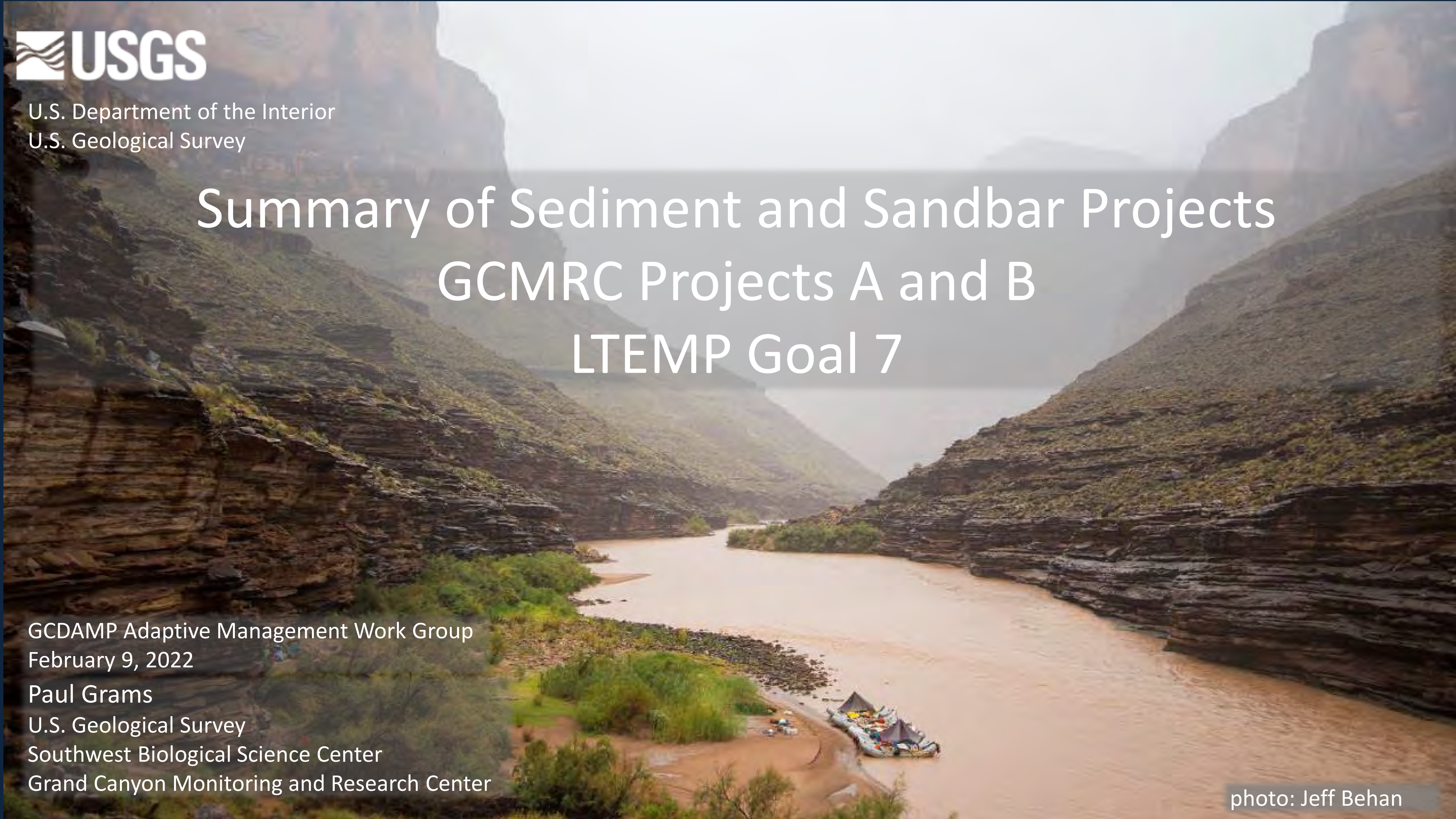


USGS

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

Summary of Sediment and Sandbar Projects
GCMRC Projects A and B
LTEMP Goal 7

GCDAMP Adaptive Management Work Group
February 9, 2022

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

photo: Jeff Behan

Acknowledgements

Project A personnel:
David Topping, Ron Griffiths, Nick Voichick, David Dean, Joel Unema

Project B personnel:
Paul Grams, Matt Kaplinski, Joseph Hazel, Katie Chapman, Robert Tusso, Keith Kohl, Thomas Gushue, James Hensleigh, Shannon Sartain, and Caitlin Andrews

Collaborators and field assistants:
GCRG, Jeff Behan, David Topping, Erich Mueller, Sinjin Eberle, Jesse Collier, Daniel Buscombe, Robert Ross, Daniel Hamill, David Rubin, Joel Sankey, Jack Schmidt, Scott Wright, Rod Parnell, Bryan Cooperrider, Karen Koestner, Emily Thompson, Daniel Hadley, Ryan Semptua, Geoff Gourley. Somer Morris. Lydia Manone, Lauren Tango, John O'Brien Morgan Barnard, Pete Koestner, Logistics team: Ann-Marie, Seth Felder, Dave Foster, Clay Nelson, Lucien Bucci, and Fritz!

NORTHERN ARIZONA UNIVERSITY

GRAND CANYON RIVER GUIDES

photo: Geoff Gourley

Joe Hazel retired in June 2021 after 30+ years at Northern Arizona University and as a cooperator with Reclamation and USGS on sandbar and sediment-related projects in Grand Canyon

USGS

Projects A and 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 A:
  - Continuous monitoring of discharge and fine-sediment at mainstem gages
  - Computation of sediment budgets for HFE planning and sand-storage monitoring
- Project B:
  - Annual sandbar and campsite monitoring at 45 long-term monitoring sites
  - Periodic channel mapping to measure changes in high- and low-elevation sand throughout Glen Marble, and Grand Canyons

USGS

Project A and B: Publications (2021)

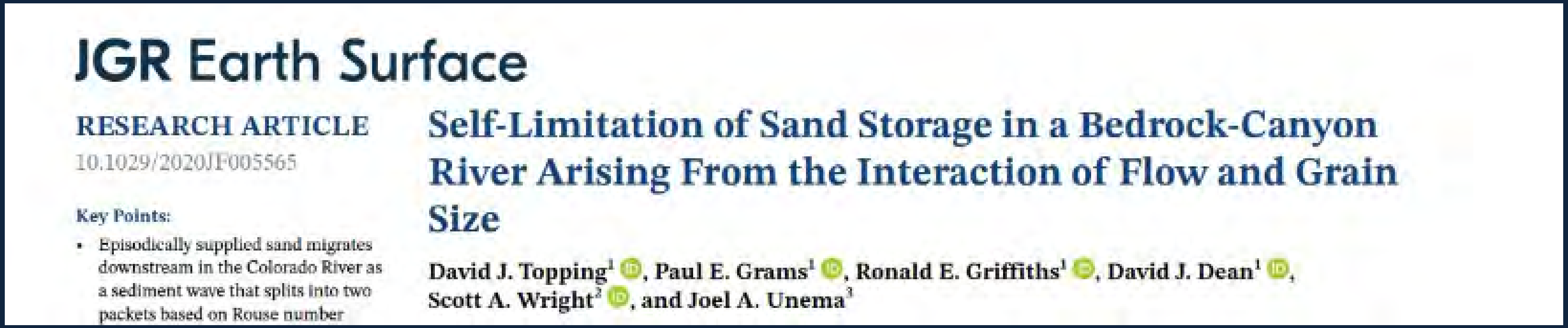
- Alvarez, L.V., and Grams, P.E., 2021, An eddy-resolving numerical model to study turbulent flow, sediment, and bed evolution using detached eddy simulation in a lateral separation zone at the field-scale: Journal of Geophysical Research: Earth Surface, v. 126, no. 10, e2021JF006149, https://doi.org/10.1029/2021JF006149.
- Durning, L.E., Sankey, J.B., Yackulic, C.B., Grams, P.E., Butterfield, B.J. and Sankey, T.T, 2021, Hydrologic and geomorphic effects on riparian plant species occurrence and encroachment—Remote sensing of 360 km of the Colorado River in Grand Canyon: Ecohydrology, e2344, https://doi.org/10.1002/eco.2344.
- Mueller, E.R., and Grams, P.E., 2021, A morphodynamic model to evaluate long-term sandbar rebuilding using controlled floods in the Grand Canyon: Geophysical Research Letters, v. 48, no. 9, e2021GL093007, https://doi.org/10.1029/2021GL093007.
- Sabol, T.A., Griffiths, R.E., Topping, D.J., Mueller, E.R., Tusso, R.B., and Hazel, J.E., Jr., 2021, Strandlines from large floods on the Colorado River in Grand Canyon National Park, Arizona: U.S. Geological Survey Scientific Investigations Report 2021-5048, 41 p., https://doi.org/10.3133/sir20215048.
- Topping, D.J., Grams, P.E., Griffiths, R.E., Dean, D.J., Wright, S.A., and Unema, J.A., 2021, Self-limitation of sand storage in a bedrock-canyon river arising from the interaction of flow and grain size: Journal of Geophysical Research: Earth Surface, v. 126, e2020JF005565, https://doi.org/10.1029/2020JF005565.
- Unema, J.A., Topping, D.J., Kohl, K.A., Pillow, M.J., and Caster, J.J., 2021, Historical floods and geomorphic change in the lower Little Colorado River during the late 19th to early 21st centuries: U.S. Geological Survey Scientific Investigations Report 2021–5049, 34 p., https://doi.org/10.3133/sir20215049

Data Releases and web applications

- Grams, P.E., Alvarez, L., Kaplinski, M., and Wright, S., 2021, Repeat measurements of bathymetry, streamflow velocity and sediment concentration made during a high flow experiment on the Colorado River in Grand Canyon, March 2008: U.S. Geological Survey data release, https://doi.org/10.5066/P9O00Z44
- Grams, P.E., Hazel, J.E., Jr., Kaplinski, M., Ross, R.P., Hamill, D., Hensleigh, J., and Gushue, T., 2020, Long-term sandbar monitoring data along the Colorado River in Marble and Grand Canyons, Arizona: U.S. Geological Survey data release, https://doi.org/10.5066/P93F8JJK
- Sabol, T.A., Griffiths, R.E., Topping, D.J., Mueller, E.R., Tusso, R.B., and Hazel, Jr., J.E., 2021, Surveyed peak-stage elevations, coordinates, and indicator data of strandlines from large floods on the Colorado River in Grand Canyon National Park, Arizona: U.S. Geological Survey data release, https://doi.org/10.5066/P9GIQ9ZN
- Unema, J.A., Topping, D.J., Caster, J.J., and Kohl, K.A., 2021, Topographic data, historical peak-stage data, and 2D flow models for the lowermost Little Colorado River, Arizona, USA, 2017: U.S. Geological Survey data release, https://doi.org/10.5066/P9VGWRV1.

