Understanding the Physical Context and Processes Affecting Cultural Site Preservation

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U.S. Department of the Interior
U.S. Geological Survey

Purpose of this talk

- Describe progress made towards answering SSQs and fundamental science question
- Describe what we know about the geomorphic context of archaeological sites and the physical processes acting on them, pre- and post-dam
- Clarify how this knowledge is relevant to understanding dam effects above the level of inundation
- Acknowledge the diverse values ascribed to cultural sites, but focus on the physical basis for their existence, their current condition, and prospects for preservation

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Strategic Science Questions

- SSQ 2-1. Do dam controlled flows increase or decrease rates of erosion at arch sites and TCP sites, and if so, how?
- SSQ 2-2. How do flows impact old high-water zone (OHWZ) terraces in the CRE, and what kinds of important information about the historical ecology and human history of the CRE are being lost due to ongoing erosion of the Holocene sedimentary deposits?
- SSQ 2-3. If flows contribute to arch site/TCP erosion, what are the optimal flows for minimizing impacts to these cultural resources?
- SSQ 2-4. How effective are various treatments (e.g., check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term?
- SSQ 2-7. Are dam controlled flows affecting TCPs and other tribally-valued resources in the CRE, and if so, in what respects are they being affected, and are those effects considered positive or negative by the tribes who value these resources?

What is the fundamental question?

The fundamental question about site erosion is not whether sites (and high elevation terraces) are eroding, but whether they are eroding faster or more extensively than they would if:

A) Glen Canyon Dam did not exist, and
B) Glen Canyon Dam operations were different from pre-ROD or MLFF

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Why is this question difficult to answer?

Our ability to answer this question has been historically constrained by lack or shortage of:

- high quality pre-dam site/terrace condition data
- good control data from undammed rivers
- high quality site-specific geomorphic data
- reliable objective methods (and appropriate tools) for measuring rates of change
- local measurements of key parameters such as weather conditions, soil characteristics, etc.

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Talk Outline

- Describe the site population of interest (5 mins)
- Briefly review previous work and conclusions (10 mins)
- SSQ 2 – What have we learned about Holocene context and processes affecting cultural sites (10 mins)
- SSQ 1 – What have we learned about modern conditions and processes affecting archeological sites? (10 mins)
- SSQ- 3 – What have we learned about check dam effectiveness (10 mins)
- Where to from here?? (10 mins)

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Archaeological Sites: Many Different Values, Settings, and Types at Stake

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Archaeological Sites: Many Different Values at Stake

- Ancestral homes of Native peoples
- Tangible evidence of Native peoples' use and occupation of Grand Canyon
- Locations of intangible power

- Sources of information about human prehistory and history in Grand Canyon
- Sources of information about prehistoric and historic environmental conditions
- Opportunities for public education and recreational "enjoyment"

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Archaeological Sites have many different attributes & qualities

- Age: 8,000+ years to 50 years
- Size: 1 sq meter to over 10,000 sq m
- Artifacts: Single item→ thousands of artifacts
- Features: May or may not include: rock art, fire pits, structures, human burials, etc.
- Depth: Can be totally on the surface, buried deeply below surface, or consist of several meters of accumulated cultural debris
- Protection: May be well-protected from elements (e.g., rock shelter) or totally exposed

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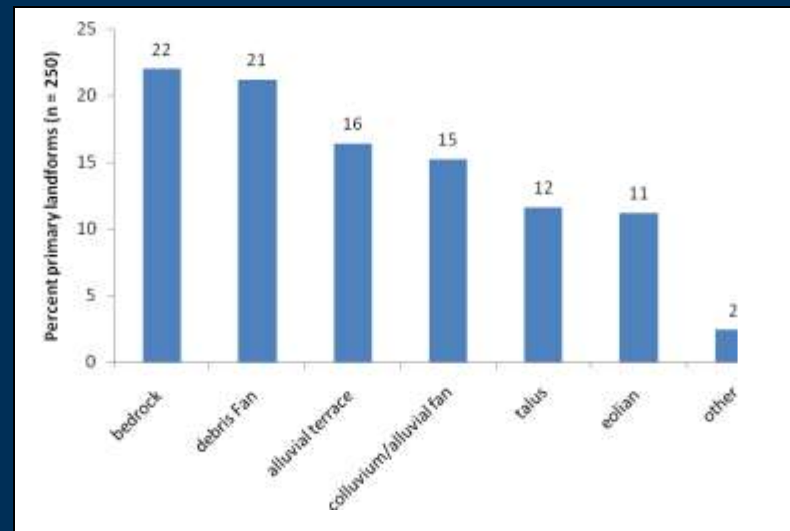
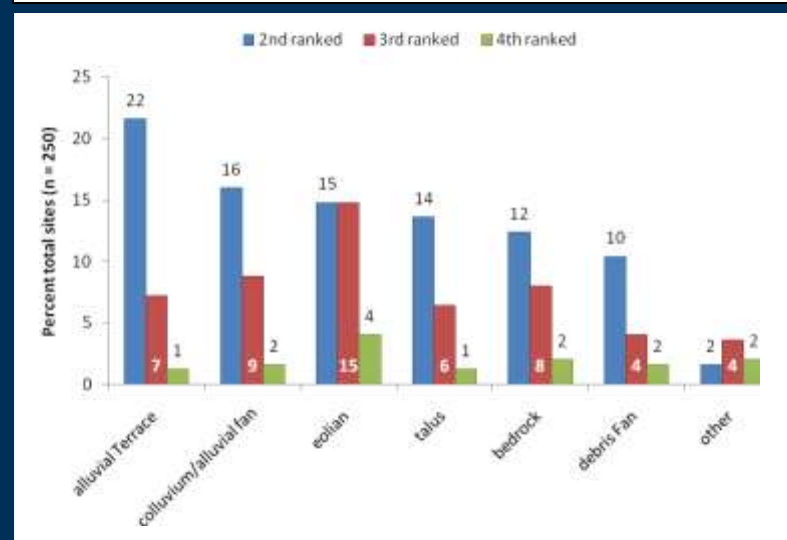
Archaeological sites occur in many different geomorphic contexts





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Traditional Cultural Properties

"A place eligible for listing on the National Register because of its association with cultural practices or beliefs of a living community that (a) are rooted in that community's history, and (b) are important in maintaining the continuing cultural identity of the community."

- Many, but not all, archeological sites are Traditional Cultural Properties
- However . . . visible evidence of human use not necessary to be a TCP, e.g.,
  - Springs
  - Mineral deposits
  - Geologic landmarks
- TCPs can also encompass landscapes (e.g. Grand Canyon, San Francisco Peaks)

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Monitoring by Grand Canyon National Park (1970s-1990s): Pre-GCMRC

- Late 1970s : monitoring begins
- Early 1980s: active erosion observed
- 1983-1986: erosion rates appear to increase coincident with high releases from Glen Canyon Dam
- 1990-1991 Inventory completed:
  - 475 = total sites documented
  - 336 sites located in APE, many in or on unconsolidated river-derived sedimentary deposits (APE)
  - many sites impacted by gullies

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What is the population of concern?

- 475 sites documented between Glen Canyon Dam and RM 240 (255 miles) 1990-1991
- 336 sites within Area of Potential Effect from dam ops (includes both GLCA and GRCA)
- 14 sites subsequently determined ineligible
- *Thus 322 archaeological sites in the APE total*

- Note: Geomorphic database discussed in this talk is includes 232 sites in GRCA only

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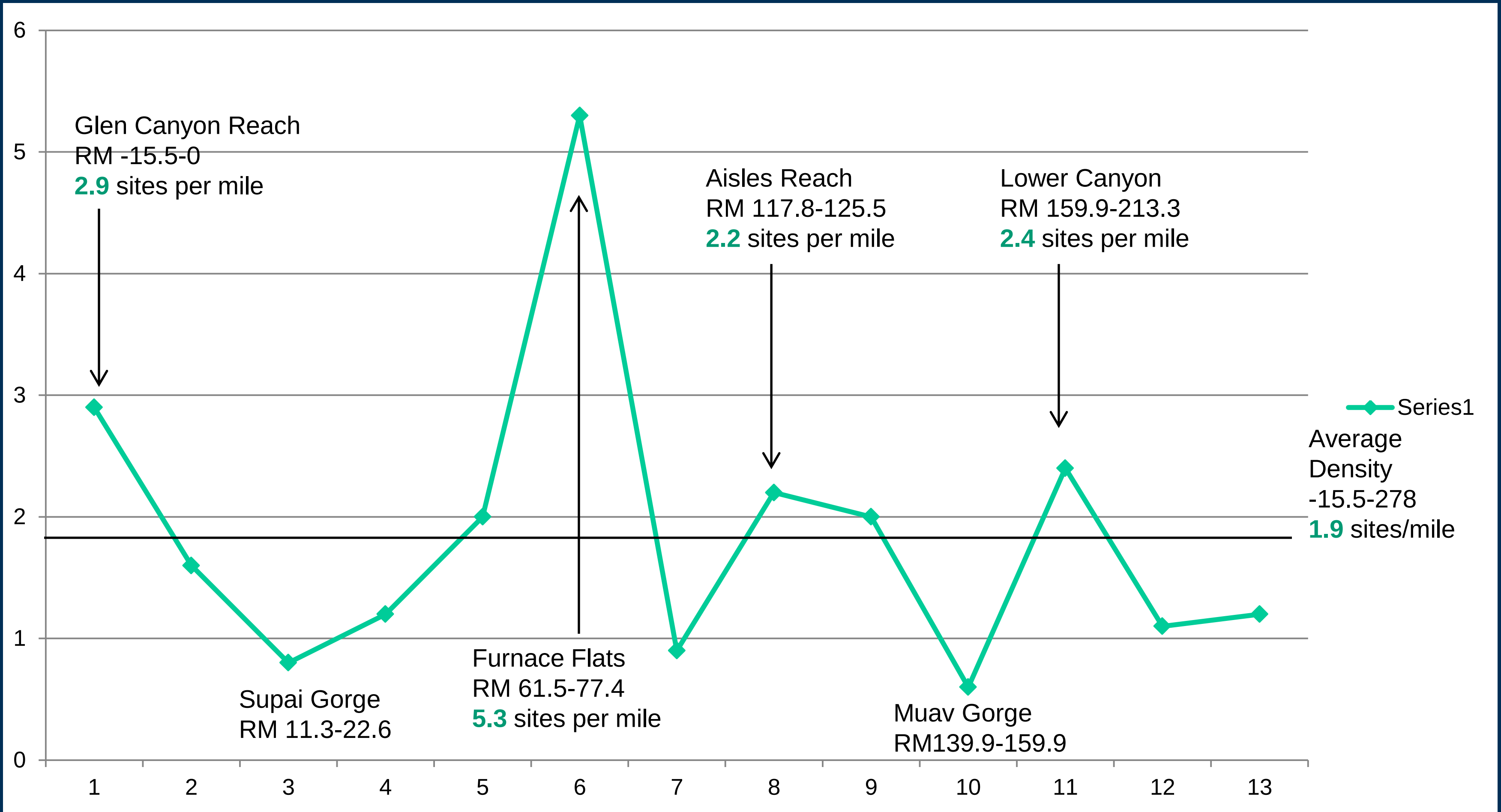
Archaeological Site Density Varies by Geomorphic Reach



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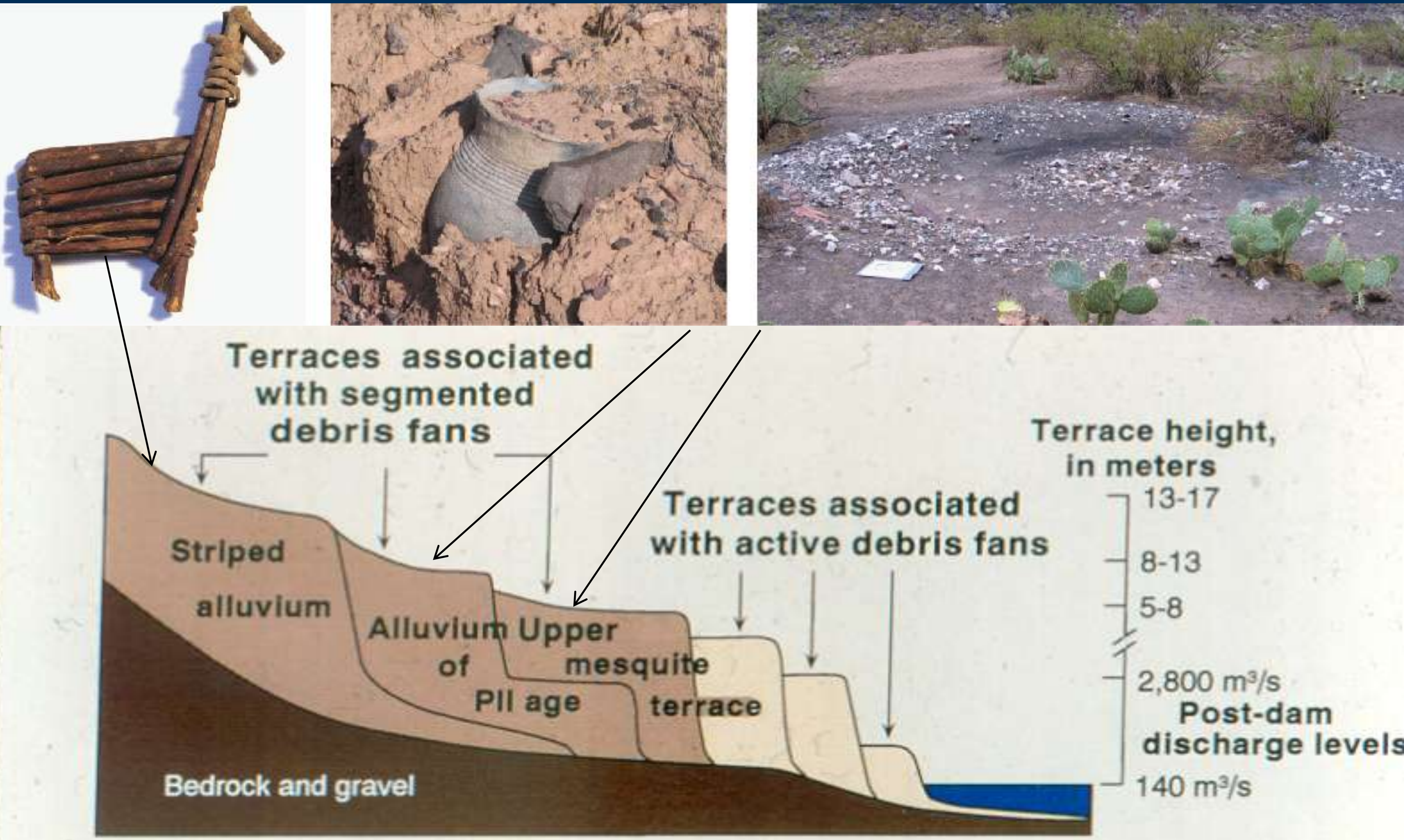

