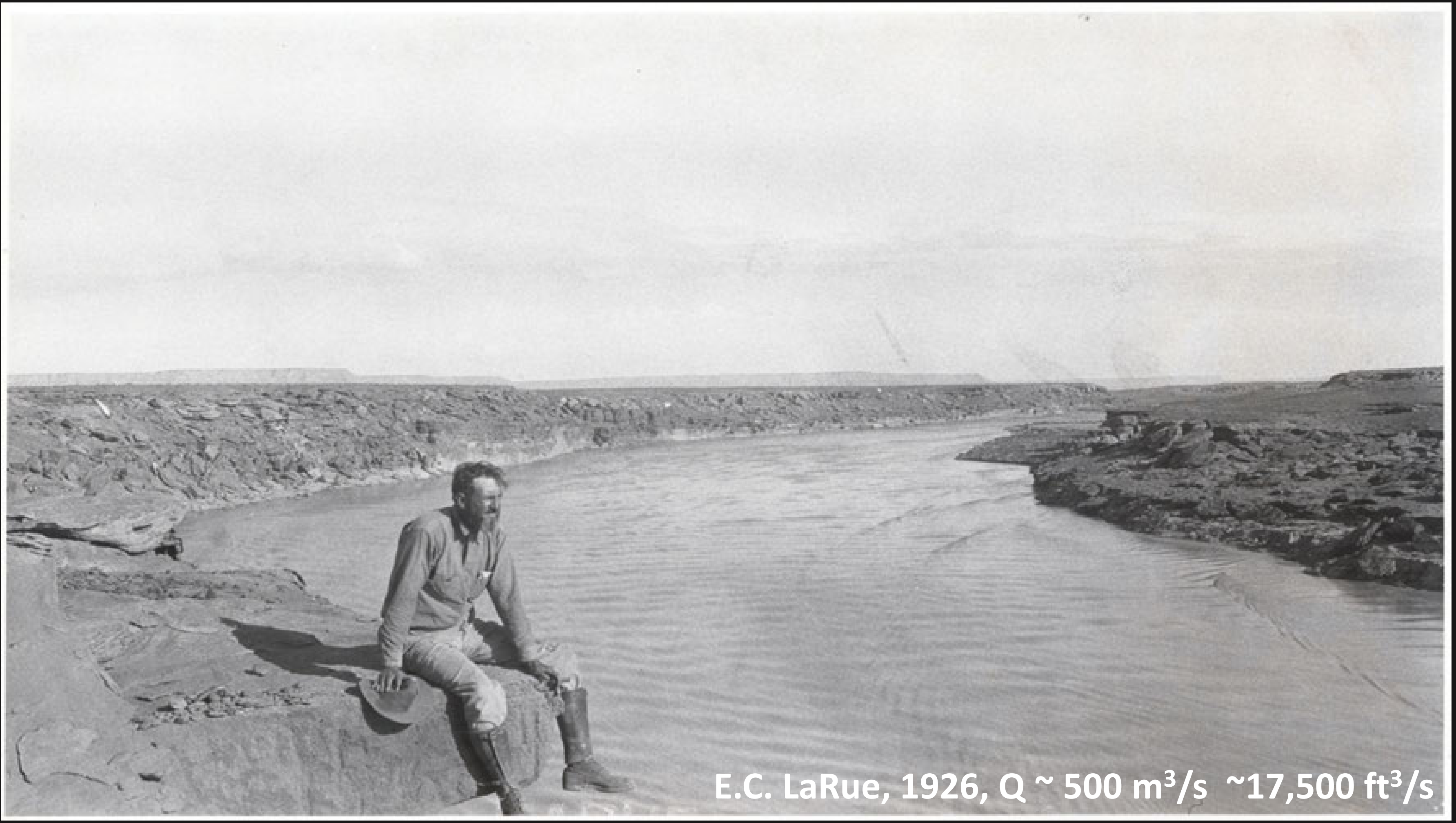
Geomorphic Change and Biogeomorphic Feedbacks in the Little Colorado River, AZ

Project A – LTEMP Sediment Goal

David J. Dean, David J. Topping



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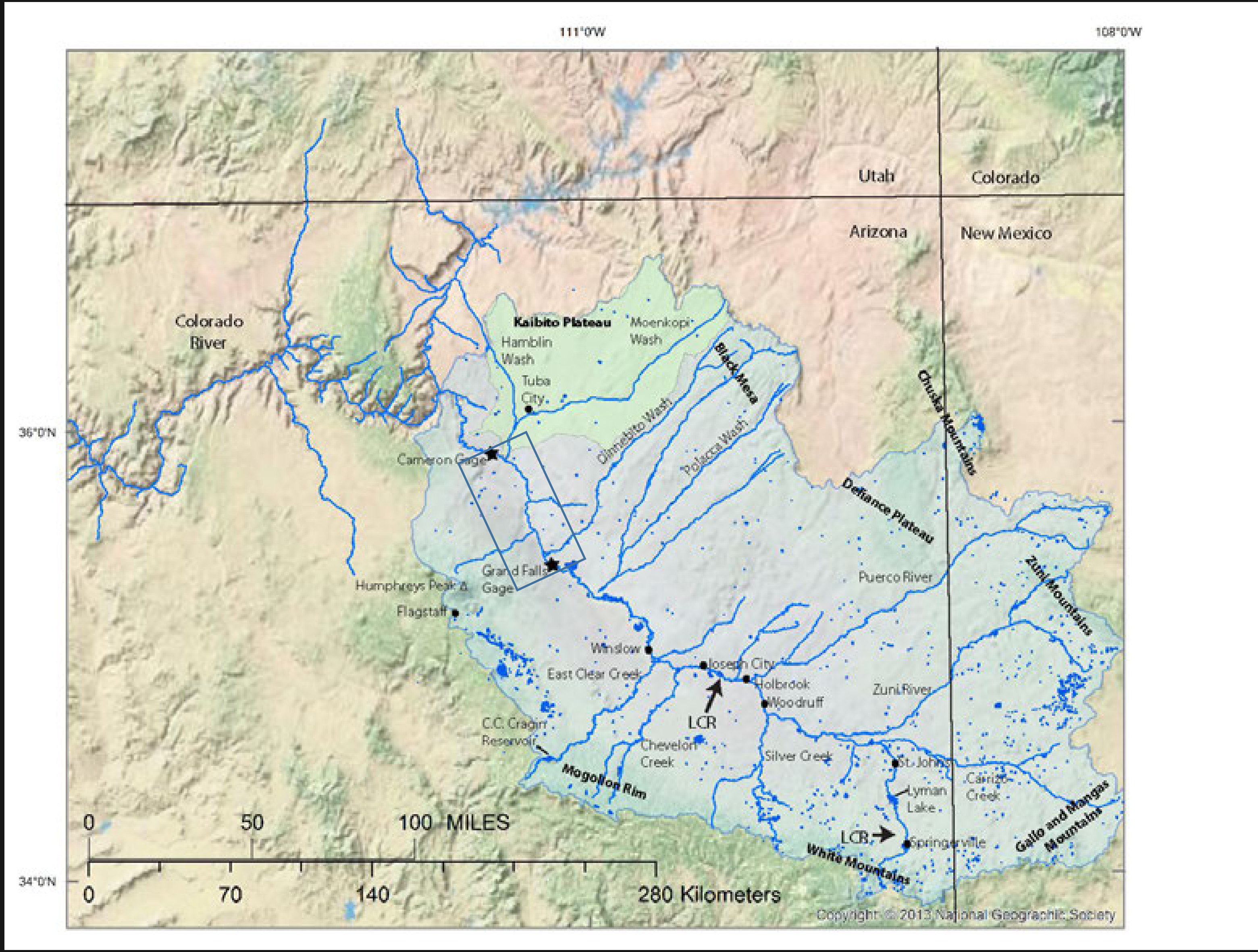
The Little Colorado River Basin



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The Little Colorado River: A Century of Change

- A formerly braided river – now single-threaded

- The former channel devoid of riparian vegetation – now dense floodplain forests (non-native tamarisk)

Study objectives:

1) Determine magnitude, timing, and rate of geomorphic change, and the reasons for that change.

2) How has this affected sediment delivery to the Colorado River in Grand Canyon?

3) How do geomorphic changes in LCR affect floods in lower LCR?

H.E. Gregory

D.J. Dean

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Historical Context: Land Use and Human Development within the LCR Basin (1)

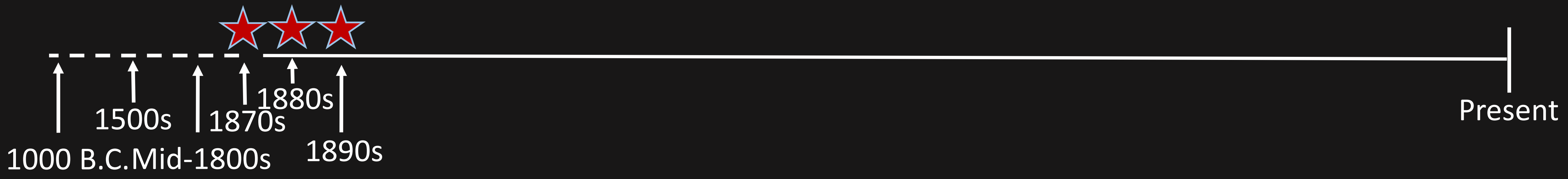
- Irrigated agriculture at small scales was practiced by the Ancentral Puebloans possibly as early as 1000 B.C. (Damp et al., 2002)

- Spanish explorers in the mid to late 1500s described many groves of cottonwoods and willows. Cottonwood galleries compared to that of the Rio Grande in New Mexico (Colton, 1937).

- U.S. army officers leading expeditions through the LCR valley in the 1800s described a river that contained bayous and sloughs, large cottonwoods, and plentiful grasslands (Sitgreaves, 1854; Stacey and Beale, 1929).

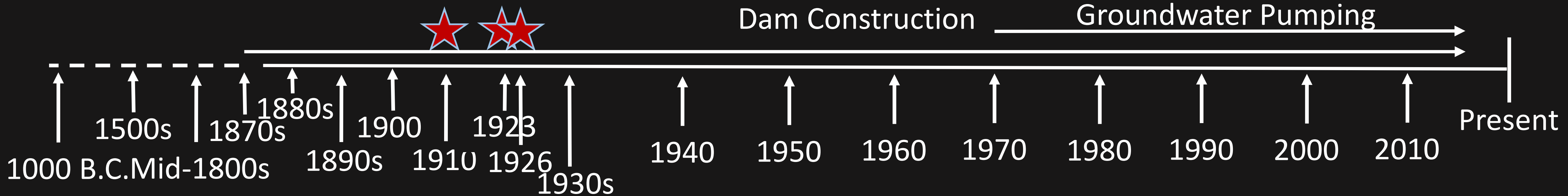
Historical Context: Land Use and Human Development within the LCR Basin (2)

- In the 1870s, Mormon settlers began building diversion dams and irrigation networks.
- Completion of the railroad in the 1880s brought ranchers and their large herds of sheep and cattle (150,000 head of cattle, 120,000 head of sheep).
- "Widespread denudation" (gullying/erosion) of the LCR ranges had occurred by the 1890s. Mostly in headwaters (Balling and Wells, 1990; Gellis, 1998). Primary cause believed to be above average rainfall (Graf 1986).
- Riparian corridor was denuded for railroad construction/settlements/dam building.



Historical Context: Land Use and Human Development within the LCR Basin (3)

- 23 **dam failures** between 1876 and 1900.
- **Lyman Lake** constructed in 1910; It failed in 1915 and was rebuilt in 1920 and 1949. Stores 2X the annual stream flow of the LCR upstream.
- A flood of over **3,400 m^3/s (120,000 ft^3/s)** occurred in September 1923. Largest flood since 1870.
- Stream gaging began in 1926; **substantial changes to LCR hydrology/geomorphology** had already occurred.



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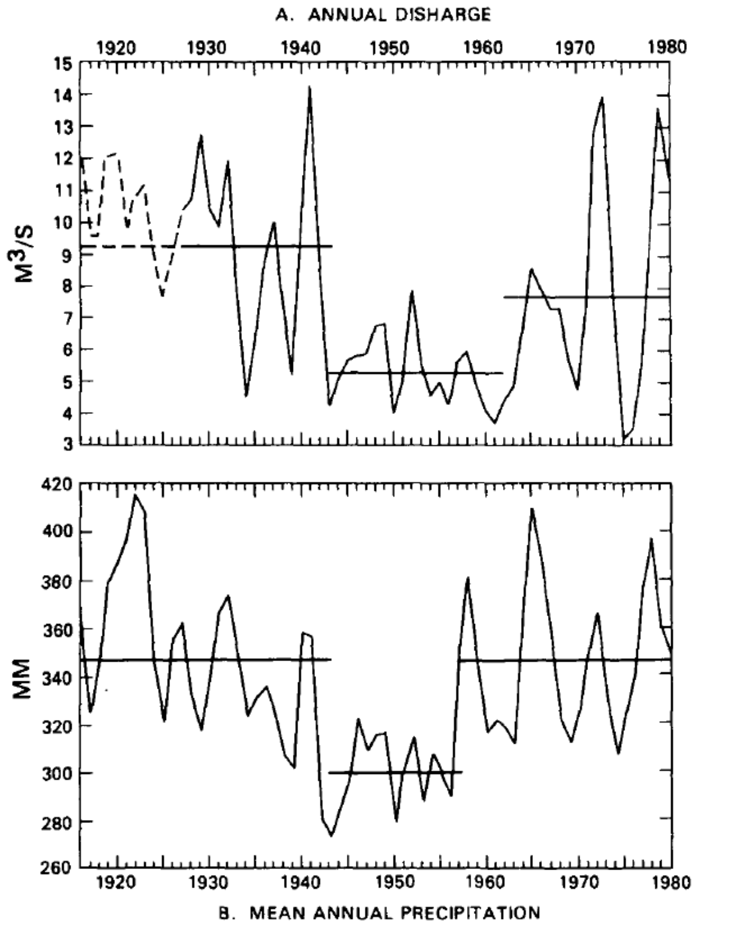
Previous Work on the LCR:

Between the early 1900s and the 1980s:

- Three alternating periods of erosion and deposition
  - 1900-1940s – frequent large floods, high annual discharge – the channel was wide and sandy
  - 1940s-1950s – precipitation and discharge decreased – the channel narrowed and floodplains developed – salt cedar (*Tamarisk* spp.) became widely established on these floodplains
  - 1950/60s-1980s – precipitation and discharge increased – the largest floods caused additional overbank deposition and vertical accretion.

