Evaluation of LTEMP sand management

Increase and retain fine sediment [sand, silt, and clay] 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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Learning following the 1996 controlled flood (the first HFE)

- This HFE was not timed to follow tributary sand inputs; tributary sand supply was low, and dam releases were relatively high during the year before this experiment

- Sand supply more limited than thought in 1995 EIS

- Low-elevation parts of eddies scoured more in Marble Canyon than in Grand Canyon during HFE (Hazel and others, 1999; Schmidt, 1999)

- Post-facto analyses of all available sediment-transport data found that tributary sand did not accumulate over years in the Colorado River at moderate and higher dam releases (Topping and others, 2000a, b)

- To not "mine" background sand, HFEs recommended to be tested following large Paria River sand inputs (Rubin and others, 2002)

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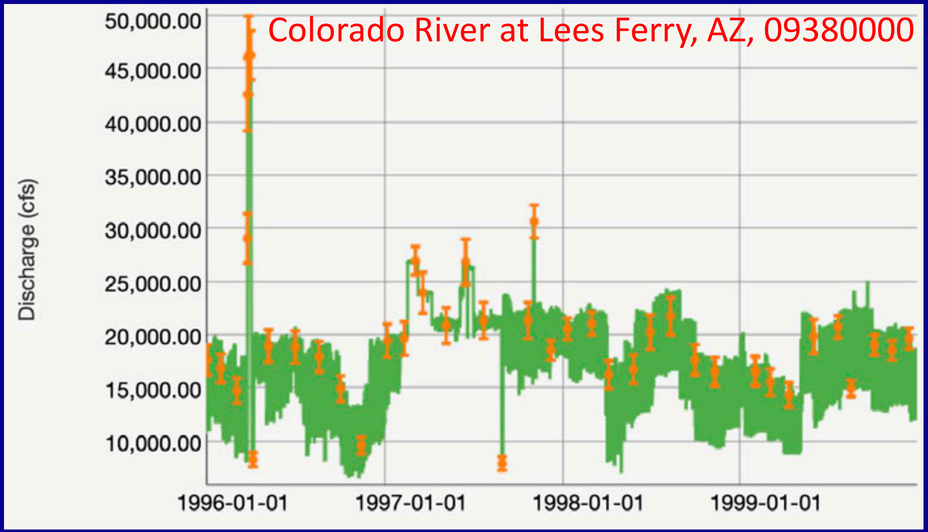
Much sand was scoured during equalization and upper-balancing-tier flows in the late 1990s and has not been fully replaced

- ~12 million metric tons of sand were eroded during the late 1990s (~6 from Marble Canyon and ~6 from Grand Canyon), Topping and others (2021)
- 1997 included the second longest period of sustained high flow since gaging began in May 1921 (200.7 days > 18,500 cfs); 1984 was the longest, Topping and others (2003)
- This scour manifest as major decrease in channel bed-sand area between 1996 and 2004 HFEs (Topping and others, 2010) and reflected in sandbar surveys



Data from USGS (2026a)

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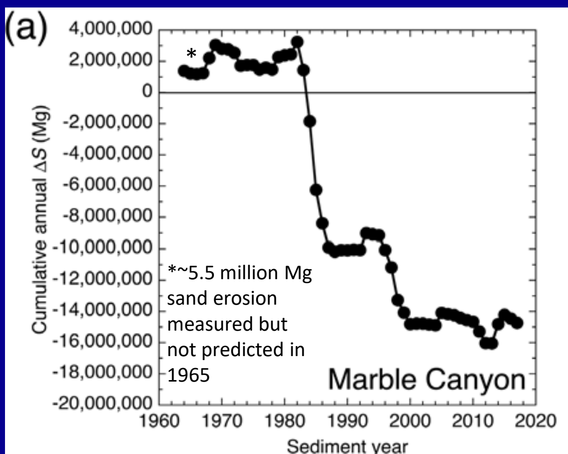
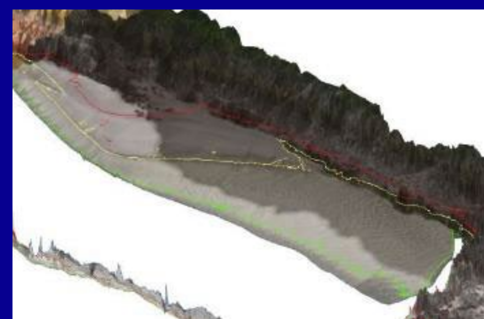
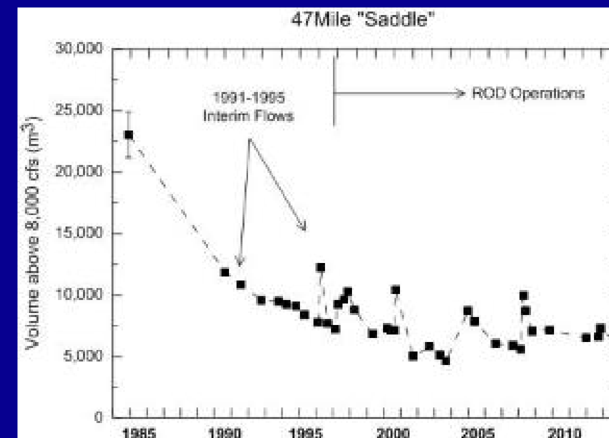
Downward spiral has likely occurred in long-term sand mass balance… and reflected in at least some of the sandbars

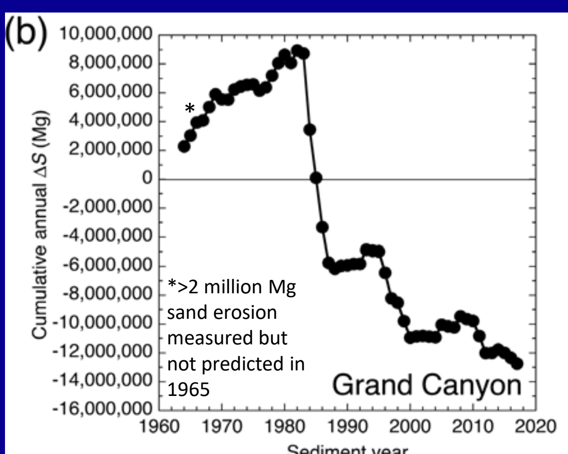
>28 million metric tons of sand eroded since 1963, mostly during 3–4 periods of high dam releases (Topping and others, *JGR*, 2021)

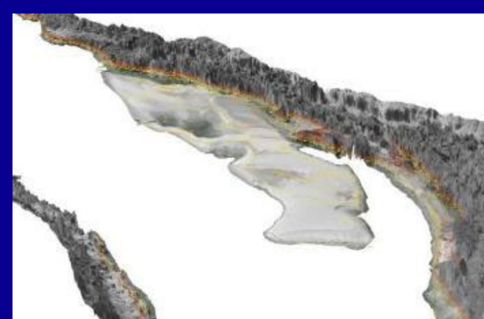
~12 million metric tons eroded in late 1990s alone (6 from Marble and 6 from Grand)

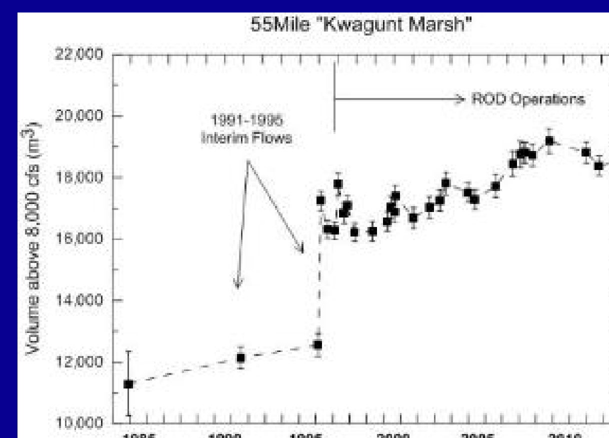












Figures from Topping and others (*JGR*, 2021)

Draft figures from Gushue, Weber, Grams, Hazel (do not cite)

2004 HFE learning

- Results suggested repeated fall HFEs after large Paria River sand inputs could be used to rebuild sandbars

- More sand would be required than is typically available to "restore" all sandbars during a single HFE…
  test cumulative effects over multiple HFEs (Topping and others, 2006; Wright and others, *GSA Today*, 2008; Grams and others, *EOS*, 2015)

- *"More sand* could be achieved directly by augmentation from sand trapped in the reservoir impounded by Glen Canyon Dam or perhaps indirectly by following each large tributary input of sand with short-duration controlled floods. Frequent short-duration controlled floods under sand-enriched conditions could result in the downstream propagation of the gains in total eddy-sandbar area and volume observed in the upstream half of Marble Canyon during the 2004 controlled-flood experiment." (Topping and others, 2006)

