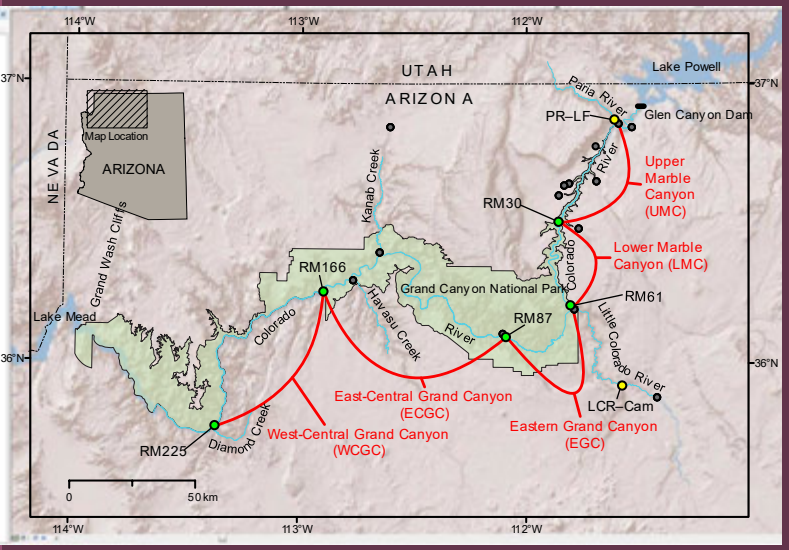
Sand supply, transport, and deposition

David Topping, Paul Grams, and Joel Sankey

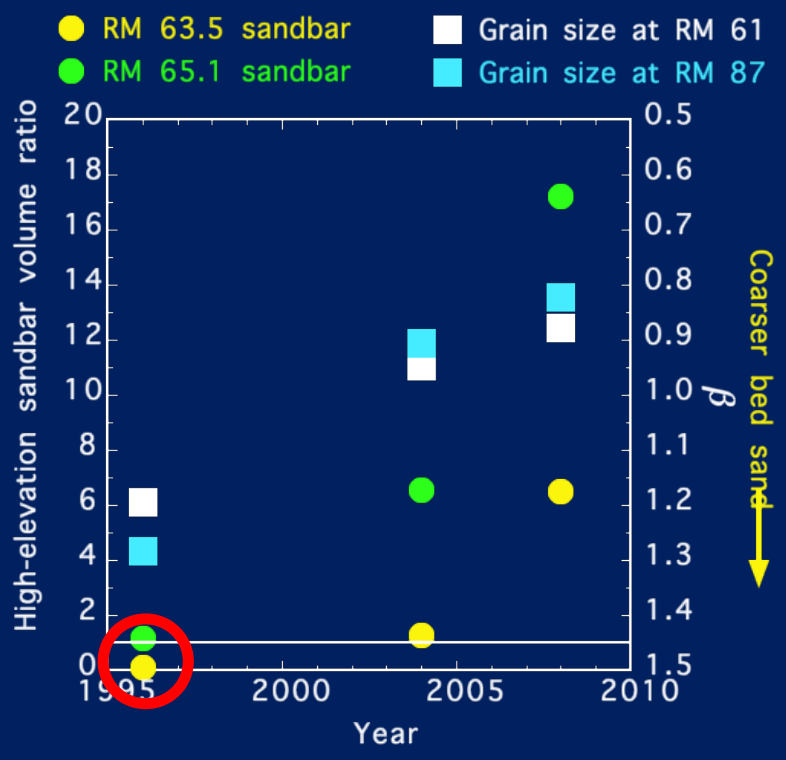


Paria River is by far the dominant modern supplier of sand (Topping and others, *JGR*, 2021),
but a large percentage (~30-50%) of the sand stored in sandbars is relict "pre-dam" sand (Chapman and others, *GSA Bulletin*, 2020)

