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# Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

Glen Canyon Dam Adaptive Management Program Annual Reporting Meeting,
January 14, 2020, Phoenix, AZ

**Joel B. Sankey (jsankey@usgs.gov)**
US Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, AZ


# Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites

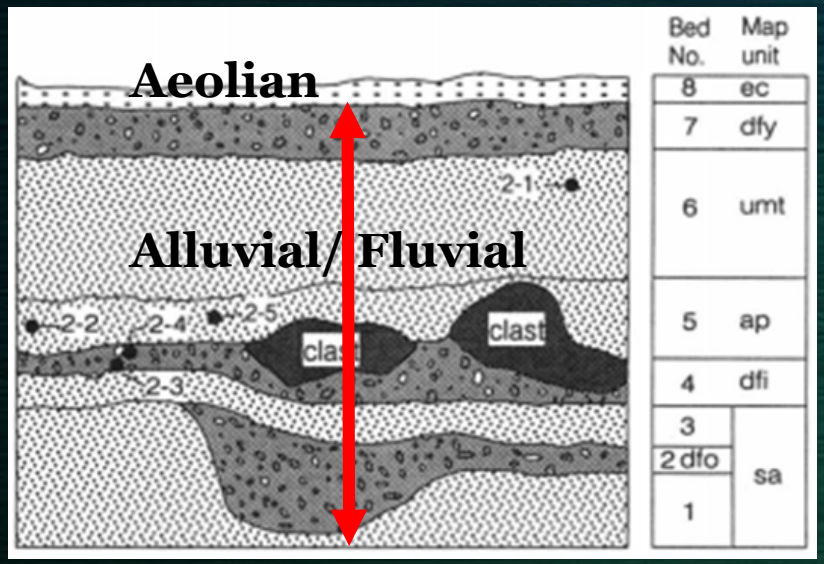
## Project D.1 Geomorphic Effects of Dam Operations and Vegetation Management for Archaeological Sites


- Joel B. Sankey, US Geological Survey, SBSC, GCMRC, Flagstaff, AZ
- Joshua Caster, US Geological Survey, SBSC, GCMRC, Flagstaff, AZ
- Helen Fairley, US Geological Survey, SBSC, GCMRC, Flagstaff, AZ
  - Jen Dierker, National Park Service, Grand Canyon, AZ
  - Mike Kearsley, National Park Service, Grand Canyon, AZ


LTEMP Resource and Goal

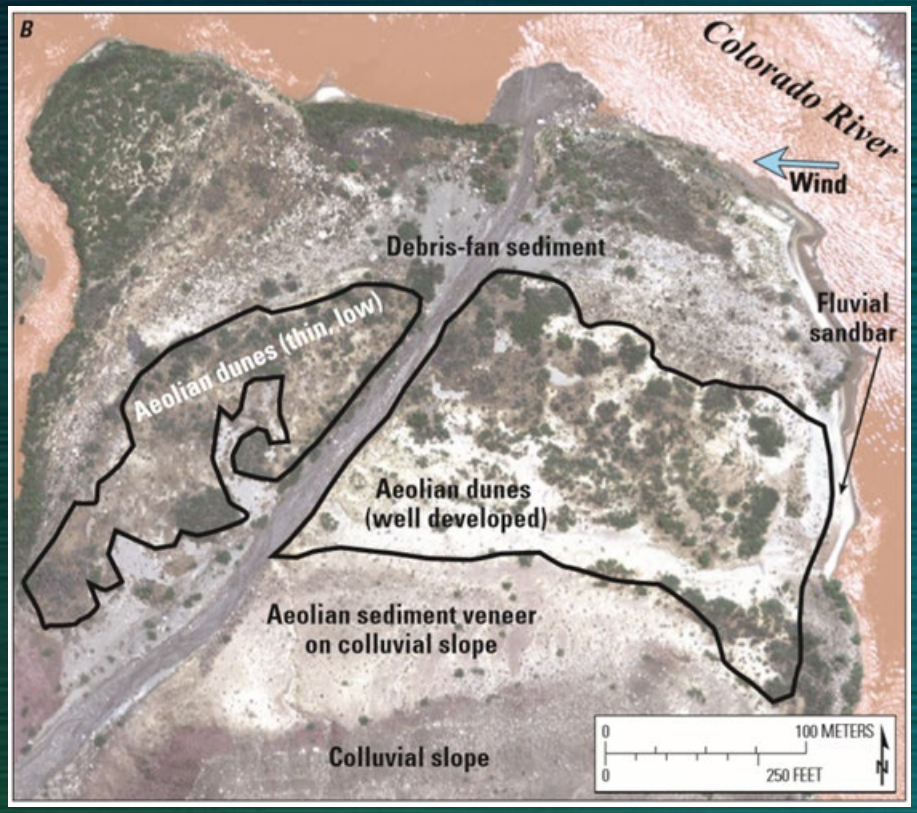
- Archaeological and Cultural Resources
  - Maintain the integrity of potentially affected NRHP-eligible or listed historic properties in place, where possible, with preservation methods employed on a site-specific basis.

# The majority of river corridor archaeological sites in Grand Canyon are on river sand reworked by water and wind.




Hereford and others, 1993

Stratigraphy near Palisades Creek, Colorado River Corridor




East and others, 2016

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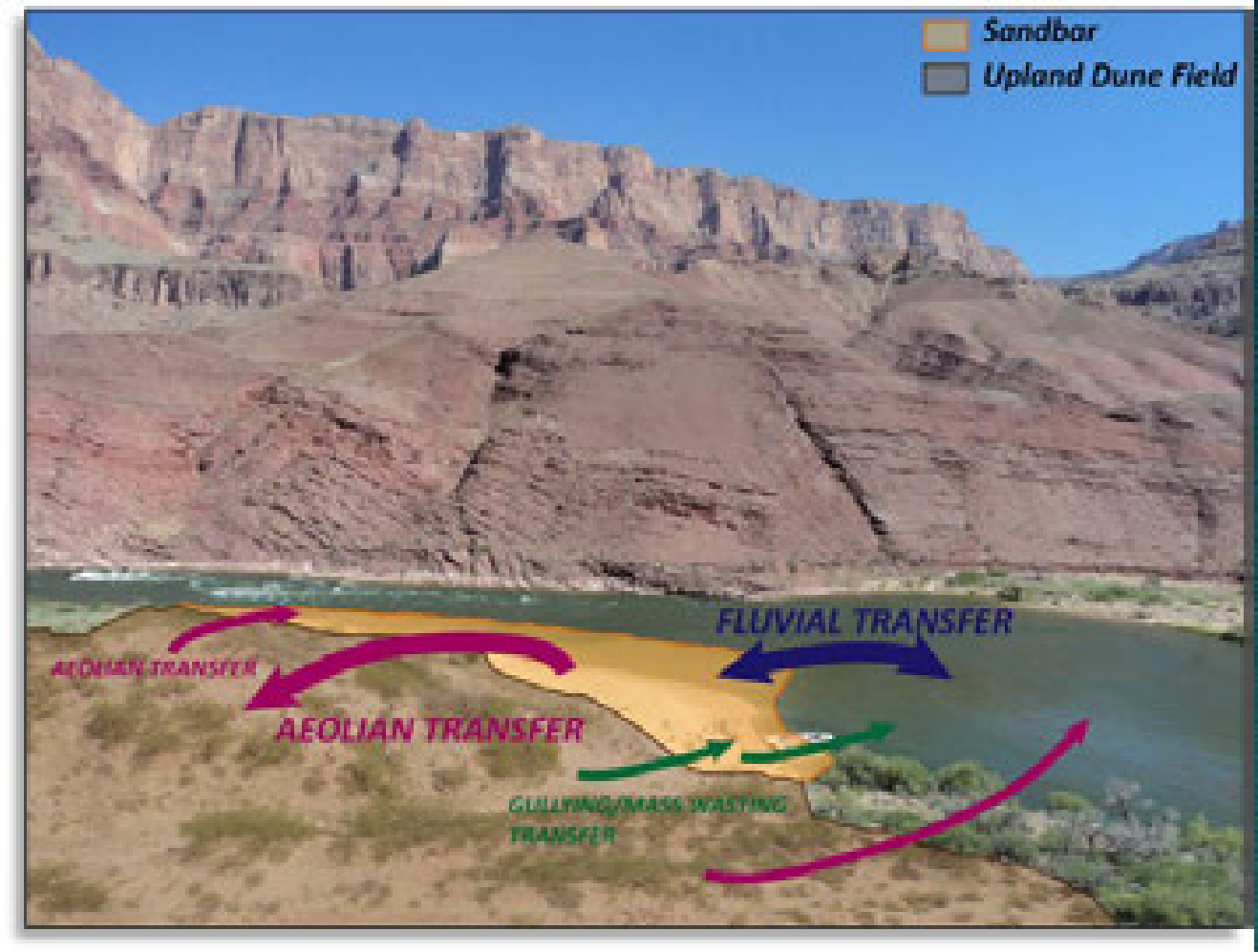
# The geomorphic condition of archaeological sites is affected by how Colorado River sand is transferred among landforms in Grand Canyon




Kasprak and others, 2018

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# Many archaeological sites are degraded by gully erosion, but windblown river sand can help provide a protective cover to preserve sites in place



