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

Goal 7 Metrics: Sediment

Glen Canyon Dam Adaptive Management Program
Annual Reporting Meeting
April 8, 2025

Paul Grams and David Topping
U.S. Geological Survey
Southwest Biological Science Center
Grand Canyon Monitoring and Research Center

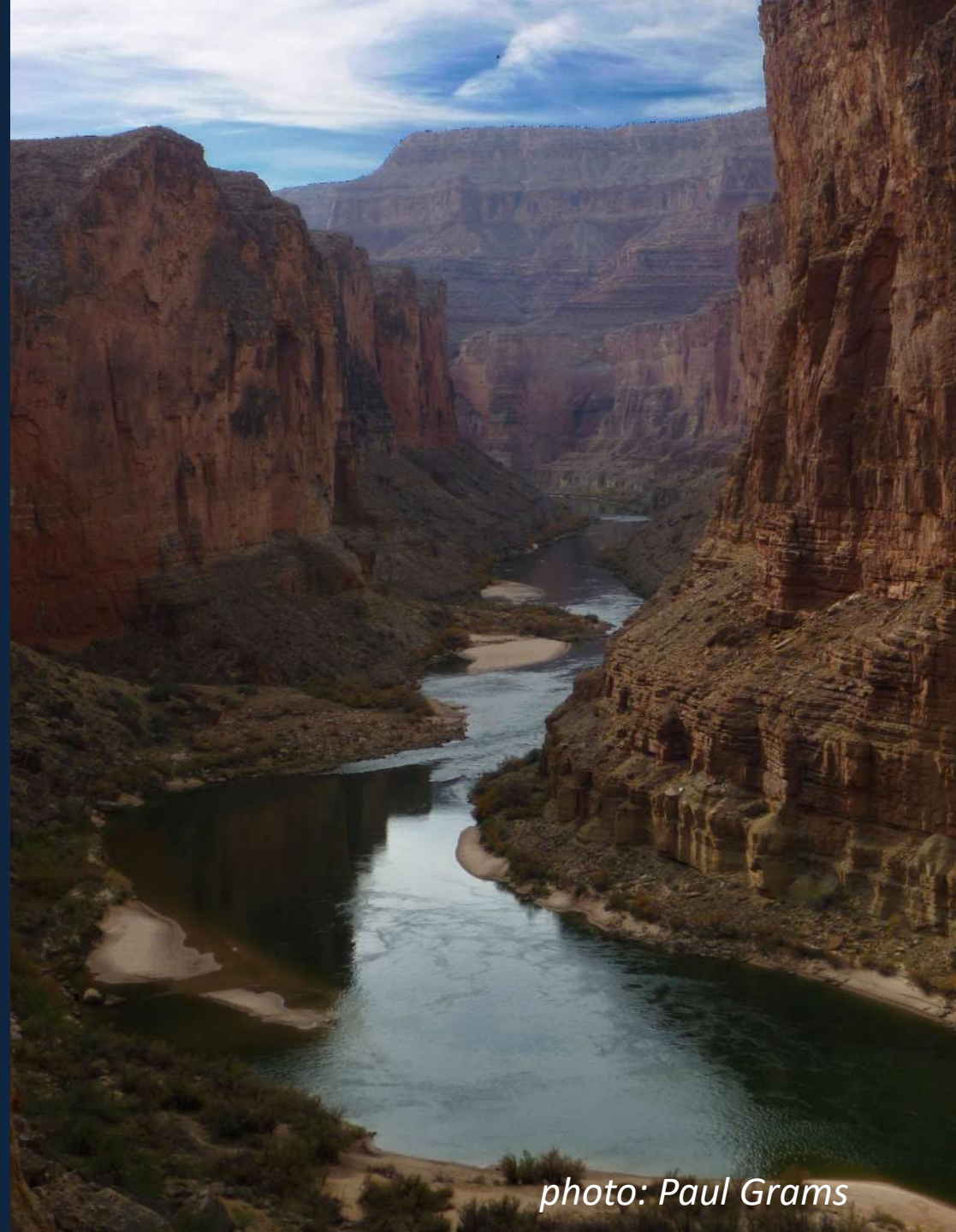

photo: Paul Grams

LTEMP Goal 7: *"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."*

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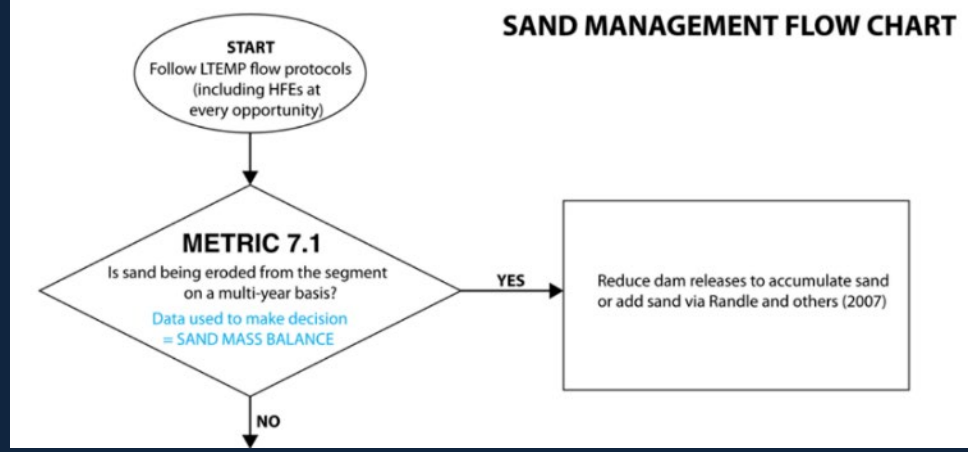
  - Is the sand supply sufficient to maintain the high-elevation sandbars?



Topping and others (in review)

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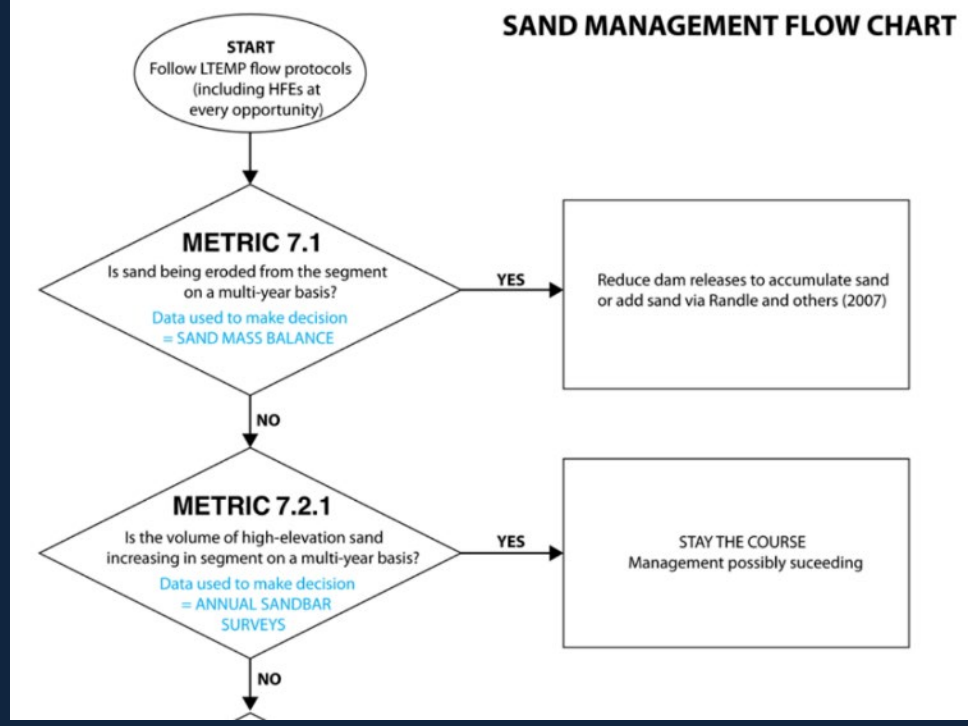

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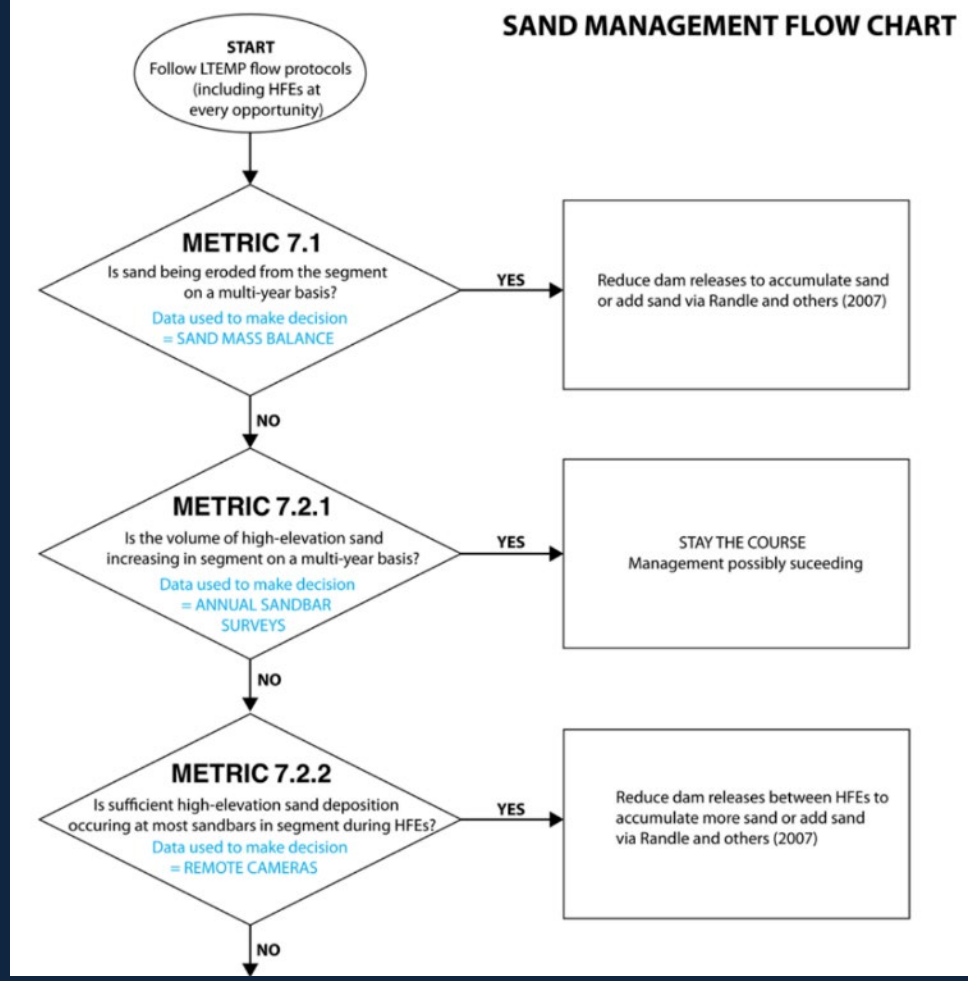

Topping and others (in review)

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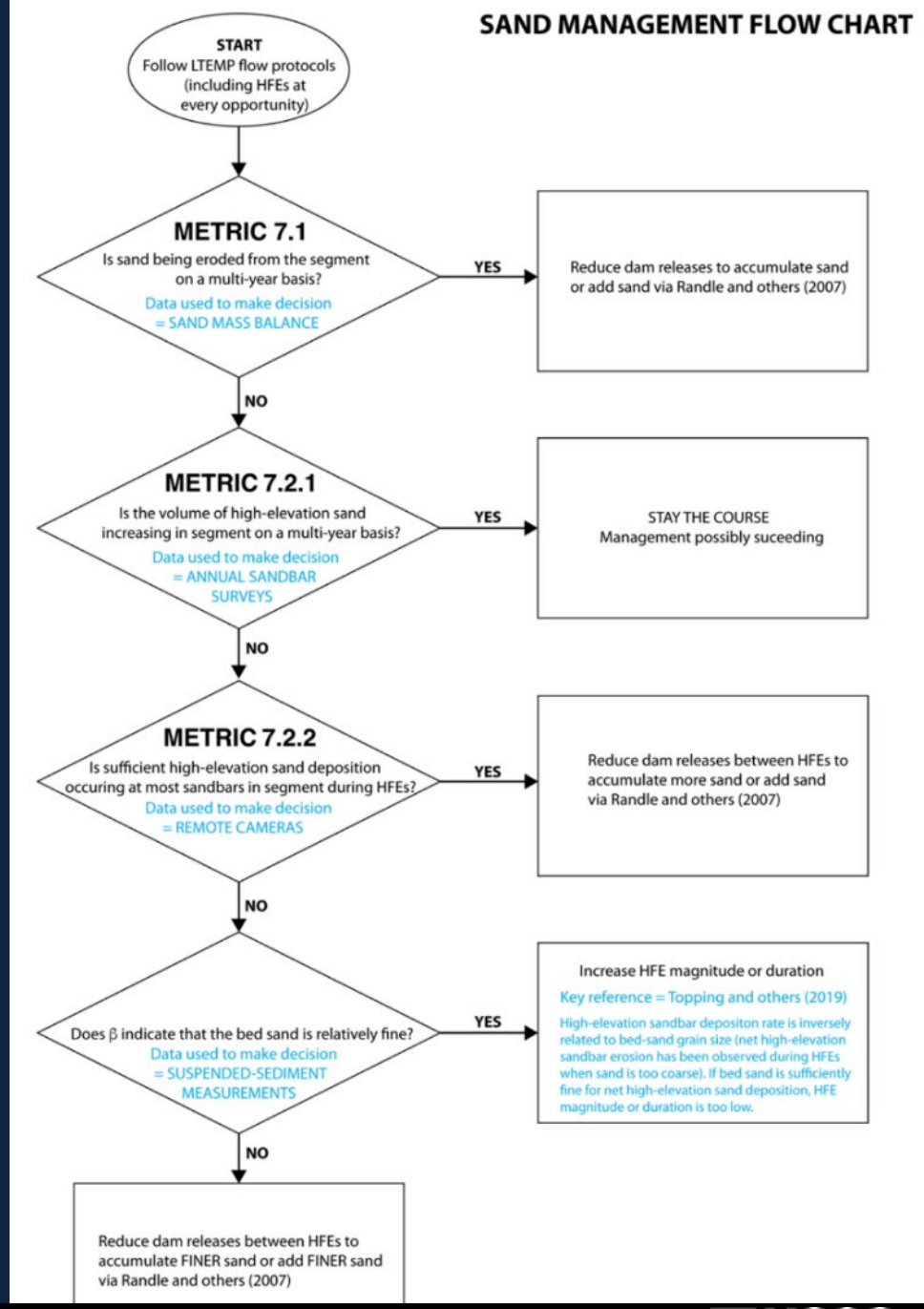

Topping and others (in review)

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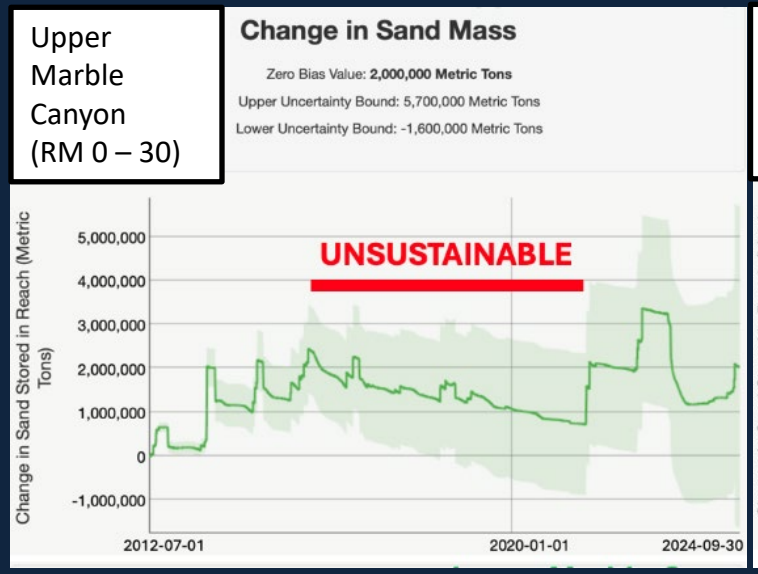
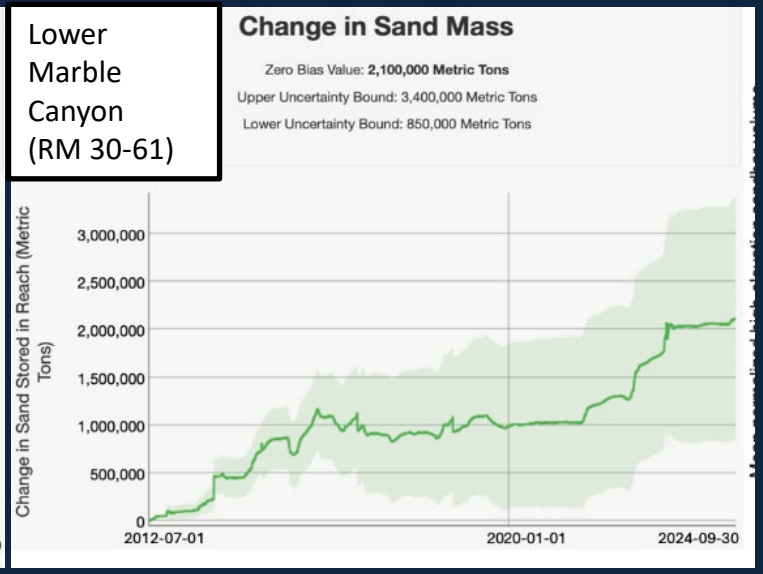
- Metric 7.1 Sand Supply by River Segment (the Sand Bank Account)
  - Is sand being eroded from any segment on a multi-year basis?