USGS science for a changing world

Two conditions must be met to enlarge high- elevation sandbars

1) High stage
2) Large amount of relatively fine sand on the bed

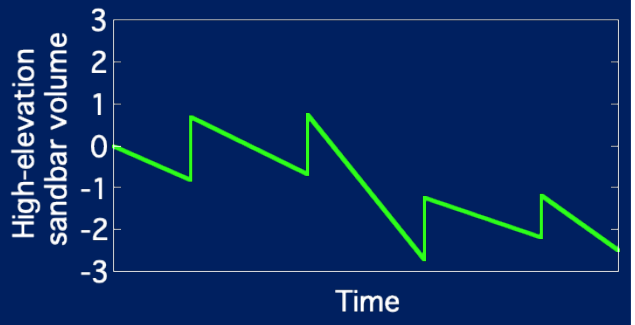


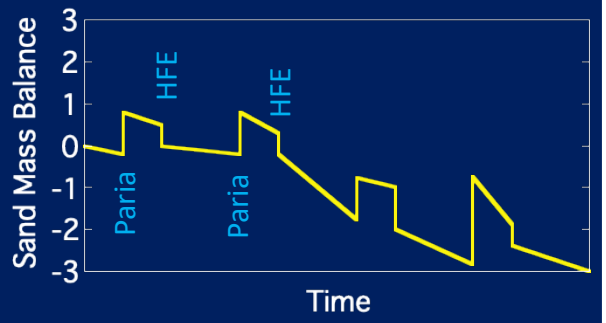
Post-HFE volume only 10% of pre-HFE volume when bed-sand was coarse during 1996 HFE

Figure from Topping and others (2019)

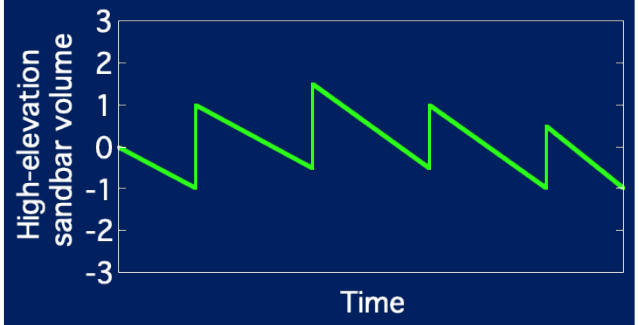
USGS
science for a changing world

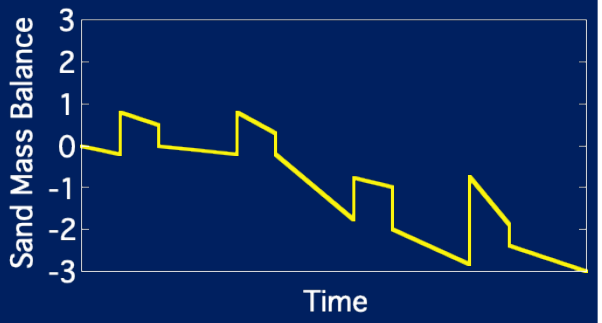
Sustainable management of sand under the LTEMP sediment goal requires neutral to positive trends in both the sand mass balance (i.e., the bank account) and the high-elevation sandbar volume (i.e., your expenditures) over decades



