Archaeological Sites are Eroding in Grand Canyon Owing to Six Decades of Glen Canyon Dam Operations: Floods, Low Flows and Vegetation Management Can Help

Glen Canyon Dam Adaptive Management Program
Annual Reporting Meeting 2023

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Program Goals: Archaeological and Cultural Resources

GCDAMP Regulatory Goals:

- **GCPA goal**: protect, mitigate adverse impacts to, and improve … natural and cultural resources…
- **LTEMP and NHPA goal**: "Preservation in place."
    - Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

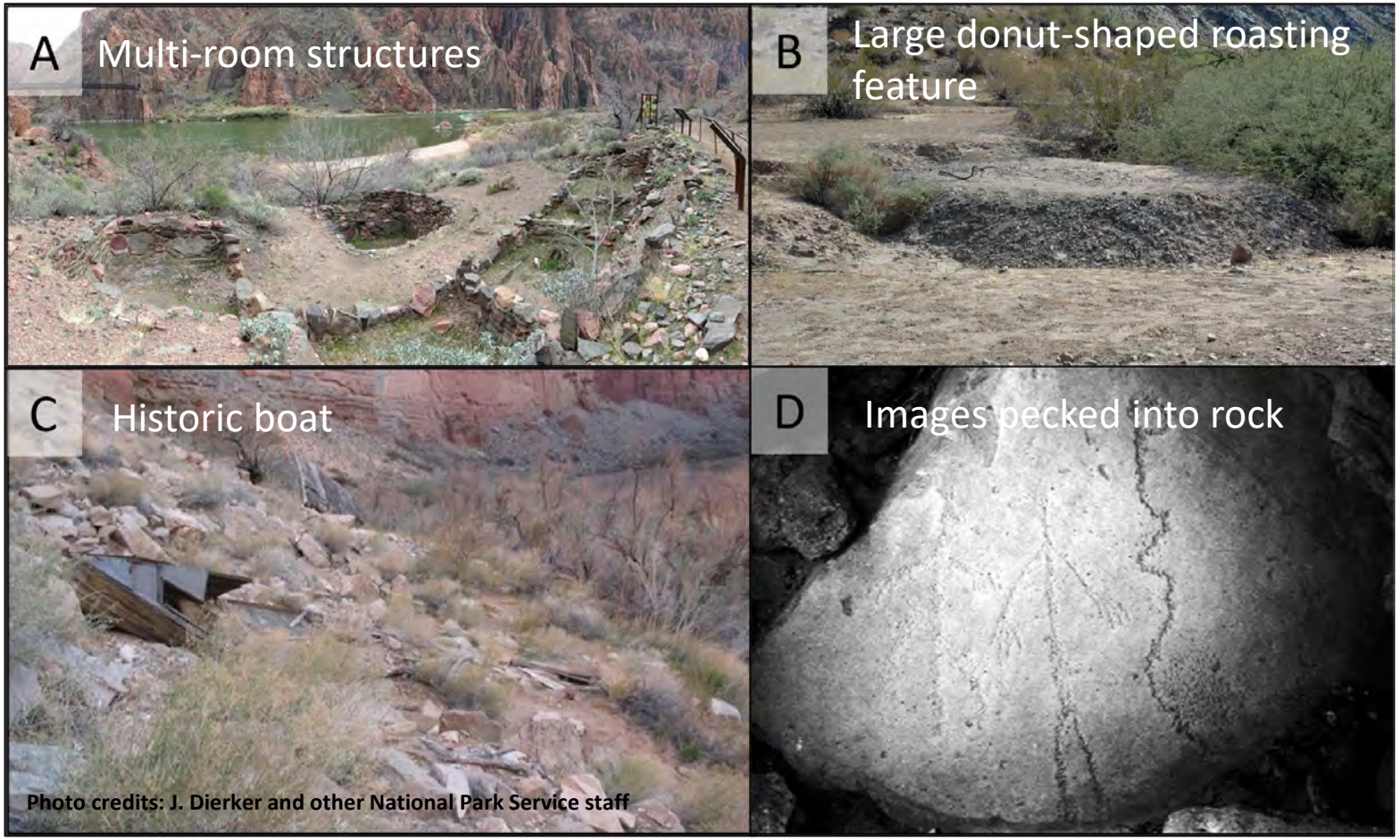
TWP Projects: Archaeological and Cultural Resources

Triennial Workplan (TWP) projects collectively examine whether and how dam operations and experiments like HFEs, vegetation management, and site management by NPS help to achieve the LTEMP goal of preservation in place:

- GCMRC TWP
  - **Project Element D.1. Dam Operations, Vegetation Management, Archaeological Sites (USGS, Sankey, Fairley)**
    - FY2021/2022/2023 ($258k/250k/266k)
  - Project Element O.3. Aeolian Response to a Spring Pulse Flow (USGS, Sankey, Fairley)
    - FY2021 ($10k)
- Reclamation TWP
  - Project Element D.3. Cultural Resources Monitoring – Grand Canyon (NPS, Brennan, Dierker)
  - Project Element C.7. GRCA Experimental Vegetation Treatment (NPS, Pilkington)

Photo credit: L. Caster (USGS)

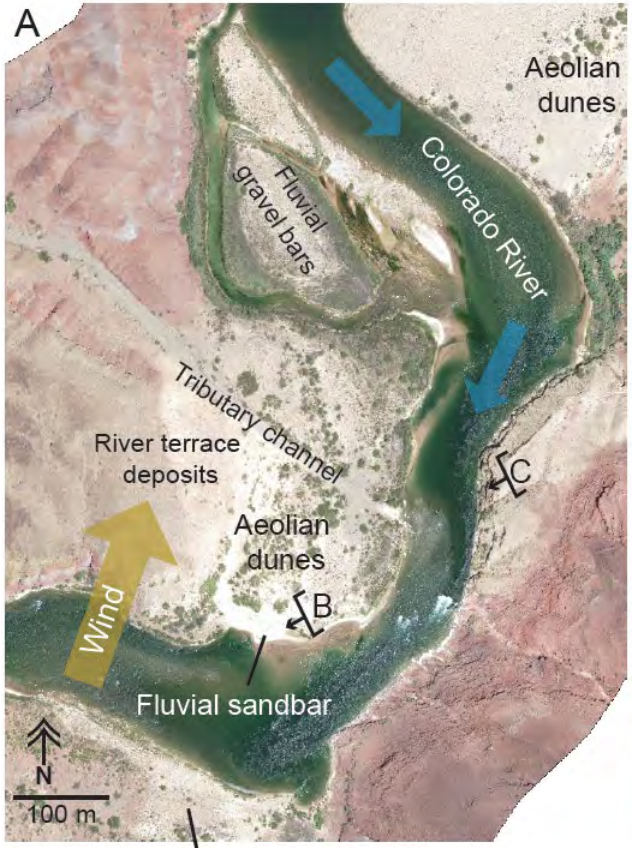
Human Activity and Archaeology Along the Colorado River in Grand Canyon

