Final Results of Aeolian Sediment-Transport Study: Implications for Future Weather Monitoring in the Colorado River Ecosystem

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Motivation Behind Study:

Erosion of cultural features believed to be tied to reduced sediment sources: loss of open, dry sandbar area → less sand supply for aeolian deposits → deflation by wind, erosion by gullies

River-level sand bar

Sand dunes above river

Erosion Processes at Archaeological Sites

INCISION

Roasting feature undercut by gully

DEFLATION

Wind deflation exposes artifacts

To understand erosion and deposition processes affecting cultural sites:

- Studied sedimentary history, geomorphology in detail using vertical sediment exposures
- Weather data collected at 6 sites; equipment operated from November 2003 to January 2006:
  - Rainfall
  - Wind speed and direction
  - Aeolian sand transport
- All data sets used together to identify processes affecting archaeological areas, potential effects of dam operations

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Sedimentary and Geomorphic Studies

- Archaeological sites on <u>fluvial</u>, <u>aeolian</u>, slope-wash, distal debris-flow, and colluvial deposits. Many covered / preserved in aeolian sand.
- Site-specific evaluation of sediment at sites (Palisades, Comanche, Arroyo Grande):
  - Landscape evolution in the past
  - Modern landscape processes: sensitivity to dam operations
- Draut et al., 2005 SIR report; *Geomorphology*, in review; Univ. of Arizona book chapter, in review

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Criteria for evaluating site sensitivity to dam operations (regarding aeolian sand transport):

1. What is the depositional context of sediment on which the site was formed? (Aeolian, or other?)
2. What is the depositional context of sediment that has buried the site? (Aeolian, or other?)

If aeolian sediment is determined to be relevant to this site:

3. Is there evidence for loss of aeolian sediment that has previously covered the site? (yes/no)
4. What is the source of aeolian sediment covering the site?
5. Has that aeolian sand source been reduced? (yes/no)
6. Could renewed aeolian sand deposition have a significant restorative effect on this site? (yes/no)
7. How could that be accomplished?

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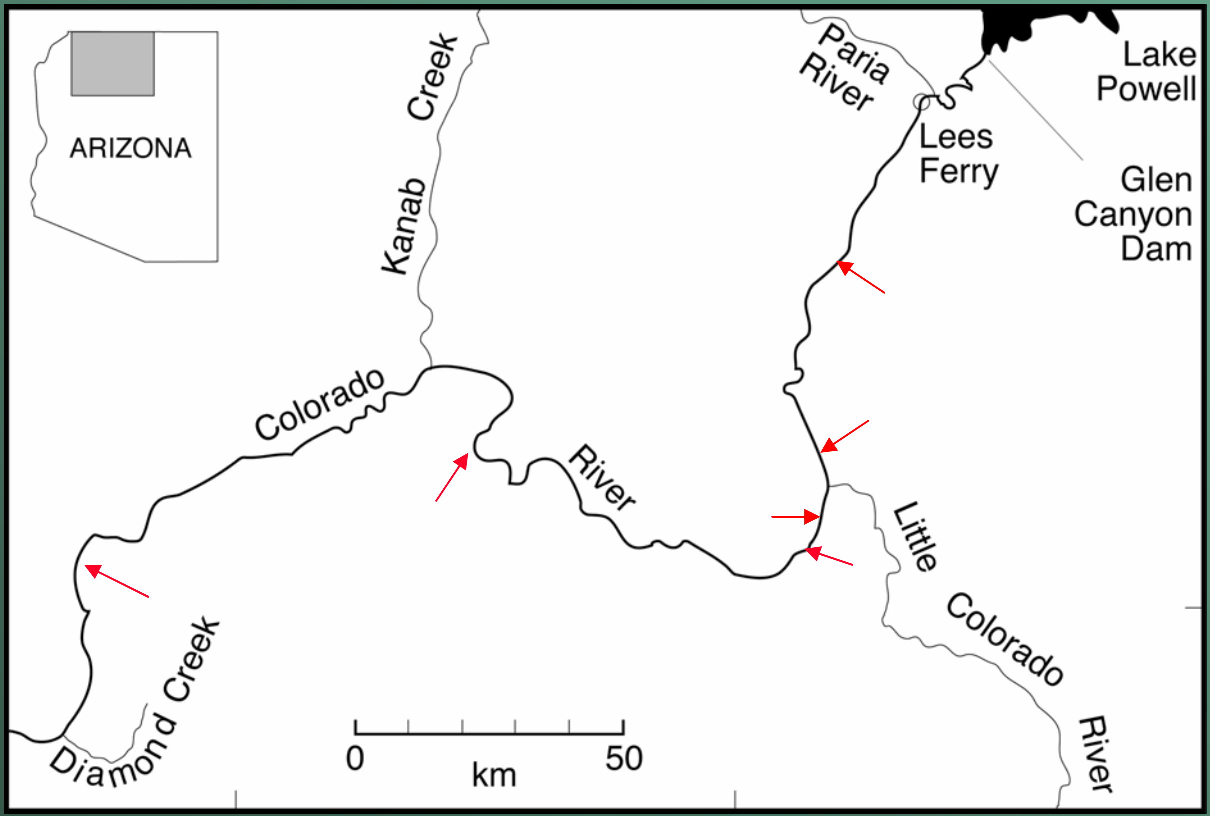
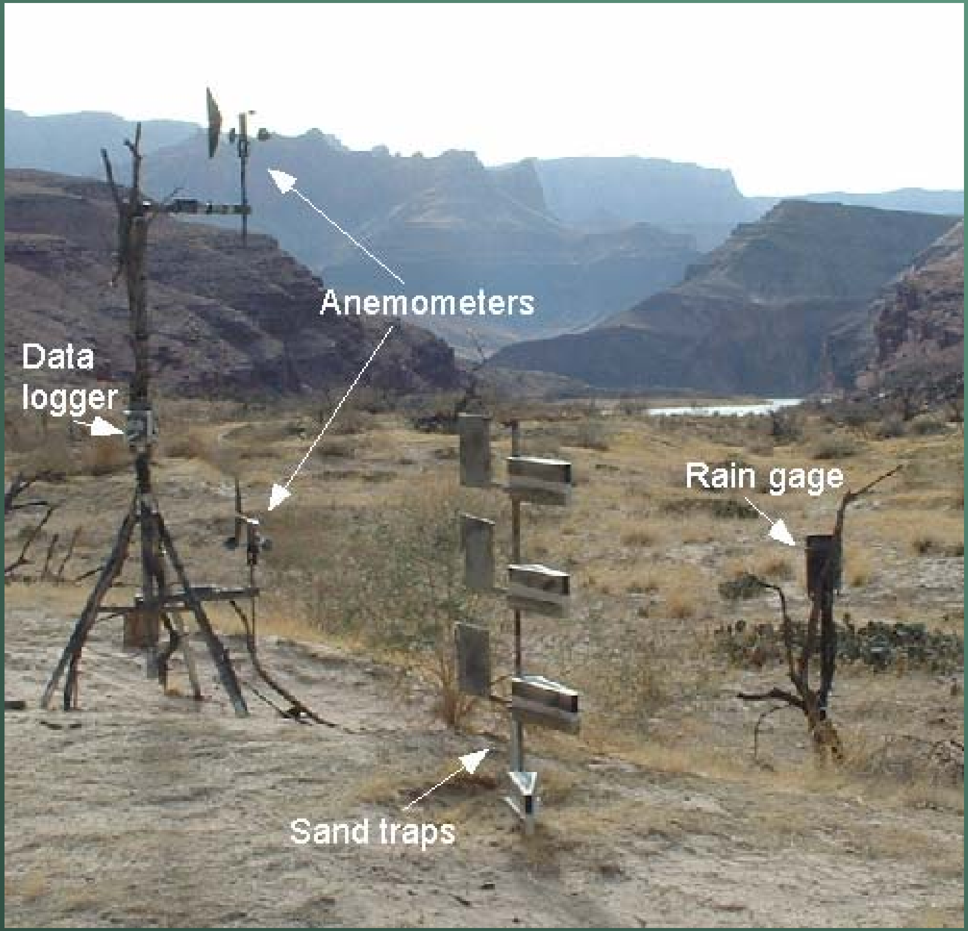
Weather Stations: Locations