- Streamflow, sediment, and water quality web application: http://www.gcmrc.gov/discharge_qw_sediment/
- Images from remote camera monitoring of sandbars: https://grandcanyon.usgs.gov/gisapps/sandbarphotoviewer/RemoteCameraTimeSeries.html
- Images from GCRG adopt-a-beach program: https://grandcanyon.usgs.gov/gisapps/adopt-a-beach/index.html
- Data from long-term sandbar monitoring sites: https://www.usgs.gov/apps/sandbar/

Major results from recent publications


JGR Earth Surface

RESEARCH ARTICLE
10.1029/2020JF005565

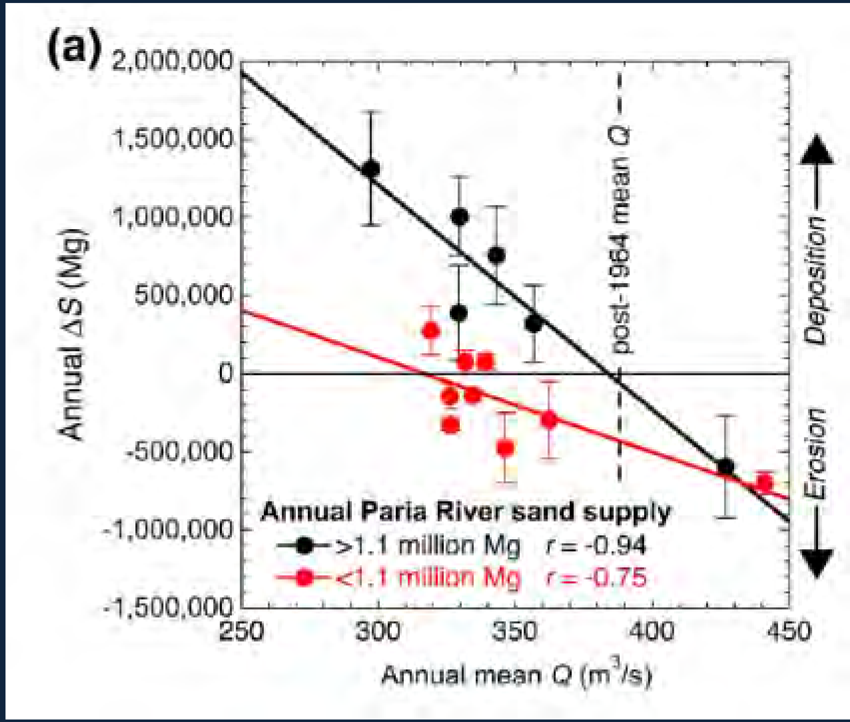
Key Points:

- Episodically supplied sand migrates downstream in the Colorado River as a sediment wave that splits into two packets based on Rouse number

Self-Limitation of Sand Storage in a Bedrock-Canyon River Arising From the Interaction of Flow and Grain Size

David J. Topping[1], Paul E. Grams[1], Ronald E. Griffiths[1], David J. Dean[1], Scott A. Wright[2], and Joel A. Unema[3]

Plot shows sand accumulation and depletion is consistently related to tributary inputs and dam releases



- **Sand accumulation is possible** when tributary sand supply exceeds ~130% of average and dam-released discharges are below the 1964–2017 average (~9.9 million acre-feet)

- **Sand depletion is likely** when inputs are below average and releases are above average

Topping and others (2021)

USGS

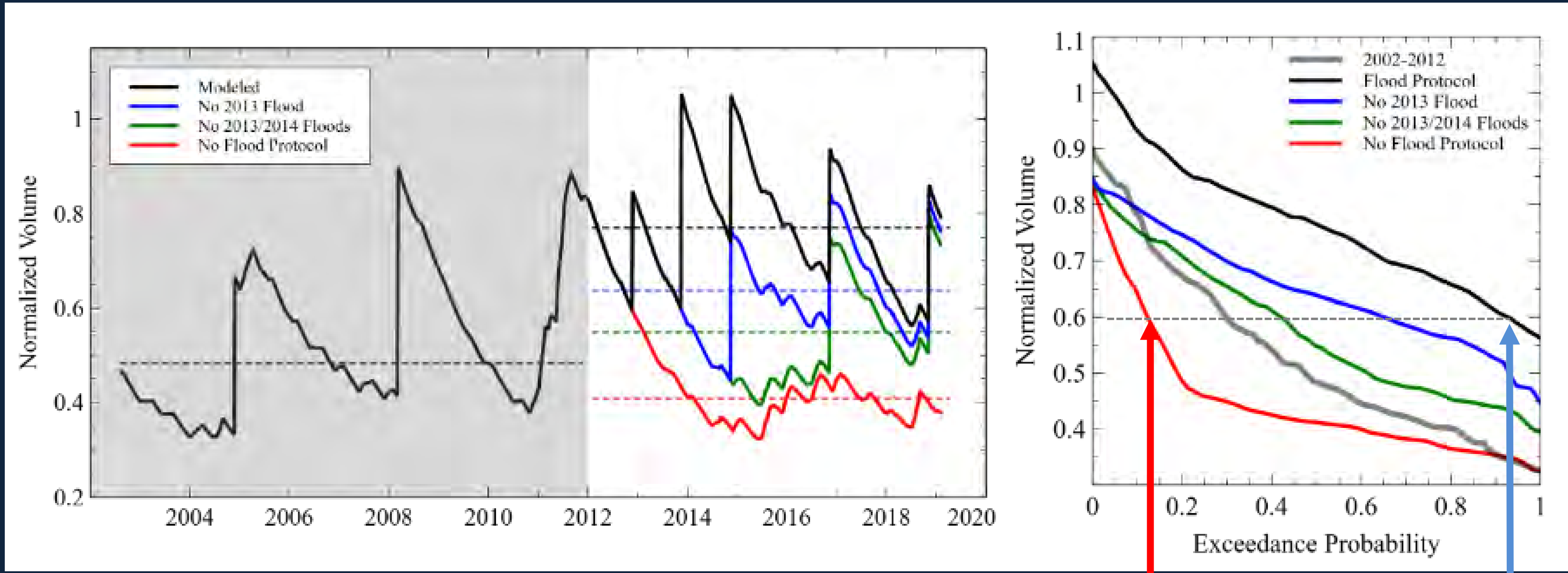
A Morphodynamic Model to Evaluate Long-Term Sandbar Rebuilding Using Controlled Floods in the Grand Canyon

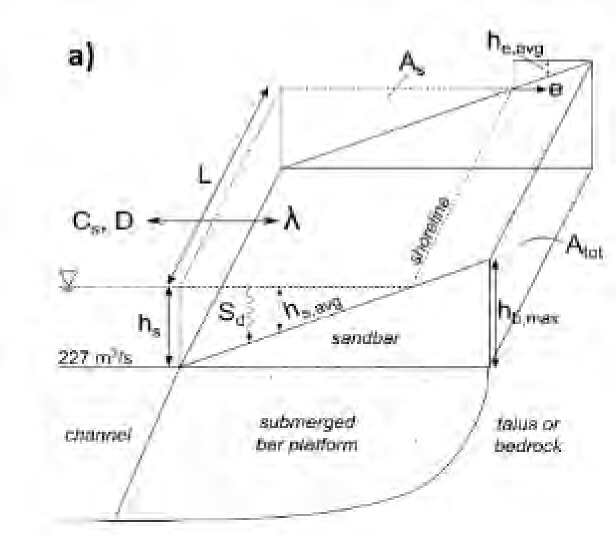
Erich R. Mueller[1] and Paul E. Grams[2]

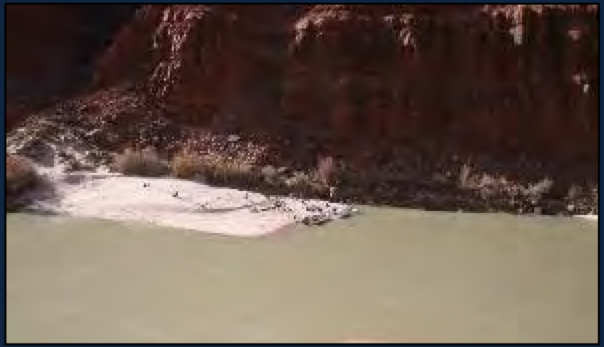
Geophysical Research Letters

Model simulations reducing the number of HFEs

Proportion of time sandbars are larger during HFE protocol.







Fewer HFEs = reduced sandbar size

Without protocol, sandbars are at 60% of "maximum" less than 20% of the time

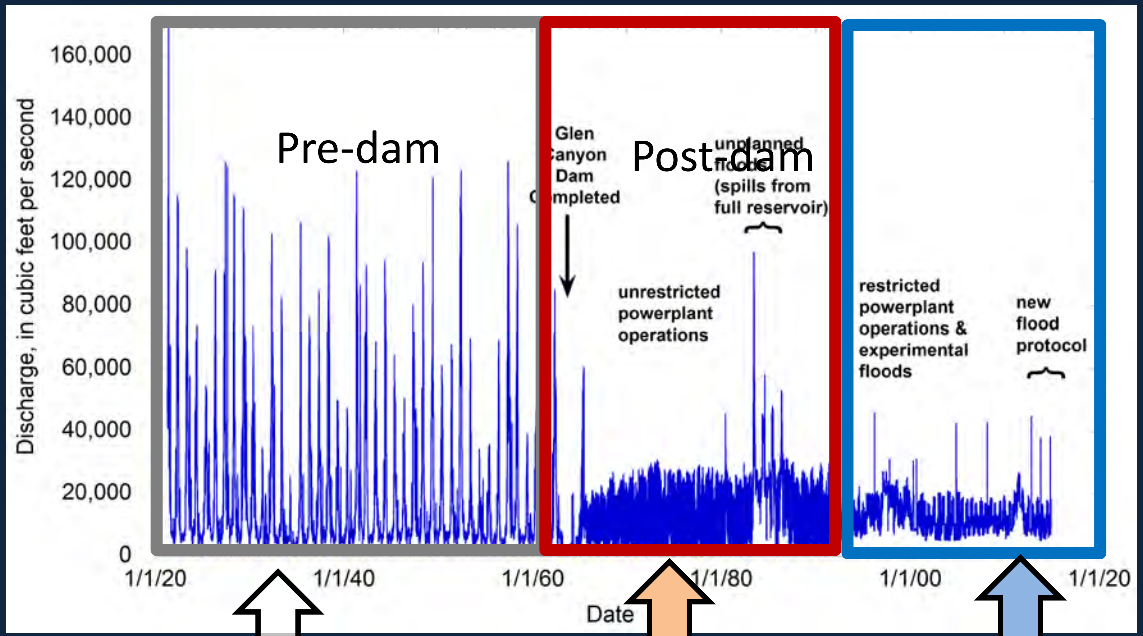
With HFE protocol: sandbars are larger than 60% of "maximum" more than 90% of the time

Mueller and Grams (2021)

