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Aeolian landscapes and sediment movement in the Colorado River corridor

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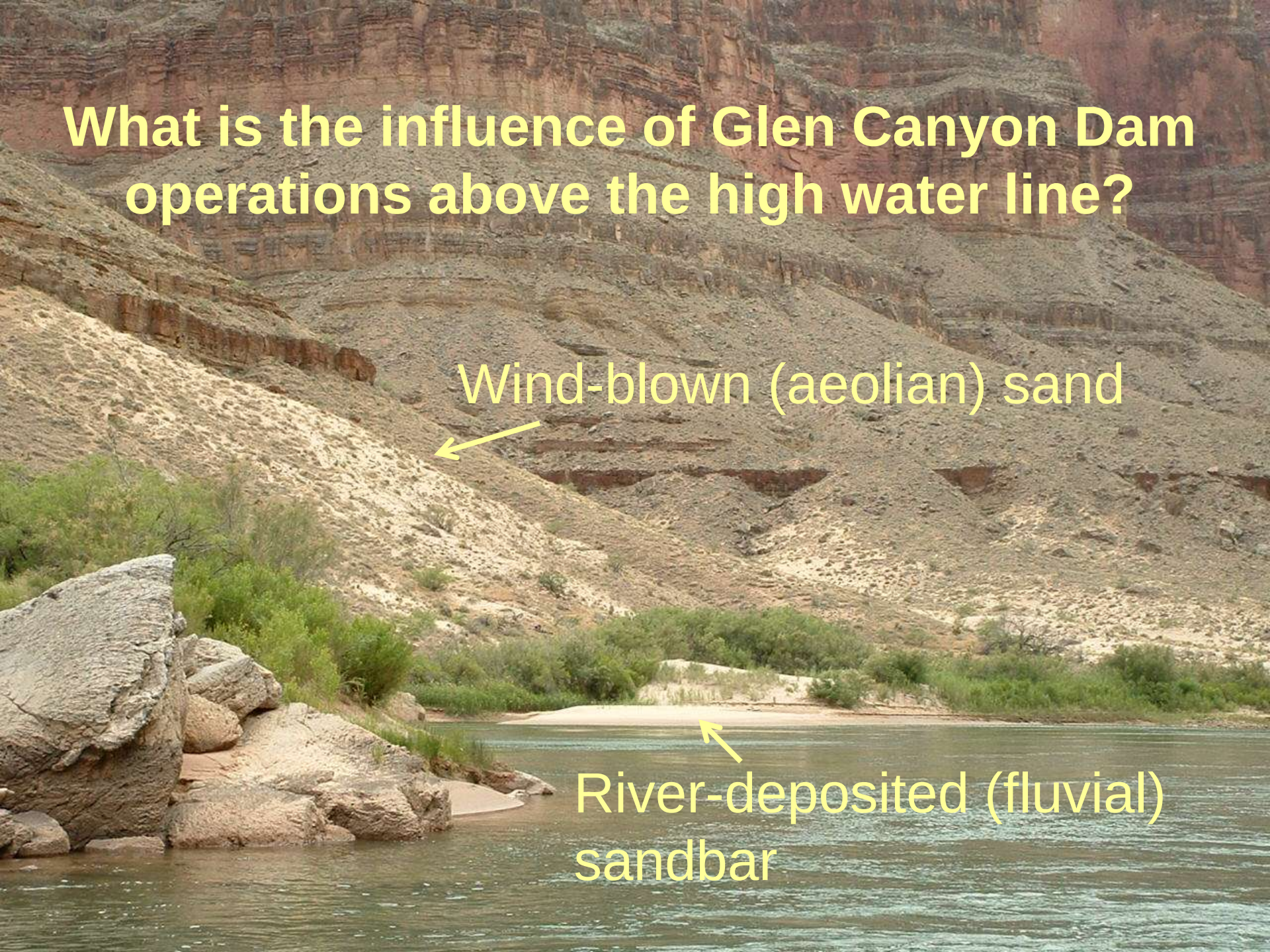
What is the influence of Glen Canyon Dam operations above the high water line?
Wind-blown (aeolian) sand
River-deposited (fluvial) sandbar

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 have not been studied elsewhere
- Colorado River is ideal study environment

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Scientific Context

- **Fluvial-aeolian sediment links occur in many places, but often anthropogenic overprinting**
- **Colorado River canyons offer exceptionally good place to understand processes applicable in many other settings**

Dunes in Columbia River gorge; G.K. Gilbert, 1899

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Motivation: understand erosion processes at archaeological sites and other upland areas

INCISION

Roasting feature undercut by gully

DEFLATION

Wind deflation exposes artifacts

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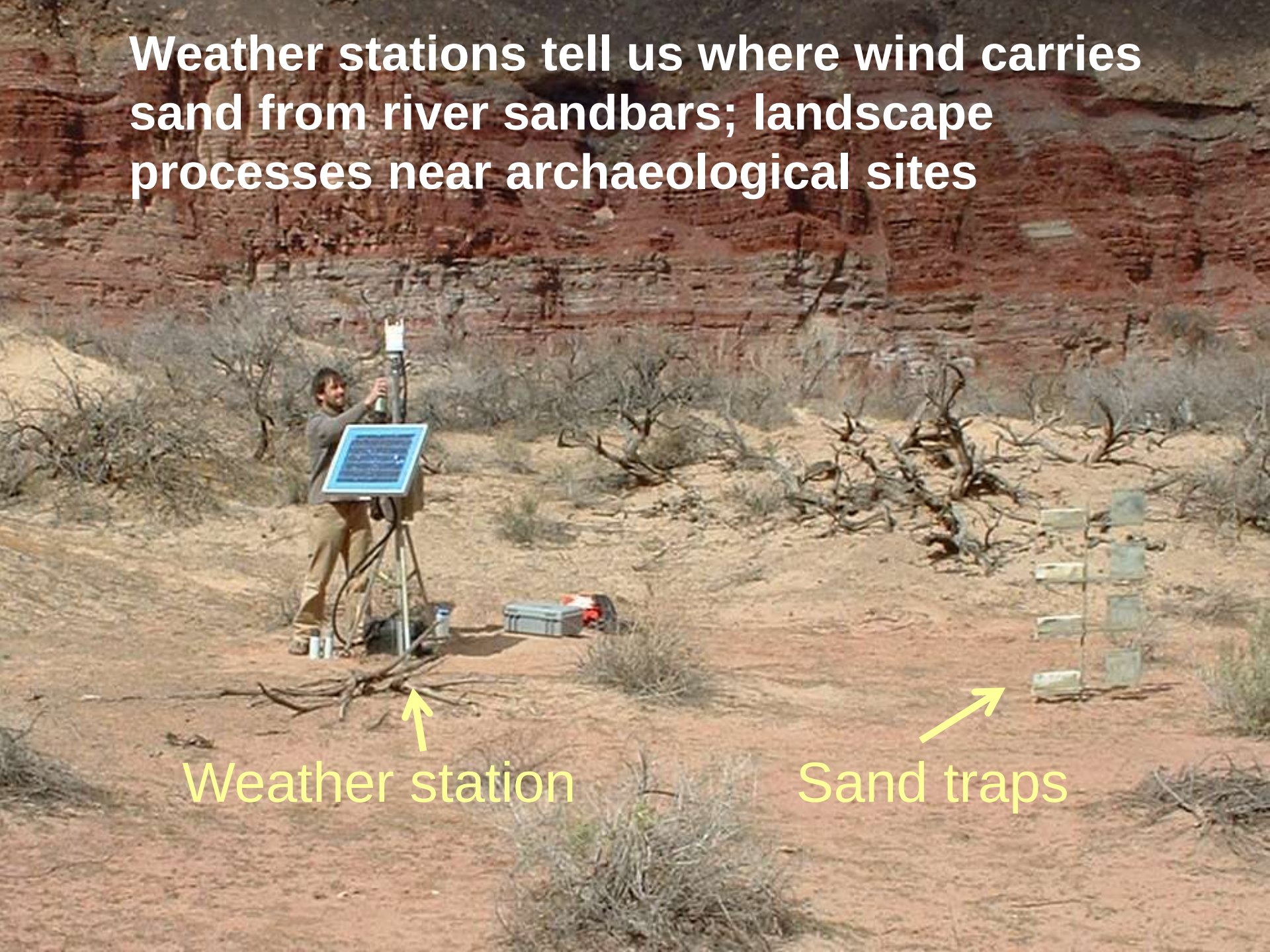
Wind-blown sand forms aeolian dunes


Weather stations tell us where wind carries sand from river sandbars; landscape processes near archaeological sites
Weather station
Sand traps

Measure ground cover (biologic soil crust, vegetation, open sand space)

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Thanks to Grand Canyon Youth!

