Aeolian landscapes and archaeological sites: 2012 progress and new work plan (Project J)

January 23, 2013

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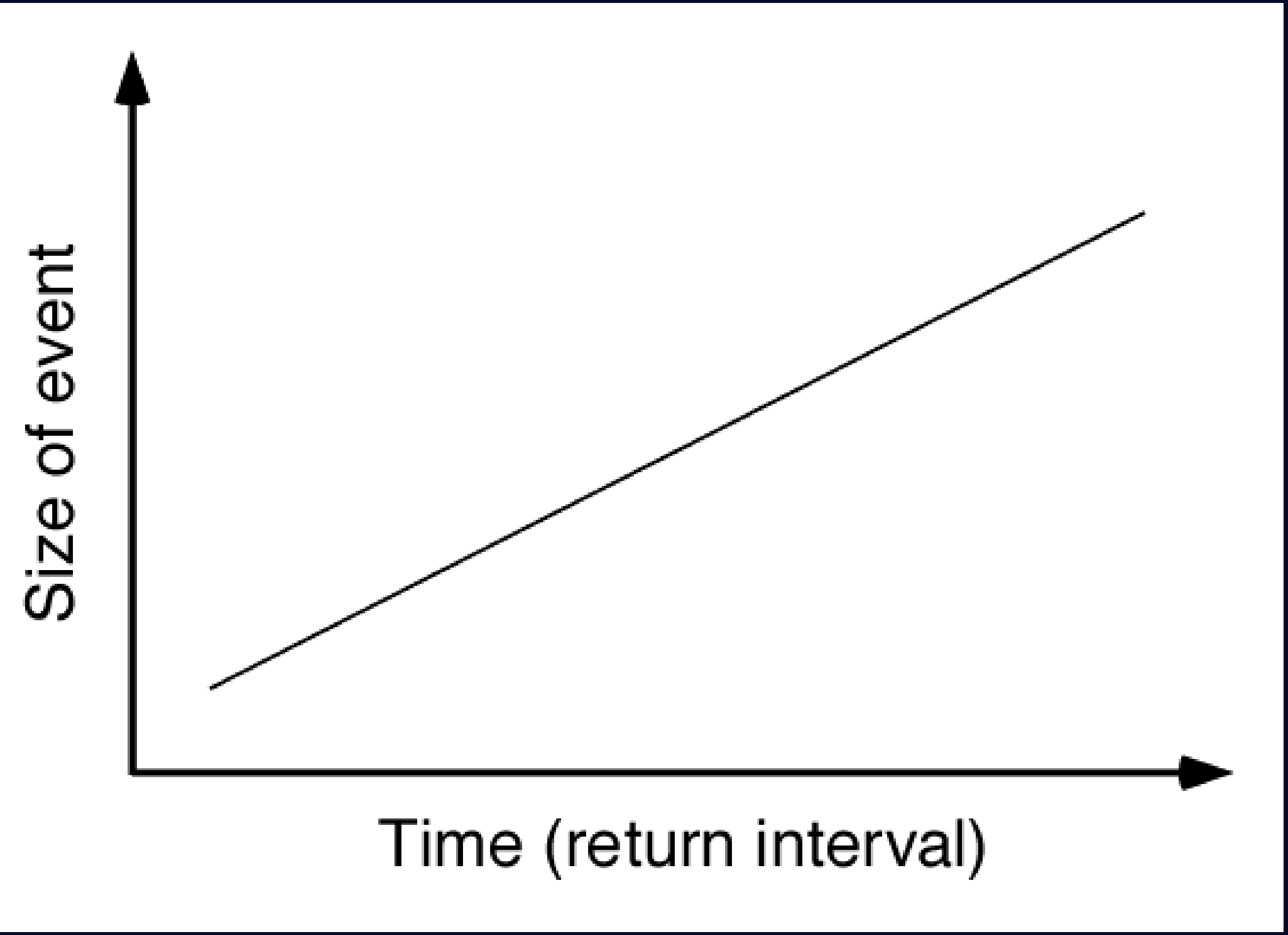
Processes shaping the landscape



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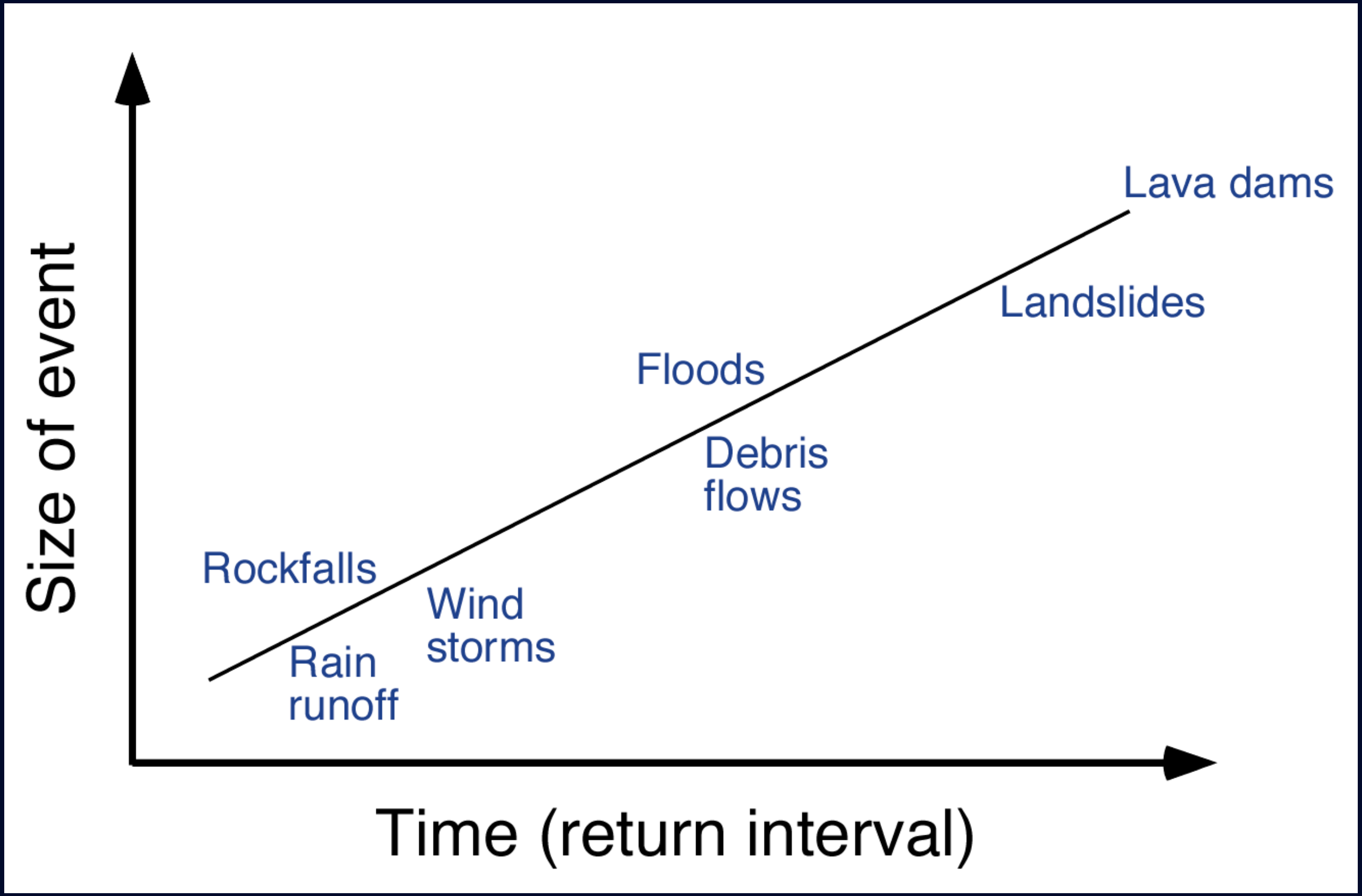
Processes shaping the landscape



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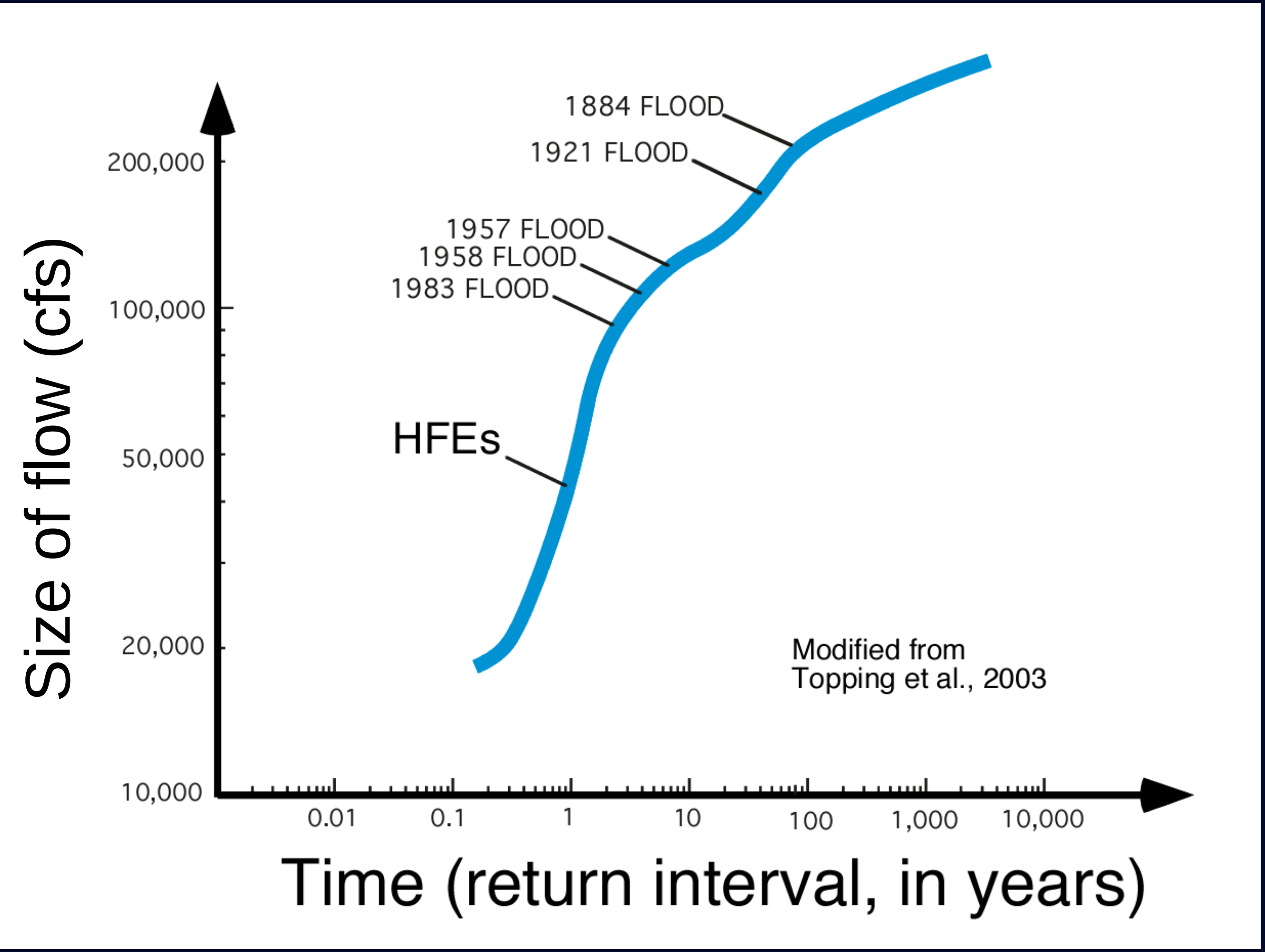
Processes shaping the landscape



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What happens to upland landscapes = what happens to archaeological sites

- To understand processes and risks of site erosion, study at site- and landscape-scale
- Highly likely that many yet-undocumented arch sites are within river-corridor dune fields

Scientific Context

- Fluvial (river) and aeolian (wind) sediment interactions are common worldwide, but the two processes are rarely studied together
- Scientific community sees need for more integrated studies (e.g., Belnap et al. 2011)
- Effects of river regulation on aeolian sand, upland geomorphology have not been studied elsewhere

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2012 paper in Journal of Geophysical Research – Earth Surface

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 117, F02022, doi:10.1029/2011JF002329, 2012

Effects of river regulation on aeolian landscapes, Colorado River, southwestern USA

Amy E. Draut[1]