Terraces associated
with segmented
debris fans
Terrace height,
in meters
Terraces associated
with active debris fans
13-17
8-13
5-8
2,800 m³/s
Post-dam
discharge levels
140 m³/s
Striped
alluvium
Alluvium
of
PII age
Upper
mesquite
terrace
Bedrock and gravel

GCES Phase II Key Findings Re: Geomorphic Context of Archaeological Sites

- Multiple periods of alluviation during past 5,000+ years
- Aggradation periods were separated by episodes of down-cutting – linked to regional climate cycles
- Sites not evenly distributed
  - sites more concentrated in widest reaches with alluvial deposits
  - older sites often buried, generally higher in elevation
  - younger sites more often exposed on terrace surfaces

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GCES II Key Findings Re: Dam Effects

- Few sites directly adjacent to active river channel, therefore few “direct” effects from inundation
- Original estimate was ~36 sites subject to direct inundation from flows up to 97,000
- Recent (2010) GIS analysis indicates:
  - 5-19 sites affected by 45,000 cfs flow (9 most likely)
  - 17-82 sites affected by 97,000 cfs flow (48 most likely)

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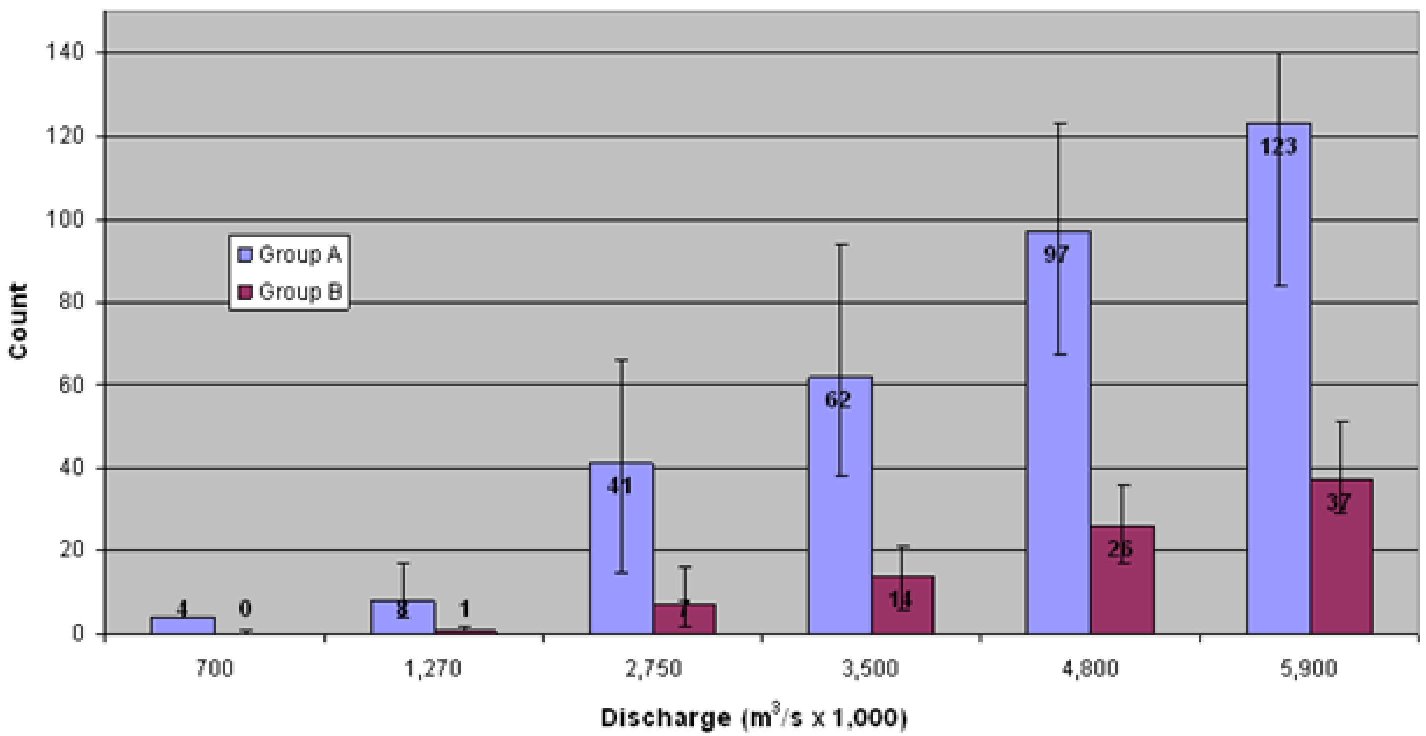
GIS analysis can predict inundation

Group A = 151 treatment + 10 MNA/NPS excavated sites; Group B = 81 other sites in GRCA (GLCA not included because shoreline model does not extend above Lee Ferry)



	Group A		Group B	
Discharge (m^3/s)	Maximum	Minimum	Maximum	Minimum
708	4	4	1	0
1,274	17	4	2	1
2,747	66	15	16	2
3,540	94	38	21	6
4,814	123	67	36	17
5,947	140	84	51	29

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GIS Analysis can predict area of inundation at each site by river stage

Site key	Site category	700+ m³/s	700 m³/s	700- m³/s	1,270+ m³/s	1,270 m³/s	1,270- m³/s
C:13:010	Group A (MNA)	0.0	0.0	0.0	1,099.3	125.1	0.0
C:13:291	Group A (MNA)	36.6	5.6	1.5	190.7	83.7	36.8
C:13:347	Group A (MNA)	0.0	0.0	0.0	3.2	0.0	0.0
C:13:371	Group A (MNA)	0.0	0.0	0.0	256.1	56.8	0.0
A:15:047	Group A	27.4	8.3	4.2	258.8	115.2	34.3
A:16:158	Group A	0.0	0.0	0.0	2.9	0.0	0.0
A:16:159	Group A	0.0	0.0	0.0	22.7	4.0	0.0
B:15:124	Group A	23.5	12.6	1.6	12.5	12.5	12.5
C:02:094	Group A	0.0	0.0	0.0	0.6	0.0	0.0
C:02:098	Group A	0.0	0.0	0.0	19.7	4.9	0.0
C:05:004	Group A	0.0	0.0	0.0	6.5	0.0	0.0
C:06:005	Group A	0.0	0.0	0.0	12.2	0.0	0.0
C:09:088	Group A	7,629.0	6,358.0	5,359.6	1,5331.5	1,2386.1	9,297.3
C:13:005	Group A	0.0	0.0	0.0	14.3	0.0	0.0
C:13:009	Group A	0.0	0.0	0.0	1.4	0.0	0.0
C:13:322	Group A	0.0	0.0	0.0	0.3	0.0	0.0
G:03:038	Group A	0.0	0.0	0.0	0.4	0.0	0.0
A:16:161	Group B	0.0	0.0	0.0	7.6	0.0	0.0
B:11:279	Group B	0.2	0.0	0.0	6.8	1.1	0.6

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Data from 45,000 cfs virtual shoreline analysis

GCES II Key Findings, continued

- **USGS 1989-1995 findings re: dam effects:**
  - **Dam effects mainly indirect - tied to reduction in sediment supply , absence of high flows**
  - **Without periodic sediment-rich floods, sediment is not being replenished at higher elevations**
    - **no natural backfilling of gullies by flood deposits**
    - **reduction in aeolian sand source leads to surface deflation**
    - **loss of aeolian cover reduces infiltration → more run-off**

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“Hereford Hypothesis”

1. In pre-dam times, large areas were blanketed by dunes derived from reworked flood deposits and exposed sand bars
2. Gullies developed for same reasons they do today (rainfall run-off leading to overland flow across erodable alluvium)
3. Many pre-dam gullies never reached the river; they dissipated in the dunes or on sandy terrace surfaces before reaching river - Terraces served as the “effective base level”
4. Over time, shallow gullies on terrace surfaces propagated towards main channel – once integrated with main channel, erosion through terrace deposits accelerated by head cutting
5. However, pre-dam gullies typically would be in-filled by wind-blown sand or backfilled by flood deposits before reaching the river or before head-cutting could progress too far
6. <u>Post-dam</u>: aeolian cover deflated; natural processes that formerly backfilled gullies have diminished; rain still falls
7. so . . . gullying is now a “one-way street”

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Gully Erosion from Sept. 2006 storm

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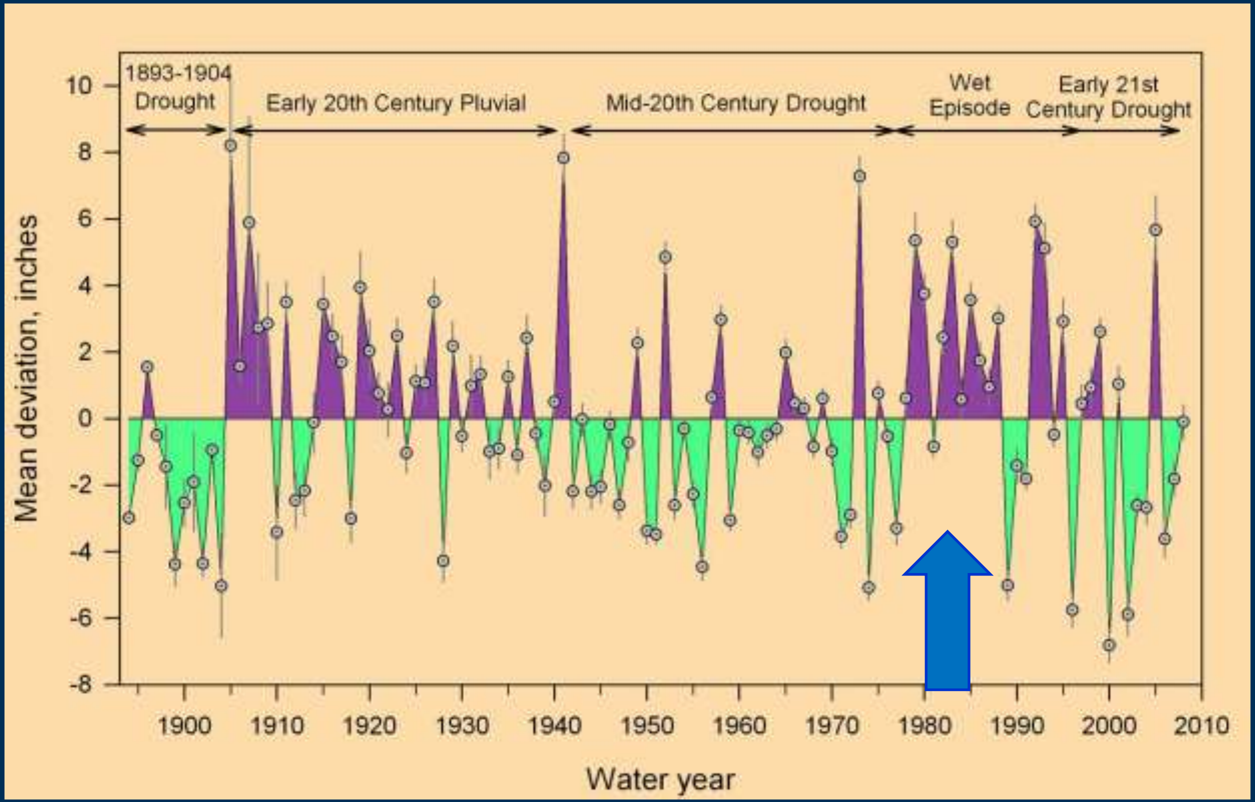
GCES II Key Findings, continued

- **Gully erosion driven by run-off, overland flow**
- **Observations of late 1970s –1980s erosion reflects effects of increased precipitation during that period**



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Documenting Holocene Processes and Effects on Archaeological Sites

SSQ 2-2. How do flows impact old high-water zone (OHWZ) terraces in the CRE, and what kinds of important information about the historical ecology and human history of the CRE are being lost due to ongoing erosion of the Holocene sedimentary deposits?