East and others, 2016

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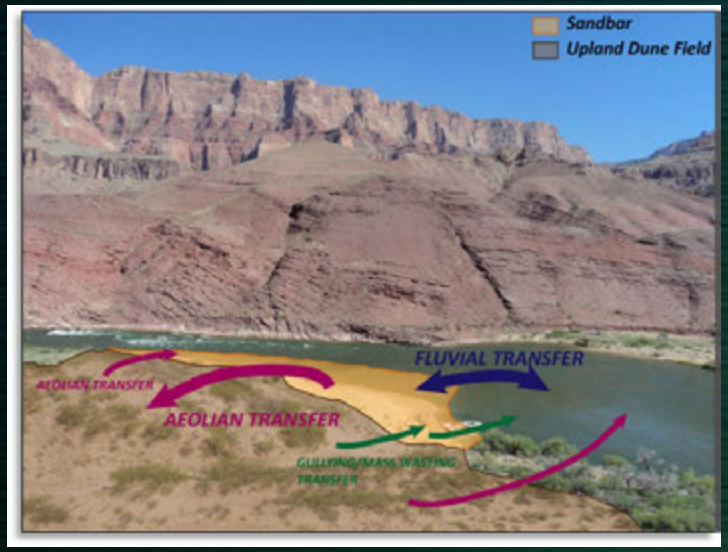
# Grand Canyon geomorphic site classification

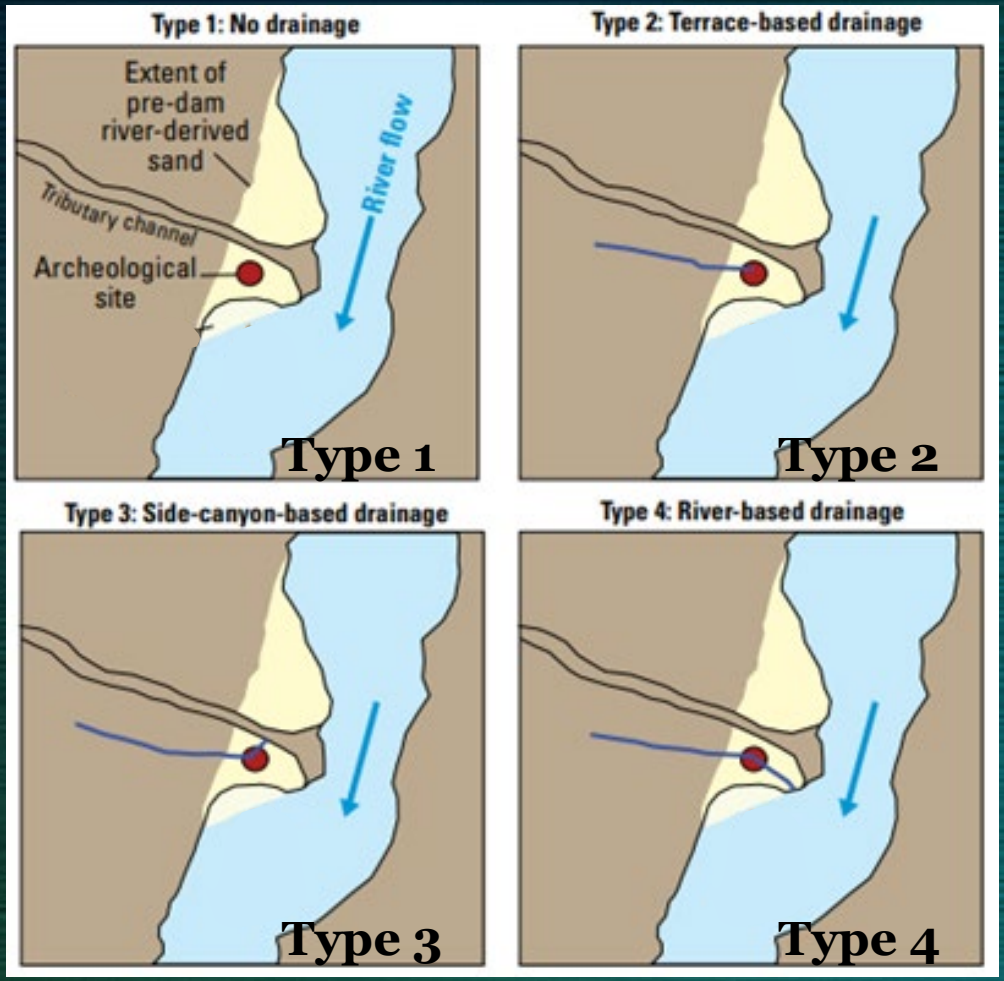
**Drainage Classification:**

Type 1 = low gully impact potential

Type 4 = high gully impact potential




Kasprak and others, 2018




East and others, 2017

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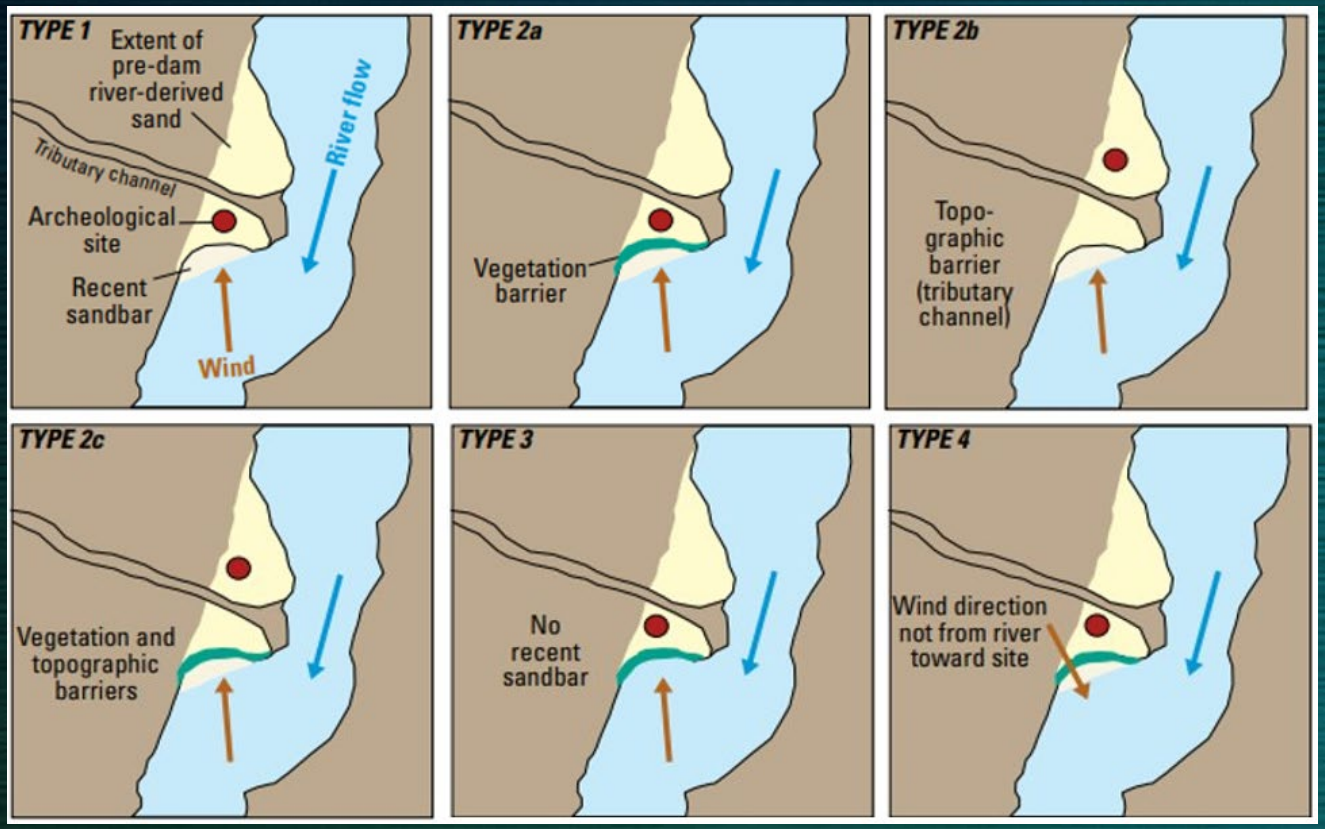
# Grand Canyon geomorphic site classification

**Aeolian Classification:**

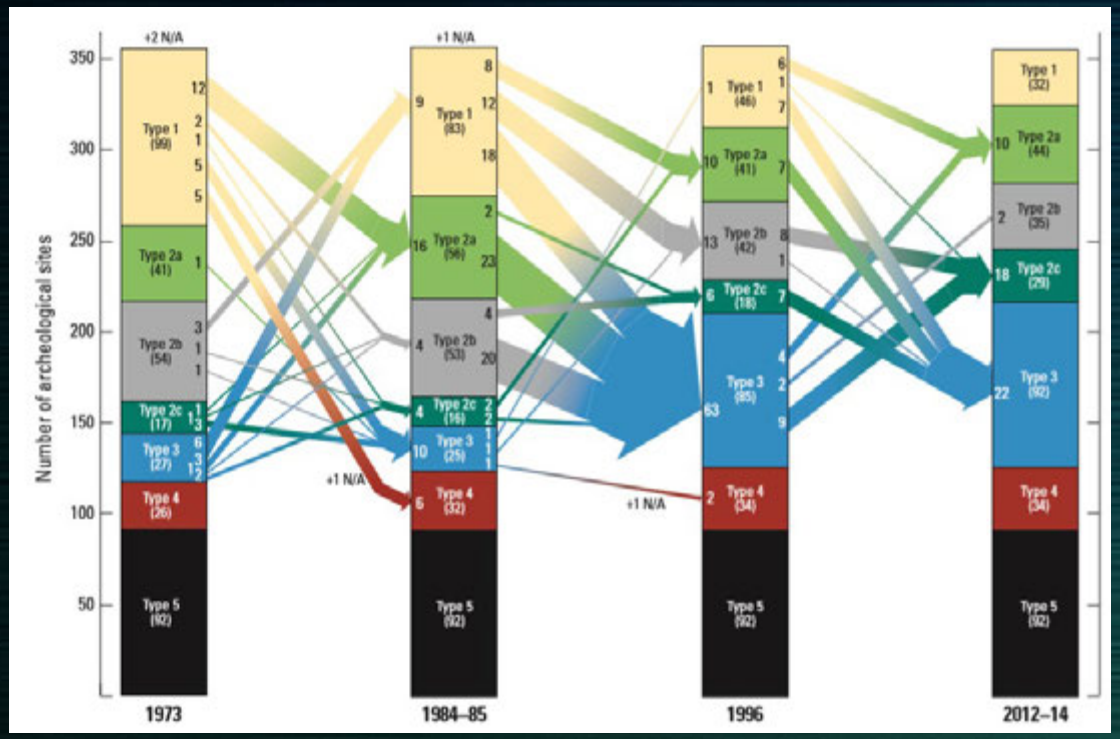
- Type 1: > Sand availability
- Types 2 – 4: Reduced sand availability
- Type 5: No river sand availability


