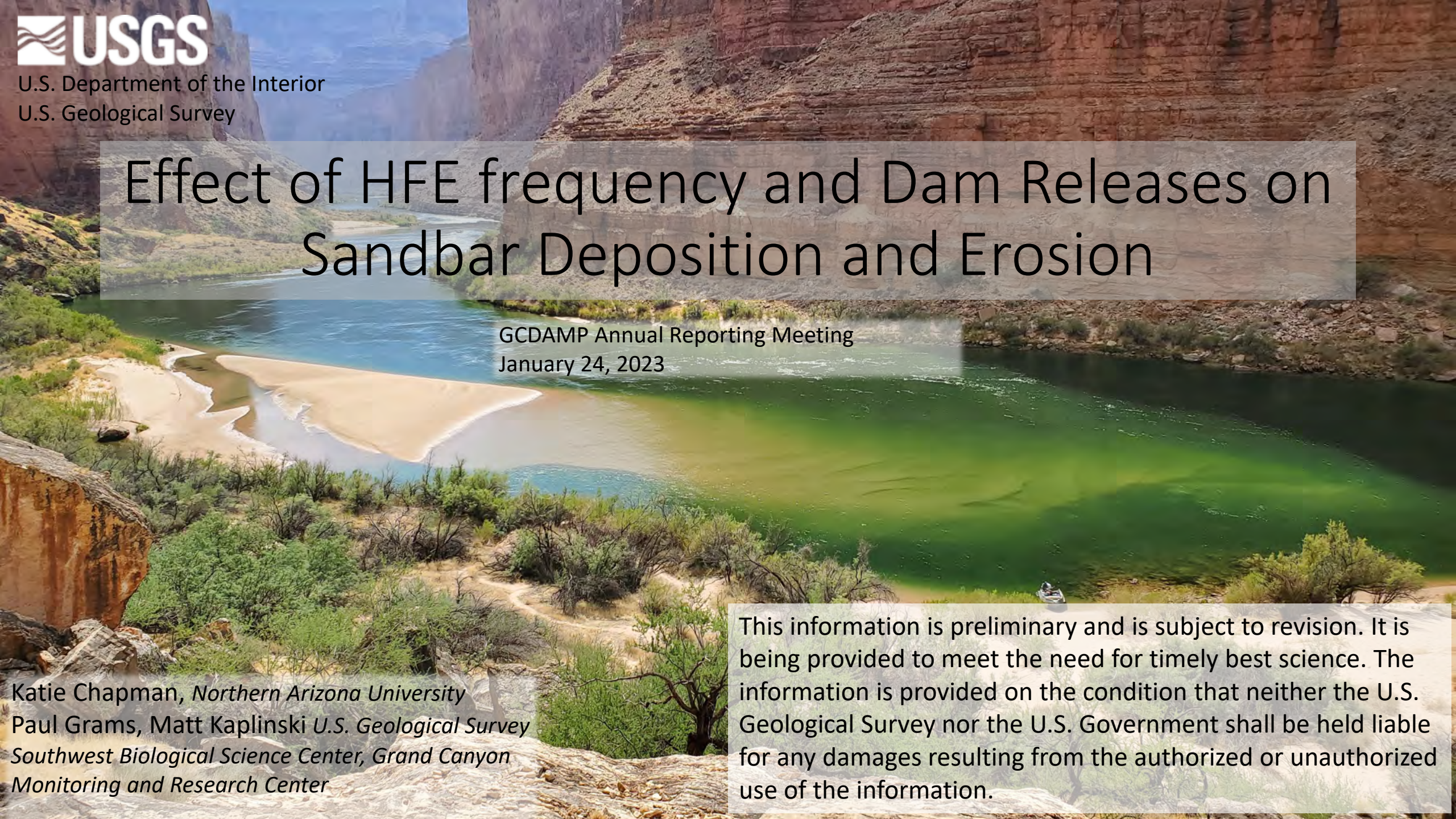

U.S. Department of the Interior
U.S. Geological Survey

Effect of HFE frequency and Dam Releases on Sandbar Deposition and Erosion

GCDAMP Annual Reporting Meeting
January 24, 2023

Katie Chapman, *Northern Arizona University*
Paul Grams, Matt Kaplinski *U.S. Geological Survey Southwest Biological Science Center, Grand Canyon Monitoring and Research Center*

Acknowledgements

Project B personnel:

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Collaborators and Field Assistants

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GRAND CANYON RIVER GUIDES

NAMDOR

USGS

Project B1:
Sandbar monitoring

LTEMP sandbar resource 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."

OBJECTIVES

- **Measure sandbar response** to individual recurring HFEs, as well as daily flows between HFEs
- Monitor the effects of dam operations (HFEs and otherwise) on overall sand conservation
- Investigate the interactions between dam operations, sand transport, and eddy sandbar dynamics

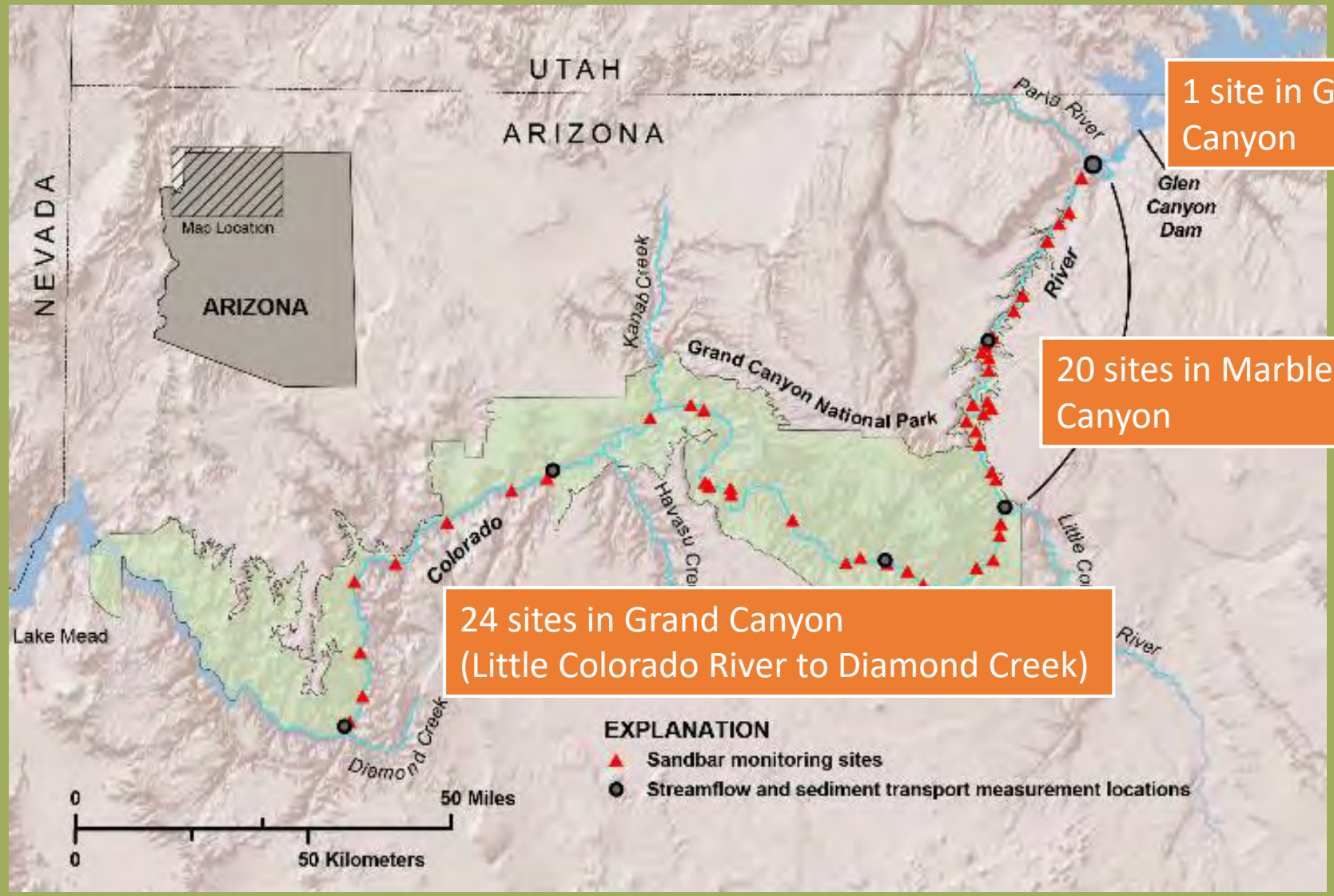
QUESTION

- **Can sandbar building during HFEs exceed sandbar erosion** during periods between HFEs, such that sandbar size can be increased and maintained over several years?

ASSESSMENT: YES, but HFEs **need to occur more frequently** than in the last 5 years

- **HFEs required** for significant, high elevation sand deposition
- 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 continued to decrease** due to 4 years without an HFE

45 Sandbar monitoring sites total; 30+ year dataset



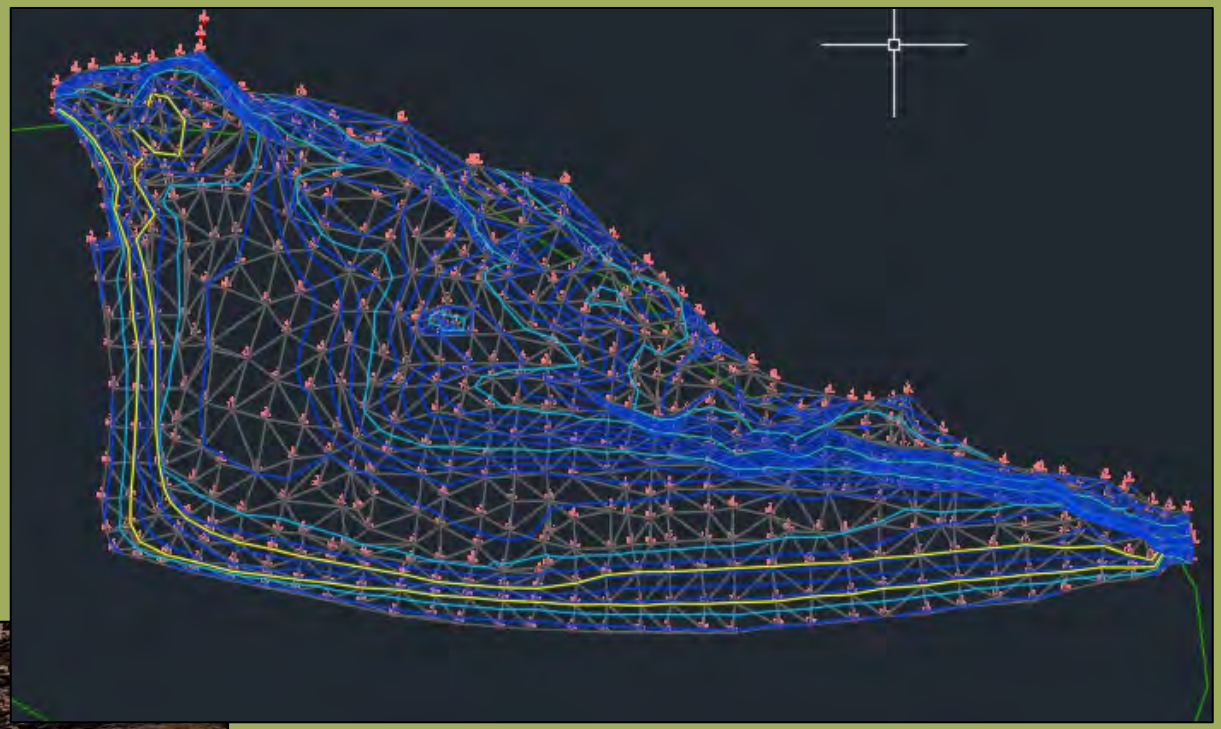
Monitoring Data

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


Photo Credit: Shannon Sartain

Survey Methods:

- Traditional total station and surveyors
- only method that can accurately measure all the terrain



- vegetation encroachment: remote methods like lidar don't work

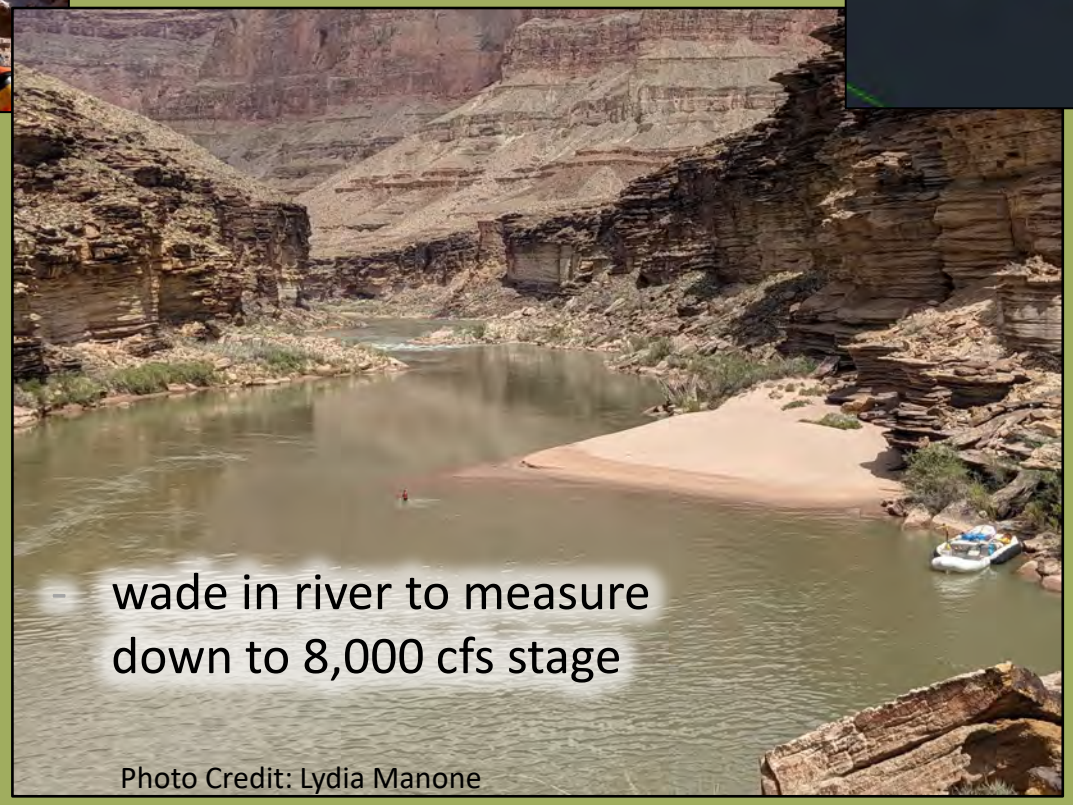

- wade in river to measure down to 8,000 cfs stage

Photo Credit: Lydia Manone

Processing:

- connect all the points into a faceted surface (TIN)

- sample at 1m grid spacing

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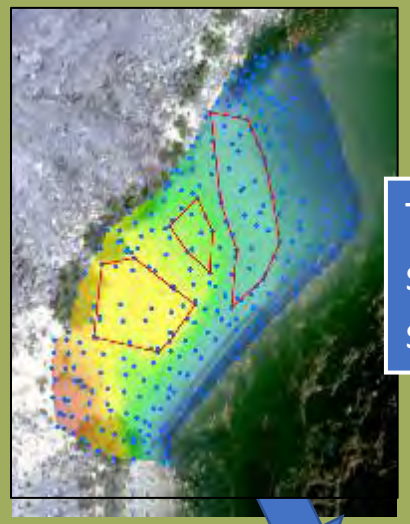
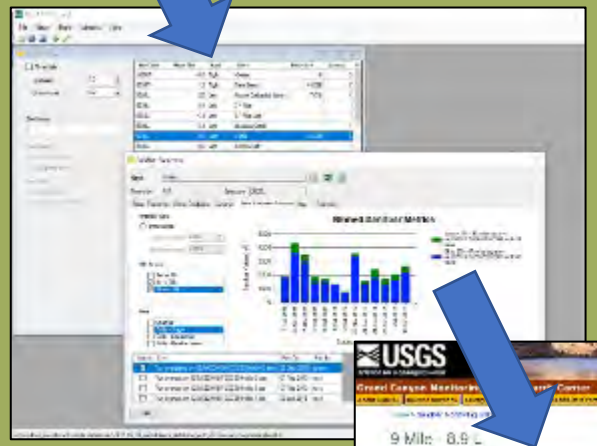
Sandbar monitoring data

Data collection: old school total station and survey rod

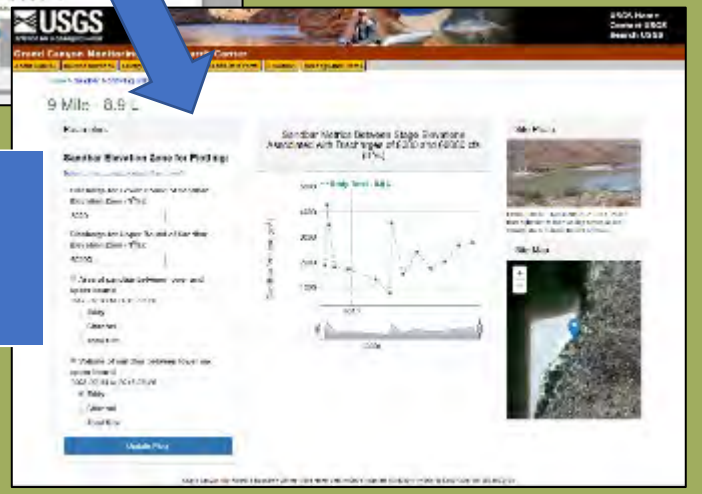


21st century data processing and analysis

Topographic surfaces modeled in survey software



Data processed and analyzed in sql database



Data served in sandbar web application

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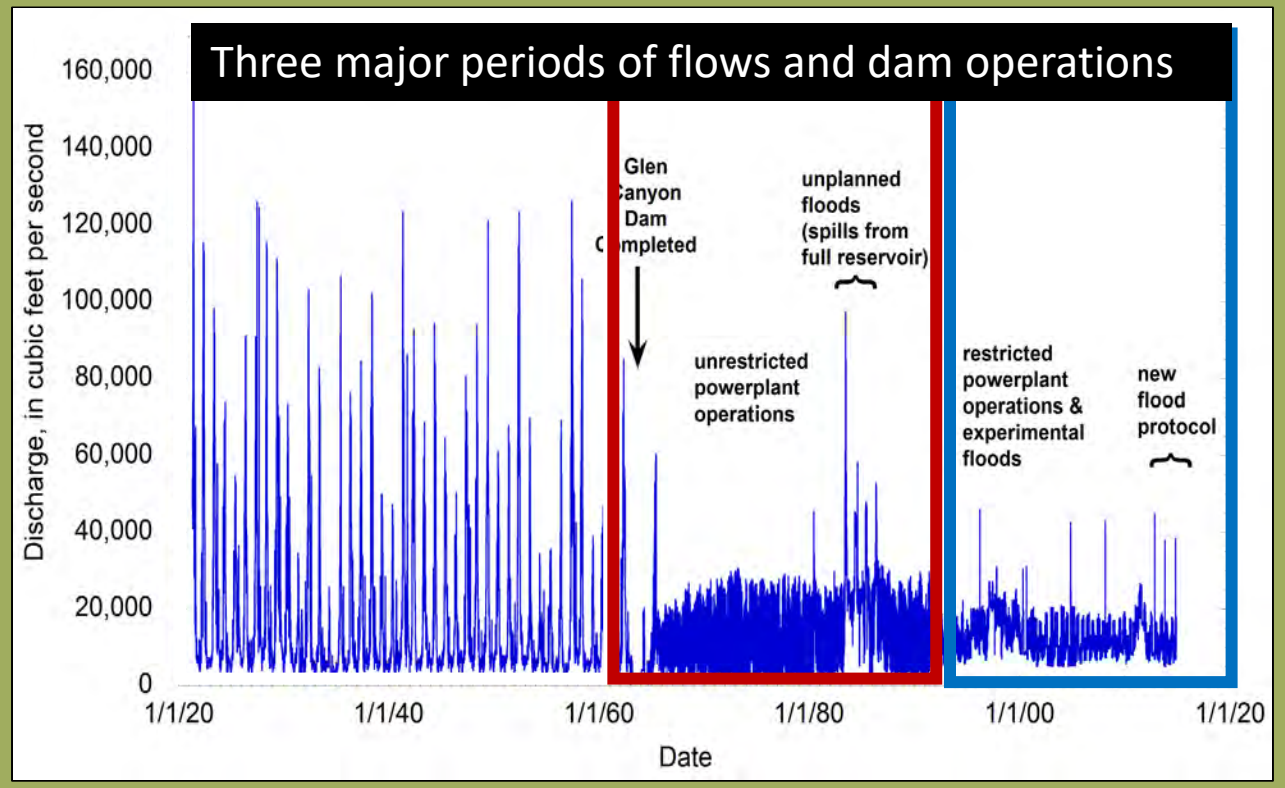
www.gcmrc.gov/sandbar OR www.usgs.gov/apps/sandbar

USGS

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



HFE-related Science and Management Questions:

- With frequent HFEs, will sandbars increase in size and abundance?
- Can HFE deposit sandbars serve as long-term storage of sand?

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
- **High Flow Experiments (HFEs)**
  - triggered by sand supply from Paria River

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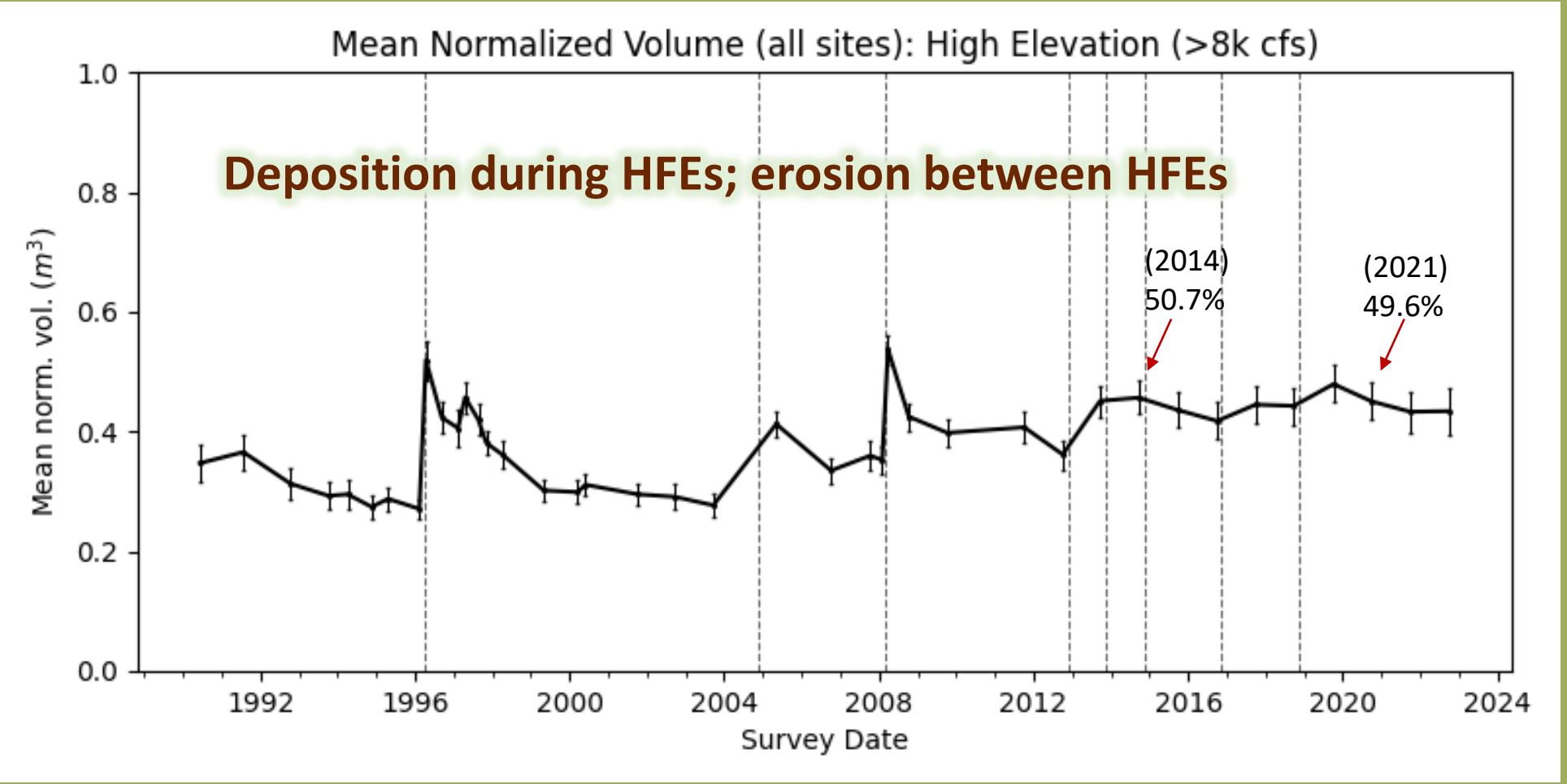
Average Normalized Sandbar Volume, 1990-2022



- currently at mean norm **volume less than in 2013**

- Missed the opportunity to essentially pick up where we left off in 2014

2014: **~1.21** million tons sand
median Q: **~11700 cfs**
max Q: **~17.5k cfs**
>9000 cfs **~83% time**

2021: **~1.42** million tons sand
median Q: **~11900 cfs**
max Q: **~16400 cfs**
>9000 cfs **~75%** time

2022: **~1.46** million tons sand
median Q: **~9600 cfs**
max Q: **~15500 cfs**
>9000 cfs **~85% time**

