Flow Alteration, Vegetation Dynamics, and the Influence of Glen Canyon Dam on Sediment Connectivity along the Colorado River in Grand Canyon

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4 February 2020

<u>with</u> Joel Sankey, Joshua Caster, Amy East, Paul Grams [USGS]
Dan Buscombe, Brad Butterfield, Laura Durning [Northern Arizona University]

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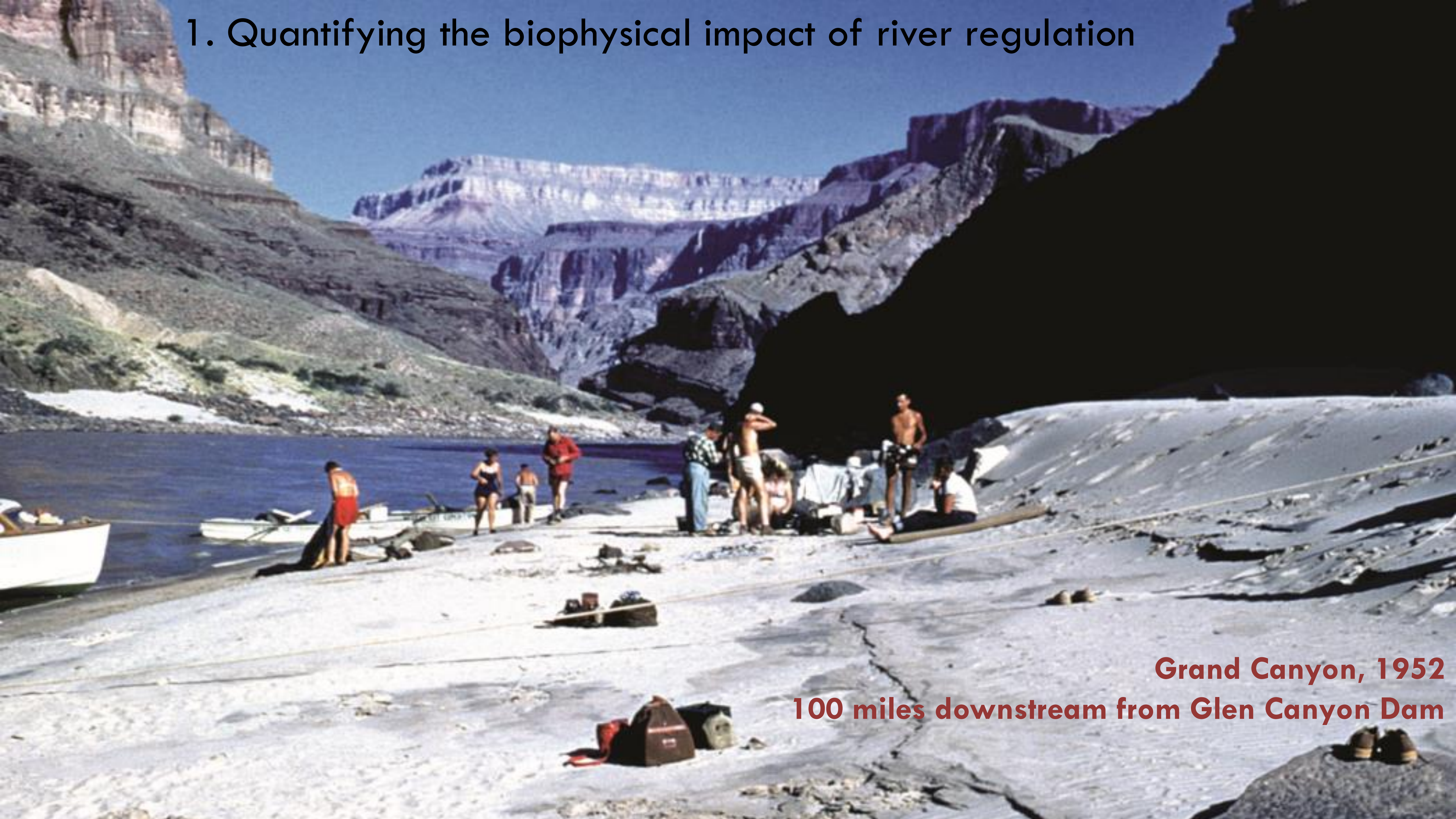
I use geospatial science/GIS
to understand impacts of dams
on rivers of the Southwestern U.S.

UTAH GEOSPATIAL CONSORTIUM

Center for COLORADO RIVER Studies

Right now, my research covers two main themes…

1. Quantifying the biophysical impact of river regulation



Grand Canyon, 1952
100 miles downstream from Glen Canyon Dam

1. Quantifying the biophysical impact of river regulation

Grand Canyon, 2003
100 miles downstream from Glen Canyon Dam

2. Recovery timescales of large reservoir inundation

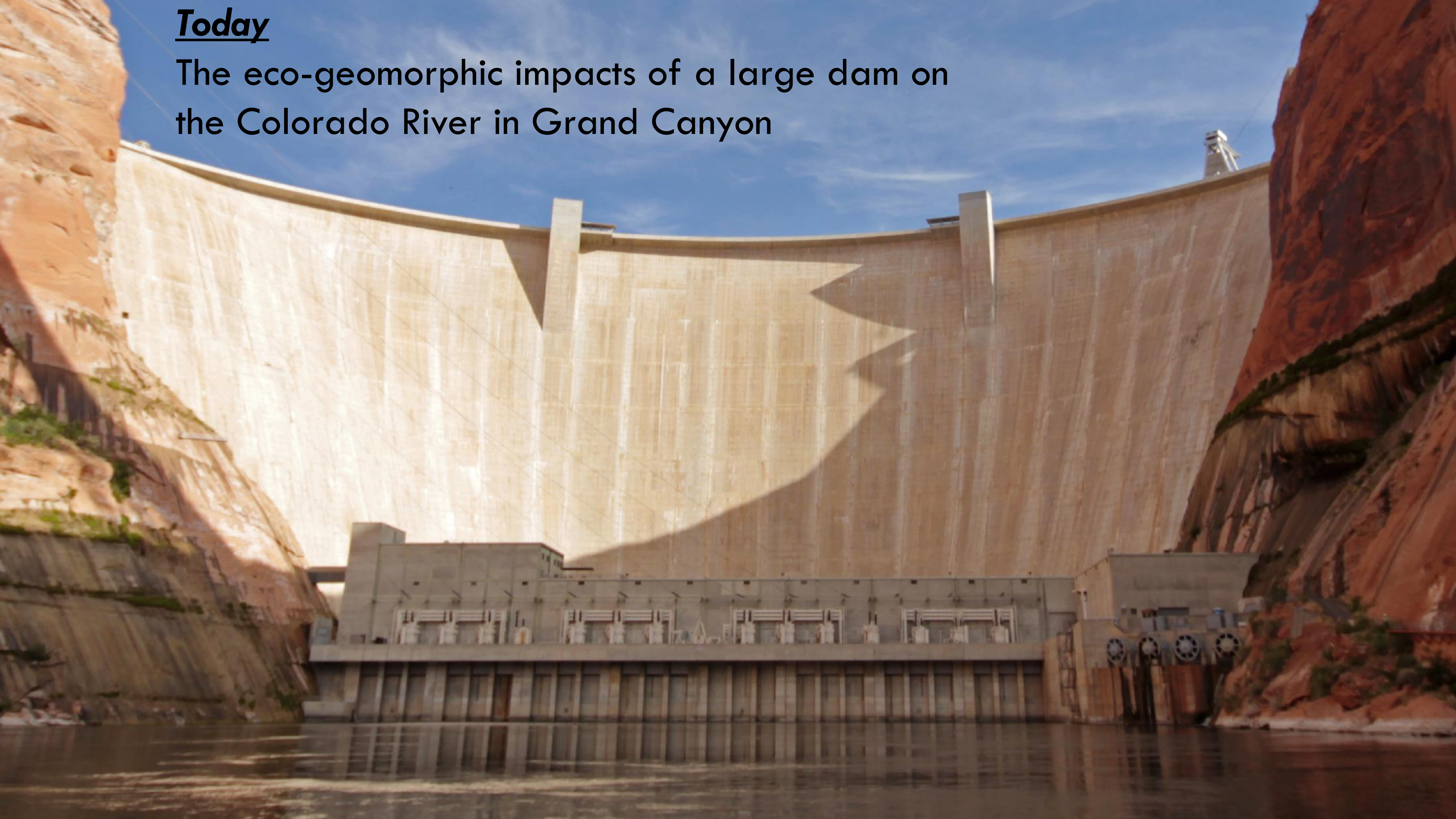
Colorado River Delta, Upper Lake Powell, near Hite, Utah

2. Recovery timescales of large reservoir inundation

2. Recovery timescales of large reservoir inundation

Today

The eco-geomorphic impacts of a large dam on the Colorado River in Grand Canyon



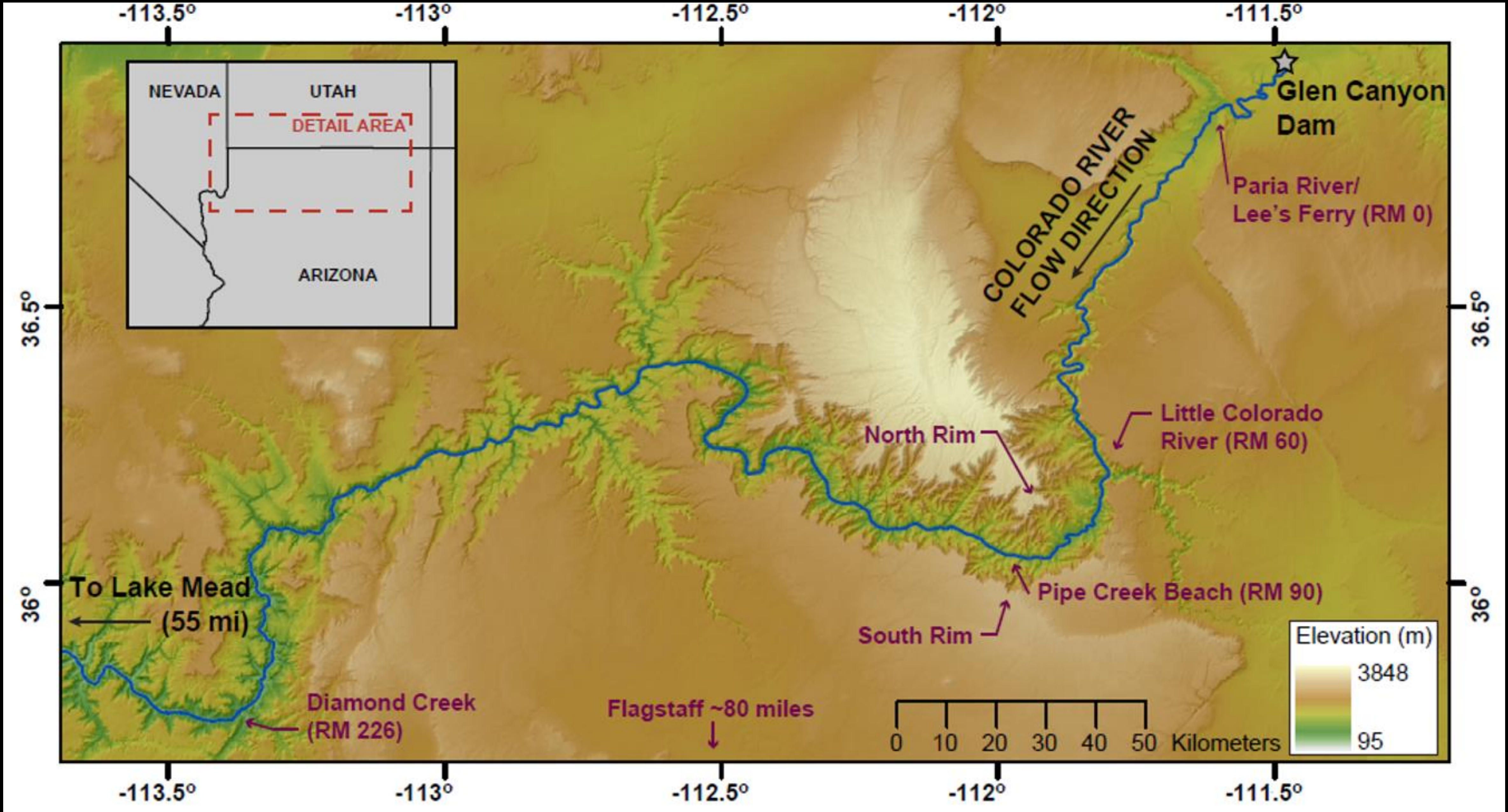
Colorado River Compact, 1922

An attempt to preserve water security for 7 western states under rapidly expanding populations and water needs

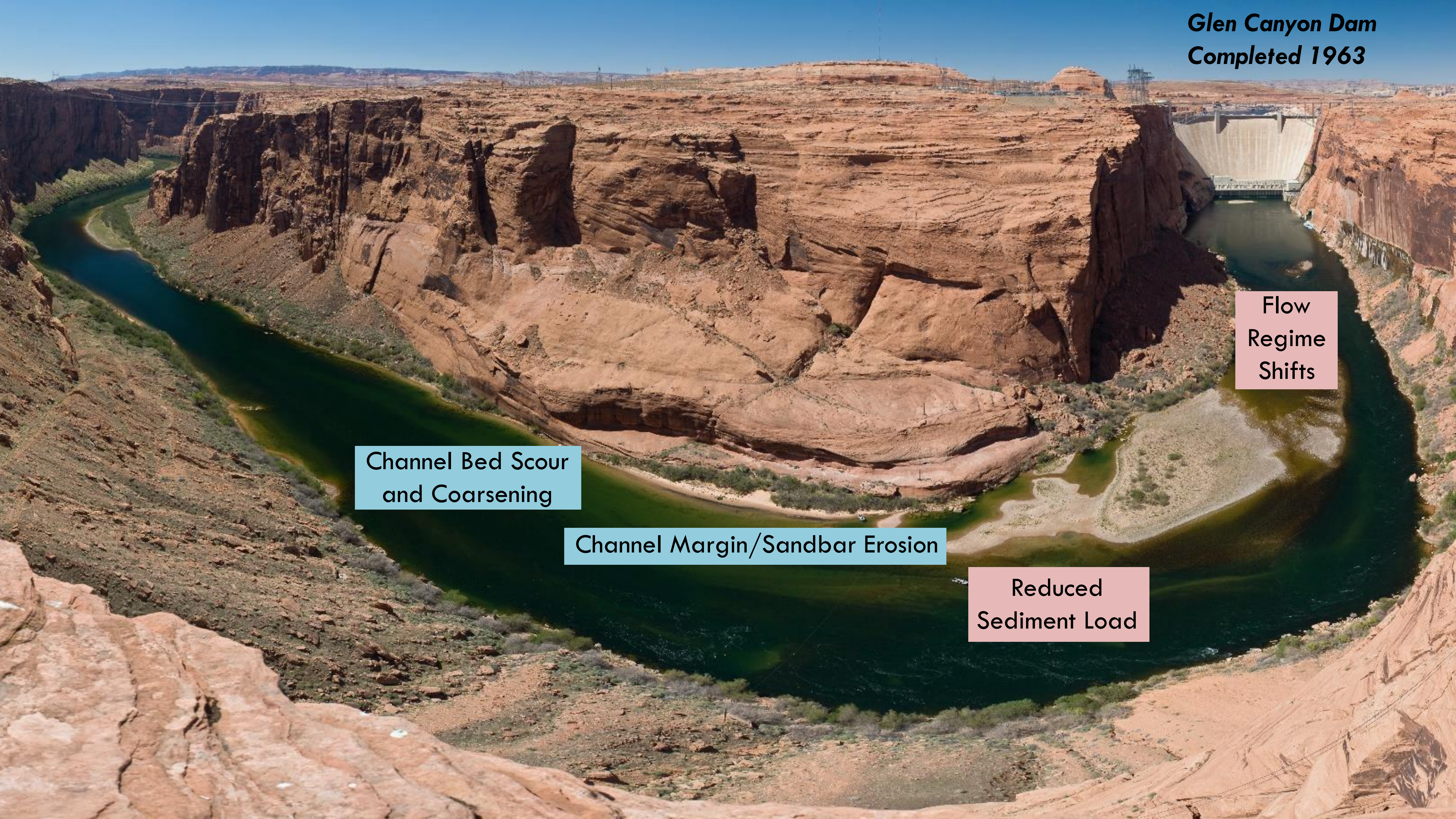
Upper Basin states must deliver ~7.5 million acre-feet of water to the Lower Basin each year

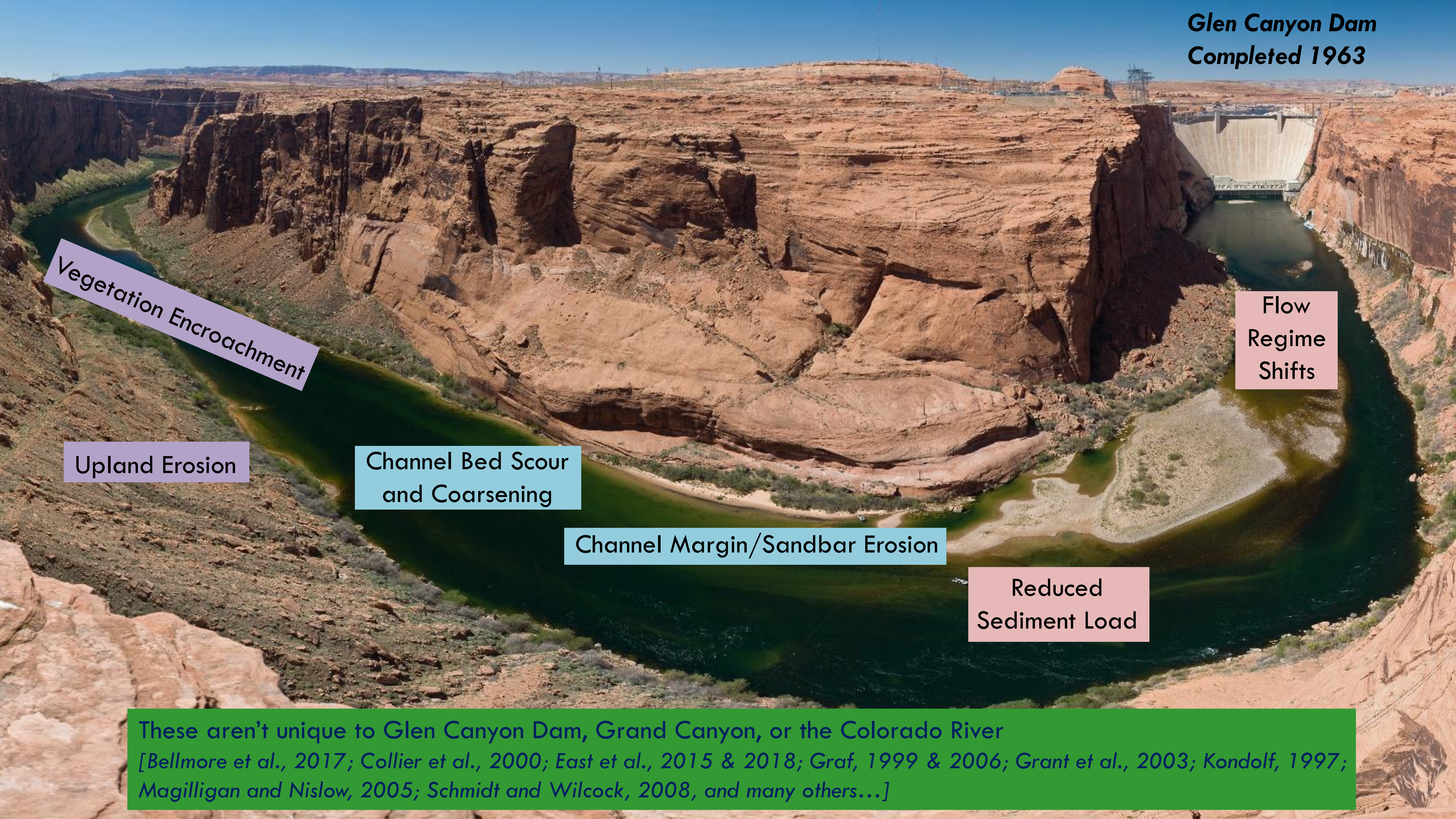
Lake Powell/Glen Canyon Dam provide a means for ensuring that water is there to be delivered


Lake Powell filling behind nearly-complete Glen Canyon Dam, 1963, Ed Gibson


-113.5°
-113°
-112.5°
-112°
-111.5°
36.5°
36°
NEVADA
UTAH
DETAIL AREA
ARIZONA
Glen Canyon Dam
COLORADO RIVER FLOW DIRECTION
Paria River/
Lee's Ferry (RM 0)
Little Colorado
River (RM 60)
North Rim
Pipe Creek Beach (RM 90)
South Rim
To Lake Mead
(55 mi)
Diamond Creek
(RM 226)
Flagstaff ~80 miles
0 10 20 30 40 50 Kilometers
Elevation (m)
3848
95


Glen Canyon Dam
Completed 1963
Flow Regime Shifts
Reduced Sediment Load


Glen Canyon Dam
Completed 1963
Flow
Regime
Shifts
Channel Bed Scour
and Coarsening
Channel Margin/Sandbar Erosion
Reduced
Sediment Load