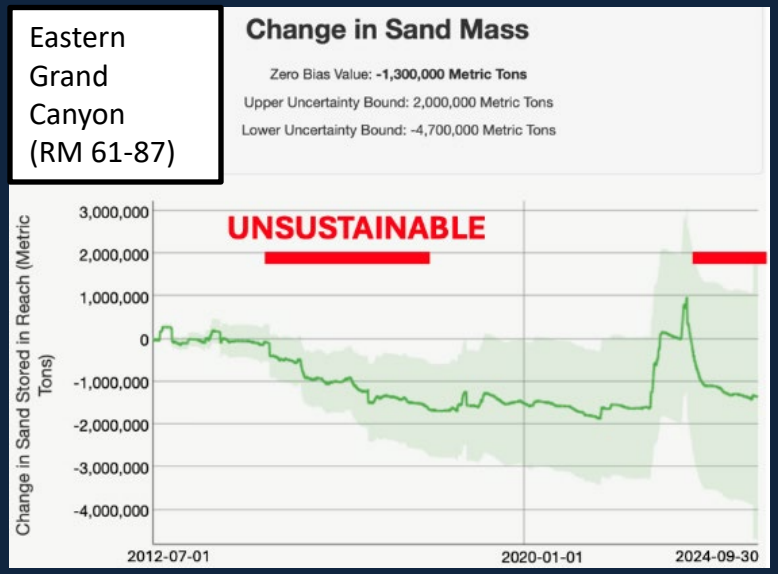
Upper Marble Canyon (RM 0 – 30)



Lower Marble Canyon (RM 30-61)

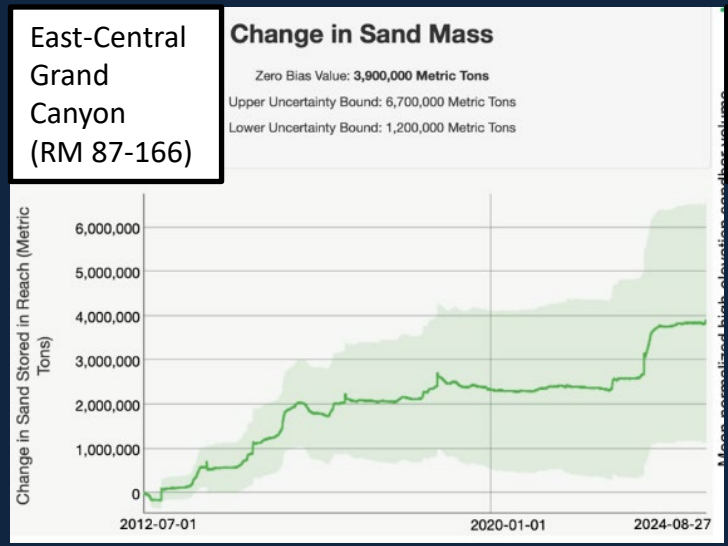


Eastern Grand Canyon (RM 61-87)

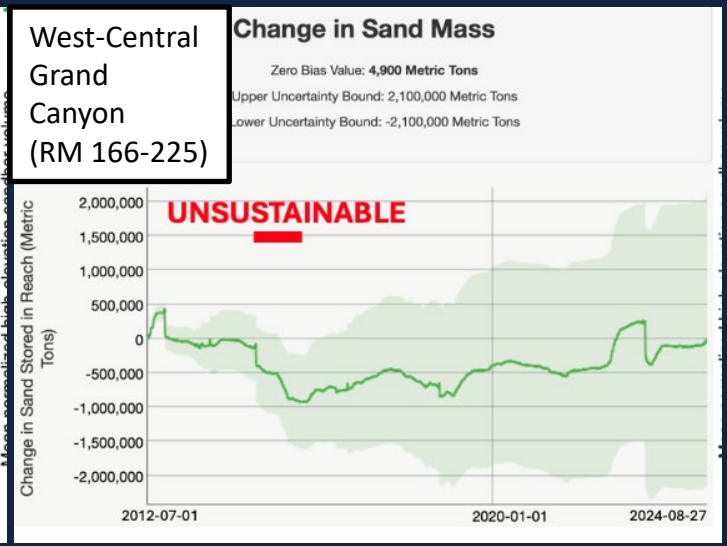


Although there have been periods of declining mass balance in some segments, most declines have been offset by tributary inputs and rebounds in storage.
** Eastern Grand Canyon has had largest declines, but still stable within uncertainty.*

East-Central Grand Canyon (RM 87-166)



West-Central Grand Canyon (RM 166-225)



Topping and others (in review); www.gcmrc.gov/discharge_qw_sediment

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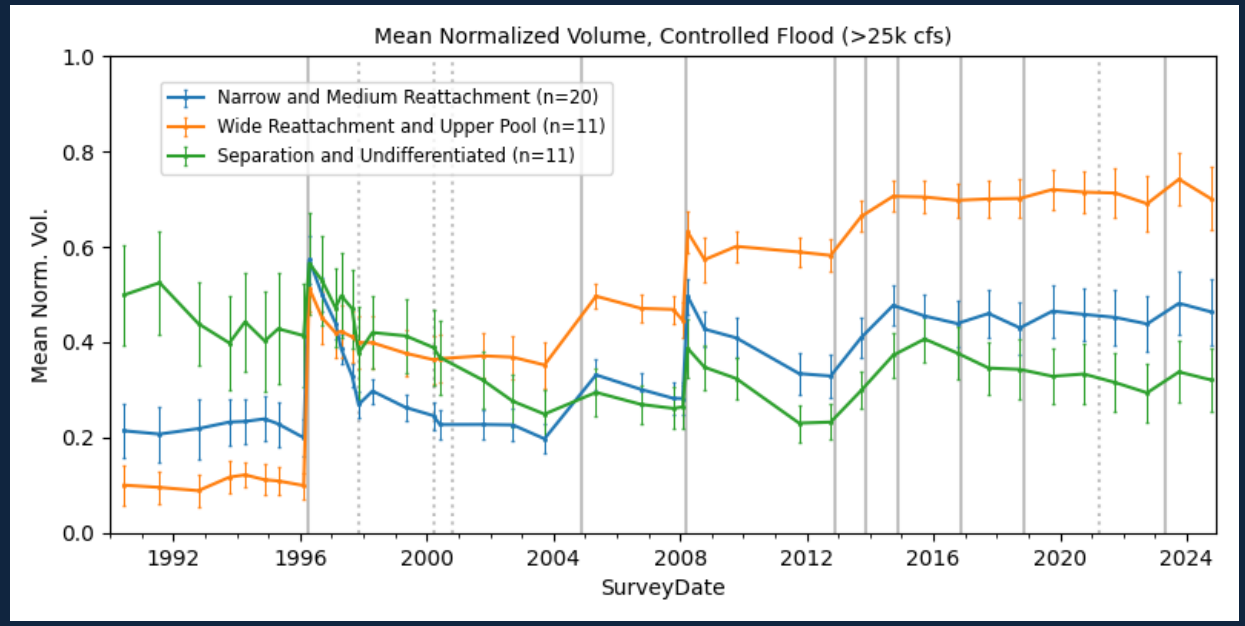
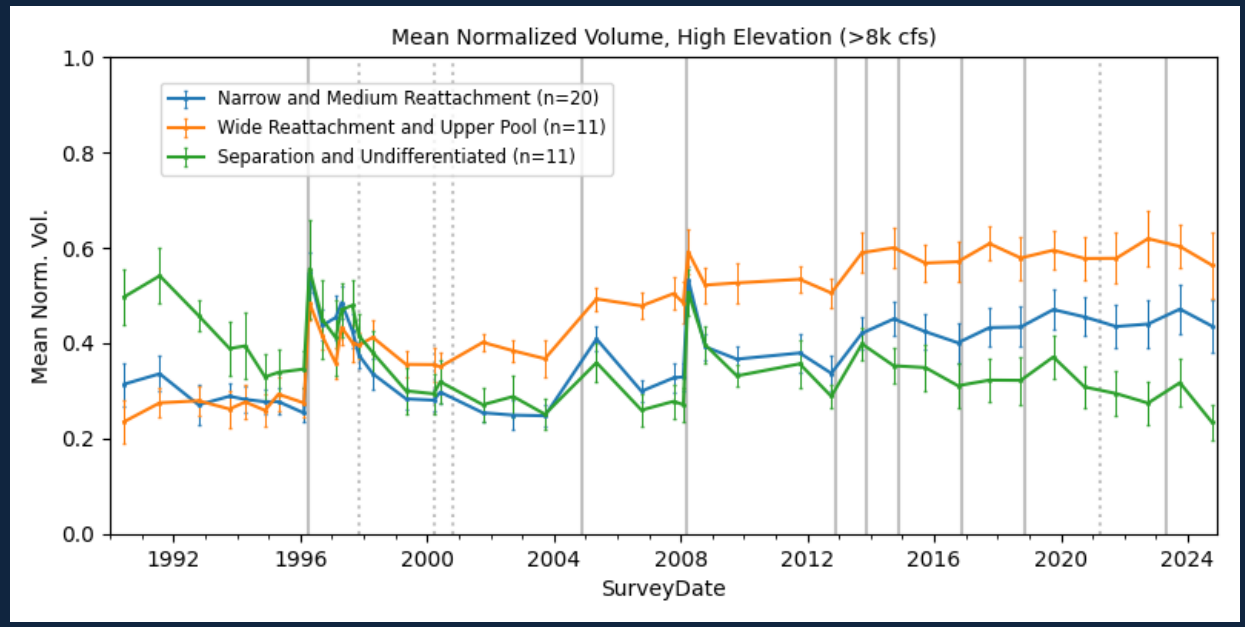
- Metric 7.2.1 Normalized Sandbar Volume
  - Is the volume of high-elevation sand increasing on a multi-year basis?

Stable or increasing for most bar types when HFEs are implemented.
** Separation bars and undifferentiated bars have decreased since 2016. Likely limited by HFE magnitude as shown by (Hazel et al., 2022).*

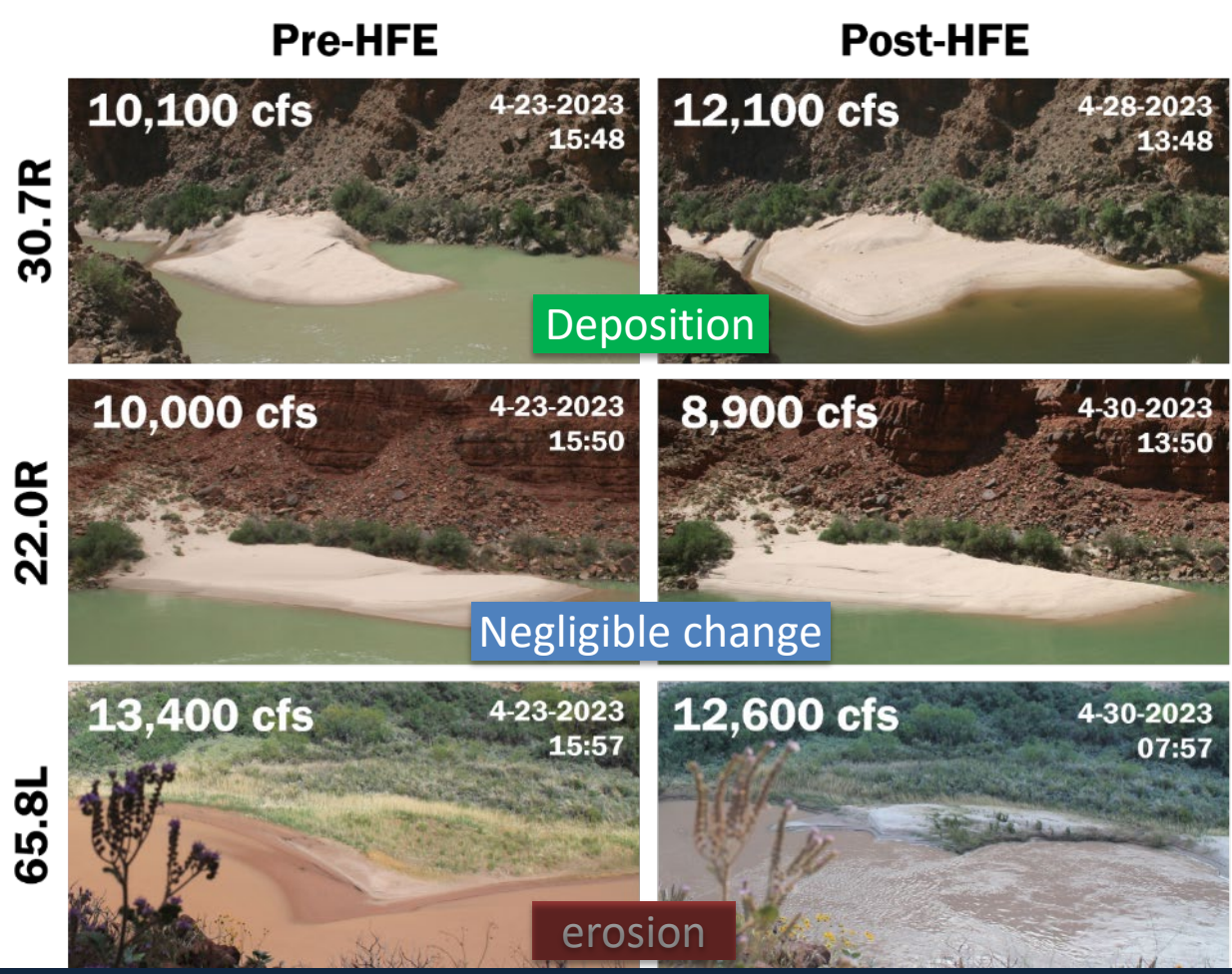




- Metric 7.2.2 Mean Sandbar Response to HFEs
  - Is sufficient high-elevation deposition occurring at most sandbars during HFEs?

Sandbar size has increased at 50-60% of sites for every HFE since 2012.