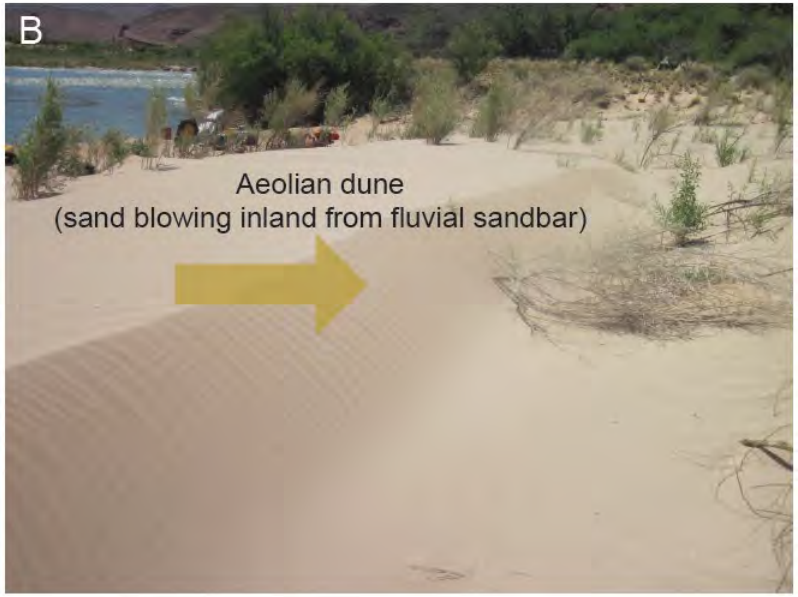


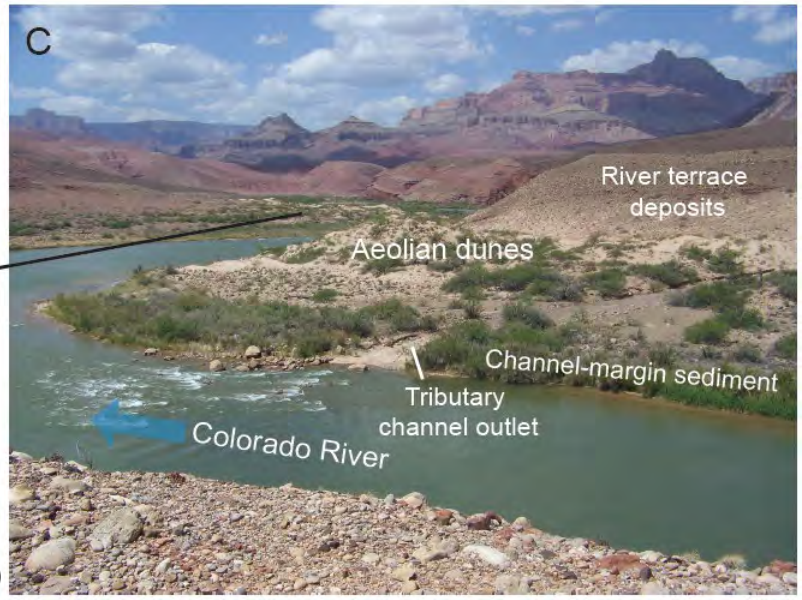
- People have used resources on the Colorado River in Grand Canyon for at least 9,000 years
  - Indigenous peoples have inhabited region periodically since time immemorial
  - European explorers first visited the canyon 480 years ago
- Today, evidence of those ancestral peoples and recent historic activities is displayed in hundreds of archaeological sites along the river in Grand Canyon National Park

https://www.nps.gov/grca/learn/historyculture/arch.htm

Geomorphic Setting of River Corridor Archaeological Sites in Grand Canyon National Park







- Colorado River-sourced sediment deposits contain much of the river corridor archaeological record in Grand Canyon

Photo credits: J. Sankey (USGS)

NPS and USGS Monitor and Research Effects of Humans and Natural Processes on Archaeological Site Condition

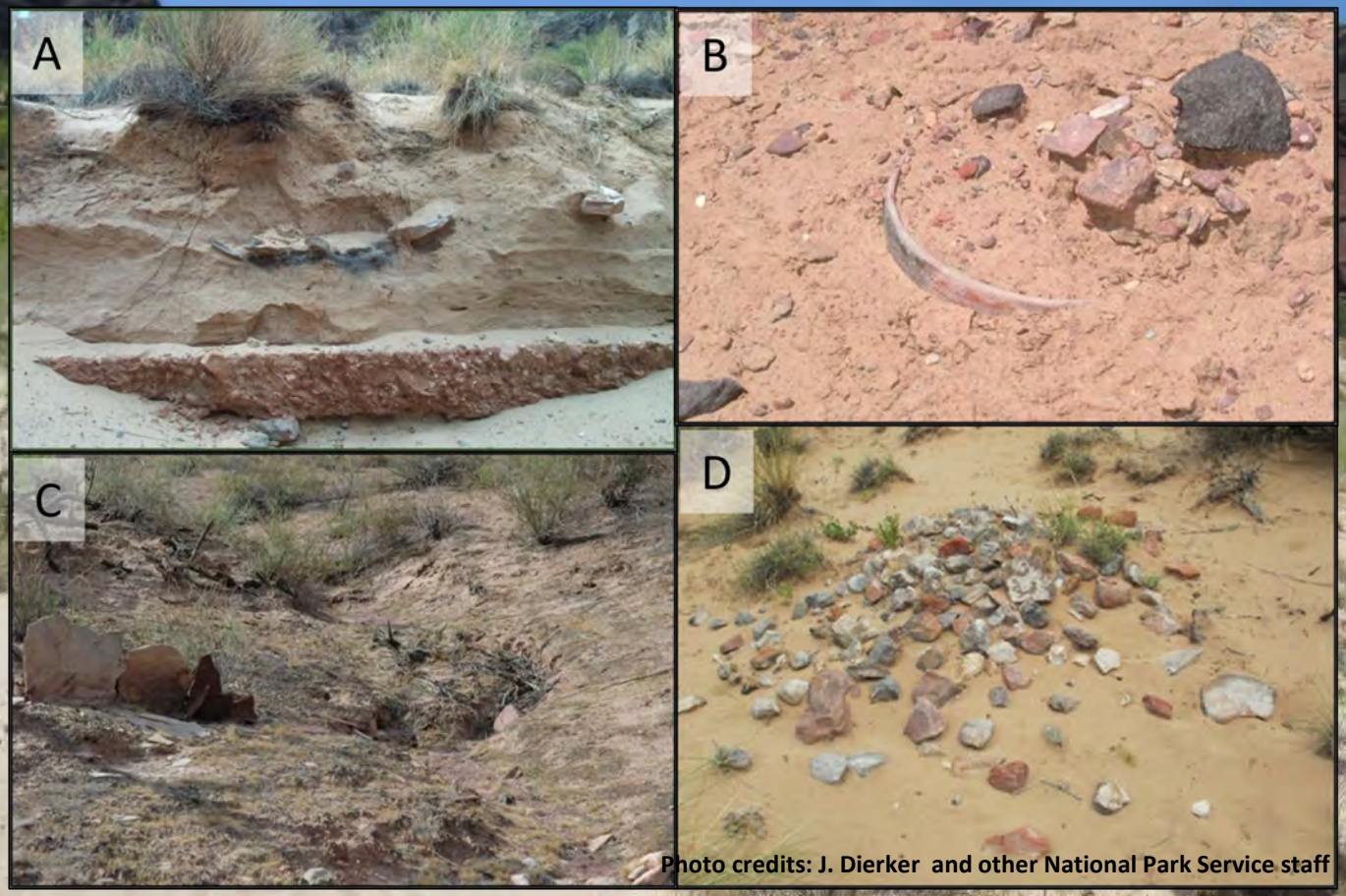


Photo credits: J. Dierker and other National Park Service staff

Examples of erosion documented by NPS monitoring site visits

A) Cutbank erosion in alluvial terrace exposes prehistoric hearth, B) Rainfall-runoff erosion and lack of burial by sand expose prehistoric bowl, C) Gully eroding base coarse of structure, D) Wind erosion and lack of burial by sand result in loss of matrix surrounding fire-altered rock

NPS and USGS Monitor and Research Effects of Humans and Natural Processes on Archaeological Site Condition

