From Particles to Plans: How Flood Sediments Inform Flood Risk Management

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WHERE, WHEN, AND WHY OF EXTREME FLOODS

Europe's deadly floods leave scientists stunned

Despite improvements, flood forecasting sometimes fails to flag risks along smaller streams

20 JUL 2021 · BY WARREN CORNWALL

SCIENCEINSIDER

AP News

Deadly flooding is hitting several countries at once. Scientists say this will only be more common

People wade through a street due to a heavy rain in Kurume, Fukuoka prefecture, southern Japan Monday, July 10, 2023. Scientists have long warned that more extreme rainfall is expected in a warming world. (Kyodo News via AP)

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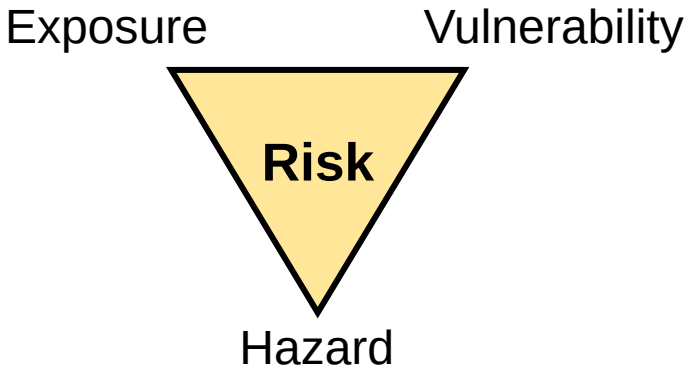
ASSOCIATED PRESS



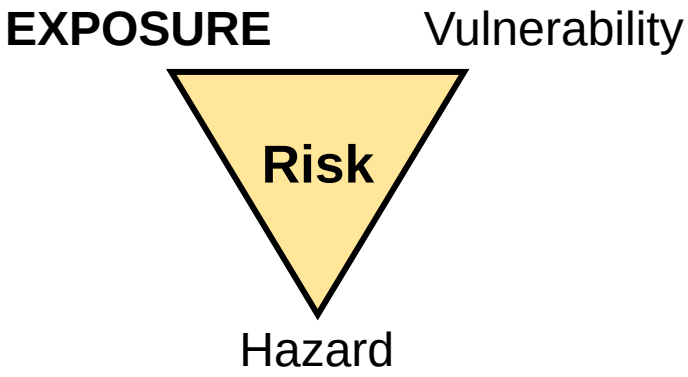
Flood disasters are occurring more frequently

Between 2000 and 2015, the world pop. exposed to flooding increased by **20 to 24%**.

(Tellman et al. 2021, *Nature* 596)


Photo Source: ASI/Land Tirol/BH Landeck


Photo Source: Army Corps of Engineers



Flood disasters are occurring more frequently

80% of all North American dams are older than 50 years old

(United Nations University Institute for Water, Environment and Health, 2021)

Exposure **VULNERABILITY**

Risk

Hazard

Flood disasters are occurring more frequently

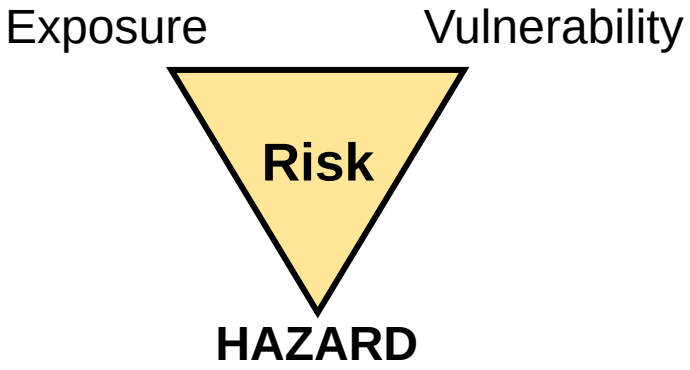
FDRG

Extreme rainfall is increasing (high confidence) & extreme flooding will *likely* increase (medium confidence).