Two views of the South Canyon sandbar…
one of the biggest 2004 winners

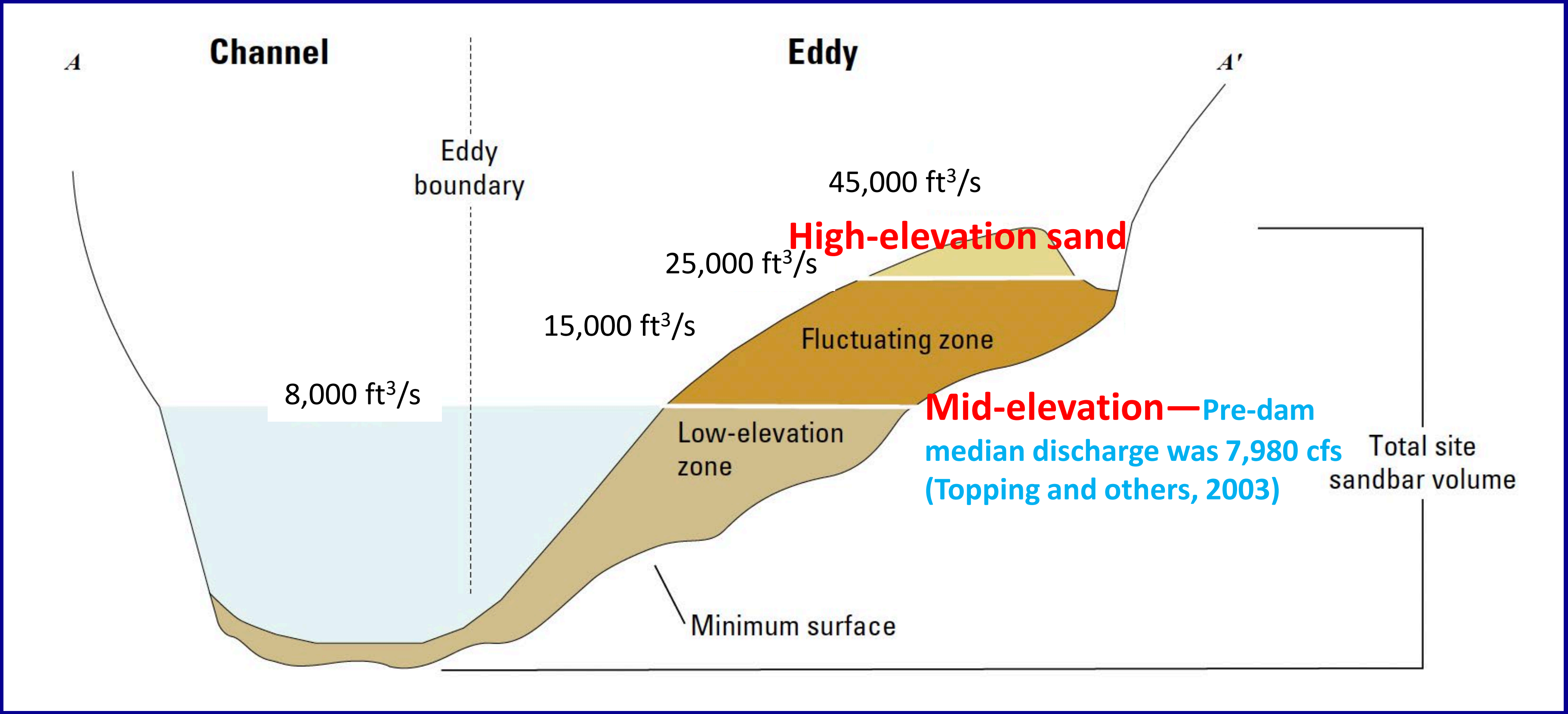
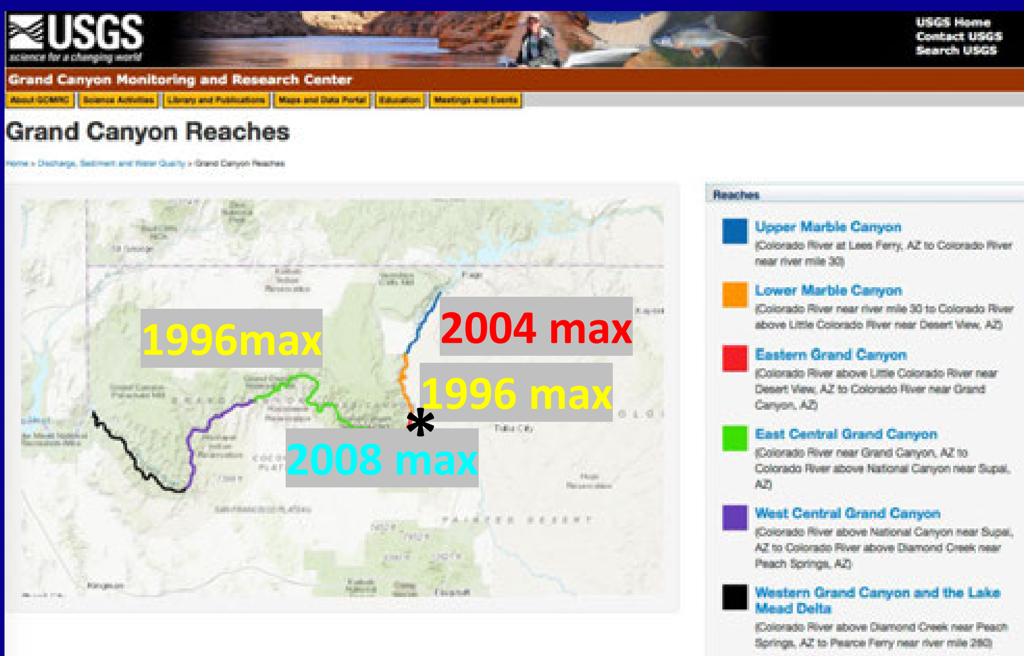


Figure modified from Hazel and others (*USGS-PP*, 2022)

- ~30–50% of the sand stored in sandbars is relict "pre-dam" sand (Chapman and others, *GSA Bulletin*, 2020)
- Stratigraphic and ground-penetrating-radar data indicate pre-dam sand at depth in at least some sandbars (Barnhardt and others, *USGS-OFR*, 2001)

1996–2008 HFE summary

Efficiency of sandbar deposition during HFEs depends on segment-level sand enrichment either from recent tributary sand inputs (as in 2004 and 2008) or from greater background storage, i.e., mining the sand bank account (as in 1996) (Grams an others; 2013; Topping and others, 2006, 2010, 2019; Schmidt and Grams, 2011)



By-segment HFEs with maximum above-mid-elevation sandbar volume ratio

- RM 1–35 **2004**
- RM 43–55 **1996**
- RM 63–104 **2008**
- RM 119–225 **1996**

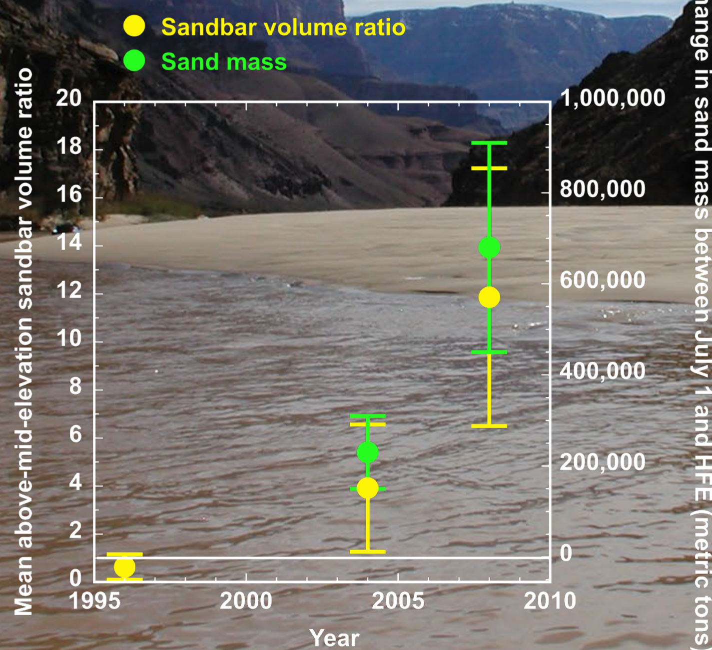
*LCR supplied ~3.7 million tons of sand before 2008 HFE

Data from USGS (2026b)

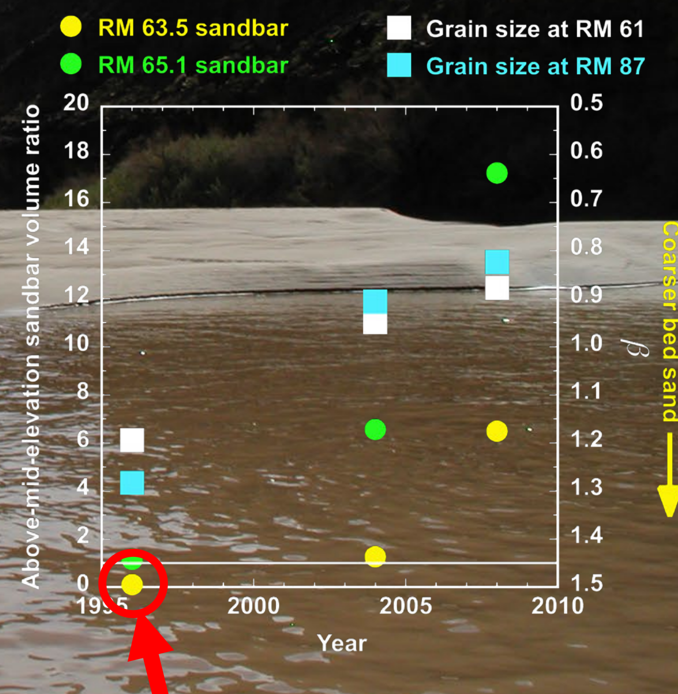
Two conditions must be met to enlarge high-elevation sandbars

1) High stage (see Figure 47 in Hazel and others, 2022)

2) Large amount of relatively fine sand on the bed



Sandbar *n* = 2
(RM 63.5, 65.1)



Post-HFE volume above 8,000 cfs only 10% of pre-HFE volume when bed-sand was coarse during 1996 HFE!

