The Individual and Additive Effects of Hydrologic Alteration and Vegetation Encroachment on Sediment Connectivity in Grand Canyon

Alan Kasprak

U.S. Geological Survey

24 January 2017

TWP Project 4.1 Research

with Daniel Buscombe, Joshua Caster, Amy East, Paul Grams, Helen Fairley, and Joel Sankey

USGS Grand Canyon Monitoring and Research Center

Flagstaff, Arizona

USGS
science for a changing world

The Individual and Additive Effects of Hydrologic Alteration and Vegetation Encroachment on Sediment Connectivity in Grand Canyon

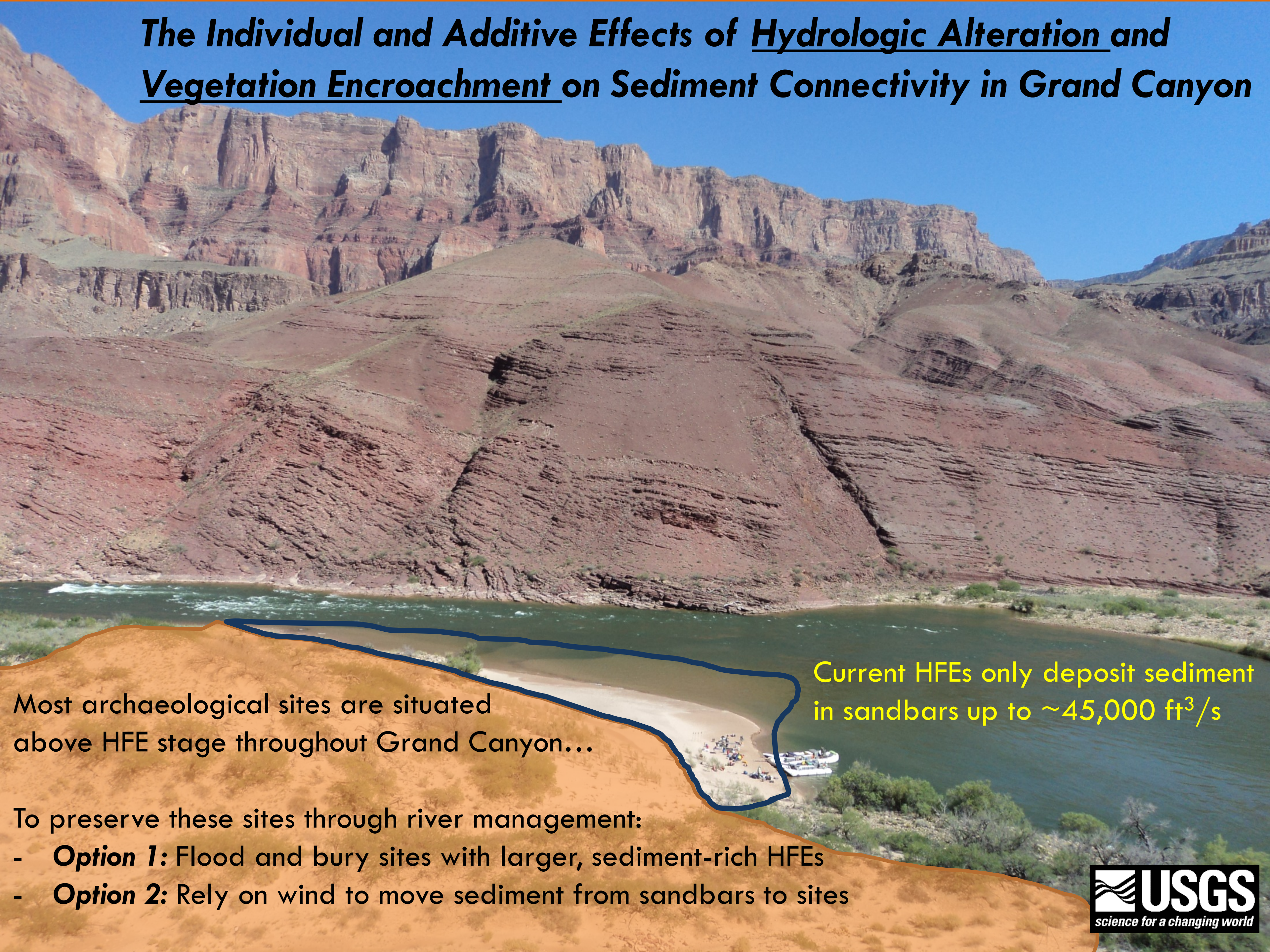
Most archaeological sites are situated above HFE stage throughout Grand Canyon…

To preserve these sites through river management:

- ***Option 1:*** Flood and bury sites with larger, sediment-rich HFEs
- ***Option 2:*** Rely on wind to move sediment from sandbars to sites

USGS science for a changing world

The Individual and Additive Effects of Hydrologic Alteration and Vegetation Encroachment on Sediment Connectivity in Grand Canyon



Current HFEs only deposit sediment in sandbars up to ~45,000 ft^3/s

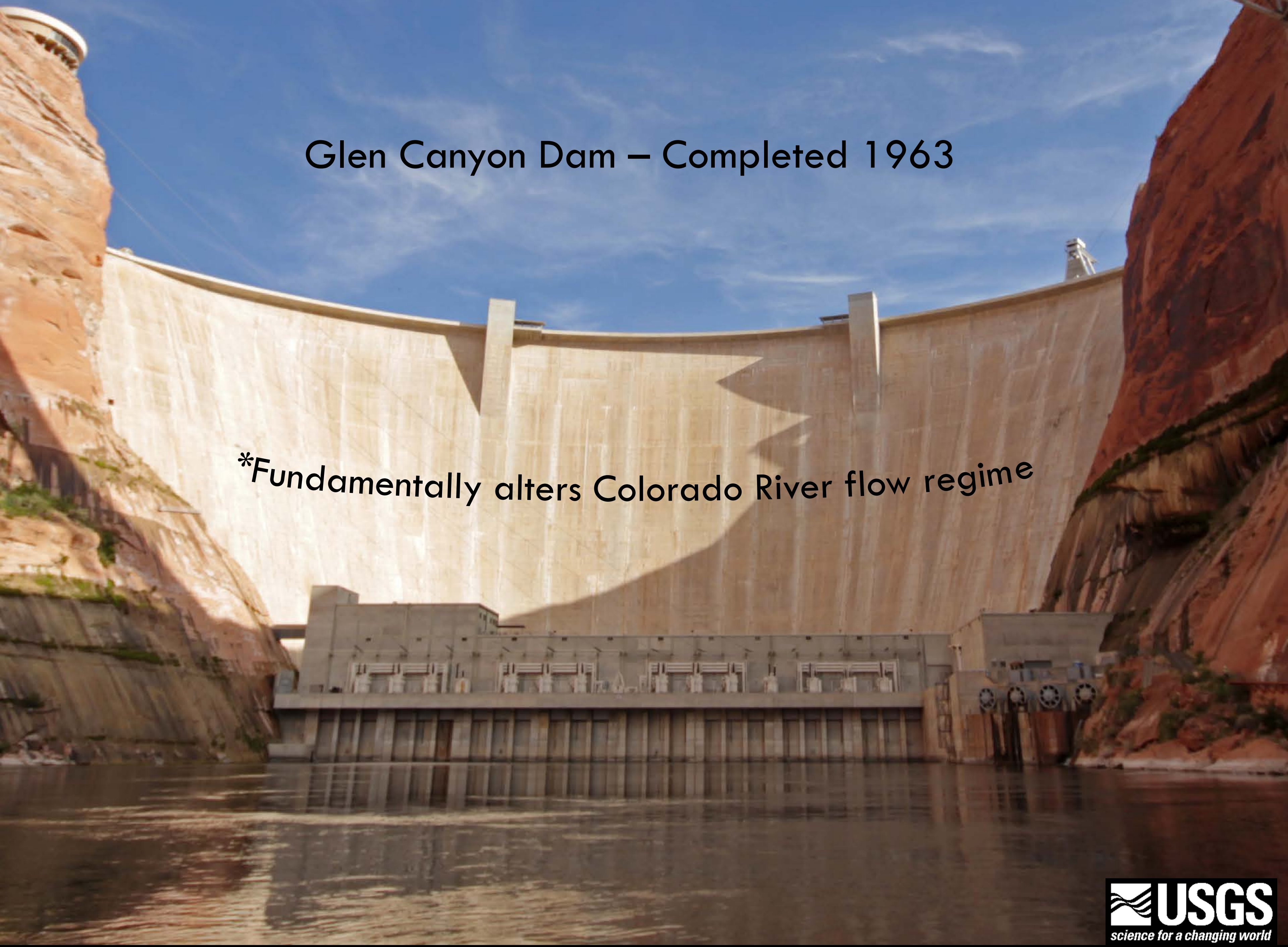
Most archaeological sites are situated above HFE stage throughout Grand Canyon…

To preserve these sites through river management:

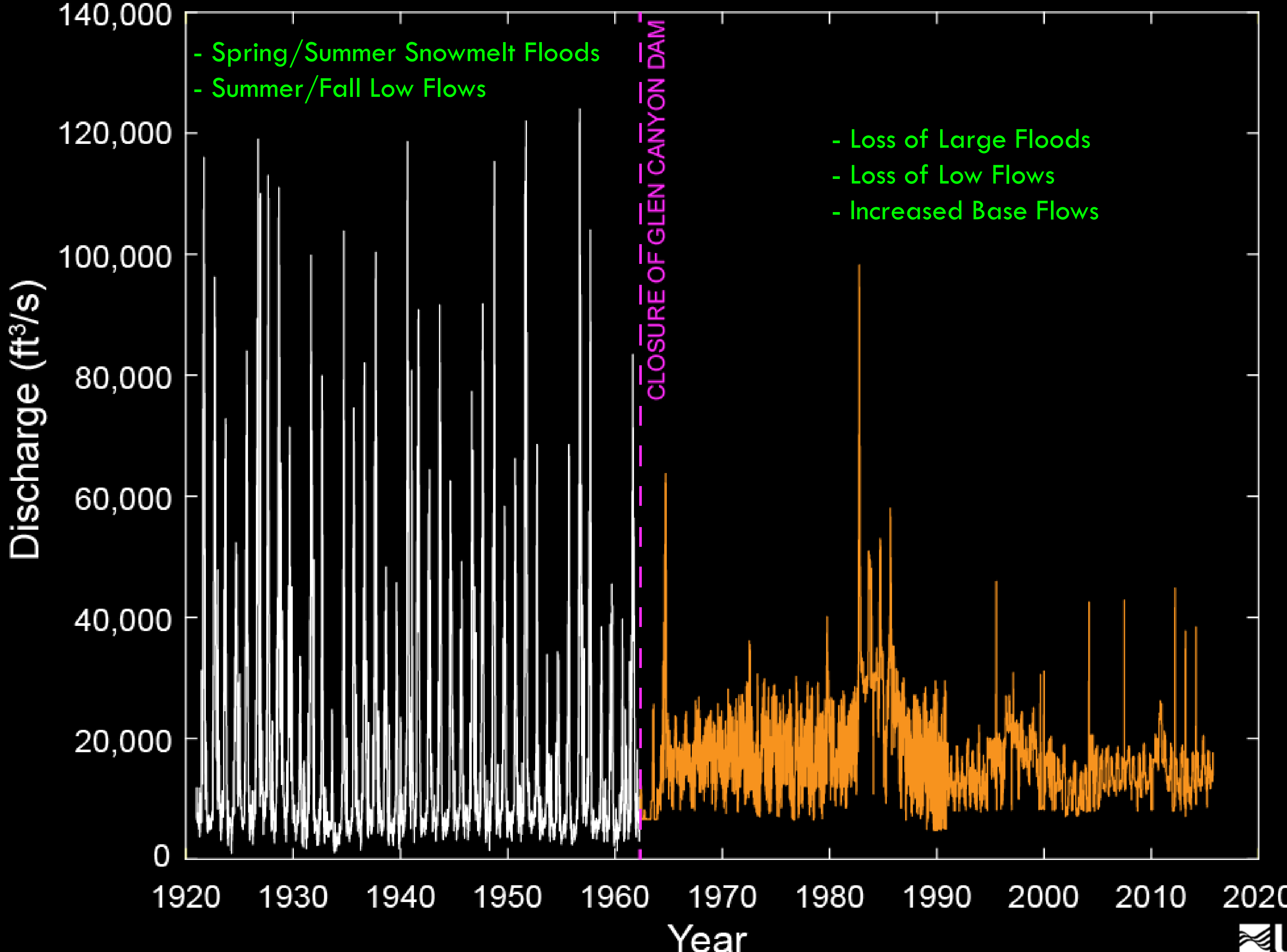
- ***Option 1:*** Flood and bury sites with larger, sediment-rich HFEs
- ***Option 2:*** Rely on wind to move sediment from sandbars to sites

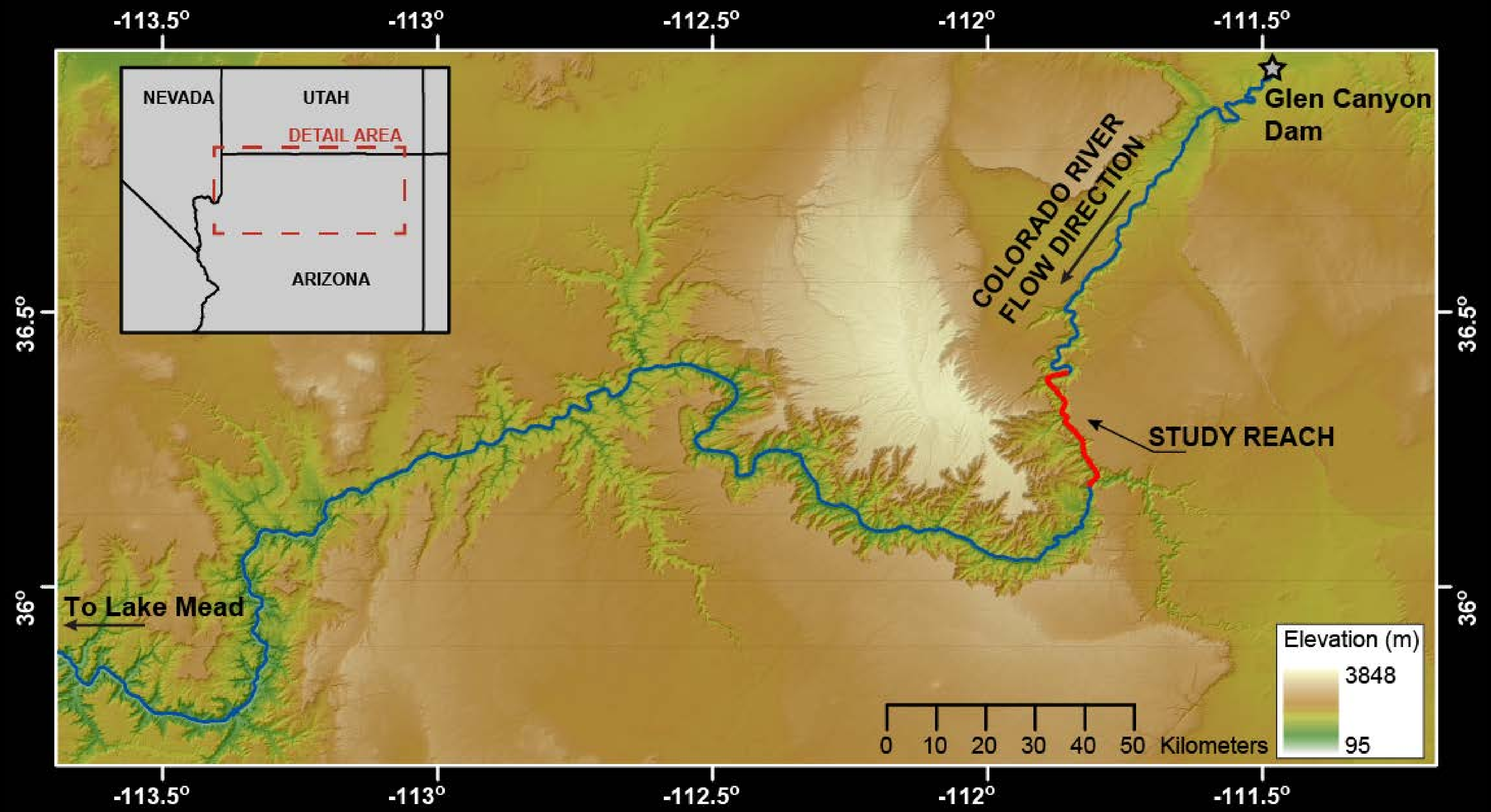
USGS
science for a changing world


The Individual and Additive Effects of Hydrologic Alteration and Vegetation Encroachment on Sediment Connectivity in Grand Canyon
Current HFEs only deposit sediment in sandbars up to ~45,000 ft^3/s
Most archaeological sites are situated above HFE stage throughout Grand Canyon
AEOLIAN TRANSPORT
To preserve these sites through river management:
- ~~Option 1: Flood and bury sites with larger, sediment-rich HFEs~~
- Option 2: Rely on wind to move sediment from sandbars to sites
USGS
science for a changing world