** Analysis of remote camera images is not a quantitative measure of sand volume.*



Observed response	2012 HFE (n = 33)	2013 HFE (n = 42)	2014 HFE (n = 42)	2016 HFE (n = 43)	2018 HFE (n = 43)	2023 HFE (n=43)	Average
	Immediately following HFE						
Large deposition	12%	19%	14%	14%	12%	30%	17%
Moderate deposition	39%	33%	43%	42%	54%	33%	41%
Negligible change	39%	36%	31%	33%	22%	28%	31%
Moderate erosion	9%	10%	10%	7%	10%	9%	9%
Large erosion	0%	2%	2%	5%	2%	0%	2%

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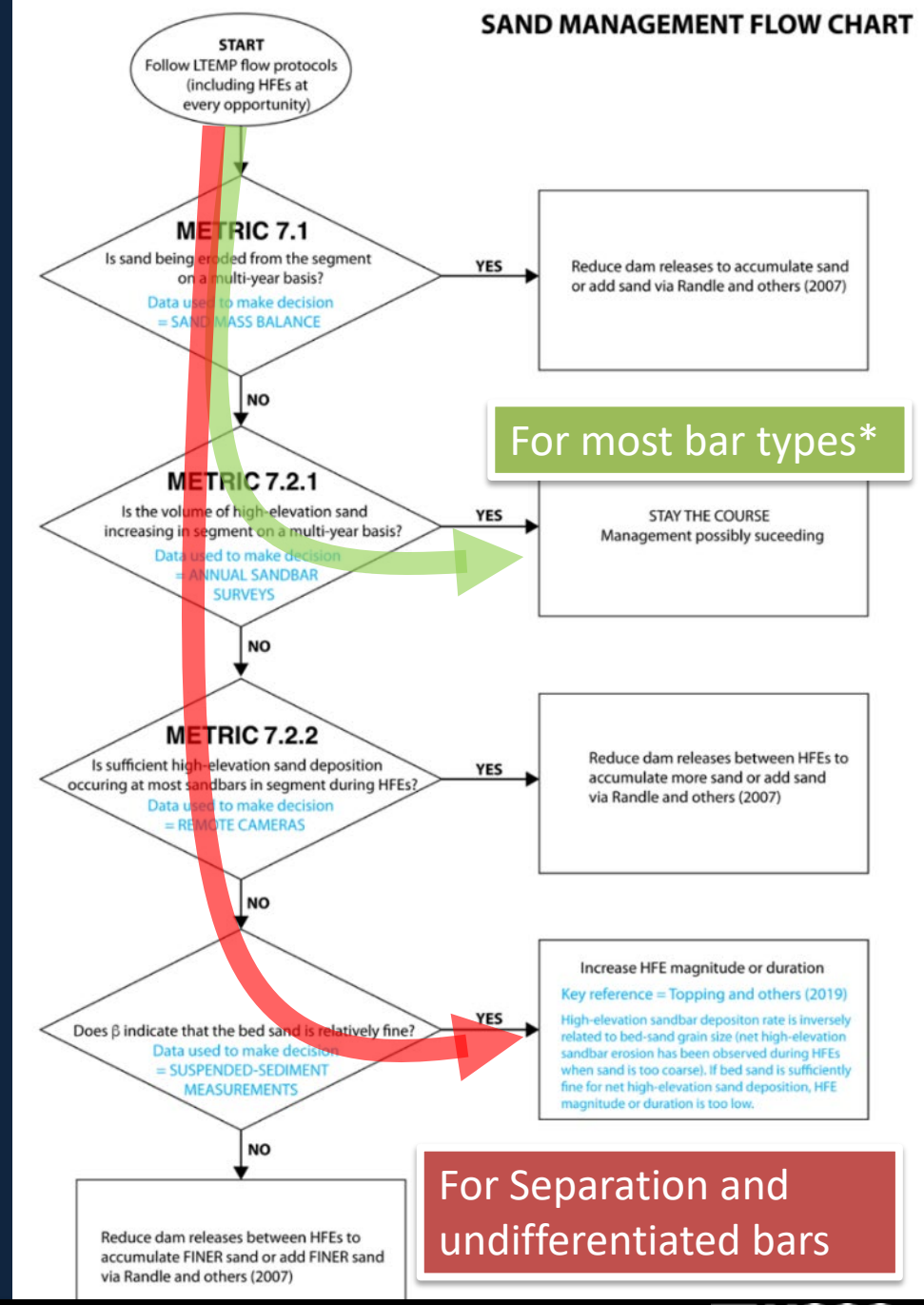
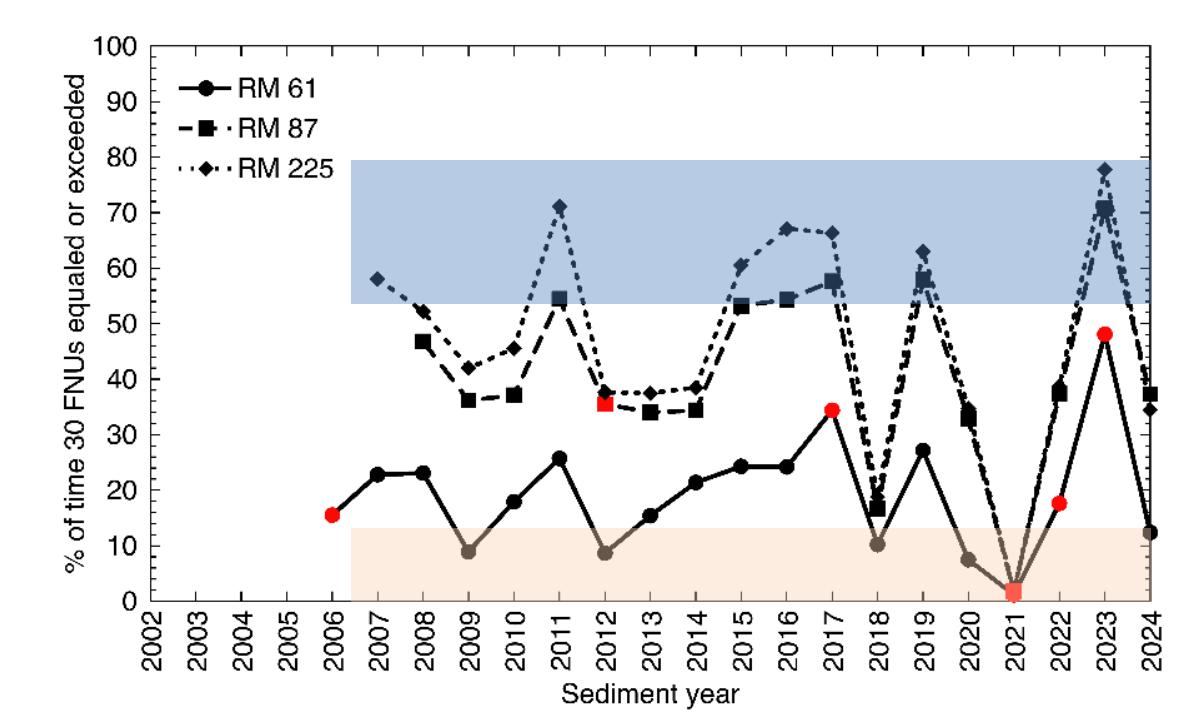
* Not equal success in all reaches (covered in next talk by David Topping)

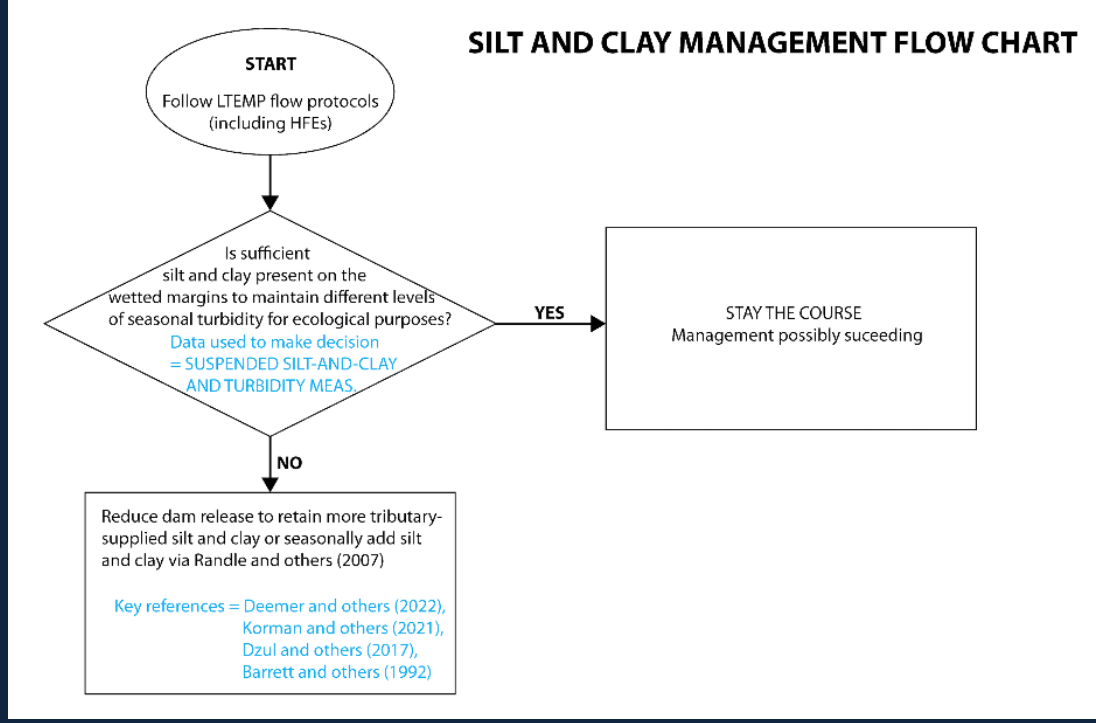


Topping and others (in review)

LTEMP Goal 7: *"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."*

- Metric 7.3 Silt and Clay Retention by River Segment
  - Is sufficient silt and clay being retained on the wetted channel margins to maintain seasonal turbidity for ecological purposes?





Years with high retention of silt and clay.

Years with low retention of silt and clay.

Topping and others (in review); www.gcmrc.gov/discharge_qw_sediment

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Project B: Riverbed and sandbar response to dam operations and high-flow experiments

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Paul Grams
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photo: Michael Collier

Acknowledgements

Project B personnel:

Paul Grams, Katie Chapman, Matt Kaplinski, Keith Kohl, Gerard Salter, Shannon Sartain, and Robert Tusso

GIS and website support:

Thomas Gushue and Erica Byerley

Collaborators and cooperators:

David Topping and Project A, Erich Mueller, Scott Wright

photo: Geoff Gourley

photo: Jeff Behan

photo: Geoff Gourley

Additional collaborators and field assistants:
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NORTHERN ARIZONA UNIVERSITY

GRAND CANYON RIVER GUIDES

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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
  - B.4* Sediment and Sandbar Modeling
- 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 and model interactions between dam operations, sand transport, and eddy sandbar dynamics.
- Cooperators: *Grand Canyon River Guides, *Southern Utah University, Northern Arizona University

** Not funded in FY2025-2027 TWP.*

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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 monitoring efforts and modeling:
  - Annual sandbar and campsite monitoring (sandbar surveys and daily photographs)
    - Annual assessment of the effects of HFEs and other dam operations on selected sandbars and campsites.
    - Assessment of immediate response to HFEs by network of remote time-lapse cameras
  - Periodic channel mapping (Combined topographic and bathymetric mapping)
    - Evaluation of LTEMP performance by measuring long-term trends in sand area, volume, and distribution from a large sample of sandbars.
    - Measurement of long-term trends in sand storage on the riverbed.
  - *Modeling to predict fine sediment transport and sandbar response

** Not funded in FY2025-2027 TWP.*

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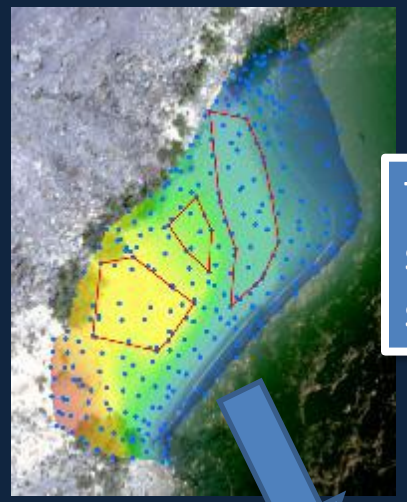
Sandbar monitoring

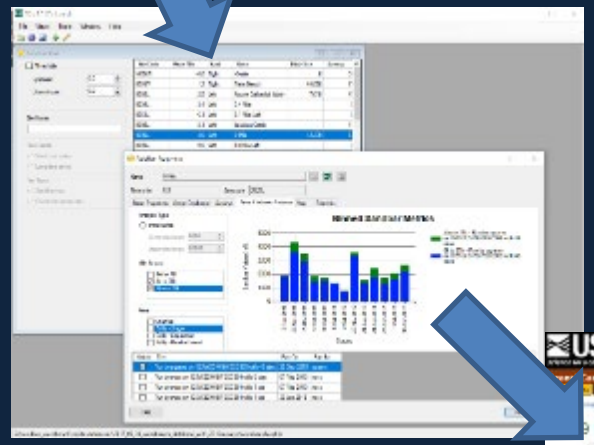
Data collection: total station and survey rod

Allows data collection down to 8,000 cfs stage and in dense vegetation. Neither of which can be done reliably with modern methods (lidar etc.)

data processing and analysis

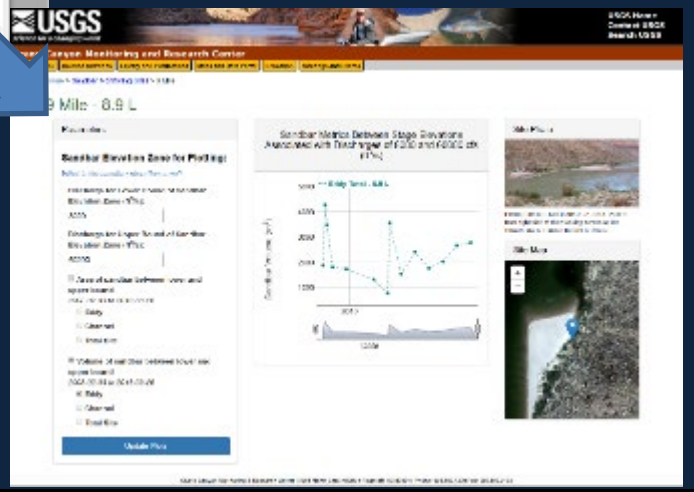


Topographic surfaces modeled in survey software



Data processed and analyzed in sql database

Data served in sandbar web application



Hazel and others (2022); www.usgs.gov/apps/sandbar

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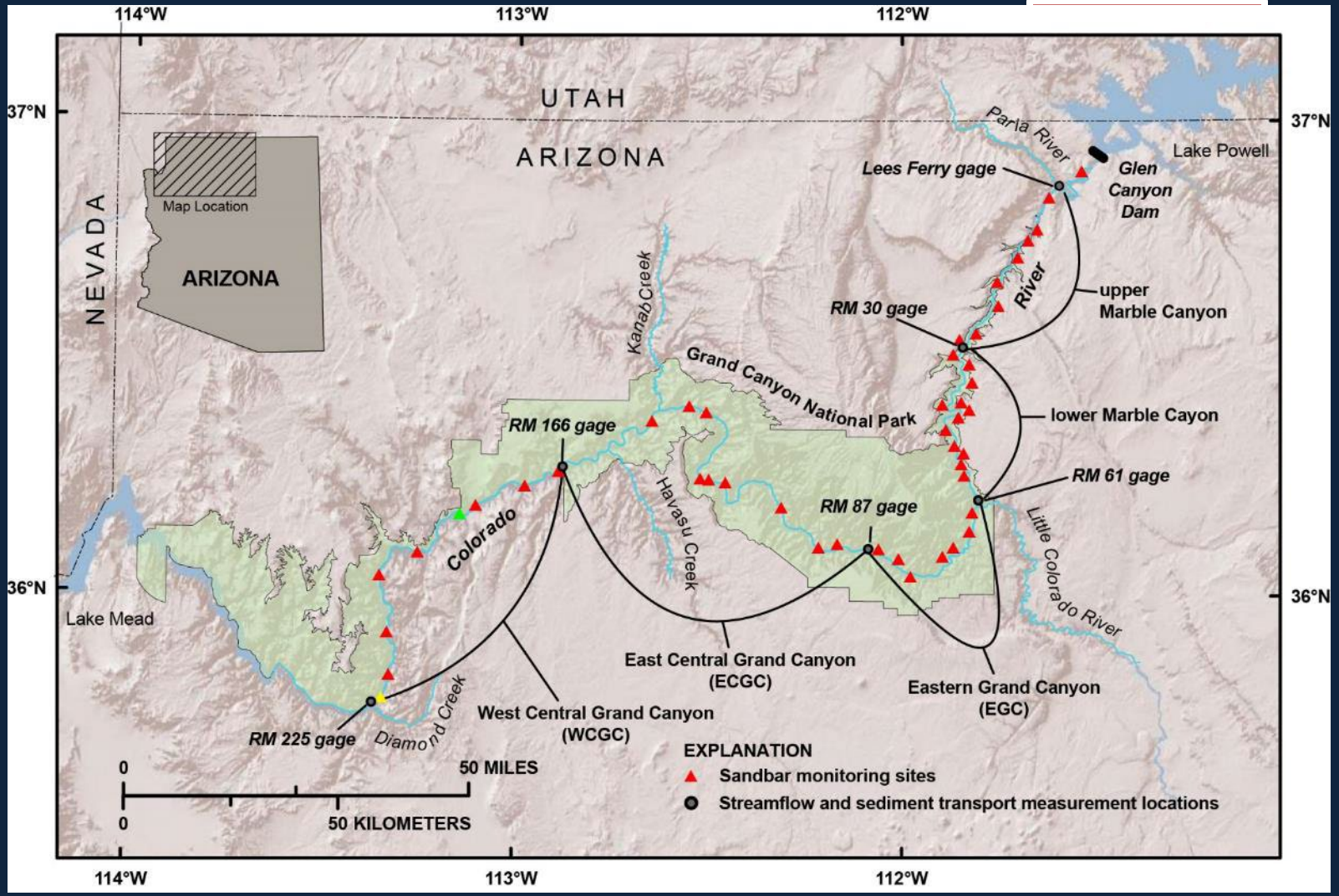
Sandbar monitoring study sites