Figures modified from Topping and others (2019)

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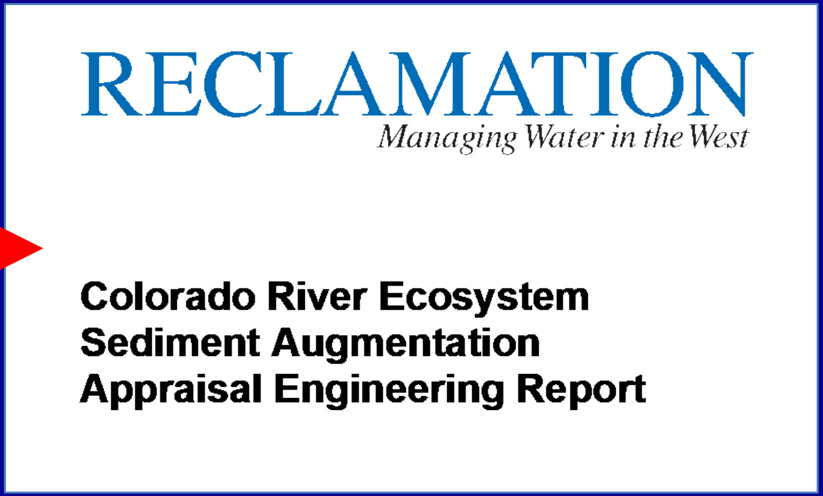
Basics of sand management

- Sand supply is <5% of pre-dam
- Keep dam releases low for part to much of the year to accumulate sand **OR**


RECLAMATION
Managing Water in the West

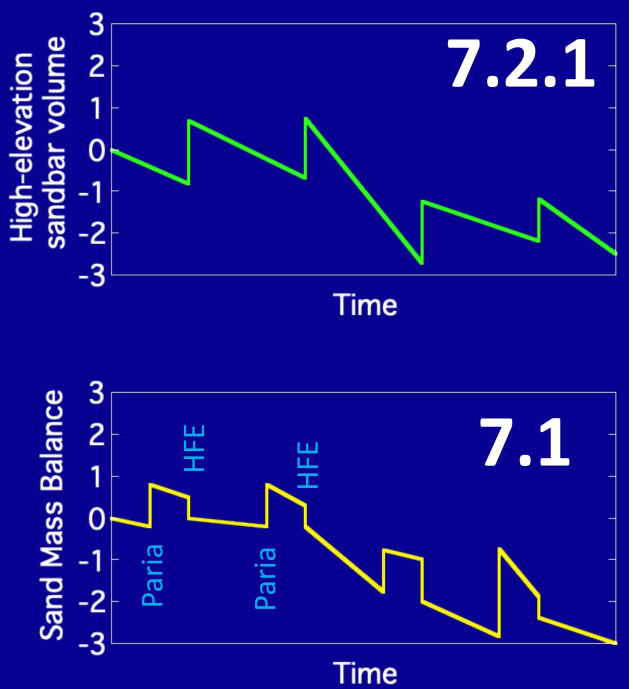
Colorado River Ecosystem Sediment Augmentation Appraisal Engineering Report

Randle and others (2007)

- Episodic short-duration artificial floods (HFEs) to rebuild sandbars
- Avoid sustained high releases (e.g., equalization) that greatly exceed the sand supply and result in widespread erosion

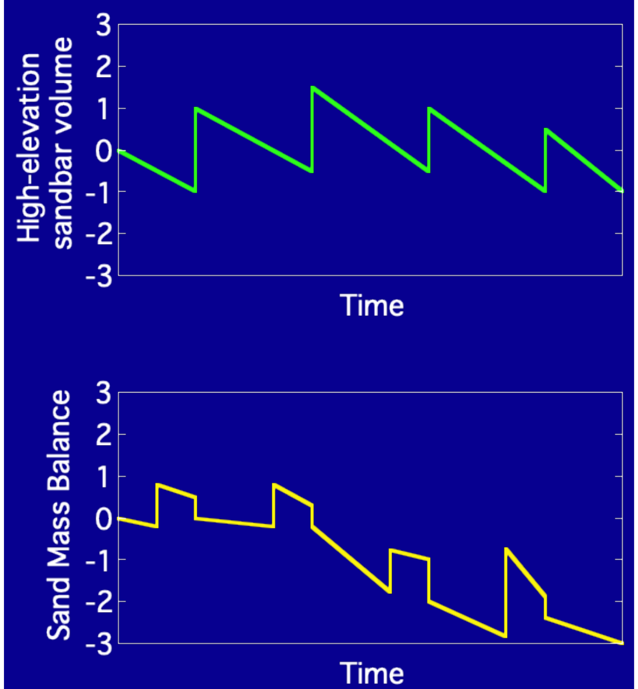
Sustainable management of sand under the LTEMP sediment goal thus requires neutral to positive trends in both **METRIC 7.1**, the sand supply (i.e., the sand mass-balance bank account) and **METRIC 7.2.1**, the high-elevation sandbar volume (i.e., your expenditures) over multiple years

Scenario 1



Not sustainable

Scenario 2

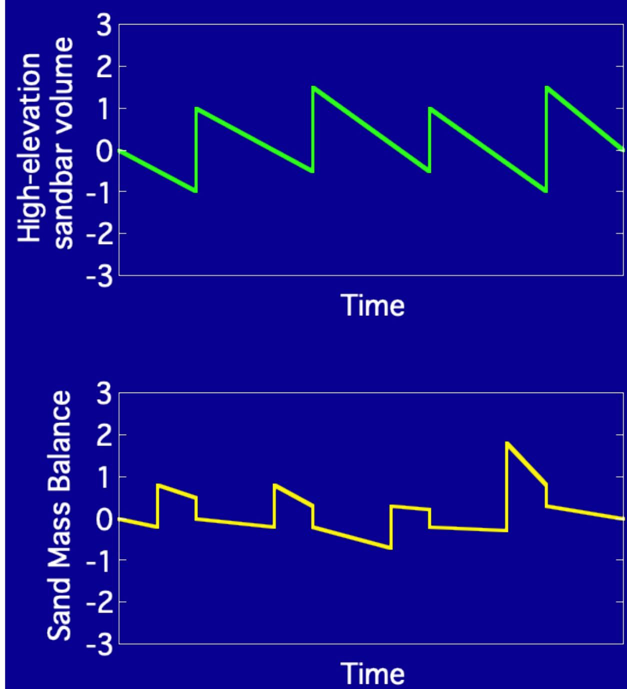


Not sustainable

Bank account mined to deposit sandbars

"Living on credit"

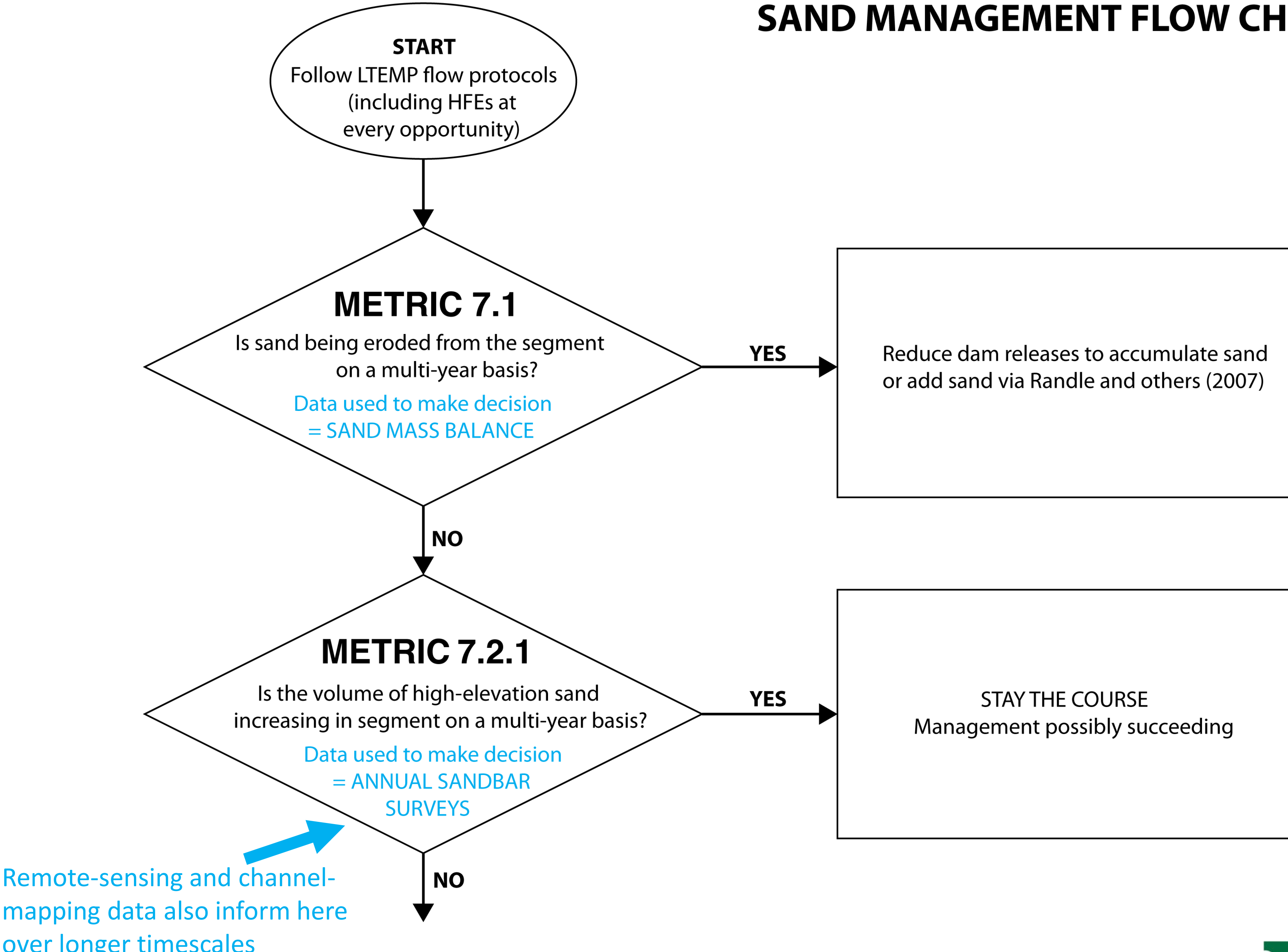
Scenario 3



Sustainable

"Living within your means"