(IPCC Report, 2022)


Photo Source: ASI/Land Tirol/BH Landeck


Photo Source: Army Corps of Engineers

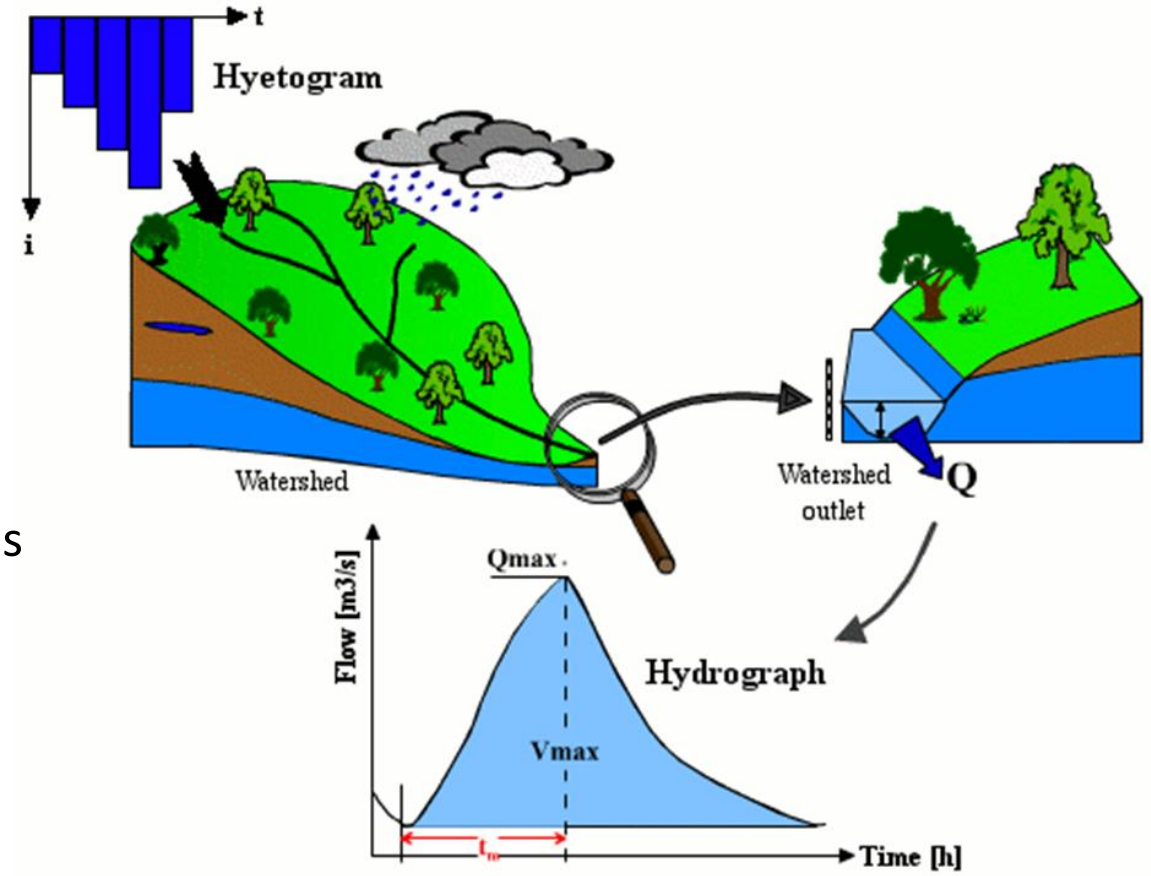


Flood disasters are occurring more frequently

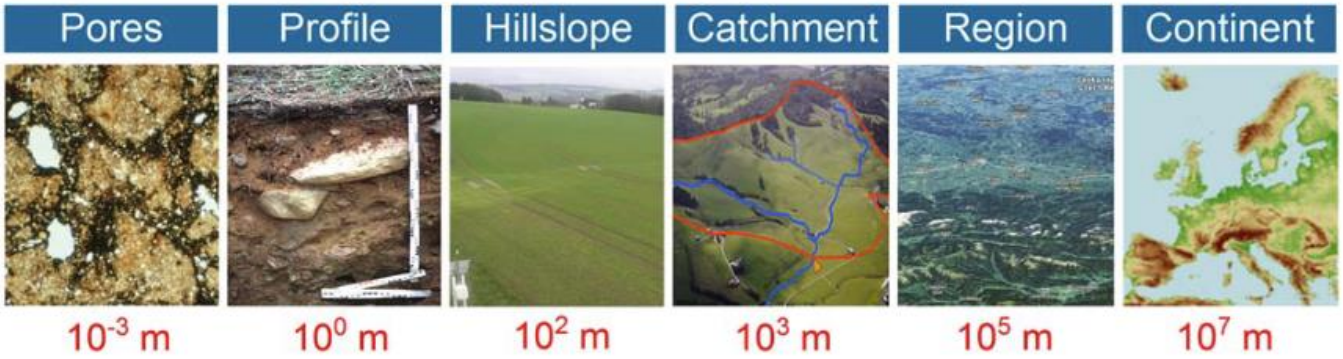
Challenge #1:
The drivers of extreme floods are poorly understood within the complex fluvial system

Flood Drivers:

1. Meteorological processes
2. Watershed processes
3. Channel processes

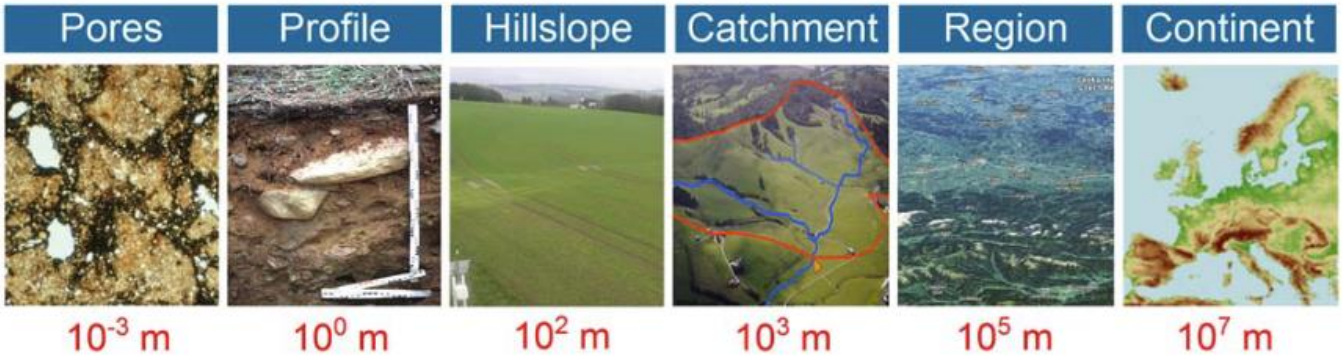


Floods are threshold responses in a complex system



Günter Blöschl, 2022

Floods are threshold responses in a complex system



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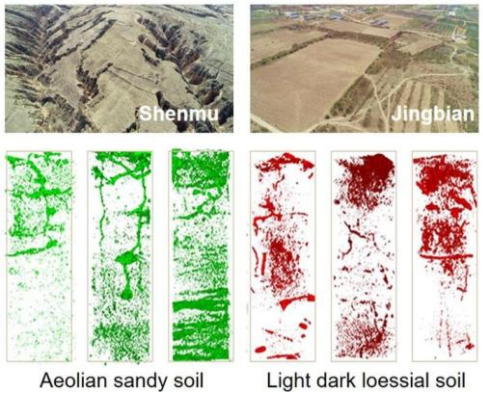