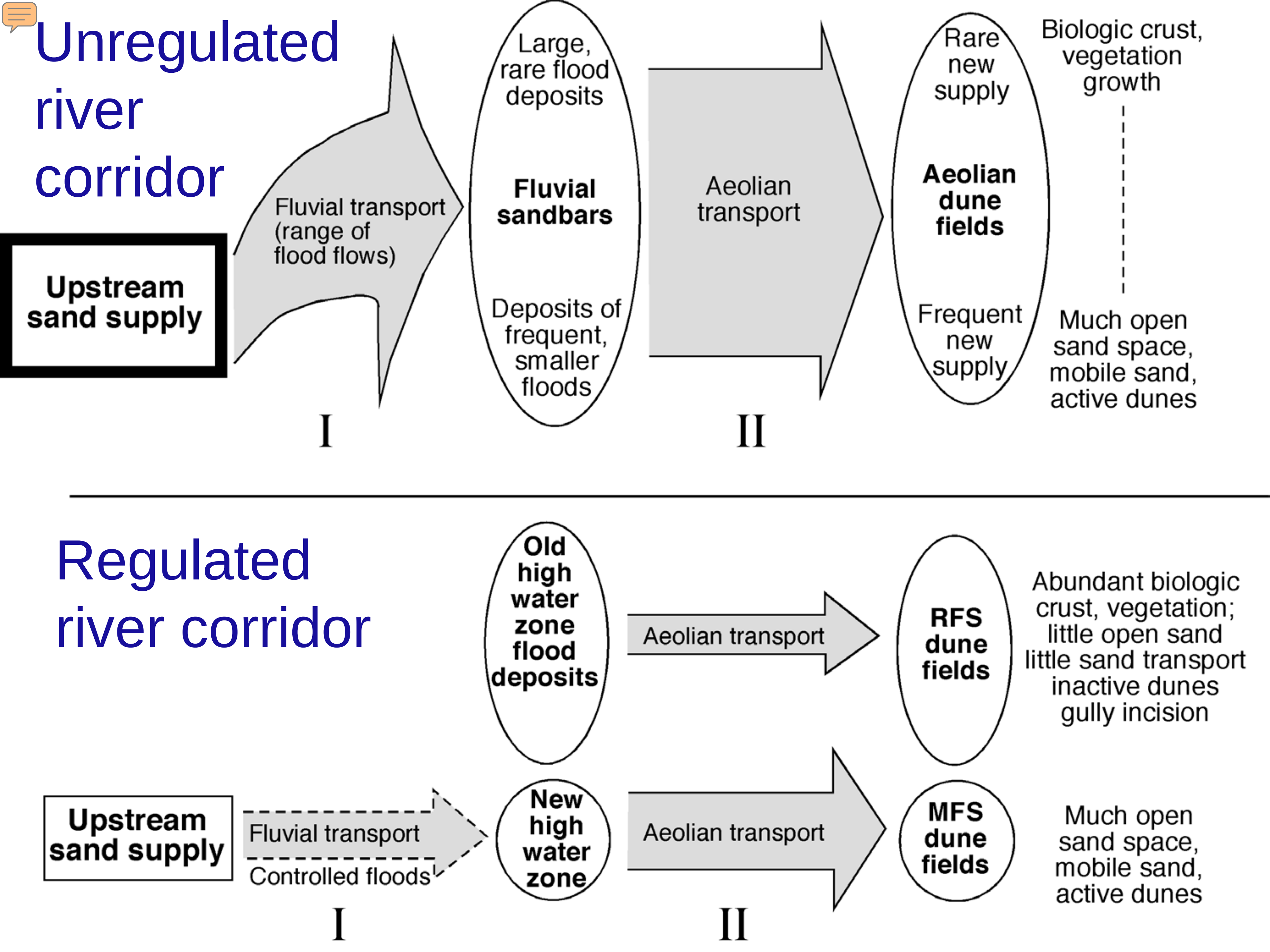
Received 4 January 2012; revised 20 March 2012; accepted 26 March 2012; published 16 May 2012.

[1] Connectivity between fluvial and aeolian sedimentary systems plays an important role in the physical and biological environment of dryland regions. This study examines the coupling between fluvial sand deposits and aeolian dune fields in bedrock canyons of the arid to semiarid Colorado River corridor, southwestern USA. By quantifying significant differences between aeolian landscapes with and without modern fluvial sediment sources, this work demonstrates for the first time that the flow- and sediment-limiting effects of dam operations affect sedimentary processes and ecosystems in aeolian landscapes above the fluvial high water line. Dune fields decoupled from fluvial sand supply have more ground cover (biologic crust and vegetation) and less aeolian sand transport than do dune fields that remain coupled to modern fluvial sand supply. The proportion of active aeolian sand area also is substantially lower in a heavily regulated river reach (Marble–Grand Canyon, Arizona) than in a much less regulated reach with otherwise similar environmental conditions (Cataract Canyon, Utah). The interconnections shown here among river flow and sediment, aeolian sand transport, and biologic communities in aeolian dunes demonstrate a newly recognized means by which anthropogenic influence alters dryland environments. Because fluvial–aeolian coupling is common globally, it is likely that similar sediment-transport connectivity and interaction with upland ecosystems are important in other dryland regions to a greater degree than has been recognized previously.

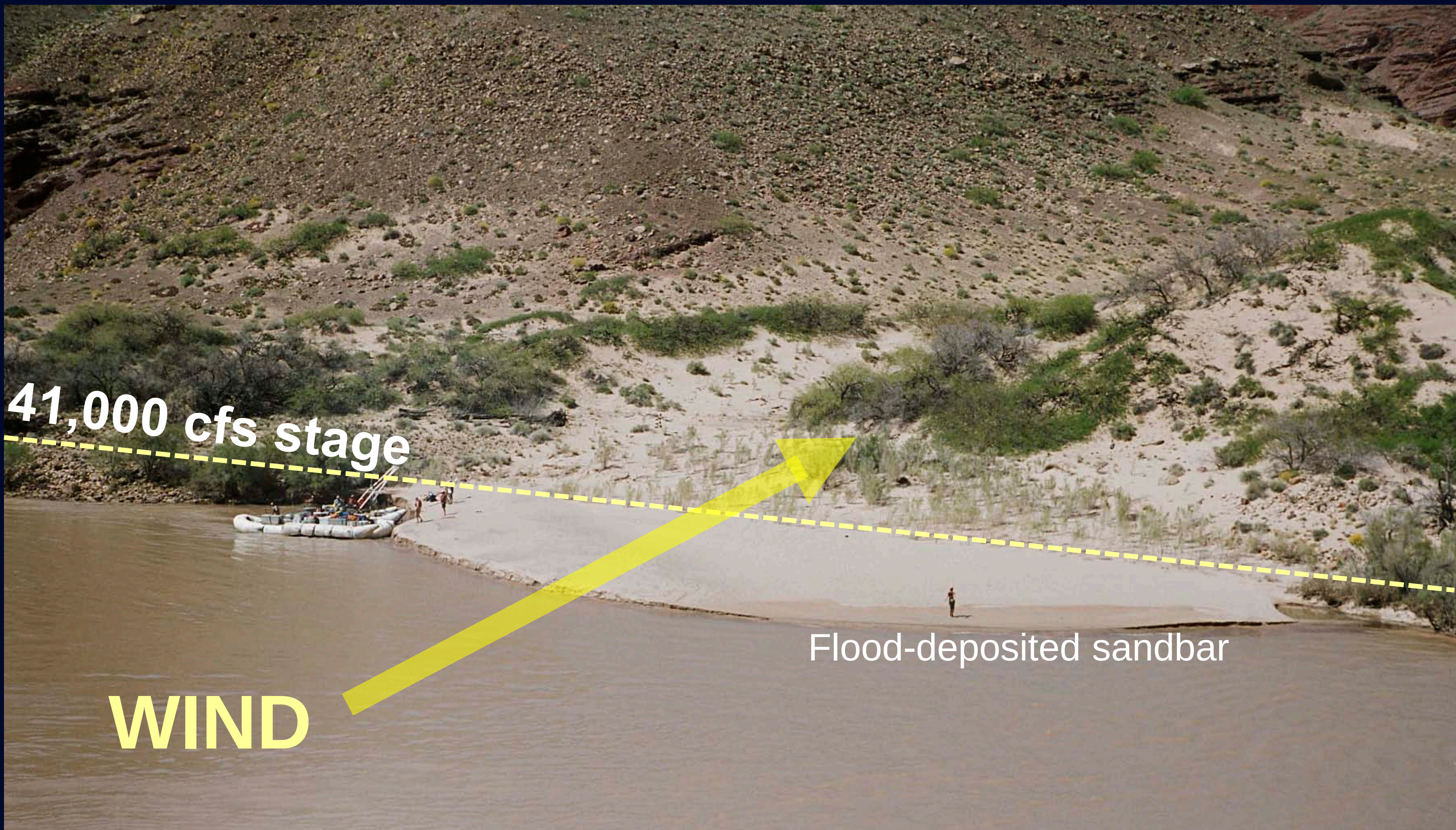
Citation: Draut, A. E. (2012), Effects of river regulation on aeolian landscapes, Colorado River, southwestern USA, *J. Geophys. Res.*, *117*, F02022, doi:10.1029/2011JF002329.

2012 paper in Journal of Geophysical Research – Earth Surface

- Significant differences (physical and biological) between aeolian landscapes with and without modern fluvial sand source
- Significant differences between aeolian landscapes of Grand, Cataract Canyons
- Conceptual model: floods, windblown sand supply, upland geomorphology and ecology

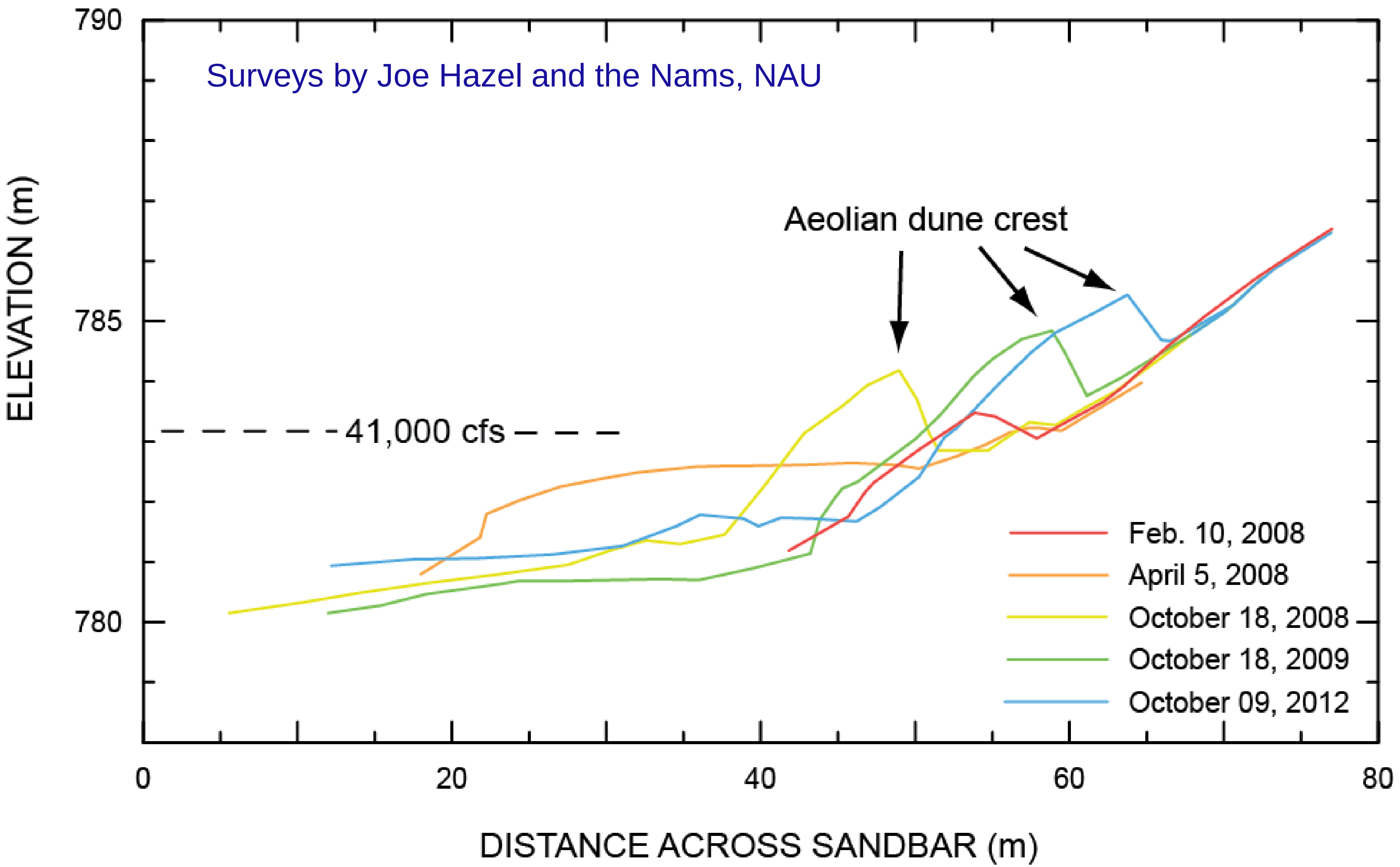

Unregulated river corridor
Upstream sand supply
Fluvial transport (range of flood flows)
Large, rare flood deposits
Fluvial sandbars
Deposits of frequent, smaller floods
Aeolian transport
Rare new supply
Aeolian dune fields
Frequent new supply
Biologic crust, vegetation growth
Much open sand space, mobile sand, active dunes
I
II
Regulated river corridor
Old high water zone flood deposits
Aeolian transport
RFS dune fields
Abundant biologic crust, vegetation; little open sand little sand transport inactive dunes gully incision
Upstream sand supply
Fluvial transport
Controlled floods
New high water zone
Aeolian transport
MFS dune fields
Much open sand space, mobile sand, active dunes
I
II

