Fluvial-aeolian sediment connectivity during the current HFE protocol: effects for dunefields and archaeological sites

Project 4 of the Triennial Workplan
Elements 4.1 and 4.2 (Research and Monitoring)

Glen Canyon Dam Adaptive Management Plan
Annual Reporting Meeting, January 24th 2017

Joel B. Sankey, USGS GCMRC

Alan Kasprak, USGS GCMRC

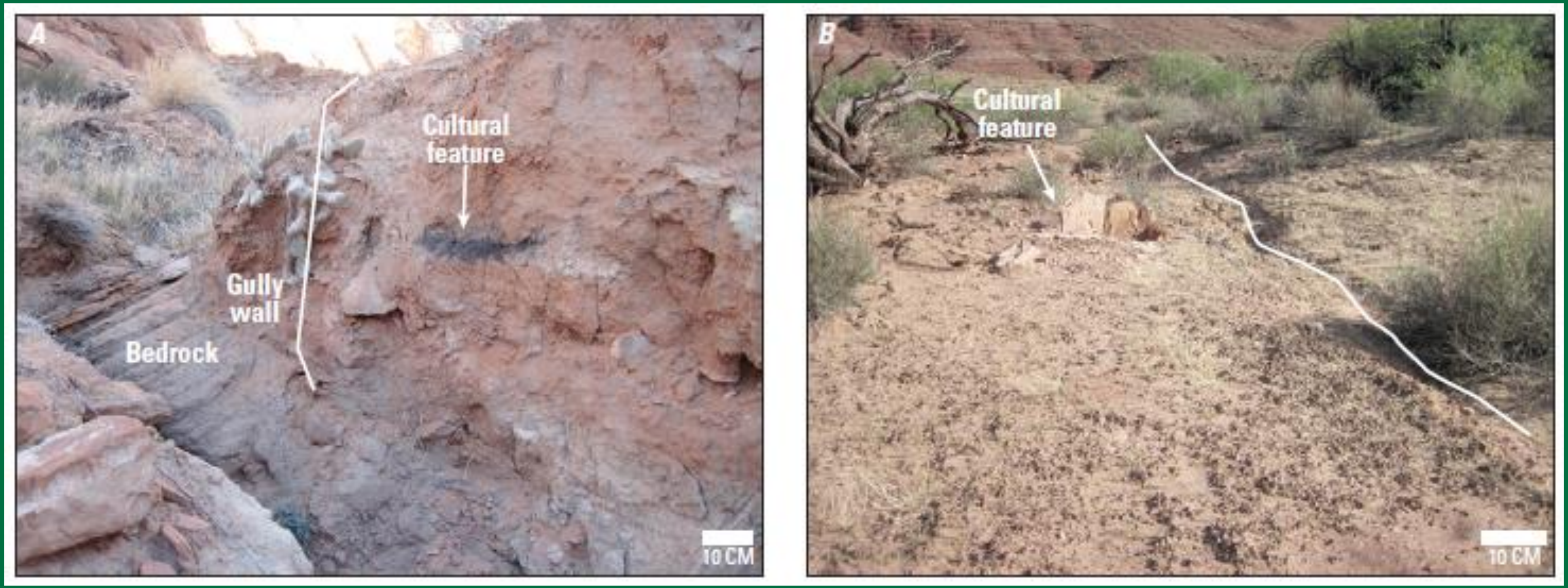
Joshua Caster, USGS GCMRC

Helen C. Fairley, USGS GCMRC

Amy E. East, USGS PCMSC

USGS science for a changing world

Landscapes downstream from Glen Canyon Dam contain archaeological resources that are affected by geomorphic processes



(East et al., 2016)

Sand can potentially help preserve archaeological features by direct burial and/or by mitigating gullying and other erosion

(East et al., 2016)

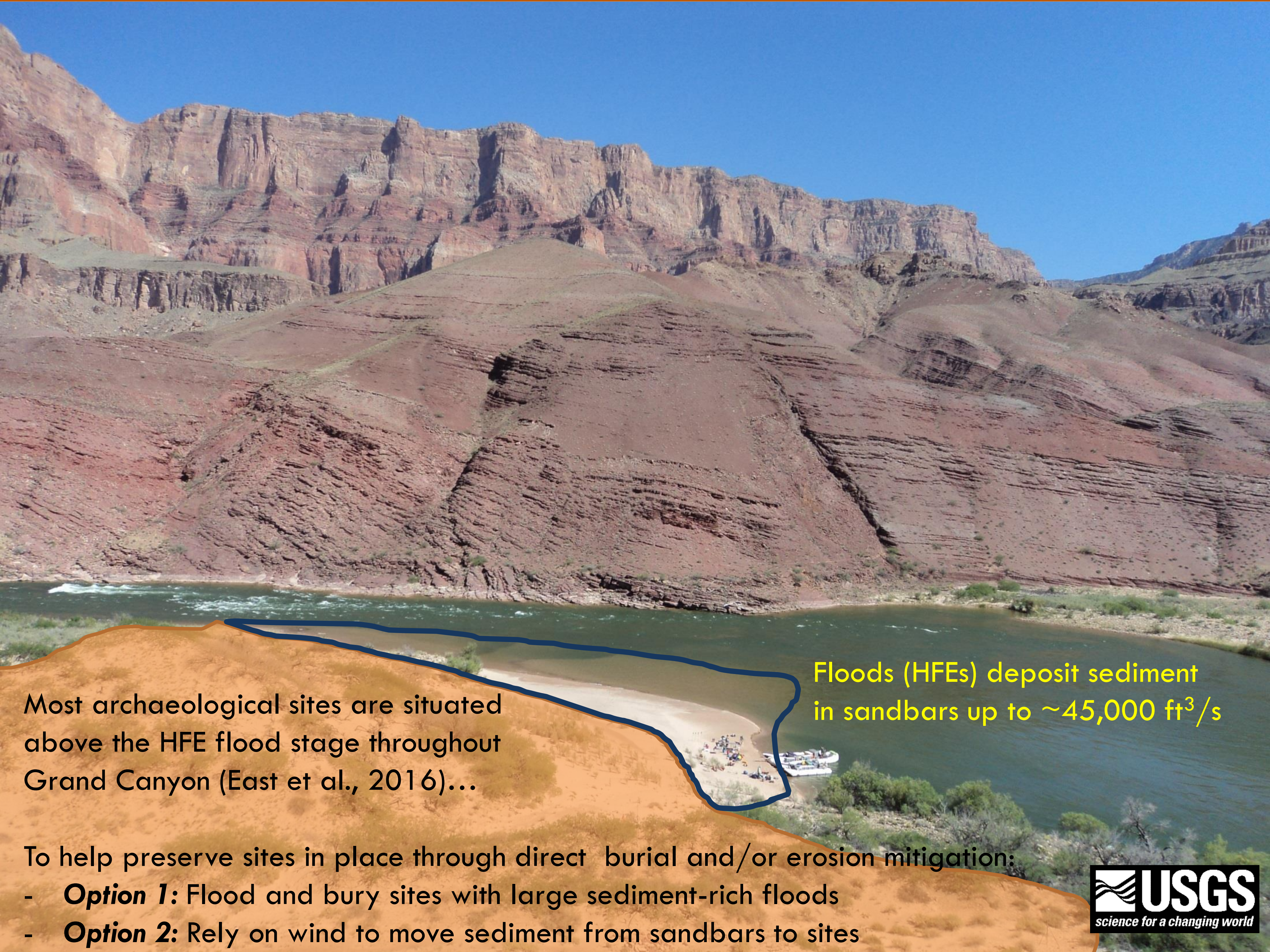
Sand is sourced from the Colorado River,

- And can be deposited on archaeological features or within gullies via
  - Fluvial (river) deposition
  - Aeolian (wind) deposition

- Most archaeological sites are above the highest contemporary river stage, so aeolian deposition is the most likely mechanism for preservation and/or erosion mitigation

(East et al., 2016)

USGS
science for a changing world


Floods (HFEs) deposit sediment in sandbars up to ~45,000 ft^3/s
Most archaeological sites are situated above the HFE flood stage throughout Grand Canyon (East et al., 2016)…
To help preserve sites in place through direct burial and/or erosion mitigation:
- *Option 1:* Flood and bury sites with large sediment-rich floods
- *Option 2:* Rely on wind to move sediment from sandbars to sites
USGS
science for a changing world

Most archaeological sites are situated above the HFE flood stage throughout Grand Canyon(East et al., 2016)…

To help preserve sites in place through direct burial and/or erosion mitigation:

- ~~***Option 1:*** Flood and bury sites with large sediment rich floods~~
- ***Option 2:*** Rely on wind to move sediment from sandbars to sites

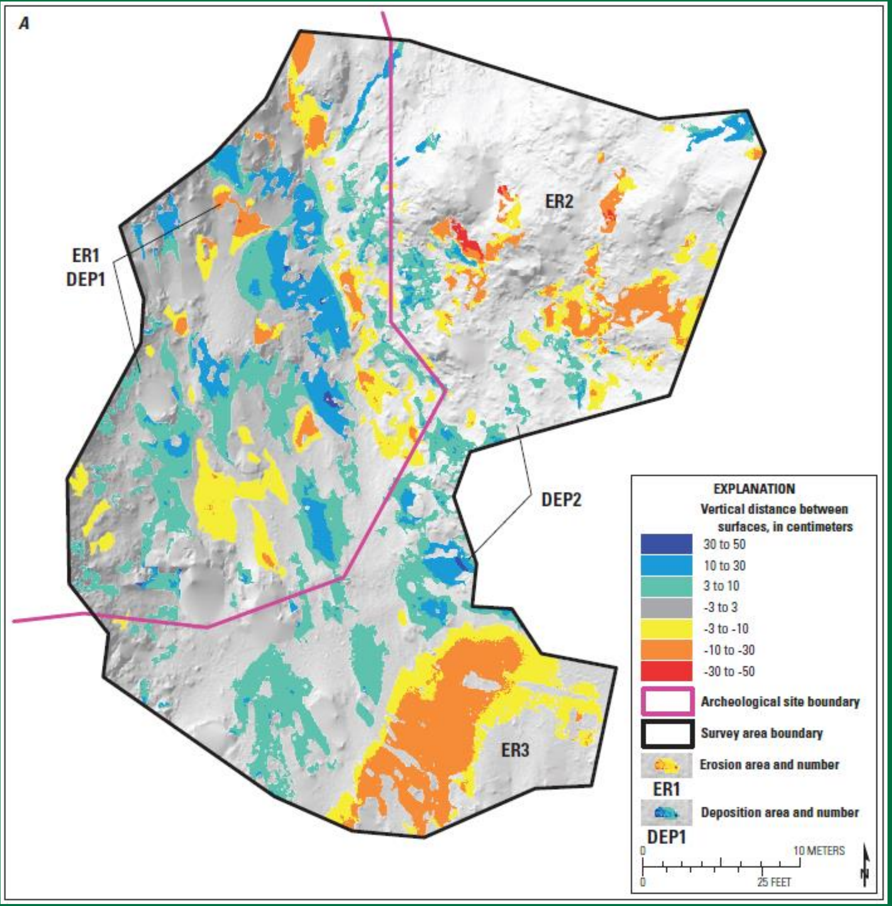
East et al., 2016, Conditions and processes affecting sand resources at archeological sites in the Colorado River corridor below Glen Canyon Dam, Arizona: U.S. Geological Survey Professional Paper 1825, 104 p., http://dx.doi.org/10.3133/pp1825.