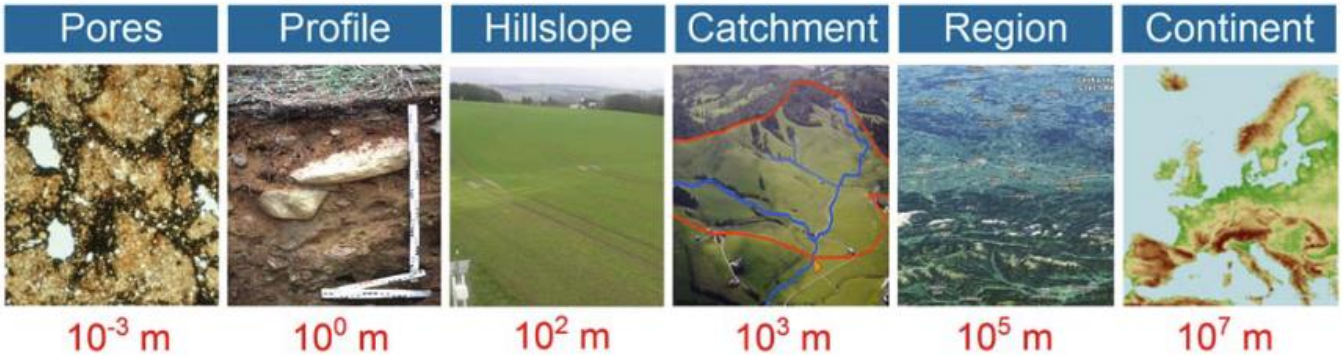
Ex. macropore connection



Ju et al. 2020 *Catena*

Floods are threshold responses in a complex system



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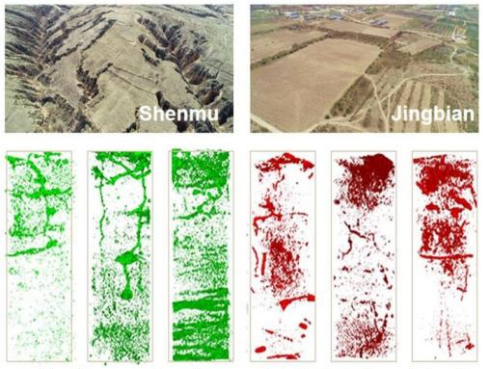

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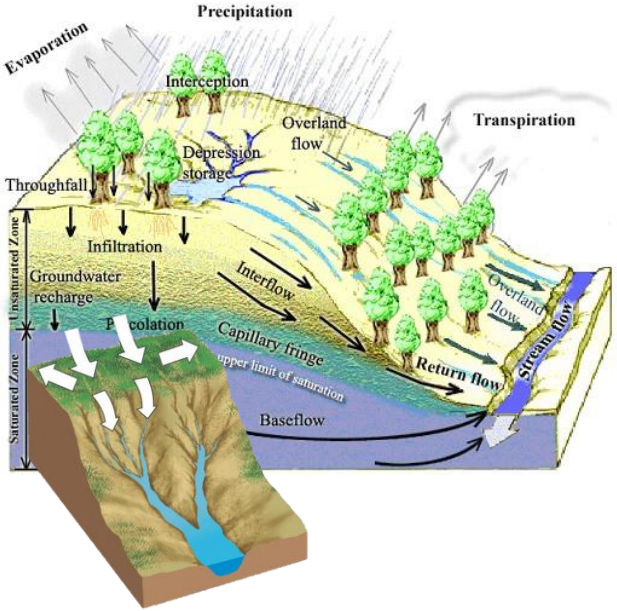
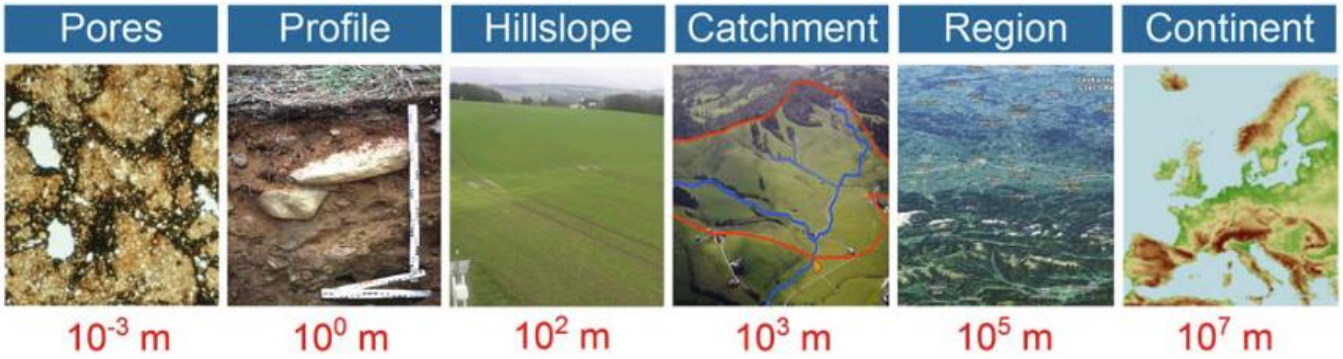