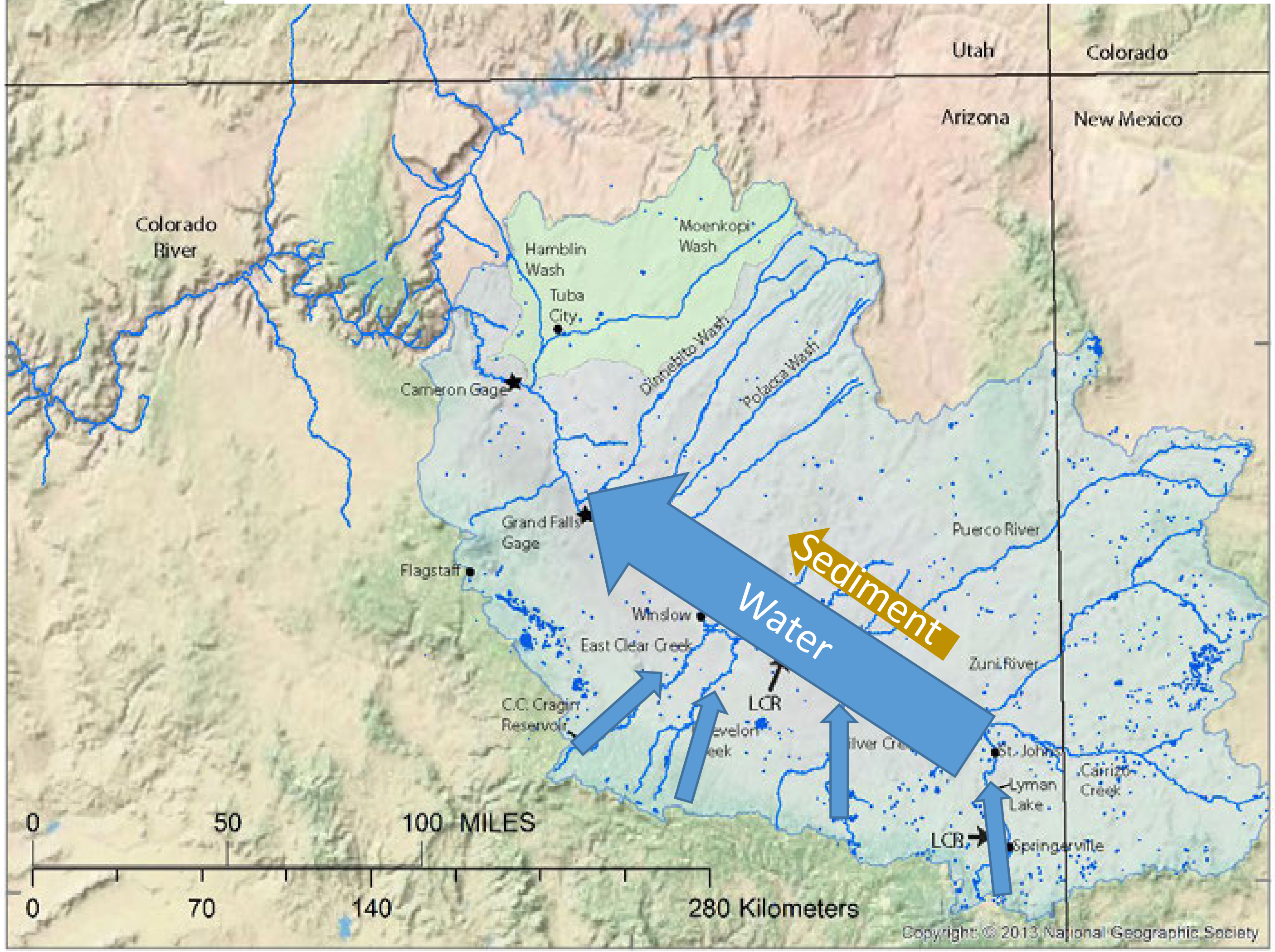


Hereford, 1984

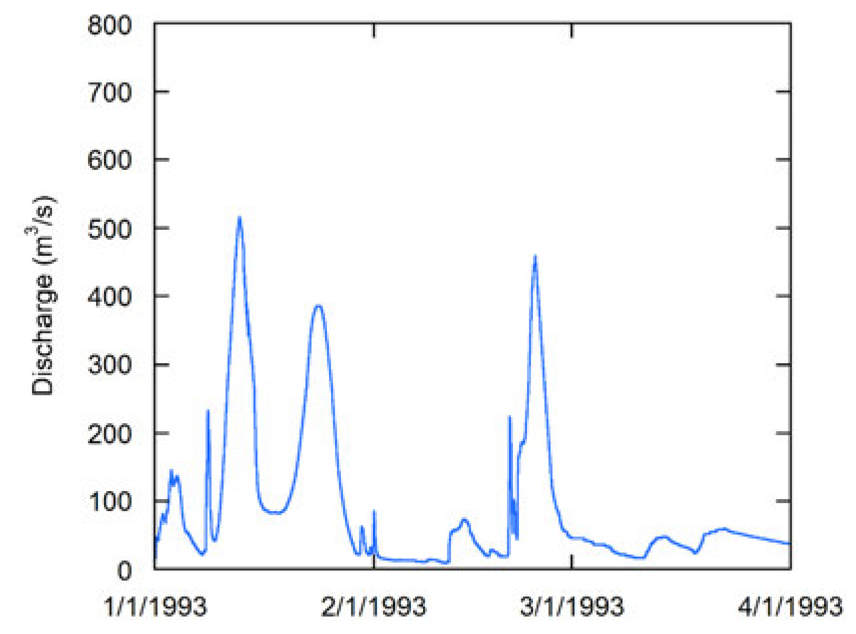
Conclusion: hydrologic and geomorphic changes were primarily driven by changes in climate.

Hydrology – Winter/Spring

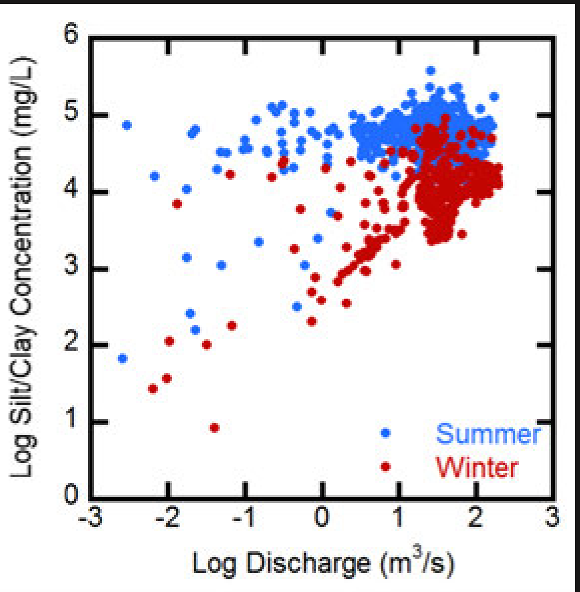
- Long-duration winter/spring runoff driven by large frontal storms.
- Floods can be large, but suspended-sediment concentrations are generally small



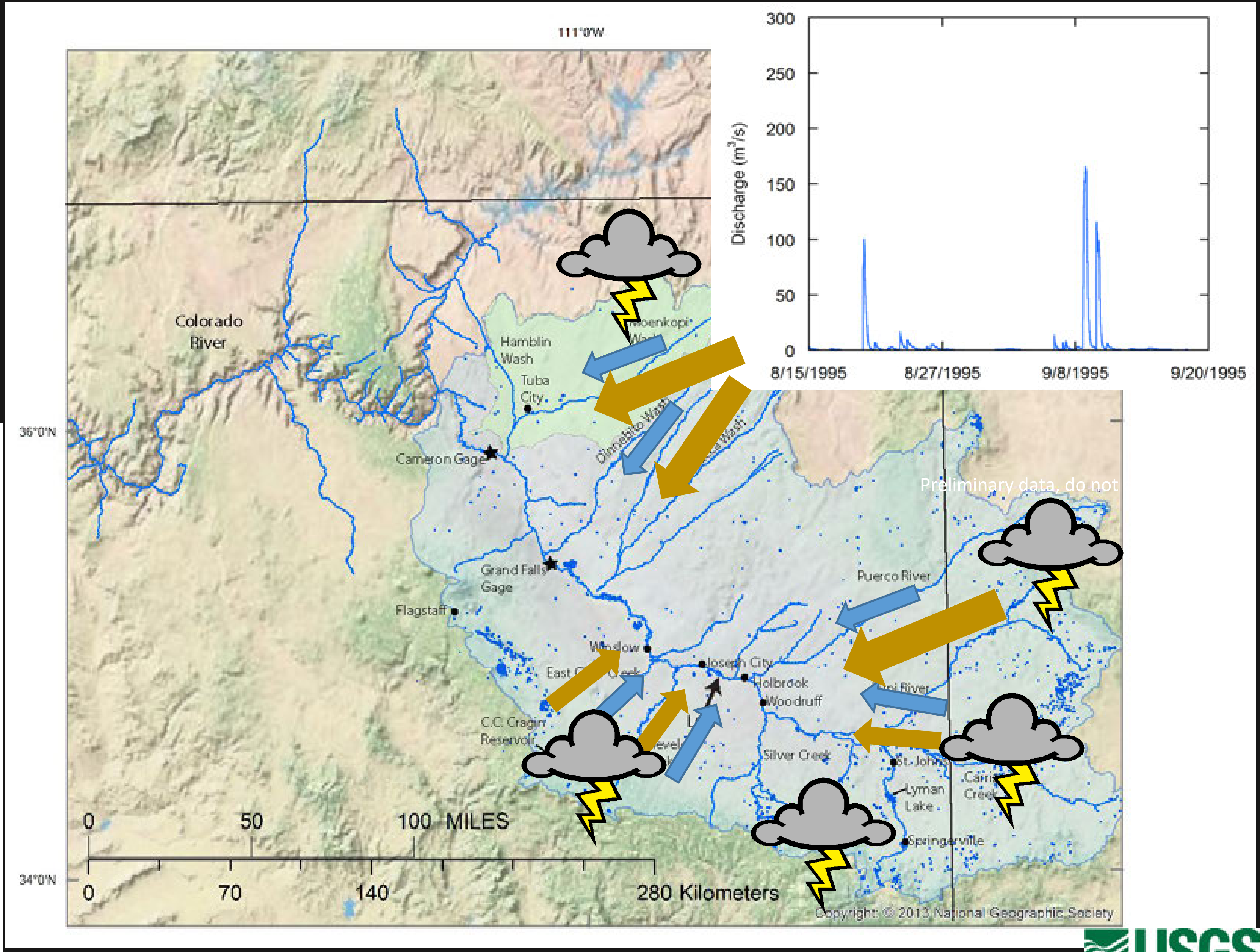
Preliminary data, do not cite.



Hydrology – Summer/Fall



- Short-duration, high-intensity, summer/fall floods driven by convective thunderstorms
- Floods can be large, and suspended-sediment concentrations can be huge. Sediment can be deposited within/on LCR channel and floodplain, or delivered to the Colorado River.



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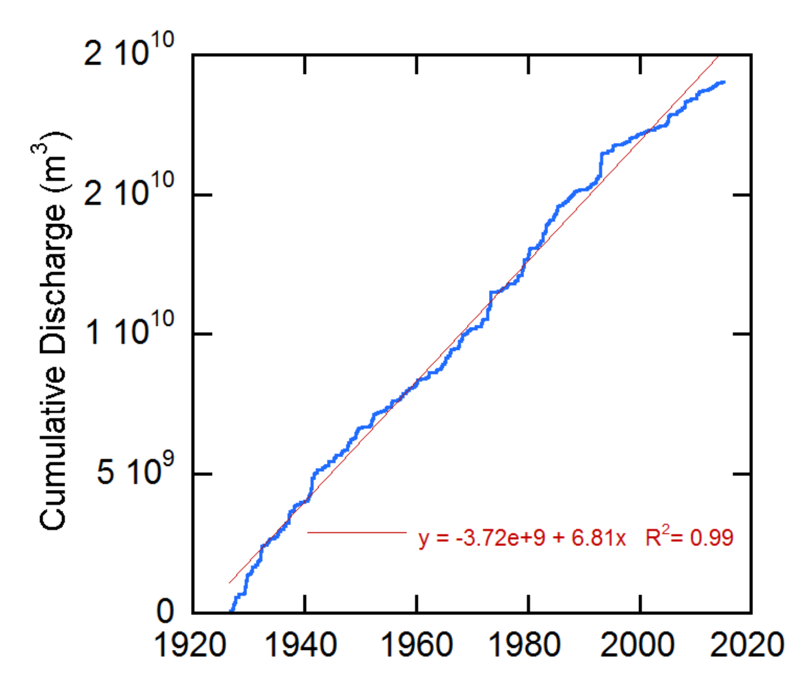
Re-evaluating the Timing of Historical Hydrologic Changes

- We created a cumulative discharge curve of LCR stream flow data
- Detrended the data to determine periods of high and low stream flow.
- Our findings are consistent with Hereford's (1984)
- The most recent low-flow period has had the lowest flow over the entire period of record.