Glen Canyon Dam – Completed 1963
*Fundamentally alters Colorado River flow regime
USGS
science for a changing world

Colorado River at Lee's Ferry





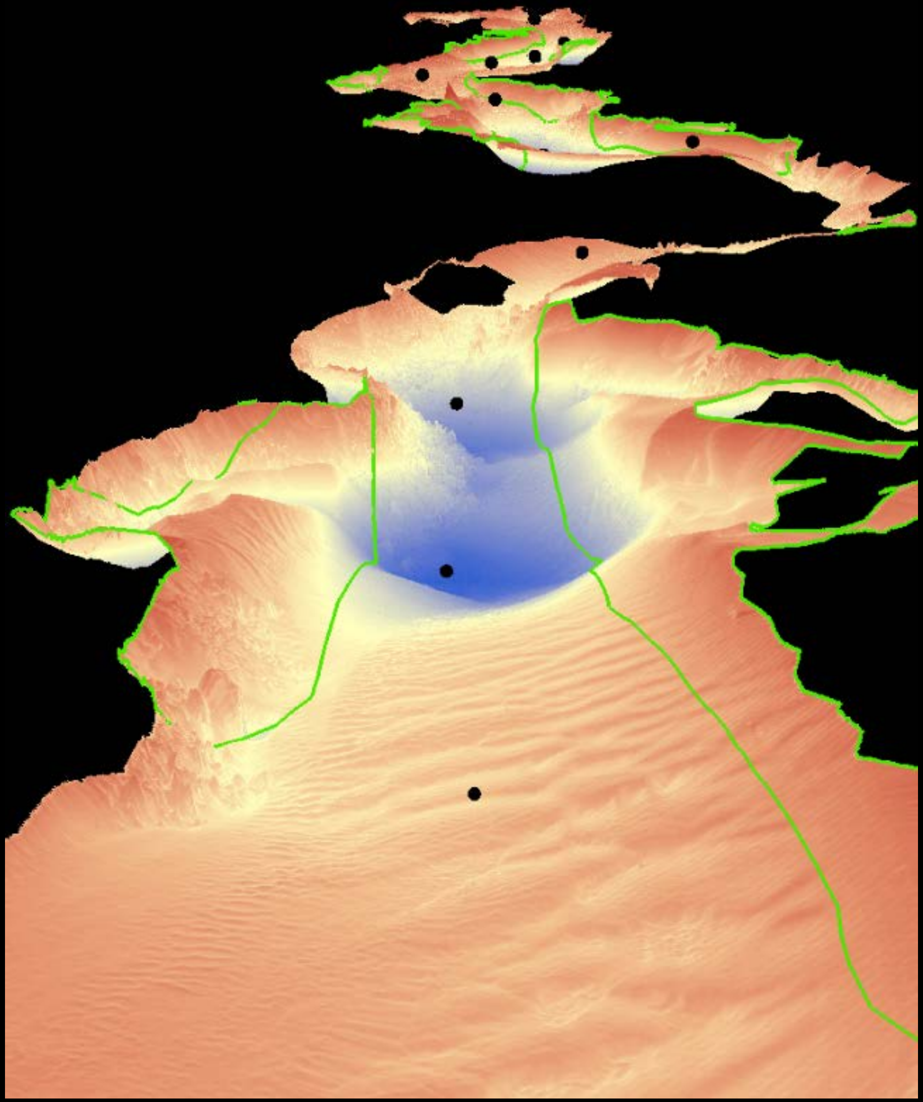
Study Area:

- 16 mile river reach of Colorado River in Grand Canyon National Park
- From 45 to 61 miles downstream of Glen Canyon Dam

Mapping Sand Along the Colorado River in Grand Canyon – May, 2009

Channel bed mapping with multibeam sonar

Total station surveys of exposed sand

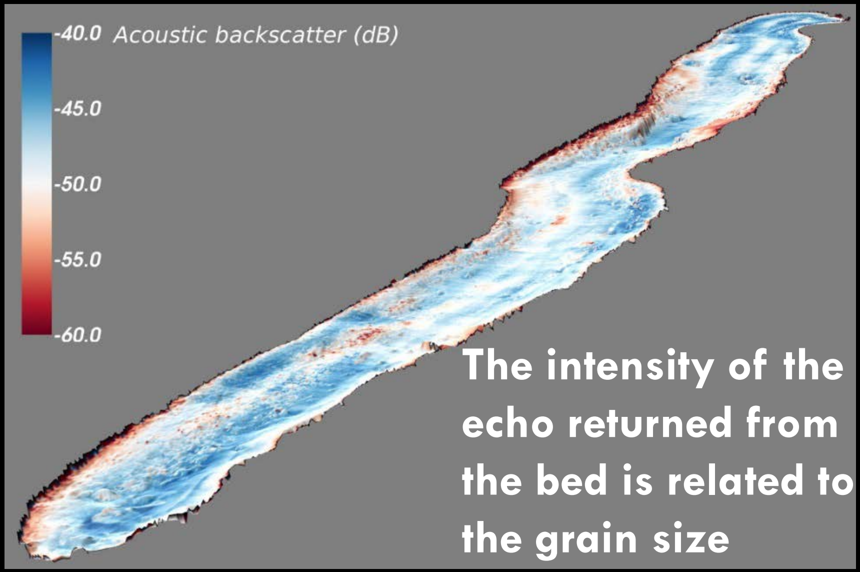


Upstream-looking DEM
(black dots are 1/10 mile intervals)

**preliminary results, do not cite*

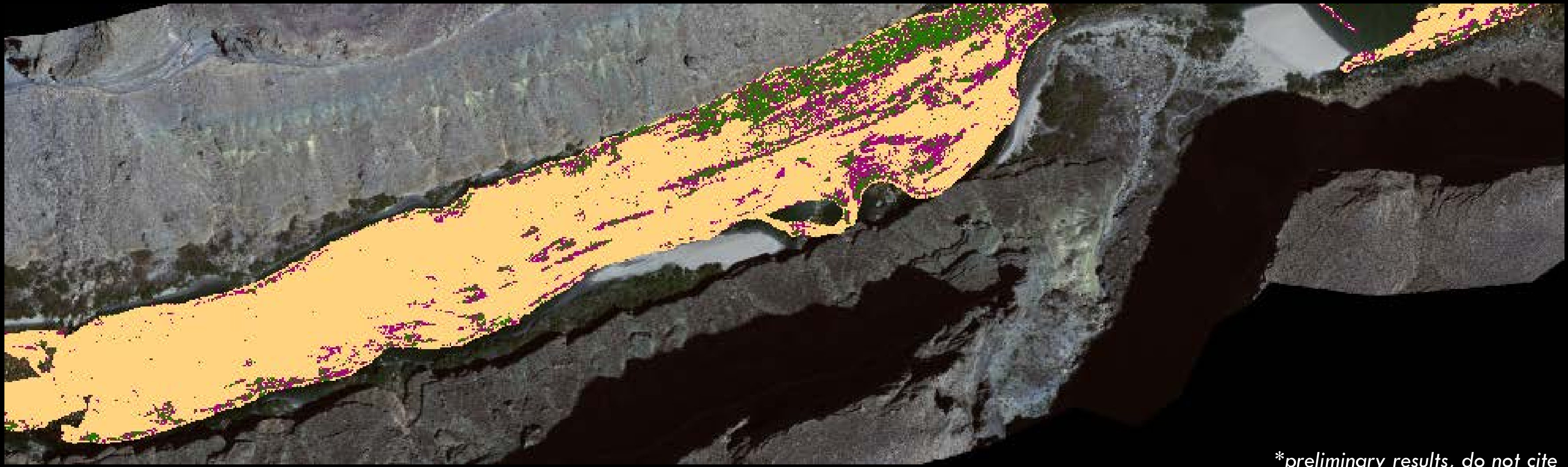
USGS
science for a changing world

Multibeam Sonar Bed Classification



Buscombe et al., 2014; JGR-ES

Validation using underwater camera



**preliminary results, do not cite*

Sand Gravel Cobble/Boulder

2009 Sand Mapping: Active Channel

Active Channel Sand

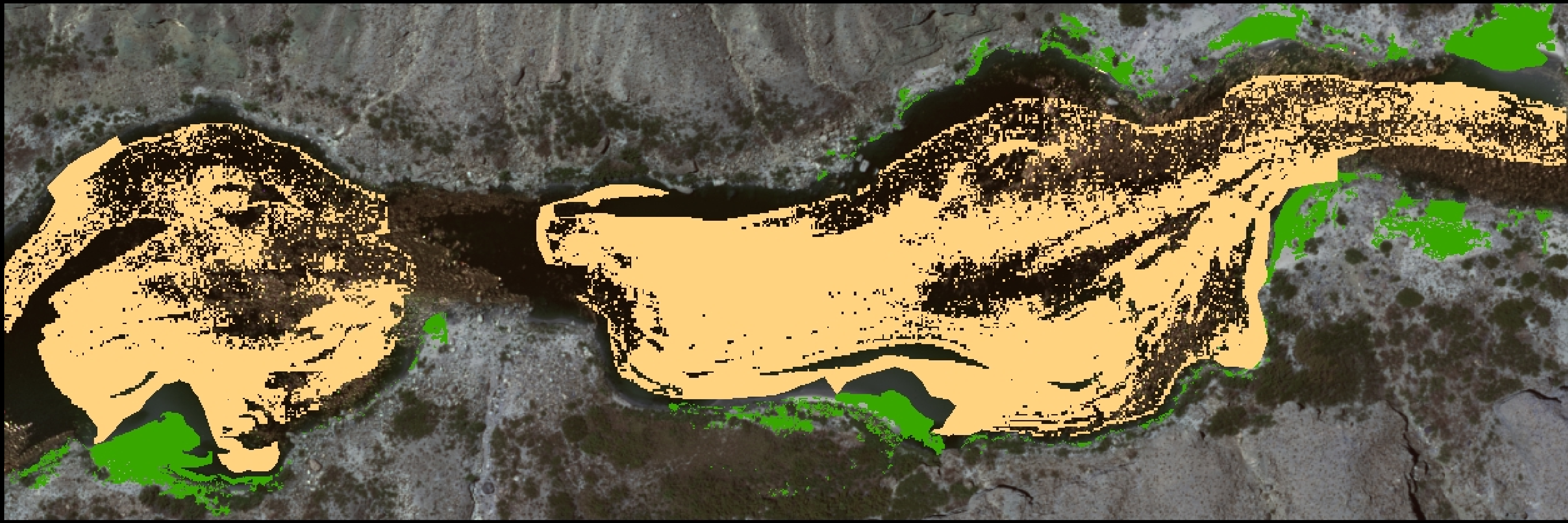
preliminary results, do not cite

From multibeam and total station surveys

…but this only gets us to the 45,000 ft^3/s stage.

Historic floods deposited sand up to 210,000 ft^3/s

2009 Sand Mapping: Active Channel *and* Remote Upland Mapping



Active Channel Sand

Remotely Mapped Upland Sand

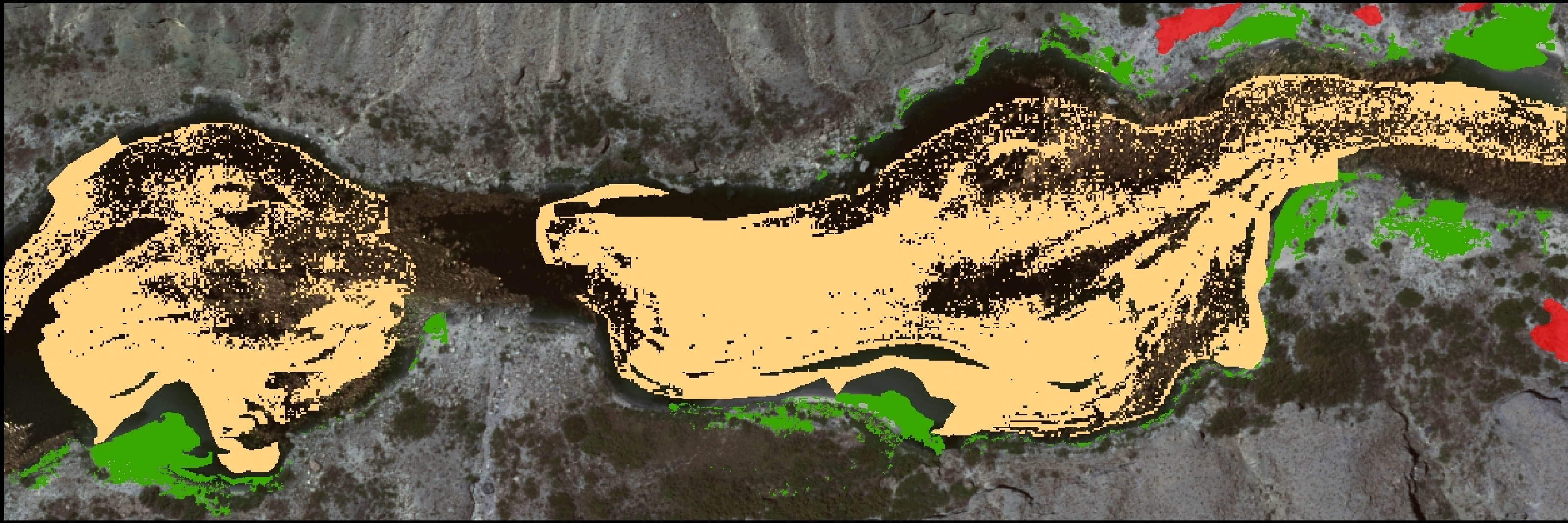
**preliminary results, do not cite*

From multibeam and total station surveys in 2009

From classification of 2009 aerial photos

USGS
science for a changing world

2009 Sand Mapping: Active Channel *and* Remote *and* Manual Upland Mapping



Active Channel Sand

Remotely Mapped Upland Sand

Manually Mapped Upland Sand

From multibeam and total station surveys

From supervised classification of 2009 aerial photos

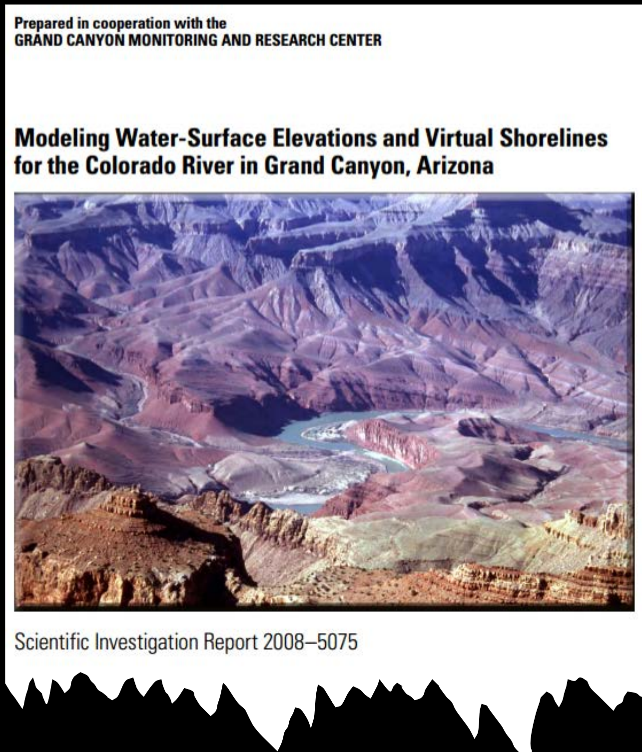
From field mapping on river trips

Mapped every square meter of sand from the channel bed to historic flood of record (210,000 ft^3/s) over 16 mile reach