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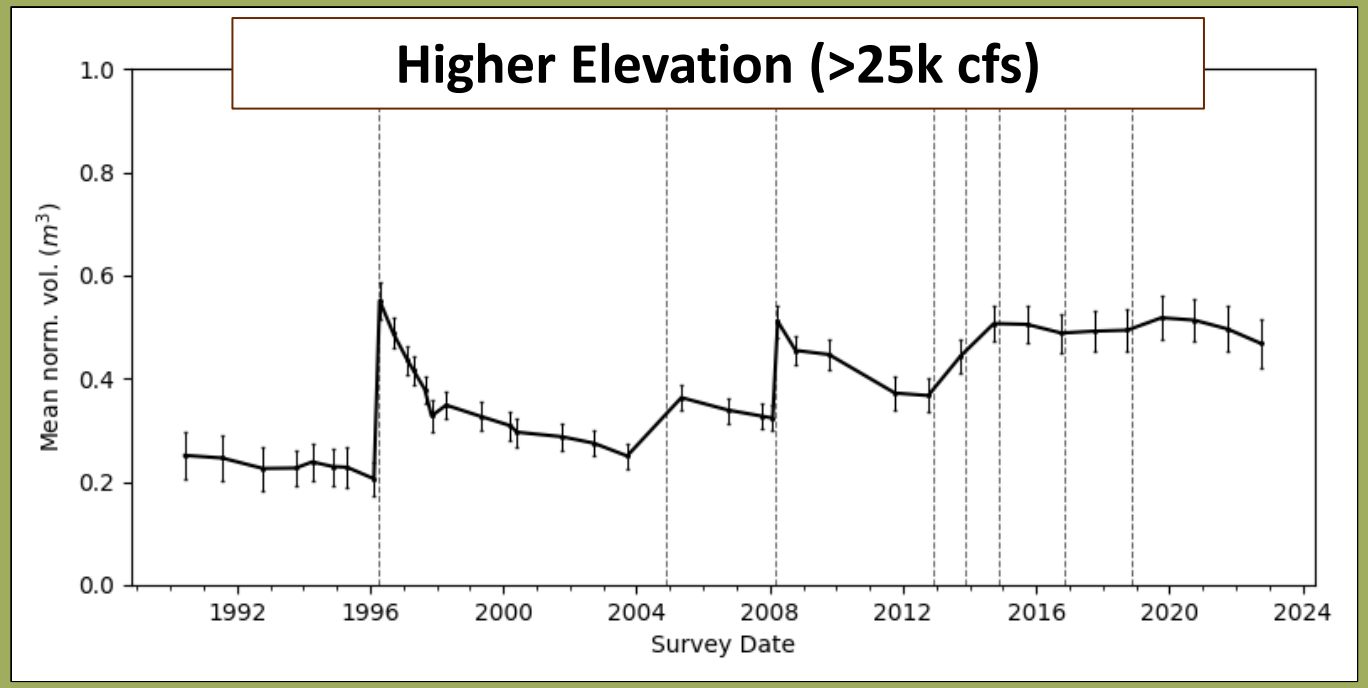
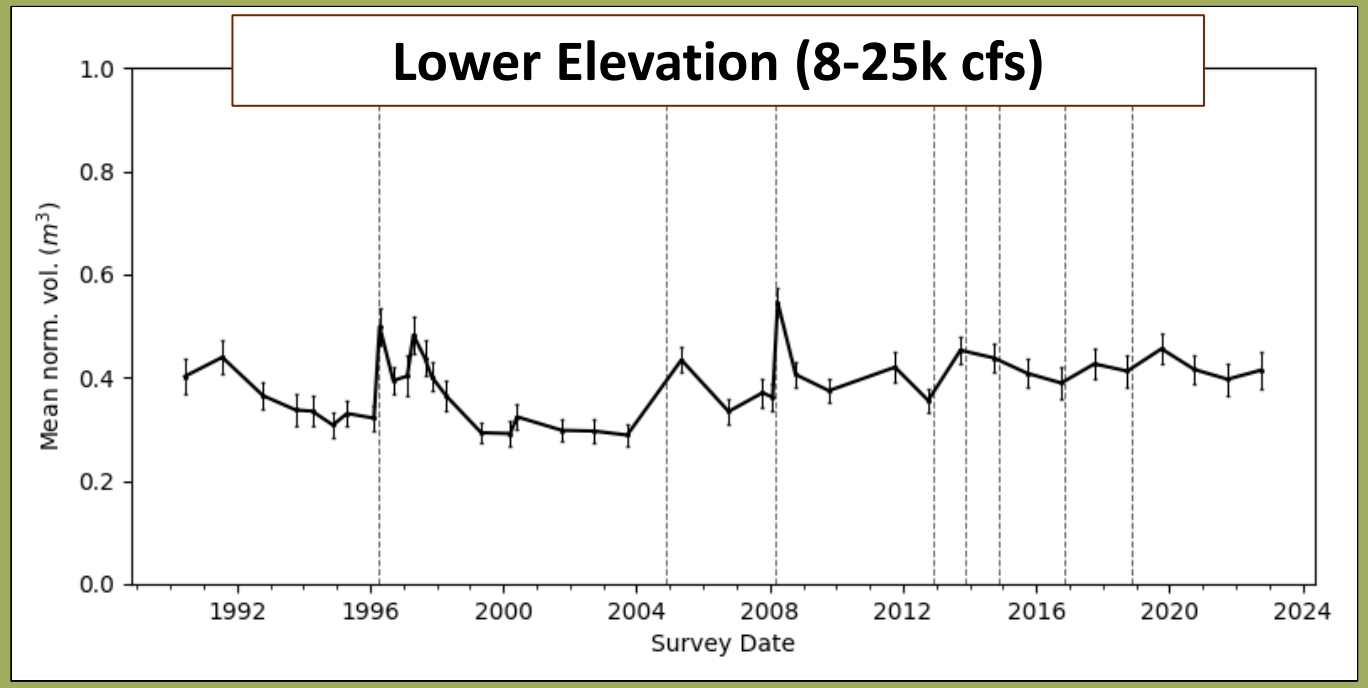
Mean Normalized Volume (m^3)





Higher (>25k cfs) elevation

-gradually, but reliably, erode in interim flows between HFEs

BOTH: typically, though not always increase during HFEs

Lower (8-25k cfs) elevation

- Inundated by daily flows -> transport
- monthly flow regime changes -> erosion
- fluctuates more
- doesn't always erode between HFEs

- 2022: volume increased

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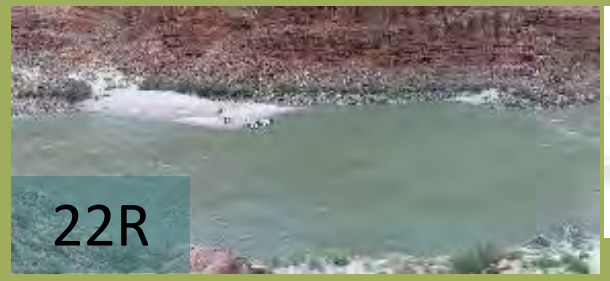
Behavior differs by site type

Reattachment Bars

Increasing channel width

Increasing vegetation

Narrow



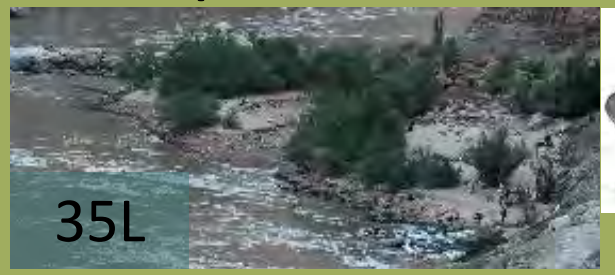
Medium

Wide

Other Bar Types

Undifferentiated

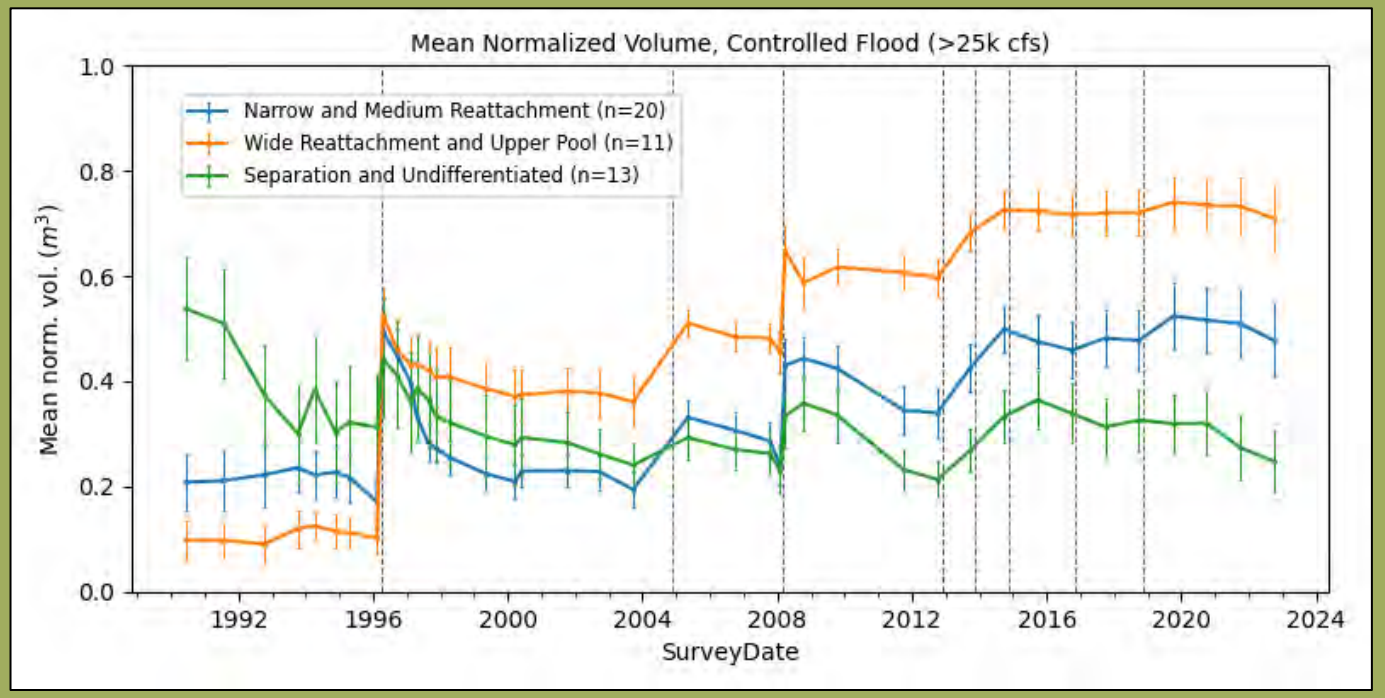
Separation



Upper pool

Mueller and others (2018)

USGS



Higher Elevation

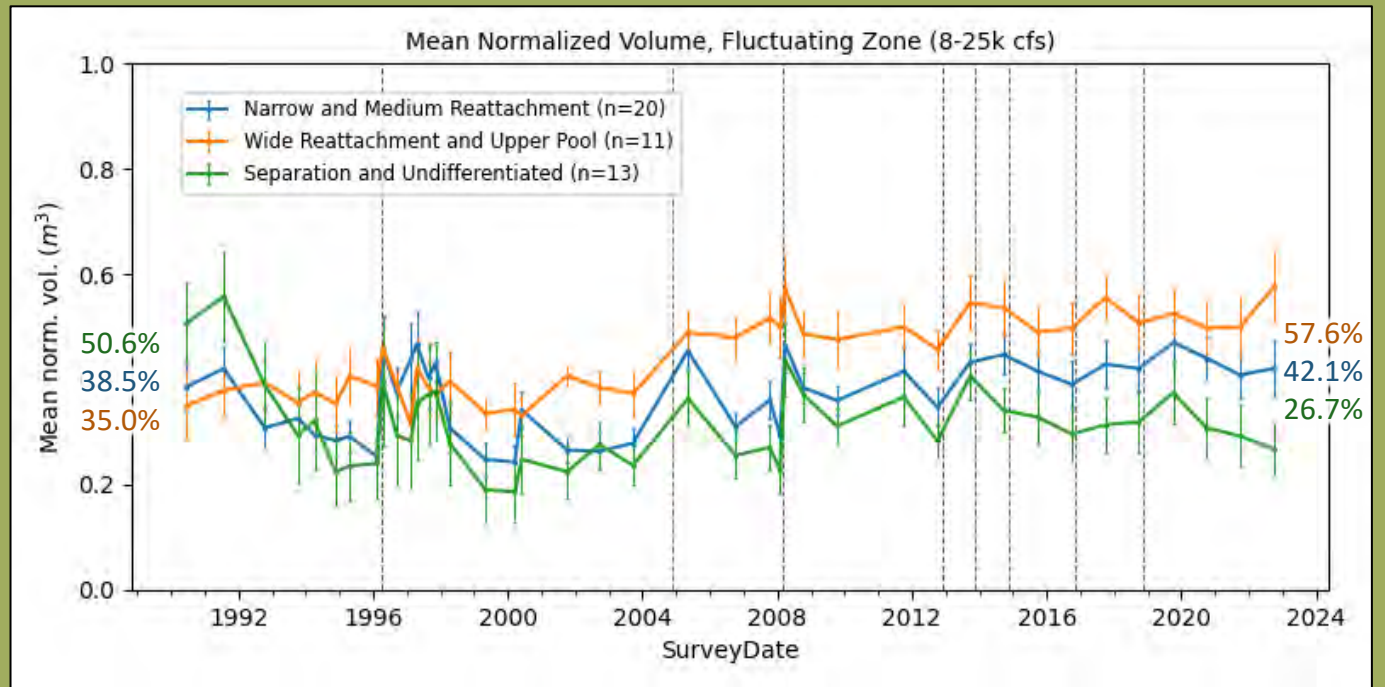
- All types: decrease in volume without HFEs

Reattachments and Upper pools respond better to HFEs:

- larger than in 1990 versus Separation and Undifferentiated bars: smaller than in 1990
- since 2012: All sizes of reattachment and upper pool bars have more deposition during HFEs, retain sand better during interim flows

Last 10 years: all three pairs are lower than in 2013 not just Separation and Undifferentiated bars pulling down the average