The problem: Landscapes downstream from Glen Canyon Dam contain archaeological resources that are affected by fluvial (river), aeolian (wind), and hillslope (gravity and rainfall-runoff) geomorphic processes.

The question: Can Colorado River sediment enhance the preservation of river-corridor archeological resources in these landscapes through aeolian sand deposition and mitigation of gully erosion?

The results: Relatively few archeological sites are now ideally situated to receive aeolian sand supply from sandbars deposited by recent controlled floods (HFEs) from Glen Canyon Dam (decreased from 98 sites in 1973 to 32 in 2012)

Landscape Change at Archeological Sites Receiving Sand Supply After HFEs (East et al., 2016)



USGS

Landscape Change at Archeological Sites Receiving Sand Supply After HFEs (East et al., 2016)

Results and conclusions relative to dam operations and river management

- Geomorphic change detection spanning the 2012 & 2013 HFEs
  - Archaeological monitoring sites were coupled with upwind river sand supplies (sandbars)
  - Sand loss from erosion generally exceeded aeolian deposition of river-derived sand

- Considerations for future work
  - River-sourced sand deposition is a time-dependent process, and the outer limit of that process may extend for many years after any individual HFE
  - HFEs with targeted vegetation removal could produce a net sediment surplus at some sites
  - Need new analysis methods and additional data

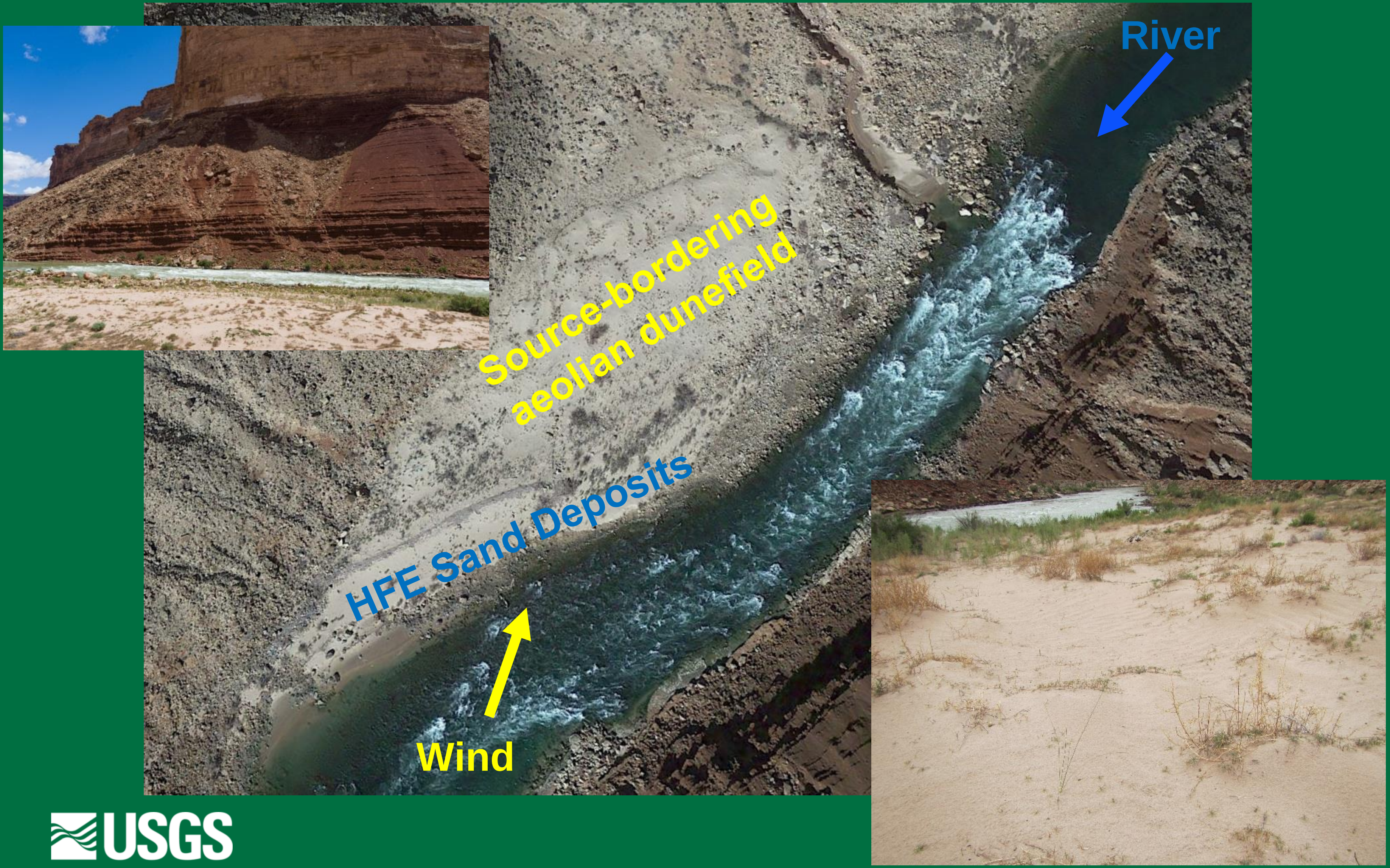
USGS science for a changing world

Project 4: New Approaches

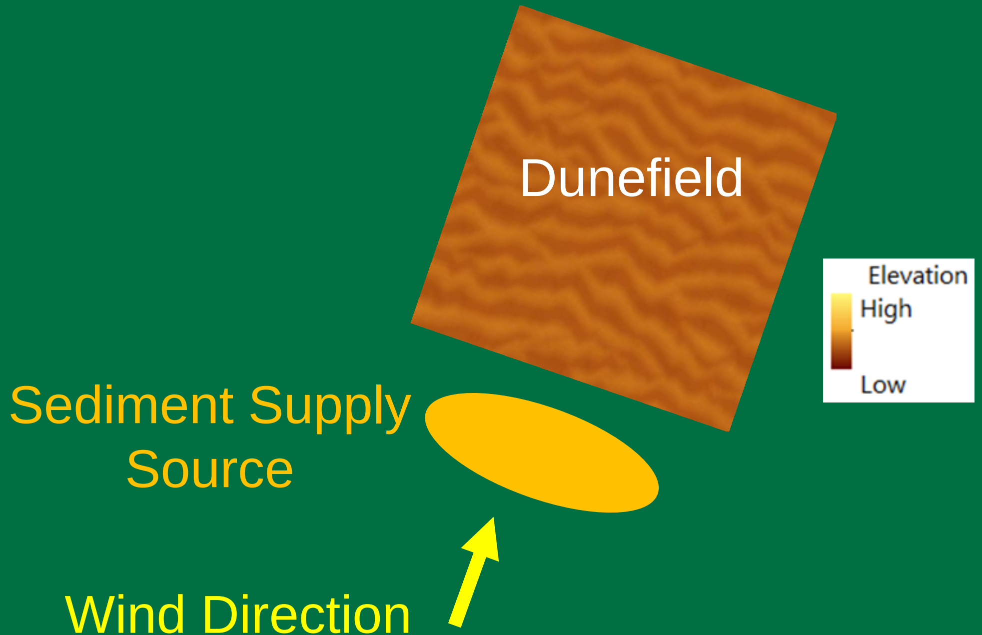
- Use modelling to demonstrate expected characteristics of archaeological sites in dunefields that are re-supplied with windblown sand from HFE deposits

- Use geomorphic change detection of lidar survey monitoring data to make inferences for individual sites and dunefields during the time period of the current HFE protocol
  - 2012, 2013, & 2014 HFEs

Fluvial-aeolian sediment connectivity during the current HFE protocol: effects for dunefields and archaeological sites



Modelling dunefield changes as a function of sediment supply

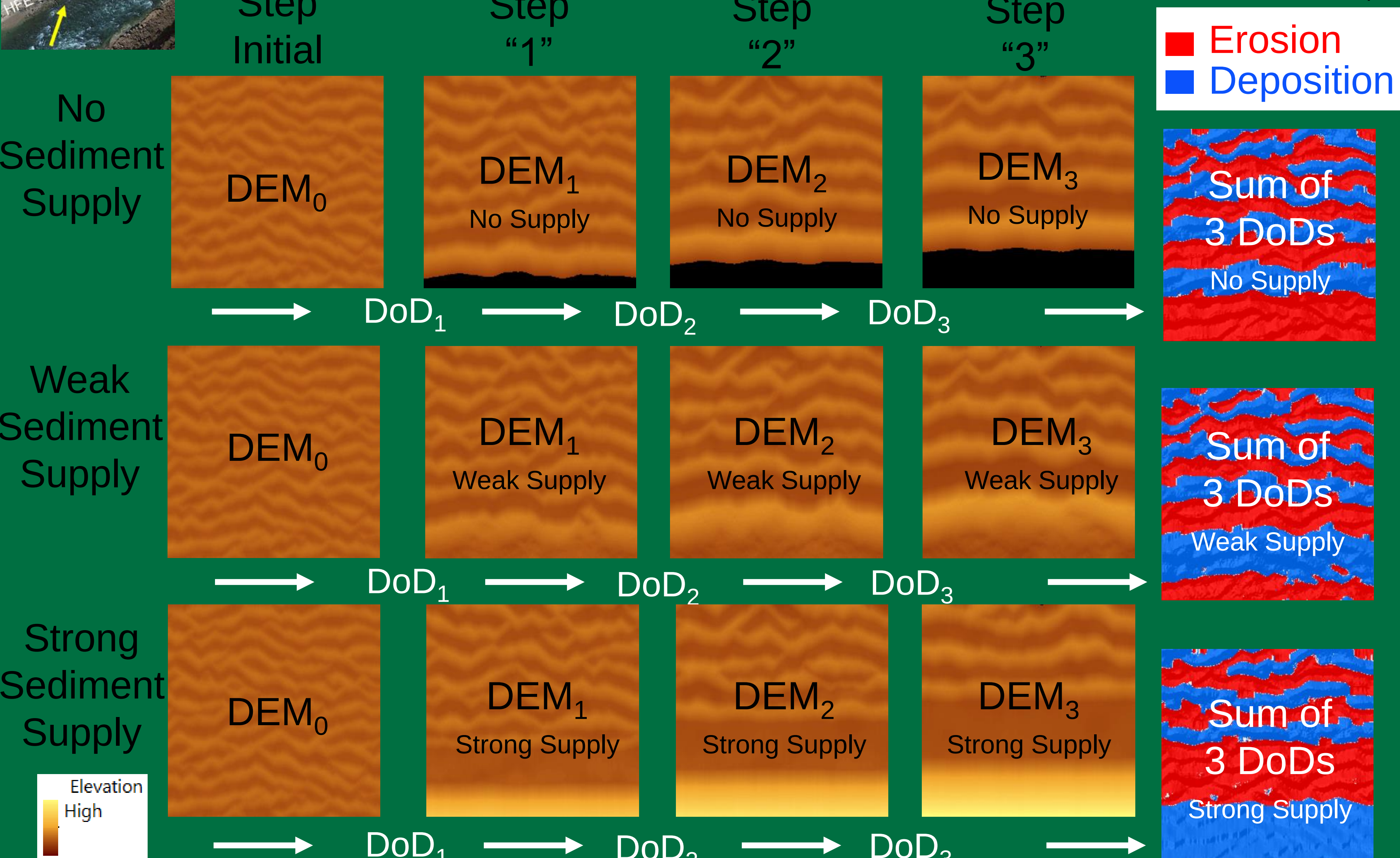


Model dunefield change with consistent wind direction and upwind sediment source area for 3 consecutive “HFE” time periods