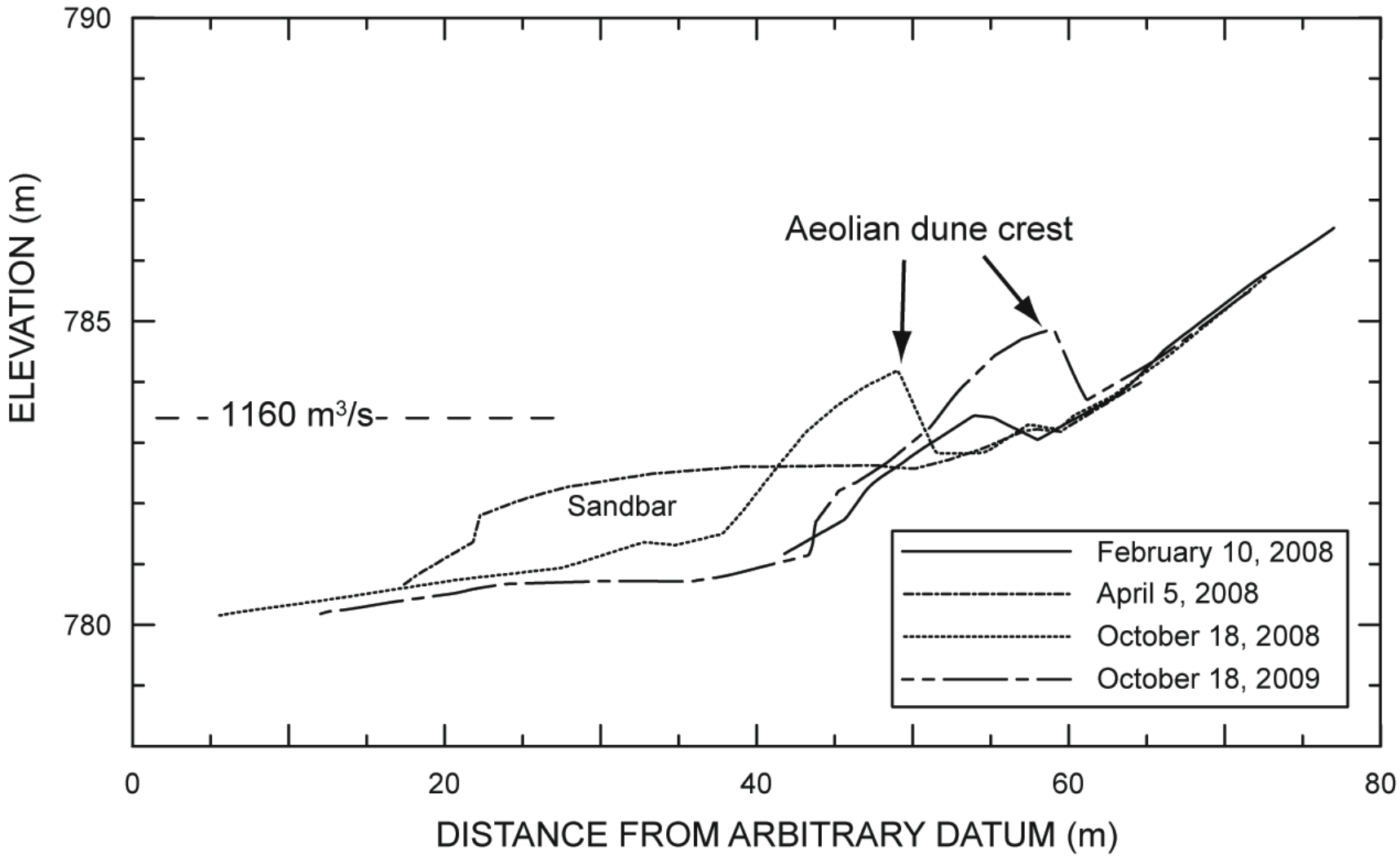
Link between river sediment and aeolian landscapes

- Aeolian dunes get sand from fluvial (flood) sandbars
- Aeolian dunes without modern sand supply develop much more biologic soil crust, becoming more prone to gully incision

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


New river sand moves inland by wind
Controlled floods can supply new wind-blown sand to aeolian dunes where wind direction is right

New river sand moves inland by wind



Surveys by Joe Hazel and the Nams

Modern vs. Relict aeolian landscapes

Some get new sand from modern sandbars

These sites have an HFE sandbar just upwind

Others don't.

These don't

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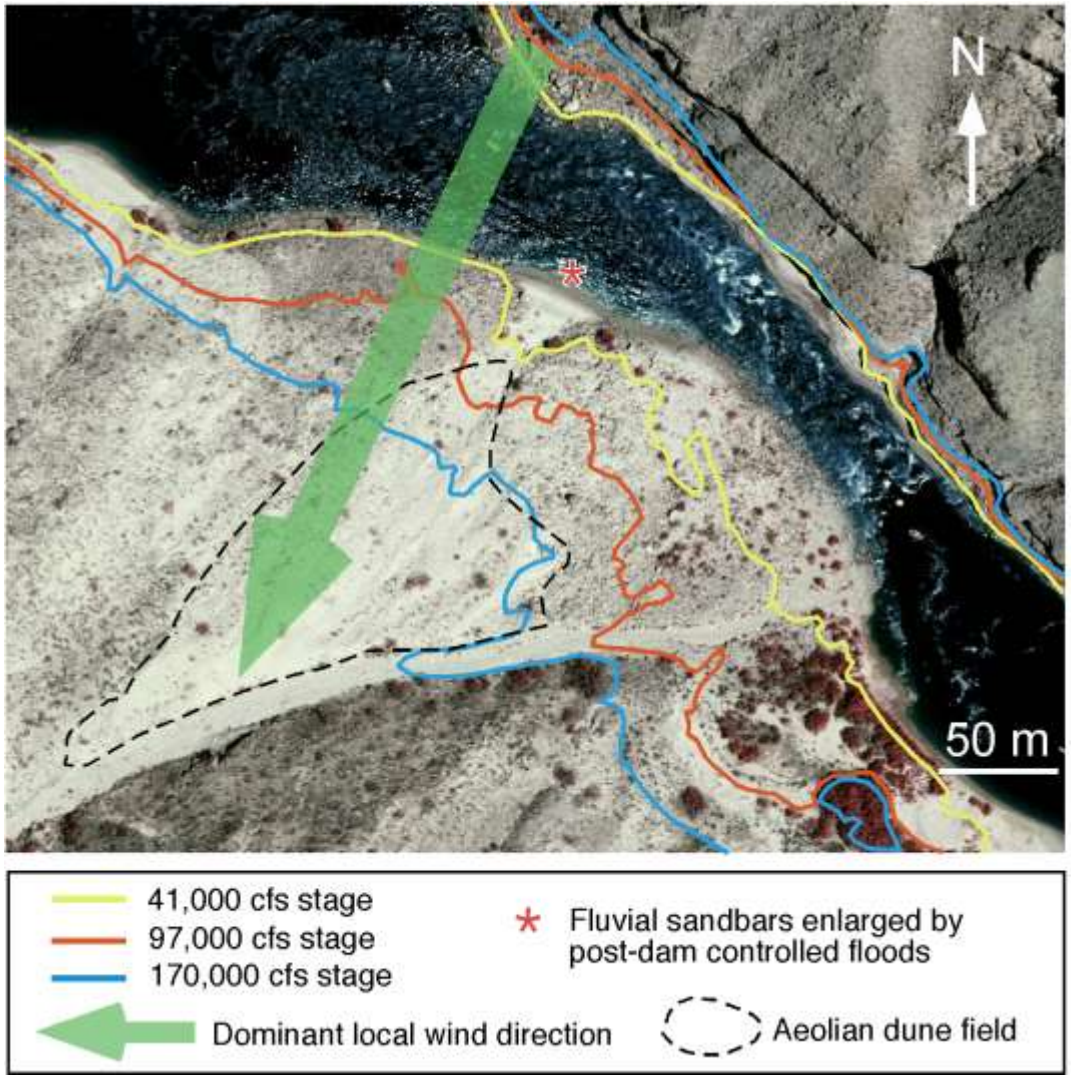
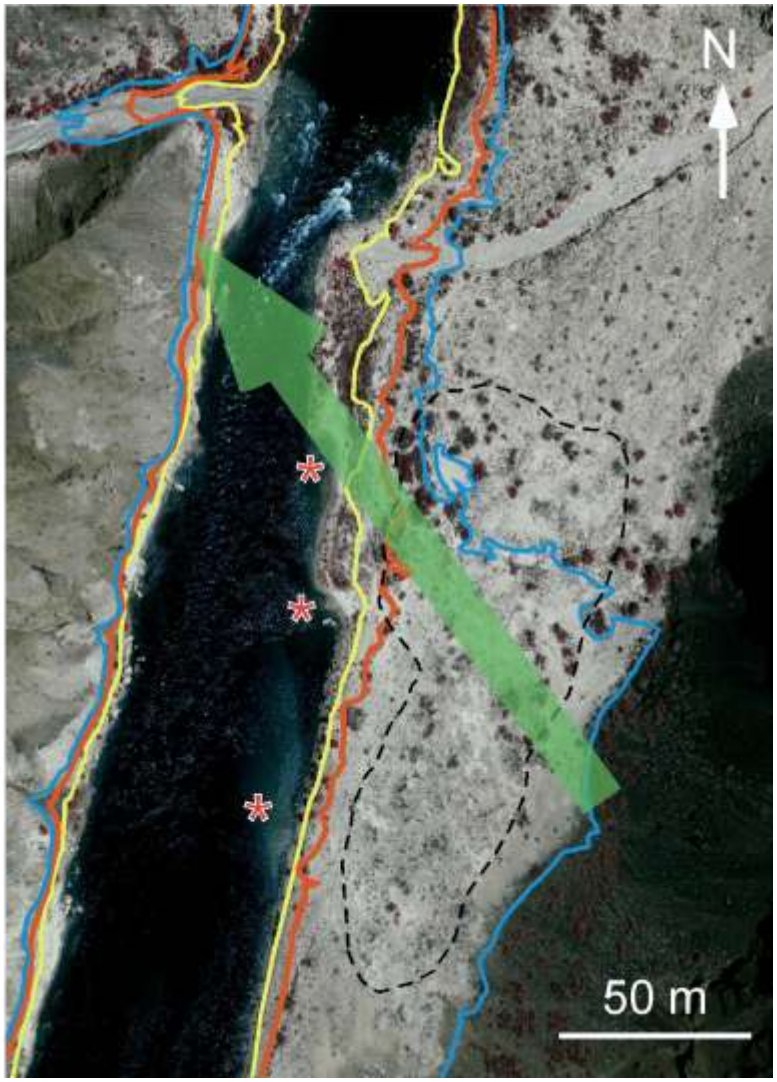
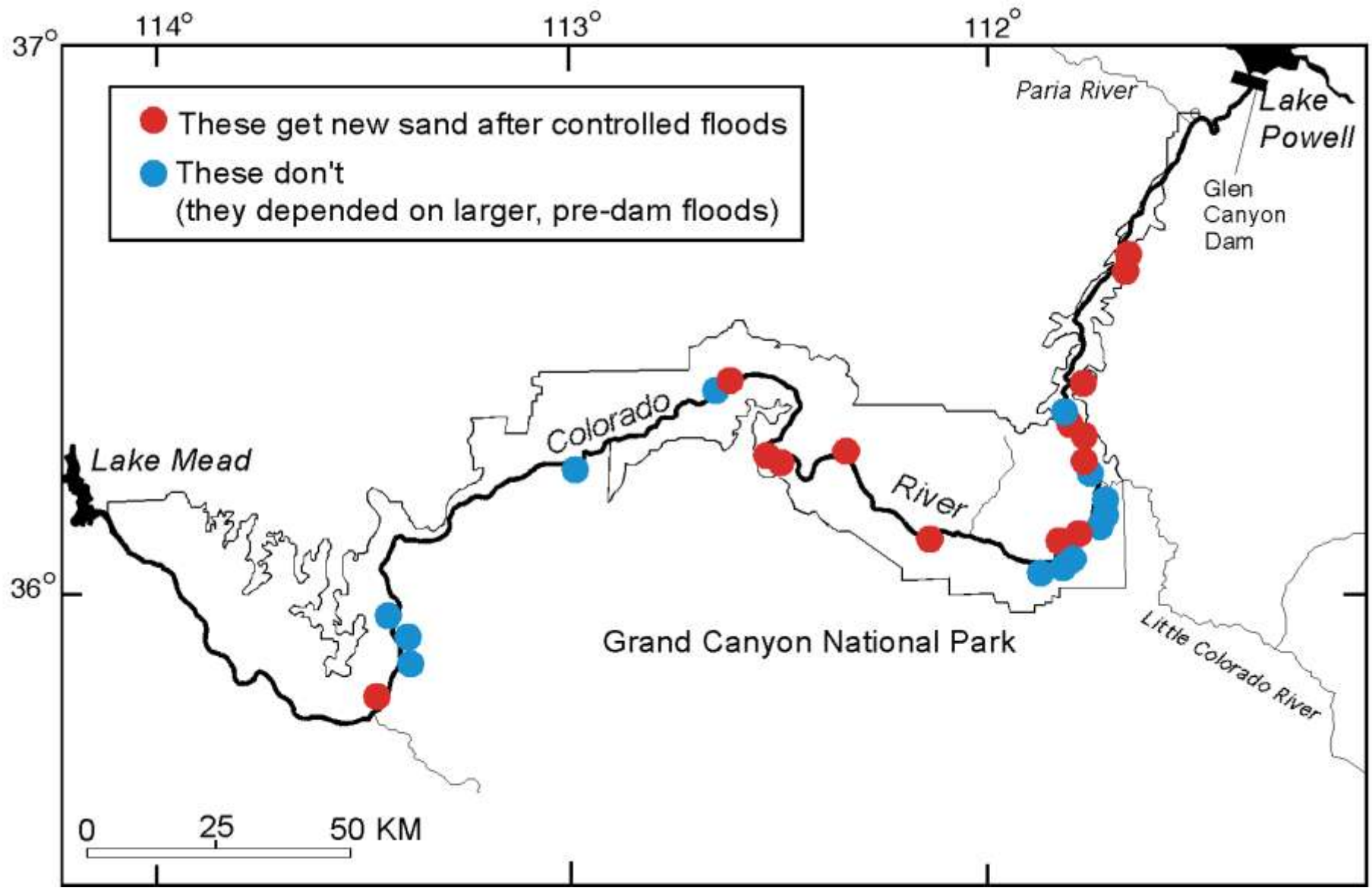
Modern vs. Relict aeolian landscapes