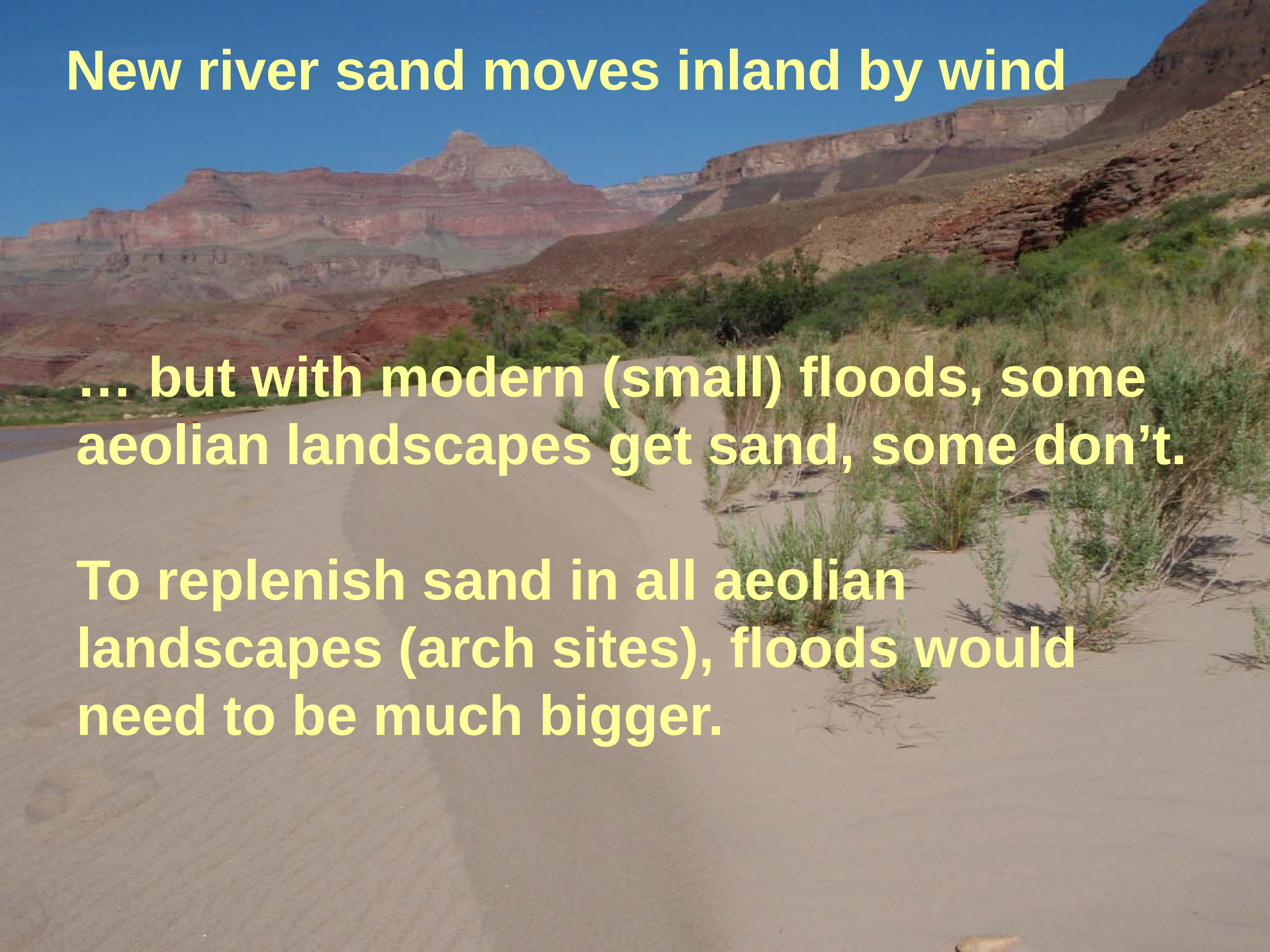
Aeolian landscapes form downwind of river sandbars: "source-bordering dunes" (Bullard & McTainsh, 2003)




New river sand moves inland by wind
HFEs supply new wind-blown sand to aeolian dunes where wind direction is right…

New river sand moves inland by wind





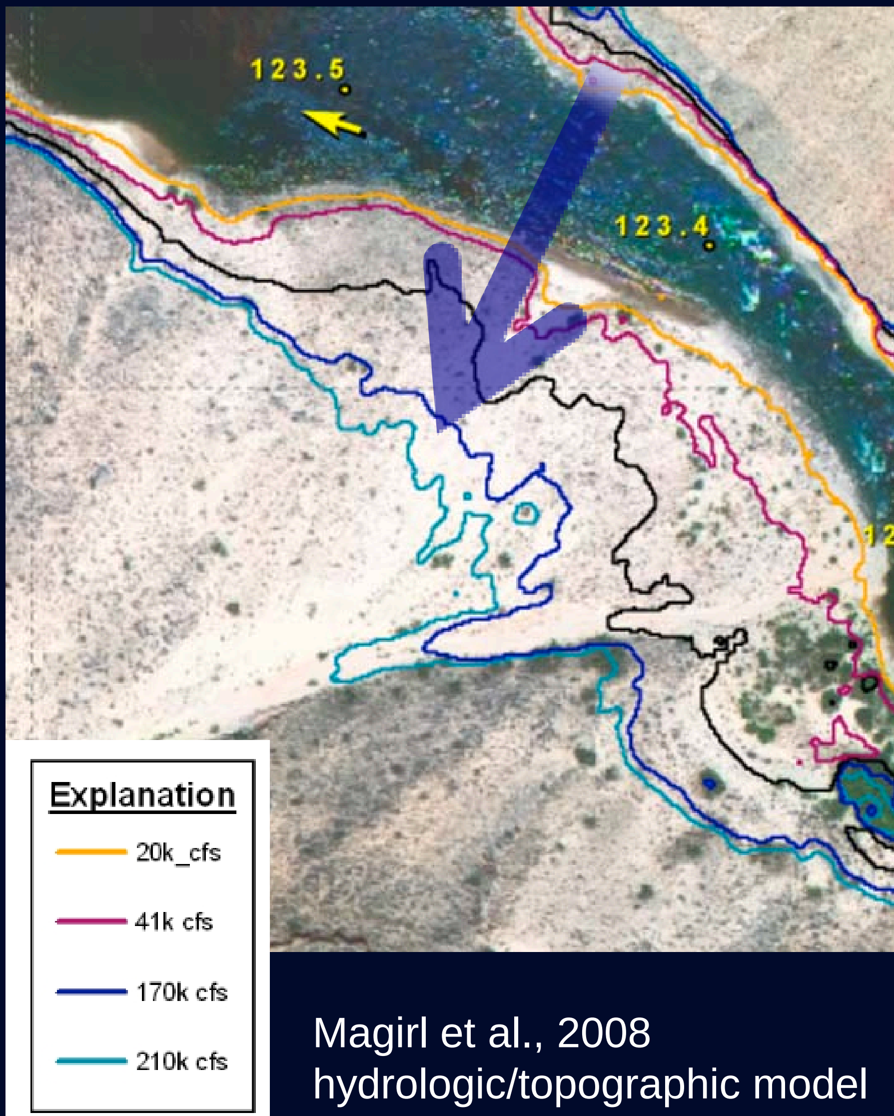
New river sand moves inland by wind

… but with modern (small) floods, some aeolian landscapes get sand, some don’t.

To replenish sand in all aeolian landscapes (arch sites), floods would need to be much bigger.

Modern vs. Relict aeolian landscapes

Some get new sand from modern sandbars

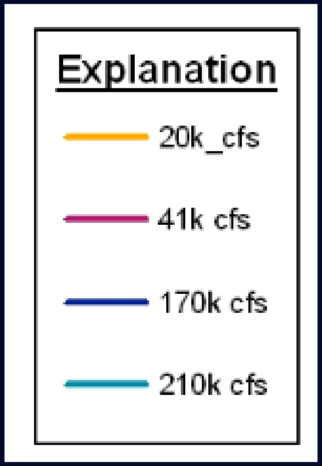


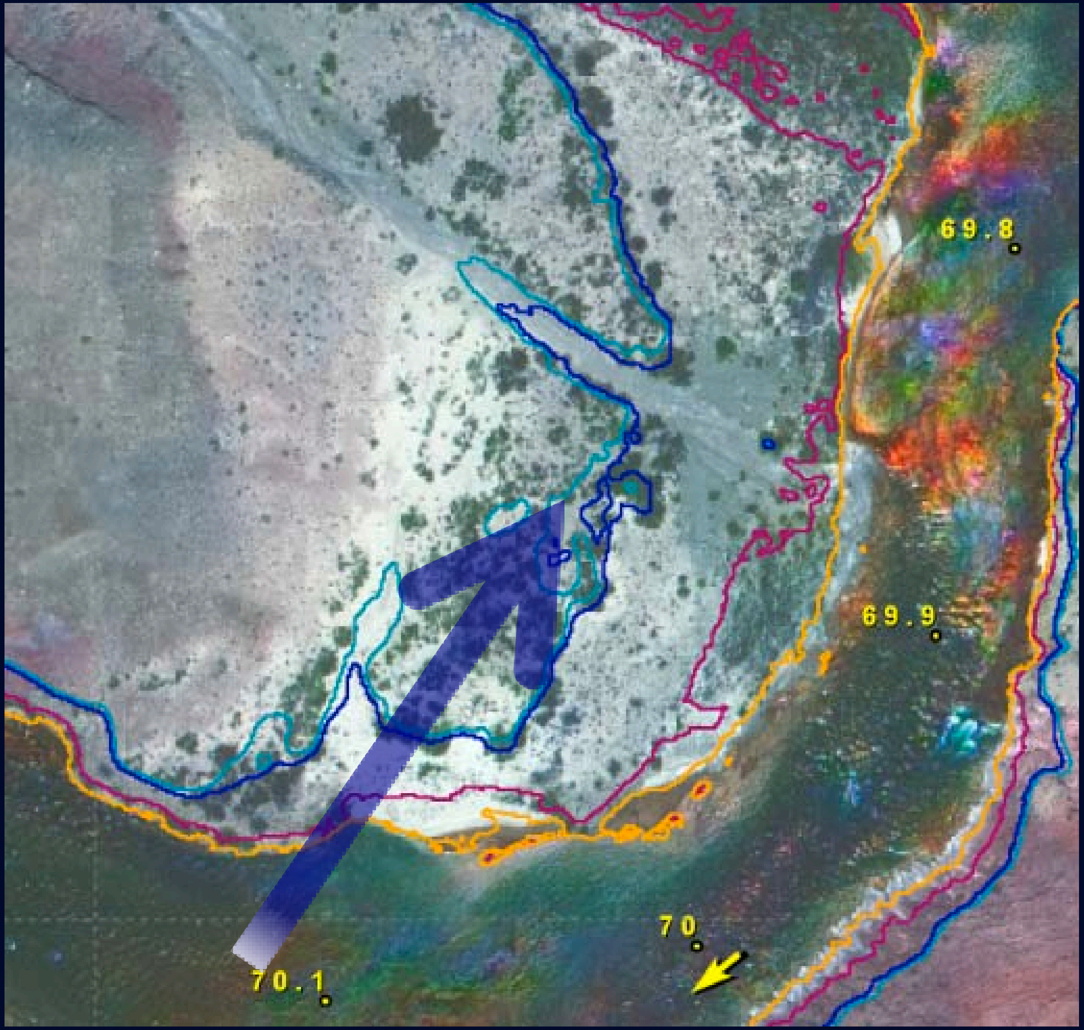
Magirl et al., 2008
hydrologic/topographic model

Flow

Others don't.