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Nine Mile Draw

Pederson and others, 2011

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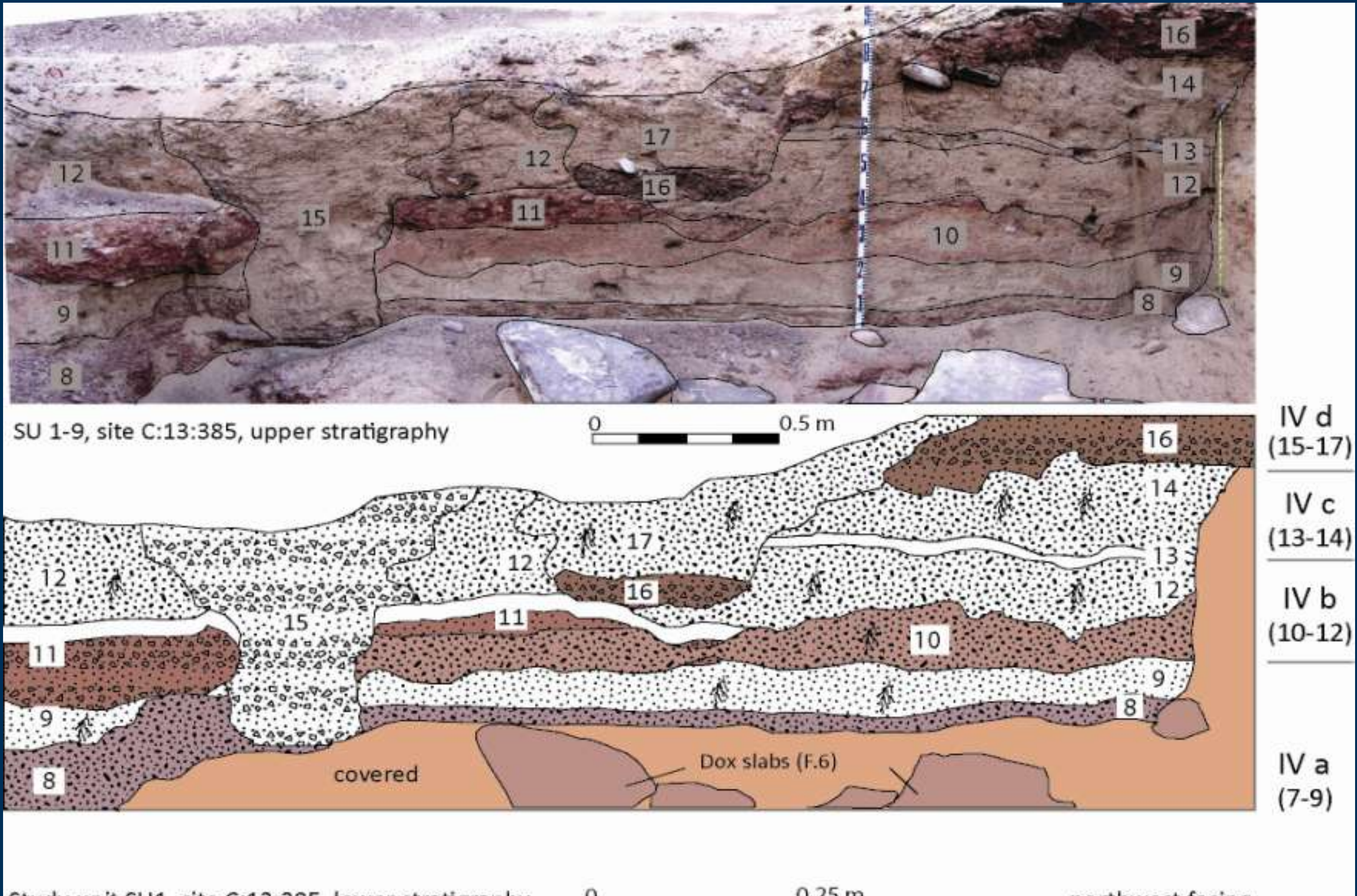
USU 289: ~300 yr
USU 288: ~2500 yr
SU-5
14C
F8
cal B.P. 2780-2400
ashy lens
USU 458: ~1500 yr
USU 355: ~3000 yr
USU 284: ~5000 yr
USU 283: ~800 yr
1 m