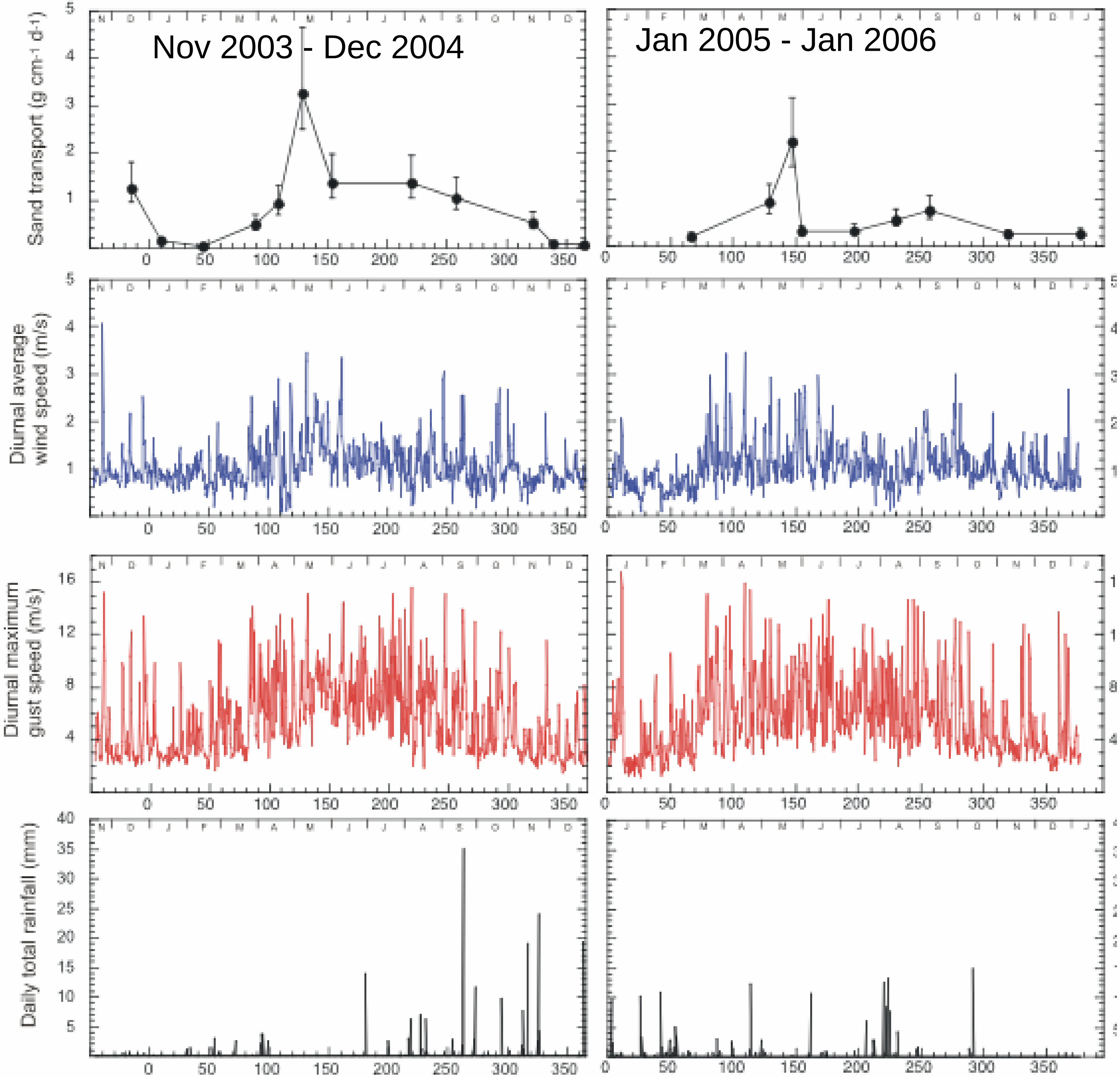


Six study sites (9 weather stations)

Weather Stations: Measurement Capabilities

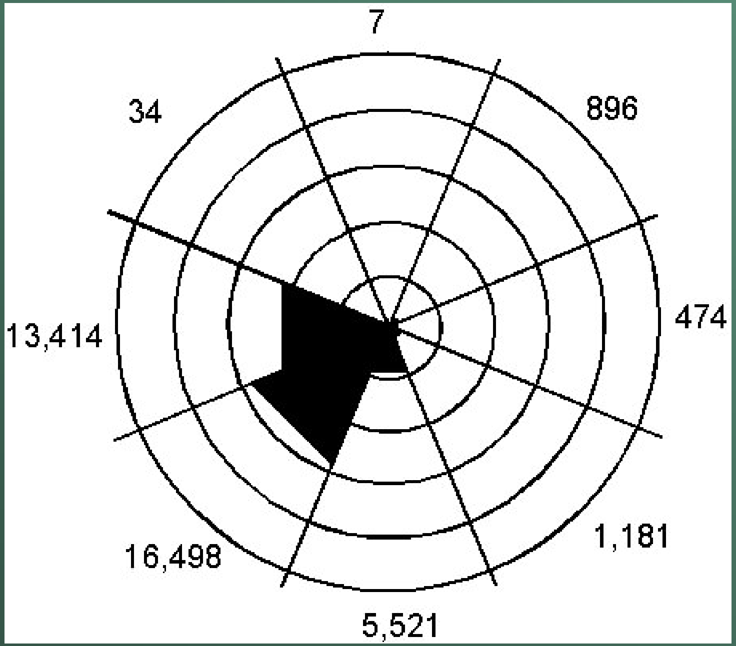


- Anemometers measured wind speed and direction
- Sand traps: integrate sand transport 0-1 m above the land surface
- Rain gauges measure rainfall that can cause gully incision; also determines when sand too wet to transport