Ex. Concentrated flows through gullies

Floods are threshold responses in a complex system



Günter Blöschl, 2022

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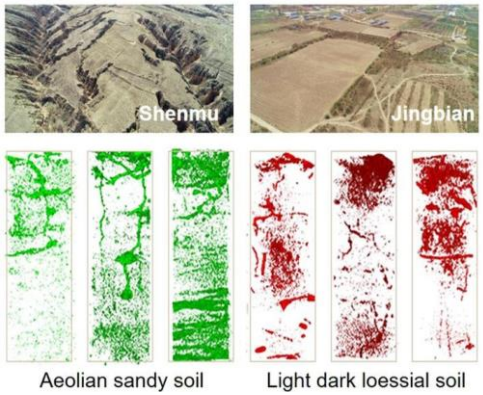

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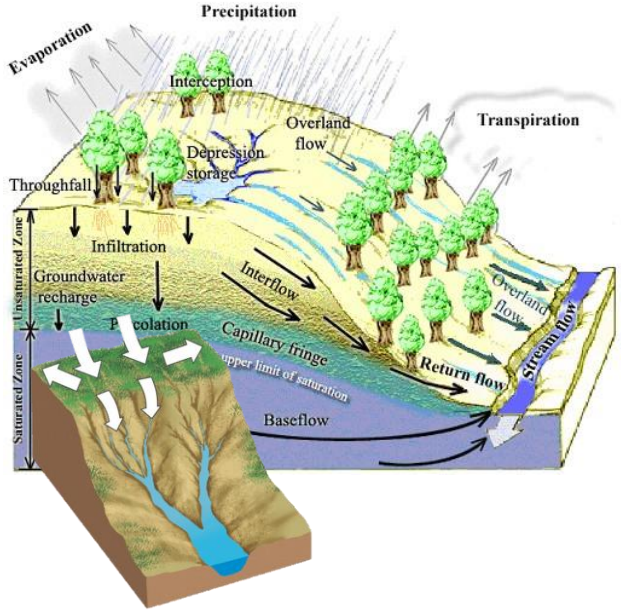
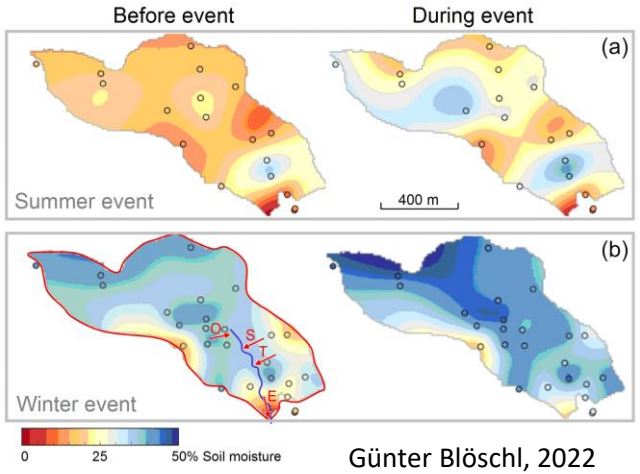