These aren't unique to Glen Canyon Dam, Grand Canyon, or the Colorado River

[Bellmore et al., 2017; Collier et al., 2000; East et al., 2015 & 2018; Graf, 1999 & 2006; Grant et al., 2003; Kondolf, 1997; Magilligan and Nislow, 2005; Schmidt and Wilcock, 2008, and many others…]

<u>Today:</u>

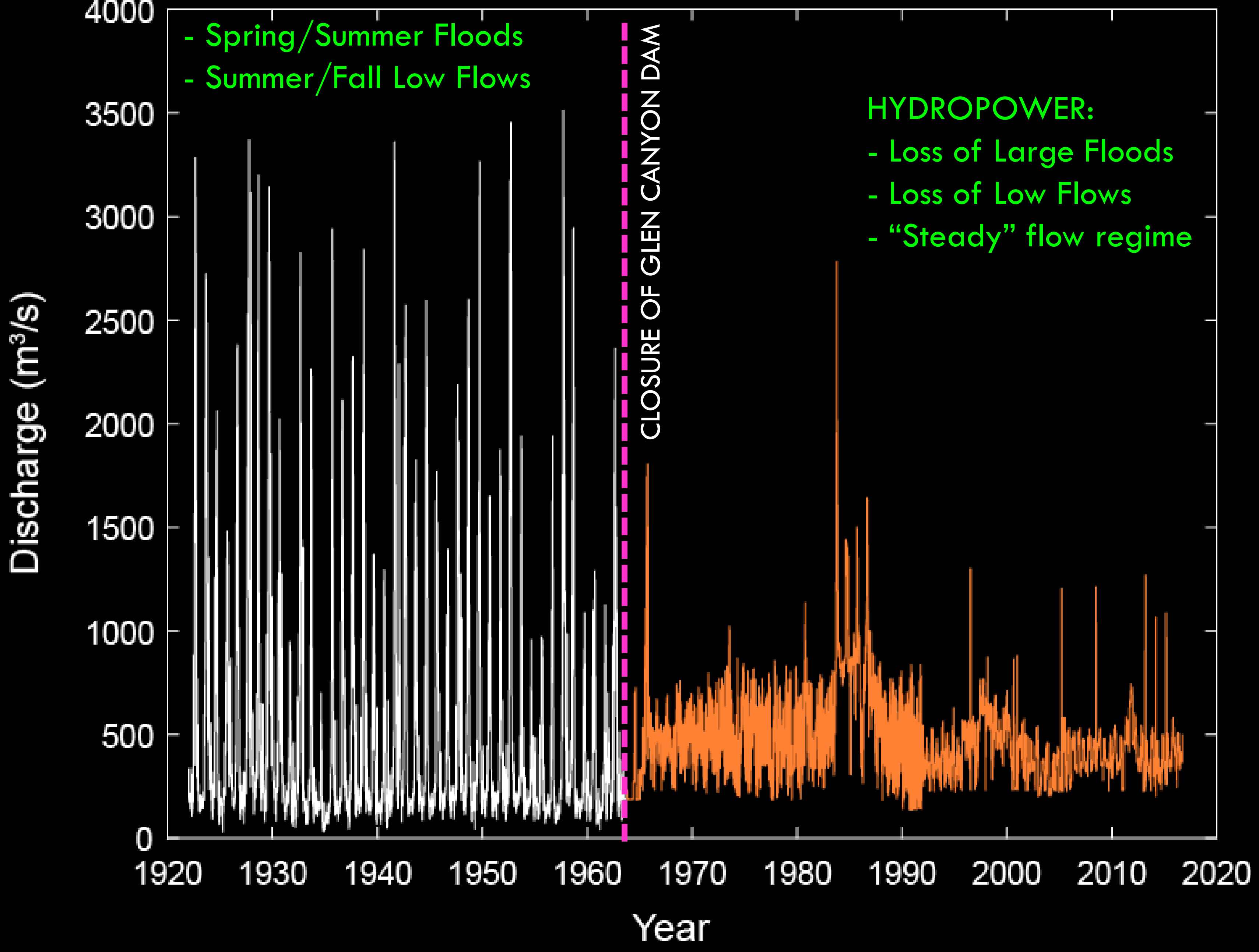
Two alterations to Colorado River driven by Glen Canyon Dam

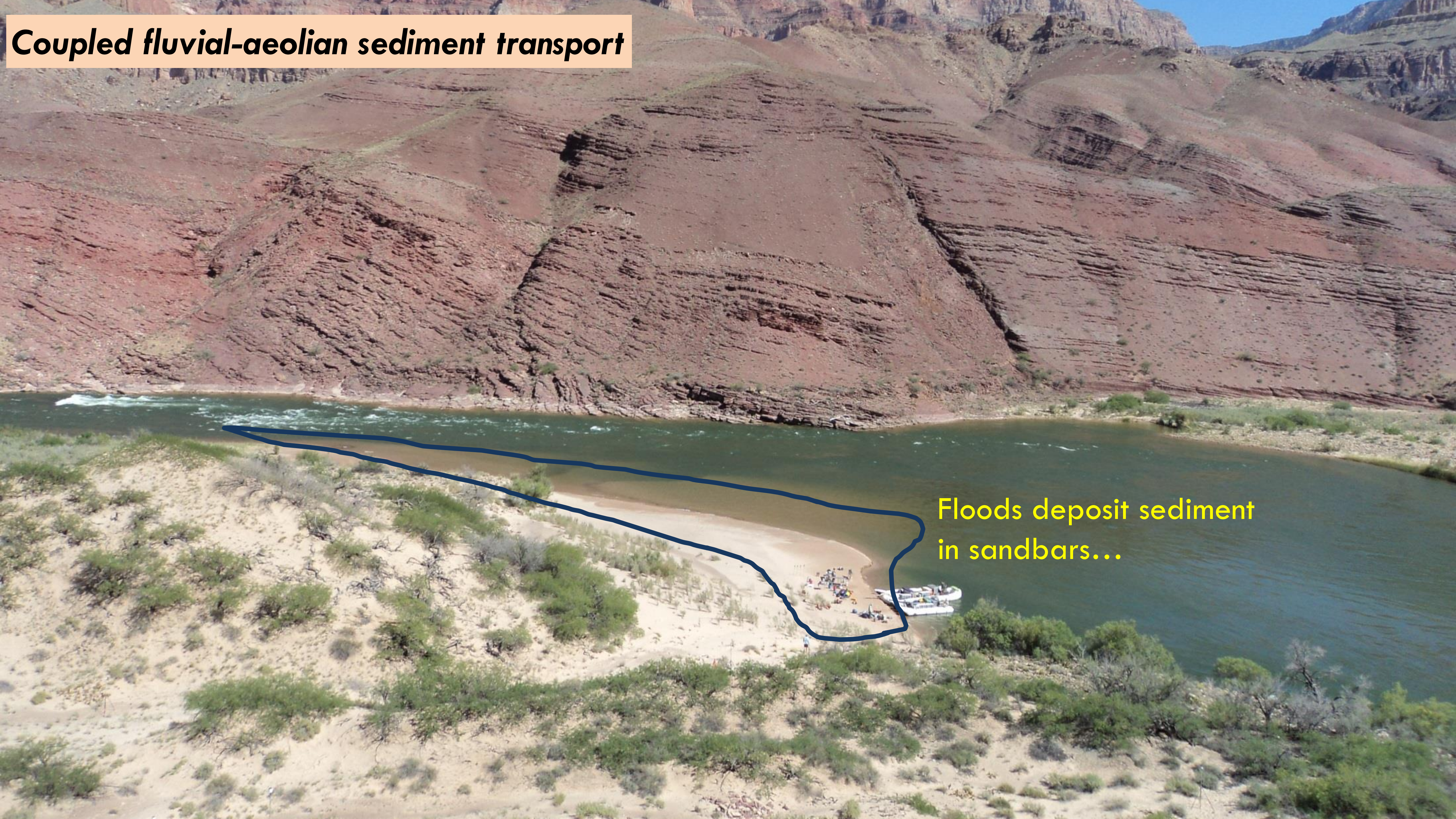
- *Flow Regime Shift (Direct Effect)*
- *Vegetation Encroachment (Indirect Effect)*

…and how these have fundamentally altered **<u>exposed sand area</u>** at **<u>big spatial scales</u>**

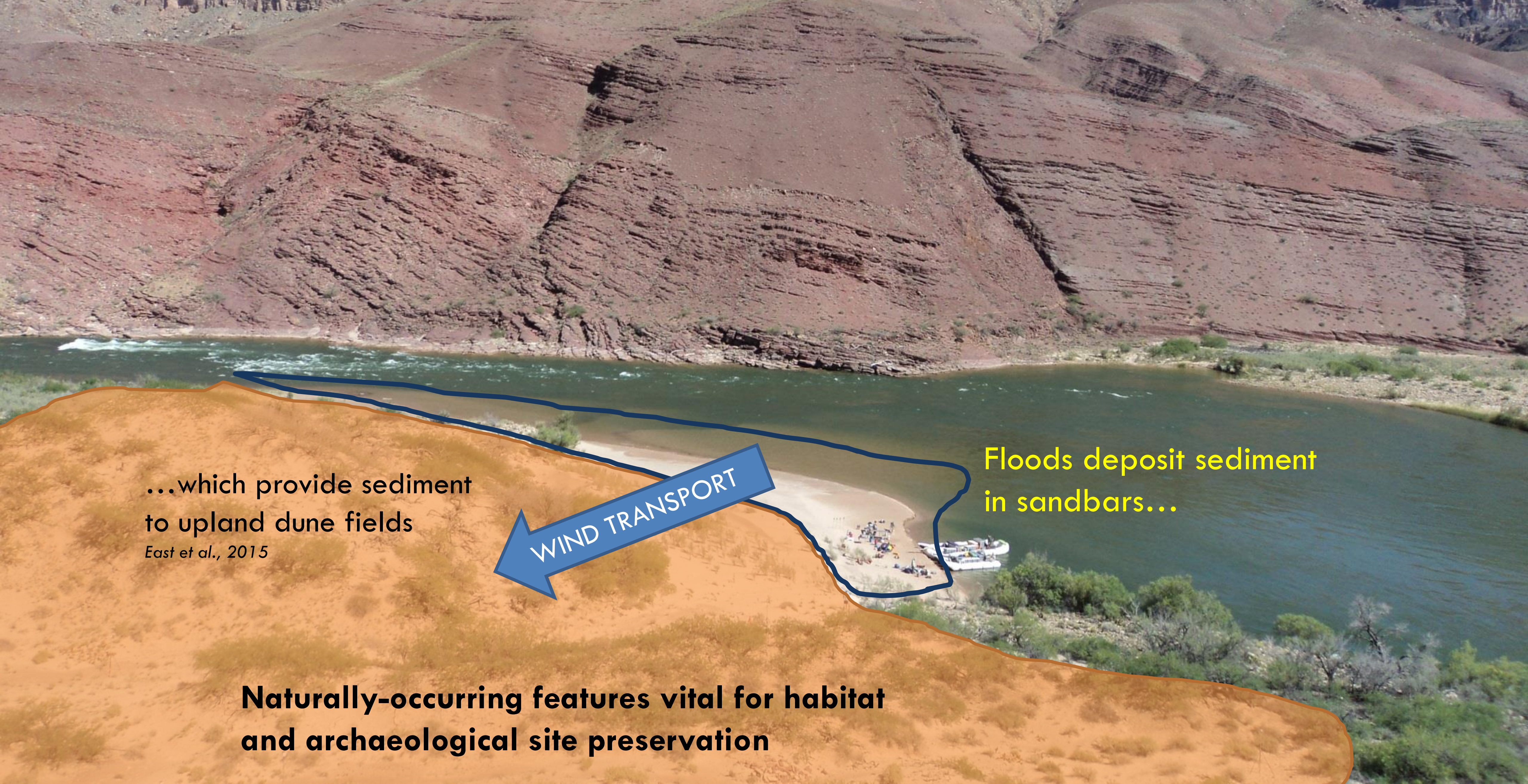
Colorado River at Lees Ferry

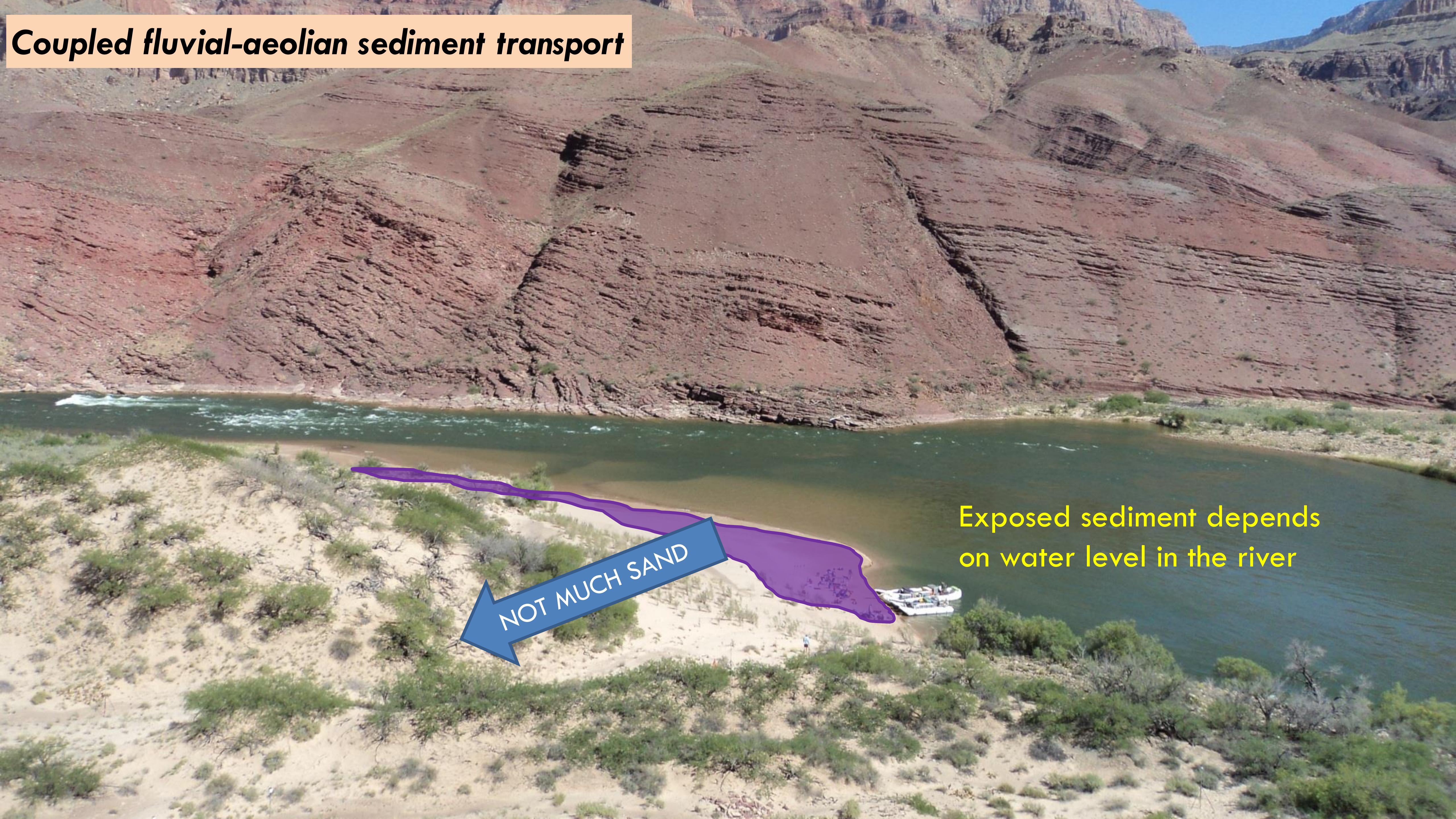
(~ 25 km downstream from Glen Canyon Dam)

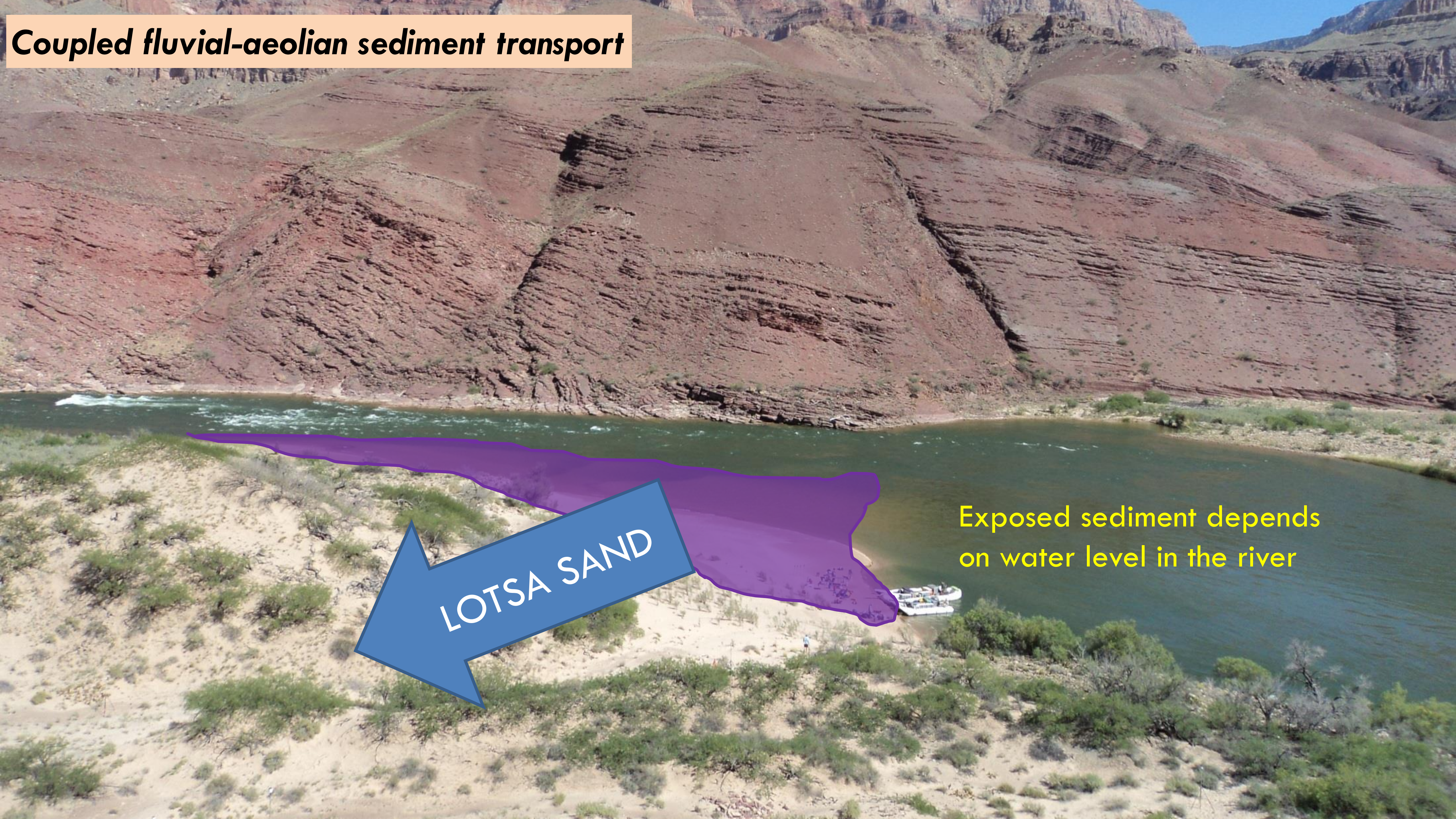



Coupled fluvial-aeolian sediment transport
Floods deposit sediment
in sandbars…

Coupled fluvial-aeolian sediment transport

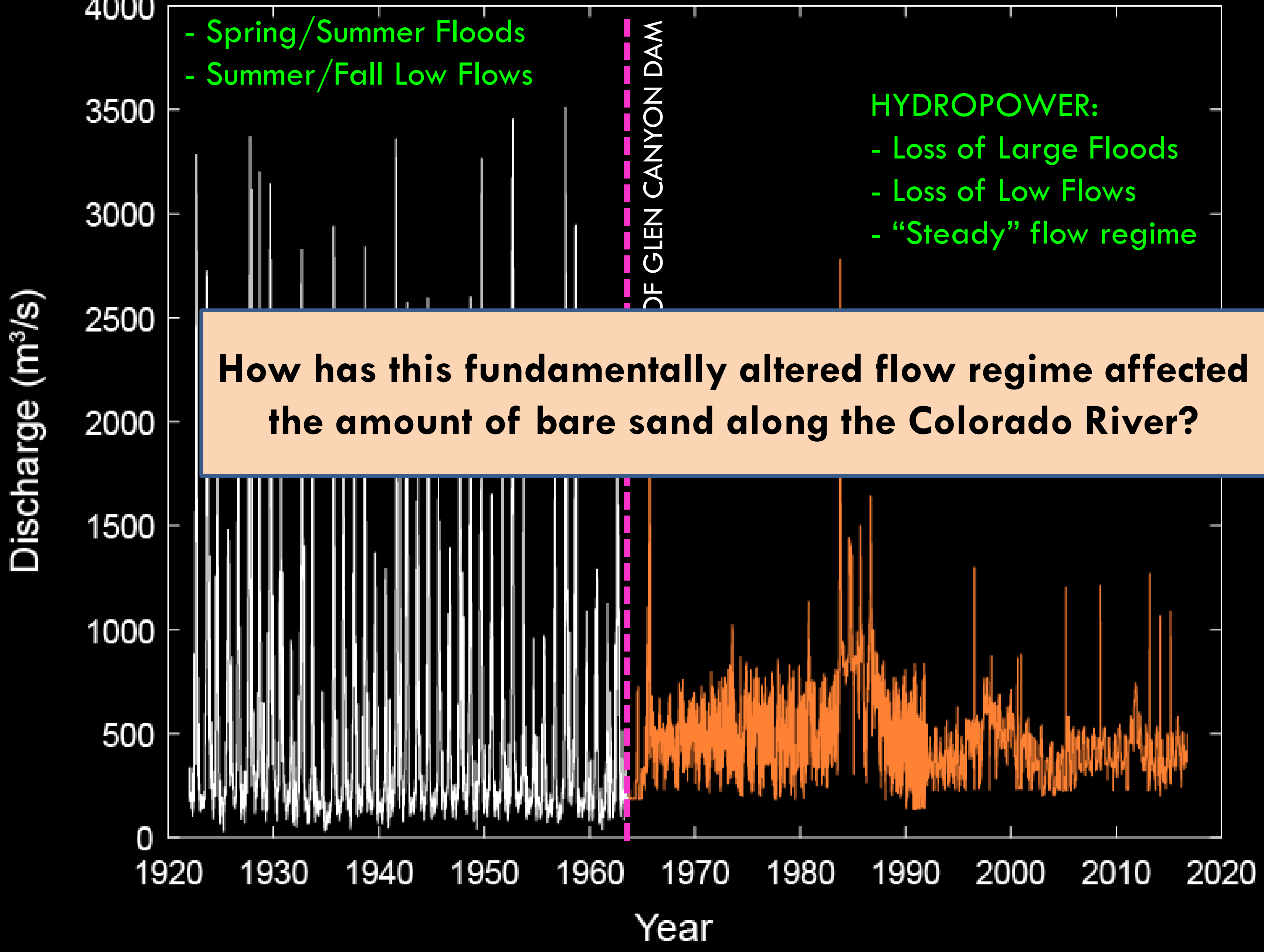



Coupled fluvial-aeolian sediment transport
NOT MUCH SAND
Exposed sediment depends on water level in the river