1. No sediment supply
2. Weak sediment supply
3. Strong sediment supply

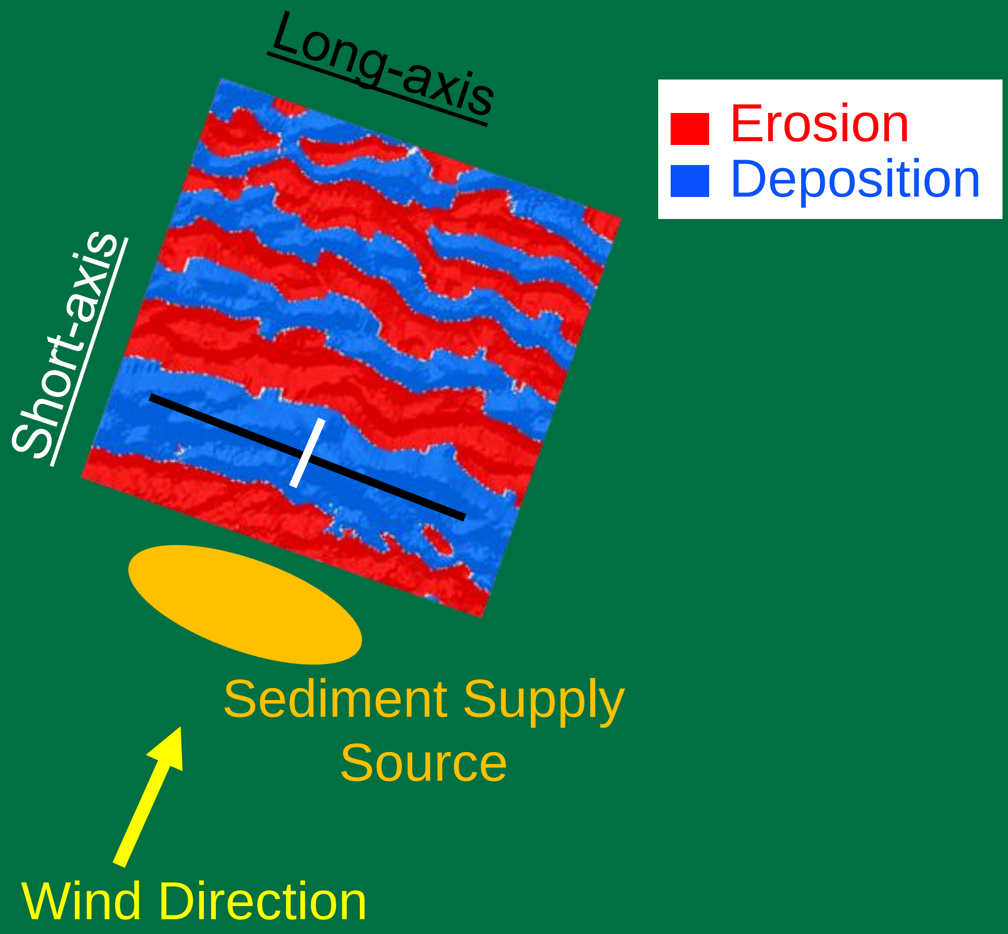
Modelling dunefield changes as a function of sediment supply

(preliminary results, please don't cite)



(preliminary results, please don't cite)

Modelling dunefield changes as a function of sediment supply



Model Scenario	Net change in sediment volume
No sediment supply	-
Weak sediment supply	+
Strong sediment supply (x10¹)	++

USGS

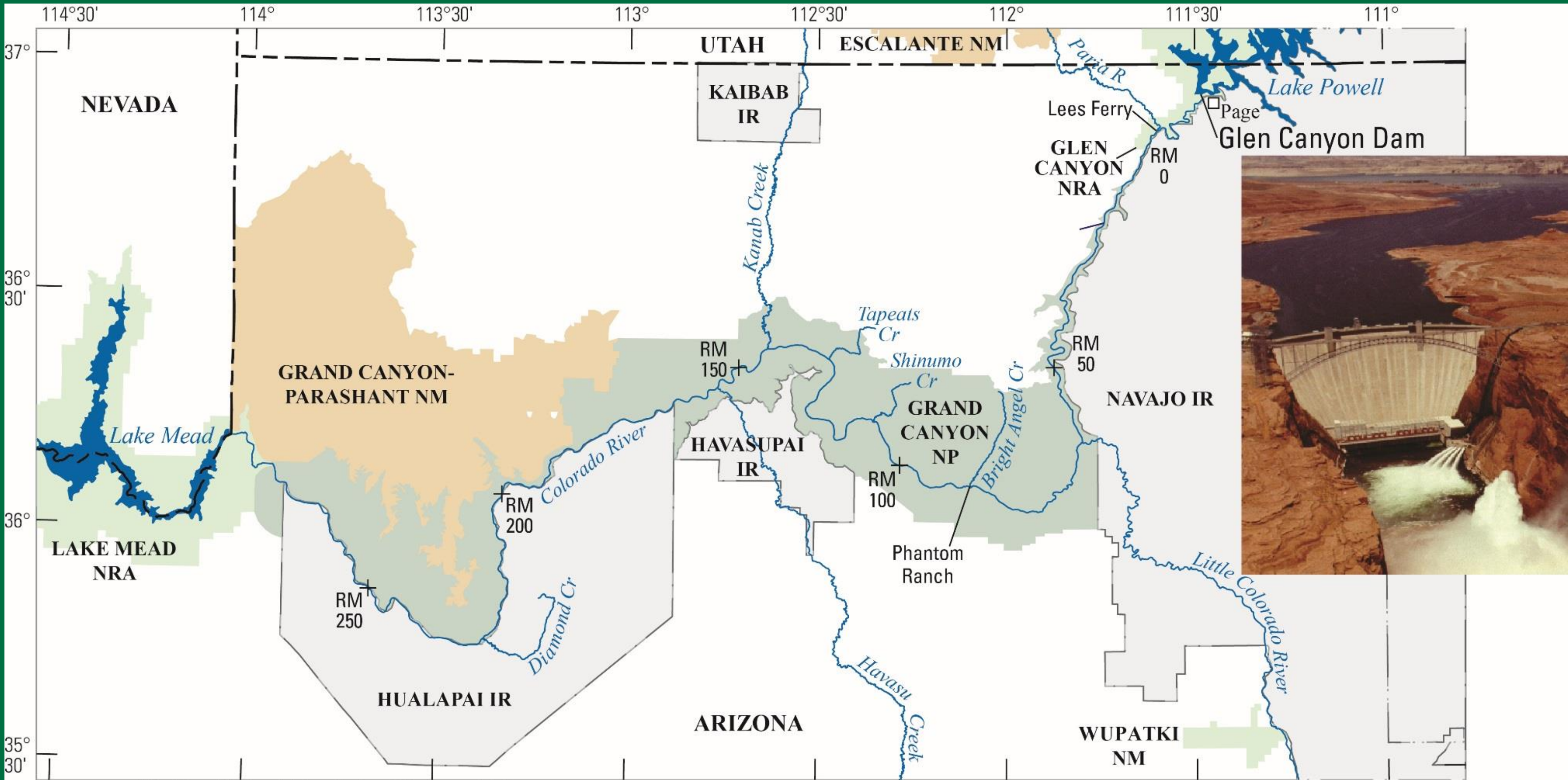
(preliminary results, please don't cite)

Modelling dunefield changes as a function of sediment supply

Does it actually work like this in Grand Canyon?

	e in lume
Strong sediment supply (x10^1)	++

(preliminary results, please don't cite)

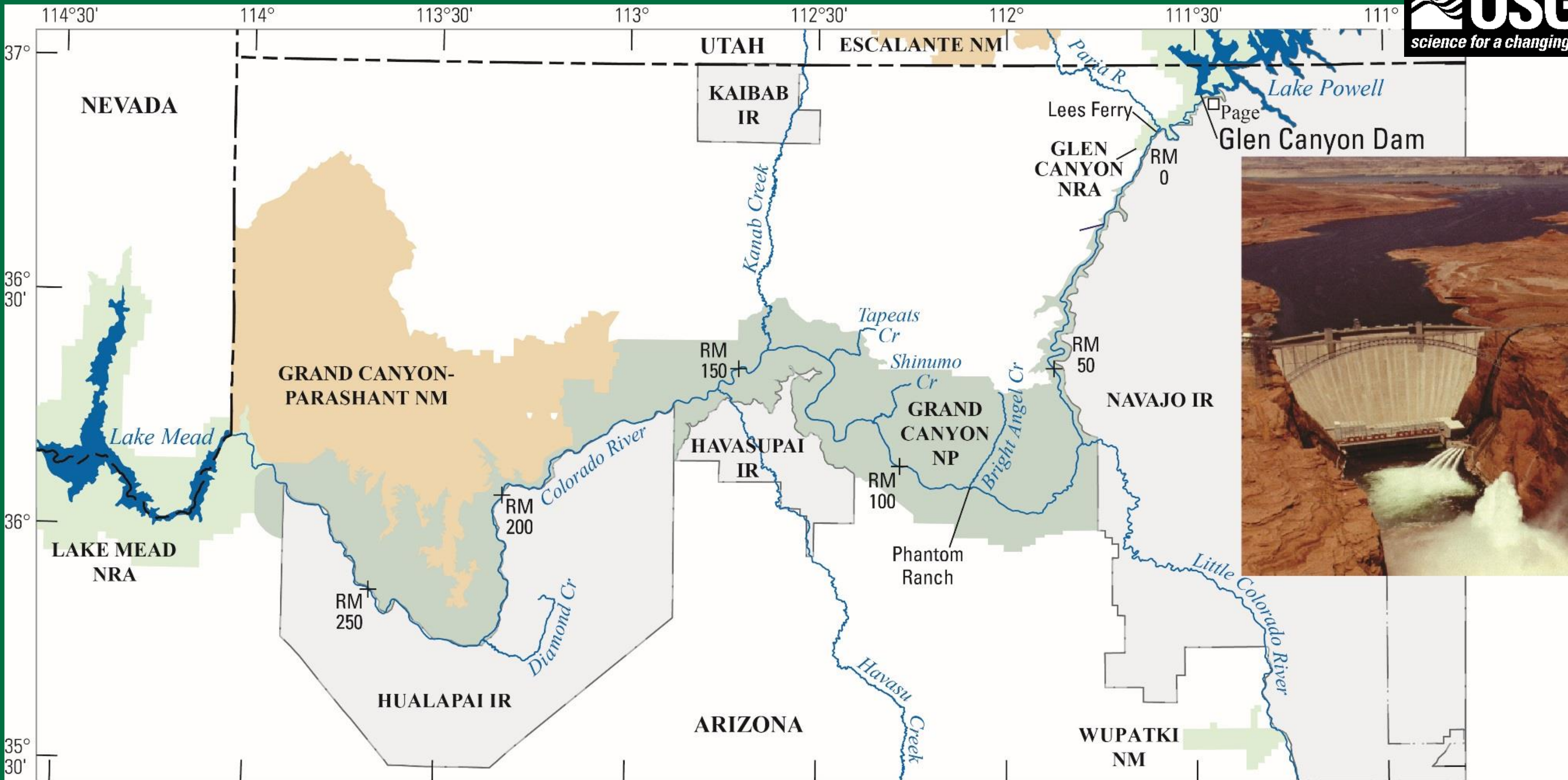


Grand Canyon:

- Four sites
- Lidar Surveys
  - Pre-2012 HFE
  - Pre-2013 HFE
  - Pre-2014 HFE
  - Post-2014 HFE

Glen Canyon:

- Three sites
- Lidar Surveys
  - Pre-2012 HFE
  - Pre-2013 HFE
  - Post-2014 HFE

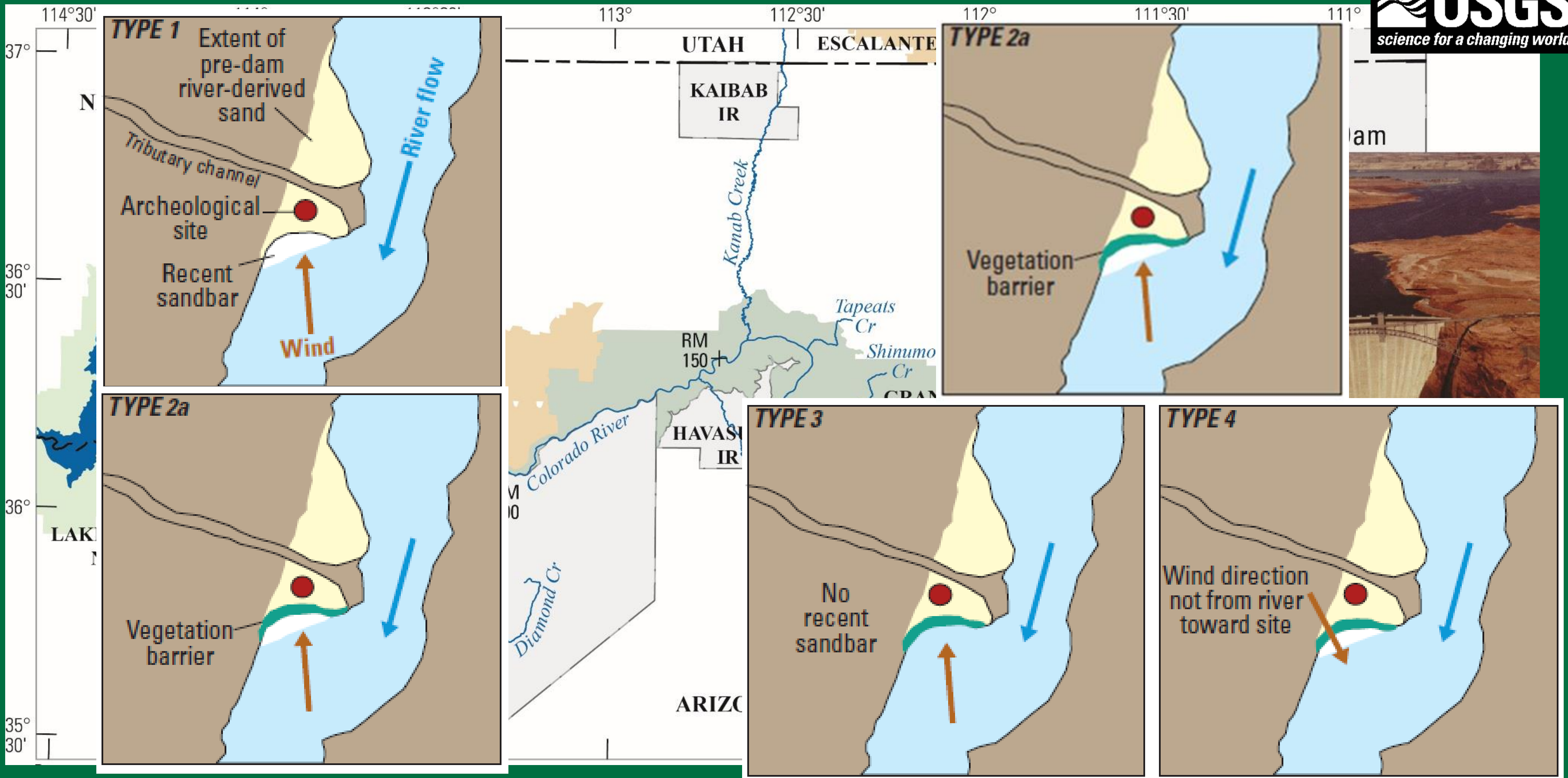


Grand Canyon Sites

- Downstream of the Paria
- High HFE sediment supply
- Optimal sediment connectivity
- Source-bordering aeolian dunefields on terraces, debris fans, or colluvial/alluvial hillslopes

Glen Canyon Sites

- Upstream of the Paria
- Low/No HFE sediment supply
- Sub-optimal sediment connectivity
- River terraces w/ minimal aeolian dunefield morphology



Grand Canyon Sites

- Downstream of the Paria
- High HFE sediment supply
- Optimal sediment connectivity
- Source-bordering aeolian dunefields on terraces, debris fans, or colluvial/alluvial hillslopes

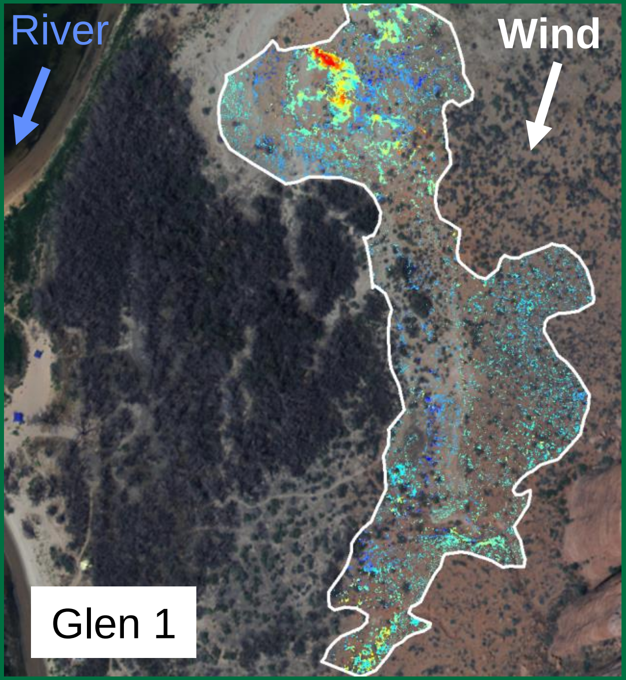
Glen Canyon Sites

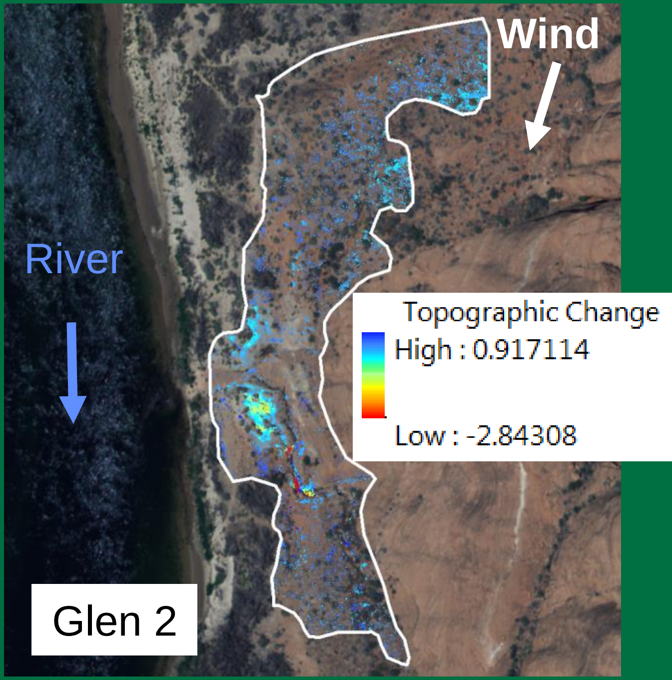
- Upstream of the Paria
- Low/No HFE sediment supply
- Sub-optimal sediment connectivity
- River terraces w/ minimal aeolian dunefield morphology