Kasprak and others, 2018




East and others, 2016; 2017

# Using the classifications to monitor changes in the geomorphic condition of archaeological sites




East and others, 2016


- > 350 River Corridor sites being monitored
- Classifications are efficient, with site visits and remote observations
- Observed changes provide clues to site condition

...but classification is qualitative and must be evaluated against quantitative data

# Vegetation changes since river regulation

1973

2019

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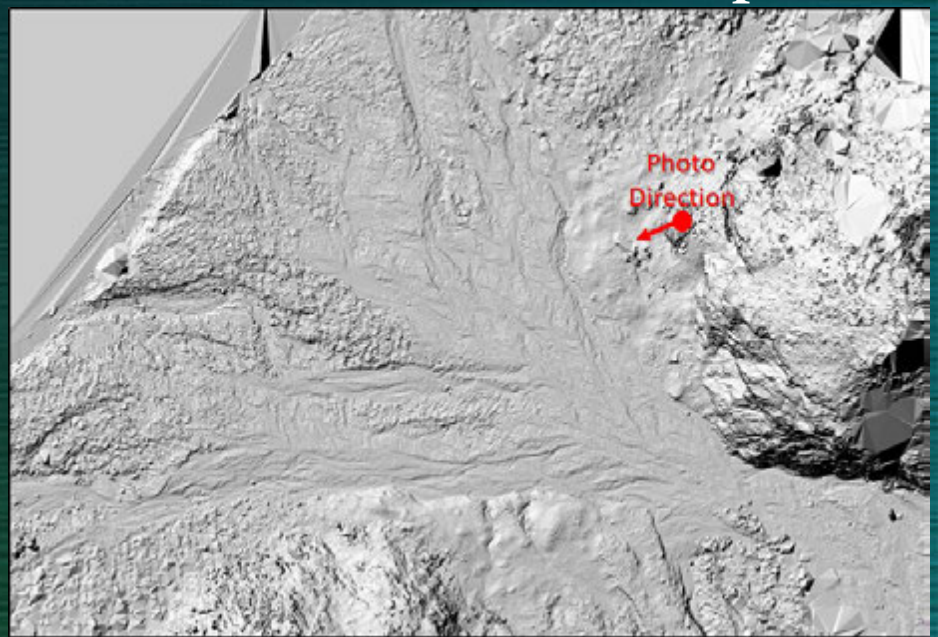
# Supplementing site classification monitoring with topographic site monitoring


Since 2006, GCMRC has monitored a sample of sites with ground-based terrestrial lidar


**Lidar relief map**




Lidar provides a quantitative record of observed field conditions

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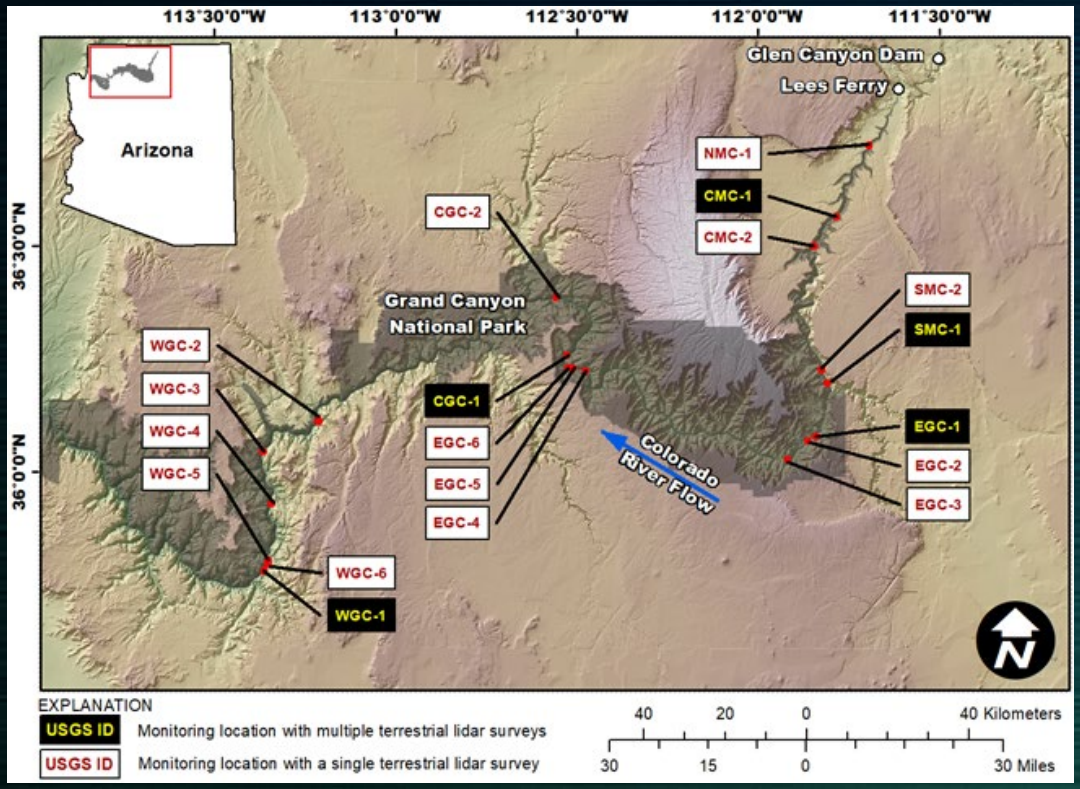
# Grand Canyon topographic site monitoring now and in the future



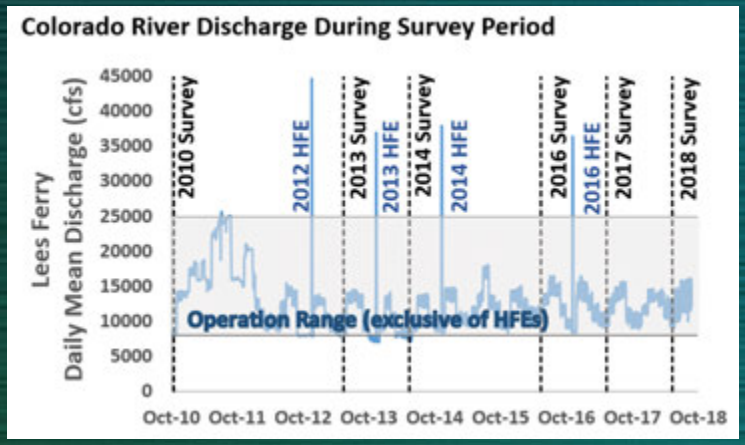

**Terrestrial Lidar Monitoring of the Effects of Glen Canyon Dam Operations on the Geomorphic Condition of Archaeological Sites in Grand Canyon National Park 2010-2018**

By Joshua Caster[1], Joel B. Sankey[1], Helen Fairley[1] and Alan Kasprak[1,2]

[1]US Geological Survey, Grand Canyon Monitoring and Research Center, Flagstaff, Arizona
[2]Utah State University, Department of Watershed Sciences, Logan, Utah

Acknowledgements

This study was supported by funding from the Bureau of Reclamation through the U.S. Geological Survey (USGS) Grand Canyon Monitoring and Research Center and was conducted in collaboration with the National Park Service (NPS; Grand Canyon National Park). We thank Jennifer Dierker (NPS) for valuable guidance in the field and discussions regarding landscape processes and archeological sites. The ideas of Amy East and Brian Collins were instrumental to our conceptual understanding of landscape processes discussed herein. Aaron Borling, Nat Bransky, Skye Corbett, Joe Hazel, Keith Kohl, Mark Mastin, and Paul Rauss provided survey support. Carol Fritzinger coordinated field logistics; boatmen Carolyn Alvord, Don Bacco, Kirk Burnett, Jeremy Draper, Seth Felder, Dave Foster, Don Massman, Mark Perkins, Dennis Harris, and Dom Zanzucchi contributed in numerous ways to the field operations and data collection.