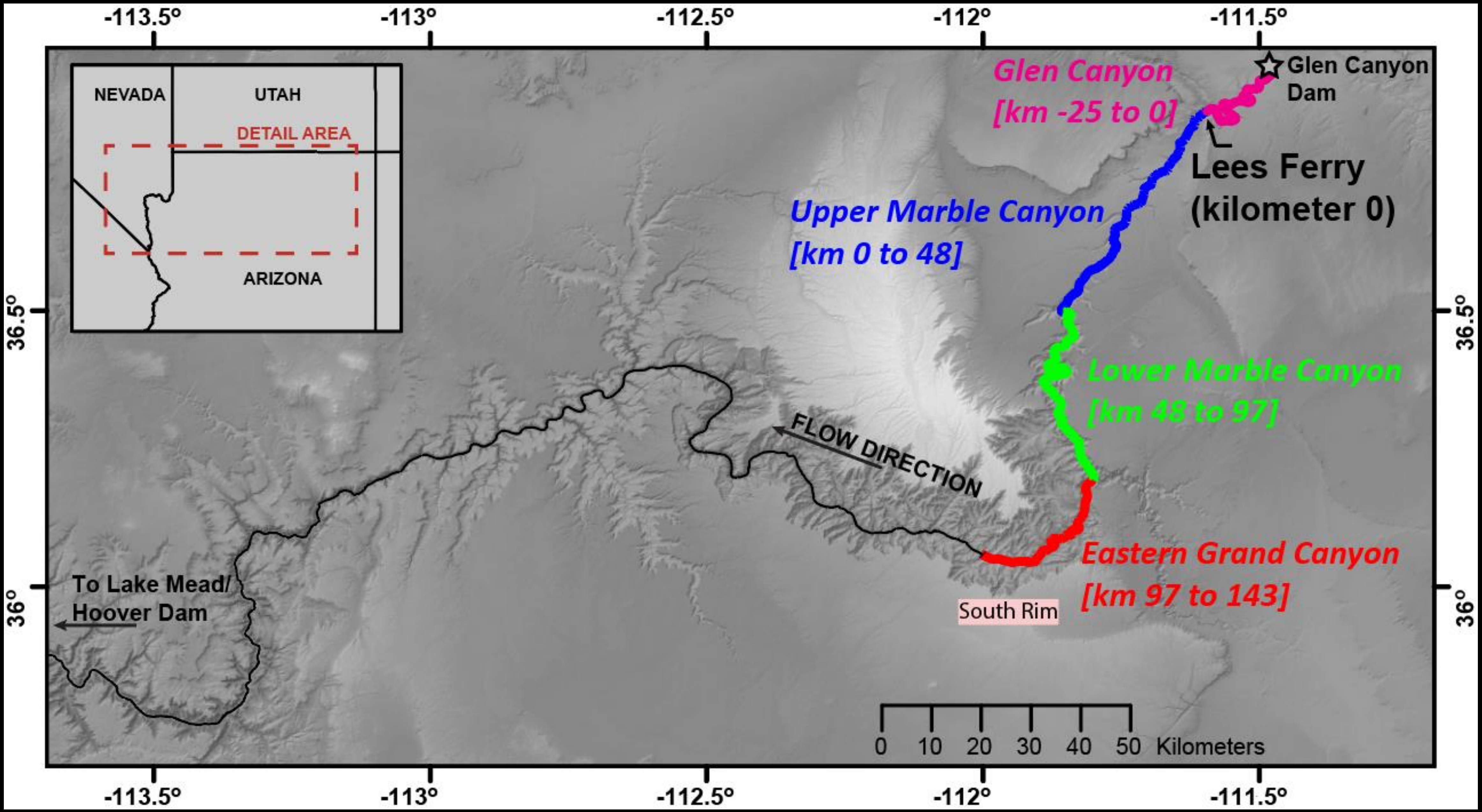

Coupled fluvial-aeolian sediment transport
LOTSA SAND
Exposed sediment depends on water level in the river

Colorado River at Lees Ferry

(~ 25 km downstream from Glen Canyon Dam)

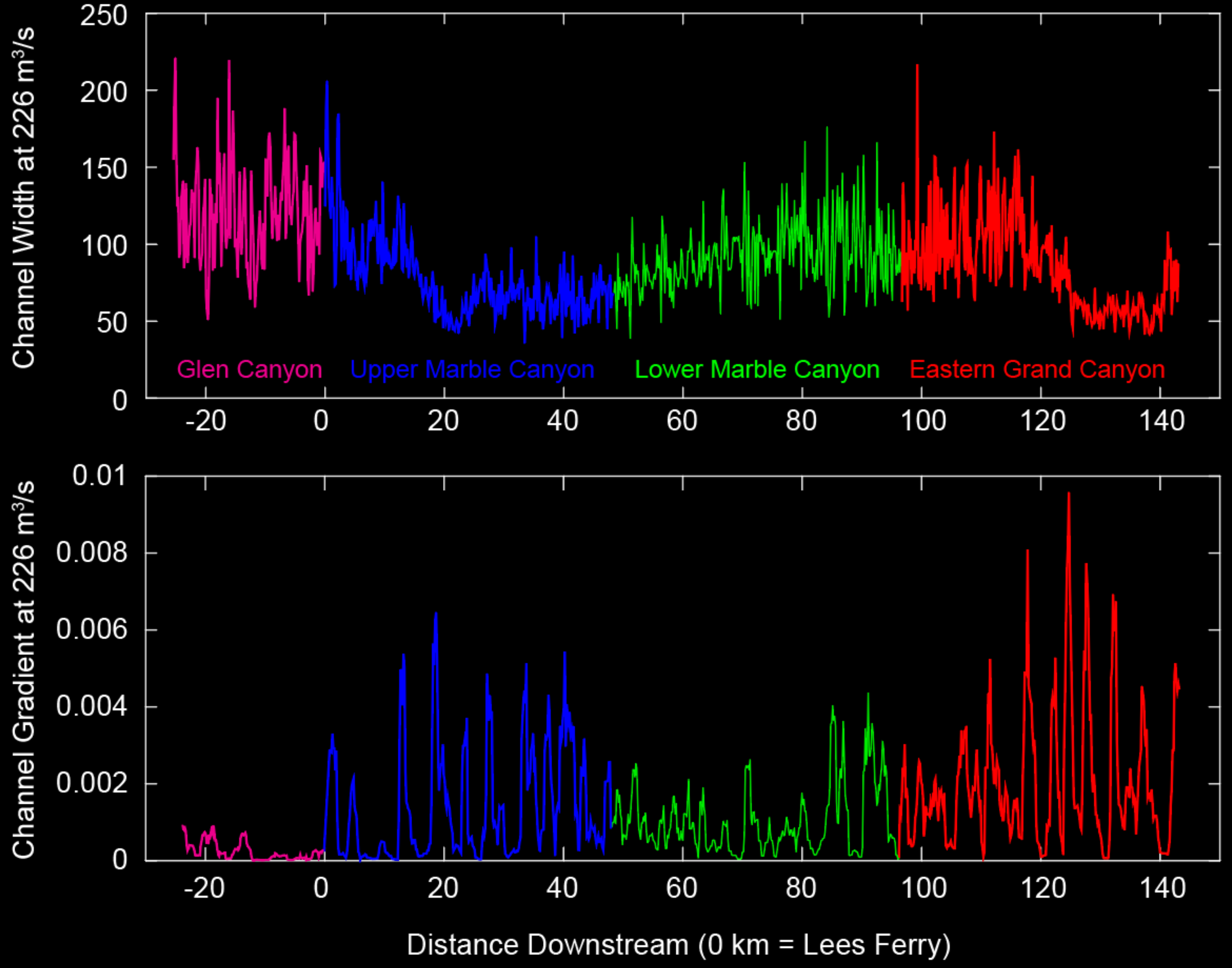


How has this fundamentally altered flow regime affected the amount of bare sand along the Colorado River?



168 km reach of Colorado River in Grand Canyon National Park

These Four Sub-Reaches are Geomorphically Distinct…



Glen Canyon

- *wide channel*
- *low gradient*
- *legacy of scour from Glen Canyon Dam [Grams et al., 2007, GSA-B]*

Upper Marble Canyon

- *transitional wide to narrow channel*
- *series of pools and drops*

Lower Marble Canyon

- *moderate width channel*
- *low gradient punctuated by rapids*

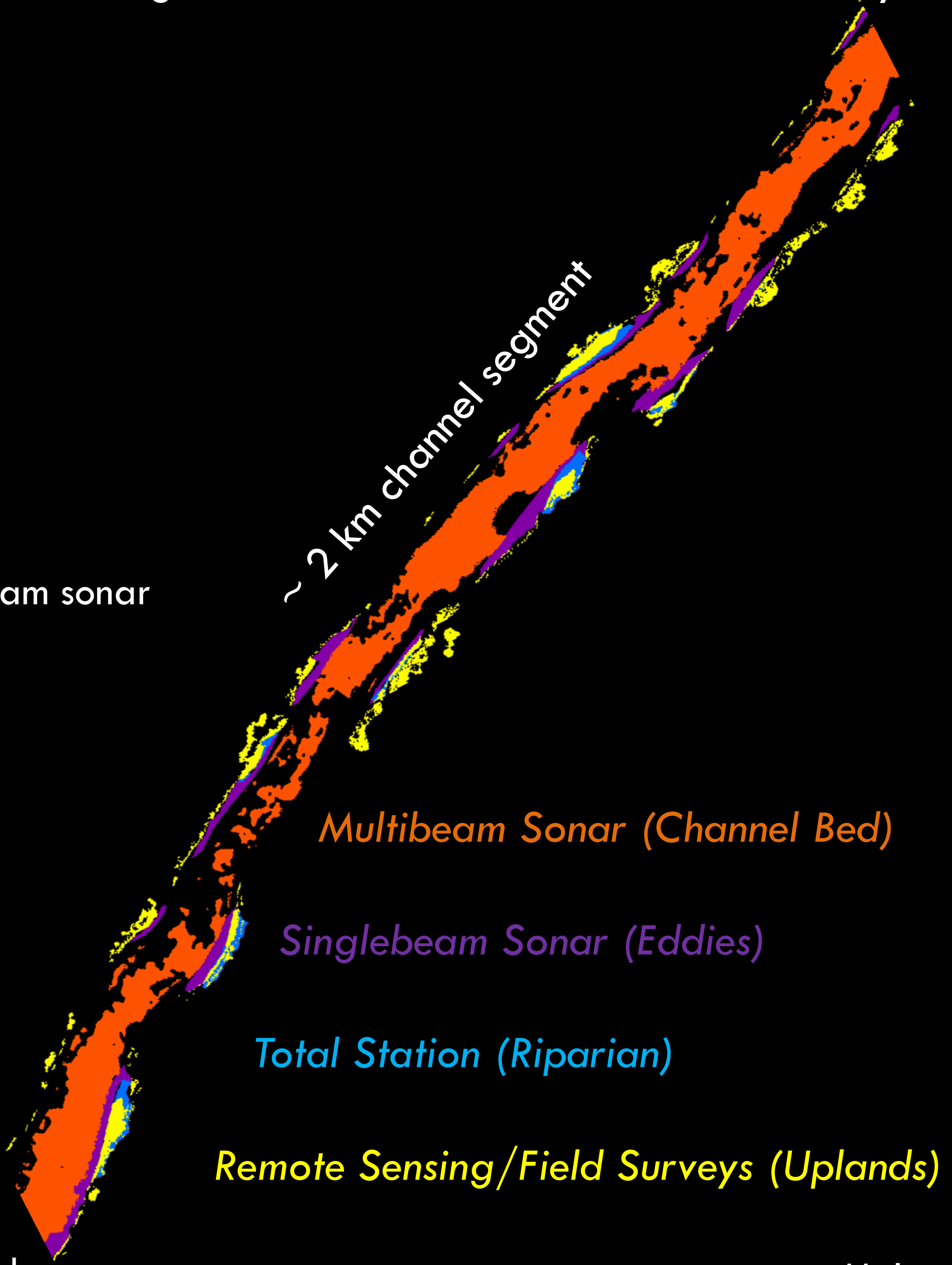
Eastern Grand Canyon

- *transitional wide to narrow channel*
- *steady gradient followed by pools-rapids*

How does the form of the channel in these reaches influence bare sand response to flow regime?

Mapping Sand Along the Colorado River in Grand Canyon – 2009 - 2015

Main channel sand mapped with multibeam sonar

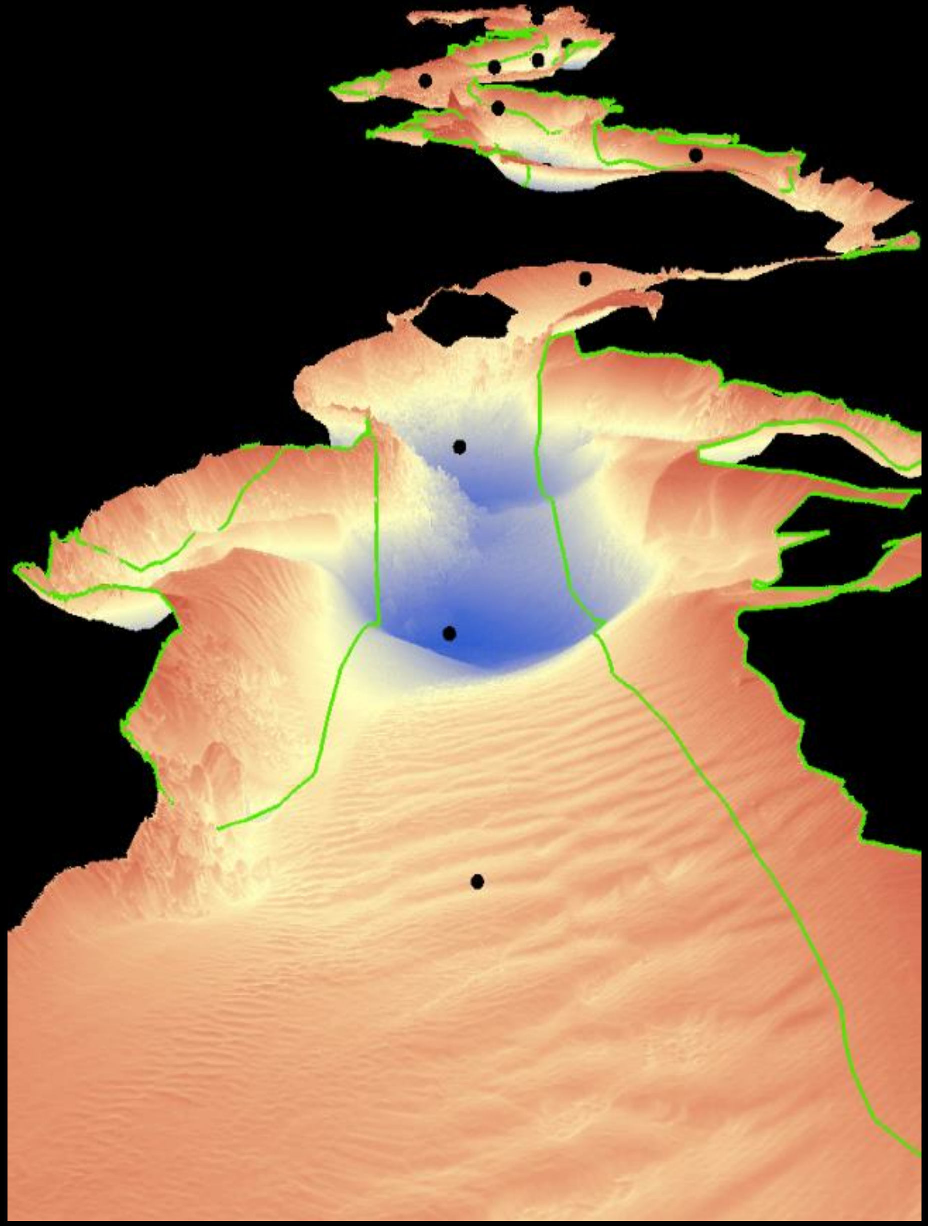


Riparian sand mapped with total station

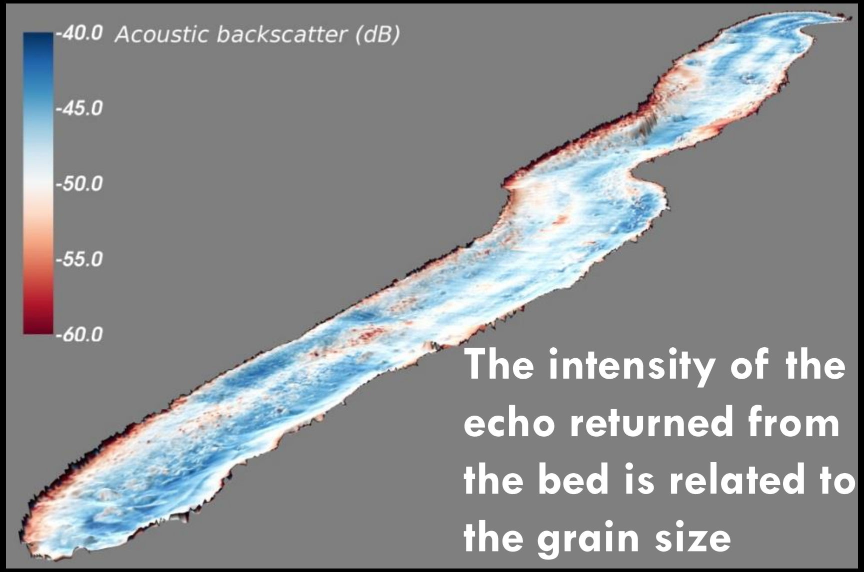
Channel margin sand mapped with singlebeam sonar