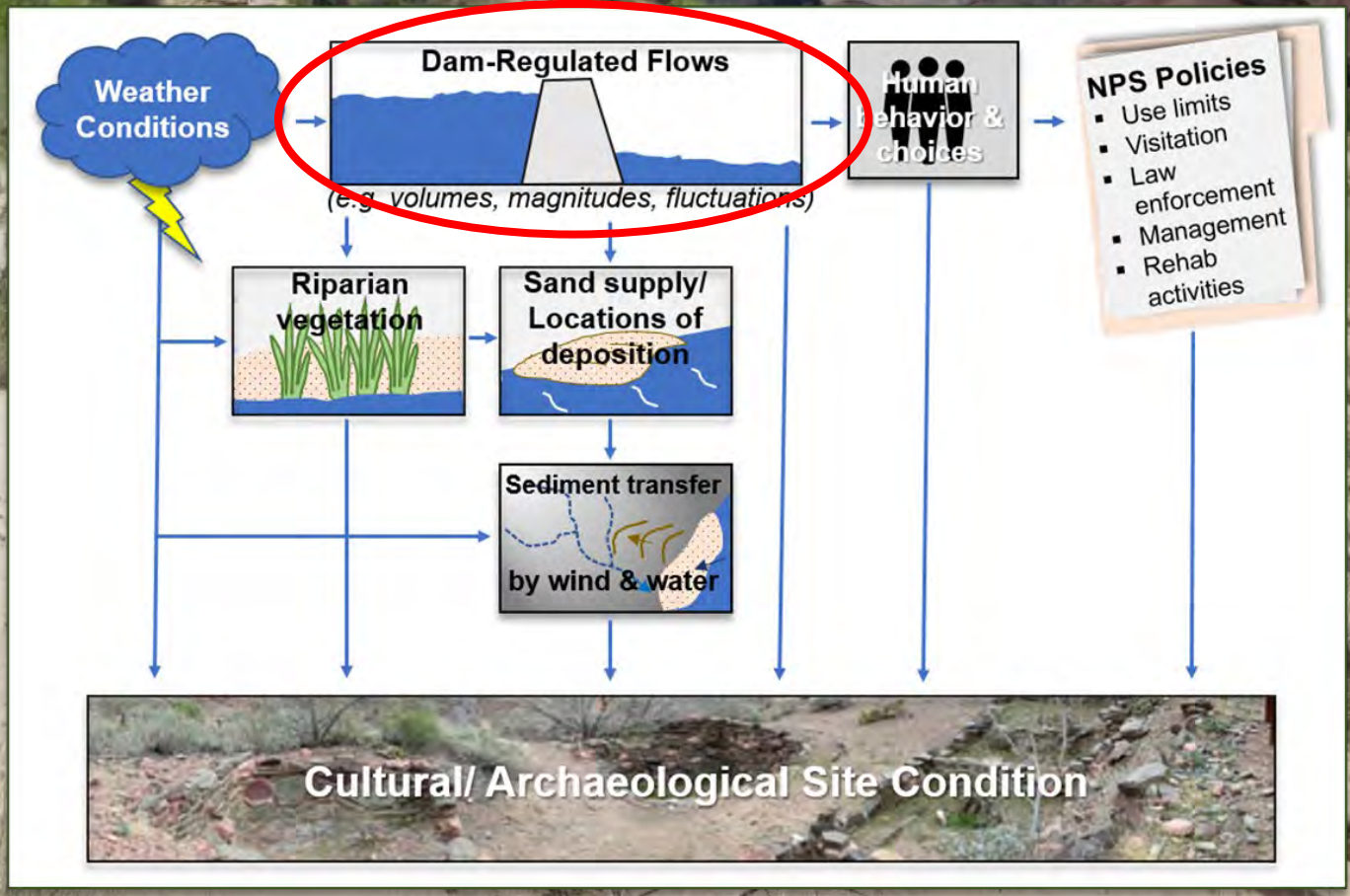


Photo credit: J. Caster (USGS)

Lack of floods & decrease in windblown (aeolian) river sand supply have resulted in expanded gullying at archaeological sites from pre- to post-dam time

Gullying at archaeological sites: some examples

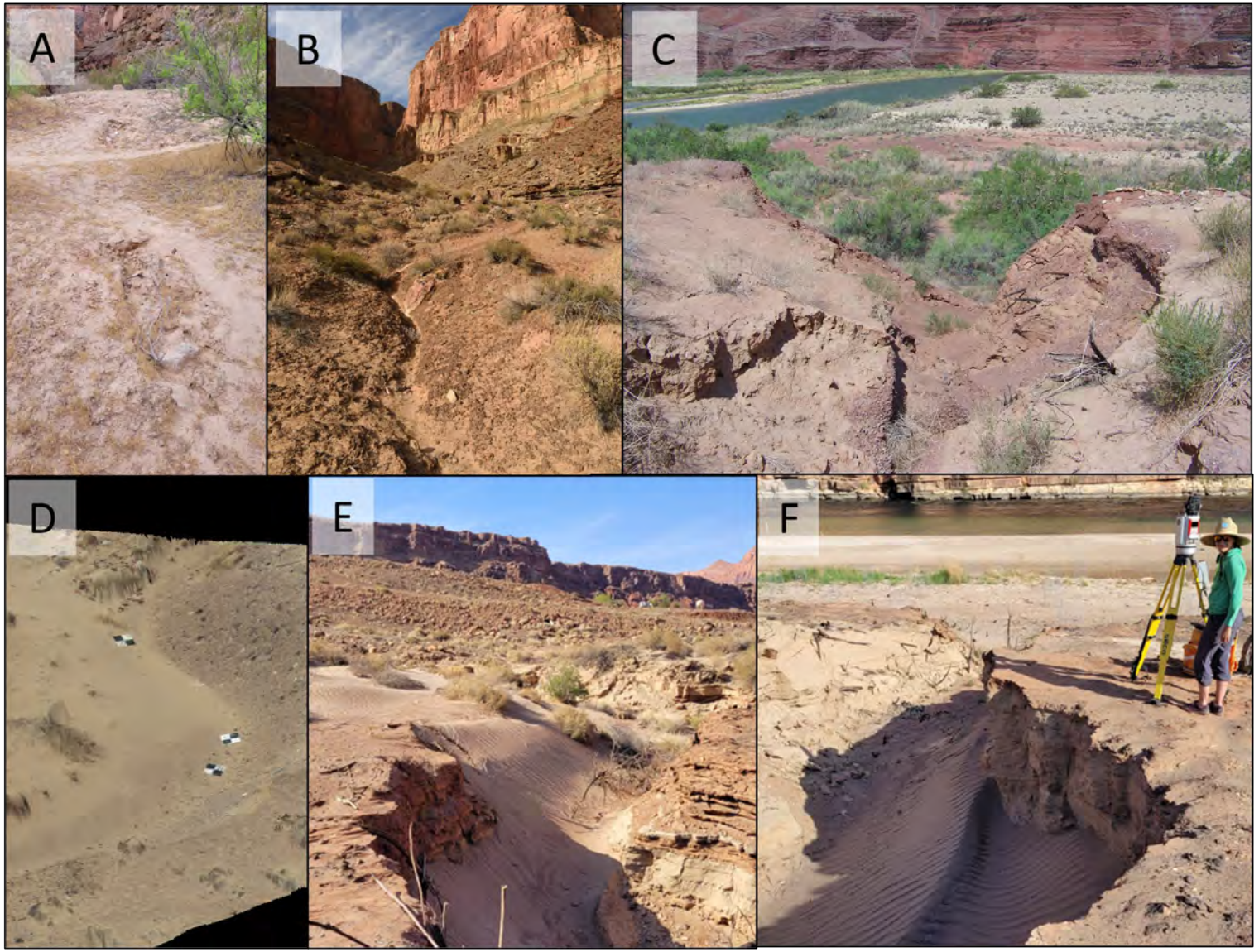


Photo credits: J. Caster and J. Sankey (USGS)

Long-term increases in riparian vegetation on sandbars have decreased windblown (aeolian) sand supply from sandbars to archaeological sites

