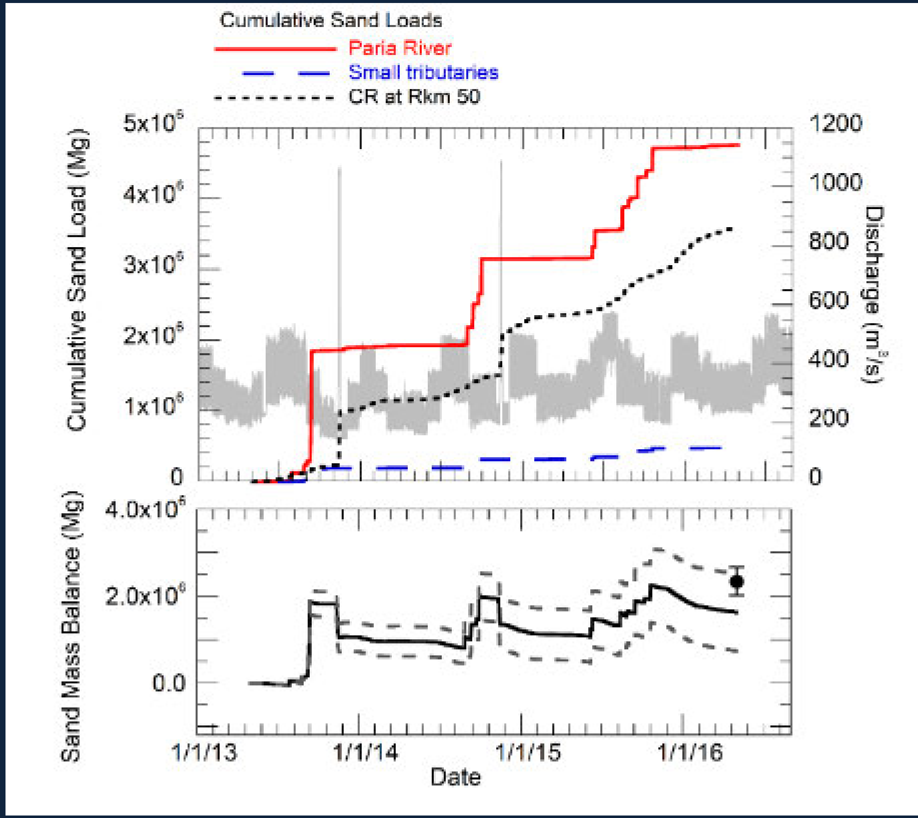
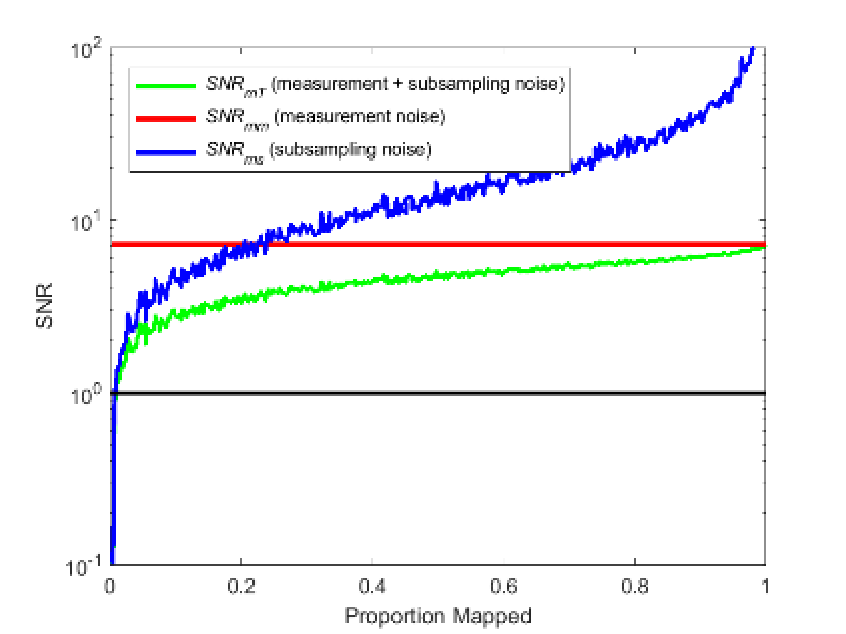
Channel mapping results: Upper Marble Canyon, 2013-2016