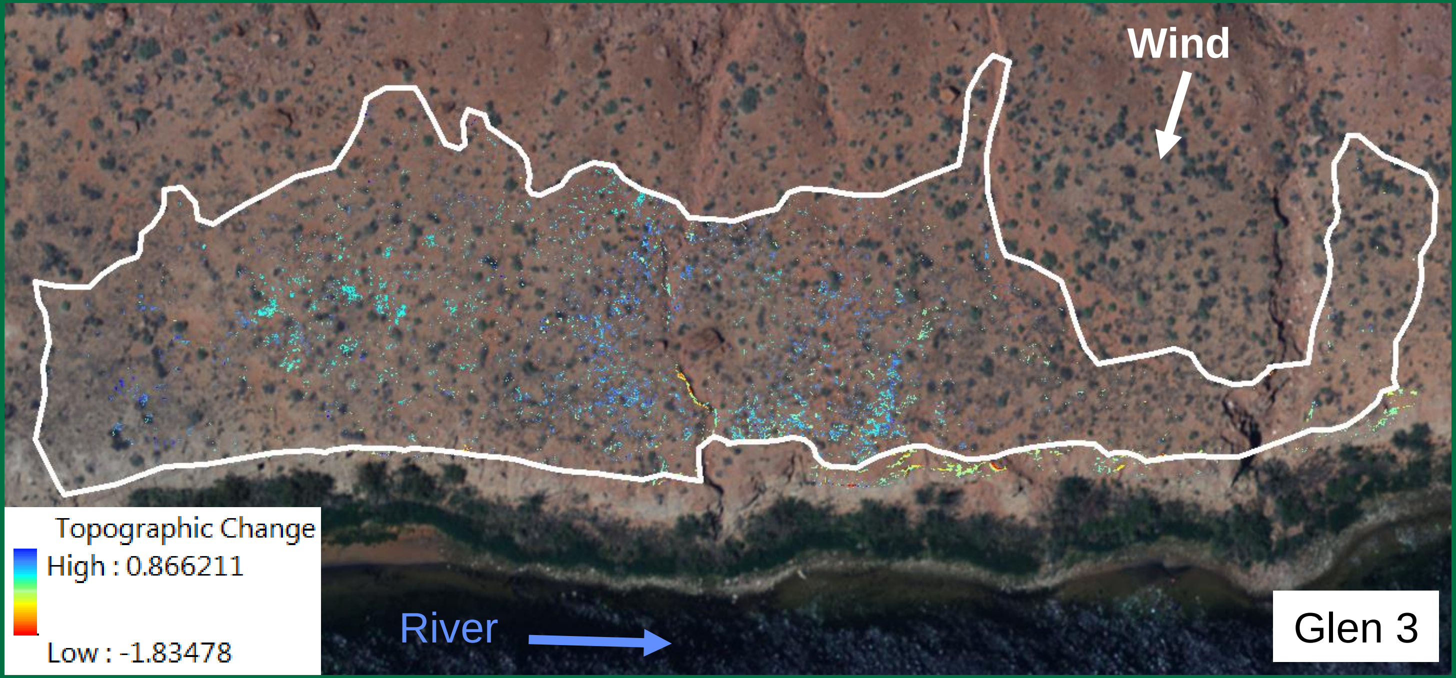
Glen Canyon Sites

Sum of 2 DoDs Spanning 2012, 2013, & 2014 HFEs at 3 Glen Canyon Sites

(preliminary results, please don’t cite)

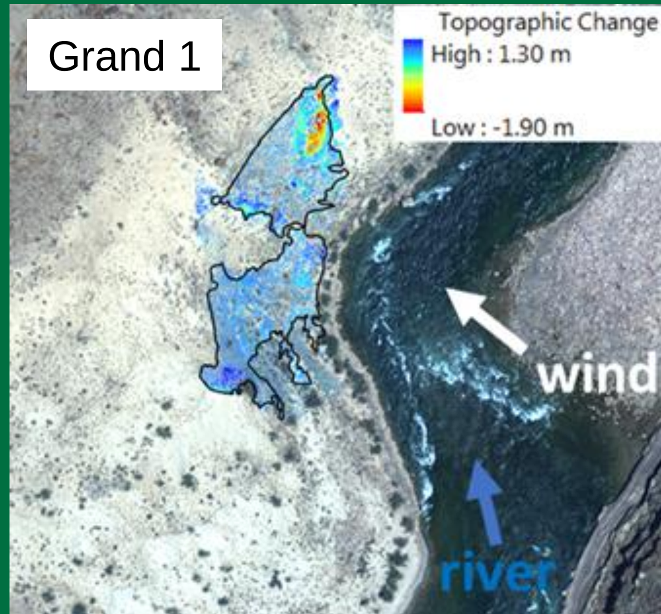


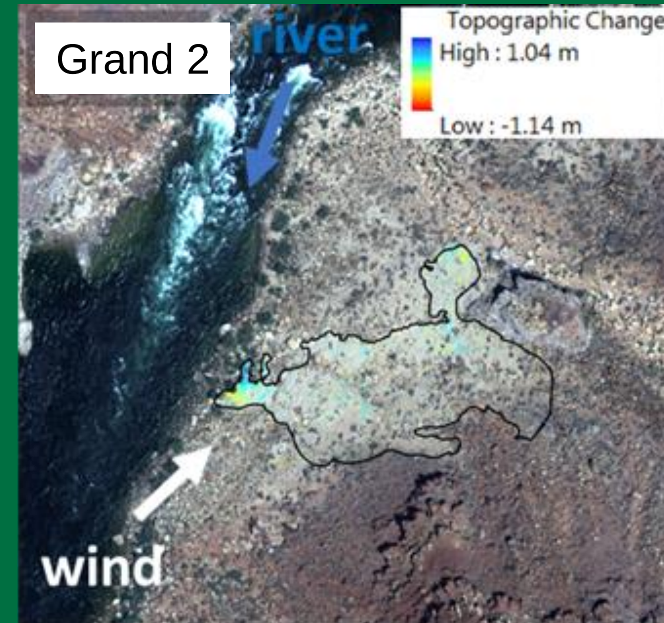


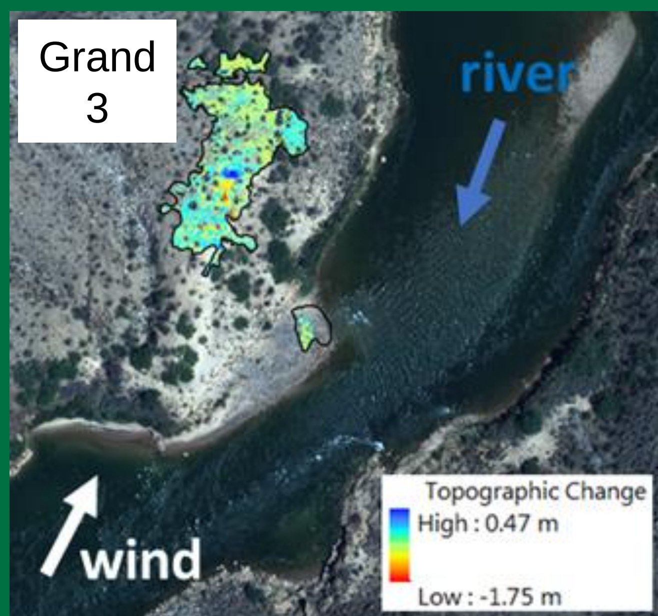


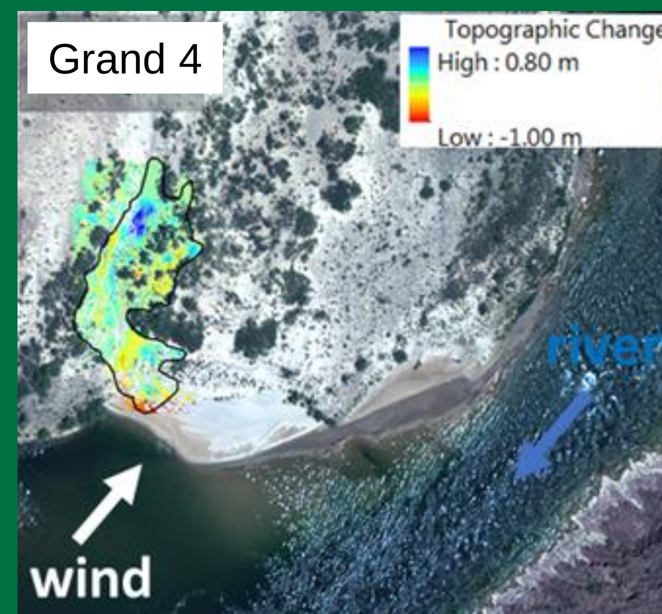
USGS

Grand Canyon Sites









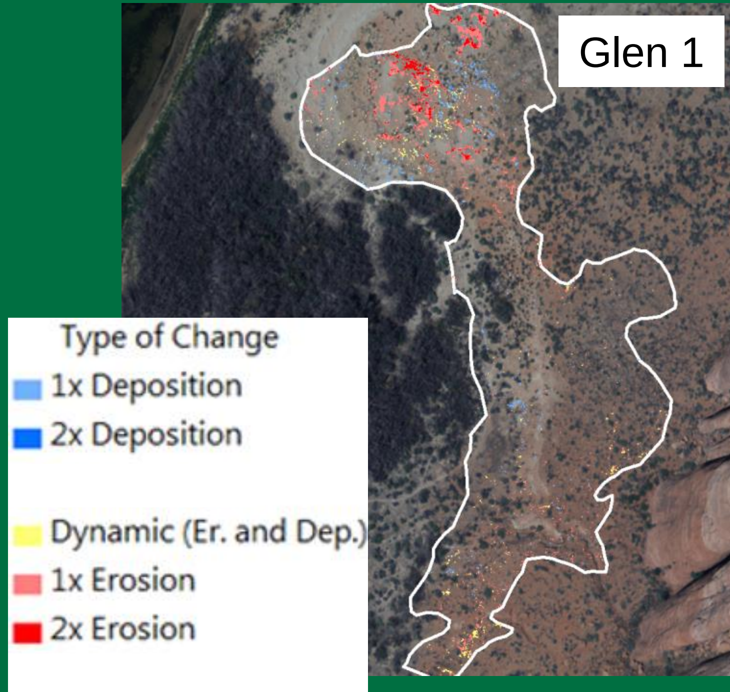
Sum of 3 DoDs Spanning 2012, 2013, & 2014 HFEs at 4 Grand Canyon Sites

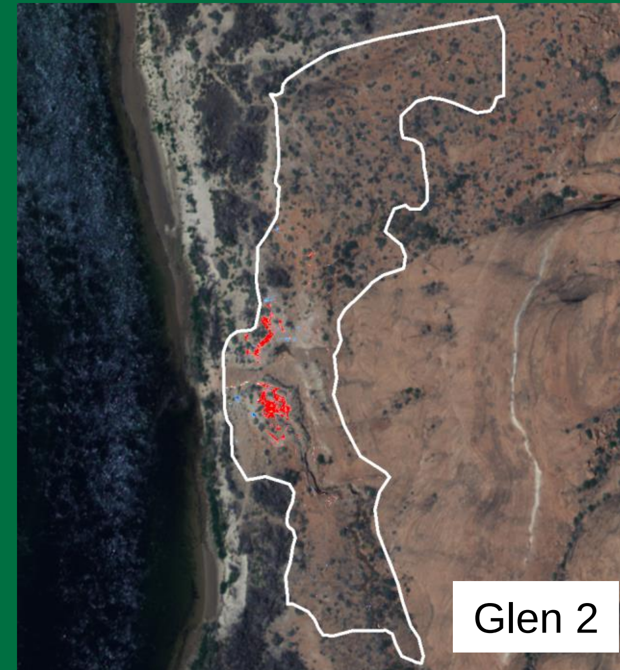
(preliminary results, please don't cite)

Glen Canyon Sites

Aeolian Topographic Changes in 2 DoDs Spanning 2012, 2013, & 2014 HFEs at 4 Glen Canyon Sites

(preliminary results, please don't cite)