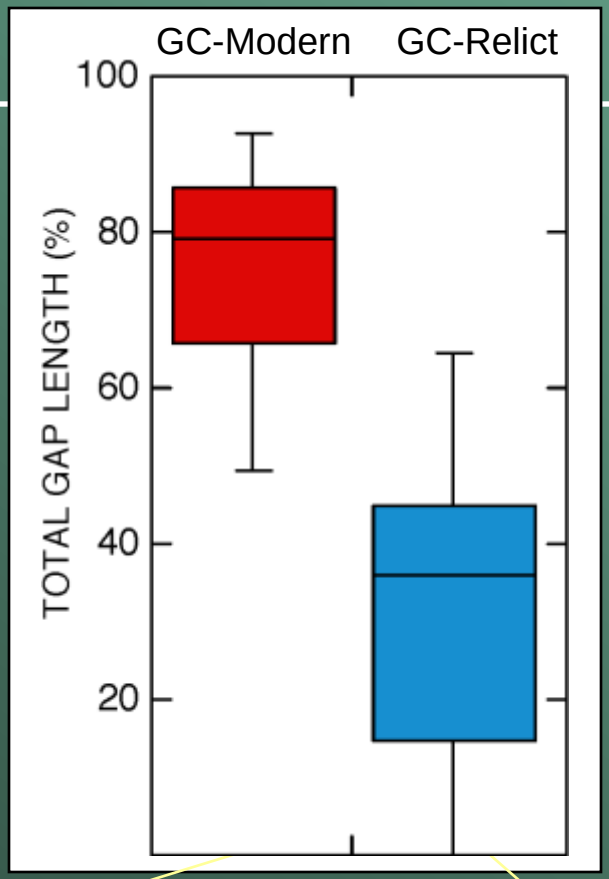


Flow models by Magirl et al. (2008)

Compare ground cover in 2 groups of dune-fields



Open, bare sand space



These sites get modern wind-blown sand supply after HFEs

These don't

Box-and-whisker plots:

3rd quartile ($x_{0.75}$)

Median (2nd quartile, $x_{0.5}$)

1st quartile ($x_{0.25}$)

Whiskers: highest and lowest non-outlier points

Outliers: any points > 1.5 times the inter-quartile range (box length)

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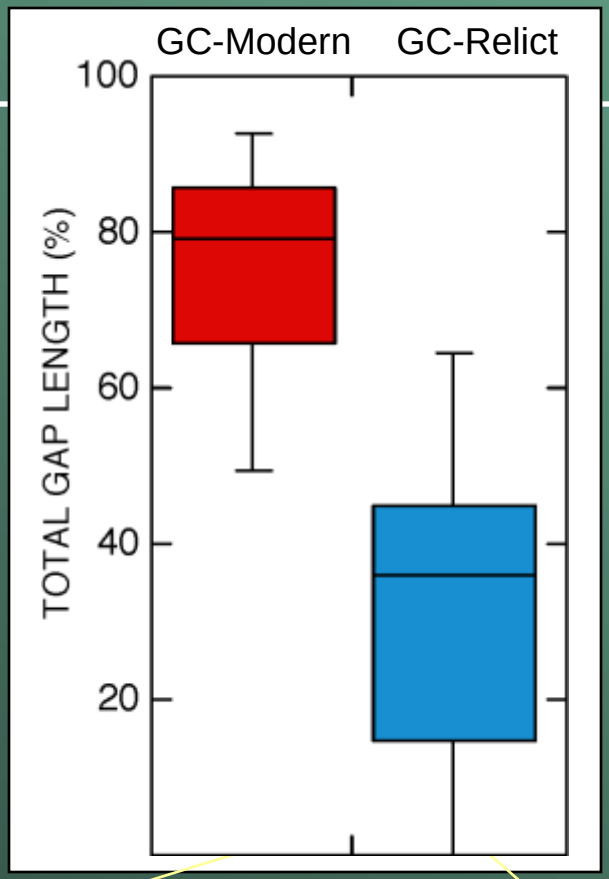
Open, bare sand space



***t*-test ➔ *p* value**

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

$p < 0.00001$

These sites get modern wind-blown sand supply after HFEs

These don't

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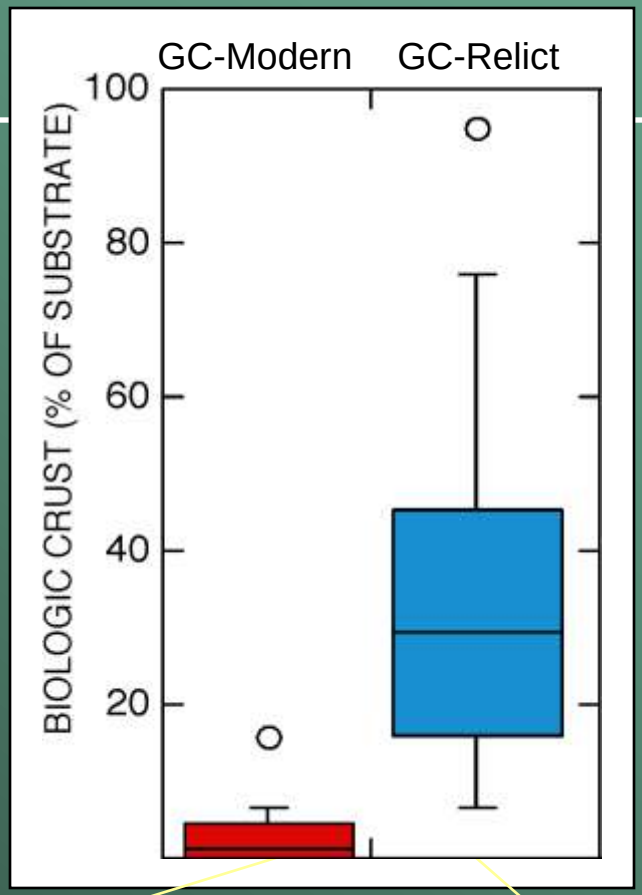
Biologic soil crust



$p < 0.005$

These sites get modern wind-blown sand supply after HFEs

These don't

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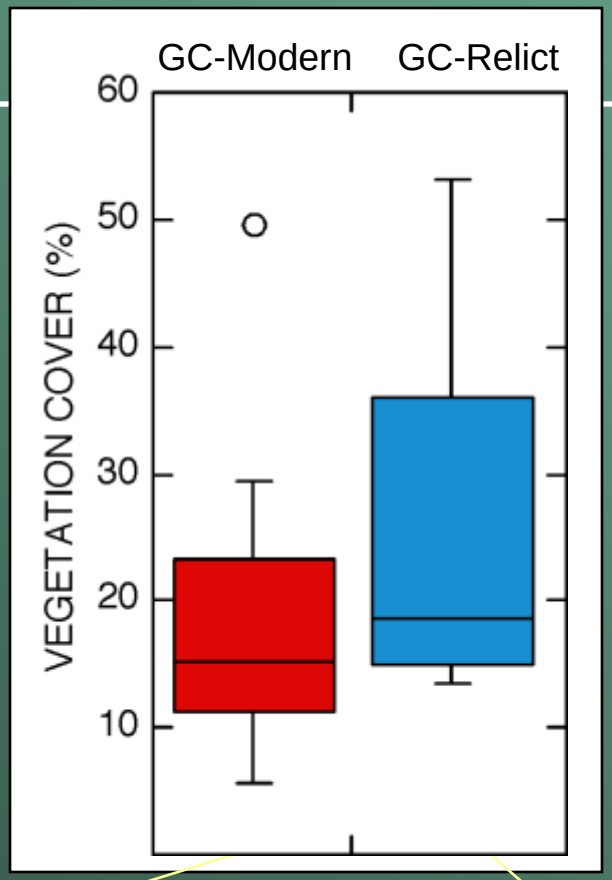
Vegetation cover



