Projected Climate and Geomorphic Changes in the Little Colorado River Watershed and Potential Links to Humpback Chub Habitat

With Emphases on Vegetation, Hydrology, and Sediment Transport

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Little Colorado River, 1927

Courtesy of NPS

Courtesy of Melanie Fischer, USFWS

USGS science for a changing world

First:

A broad perspective of geomorphic change in Western rivers…

Little Colorado River

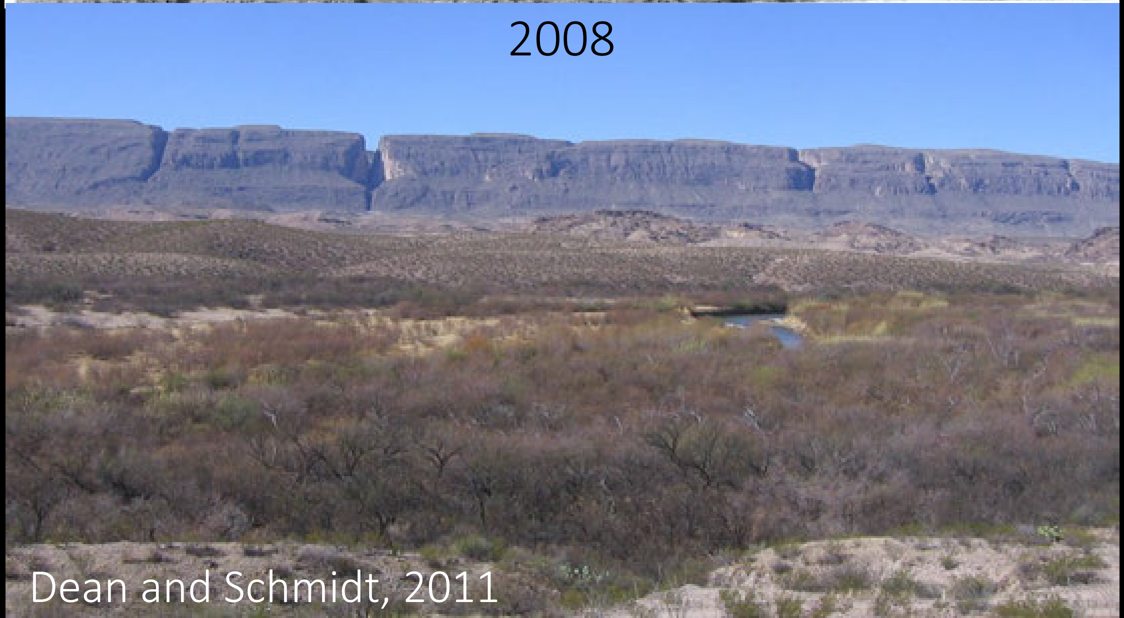
Little Colorado River, AZ
Looking Downstream from
Highway 89 bridge
near Cameron, AZ

Dean and Topping, 2019

Moenkopi Wash

Moenkopi Wash, AZ,
Looking upstream from
Hwy 89 bridge
Near Cameron, AZ

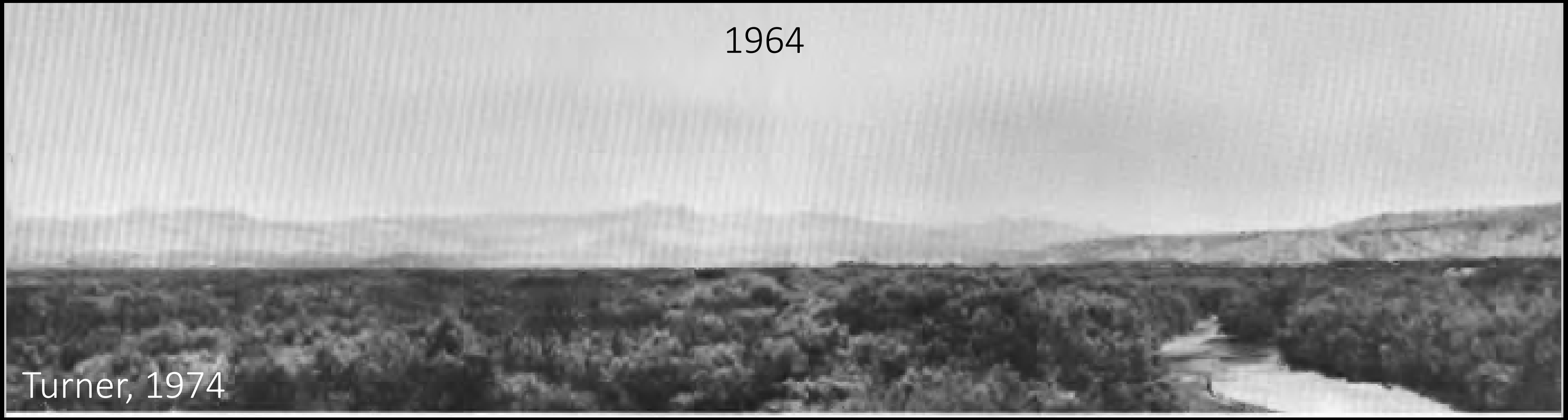
Rio Grande/Bravo



Dean and Schmidt, 2011

Rio Grande/Bravo,
Big Bend National Park, TX,
Taken downstream from Castolon,TX

Gila River, near Calva, AZ



Turner, 1974

Common Themes From the Above Slides

1) Narrower Channels

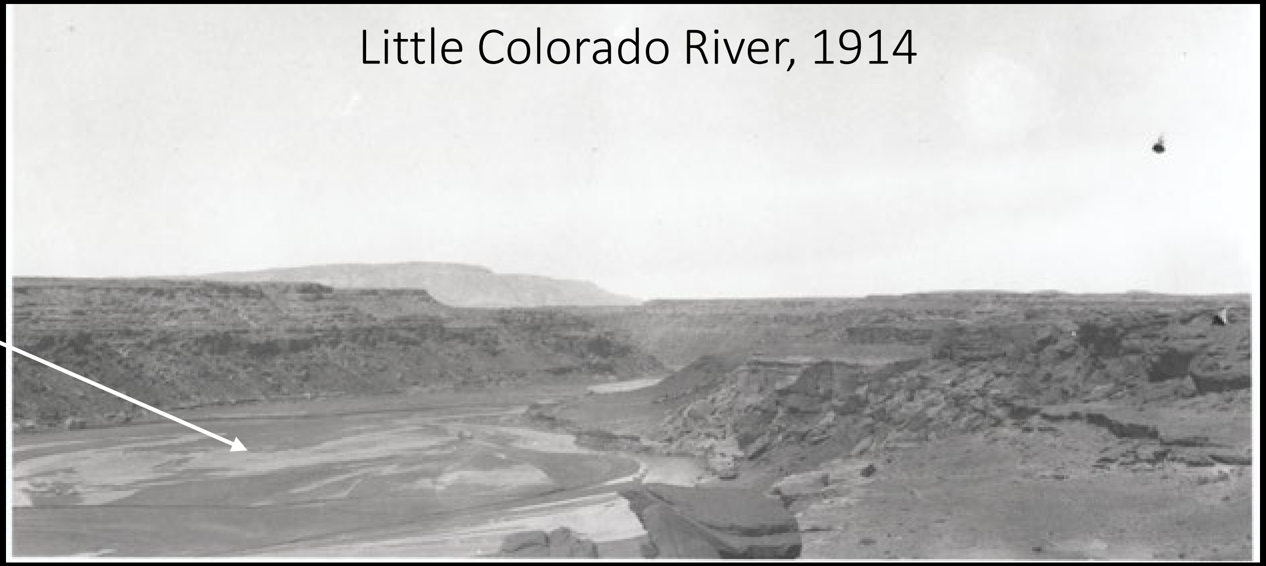
2) Increase in Vegetation

3) Arid/Semi-arid environments (drylands)
    a) Variability in water supply
    b) Growing human populations
    c) Heavily managed water resources

But how does a river go from This

to

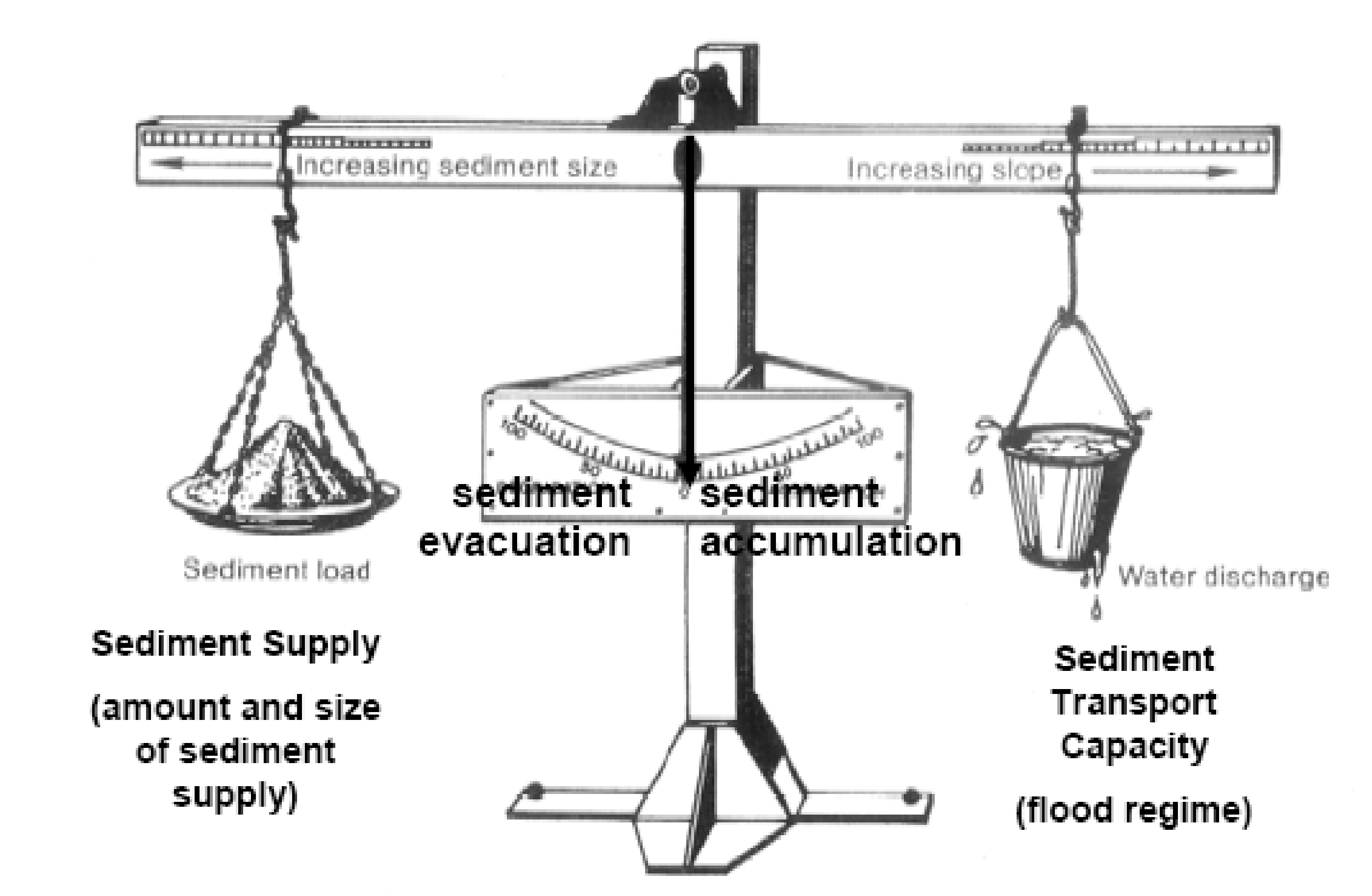
That



Dean and Topping, 2019

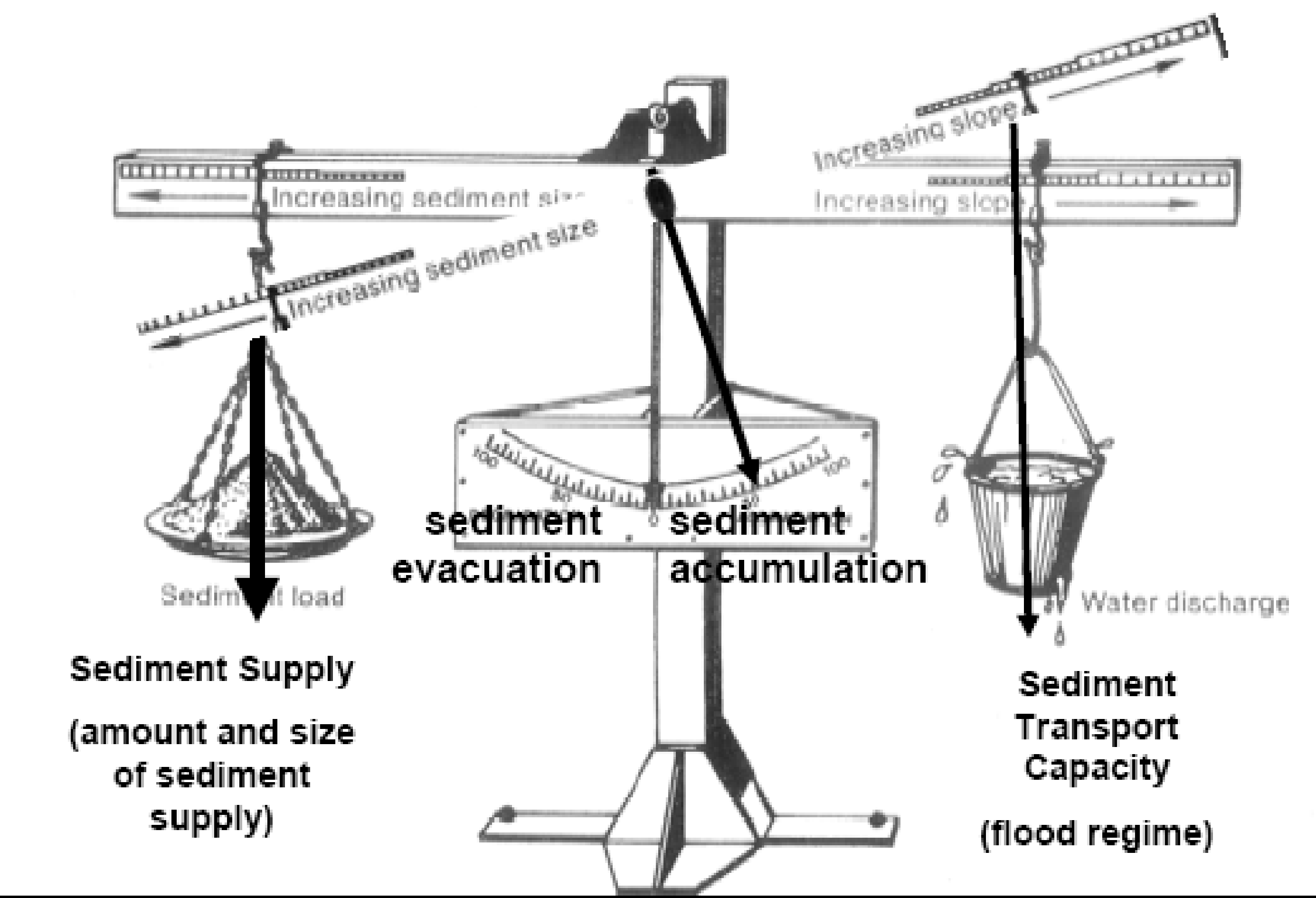
Why do channels change size and shape?

channels change form in response to changes in the *balance* between water and sediment supply



Lane, 1955, modified by Borland (1960)

Water and Sediment Balance…

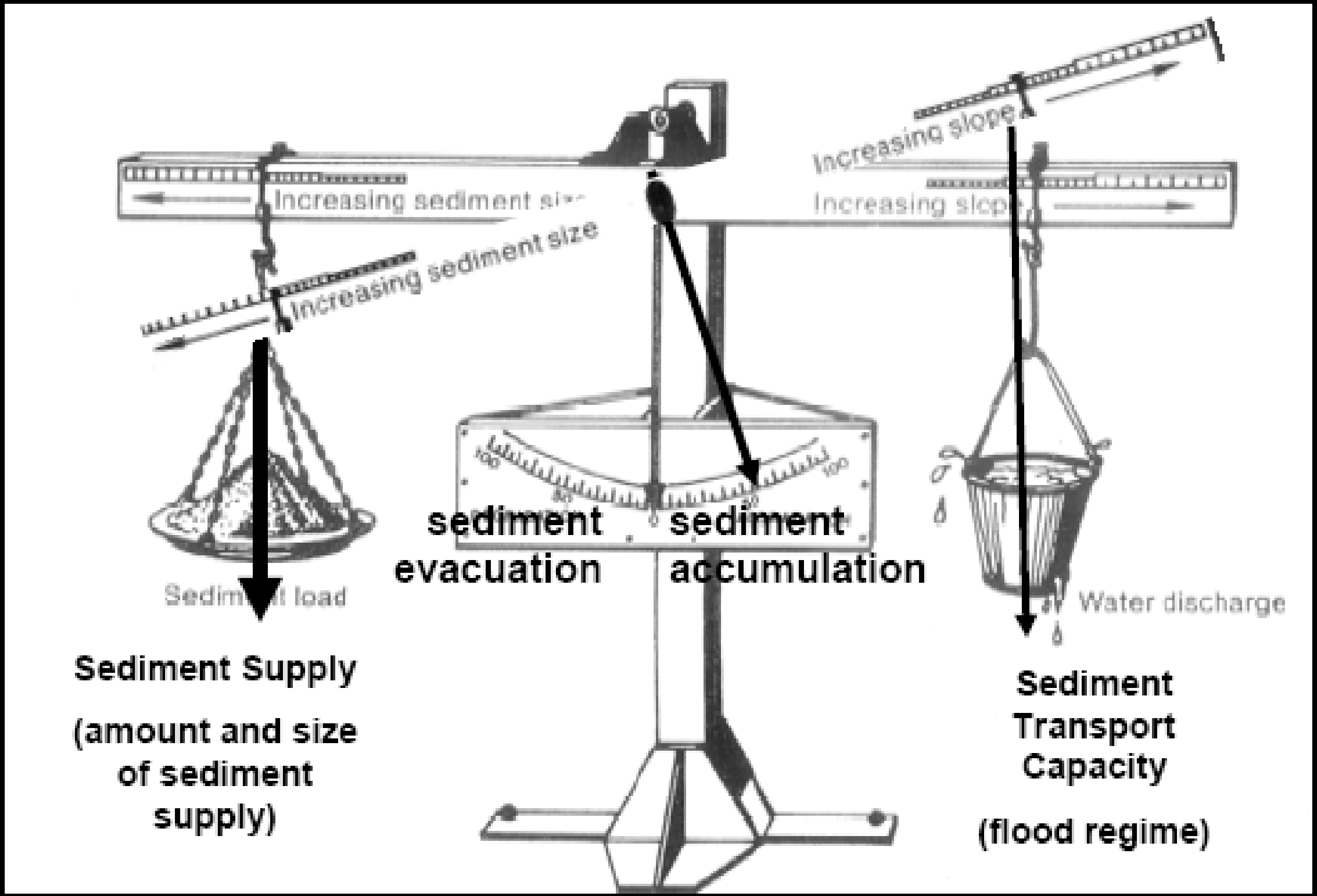


Lane, 1955, modified by Borland (1960)

Water and Sediment Balance…Gets Messy When Streamflow/Sediment Transport are Modified by Other Processes (e.g. plants) – FEEDBACKS?