USGS

Pre-dam flows, dam operations, high flows, and sandbars

Three major periods of flows and dam operations

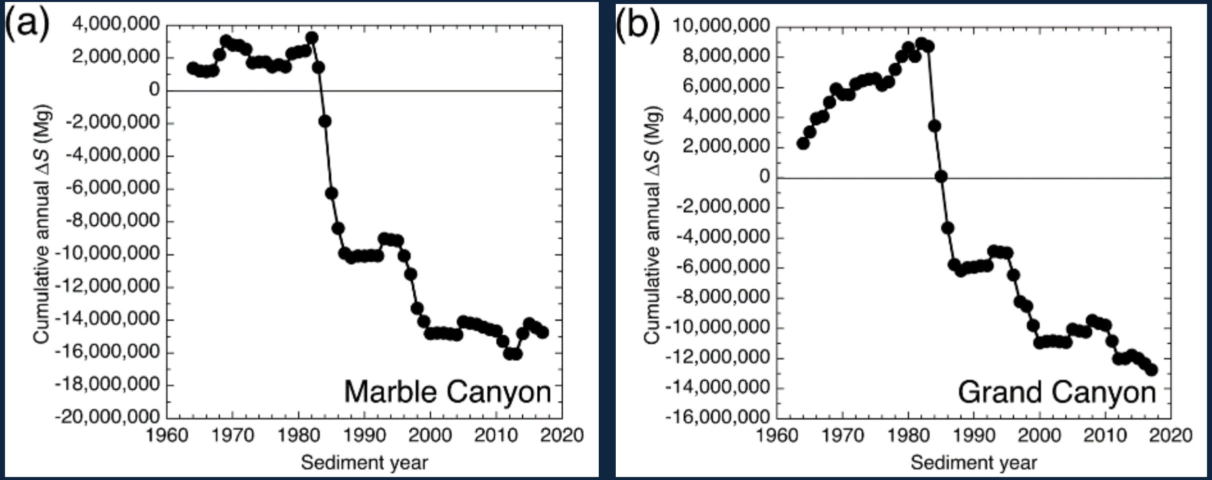


Pre-dam:
- Annual floods
- Abundant sand supply
- Large sandbars

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

Post-dam II:
- Restricted hydropower operations
- **Sand-enriched HFEs**

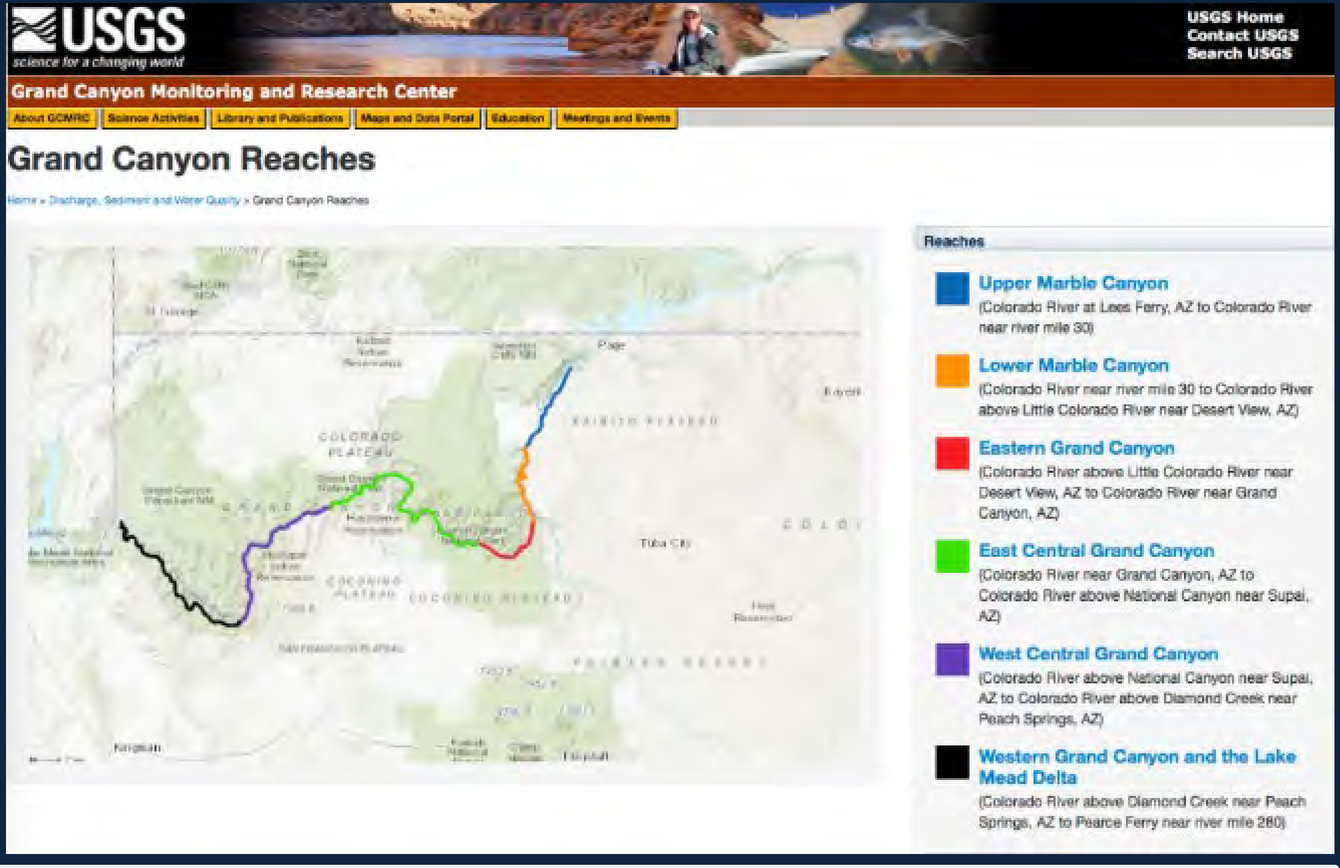
Sandbar erosion



>28 million metric tons of sand eroded since 1963, mostly during periods of sustained high dam releases (Topping and others, *JGR*, 2021)

USGS

Monitoring for fine-sediment mass balance



Continuous mass-balance sand budgets are constructed from transport measurements at 5 mainstem gages and 2 major tributaries, supplemented with calibrated estimates for ungagged tributaries.

Boat for sampling suspended sediment

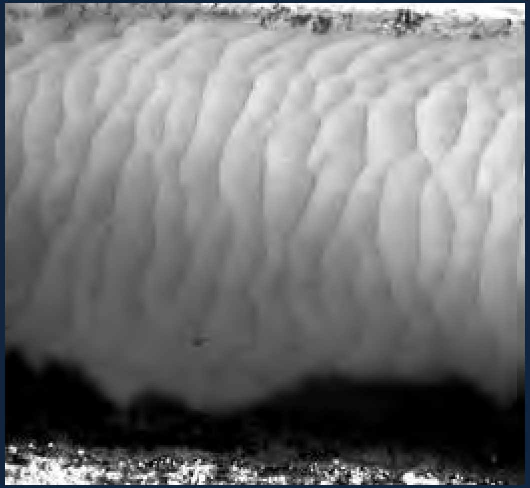


Image of riverbed during clear-water conditions. The mass-balance sand budgets monitor changes in bed storage. Although management focus is on above-water sand, 80 to 90% of the sand is on the riverbed.

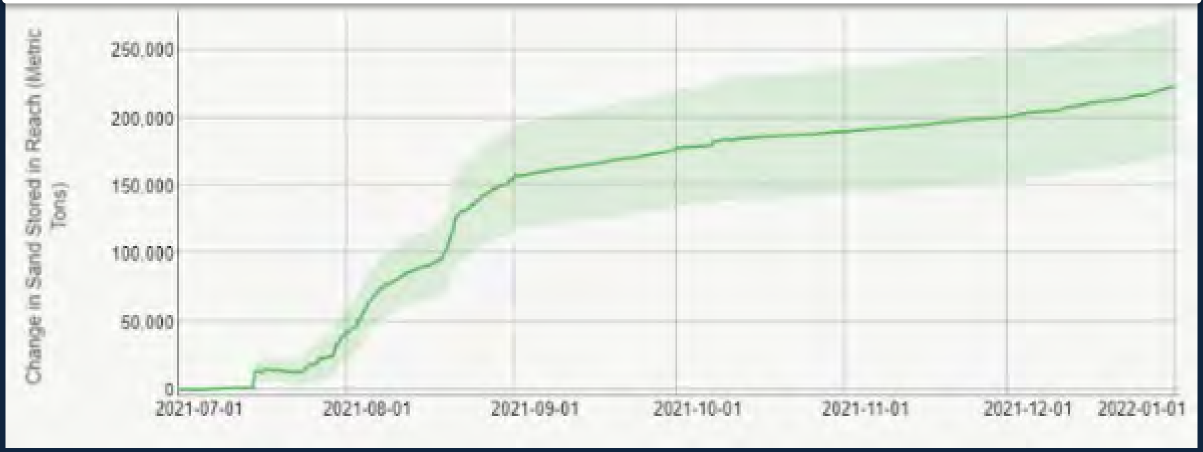
www.gcmrc.gov/discharge_qw_sediment

USGS

Sand mass balance: July 1, 2021 – December 31, 2021

Upper Mable Canyon (RM 0 to 30) mass balance

Lower Mable Canyon (RM 30 to 61) mass balance



	million metric tons
Upper Marble Canyon	+1.30 ± 0.3
Lower Marble Canyon	+0.22 ± 0.05
Eastern Grand Canyon	+0.26 ± 0.14
East-Central Grand Canyon	-0.01 ± 0.09*
West-Central Grand Canyon	-0.06 ± 0.05*

* July 1 to 8/30/2021

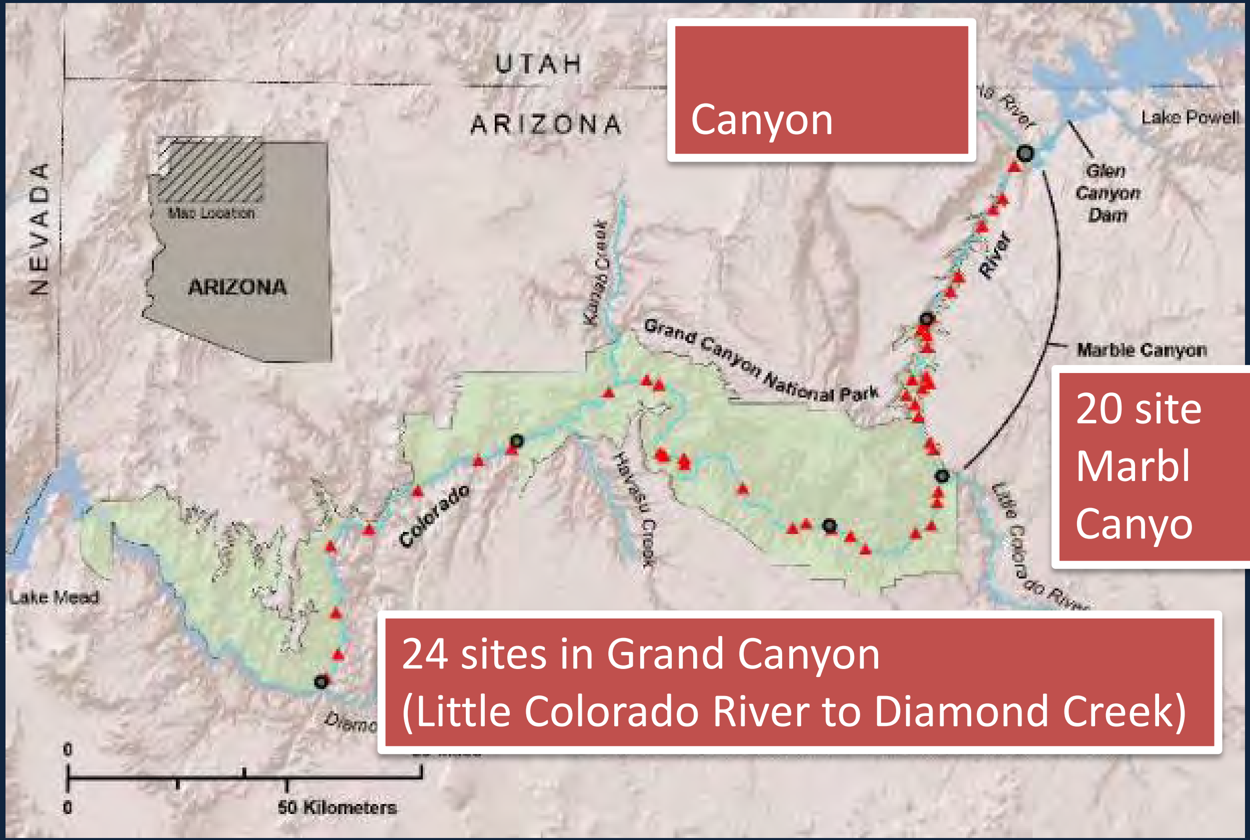
2021 Fall Accounting period

- Paria River supplied **~1.4 million metric tons of sand** (2nd largest since start of HFE Protocol)
- Little Colorado River supplied **~420,000 metric tons of sand**