$p < 0.07$

These sites get modern wind-blown sand supply after HFEs

These don't

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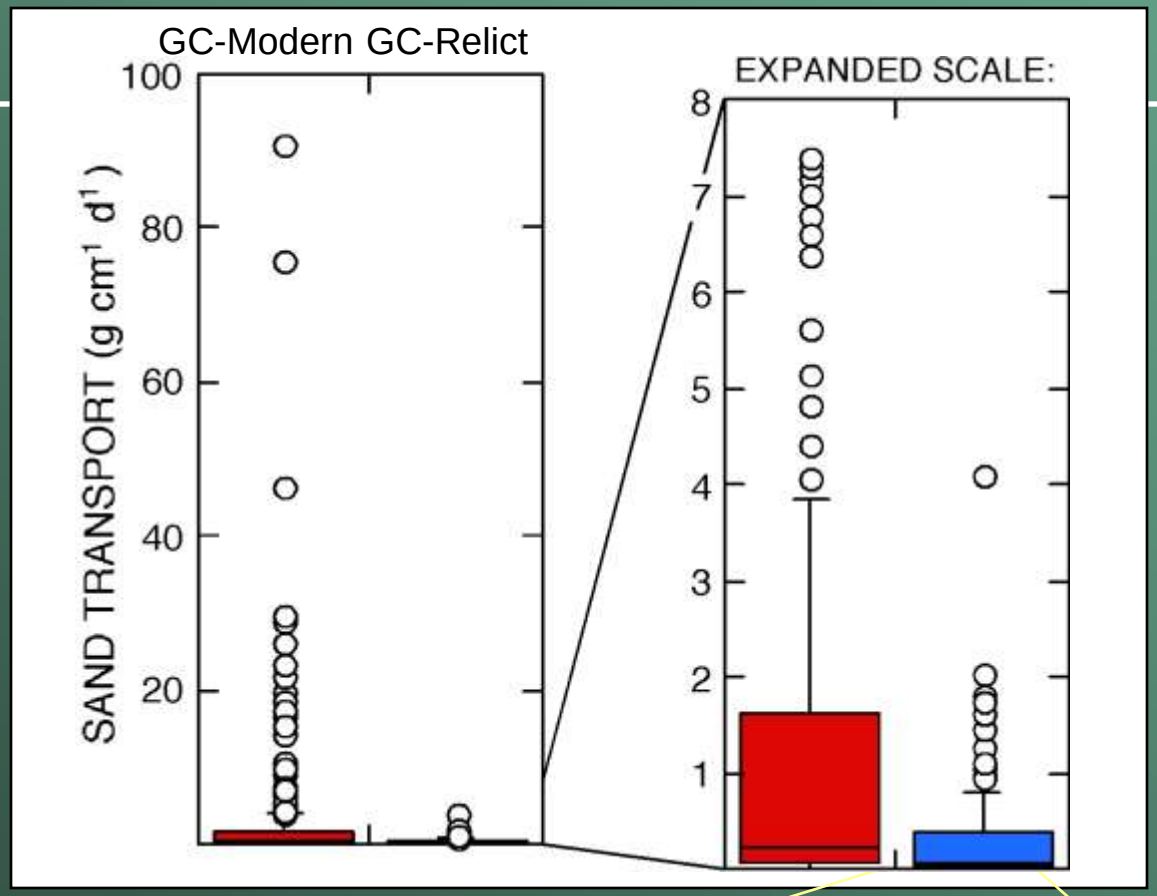
Sand transport by wind: raw data



378 measurements

at 14 sites

2003 - 2010

These sites get modern wind-blown sand supply after HFEs

These don't

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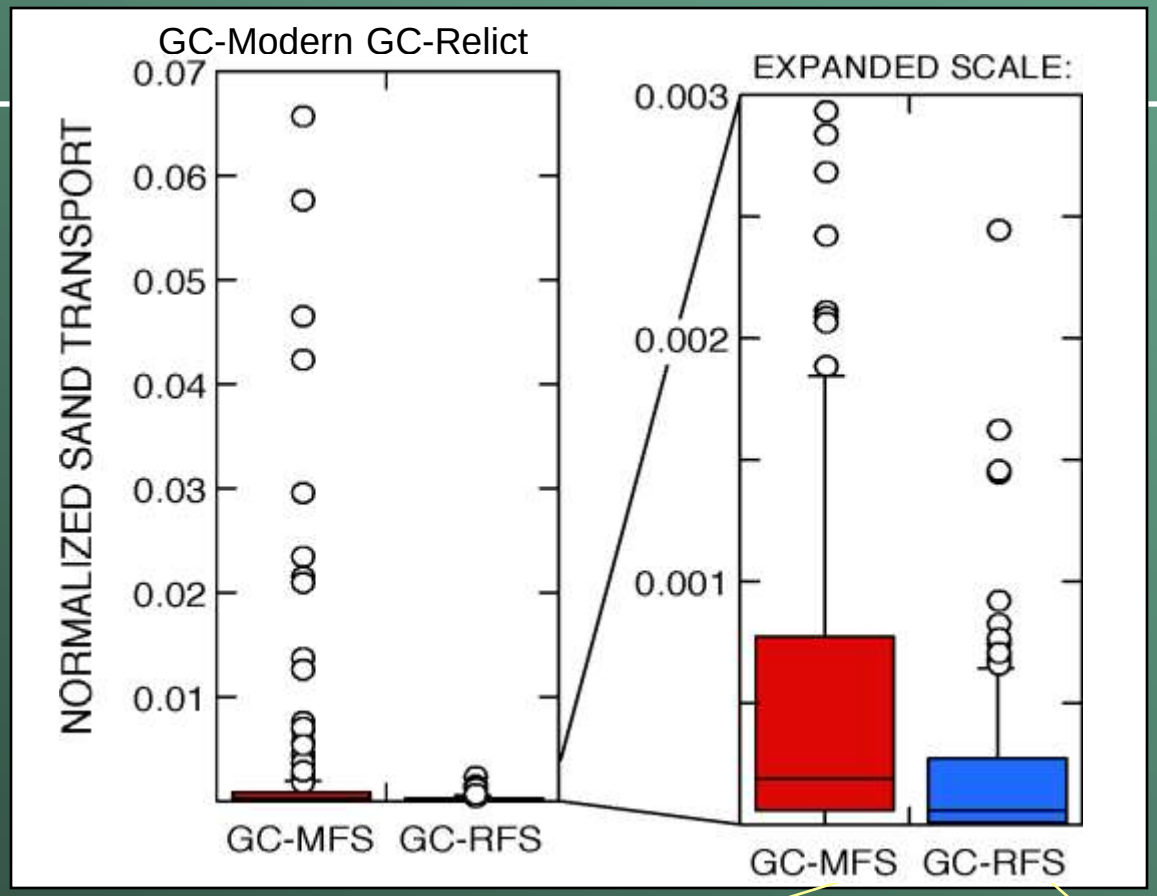
Sand transport by wind: normalized



$p < 0.05$

These sites get modern wind-blown sand supply after HFEs

These don't

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Aeolian dunes without modern sand supply:

Have:

More biologic crust

More vegetation

Less open sand

Less sand transport

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… compared with places that still get sand supply

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Relict aeolian landscapes – Implications for archeological site stability

Less sand movement on ground surface = crusts stabilize soil, dunes less mobile.

BUT, too little windblown sand to fill small gullies

Small gullies become large gullies

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Modern aeolian landscapes with sand supply – Implications for archeological site stability

More sand movement on ground surface = dunes shift, migrate

Artifacts covered/uncovered by dunes

Windblown sand can fill small gullies

Gullies can heal

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

Head of gully

Middle of gully

Terminus of gully

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Factors affecting gully incision

- Disturbance of surface cover by rain runoff or trails
- Runoff intensity controlled by rainfall intensity, infiltration capacity, slope, drainage area

- Hereford base-level hypothesis?
- A gully graded to any base level won't last long if much wind-blown sand activity

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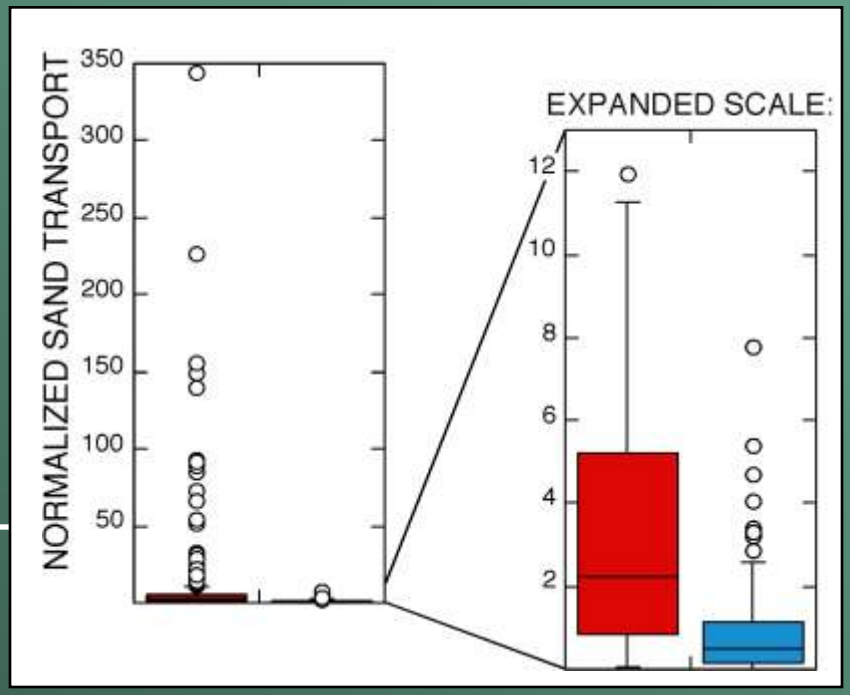
Gullies – competition between disturbance and healing