*preliminary results, do not cite

USGS science for a changing world

Hydraulic Modeling


Prepared in cooperation with the
GRAND CANYON MONITORING AND RESEARCH CENTER

Modeling Water-Surface Elevations and Virtual Shorelines for the Colorado River in Grand Canyon, Arizona

Scientific Investigation Report 2008–5075

Magirl et al., 2008

8,000 ft^3/s

20,000 ft^3/s

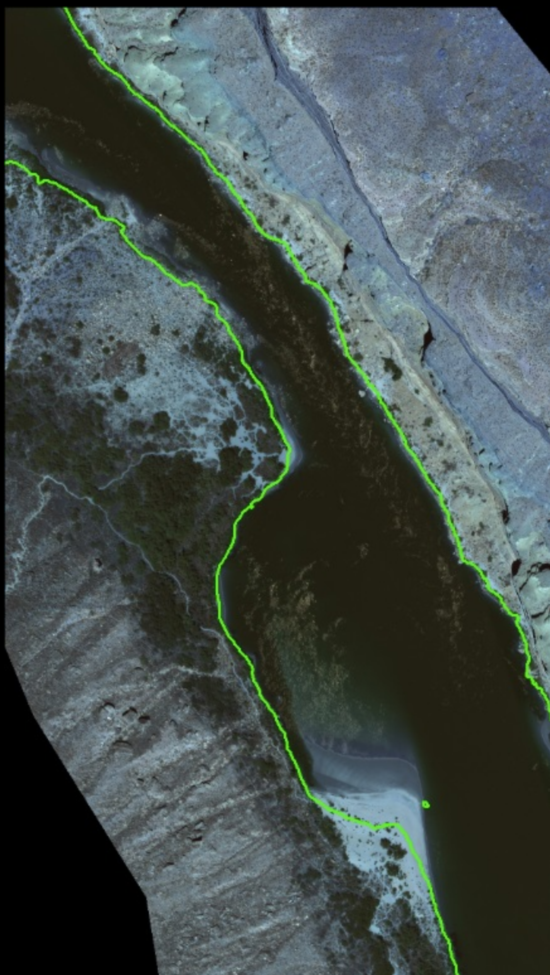
45,000 ft^3/s

210,000 ft^3/s

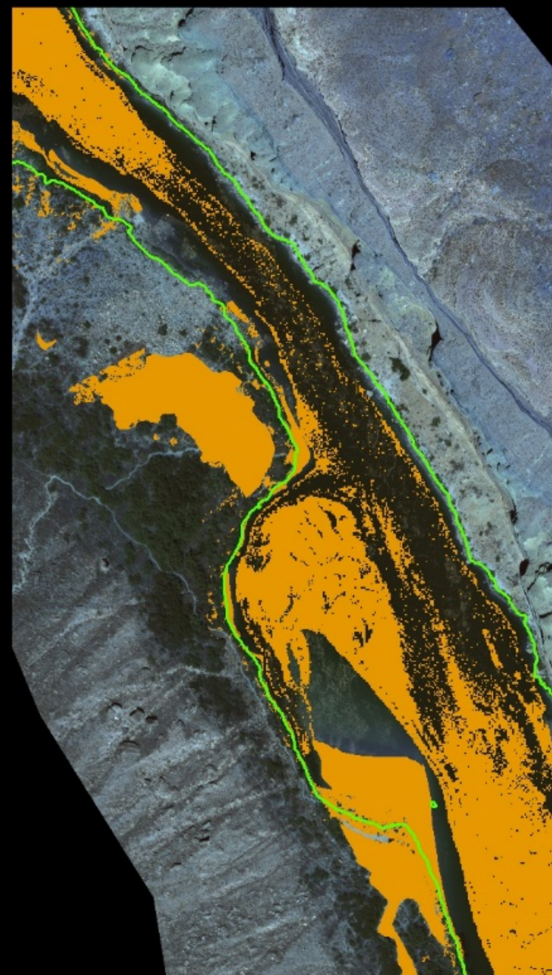
…and ten intermediate flows not shown here

What area of sand will be exposed for a given discharge from Glen Canyon Dam?