www.gcmrc.gov/discharge_qw_sediment

USGS

Sandbar monitoring data



Canyon

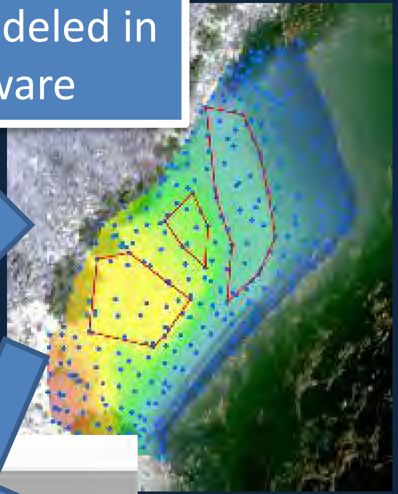
20 site
Marbl
Canyo

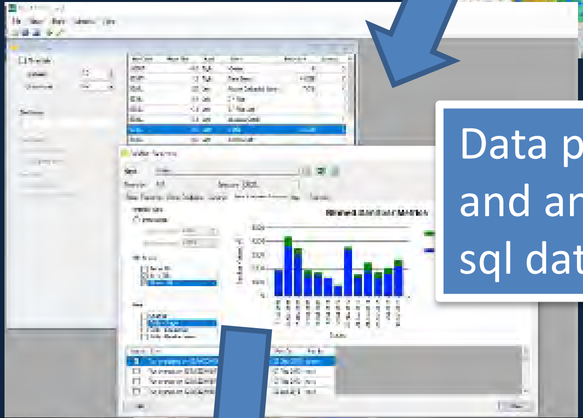
24 sites in Grand Canyon
(Little Colorado River to Diamond Creek)

- 45 monitoring sites (32 started in 1990)
- Data collected annually in October
- 42 of the sites instrumented with remote cameras