50-km reach (0-50 km downstream from Paria River)





SNR > 1 with just a small fraction of reach mapped

Mapping 50% of the reach gives SNR = 5

Upper Marble Canyon, 2013-2016

- Includes 2 controlled floods
- No summer high-volume flows
- Flux budget is +1,635,000 ± 894,000 Mg
- Morphological budget: 2,340,600 ± 324,000 Mg

- Successive large inputs from upstream tributary → large depositional signal that is easy to detect

Preliminary data, do not cite

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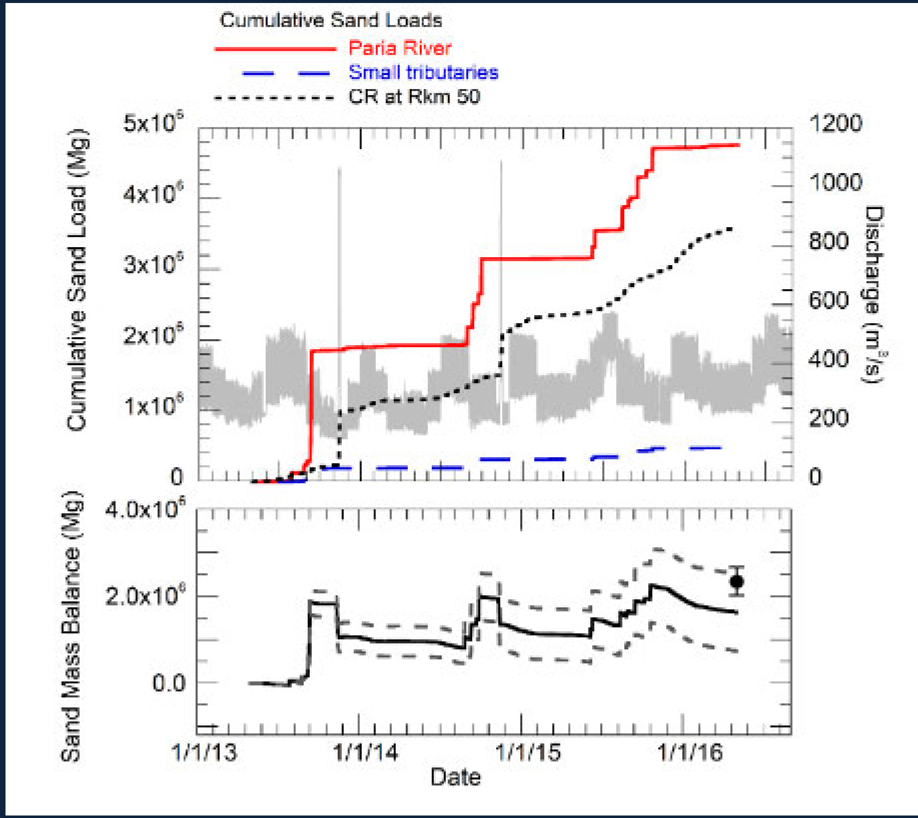
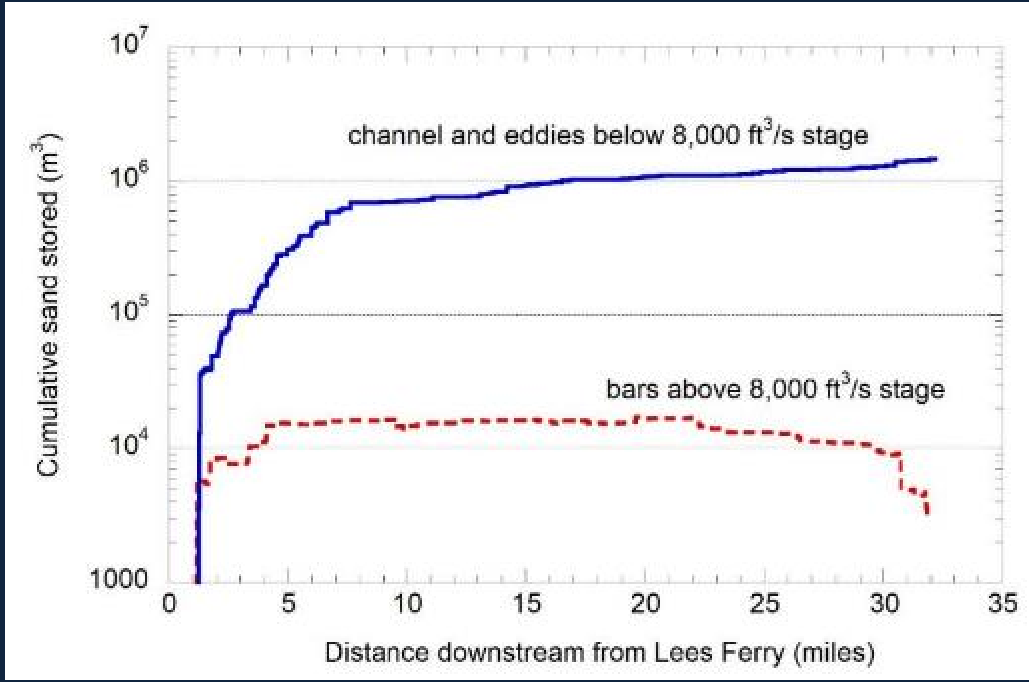
Channel mapping results: Upper Marble Canyon, 2013-2016, cont.