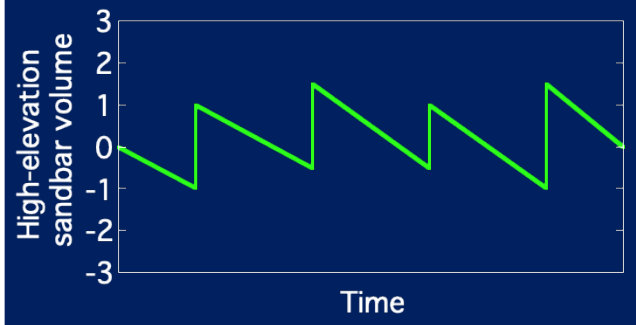


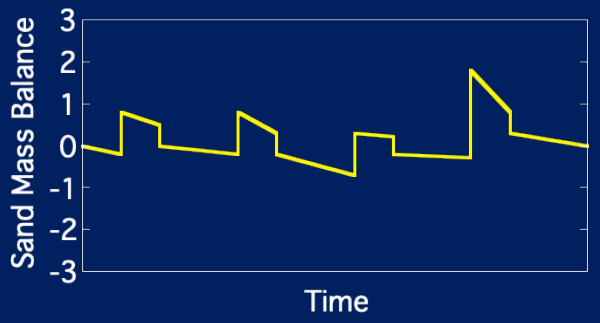
Not sustainable





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



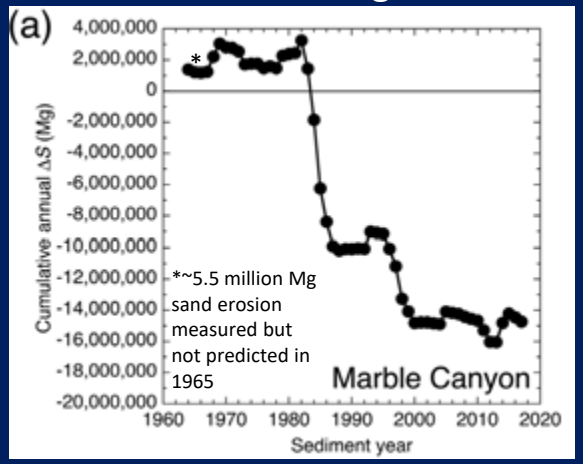


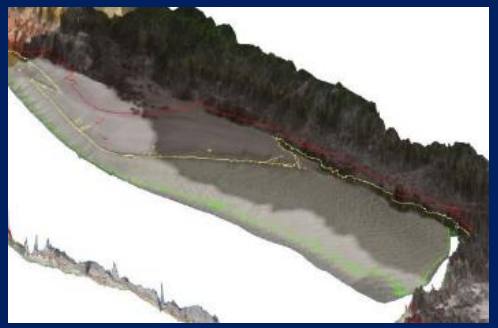
Sustainable
"Living within your means"

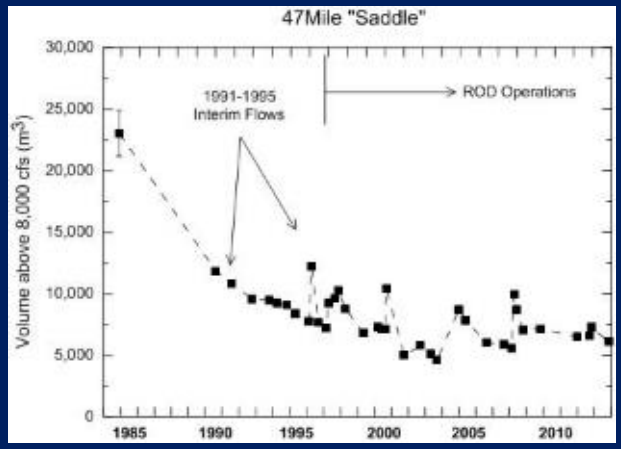
USGS
science for a changing world

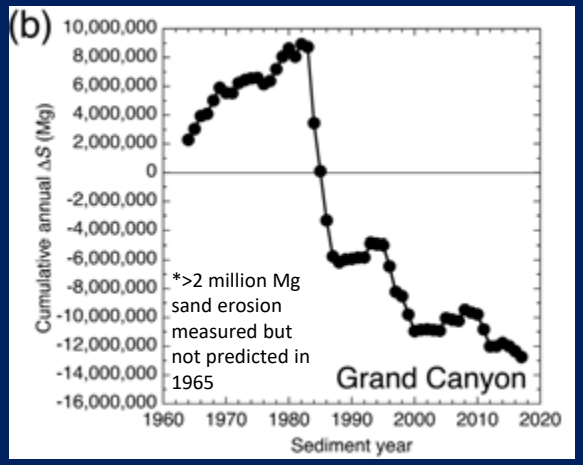
Downward spiral has likely occurred in long-term sand mass balance… and reflected in the high-elevation volume of many sandbars

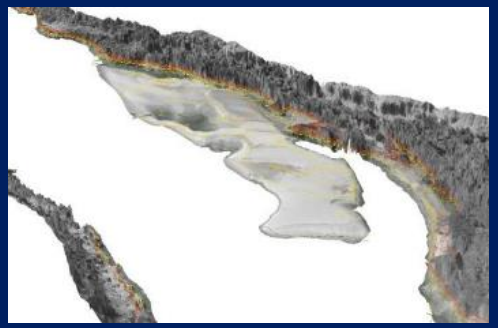
- Multi-year sand accumulation only occurs in Marble Canyon when the Paria sand supply is ≥124% of the 20-year average and only occurs in Grand Canyon when the Paria+LCR sand supply is ≥136% of the 20-year average
- Multi-year sand accumulation only occurs when dam releases ≤ post-1963 average
- >28 million metric tons of sand eroded since 1963, mostly during 3-4 periods of sustained high dam releases