Summarize the last 8 years of monitoring in a new report (Caster and others, in press):

- survey at 23 archaeological sites
- spanning four HFEs

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# Grand Canyon topographic site monitoring now and in the future

Caster and others (in press) report presents both new and previously published data placed within the established **monitoring framework**:

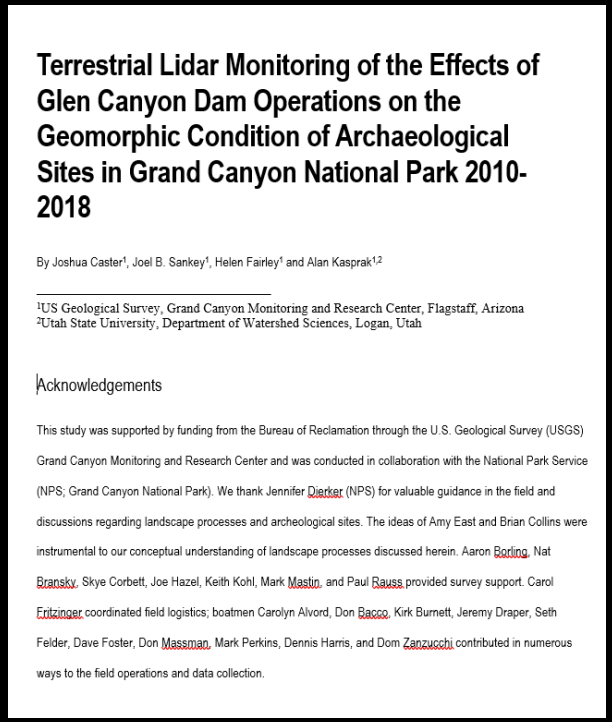
- Geomorphic classification: Large number of sites
- Ground-based survey: Sub-sample of classified sites
- Survey time interval: Variable based on geomorphic context, NPS management priorities, and HFE protocol
- Weather observations: Sub-sample of sites

Greater gully impacts

Greater sand availability

| Aeolian Type | Drainage Type 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| 1 | 0 | 2 | 1 | 5 | 8 |
| 2a | 0 | 0 | 1 | 3 | 4 |
| 2b | 2 | 0 | 3 | 0 | 5 |
| 2c | 0 | 1 | 0 | 2 | 3 |
| 3 | 2 | 2 | 0 | 0 | 3 |
| Total | 4 | 5 | 5 | 10 | 24 |

Unpublished results, do not cite



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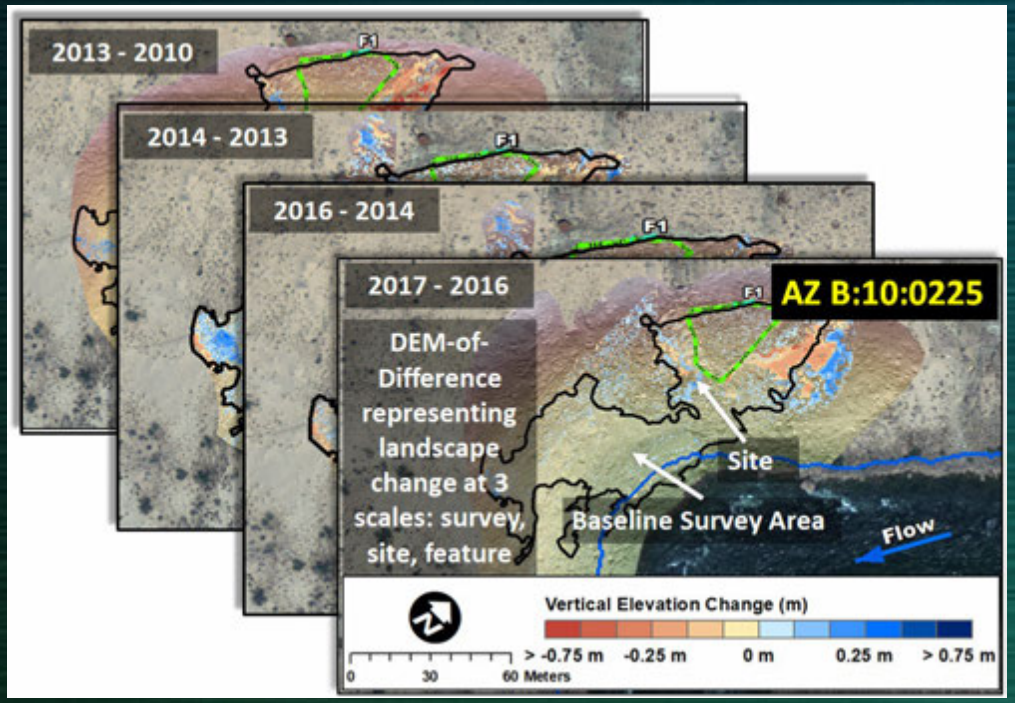
# Grand Canyon topographic site monitoring: changes in geomorphic condition

Caster and others (in press) report:

- Several monitoring locations were repeatedly surveyed between 2010 & 2018
- DEMs-of-Difference (DODs) to measure topographic change
- Synthesis of previously published data between 2010 and 2016
- New results for change detection after 2016

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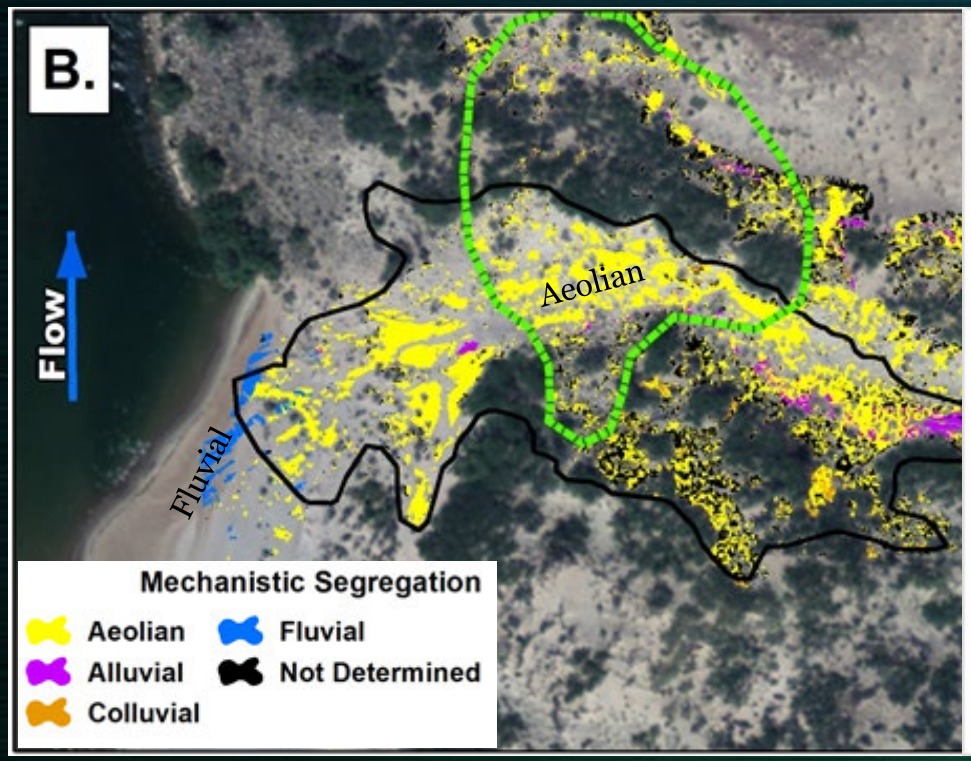
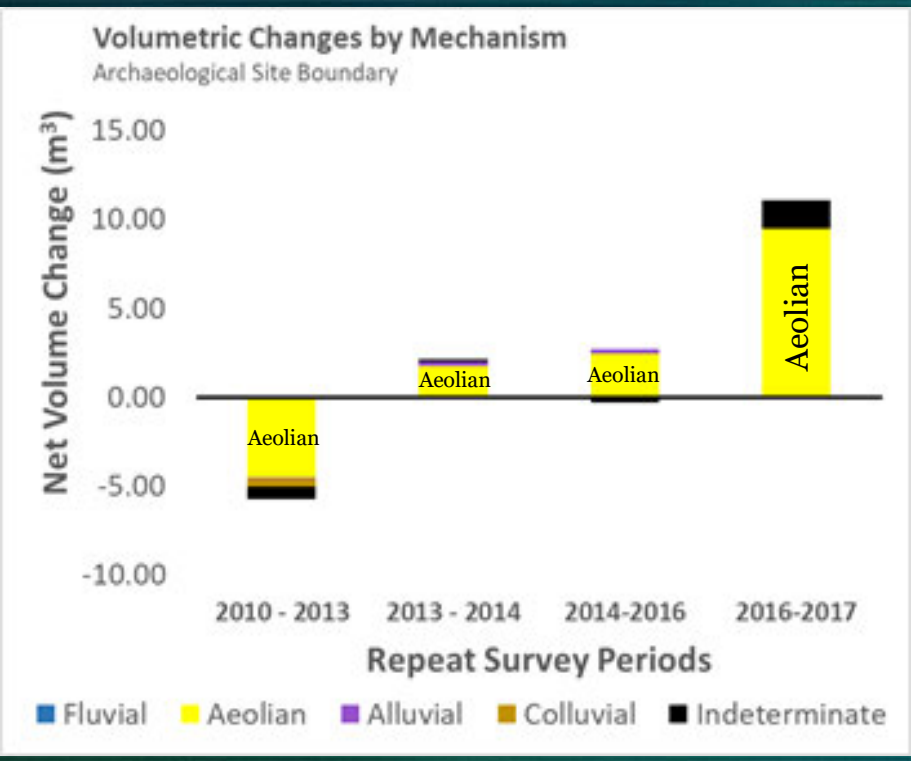
# Grand Canyon topographic site monitoring: changes in geomorphic condition