- Wind and rain data collected every 4 minutes, sand traps manually emptied every 4-6 weeks

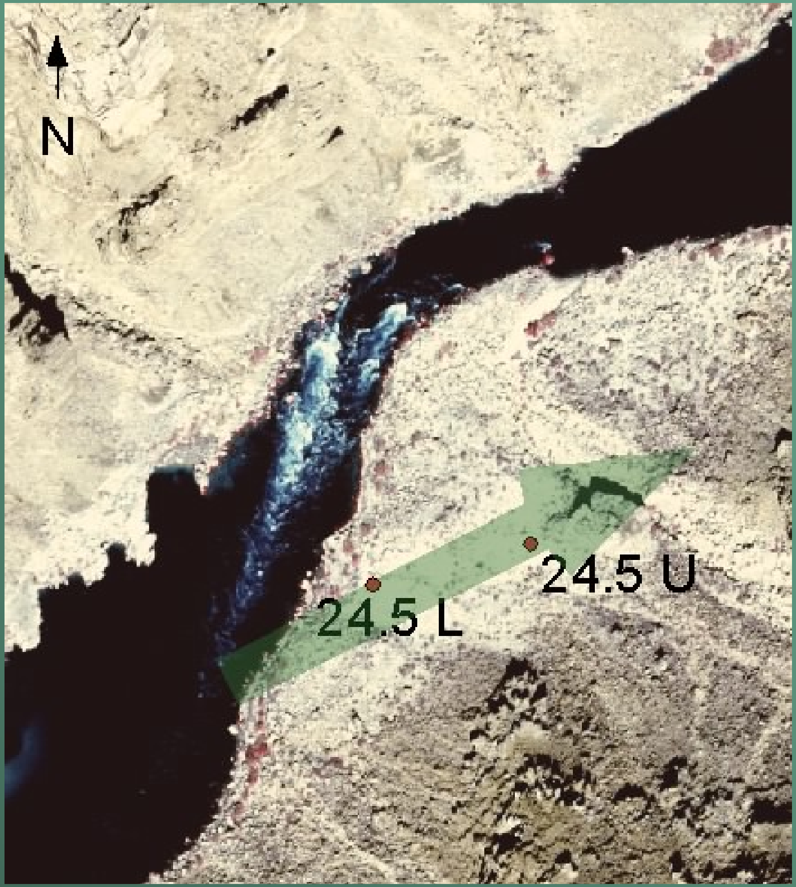


Nov 2003 - Dec 2004
Jan 2005 - Jan 2006
Sand transport (g cm-1 d-1)
Diurnal average wind speed (m/s)
Diurnal maximum gust speed (m/s)
Daily total rainfall (mm)