SAND MANAGEMENT FLOW CHART



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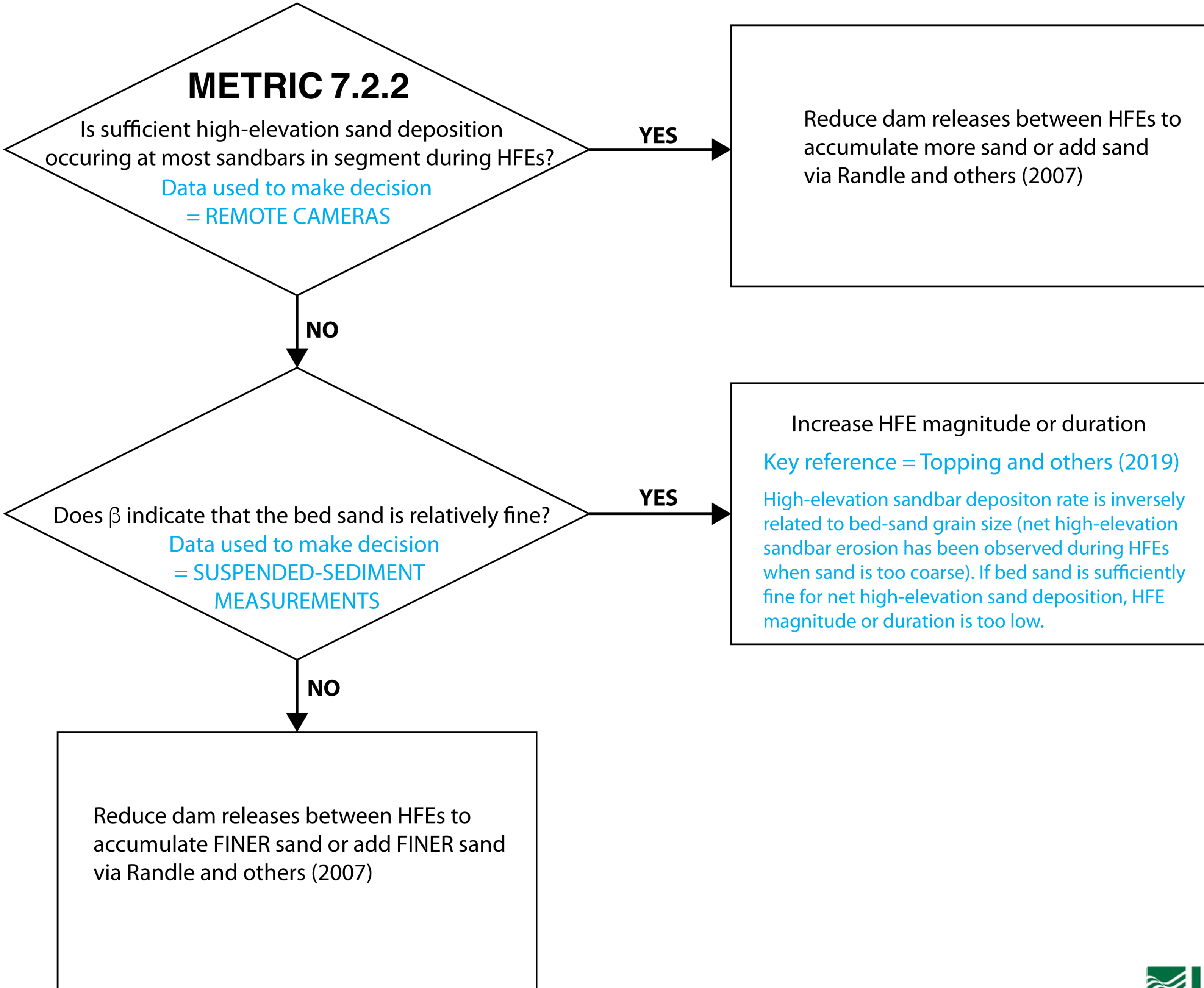
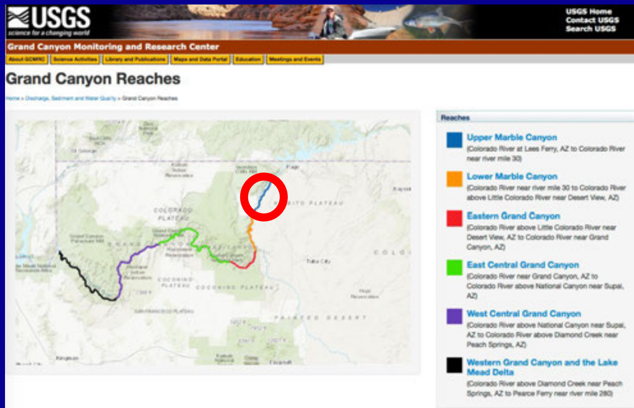
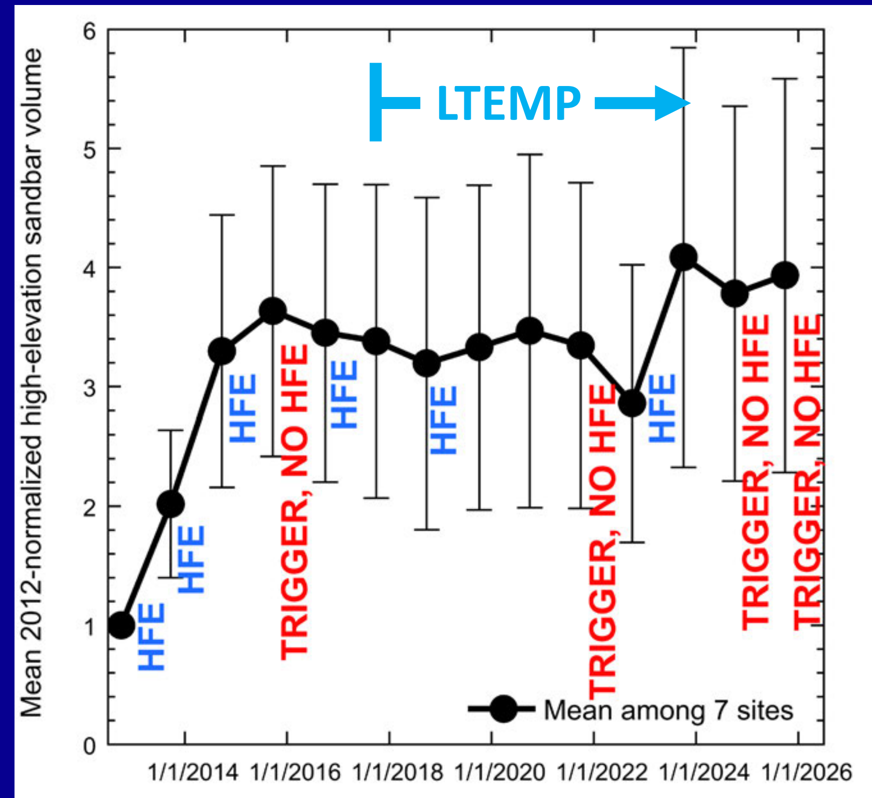

METRIC 7.2.2
Is sufficient high-elevation sand deposition occuring at most sandbars in segment during HFEs?
Data used to make decision = REMOTE CAMERAS
YES
Reduce dam releases between HFEs to accumulate more sand or add sand via Randle and others (2007)
NO
Does β indicate that the bed sand is relatively fine?
Data used to make decision = SUSPENDED-SEDIMENT MEASUREMENTS
YES
Increase HFE magnitude or duration
Key reference = Topping and others (2019)
High-elevation sandbar depositon rate is inversely related to bed-sand grain size (net high-elevation sandbar erosion has been observed during HFEs when sand is too coarse). If bed sand is sufficiently fine for net high-elevation sand deposition, HFE magnitude or duration is too low.
NO
Reduce dam releases between HFEs to accumulate FINER sand or add FINER sand via Randle and others (2007)