Little Colorado River, AZ

Dean and Topping, 2019, *GSA Bulletin*, Data Repository



Lane, 1955, modified by Borland (1960)

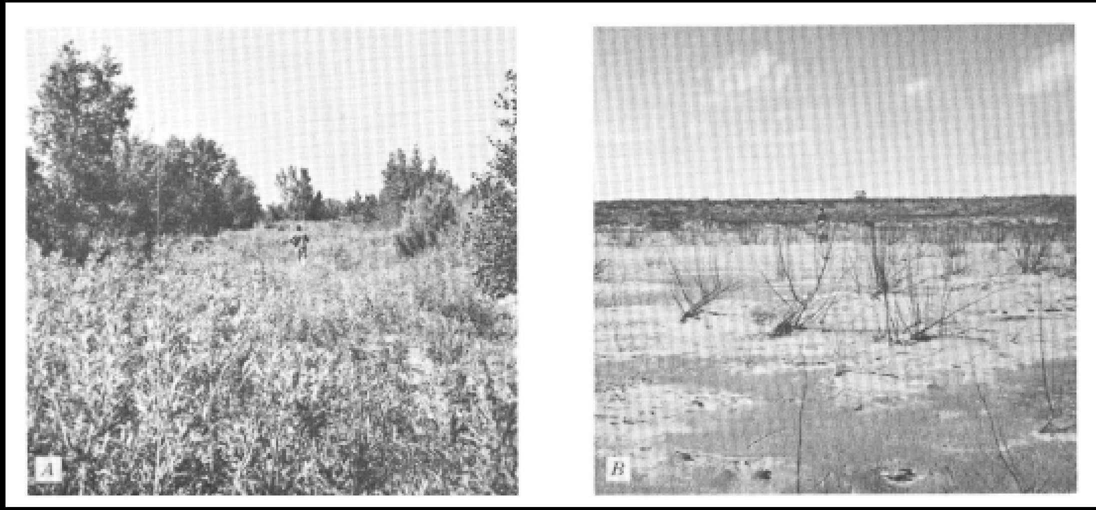
Geomorphic Effects of Vegetation: Historic Observations

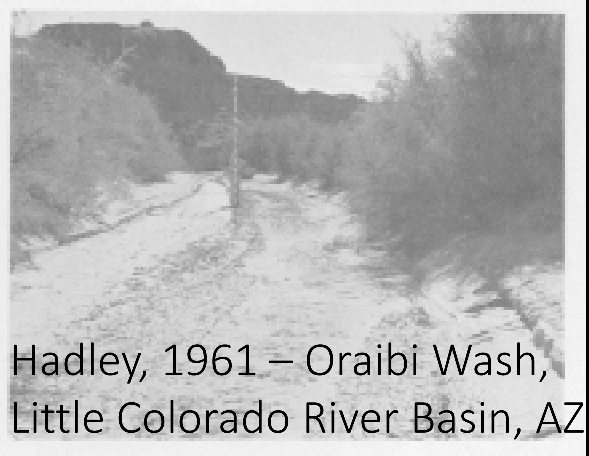

Gila River, AZ 1932


Gila River, AZ 1964

Turner, 1974

Schumm and Lichty, 1963– Cimarron River, KS




Hadley, 1961 – Oraibi Wash, Little Colorado River Basin, AZ

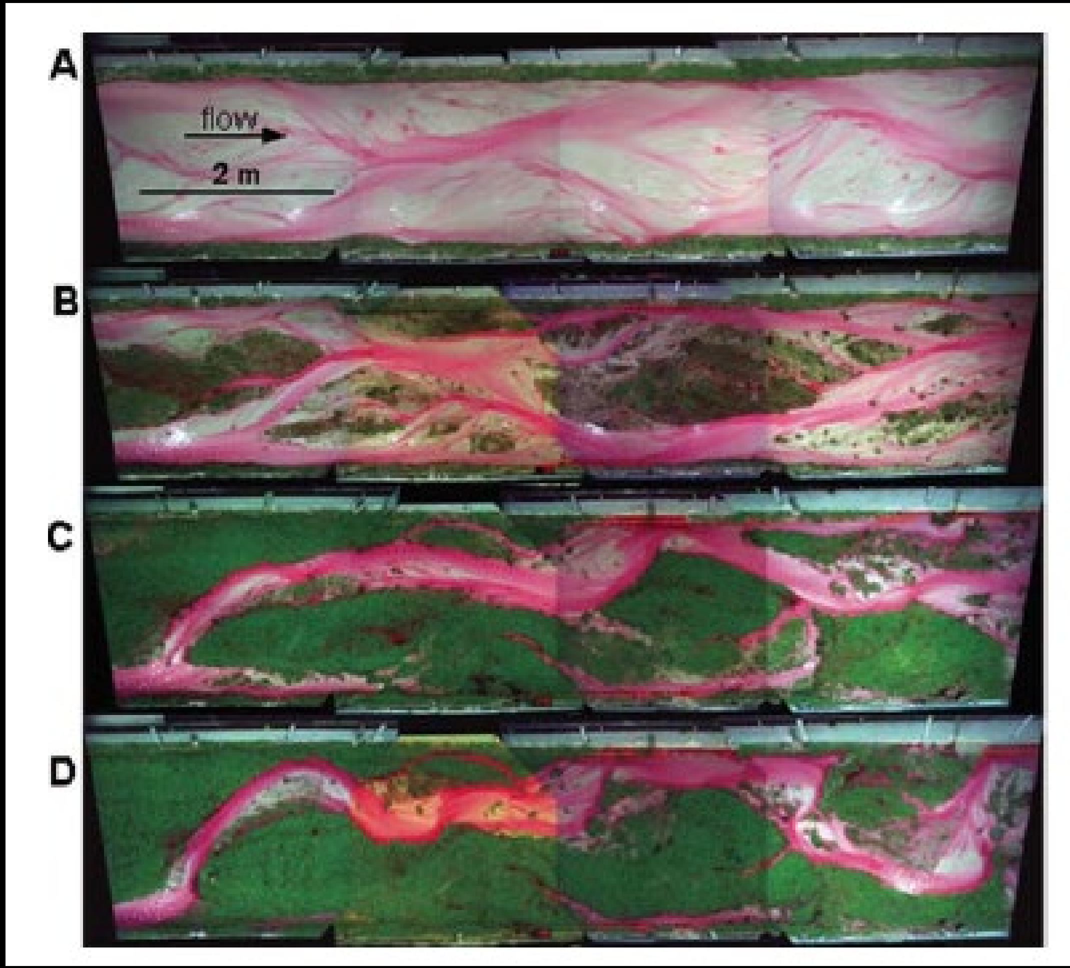
- **Vegetation aids in channel recovery after floods**
- **Vegetation establishment = abandonment of secondary channels**
- **Reaches with/without vegetation exhibit different channel patterns**

Flume Experiments:
Role of Vegetation on Channel Morphology

In this experiment, alfalfa sprouts were seeded, and allowed to grow. Flow Had simple hydrograph of low flow, and flood flow.

Tal and Paola, 2007
For other videos of their experiments, go to:
https://pubs.geoscienceworld.org/gsa/geology/article/35/4/347/129823/Dynamic-single-thread-channels-maintained-by-the

Flume Experiments:
Role of Vegetation on Channel Morphology



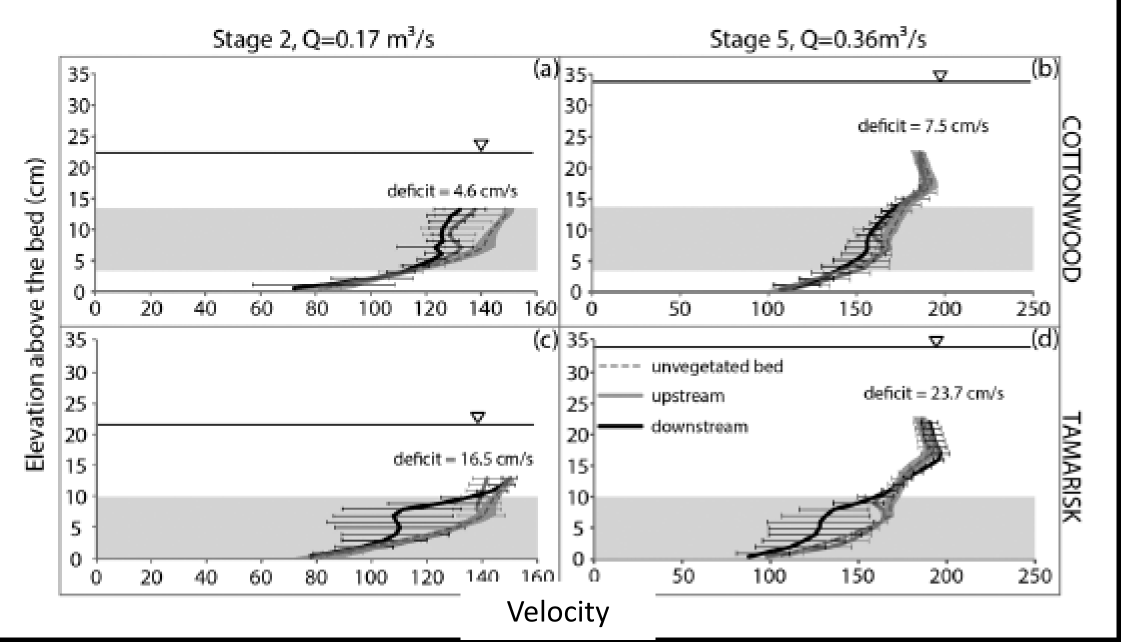
Tal and Paola, 2007
Tal et al., 2004
Gran and Paola, 2001
Braudrick et al., 2009

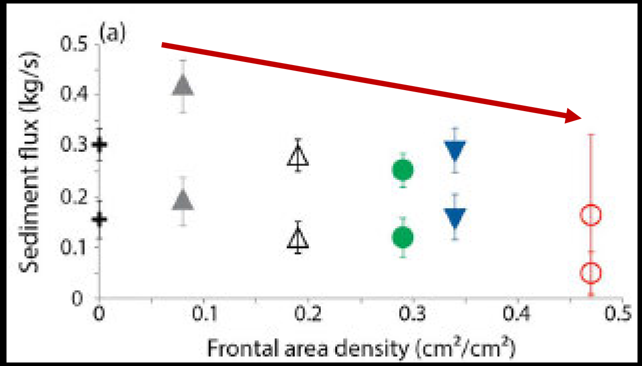
Flume Experiments:
Role of Vegetation on Channel Morphology

Nepf, 1999; Zong and Nepf, 2010;
Chen et al., 2012; Manners et al., 2015;
Diehl et al., 2017,

Flume experiments at plant scale:

- Effects on flow/Sed deposition
- Different types of plant seedlings
- Different plant/stem densities





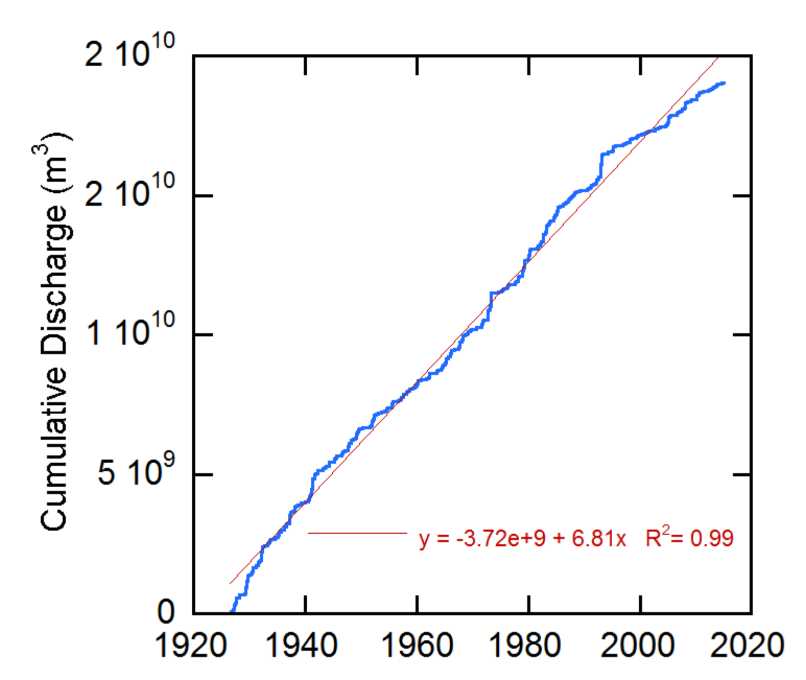
Reduced sed transport
with increasing stem density/area

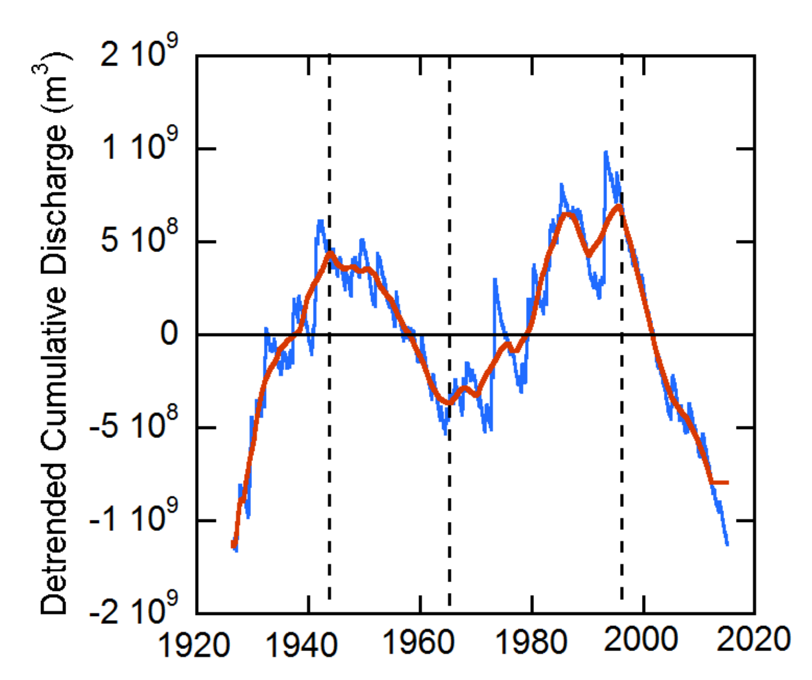
How does this apply to the Little Colorado River?
Part 1: The Alluvial Valleys

Re-evaluating the Timing of Historical Hydrologic Changes

Analyzed LCR stream flow data to determine time periods of hydrologic change

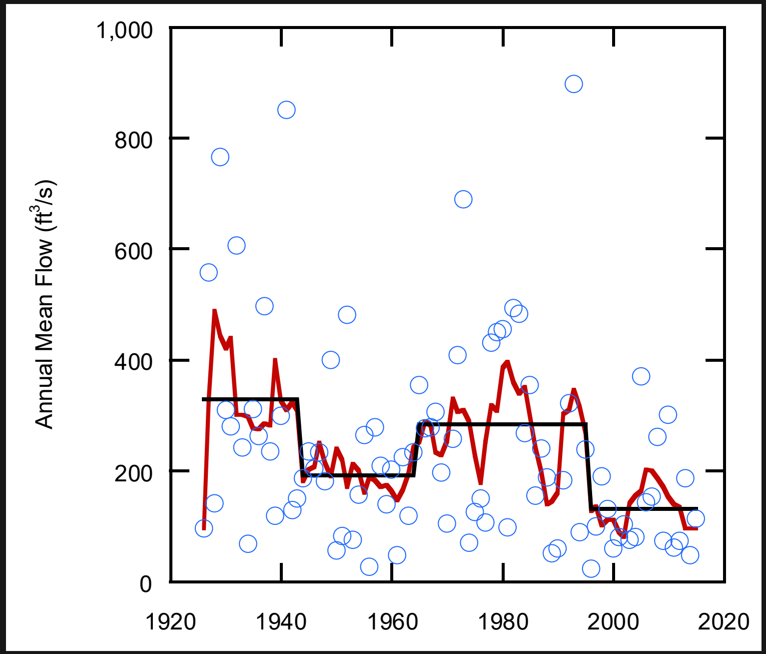
Identified four alternating periods of high and low flow