Wind and potential sand-transport direction measured at 24.5 mile

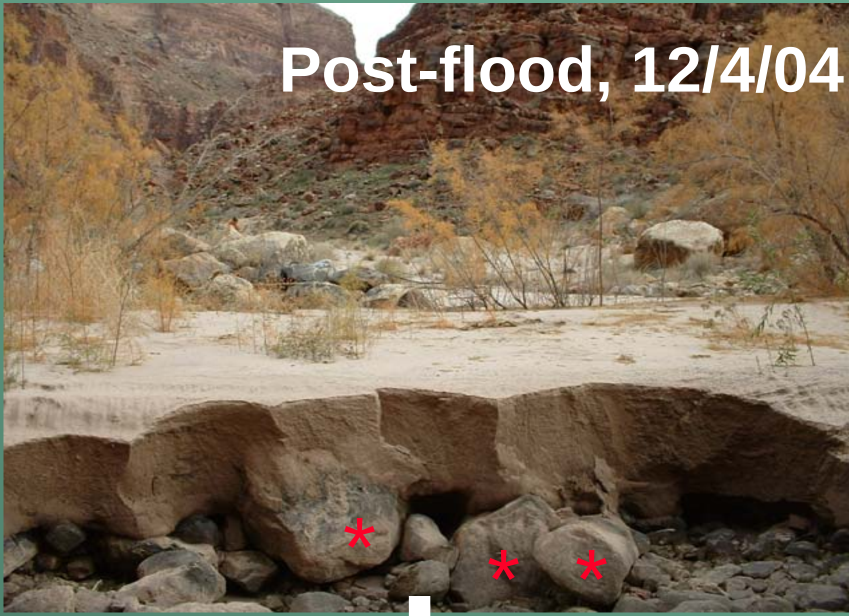


Potential sand transport, by direction. Uses sediment-transport proxy variable for wind speeds that exceeded critical threshold of motion: $Qp = (u - u_{crit})^3$

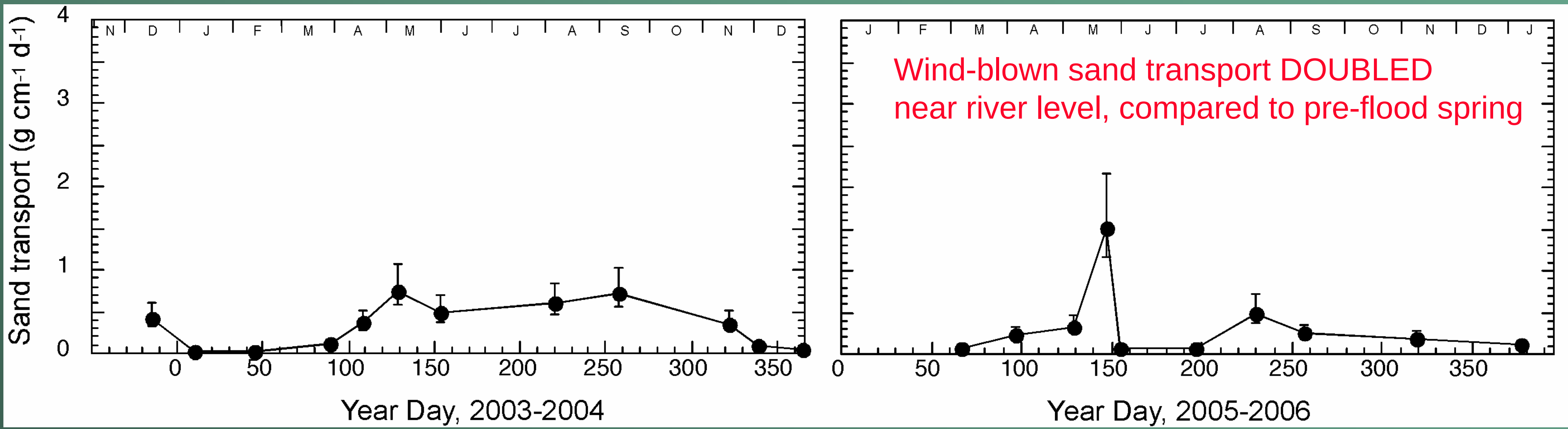


Net sand transport from river up into sand dunes (from direction of 243 degrees)