50-km reach (0-50 km downstream from Paria River)





Nearly all (>99%) of the accumulated sand is on the riverbed

Upper Marble Canyon, 2013-2016
- Includes 2 controlled floods
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- Morphological budget: 2,340,600 ± 324,000 Mg

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Preliminary data, do not cite

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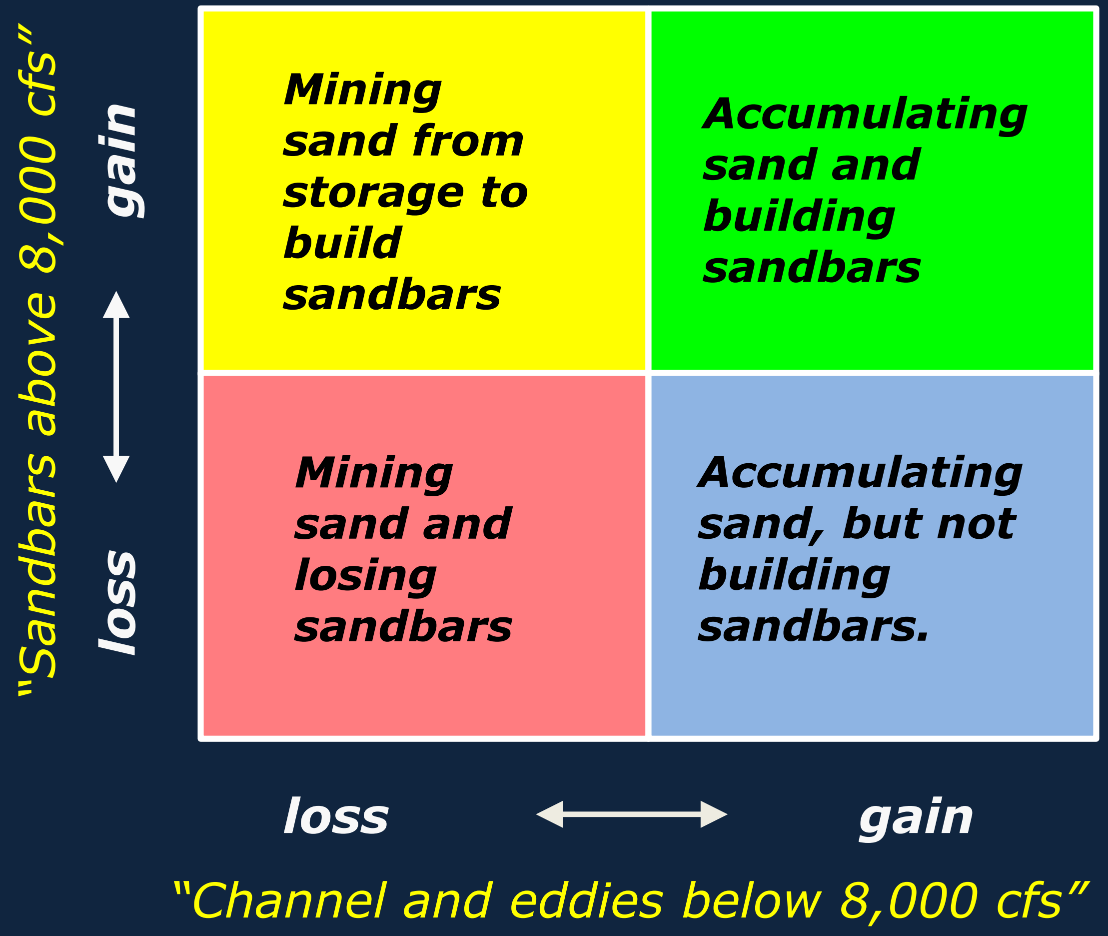
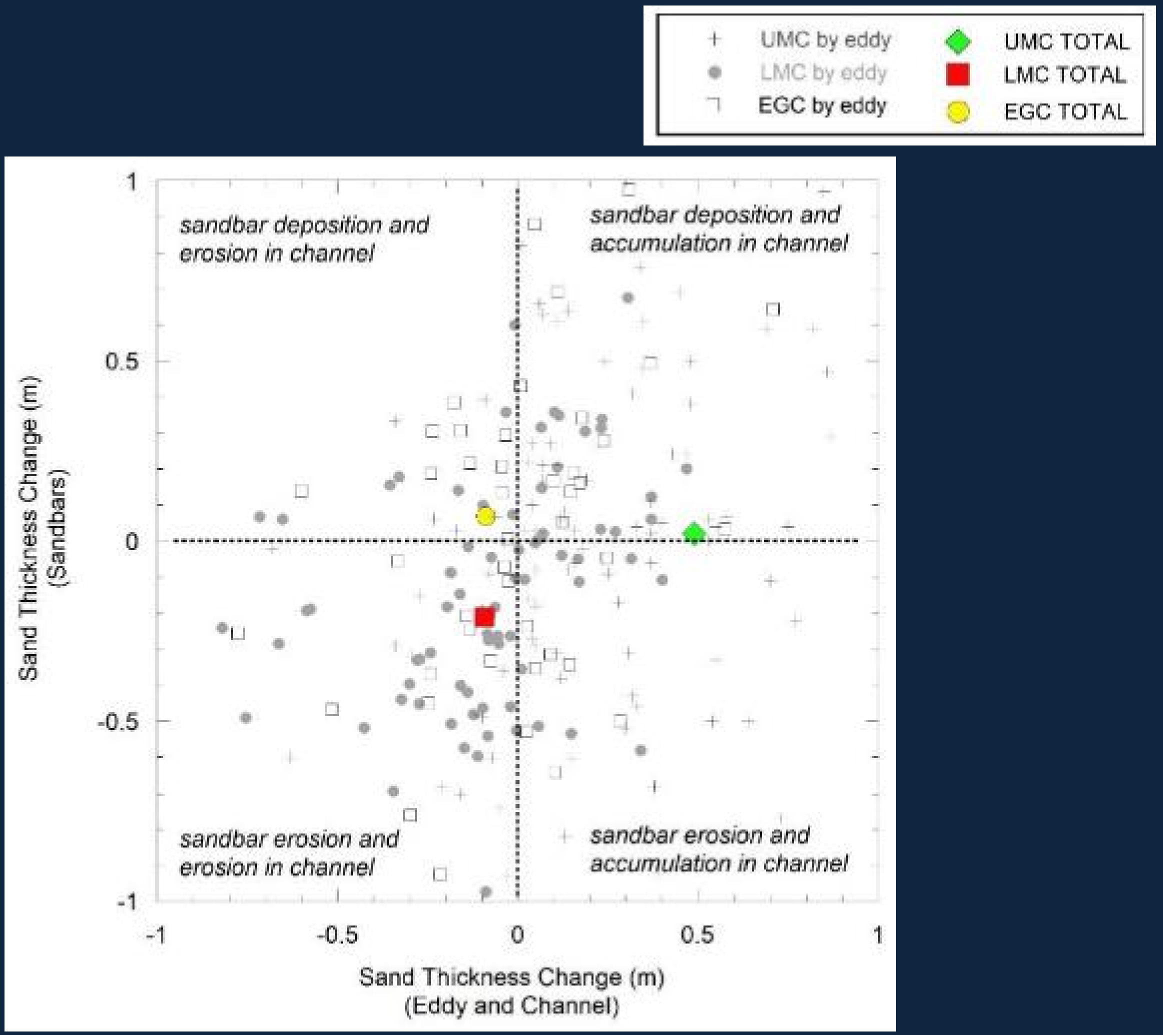
How will the channel mapping data be used to evaluate the effects of dam operations?