Upland sand mapped with remote sensing/field surveys

Multibeam Sonar Bed Classification



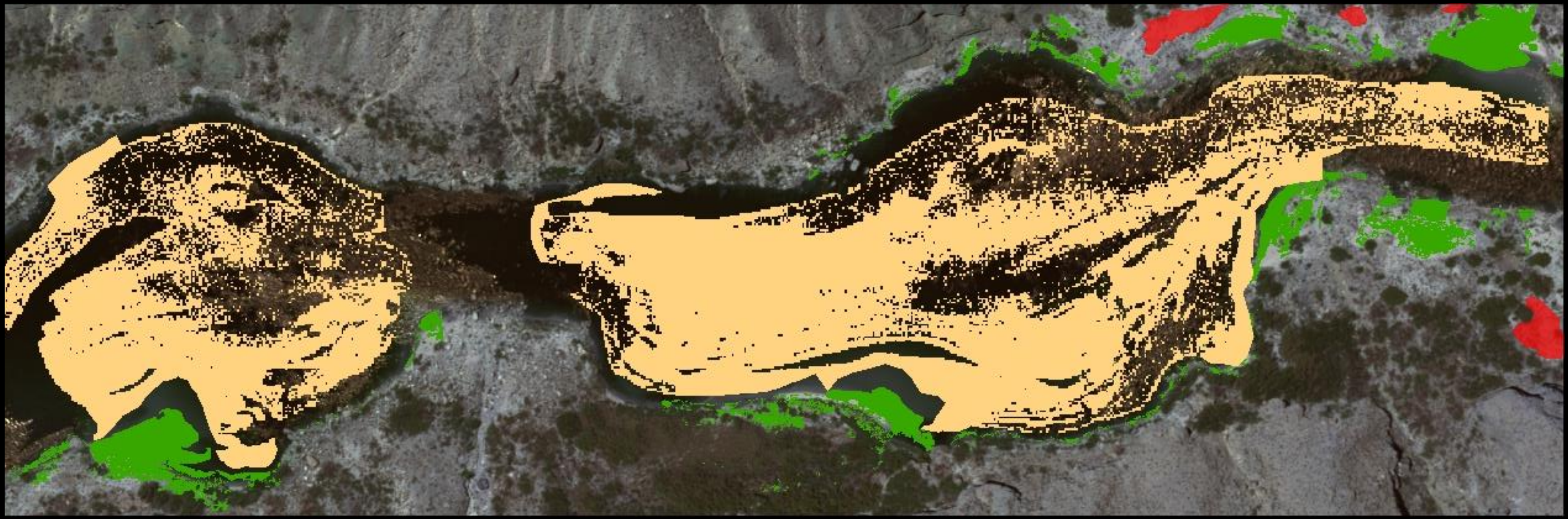
Upstream-looking DEM
(black dots are 1/10 mile intervals)



Buscombe et al., 2014; JGR-ES

Validation using underwater camera

2009 - 2015 Sand Mapping: Active Channel *and* Remote *and* Manual Upland Mapping



Active Channel Sand

From multibeam and total station surveys

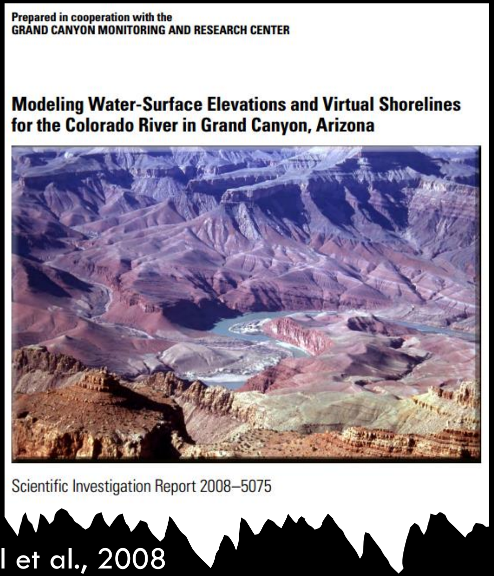
Remotely Mapped Upland Sand

From supervised classification of 2009 aerial photos

Manually Mapped Upland Sand

From field mapping on river trips

Mapped every square meter of sand from the channel bed to historic flood of record (5,947 m^3/s) over 168 km reach



Magirl et al., 2008

226 m^3/s

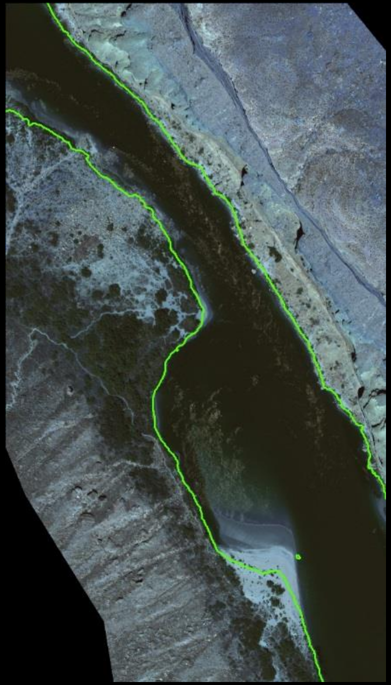
566 m^3/s

1,274 m^3/s

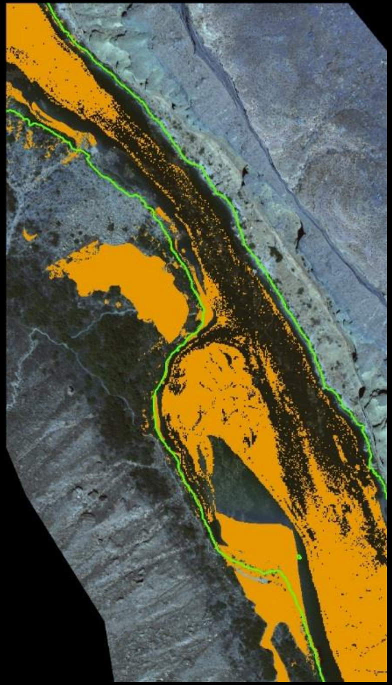
5,947 m^3/s

…and ten intermediate flows not shown here

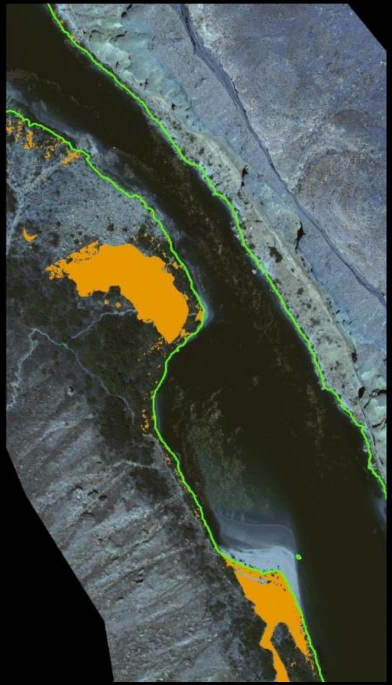
Inundation Extent at 1,274 m^3/s



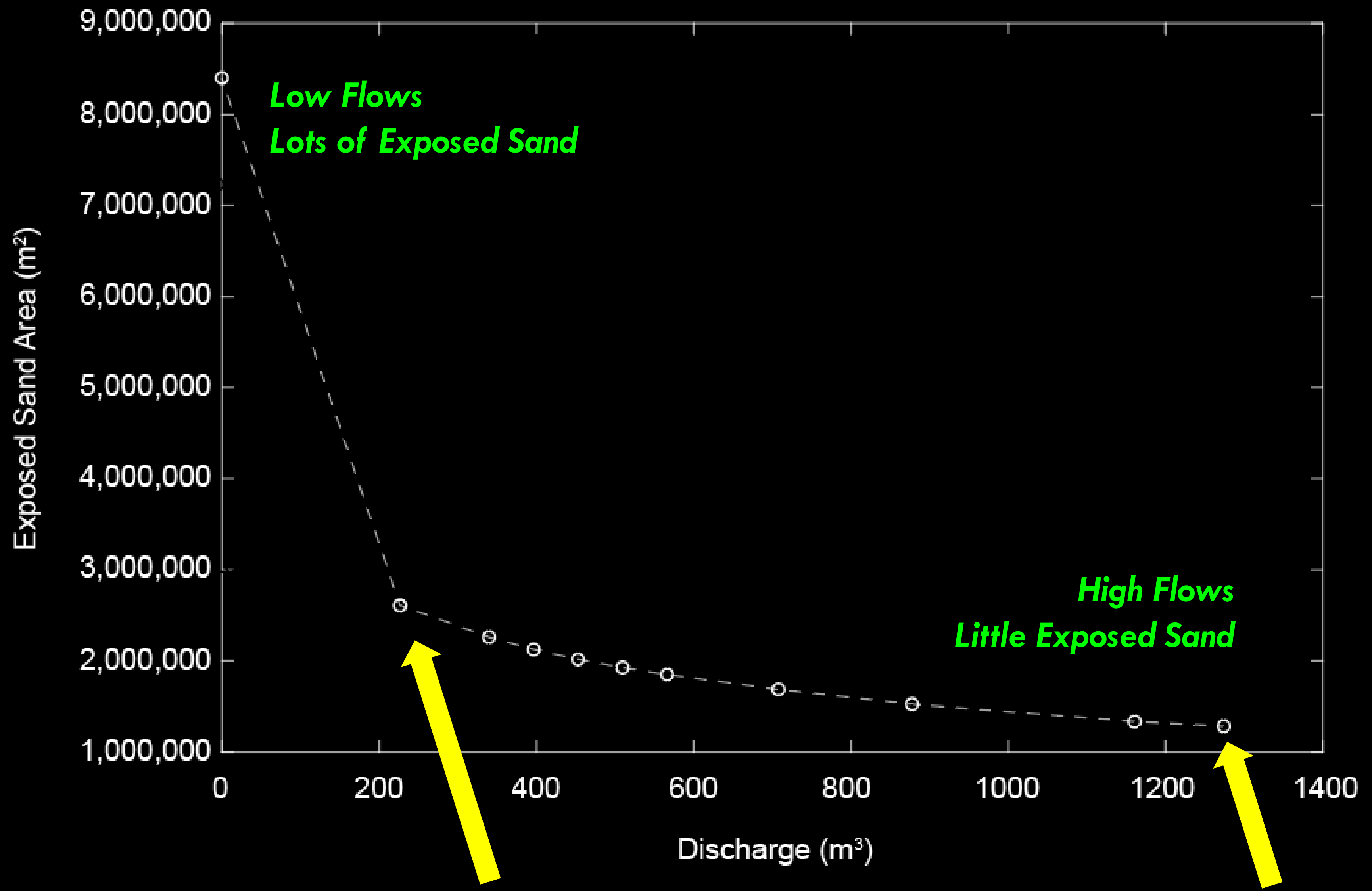
Total Sand Map



Exposed Sand at 1,274 m^3/s



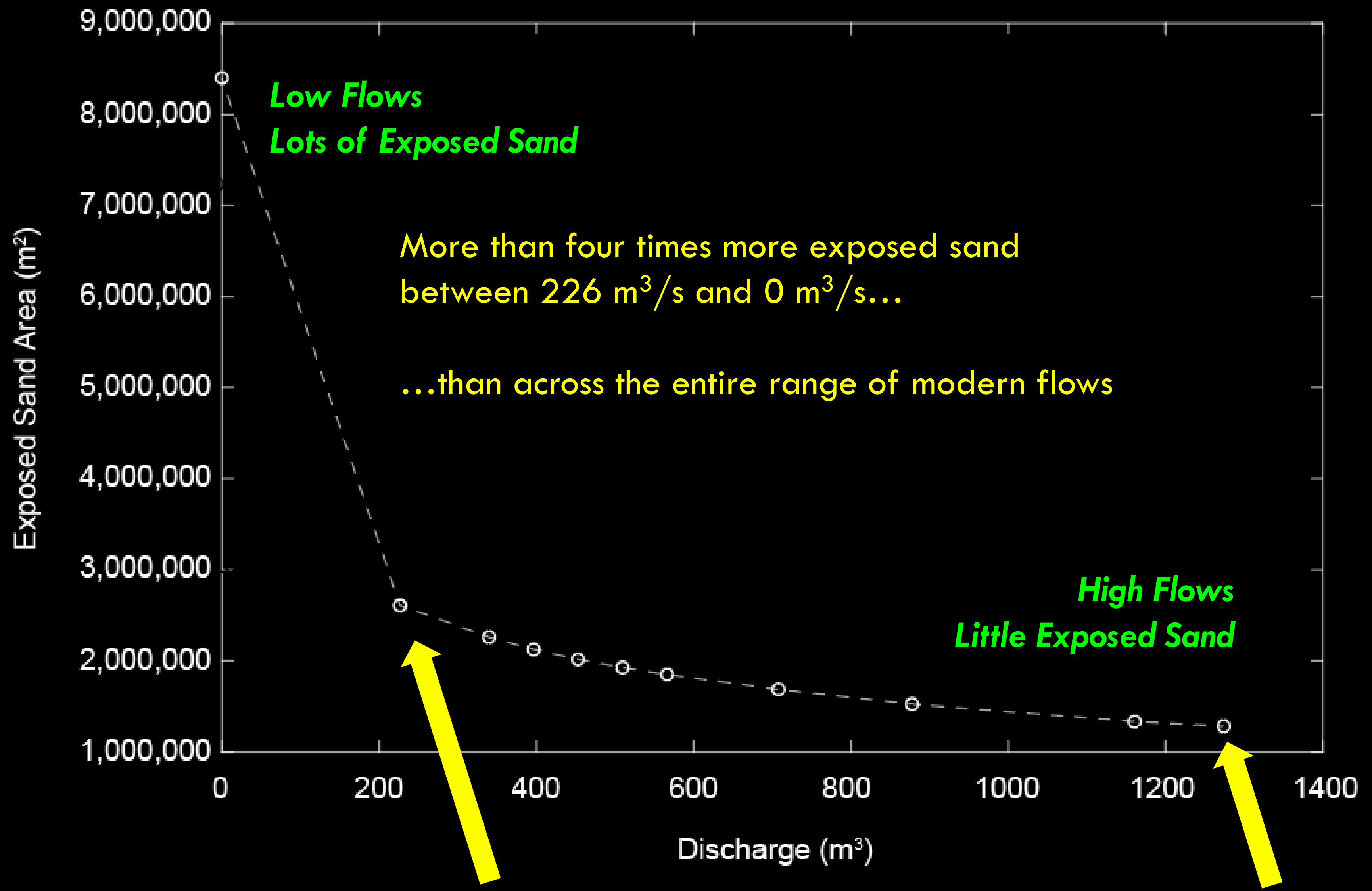
Exposed Sand as a Function of Discharge



226 m^3/s: lowest regularly-occurring flows in Grand Canyon today

1,274 m^3/s: highest regularly-occurring flows in Grand Canyon today

Exposed Sand as a Function of Discharge



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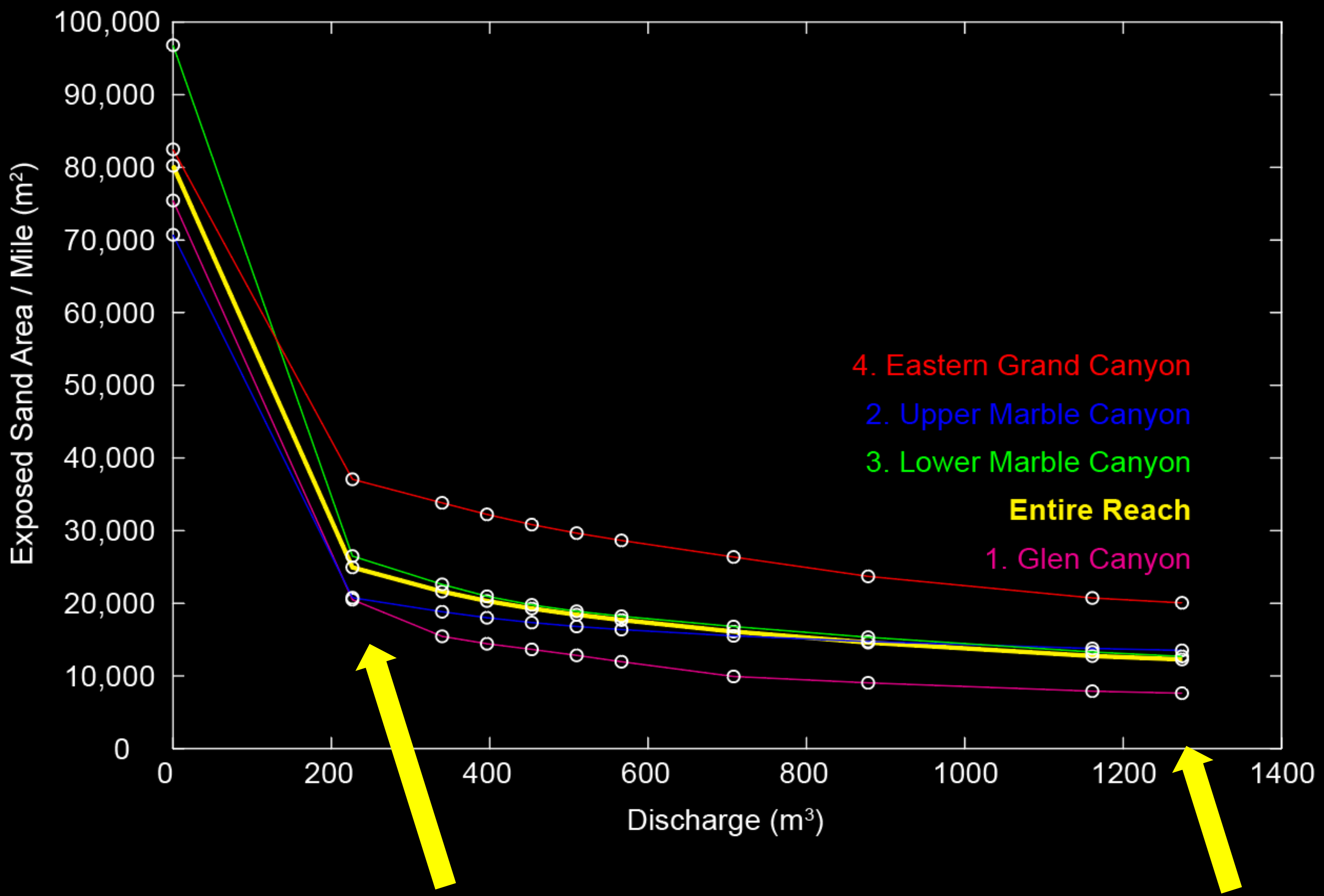
Exposed Sand as a Function of Discharge



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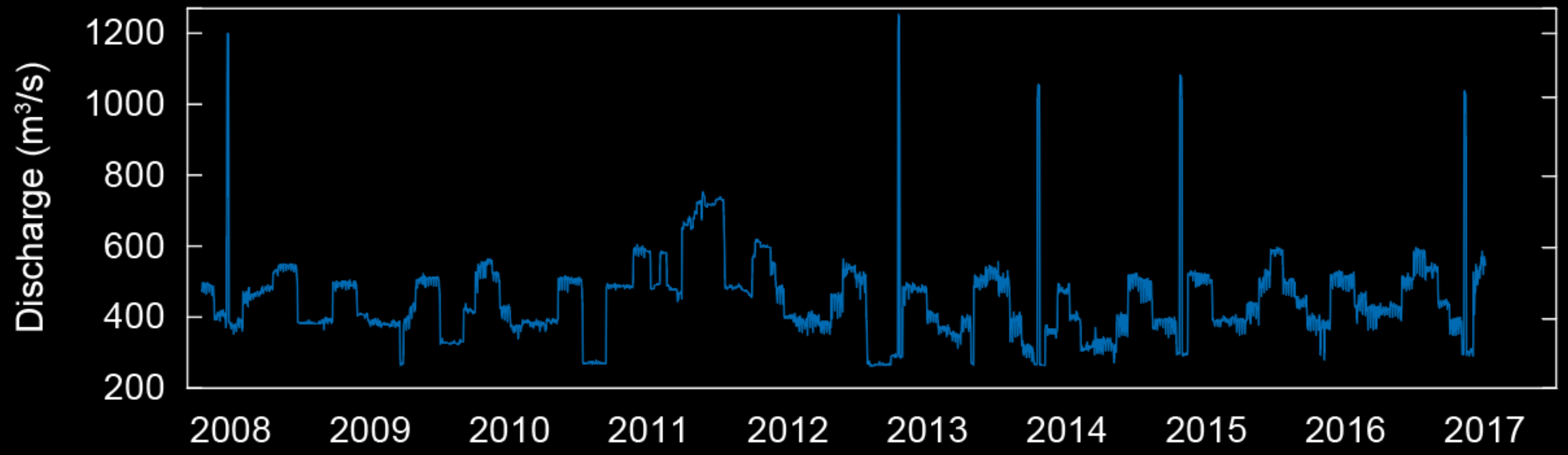
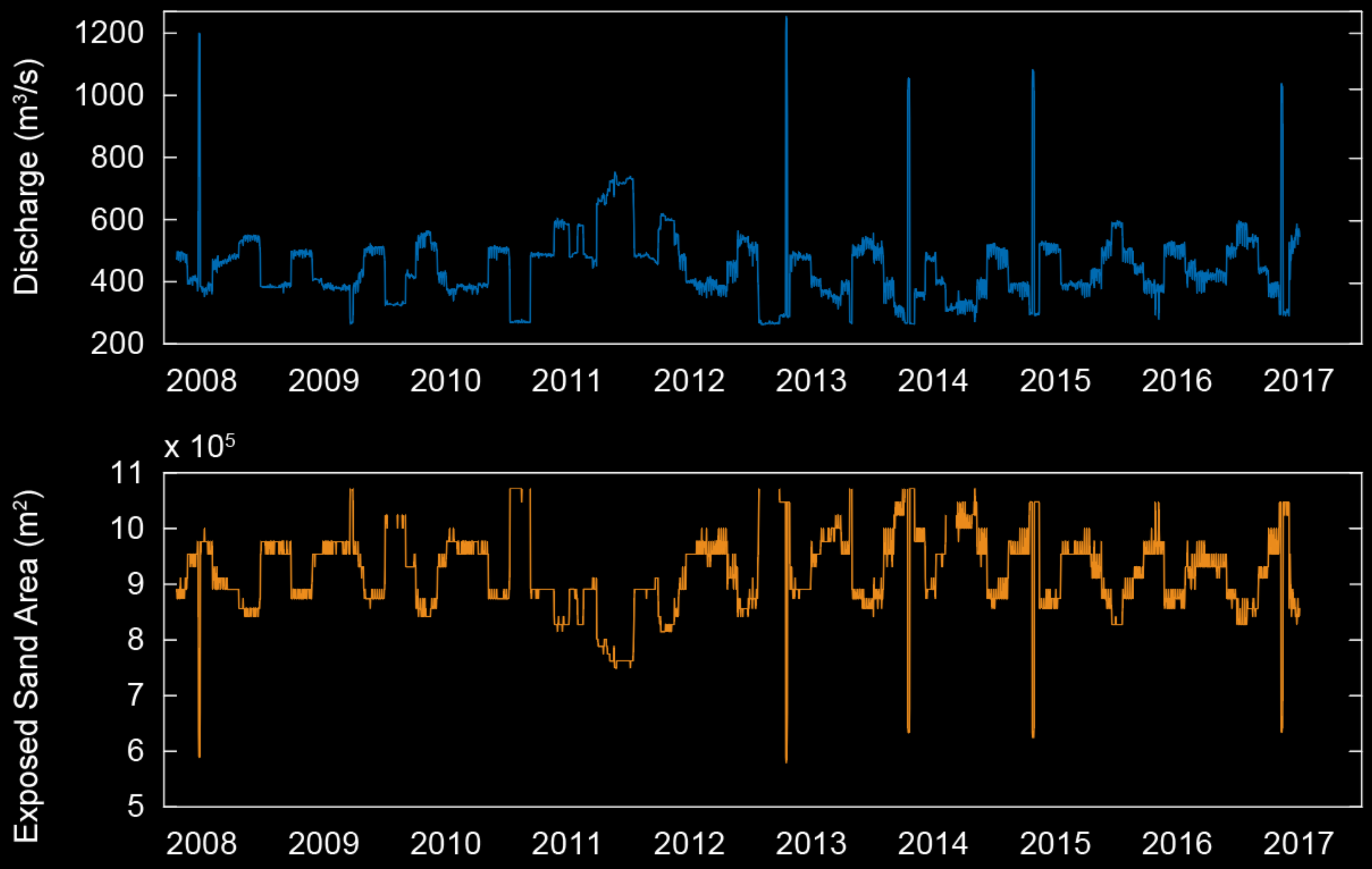
Exposed Sand as a Function of Discharge, 2008 - 2016