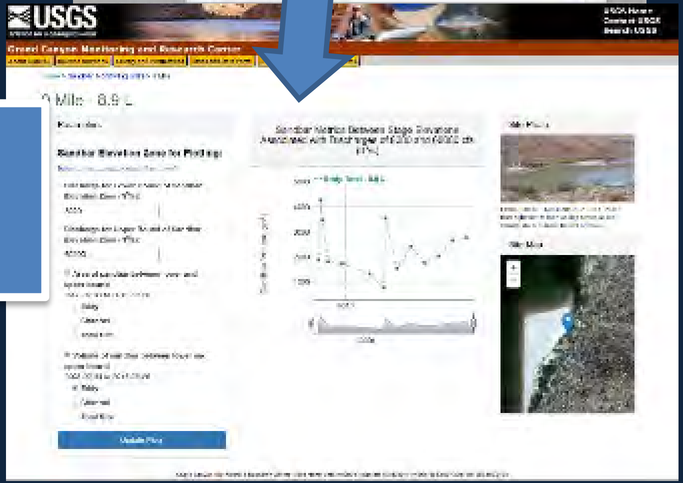
Field surveys

Topographic surfaces modeled in survey software





Data processed and analyzed in sql database



Data served in sandbar web application

www.gcmrc.gov/sandbar OR www.usgs.gov/apps/sandbar

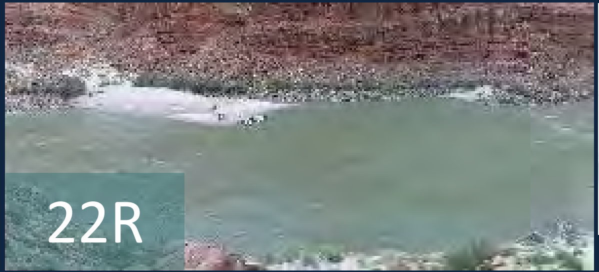
Sandbar monitoring site types

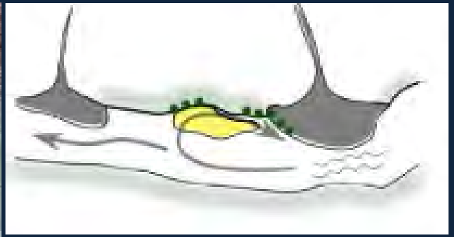
Reattachment Bars

Increasing vegetation

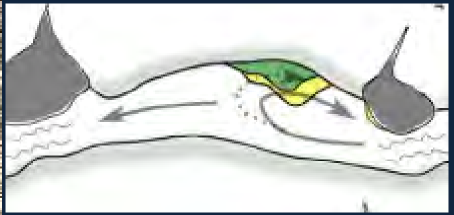
Increasing channel width

Narrow Reattachment bars

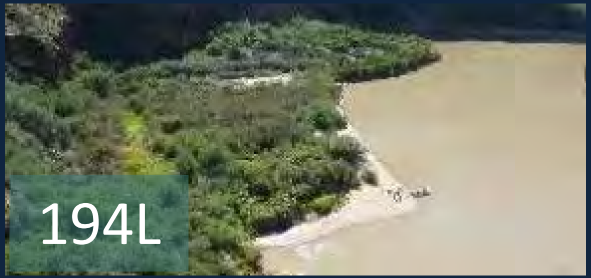


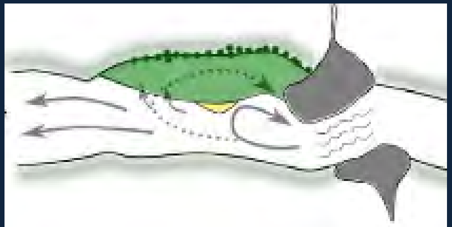


Medium Reattachment bars



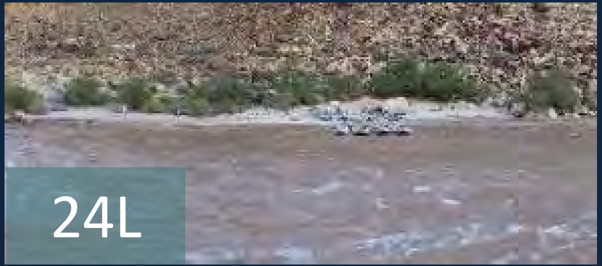
Wide Reattachment bars

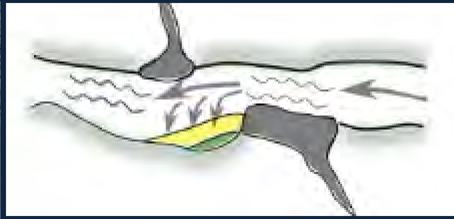




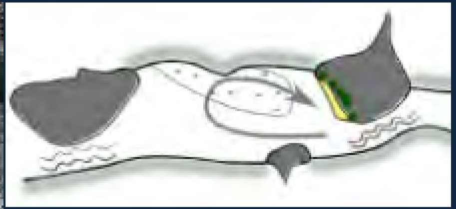
Other Bar Types

Undifferentiated bars

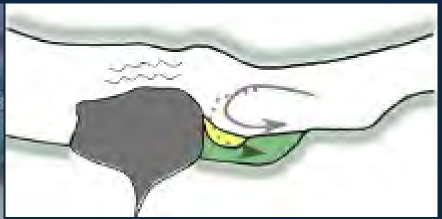




Separation bars



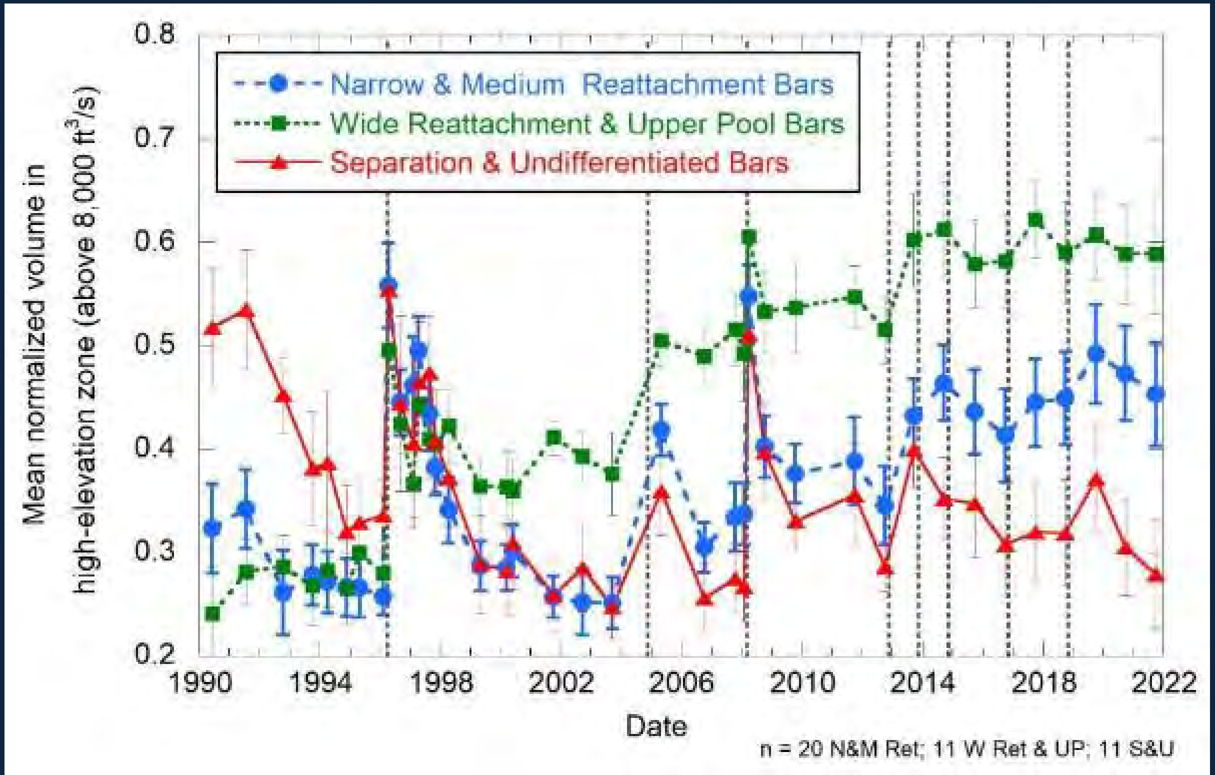
Upper pool deposits



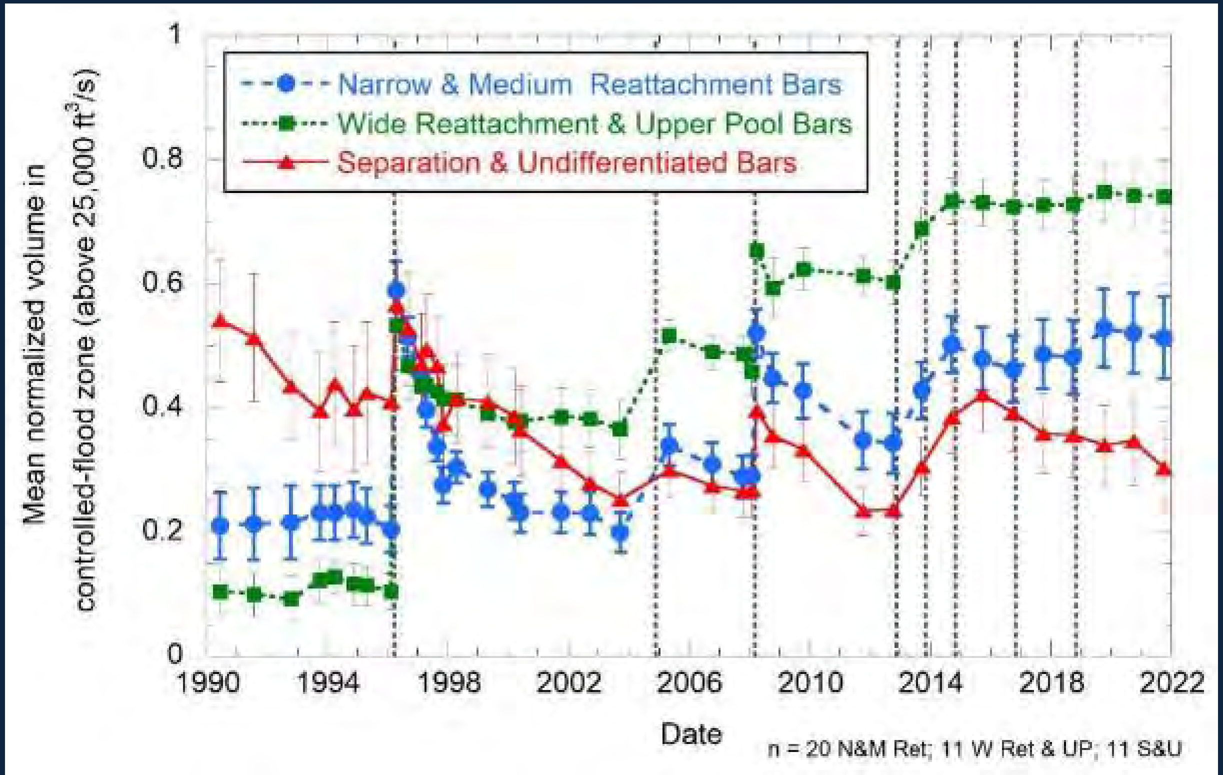
Mueller and others (2018)

Sandbar monitoring results by bar type: 1990 to 2021

Sand above 8,000 ft³/s stage



Sand above 25,000 ft³/s stage (always usable for camping)



Narrow & Medium Reattachment Bars
- Most response to HFEs.
- Moderate vegetation expansion.
- Common campsites.
- Net decrease 2020 to 2021

Separation & Undifferentiated Bars
- Variable response to HFEs.
- Moderate vegetation expansion.
- Common campsites.
- Net decrease 2020 to 2021.

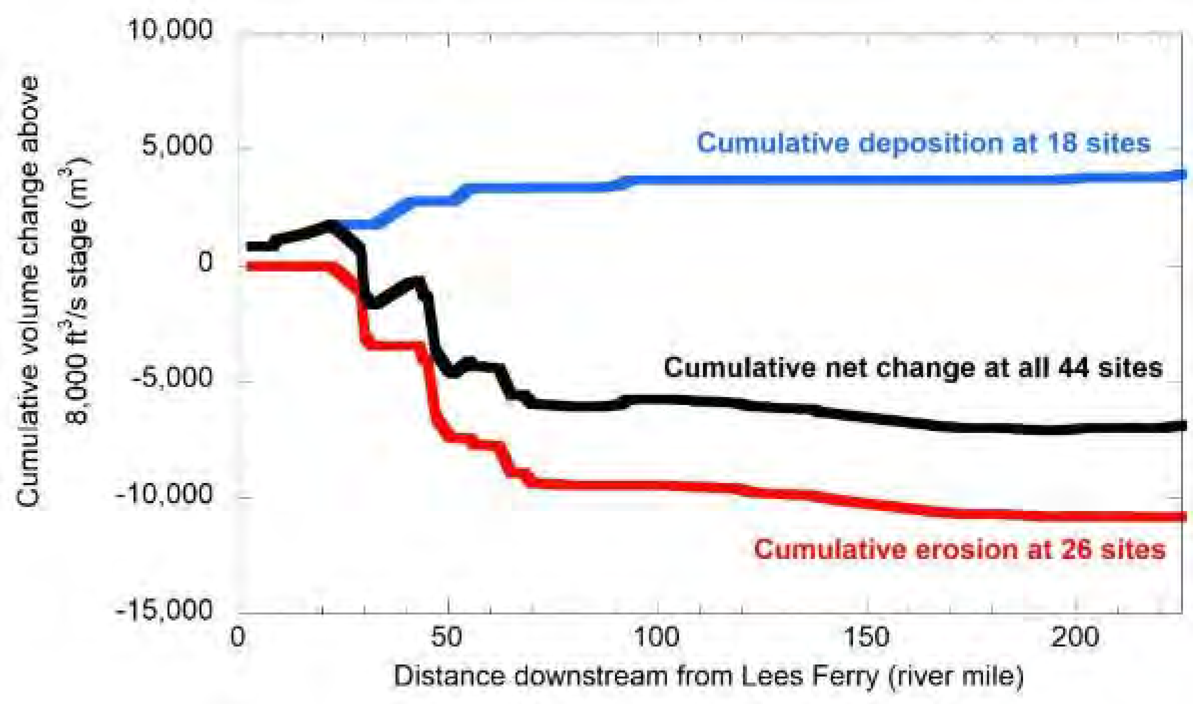
Wide Reattachment & Upper Pool Bars
- Least responsive to HFEs.
- Heavy vegetation expansion.
- Less common campsites.
- No change 2020 to 2021.

All Bar Types
- 2012 to 2019 net increase
- 2020 to 2021 decrease or no change

Preliminary results, subject to review, do not cite

USGS

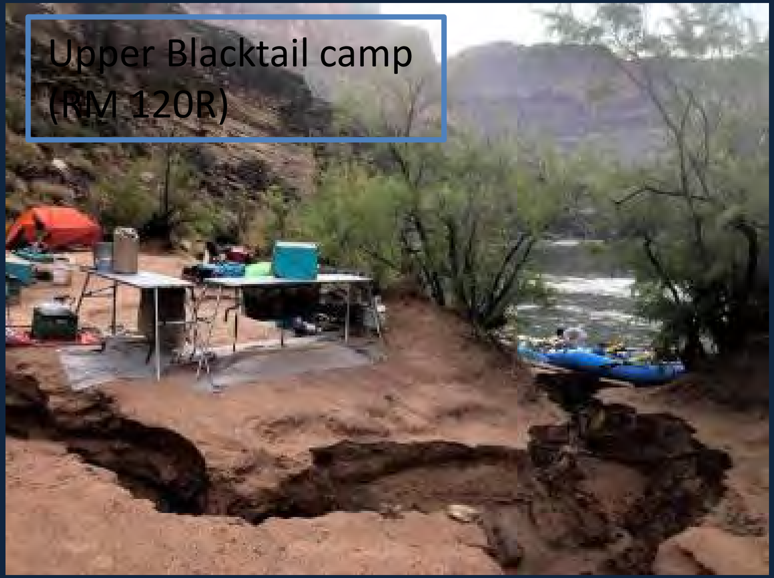
Spatial distribution of changes in Marble and Glen Canyons



Change in sand volume above 8,000 ft^3/s stage between October 2020 and October 2021

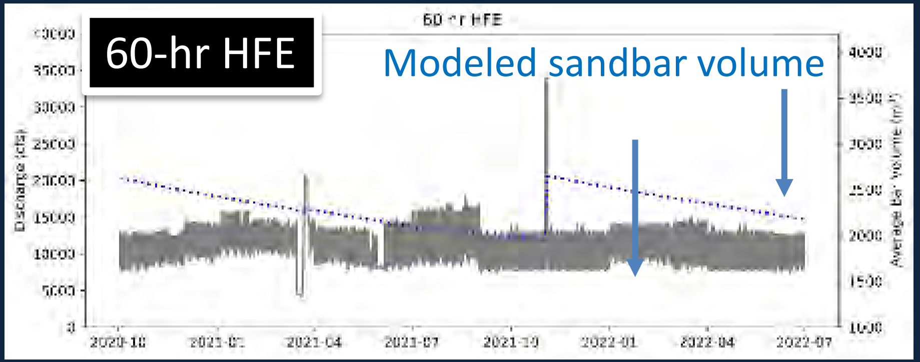
- Deposition in Upper Marble Canyon (RM 0 to RM 30)
- Mostly erosion from RM 30 to RM 70
- Slight net erosion downstream from RM 70

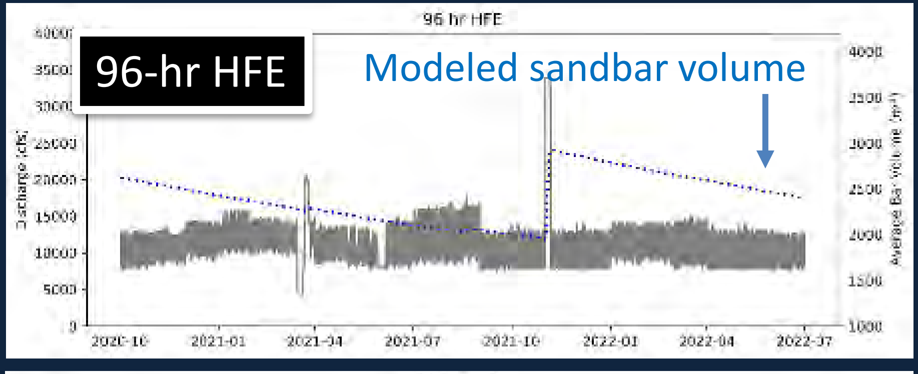
Impacts on campsites caused by summer 2021 monsoon rains