- Declining storage for 2009 to 2012 (yellow and red)
  - Bars increase in period with HFE (yellow)
- Increasing storage for 2013 to 2016 (green)
  - Bars maintain volume

Preliminary data, do not cite

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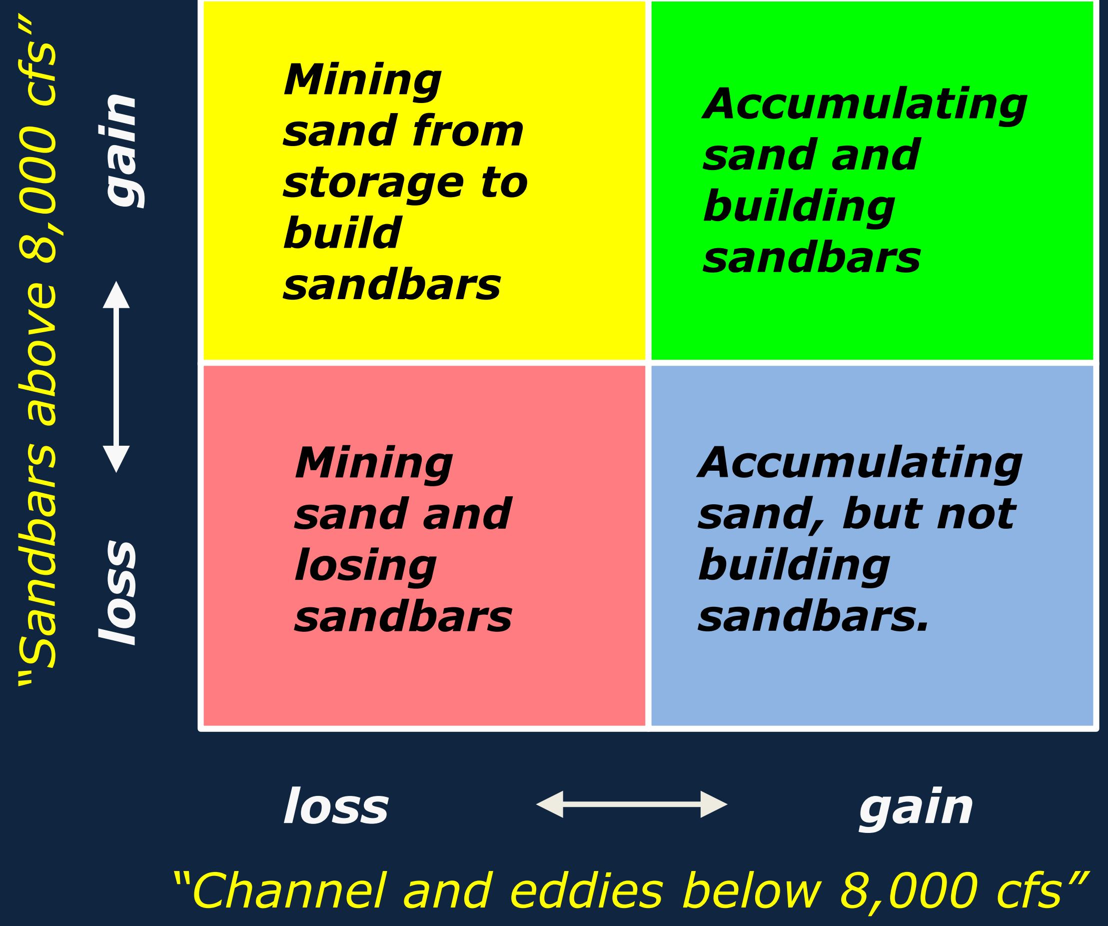
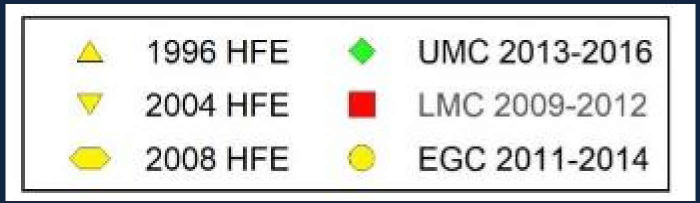
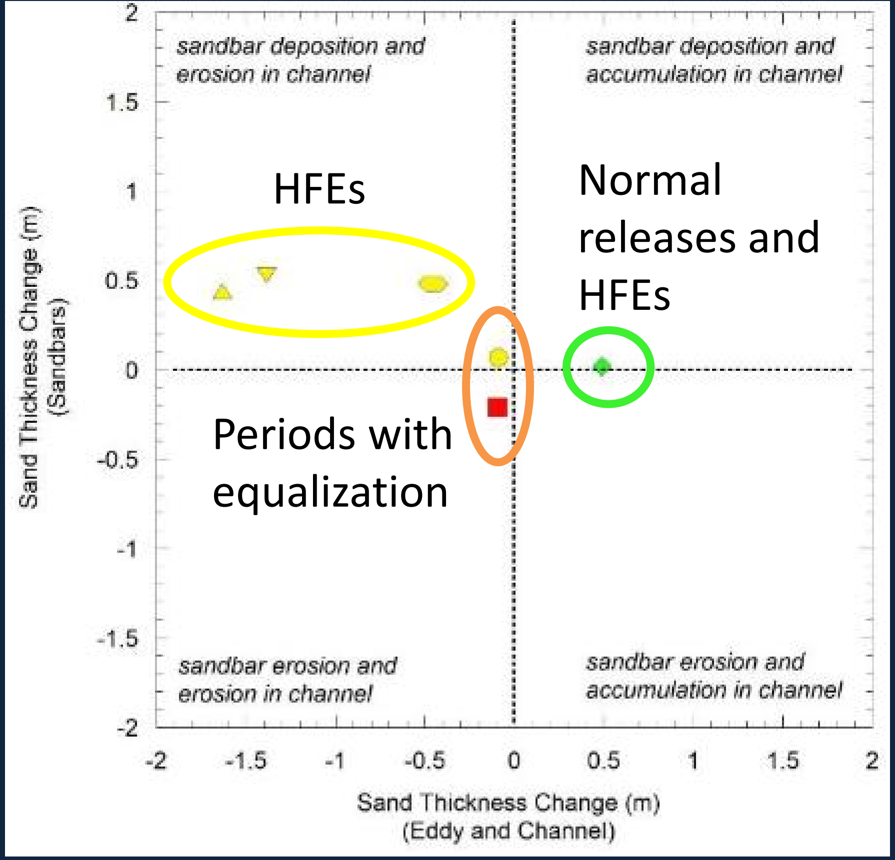
How will the channel mapping data be used to evaluate the effects of dam operations?