- Gullies form by rainfall runoff or from trailing (human/animal) that can then focus rain runoff
- Aeolian sand transport seems very important in counteracting gully incision (ex. from China also)
- Dunes with modern sand supply (little crust, active sand transport) heal gullies before they get big
- Places without modern sand supply develop big gullies



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Gullies – competition between disturbance and healing

Example from very intense monsoon storm, Navajo Nation, 2010

They had to fix the road, but gullies in active aeolian dunes healed within two months

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Proportions of active vs. inactive aeolian sand

- Mapped all aeolian sand locations in RM 44-61 (Eminence to LCR)
- Analyzed active / inactive sand area in GIS

Only 13% of aeolian sand area there is “active” (wind-rippled surfaces, slip faces; *Lancaster, 1994*)

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Compare with Cataract Canyon, Utah

- Colorado River in Canyonlands NP
- 17 river-miles below confluence of Green and Colorado Rivers, above Lake Powell
- Mostly (well, more) natural hydrology and sediment supply

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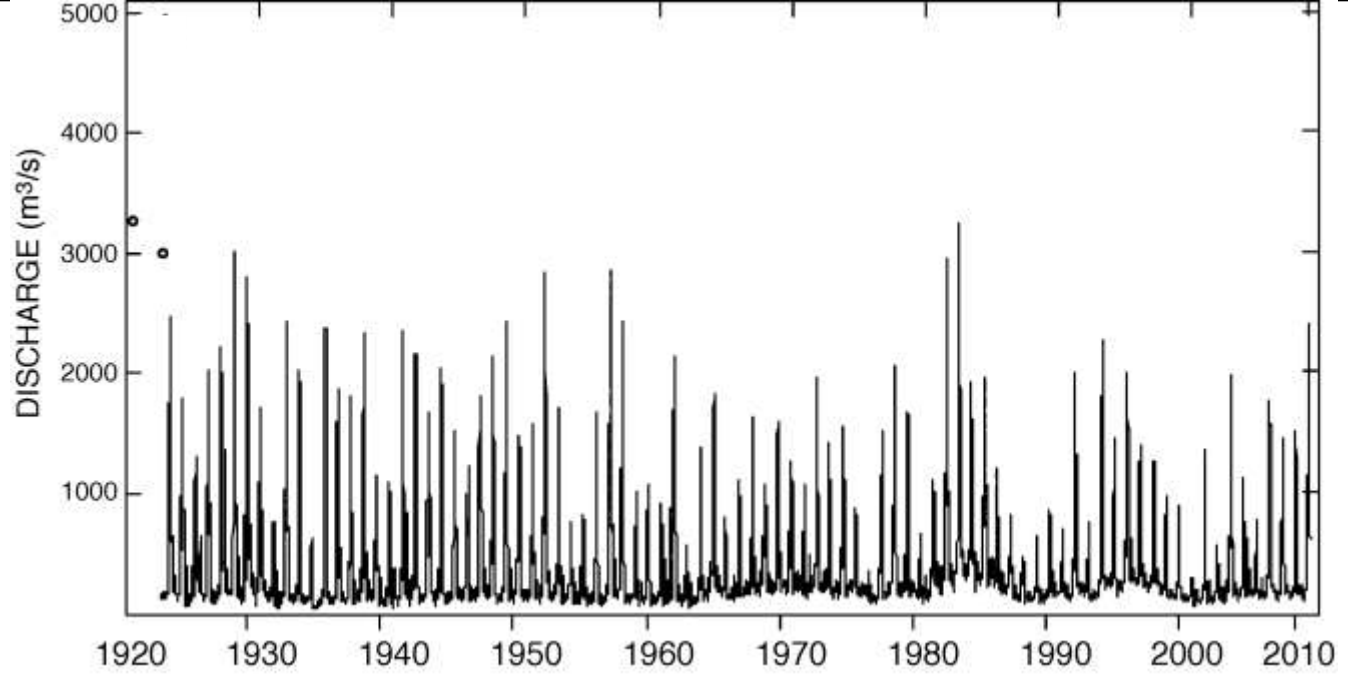
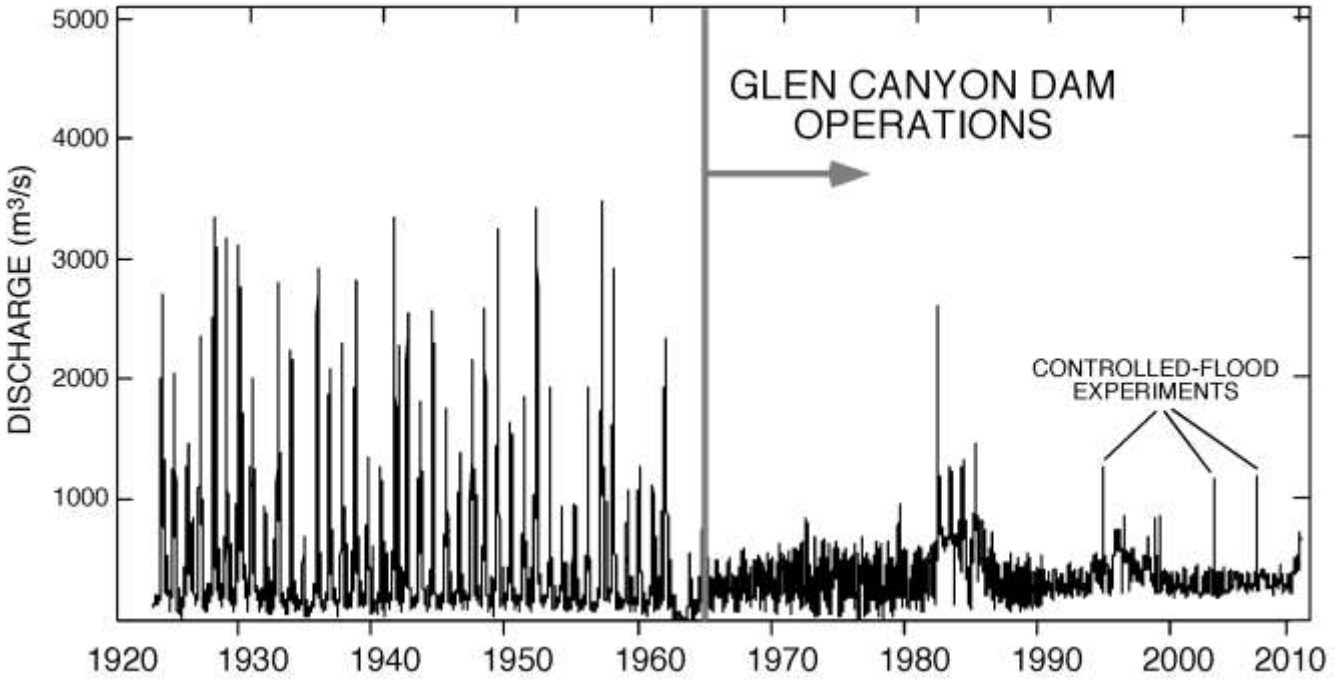
Cataract Canyon

Grand Canyon (Lees Ferry)





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Cataract Canyon

Big new sandbars left by 56,000 cfs spring flood…
Should have lots of active aeolian sand

Proportions of active vs. inactive aeolian sand, Cataract Canyon

- Mapped all aeolian sand locations in Cataract Canyon
- Analyzed active / inactive sand area in GIS

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

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Grand vs. Cataract Canyon

- **FIVE TIMES HIGHER proportion of active aeolian sand in Cataract Canyon, which has more-natural floods and sand supply**
- **Modern-fluvial-sourced aeolian dunes in Grand Canyon have similar ground cover as in Cataract (HFEs work!), but those landscapes (with modern sand supply) are rarer in Grand Canyon than in Cataract**

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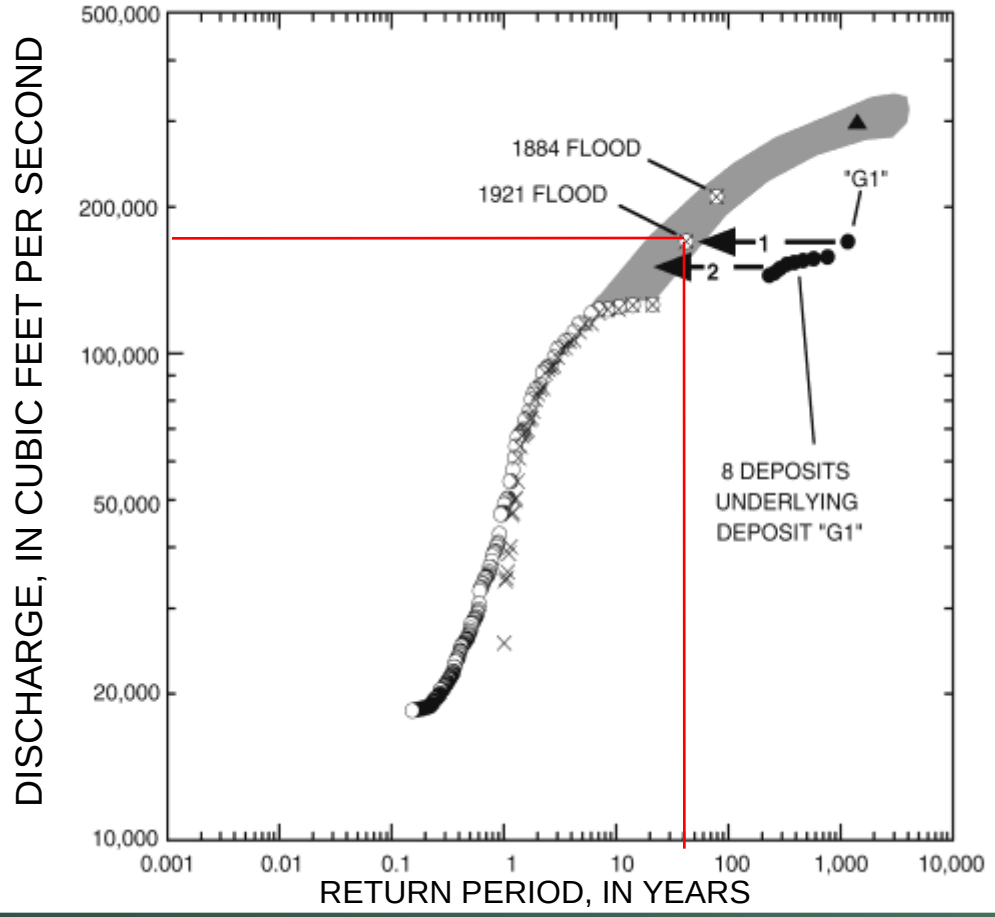
Loss of flood-sand supply to dunes: Does it matter yet?