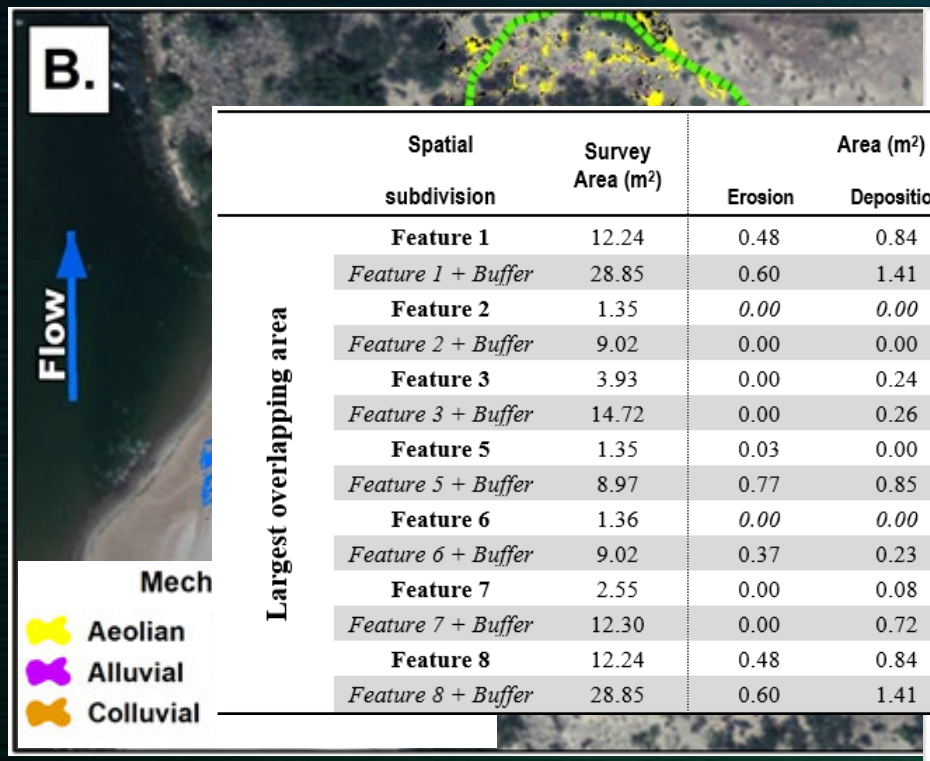
**Analyze changes in sediment storage by geomorphic process mechanism within the archaeological site…**



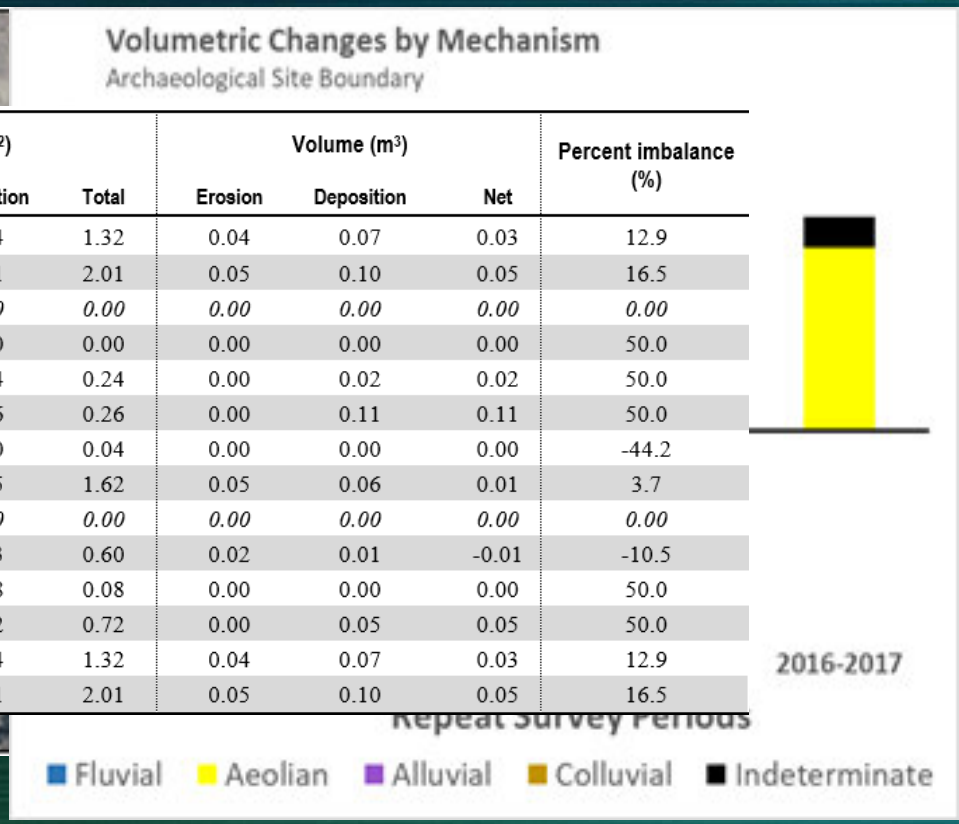



# Grand Canyon topographic site monitoring: changes in geomorphic condition

**…and within individual features in the archaeological site**




| Largest overlapping area | Spatial subdivision | Survey Area ($m^2$) | Area ($m^2$) Erosion | Area ($m^2$) Deposition | Area ($m^2$) Total | Volume ($m^3$) Erosion | Volume ($m^3$) Deposition | Volume ($m^3$) Net | Percent imbalance (%) |
|---|---|---|---|---|---|---|---|---|---|
| | **Feature 1** | 12.24 | 0.48 | 0.84 | 1.32 | 0.04 | 0.07 | 0.03 | 12.9 |
| | *Feature 1 + Buffer* | 28.85 | 0.60 | 1.41 | 2.01 | 0.05 | 0.10 | 0.05 | 16.5 |
| | **Feature 2** | 1.35 | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* |
| | *Feature 2 + Buffer* | 9.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 50.0 |
| | **Feature 3** | 3.93 | 0.00 | 0.24 | 0.24 | 0.00 | 0.02 | 0.02 | 50.0 |
| | *Feature 3 + Buffer* | 14.72 | 0.00 | 0.26 | 0.26 | 0.00 | 0.11 | 0.11 | 50.0 |
| | **Feature 5** | 1.35 | 0.03 | 0.00 | 0.04 | 0.00 | 0.00 | 0.00 | -44.2 |
| | *Feature 5 + Buffer* | 8.97 | 0.77 | 0.85 | 1.62 | 0.05 | 0.06 | 0.01 | 3.7 |
| | **Feature 6** | 1.36 | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* | *0.00* |
| | *Feature 6 + Buffer* | 9.02 | 0.37 | 0.23 | 0.60 | 0.02 | 0.01 | -0.01 | -10.5 |
| | **Feature 7** | 2.55 | 0.00 | 0.08 | 0.08 | 0.00 | 0.00 | 0.00 | 50.0 |
| | *Feature 7 + Buffer* | 12.30 | 0.00 | 0.72 | 0.72 | 0.00 | 0.05 | 0.05 | 50.0 |
| | **Feature 8** | 12.24 | 0.48 | 0.84 | 1.32 | 0.04 | 0.07 | 0.03 | 12.9 |
| | *Feature 8 + Buffer* | 28.85 | 0.60 | 1.41 | 2.01 | 0.05 | 0.10 | 0.05 | 16.5 |

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# Grand Canyon topographic site monitoring: changes in geomorphic condition

**Caster et al. (in press) monitoring results are consistent with our previously published results of how HFEs affect aeolian dunefields that contain archaeological sites.**

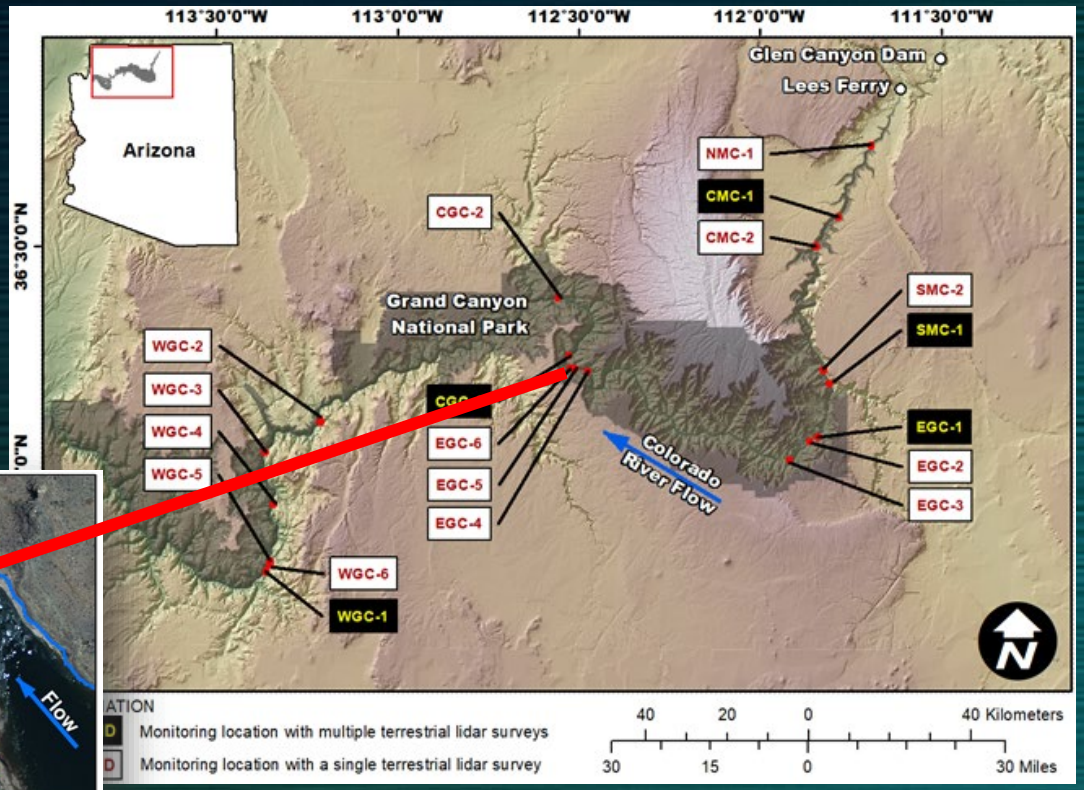
"*Sankey et al., 2018. The response of source-bordering aeolian dunefields to sediment supply changes: controlled floods of the Colorado River in Grand Canyon, Arizona, USA. Aeolian Research 32, 154-169*"