HFE-Protocol/LTEMP Period
Upper Marble Canyon



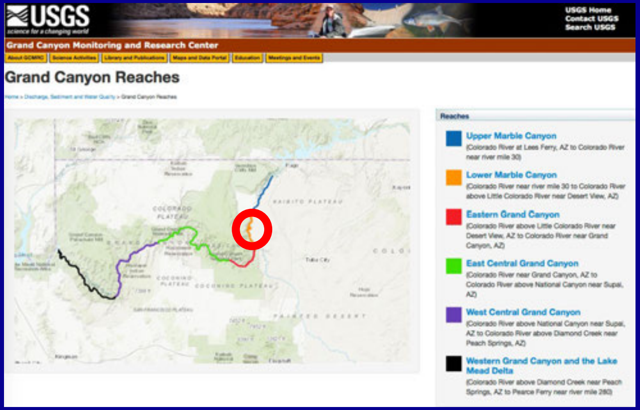
POSITIVE



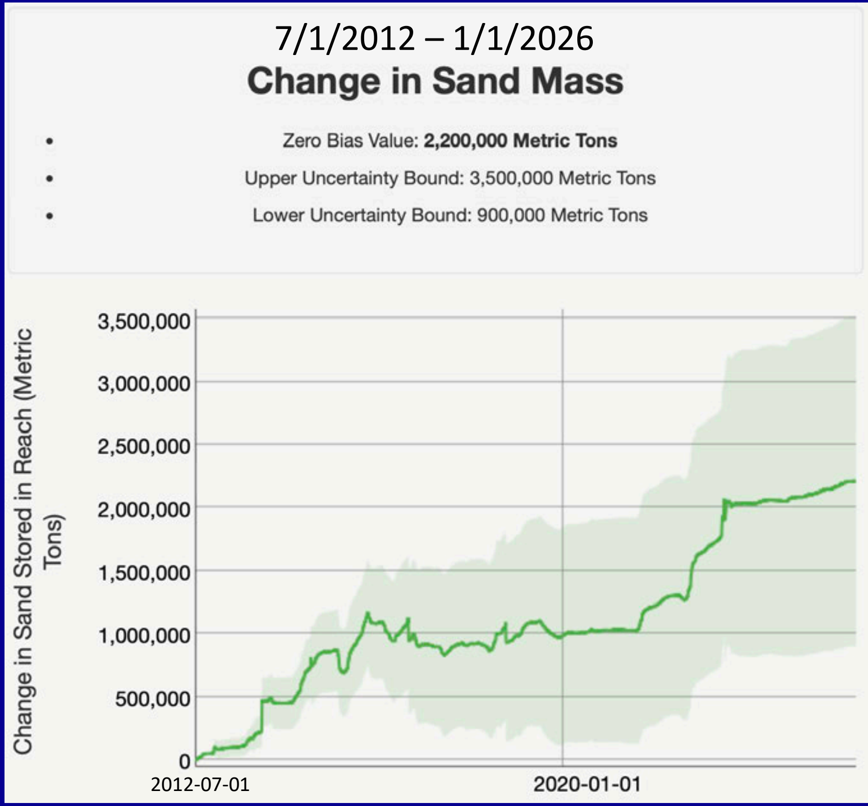
HFE Protocol: NET + ; 3/5 years +

LTEMP: NET + ; 2/8 years +

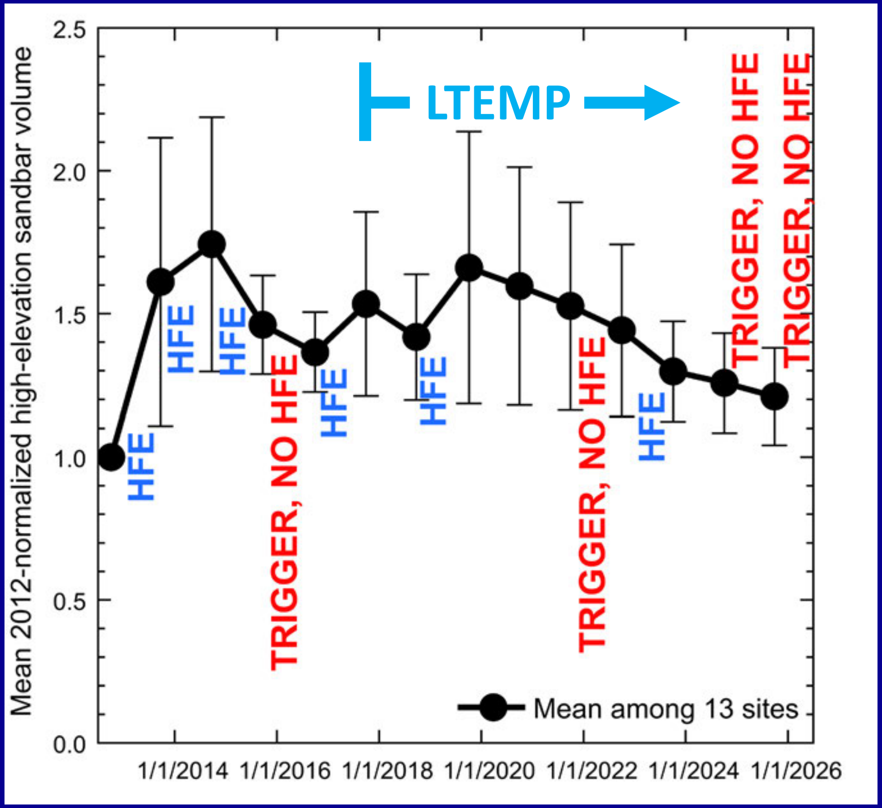
Data from USGS (2026a, b)



HFE-Protocol/LTEMP Period Lower Marble Canyon



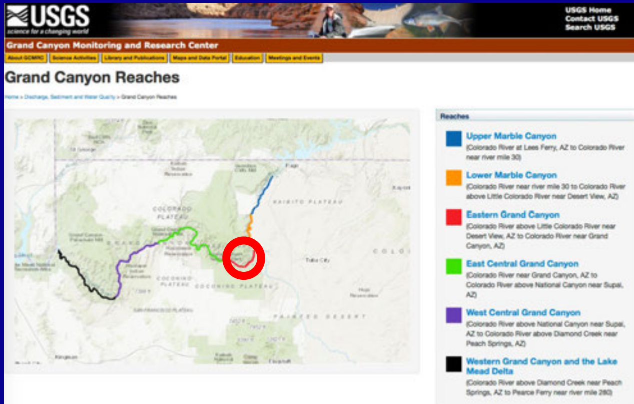
POSITIVE



HFE Protocol: NET + ; 3/5 years +

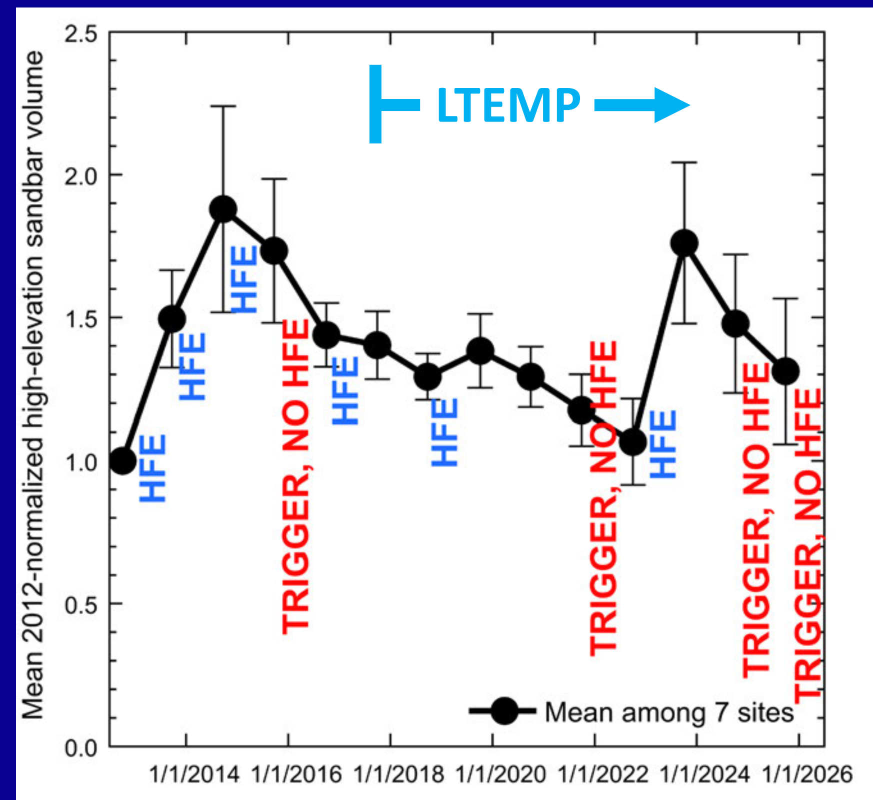
LTEMP: NET – ; 1/8 years +

Data from USGS (2026a, b)