- Flood of 170,000 cfs can supply sand to source areas for the canyon's largest relict dune fields
- Last was in 1921
- Would have ~40 yr return interval
- So, Yes it does matter by now

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Flood frequency curve
by Topping et al., 2003

What about loss of low flows?

- Loss of low flows post-dam means wind can't mobilize sand from fluvial sandbars that were formerly exposed in late summer/ fall
- Less important than loss of flood sand, because timing of low flows and driest, windiest weather would not coincide
- Pre-dam, spring winds were mostly reworking last year's flood sand deposits

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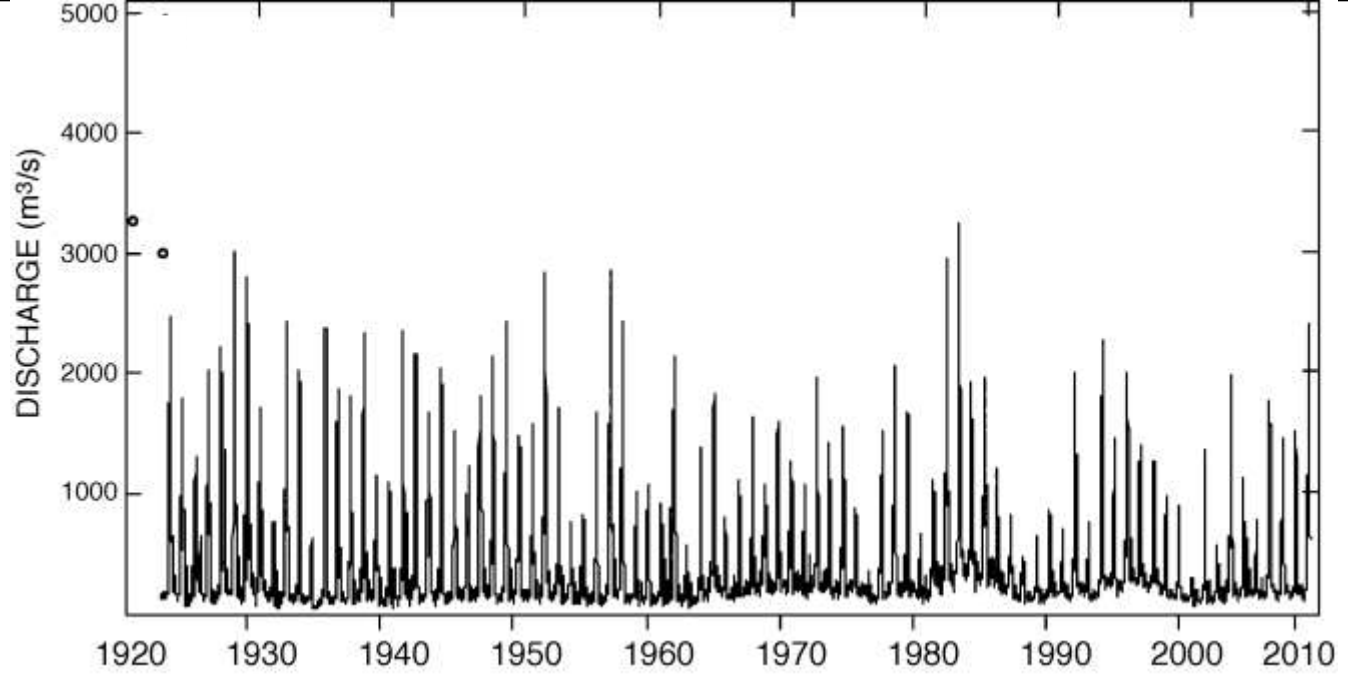
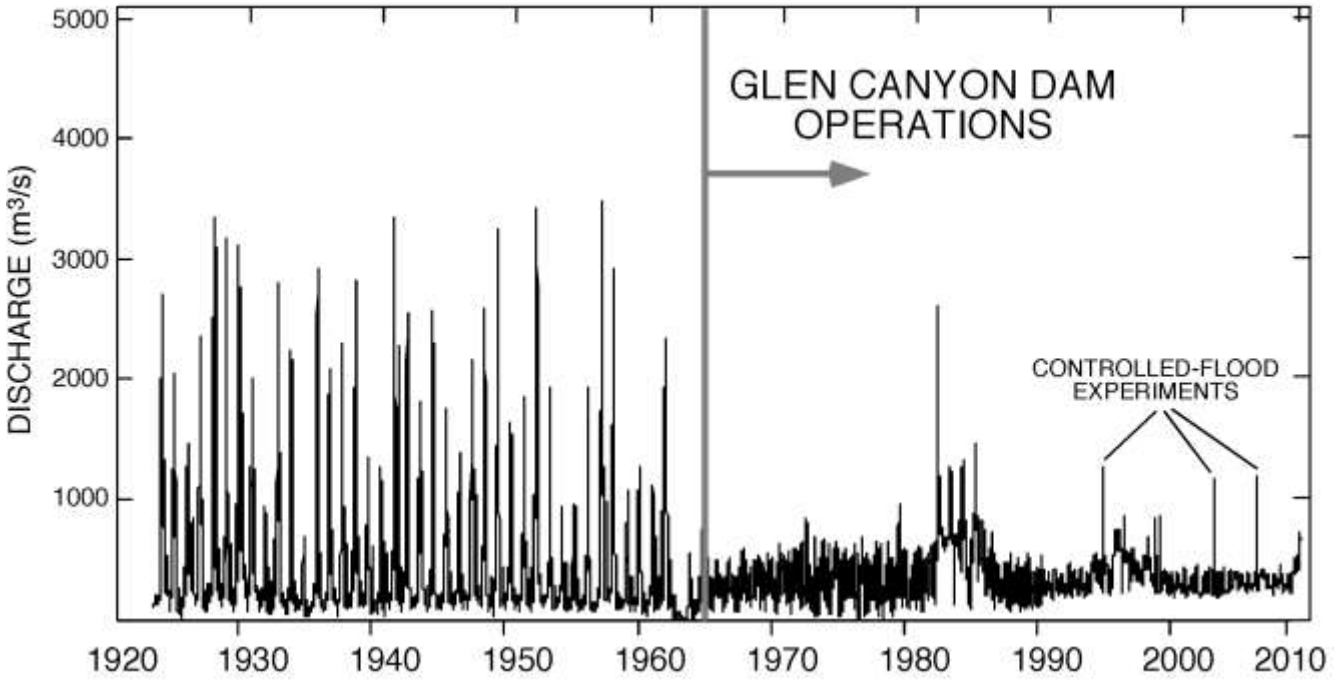
Cataract Canyon

Grand Canyon (Lees Ferry)