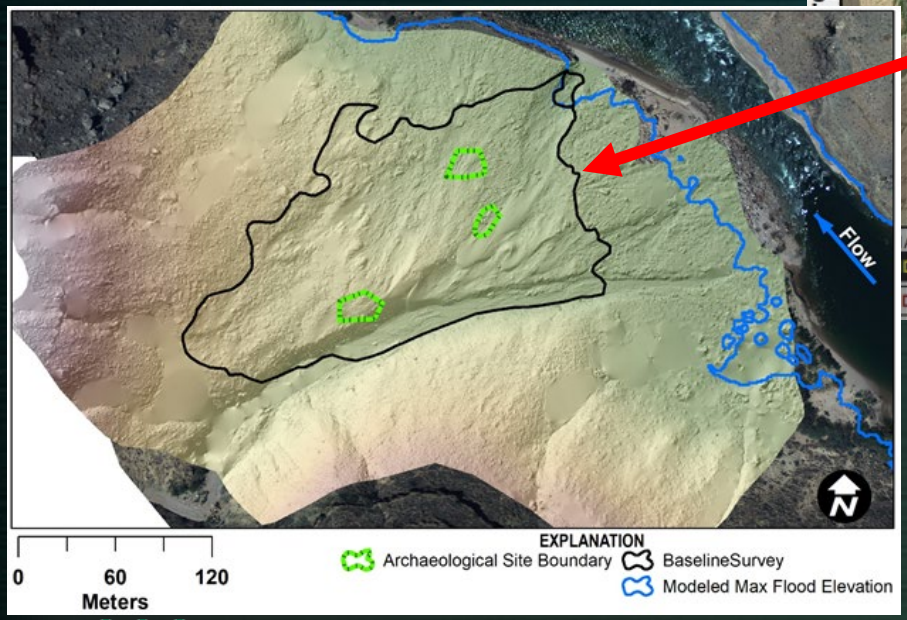
- Sediment storage increases cumulatively when HFEs are conducted consistently on an annual basis.
- HFEs do not directly inundate most of the dunefields that contain archaeological sites, however, HFEs resupply the dunefields with sand by rebuilding upwind sandbars
- Aeolian dunefields that contain archaeological sites were resupplied with windblown sand from HFE deposits in half of the instances monitored after the 2012, 2013, 2014, and 2016 HFEs
- Frequency of sediment resupply by HFEs is analogous to resupply of sandbars by HFEs
- Sediment storage decreased with 1-year hiatus from HFE in 2015.

# Grand Canyon topographic site monitoring

**Adding to our sample size**

- Since 2016 we have added **new archaeological site monitoring locations** (white boxes)




By expanding our sample size we can:

- More accurately link geomorphic classification with topographic change
- Make more robust inferences about changes to site condition

# Grand Canyon topographic site monitoring

**Evaluating changes to geomorphic site classifications**

- Changes within the geomorphic classifications can be assess to predict future results within all surveyed areas
  - Aeolian classification changes from 1996 to 2014
  - Drainage classification changes from 2000 to 2016

| Aeolian Type \ Drainage Type | Increase | Decrease | No Change | Total |
|---|---|---|---|---|
| Increase | 4 | 1 | 5 | **10** |
| Decrease | *0* | *0* | *0* | **0** |
| No Change | 3 | 1 | 10 | **14** |
| **Total** | **7** | **2** | **15** | **24** |

**No Change** = Site condition has not changed

**Decrease** = Decreased erosion potential; less degraded site condition

**Increase** = Increased erosion potential; more degraded site condition

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# Grand Canyon topographic site monitoring

## Evaluating changes to geomorphic site classifications

- Of the newly surveyed archaeological sites, more than half changed in either aeolian classification (1996-2014) and drainage classification (2000-2016)

| Aeolian Type \ Drainage Type | Increase | Decrease | No Change | Total |
|---|---|---|---|---|
| Increase | 4 | 1 | 5 | 10 |
| Decrease | *0* | *0* | *0* | 0 |
| No Change | 3 | 1 | 10 | 14 |
| Total | 7 | 2 | 15 | 24 |

**No Change** = Site condition has not changed

Unpublished results, do not cite

# Grand Canyon topographic site monitoring

## Evaluating changes to geomorphic site classifications

| Aeolian Type \ Drainage Type | Increase | Decrease | No Change | Total |
|---|---|---|---|---|
| Increase | 4 | 1 | 5 | **10** |
| Decrease | *0* | *0* | *0* | **0** |
| No Change | 3 | 1 | 10 | **14** |
| **Total** | **7** | **2** | **15** | **24** |

**Decrease** = Decreased erosion potential; less degraded site condition

Unpublished results, do not cite

# Grand Canyon topographic site monitoring

## Evaluating changes to geomorphic site classifications

- Some sites are predicted to be in a more degraded state

| Aeolian Type | Drainage Type: Increase | Drainage Type: Decrease | Drainage Type: No Change | Total |
|---|---|---|---|---|
| Increase | 4 | 1 | 5 | 10 |
| Decrease | *0* | *0* | *0* | 0 |
| No Change | 3 | 1 | 10 | 14 |
| Total | 7 | 2 | 15 | 24 |

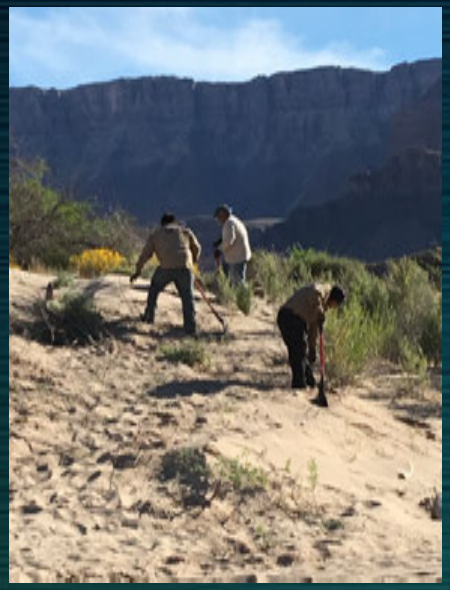
**Increase** = Increased erosion potential; more degraded site condition

Unpublished results, do not cite

# Vegetation removal experiments

In April, 2019 the NPS implemented experimental vegetation removal treatments on several sandbars in Grand Canyon to increase the supply of HFE sediment via aeolian processes to dunefields that host archaeological sites

GCMRC is monitoring the outcome of the vegetation treatments relative to future HFEs



# Vegetation removal experiments

LTEMP vegetation removal treatment conducted April, 2019
by NPS with Ancestral Lands Conservation Corps tribal crews

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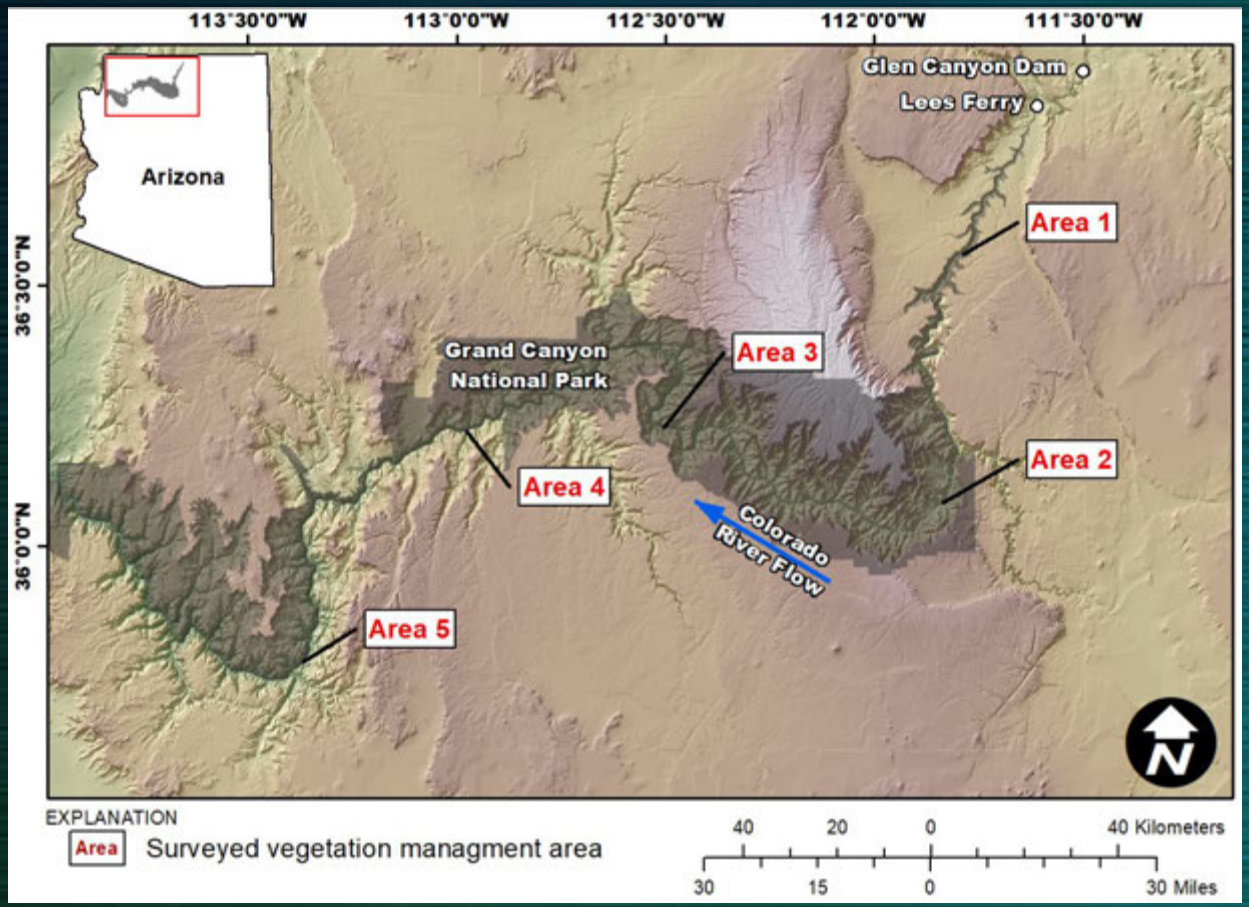
# Vegetation removal experiments