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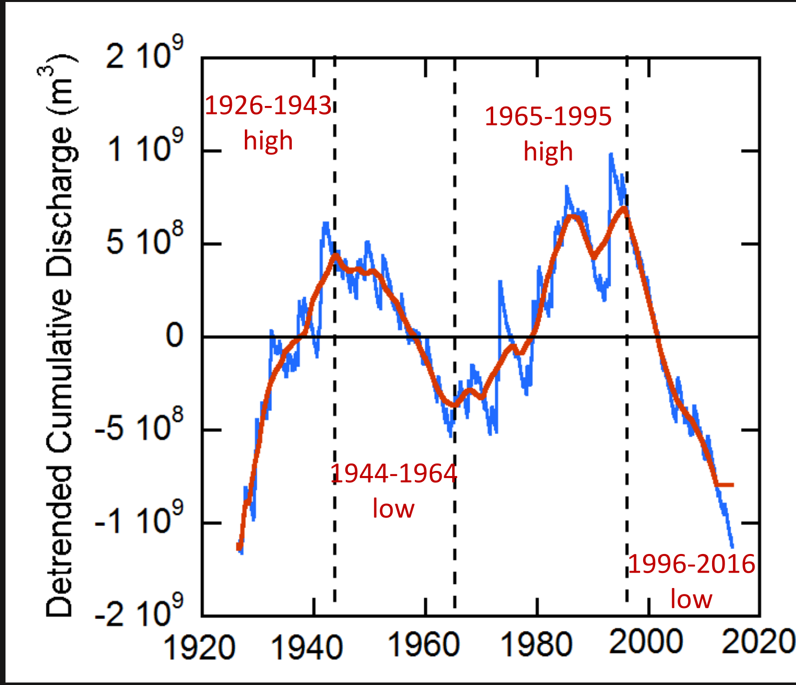

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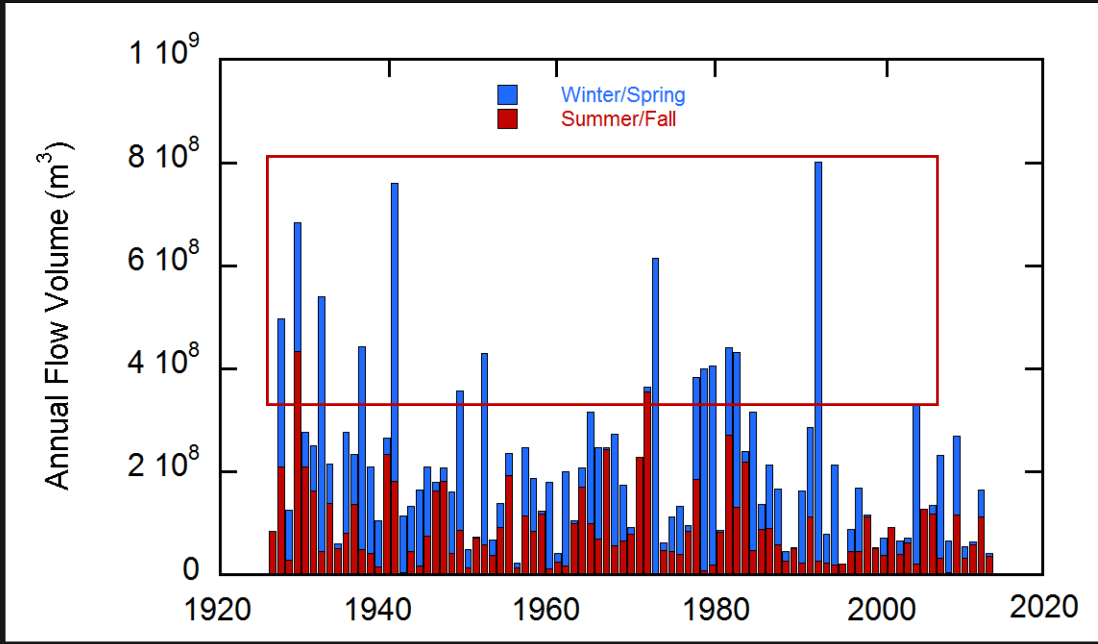
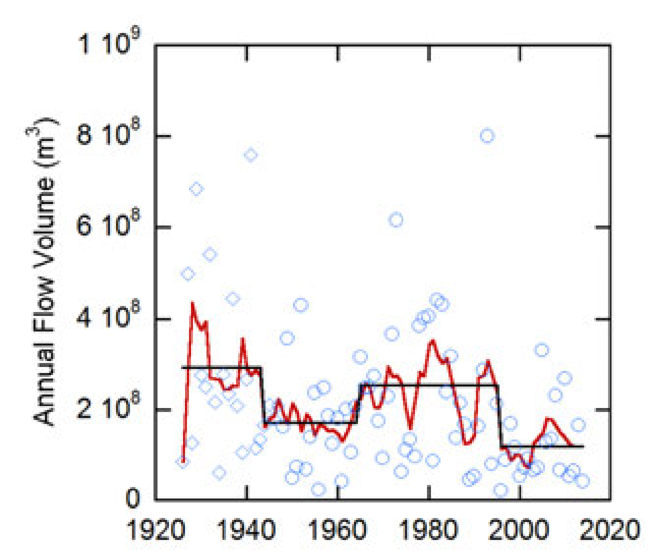
Temporal Changes in Annual Flow Volume and Peak Flow



Largest flow volumes = years dominated by winter/spring flow



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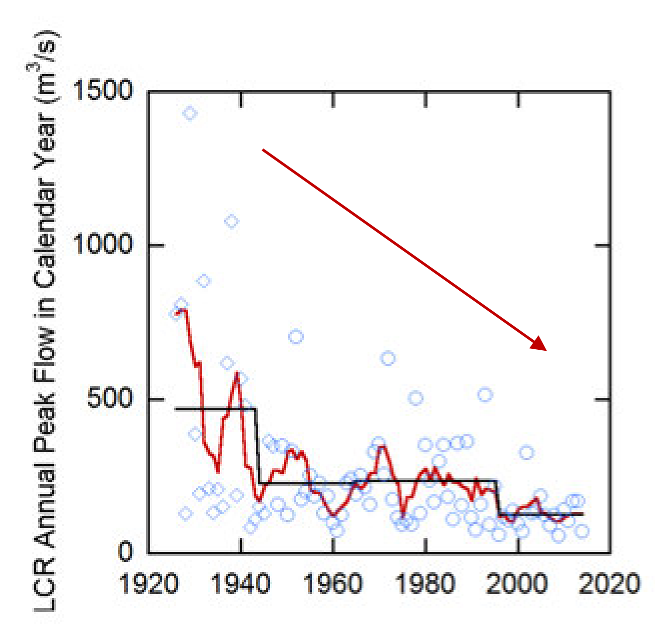

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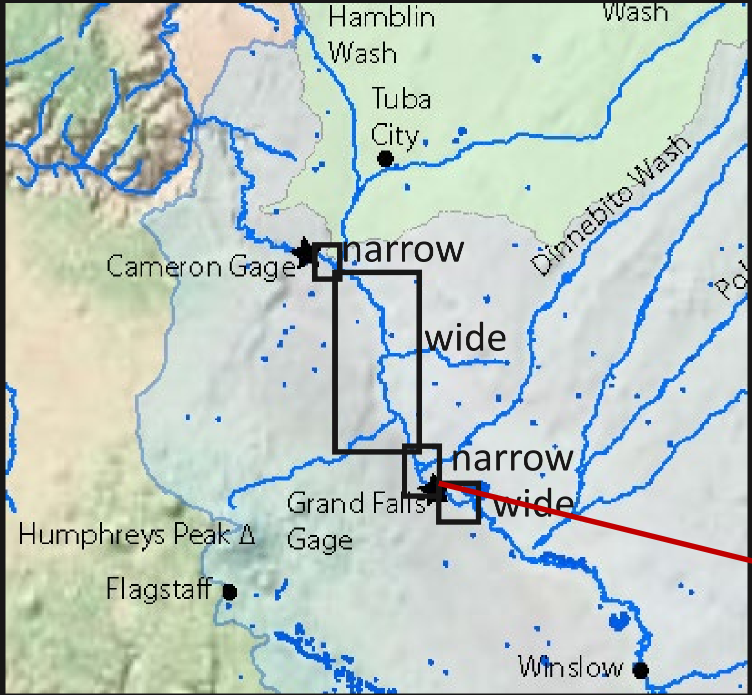
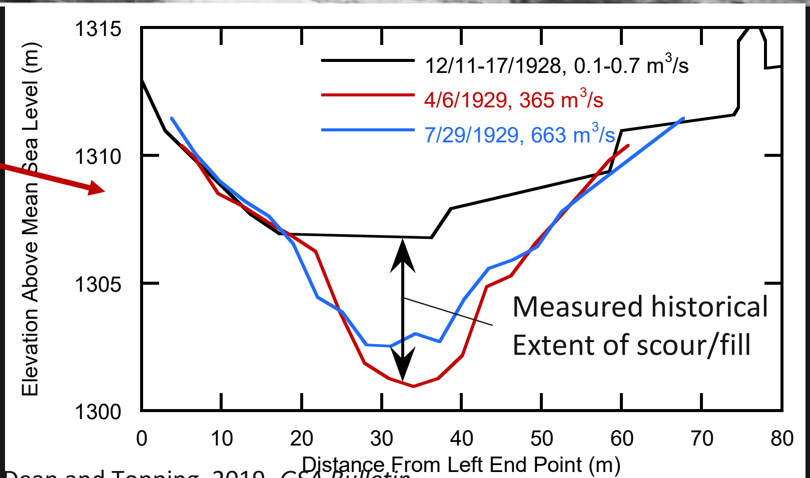
Preliminary data, do not cite.

Peak flows have continuously declined

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





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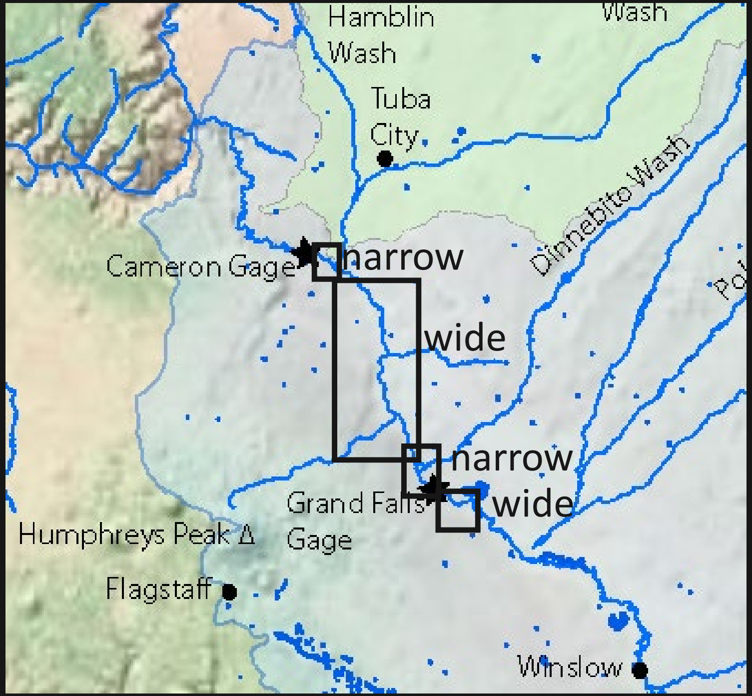
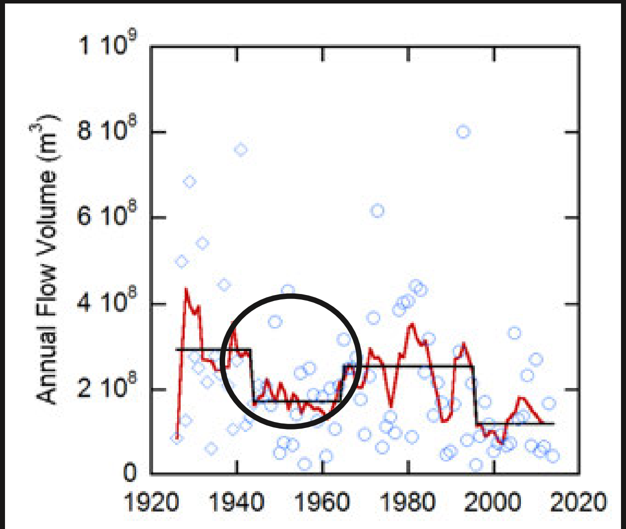
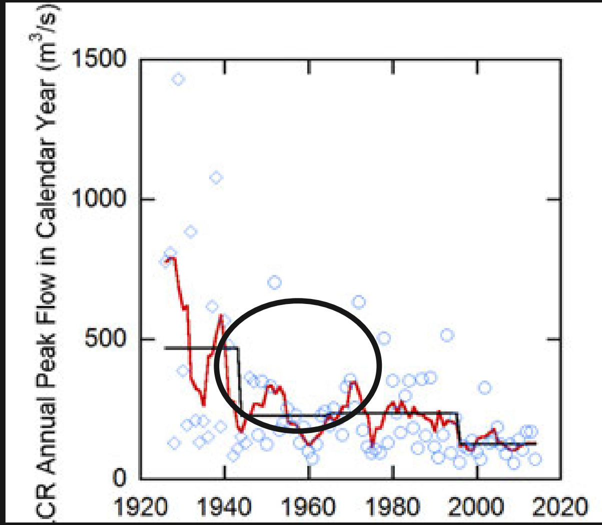
Big Floods/Wide/Braided