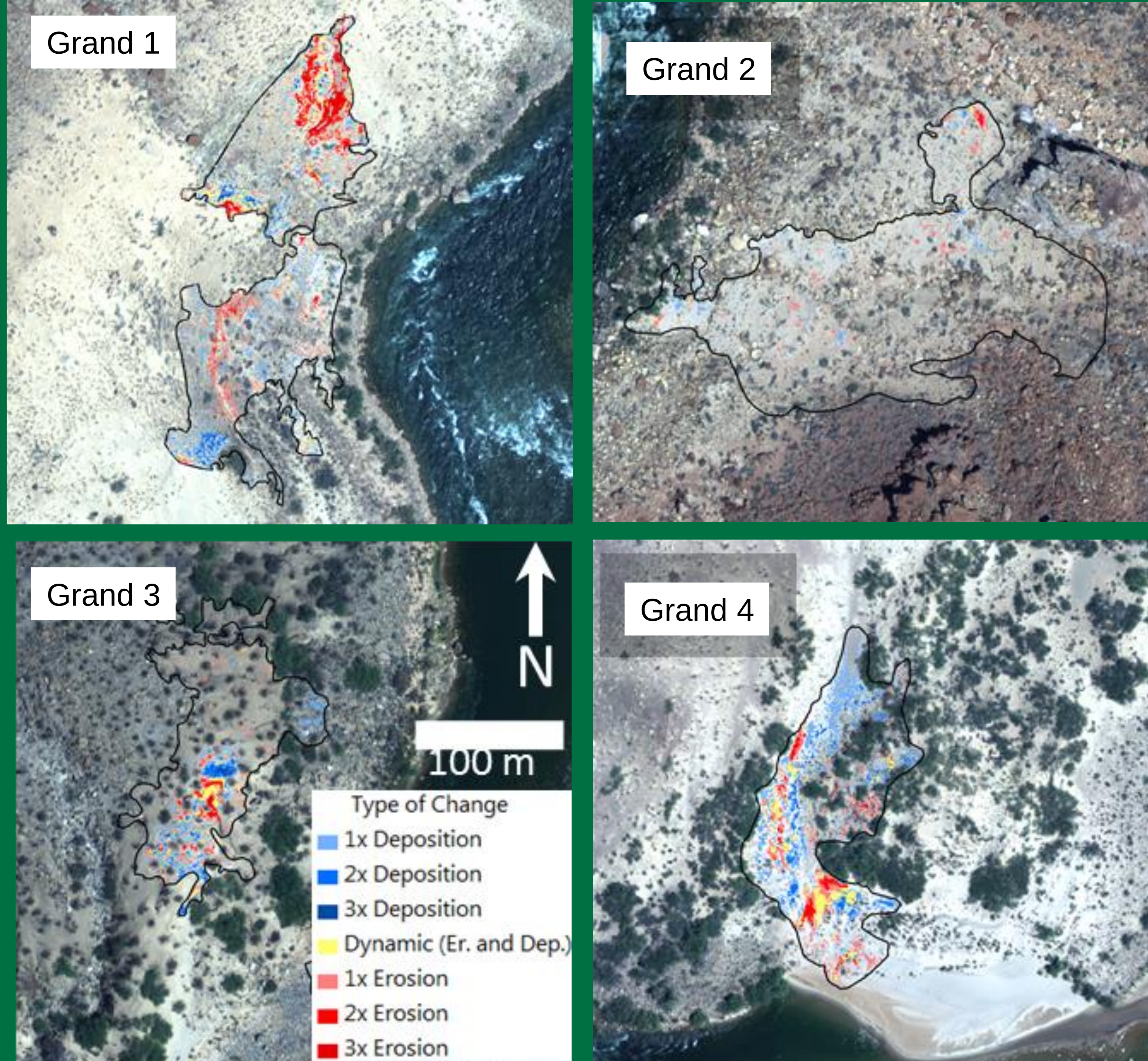




Grand Canyon Sites

Aeolian Topographic Changes in 3 DoDs Spanning 2012, 2013, & 2014 HFEs at 4 Grand Canyon Sites

(preliminary results, please don't cite)



Results

Site	Net change in aeolian sediment volume (m^3)	Average change in aeolian sediment depth (cm)	Difference between directions of wind and long-axis of erosion/deposition
Glen1	- 19.9	- 0.46	25 degrees
Glen2	-13.2	- 0.47	10 degrees
Glen3	+ 0.44	+ 0.01	19 degrees
Grand1	- 55.1	- 1.42	124 degrees
Grand2	- 2.9	- 0.05	52 degrees
Grand3	+ 2.4	+ 0.09	120 degrees
Grand4	+ 16.3	+ 0.57	80 degrees

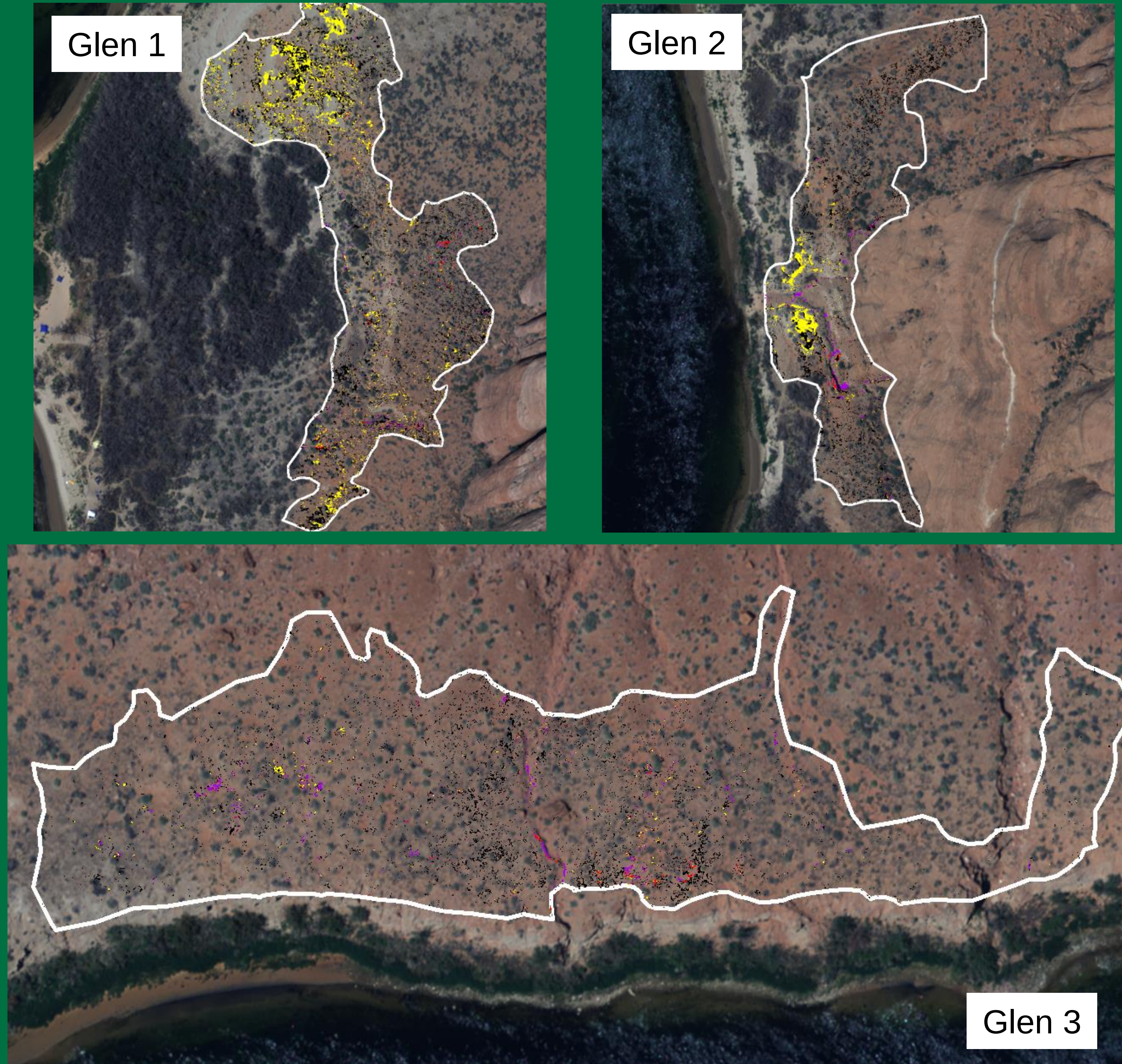
(preliminary results, please don't cite)

Results

Site	Net change in aeolian sediment volume (m^3)	Average change in aeolian sediment depth (cm)	Difference between directions of wind and long-axis of erosion/deposition
Glen1	Glen Canyon sites: • spatial patterns of erosion and deposition are not consistent with source-bordering aeolian dunefield morphology • net wind erosion or minimal deposition indicate no sediment supply		
Glen2			
Glen3			
Grand1	Grand Canyon sites: • spatial patterns of erosion and deposition are consistent with source-bordering aeolian dunefield morphology • geomorphic changes range from net wind erosion to net wind deposition and indicate no to moderate sediment supply		
Grand2			
Grand3			
Grand4			

(preliminary results, please don't cite)