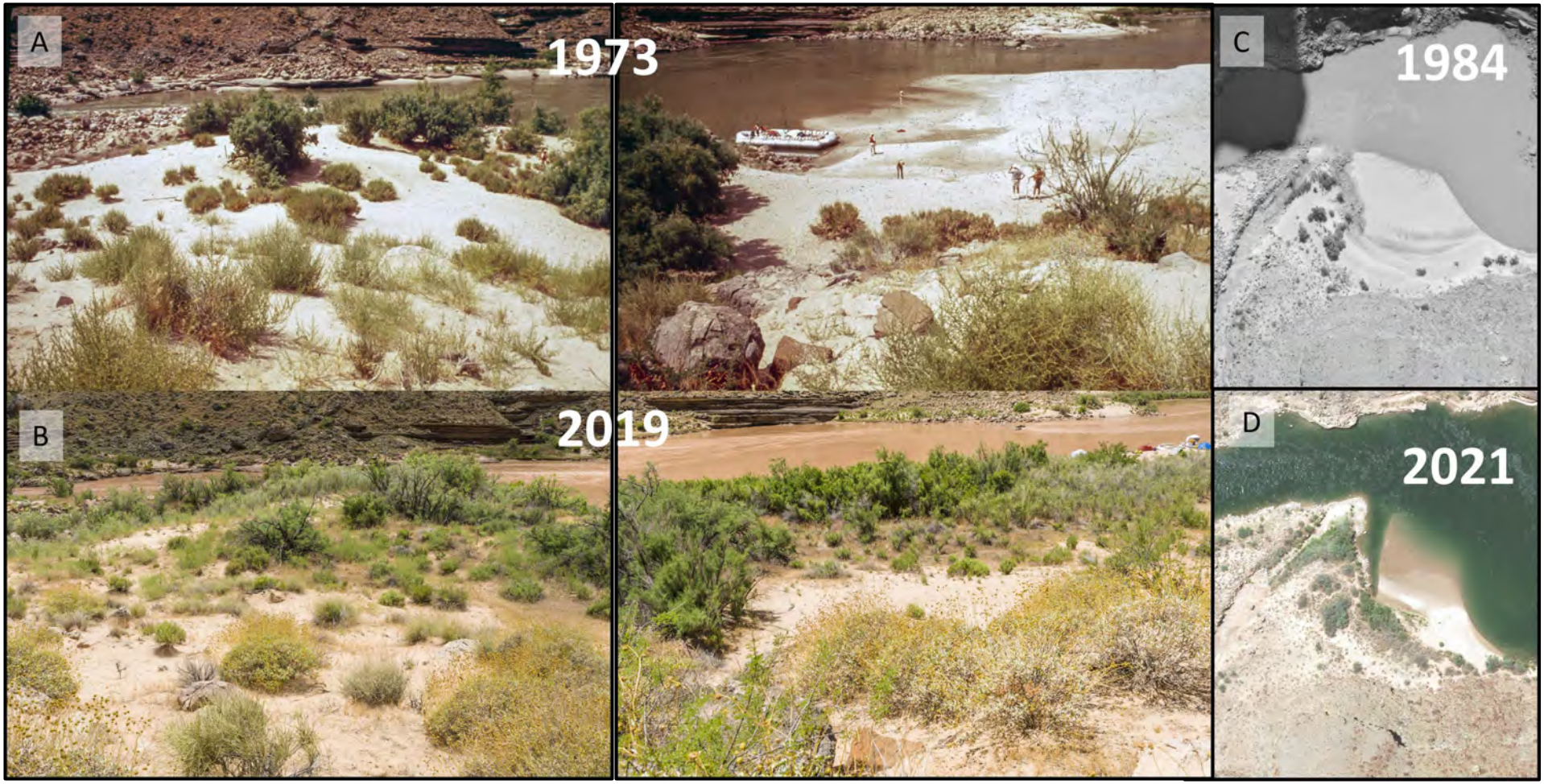


Photo Sources: 1973 (Weeden), 2019 (Fairley and Fairley), 1984 and 2021 (GCMRC Aerial Overflight Image Archives)

Thus, archaeological sites are especially vulnerable to erosion from gullying processes, but burial by windblown river sand is the ongoing contemporary mechanism that can offset that gully erosion and potentially preserve sites in-situ

Gully

Cultural Feature

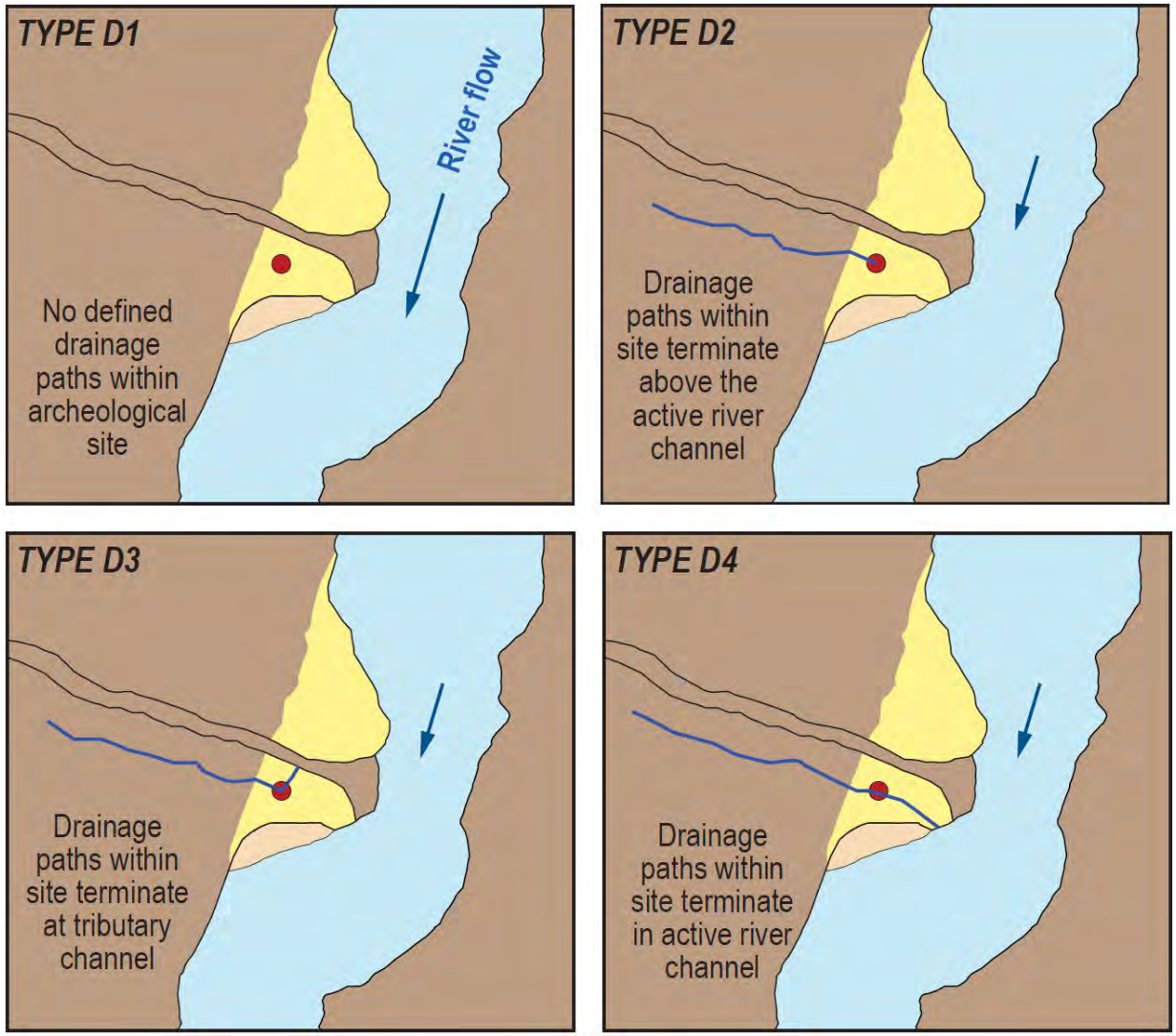
Cook et al., 2019; East et al., 2016

Objective and Methods

Assess changes to the geomorphic condition of Colorado River archaeological sites along the entire river corridor throughout Grand Canyon National Park.

Compile the results of two classification metrics applied to the population of 362 archaeological sites within the area of potential effect of operations of Glen Canyon Dam over multiple decades, along with repeat lidar survey topographic change detection metrics from a sample of these sites.