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

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







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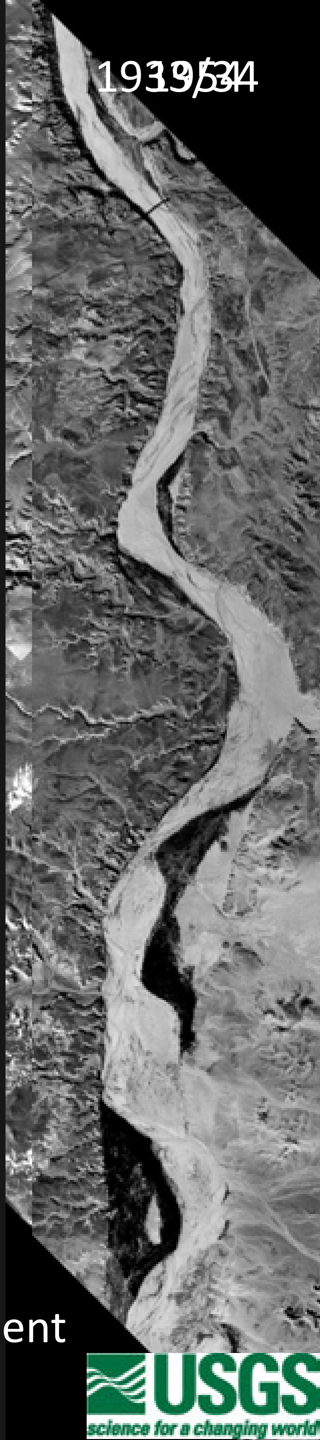
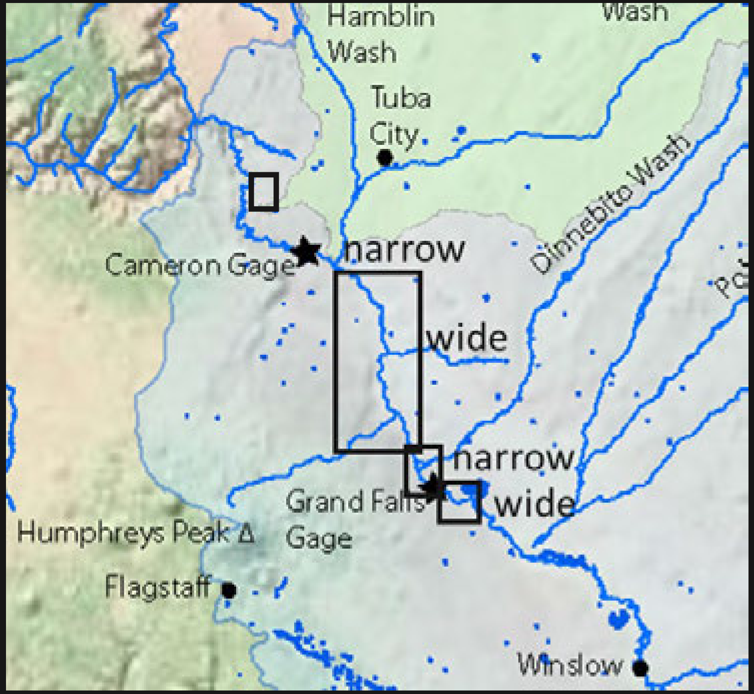


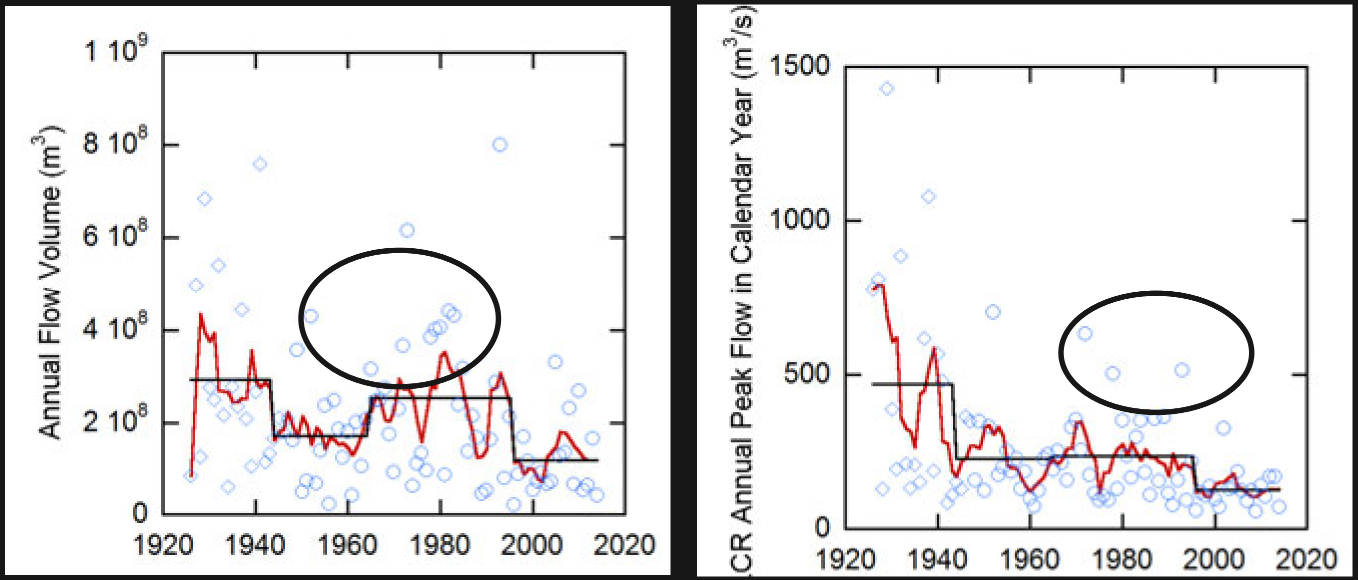
Reduced Hydrology/ Channel narrowing

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 | Present

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





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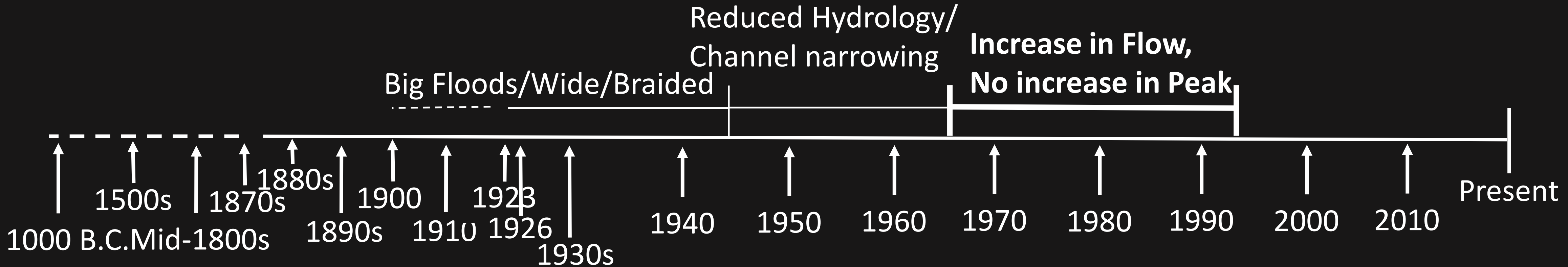
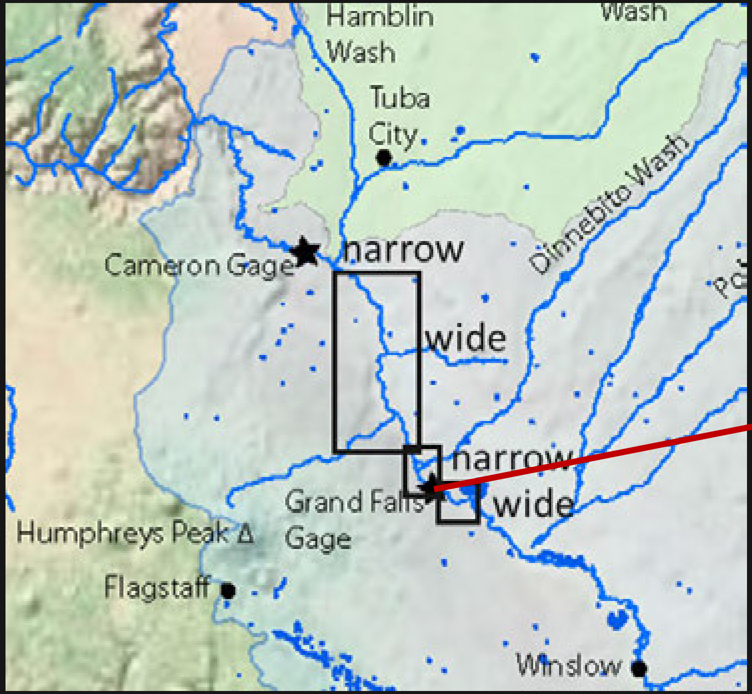
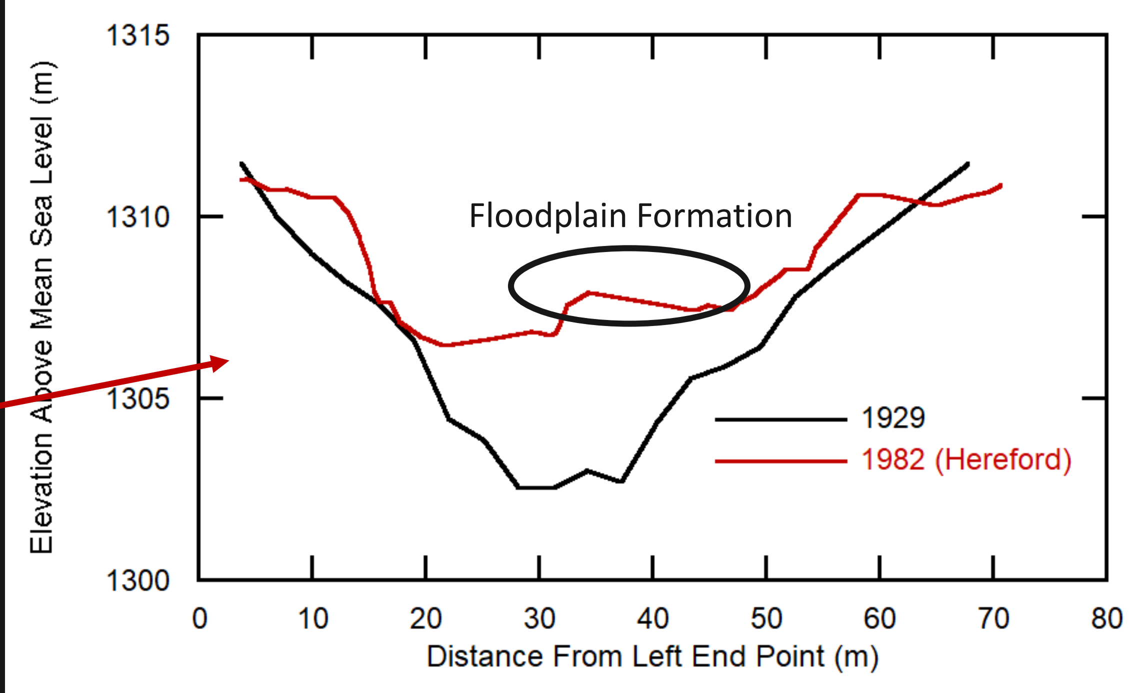


Period 3: 1965 – 1995
Continued Channel Narrowing





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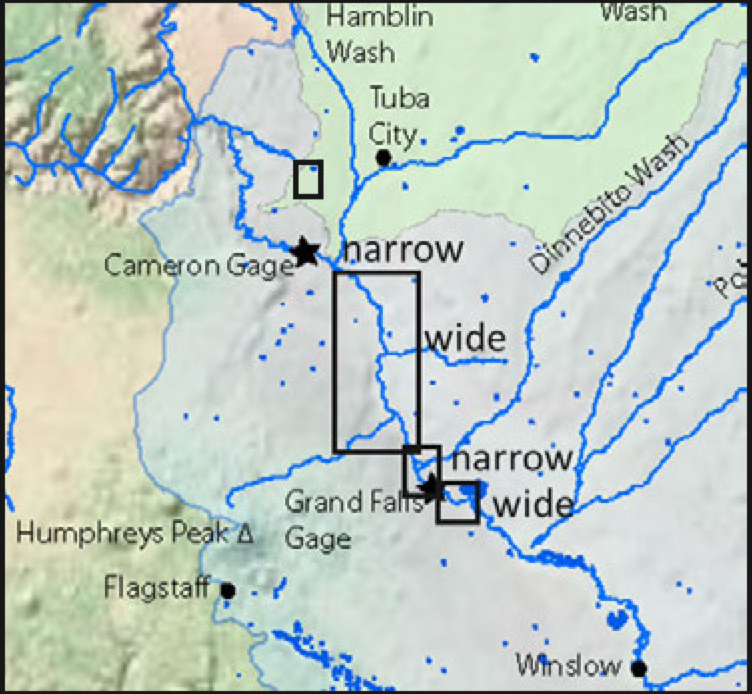
Big Floods/Wide/Braided