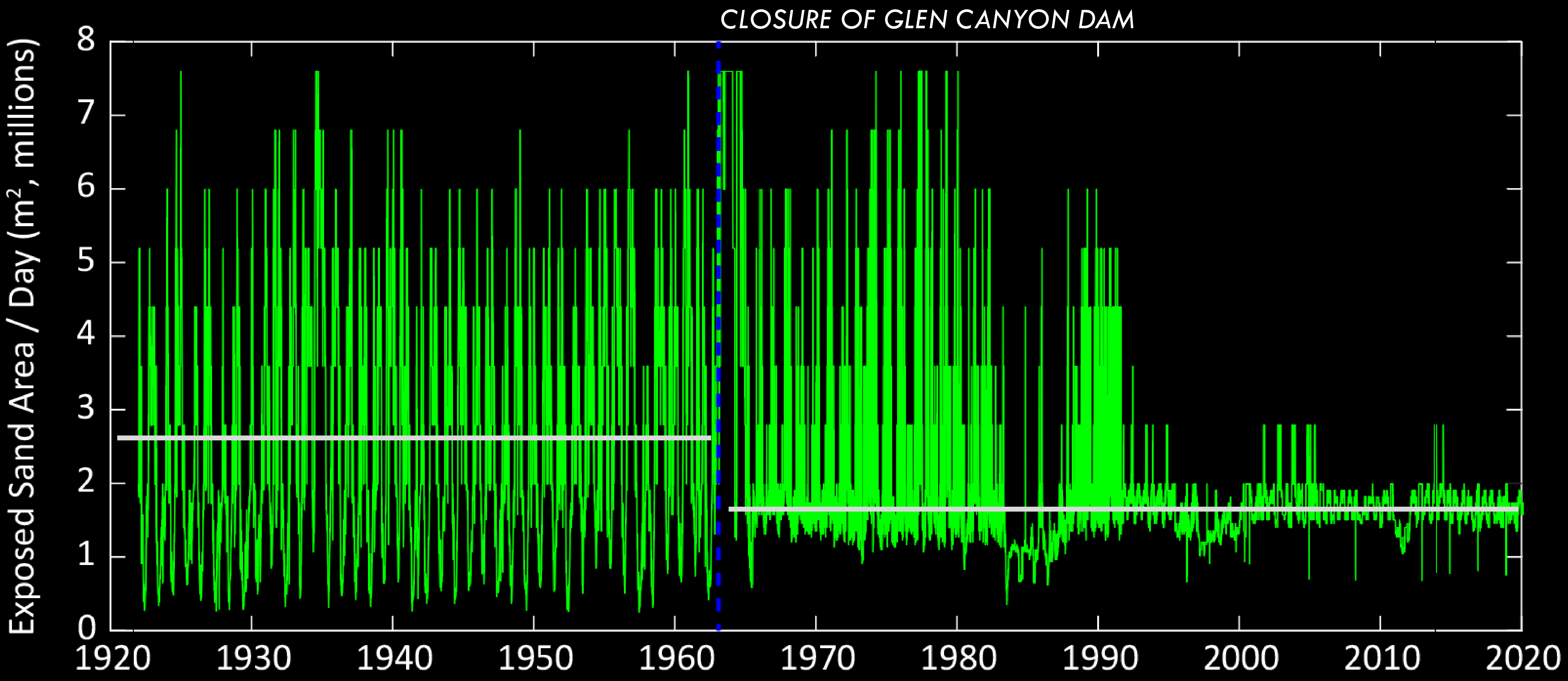
3,286 individual records of daily discharge…

Exposed Sand as a Function of Discharge, 2008 - 2016



3,286 individual records of daily discharge…

…used to compute <u>daily exposed sand areas</u>



PRE-DAM EXPOSED SAND:
2,620,002 m^2/day

29% DECREASE

POST-DAM EXPOSED SAND:
1,867,864 m^2/day

What does the future hold?

Glen Canyon Dam isn't going anywhere

…but can we operate it differently?

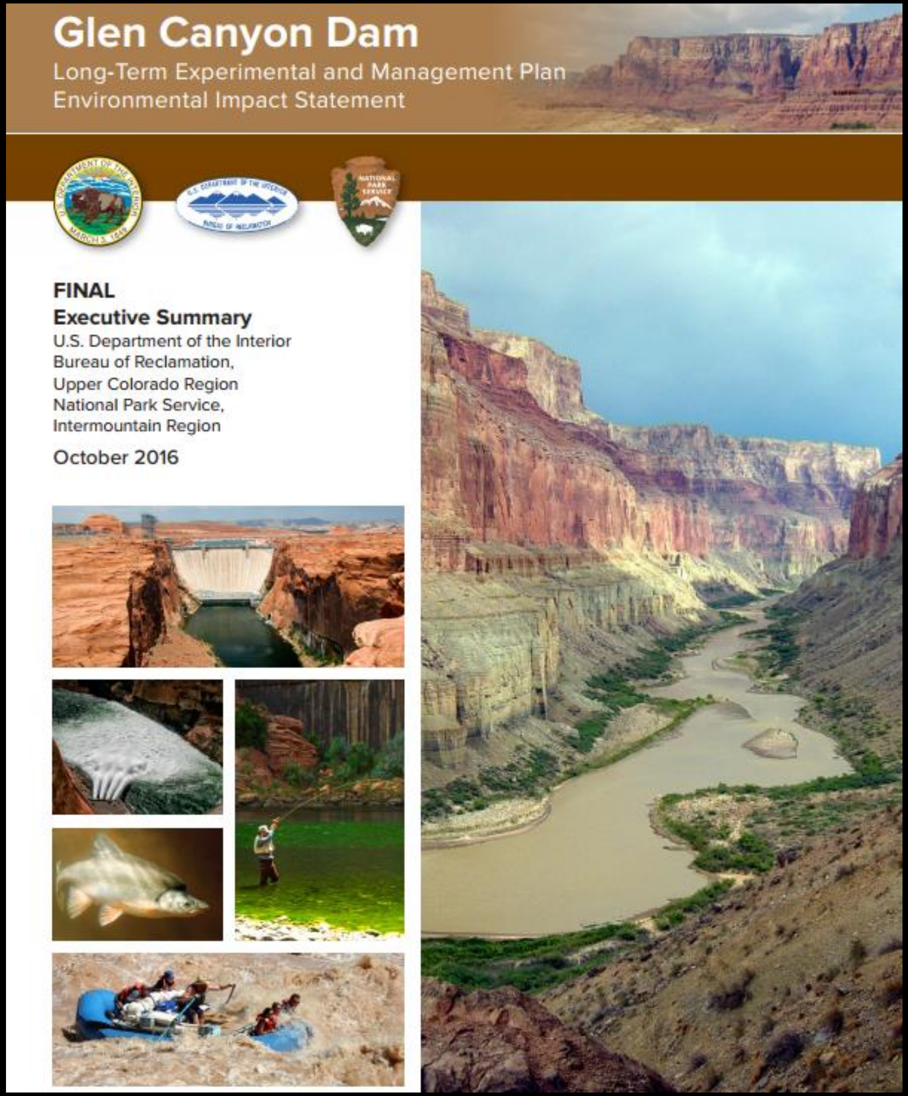
New 20-year management plan for Glen Canyon Dam staring in 2017

7 alternative operation regimes ('Alternatives A-G') analyzed for impacts on:

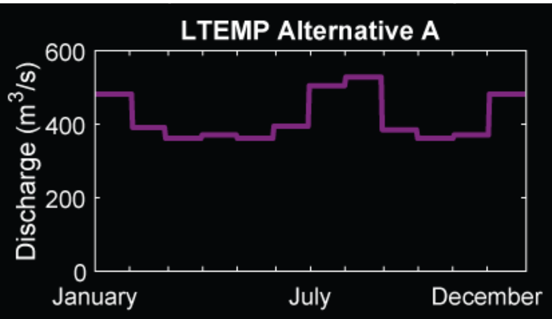
- Fish/bug populations
- Recreation
- Sediment
- Cultural site preservation
- Hydropower generation

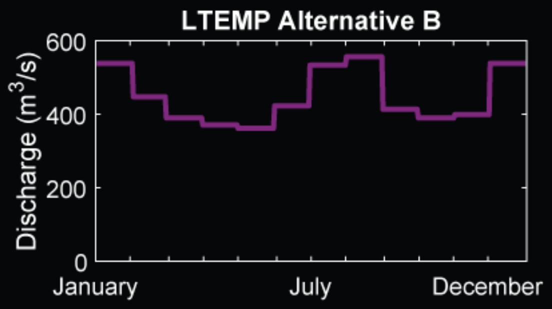
<u>"Alternative D" ultimately selected</u>

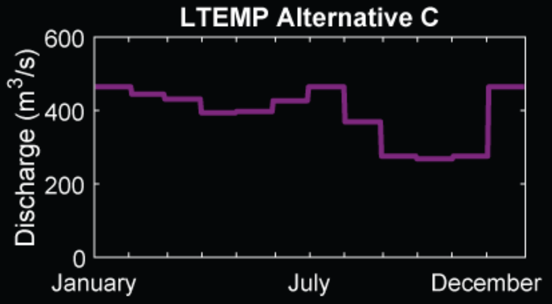
- Allows for annual experimental floods
- Allows for low flows to conserve insect communities
- Relatively similar release pattern to current operating protocol

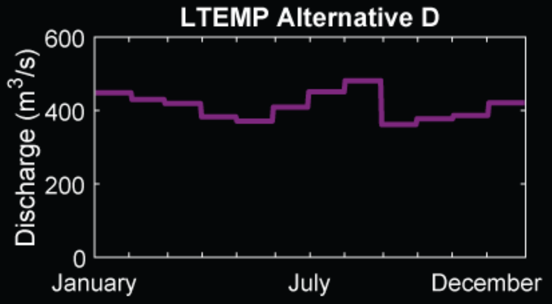


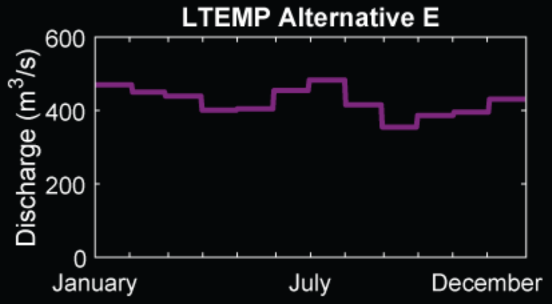
Alternative A: No change from current operation regime	**Alternative B:** Maximizing hydropower generation	**Alternative C:** Adaptive flows: invertebrates, fish, and sediment	**Alternative D:** Compromise between power generation and ecology	**Alternative E:** Native fish conservation flows	**Alternative F:** Mirroring pre-dam seasonal flow regime	**Alternative G:** Maximizing sediment conservation

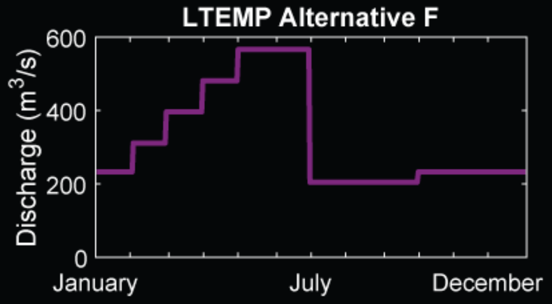


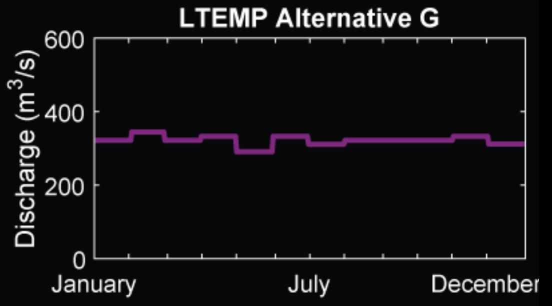




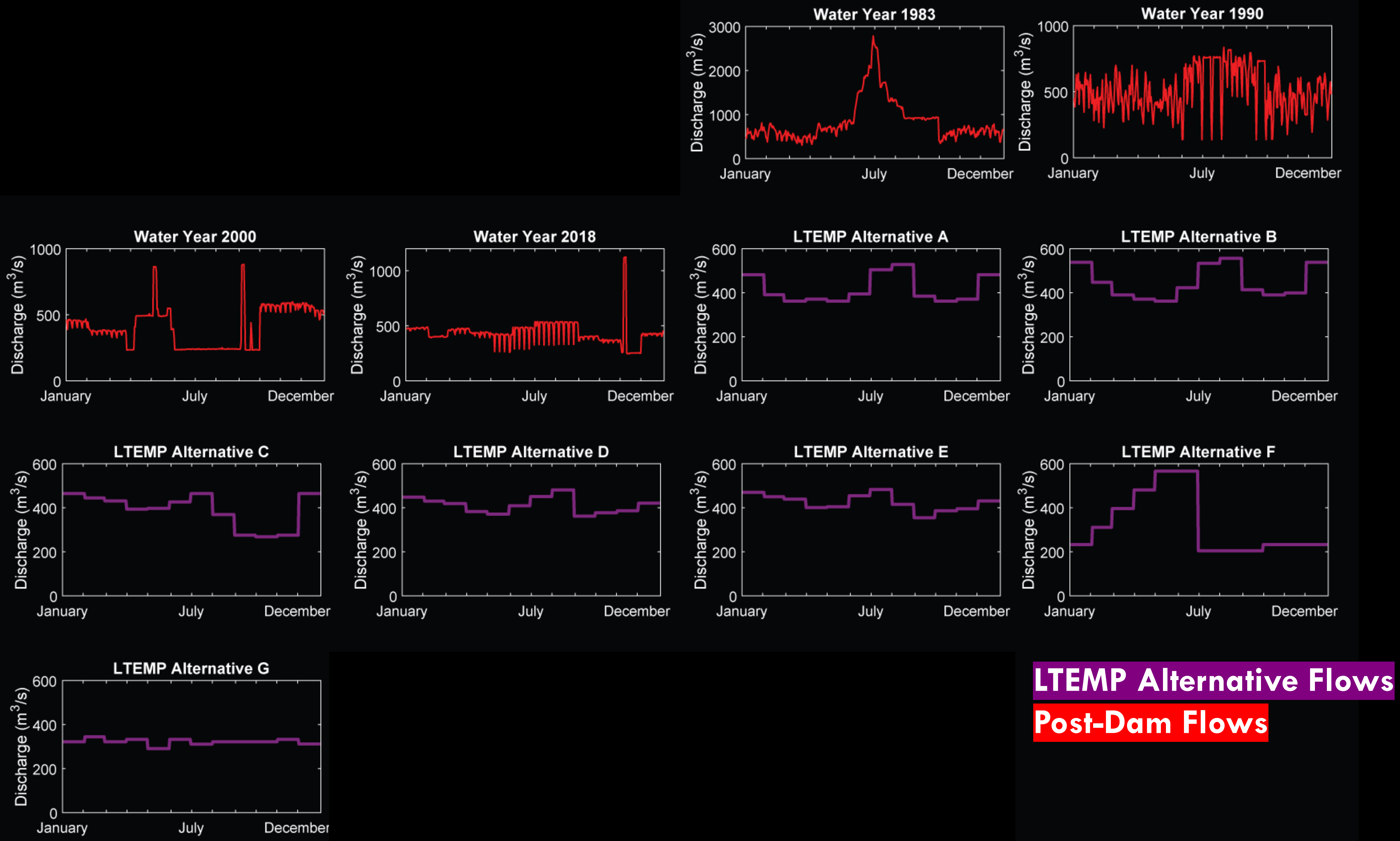


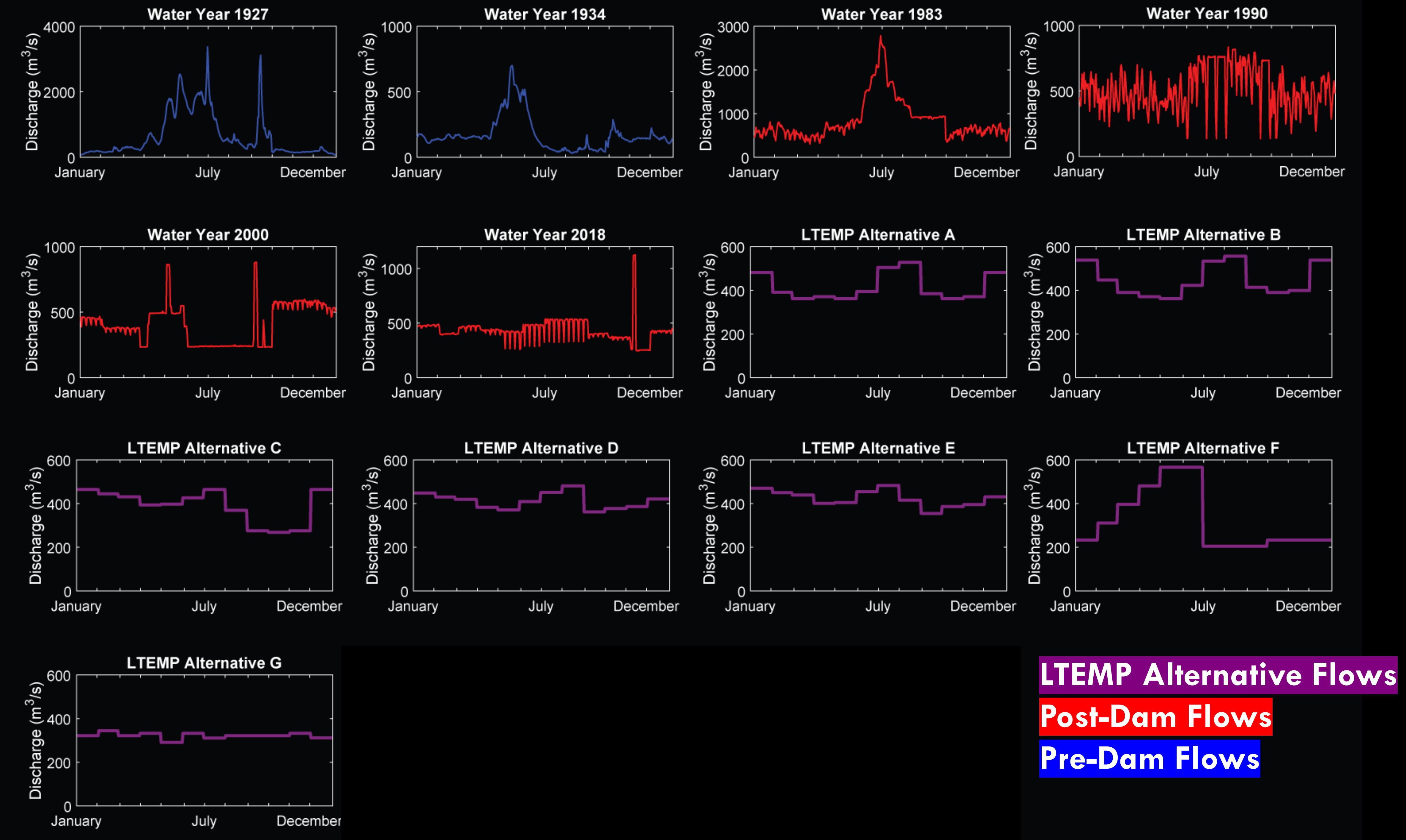






LTEMP Alternative Flows


Water Year 1983
Water Year 1990
Water Year 2000
Water Year 2018
LTEMP Alternative A
LTEMP Alternative B
LTEMP Alternative C
LTEMP Alternative D
LTEMP Alternative E
LTEMP Alternative F
LTEMP Alternative G
Discharge (m3/s)
January
July
December
LTEMP Alternative Flows
Post-Dam Flows