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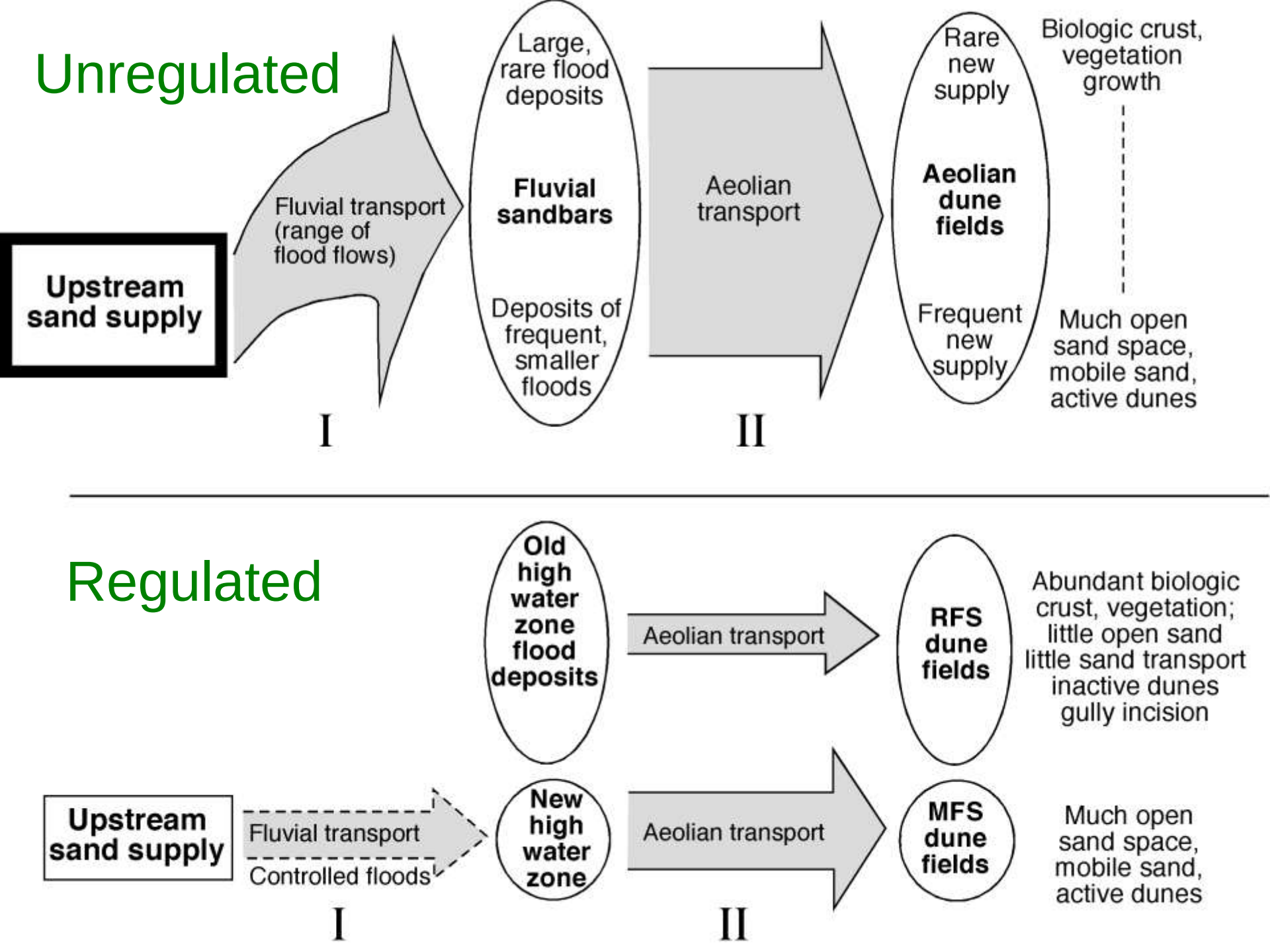
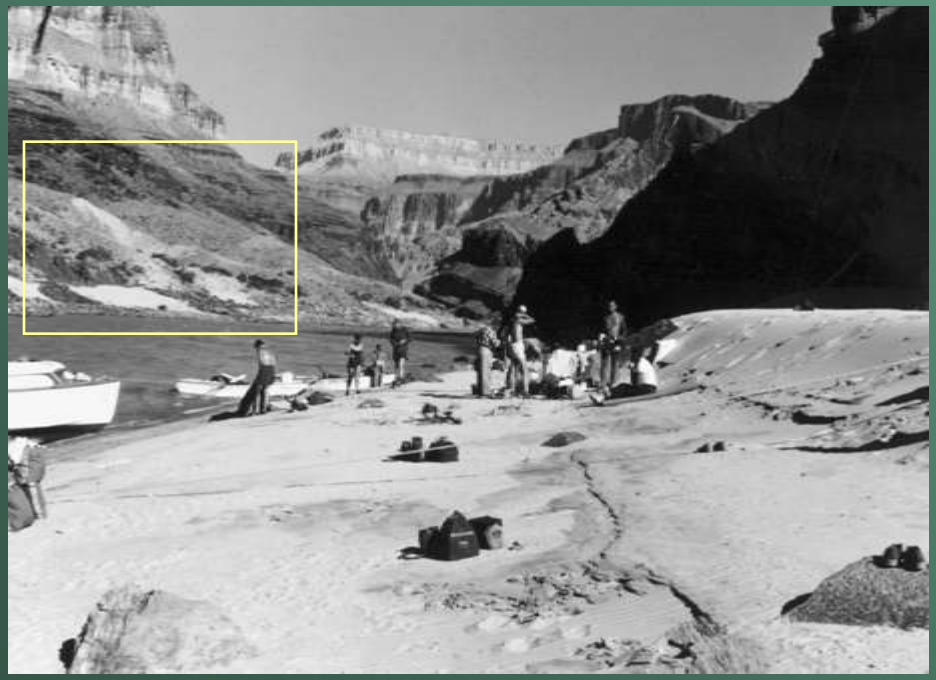
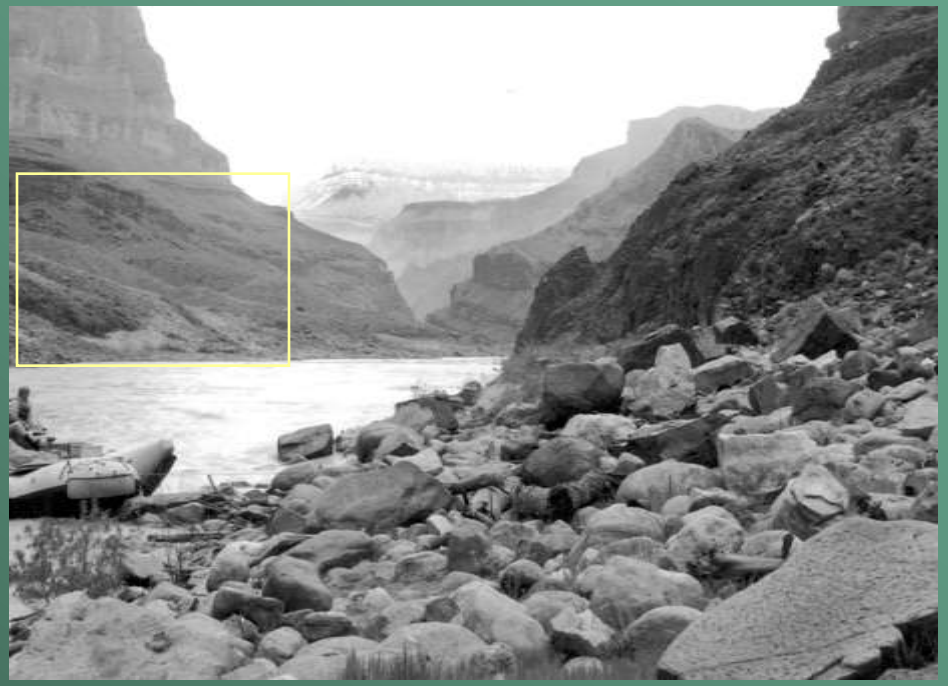

Unregulated
Upstream sand supply
Fluvial transport (range of flood flows)
Large, rare flood deposits
Fluvial sandbars
Deposits of frequent, smaller floods
I
Aeolian transport
II
Rare new supply
Aeolian dune fields
Frequent new supply
Biologic crust, vegetation growth
Much open sand space, mobile sand, active dunes
Regulated
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
I
Aeolian transport
II
MFS dune fields
Much open sand space, mobile sand, active dunes

Grand Canyon dune fields – temporal change?



1952, photo by Kent Frost



1995, photo by USGS

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Photo record pre-dam is sparse

1952

1995

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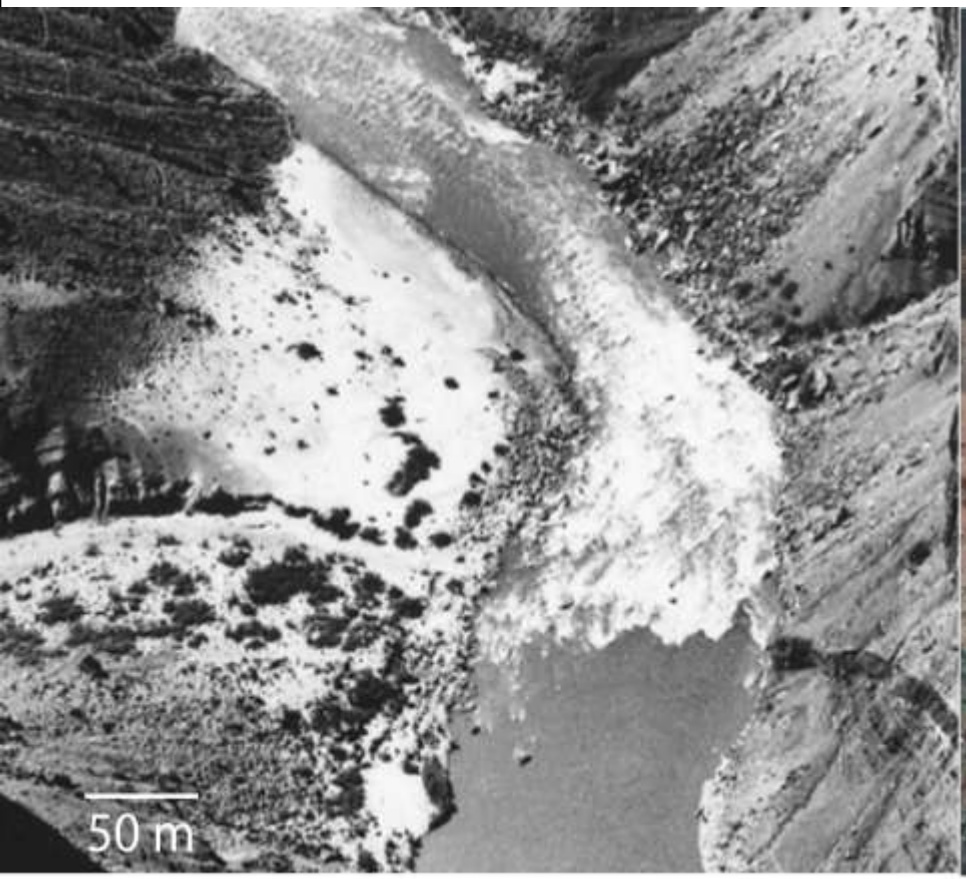
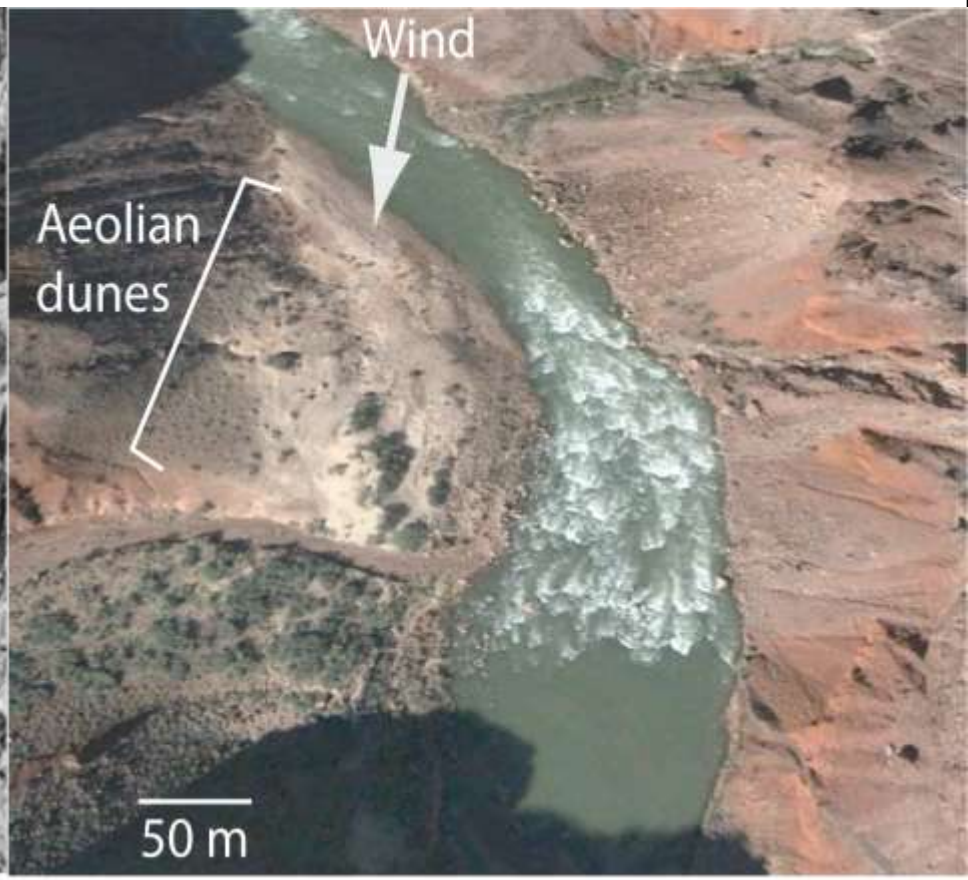
Hance dune field, 1965 and 2006