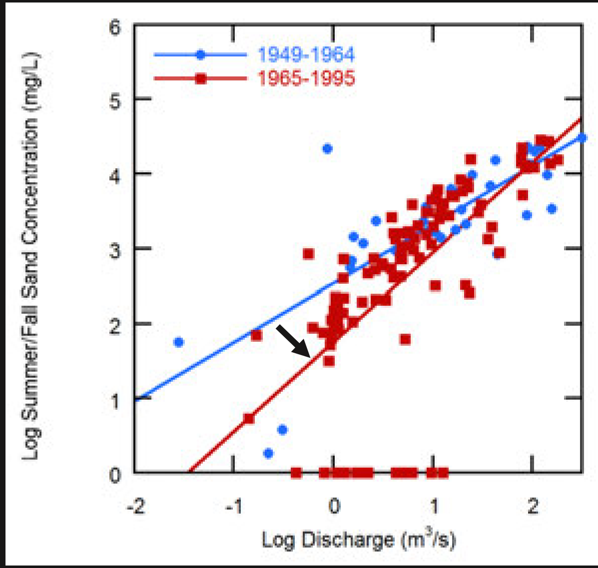
Reduced Hydrology/ Channel narrowing

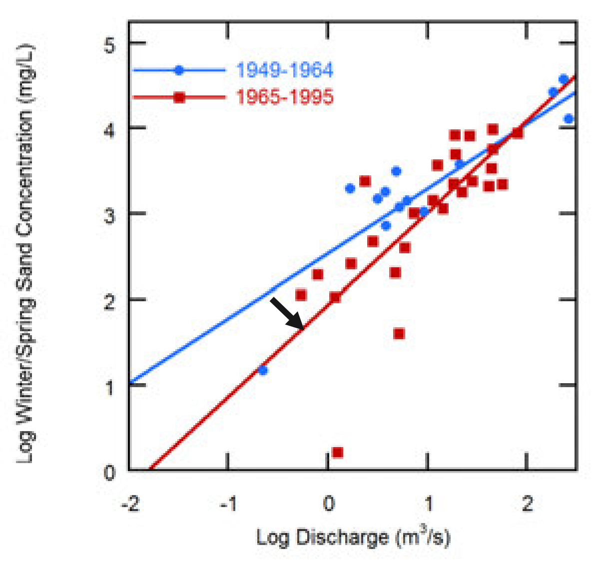
Increase in Volume, No increase in Peak

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

Period 3: 1965 – 1995
Reductions in Sediment Transport







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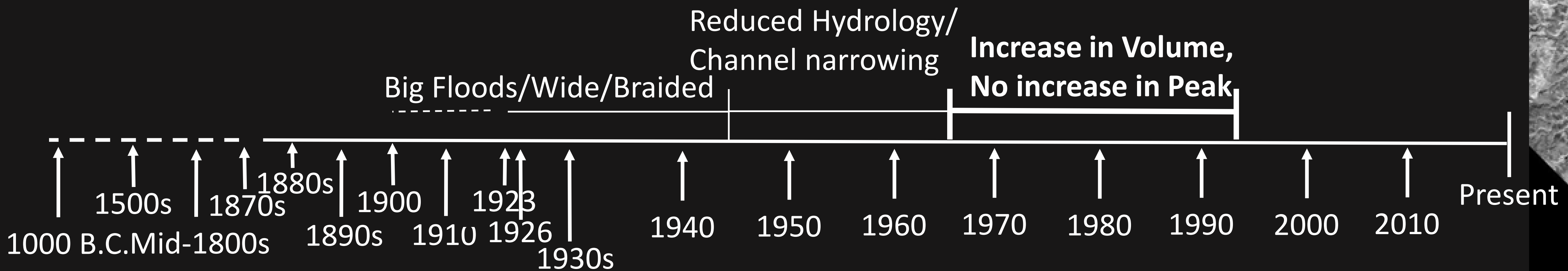
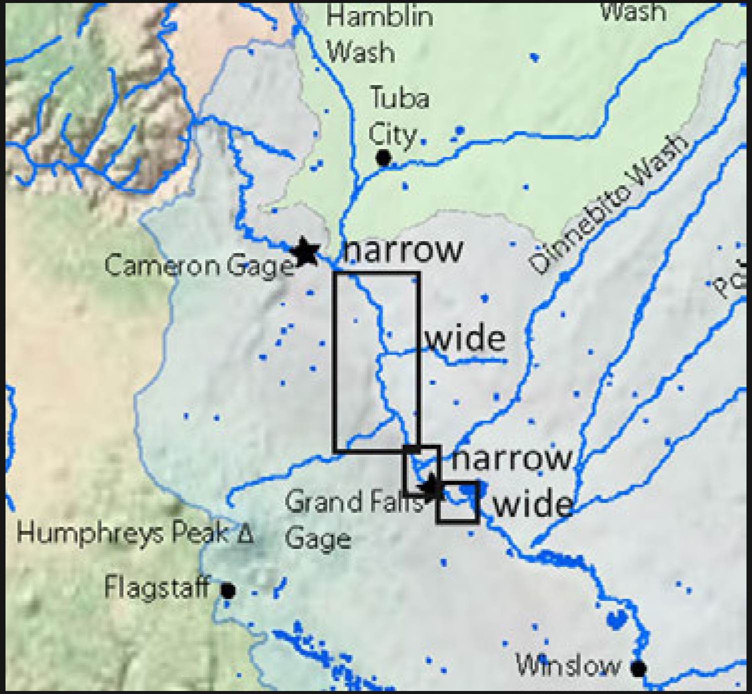
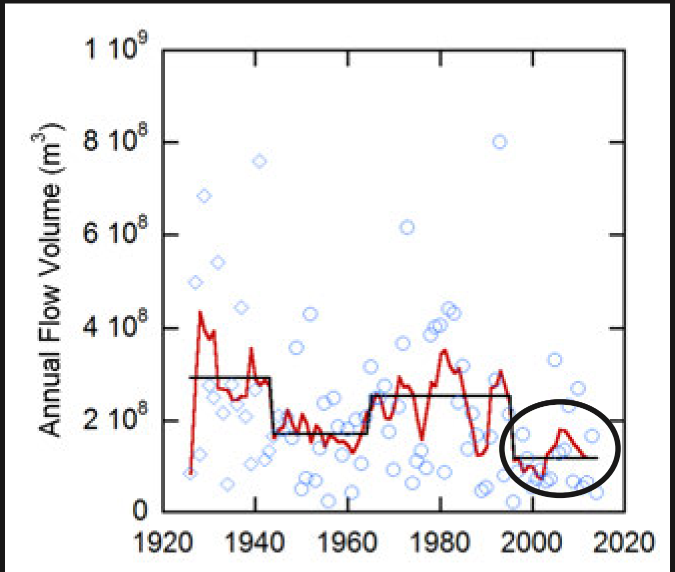
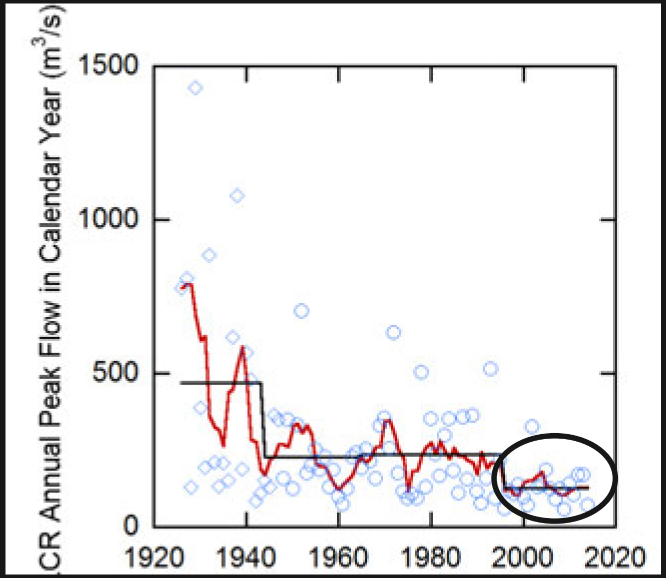


Period 4: 1996-Present
Driest Period of Gaging Record







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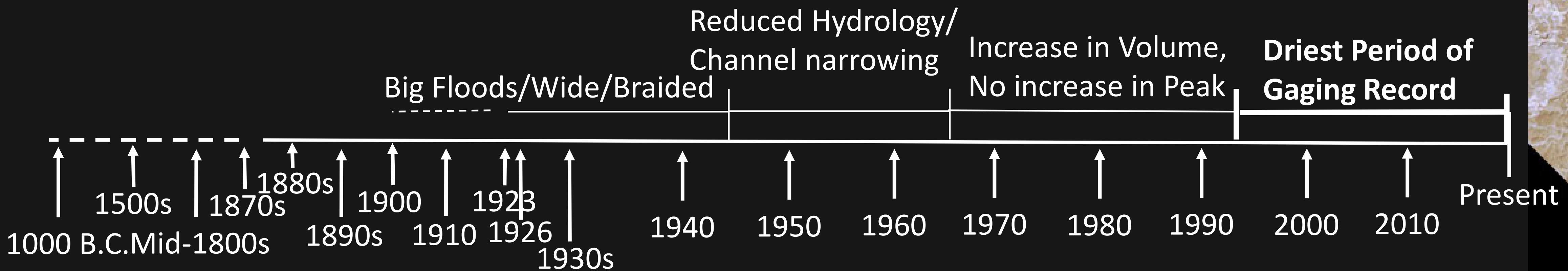

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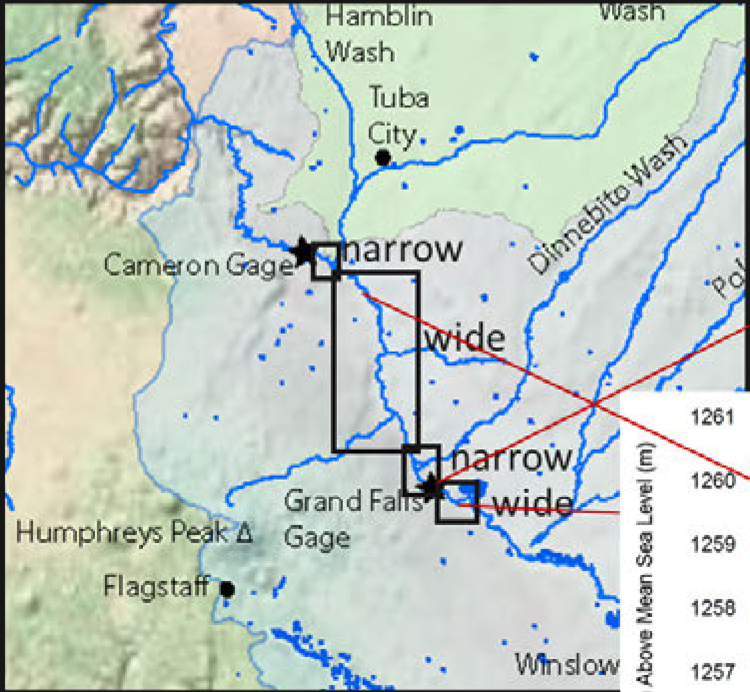
Period 4: 1996-Present
Continued Narrowing/Vegetation Expansion/Bed Aggradation



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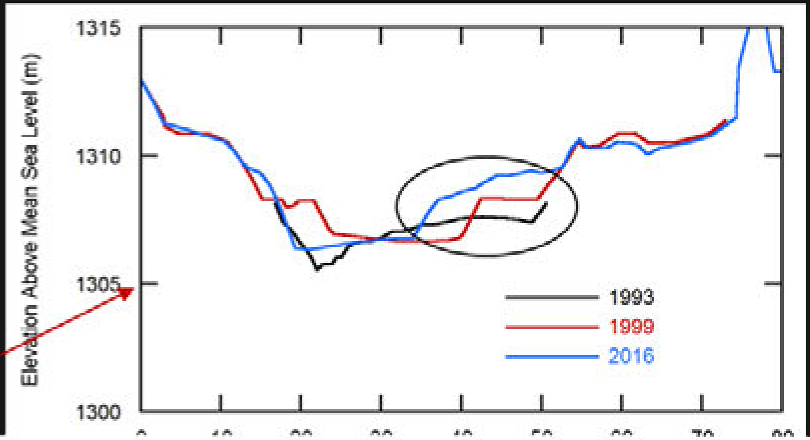

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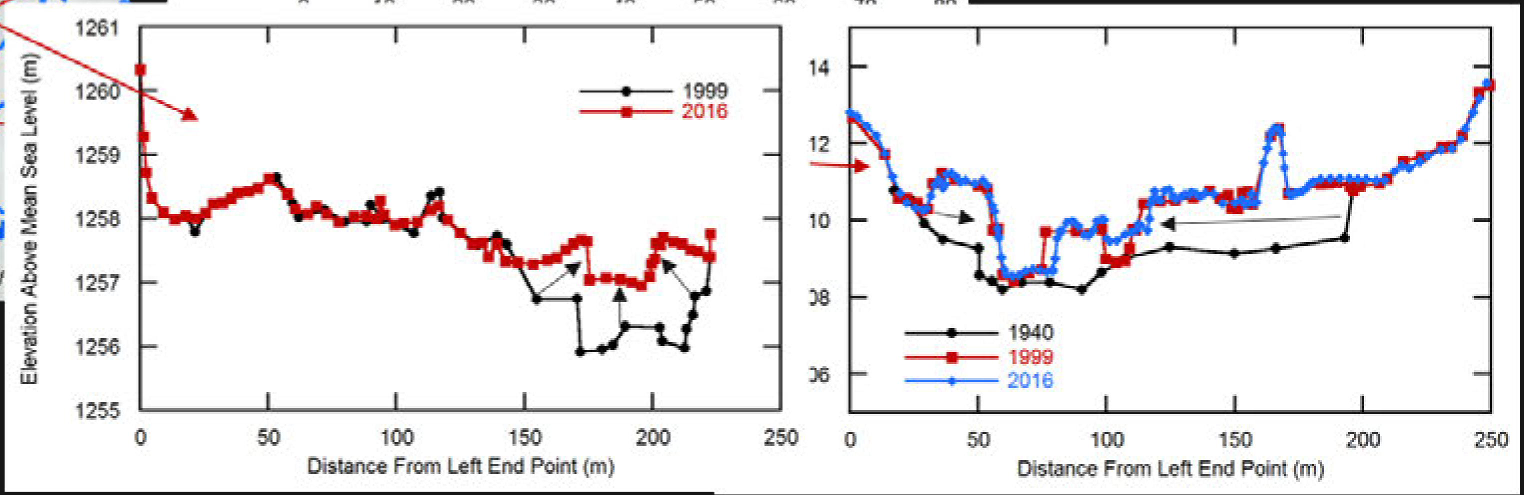

Big Floods/Wide/Braided | Reduced Hydrology/ Channel narrowing | Increase in Volume, No increase in Peak | **Driest Period of Gaging Record**

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

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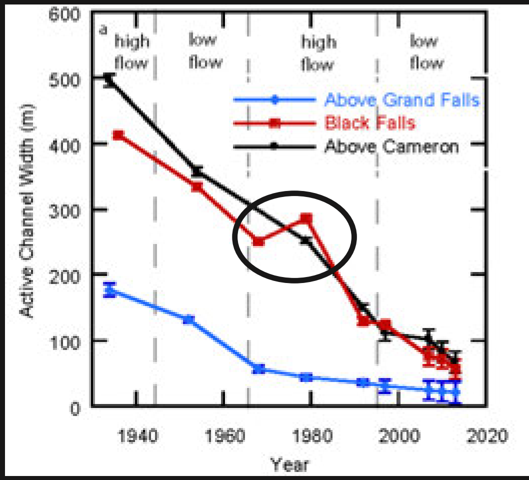
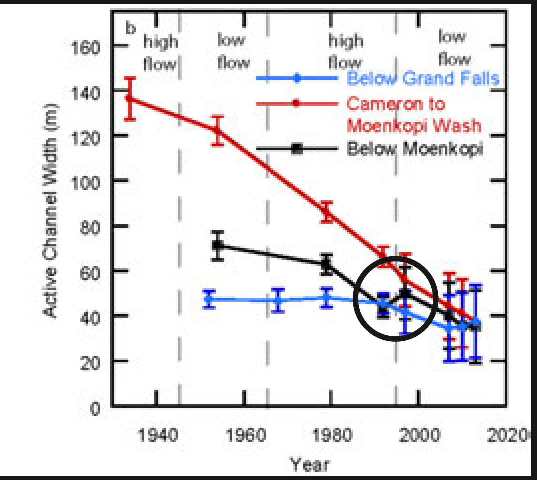
Summary: Complete Geomorphic Transformation of the LCR