Glen Canyon Sites



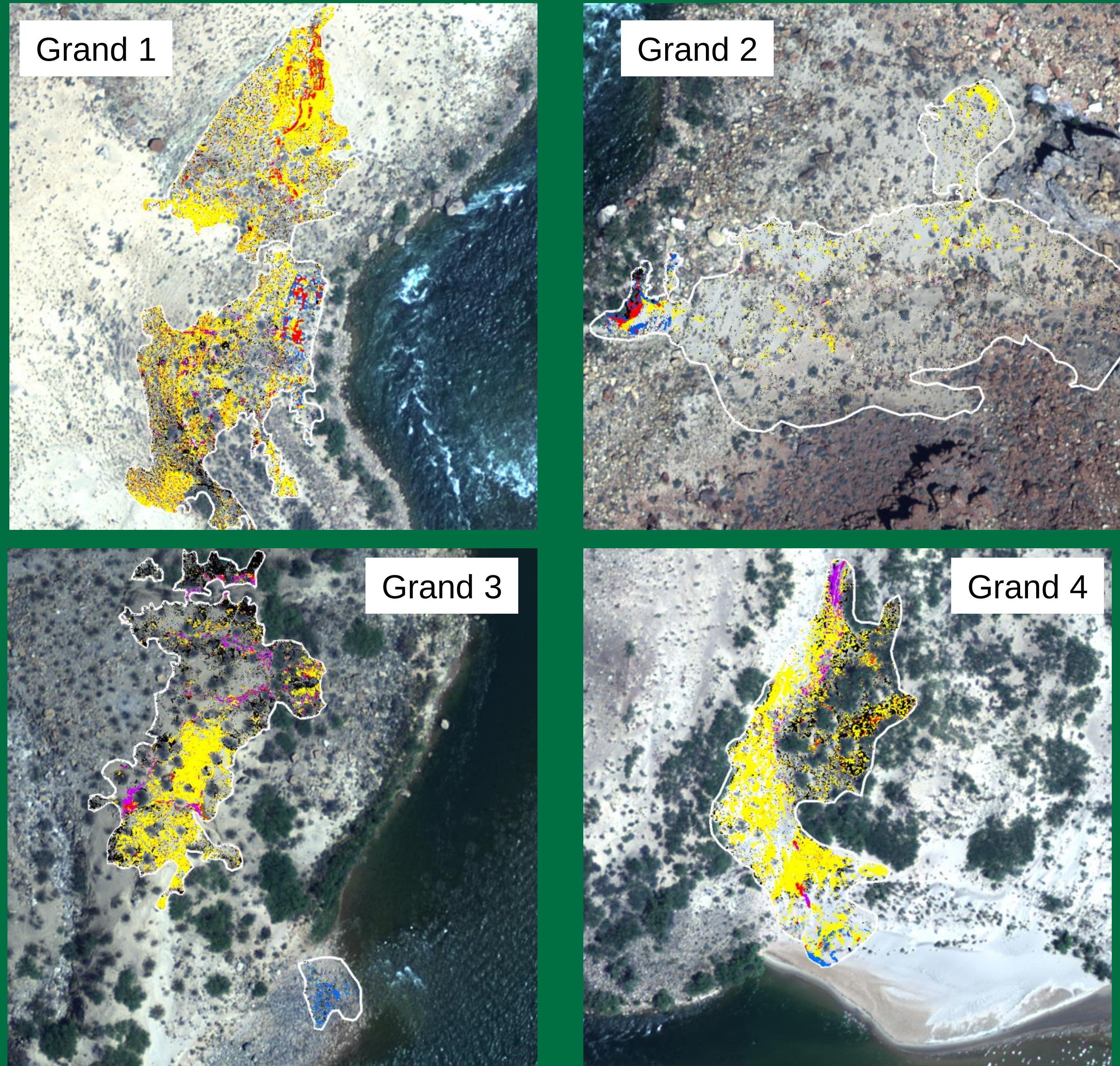
USGS

Kasprak, Caster, Bangen, Sankey, *in review, (preliminary results, please don't cite)*

Grand Canyon Sites

Predicted Transport Mechanism

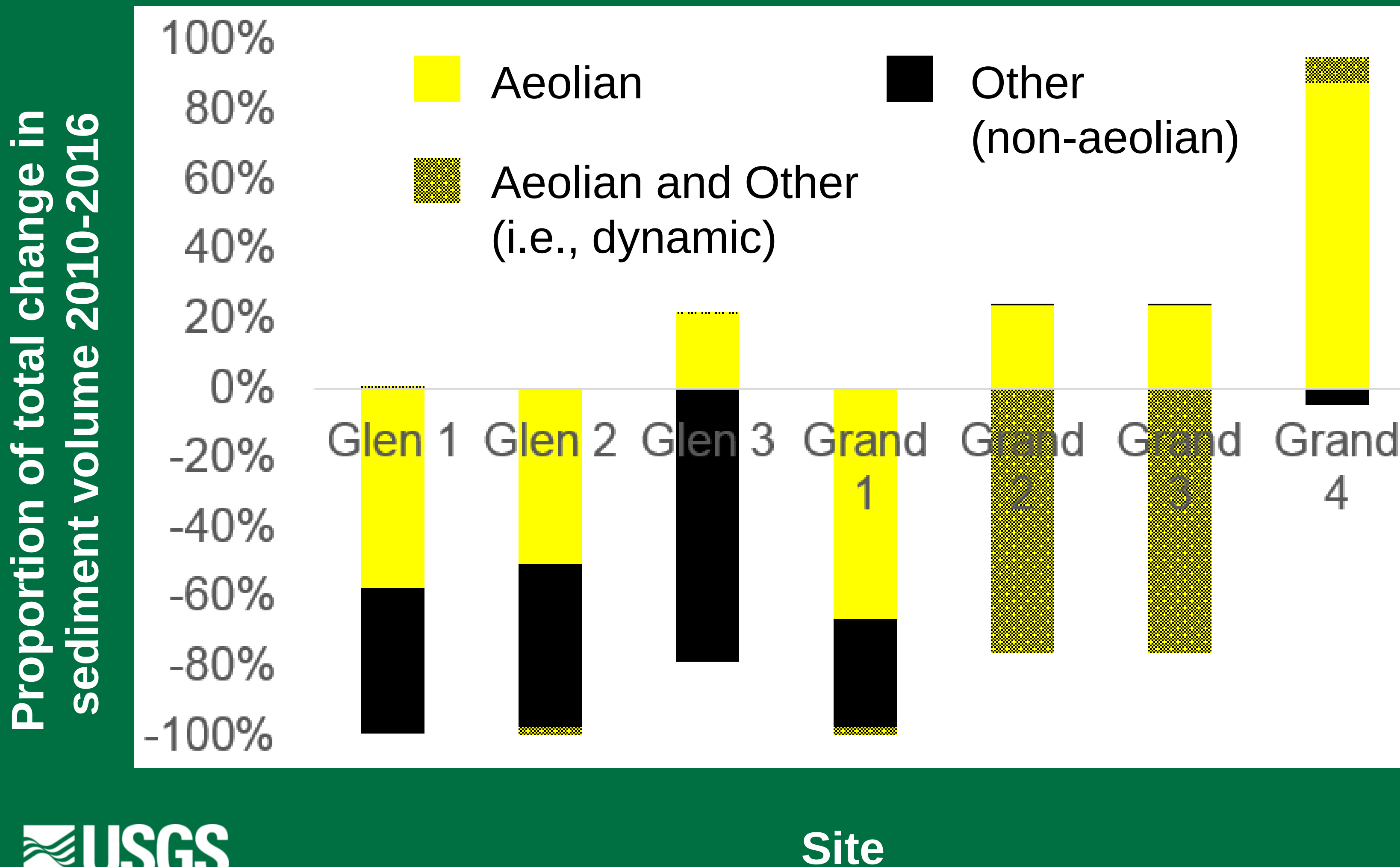
- Aeolian
- Alluvial
- Colluvial
- Fluvial
- Not Determined
- Dynamic



USGS

Kasprak, Caster, Bangen, Sankey, *in review (preliminary results, please don't cite)*