>>Potential for increasing long term sand storage? YES

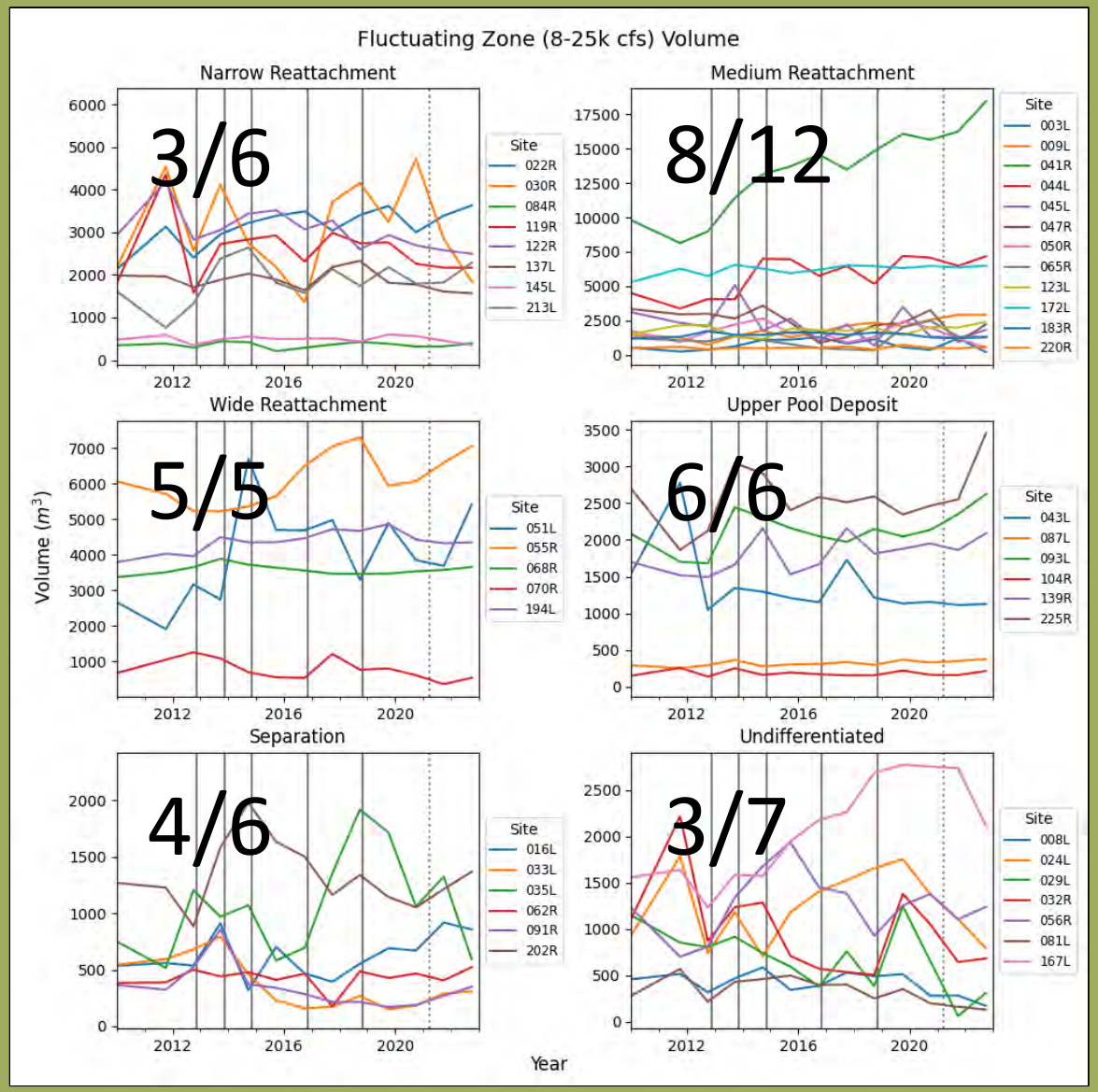


Lower Elevation (affected by daily flows):

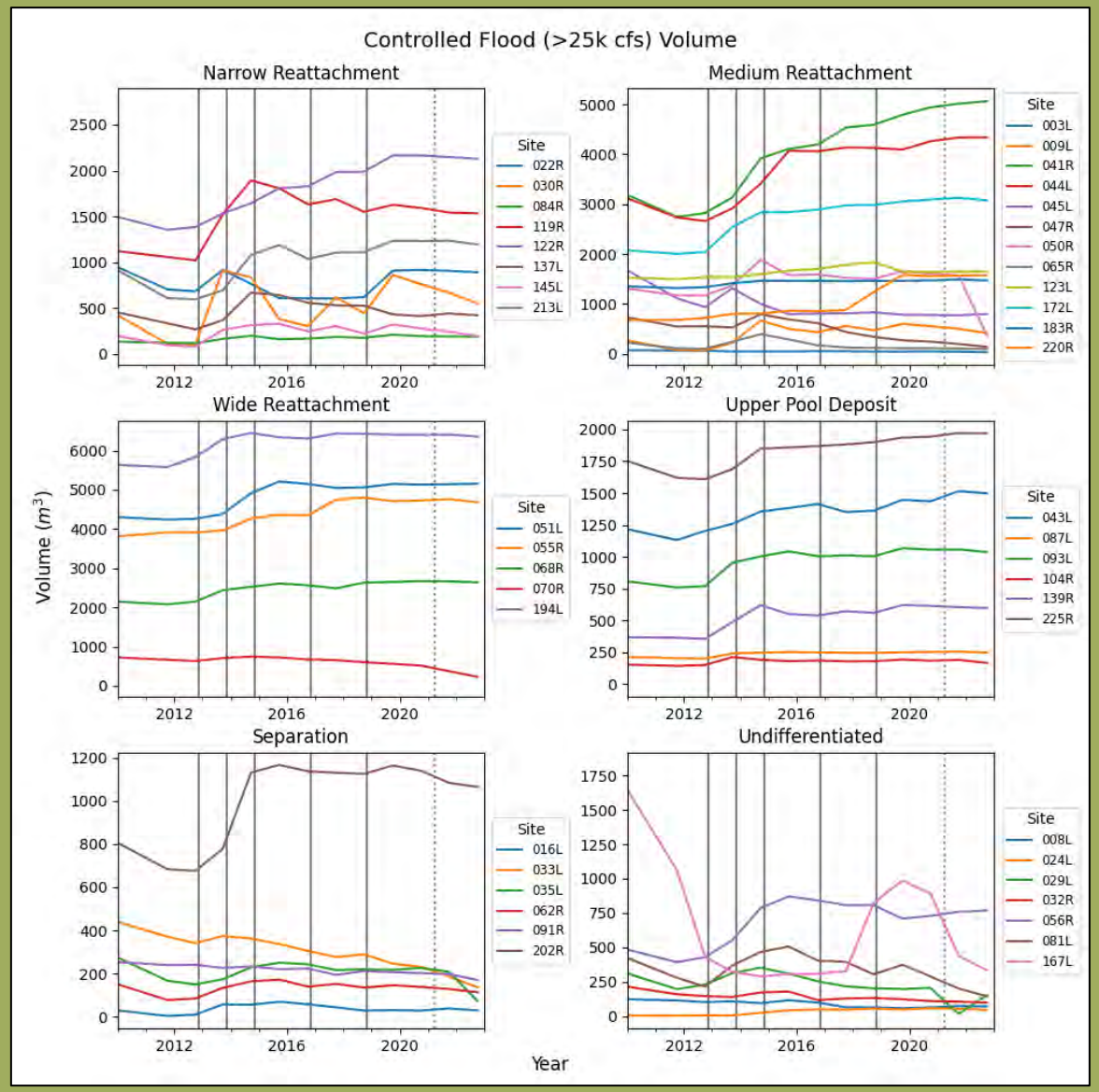
- all: fluctuate more, less predictably than higher elevation
- Smaller magnitude long term change than higher elevation
- Reattachment and upper pool bars: larger than in 1990 and 2012; more pronounced increase in narrow and medium reattachment bars
- Separation and Undifferentiated: mirrors decrease seen in high elevations

>>Potential for increasing long term sand storage? minimal

Lower Elevation (8-25k cfs) Volume:



Higher Elevation (>25k cfs) Volume



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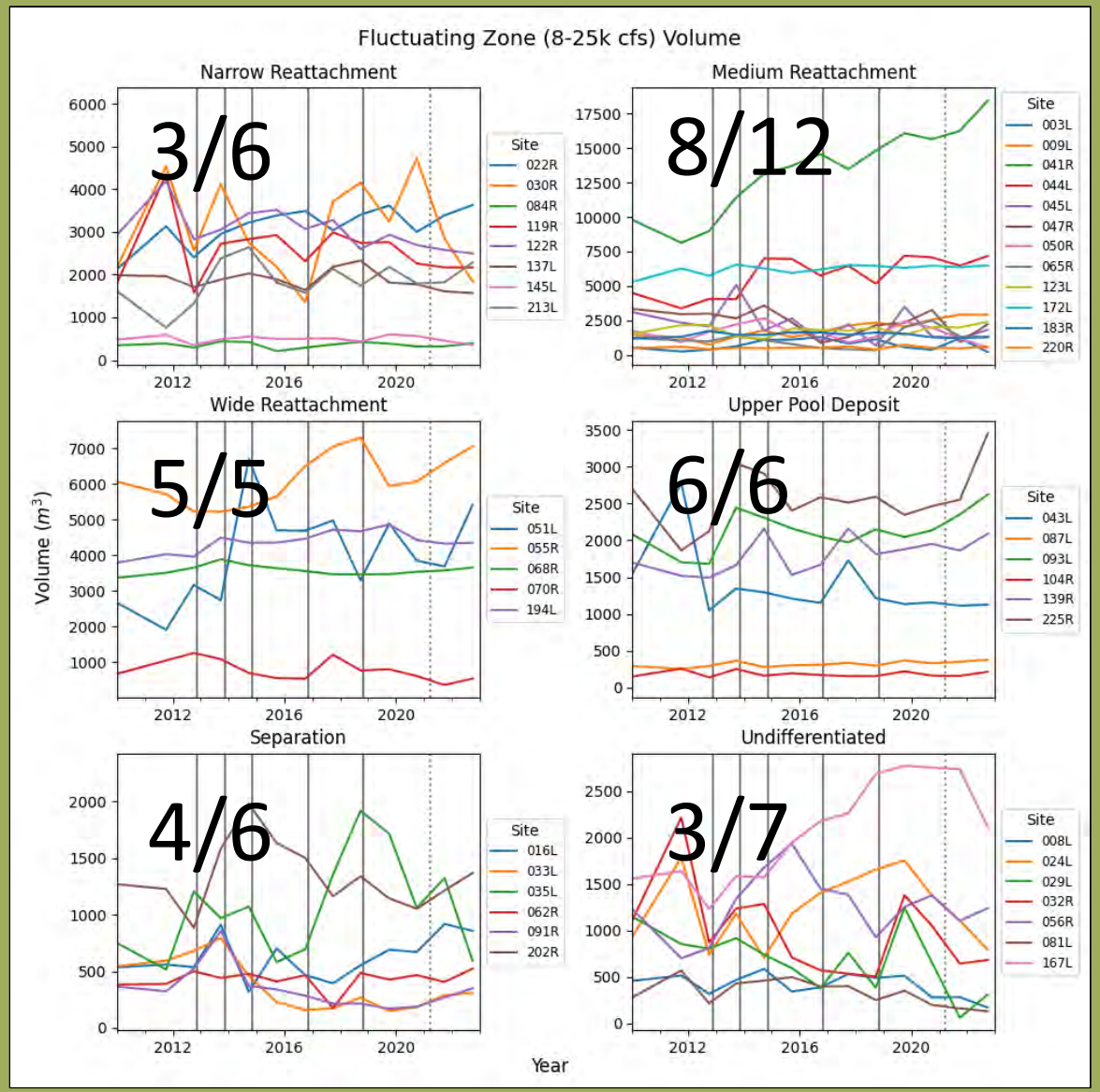
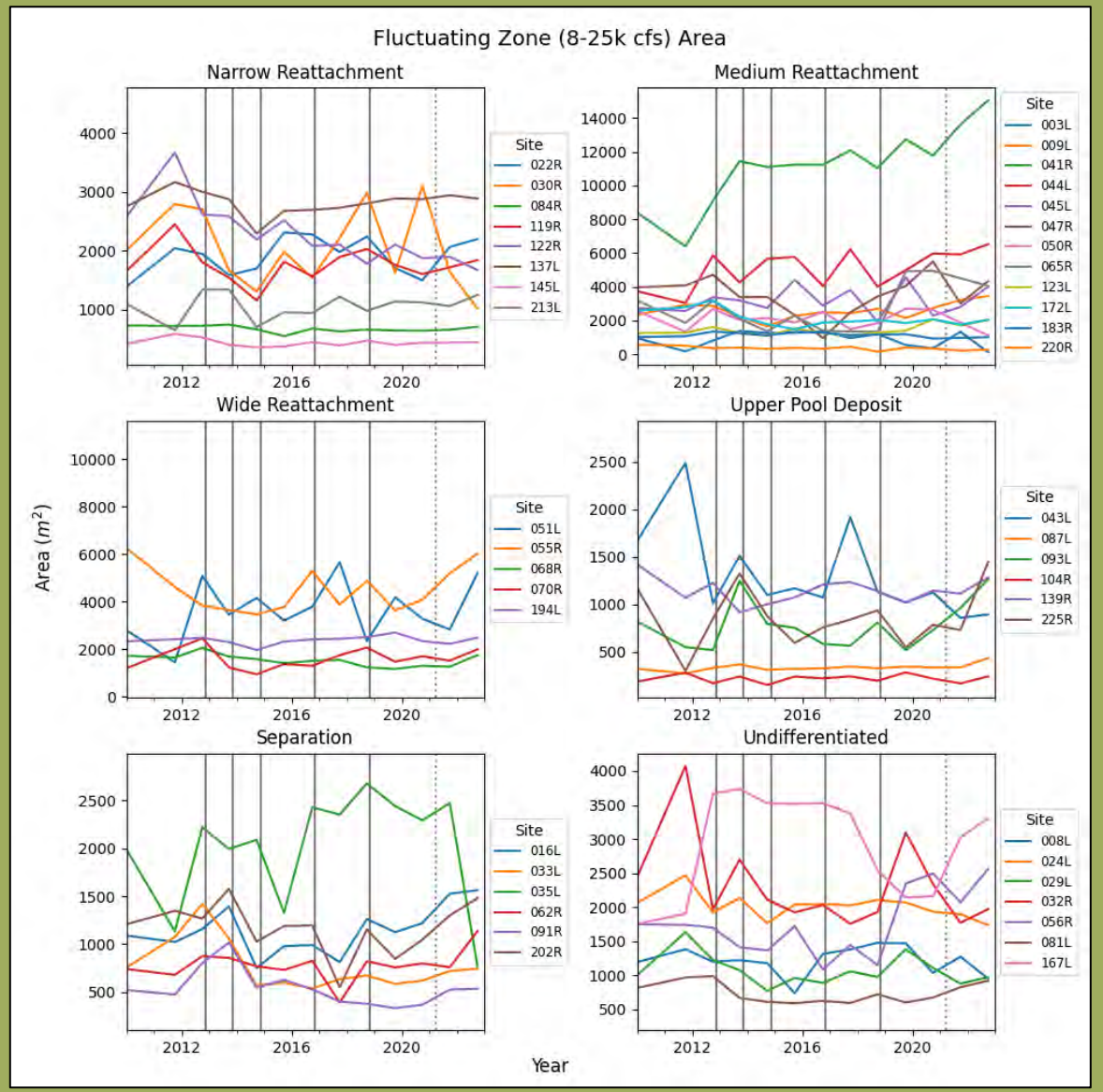
Lower Elevation (8-25k cfs) **Volume**