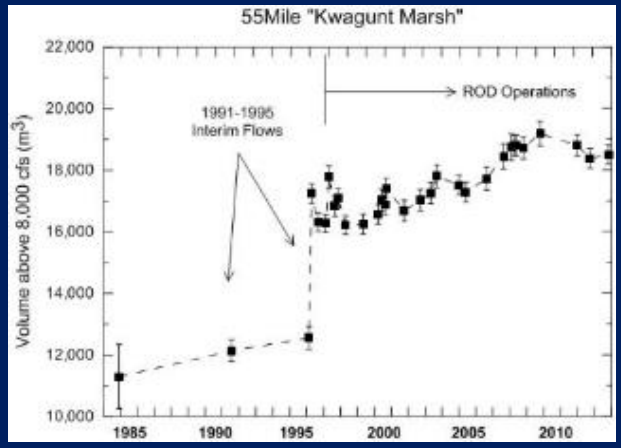












Figures from Topping and others (*JGR*, 2021)

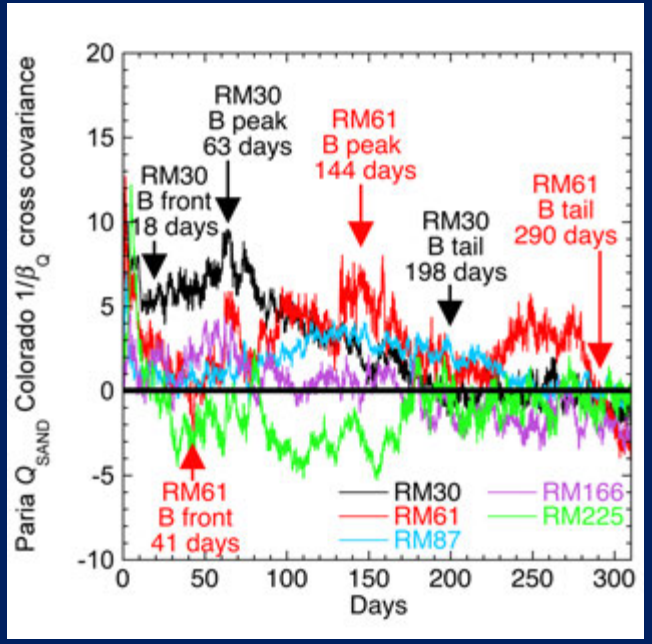
Preliminary figures from Grams, Gushue, Hazel (do not cite)

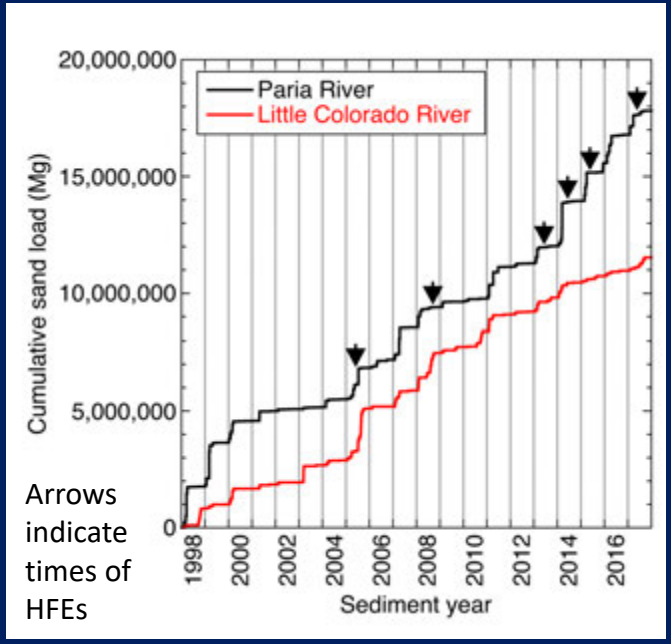
Tributary-supplied sand migrates downstream quickly in waves