5 areas selected based on:

- NPS management priorities
  - Sandbars
  - Campsites
  - Arch. Sites
- Lidar monitoring data
- Observed changes in geomorphic condition from site classification and lidar monitoring

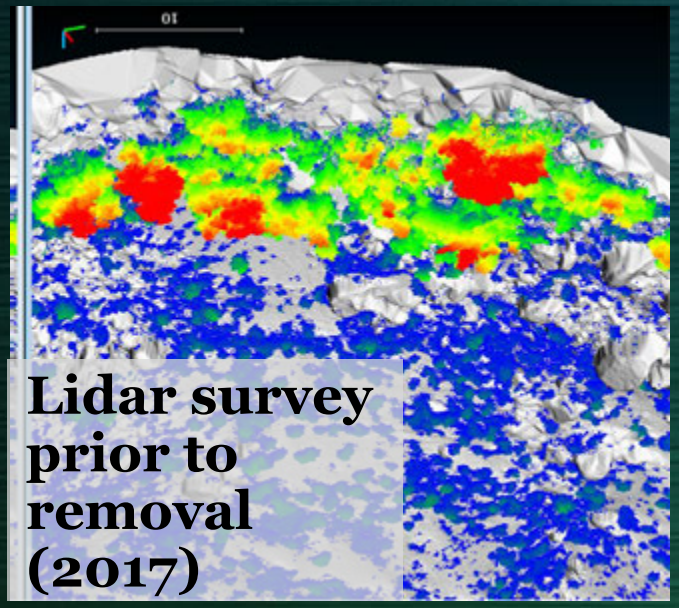


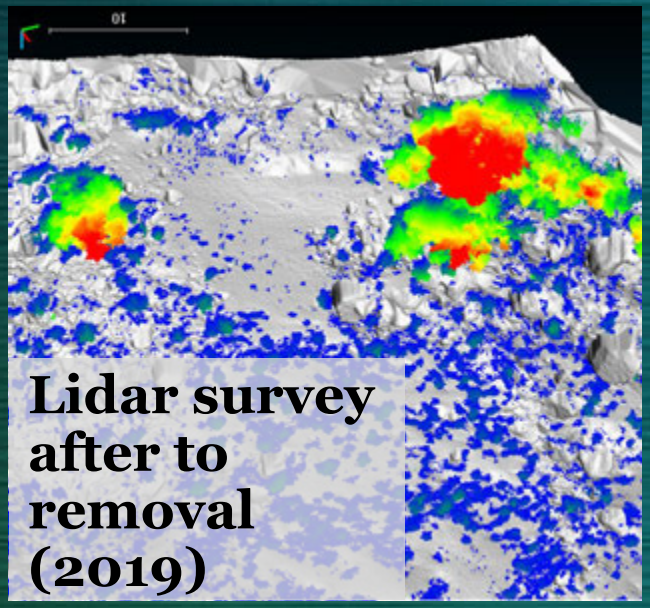
# Vegetation removal experiments

Area 1



Vegetation canopy height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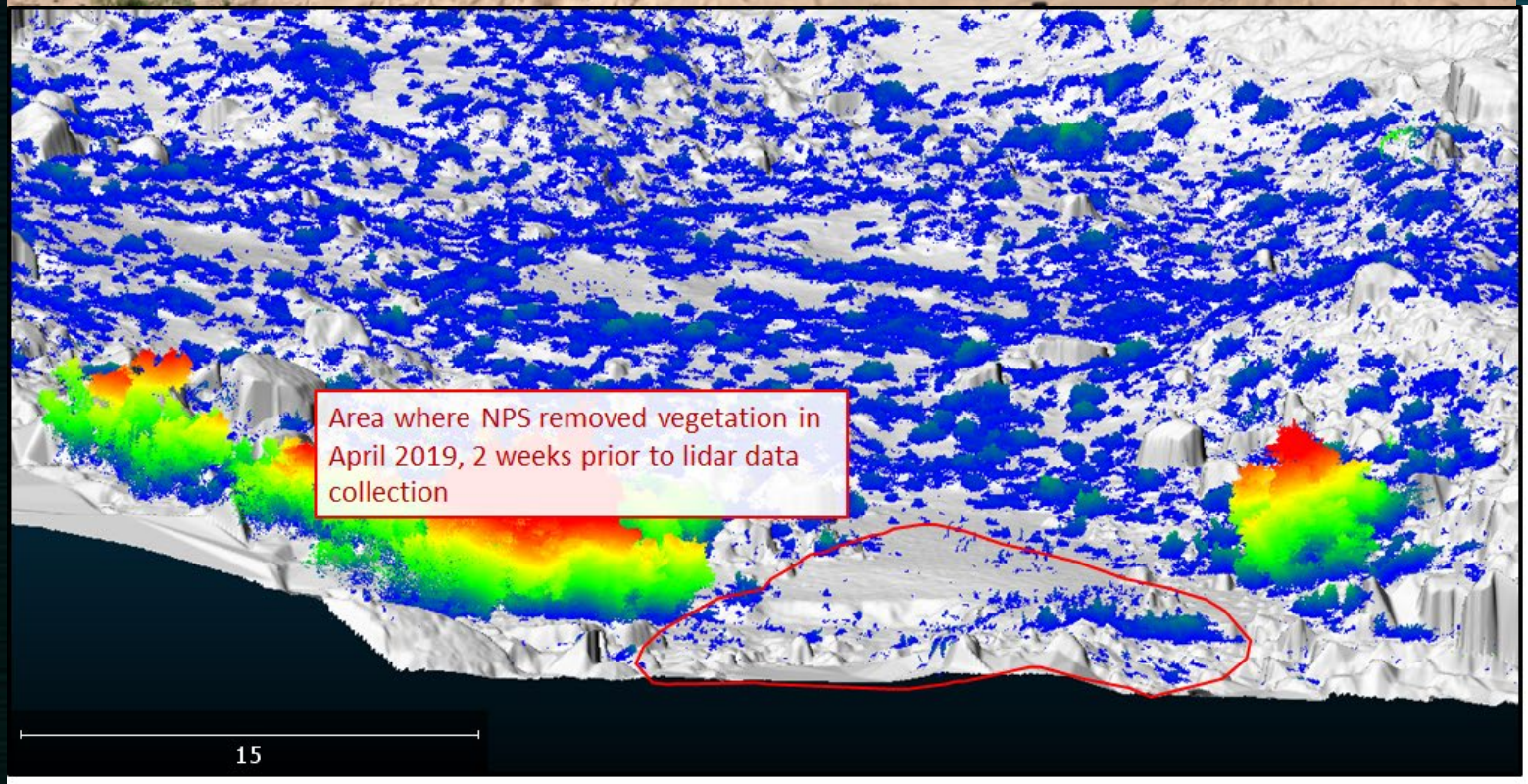
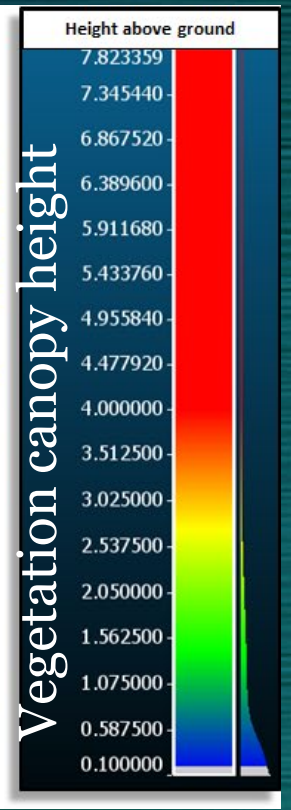
# Vegetation removal experiments