HFE-Protocol/LTEMP Period Eastern Grand Canyon

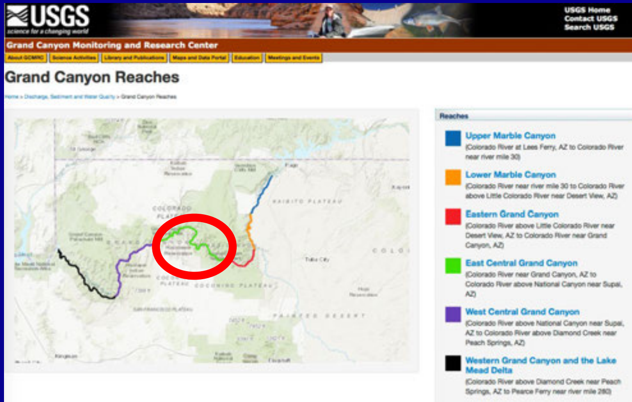
INDETERMINATE



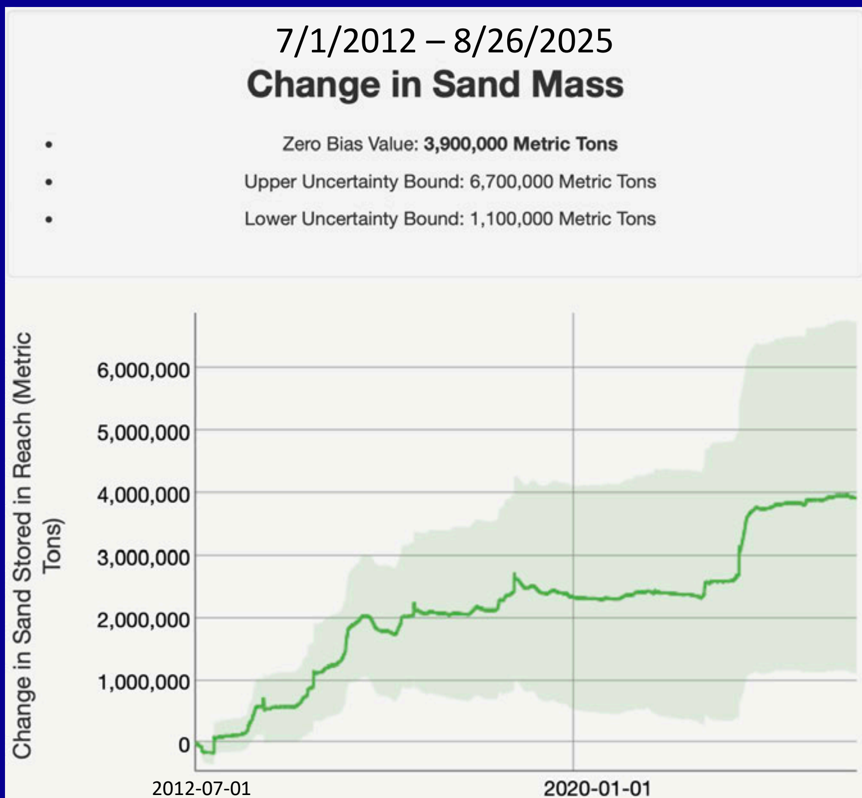
HFE Protocol: NET + ; 2/5 years +

LTEMP: NET slightly – ; 2/8 years +

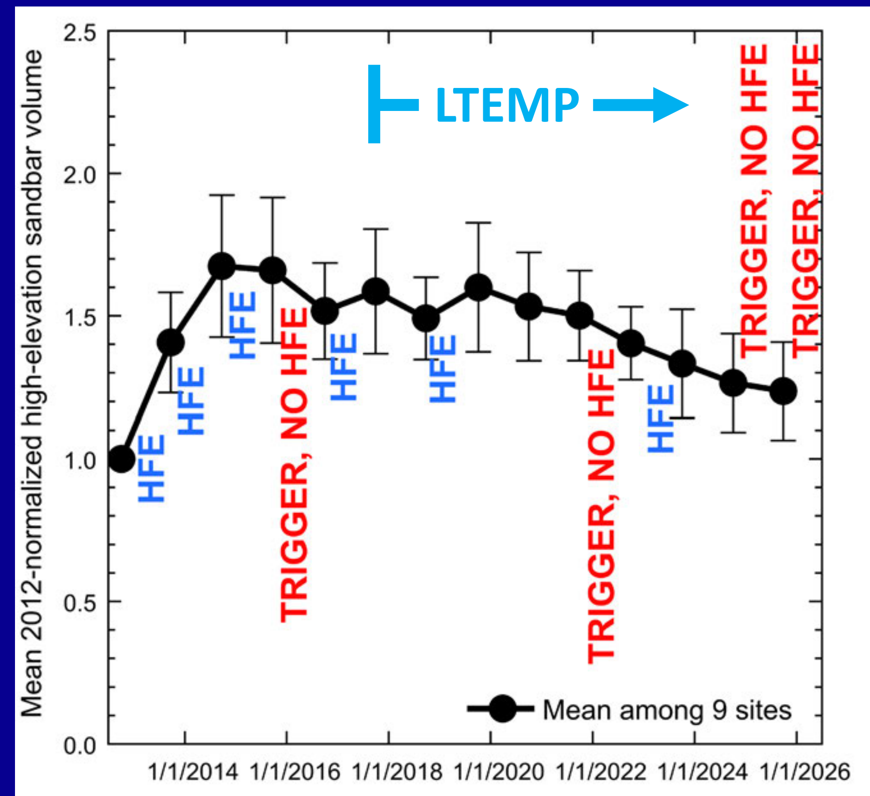
Data from USGS (2026a, b)



HFE-Protocol/LTEMP Period East-Central Grand Canyon



POSITIVE

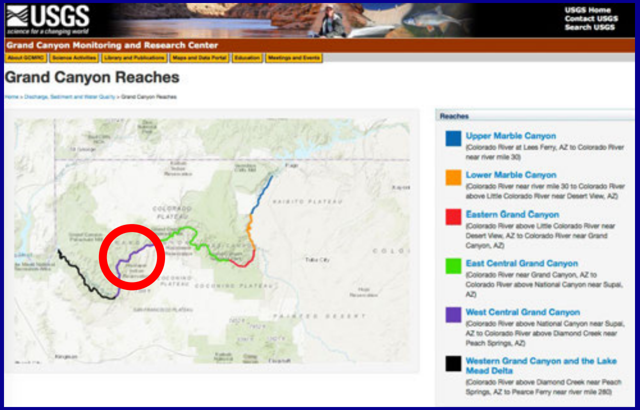


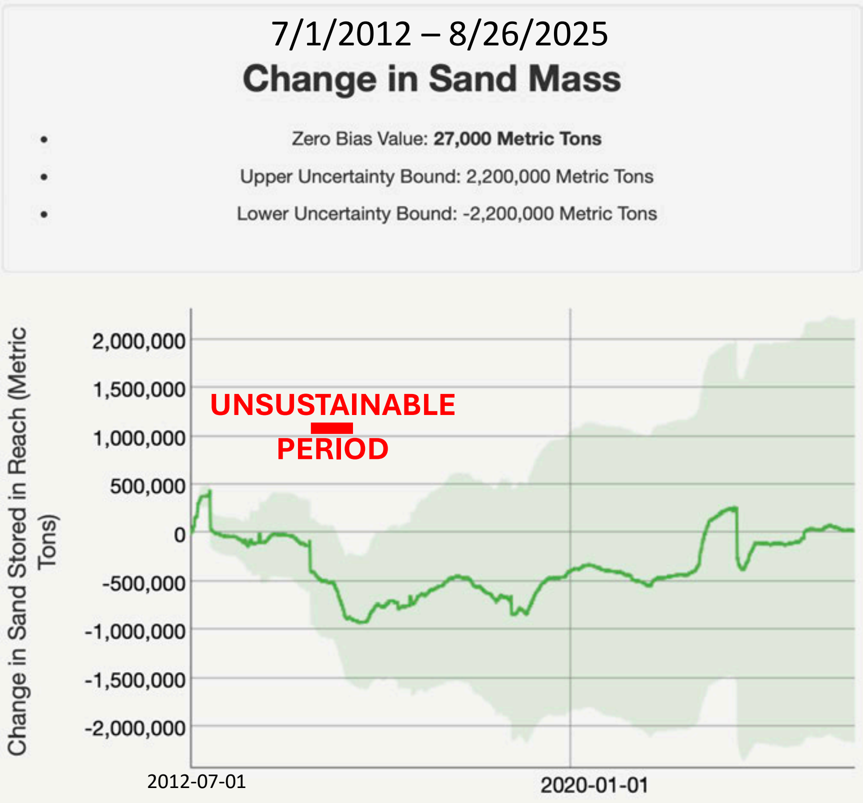
HFE Protocol: NET + ; 3/5 years +

LTEMP: NET – ; 1/8 years +

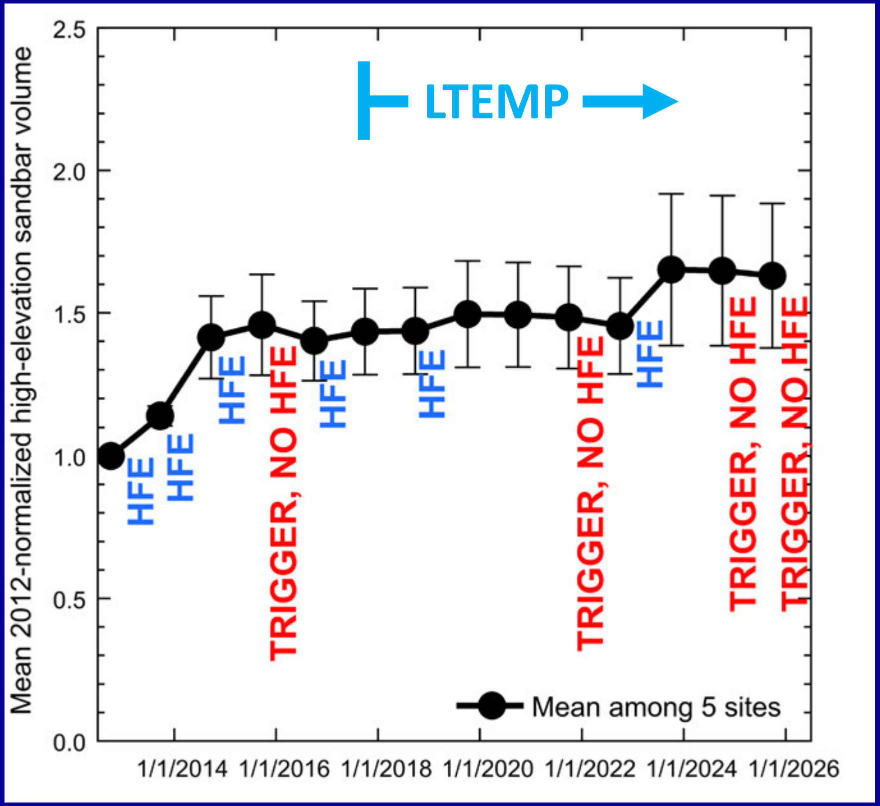
Data from USGS (2026a, b)