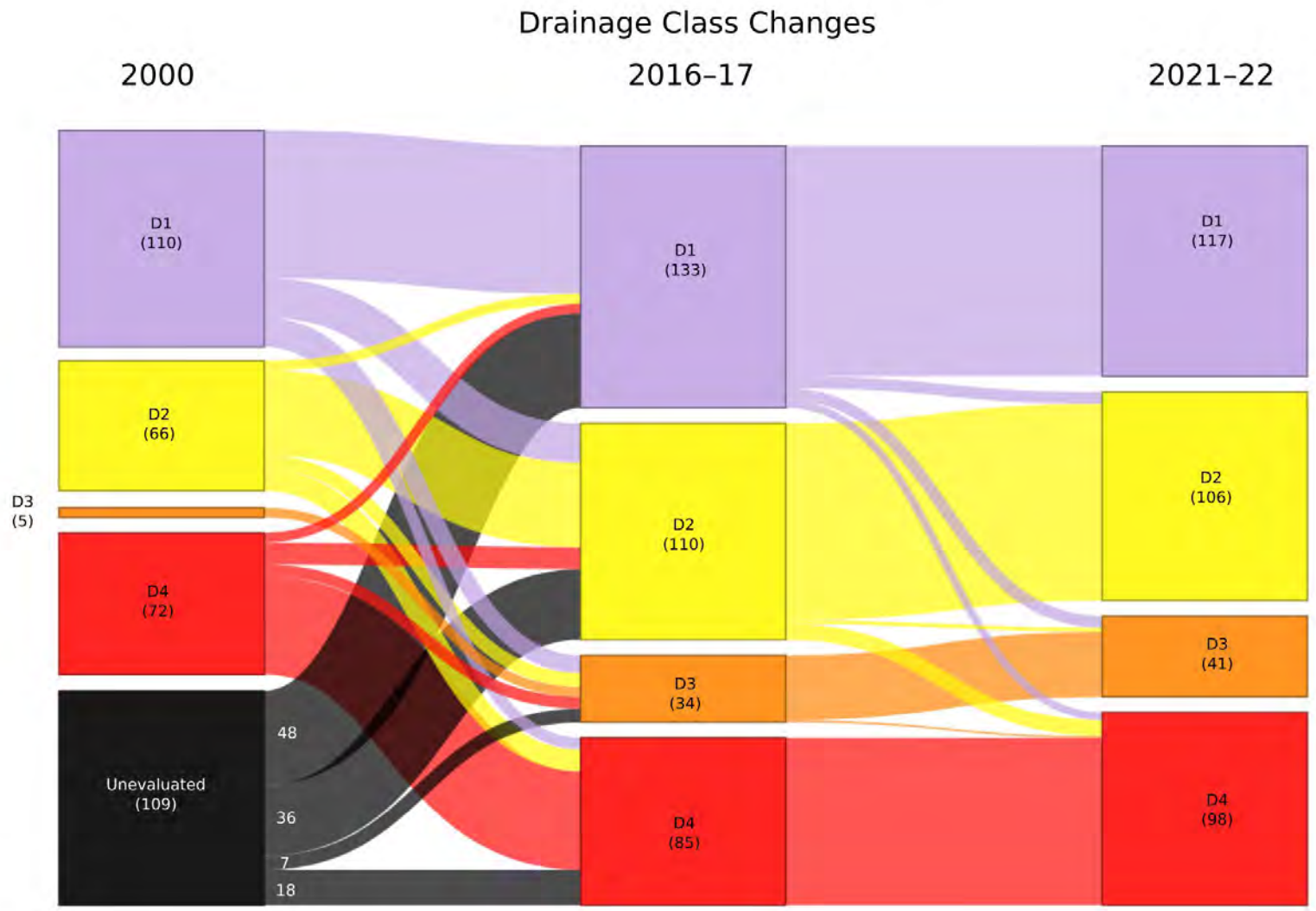
Methods: Site type classification system for extent of gullying at archaeological sites



- The drainage classification system assesses the maximum local maturity of gully networks.
- River-based (D4) and side-canyon-based (D3) drainages are graded to the lowest possible local base level in this system and represent the evolutionary endpoint of drainage development.
- Terrace-based (D2) drainages represent an intermediary stage of development and may, in the future, become river-based or side-canyon based drainages.

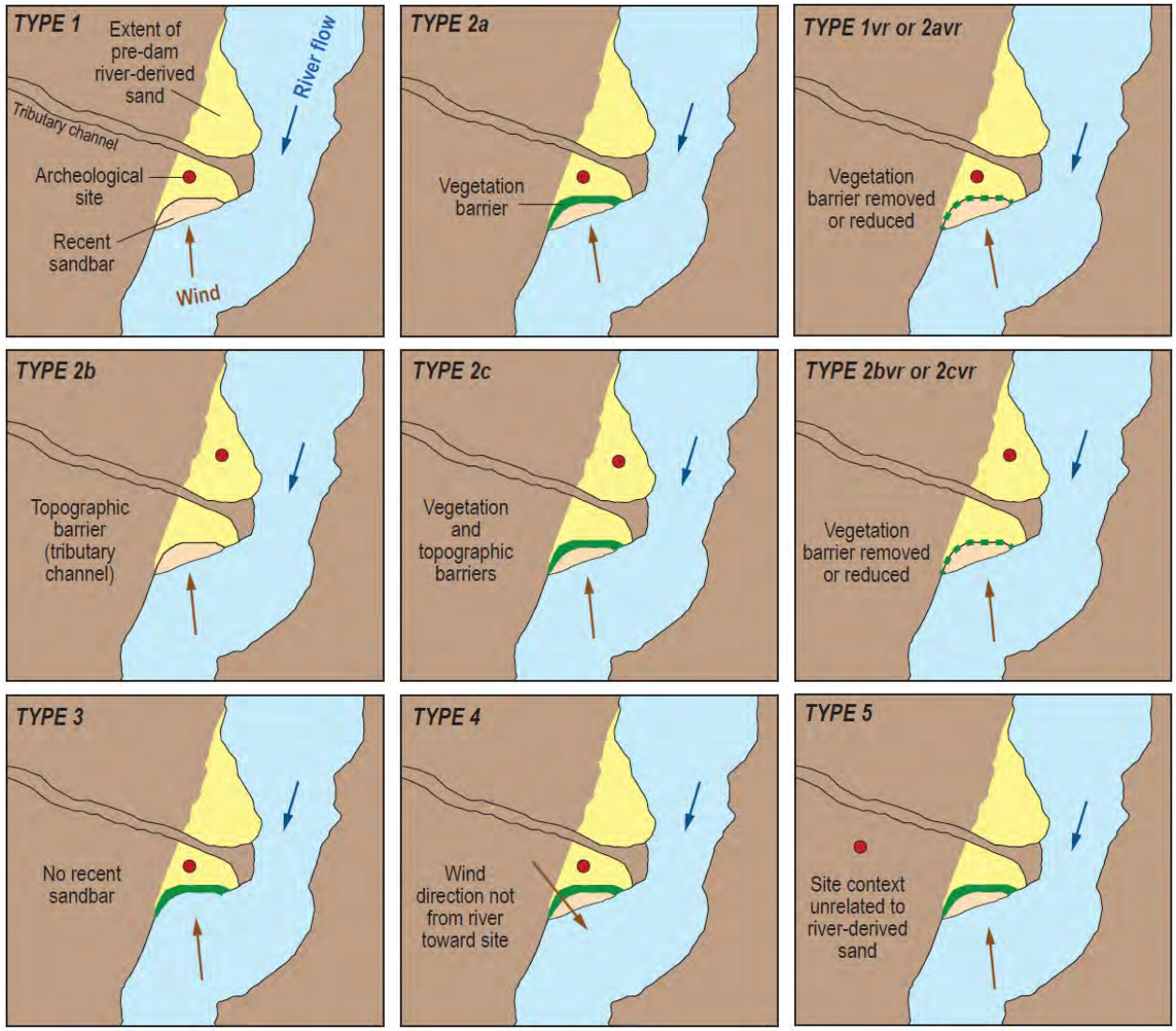
(adapted from East et al., 2016, 2017)

Results: Drainage Classification (Proposed LTEMP Performance Metric)