Monitoring Data

- 45 sites currently monitored
- 32 monitored since 1990
- Data collected annually in October
- 42 of the sites instrumented with remote cameras

Hazel and others (2022); www.usgs.gov/apps/sandbar

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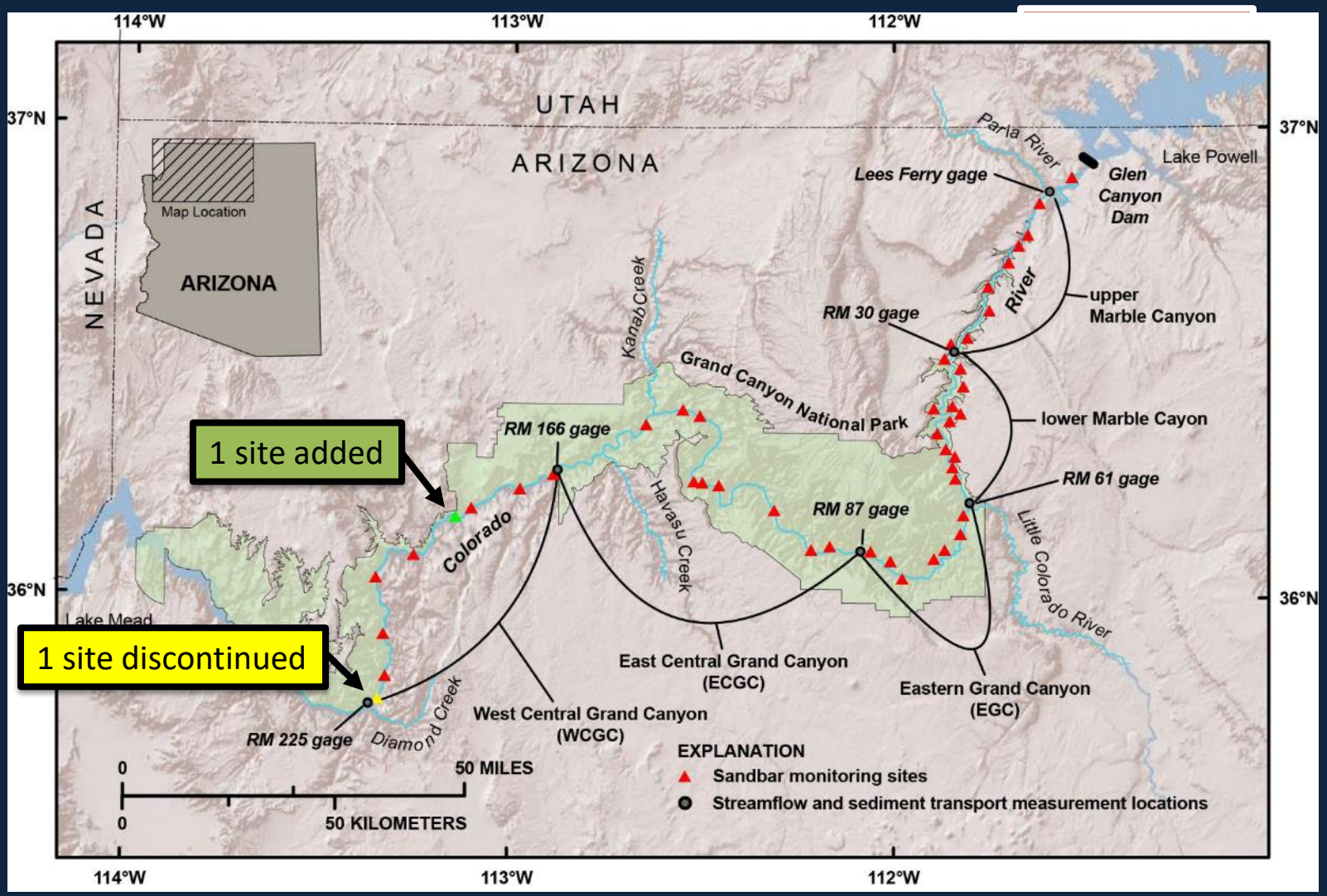

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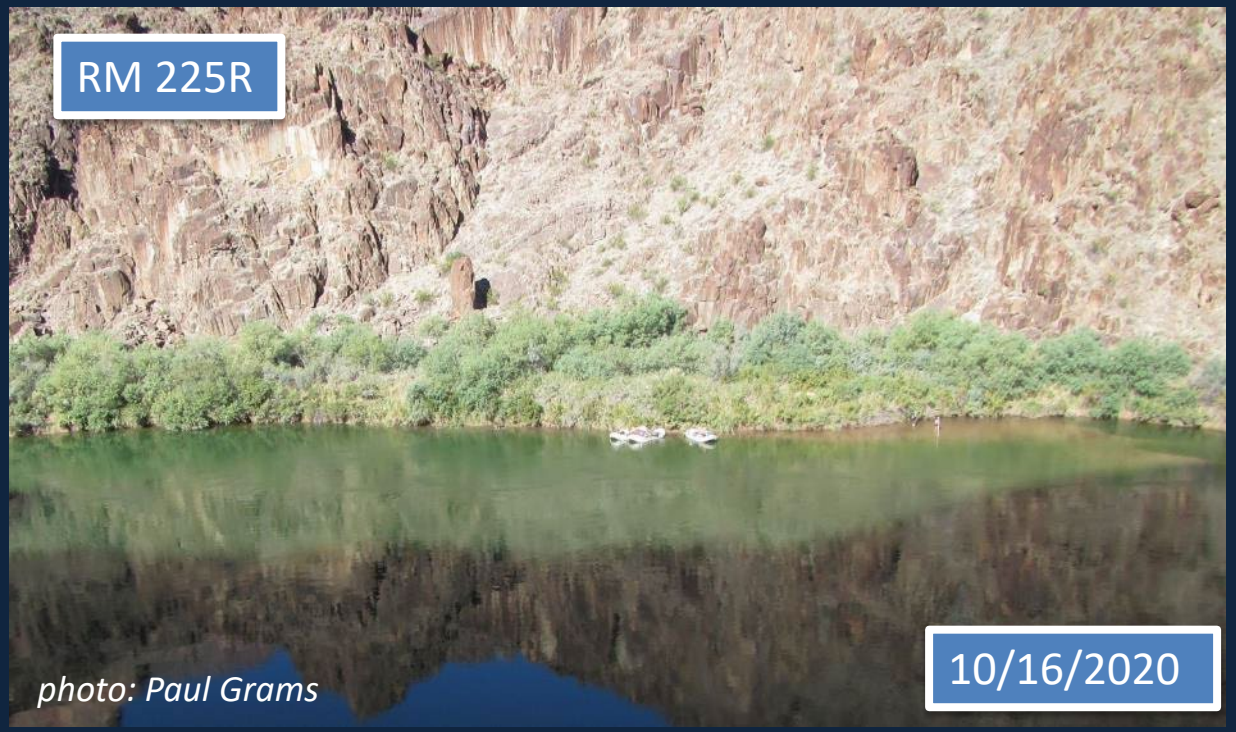
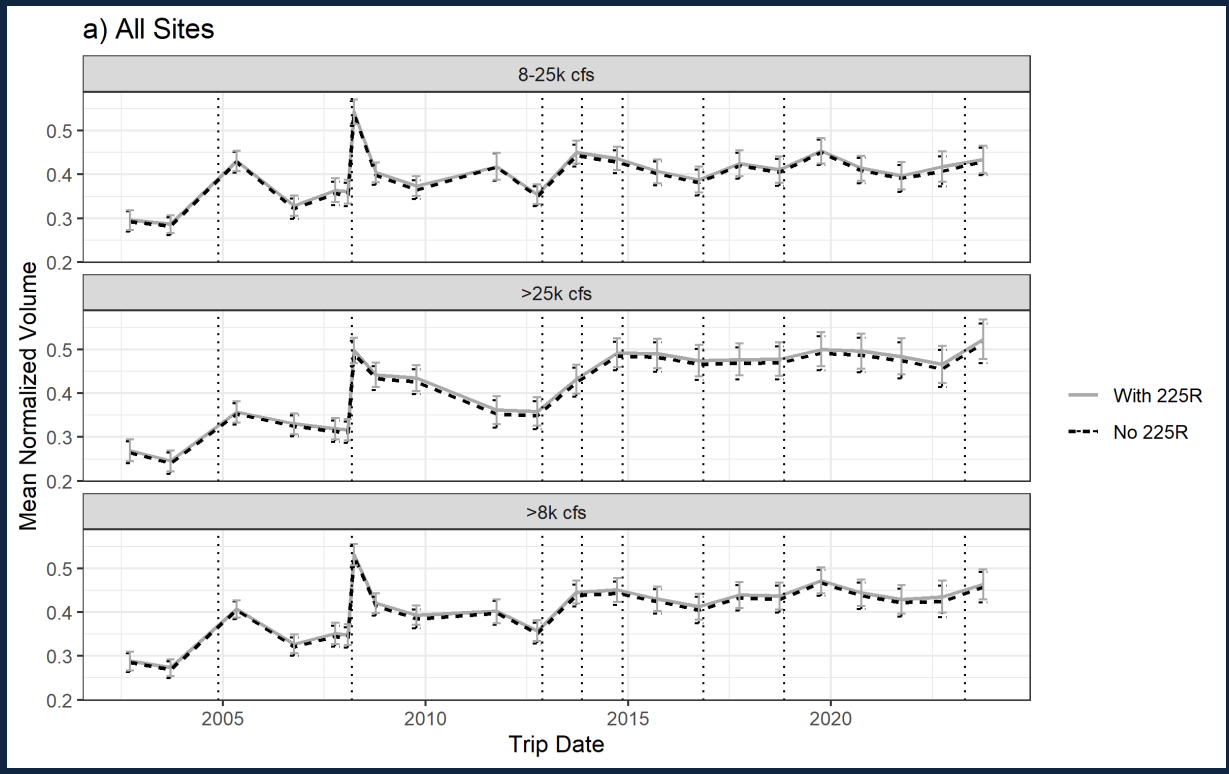
Discontinued monitoring at RM 225R (river left above Diamond Creek)



- RM 225 is a heavily vegetated sandbar.
- No longer ever used as a campsite.
- Has become difficult and hazardous to survey because of extremely dense vegetation and large rattlesnake population.



No significant difference in mean sandbar response comparing samples with and without 225R.

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New monitoring site at RM 186L

- NPS completed a major vegetation removal project to establish as a new campsite in 2024.
- We began monitoring in October 2024.

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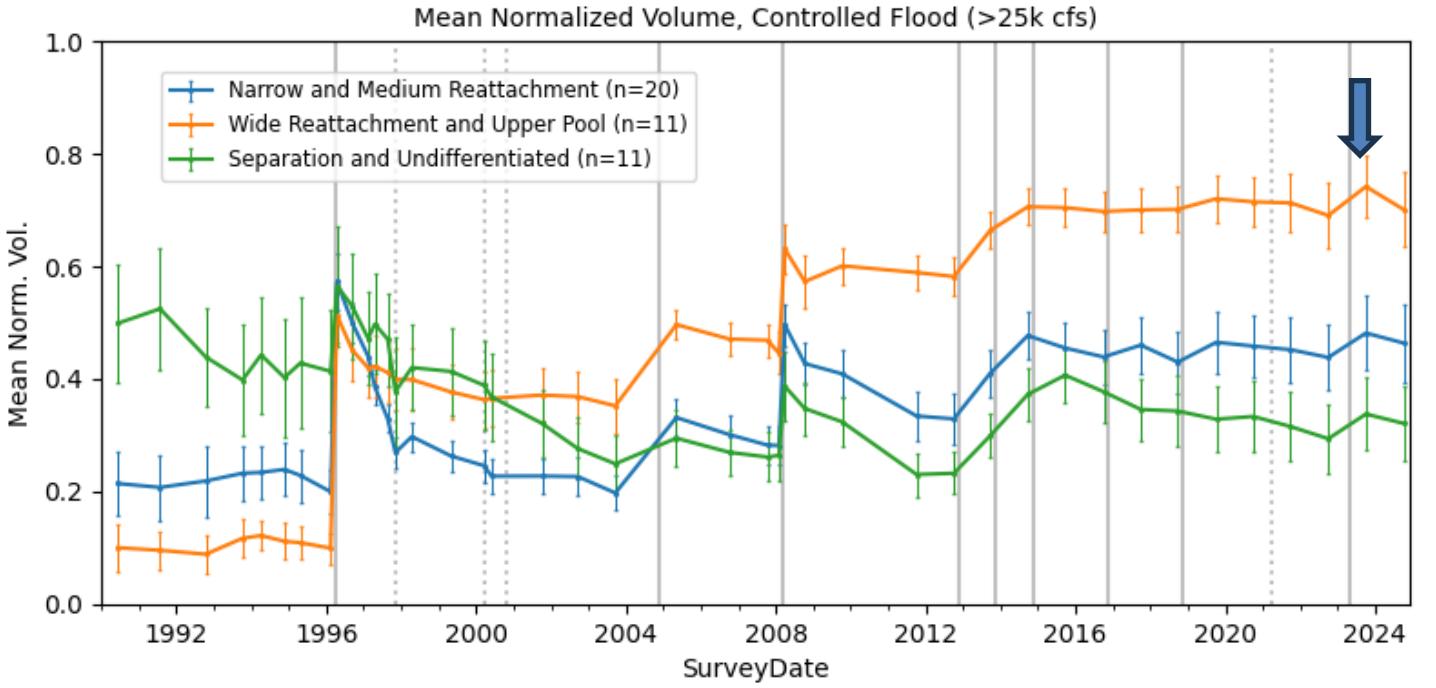
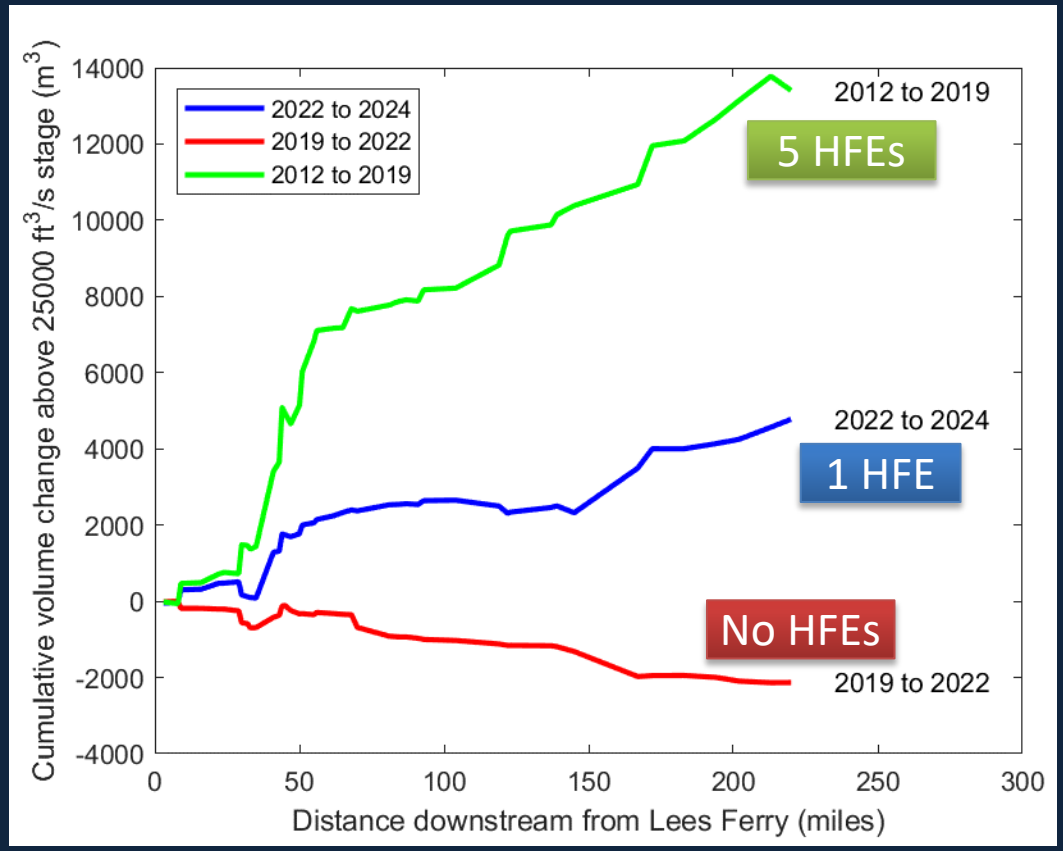
Sandbar volume: 1990-2024



*Vertical solid lines are HFEs; vertical dashed lines are 20,000-30,000 cfs "spike" flows.