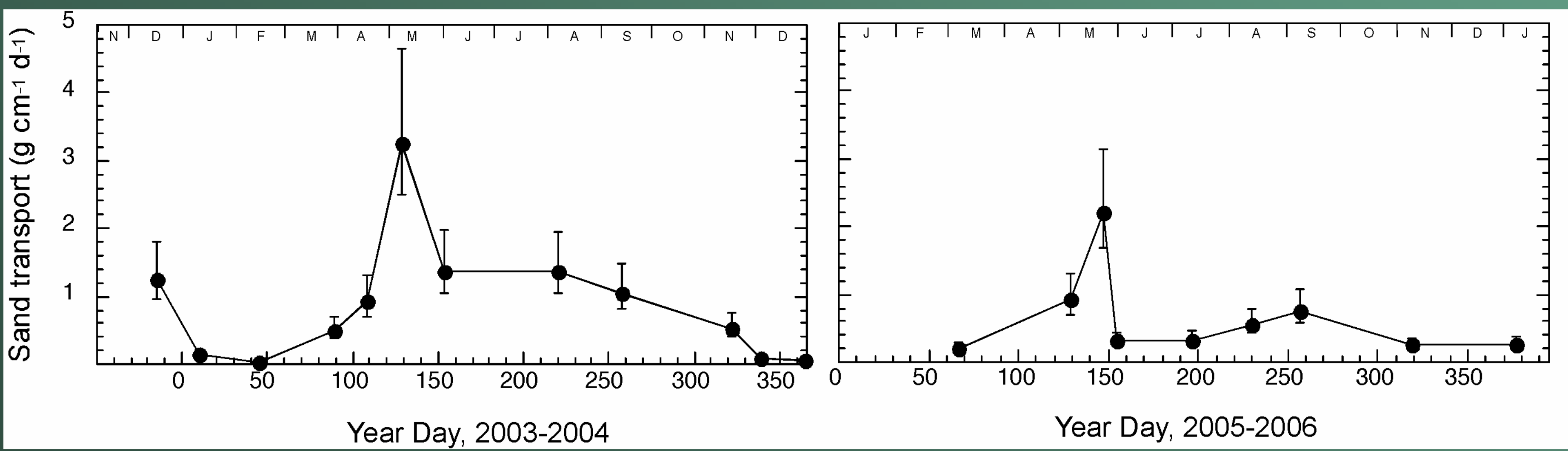
November 2004 High Experimental Flow



November 2004 High Experimental Flow

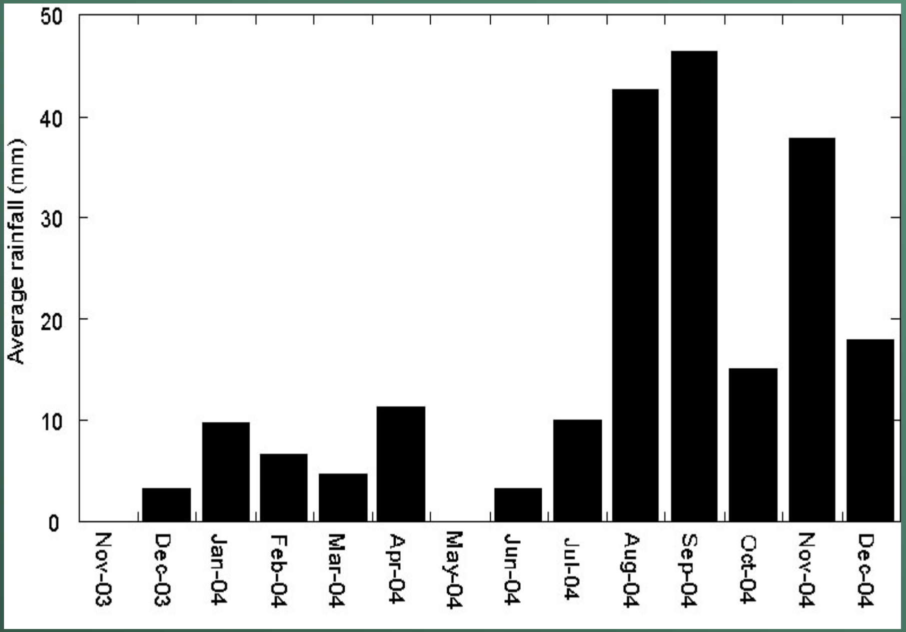


24.5 mile, Lower station (near river level)

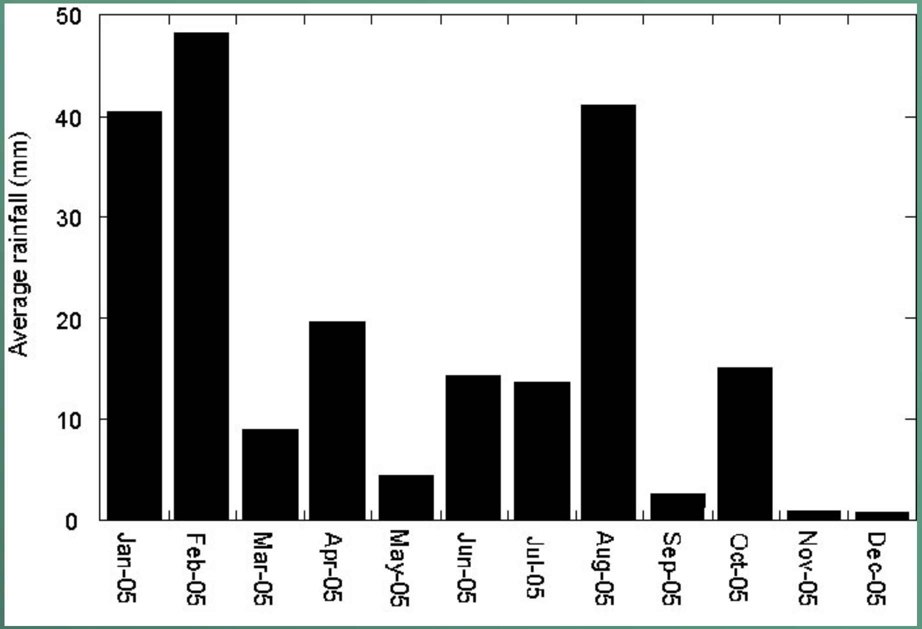


24.5 mile, Upper station (upper sand dunes)

Precipitation Trends



November 2003 to December 2004



January to December 2005

Values averaged for whole river corridor (based on 6 locations studied)
Are two years of data representative of long-term climate?