Lower Elevation (8-25k cfs) **Area**



Increase in the area occupied by sand in the 8-25k cfs (lower) elevation range

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22-Mile (Narrow Reattachment Bar)

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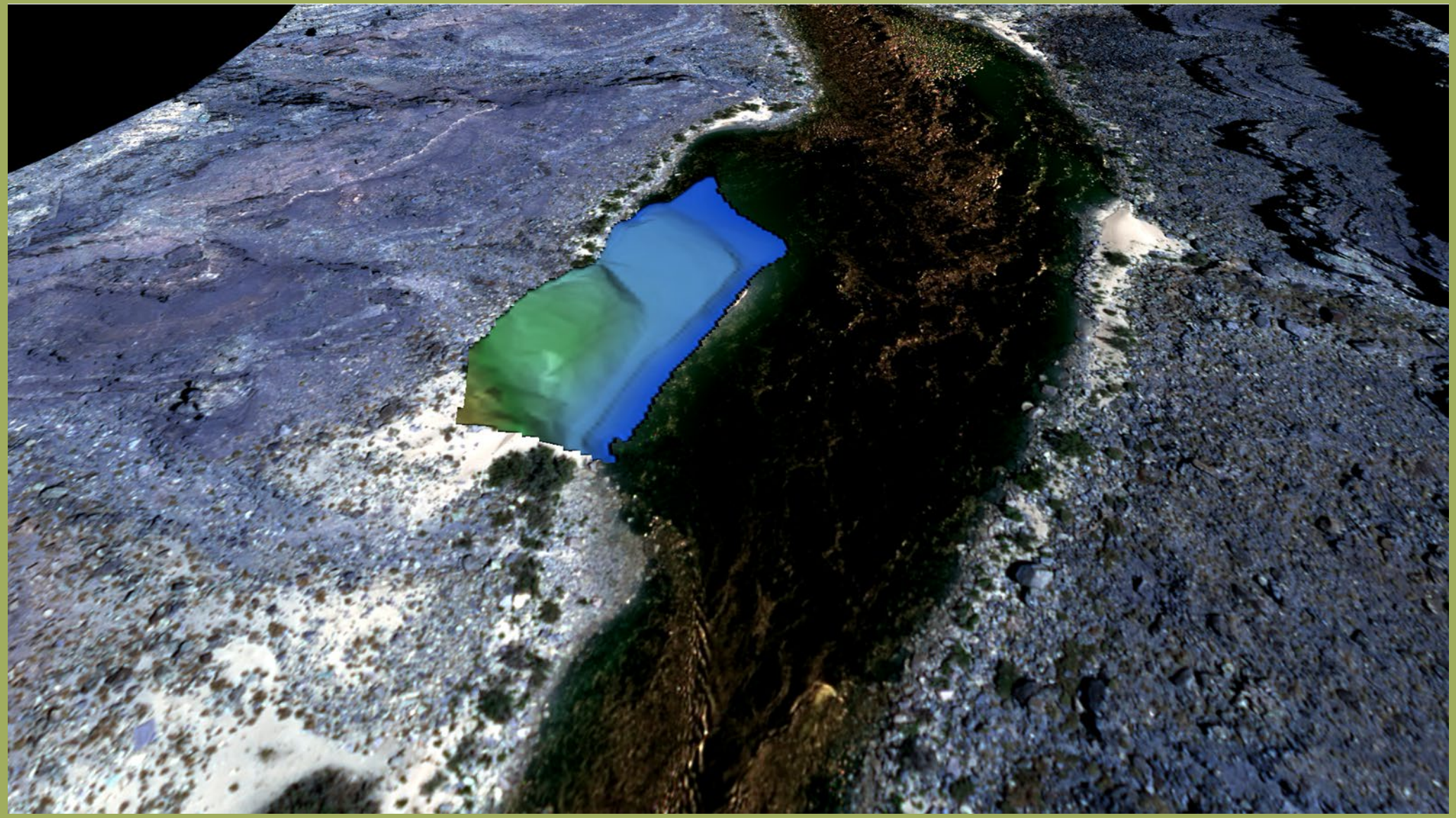
22-Mile (Narrow Reattachment Bar)



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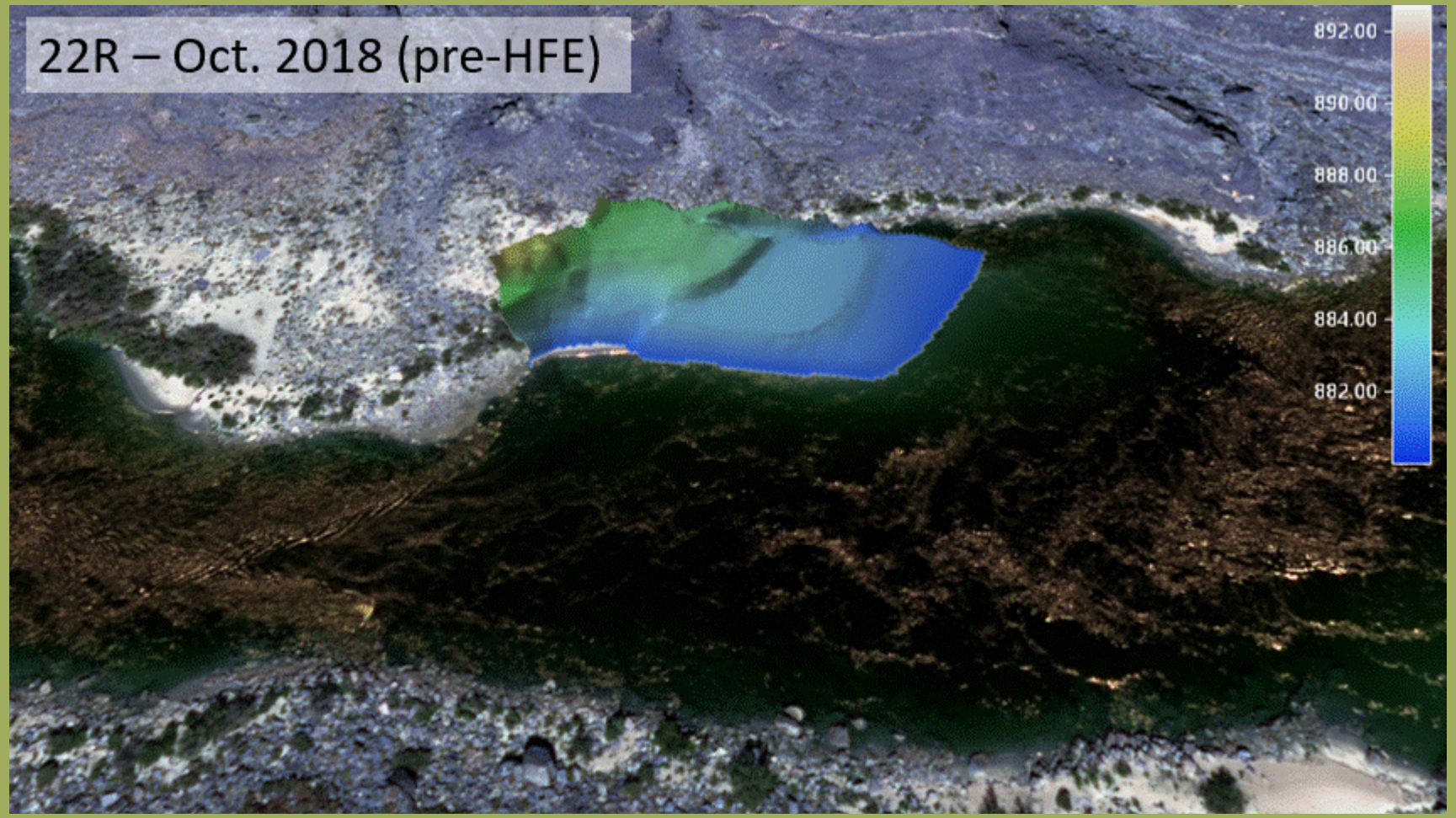
22-Mile (Narrow Reattachment Bar)



2018-2022:

High elevation bench:
- Deposition by HFE
- erosion without HFEs

- Low elevation bench expanding

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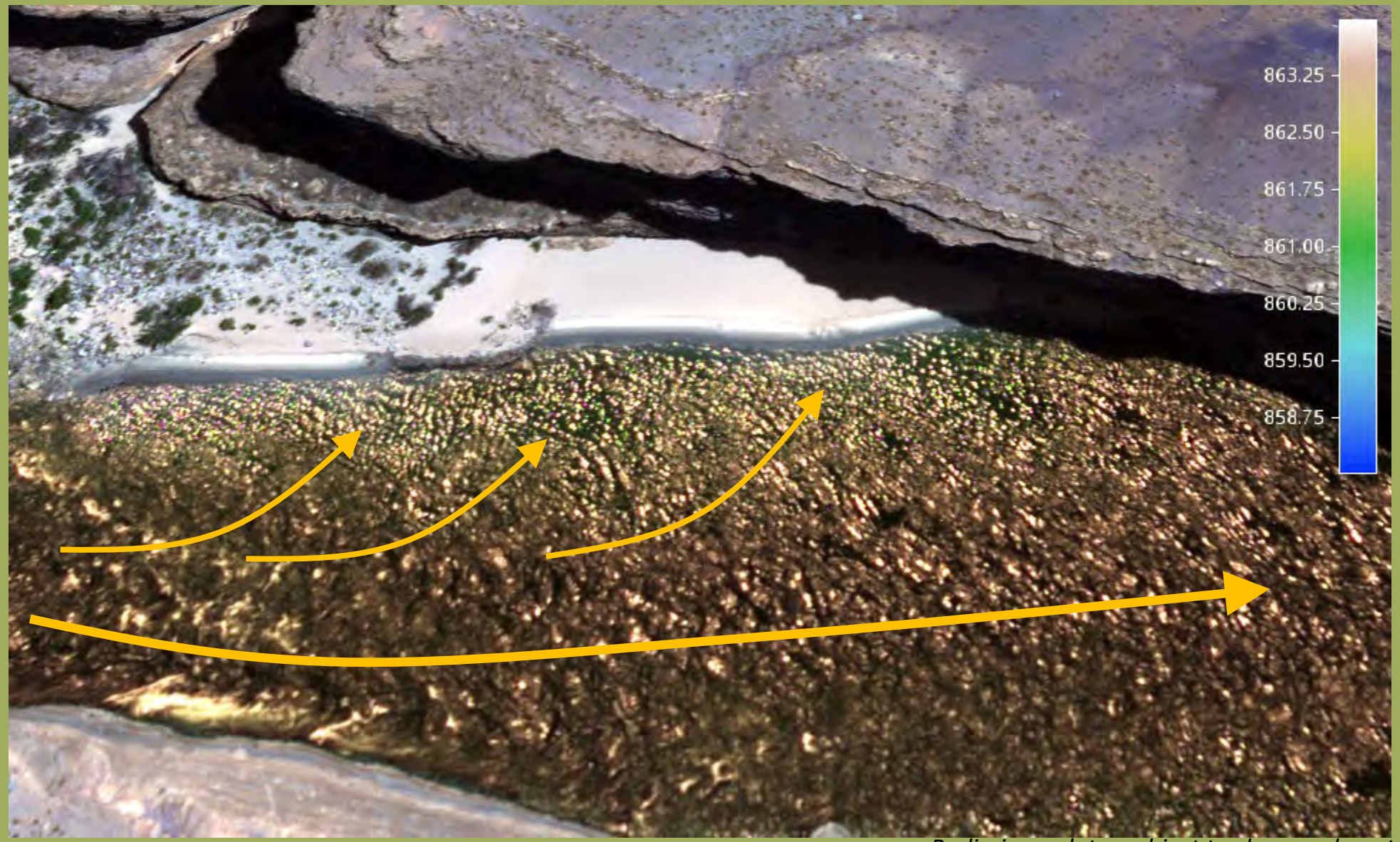
RM 29L Silver Grotto: (Undifferentiated)