- Erosion of all sandbar types since 2023.
- Bars still larger than 2022, but on downward trend.
- Downward trend since 2016 in Separation and Undifferentiated Bars. *Likely related to lower magnitude HFEs that have been implemented since 2012 (Hazel and others, 2022)*

HFE Protocol and LTEMP



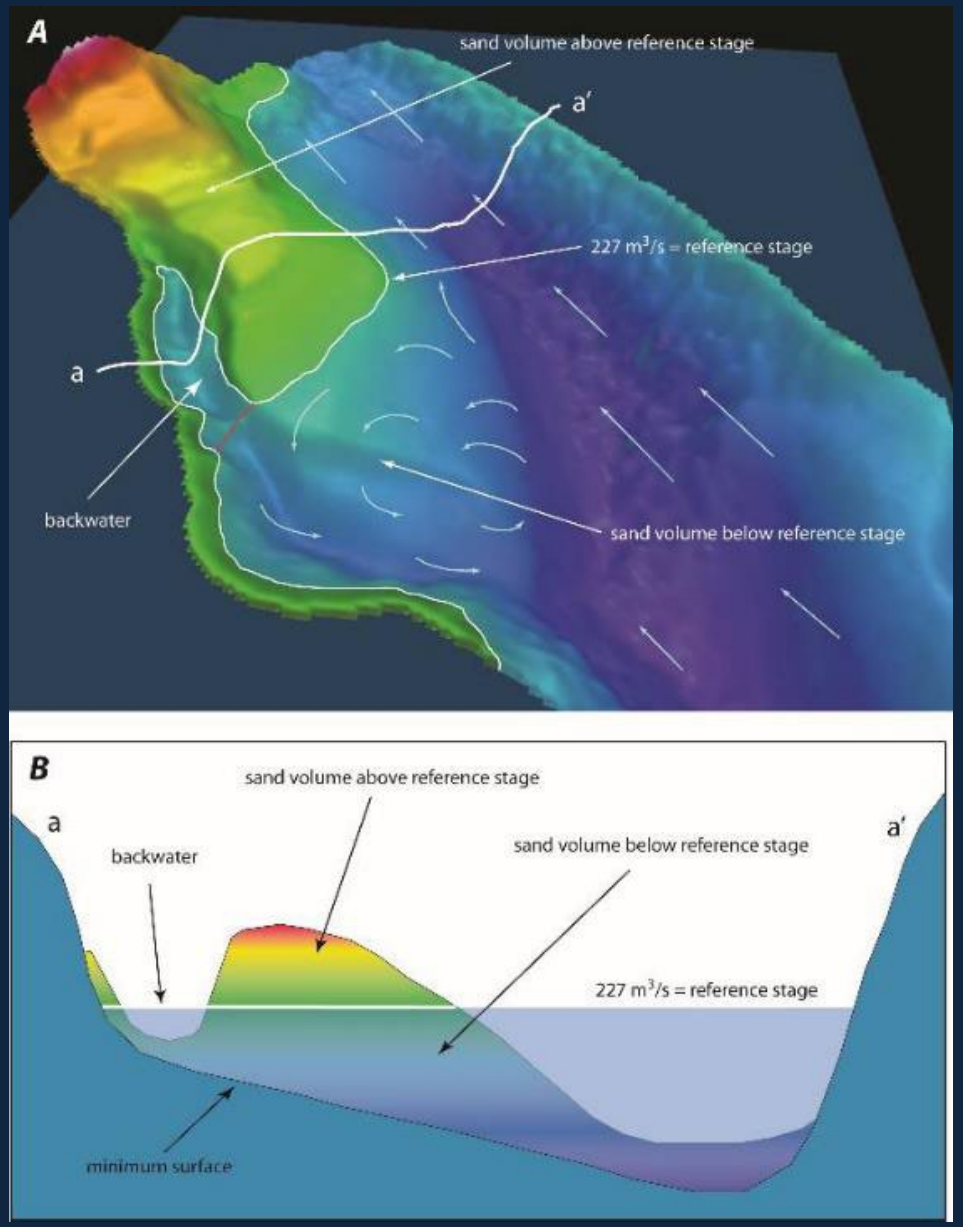
- HFE in 2023 reversed 2019 to 2022 downward trend
- Sandbars still in better shape than 2019 to 2022

Hazel and others (2022); www.usgs.gov/apps/sandbar

Repeat channel mapping for monitoring sand storage on the riverbed

Why measure sand storage by mapping the riverbed?

- Sandbar replenishment is 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



Adapted from Hazel and others (2010)

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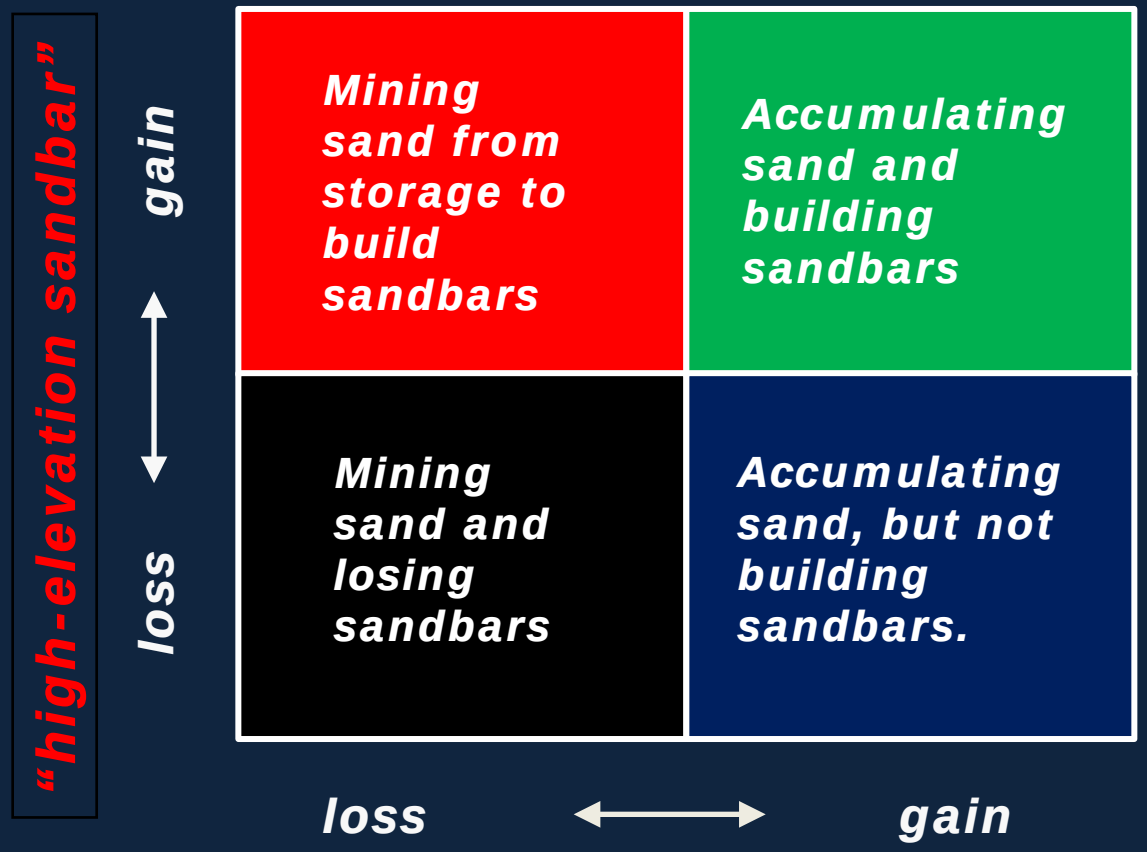
How are channel mapping data used to evaluate the effects of dam operations?



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

"high-elevation sandbar"

gain

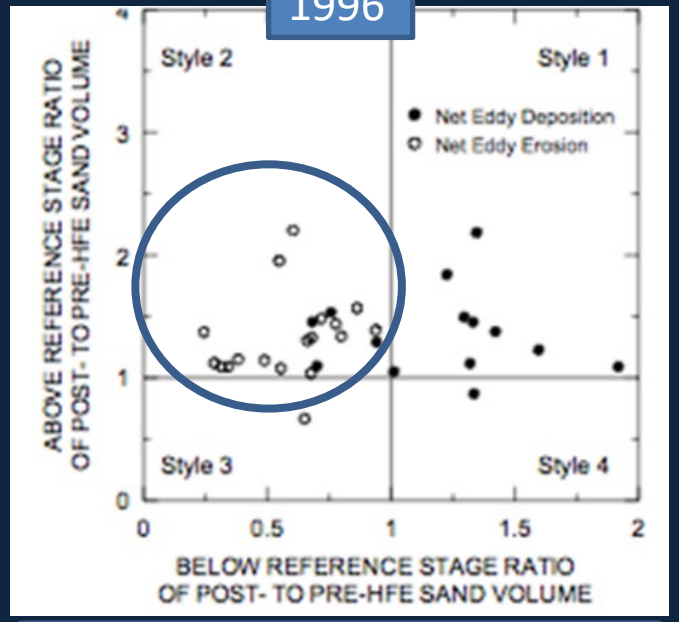
loss

Mining sand from storage to build sandbars	Accumulating sand and building sandbars
Mining sand and losing sandbars	Accumulating sand, but not building sandbars.

loss ⟷ gain

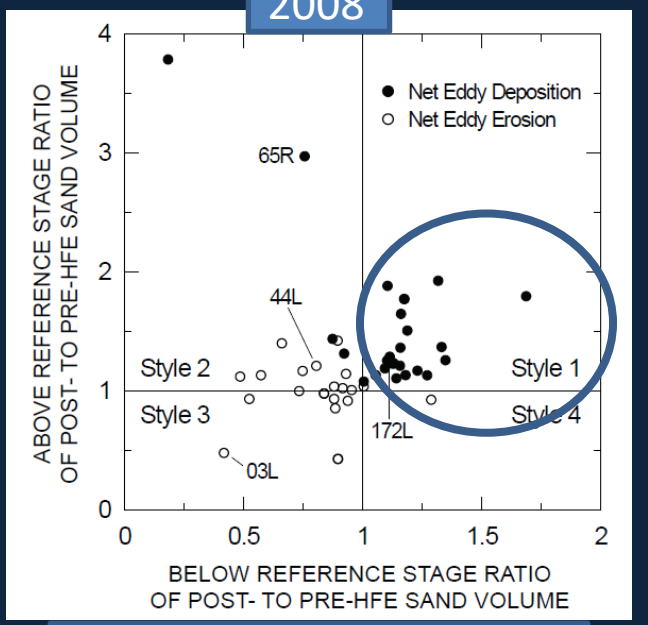
"total sand storage in channel and eddies"

1996



More sites with net eddy erosion

2008



More sites with net eddy deposition

- *The 2004 and 2008 HFEs demonstrated sandbar building under conditions of greater sand enrichment → less erosion of sand from storage in eddies and channel*

Hazel and others, 2010; Schmidt and Grams, 2011

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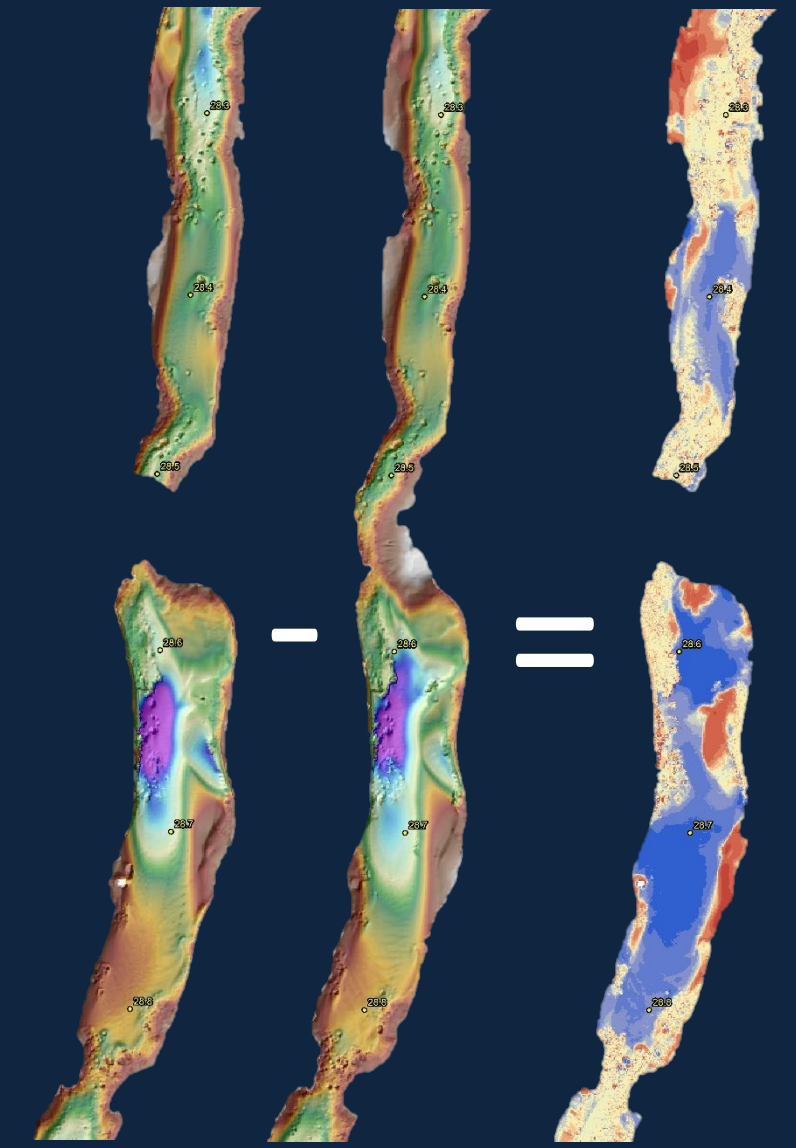
How we measure sand storage on the bed

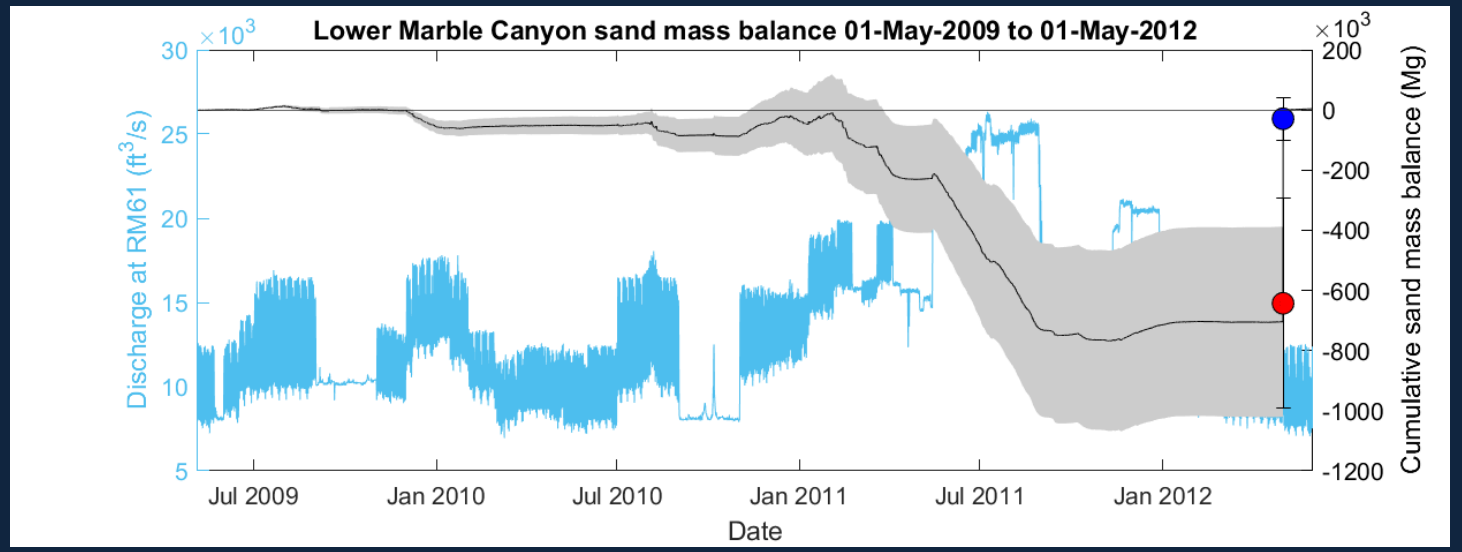
- Repeat topographic and bathymetric measurements
  - Multibeam sonar
  - Singlebeam sonar
  - Total station
- Referenced to geodetic control network
- Use backscatter to classify sand/gravel/rock
- High spatial resolution
- Uncertainty accumulates spatially – not over time