HFE-Protocol/LTEMP Period West-Central Grand Canyon





INDETERMINATE

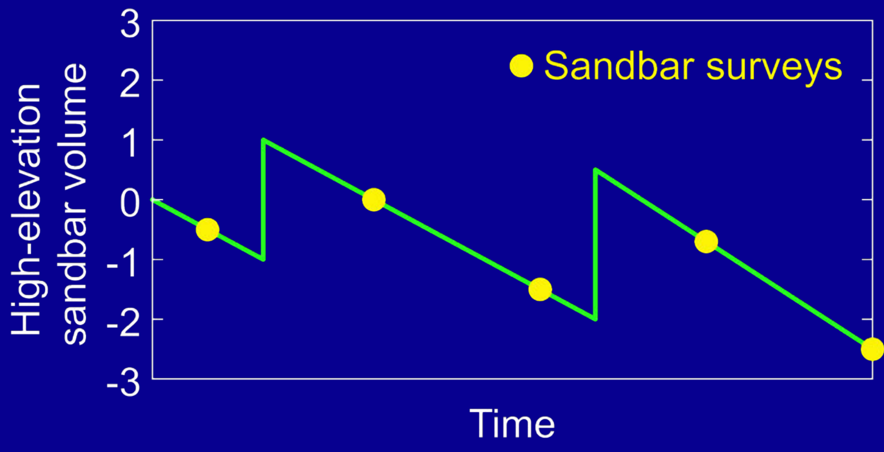


HFE Protocol: NET + ; 4/5 years +

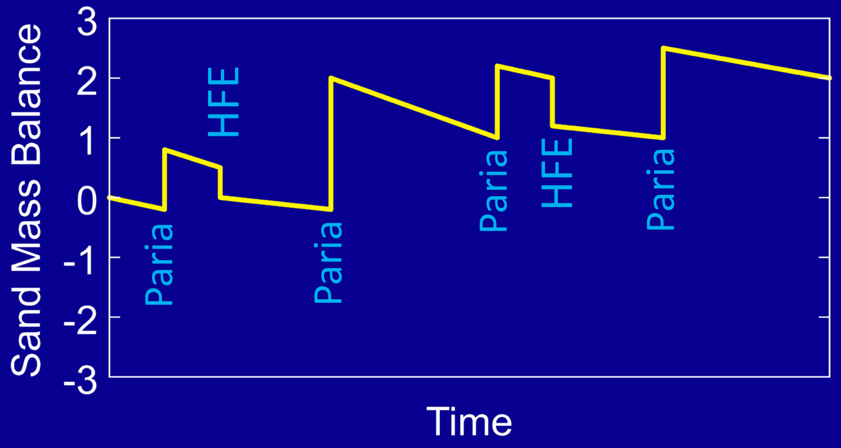
LTEMP: NET + ; 2/8 years +

Data from USGS (2026a, b)

Generalized LTEMP scenario among the 5 river segments
"Not following the experimental design"



Sandbar erosion during intervening dam operations WINS over sandbar deposition during HFEs

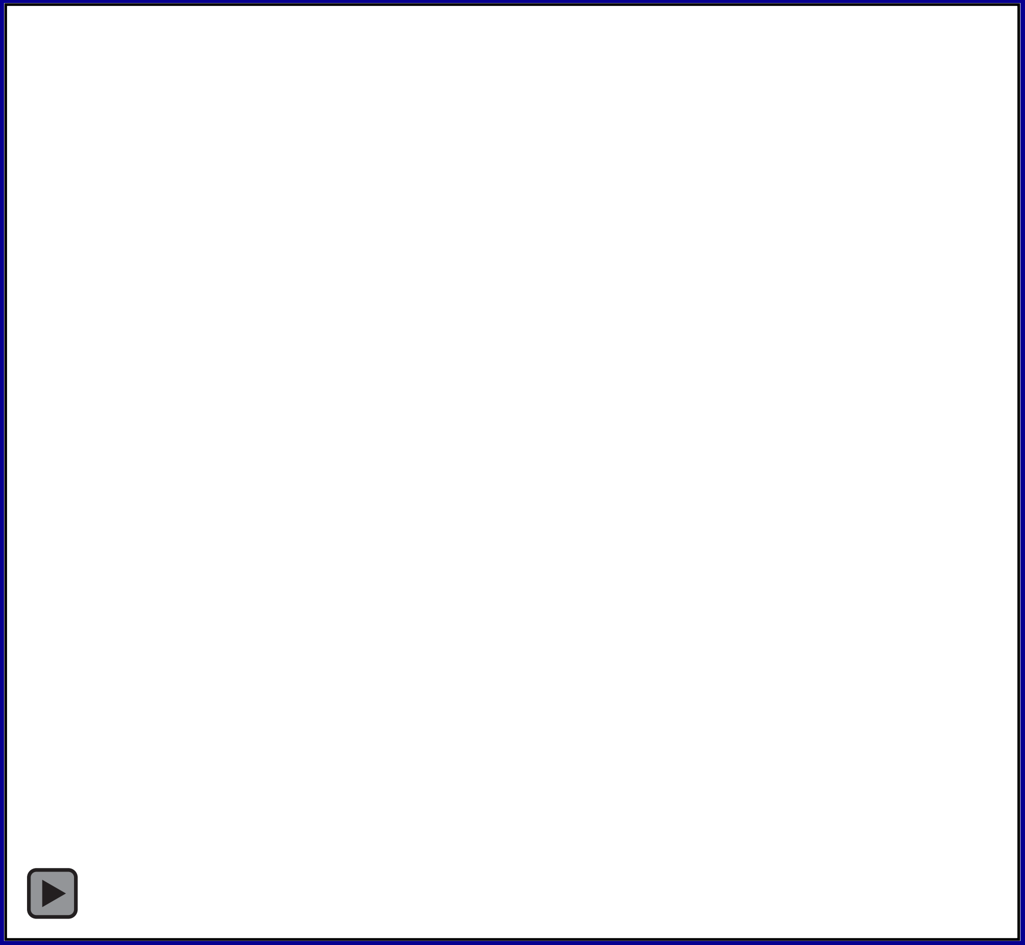


Not all "new" Paria sand is used during rare HFEs and *sand export increases as bed-sand accumulates and fines* (Topping and others, 2021)

Averages do not tell the entire story

Although only a slight decrease in mean high-elevation normalized sand volume occurred between 1990 and 2025 among the 12 long-term sandbar monitoring sites in Marble Canyon…

- High-elevation sand at half of of these sites defines a downward spiral (LOSERS)
- High-elevation sand at almost half of these sites defines an upward spiral (WINNERS)

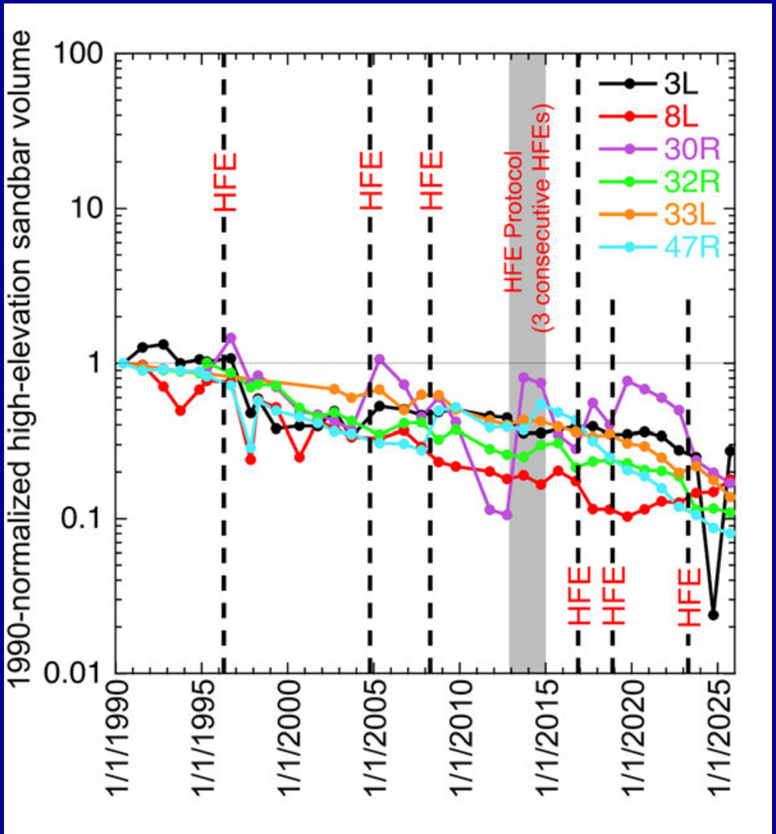


Data from USGS (2026b)

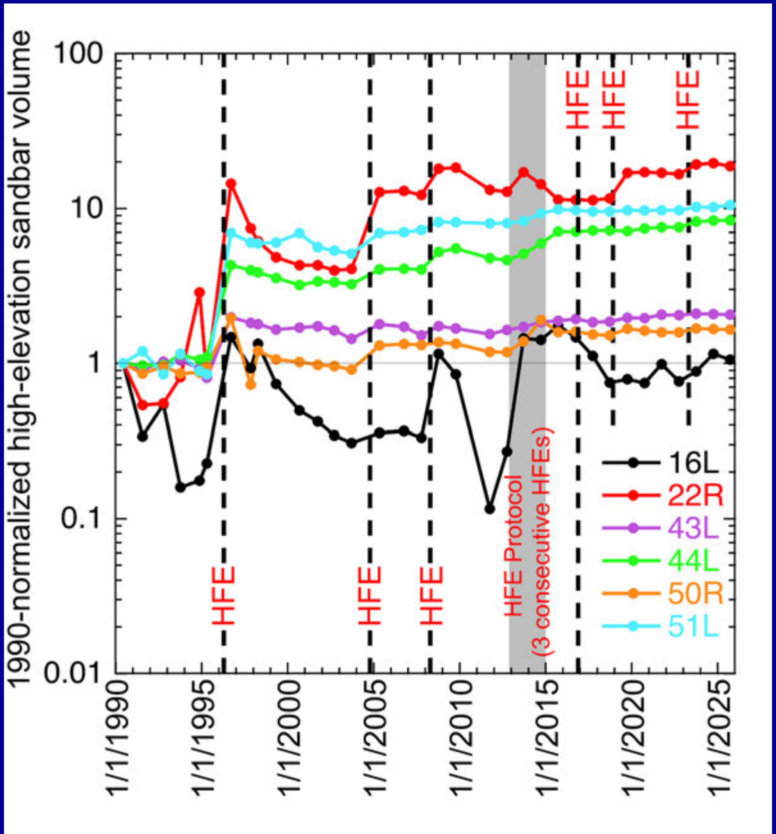
Problematic sandbars will likely keep eroding without frequent HFEs