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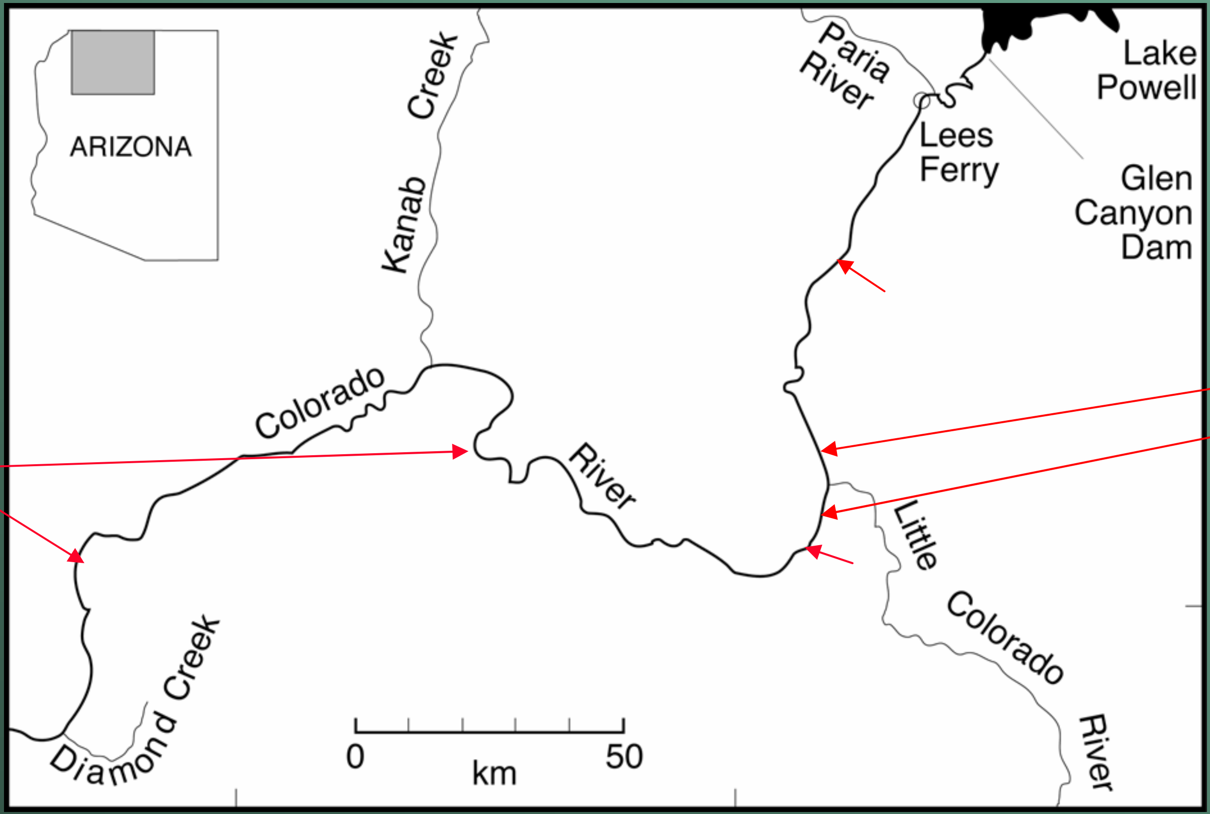
Precipitation varies greatly by location!

Wet winter of 2005 not uniform: western canyon had more rain Jan-Mar than some eastern sites had all year



2005:
Malgosa 269 mm
Palisades 133 mm
= 202% difference only 8 miles apart

Greatest single event measured: Hurricane Javier (9/18/04): up to 53 mm rain

Weather Station Network: Findings

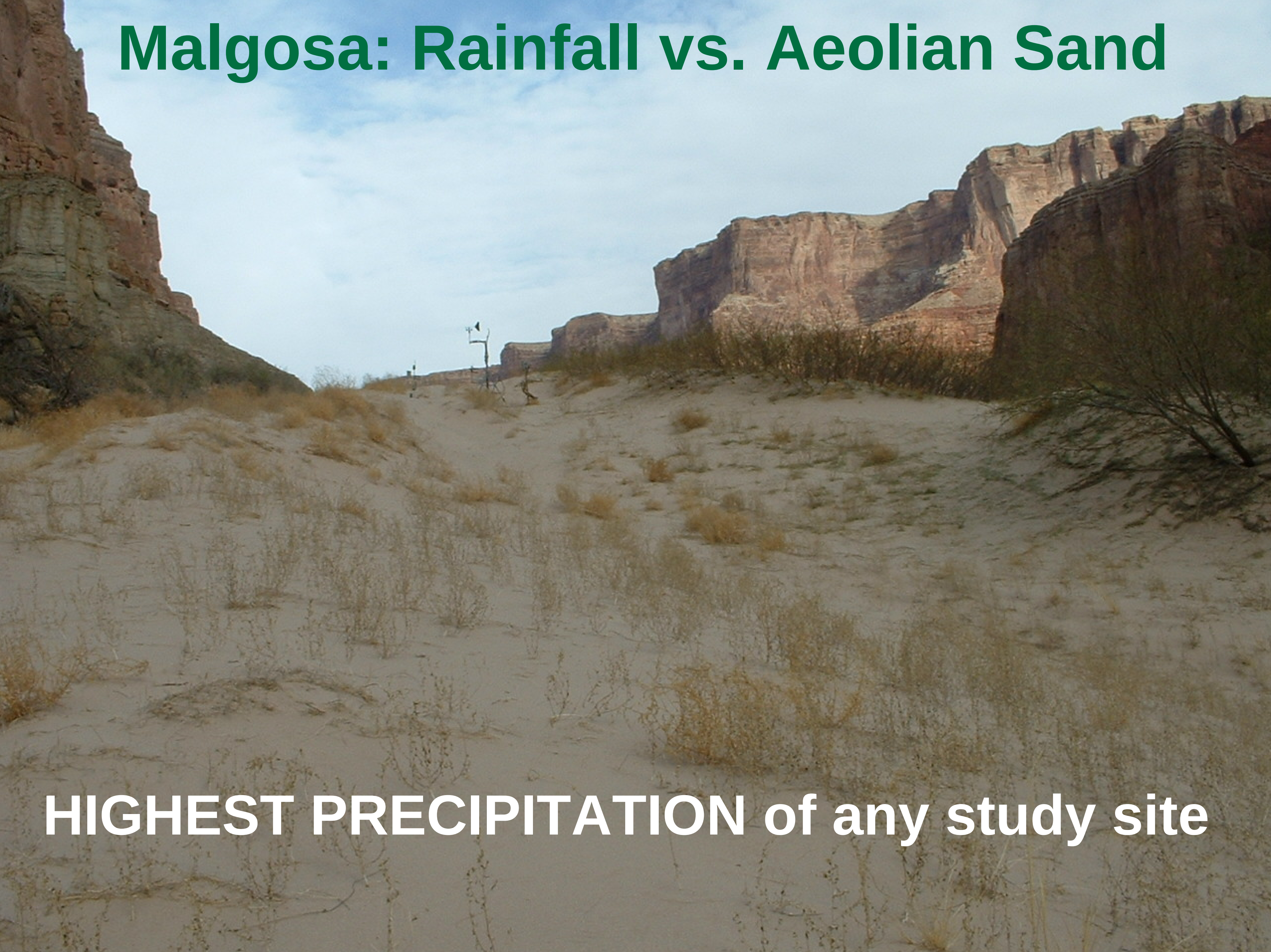
- Rainfall HIGHLY variable by location
- Aeolian sand transport 10 x greater in dune fields without much vegetation or cryptogamic crust
- Wind speeds highest in spring (April - early June), when sand transport is 5-15 times greater than in other times of year (<u>implications for timing floods</u>)
- Effects of 2004 flood: where some (dry, exposed) flood sand remained in spring ‘05, and where wind direction was right, aeolian sand transport was significantly higher than in pre-flood spring
- Draut and Rubin, 2005 OFR; 2006 OFR in review