Repeat channel mapping in Lower Marble Canyon

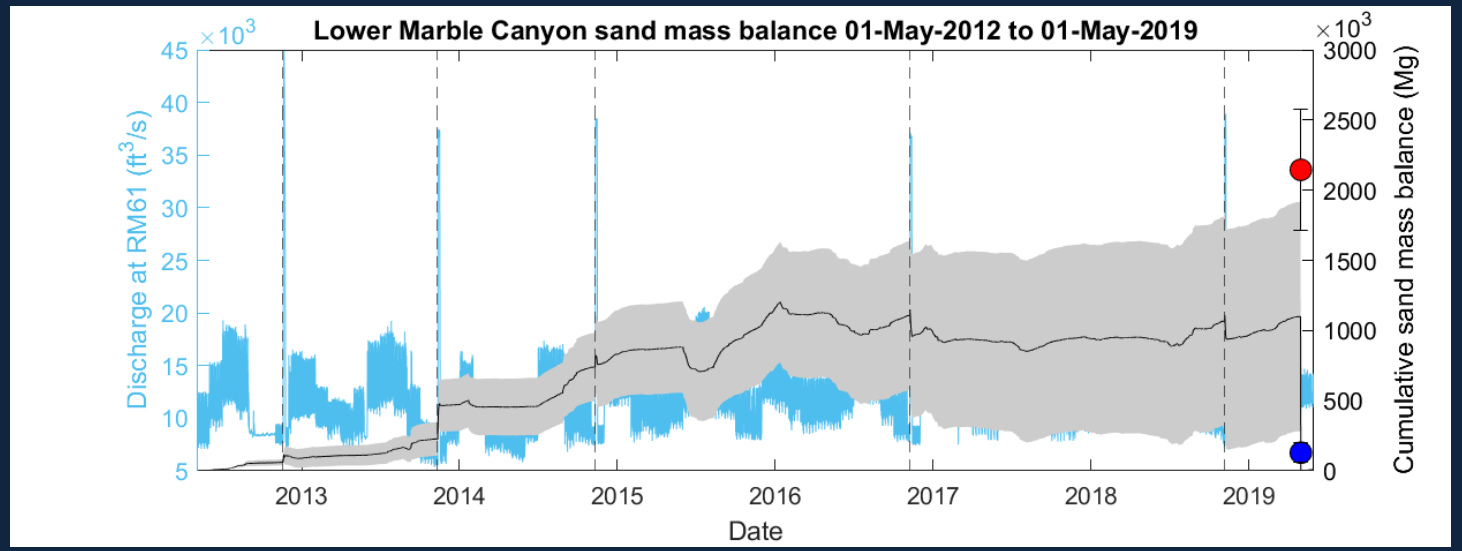
2009 to 2012

- Repeat measurements of channel bed (red points) verify mass balance sand budget (black line with gray uncertainty band)
- Period of sand erosion during equalization flows
- Sand volume change above 8,000 ft^3/s stage (blue) is ~4% of total erosion (red)



2012 to 2019

- Repeat measurements of channel bed (red points) verify mass balance sand budget (black line with gray uncertainty band)
- Period of sand accumulation
- Sand volume change above 8,000 ft^3/s stage (blue) is ~6% of total accumulation (red)



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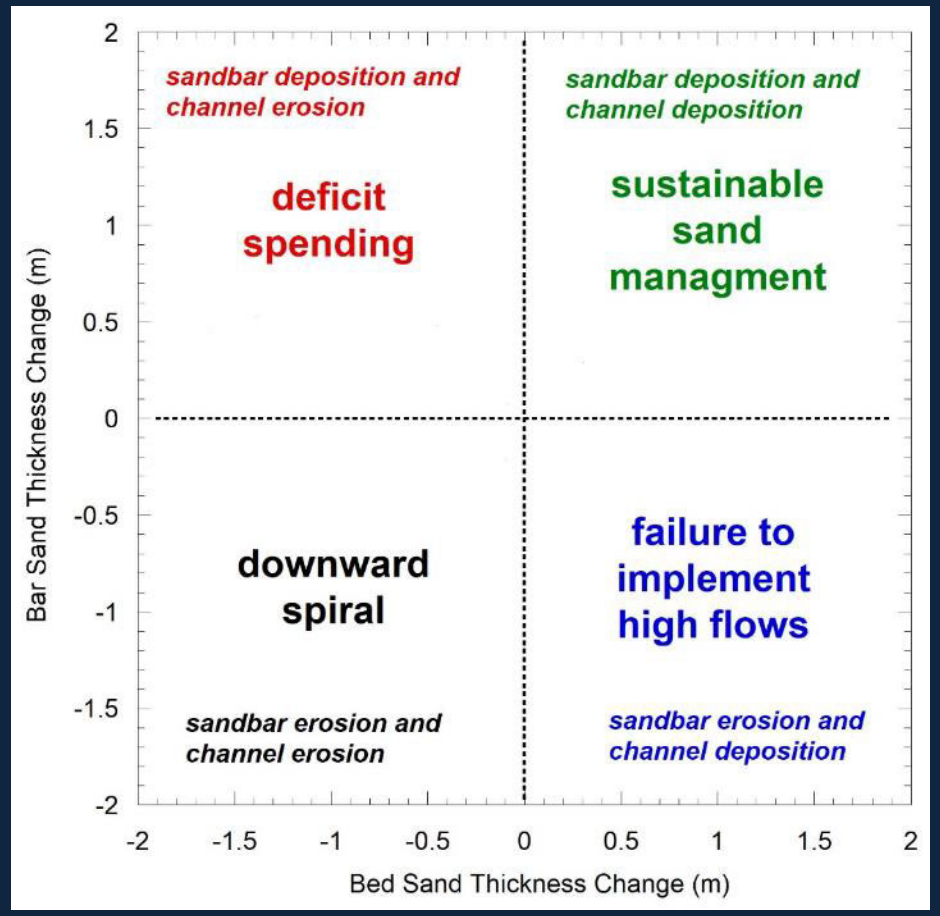
Repeat channel mapping: Implications for high flows and dam management



Repeat channel mapping: Implications for high flows and dam management

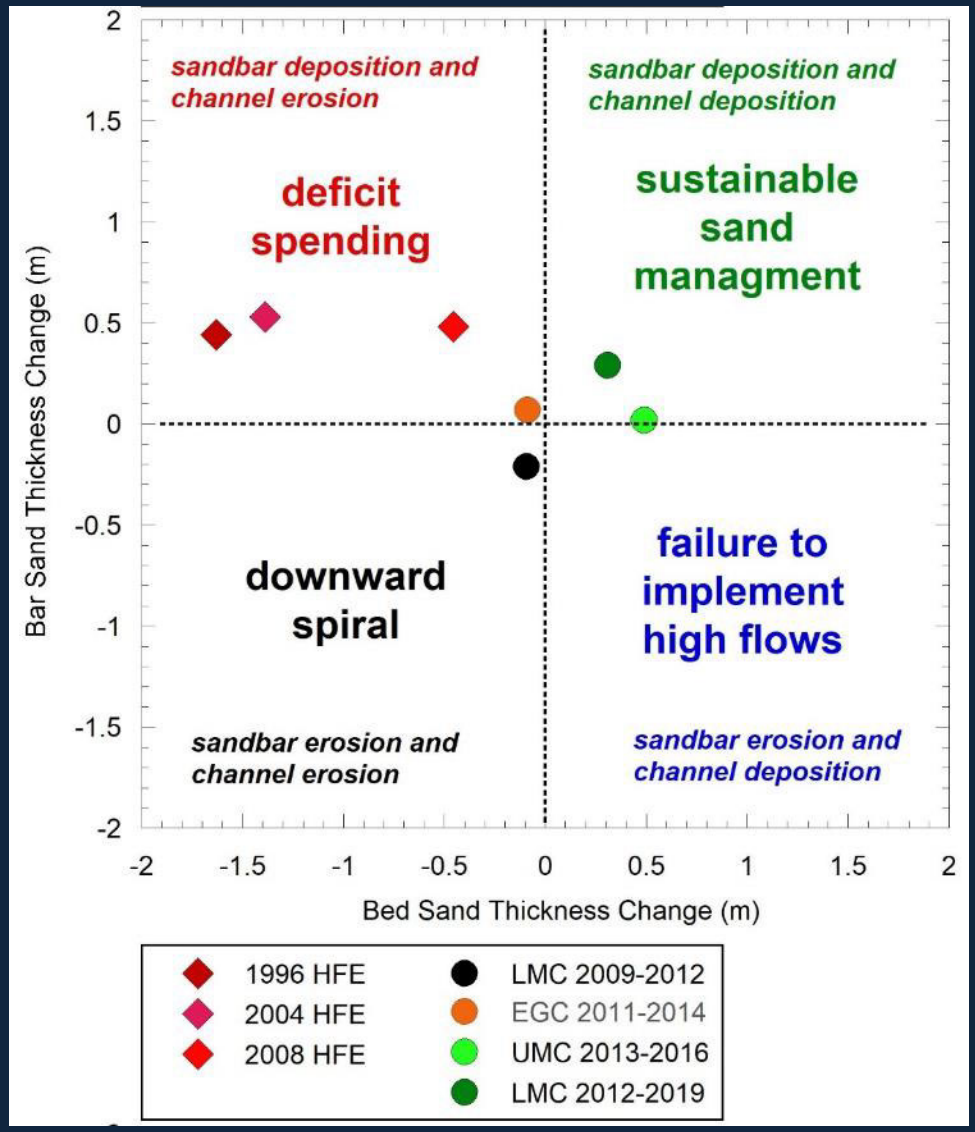
Repeat measurements during HFEs (diamonds)

- HFEs are "deficit spending"
- Need to mobilize all the sand to build sandbars and a large fraction is exported
- But a short-term negative that can be recovered from

Repeat measurements over many years (circles)

- Downward spiral: Equalization flows and no HFEs
- Deficit spending: Equalization flows and HFEs
- Sustainable: No equalization flows and HFEs

The 2004 and 2008 HFEs demonstrated sandbar building under conditions of greater sand enrichment was most effective with less erosion of sand from storage in eddies and channel (Hazel and others, 2010; Schmidt and Grams, 2011).



Schmidt and Grams, 2011; Grams et al. 2019; and Preliminary results. Do not cite.

USGS

Conclusions: Sandbars and in-channel sediment storage

Sandbar response to HFEs

- When implemented, HFEs under sand-enriched conditions cause increases in sandbar area and volume.
- From 2019 through 2022, sandbar volume decreased for most bar types because monsoon failure (2019, 2020) and low reservoir levels (2021, 2022) prevented HFE implementation for 4 consecutive years.
- Sandbars have eroded since 2023 HFE
- Deposition at some sandbars is likely stage-limited (bars not likely to get larger without larger HFEs).

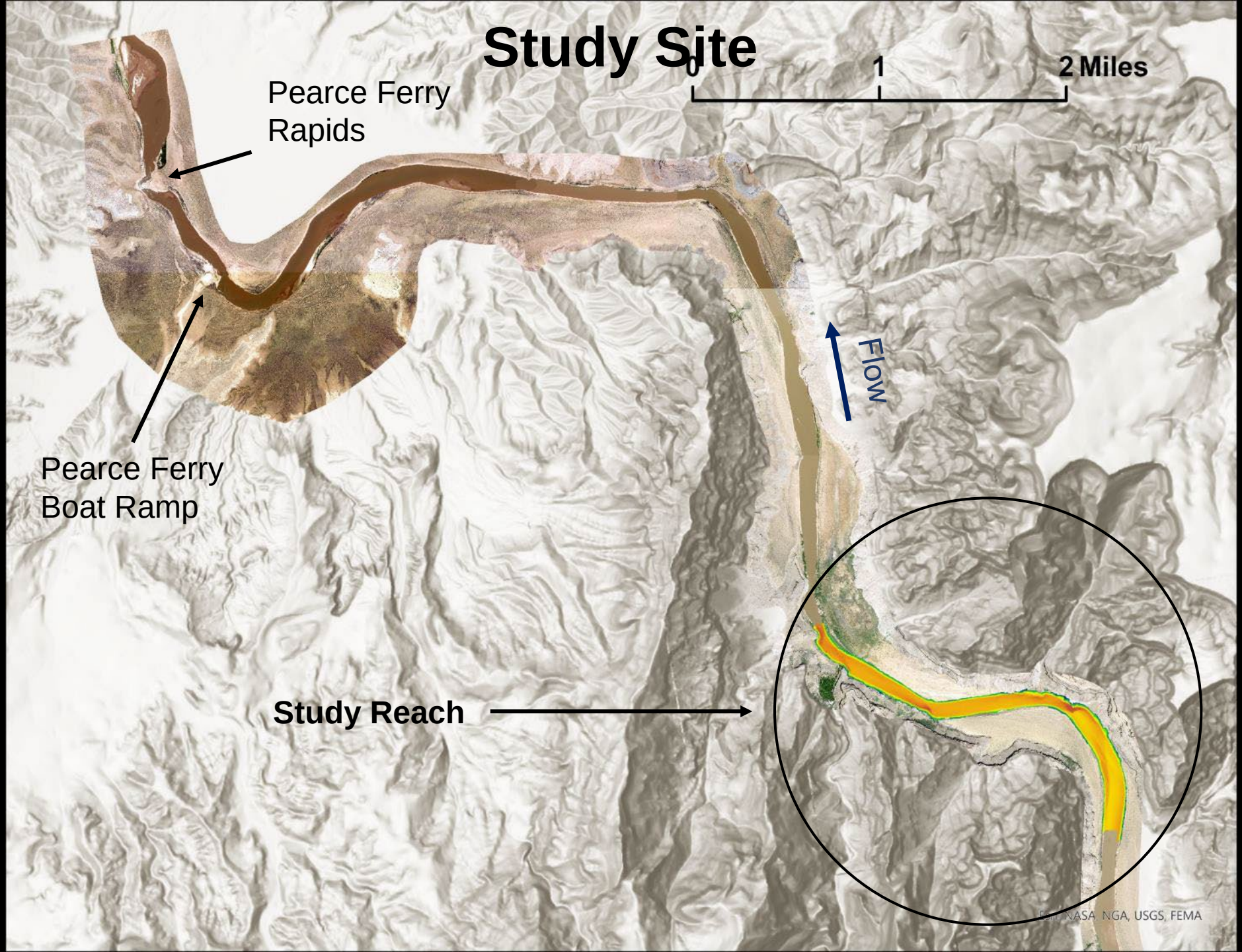
Changes in sand storage

- Lower Marble Canyon has alternately gained and lost sand as function of dam operations and tributary sediment supply.
- Measurements indicate “sustainable” sand management has only occurred during periods that include both HFEs and “normal” reservoir operations (no equalization flows).

Channel Response to High Flows in Western Grand Canyon

Objective: Understand and quantify relation between **changes in bed configuration** in Western Grand Canyon and **dam releases**.

Do certain dam operations reduce, exacerbate or mitigate sediment accumulation in this reach?