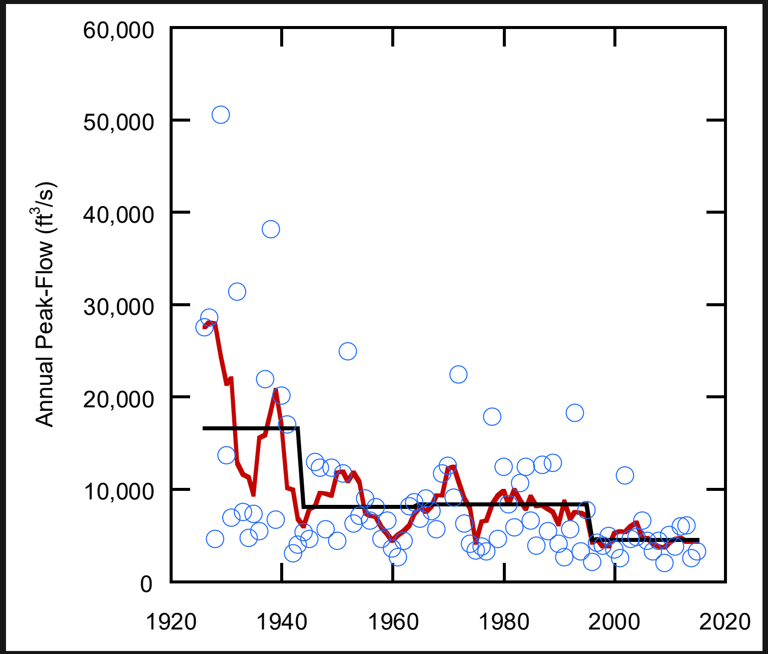


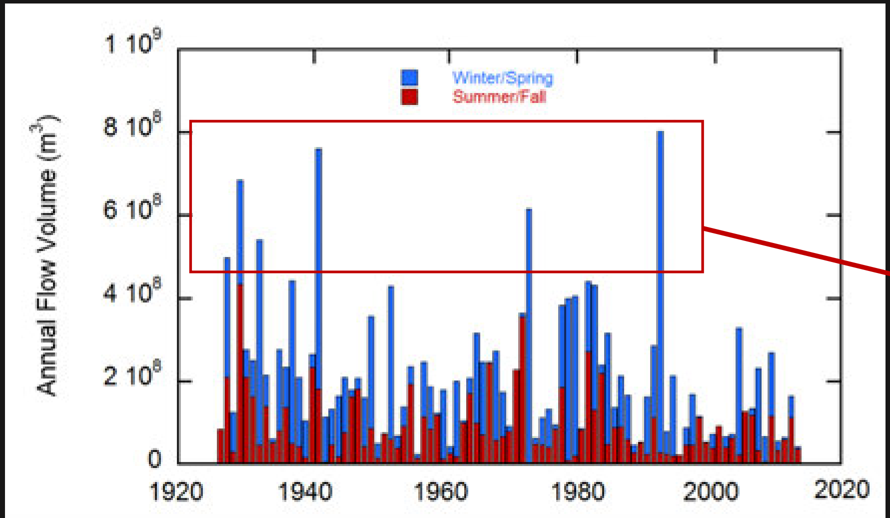


Dean and Topping, 2019, *GSA Bulletin*

Temporal Changes in Annual Mean Flow and Peak Flow





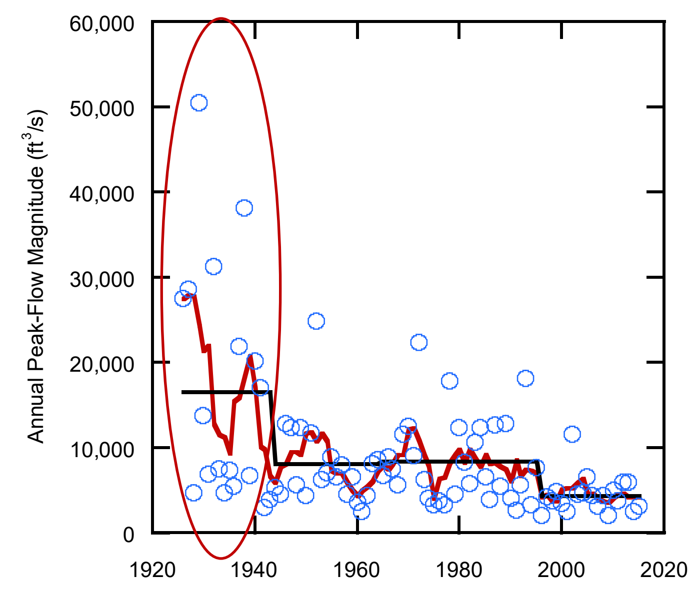


Peak flows have continuously declined over the period of record.

Years with largest flow volume are years with large winter/spring runoff.

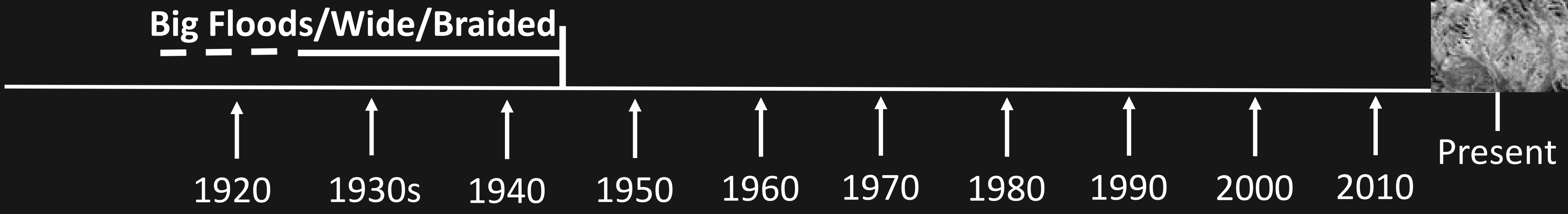
Dean and Topping, 2019, *GSA Bulletin*

Geomorphic Analysis Period 1: Early 1900s – 1943
Large Total Stream Flow and Peak Flow

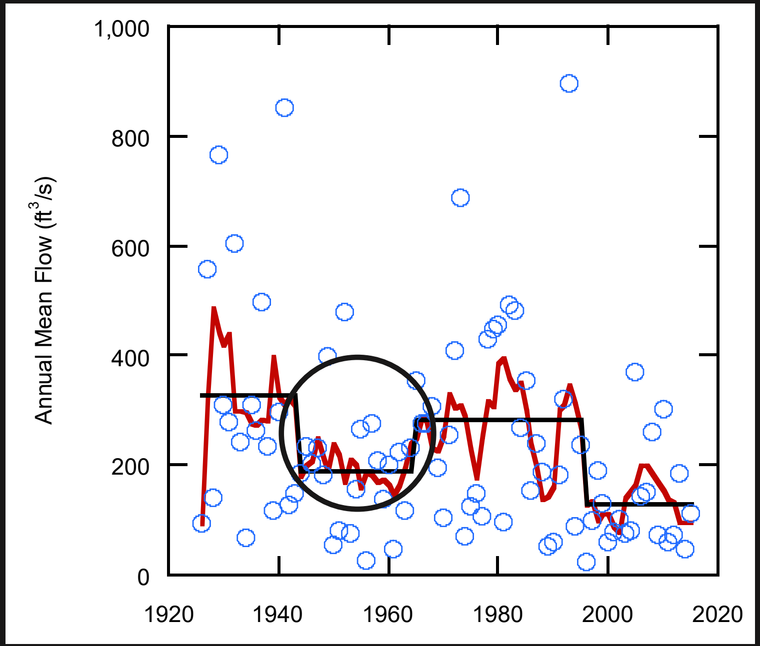


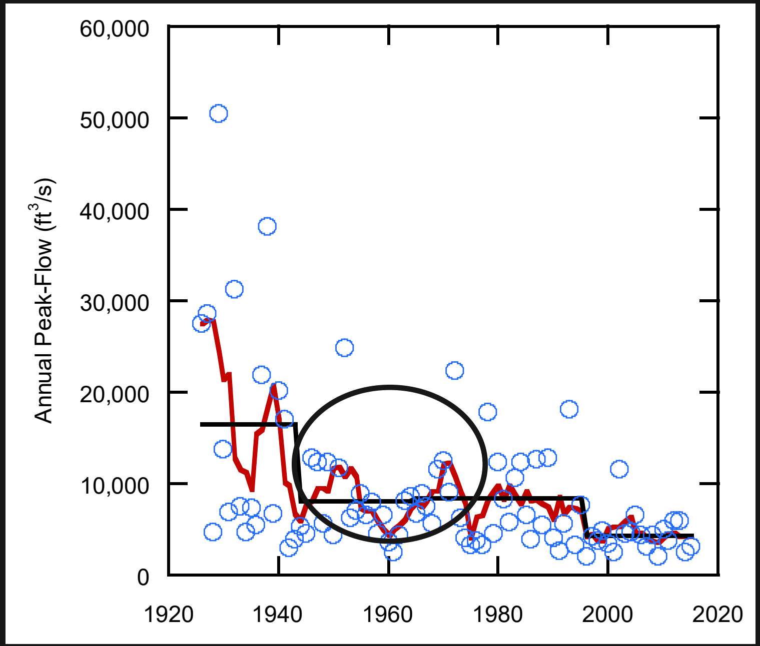
Dean and Topping, 2019, *GSA Bulletin*

- A flood of over 120,000 ft^3/s occurred in September 1923. Largest flood since 1870.



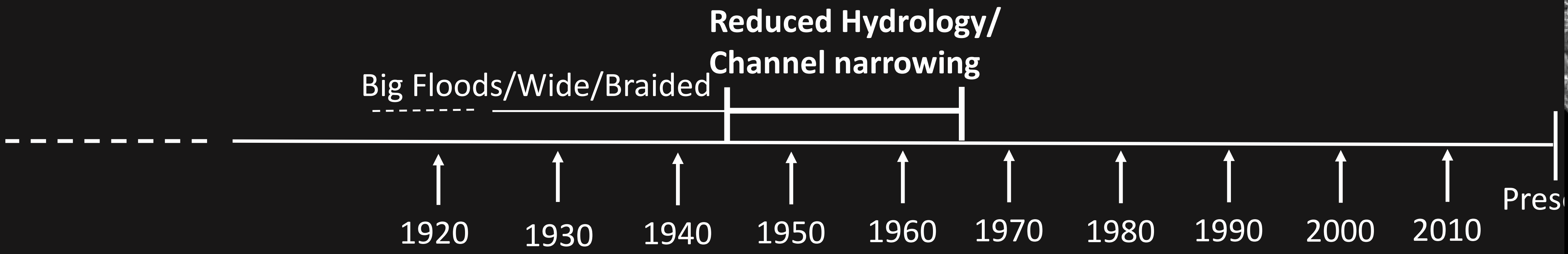
Period 2: 1944 – 1964
Reductions in Total Flow and Peak Flow: Onset of Channel Narrowing





Dean and Topping, 2019, *GSA Bulletin*

- Reduced flood disturbance allows vegetation to begin growing along channel margins.



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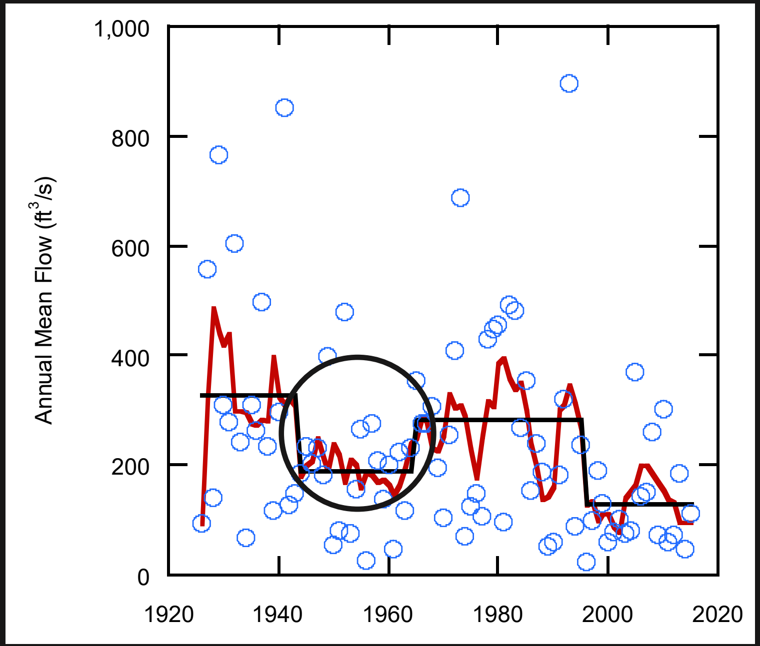

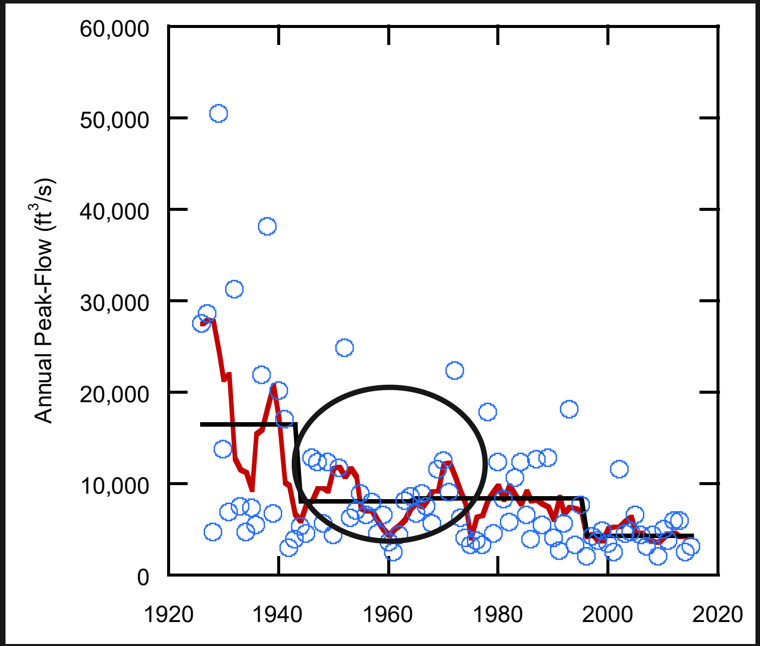

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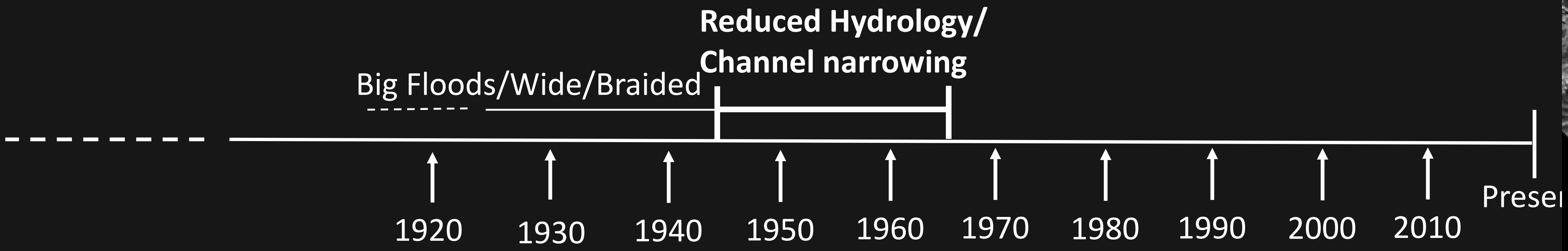
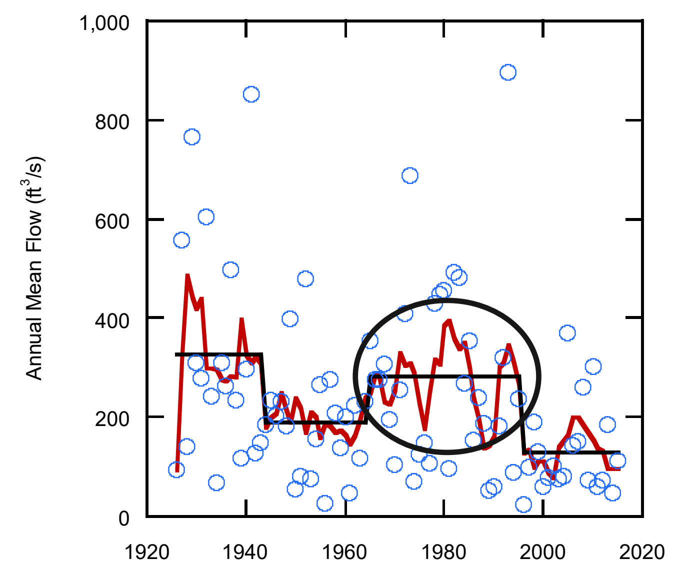
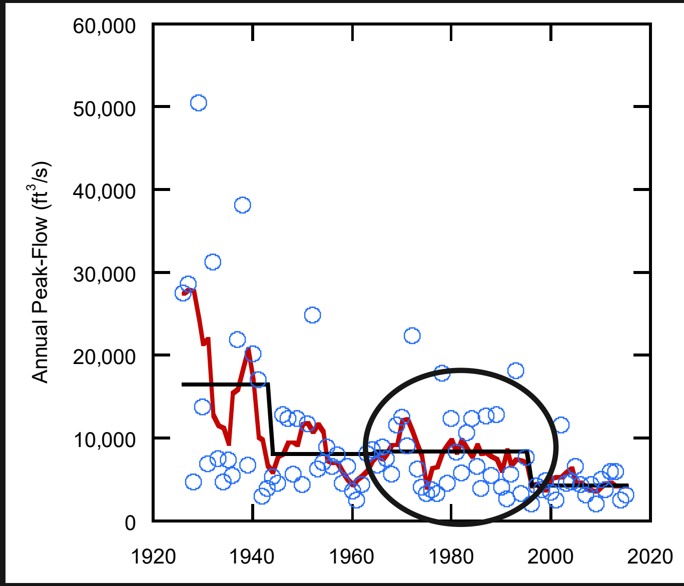