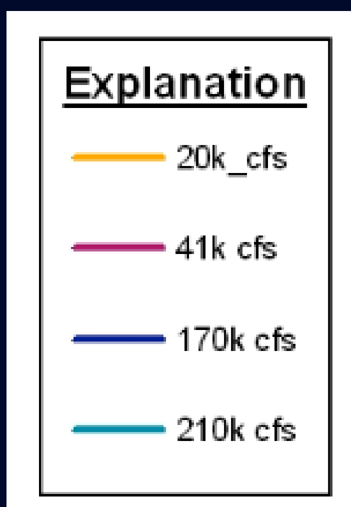
Modern vs. Relict aeolian landscapes

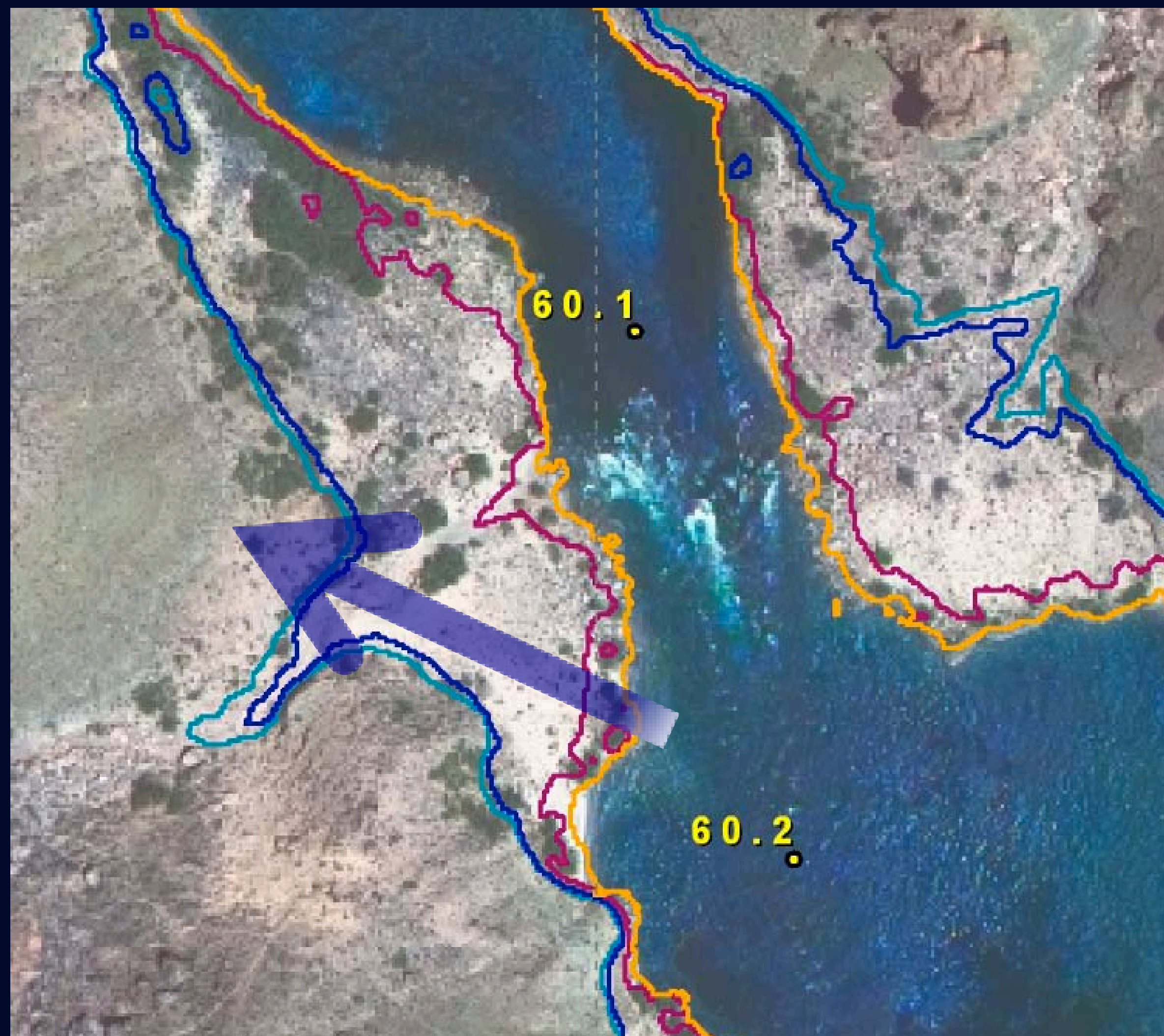




Magirl et al., 2008 hydrologic/topographic model

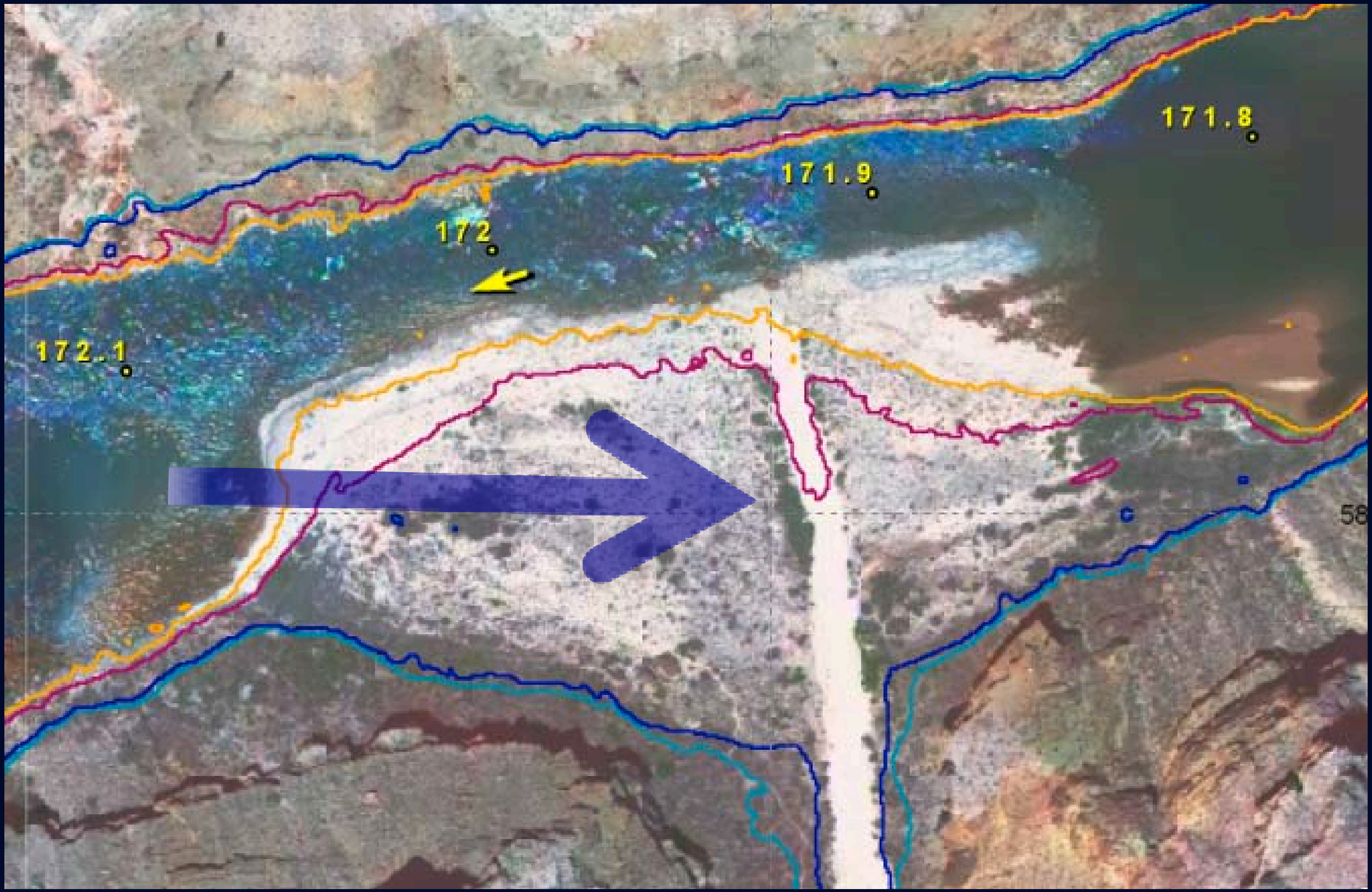
Aeolian landscapes in GRCA largely originated from ‘extreme’ floods





Magirl et al., 2008

Aeolian landscapes in GRCA largely originated from ‘extreme’ floods



Explanation

- 20k_cfs
- 41k cfs
- 170k cfs
- 210k cfs

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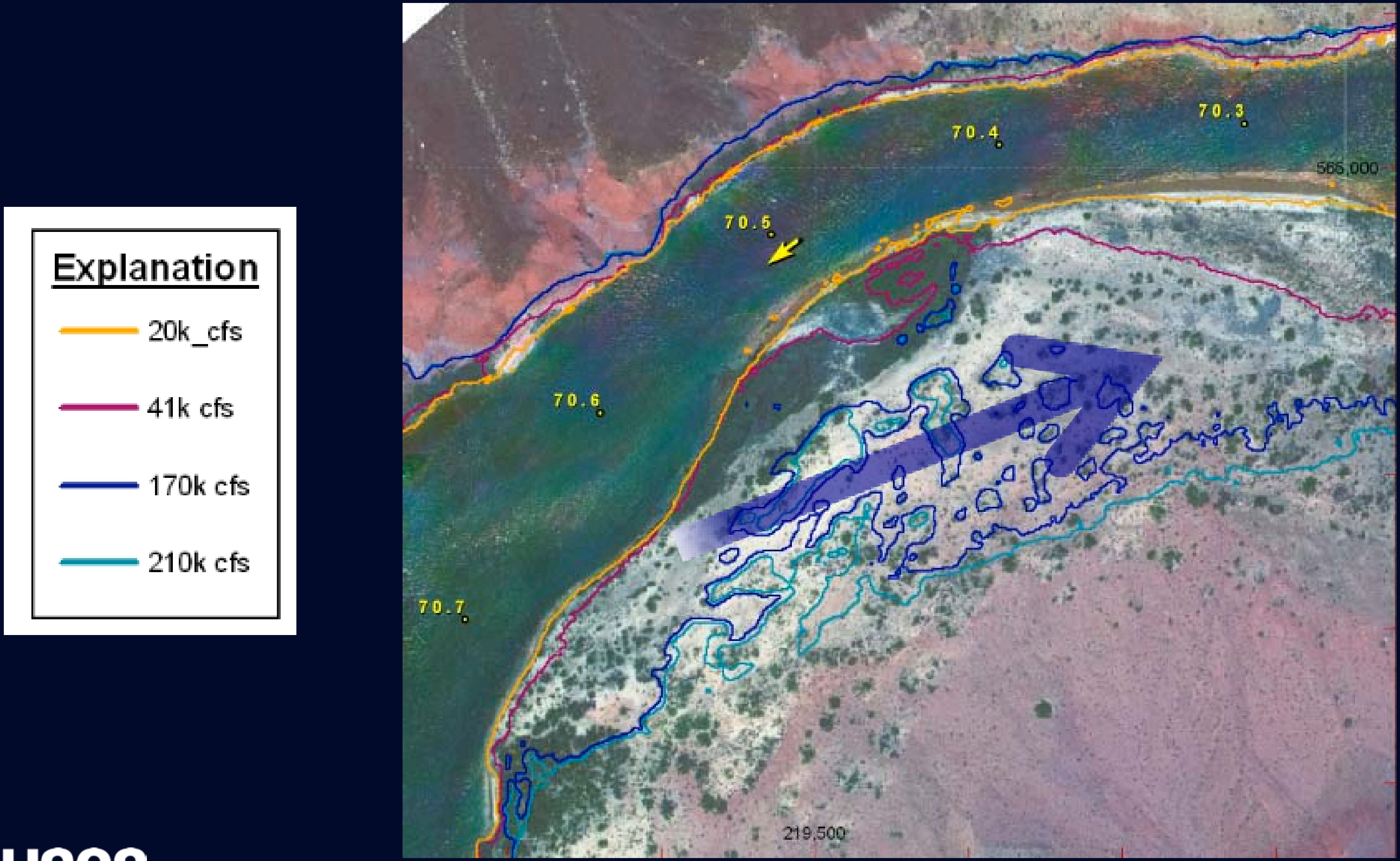
Magirl et al., 2008

Most, and largest, dune fields set by 40-year flood (170,000 cfs)