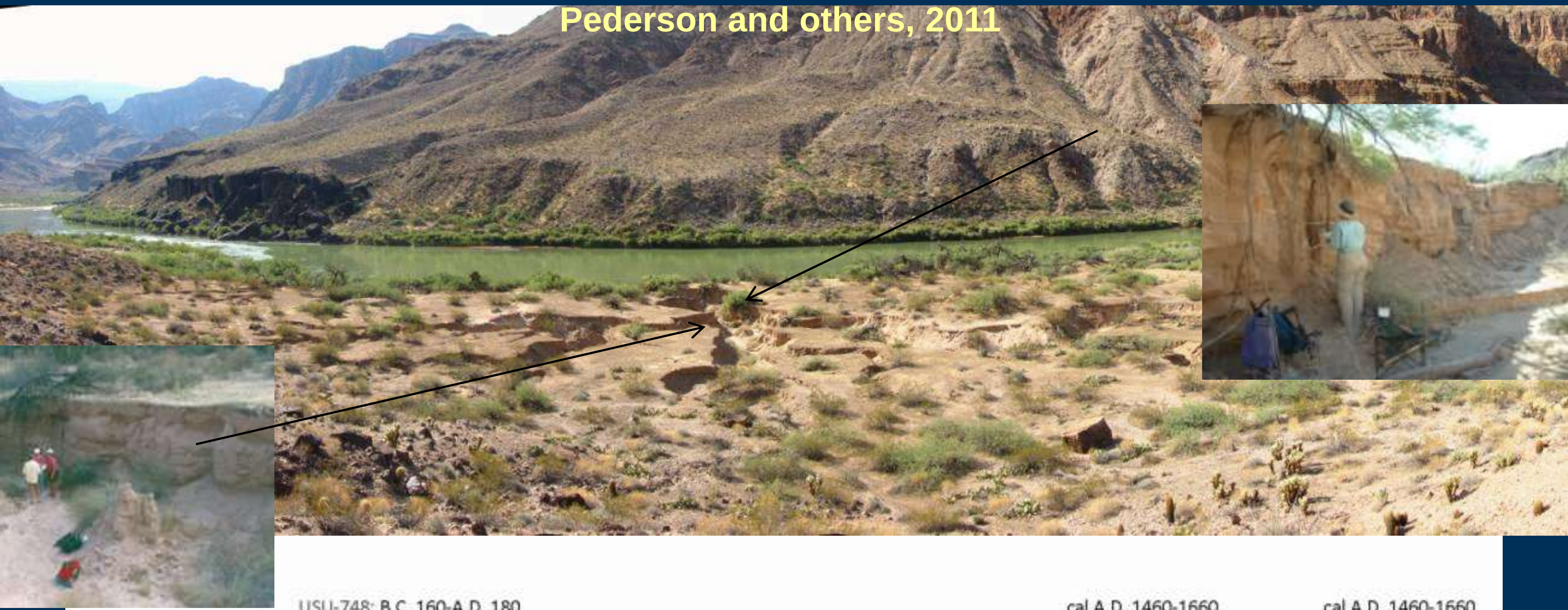
Lower Unkar, AZ C:13:385

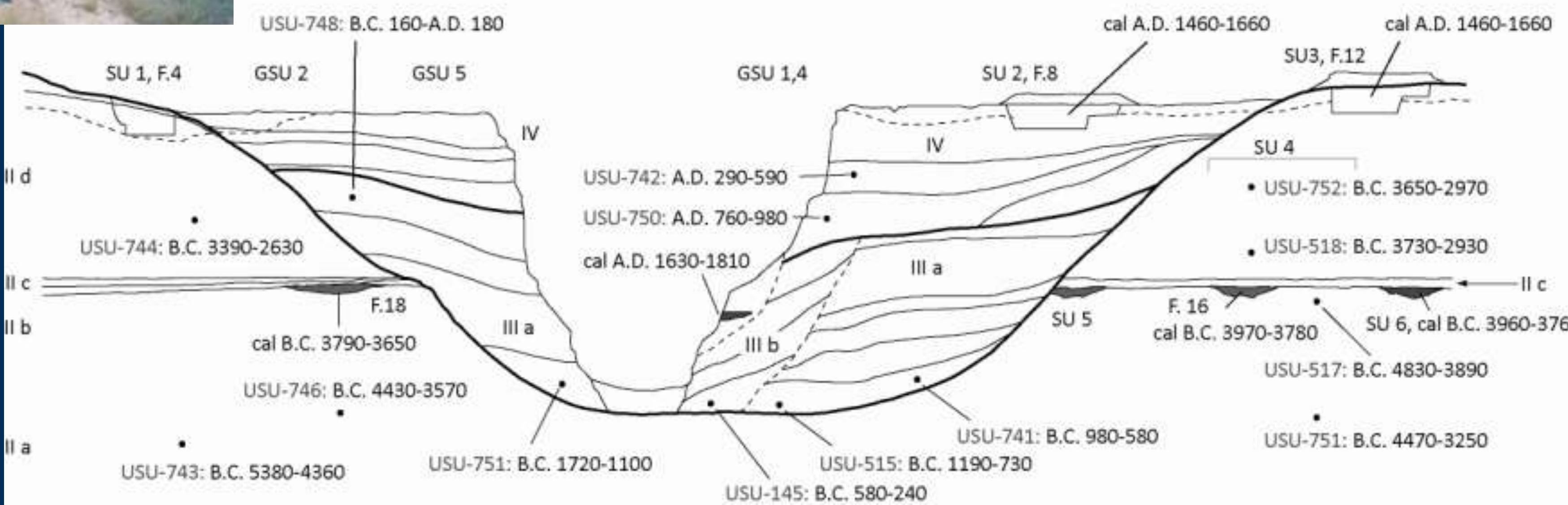
Pederson and others, 2011

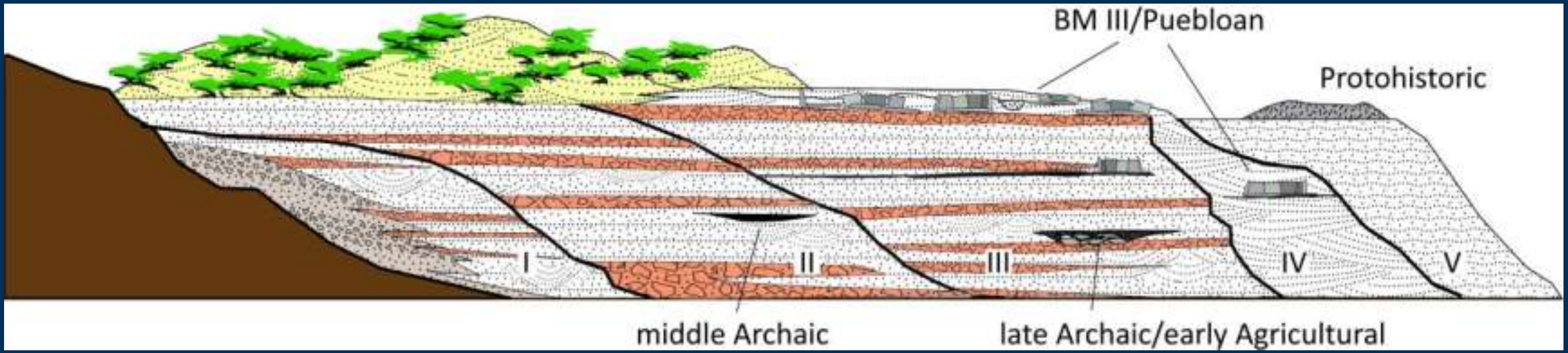


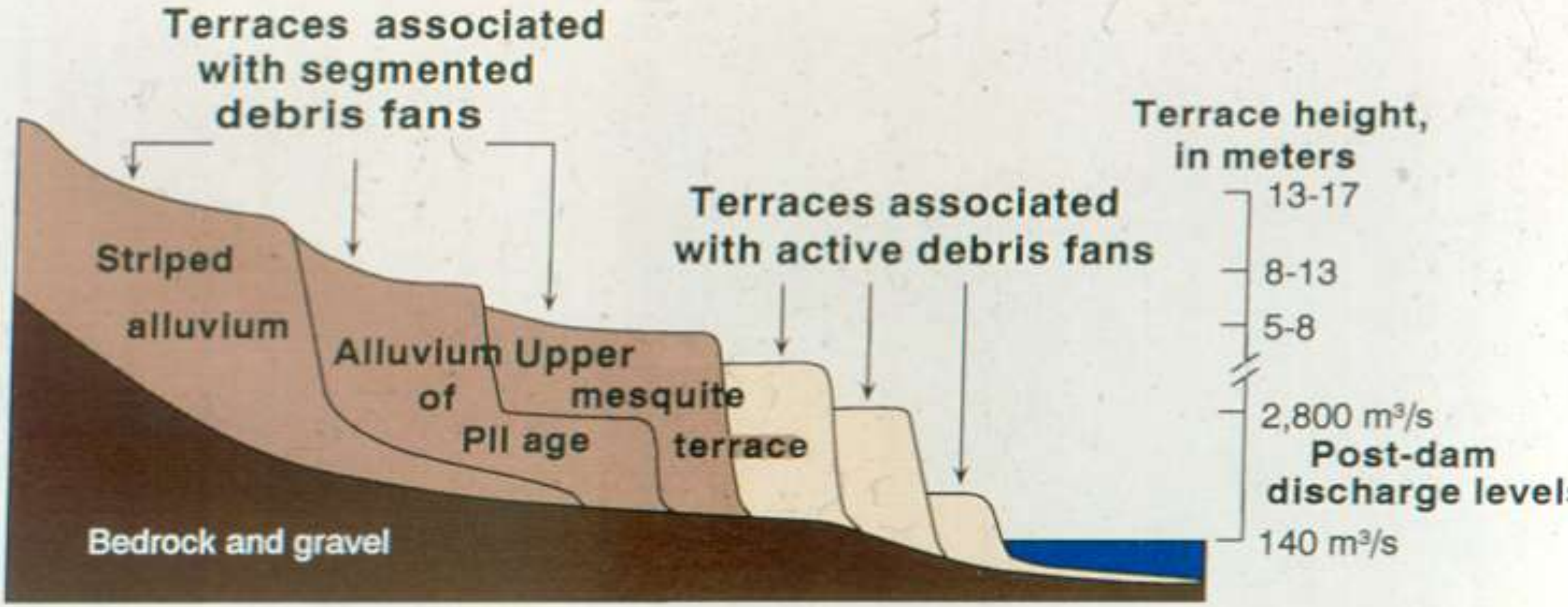
Arroyo Grande

Pederson and others, 2011

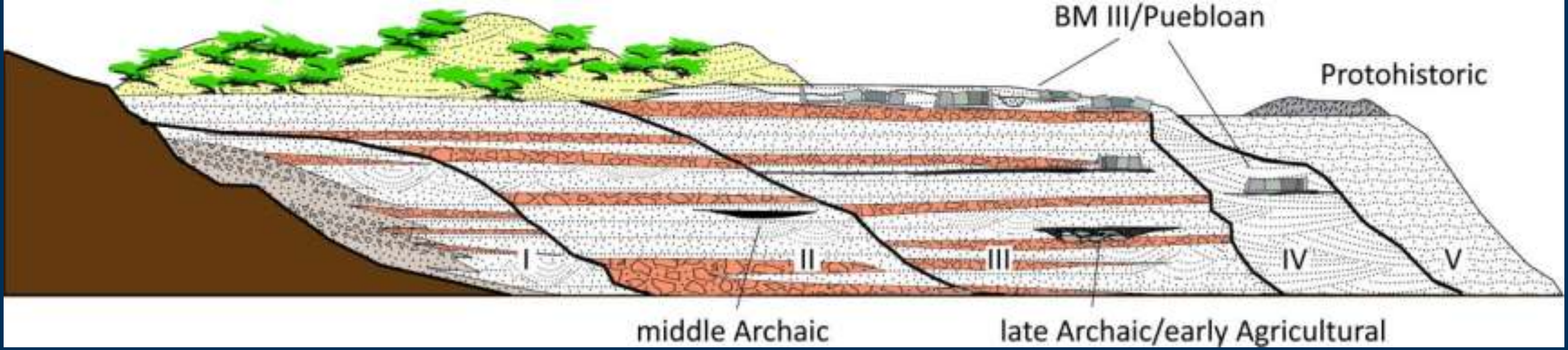


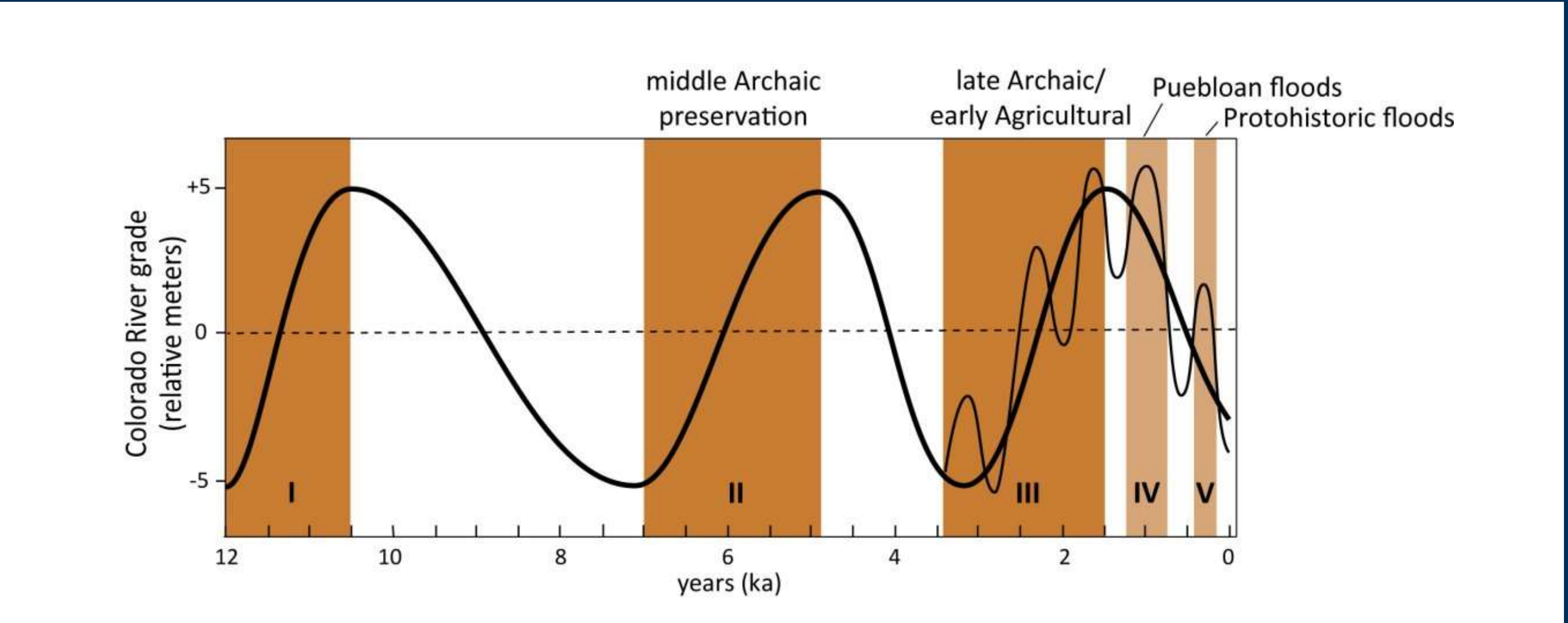



BM III/Puebloan
Protohistoric
I
II
III
IV
V
middle Archaic
late Archaic/early Agricultural


Terraces associated with segmented debris fans
Terrace height, in meters
13-17
Terraces associated with active debris fans
8-13
Striped alluvium
5-8
Alluvium of PII age
Upper mesquite terrace
2,800 m³/s
Post-dam discharge level
Bedrock and gravel
140 m³/s

Holocene included episodes of aggradation and incision over millenia scale, with superimposed paleoflood variations over centuries

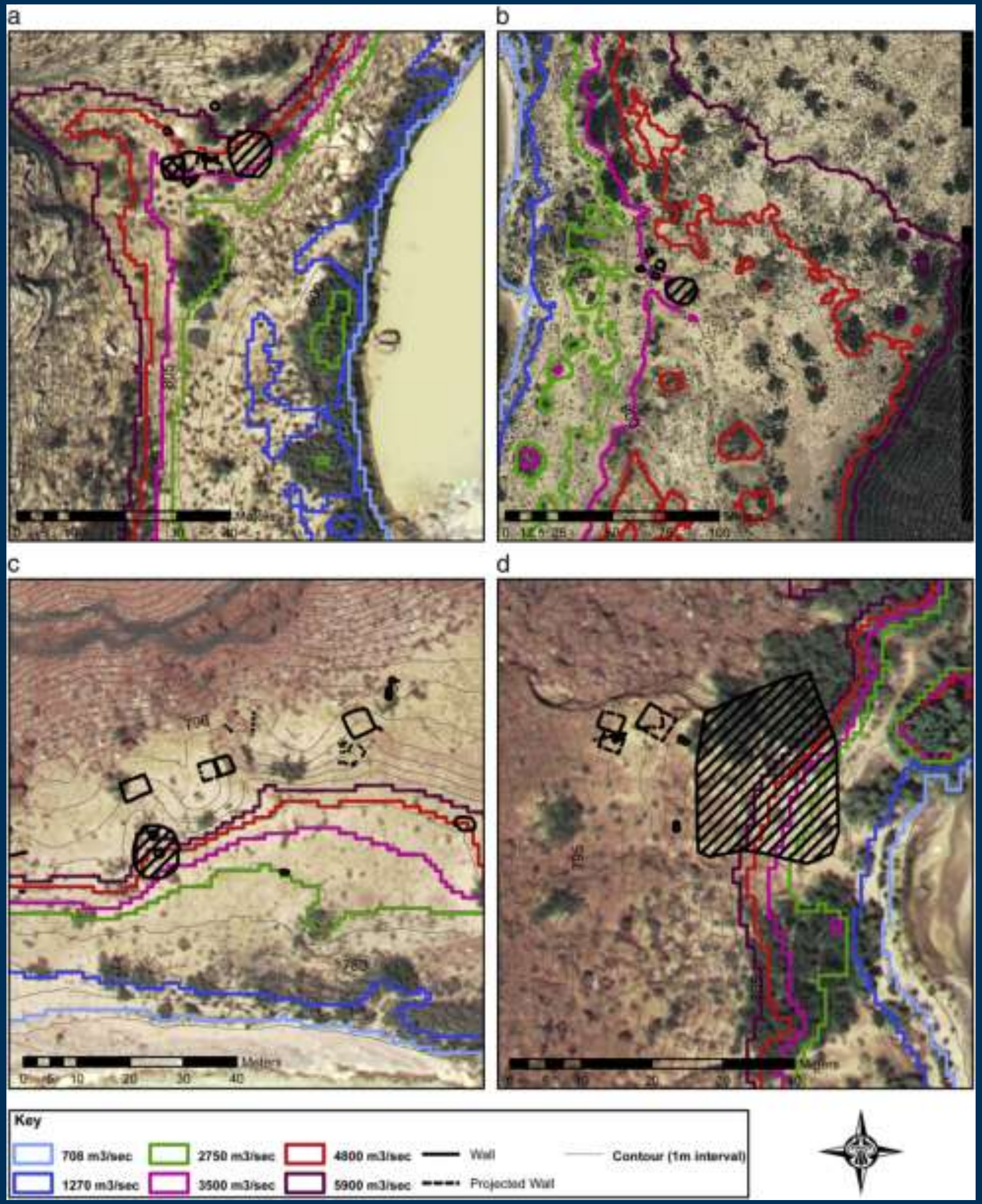




Evidence of fluvial deposition

Neff and others

- **Virtual shoreline data support interpretation of archaeological excavations**



SSQ 2-1. Do dam controlled flows increase or decrease rates of erosion at arch sites and TCP sites, and if so, how?

Numerical models may help us to answer this question in terns of how changes in sediment supply (amount and location) and surface conditions (e.g., infiltration capacity) have affected sites' susceptibility to erosion

but first we need to have some basic data about:

- Geomorphic setting characteristics
- Basic environmental parameters, i.e., soil characteristics, weather conditions, surface processes, etc.
- Appropriate tools to measure *rates* of change

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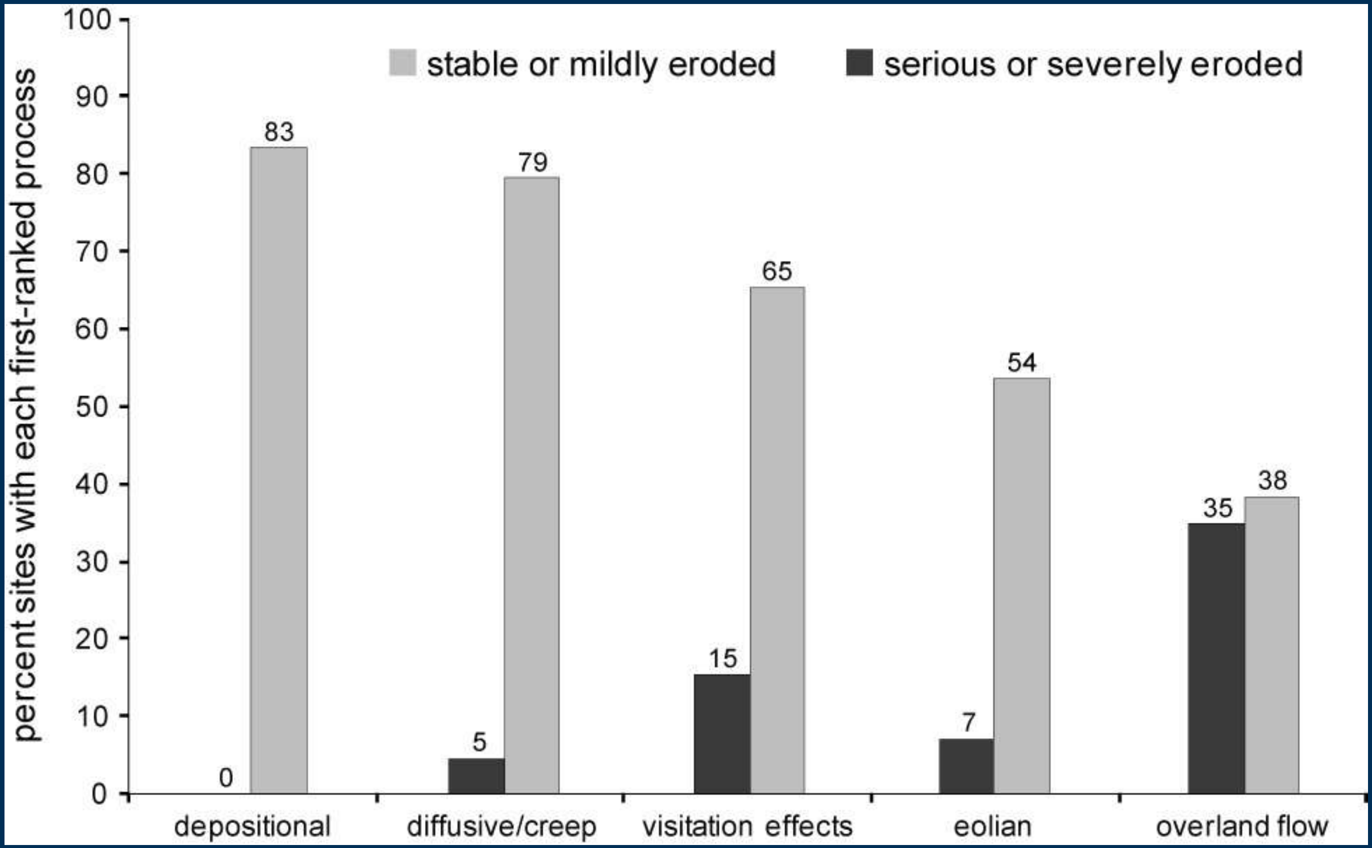
Dominant Geomorphic Processes correlated with erosion condition