Period 3: 1965 – 1995
Increase in Total Flow, No Increase in Peak Flow





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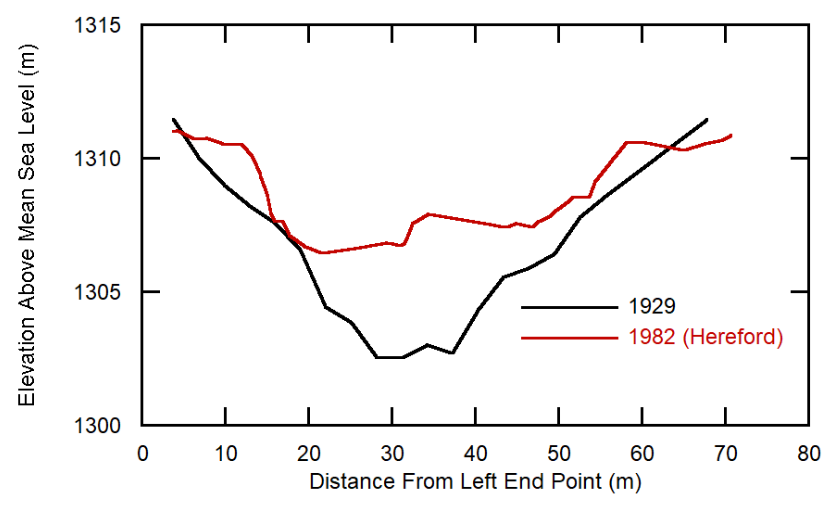

Reduced Hydrology/ Channel narrowing

Increase in Volume, No increase in Peak

Big Floods/Wide/Braided

1000 B.C. 1500s Mid-1800s 1870s 1880s 1890s 1900 1910 1923 1926 1930s 1940 1950 1960 1970 1980 1990 2000 2010 Prese

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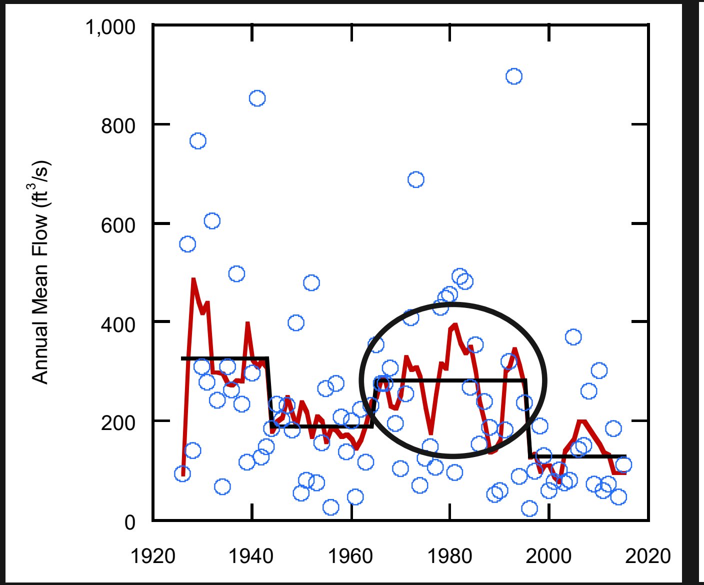

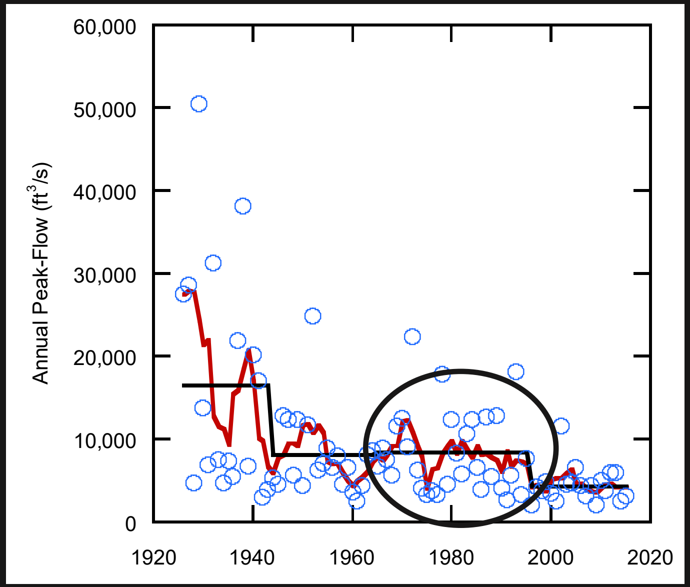

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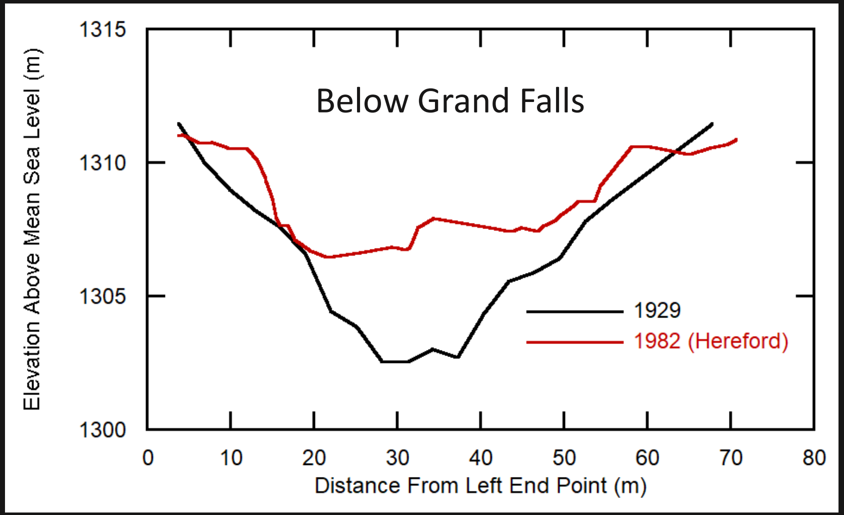

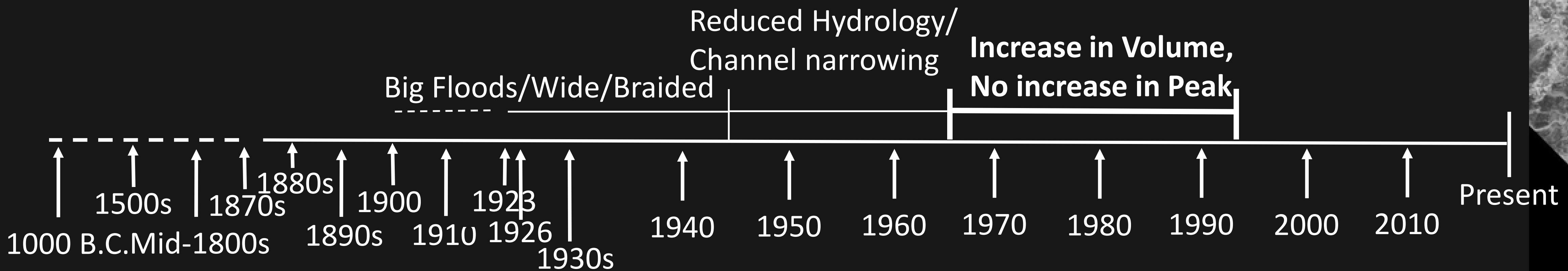

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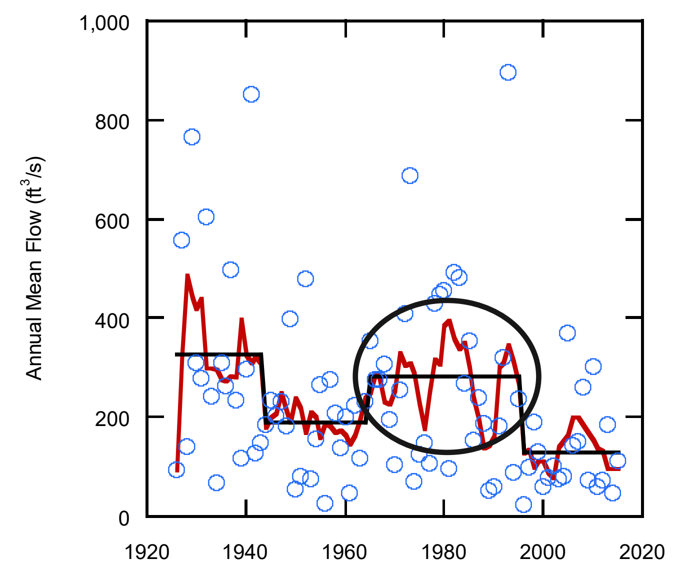

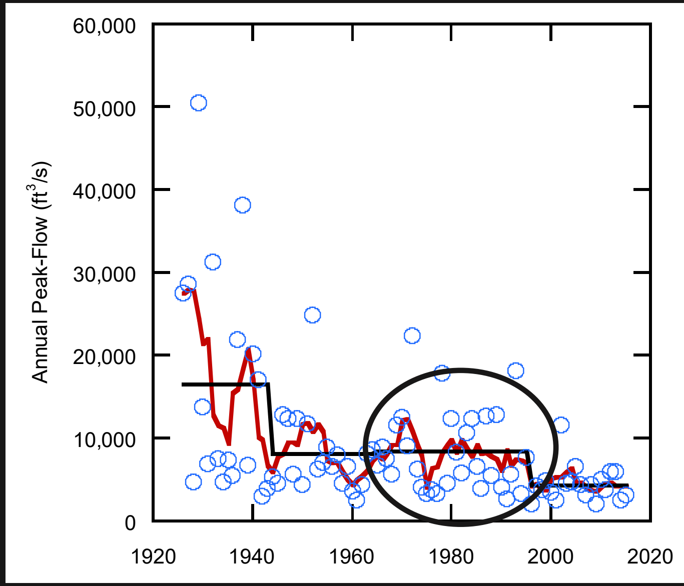

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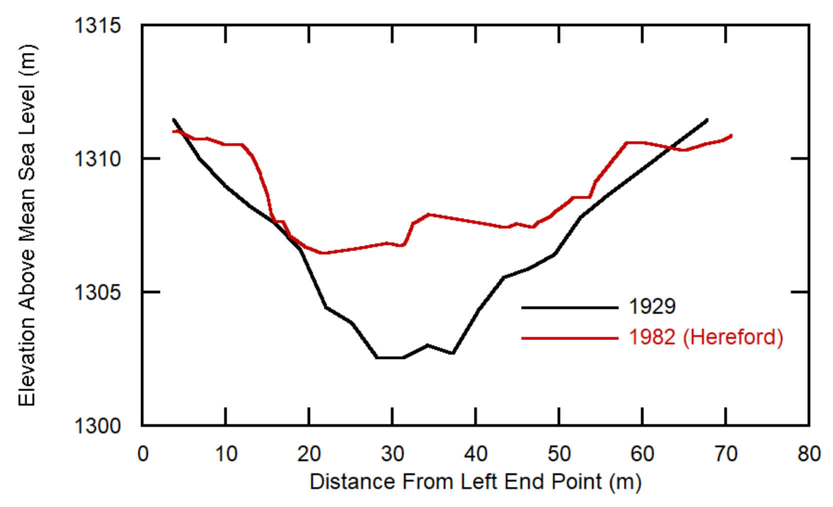
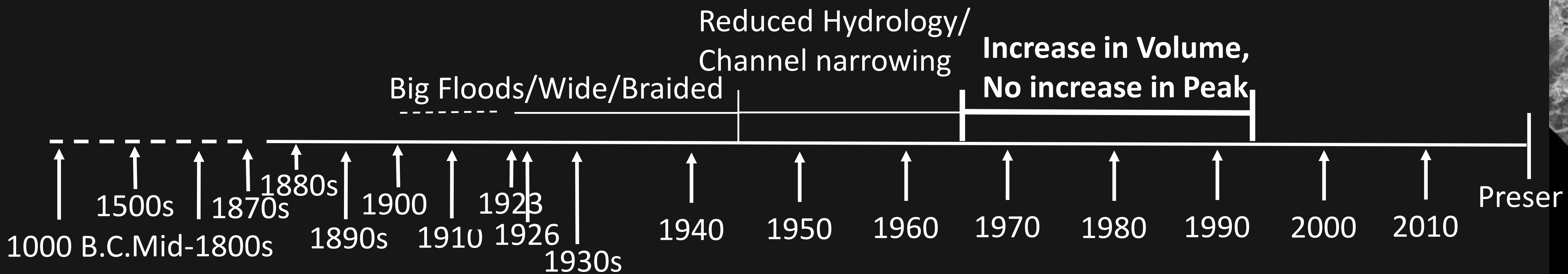
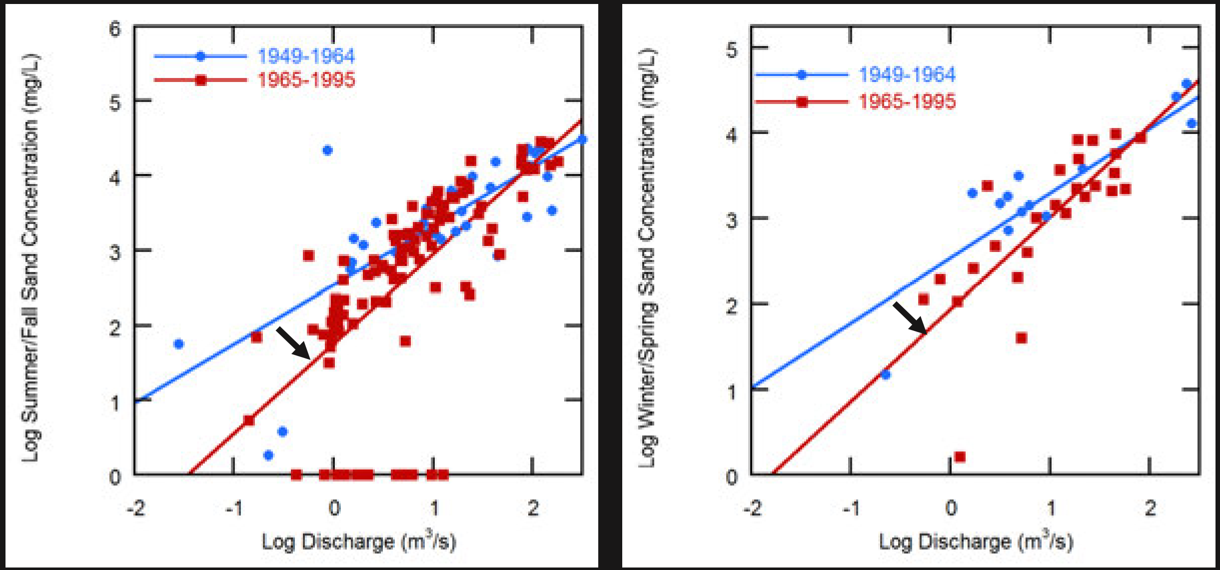


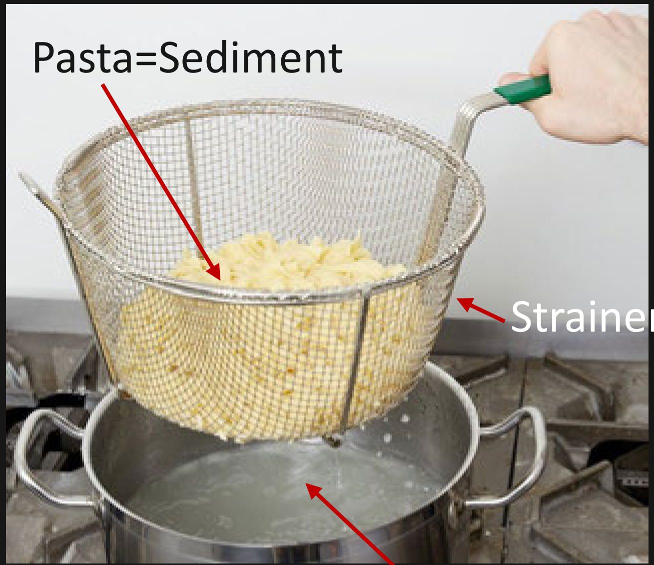


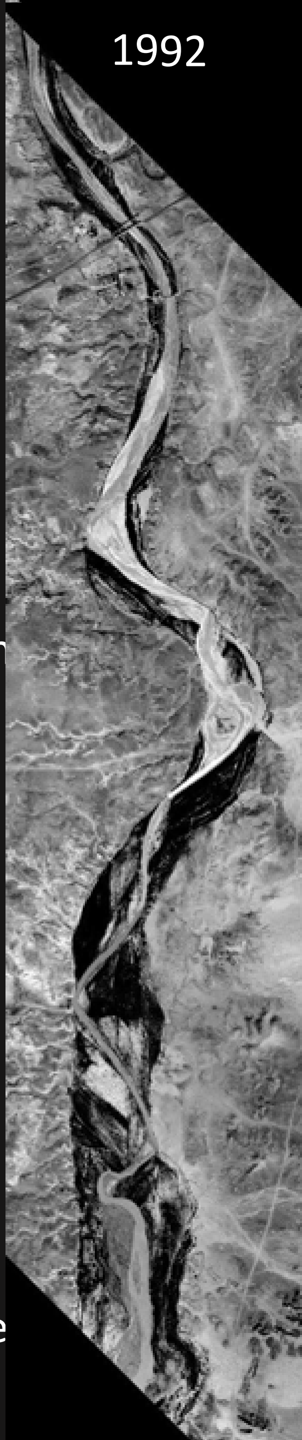
Period 3: 1965 – 1995
Reductions in Sediment Transport