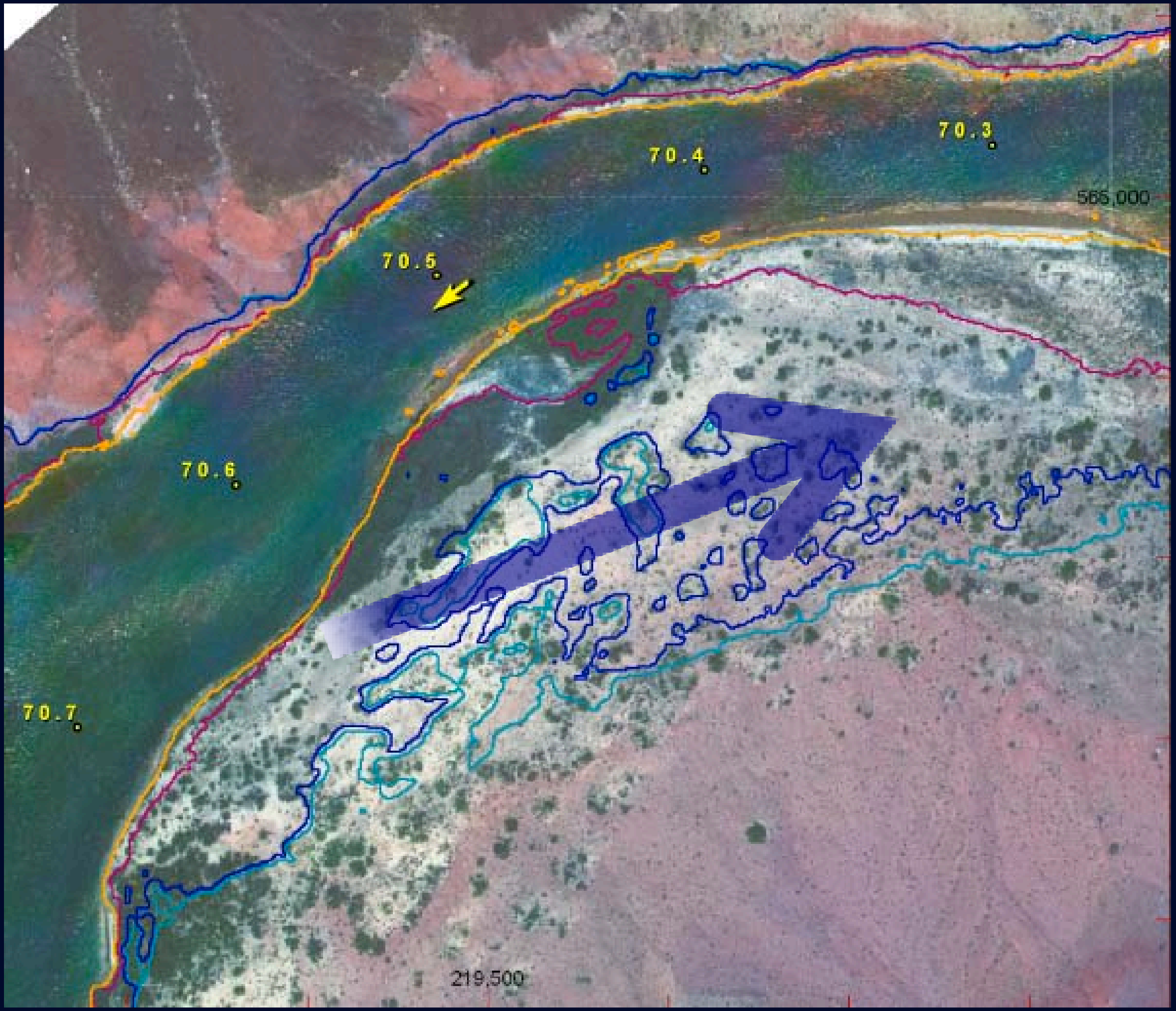


Magirl et al., 2008

USGS

Most, and largest, dune fields set by 40-year flood (170,000 cfs)

- HFEs cover a small proportion of natural (pre-dam) sand source area
- HFE deposits often too small, far away, blocked by riparian vegetation



USGS

Magirl et al., 2008

Link between river sediment and upland aeolian landscapes

- **Aeolian dunes get sand from fluvial (flood) sandbars**
- **Aeolian dunes without modern sand supply develop much more biologic soil crust, become less active**

Aeolian dunes without modern sand supply:

Have:

More biologic crust

More vegetation

Less open sand

Less sand transport

Crusts stabilize sand, dunes immobile.

USGS

… compared with places that still get sand supply

More sand transport = dunes shift, migrate.
Artifacts covered/uncovered by dunes

Comparing active vs. inactive aeolian sand

"Active" aeolian sand has wind-rippled surfaces, slip faces at angle of repose
(Lancaster, 1994)

USGS

Comparing active vs. inactive aeolian sand

Project J preview: Gullies in places like this →

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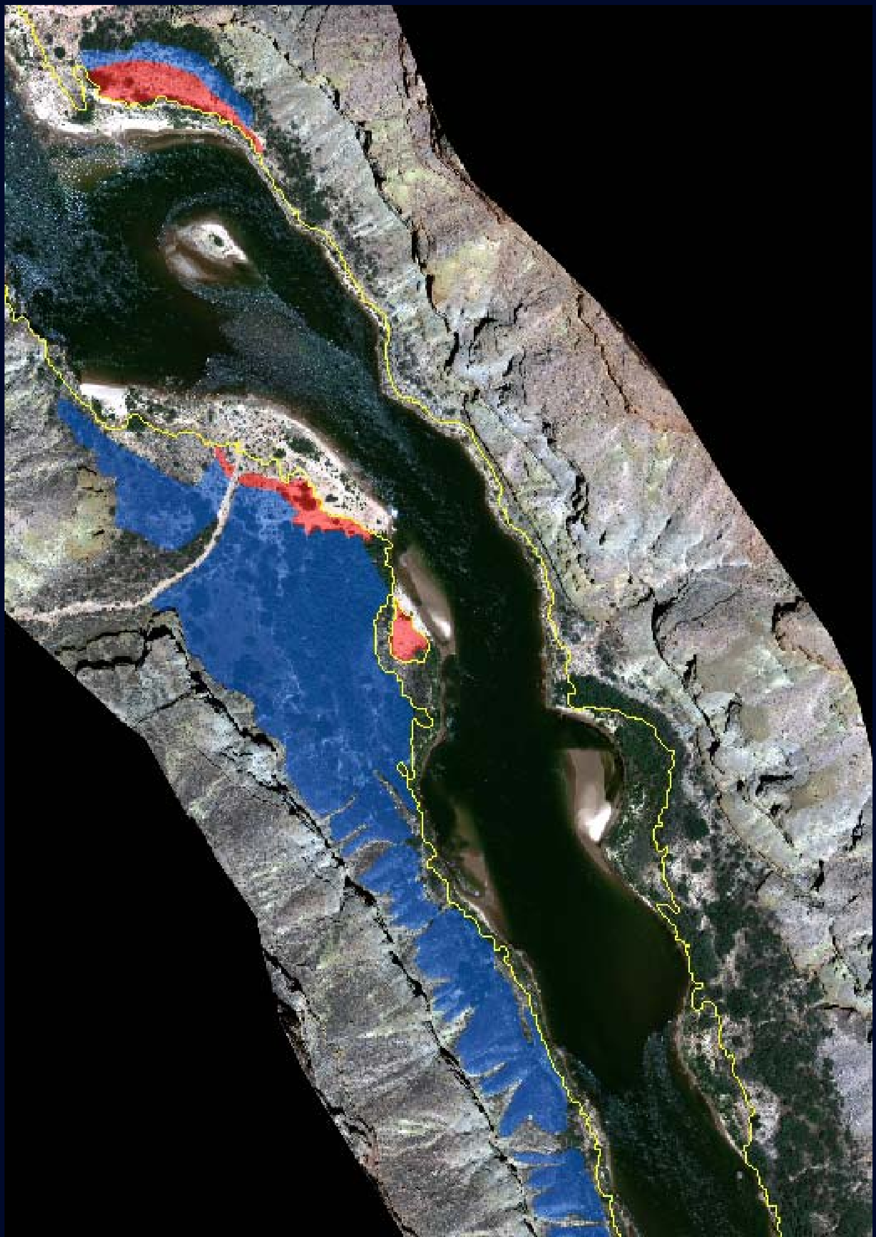
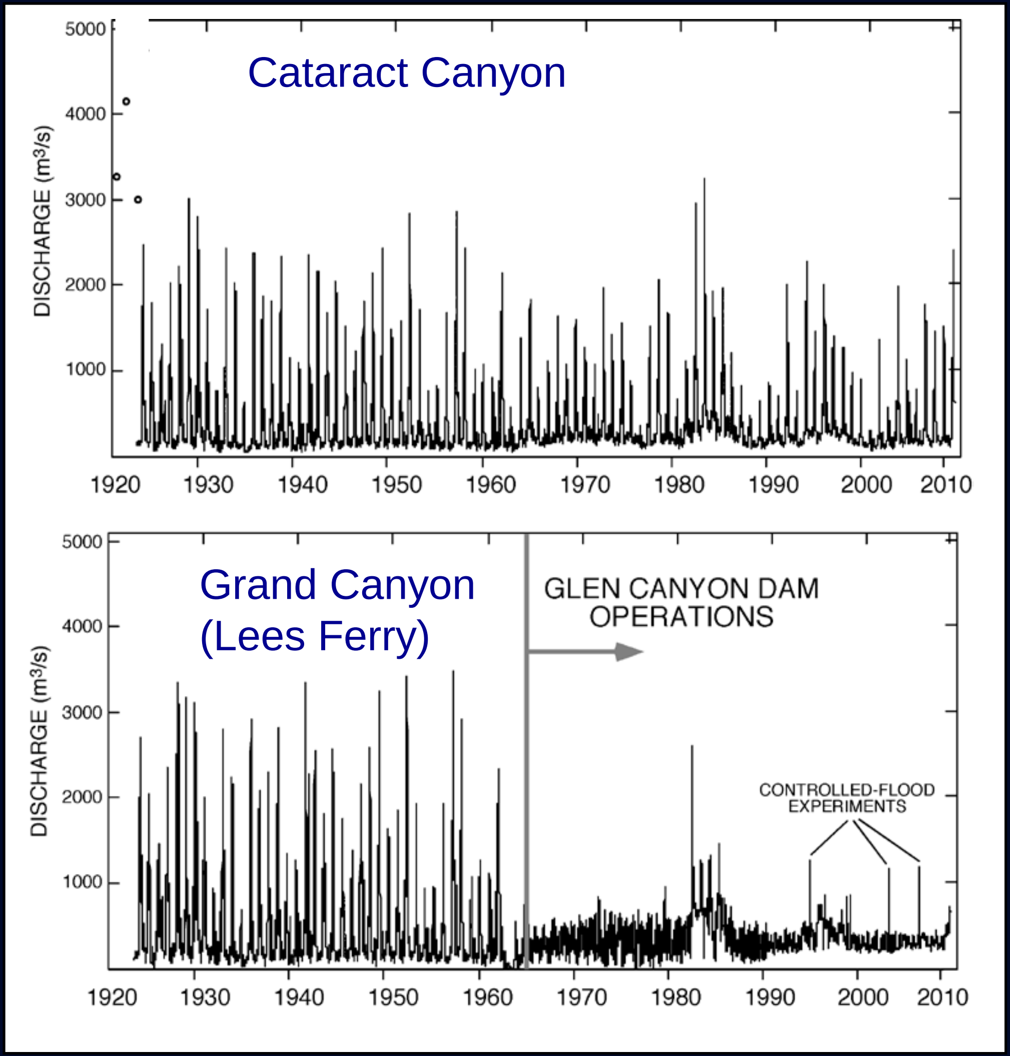
Proportions of active vs. inactive aeolian sand

- Mapped all aeolian sand locations in RM 44-61
- Analyzed active / inactive sand area in GIS

Only 13% of aeolian sand area there is active



Compare with Cataract Canyon, Utah



65% of aeolian sand area is active (Marble Canyon reach had 13%)