Preliminary results, subject to change, please don't cite

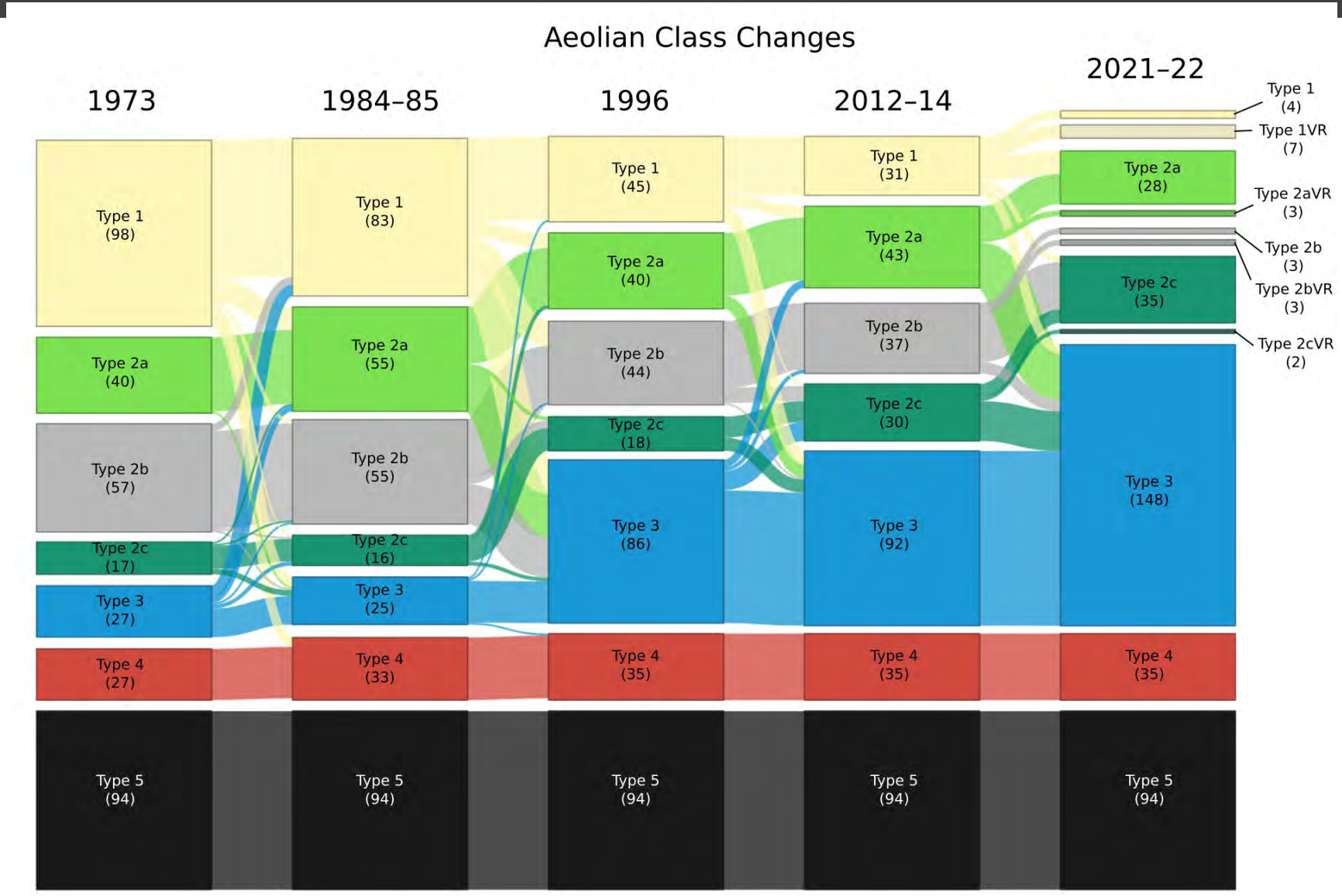
Methods: Site type classification system for windblown (aeolian) sand supply from sandbars to archaeological sites



Fluvial Sediment Connectivity (FSC) (a.k.a. "Aeolian Classification") is a ranked classification of the relative potential for archaeological sites to receive windblown sand from upwind river sandbar deposits which might keep sites buried with a protective cover of sand that can potentially offset erosion that otherwise occurs.

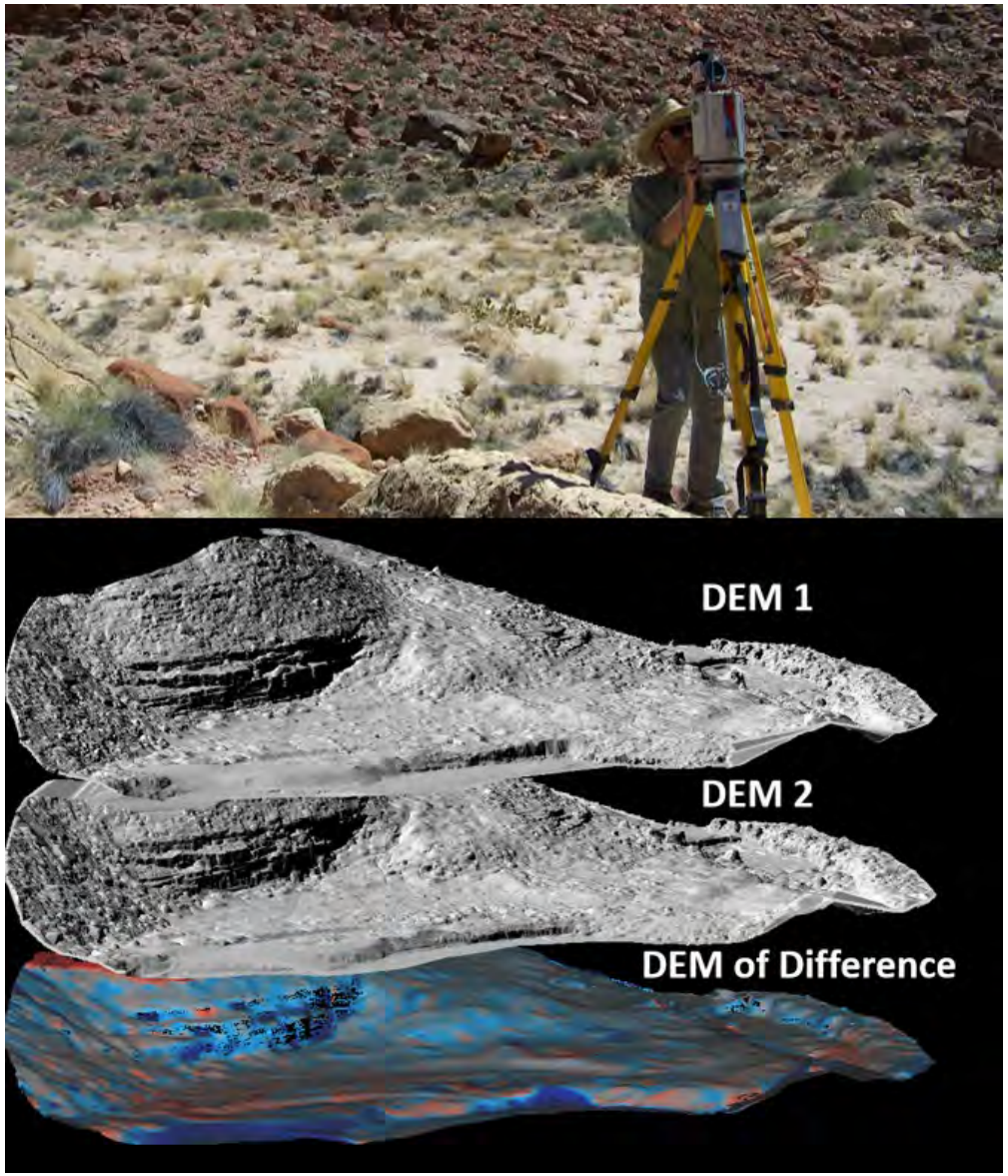
(adapted from East et al., 2016, 2017)

Results: Fluvial Sediment Connectivity Classification (Proposed LTEMP Performance Metric)