Dean and Topping, 2019, *GSA Bulletin*

The Strainer Effect





Reduced Hydrology/
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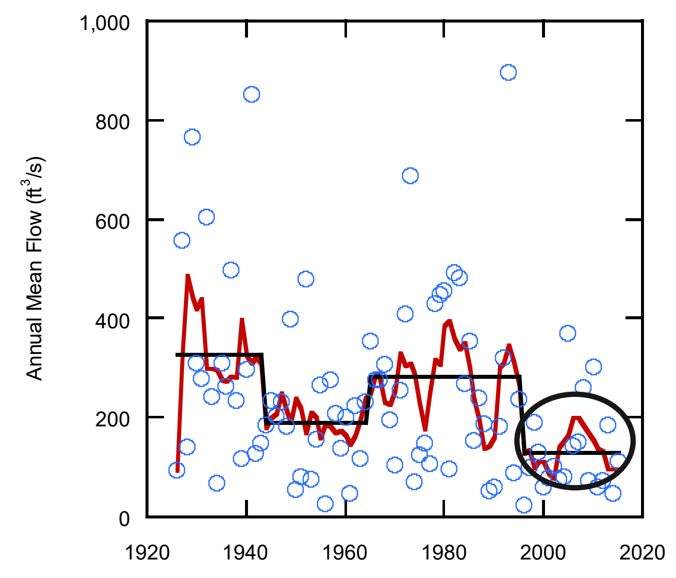
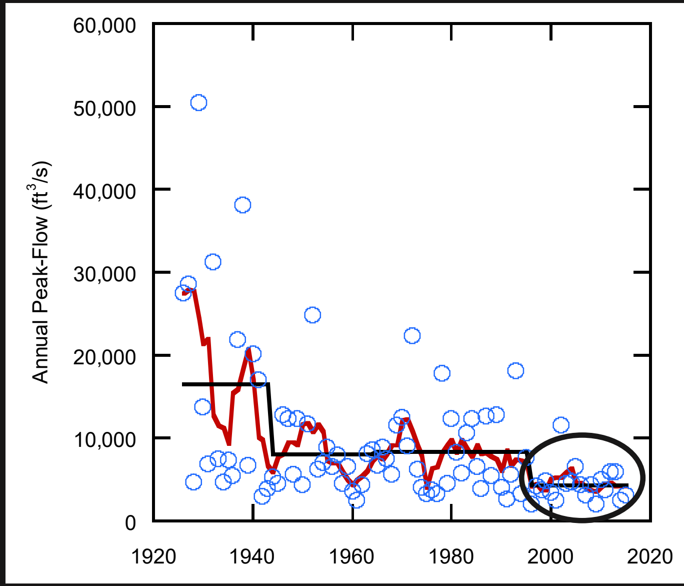
Period 4: 1996-Present
Driest Period of Gaging Record





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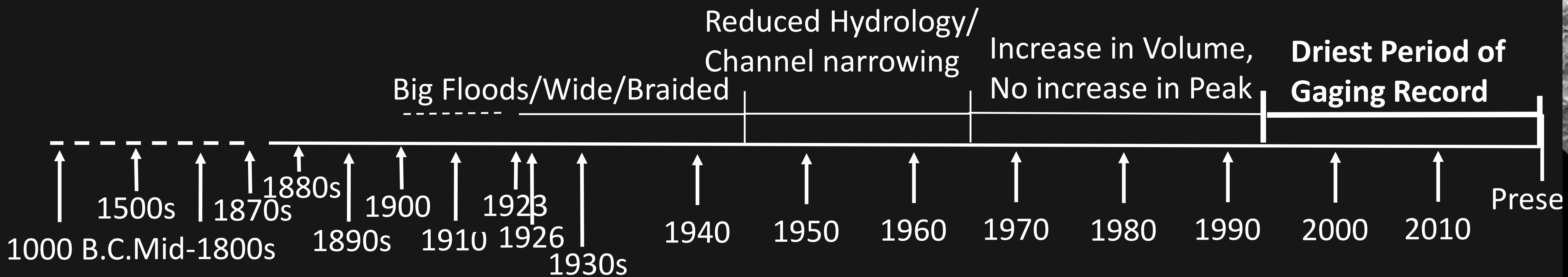

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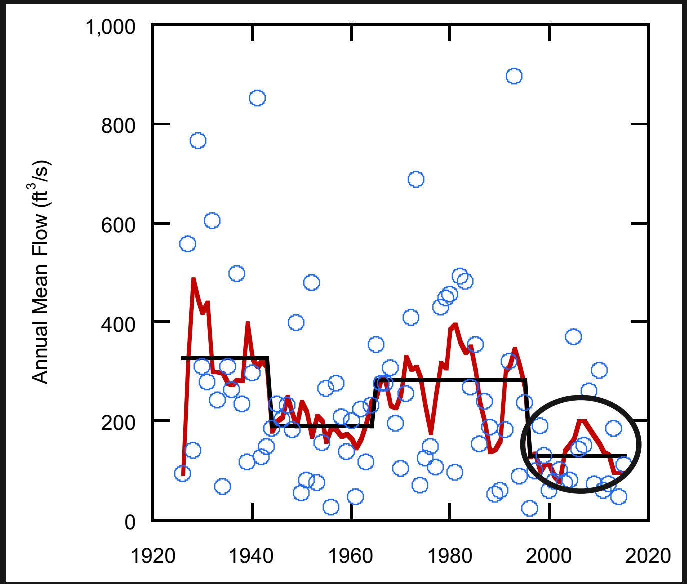

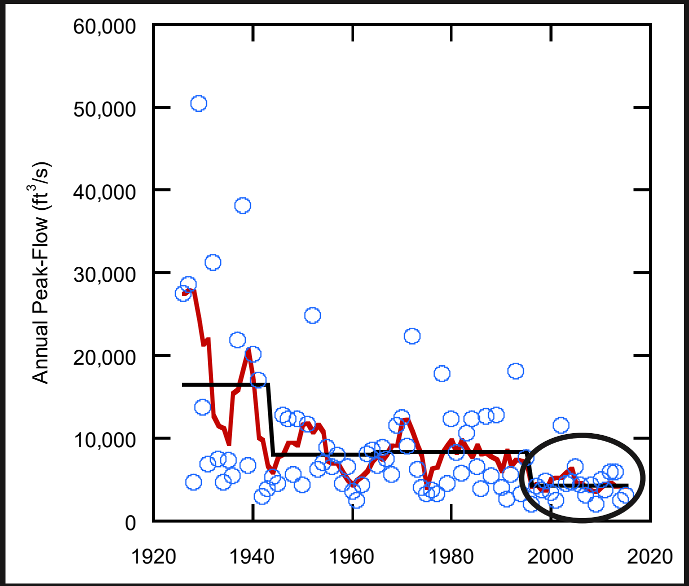

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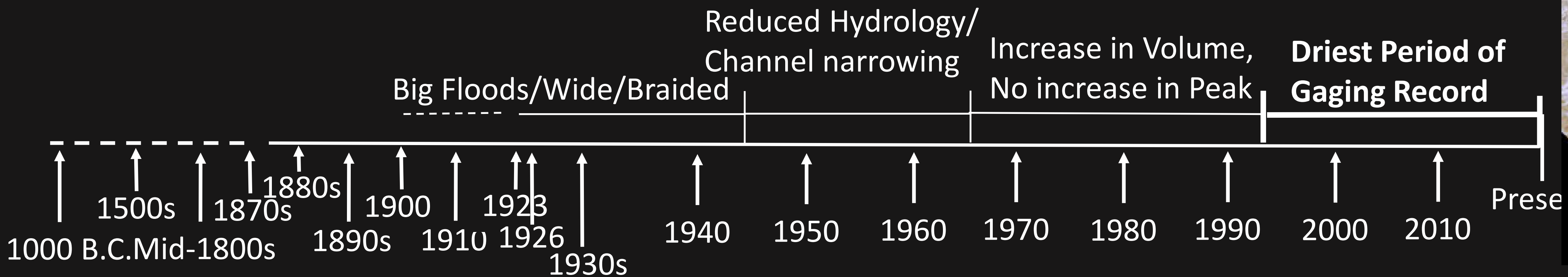

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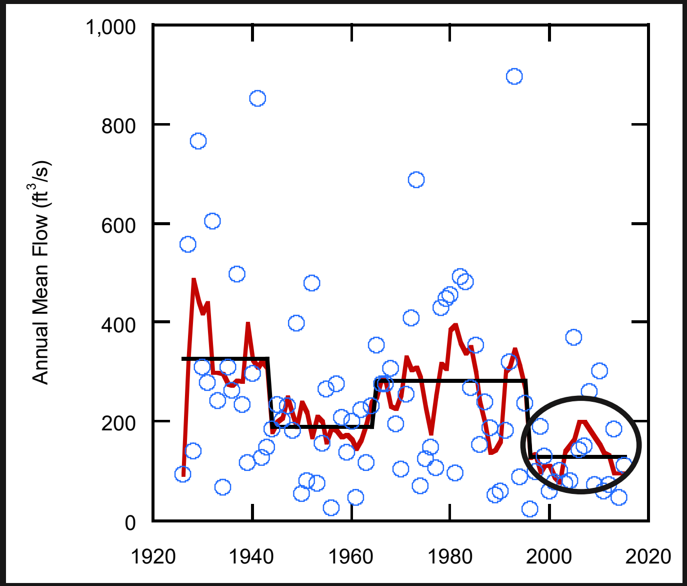

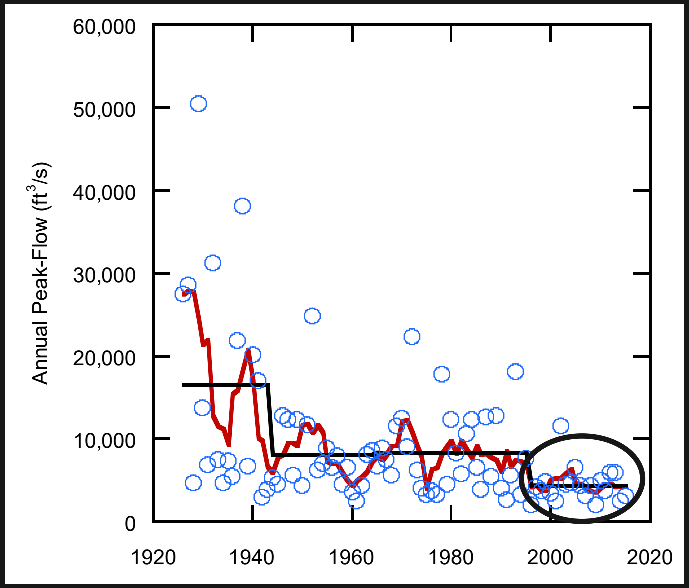

Dean and Topping, 2019, *GSA Bulletin*

Big Floods/Wide/Braided

Reduced Hydrology/ Channel narrowing

Increase in Volume, No increase in Peak

Driest Period of Gaging Record

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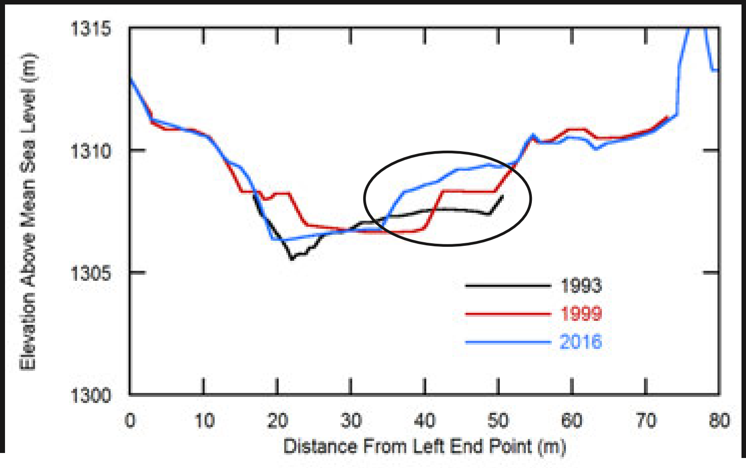
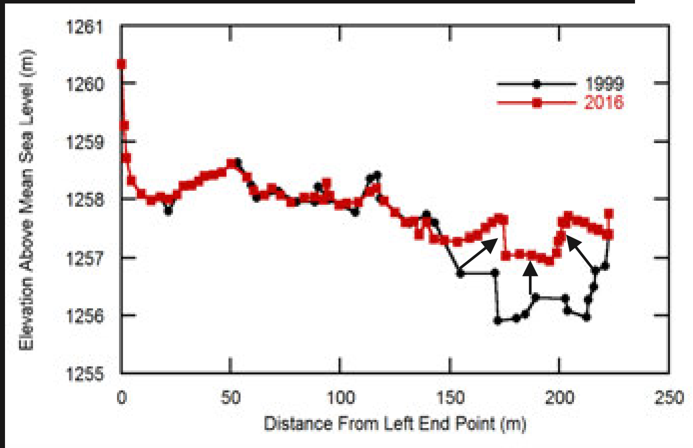
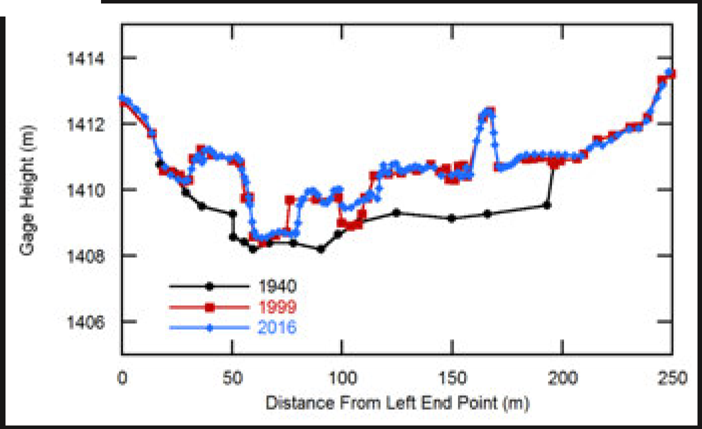
Period 4: 1996-Present
Continued Narrowing/Vegetation Expansion/Bed Aggradation





Dean and Topping, 2019, *GSA Bulletin*



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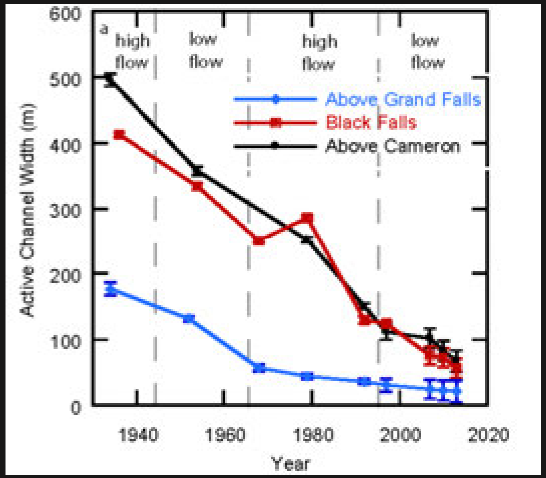
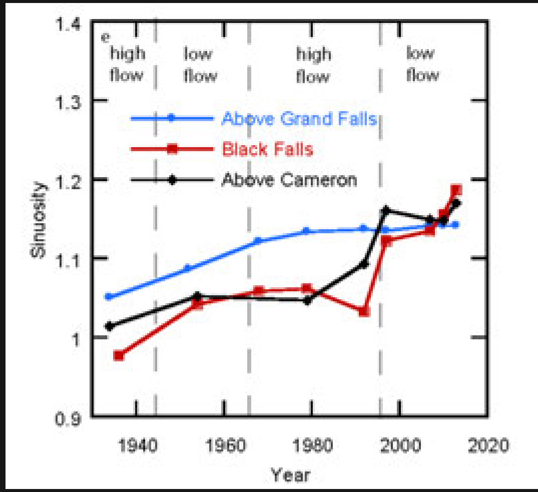
Summary: Complete Geomorphic Transformation of the LCR





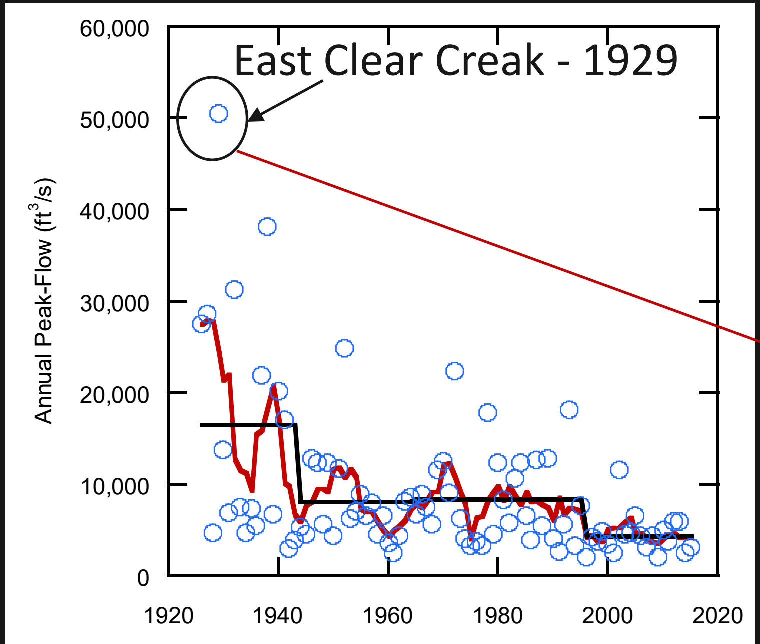
Dean and Topping, 2019, *GSA Bulletin*

- Narrowing by > 80%
- Reductions in sediment transport
- Bed aggradation in some areas
- Dense riparian forests

Reasons for Hydrologic Change: Declines in Peak Flow

Why have peak flows declined even though total flow has not?