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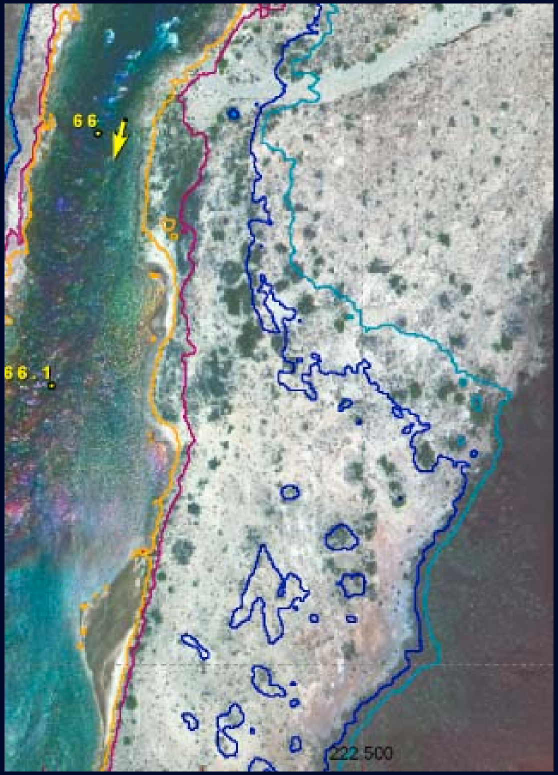
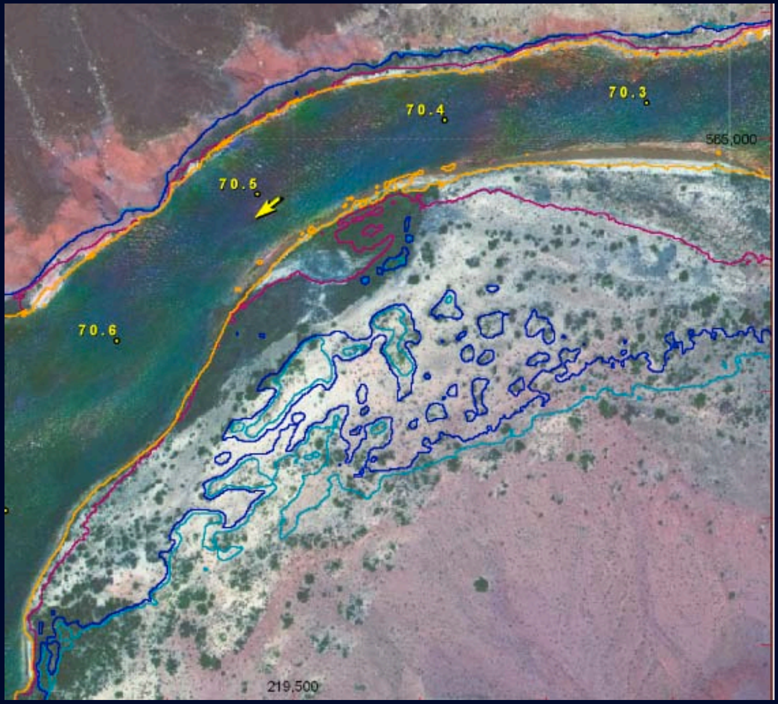
Sand activity in individual dune fields

- **Some archaeologically significant dune fields have very little active sand area (mapped RM 66-72 in 2012)**
- **Influences susceptibility to gully incision**



Palisades: 1.6% active sand



70-mile: 4.1% active sand

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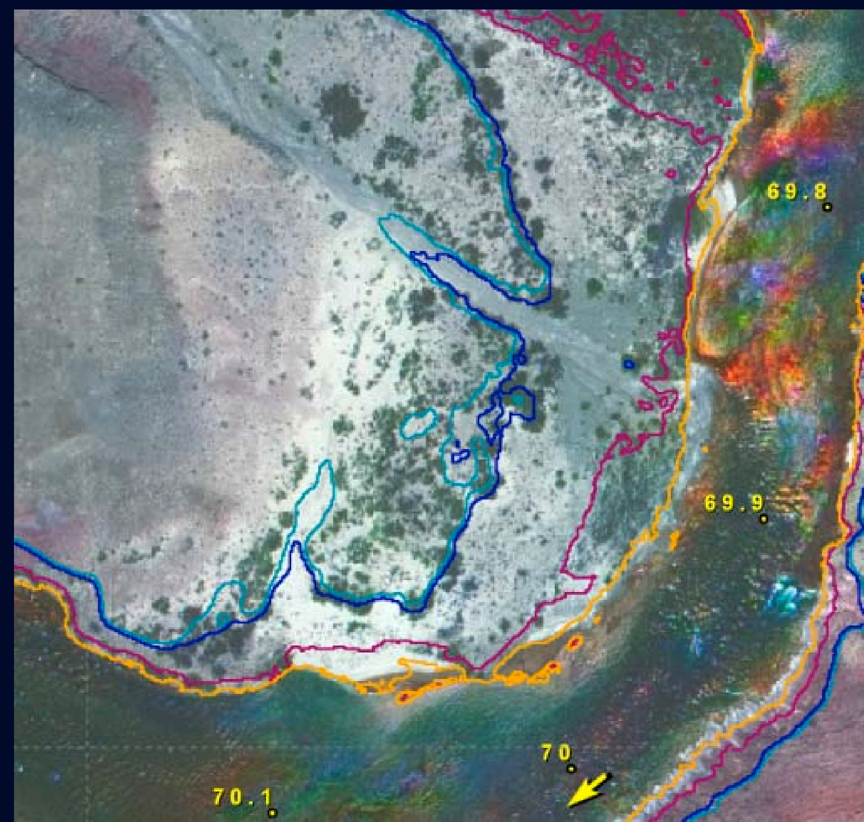
Sand activity in individual dune fields

- Dune fields clearly getting HFE sand have higher % active sand area
- Probably less susceptible to gully incision

Basalt: 27% active sand



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Project J: 2013-2014 Overview questions

- Do cultural sites erode or change faster or in a significantly different manner than they would if dam operations were different?

- How effective are HFEs at supplying aeolian sand to upland landscapes and archaeological sites, maintaining natural landscape structure and function?

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Project J: 2013-2014

- J1: Cultural-site monitoring in Glen Canyon
- J2: Archaeological site condition, landscape processes at places benefiting from HFE sand
- J3: Large-scale landscape evolution – role of aeolian sand in limiting gully erosion; role of HFEs in maintaining aeolian sand activity

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J1. Glen vs. Marble-Grand Canyon

- **Are sites in Glen Canyon significantly more eroded than those downstream from Lees Ferry where fine-sediment supply is greater?**

- **C:2:0032, C:2:0035, C:2:0075, C:2:0077**
- **Measure site topography with lidar (airborne & terrestrial), compare with previous data in Marble-Grand Canyon**
- **Compare weather records (Page vs. Phantom Ranch) with extent of erosion**
- **Input to geomorphic model of erosion (David Bedford)**

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J2. Processes at sites that receive new aeolian sand from HFEs

- **What number, proportion of archaeological sites can benefit from aeolian sand supply caused by HFEs?**

- **Aeolian sand is important at ~100 sites in Marble-Grand Canyon river corridor. Which are adjacent to and downwind of new HFE sandbars?**
- **Analyzing 2012 post-HFE oblique photos near each of those sites, using 1996 pre- and post-HFE aerial photos**
- **Short field visits in 2013 to identify local wind directions from surface geomorphology if no weather-station record nearby**

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J2. Processes at sites that receive new aeolian sand from HFEs

- At archaeological sites that receive HFE sand:
  - Is aeolian sand transport, deposition enough to offset erosion and protect archaeological sites?
  - Are gullying, deflation advanced enough to reduce site integrity?

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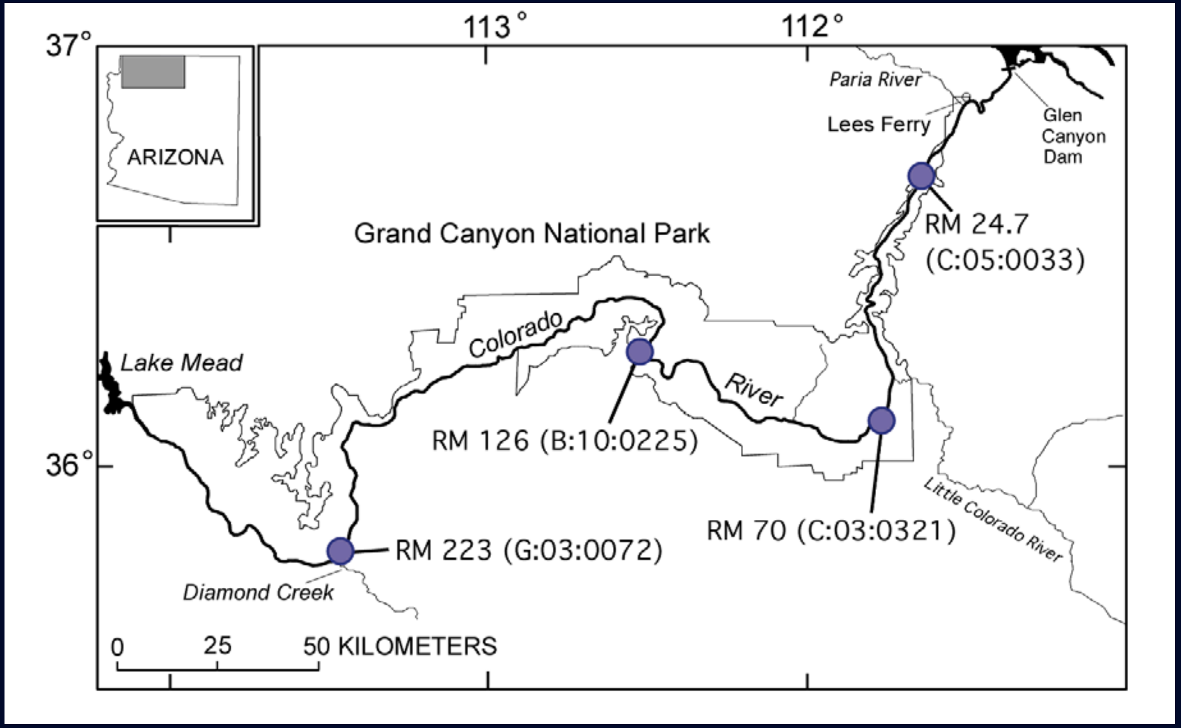
J2. Processes at sites that receive new aeolian sand from HFEs

- Measure rainfall, wind at weather stations at 4 sites
- Terrestrial lidar scanning in 2013, 2014
- Stationary cameras for daily record of site conditions



J2. Processes at sites that receive new aeolian sand from HFEs

- At archaeological sites that receive HFE sand:
  - What specific processes/conditions contribute to site stability or erosion – gullying, deflation, inflation, dune migration?

What types and rates of change at sites benefiting from HFEs?

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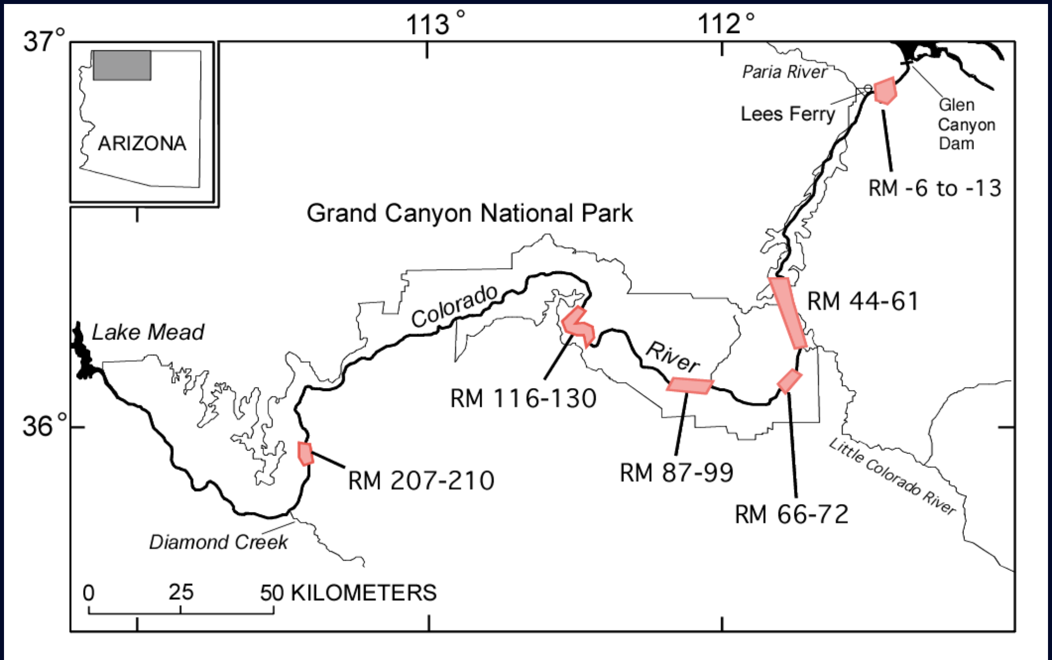
J3. Landscape-scale assessment

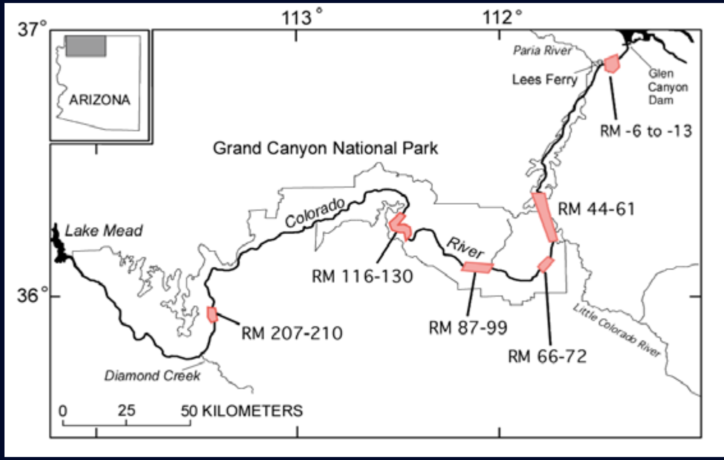
- **How does relative abundance of active / inactive aeolian sand vary in different regions of the river corridor?**



Hypothesis: Proportion of active sand will be less in wide reaches of the river corridor (where archaeological record is most extensive)

J3. Landscape-scale assessment

- **How does the degree of gully erosion differ in sediment deposits that are active vs. inactive with respect to aeolian transport?**



Hypothesis: Gullies will be more extensive, longer-lasting in inactive than in active sand.