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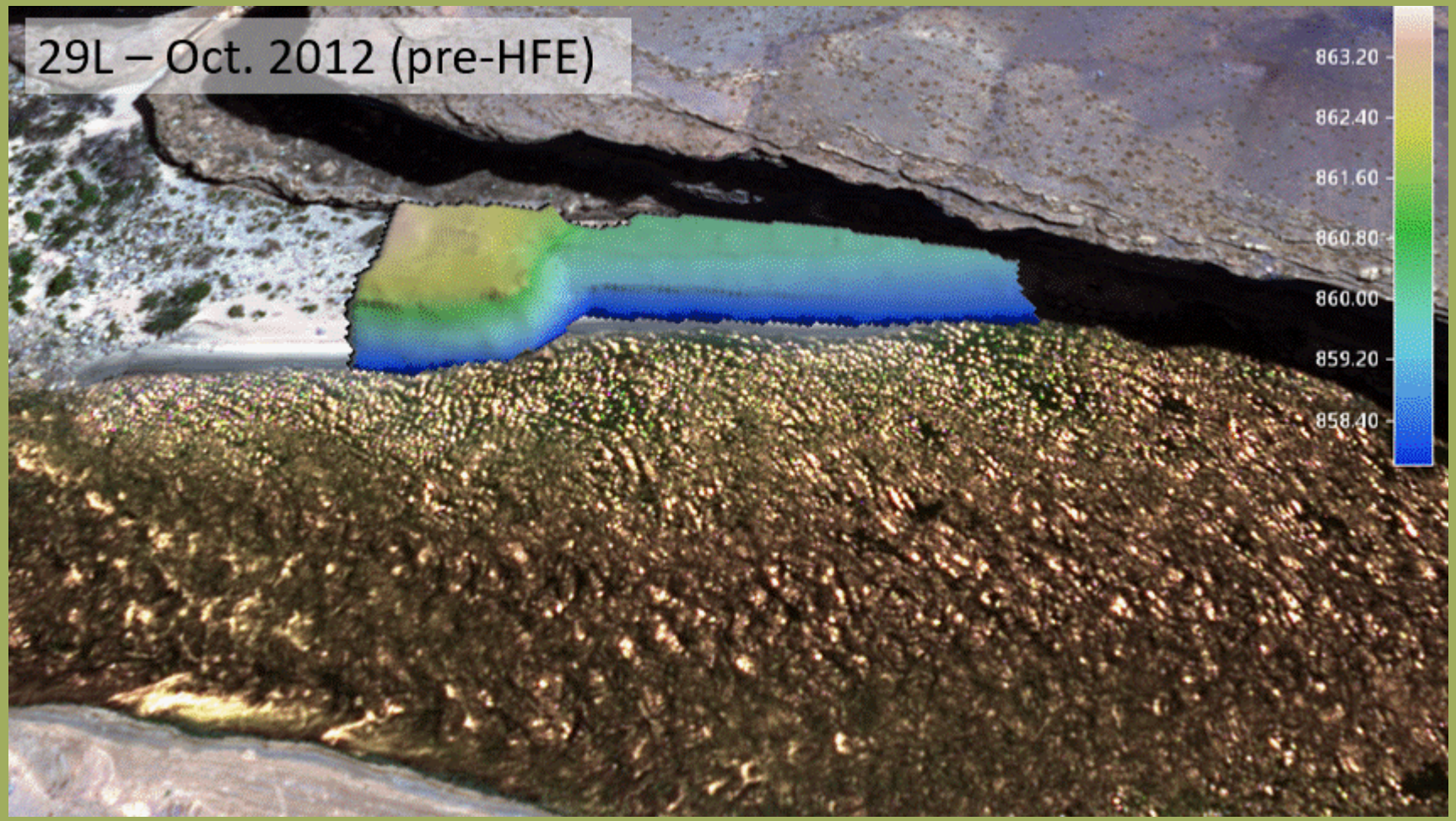
RM 29L Silver Grotto: (Undifferentiated), 2012-2015



2012-2015: before then after three HFEs in a row

- Upstream high elevation bench is maintained
- Downstream high elevation bench is *not* built up by successive HFEs

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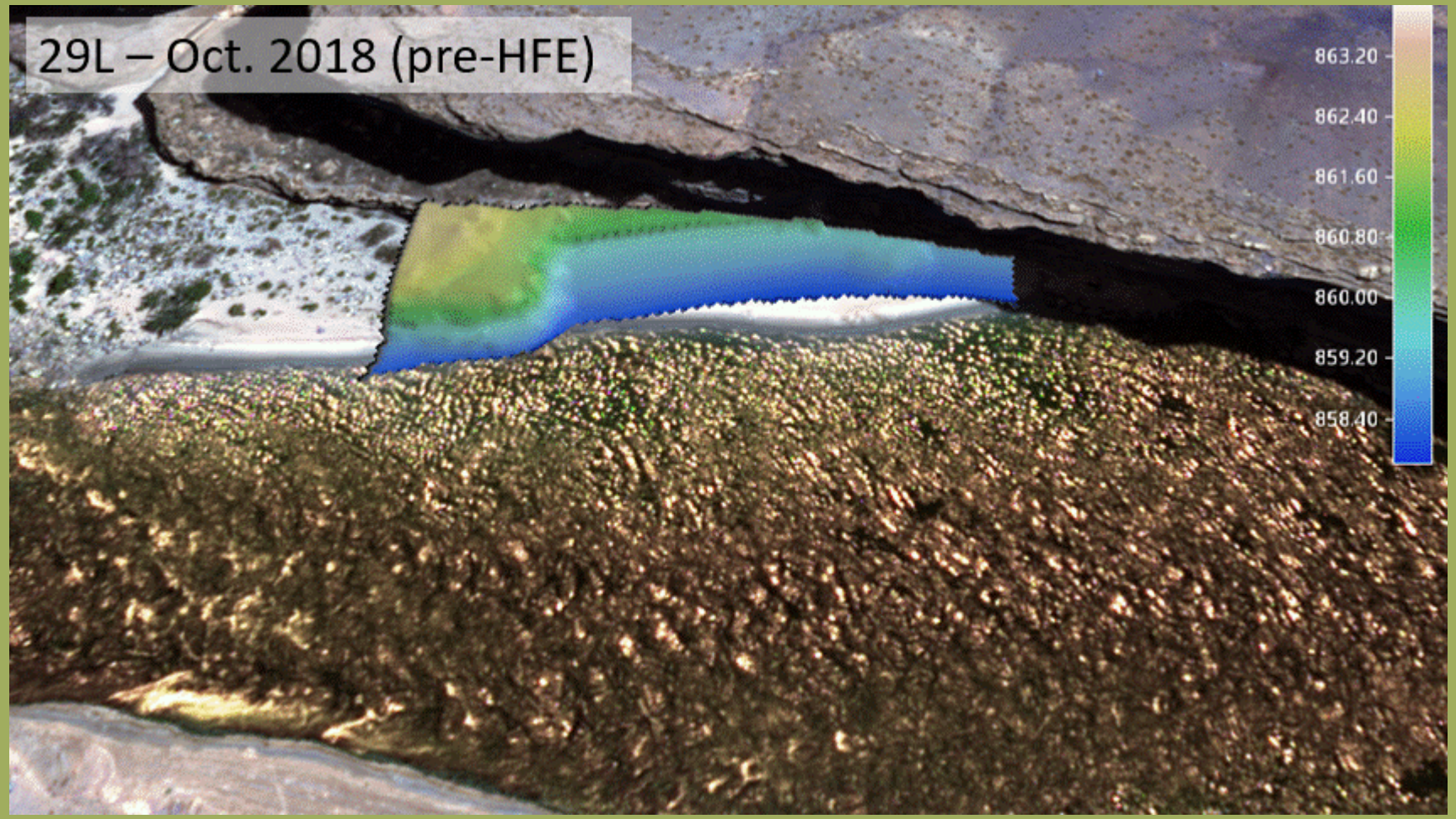
RM 29 Silver Grotto (Undifferentiated) 2018-2022



2018-2022: Deposition by 2018, erosion since

- Low elevation sand gains volume during HFE
- High elevation bench eroded by daily flows (cutbank on downstream half), 2019-2021
- Gullying erosion (upstream end)

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119-Mile: narrow reattachment bar

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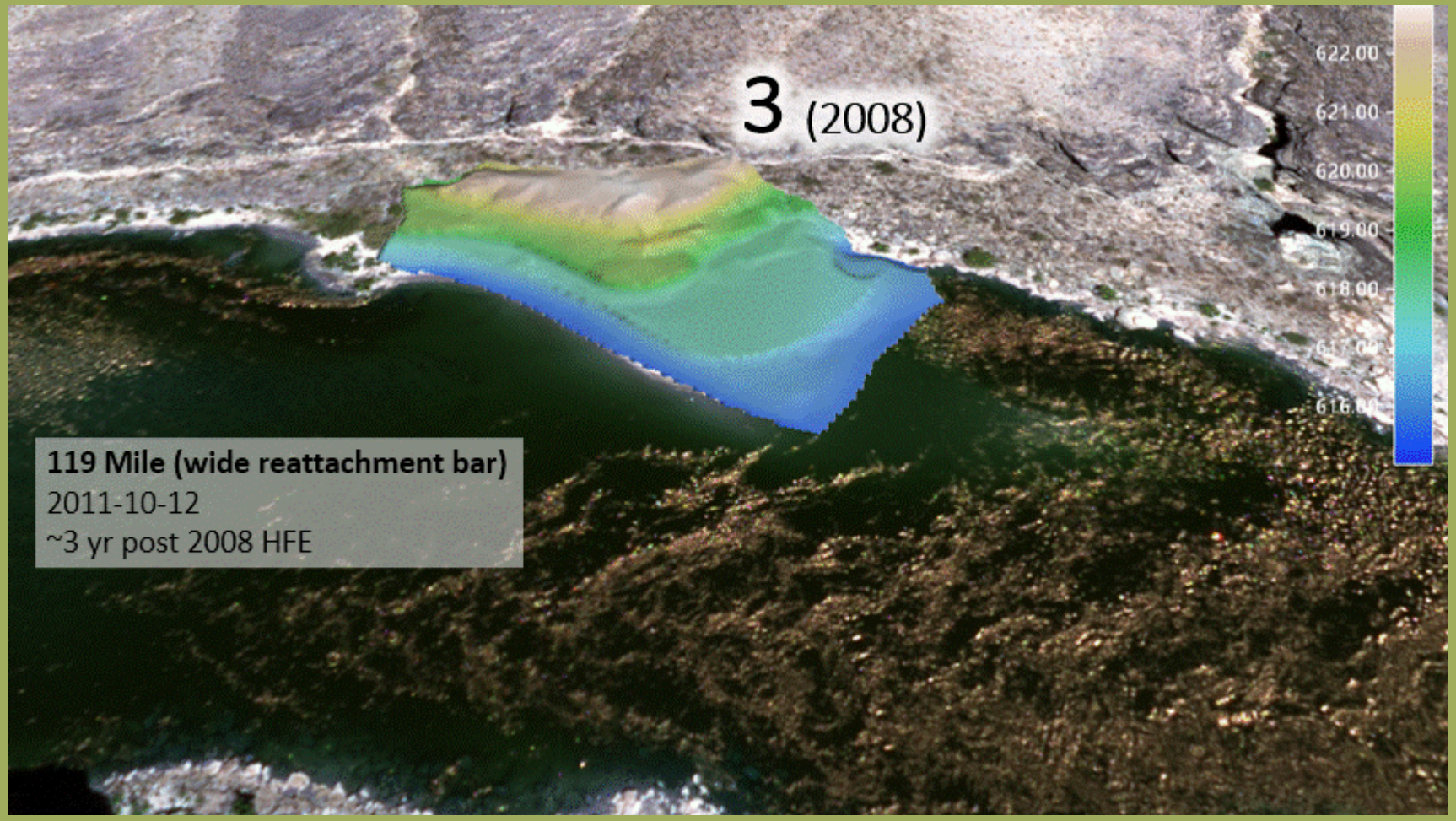
RM 119 (Narrow Reat.) 2011 - 2022



2011-2022: HFE deposition, cutbank erosion, low bench fluctuation

- Higher elevation bench builds during HFEs
- Cutbank at downstream end of bar eroding in interim flows
- Low elevation bench grows in last 4 years since 2018 HFE
- High elevation bench fairly stable in last 4 years