All aeolian deposits are not created equal

- **Some formed by sand transported from river-level sandbars (45,000 cfs floods can replenish their sand)**
- **Some formed by *in situ* reworking of large pre-dam flood deposits (much larger floods would be needed to replenish sand on a large scale)**

Our perspective…

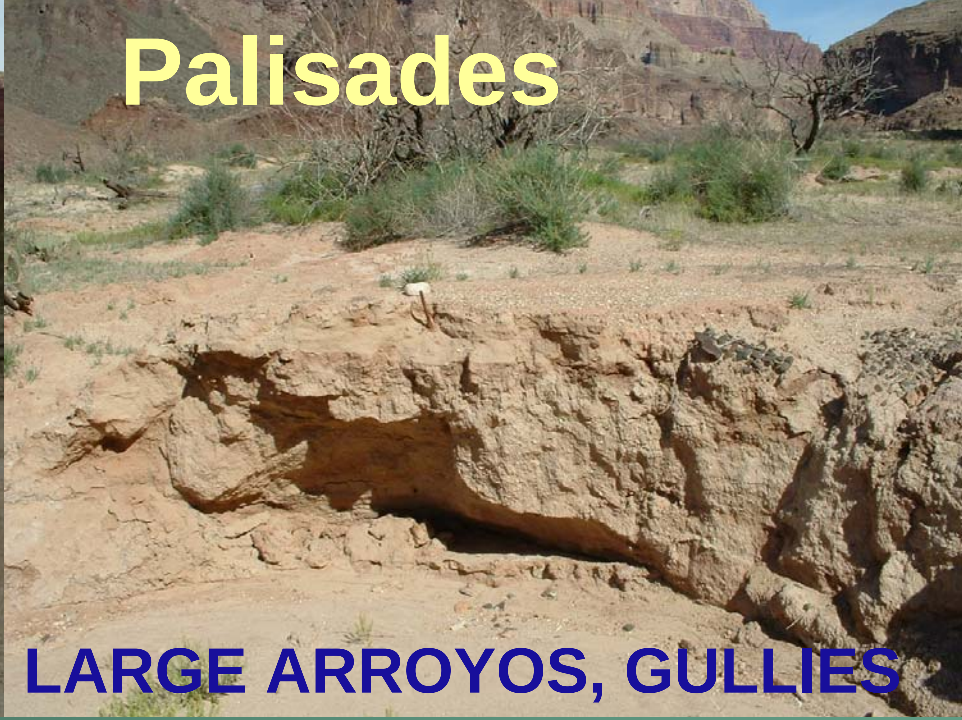
- We view this archaeological-site preservation problem as a **competition between two processes**: (1) **rainfall** (creating gullies) and (2) **aeolian redistribution of sand** (providing sand cover and filling in gullies… gullies naturally trap sand).
- No way to prevent rainfall; research on rainfall is mainly for documentation purposes
- The second process, aeolian transport of sand, is the major one that management policies can affect. For management purposes, **studying restorative sand transport** (and its ability to fill in gullies and provide sand to dunes) is a **more important focus.**


Malgosa: Rainfall vs. Aeolian Sand
HIGHEST PRECIPITATION of any study site


Palisades: Rainfall vs. Aeolian Sand
LOWEST PRECIPITATION of any study site

- HIGHEST PRECIPITATION
- HIGH AEOLIAN SAND TRANSPORT
- NO GULLIES OR ARROYOS

- LOWEST PRECIPITATION
- LOW-MODERATE AEOLIAN SAND TRANSPORT
- LARGE ARROYOS, GULLIES ERODING ARCHAEOLOGICAL SITES



→ AEOLIAN SAND TRANSPORT IS AN EXTREMELY IMPORTANT FACTOR COUNTERACTING GULLY EROSION

and can be managed using dam operations to maximize open, dry sandbar area in spring windy season (when most sand transport occurs).