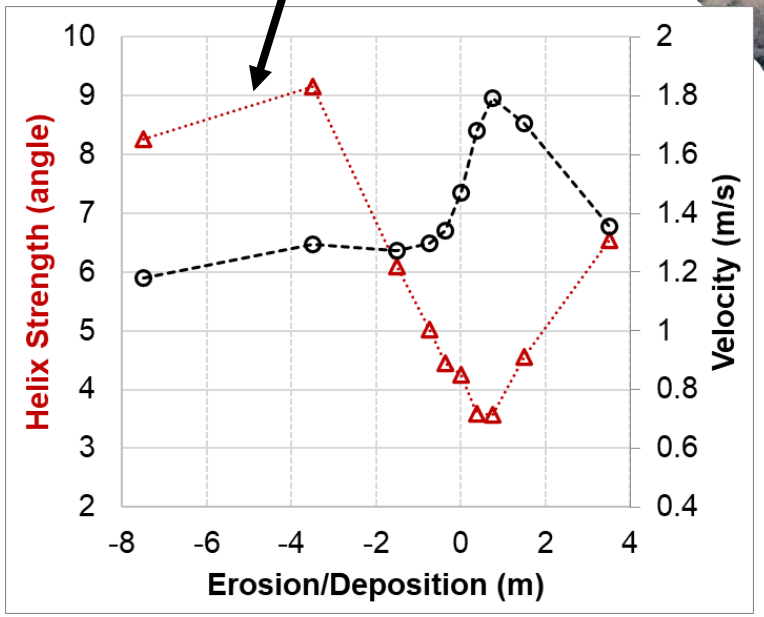

Study Site
0
1
2 Miles
Pearce Ferry
Rapids
Pearce Ferry
Boat Ramp
Flow
Study Reach
NASA, NGA, USGS, FEMA

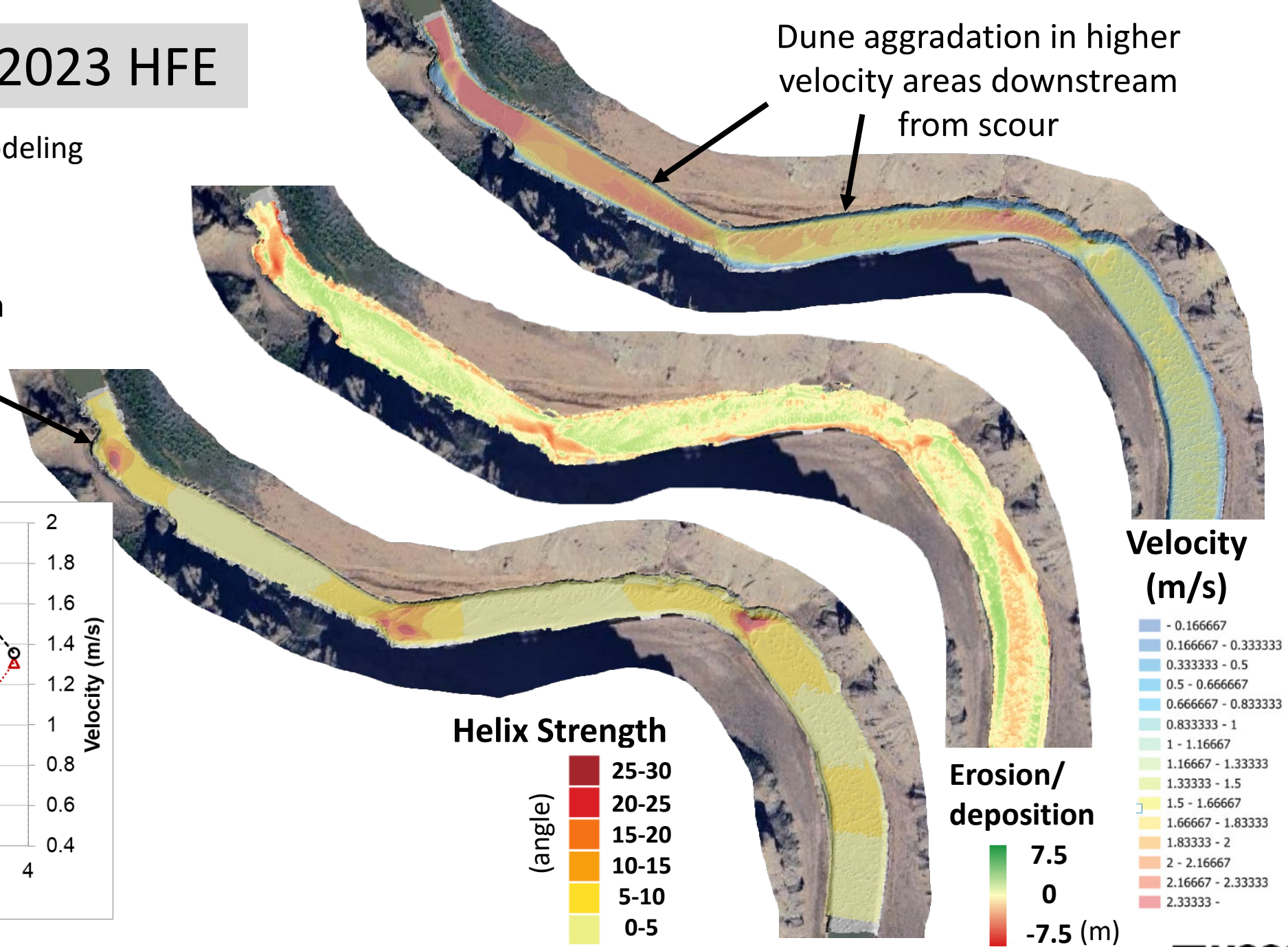
Changes during 2023 HFE

2-dimensional streamflow modeling

Dune aggradation in higher velocity areas downstream from scour

Scour in zones with strong secondary (helical) flow





Preliminary results, do not cite.

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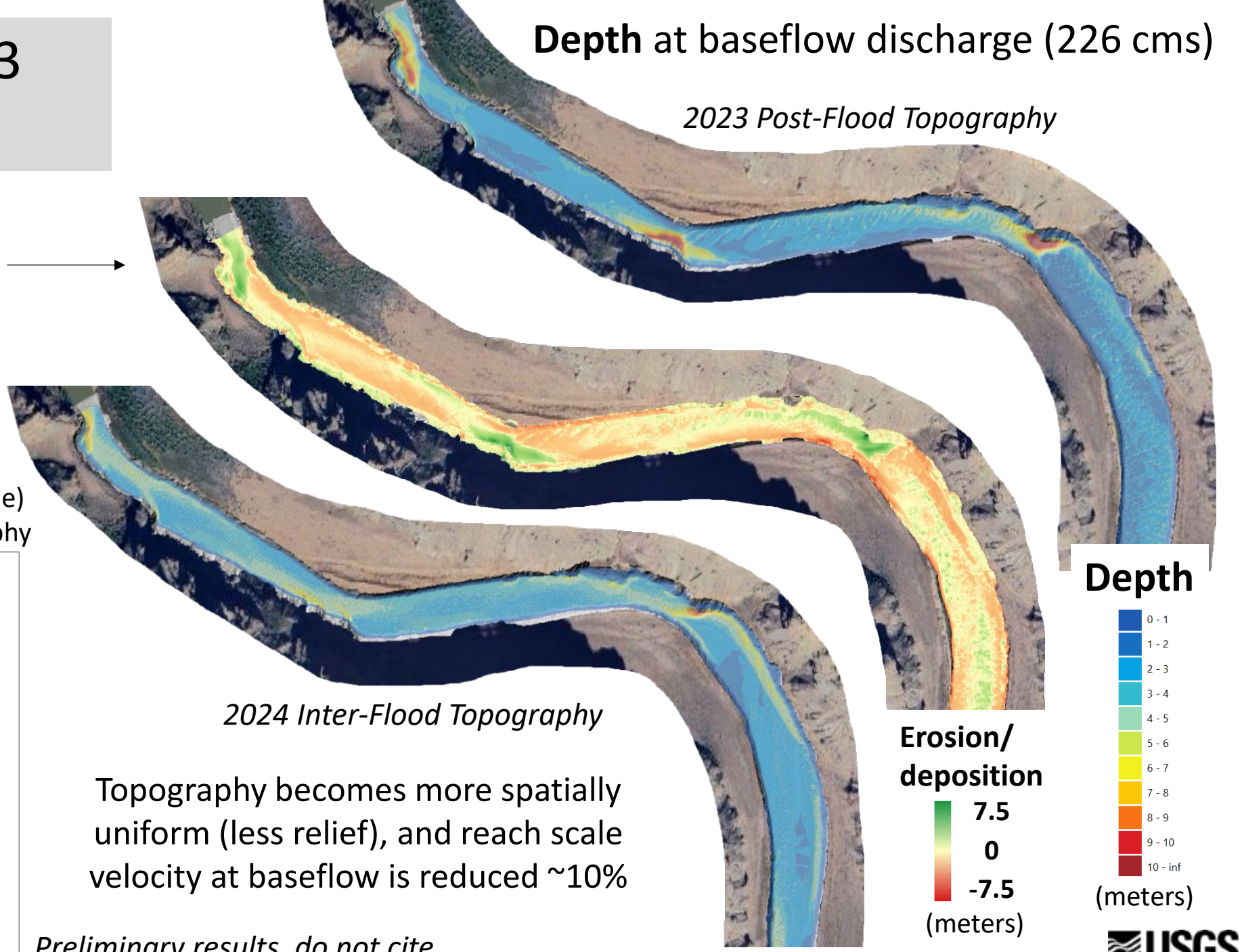
Changes from 2023 HFE to 2024

Pattern of erosion and deposition reverses during the inter-flood period →

Depth at baseflow discharge (226 cms)

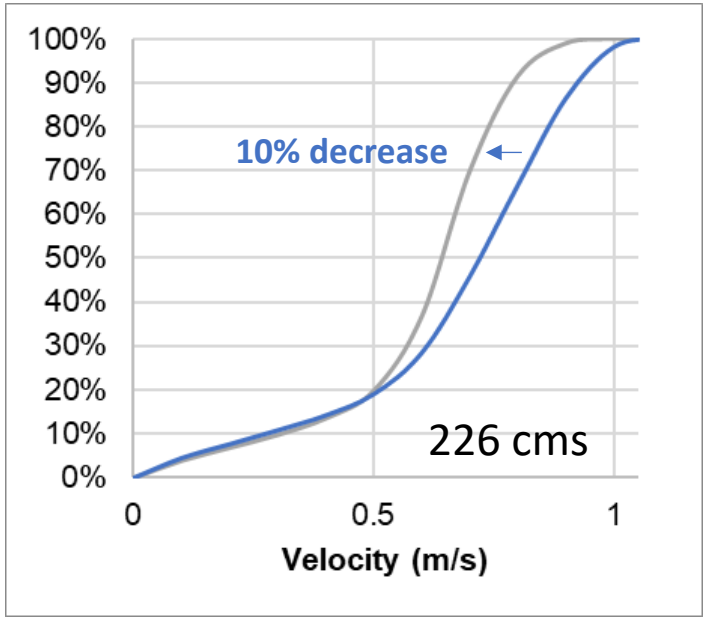
2023 Post-Flood Topography

2024 Inter-Flood Topography



Topography becomes more spatially uniform (less relief), and reach scale velocity at baseflow is reduced ~10%

Modeled cumulative velocity distribution using 2023 (post-flood, blue) versus 2024 (inter-flood, gray) topography



Preliminary results, do not cite.

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Conclusions: Channel Response to High Flows in Western Grand Canyon

- The bed in the reach is dynamic and does change systematically in response to flows
  - 2 to 3 m of scour and fill in scour holes during high flows (SDF and HFE)
  - ~ 0.5 m of bed variability in dune fields across all flows
  - Slight aggradation of dunes during high flows, but followed by return to pre-HFE bed elevations after return to normal operations
- Mean condition of the channel is relatively stable
  - No long-term increases or decreases in bed elevation or sediment volume
  - Likely controlled by downstream Pearce Ferry Rapid
- Banks are eroding
  - Could lead to long-term increases in width and shallower channel.

→ HFEs may cause temporary increases in the heights of sandbars that may temporarily affect navigation.

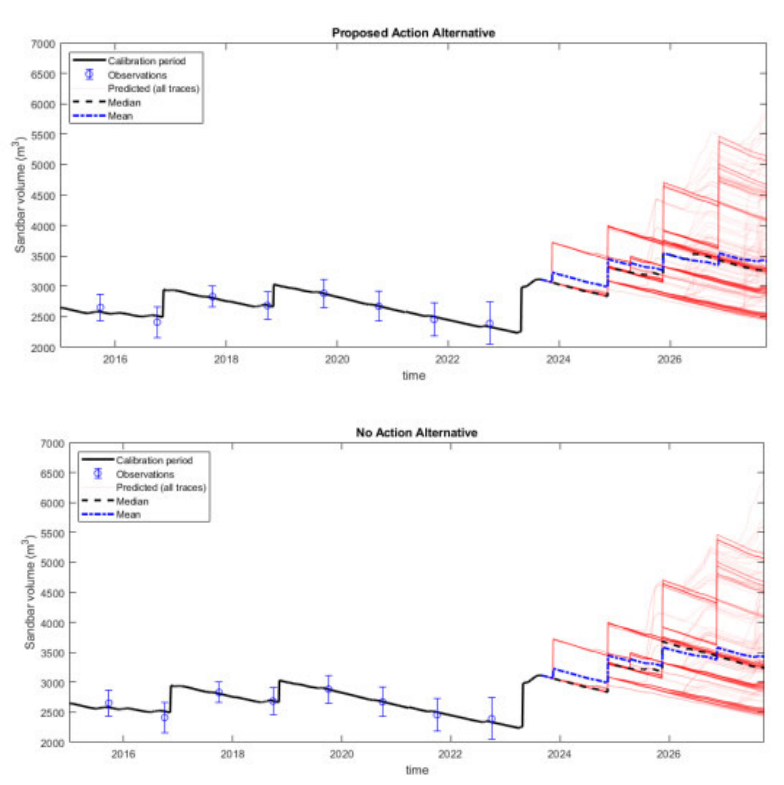
→ But those changes are temporary, and bars return to “normal” heights (possibly still challenging for navigation).

→ Additional monitoring (repeat bed measurements) would be needed to precisely constrain timing and flows needed for channel adjustment.

Sediment and sandbar modeling in FY 2024

- Preliminary fine sediment (silt and clay) routing model for Marble Canyon was developed (Salter and others, 2023)
  - Work on this was paused to work on Reclamation NEPA compliance: IG SEIS, LTEMP SEIS, post-2026 EIS
- Sediment and sandbar modeling for Interim Guidelines SEIS
- Alternative development and sediment and sandbar modeling for LTEMP SEIS
- Alternative development and sediment and sandbar modeling for post-2026 EIS.
  - Model improvements and alternative development funded by NPS (IRA funds).
  - Analysis of alternatives funded by Reclamation.
- Modeling support for Fall 2024/Spring 2025 potential HFE

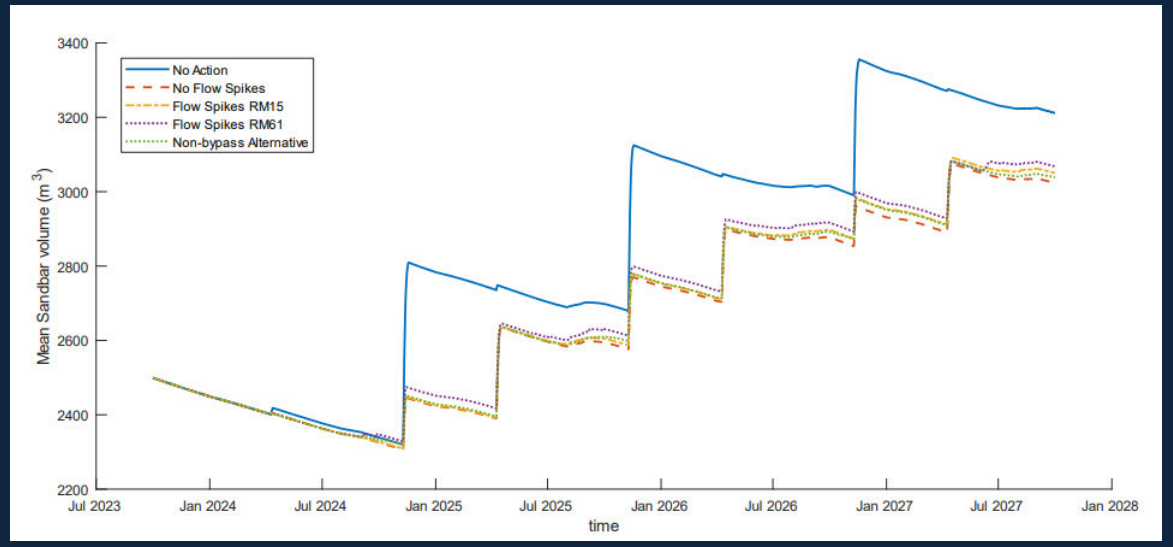
Modeling for IG SEIS

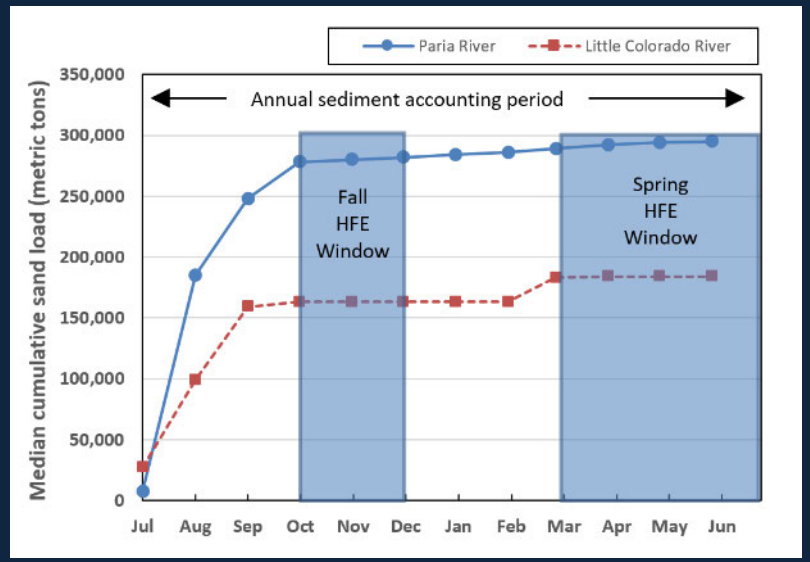


- Impact on sediment most affected by likelihood of Powell dropping below powerplant capacity and preventing HFE implementation.
- There were differences in individual traces, but no significant difference between alternatives.