True so far – of 1277 m of gully length mapped in RM 66-72, 98% in inactive sand deposits

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J3. Landscape-scale assessment

- **To what extent does aeolian sediment transport counteract or prevent gully incision?**

Hypothesis: Aeolian sediment limits gully incision such that gullies are absent in places where, if not for aeolian sediment transport, they would be present.

- **Aerial photograph analysis on decadal scales (Joel Sankey)**
- **Modeling (David Bedford) – model runoff on existing, smoothed terrain: does model predict gullies where instead dunes exist?**

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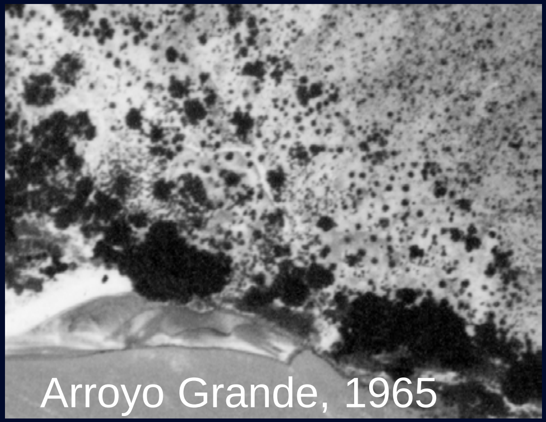
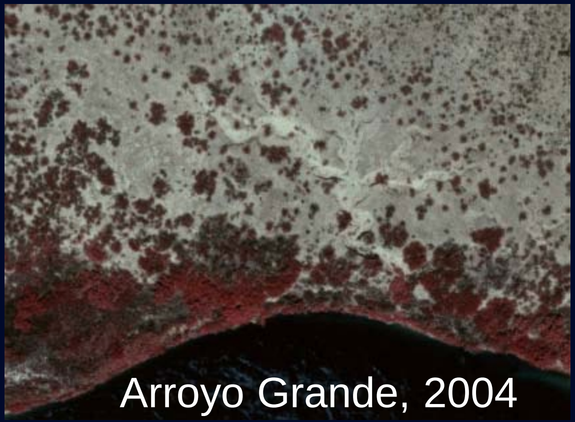

Arroyo Grande, 1965


Arroyo Grande, 2004

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Questions?

With thanks to:
Helen Fairley, Brian Collins, Joel Sankey, David Bedford, Skye Corbett
Josh East, Bob Tusso, Tom Gushue, Josh Logan

Ecosystem role of biologic crust

- Lichens, moss, cyanobacteria, fungi, algae
- Changes soil chemistry, nutrientes, plants, herbivore diet & abundance
- Loss of aeolian sand supply translates into upland ecosystem

Heavily crusted dunes at Granite Park

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What about loss of low flows?

- Loss of low flows post-dam means wind can’t mobilize sand from fluvial sandbars that were exposed in late summer/ fall
- Less important than loss of flood sand, because timing of low flows and driest, windiest weather didn’tcoincide. Pre-dam spring winds mostly reworked last year’s flood sand
- Low flows don’t expose sand upwind of large, archaeologically important dune fields

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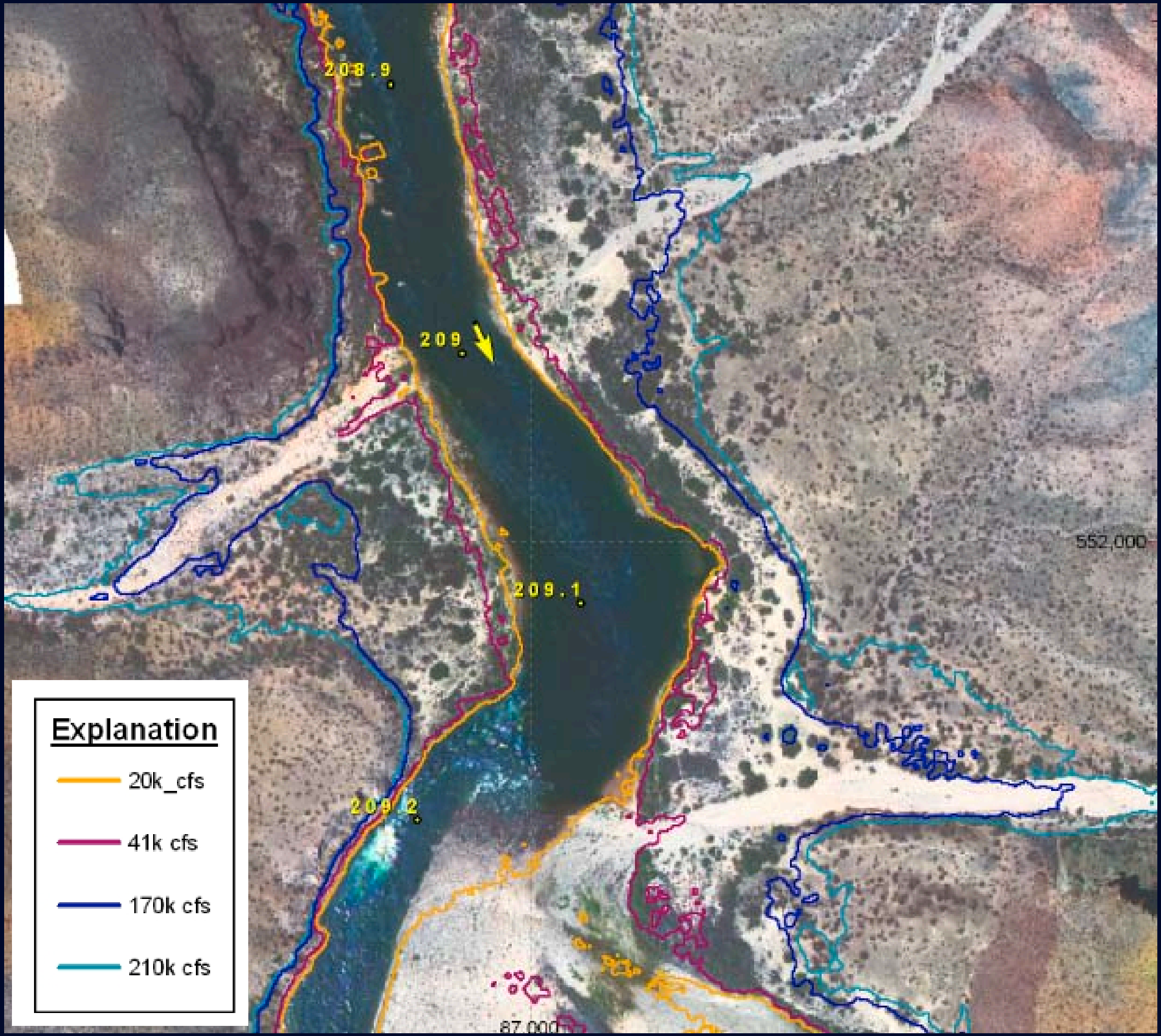
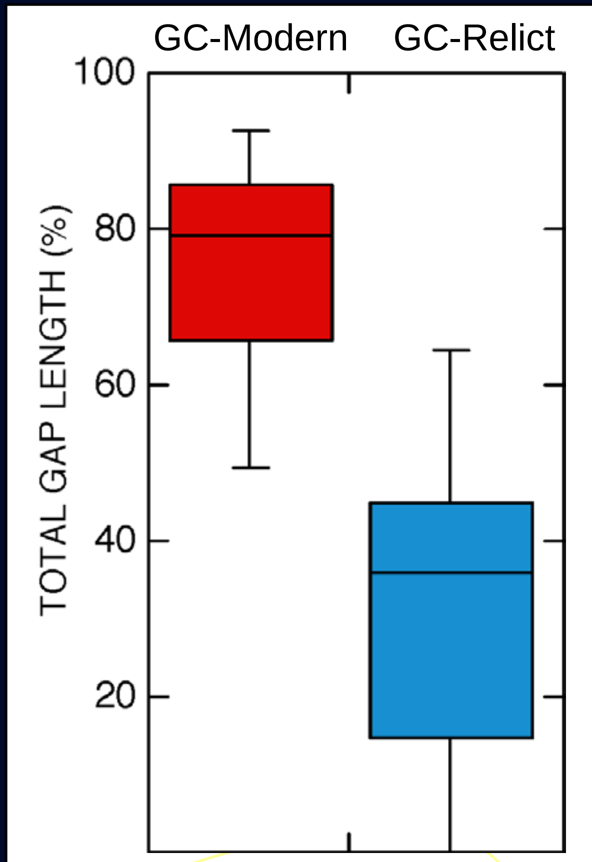
Most, and largest, dune fields set by 40-year flood (170,000 cfs)



- HFEs cover a small proportion of natural (pre-dam) sand source area
- HFE deposits often too small, far away, blocked by riparian vegetation

Open, bare sand space

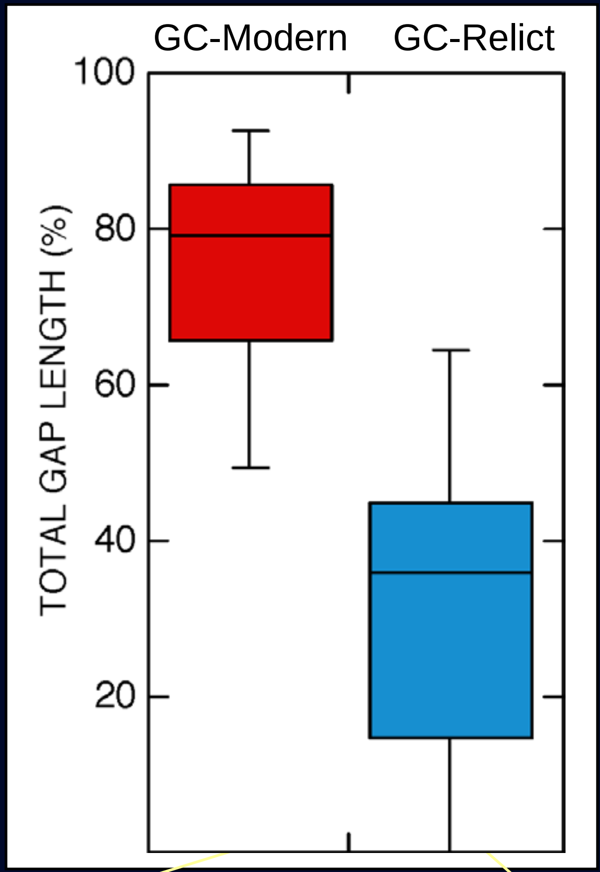


These sites get modern wind-blown sand supply after HFEs

These don't

Box-and-whisker plots:

Open, bare sand space



These sites get modern wind-blown sand supply after HFEs

These don't

***t*-test ➔ *p* value**

Low *p* values mean the two groups are significantly different

$p < 0.00001$

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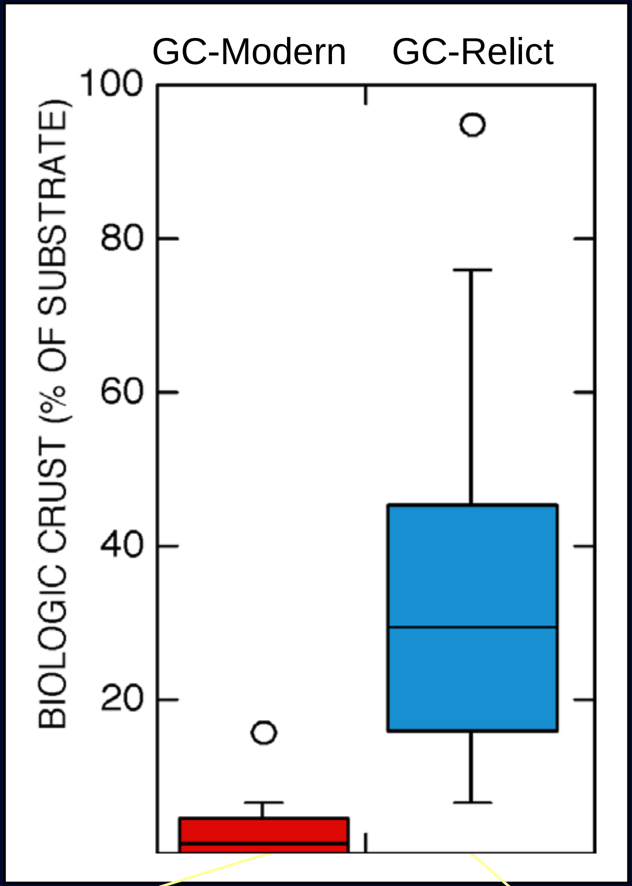
Biologic soil crust