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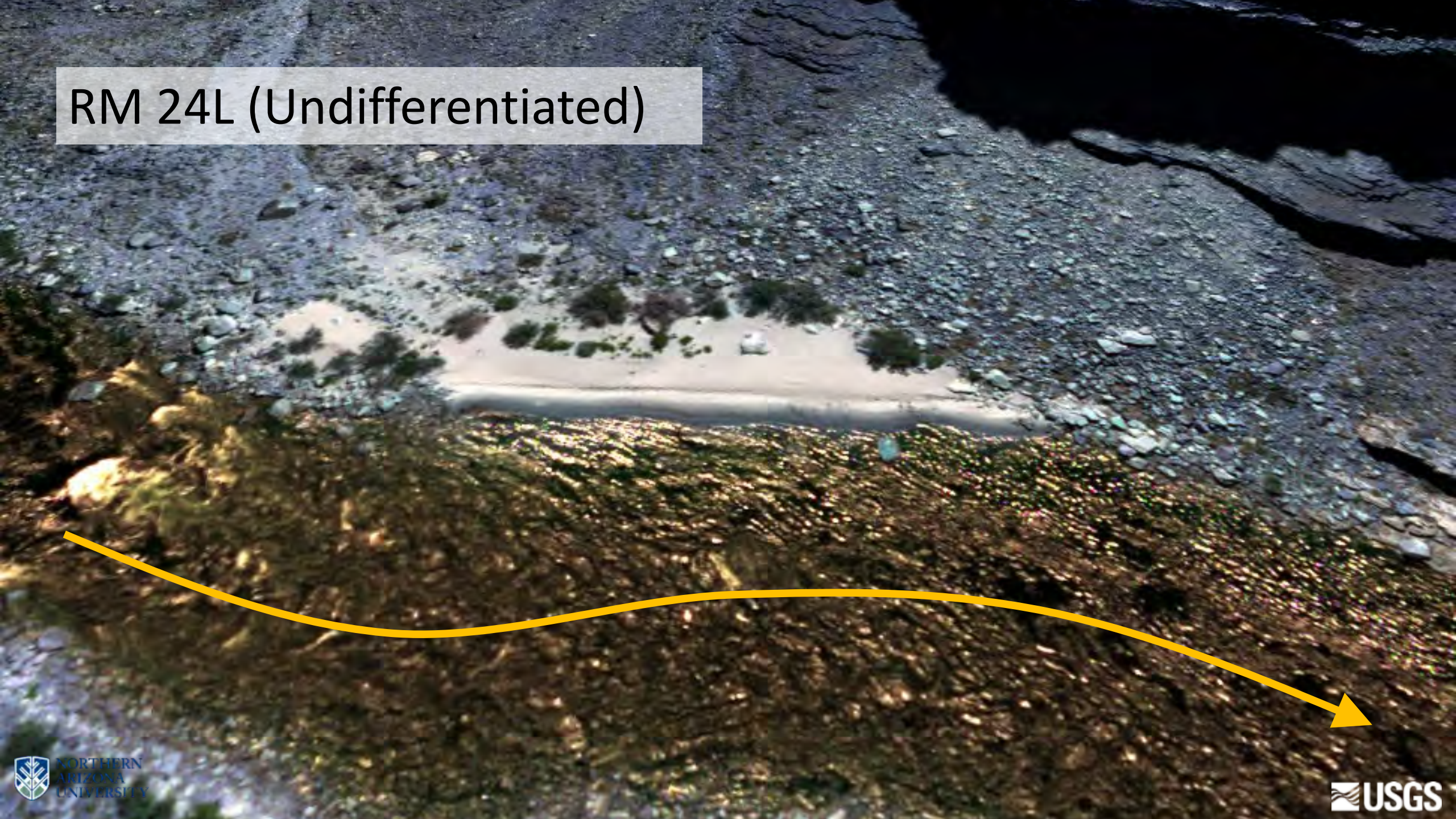
RM 24L (Undifferentiated)



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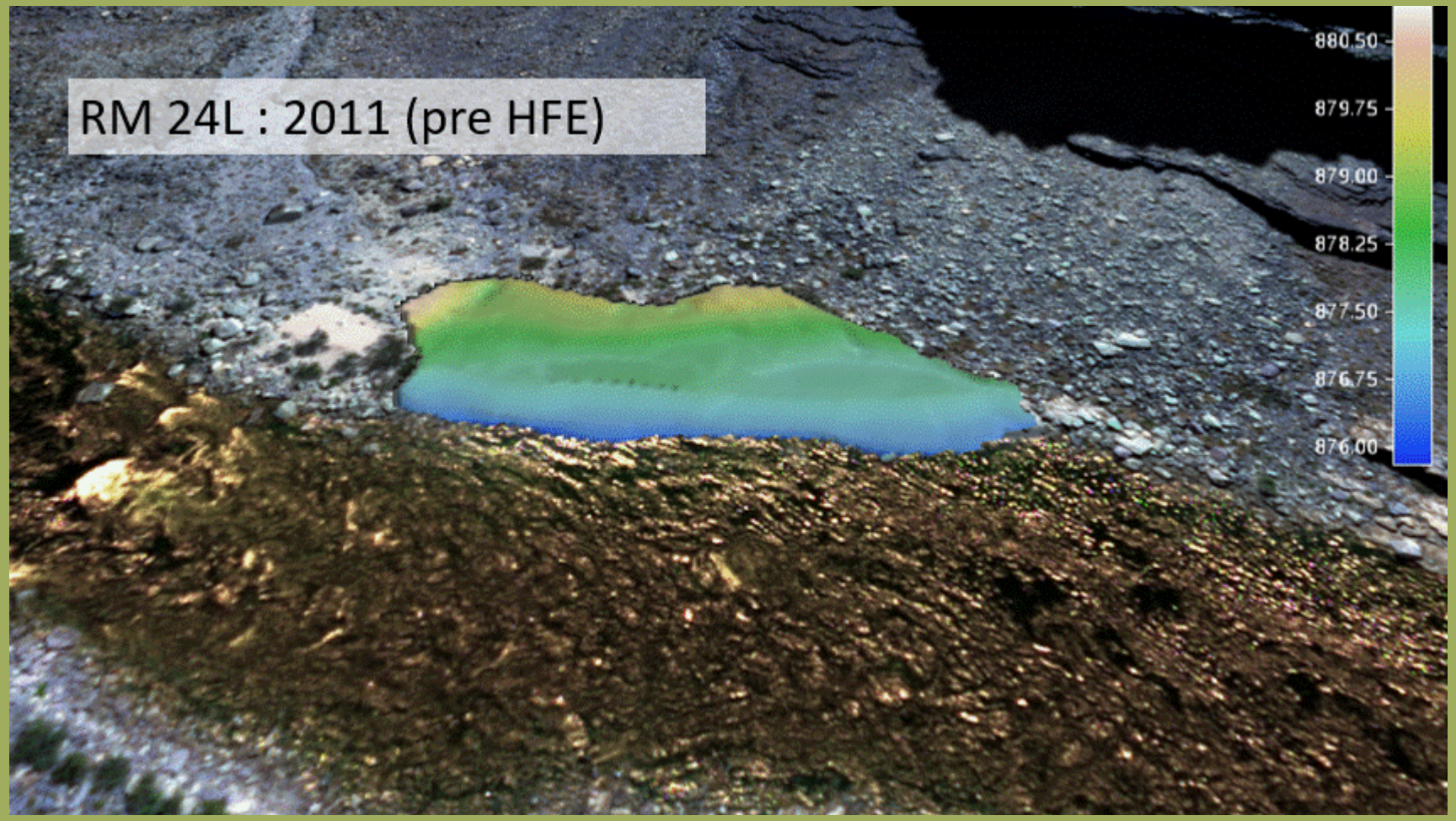
RM 24L (Undifferentiated) 2011-2022



2011-2022: Gully erosion and repair

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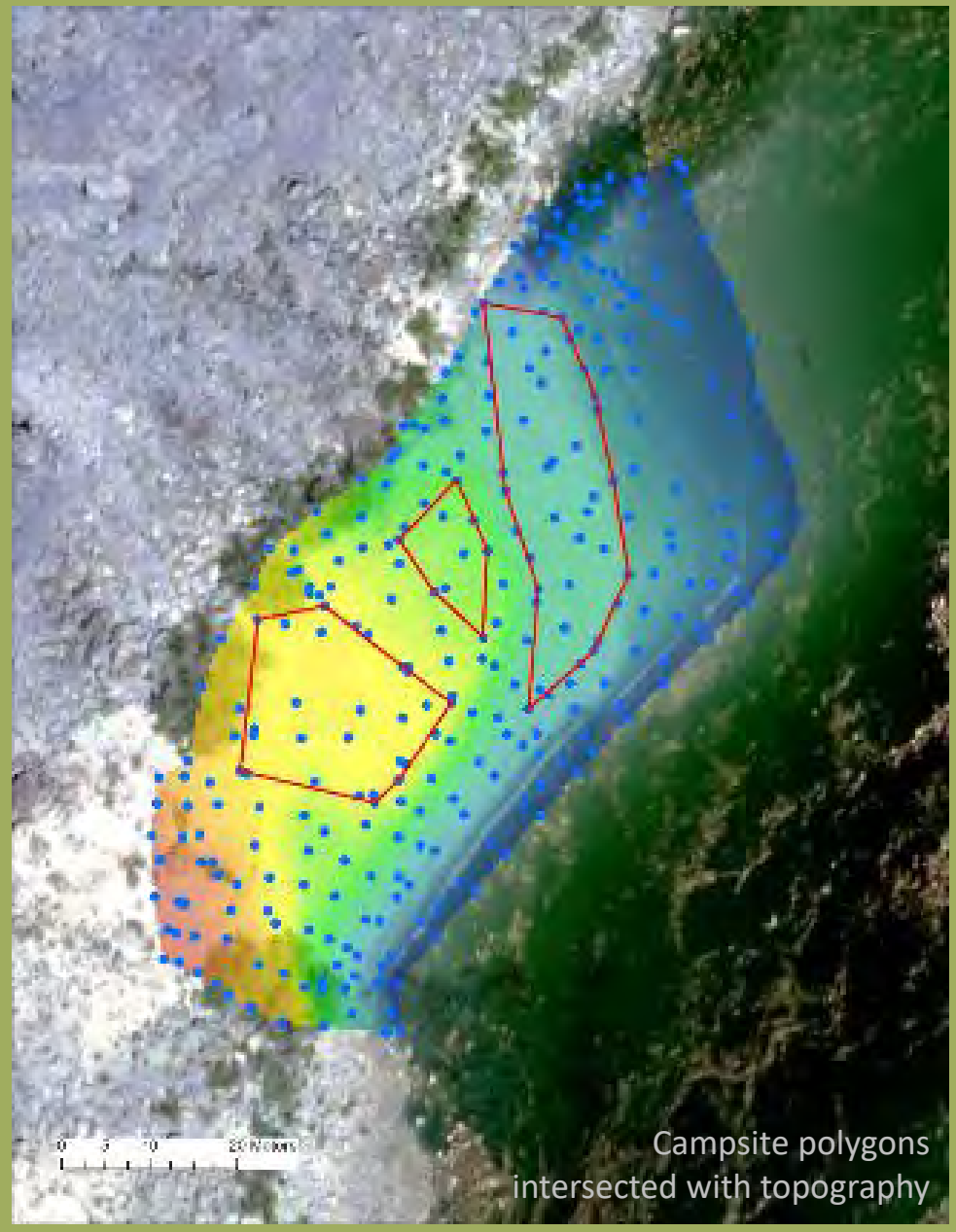
Measurement of campsite area

- Define campsite areas by field survey to create polygons of campsites
- **Campsite Area** = flat, horizontal (ish), no vegetation
- Intersect with topography to compute area for multiple elevation bins



Campsite polygons intersected with topography

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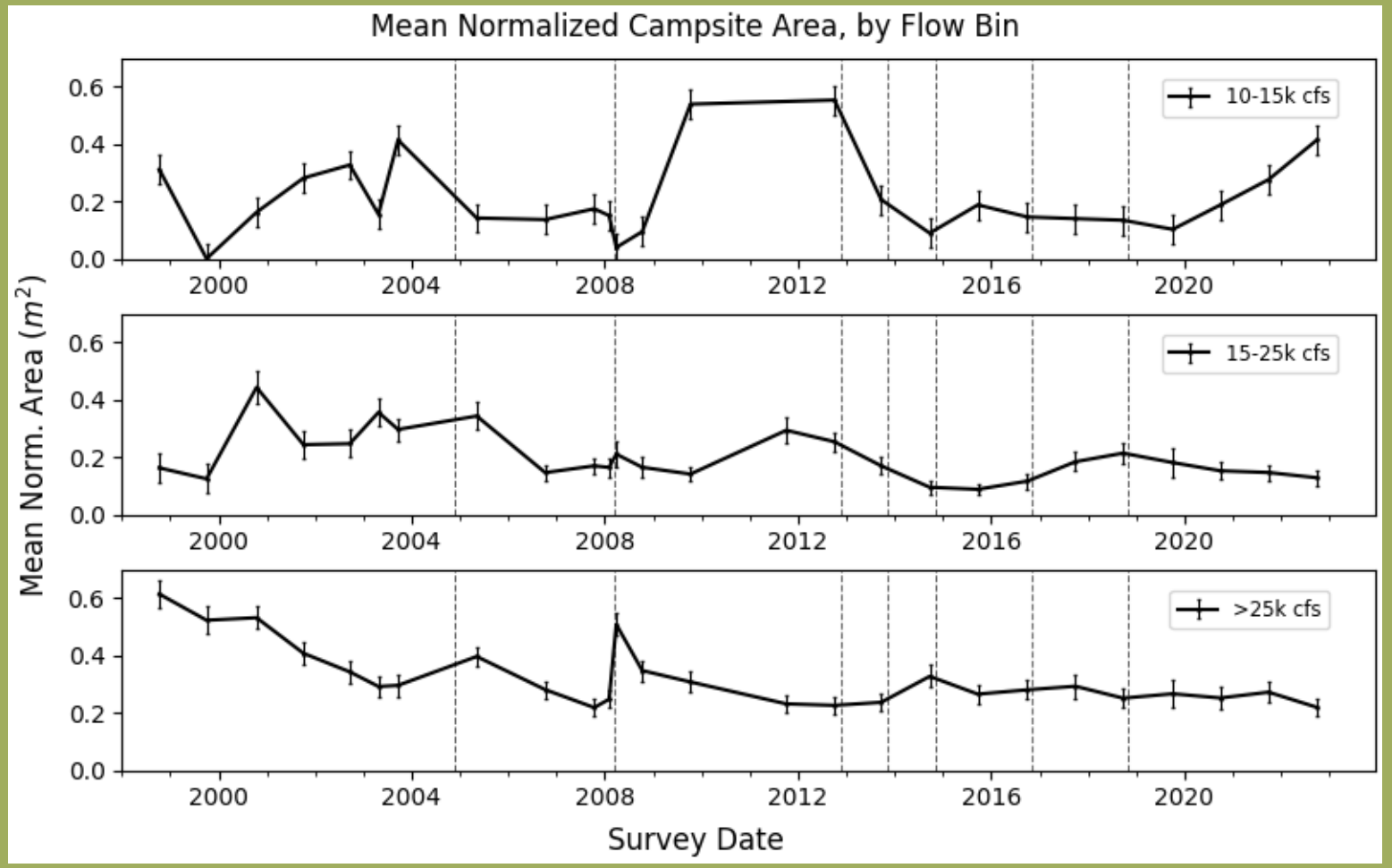
Campsite Areas