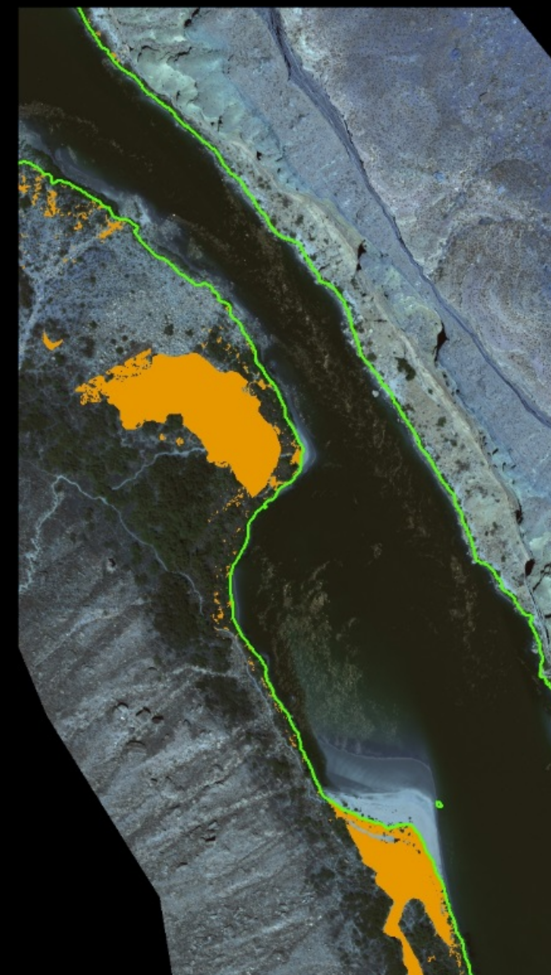
For every modeled inundation extent…



…take the map of total sand

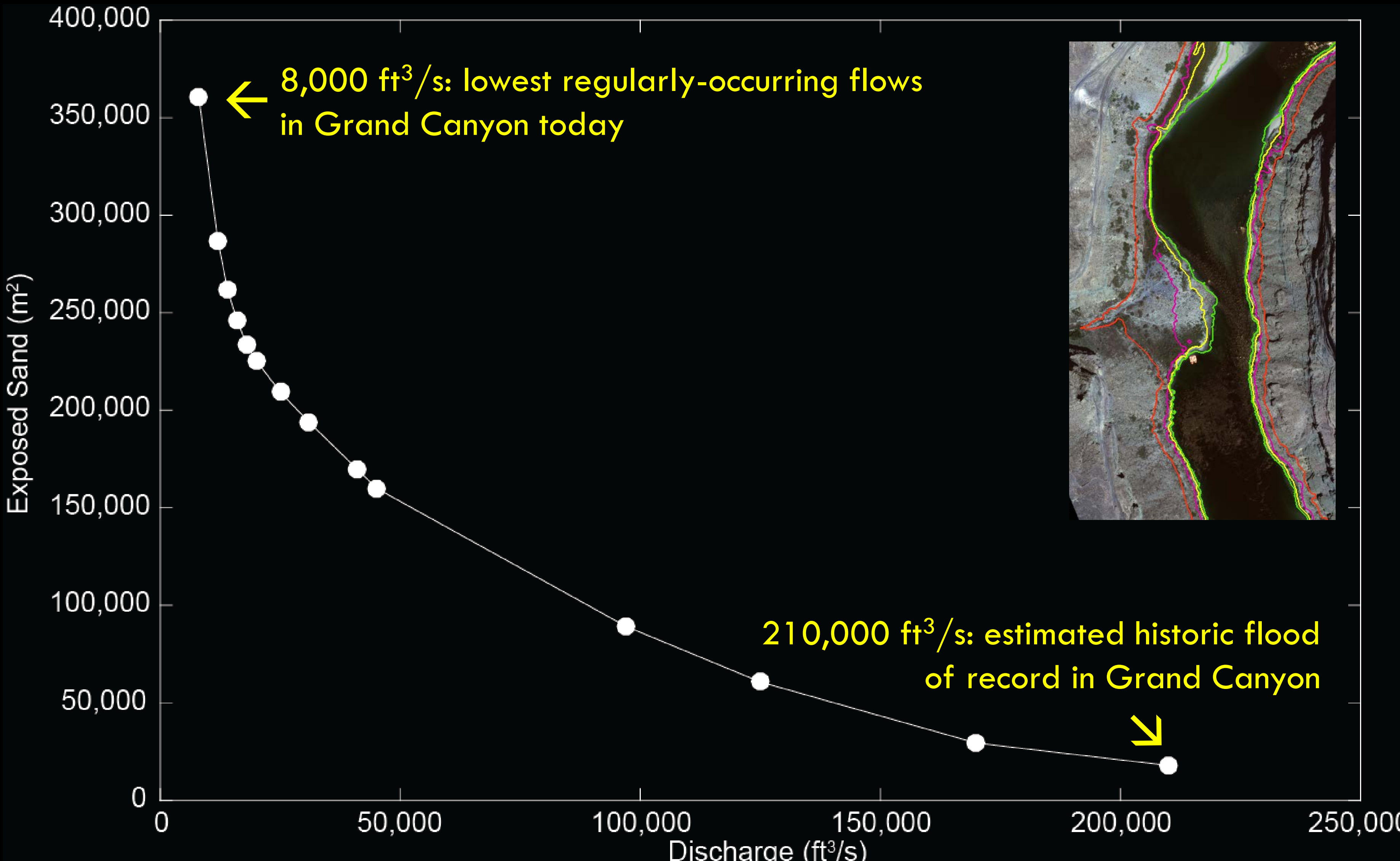


…and cut out anything that's underwater



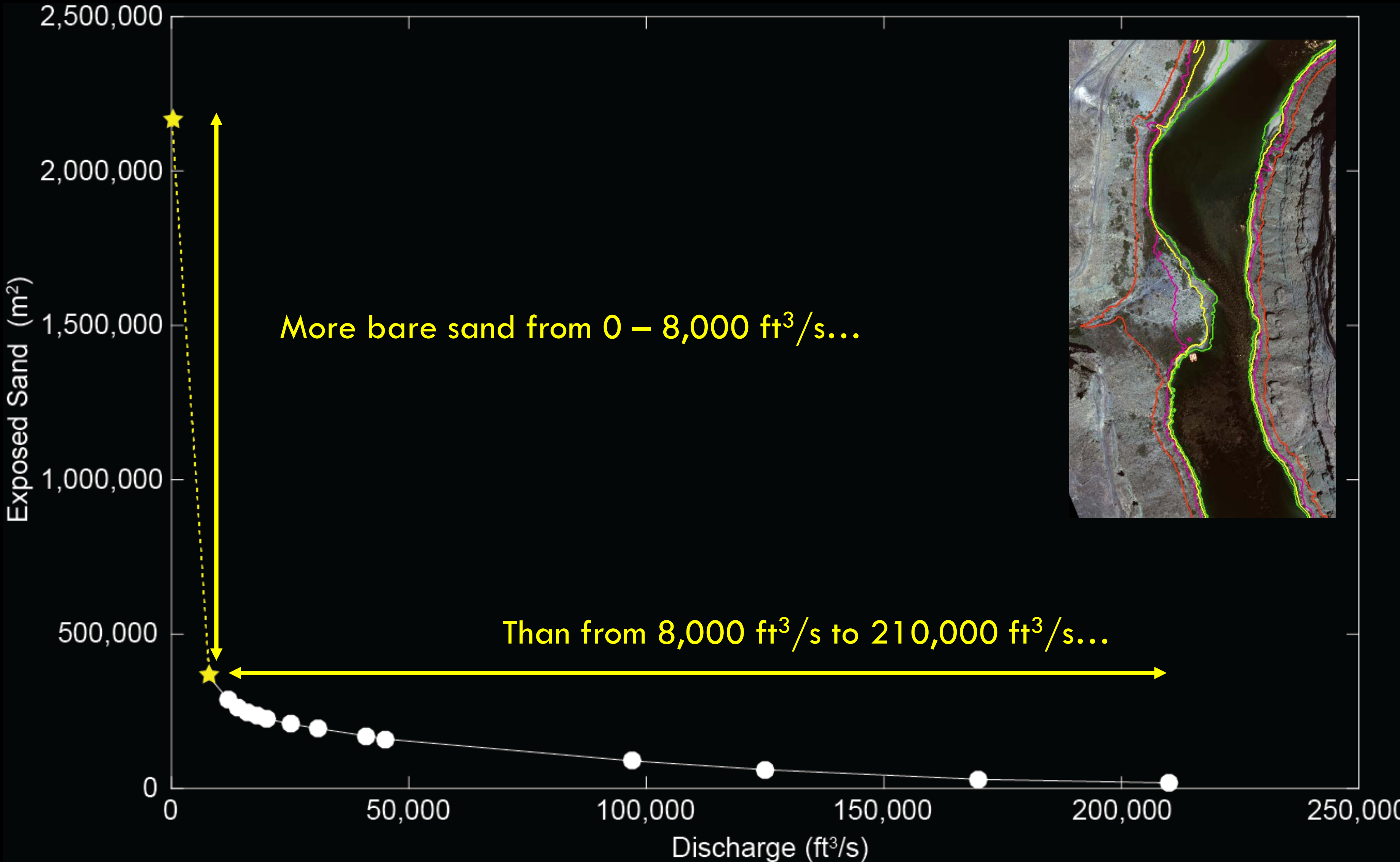
**preliminary results, do not cite*

Exposed Sand as a Function of Discharge



*preliminary results, do not cite

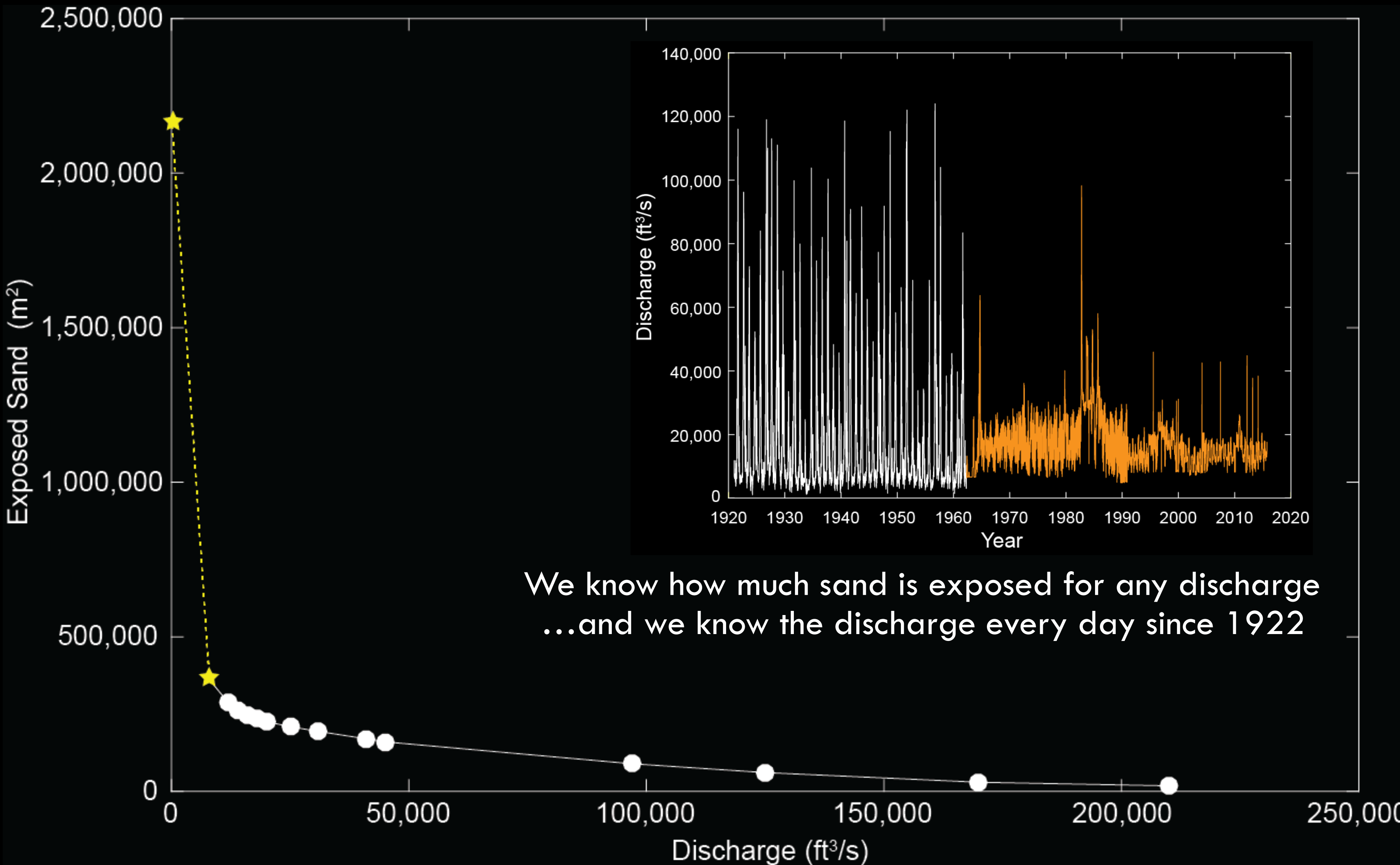
Exposed Sand as a Function of Discharge



**preliminary results, do not cite*

USGS
science for a changing world

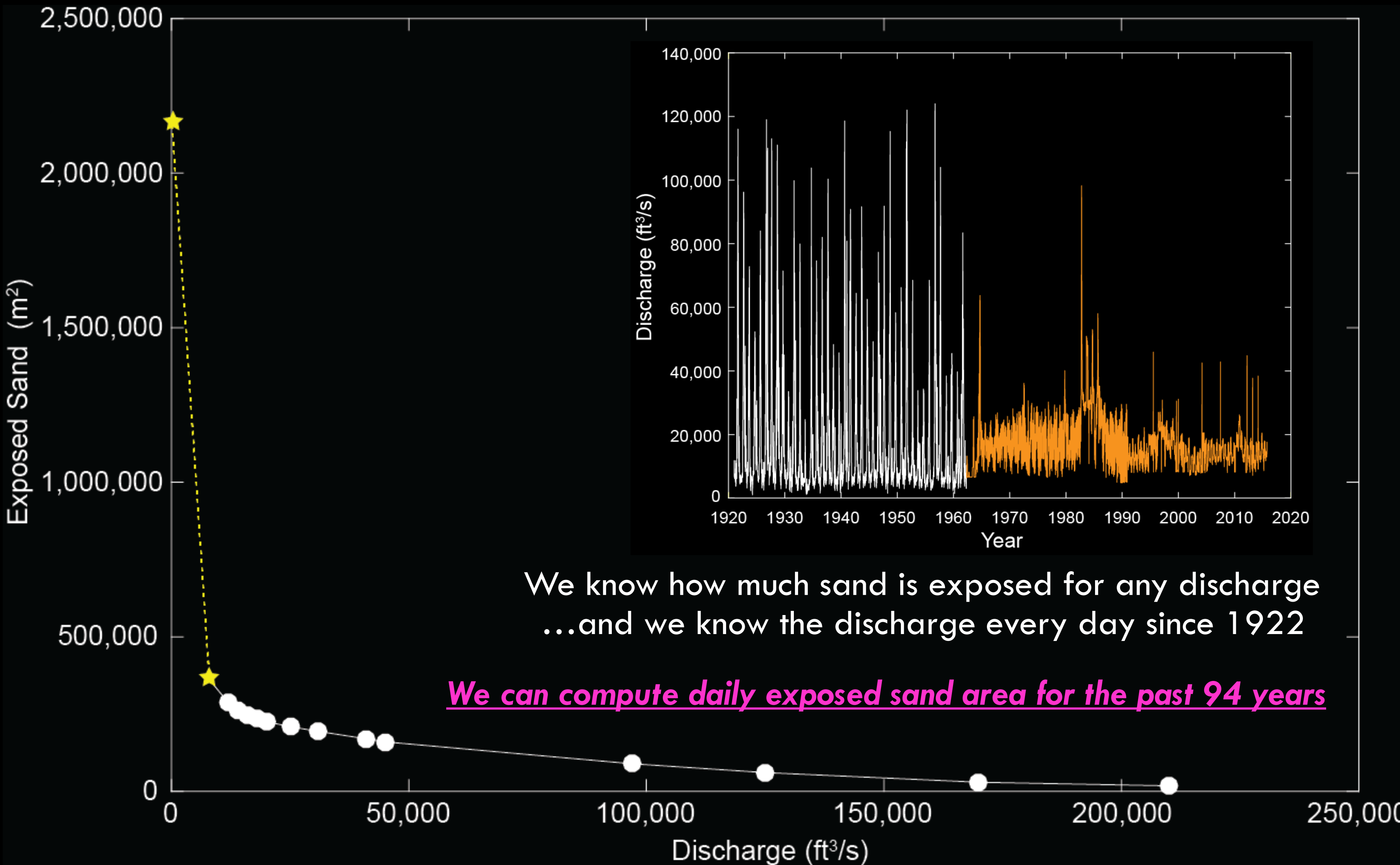
Exposed Sand as a Function of Discharge



We know how much sand is exposed for any discharge
…and we know the discharge every day since 1922

*preliminary results, do not cite

Exposed Sand as a Function of Discharge

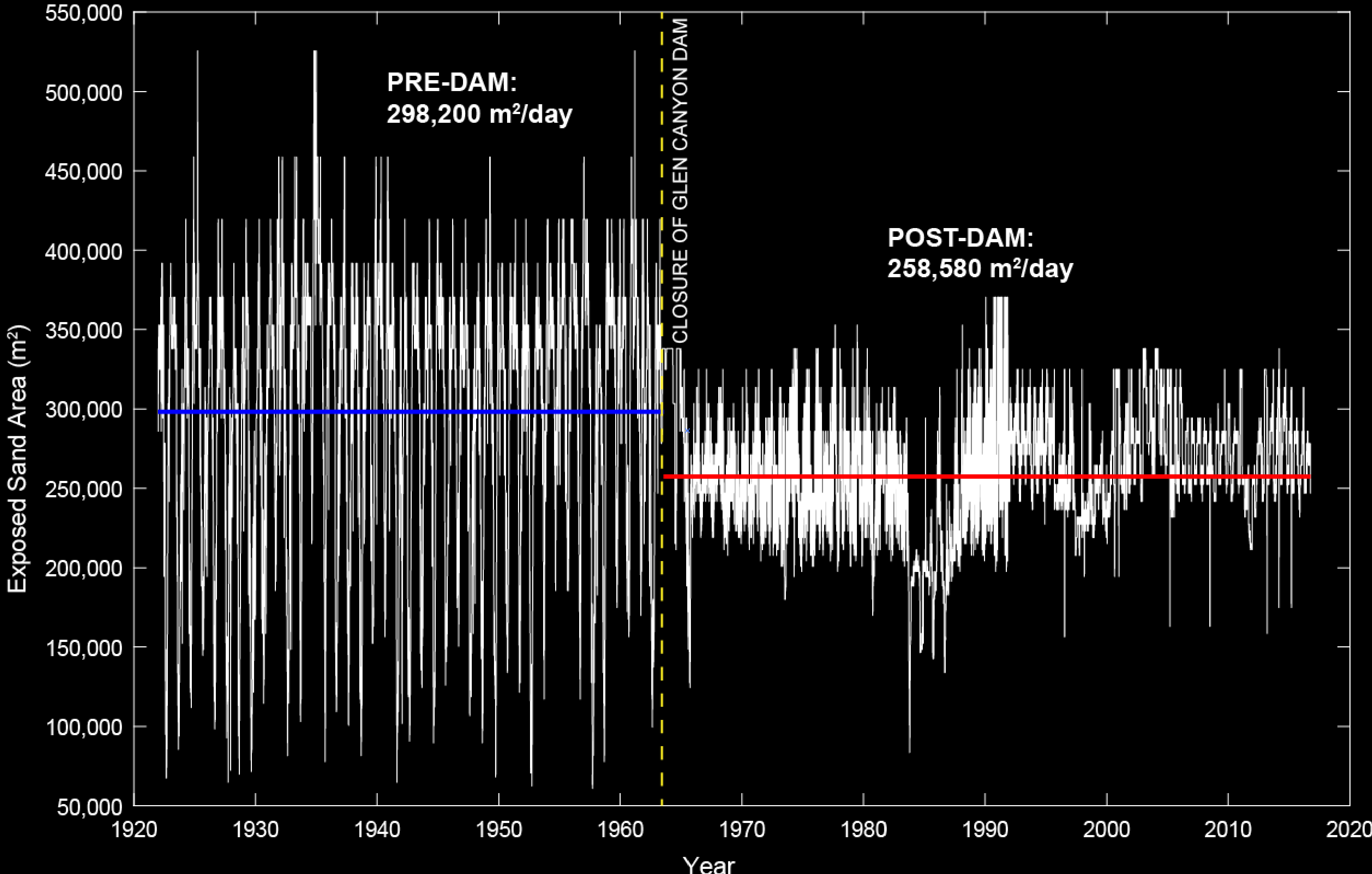


We know how much sand is exposed for any discharge
…and we know the discharge every day since 1922