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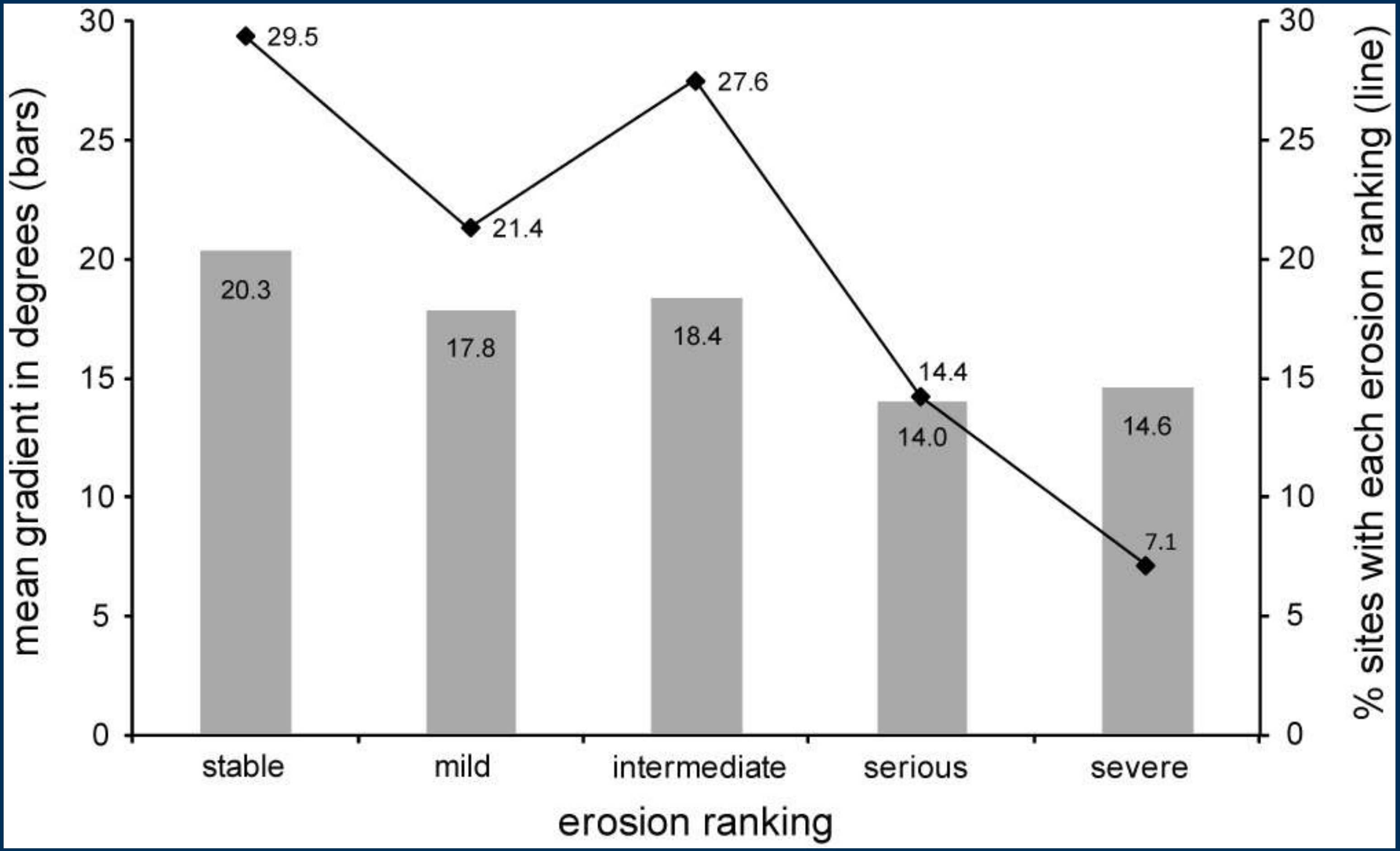
Erosion ranking in relation to slope



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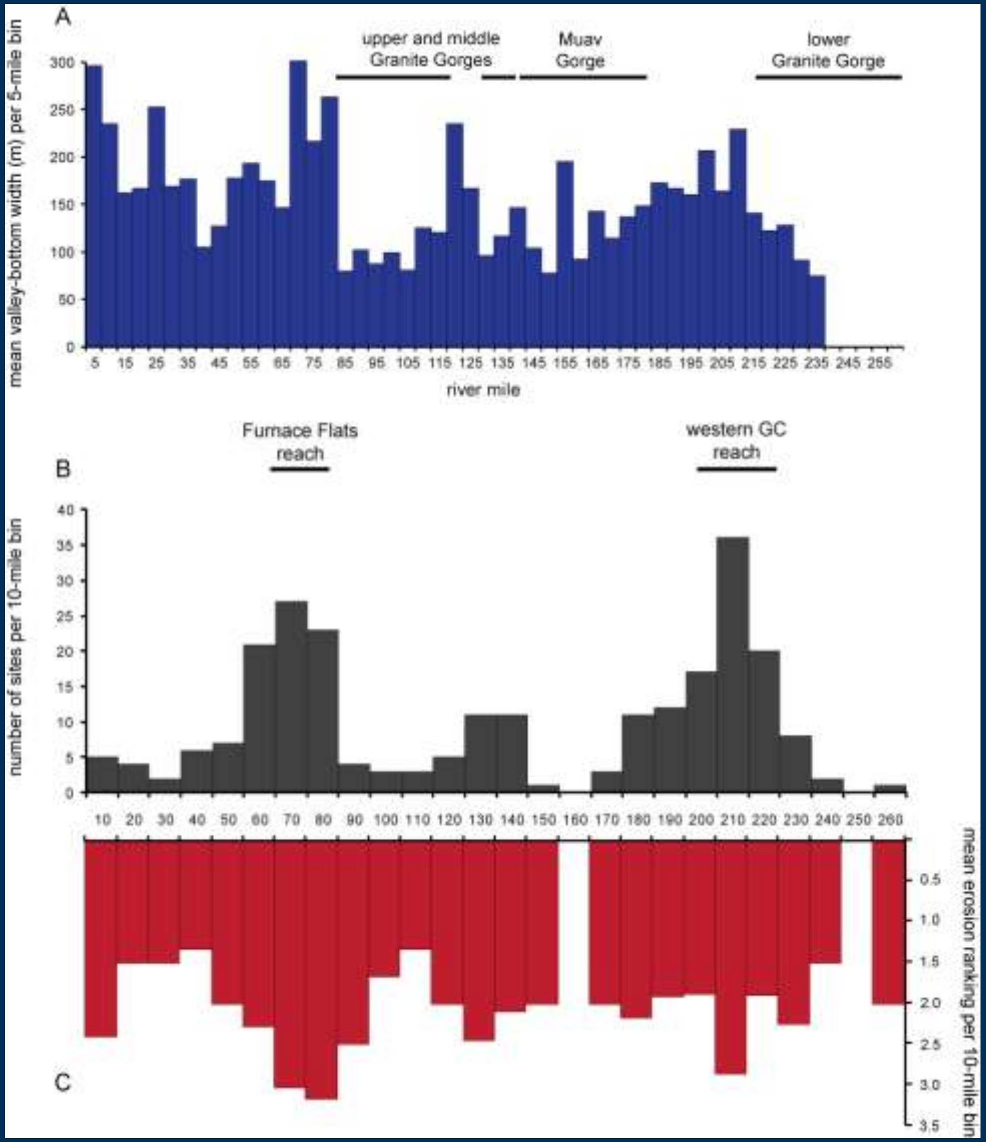
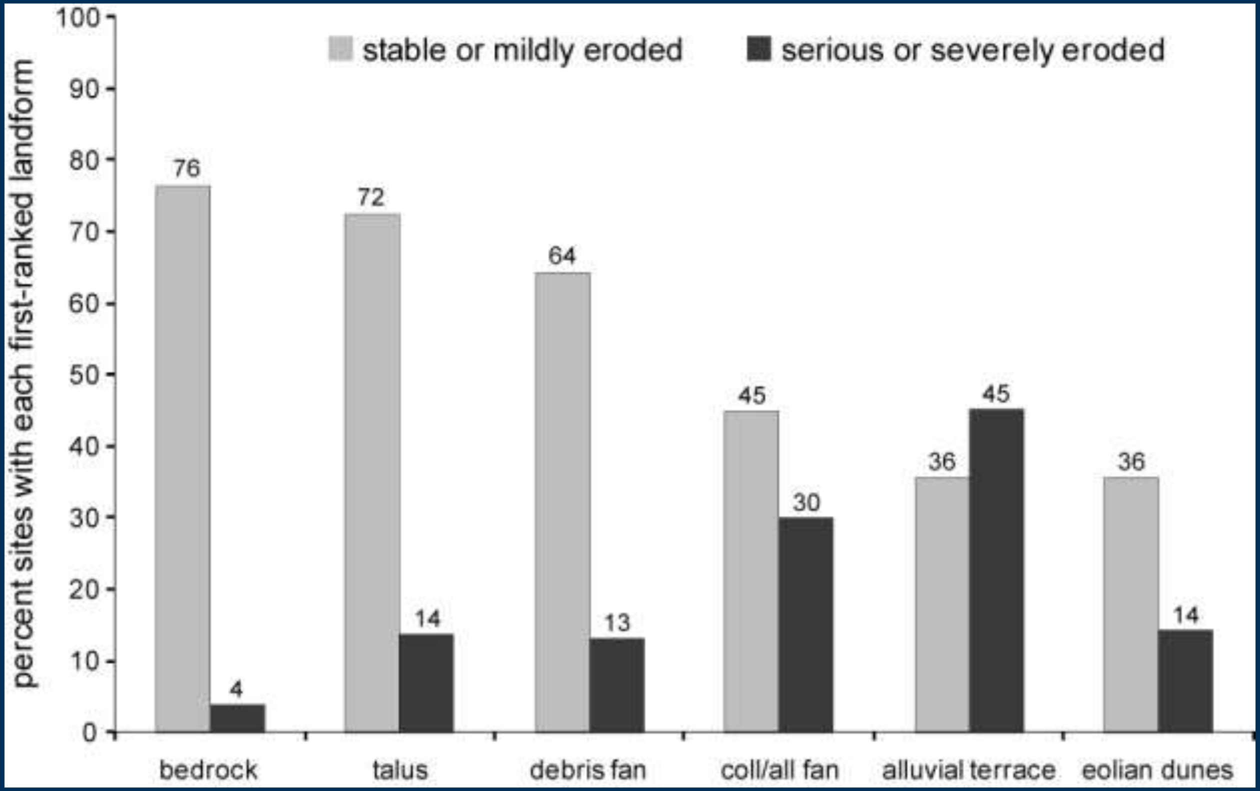
Erosion in relation to reach width



Most eroded sites associated with alluvial terraces (fine sand substrate)



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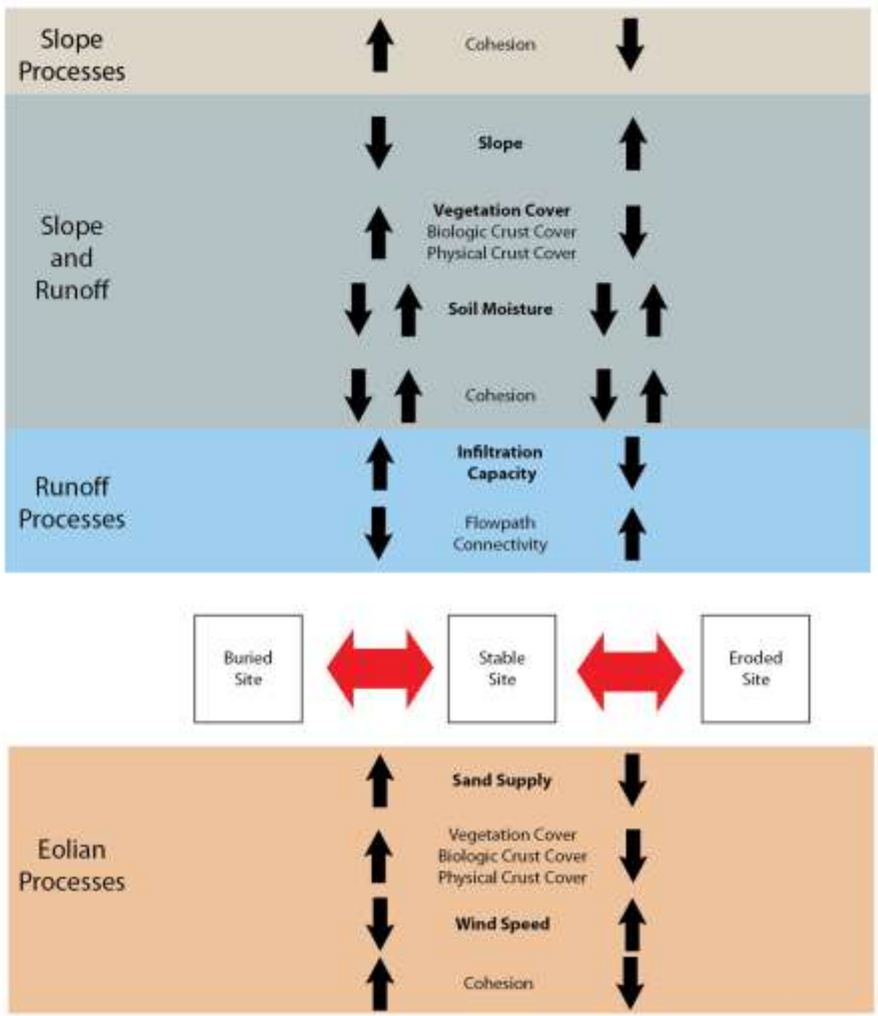
Modeling Effects of Surface Processes at Archaeological Sites



Note: Direction of arrow indicates that a change in that direction (increase or decrease) of the property or process may shift site stability. Double arrows indicate a threshold-type change where small changes may drive the state in one direction, but larger changes in the indicated direction may drive the site towards the other state

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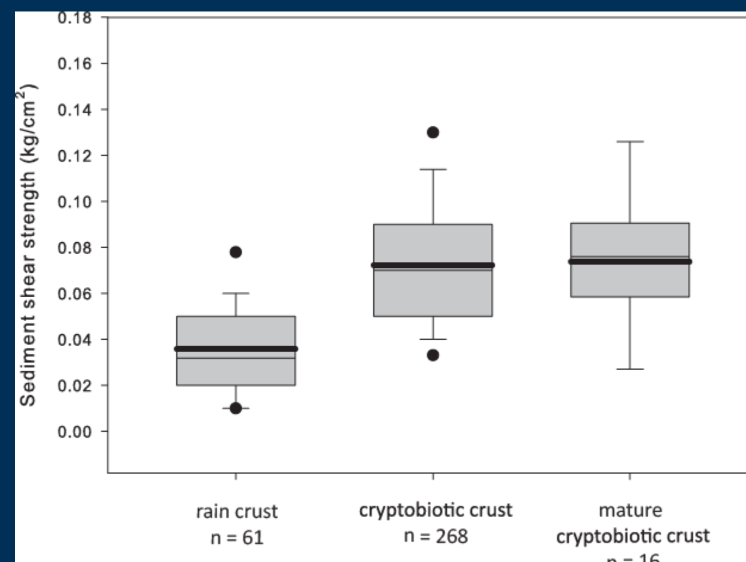
$P_i - I_c$ = runoff
all vary *systematically* across sites
$\tau = \gamma DS$ (topo)
erosion = τ – cohesion (biota,soil properties)