Preliminary results, subject to change, please don't cite

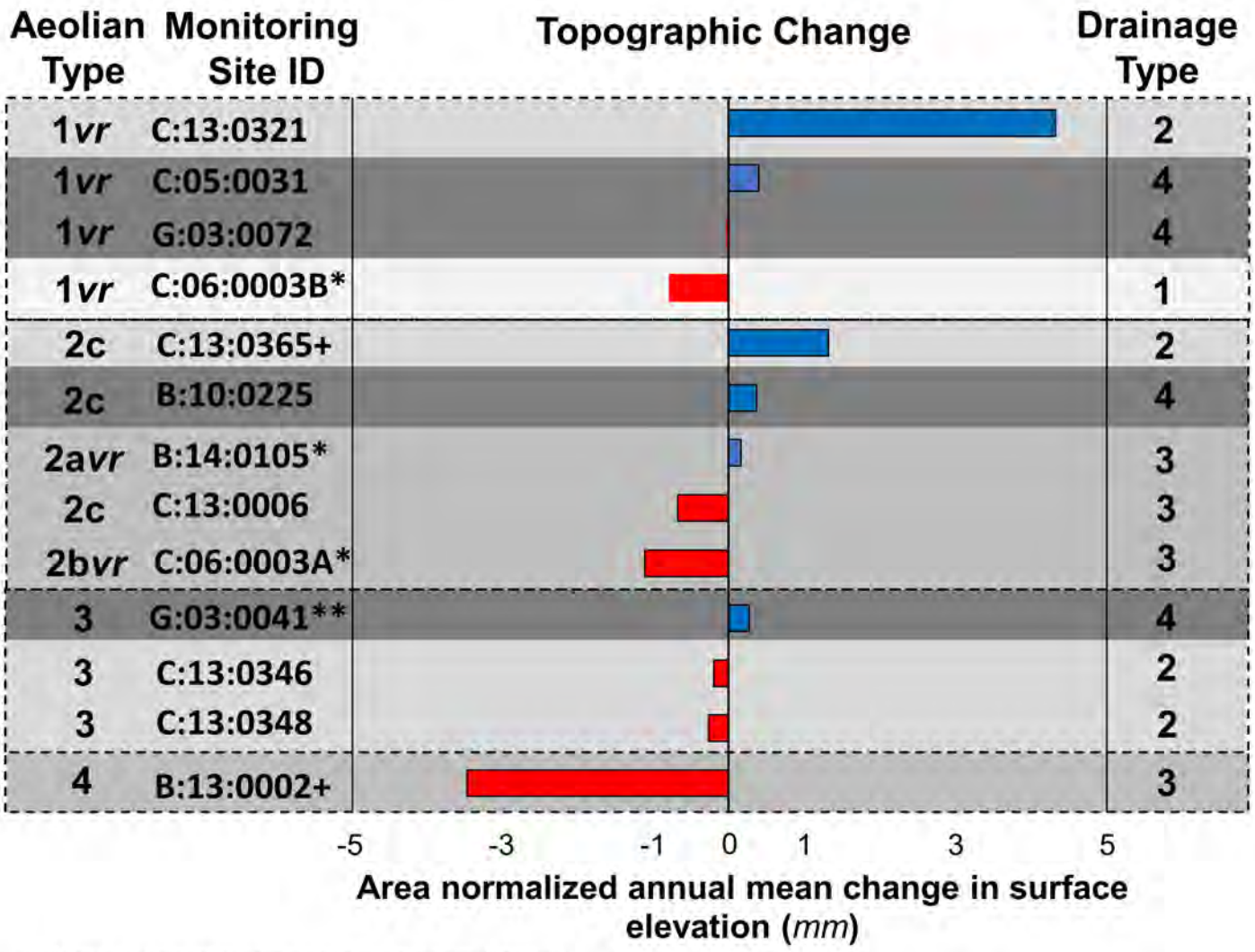
Methods: Lidar Topographic Change Detection



Repeat lidar surveys are used to accurately measure topographic changes associated with erosion and deposition of sediment over time within archaeological sites and surrounding landscape

(Caster et al., 2022)

Results: Lidar Topographic Change Detection (Proposed LTEMP Performance Metric)



\+ *Annual mean represents a one-year survey interval*

* *Annual mean calculated from a survey interval of four years or less*

** *Annual mean calculated from survey interval of more than 10 years*

Caster et al., 2022

Summary

- Condition of 362 Colorado River archaeological sites assessed
- River-sourced aeolian sand decreased since 1973, making most sites more erosion-prone
- Proportion of sites eroding by gully processes has increased since 2000
- Erosion is counter to management goal to maintain or improve site integrity *in situ* (preservation in place)
- Environmental management opportunities: floods, low flows, riparian plant removal

Preliminary results, subject to change, please don't cite

Photo credit: J. Caster (USGS)

Management opportunities

Three ways to increase wind transport of river-sourced sand to much-higher-elevation locations of archeological sites to help decrease or reverse erosion and increase potential for preservation in place

Increase supply of upwind bare sand by:

1. HFE high-elevation sandbar deposition
2. lowering dam releases to expose sand that is normally underwater

Minimize vegetation on sandbar blocking wind transport of sand:

3. ongoing NPS/GCMRC LTEMP vegetation-management experiments

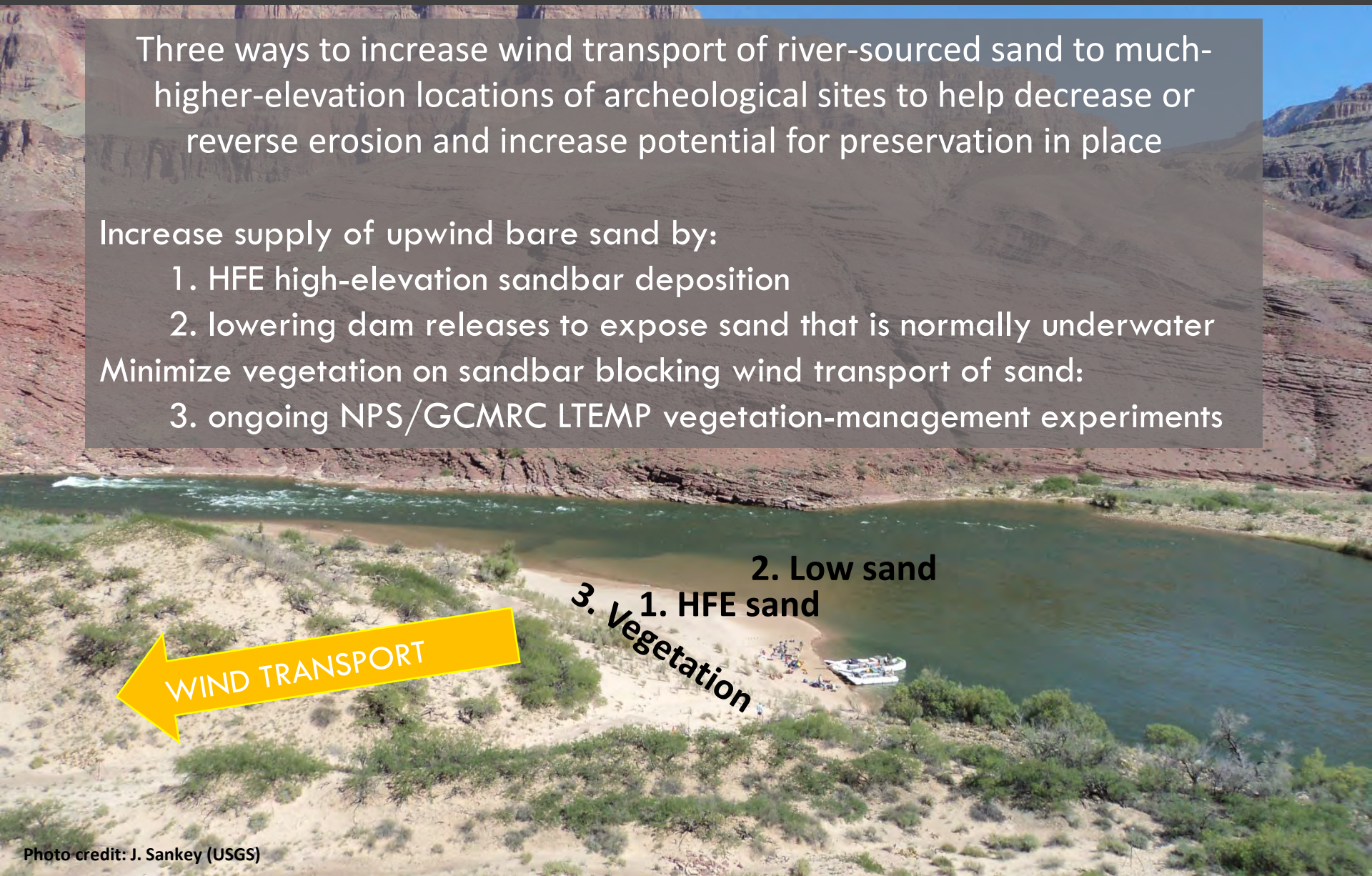


Photo credit: J. Sankey (USGS)

Management opportunity: Floods

1. Increase supply of upwind bare sand by HFE high-elevation sandbar deposition
    - Windblown river sand deposited in dunefield archaeological sites increases cumulatively when upwind river sandbars are resupplied by consecutive annual HFEs (Sankey et al., 2018)