Water Year 1927
Water Year 1934
Water Year 1983
Water Year 1990
Water Year 2000
Water Year 2018
LTEMP Alternative A
LTEMP Alternative B
LTEMP Alternative C
LTEMP Alternative D
LTEMP Alternative E
LTEMP Alternative F
LTEMP Alternative G
Discharge (m3/s)
January
July
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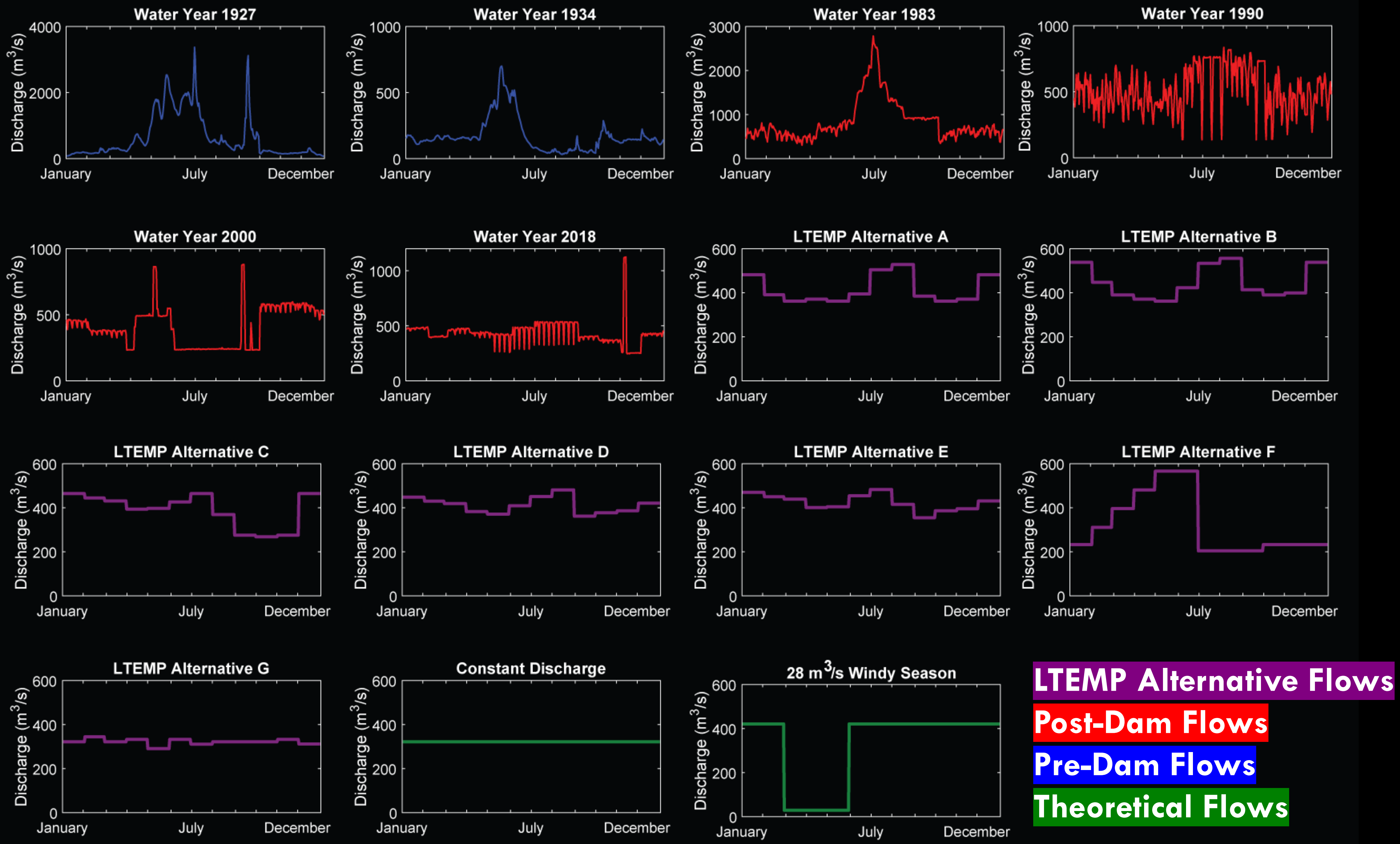
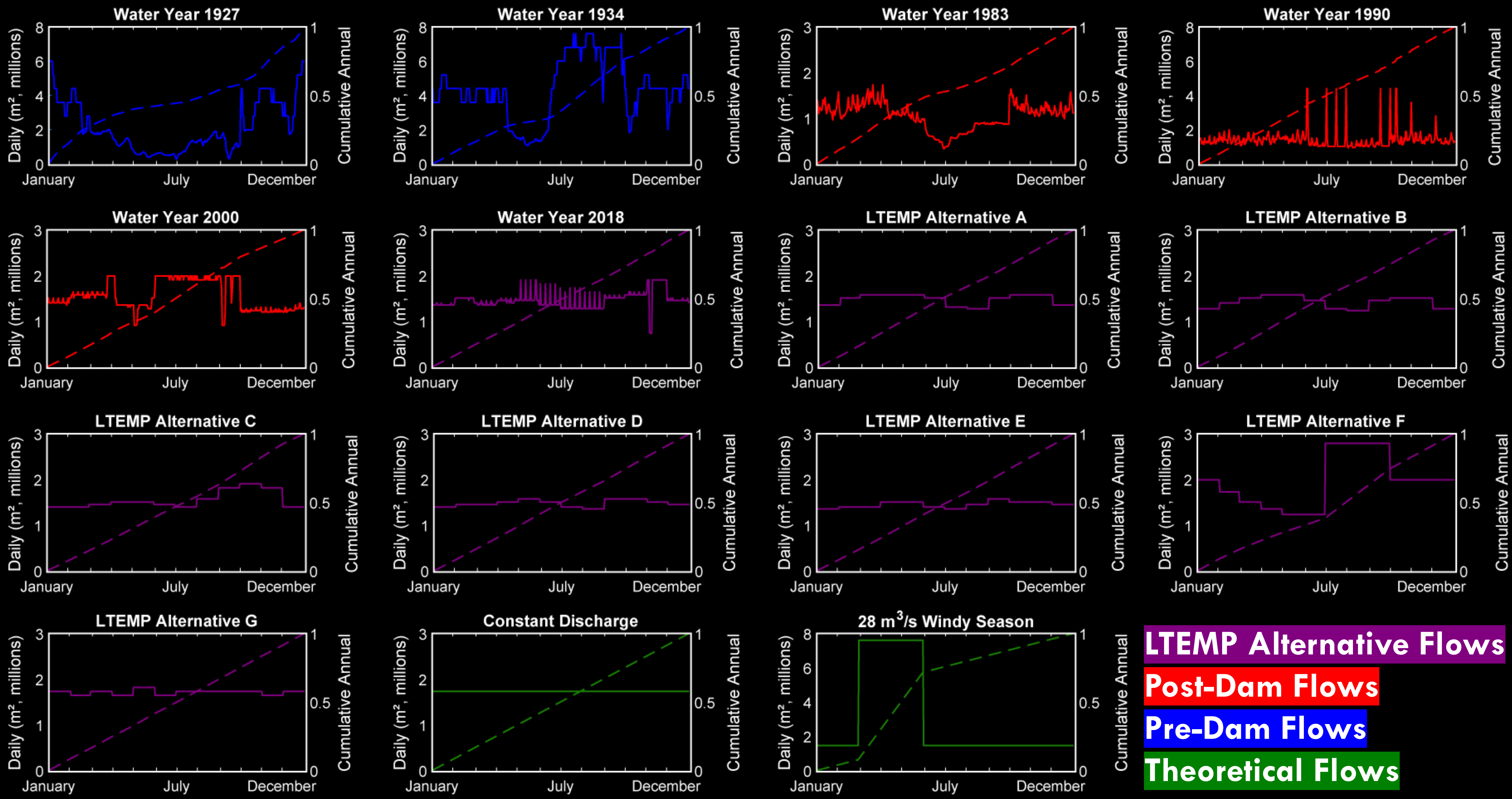
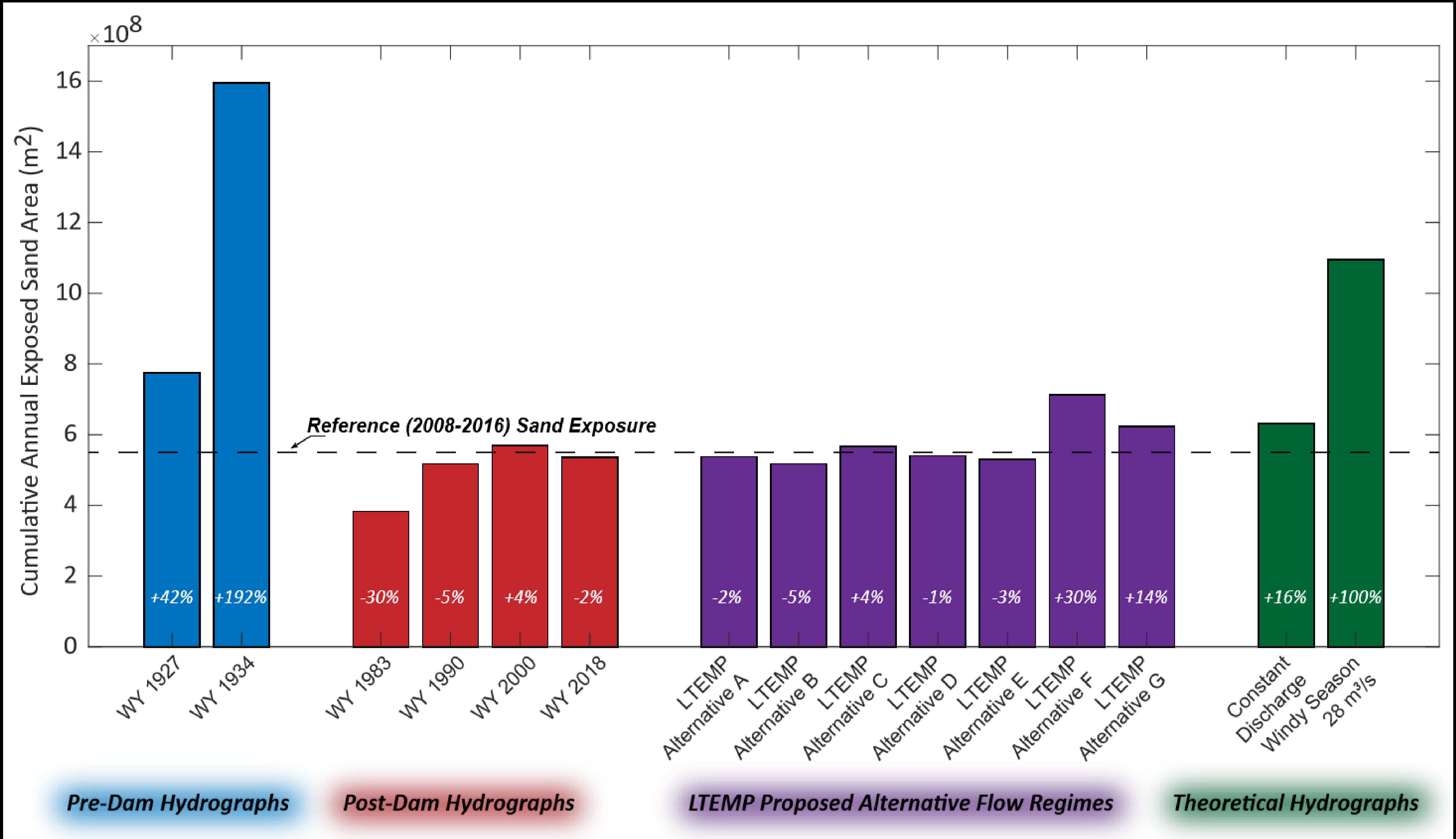
LTEMP Alternative Flows
Post-Dam Flows
Pre-Dam Flows


Water Year 1927
Water Year 1934
Water Year 1983
Water Year 1990
Water Year 2000
Water Year 2018
LTEMP Alternative A
LTEMP Alternative B
LTEMP Alternative C
LTEMP Alternative D
LTEMP Alternative E
LTEMP Alternative F
LTEMP Alternative G
Constant Discharge
28 m³/s Windy Season
Discharge (m³/s)
January
July
December
LTEMP Alternative Flows
Post-Dam Flows
Pre-Dam Flows
Theoretical Flows



Water Year 1927
Water Year 1934
Water Year 1983
Water Year 1990
Water Year 2000
Water Year 2018
LTEMP Alternative A
LTEMP Alternative B
LTEMP Alternative C
LTEMP Alternative D
LTEMP Alternative E
LTEMP Alternative F
LTEMP Alternative G
Constant Discharge
28 m^3/s Windy Season
Daily (m², millions)
Cumulative Annual
January
July
December
LTEMP Alternative Flows
Post-Dam Flows
Pre-Dam Flows
Theoretical Flows



×10^8
Cumulative Annual Exposed Sand Area (m^2)
16
14
12
10
8
6
4
2
0
Reference (2008-2016) Sand Exposure
+42%
+192%
-30%
-5%
+4%
-2%
-2%
-5%
+4%
-1%
-3%
+30%
+14%
+16%
+100%
WY 1927
WY 1934
WY 1983
WY 1990
WY 2000
WY 2018
LTEMP Alternative A
LTEMP Alternative B
LTEMP Alternative C
LTEMP Alternative D
LTEMP Alternative E
LTEMP Alternative F
LTEMP Alternative G
Constant Discharge
Windy Season 28 m³/s
Pre-Dam Hydrographs
Post-Dam Hydrographs
LTEMP Proposed Alternative Flow Regimes
Theoretical Hydrographs

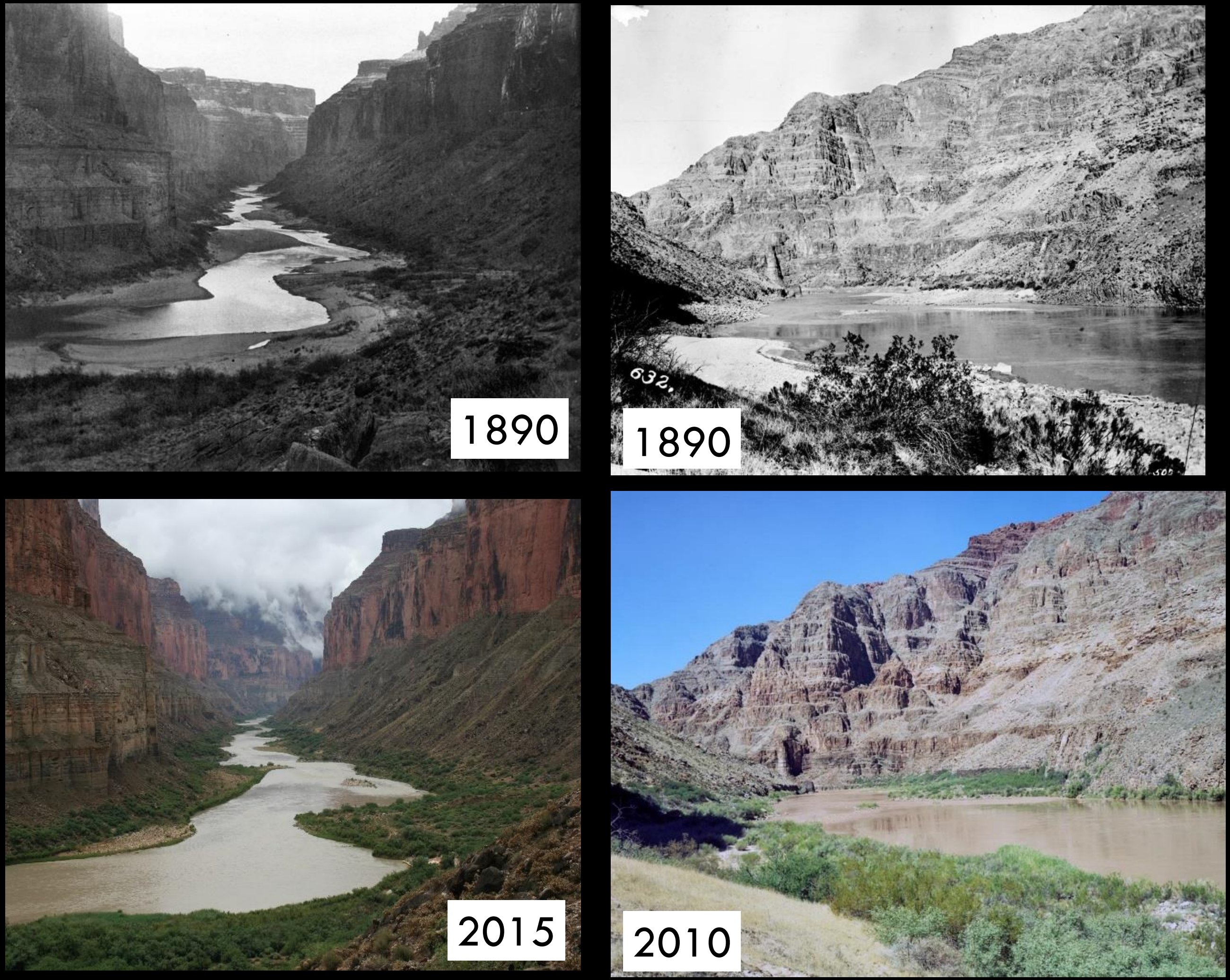
<u>Today:</u>

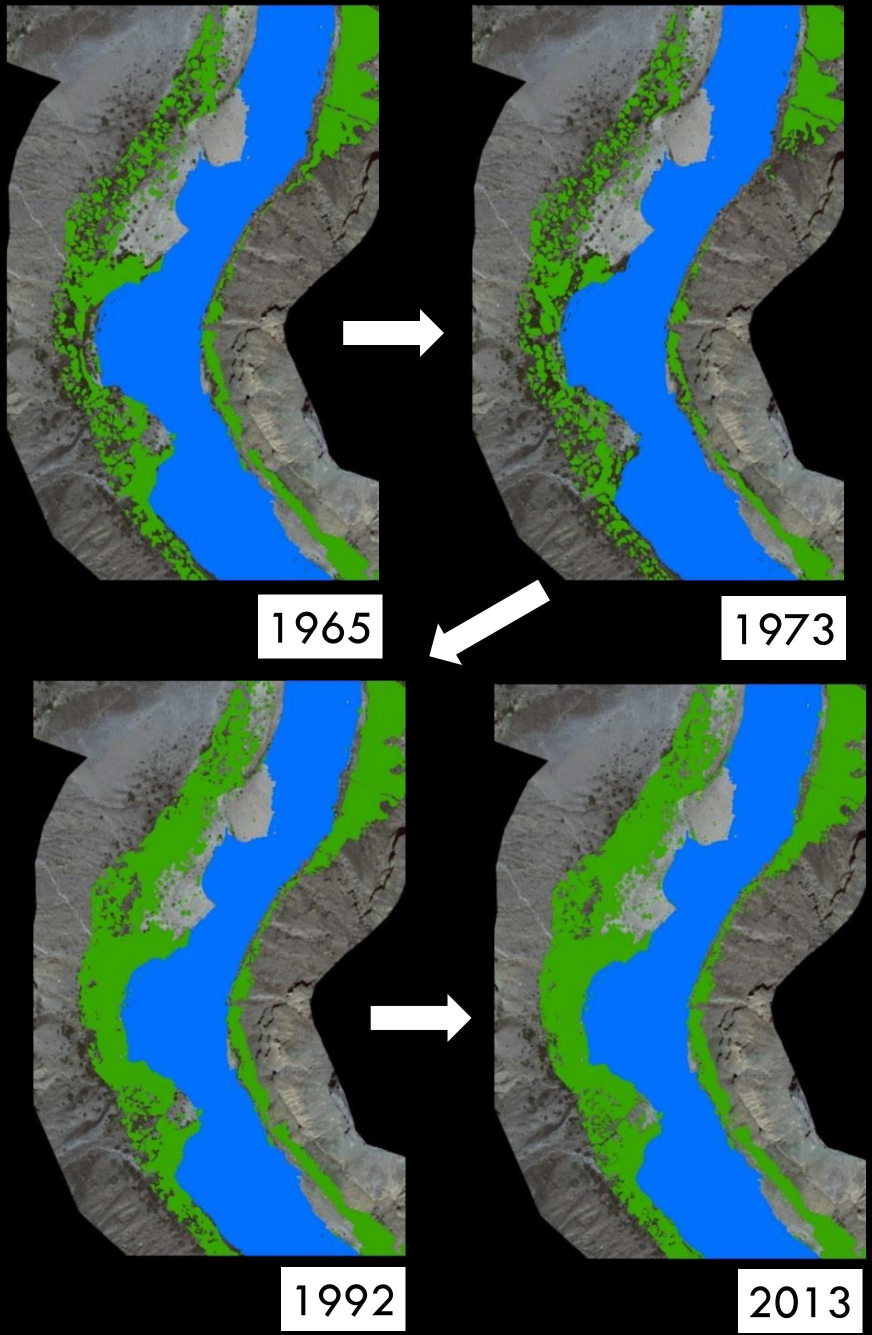
Two alterations to Colorado River driven by Glen Canyon Dam