- HFEs
  - Use sand from storage in channel to build bars
- Long-term
  - Goal is to maintain storage and build sandbars

Preliminary data, do not cite

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Conclusions: Long-term sand budget in Grand Canyon

- After 30+ years, we now have reliable measurements of the sand mass balance with well-constrained uncertainty.
  - Morphologic and flux budgets agree
  - We will be able to detect long-term changes
  - Must map at least 50% of each segment to detect change when signal is weak (more is better)
- Periods with high summer release volumes cause evacuation
- Periods with normal summer release volumes and strong tributary inputs result in accumulation
- Use of controlled floods for rebuilding sandbars may be sustainable
  - But, depends on the relative frequency of high water volume years vs. tributary supply

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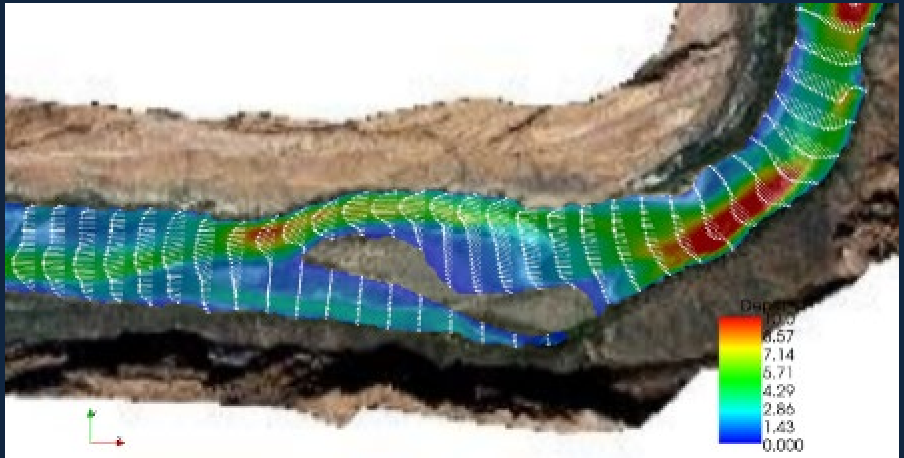
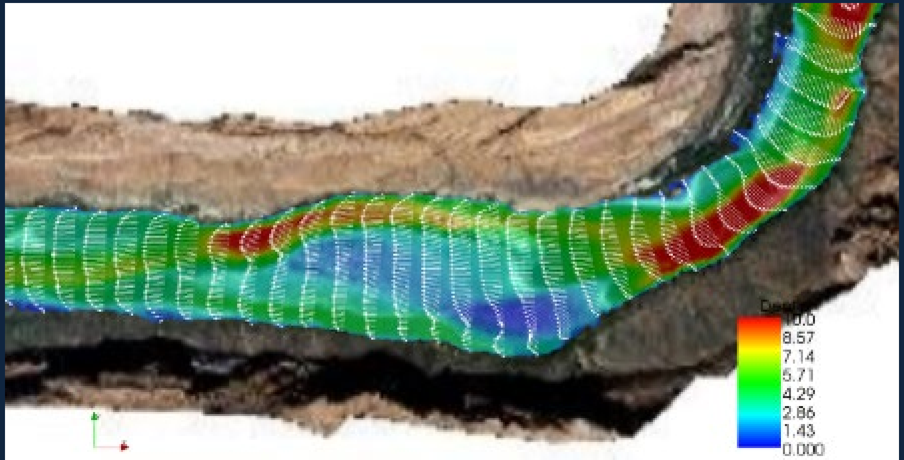
Channel mapping data applications

- Flow modeling
  - New 2d flow model for Glen Canyon
  - Now have capacity to develop similar model for Lees Ferry to Phantom Ranch
- Habitat characterization
  - Substrate type (sand, gravel, vegetation, etc.)
  - Flow depth
  - Streamflow velocity (with flow model)
- Physical habitat based sampling design now possible