<u>We can compute daily exposed sand area for the past 94 years</u>

**preliminary results, do not cite*

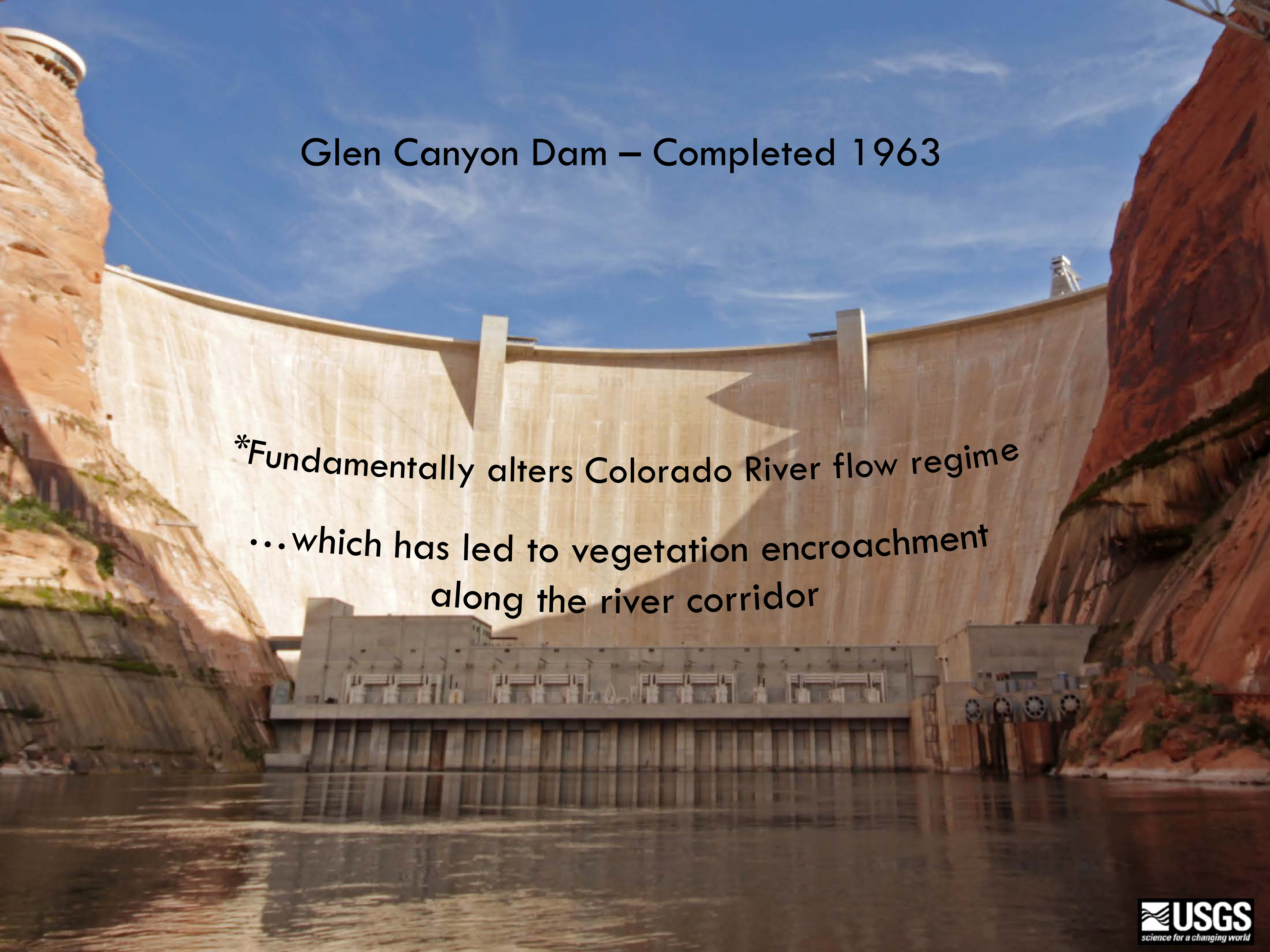
USGS
science for a changing world



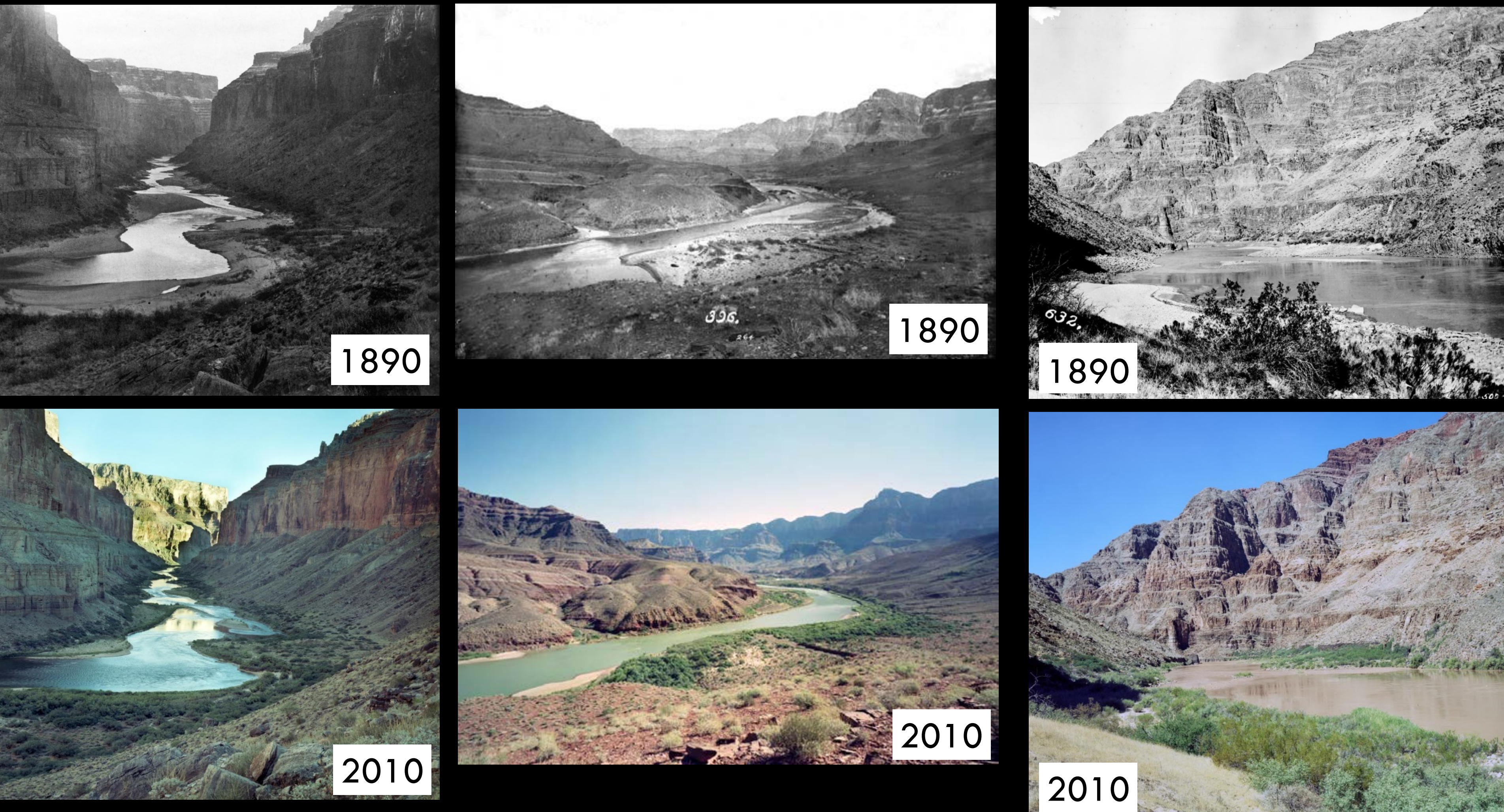
Hydrologic Alteration reduced exposed sand area by 13.5%

**preliminary results, do not cite*

USGS science for a changing world


Glen Canyon Dam – Completed 1963
*Fundamentally alters Colorado River flow regime
…which has led to vegetation encroachment along the river corridor
USGS
science for a changing world

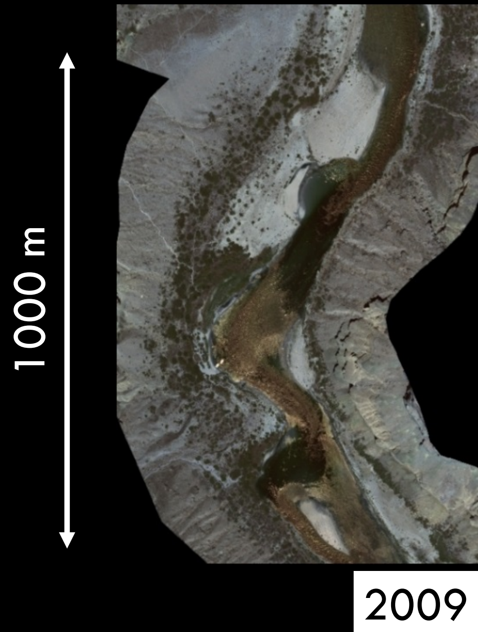
Observations of vegetation encroachment following dam construction



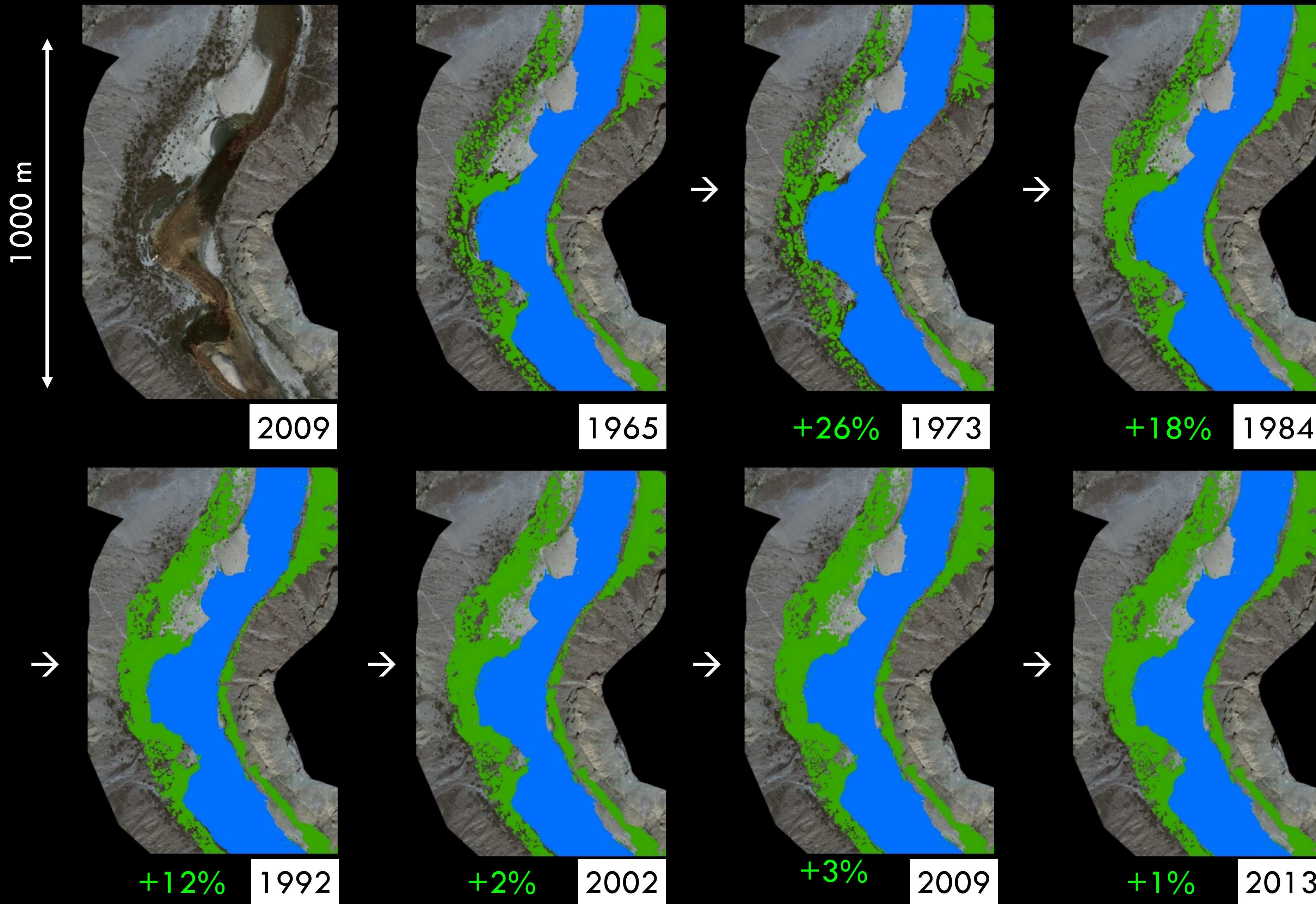
A trend toward:

- Increased vegetation area, particularly along the river
- Correspondingly reduced area of bare sand

USGS
science for a changing world

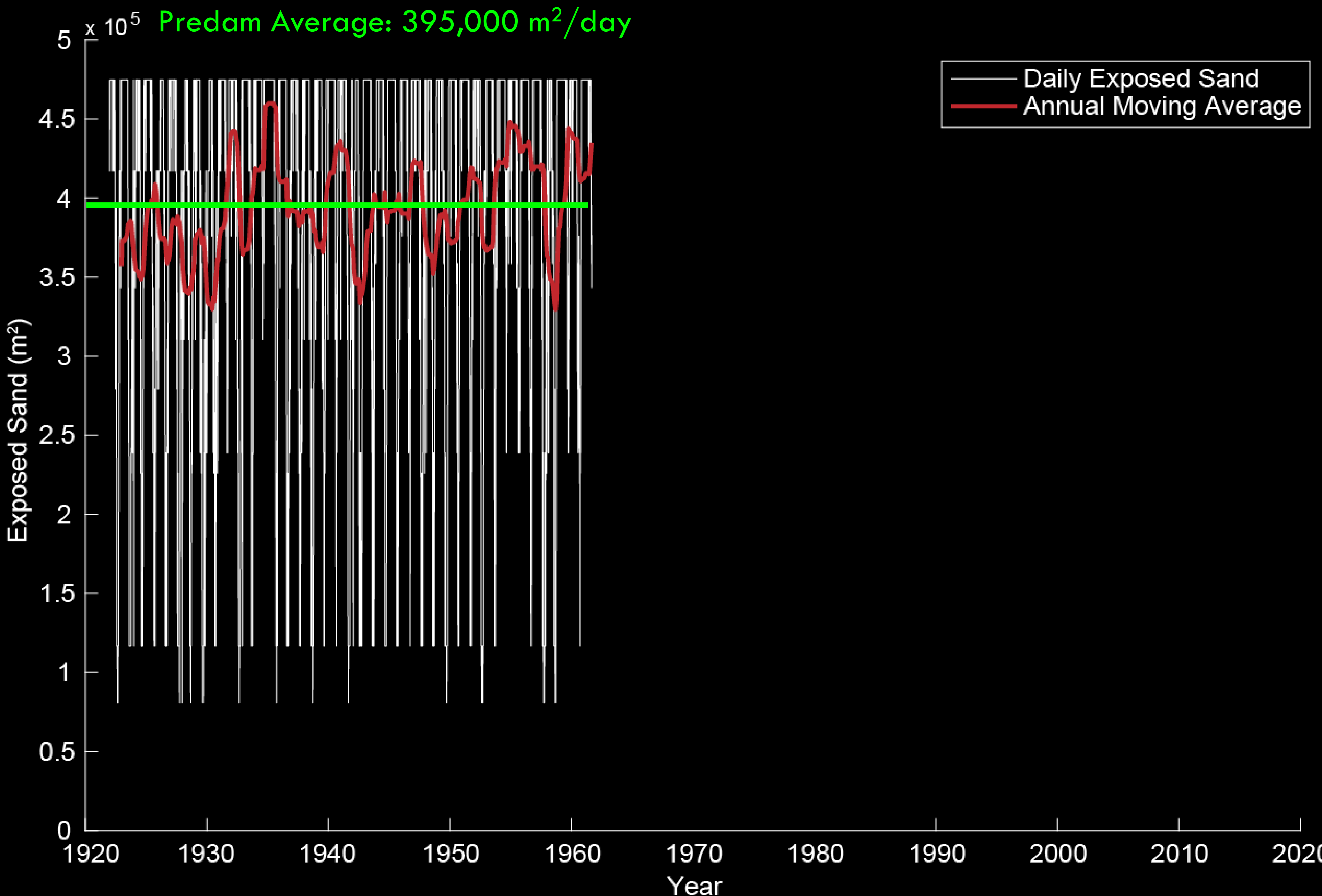


USGS
science for a changing world



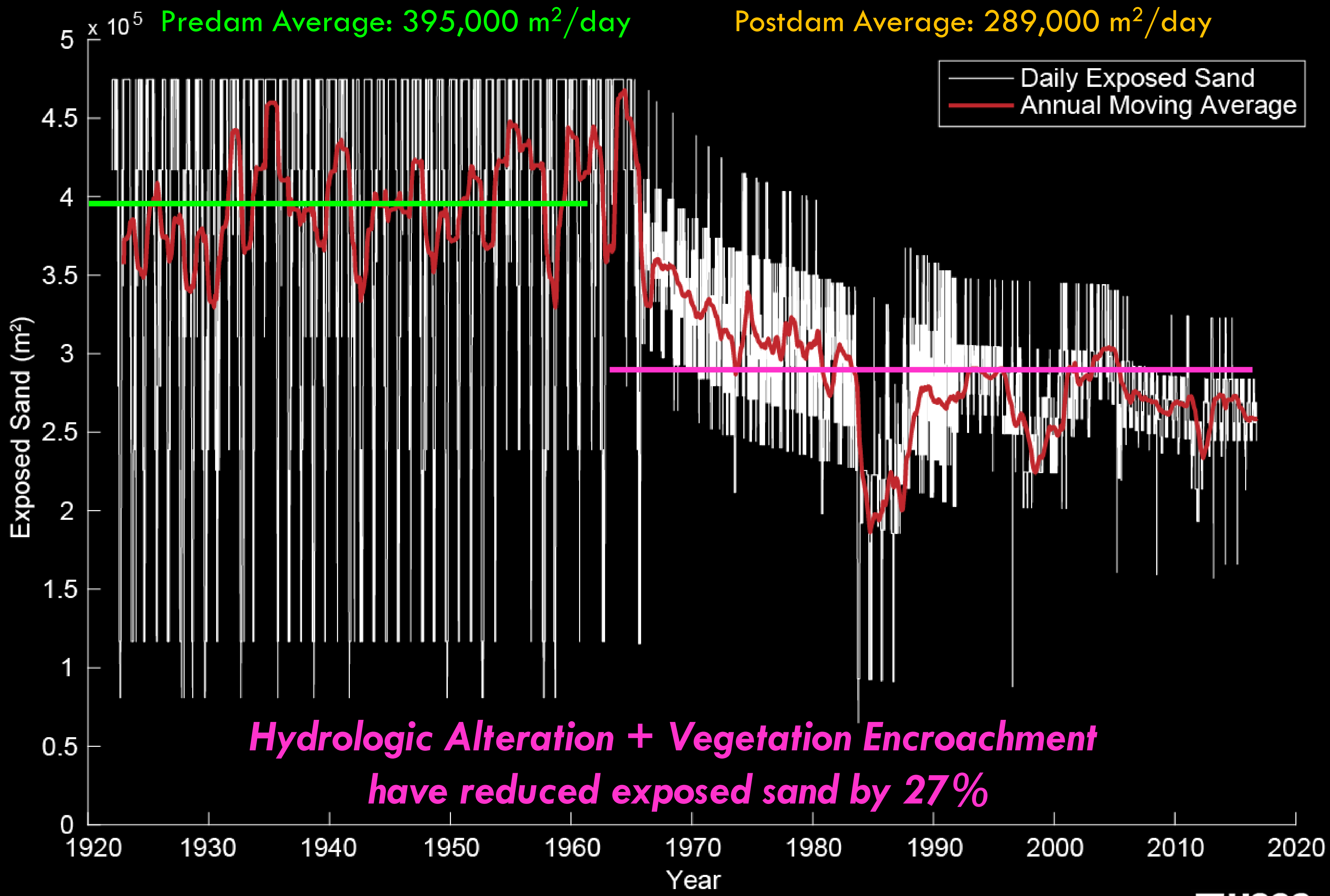
Vegetation Encroachment reduced exposed sand area by 20%