- 4 of the 6 LOSERS gained high-elevation sand during the 2012–2014 HFE-protocol period of 3 HFEs over 3 years as observed in surveys conducted 11 months after each of those HFEs
- 5 of the 6 WINNERS gained sand during that period of frequent HFEs

Marble Canyon Losers



Marble Canyon Winners



Data from USGS (2026b)

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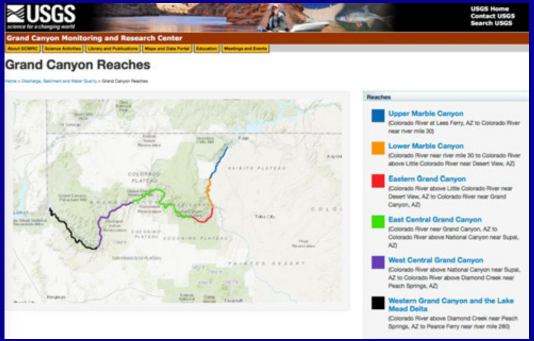
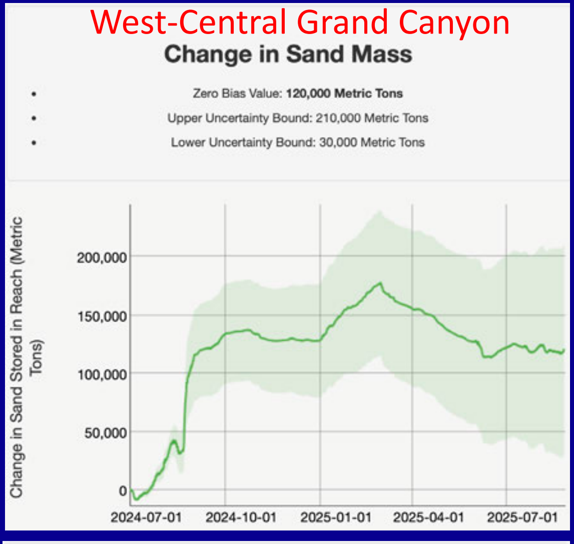
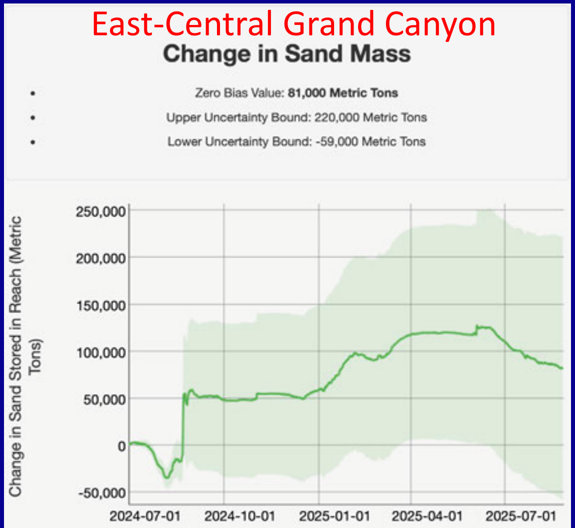
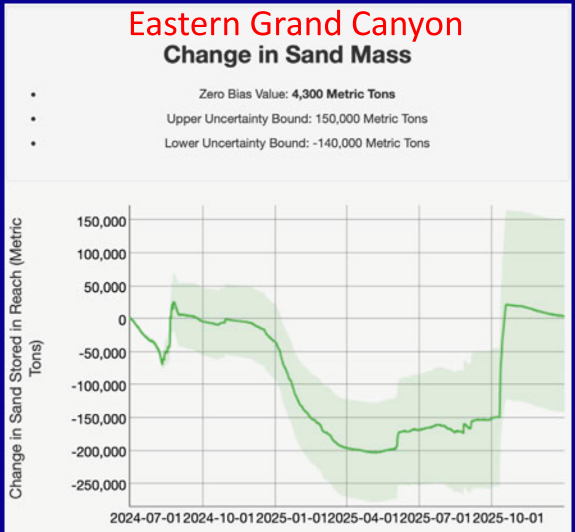
We will still have a robust HFE trigger in spring 2026 and most segments are positive

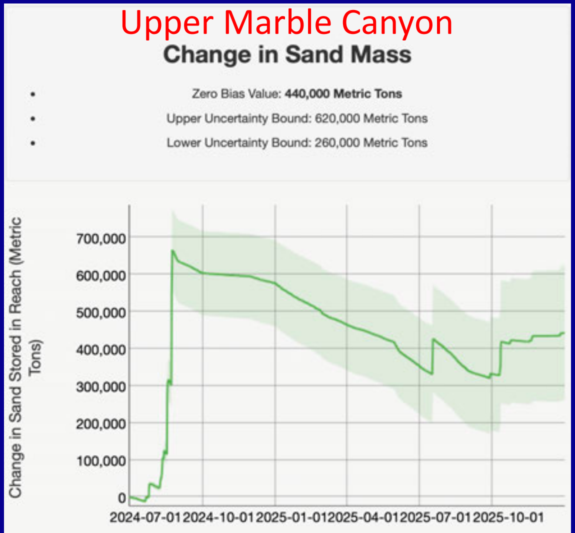


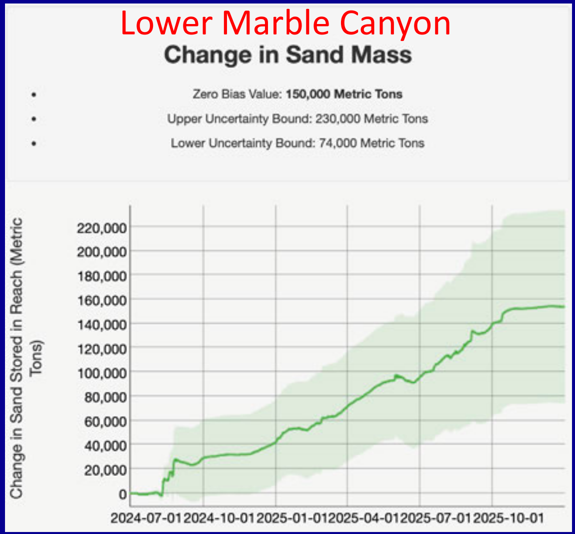




- Since July 1, 2024, the Paria River has supplied 860,000 to 1,100,000 metric tons of sand
- > 330,000 metric tons of this sand is still in Marble Canyon
- Between now and the spring, there will be a transfer of some sand from Upper to Lower Marble Canyon with little net change in all of Marble Canyon







Data from USGS (2026a)

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Conclusions

- Results were promising during the “period of frequent HFEs” (2012–2016; HFE Protocol period) when sandbar deposition during HFEs generally outweighed sandbar erosion during intervening dam operations
- HFEs during 2012–2016 were conducted following 4 out of 5 triggers
- Results have been mixed to negative during the “period of infrequent HFEs” (2017–present; LTEMP period) when sandbar erosion during intervening dam operations has generally outweighed sandbar deposition during HFEs
- Only 2 HFEs were conducted during 2017–2025 despite there being 5 triggers
- Learning has been hampered during LTEMP owing to lack of HFEs despite there being triggers
- What about low reservoir elevations?

Thank you

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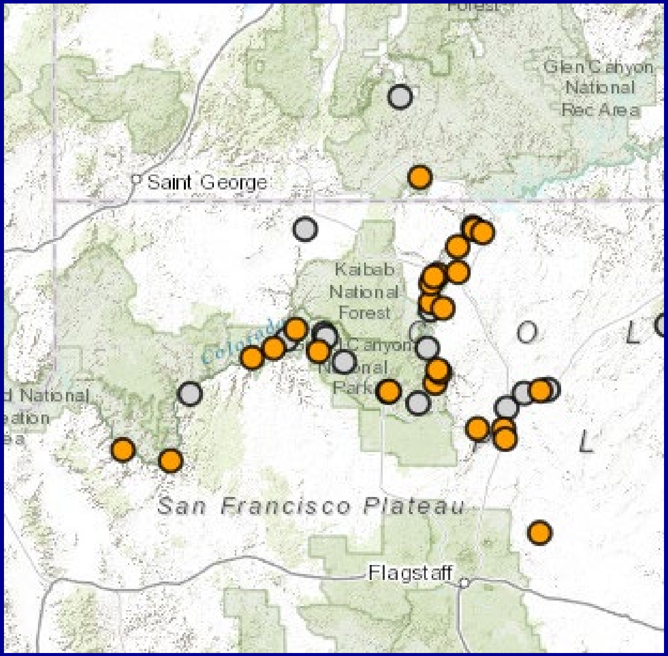
Project A: Streamflow, Water Quality, and Sediment Transport and Budgeting in the Colorado River Ecosystem

Project A collects the physical data that directly link dam operations to all resources in the downstream Colorado River; data inform 10 LTEMP goals; data used to trigger, design, and evaluate HFEs



- Element 1: Stream gaging
  - Stage
  - Discharge
- Element 2: Water quality
  - Water temperature
  - Salinity (specific conductance)
  - Turbidity
  - Dissolved Oxygen
- Element 3: Sediment transport and budgeting
  - Suspended- and bed-sediment data
  - Sediment loads (silt and clay loads and sand loads)
  - User-interactive sand budgets in 6 reaches from Lees Ferry to Lake Mead
- All elements
  - Database and website

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