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Gully at 24.5 mile, filled by aeolian sand blown from the November 2004 flood deposit

Head of gully

Middle of gully

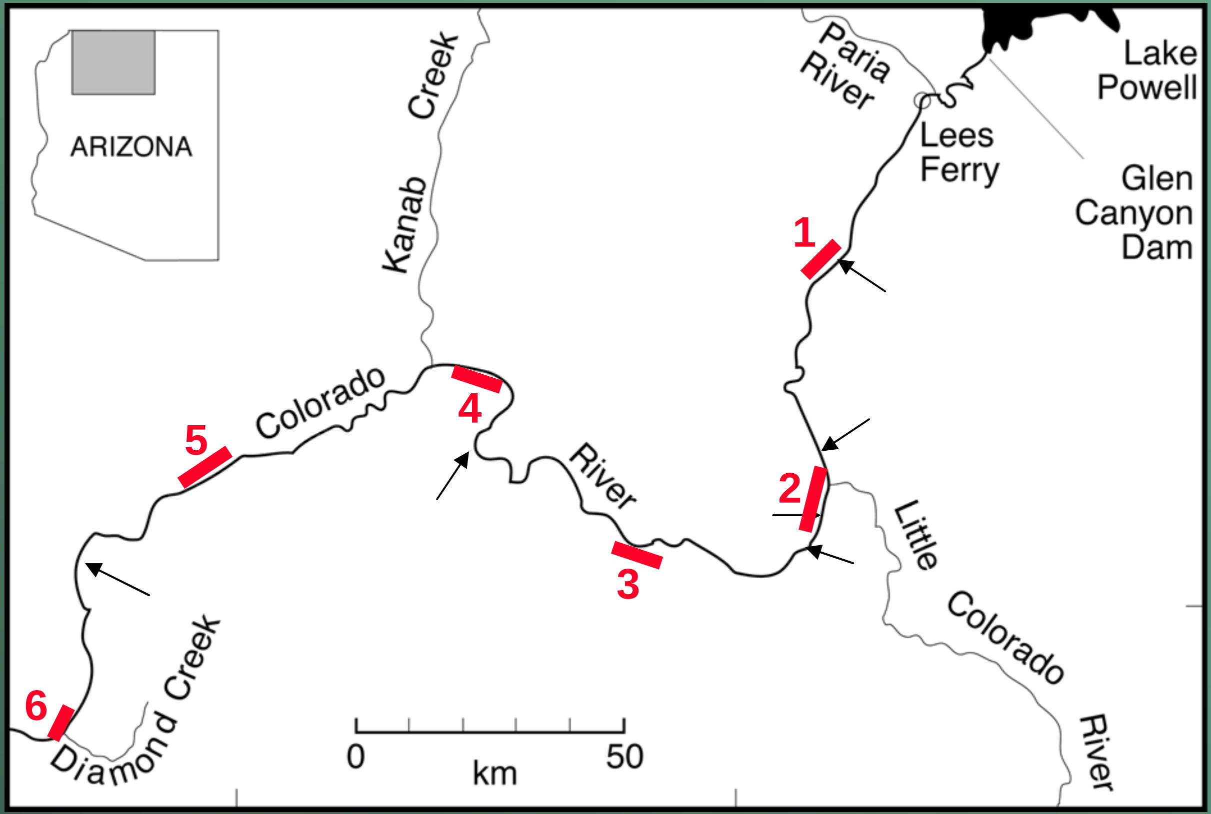
Terminus of gully

Recommended Future Work

- Long-term weather station network, with stations distributed along river corridor (minimum 6 stations, in representative areas of the canyon, located in little-visited areas and camouflaged). Broaden data collection by adding air temperature, relative humidity, barometric pressure sensors.
- Detailed numerical modeling of wind dynamics and aeolian sediment transport at selected (archaeologically relevant) sites. Build on modeling work done by this study to evaluate the effects of sediment-supply limitation on sand transport: <u>important implications for management</u>.
- Design new, automated, sand traps that record high-resolution data (ideas in progress by Rubin, Chezar, and Draut at USGS, Santa Cruz).

Recommended Locations for Future Weather Stations

- Minimum 6 locations, distributed along RM 0-226
- Representative reaches (persistent canyon orientation)
- Areas of low visitation



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Weather Station Costs

	Onset Corp.	Campbell Scientific	Vaisala
Basic station (wind, precip, temp)	$1,900	$3,420	$9,720
Basic + relative humidity, barometric pressure	$2,060	$4,750	$10,910
Basic station with GOES telemetry	Not available	$8,000	$14,130
Basic + humidity, baro pressure, with GOES telemetry	Not available	$8,870	$15,330

- **Maintenance, repairs: $1500 - $2500 total per year**
- **Advisable to purchase at least one set of spare equipment**
- **Salary, benefits for one employee at approximately half time**

Value of Future Weather and Aeolian Sand Monitoring and Research

- Longer-term records smooth out seasonal, annual, El Nino-scale variation $\rightarrow$ better climate record for use in many cultural, biological, physical-science studies
- Better resolve causes of gully formation (erodible substrate? Base level? Drainage-basin geometry? Unusually high rainfall?) $\rightarrow$ understand natural vs. human influence
- Better understand how changing open, dry sandbar area (by erosion, vegetation, or building sandbars during floods) affects aeolian sand transport $\rightarrow$ condition of dune fields and associated cultural sites.
- Expand to more study sites $\rightarrow$ continue to resolve effects of dam operations, if any, at specific sites

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With thanks to:

- Jan Balsom, Jennifer Dierker, Helen Fairley, Joe Hazel, Ralph Hunter, Matt Kaplinski, Lisa Leap, Ted Melis, Fred Nials, Dave Topping, Mike Yeatts; many field assistants
- Carol Fritzinger and many river guides