*preliminary results, do not cite



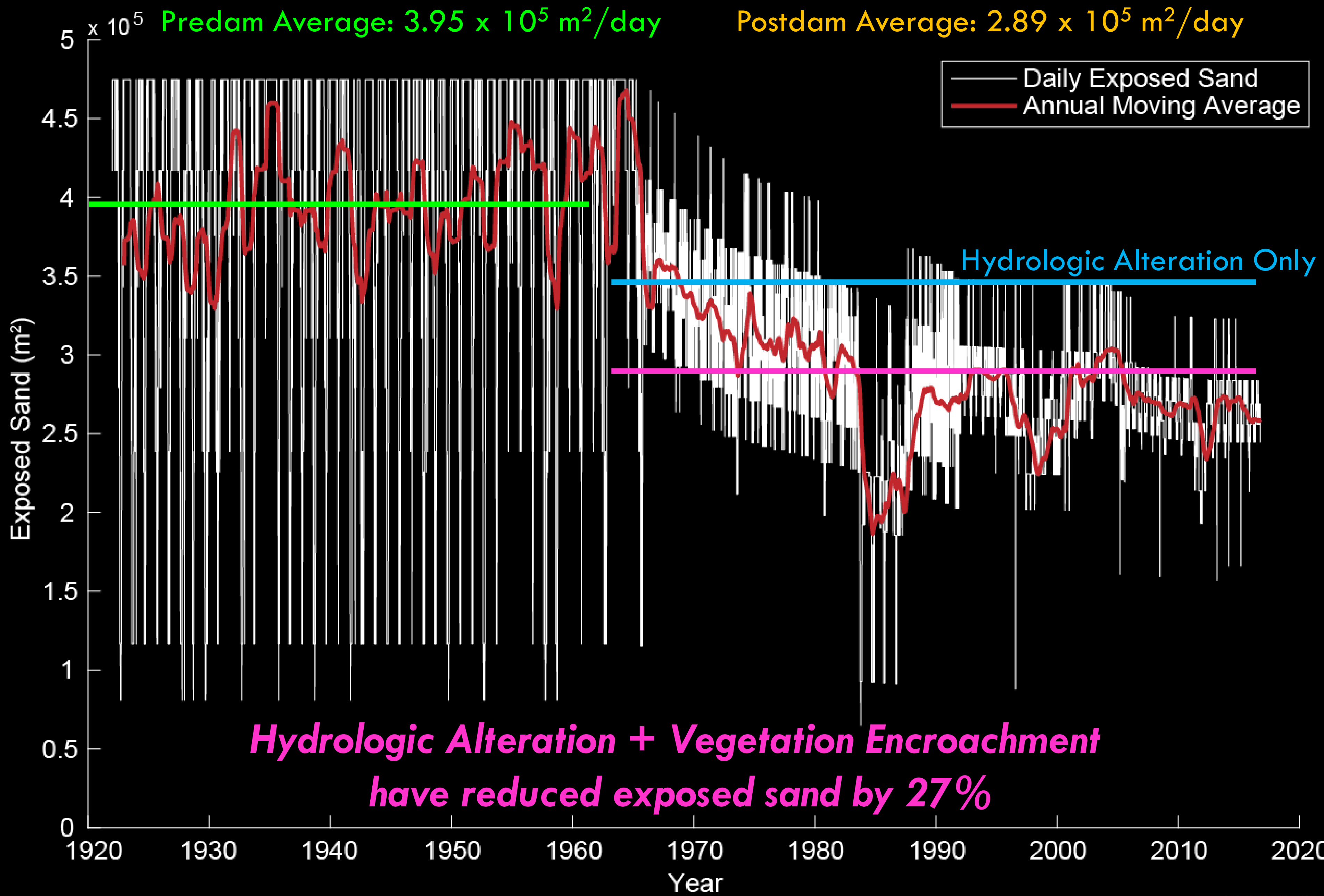
*preliminary results, do not cite

USGS
science for a changing world



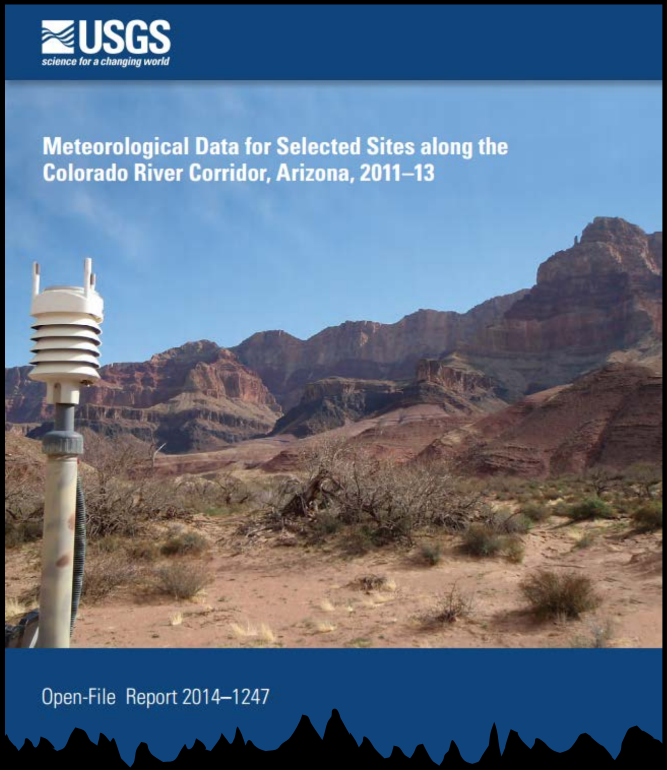
*preliminary results, do not cite

USGS science for a changing world



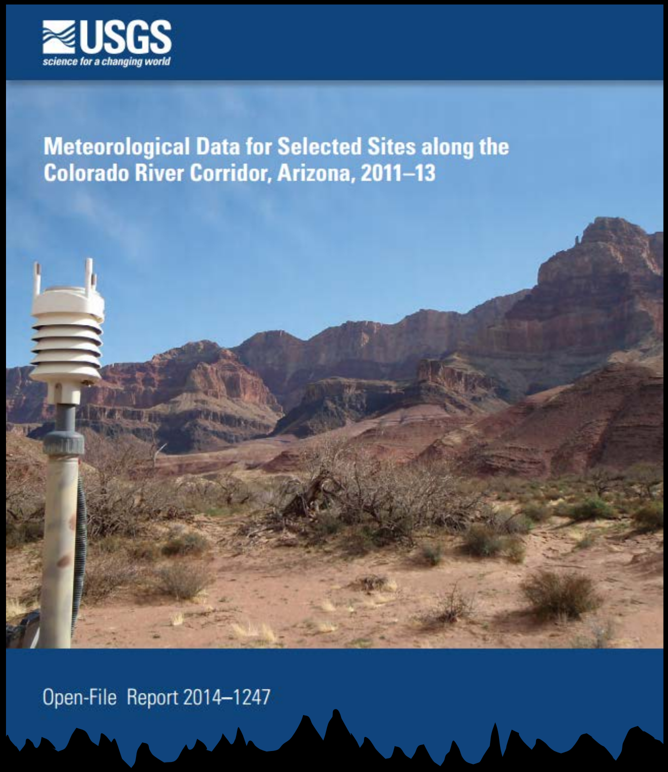
*preliminary results, do not cite

What about the Wind?

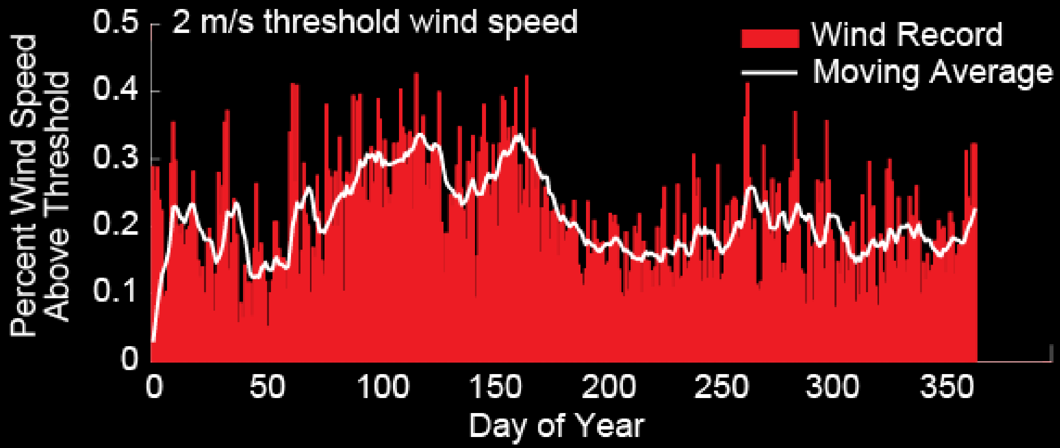


Caster, East et al., 2014

What about the Wind?



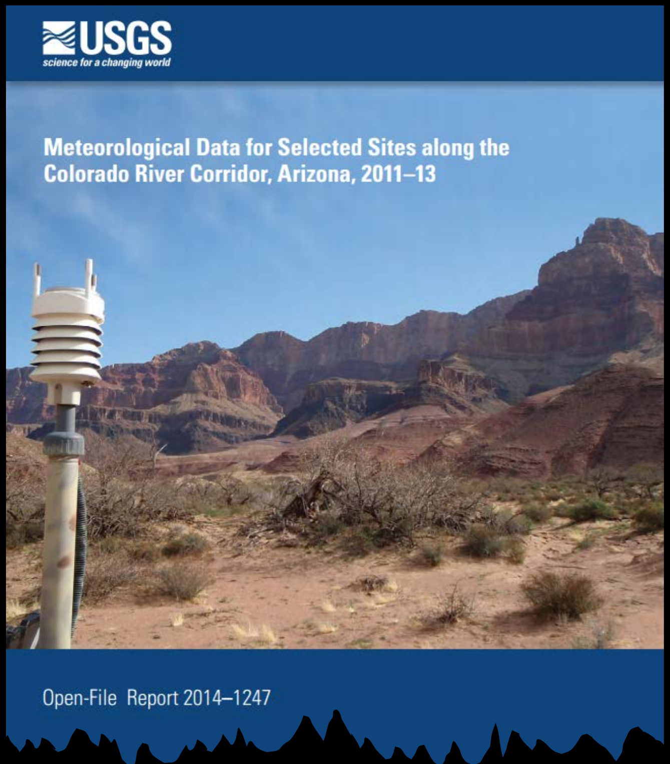
Caster, East et al., 2014



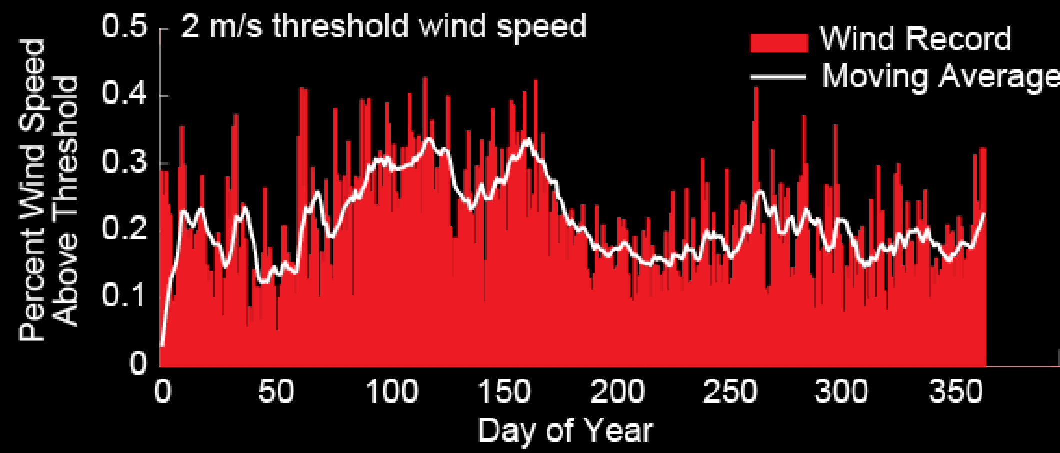
**preliminary results, do not cite*

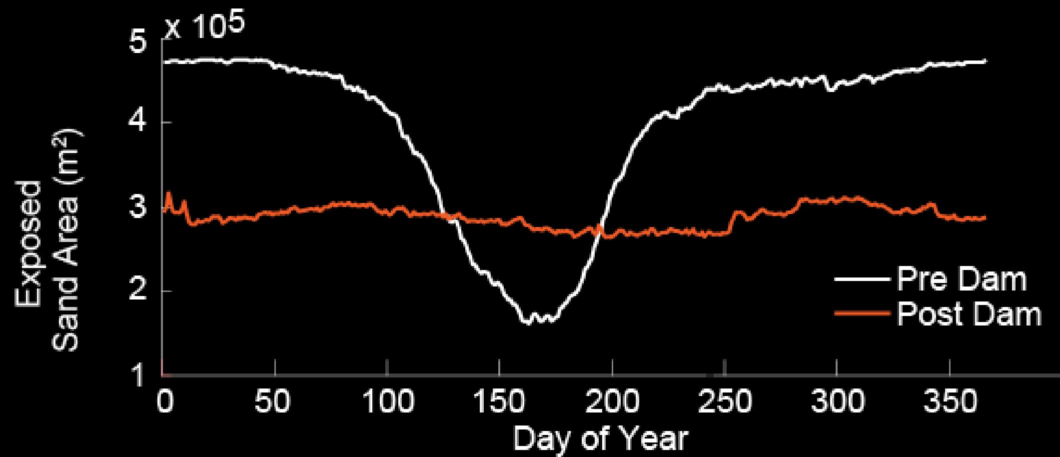
USGS
science for a changing world

What about the Wind?