Area 1

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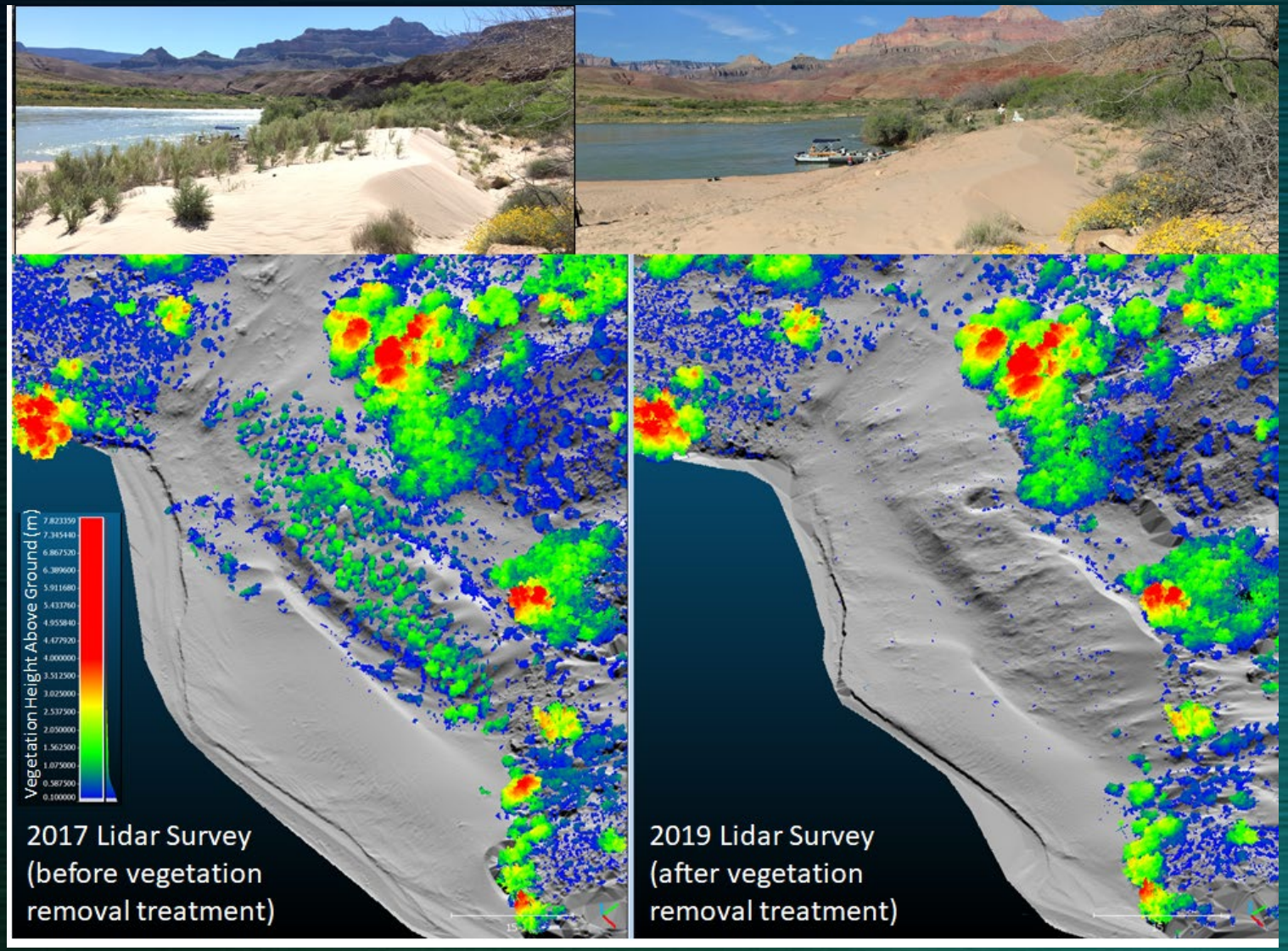
# Vegetation removal experiments

Area 2

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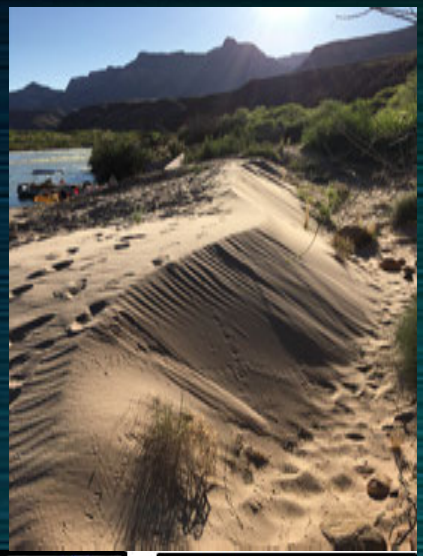
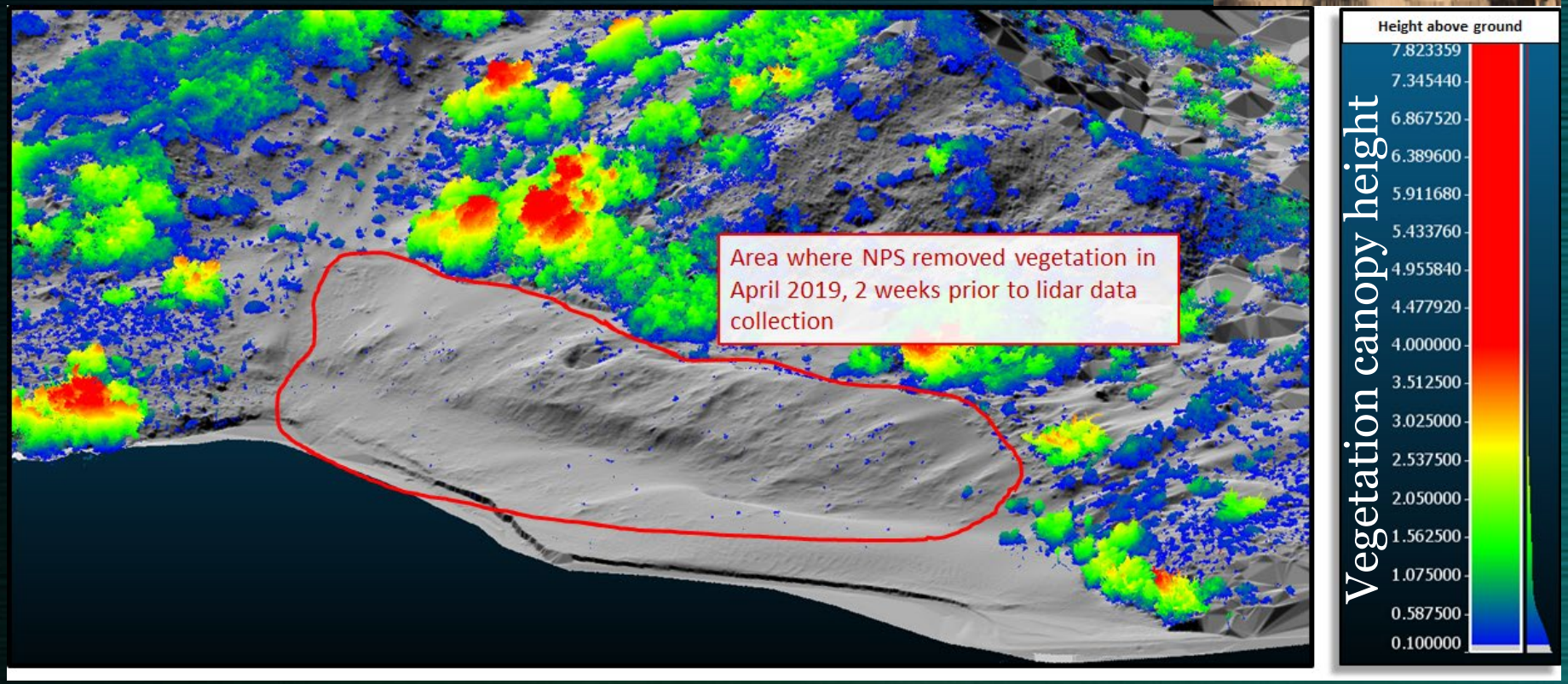
# Vegetation removal experiments



## Area 2



# Vegetation removal experiments

## Area 2

1 week prior to removal

2 weeks after removal

1 month after removal

2 months after

3 months after

6 months after

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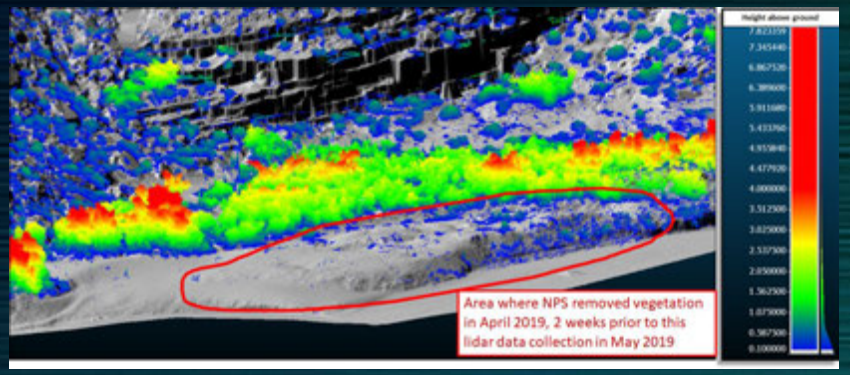
# Vegetation removal experiments




## Area 3

1 week prior to removal

2 weeks after removal

1 month after removal

2 months after

3 months after

6 months after

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# Implications and Future Work

- In April, 2020 the NPS will revisit the sites and conduct maintenance and additional experimental vegetation removal treatments to increase aeolian sediment supply to several dunefields that host archaeological sites
- GCMRC will monitor the outcome of the treatments relative to future HFEs in ongoing monitoring of the geomorphic condition of archaeological sites

# Work Cited


Caster, J., Sankey, J.B., Fairley, H., Kasprak, A., in press, Terrestrial Lidar Monitoring of the Effects of Glen Canyon Dam Operations on the Geomorphic Condition of Archaeological Sites in Grand Canyon National Park 2010-2018: U.S. Geological Survey Open-File Report number pending

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