Soil characteristics: infiltration capacity, conductivity, shear strength

Hydraulic conductivity from 0.001 - 0.005 cm/s from mud crust to loose sand

Soil crust strength increases as it develops, from 0 - 0.08 kg/cm^2

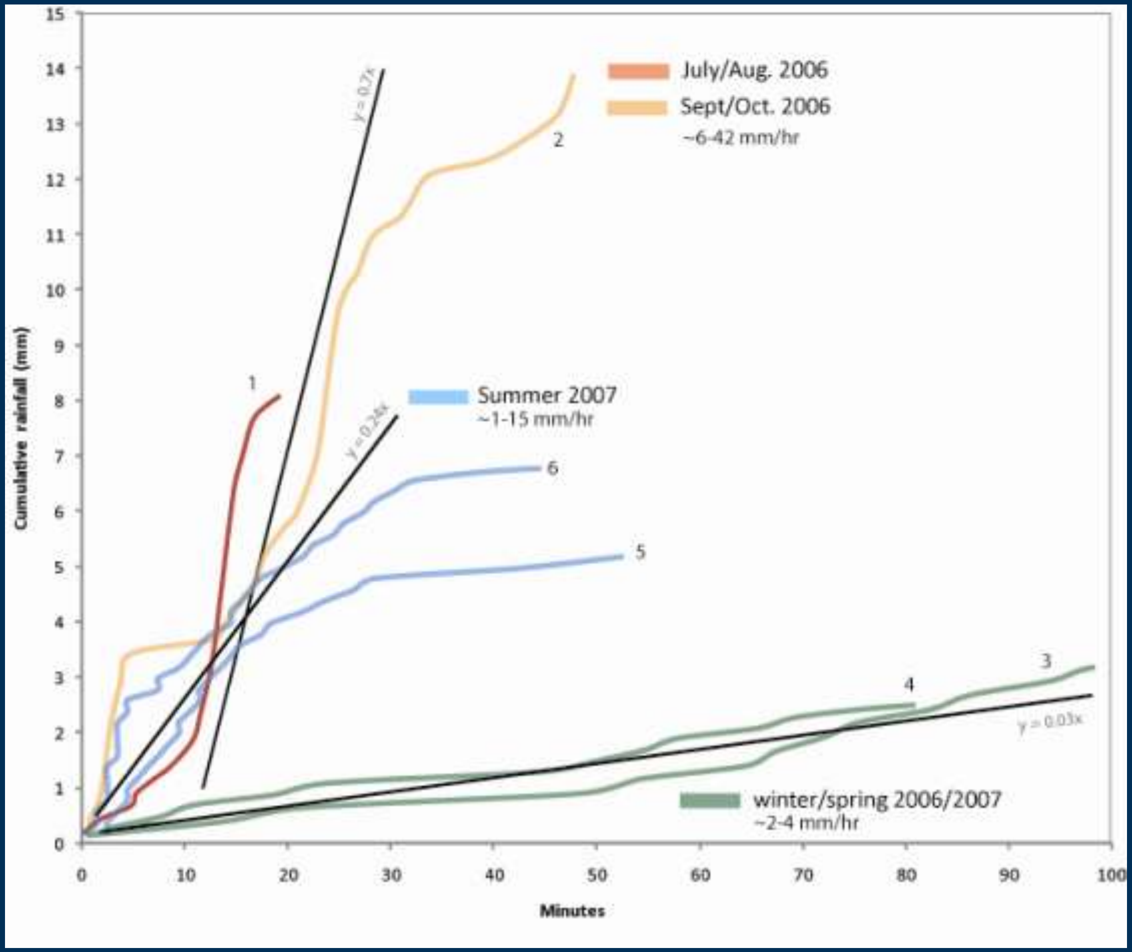


Gully Erosion and Precipitation Rates: High Inter-annual and spatial variability

ppt rates
70 -120 mm/hr

comparable to

soil infiltration
30-180 mm/hr



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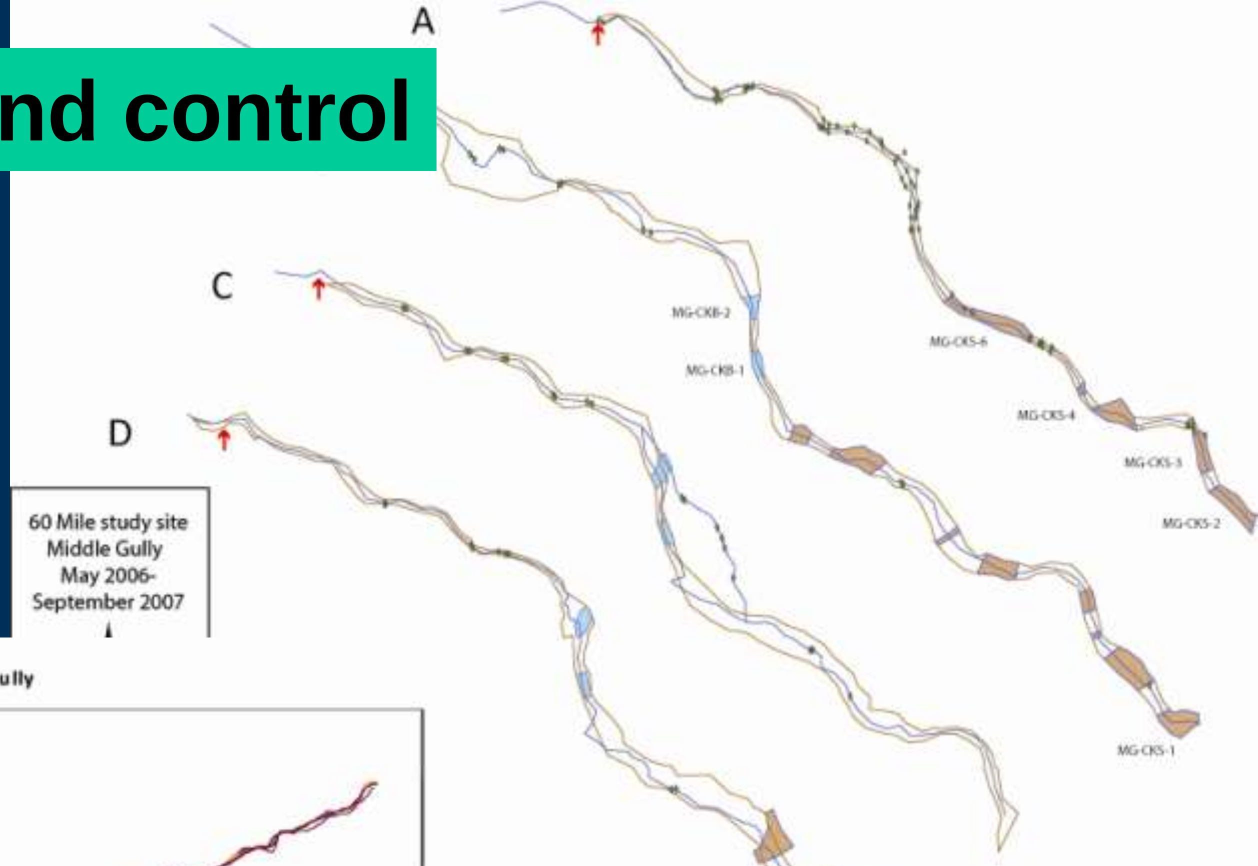
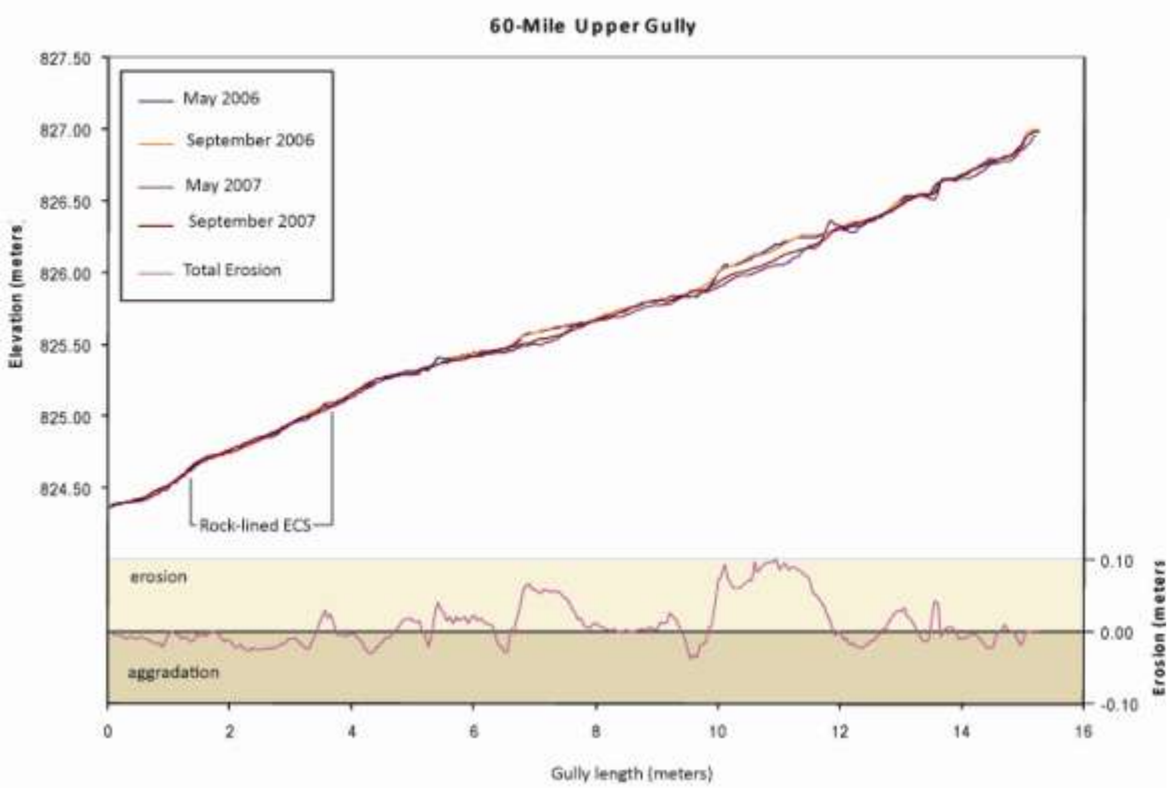
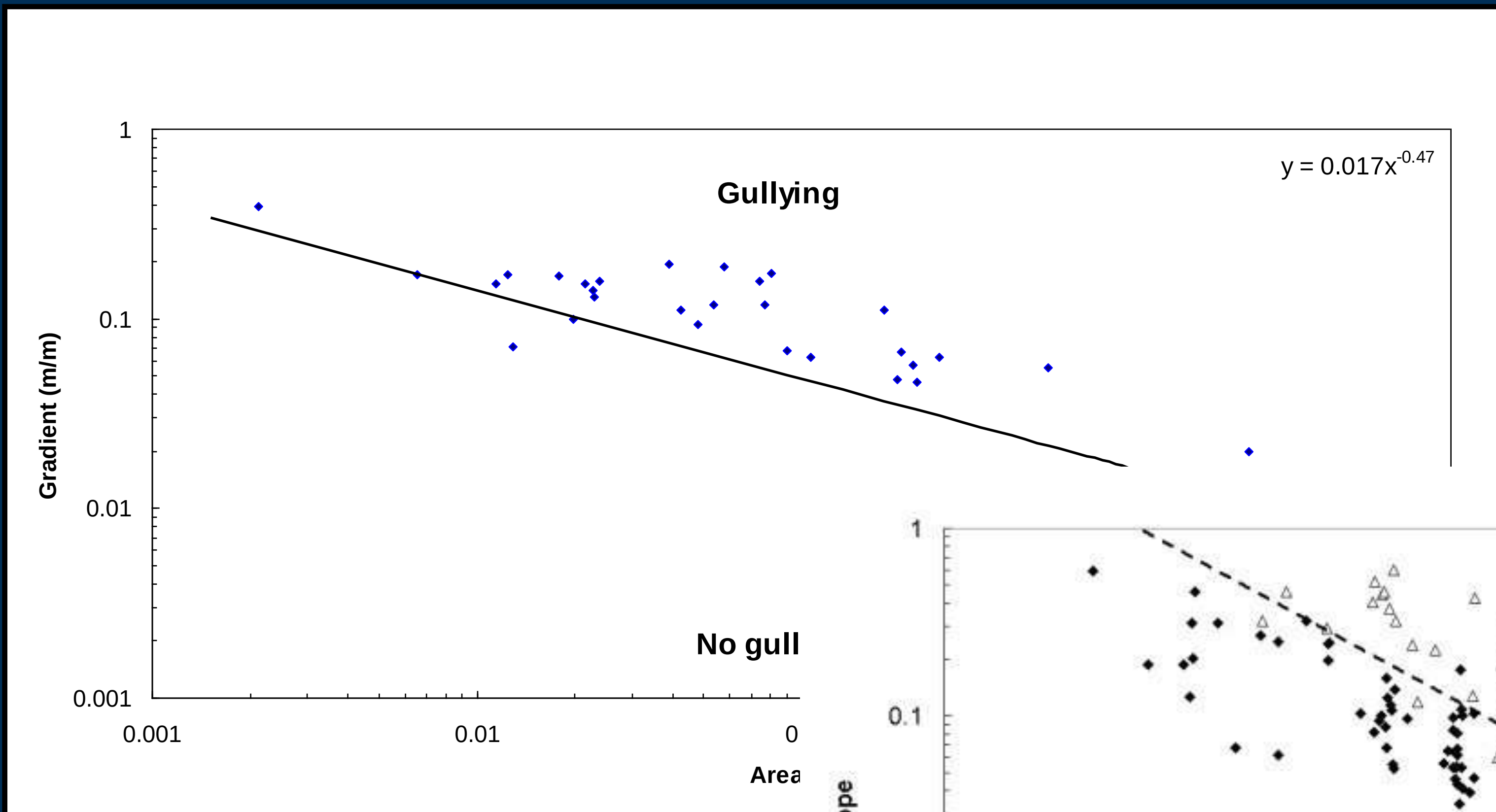
Gully erosion and control