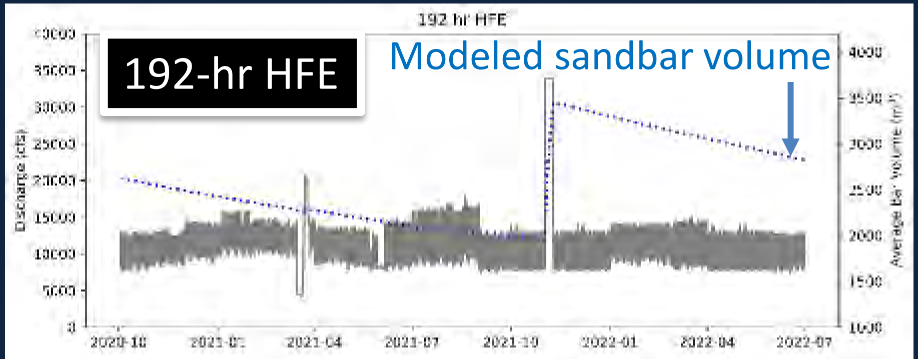


Sandbar model to test HFE scenarios for Fall 2021 following large Paria sand inputs

Paria River summer 2021 sand inputs:
More than 1.3 million metric tons





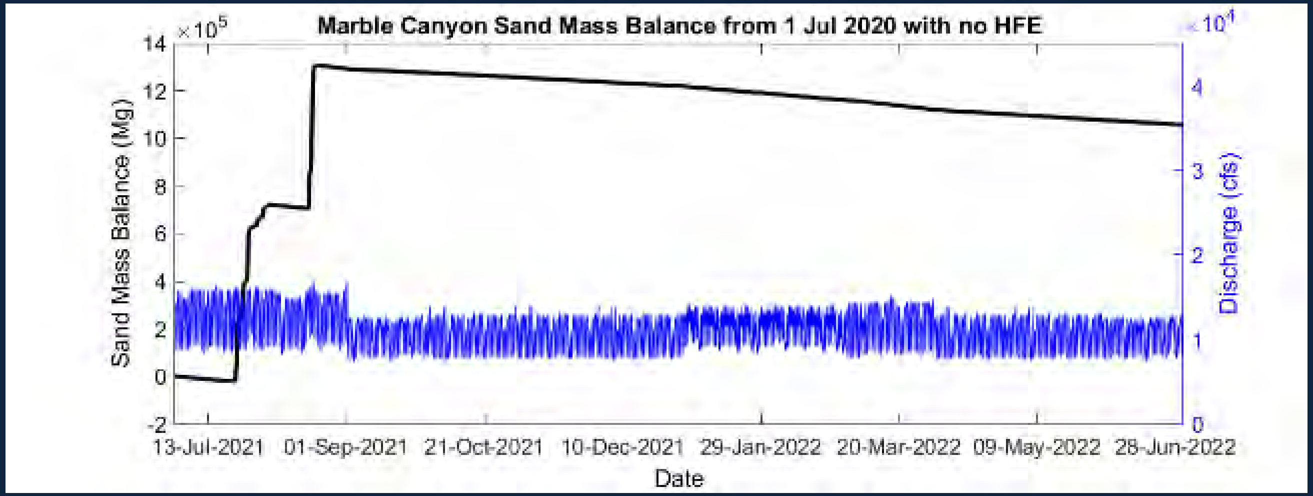


Predicted sandbar volume through summer 2022, beginning with observed size in October 2020.

Preliminary results based on Mueller and Grams (2021) model, subject to review, do not cite

USGS

Large 2021 inputs from Paria River combined with relatively low dam releases → Lots of sand still remains in Mable Canyon

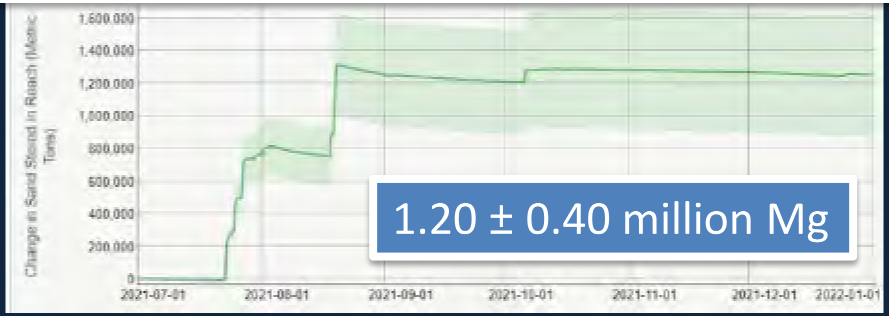


Predicted Mable Canyon (RM 0 to 61) mass balance*

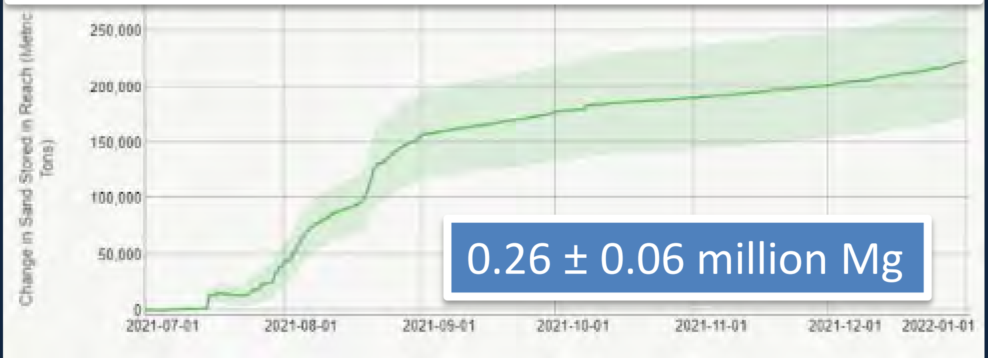
*Includes measured tributary inputs through 8/31/2021, assumes zero additional inputs.

- Modeled predicted Feb. 1 mass balance: **1.2 million Mg**
- Observed Feb. 2 mass balance: **1.5 ± 0.5 million Mg**
- Expect to end sediment year on 6/30/2022 with at least ~1 million Mg positive sand balance in Marble Canyon

Upper Mable Canyon (RM 0 to 30) mass balance: 7/1/21 to 2/1/22



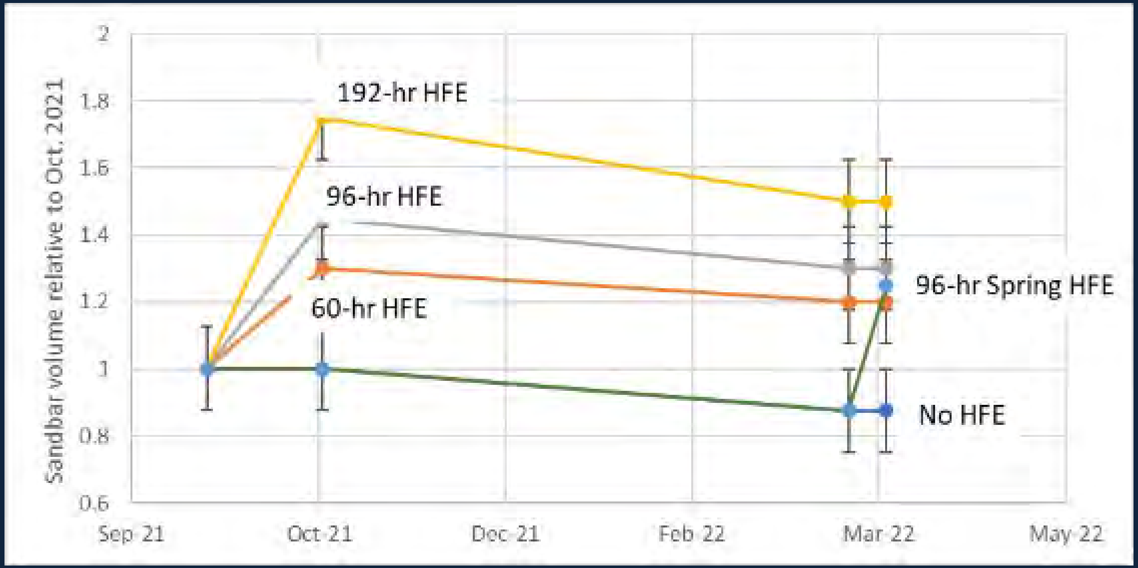
Lower Mable Canyon (RM 30 to 61) mass balance: 7/1/21 to 2/1/22

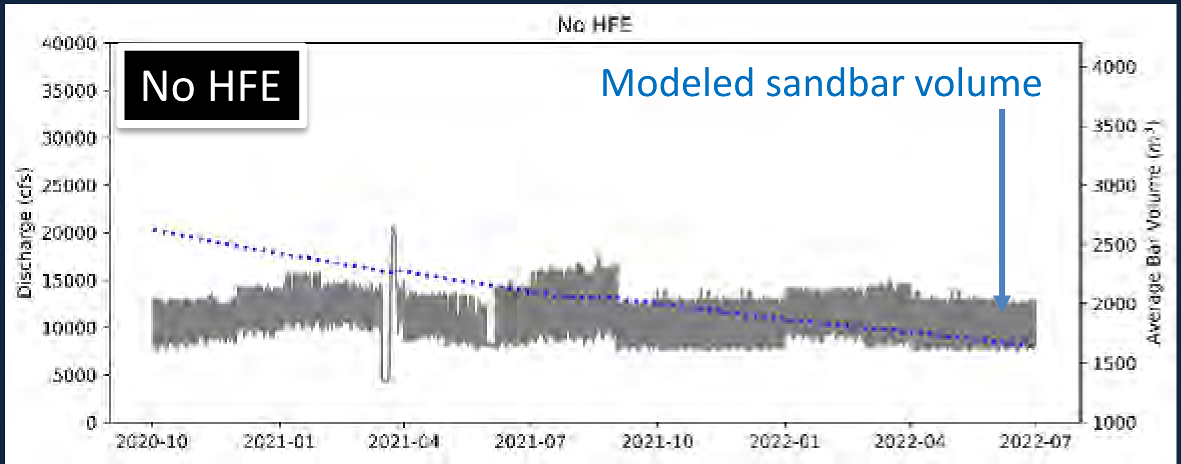


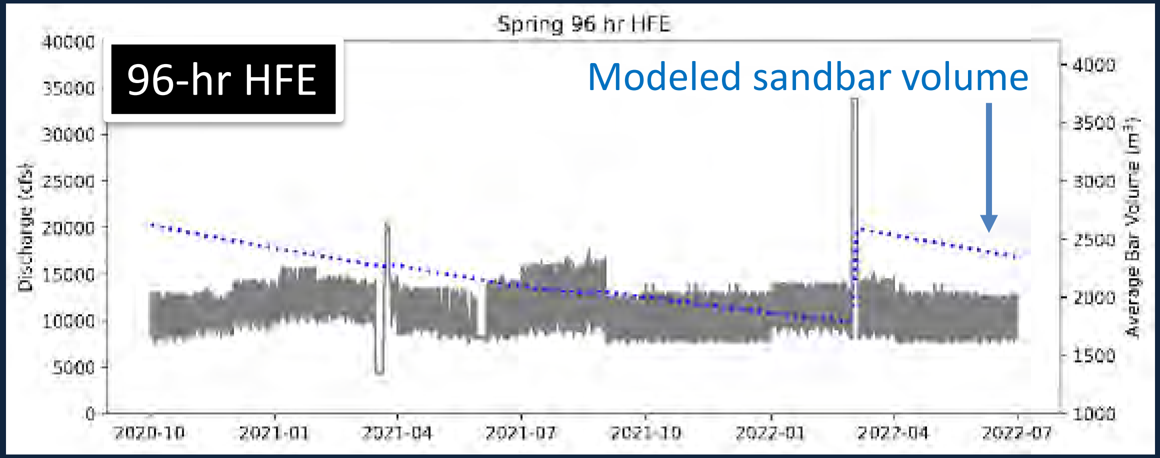
Preliminary results based on Wright and others (2010) model, subject to review, do not cite