- **Hypothesis 1:** Water management/dams = captured floodwater, reduced peak flows.
  - >100 reservoirs in basin, 3,700 stock ponds
- e.g. Diversion of water from East Clear Creek into the Salt River basin ≈ 4% of the total flow measured near Cameron.



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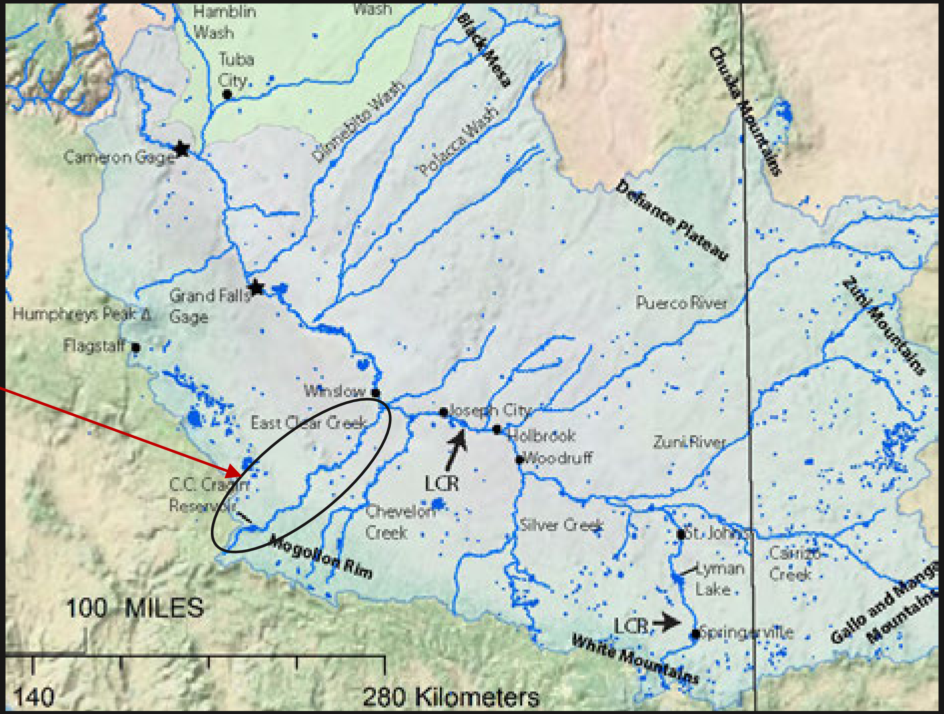

Reasons for Hydrologic Change: Declines in Peak Flow

Why have peak flows declined even though total flow has not?

Hypothesis 2: Geomorphic change/Biogeomorphic feedbacks have affected flood conveyance and cause flood attenuation.

- Large floods inundate floodplains
- Floodplain vegetation slows flow velocities and disrupts conveyance. Vegetation stabilizes floodplains

Case Study: The Little Colorado River, AZ - Ecogeomorphology

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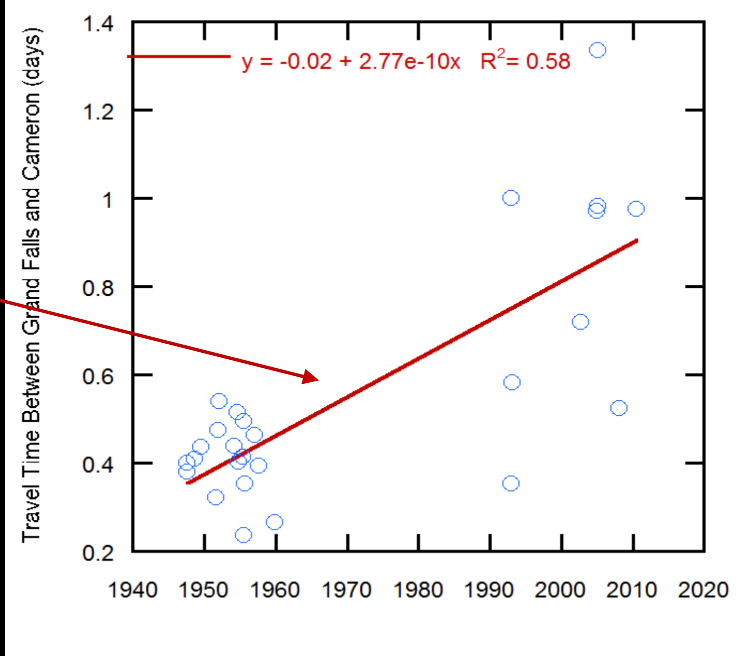
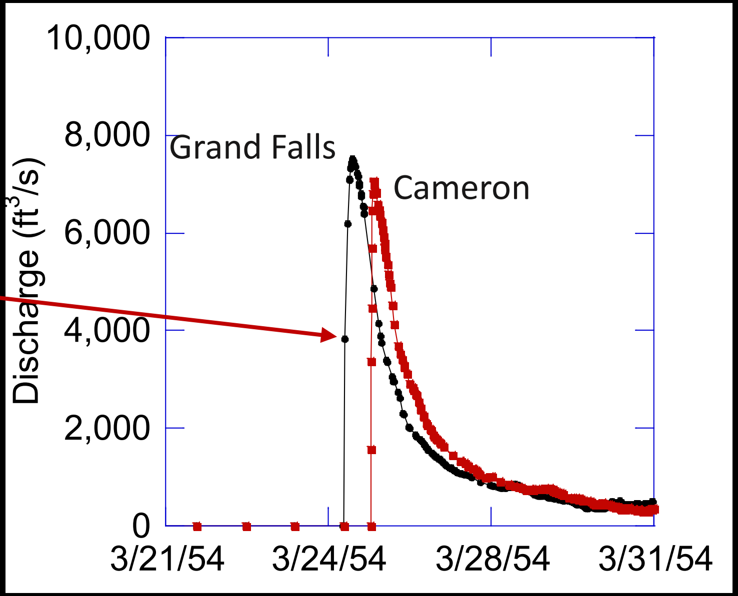
Increase in Travel Time of Floods!!

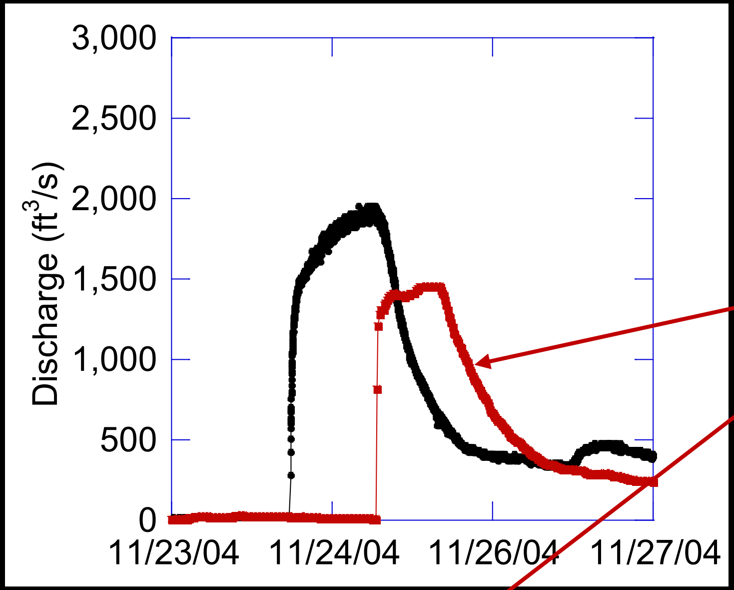


Dean and Topping, 2019

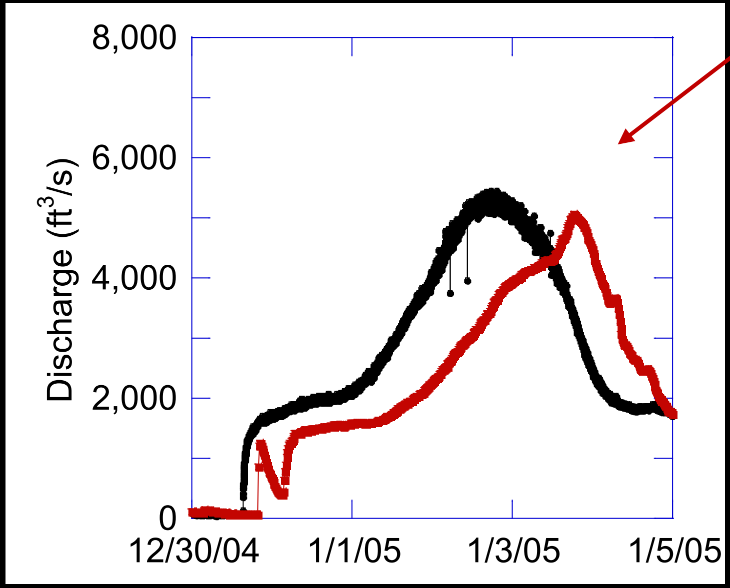
Change in Flood Shape

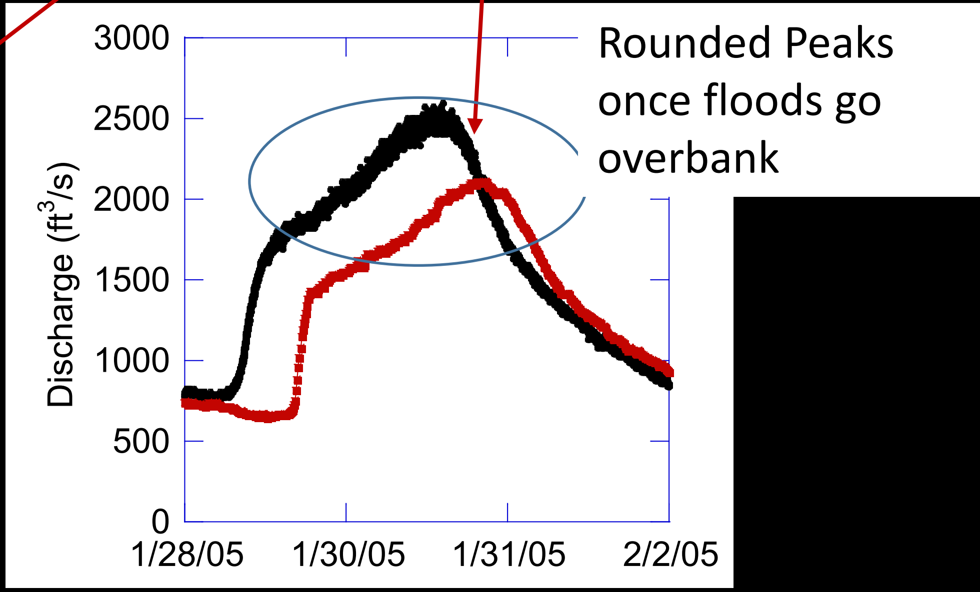
This is what flood hydrographs used to look like





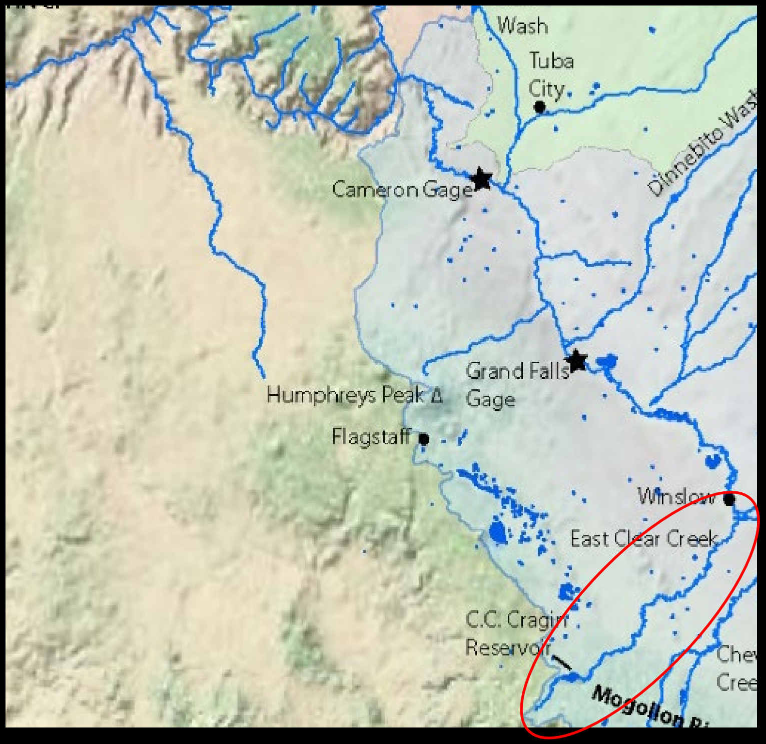
This is what they look like now

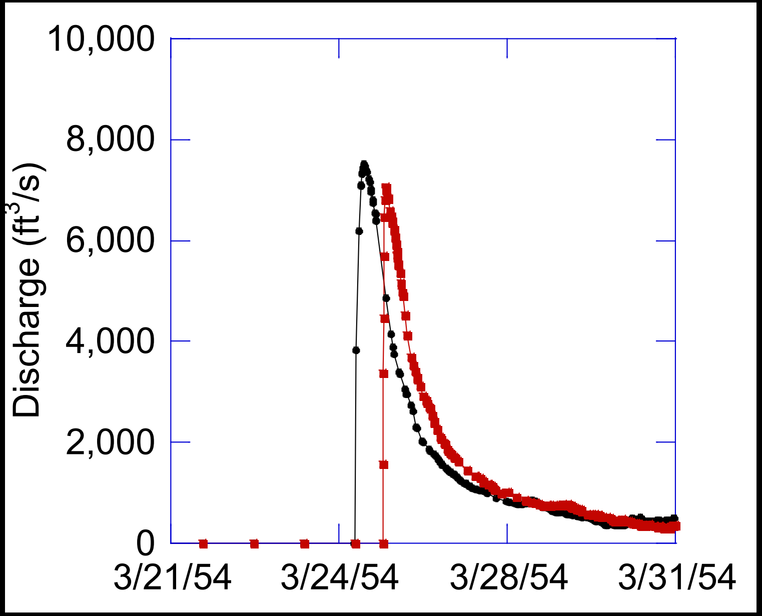




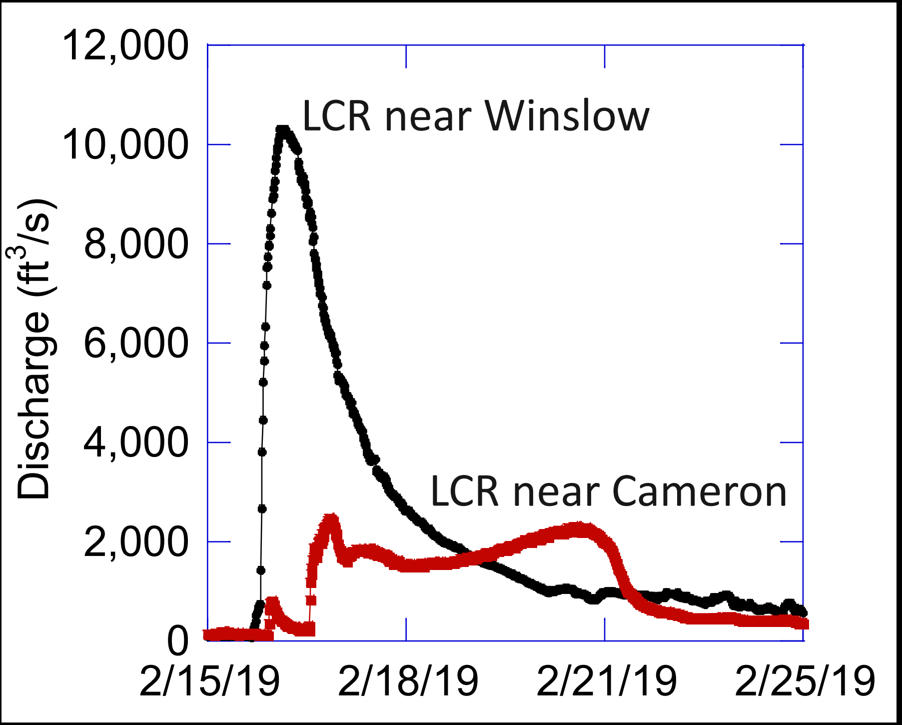
Dean and Topping, 2019; Block, LCR, 2014; Burkham 1976; Turner 1974; Gellis et al., 2017

February 2019 Flood Attenuation





Rain on Snow- East Clear Creek



preliminary data, do not cite

- Flood peak attenuation by ~85%
- No large reservoirs or diversion structures
- Attenuation likely solely caused by the bio-geomorphic feedbacks.