- Tributary floods generate sand waves with fronts that migrate to Lake Mead within a week (~7% of Paria River sand and ~27% of LCR sand is never retained in CRe)

- Maximum bed–sand fining in these waves persists in UMC for <63 days and in LMC for <144 days after large Paria River floods (finest bed sand leads to highest HFE sandbar-deposition rates; this result thus constrains optimal HFE timing)

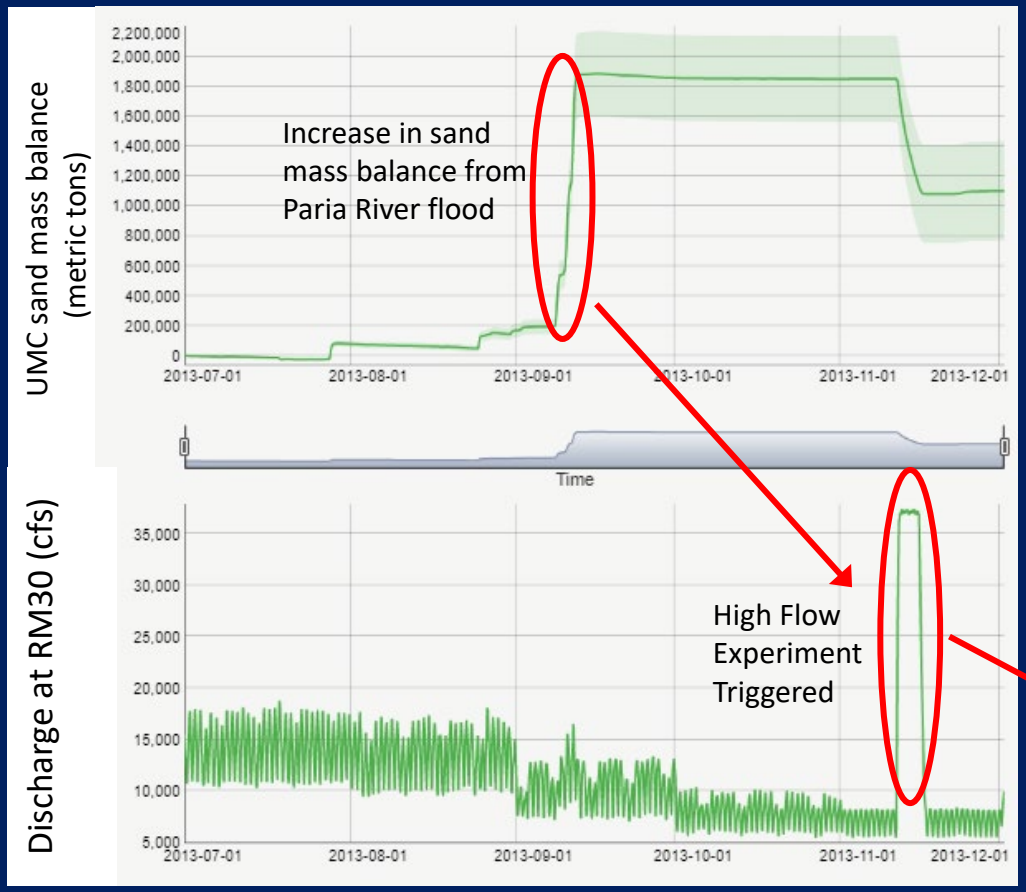
- Since the beginning of the HFE protocol in 2012, the Paria River sand supply has been 113% of its 20-year average and dam releases have been 88% of the post-1963 average