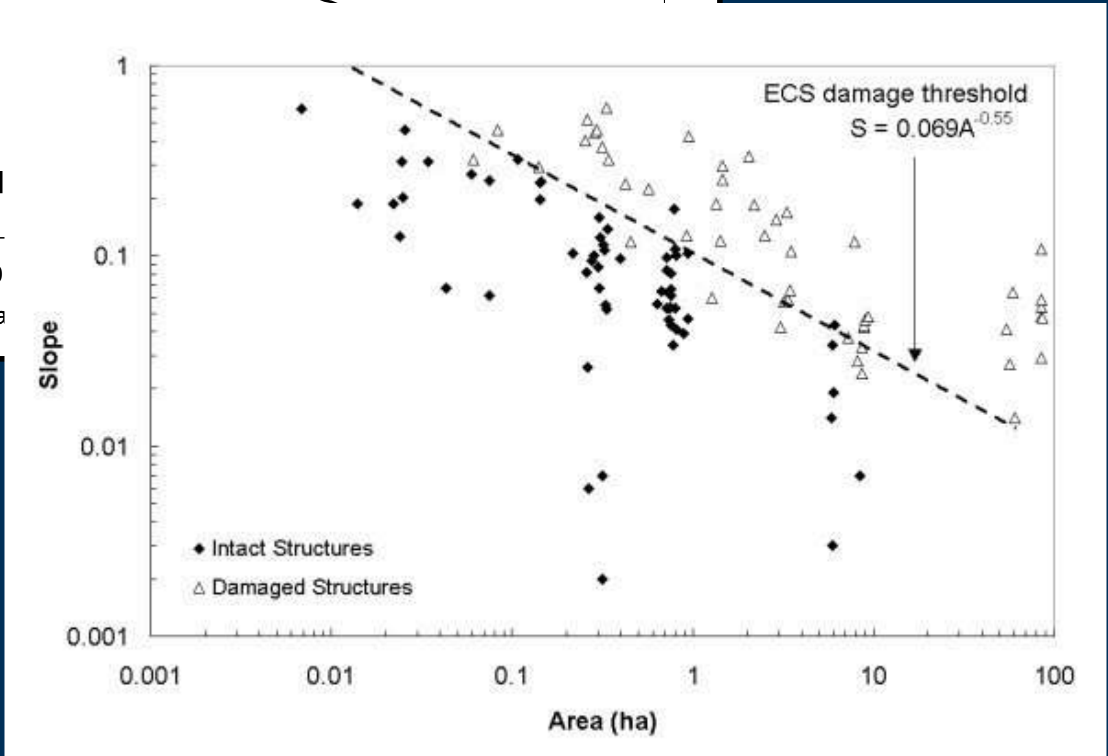
USU studies =
a LOT
of surveying





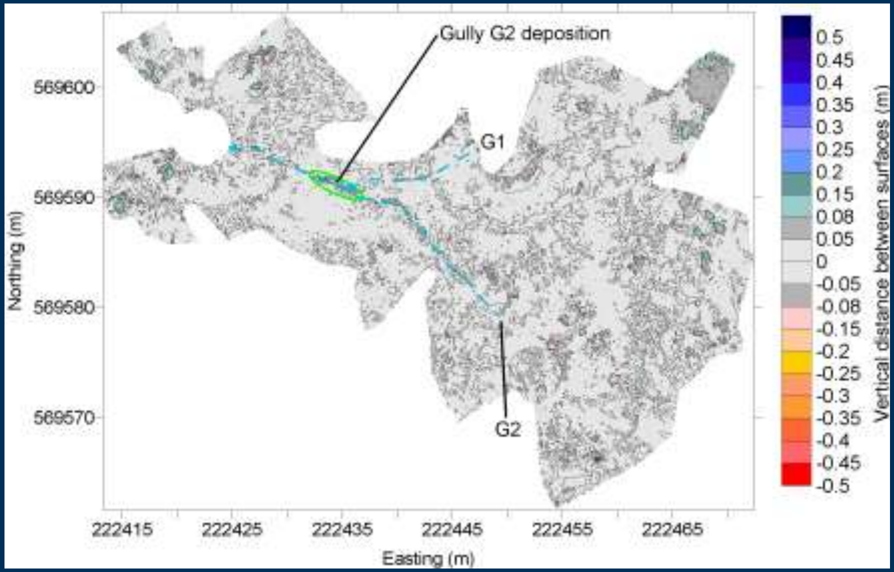
Gully erosion: topo slope-area threshold



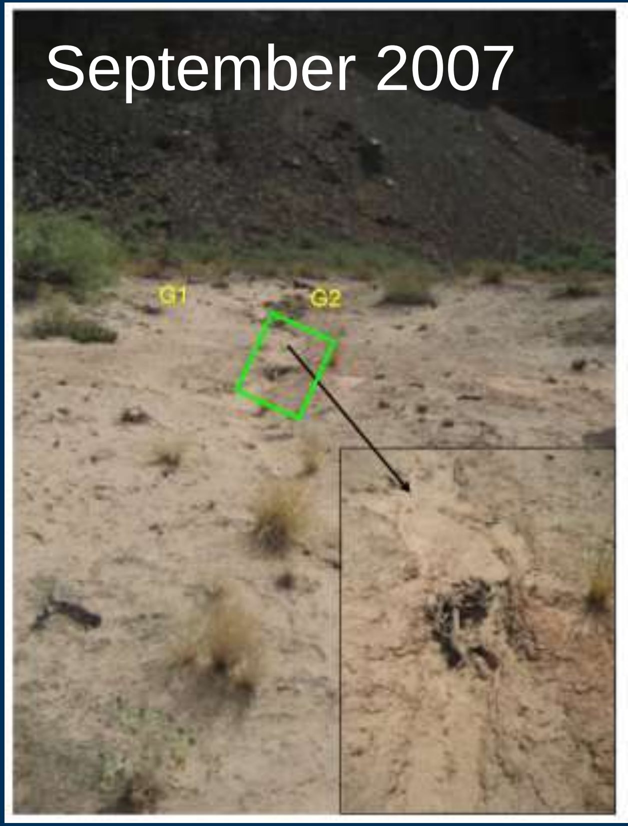


AZ C:13:0336 – Palisades Area

- **Alluvial terrace overlain by dune sands; cut by several gullies.**
- **Gully infilling document at check dam during 2006-2007.**



May 2006 – September 2007



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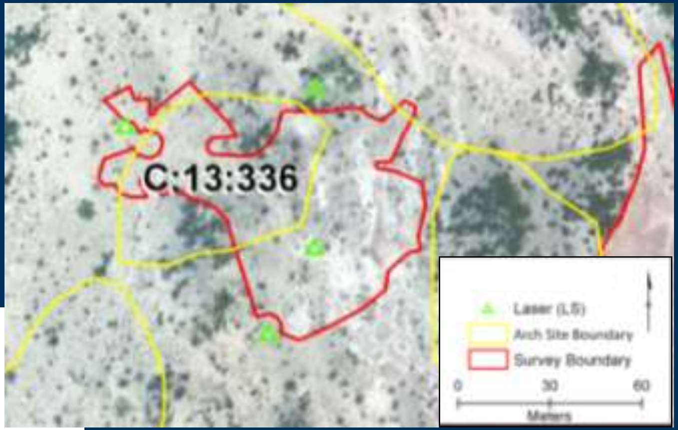
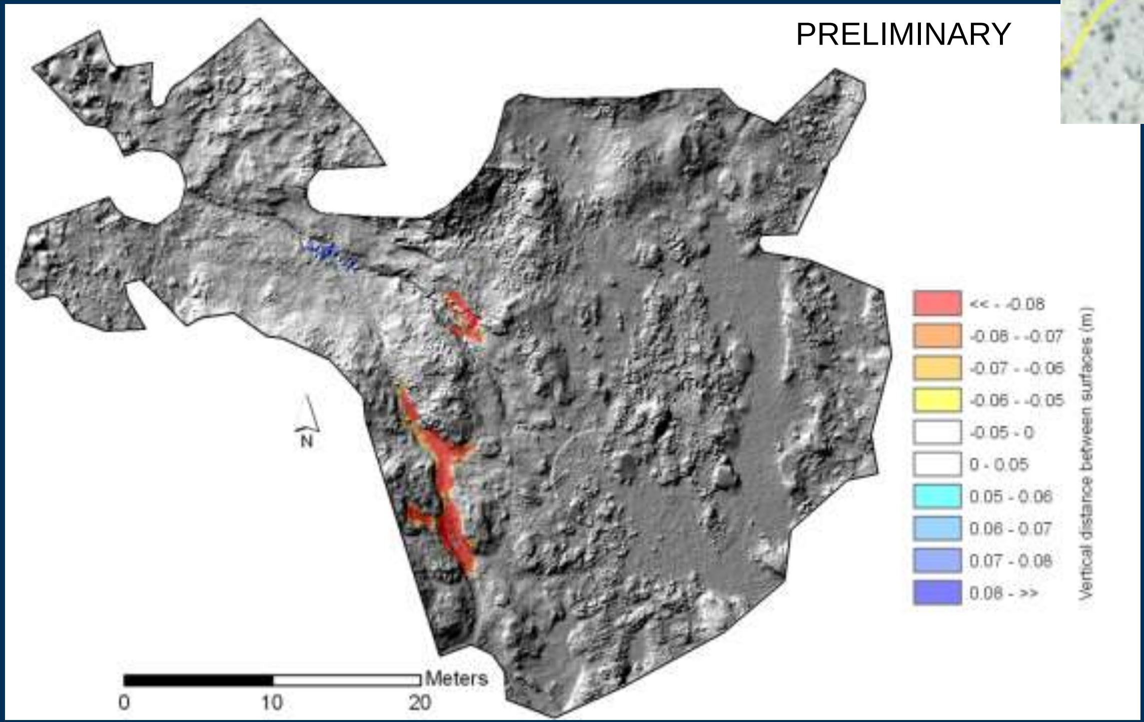
AZ C:13:0336 – Palisades Area

- **Gully erosion (>8 cm) from 2007-2010; continued in 2010**
- **Main geomorphic process is overland flow; possibly following a human trail**





Implication is that check dam may be locally effective, but gullying continues

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May 2007 – April 2010

Check Dam Studies

SSQ 2-4. How effective are various treatments (e.g., check dams, vegetation management, etc.) in slowing rates of erosion at archaeological sites over the long term?

1. **Check dams "work" (i.e., they temporarily retain sediment) as long as they are maintained AND IT DOES NOT RAIN HARD**

2. **Inevitably, a major storm event will occur that causes check dam failure (flanking, blow-outs, etc.)**

3. **Currently, check dams in GC are not engineered with reference to known/anticipated physical parameters – but they could be.**

4. **Do check dams reduce rates of gully incision over the long run? This remains unknown.**

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New HFE Science Question

Will multiple high flows conducted over a period of 10 years improve archaeological site condition as reflected in increased sand deposition, increased site stability, and reduction in rates of erosion?

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Need the right tools and data to answer this long-term question

- **Need methods to quantify changes occurring at archaeological sites specifically**
  - Track surface erosion and stability indicators (with and without erosion-control treatments)
- **Also need to be able to track changes over broader areas (and link back to arch sites)**
  - Track creation/retention/erosion of channel margin deposits and eddy sand bars that serve as sand sources
  - Track differences in transport conditions between low elevation (often damp) vs. high elevation (typically dry) sand bars
  - Measure vegetation encroachment (for effects on sand transport)
  - Continuous weather records for precip. and wind (minimally)

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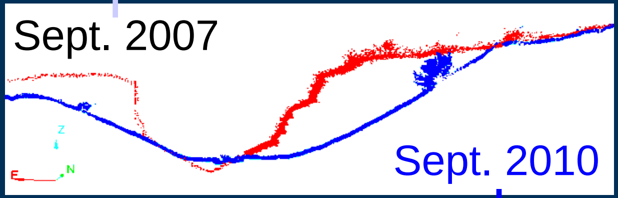
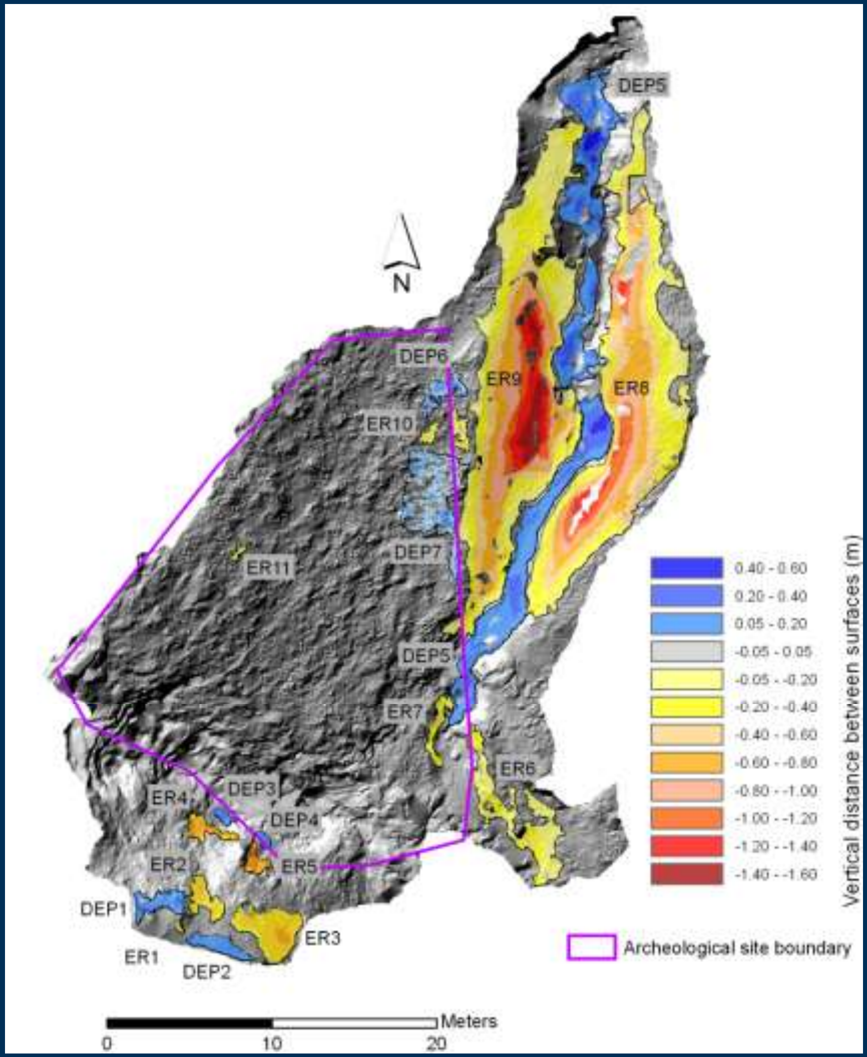
AZ B:10:0025 – Middle Granite Gorge