USGS

Predicted sandbar volume in April 2022 for: no HFE, Fall HFE, and Spring HFE







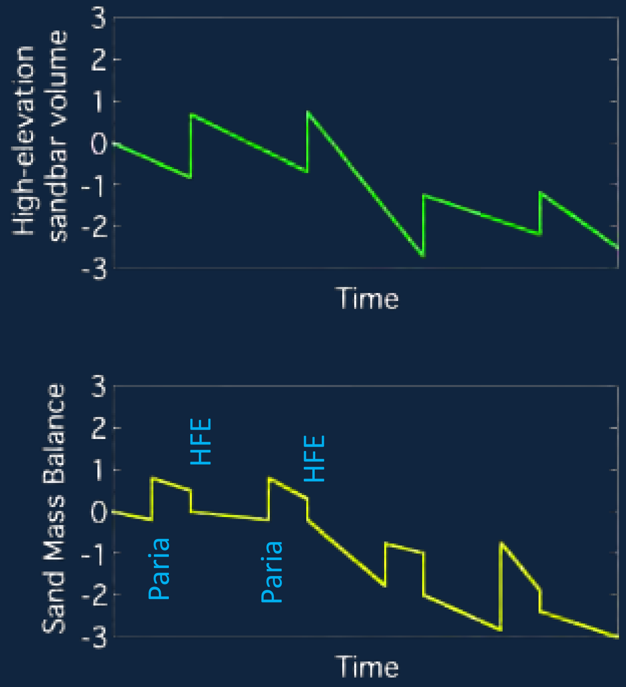
Owing to the combination of large 2021 sand inputs and low dam releases, models indicate a spring HFE would be only slightly less effective than a fall HFE for building sandbars

* Modeling based on sediment inputs through mid-September 2021 and anticipated dam releases

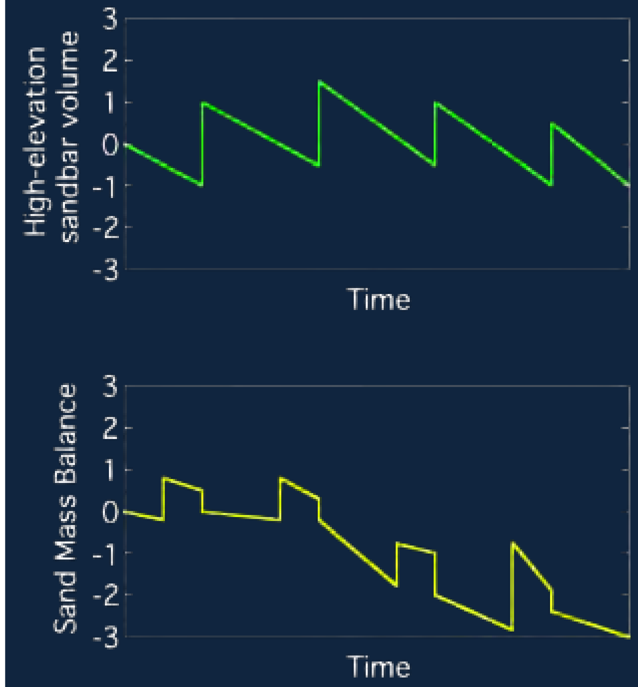
Preliminary results based on Mueller and Grams (2021) model, subject to review, do not cite

Sustainable management of sand under the LTEMP sediment goal requires neutral to positive trends in both the sand mass balance (i.e., the bank account) and the high-elevation sandbar volume (i.e., expenditures) over decades

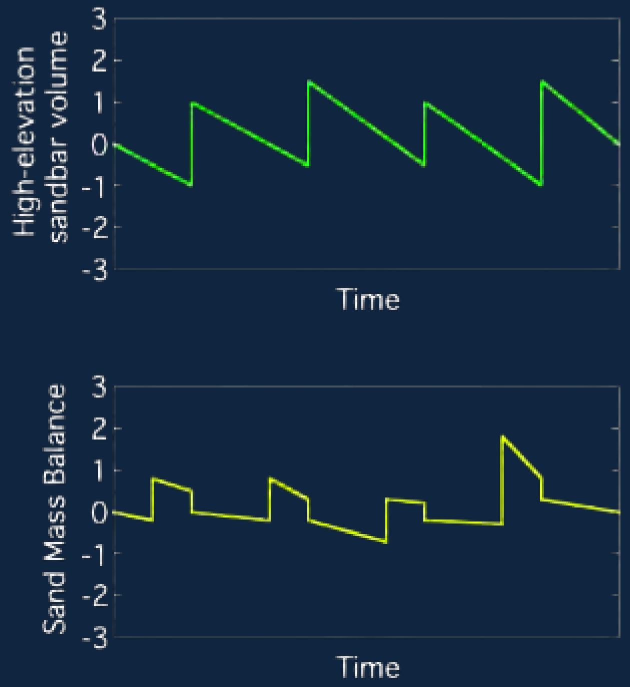
Hypothetical sandbar and sand mass balance scenarios



Not sustainable

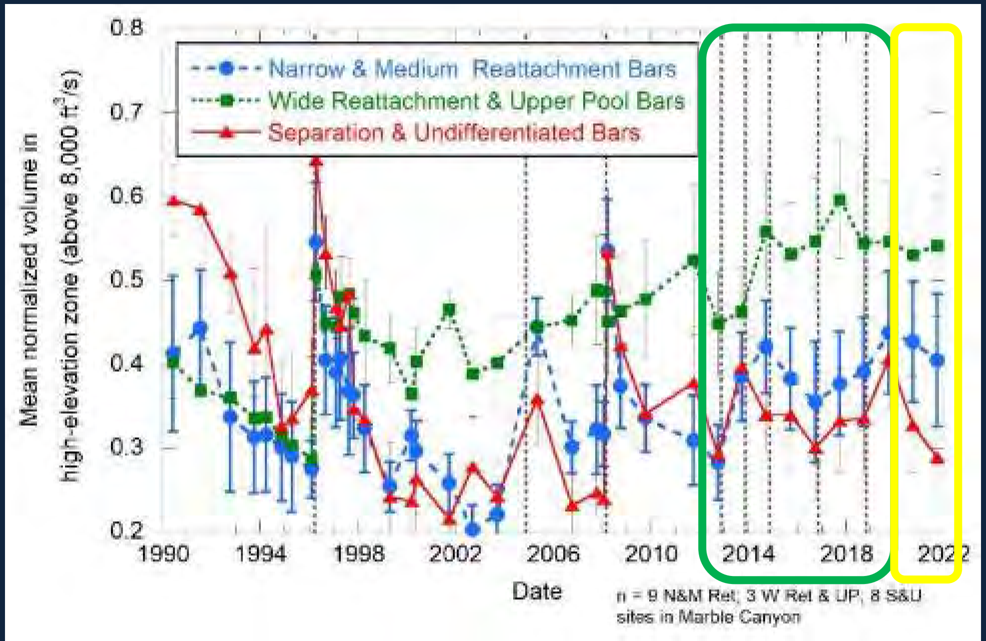


Not ultimately sustainable because sandbar response lags mass balance
"Living on credit"

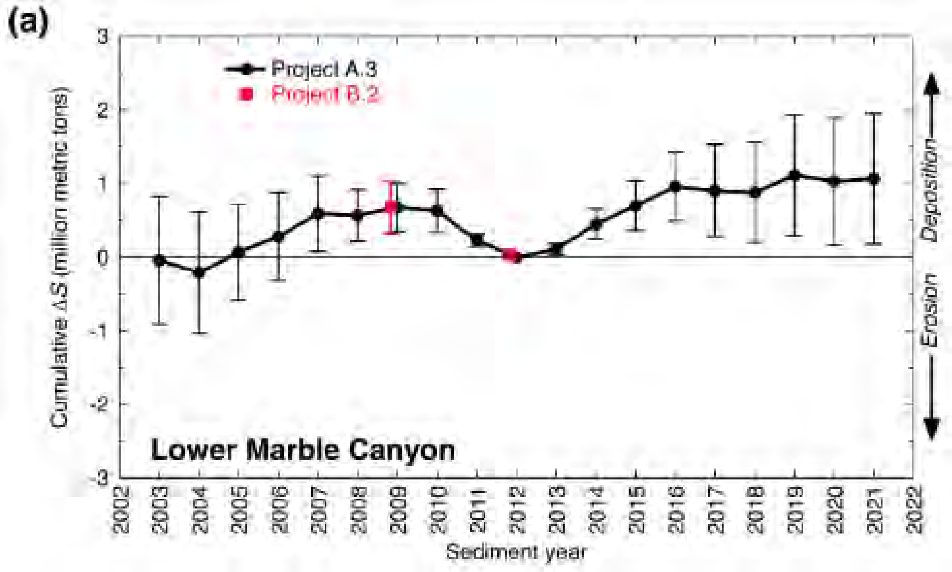


Sustainable
"Living within your means"

Metrics example: High-elevation sand and the sand bank account



Preliminary results, subject to review, do not cite

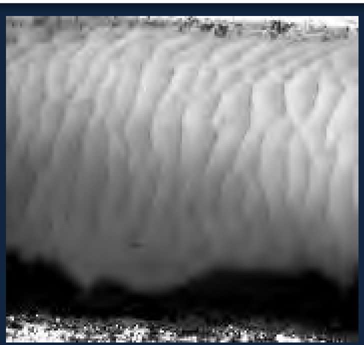


Marble Canyon:

POSSIBLE SUCCESS: 2012 to 2019

Normalized volume increase above 8,000 cfs elevation in most bar types

Increasing/stable low-elevation sand storage in "bank account"

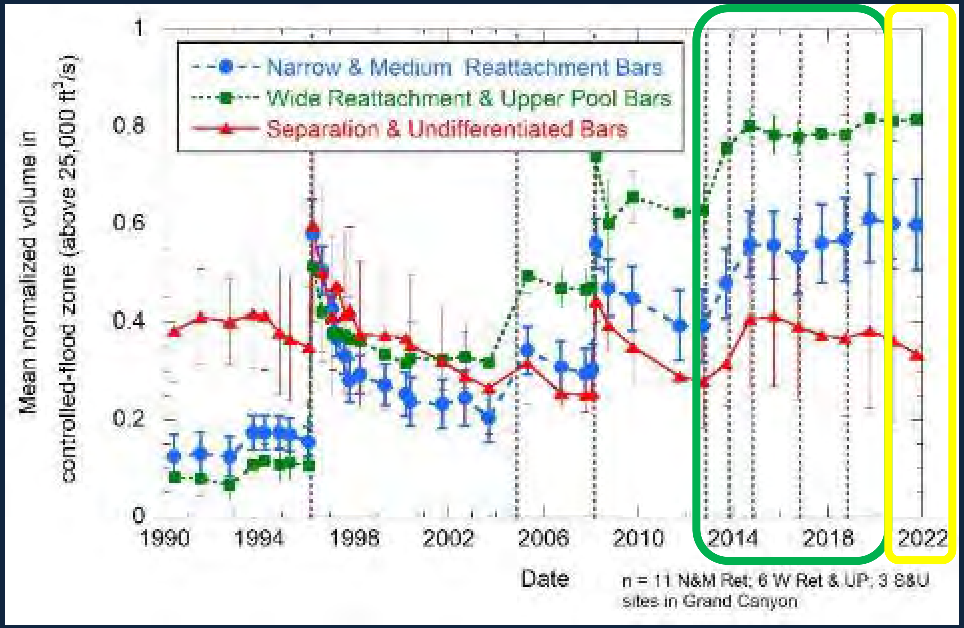


Likely sustainable: Meeting sediment goal for high-elevation sandbars **(if HFEs continue)** and maintaining storage in bank account.