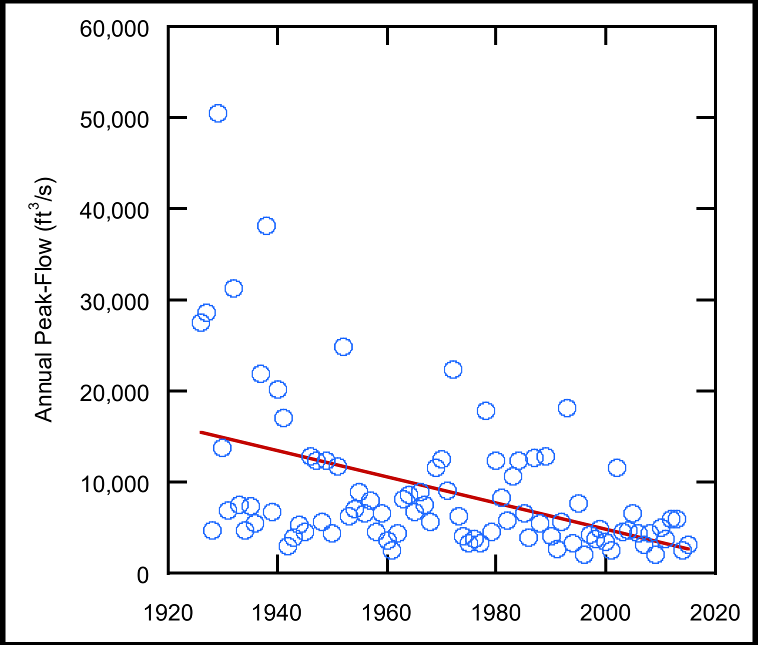
Reasons for Hydrologic Change: Declines in Peak Flow

Why have peak flows declined even though total flow has not?

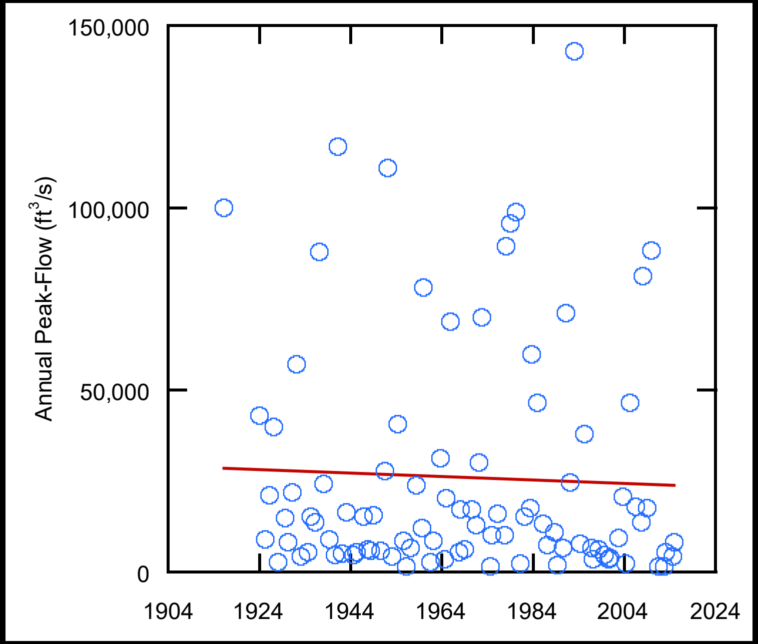
Hypothesis 3: Climate Change has resulted in storms that don't produce big floods.

- But adjacent basins, with similar climate, don't show peak flow reductions

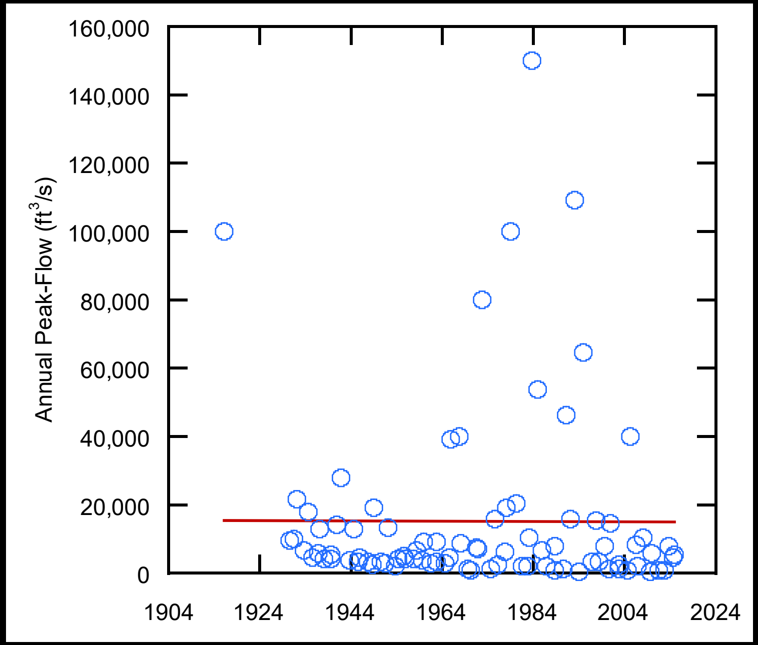
Little Colorado River



Salt River near Roosevelt, AZ



Gila River near Calva, AZ



Dean and Topping, 2019, *GSA Bulletin*

Reasons for Hydrologic Change: Declines in Peak Flow

Why have peak flows declined even though total flow has not?

Hypothesis 1: Water Management/Dams/Stock Ponds

- Water management has some effect, but additional quantification needed

Hypothesis 2: Biogeomorphic feedbacks (channel narrowing/vegetation encroachment)

- Likely the strongest effect.
- Big floods can originate in Clear/Chevelon Creeks – rapid attenuation occurs

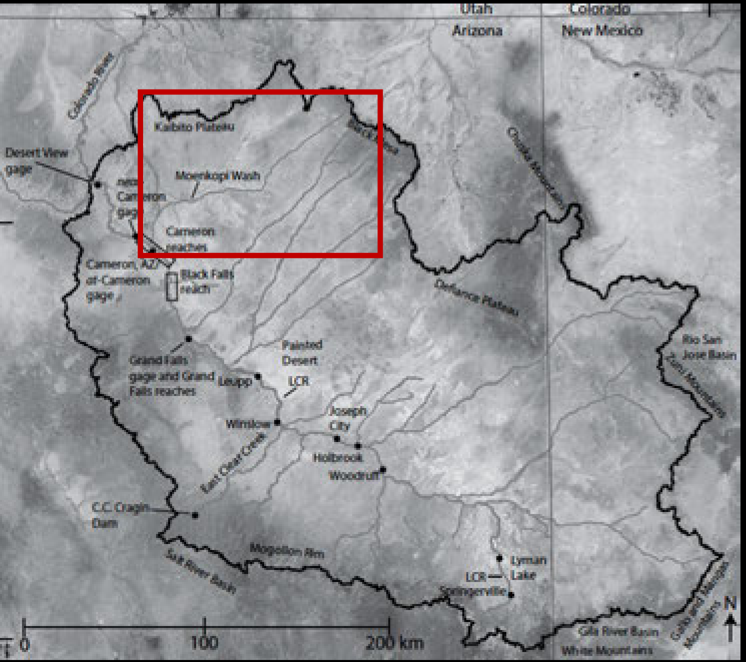
Hypothesis 3: Climate Change

- Peak flow has not declined in adjacent basins with similar climate
- Precipitation records don’t support this

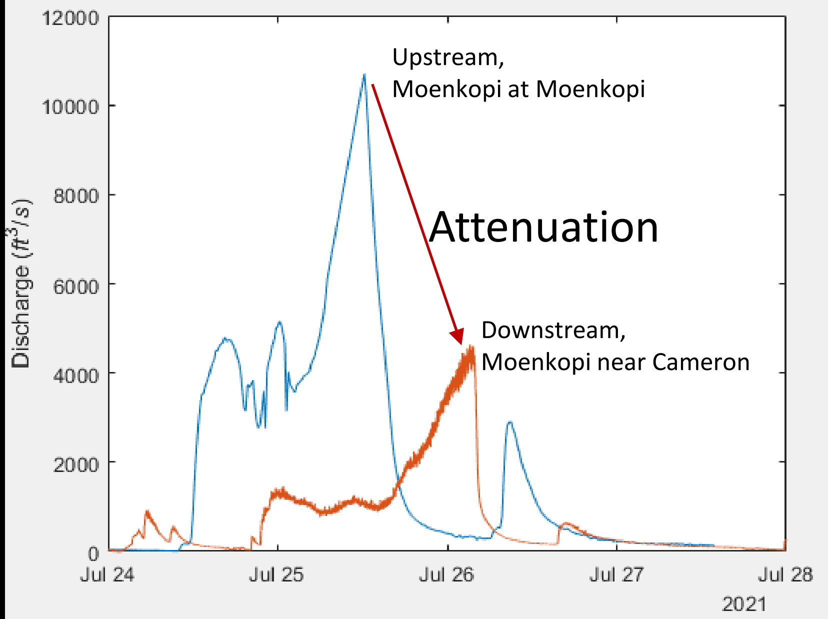
Effects of Future Climate Change (i.e. Rising Temps, Decline in Precipitation)

- Affect soil moisture - could have a large impact on base flows.
- Further declines in flood flow (most importantly in the winter/spring).

One Last Note about Moenkopi Wash



- Supplies ~32% of the sand and 27% of the silt & clay transported past LCR Cameron gage
- >60% of the annual flood peaks in LCR were either entirely or partially from Moenkopi Wash over the last 20 years
- But lots of geomorphic change in Moenkopi as well. Working to quantify its affects.



Switching Gears:

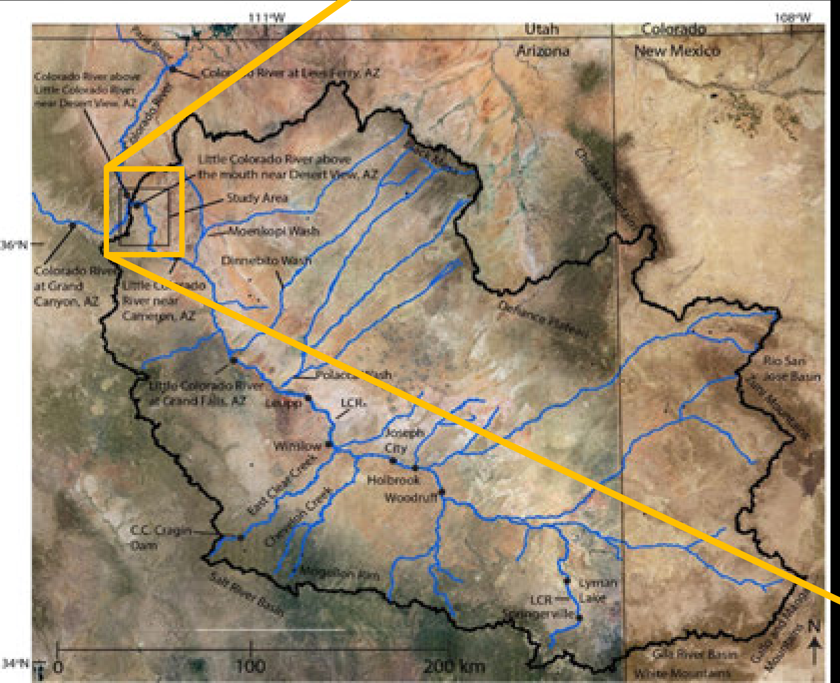
Part 2: The LCR Gorge

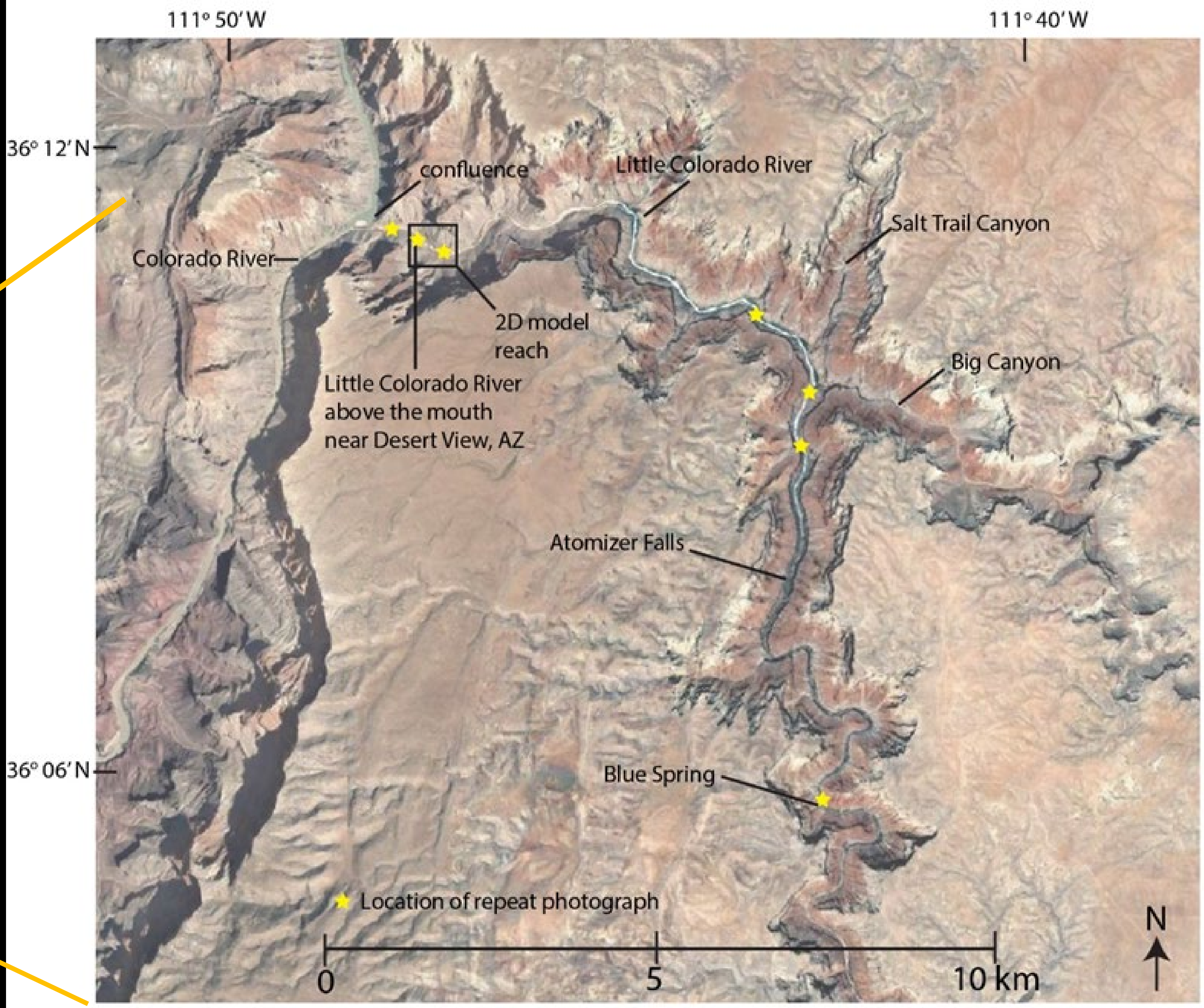
Historical Floods of Geomorphic Change in the Lower Little Colorado River During the late 19th to early 21st Centuries

Joel Unema, David Topping, Keith Kohl, Michael Pillow, Joshua Caster

Scientific Investigations Report 2021-5049

Study Area

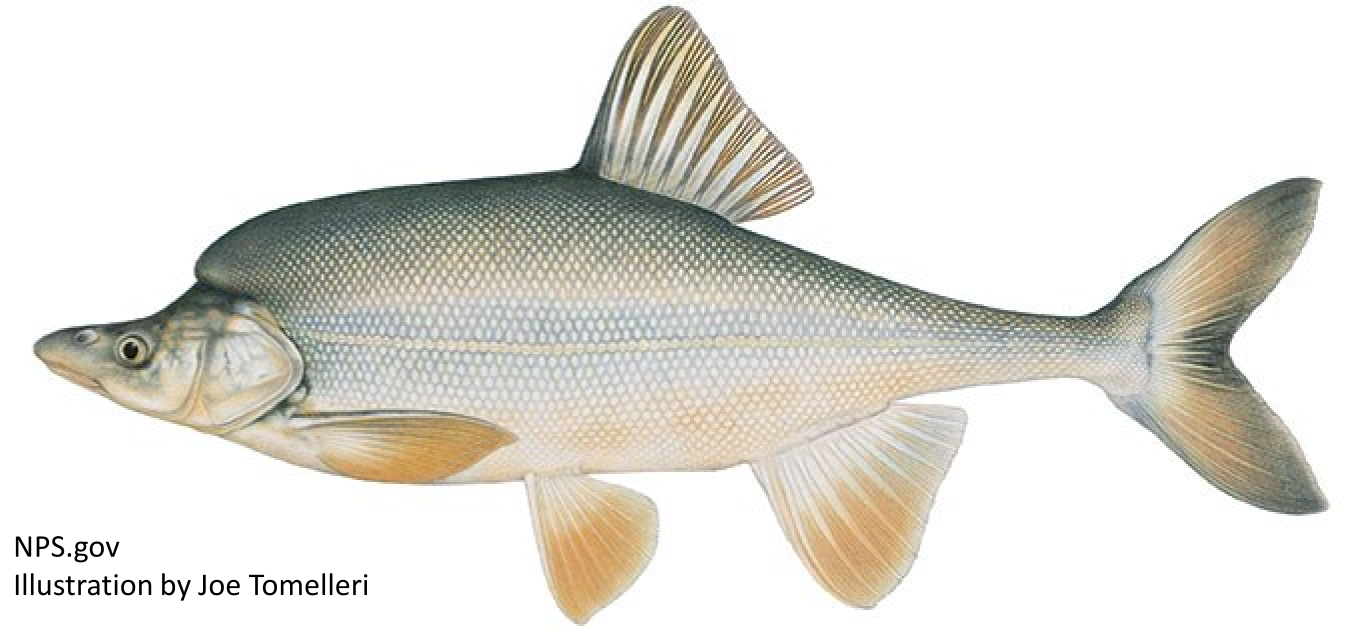

Utah
Arizona
Colorado
New Mexico
Study Area
Moenkopi Wash
Dinnebito Wash
Little Colorado River above the mouth near Desert View, AZ
Colorado River at Lees Ferry, AZ
Winslow
Holbrook
Woodruff
Joseph City
Leupp
100
200 km