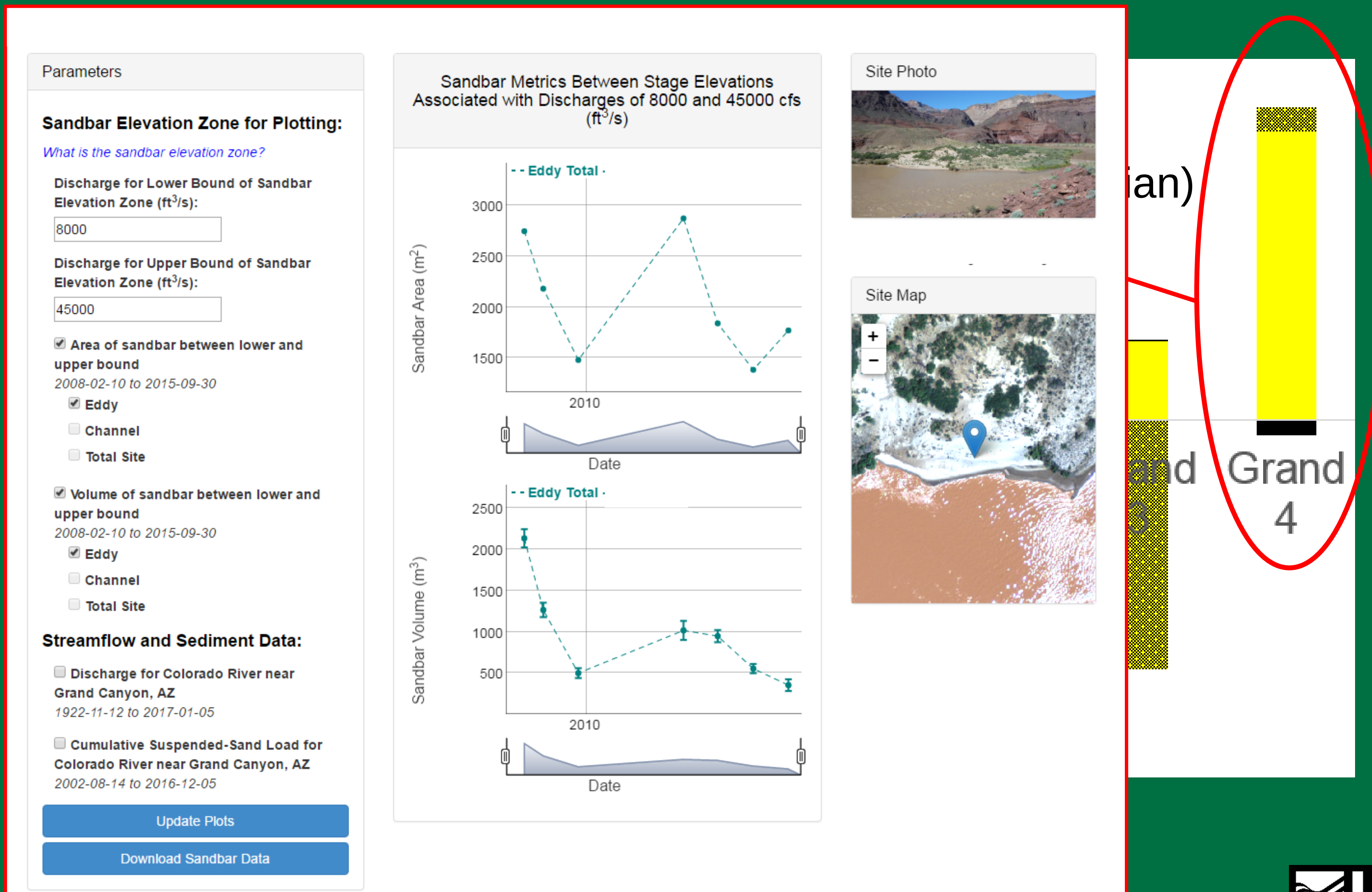
Results



USGS

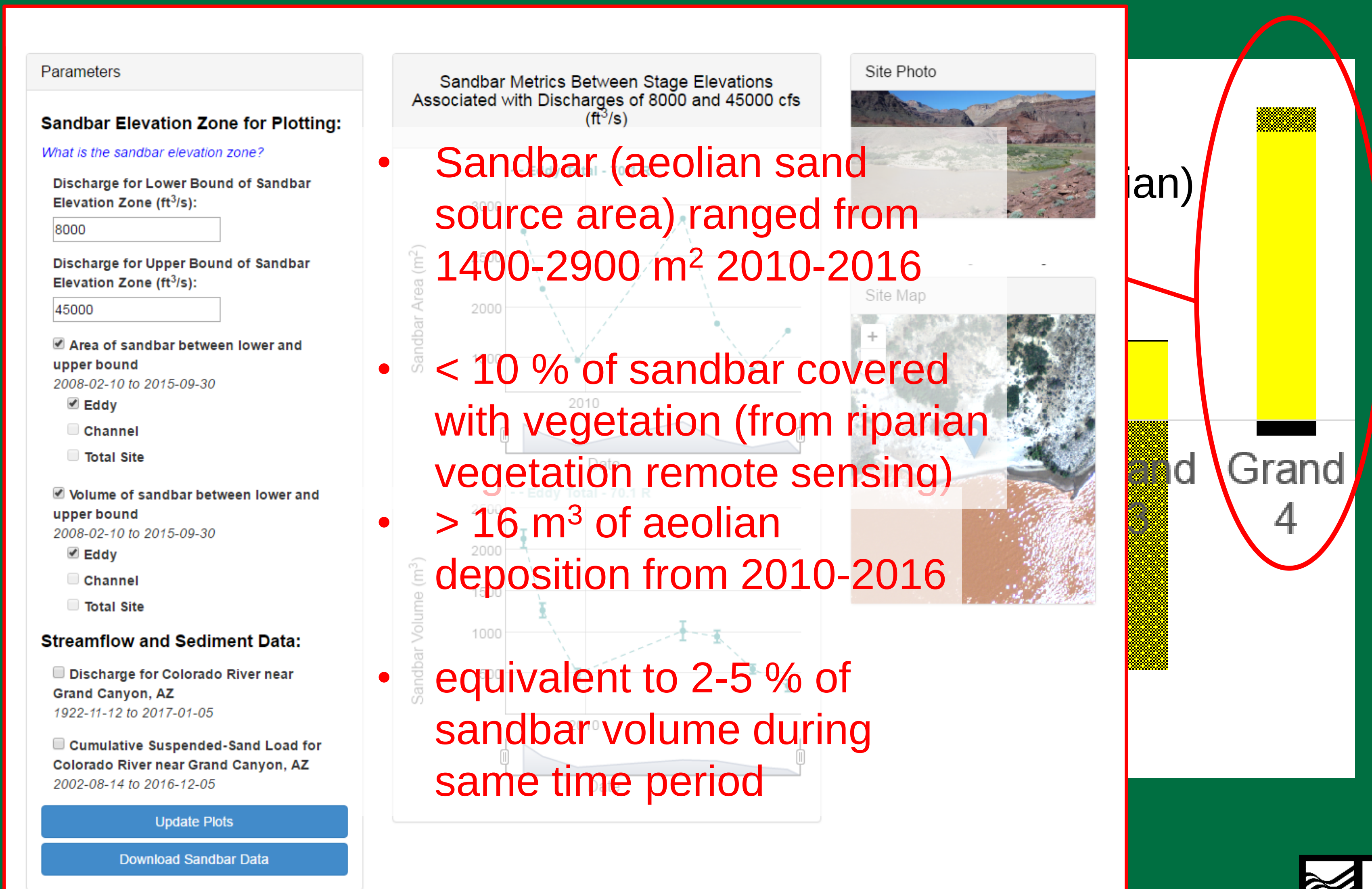
(preliminary results, please don't cite)

Results relative to river management



(preliminary results, please don't cite)

Results relative to river management



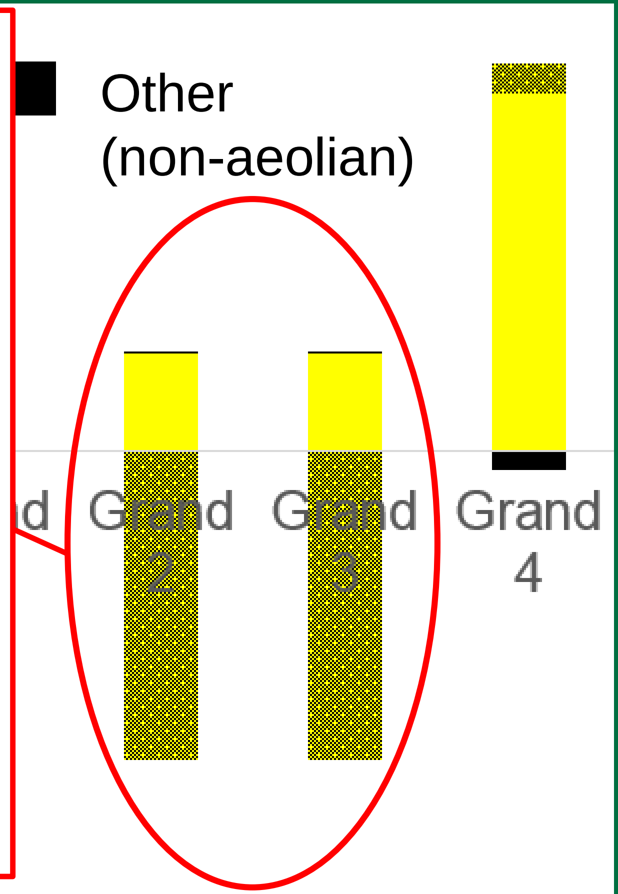
- Sandbar (aeolian sand source area) ranged from 1400-2900 m^2 2010-2016
- < 10 % of sandbar covered with vegetation (from riparian vegetation remote sensing)
- > 16 m^3 of aeolian deposition from 2010-2016
- equivalent to 2-5 % of sandbar volume during same time period

(preliminary results, please don't cite)

Results relative to river management

Proportion of total change in sediment volume 2010-2016

- Sandbars (aeolian source areas) are approx. 400 and 1500 m², respectively
- Vegetation covers approx. 240 and 320 m² of the sandbars
- Management opportunity
  - Vegetation removal might increase the size of the sand source area by 150 and 25 %, respectively



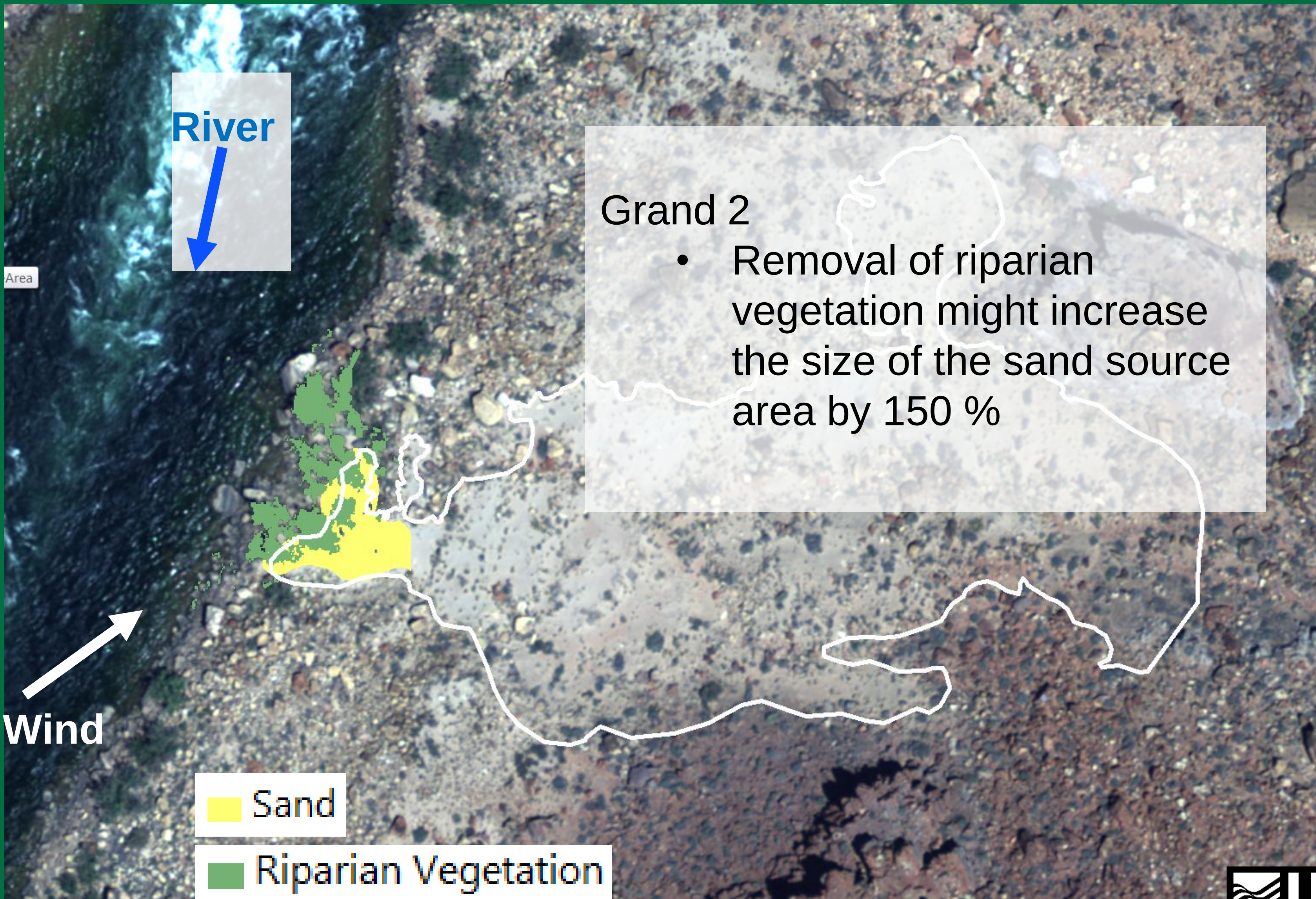
Site

(preliminary results, please don't cite)

Results relative to river management

Grand 2

- Removal of riparian vegetation might increase the size of the sand source area by 150 %



(preliminary results, please don't cite)

Conclusion

- Status and trends of fluvial-aeolian sediment for dunefields and archaeological sites

  - Long-term (1973-present; East et al., 2016): The number and proportion of archaeological sites that are ideally situated to receive aeolian sand supply from sandbars deposited by floods from Glen Canyon Dam has decreased from 98 in 1973 to 32 as of 2012

  - Project 4 suggests that of the “ideally situated sites”:
    - Some have sediment resupply from HFEs
    - Some have no sediment resupply from HFEs
    - Some are good candidates for experimental vegetation removal to enhance sediment resupply from HFEs
      - (and we can identify specific sites)

USGS

Conclusion

- Future work and management actions
  - Research and monitoring to sustain and add to the lidar survey and change detection datasets
  - Conduct experimental vegetation removal at a small number of targeted sites and then continue monitoring whether the vegetation removal and HFE combination enhances sediment connectivity

The End

Thanks for listening!

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 and Glen Canyon National Recreation Area).
- We thank:
  - Brian Collins, Skye Corbett, David Bedford, David Rubin, Jack Schmidt, Paul Grams, Ted Melis, Ivo Lucchitta, Richard Hereford, Bob Webb, Keith Kohl, Carol Fritzonger, Seth Felder, Dave Foster, Mark Mastin, Katherine Jacques, Jacqueline Olson (USGS),
  - Jennifer Dierker, Thann Baker, Rosemary Sucec (NPS),
  - Mary Barger (Bureau of Reclamation),
  - Aaron Borling, Dennis Harris, Joe Hazel, Paul Rauss, Carolyn Alvord, Don Bacco, Kirk Burnett, Mark Perkins, Dom Zanzucchi (various affiliations)

USGS

science for a changing world