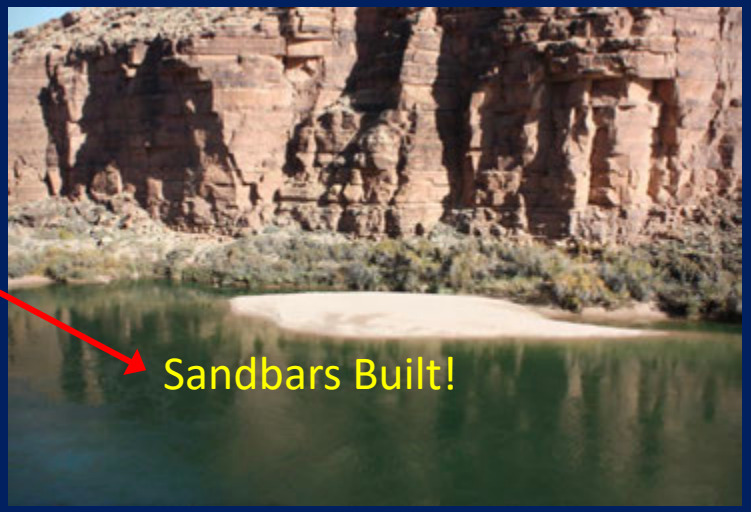




Figures from Topping and others (*JGR*, 2021)

High Flow Experiment (HFE) protocol





Data and figures from: https://www.gcmrc.gov/discharge_qw_sediment/

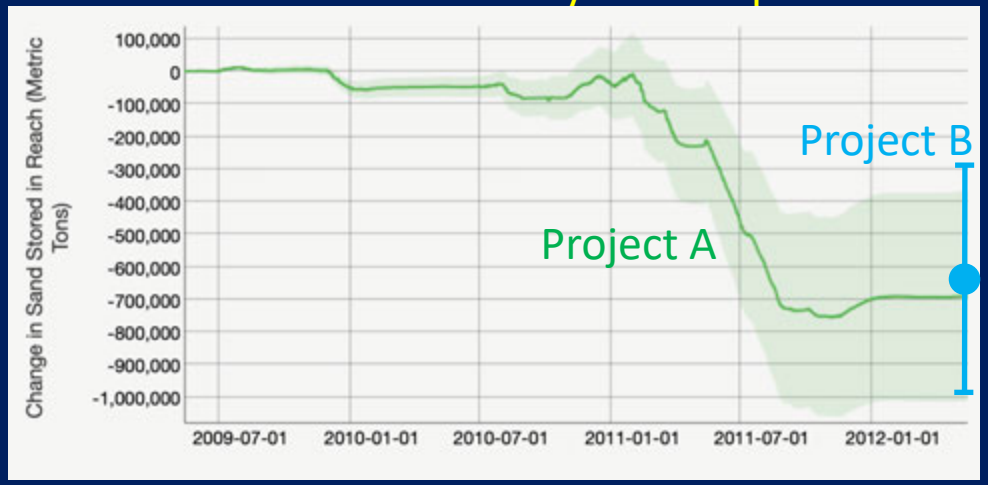
USGS science for a changing world

Evaluation of management success

- Monitor annual integrated effects of all dam releases on high-elevation sandbars through project B

- Monitor sand mass balance over different timescales through project A (15 minutes to <decade) and project B (multiple years to >decades)

Lower Marble Canyon example



Similar favorable comparisons found between Project's A and B results for Upper Marble Canyon and Eastern Grand Canyon during different periods

Results from Grams and others (*ESPL*, 2019) and Topping and others (*JGR*, 2021)