Caster, East et al., 2014

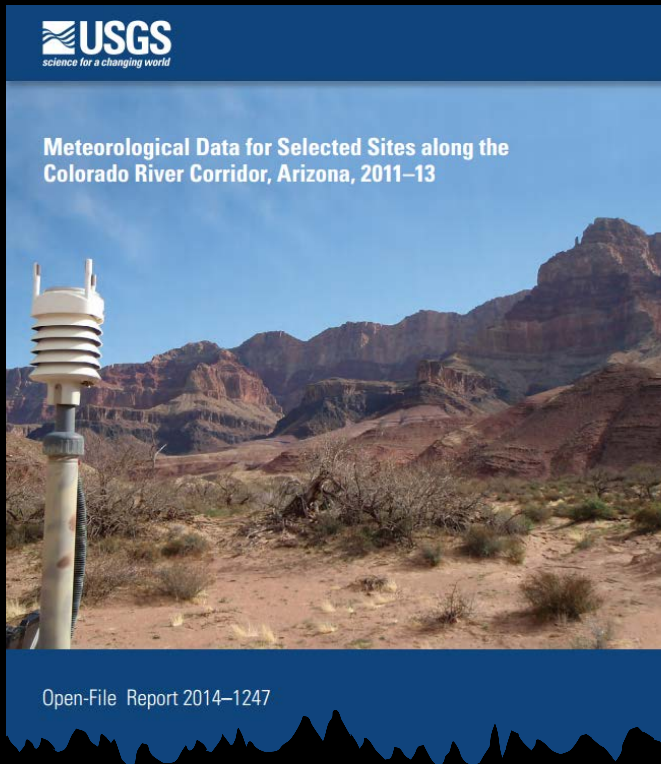




**preliminary results, do not cite*

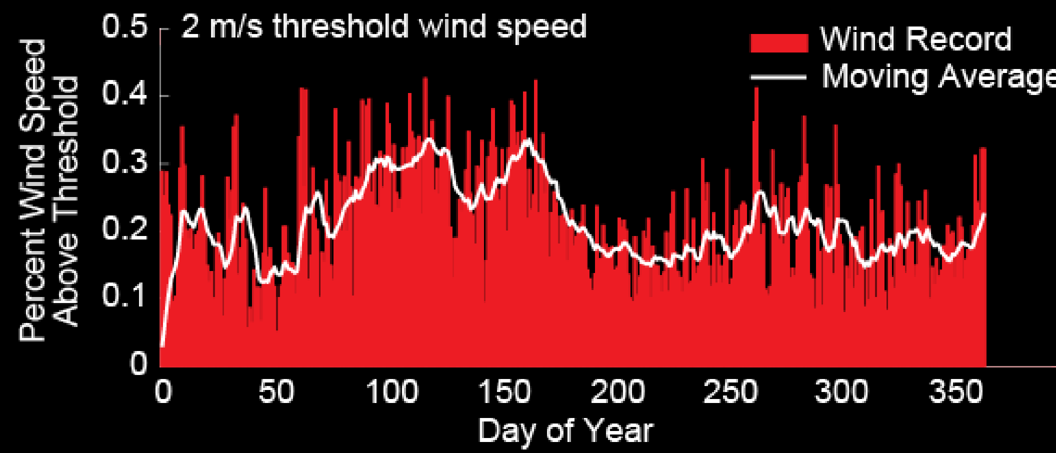
USGS
science for a changing world

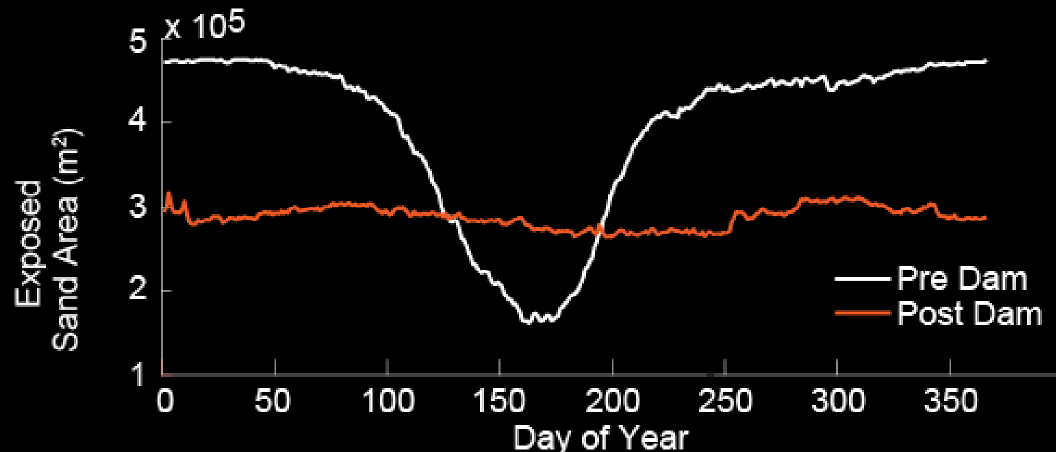
What about the Wind?

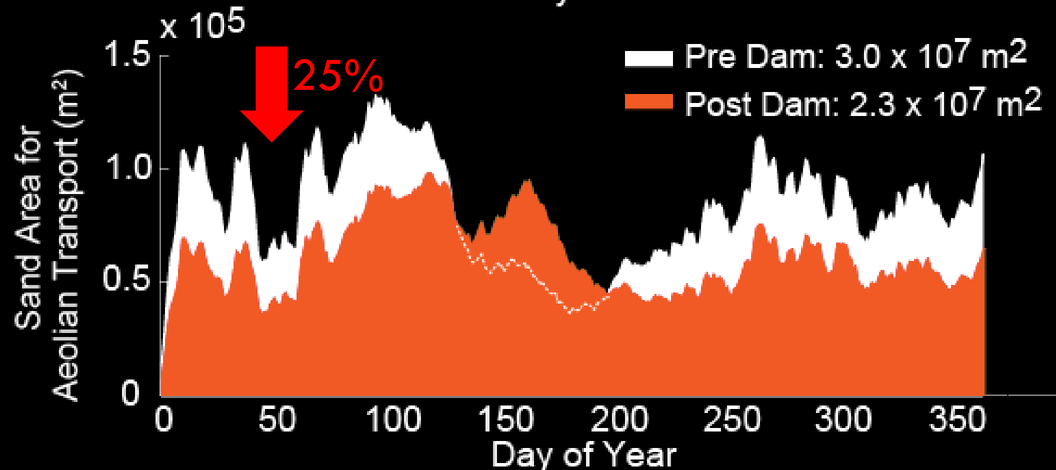


Caster, East et al., 2014

The product of ***wind data*** *and* ***sand area*** *provide an estimate of* ***sand transport rate*** *throughout the year* →



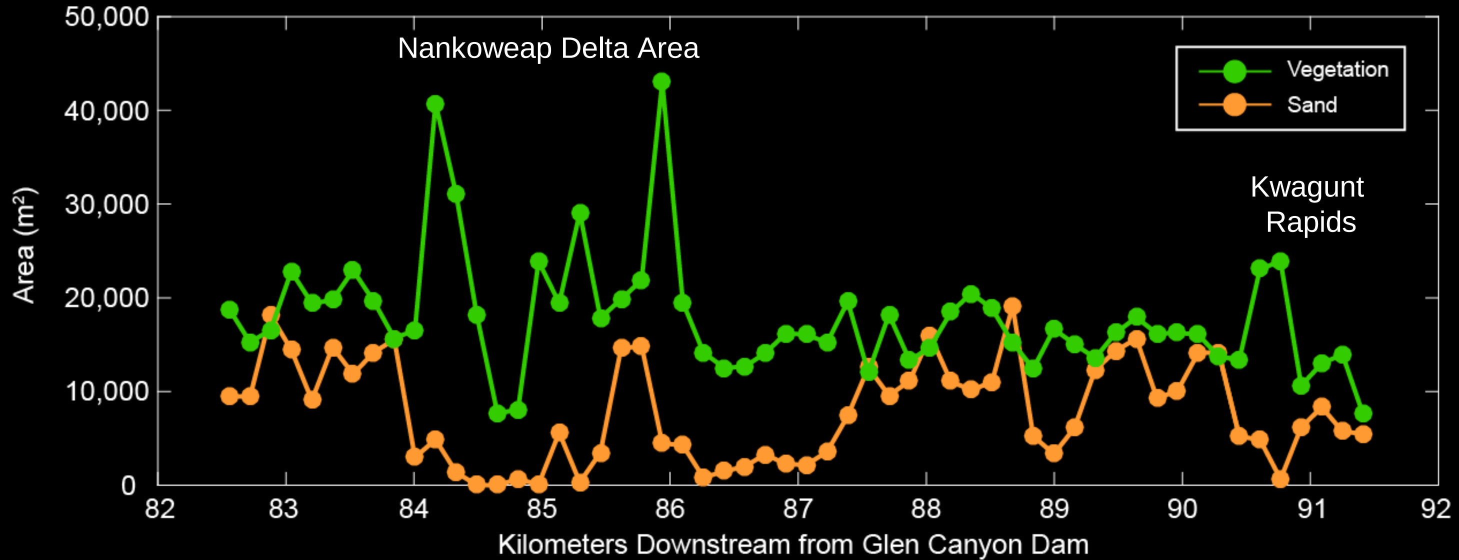




USGS science for a changing world

**preliminary results, do not cite*

Relevance to Glen Canyon Dam Operations



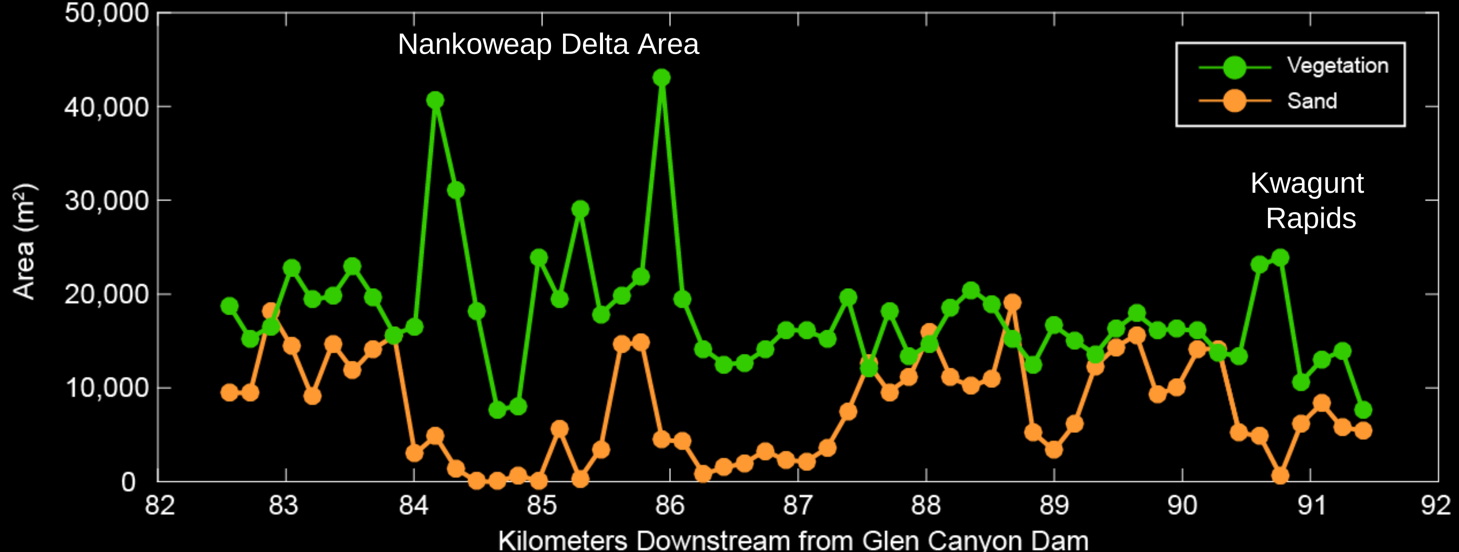
Neither sand nor vegetation are uniformly distributed along the river…

→ Opportunities for vegetation removal

→ Use stage-discharge models to tailor flows for sand exposure

preliminary results, do not cite

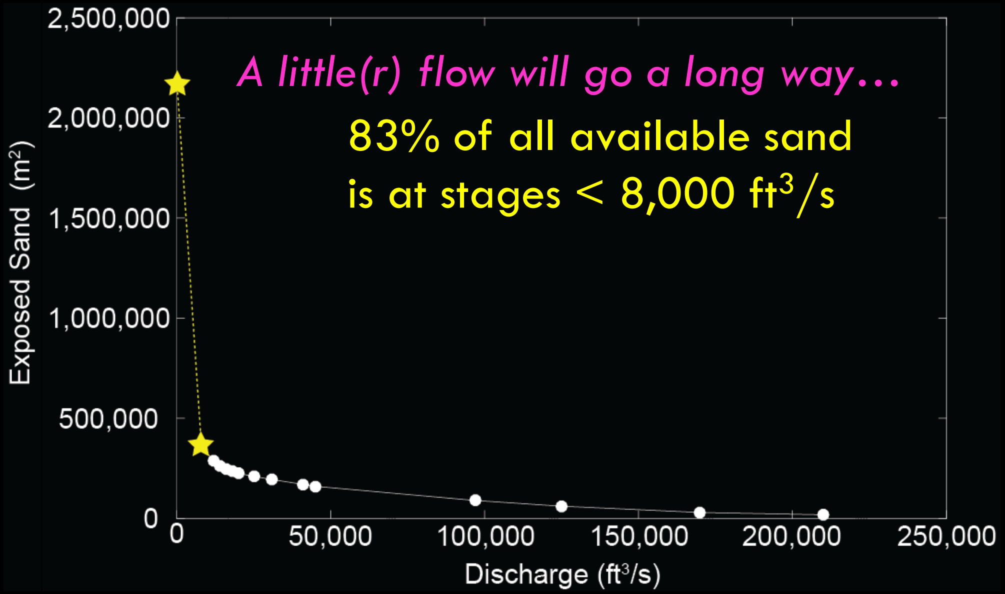
Relevance to Glen Canyon Dam Operations



Neither sand nor vegetation are uniformly distributed along the river…

→ Opportunities for vegetation removal

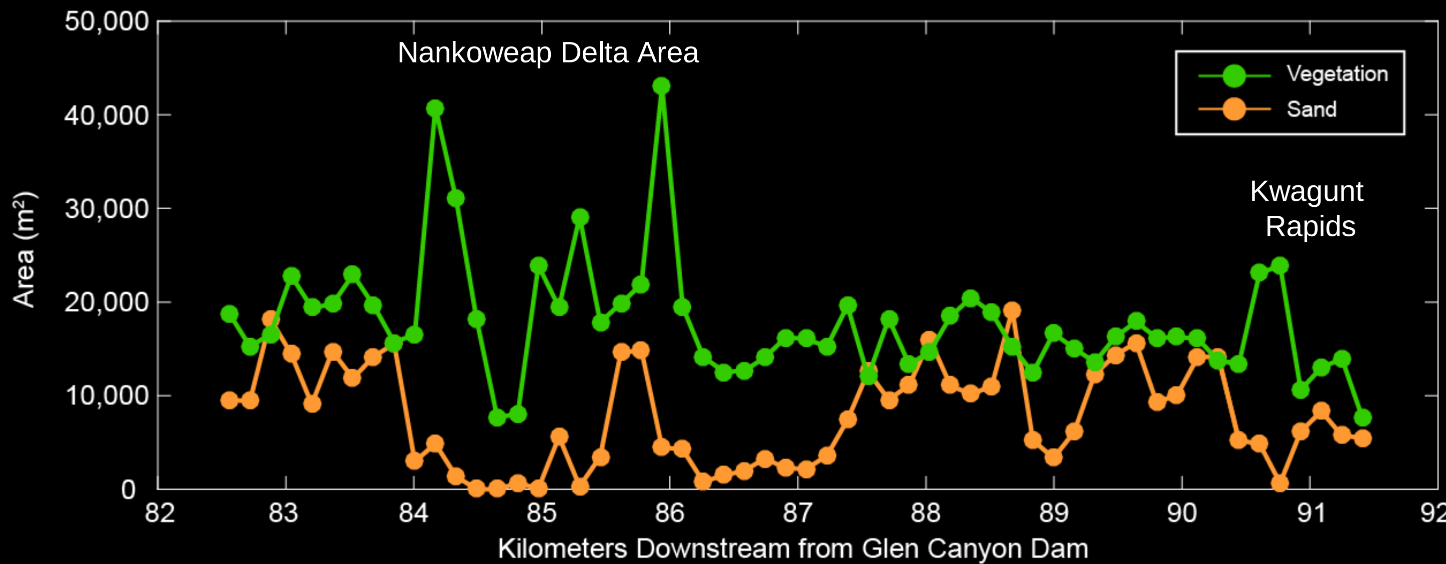
→ Use stage-discharge models to tailor flows for sand exposure