September 2007 – September 2010

Summary of net topographic change between April 2007 and September 2010

Site number (monitoring period)	Area w/ measured erosion (m^2)	Area w/ measured deposition (m^2)	Total percent of site area modeled w/change (percent)	Average, maximum height of erosion (cm)	Average, maximum height of deposition (cm)	Approx. volume of erosion (-) and deposition (+) (m^3)
AZ:C:13:0006 (Sept. 2007-April 2010)	27.0	8.8	2.8	15, 33	9, 22	**-3.3/+0.8**
AZ:C:13:0336 (Sept. 2007-April 2010)	39.1	2.2	2.9	7, 27	7, 15	**-3.6/+0.2**
AZ:C:13:0099 (Sept. 2007-April 2010)	103.0	22.5	19.6	12, 63	12, 59	**-17.3/+2.8**
AZ:C:13:0099 playa (Sept. 2007-April 2010)	3.6	0.4	0.1	7,13	6, 7	**-0.2/+0.02**
AZ:C:13:0348 and AZ:C:13:0346 (Sept. 2007-Sept. 2010)	85.3	21.2	3.5	9, 28	7, 13	**-8.6/+1.3**
AZ:B:10:0225 (Sept. 2007-Sept. 2010)	254.2	81.3	28.7	22, 160	13, 55	**-120.3/ +11.2**
AZ:G:03:0072 US (Sept. 2007-Sept. 2010)	92.1	50.8	11.8	11, 52	16, 60	**-13.8/+6.4**
AZ:G:03:0072 DS (Sept. 2007-Sept. 2010)	**0**	**0**	**0**	**0, 0**	**0, 0**	**0/0**

Current/ Future Direction

- **Develop numerical model to further investigate cause and effect relationships (Bedford)**
- **Populate model with currently available data**
  - **Measured topo change (Collins)**
  - **Weather data (Draut, Pederson)**
  - **Geomorphologic and soil data (Pederson and O'Brien)**
- **Example – AZ:C:13:0006**
  - **Site is within river influence and subject to gullying**
  - **In 2007 - wind vector sum = 43712 m^3/s^3 from 121° (SE)**
  - **Between May 2006 and May 2007, net deposition of sand = 17.6 m^3**
  - **Result was deposition and absence of new gullying at this gully location**

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Conclusions, Part I

- Holocene alluvial deposits record multiple cycles of aggradation and erosion
- Gullying occurred pre-dam
- Causes of gullying pre- and post dam are similar: excess overland flow – relative to surface conditions (Exner Equation!)
- Does this mean dam operations have not affected erosion rates of alluvial deposits?

Not necessarily . . .

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Conclusions, Part II

- Dam operations affect key parameters that influence landscape susceptibility to erosion
  - sediment supply
  - sand source & transport conditions (bar size, elevation, dampness, etc.)
  - soil / surface characteristics
  - vegetation cover

AND

- Current dam operations limit the processes that naturally mitigated pre-dam erosion (e.g., back filling of gullies by flood sand, aeolian infilling)

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Conclusions, Part III

- **We can not manage primary "drivers" of erosion:**
  - **Climate and weather (rainfall, wind)**
  - **Canyon topography, bedrock slopes**
- **We <u>can</u> manage sediment supply & elevation, surface conditions, vegetation, through modified dam ops**

- **Check dams can retain sediment for short periods; they are prone to fail in large storm events (unless engineered to withstand expected erosional forces)**

- **Under <u>current</u> conditions, gully erosion is likely to continue, with or without check dams**

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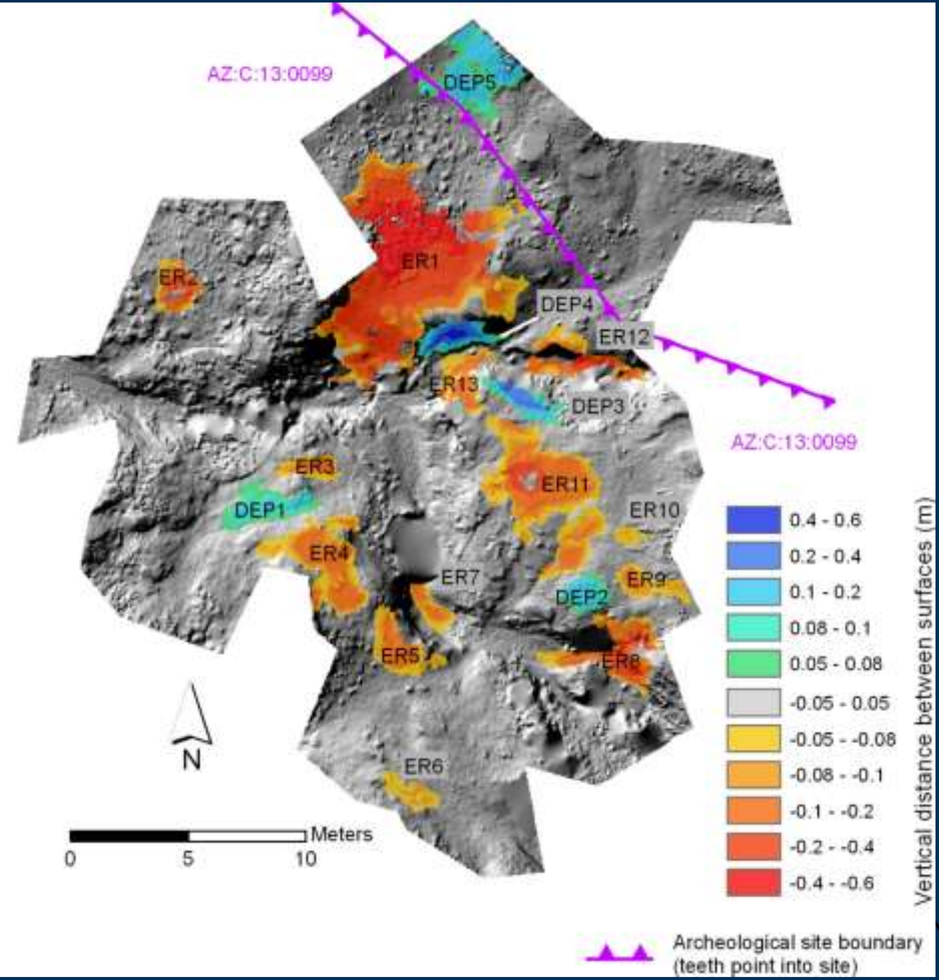
Questions?

AZ C:13:0099 – Palisades Area



NARY

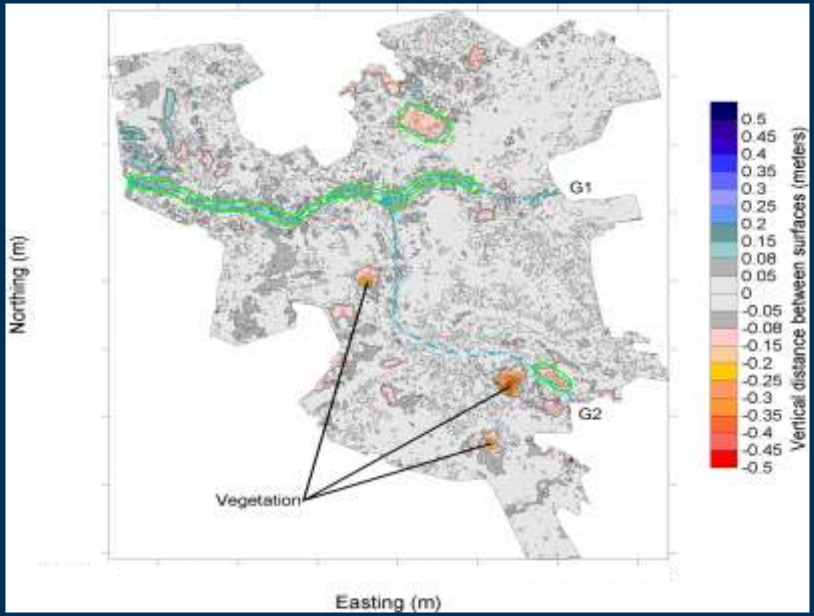
- Major erosion/ deposition during 2007-2010
- 2008 excavations primary source of changes
- Additional gully widening between 2007-2010

Sept. 2007 – April 2010

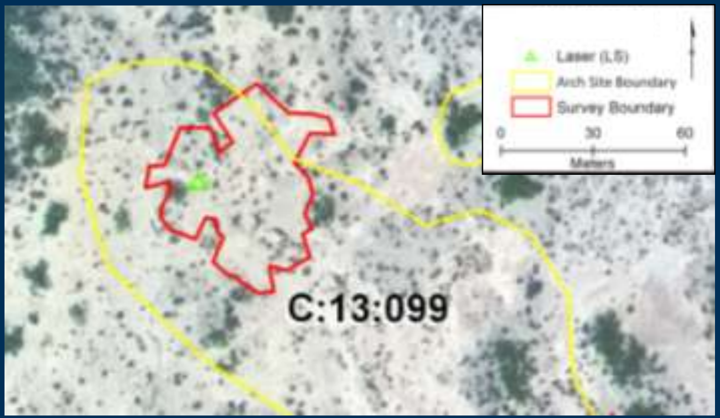
USGS

AZ C:13:0099 – Palisades Area

- **Alluvial terrace overlain by dune sands and cut by several gullies.**
- **Gully sidewall and sand dune erosion, and gully bottom infilling during 2006-2007.**



May 2006 – Sept. 2007



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Change detection summary - May 2006 – Sept. 2010

Site Number	5/2006-5/2007	5/2007-9/2007	9/2007-4/2010	4/2010-9/2010
AZ:C:05:0031	n/a	n/a	n/a	E
AZ:C:13:0006	E + D	E	E + D	0
AZ:C:13:0336	D	D	E + D	E
AZ:C:13:0099	E + D	E + D	E + D	0
AZ:C:13:0099 Playa	E	0	E + D	0
AZ:C:13:0321	n/a	n/a	n/a	E
AZ:C:13:0009	n/a	n/a	n/a	0
AZ:C:13:0348	0	0	0	
AZ:B:01:0225	n/a	n/a	E + D	
AZ:G:03:0041	D	D	n/a	n/a
AZ:G:03:0002	0	0	n/a	n/a
AZ:G:03:0072 (US)	E	E	E + D	
AZ:G:03:0072 (DS)	0	0	E	

E	Erosion
D	Deposition
E + D	Erosion & deposition
0	No changes
n/a	Site not monitored

Multiple projects over the years

SWCA

- 1999-2001 Site vulnerability model (Thompson and Potochnik)

Utah State University Studies, 2001-2009

- 2001-03   gullying, checkdam effectiveness, Phase I (Pederson and other, 2003, 2005)
- 2005-07   geoarch treatment plan (Pederson and Damp 2007)
- 2006-09   gullying, checkdam effectiveness, Phase II
- 2006-09   site assessment database development

US Geological Research

- 2003-2007 Aeolian Research Project (Rubin, Draut and others)
- 2007-2011 Cultural Monitoring R&D Project (Fairley, Collins, Draut, and others)

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Interpretations

- Most archaeological sites have undergone some topographic changes during the monitoring period
- Some sites have changed very little or not at all
- Changes have occurred during all time frames
- Erosion and deposition can occur concurrently within a single site
- Current data does not allow a predominant signal for <u>all</u> sites (erosion or deposition) to be identified
- Current data does allow a predominant signal for <u>each</u> site to be identified
- Dates of data collection precluded effects of HFE from being extracted from overall change detection signals

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Summary of net topographic change between April and September 2010

Site number (monitoring period)	Area w/ measured erosion (m^2)	Area w/ measured deposition (m^2)	Total percent of site area modeled w/change (percent)	Average, maximum height of erosion (cm)	Average, maximum height of deposition (cm)	Approx. volume of erosion (-) and deposition (+) (m^3)
AZ:C:05:0031 (April 2010-Sept. 2010)	134.9	0	5.4	4, 30	0, 0	**-5.7/0**
AZ:C:13:0006 (April 2010- Sept. 2010)	2.2	0	0.2	6, 16	0, 0	**-0.1/0**
AZ:C:13:0336 (April 2010- Sept. 2010)	16.5	1.5	1.3	3, 9	3, 5	**-0.6/+0.1**
AZ:C:13:0099 (April 2010- Sept. 2010)	0.4	2.3	0.4	4, 6	5, 9	**-0.02/+0.1**
AZ:C:13:0099 playa (April 2010- Sept. 2010)	0.02	0	0.001	5, 6	0, 0	**-0.001/0**
AZ:C:13:0321 (April 2010-Sept. 2010)	**13.9**	**0**	**10.0**	**4, 14**	**0, 0**	**-0.6/0**

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