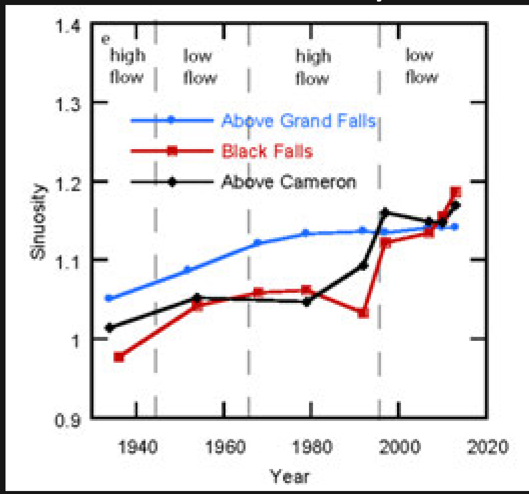
Wide Alluvial Valleys



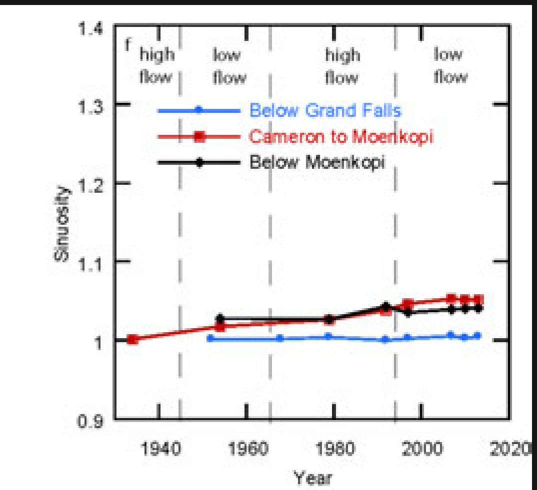
Narrow Alluvial Valleys



Wide Alluvial Valleys



Narrow Alluvial Valleys



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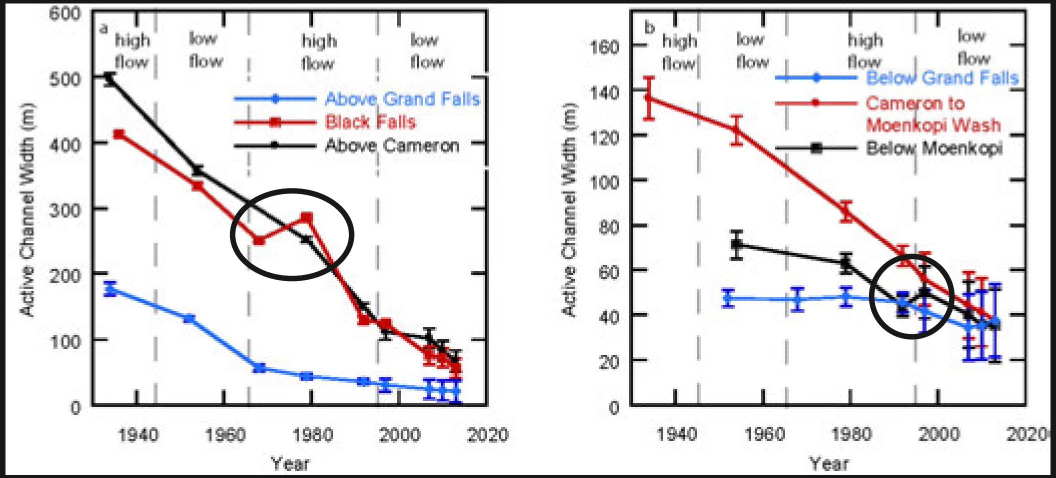
- Narrowing by > 80% in wide alluvial valleys
- Reductions in sediment transport
- Substantial bed aggradation in some areas
- Dense riparian forests now exist.

Channel Widening During Large, Long Duration Floods



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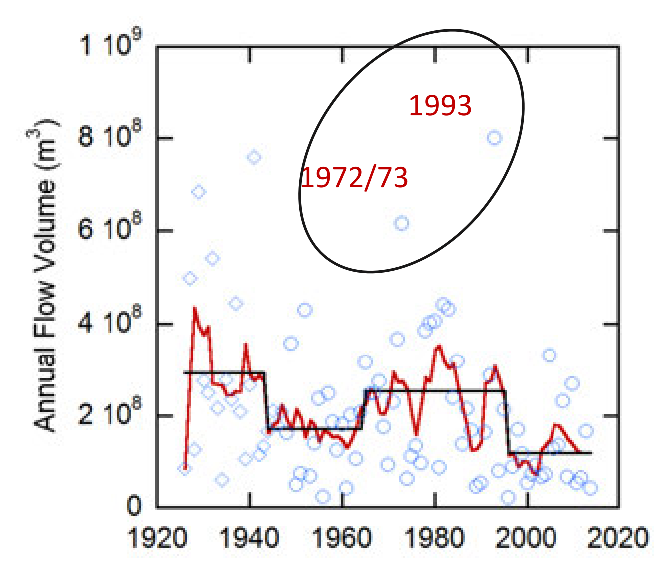

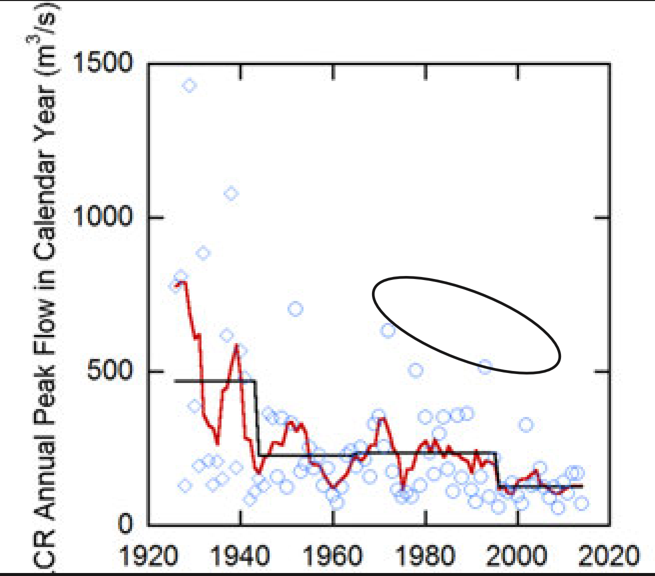

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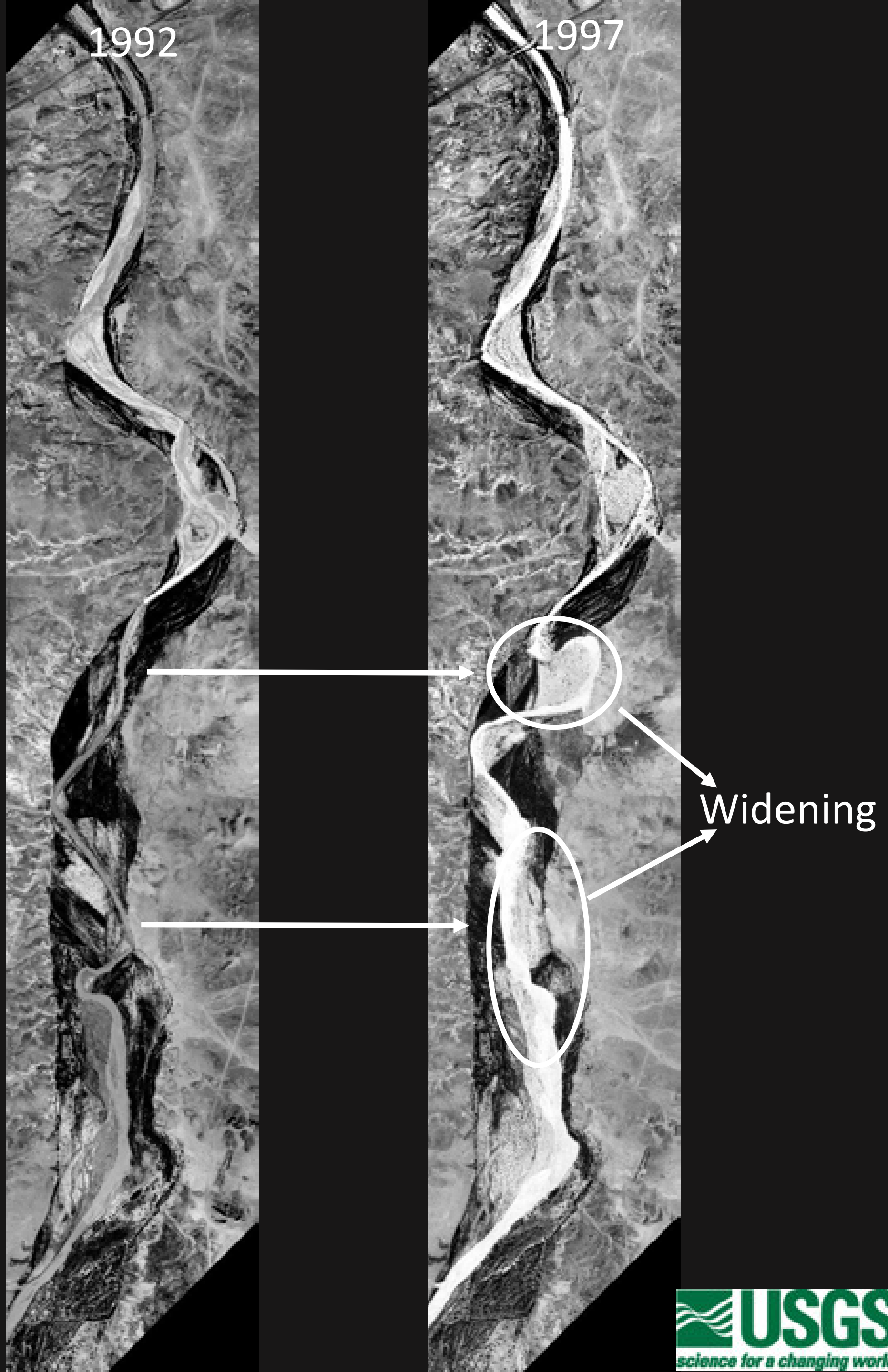

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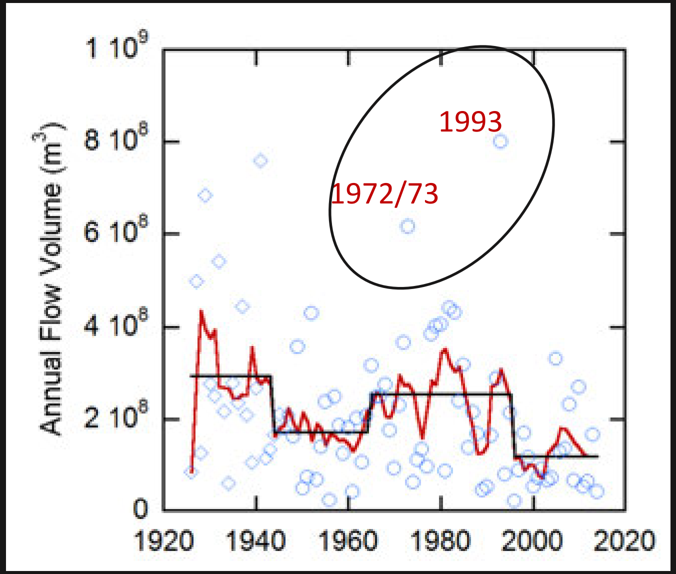
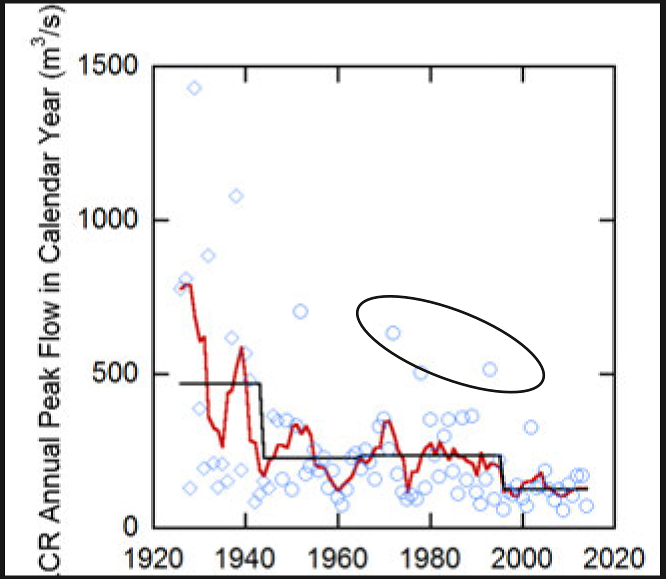
Channel Widening During Large, Long Duration Floods

Large, long duration floods ≈ channel widening

Narrowing resumes shortly thereafter.

These floods usually occur during the winter/spring.