*preliminary results, do not cite

USGS science for a changing world

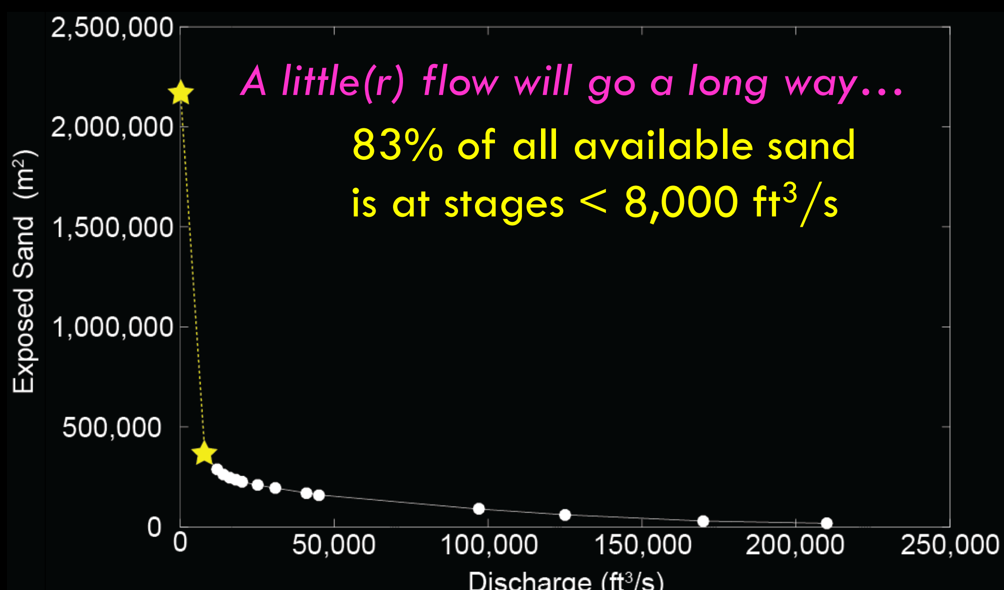
Relevance to Glen Canyon Dam Operations

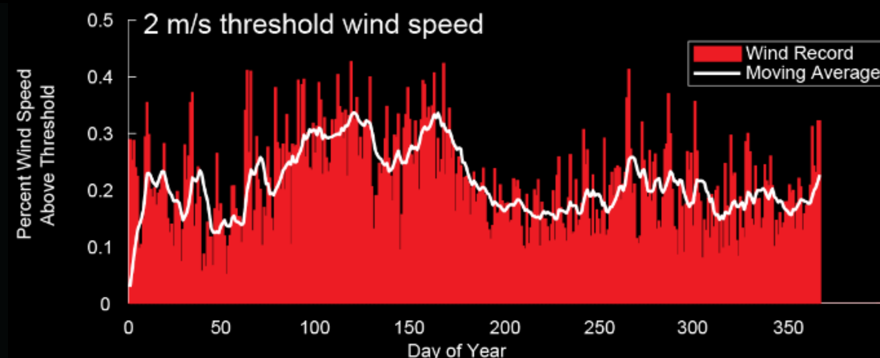


Neither sand nor vegetation are uniformly distributed along the river…

→ Opportunities for vegetation removal

→ Use stage-discharge models to tailor flows for sand exposure



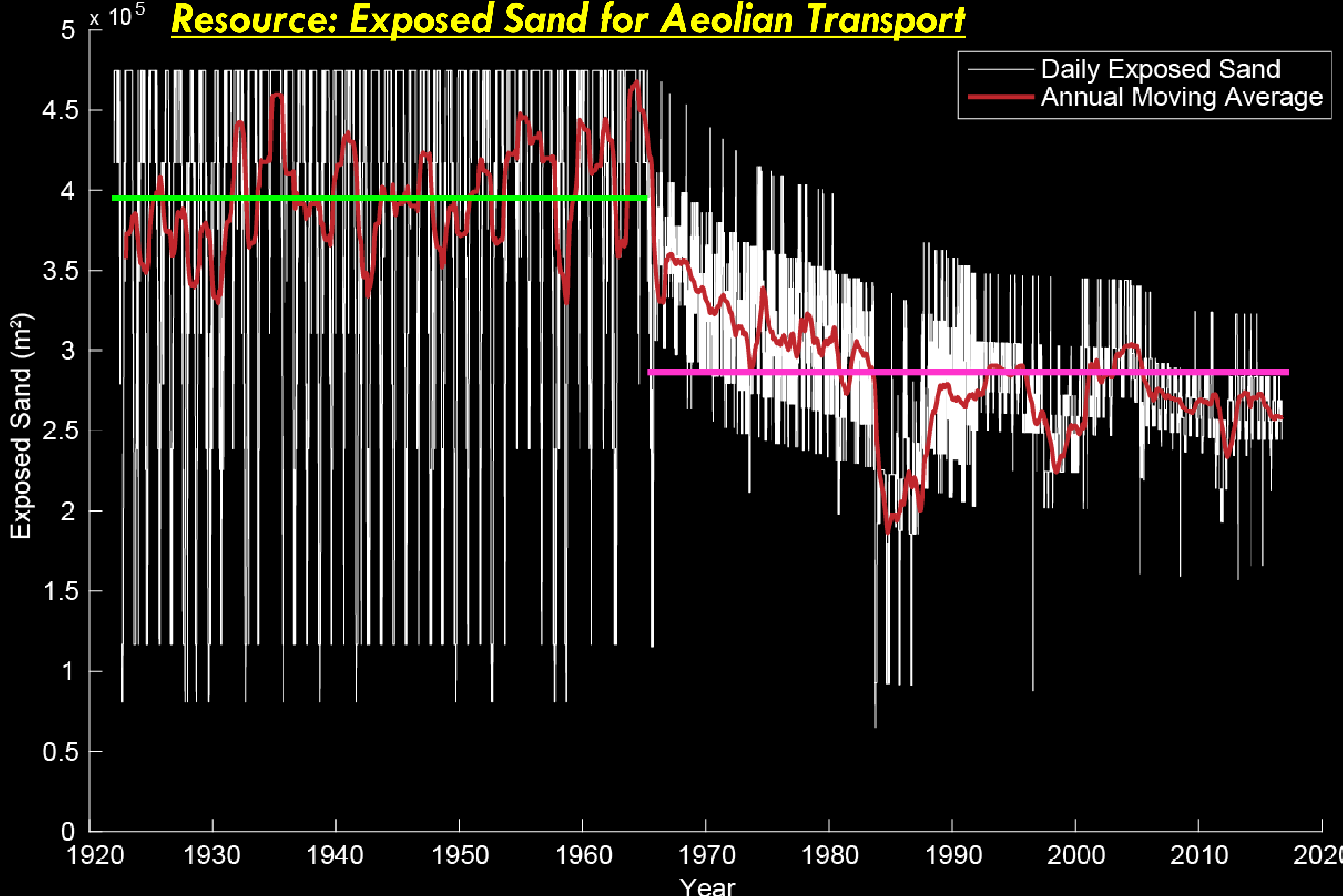


…at the right time of year!

**preliminary results, do not cite*

USGS science for a changing world

Resource: Exposed Sand for Aeolian Transport



TREND: Generally stabilizing over the last ~15 years

STATUS: Reduced by 27% compared to pre-dam period

**preliminary results, do not cite*

Funding from *Glen Canyon Dam Adaptive Management Program and National Center for Earth Surface Dynamics 2*

Thanks to *Kirk Burnett, Laura Cagney, Geoff Chain, Maddie Friend, Dennis Harris, Joe Hazel, Matt Kaplinski, Rob Ross, Bob Tusso*

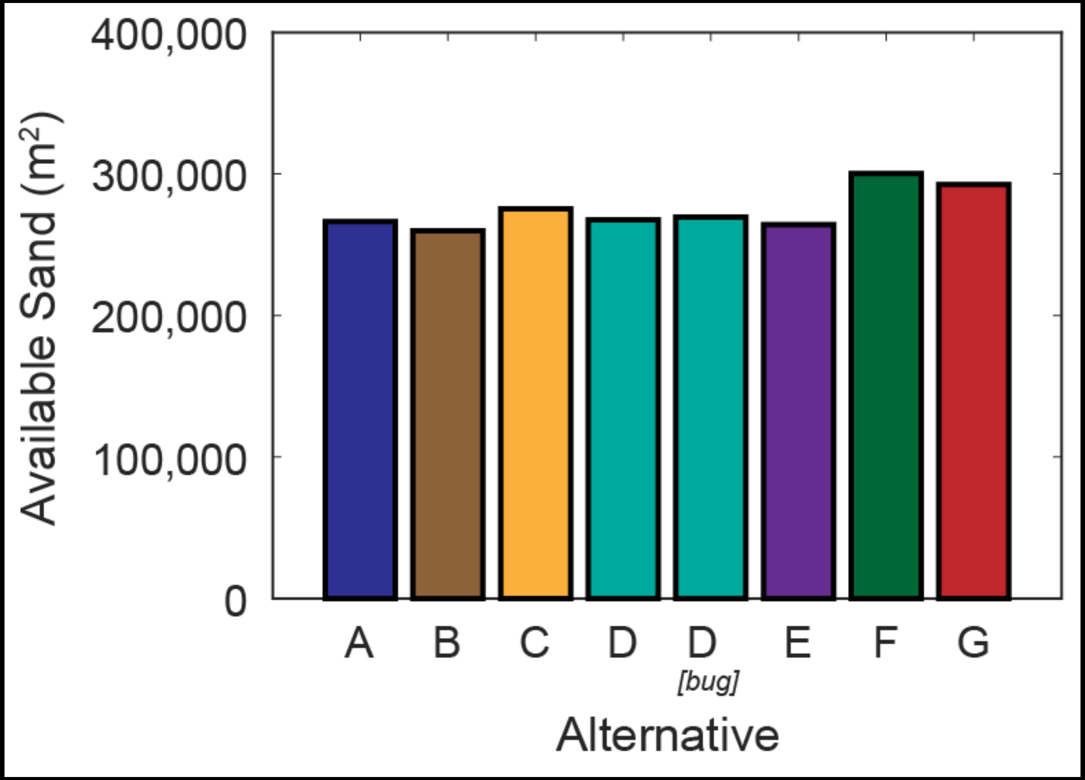
Alternative Flow Regimes

[effect of discharge regimes on sand availability]

8.23 maf year, one year analysis

- Not much difference between each alternative scenario

…because no alternative provides for **daily maximum flows < 8,000 ft^3/s,** with the exception of alternative F



*preliminary results, do not cite

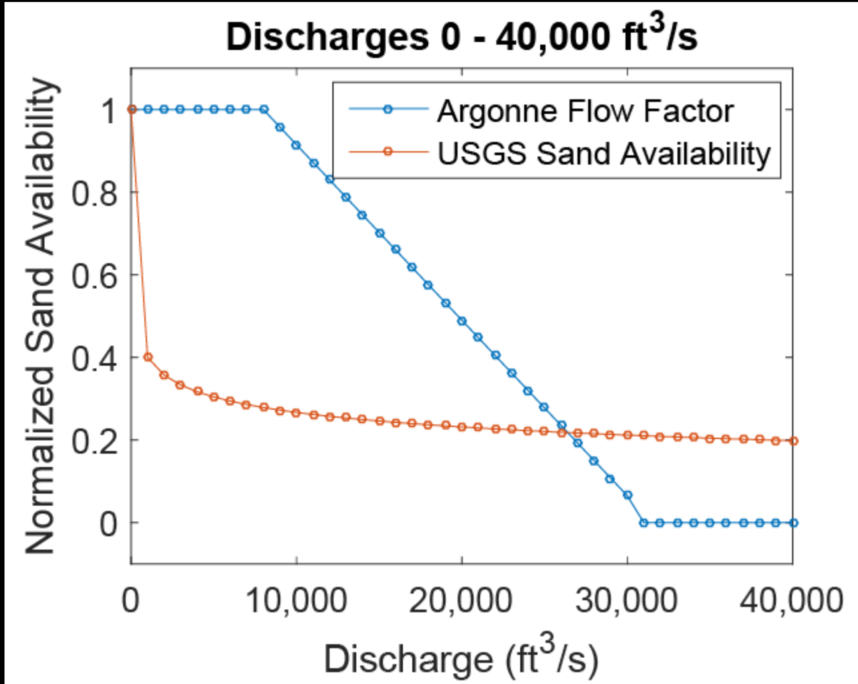
Argonne National Lab – Flow Factor

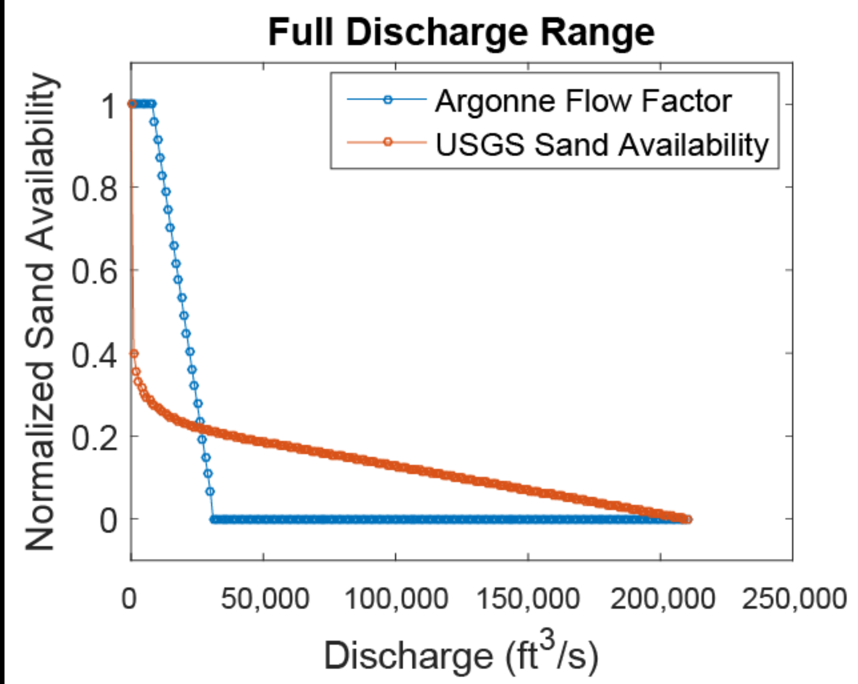
[influence of discharge on sand availability for wind transport]

$$\textit{Flow Factor} = \begin{cases} if \quad Q_{max} & \leq 8,000 \text{ ft}^3/\text{s}: \quad 1 \\ if \quad 8,000 \text{ ft}^3/\text{s} \leq Q_{max} & \leq 31,500 \text{ ft}^3/\text{s}: \quad \mathbf{1.34 - 0.0000425} * Q_{max} \\ if \quad Q_{max} & \geq 31,500 \text{ ft}^3/\text{s}: \quad \mathbf{0} \end{cases}$$

Major Differences:

1. *Discharges < 8,000 ft³/s are **not constant** in terms of sand exposure*
2. *Differences in the importance of 8,000 ft³/s to 31,500 ft³/s discharges*
3. *Discharges > 31,500 ft³/s may matter*





**preliminary results, do not cite*