- *Flow Regime Shift (Direct Effect)*
- *Vegetation Encroachment (Indirect Effect)*

…and how these have fundamentally altered <u>**exposed sand area**</u> at <u>**big spatial scales**</u>

Observations of vegetation encroachment following dam construction





A trend toward:

- Increased vegetation area, particularly along the river
- Correspondingly reduced area of bare sand


1923, E.C. LaRue, USGS
103

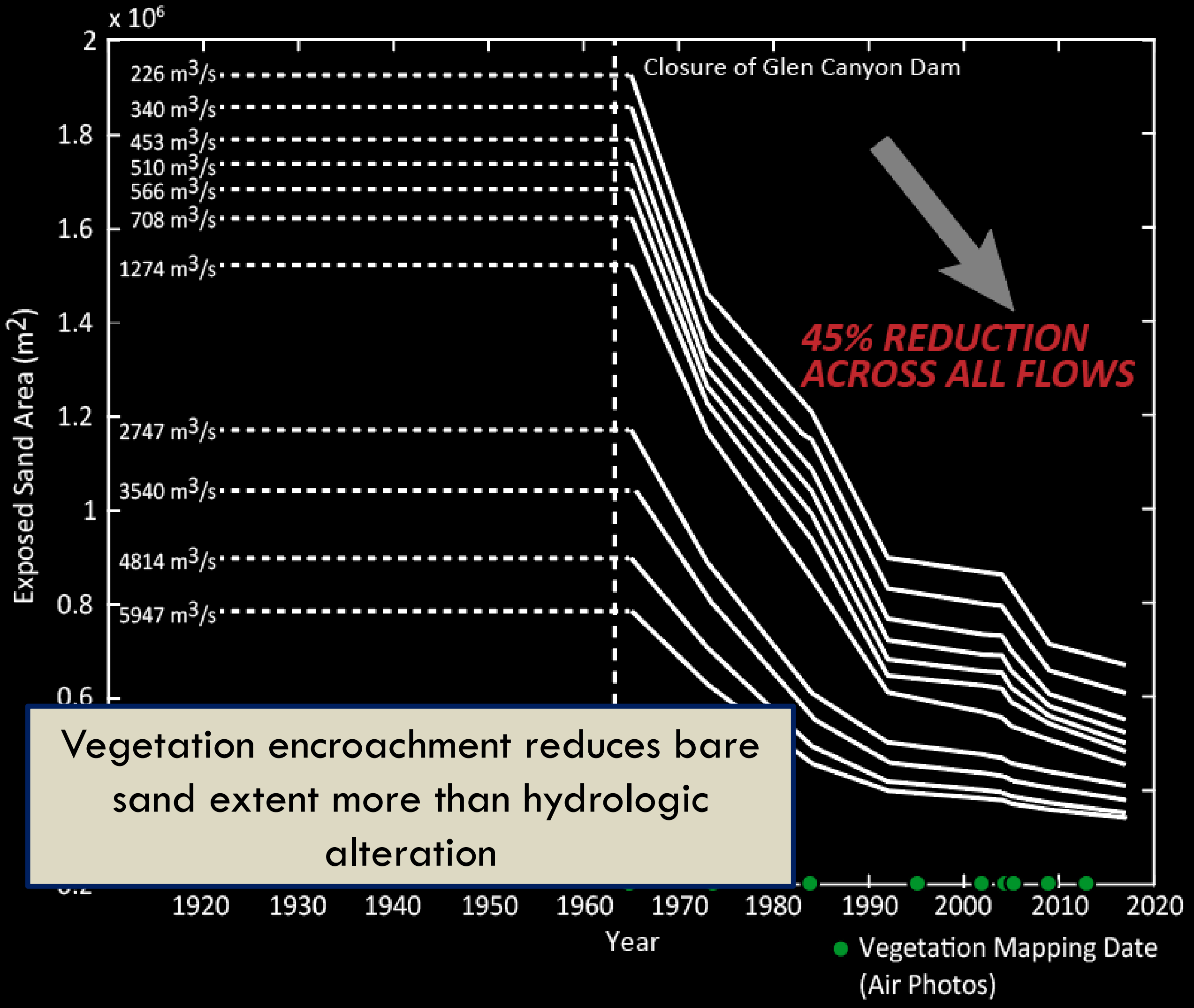
2017, A. Fairley, USGS


1923, E.C. LaRue, USGS
82

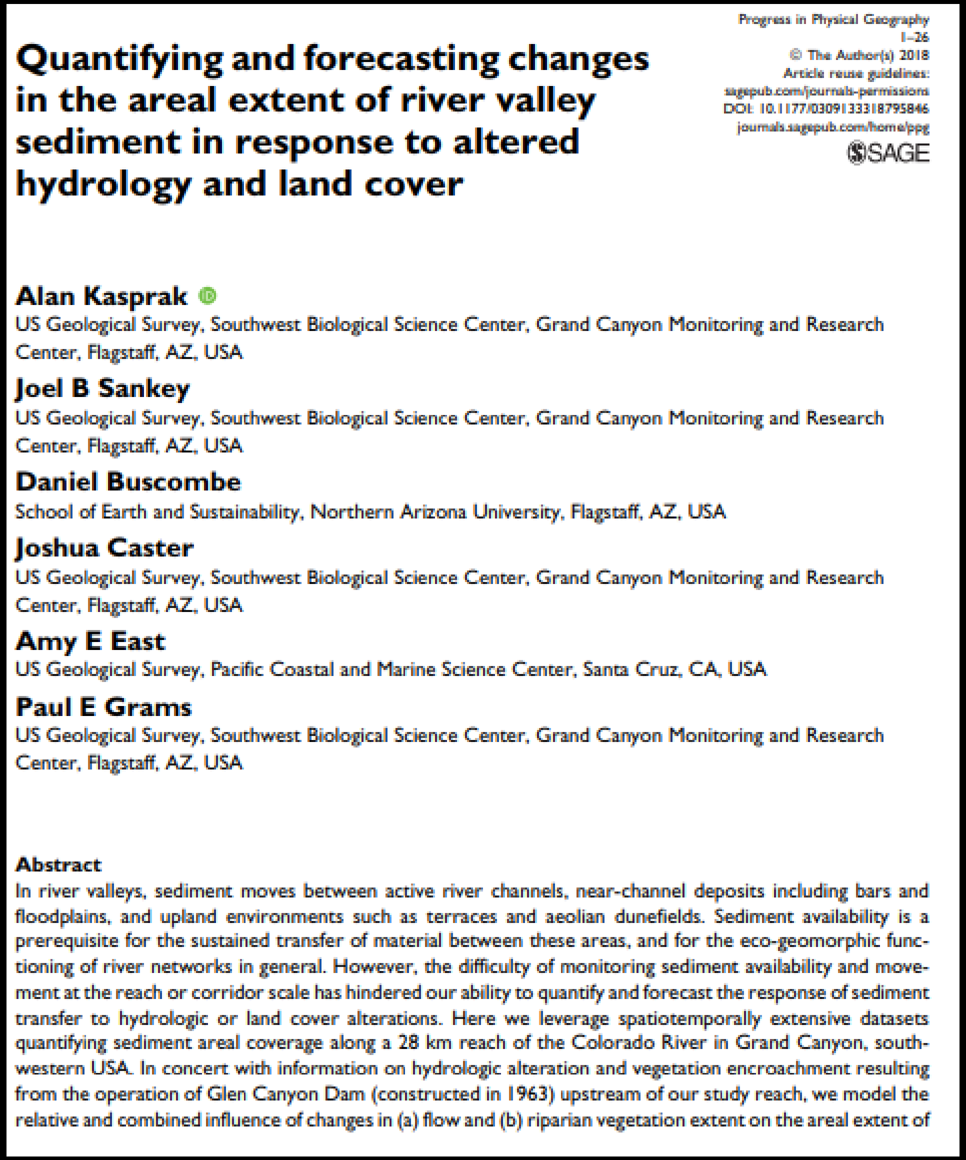

2017, A. Fairley, USGS

__In a 28 km segment in Lower Marble Canyon, we found:__

- Large-scale reduction in bare sand area following dam construction
- Most sand loss occurred in first ~30 years after Glen Canyon Dam
- Most rapid growth at low stages



Vegetation encroachment reduces bare sand extent more than hydrologic alteration



Progress in Physical Geography
1–26

DOI: 10.1177/0309133318795846
journals.sagepub.com/home/ppg
SAGE

Quantifying and forecasting changes in the areal extent of river valley sediment in response to altered hydrology and land cover

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School of Earth and Sustainability, Northern Arizona University, Flagstaff, AZ, USA

Joshua Caster
US Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, Flagstaff, AZ, USA

Amy E East
US Geological Survey, Pacific Coastal and Marine Science Center, Santa Cruz, CA, USA

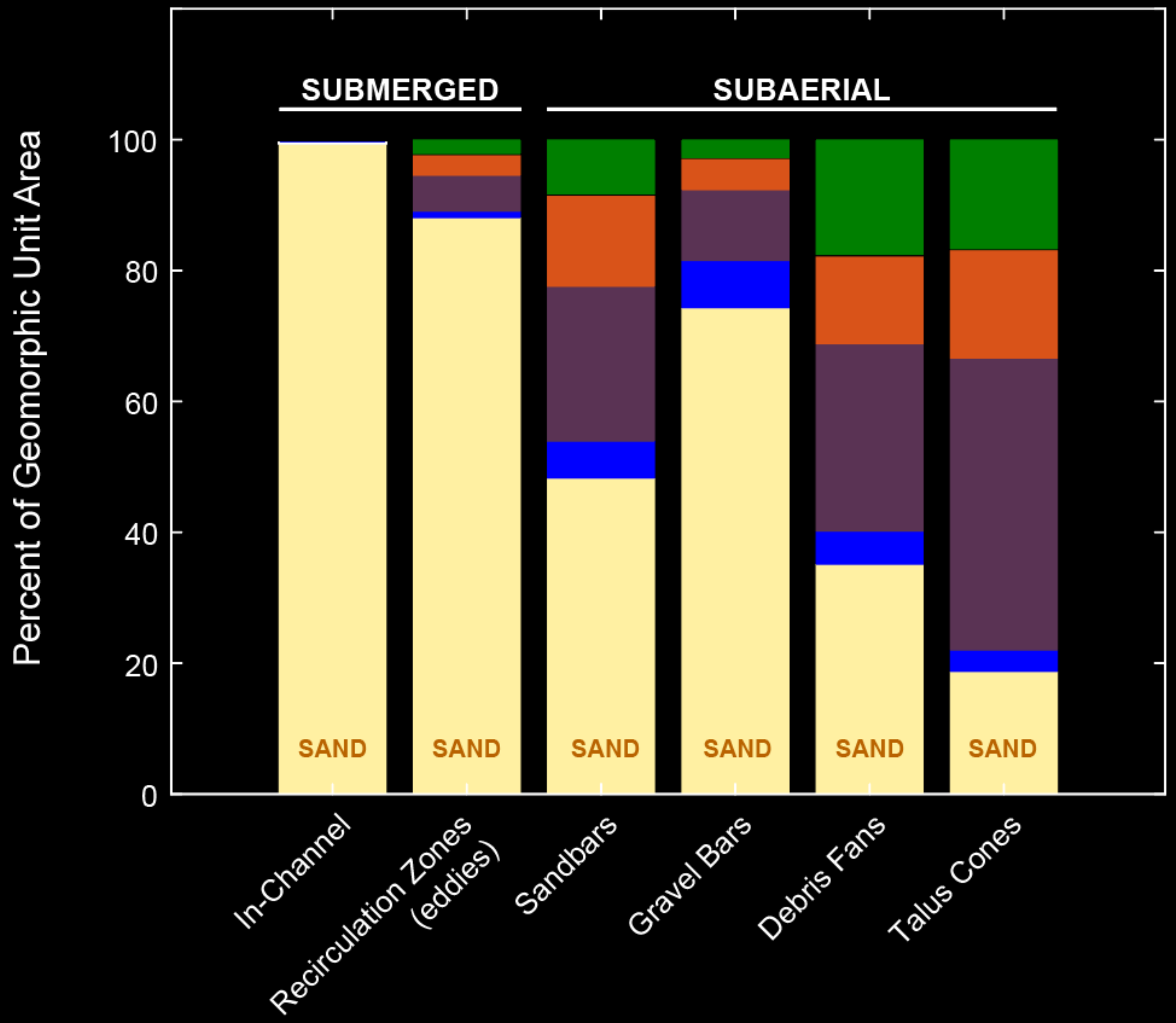
Paul E Grams
US Geological Survey, Southwest Biological Science Center, Grand Canyon Monitoring and Research Center, Flagstaff, AZ, USA

Abstract

In river valleys, sediment moves between active river channels, near-channel deposits including bars and floodplains, and upland environments such as terraces and aeolian dunefields. Sediment availability is a prerequisite for the sustained transfer of material between these areas, and for the eco-geomorphic functioning of river networks in general. However, the difficulty of monitoring sediment availability and movement at the reach or corridor scale has hindered our ability to quantify and forecast the response of sediment transfer to hydrologic or land cover alterations. Here we leverage spatiotemporally extensive datasets quantifying sediment areal coverage along a 28 km reach of the Colorado River in Grand Canyon, southwestern USA. In concert with information on hydrologic alteration and vegetation encroachment resulting from the operation of Glen Canyon Dam (constructed in 1963) upstream of our study reach, we model the relative and combined influence of changes in (a) flow and (b) riparian vegetation extent on the areal extent of

What's the ***current*** and ***projected future*** composition of vegetation throughout this 168 km reach?

Current Vegetation:
[classified by Durning et al. (2018) via 4-band, 0.2 m aerial imagery]



RIPARIAN HERBS

(e.g., phragmites, Bermuda grass)

NATIVE RIPARIAN SHRUBS

(e.g., baccharis, willow, mesquite)

NON-NATIVE RIPARIAN SHRUBS

(e.g., tamarisk)

XERIC SHRUBS/GRASSES

(e.g., brittlebush, creosote, annual/perennial grasses)

In a 28 km segment in Lower Marble Canyon, we found:

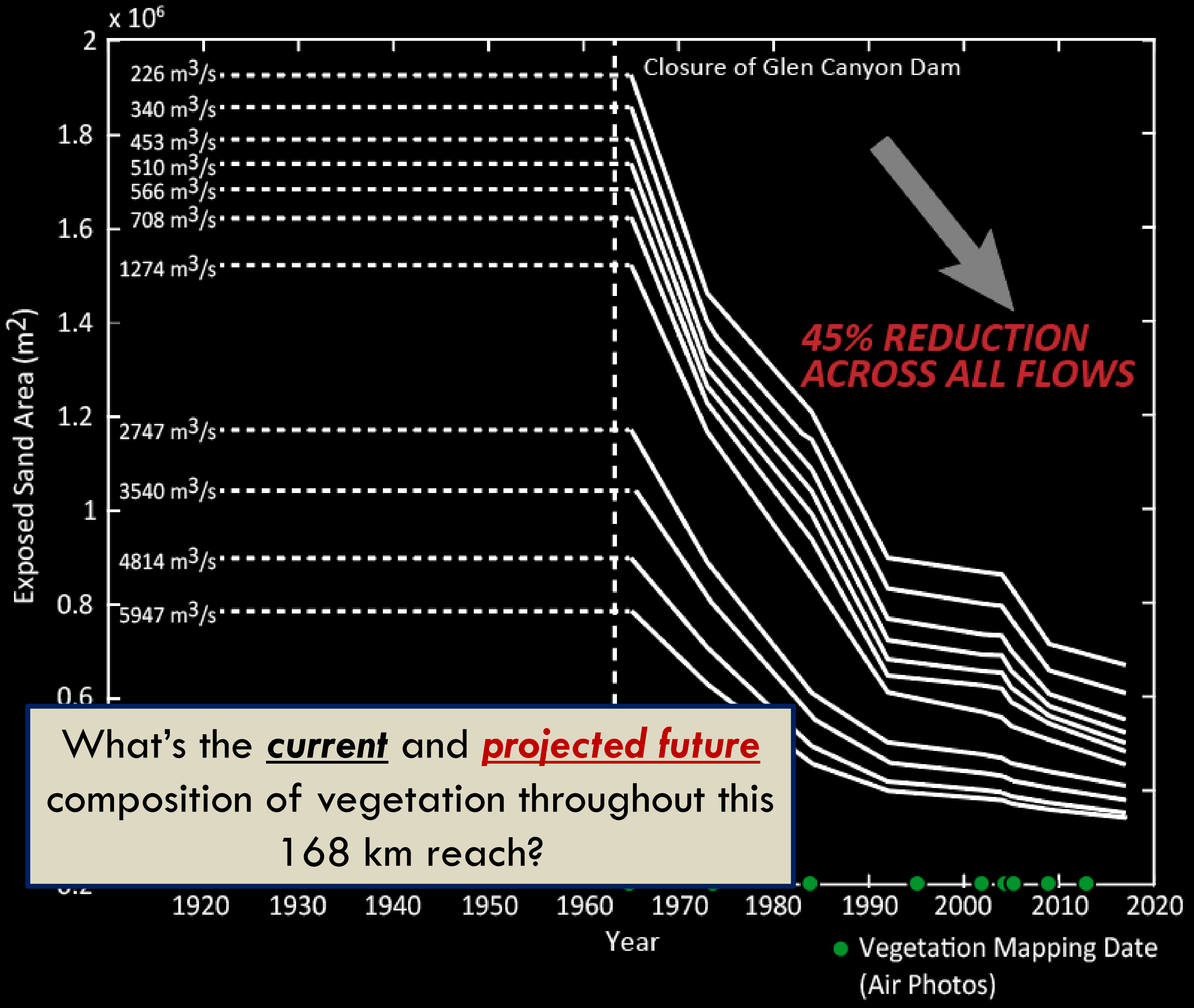
- Large-scale reduction in bare sand area following dam construction
- Most sand loss occurred in first ~30 years after Glen Canyon Dam
- Most rapid growth at low stages

RESEARCH ARTICLE

Applied Vegetation Science

Hydrological regime and climate interactively shape riparian vegetation composition along the Colorado River, Grand Canyon

Bradley J. Butterfield[1] | Emily Palmquist[1,2] | Barbara Ralston[3]



What's the ***current*** and ***projected future*** composition of vegetation throughout this 168 km reach?