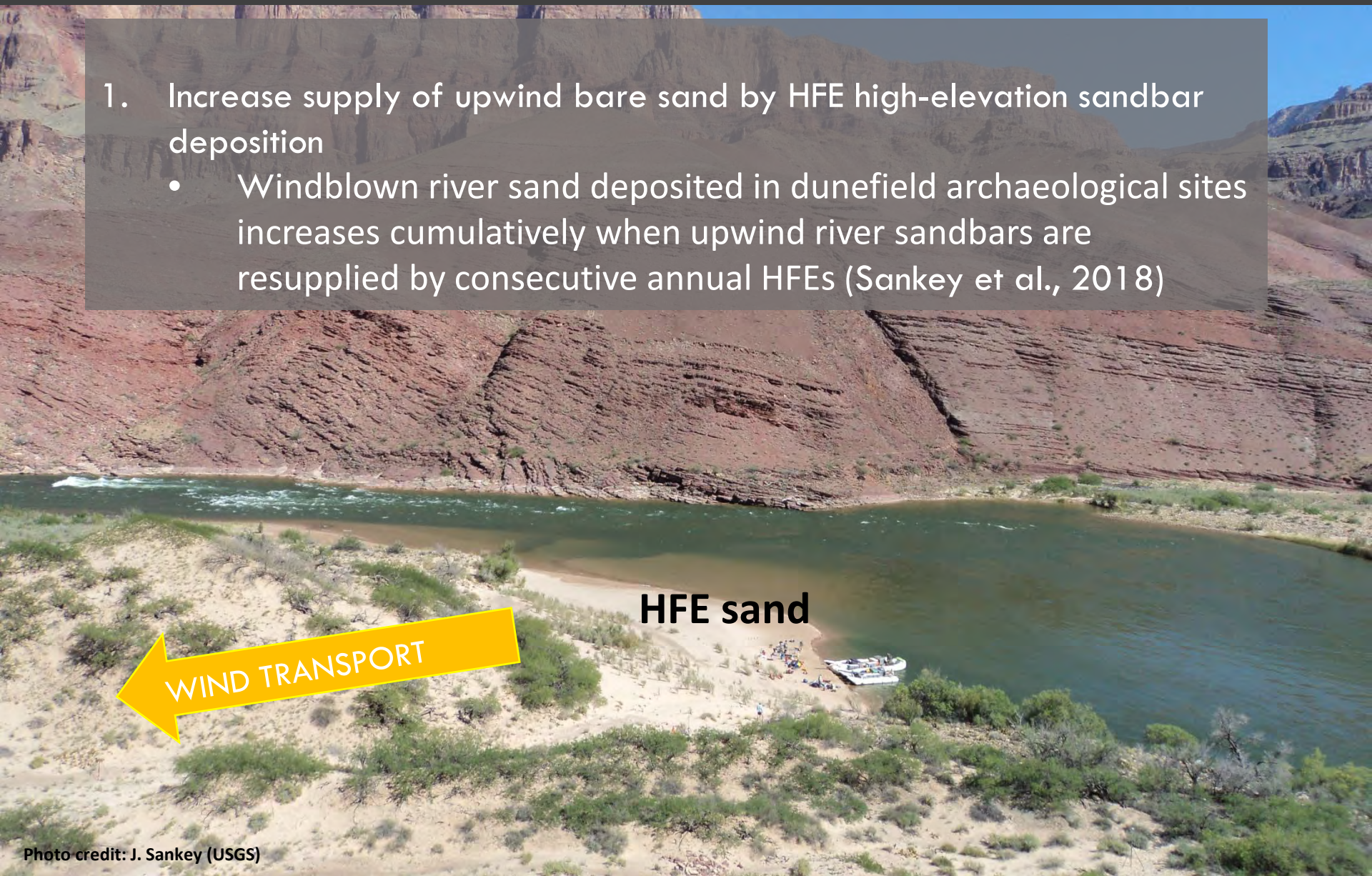


Photo credit: J. Sankey (USGS)

Management opportunity: Low Steady Flows

2. Increase supply of upwind bare sand by lowering dam releases to expose sand that is normally underwater
   - Low steady flows and wind offer alternative to flooding for maintaining sandy landscapes in Grand Canyon (Sankey et al., 2022)
     - Lowering river discharge to ~ 4,000 CFS during the 2021 Spring Disturbance flow exposed ~26,000 m^2 of sand per kilometer of river; >100% increase in source area for windblown sand supply (Kasprak, 2021)
     - 2-3 days of low steady flow duration sufficient for river sand to dry and be transported by wind (Sankey et al., 2022)

Photo credit: J. Sankey (USGS)

Management opportunity: Riparian vegetation removal

3. Ongoing NPS/GCMRC LTEMP vegetation management experiments remove the barrier of invasive riparian vegetation on sandbars that blocks wind transport to archaeological sites.
   - Initially Implemented 2019, repeated 2020/2021/2022…
   - Project report on findings in this year (FY23 Workplan Deliverable)
   - Preliminary results indicate more windblown sand deposition on some sandbar campsites and downwind archeological sites than before vegetation removal (Pilkington, 2022; Caster ARM 2023 Poster)
   - However, implemented based on assumption we'd have HFEs!

Preliminary results, subject to change, please don't cite

Photo credit: J. Sankey (USGS)

Conclusions

- Majority of Colorado River archaeological sites are eroding and are more erosion prone owing to six decades of Glen Canyon Dam Operations
- Erosion is counter to management goal to maintain or improve site integrity *in situ* (preservation in place)
- Environmental management opportunities to increase *in-situ* preservation potential by slowing down or reversing site erosion are floods, low flows, and riparian plant removal
- When *in-situ* preservation fails, site excavations become the management option

USGS science for a changing world

Photo credit: J. Caster (USGS)

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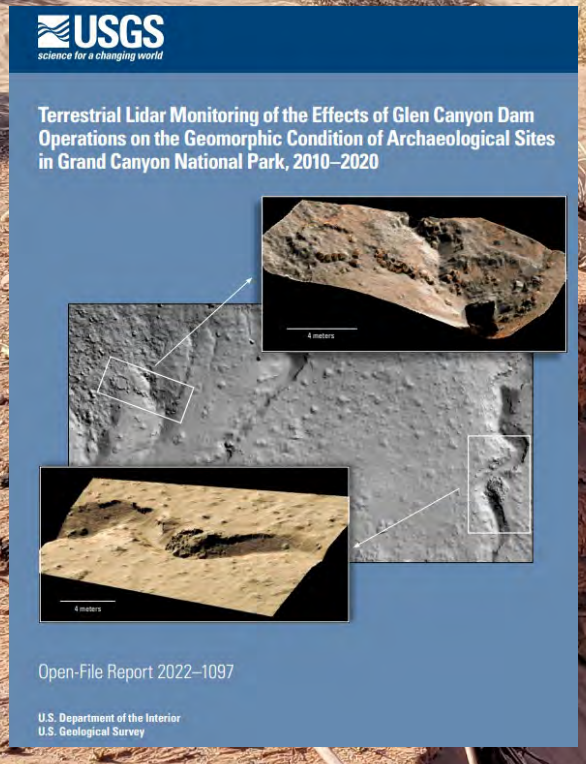
Key References and 2022 Deliverables



ARTICLE

Parks Look for Ways to Alleviate Glen Canyon Dam's Downstream Impacts

Glen Canyon National Recreation Area, Grand Canyon National Park

Vegetation experiments are helping restore Colorado River sites in Grand Canyon and Glen Canyon.

By Lonnie H. Pilkington, Joel B. Sankey, Daniel L. Boughter, Taryn N. Preston, and Cam C. Prophet

About this article

This article was originally published under "Features" in Park Science magazine, Volume 36, Number 1, Summer 2022 (June 22, 2022)

Looking upstream at the Colorado River in Grand Canyon. The bright patch of sand in the center of the photo is the Basalt campsite, recently cleared of encroaching vegetation. Image credit: U.S. Geological Survey/Joel Sankey

JGR Earth Surface

Research Article | Open Access

The Influence of Drying on the Aeolian Transport of River-Sourced Sand

Joel B. Sankey, Joshua Caster, Alan Kasprak, Helen C. Fairley

First published: 30 November 2022 | https://doi.org/10.1029/2022JF006816

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Aeolian Research

Volume 32, June 2018, Pages 154-169

The response of source-bordering aeolian dunefields to sediment-supply changes 2: Controlled floods of the Colorado River in Grand Canyon, Arizona, USA ☆

Joel B. Sankey *, Joshua Caster *, Alan Kasprak *, Amy E. East [b]

Photo credit: J. Caster (USGS)