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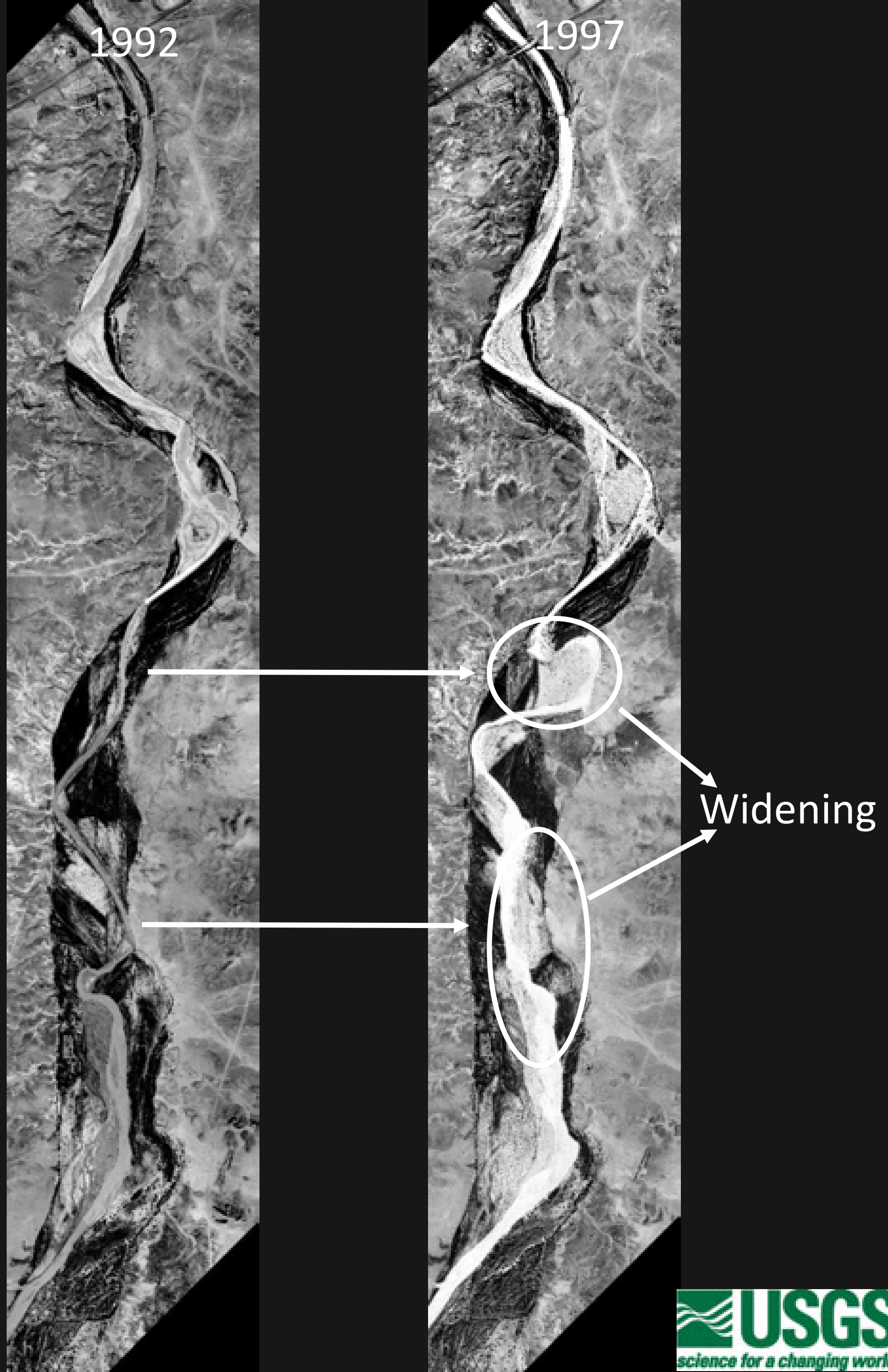
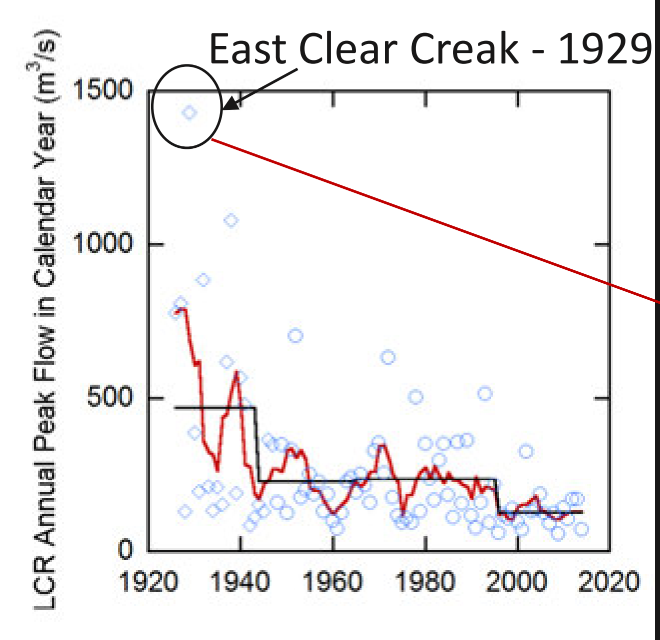


Reasons for Hydrologic Change: Declines in Peak Flow

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

- **Hypothesis 1:** Water management/dams = captured floodwater, disrupted flood conveyance, 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 at Cameron.



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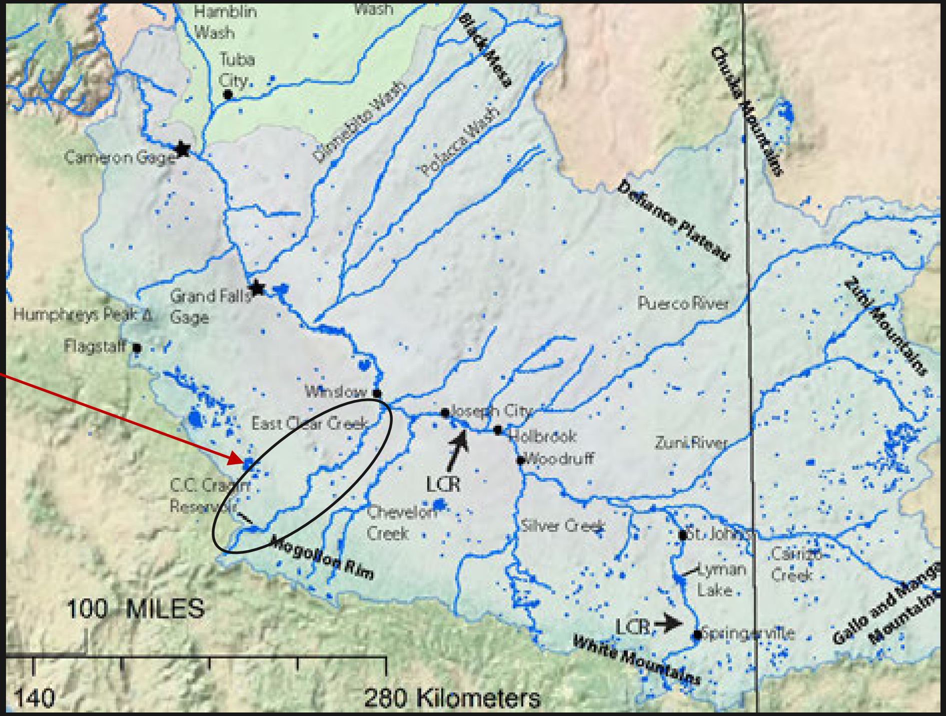

Reasons for Hydrologic Change: Declines in Peak Flow

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

Hypothesis 2: Biogeomorphic processes (channel narrowing, floodplain development, vegetation establishment) has affected floodwave propagation, and causes flood attenuation.

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

1940

2016

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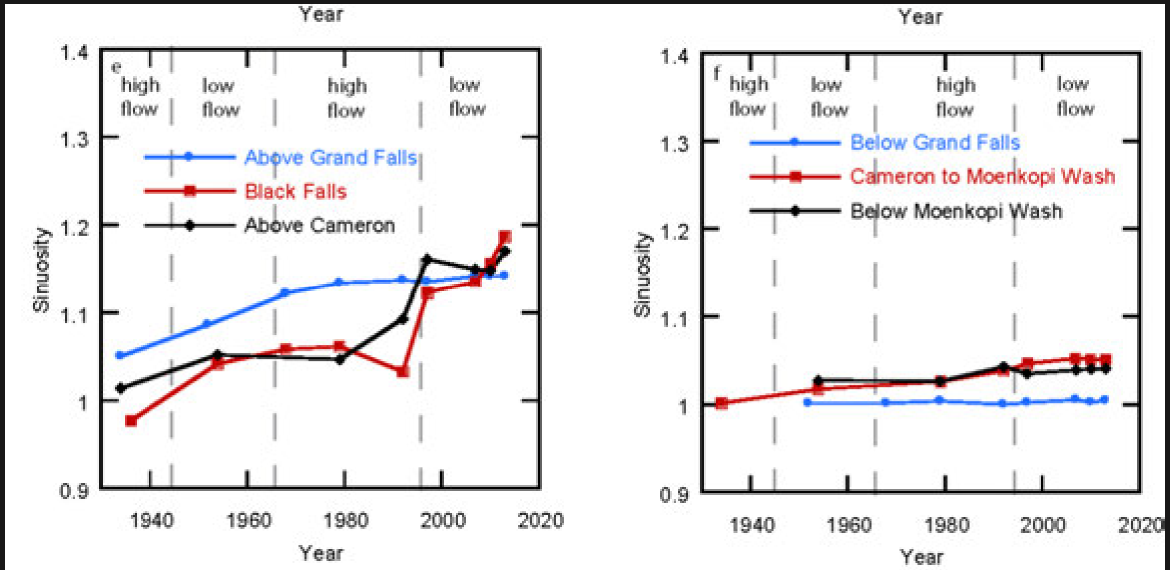
Biogeomorphic feedbacks in the LCR

- Increases in Sinuosity = decreases in slope of ~ 30% (less streampower)
- Increases in veg = increased drag of channel banks and floodplains?
- Sequestration of floodwater on the expanded floodplains?

Wide Alluvial Valleys

Narrow Alluvial Valleys



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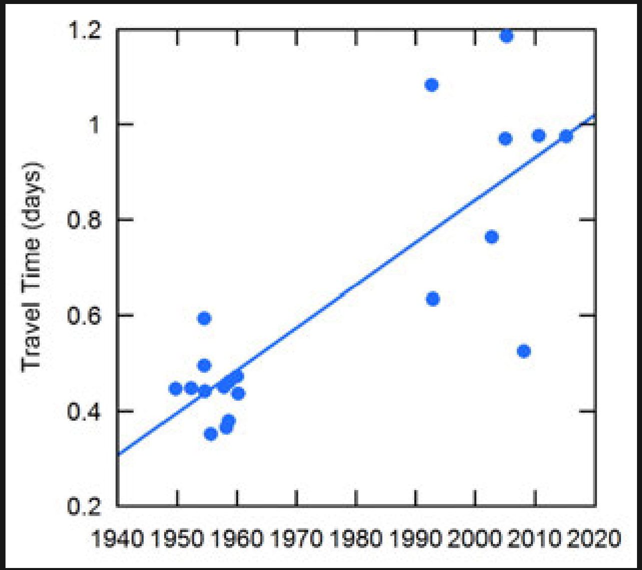
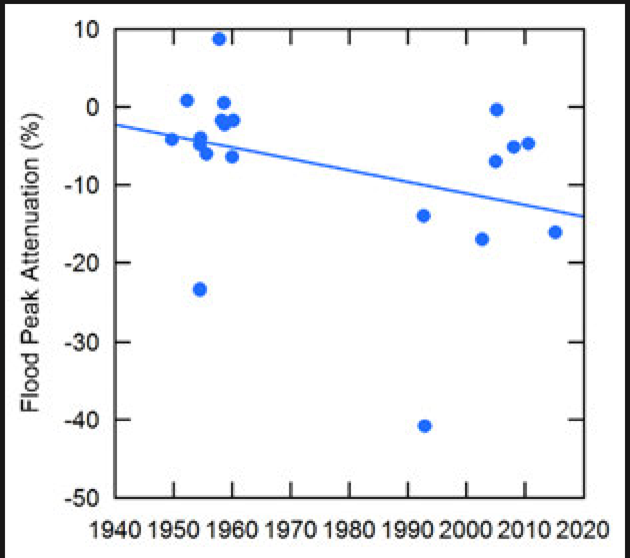
Changes in Travel Time of Floods/Attenuation Between Grand Falls and Cameron





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Increased travel time = Greater flood attenuation, potentially a cause of peak flow decline?

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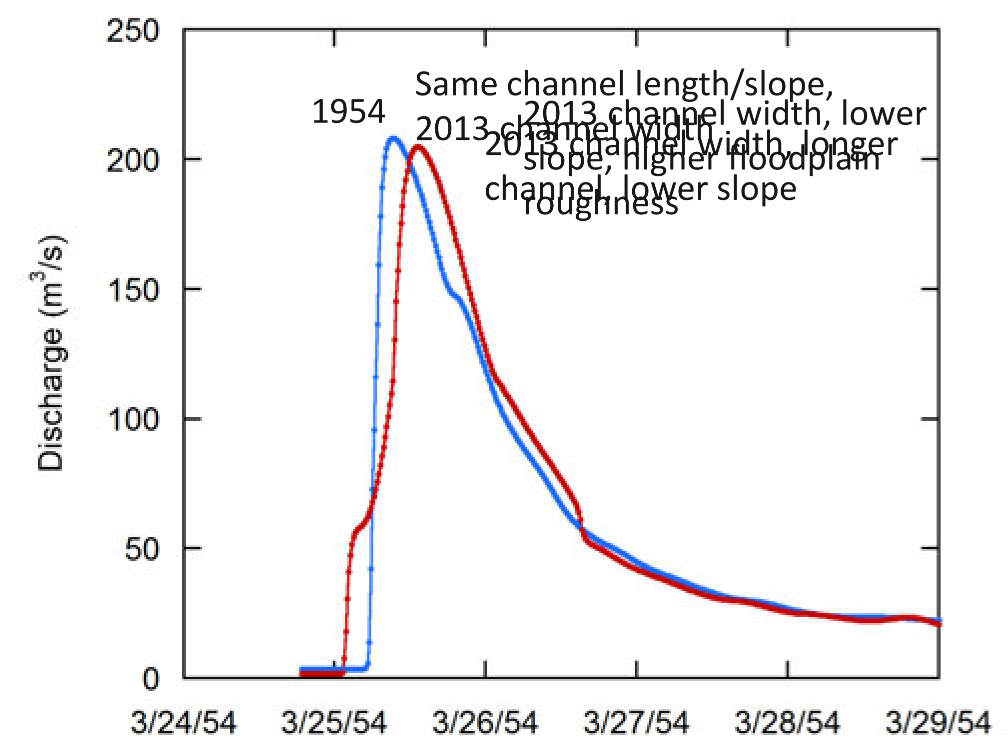
Biogeomorphic feedbacks in the LCR: 1D Flood Routing