Vegetation Suitability Modeling (future conditions)

Predicted binary (i.e., suitable/unsuitable) habitat for 75 plant species, which we aggregated into four groups

Suitability =

f (elevation above daily peak flow)

f (maximum inundation duration)

…over period October 2017 – October 2018

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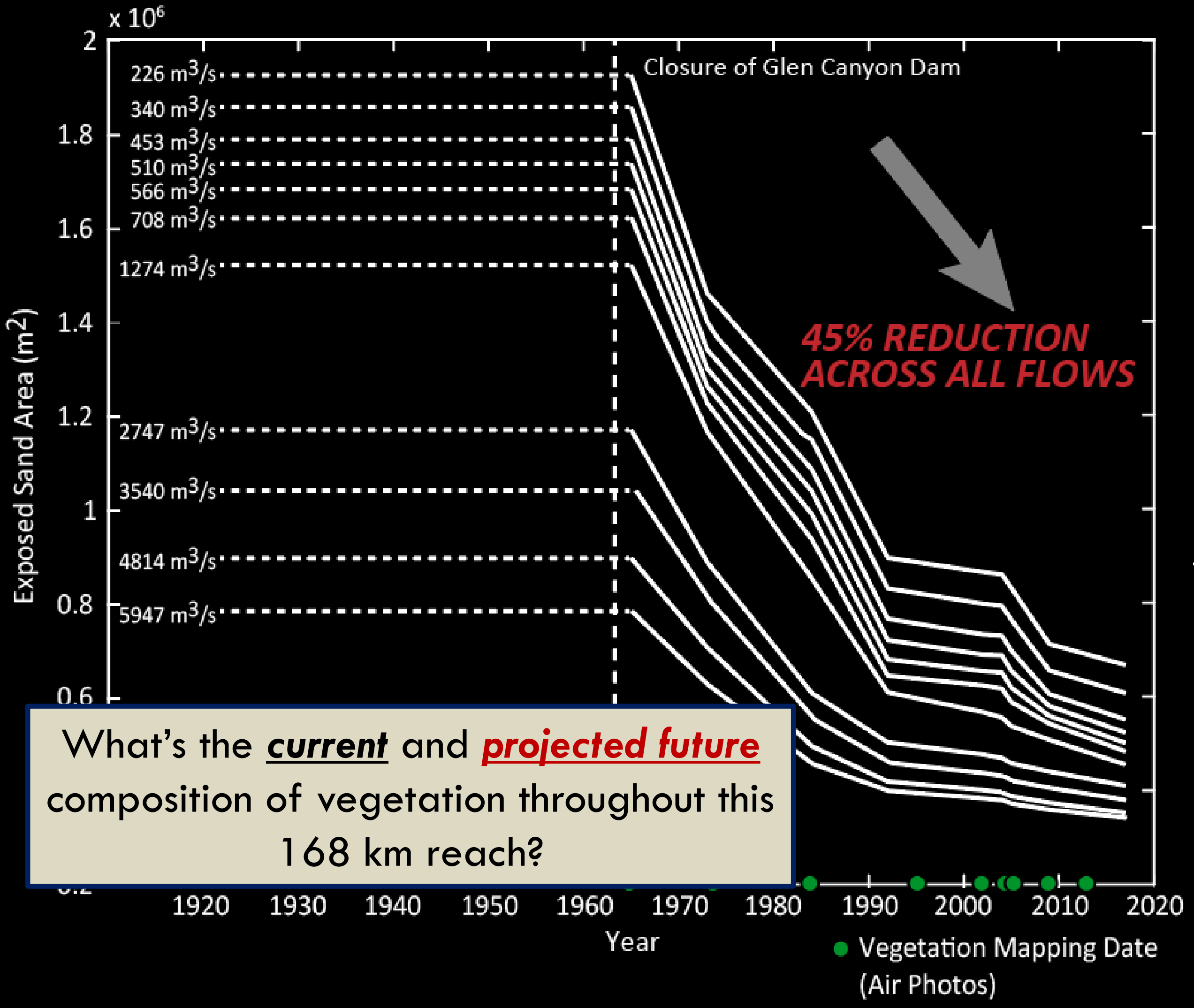

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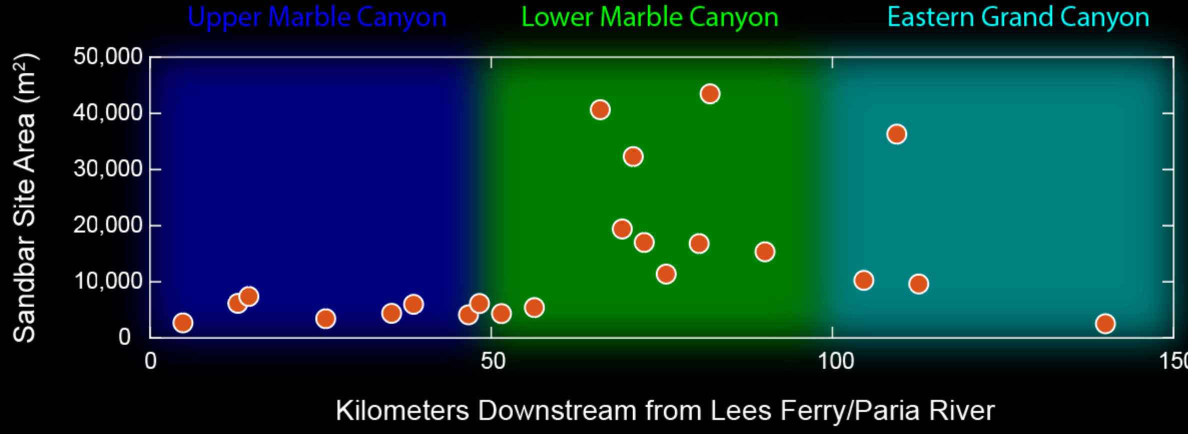
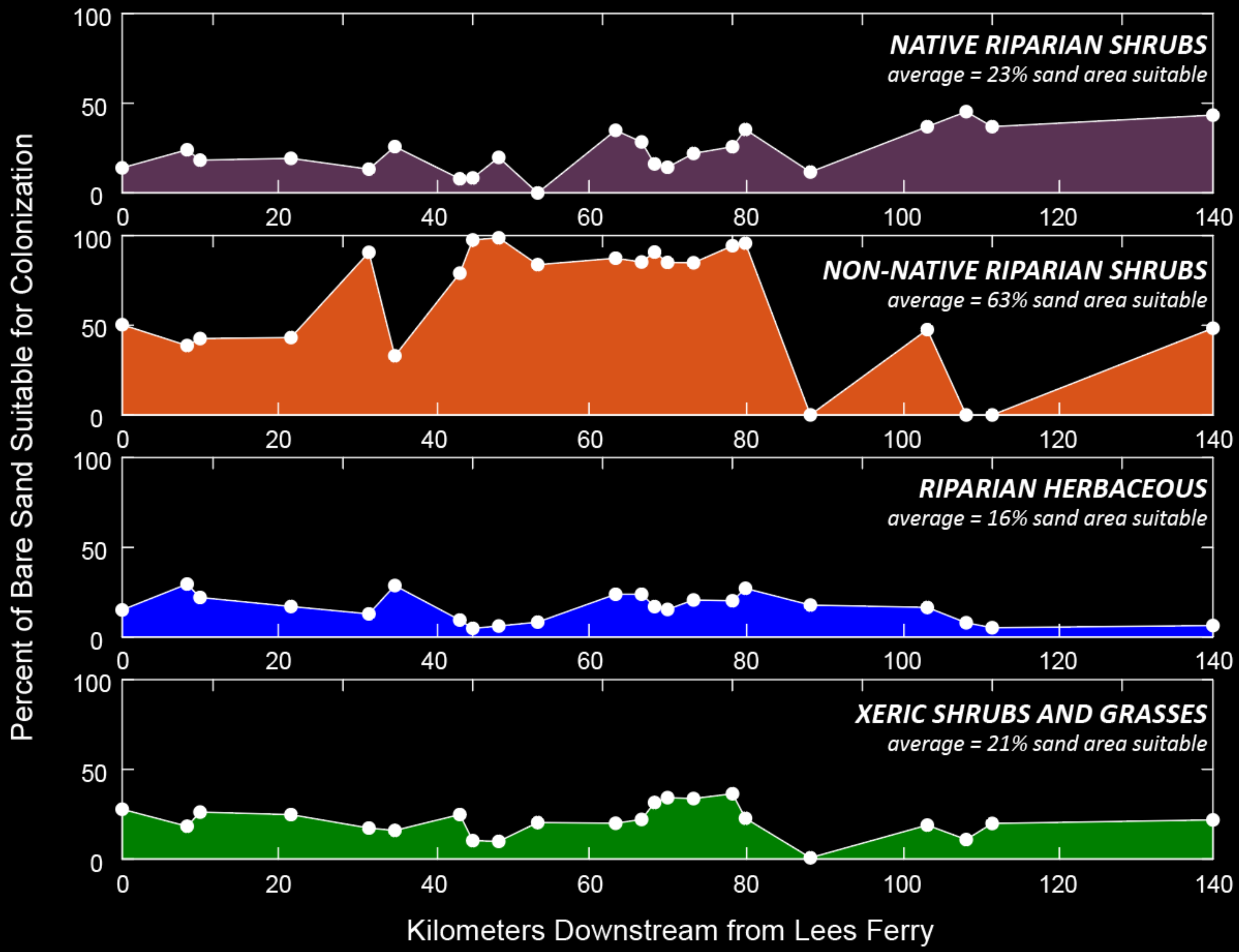
Suitability modeling completed at 25 sandbars

[gcmrc.gov/sandbar]





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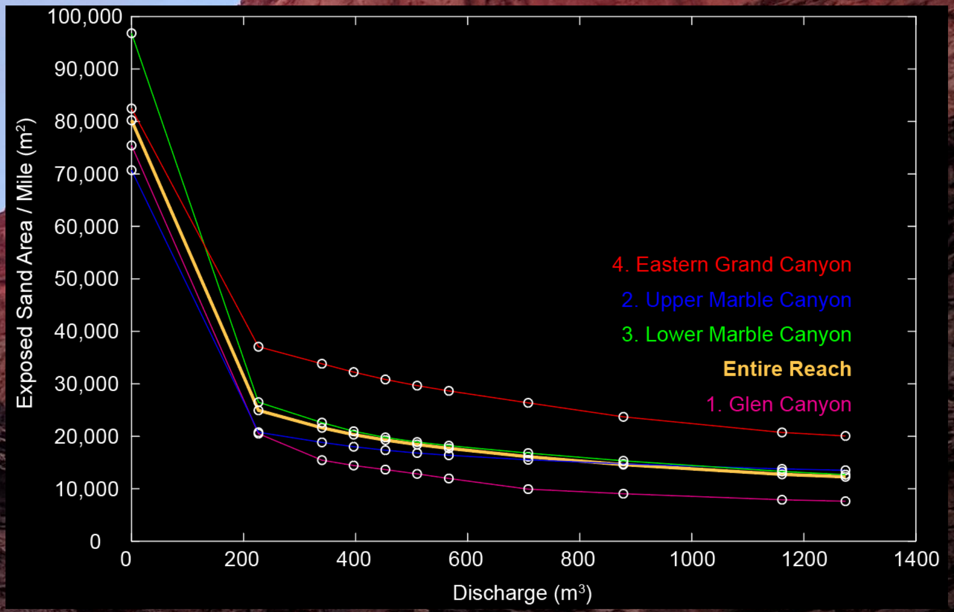
In many locations,
Vegetation is likely to colonize most of the remaining bare sand area

Take-Home 1: the majority of the bare sand throughout this 168 km reach is underwater; any reductions in current low flows have the potential to expose a great deal of sand.



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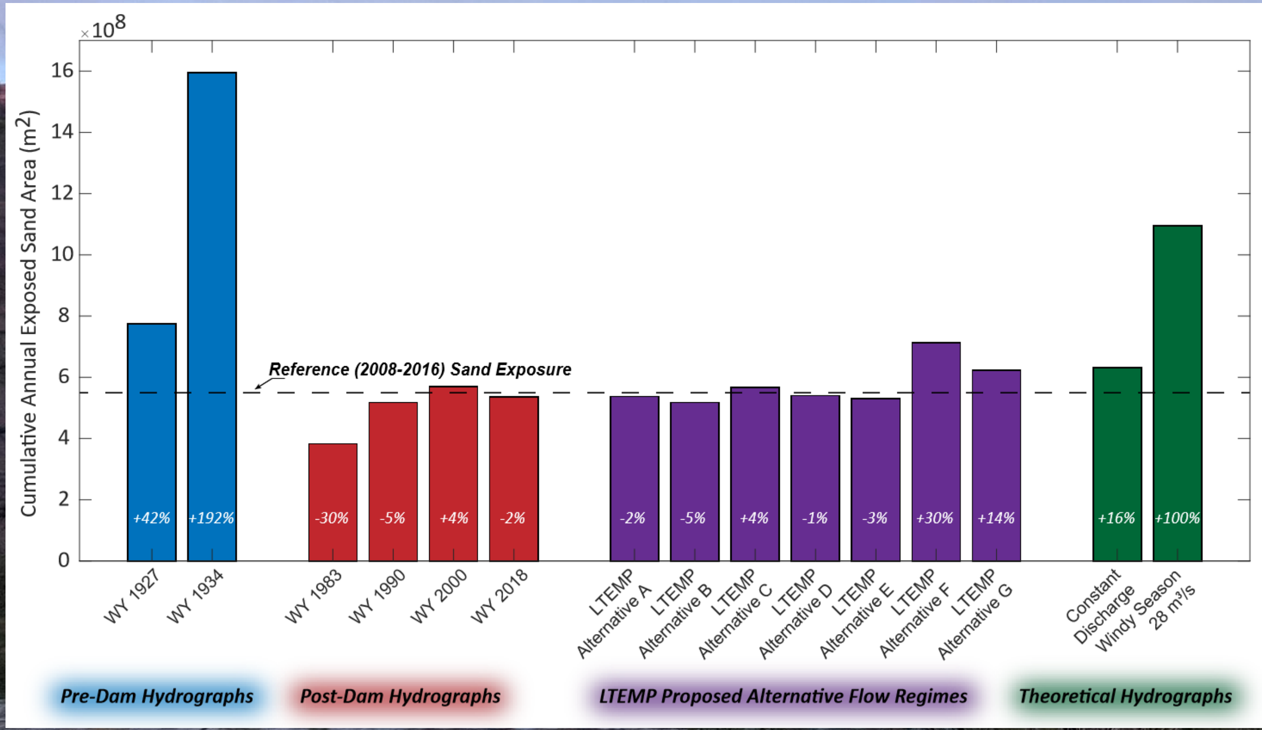

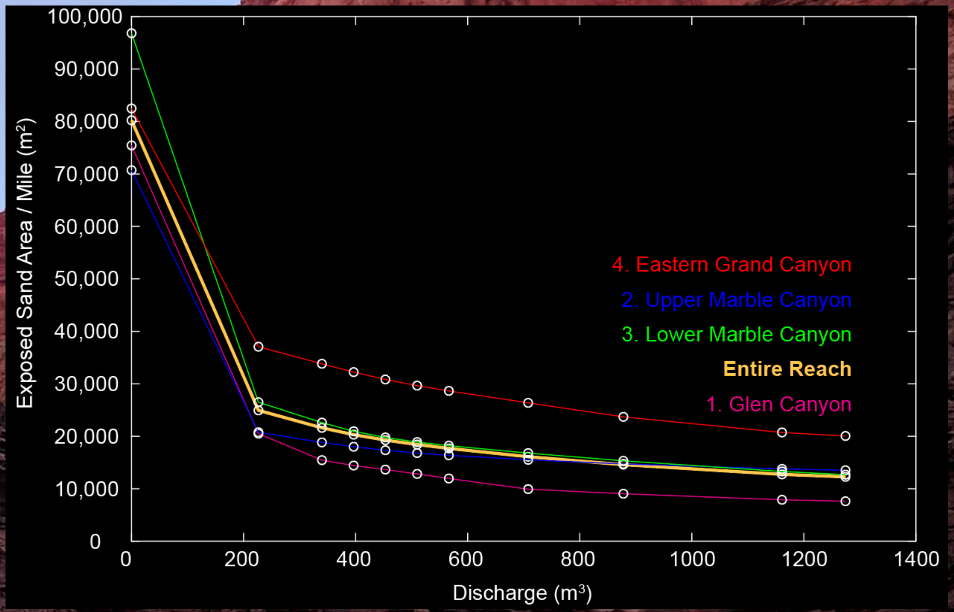

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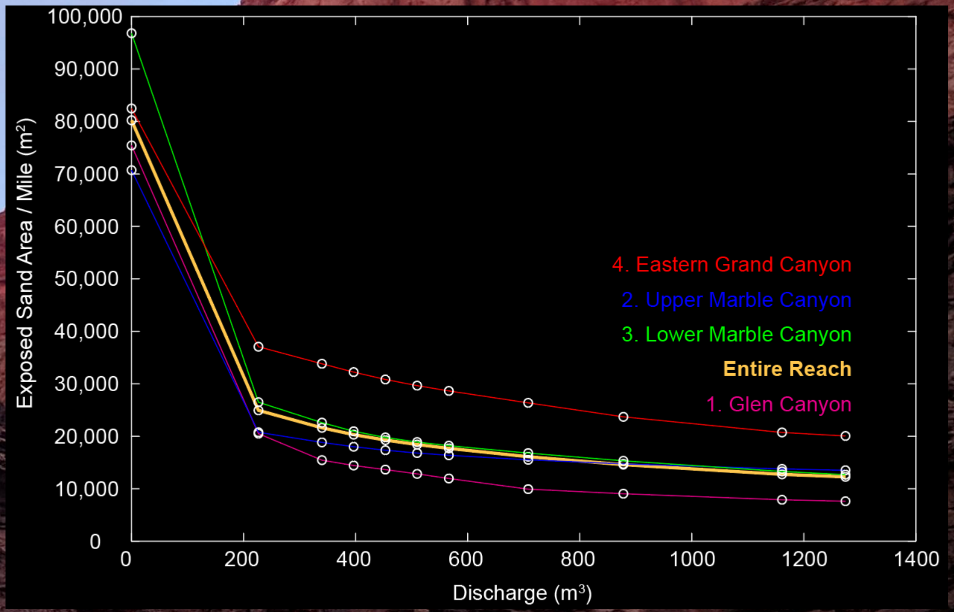

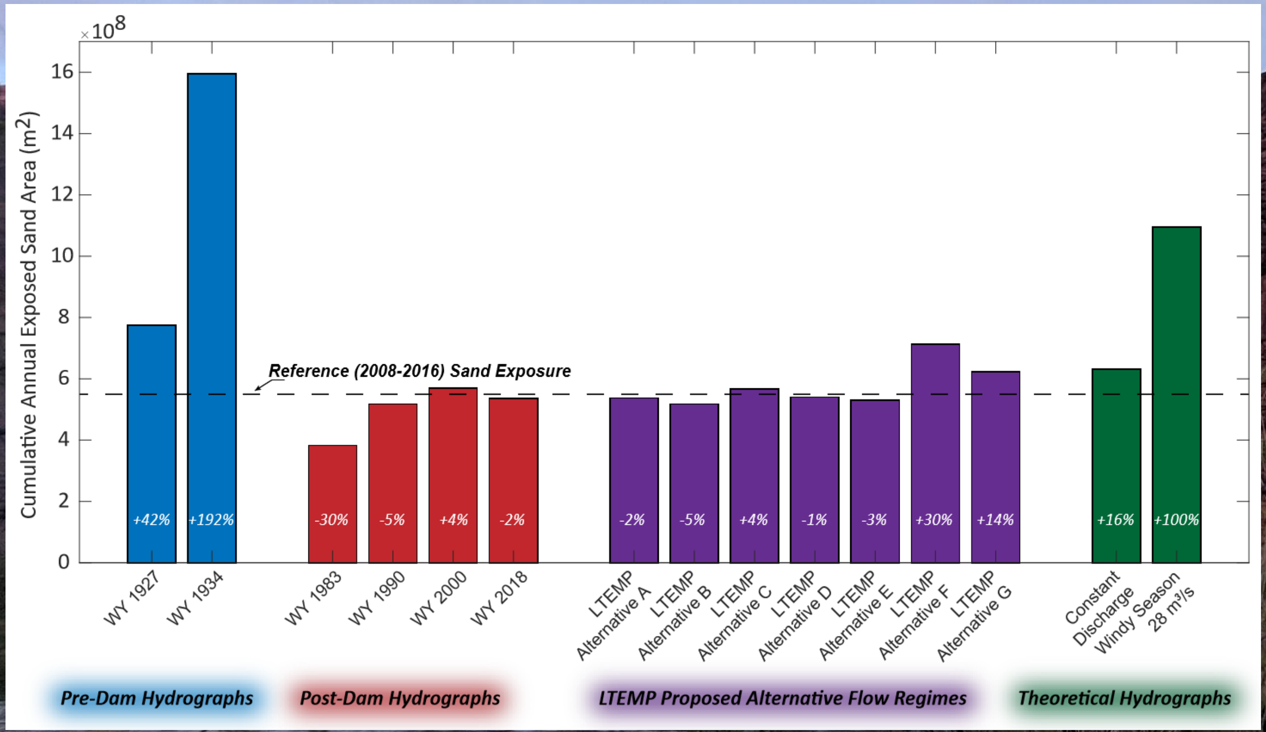

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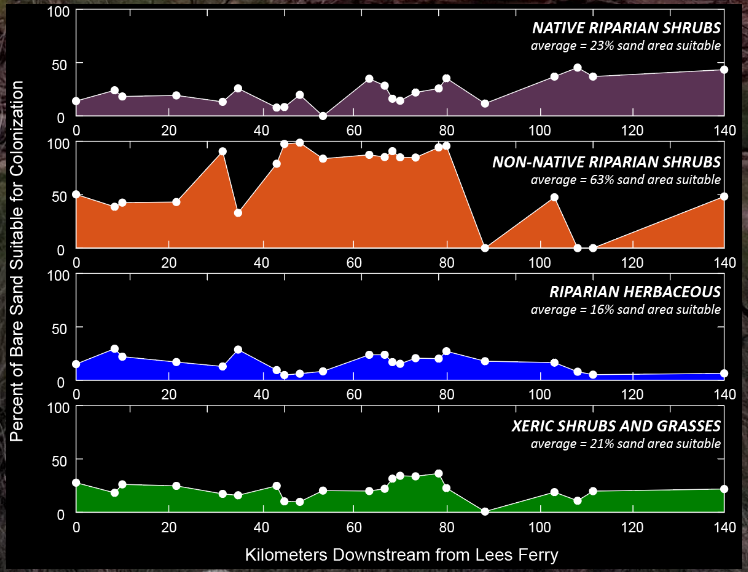

<u>Take-Home 3</u>: Potential for future vegetation encroachment is variable by site, but we can expect lots more plants in the future

Funding from *Glen Canyon Dam Adaptive Management Program and National Center for Earth Surface Dynamics 2*

Thanks to *Geoff Chain, Helen Fairley, Joe Hazel, Matt Kaplinski, Erich Mueller, Emily Palmquist, Barbara Ralston, Rob Ross, Jack Schmidt, Bob Tusso, and many, many surveyors and river guides in Grand Canyon*

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Rocky Mountain Section

72nd Annual Meeting of the Rocky Mountain Section

4-5 May 2020 | Provo, Utah

Utah Valley Convention Center

ABSTRACT DEADLINE TONIGHT @ MIDNIGHT!

T12. Advances and Applications of River Science in the West

Sharon Bywater-Reyes.

Description: This session seeks abstracts concerning the development or application of science in riverine environments, including but not limited to, field, experimental, or numerical studies of hydraulics, sediment transport, interactions with biota, or river restoration.

› Submit an abstract to this session