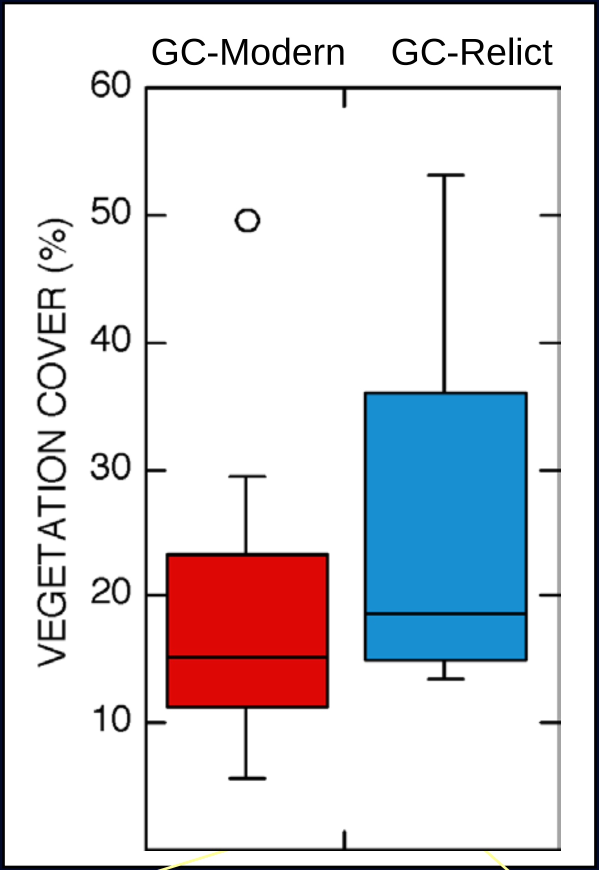
$p < 0.005$

These sites get modern wind-blown sand supply after HFEs

These don't

USGS

Vegetation cover



$p < 0.07$

These sites get modern wind-blown sand supply after HFEs

These don't

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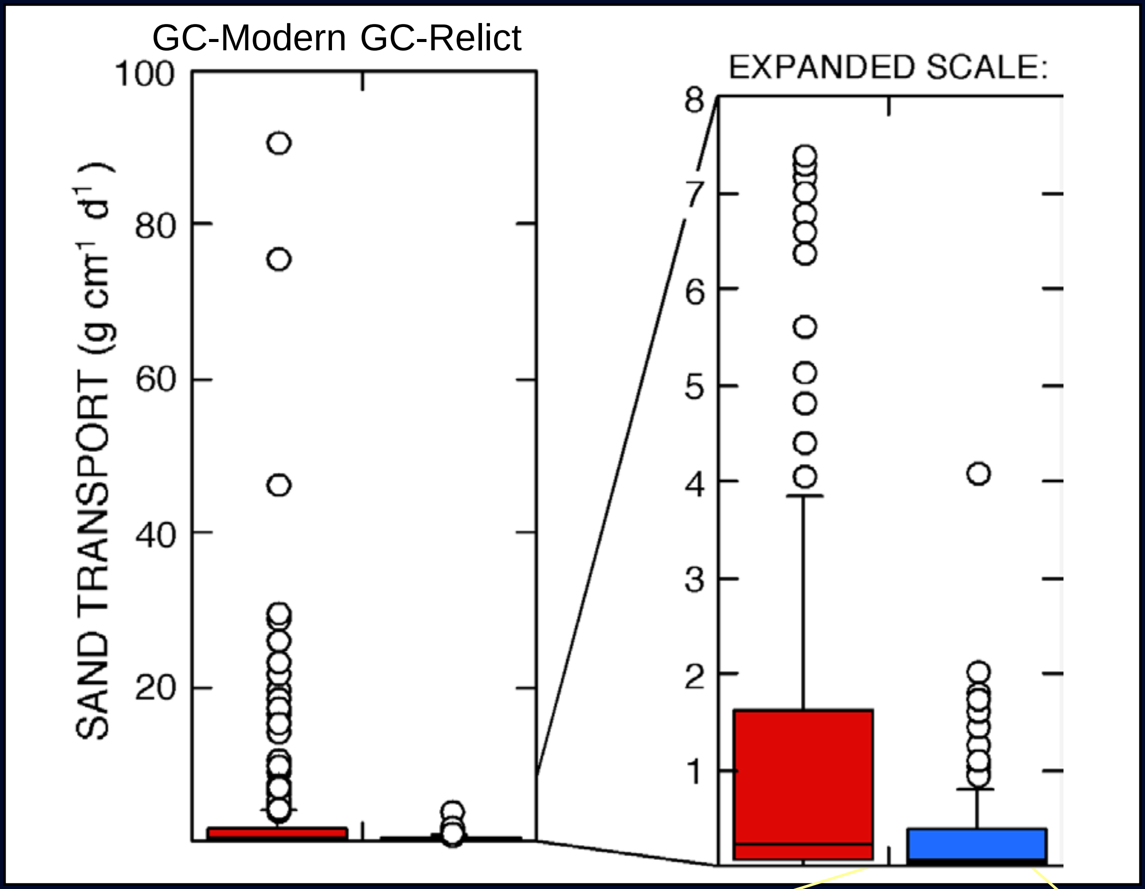
Sand transport by wind: raw data



378 measurements

at 14 sites

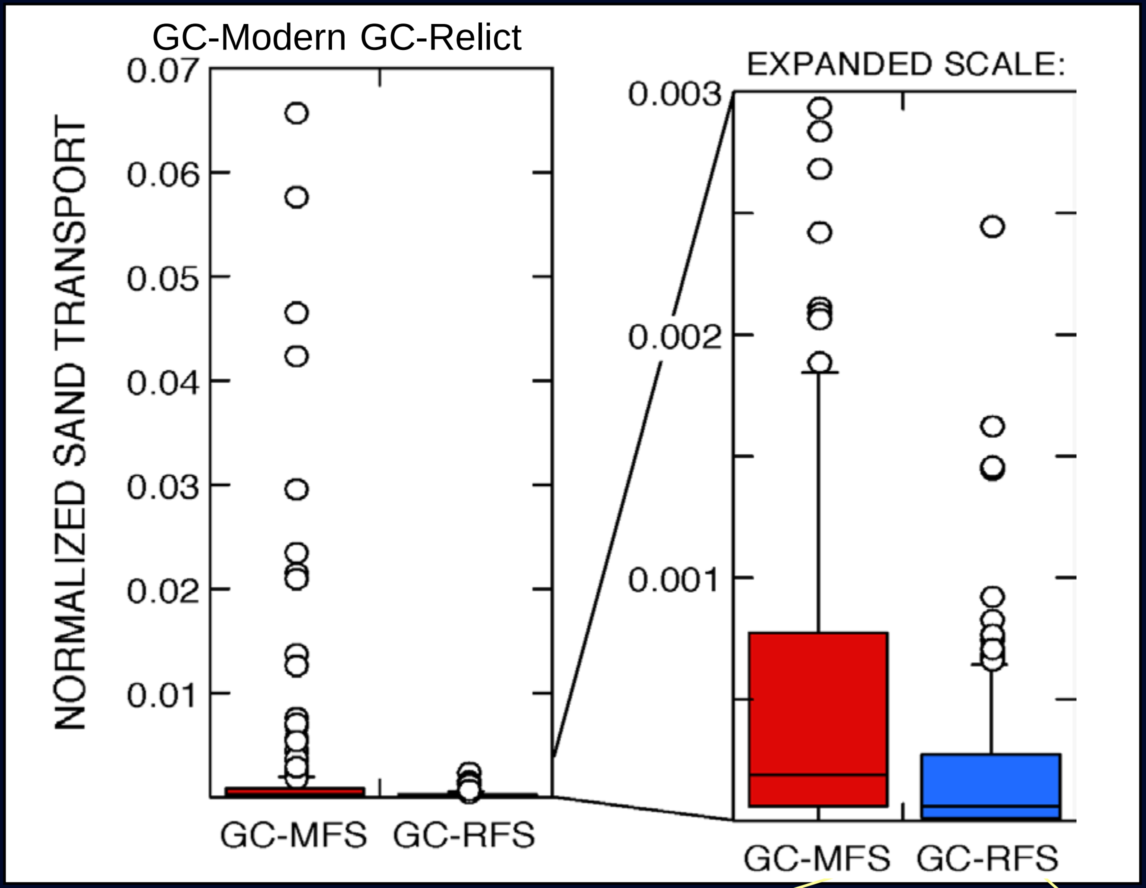
2003 - 2010

These sites get modern wind-blown sand supply after HFEs

These don't

USGS

Sand transport by wind: normalized



$p < 0.05$

These sites get modern wind-blown sand supply after HFEs

These don't

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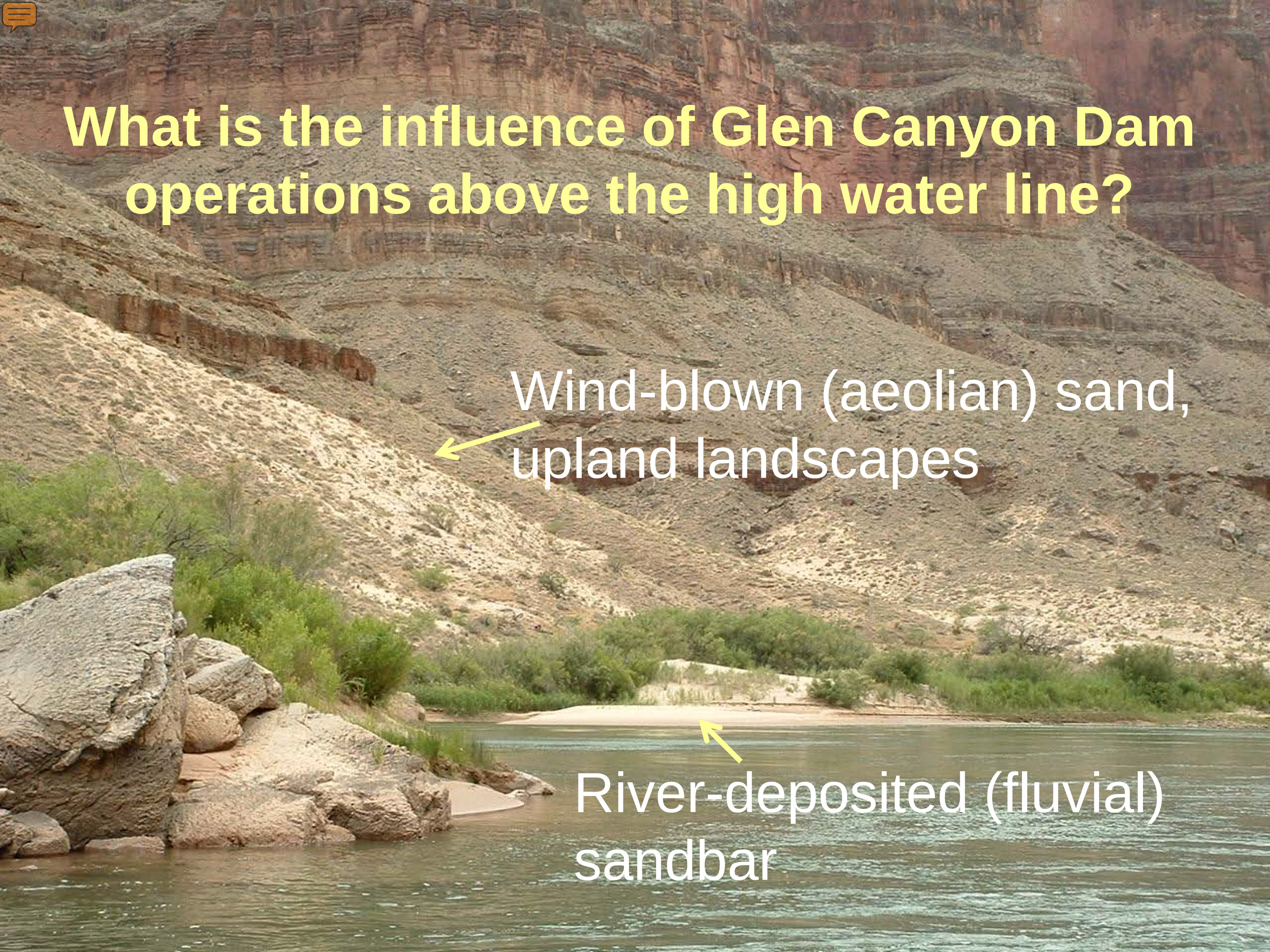
What is the influence of Glen Canyon Dam operations above the high water line?



Example of gully filled by wind-blown sand from a controlled-flood deposit

Head of gully

Middle of gully

Terminus of gully

USGS

Riparian vegetation growth will inhibit aeolian sand supply inland

Malgosa, 2005

USGS

Riparian vegetation growth will inhibit aeolian sand supply inland