Yackulic and others (2024); Salter and Grams (2024); US Department of the Interior (2024a)

Modeling for LTEMP SEIS





- Modeling to support change in sediment accounting window to allow implementation of spring HFEs
- Evaluation of alternatives for flows to disadvantage non-native fish

Grams and others (2024); US Department of the Interior (2024b)

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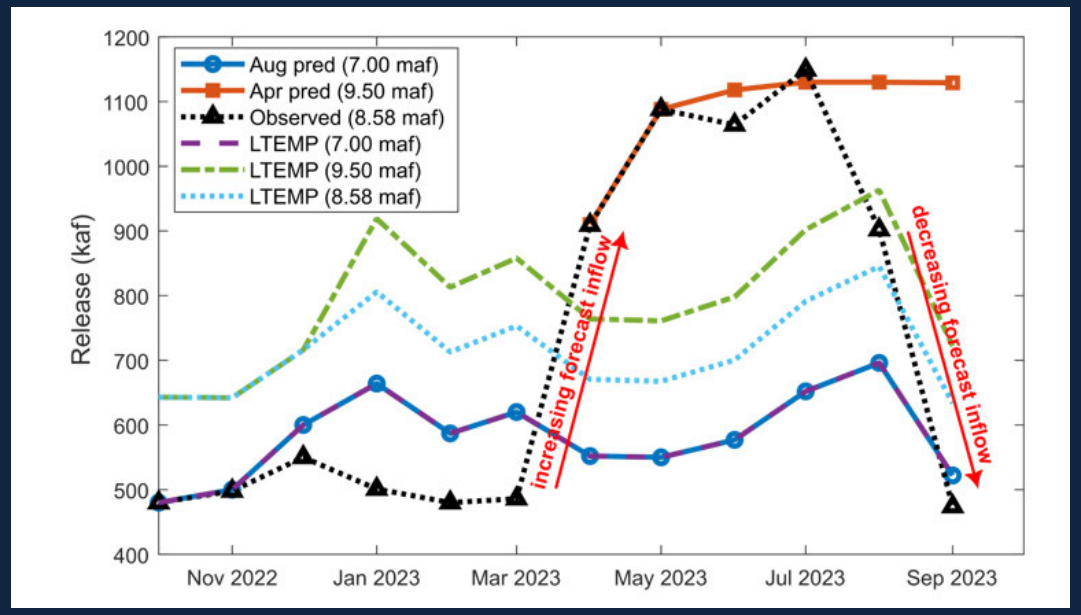
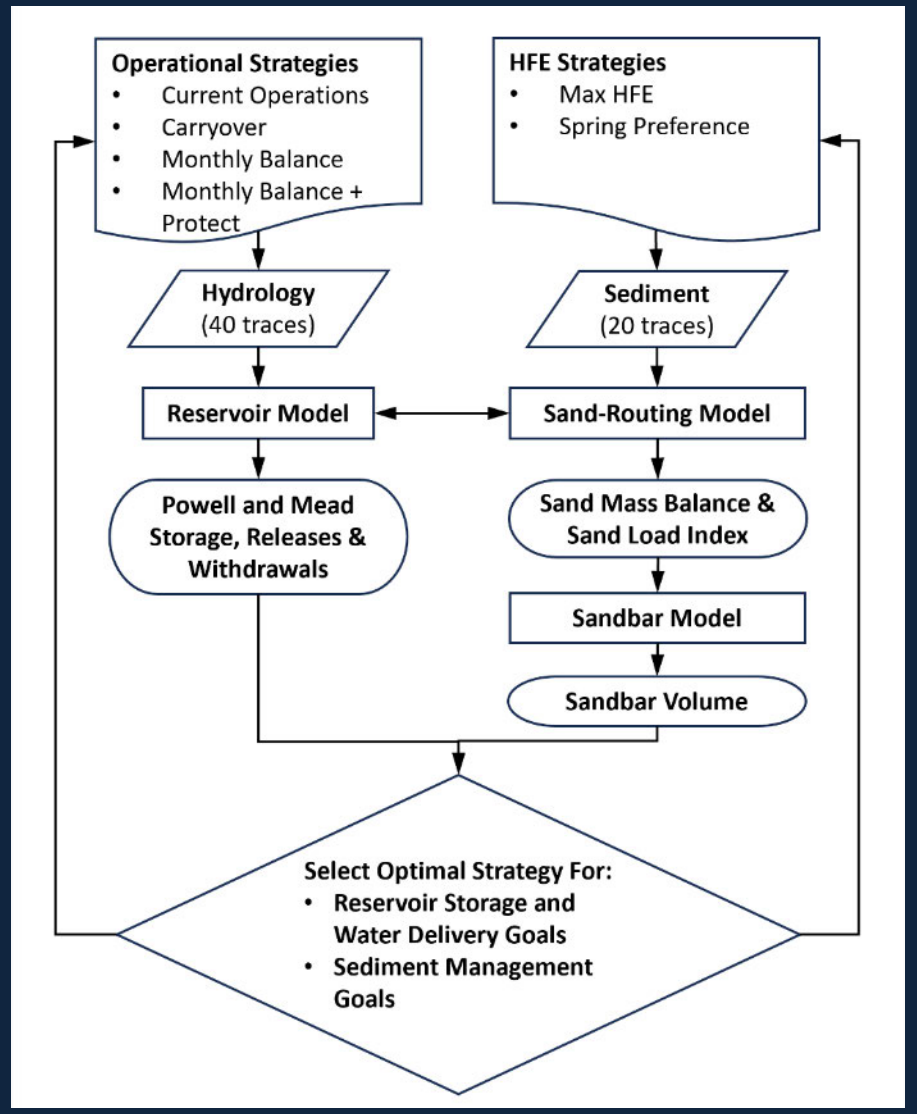
Modeling to inform alternative development for Post-2026 EIS

Objectives:

- Maintain Powell elevations to implement HFEs
- Avoid large monthly volumes that cause sediment evacuation.



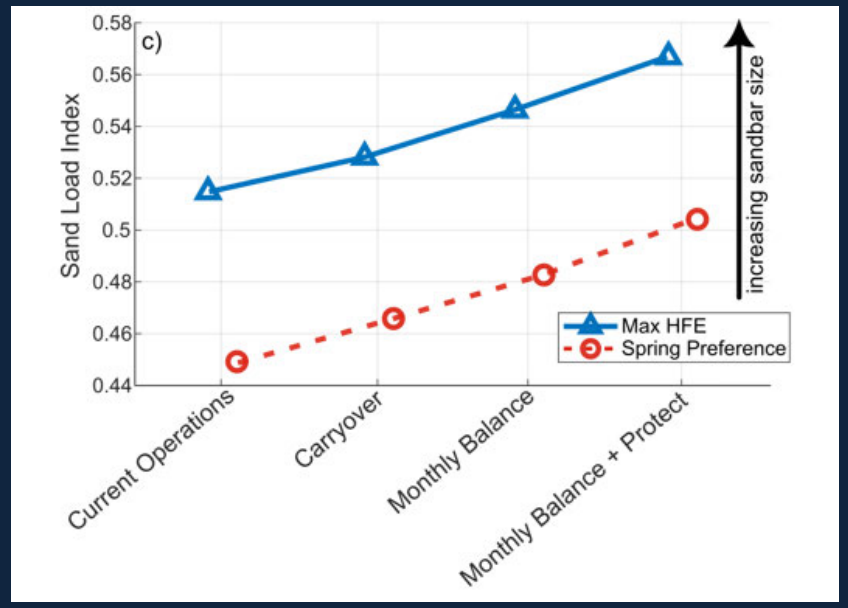


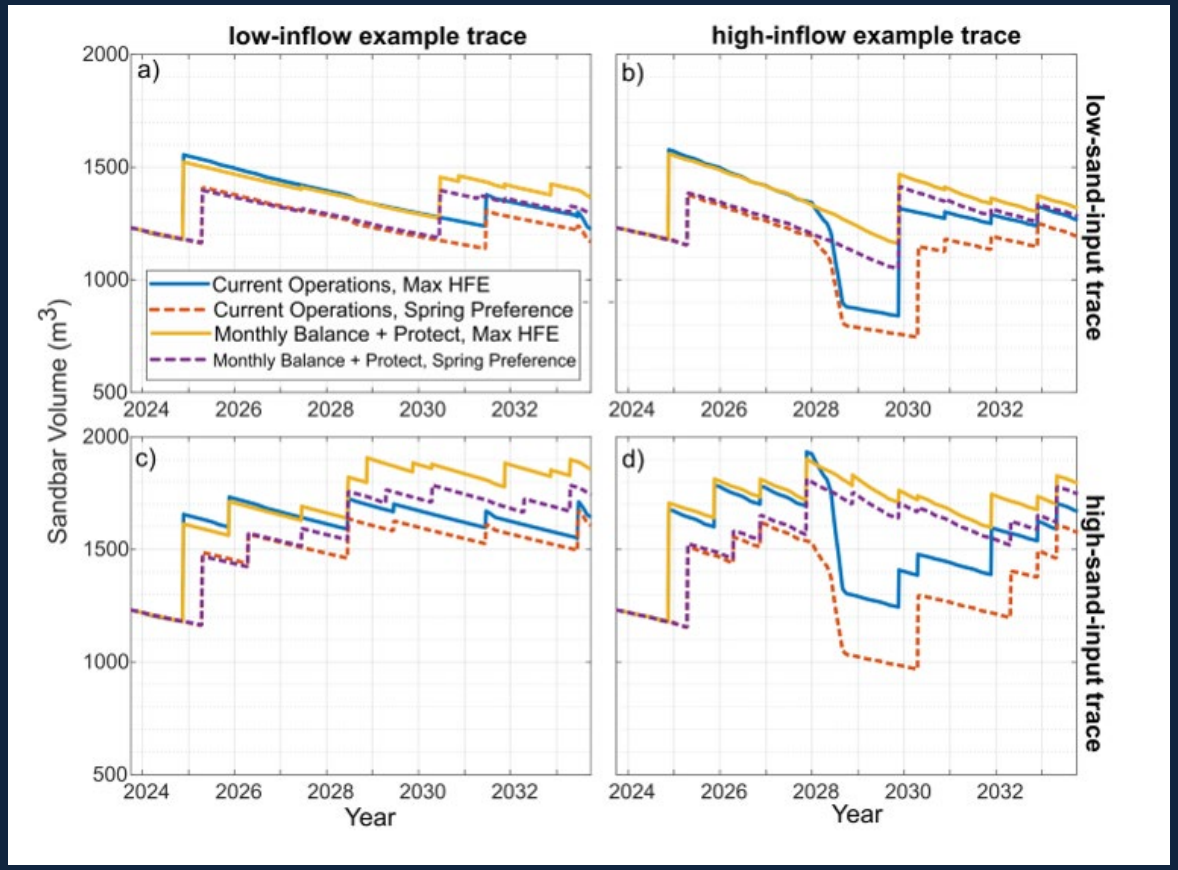
Model flow chart to find strategies for determining release volumes to meet sediment goals AND that are consistent with downstream water delivery policy (strategies that would be effective no matter the division or amount of shortage that is negotiated).

Salter and others (in review), preliminary results, do not cite

USGS

Modeling to inform alternative development for Post-2026 EIS





Main conclusions:

- Erosive high monthly releases can be reduced or eliminated via flexible new operational strategies. These strategies are compatible with a range of different policy goals of reservoir elevations and downstream deliveries.
- Operational strategies that eliminate the need for high monthly releases while maintaining Powell at a sufficient elevation to perform HFEs build the largest sandbars while avoiding long-term decline in sand mass balance. *Strategies that relaxed or eliminated water-year annual release constraints best avoided high monthly releases.*

Salter and others (in review), preliminary results, do not cite

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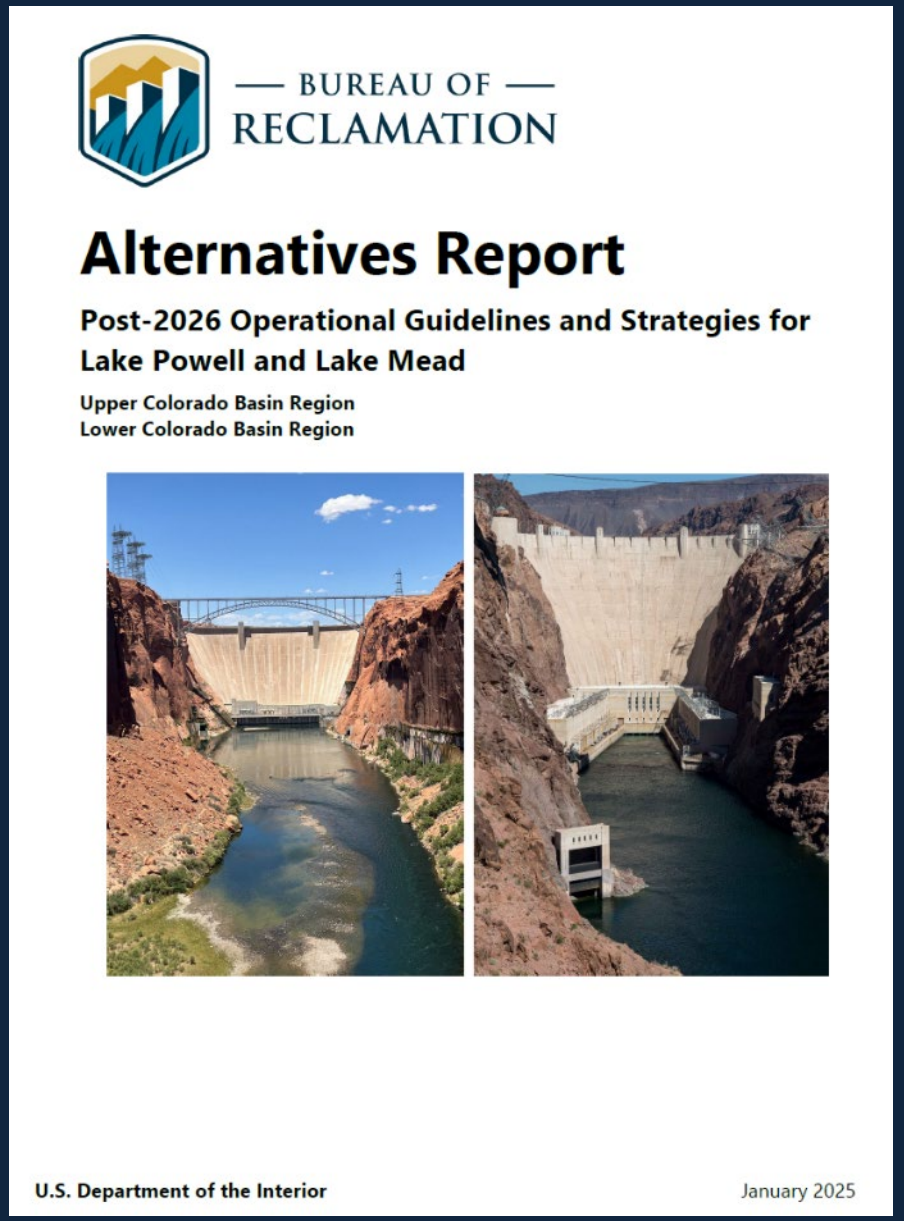
Sediment Modeling for Post-2026 EIS Alternatives

- 1200 traces per alternative
- Use sand routing model to determine HFE timing/duration and monthly volume shifts (if necessary).
- Provide HFE information to WAPA for GTMAX runs to produce hourly hydrographs
- Re-run sand routing model and run sandbar model using hourly hydrographs.
- Compare the performance of alternatives based on modeled sand mass balance and sandbar volume.



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