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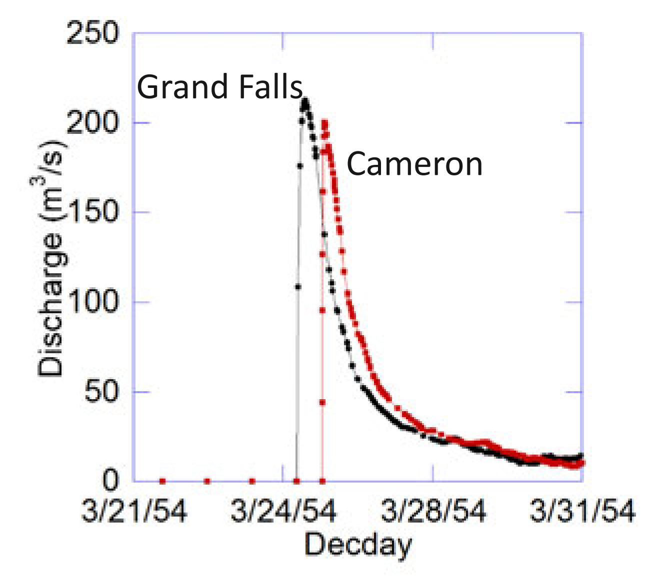
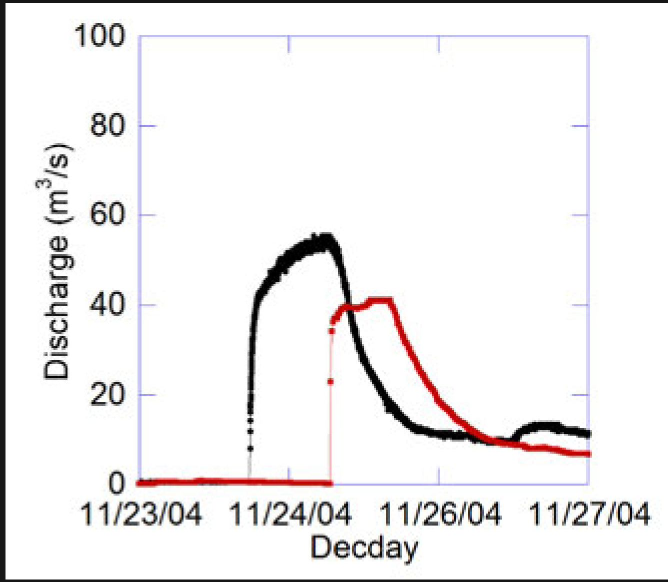
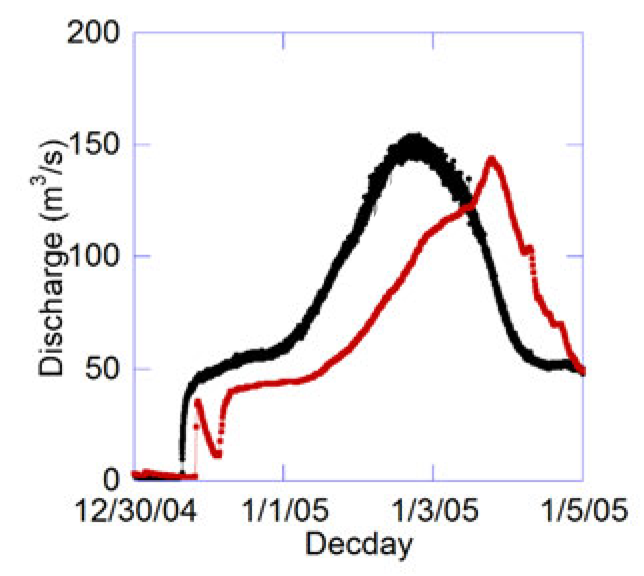
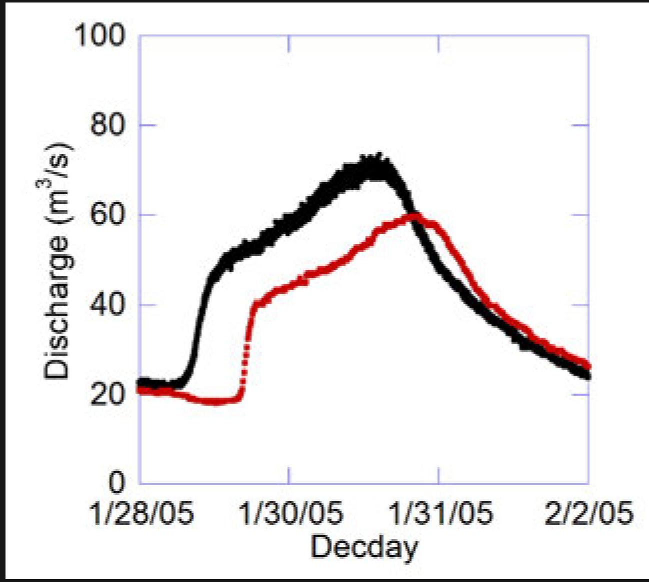
Added roughness, reductions in width, and lower channel slope disrupts the movement of floodwaves.









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

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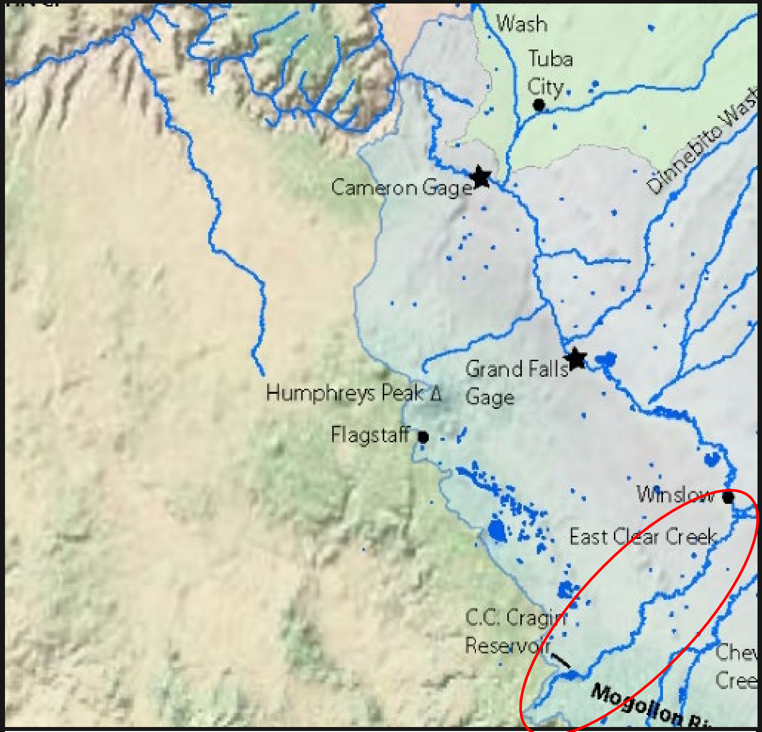
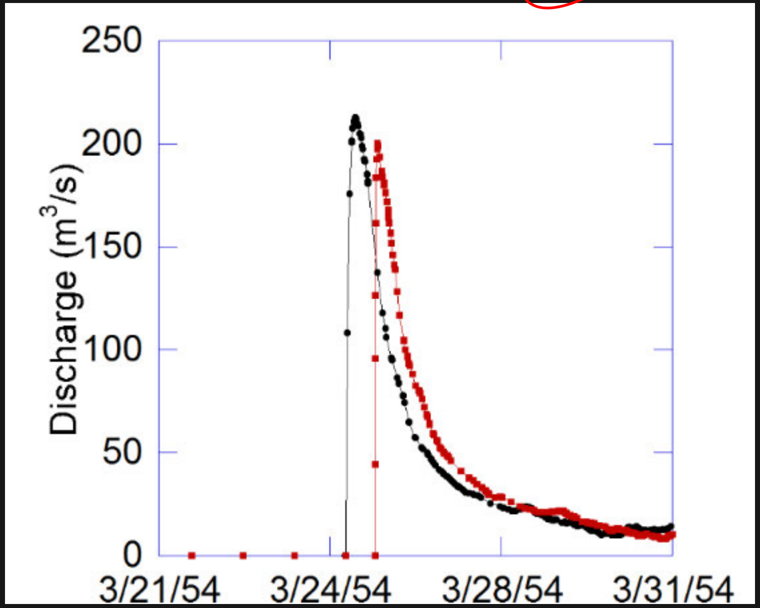
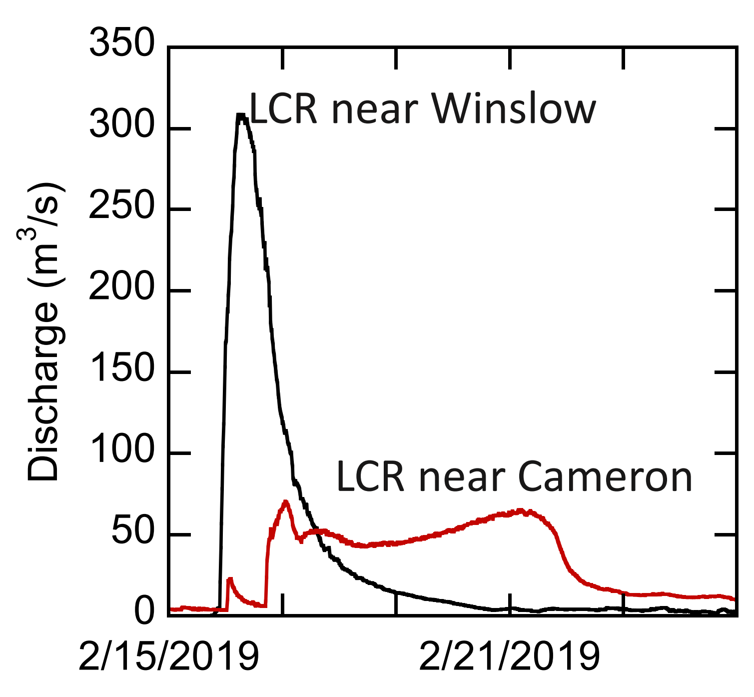
February 2019 Flood Attenuation





Preliminary data, do not cite

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.

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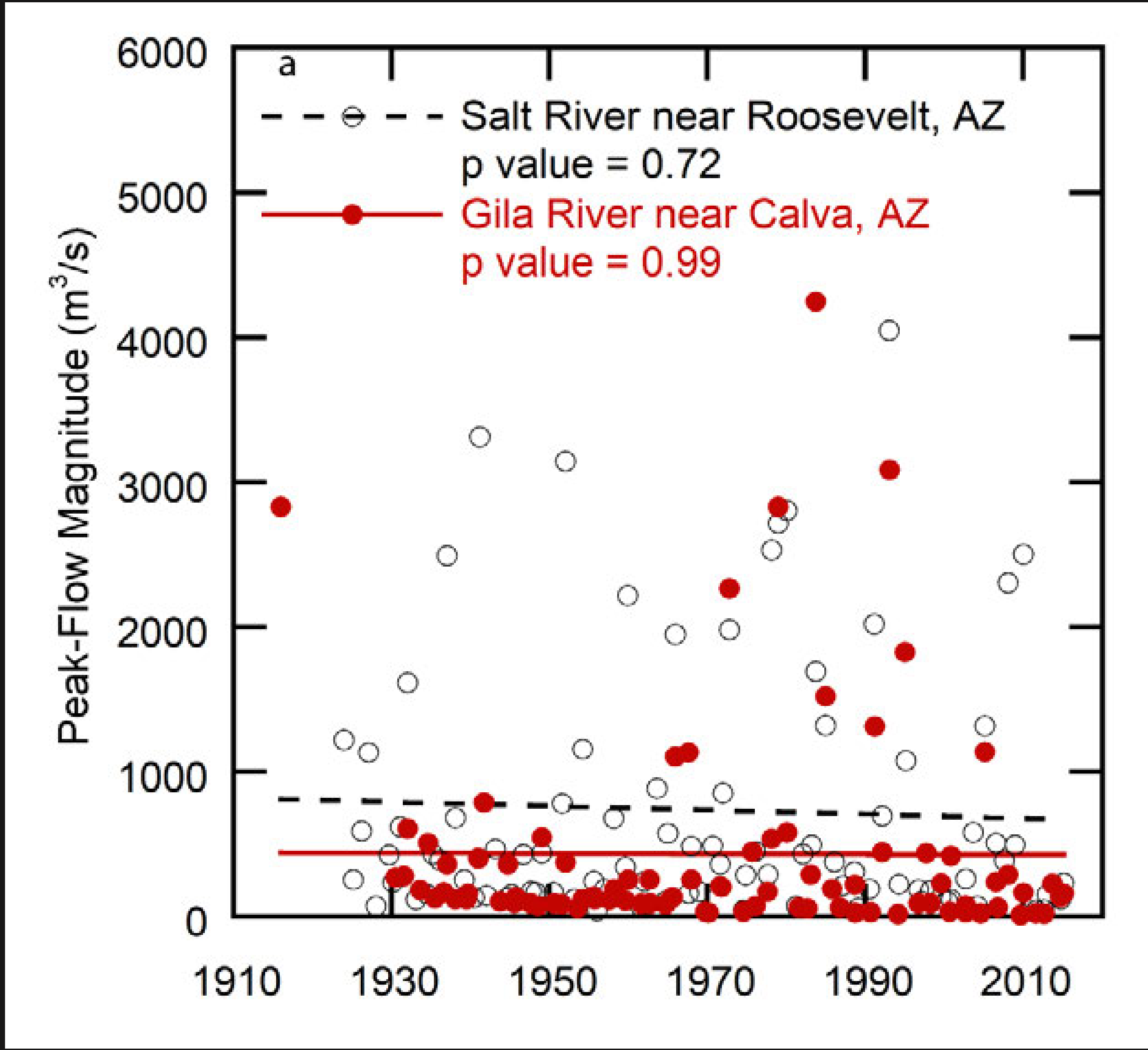
Hydrologic Change - Adjacent Basins



Dean and Topping, 2019, *GSA Bulletin*

Conclusions

- Fluctuations in total flow - changes in climate (Hereford, 1984).
- Peak flow declines, mostly in winter/spring - primary cause of channel narrowing.
- Peak flow declines in second half of 20th century
  - 1) human water use and development
  - 2) geomorphic changes within the river.
- Large, long duration floods - temporarily channel widening. Widening short lived.
- Biogemorphic feedbacks
  - Veg = increased drag/floodplain stabilization
  - Sediment accumulation → Increase in Sinuosity → Reductions in Slope → Reductions in Sediment Transport → Increased Deposition/Narrowing
  - Unlikely to see increases in flood magnitude.
- Sediment Delivery to GC…Likely permanently reduced. Further evaluations being conducted to determine magnitude of reduction.