111° 50′ W
111° 40′ W
36° 12′ N
36° 06′ N
confluence
Little Colorado River
Salt Trail Canyon
Colorado River
2D model reach
Little Colorado River above the mouth near Desert View, AZ
Big Canyon
Atomizer Falls
Blue Spring
Location of repeat photograph
0
5
10 km
N

Significance

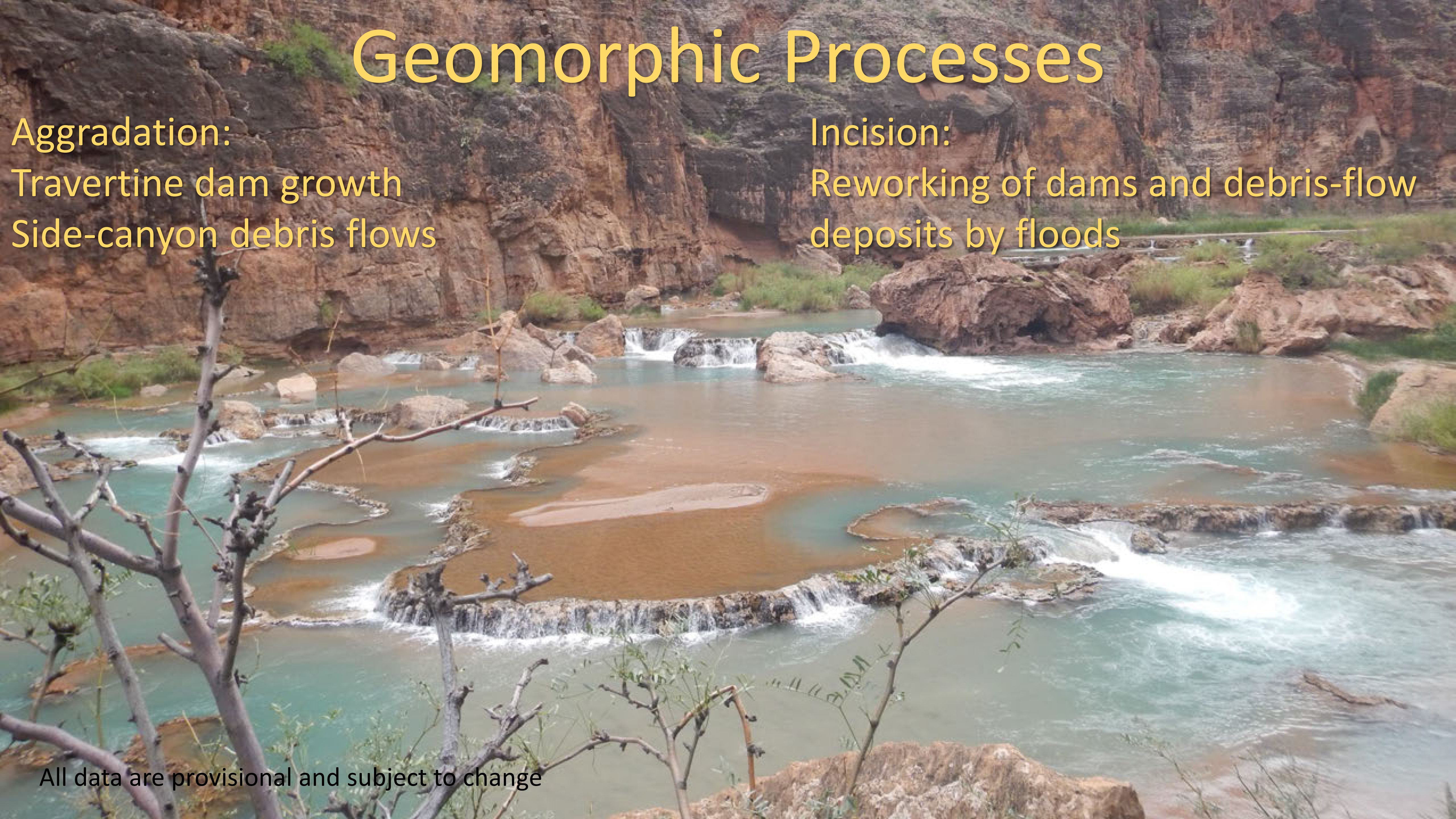
- Habitat for endangered humpback chub
    - Chub spawning is sensitive to channel conditions
    - Travertine dams can form barriers to chub movement

- Cultural Sites may be affected by travertine growth



NPS.gov
Illustration by Joe Tomelleri

Geomorphic Processes



Aggradation:

Travertine dam growth

Side-canyon debris flows

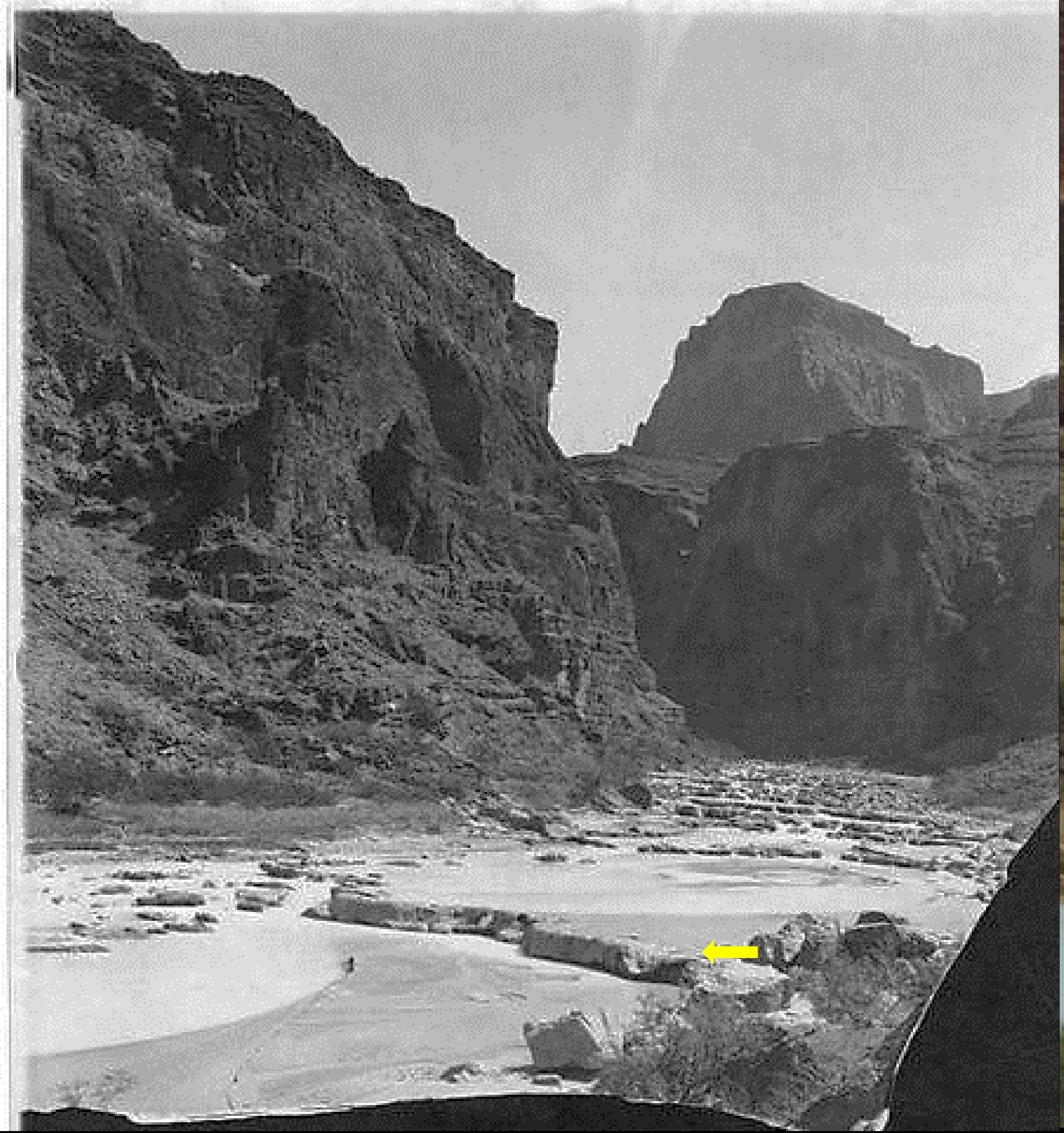
Incision:

Reworking of dams and debris-flow deposits by floods

All data are provisional and subject to change

Above Big Canyon

1911



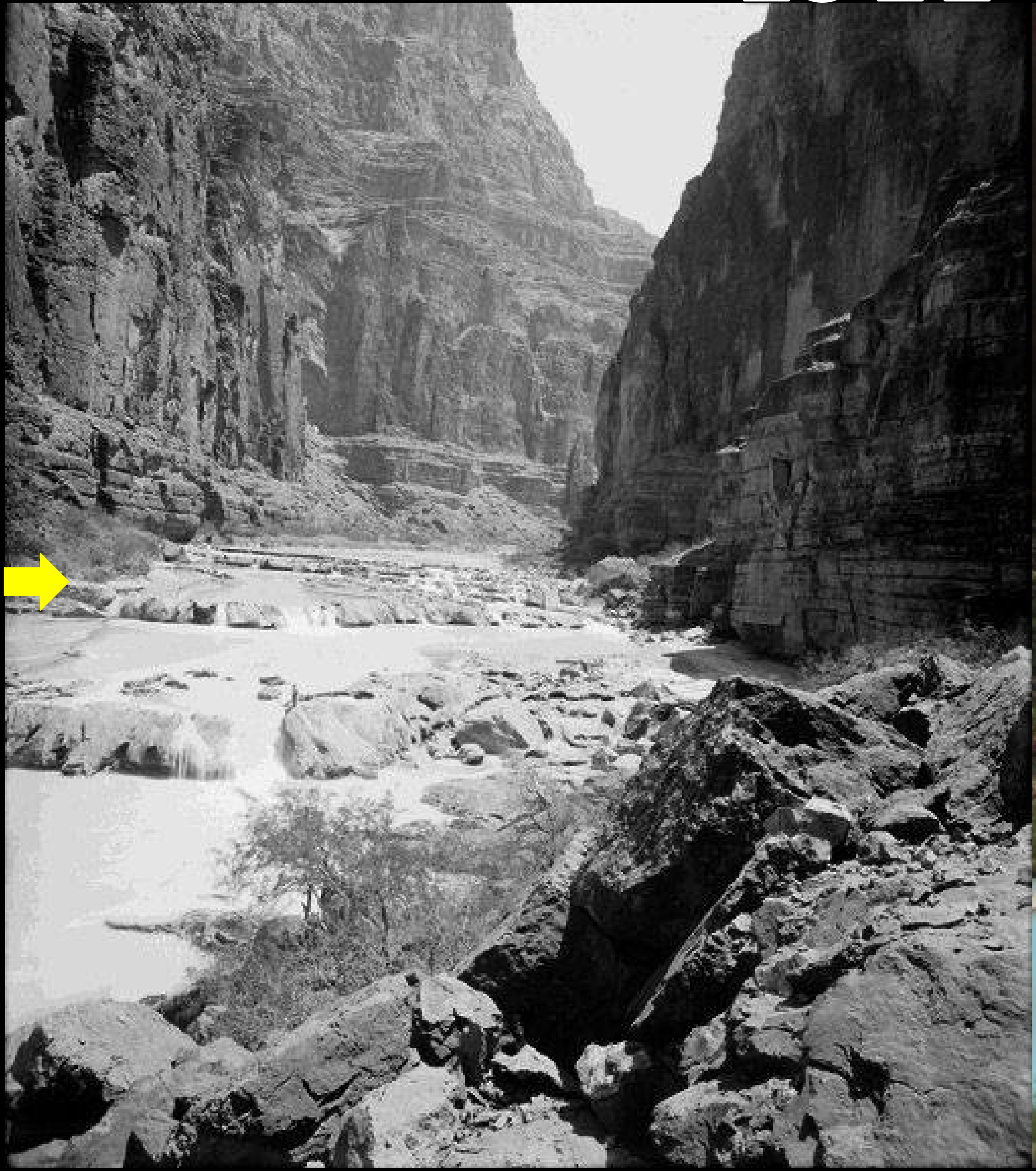
2013

All data are provisional and subject to change

Above Big Canyon

1911

2013



All data are provisional and subject to change

Near the confluence

1950's

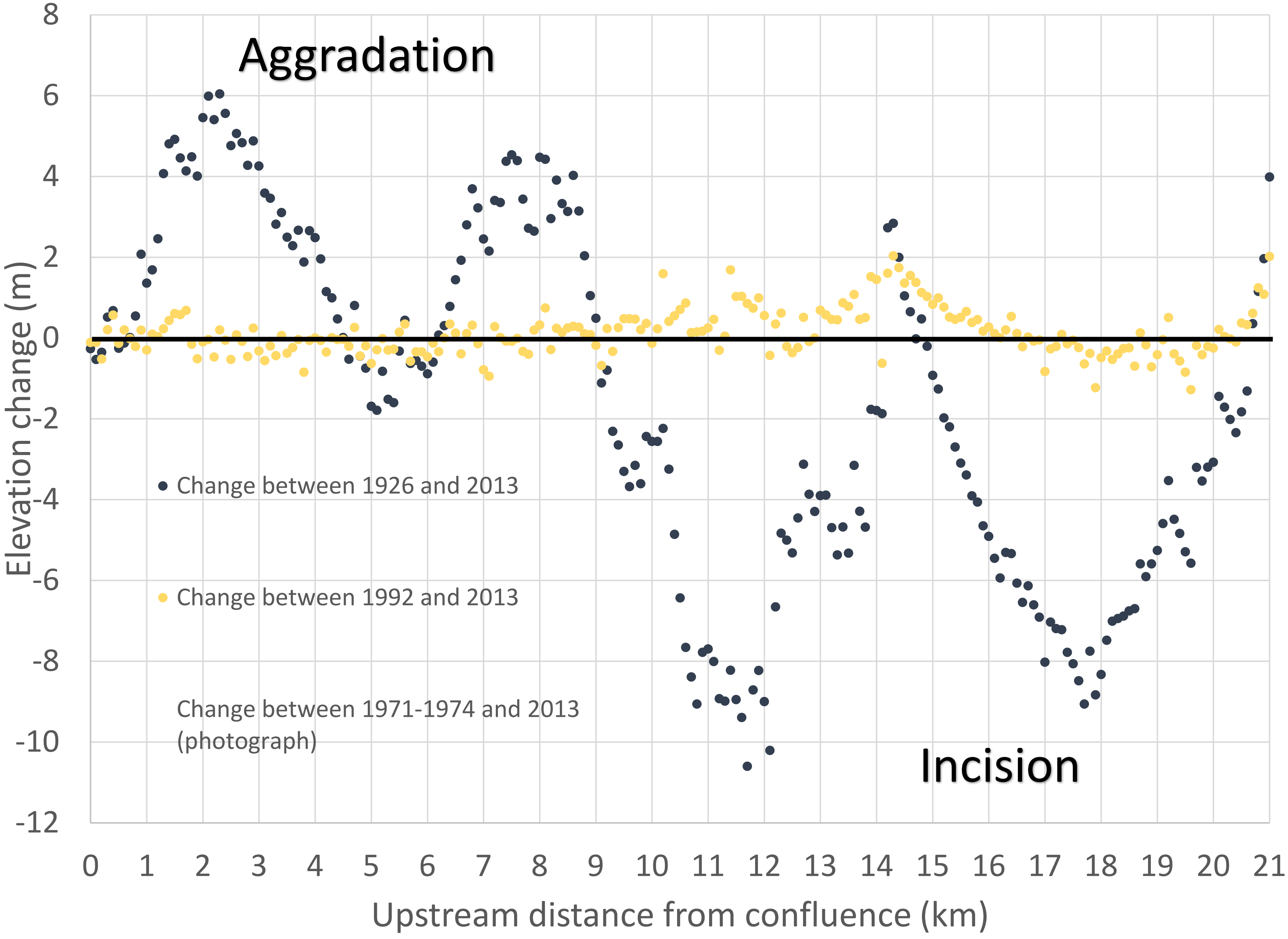
2019

All data are provisional and subject to change

Baseflow long profile change

1926 - 2013

1992 - 2013



Unema et al., 2021, USGS SIR 20215049

Conclusions

- Major incision and aggradation occurred between 1911 and 1950s
- Small change (only aggradation measured) since 1950s
- Decline in flood frequency and magnitude = Loss of disturbance

Implications

- Continued travertine dam growth and aggradation is likely without erosion by large floods
- This could lead to more physical barriers to chub movement and loss of habitat, and potentially impact cultural sites (Sipapu)