Leopold, 1969

Google Earth, Inc.

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Riparian vegetation growth will inhibit aeolian sand supply inland

Malgosa, 2005

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Riparian vegetation growth will inhibit aeolian sand supply inland

Ecosystem role of biologic crust

- Lichens, moss, cyanobacteria, fungi, algae
- Crust organisms fix nitrogen, release into soil
- Bioavailable metals
- Changes soil chemistry, plants, herbivore diet & abundance

Heavily crusted dunes at Granite Park

MacGregor and Johnson, 1971; Harper and Belnap, 2001; Belnap et al., 2001; Belnap and Lange, 2003

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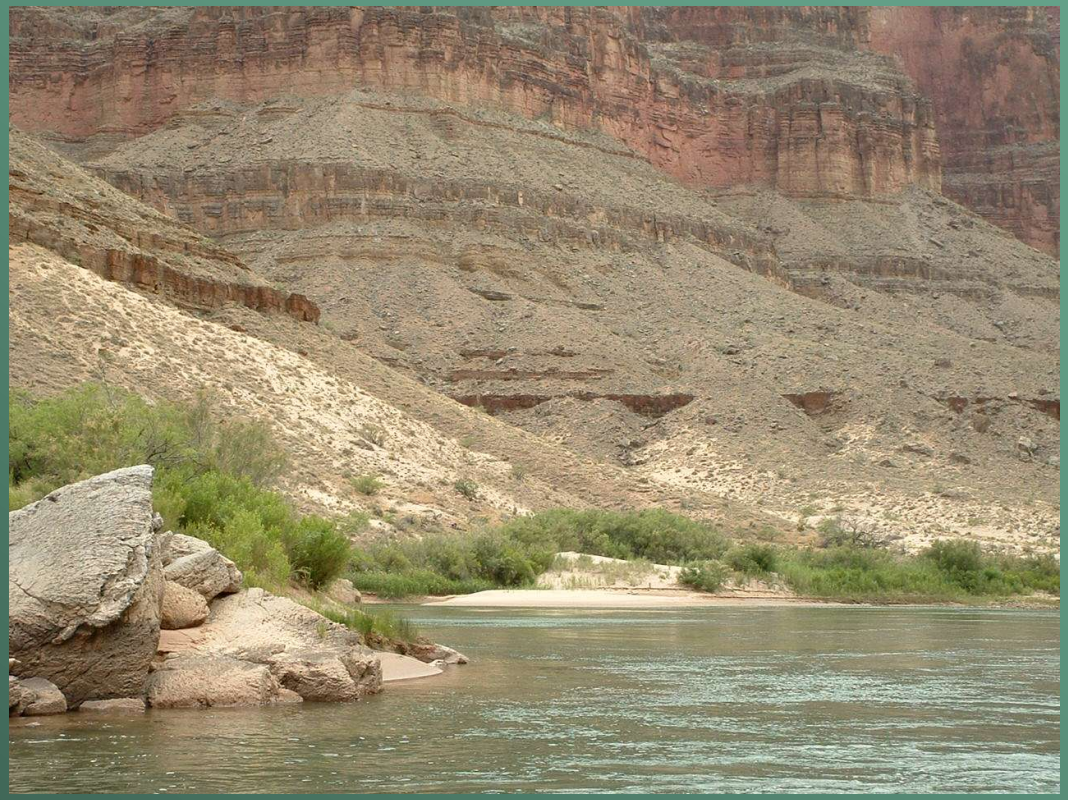
Aquatic to upland ecosystem links

- Links between aquatic and upland parts of ecosystem can begin through geologic (sediment transport) processes rather than biologic processes



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Summary - What do we know?

- Two types of aeolian landscape in Grand Canyon:
  - Modern (get new sand supply post-dam)
  - Relict (no modern sand supply = changes in ground cover, sand transport)
- Geomorphic context of sediment around arch sites
- Stability of landscapes, arch sites controlled by different processes in modern vs. relict dunes – susceptibility to gully incision
- HFE sand blowing inland effectively reproduces “natural” ground cover on modern dunes, but Grand Cyn has much lower proportion of active dunes than more-natural Cataract Canyon

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Summary - What do we know?

- Area of influence of dam operations extends tens of meters above high water line, in aeolian deposits and associated ecosystems and arch sites
- Fluvial-aeolian interactions and effects on upland ecosystems are seldom studied, Grand Canyon work is first study of its kind but has applications to many other dryland settings
- Many further directions this could go

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Where is more knowledge needed?

- Rates of change / erosion / instability of arch sites (Collins, Kayen terrestrial lidar surveys)
- Better resolve upland ecosystem differences
- Comparison between Grand Canyon and elsewhere in Colorado River basin (more natural, less regulated reaches) can be developed further
- Within Grand Canyon, how does the ratio of active and inactive aeolian sand area change spatially? Spatial variation & factors affecting susceptibility to gully erosion.

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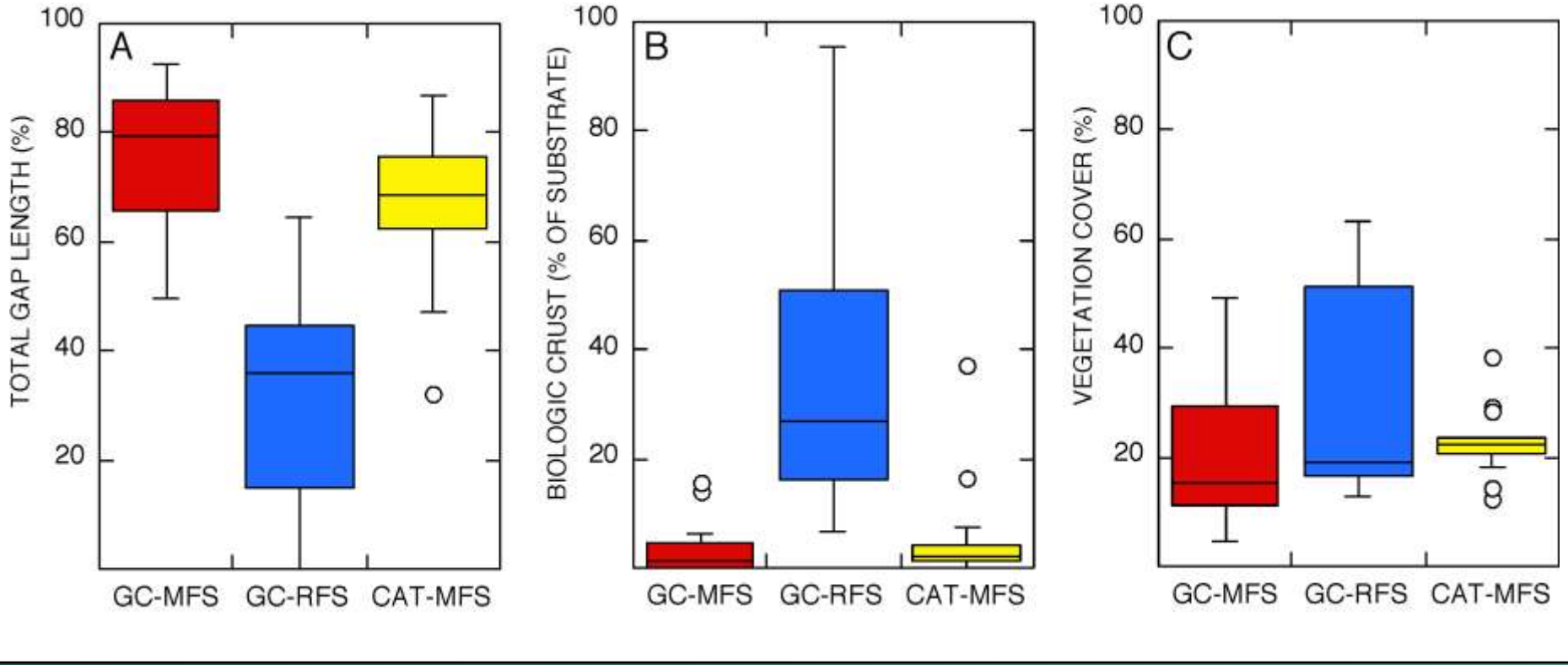
2007


2010

Grand vs. Cataract ground cover



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