- Mirror sandbar volume and area behavior
- Lowest elevation sandbars are only ones increasing in size
- Many low elevation platforms approaching ‘too low’ elevation
- 10-15k cfs: underwater? impermanent
- Higher elevation campsites shrinking due to vegetation encroachment and erosion

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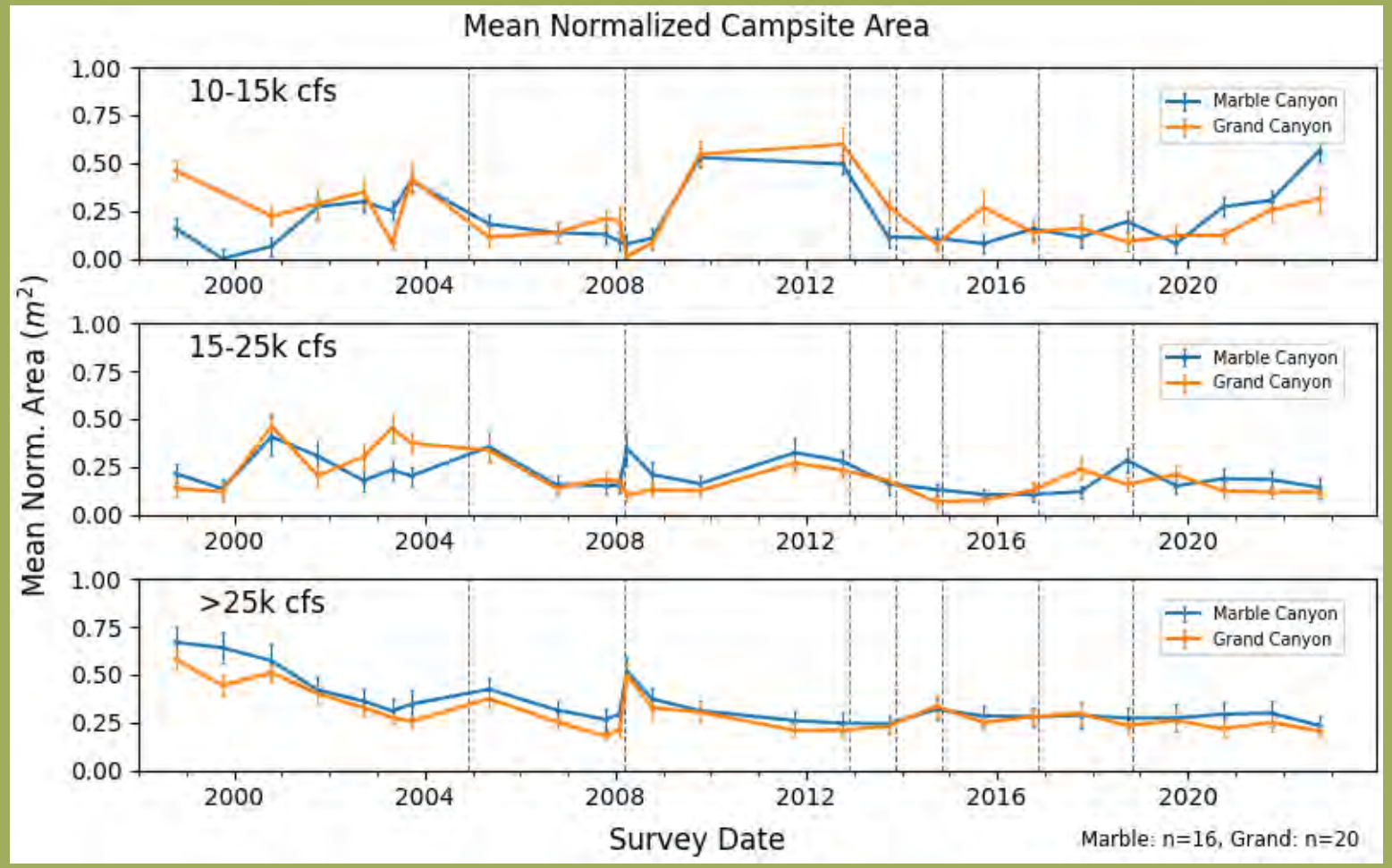
Campsite Areas: Marble vs. Grand Canyon



- 10-15k cfs elevation bin is only bin that shows a difference
- Distribution of Paria-introduced sand to these lowest elevation areas

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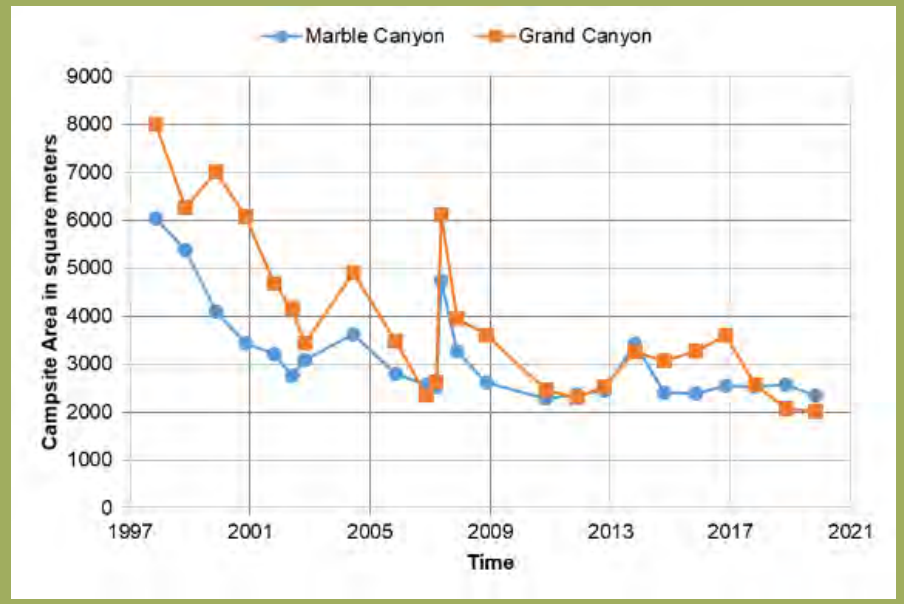
Vegetation expansion -> shrinking campsites

Major vegetation expansion at wide reattachment bars in late 1990's and early 2000's (Hadley and others, 2018)

Vegetation expansion continues to occur at many sites



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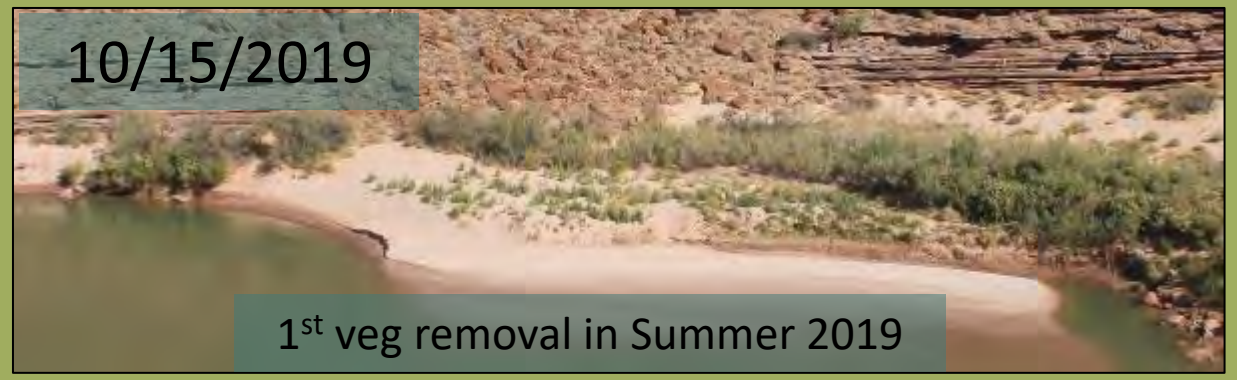
HFEs and NPS Vegetation Removal



- NPS is conducting vegetation treatment at 3 long-term sandbar monitoring sites
- monitor to see if treatment effects response to future HFEs, persistence of campsites

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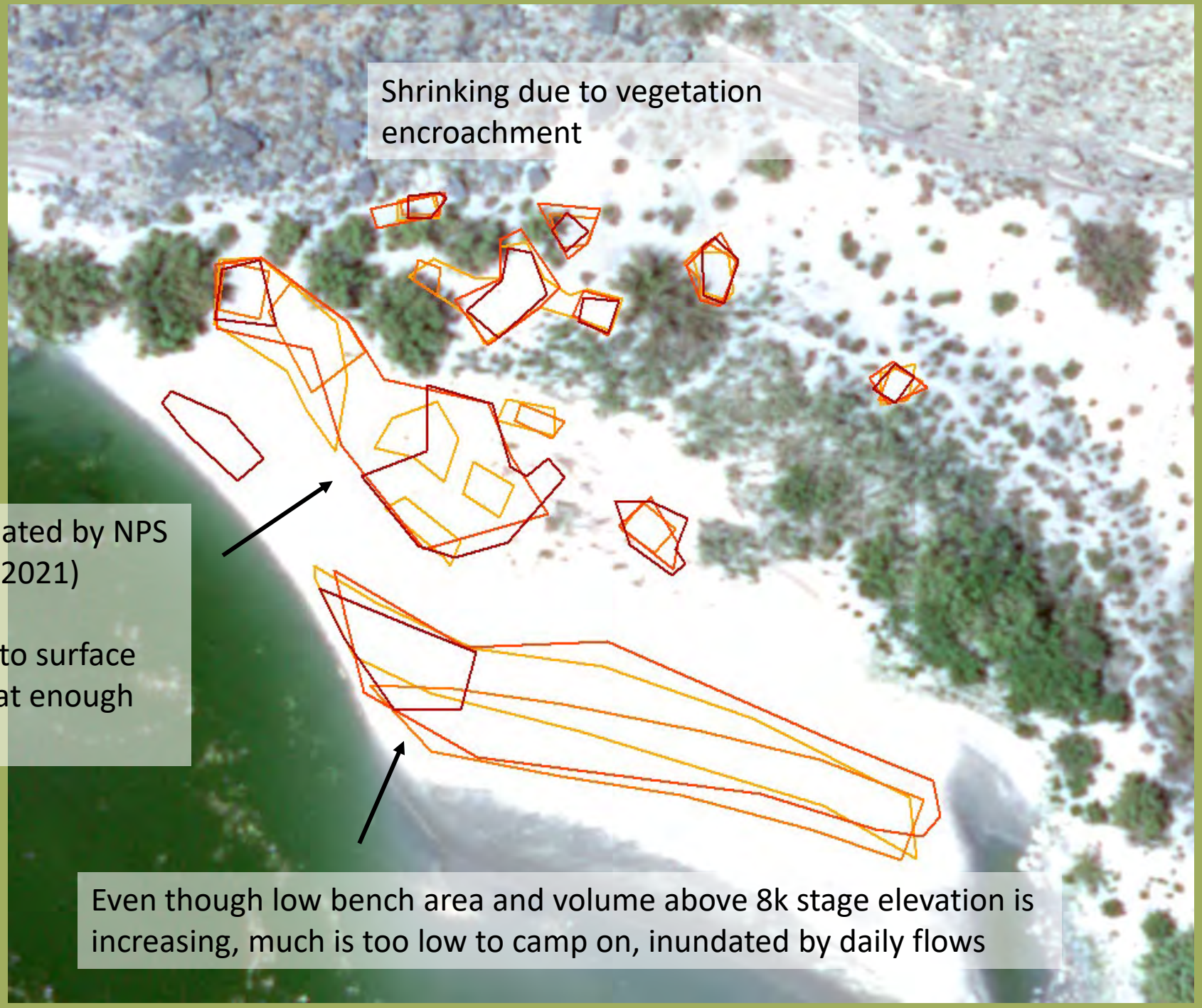
Preliminary results, subject to review, do not cite

USGS

122R: Campsite improvement due to NPS vegetation removal



USGS

Preliminary data, subject to change, do not cite

Summary

- Sand stored above 25,000 cfs stage elevation is **key to long term increases of total stored sand volume**
    - Deposition during HFEs, erosion during interim flows
    - Have lost progress made earlier in HFE protocol due to multi-year gaps between HFEs
- Lower elevation sand storage volumes increased in last year but are not reliable as long-term storage
- Vegetation encroachment and erosion -> decreasing camp area