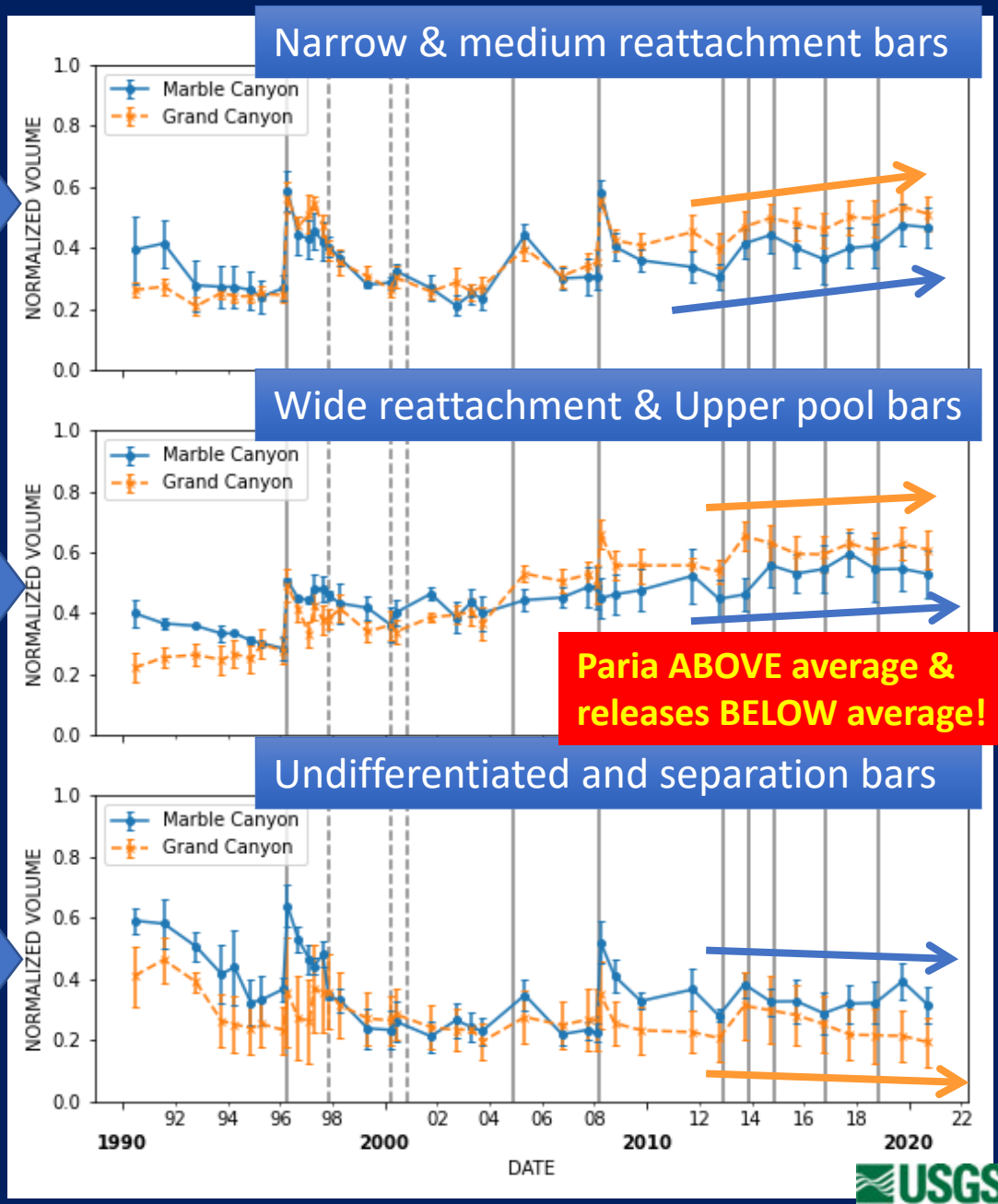
USGS science for a changing world

High-elevation sandbar changes: 1990 to 2020

Average increase in sand volume for reattachment bars and upper pool bars

Trends in Marble Canyon and Grand Canyon are similar for each bar type

Decrease in sand volume for separation and undifferentiated bar types



Paul Grams preliminary data, do not cite

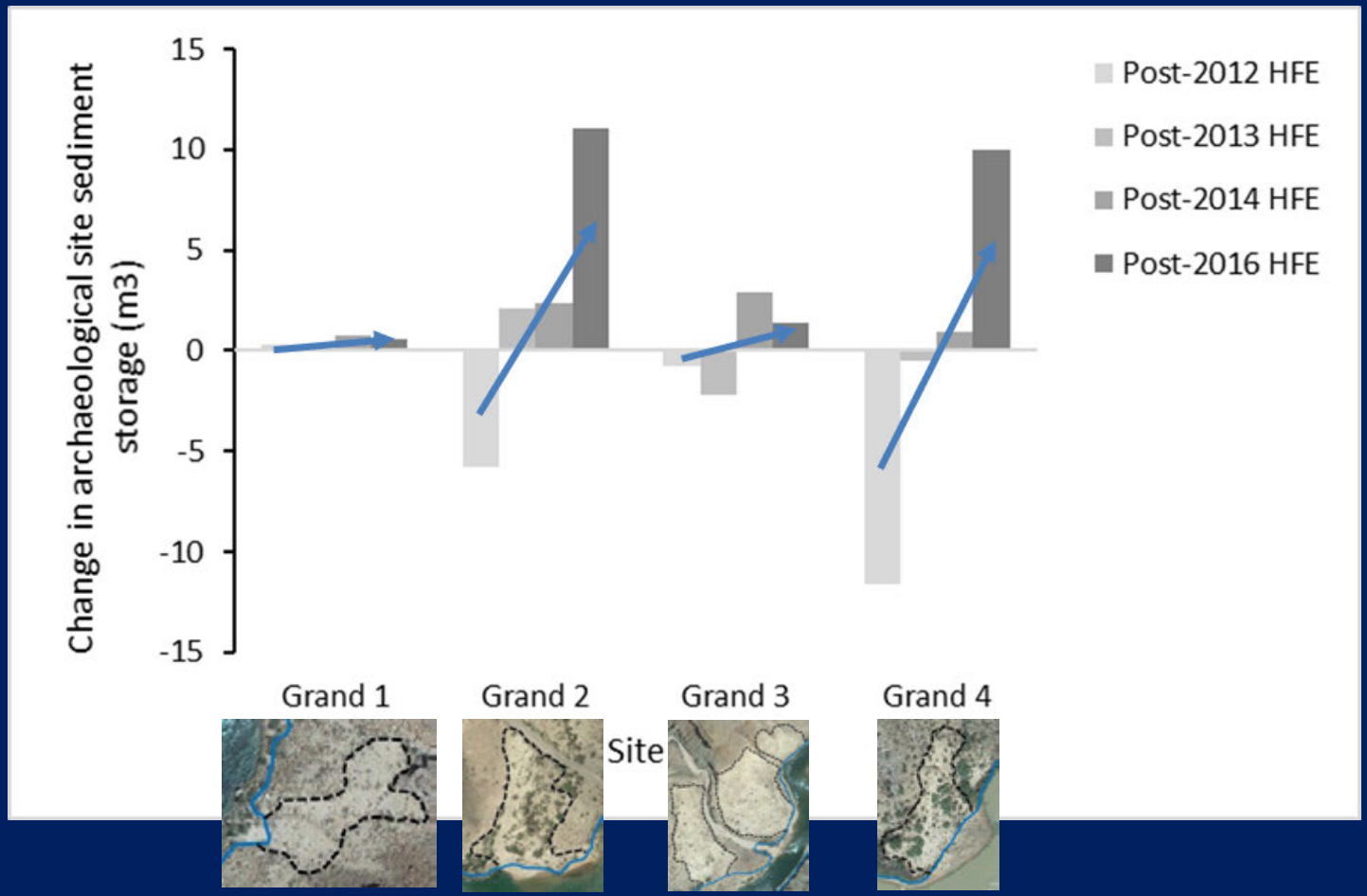
USGS science for a changing world

There are 2 requirements for the wind to transport sand to the much-higher-elevation locations of archeological sites

1) Increased supply of upwind bare sand…
   - by HFE high-elevation sandbar deposition (Sankey et al., 2018)
   - by lowering dam releases (Kasprak et al., 2021)

2) Minimal vegetation blocking the wind transport of sand (ongoing NPS/GCMRC vegetation-management experiments)

Archaeological-site dunefield response to HFEs: Consecutive annual HFEs lead to cumulative increases in sediment storage



Sankey and others (*Aeolian Research*, 2018)
Caster and others (*USGS Open-File Report*, in press)

Conclusions

- Whether the sand resources of the Colorado River in Grand Canyon National Park can be sustainably managed in perpetuity remains an open question
  - May require above-average tributary sand supply and below-average dam releases
  - A large part of the sand mass balance "bank account" is relict pre-dam sand
  - LCR sand supply has/is declining, making sand-management more difficult

- HFE protocol is "working" under above average Paria River sand supply and below average dam releases, with cumulative gains in sandbar volume from consecutive annual HFEs

- Sand volume in the aeolian dunefields covering archeological sites has increased in response to consecutive annual HFEs

- Maintaining a level of sand storage sufficient for maintaining sandbars may require timing periods of higher and lower dam releases based on the tributary sand-supply conditions…how should equalization occur?

USGS
science for a changing world