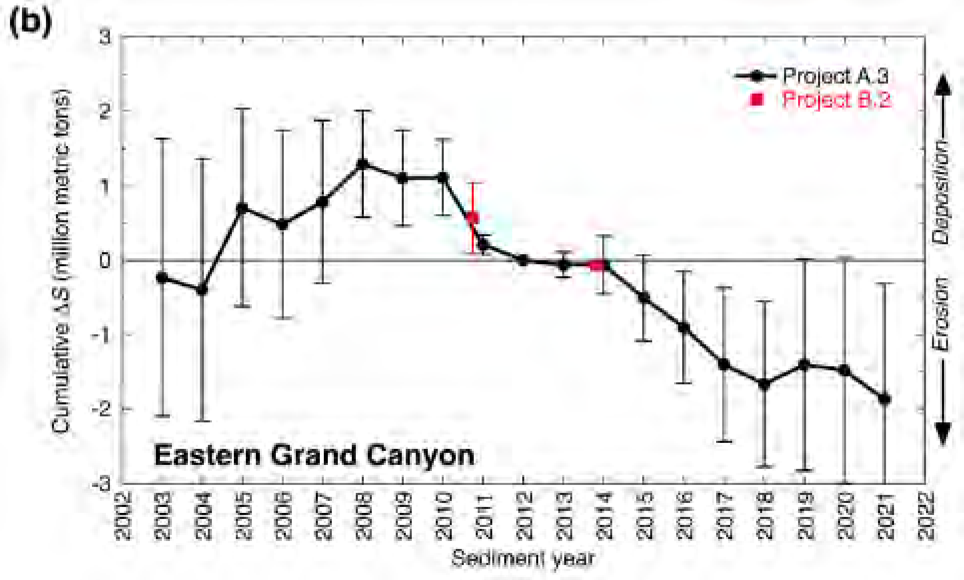
Data from Topping and others, *JGR*, 2021; USGS (2022)

USGS

Metrics example: High-elevation sand and the sand bank account

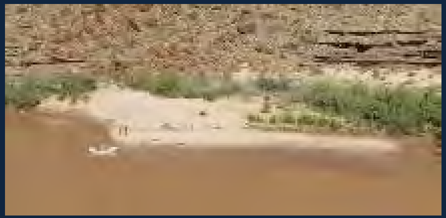


Preliminary results, subject to review, do not cite



Eastern Grand Canyon:
CAUTION: 2012 to 2019

Normalized volume increase above 8,000 cfs elevation in most bar types



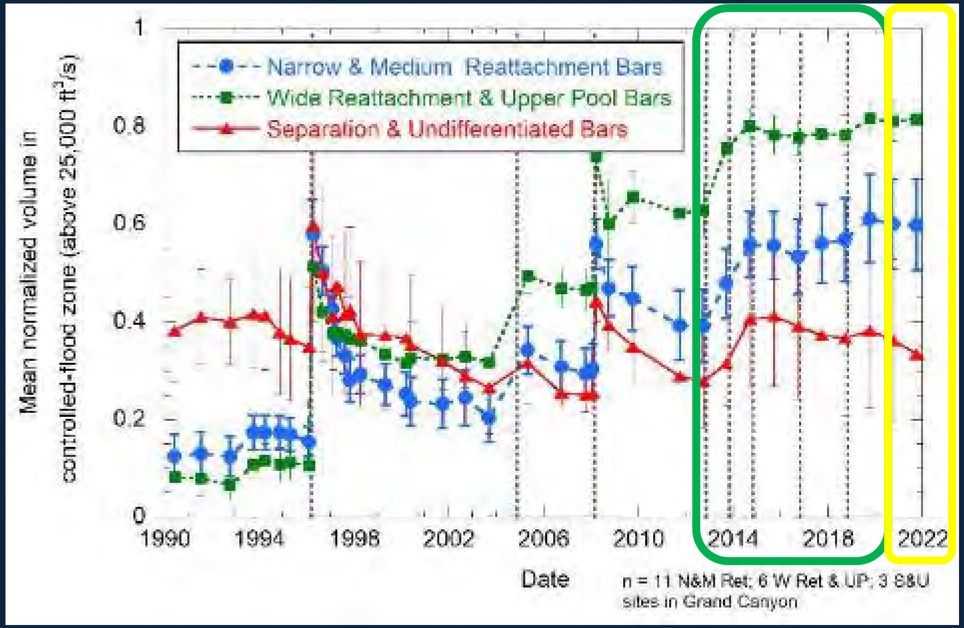
Likely unsustainable: Meeting sediment goal for high-elevation sandbars **(if HFEs continue)** but depleting storage in bank account.

Decreasing low-elevation sand storage in “bank account”

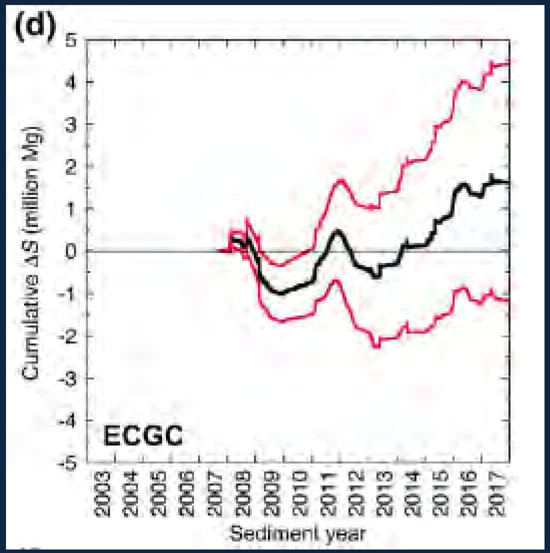
Data from Topping and others, *JGR*, 2021; USGS (2022)

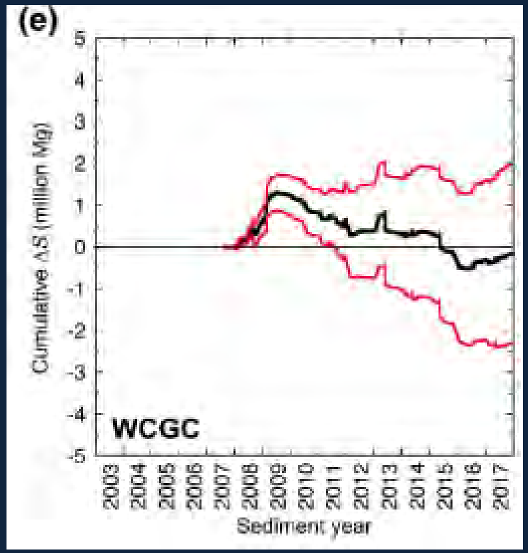
USGS

Metrics example: High-elevation sand and the sand bank account



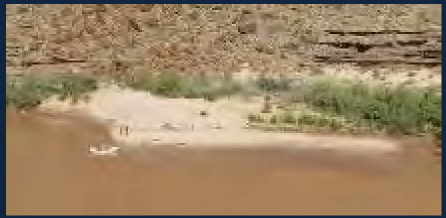
Preliminary results, subject to review, do not cite



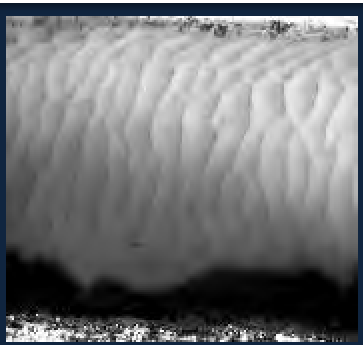


East Central and West Central Grand Canyon:
POSSIBLE SUCCESS: 2012 to 2019

Normalized volume increase above 8,000 cfs elevation in most bar types



Increasing/stable low-elevation sand storage in "bank account"



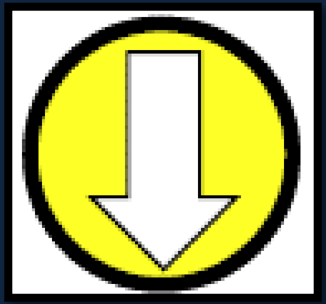
Likely sustainable: Meeting sediment goal for high-elevation sandbars **(if HFEs continue)** and maintaining storage in bank account.

Data from Topping and others, *JGR*, 2021; USGS (2022)

USGS

Projects A and 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 for sanbars are not defined, each HFE has resulted in deposition demonstrating that the general objective of retaining and/or increasing sand volume above the 8000 cfs stage can be achieved when sand inputs occur and HFEs are implemented (2012-2020).
- Prognosis:
  - Deposition at sandbars is likely stage-limited (bars not likely to get larger without larger HFEs)
  - Sandbar volume increased and maintained from 2011 to 2018 when dam releases were relatively low and sand inputs from Paria River average or above and HFEs were implemented.
  - Since 2019, sandbar volume has decreased for most bar types because monsoon failure (2019, 2020) and low reservoir levels (2021) prevented HFE implementation for 3 consecutive years.
  - Since 2012, sand storage has increased or been stable within uncertainty in all segments except Eastern Grand Canyon



Status: moderate concern because sandbars are decreasing, but still larger than before start of HFE protocol and sediment supply is good

Trend: decreasing because bars have eroded since last HFE in 2018

Confidence: high, because the monitoring is robust.

USGS

References

- Hazel, J. E., Kaplinski, M., Hamill, D., Buscombe, D., Mueller, E.R., Ross, R.P., Kohl, K., and Grams, P.E., ***in press***, Multi-Decadal Sandbar Response to Flow Management Downstream from a Large Dam: the Colorado River in Marble and Grand Canyons, Arizona. U. S. Geol. Surv. Prof. Paper xxxx.
- Mueller, E.R., Grams, P.E., Hazel, J.E., 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, doi:10.1016/j.sedgeo.2017.11.007.
- Mueller, E.R., and Grams, P.E., 2021, A morphodynamic model to evaluate long-term sandbar rebuilding using controlled floods in the Grand Canyon: Geophysical Research Letters, v. 48, no. 9, e2021GL093007, https://doi.org/10.1029/2021GL093007.
- Topping, D.J., Grams, P.E., Griffiths, R.E., Dean, D.J., Wright, S.A., and Unema, J.A., 2021, Self-limitation of sand storage in a bedrock-canyon river arising from the interaction of flow and grain size: Journal of Geophysical Research: Earth Surface, v. 126, e2020JF005565. https://doi.org/10.1029/2020JF005565
- Wright, S.A., Topping, D.J., Rubin, D.M., and Melis, T.S., 2010, An approach for modeling sediment budgets in supply-limited rivers: Water Resources Research, v. 46, p. 1–18, doi:10.1029/2009WR008600.

USGS