Hidden Slough at 20,000 ft^3/s



Hidden Slough at 40,000 ft^3/s

Preliminary data, do not cite

Flow model by Scott Wright, USGS California WSC

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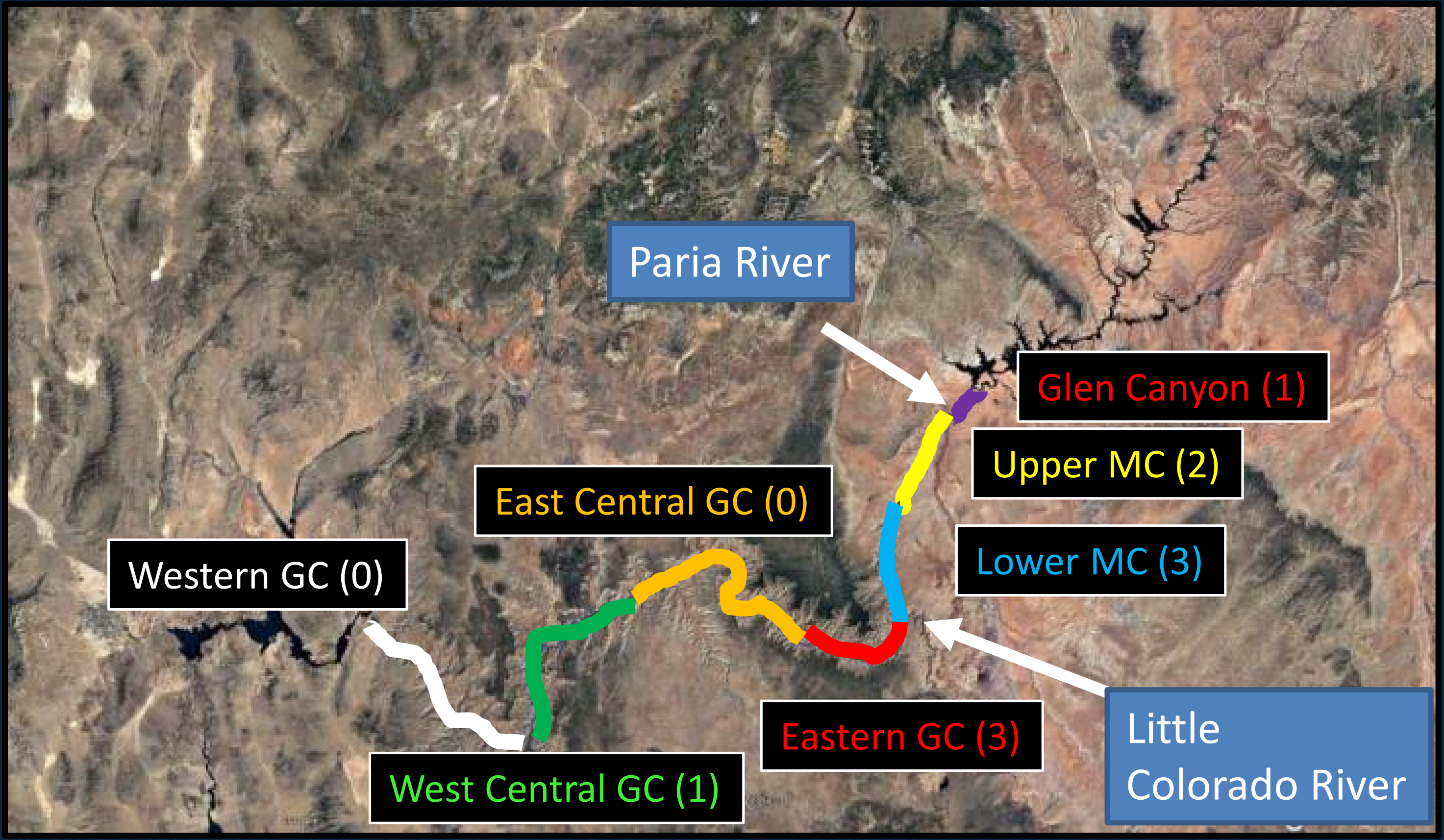
Future Channel Mapping to monitor sandbars and sand storage for LTEMP

- Annual sampling of entire canyon would be useful, but would double the project budget (to ~ $2 million)

→ Rotation mapping with goal to provide assessments at major milestones

- **Milestone 1: 10 years into HFE Protocol**
  - Reporting in 2021 (end of current work plan)
  - Repeat maps of Marble Canyon and Eastern GC at 3- to 7-yr intervals
  - Will include results from mapping completed in 2019
- **Milestone 2: 10 years into LTEMP**
  - Reporting in 2026
  - Repeat maps of Marble Canyon and Eastern GC at 5 to 7-yr intervals
  - Will include results from sampling conducted in 2021-25
- **Milestone 3: 20 years into LTEMP**
  - Reporting in 2036
  - Repeat maps of all segments at 7 to 10-yr intervals
  - Will include results from sampling conducted in 2027-35



Segment	Completed Maps
Glen Canyon	2014
Upper Marble Canyon	2013, 2016
Lower Marble Canyon	2009, 2012, 2019

Segment	Completed Maps
Eastern Grand Canyon	2011, 2014, 2019
East Central Grand Canyon	*
West Central Grand Canyon	2017
Western Grand Canyon	*

* Segment not yet mapped. Proposed for next workplan.

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Acknowledgements

Project B staff:

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Field assistants and collaborators over many years:

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