Ex. Concentrated flows through gullies

Ex. Soil moisture within the watershed

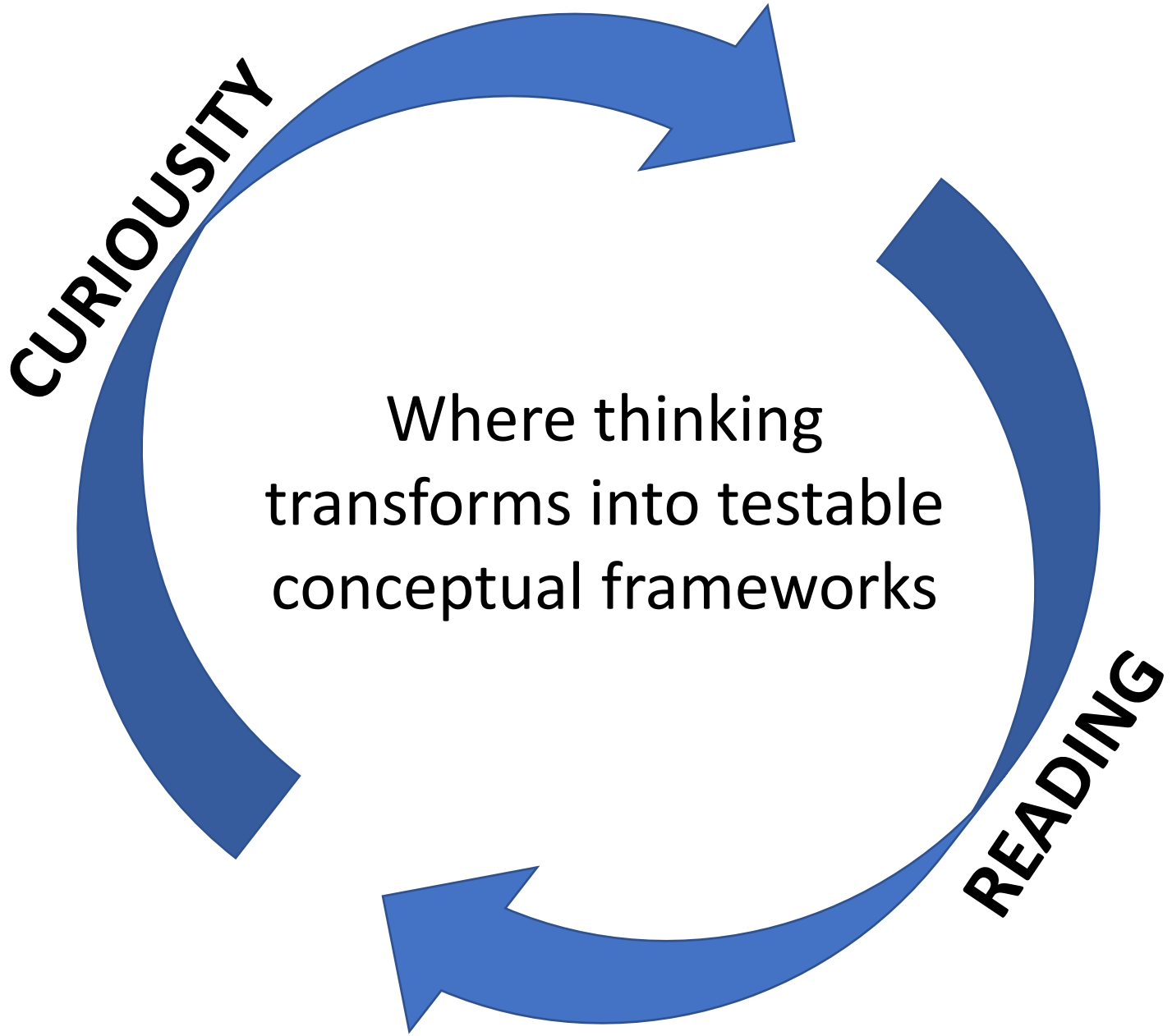


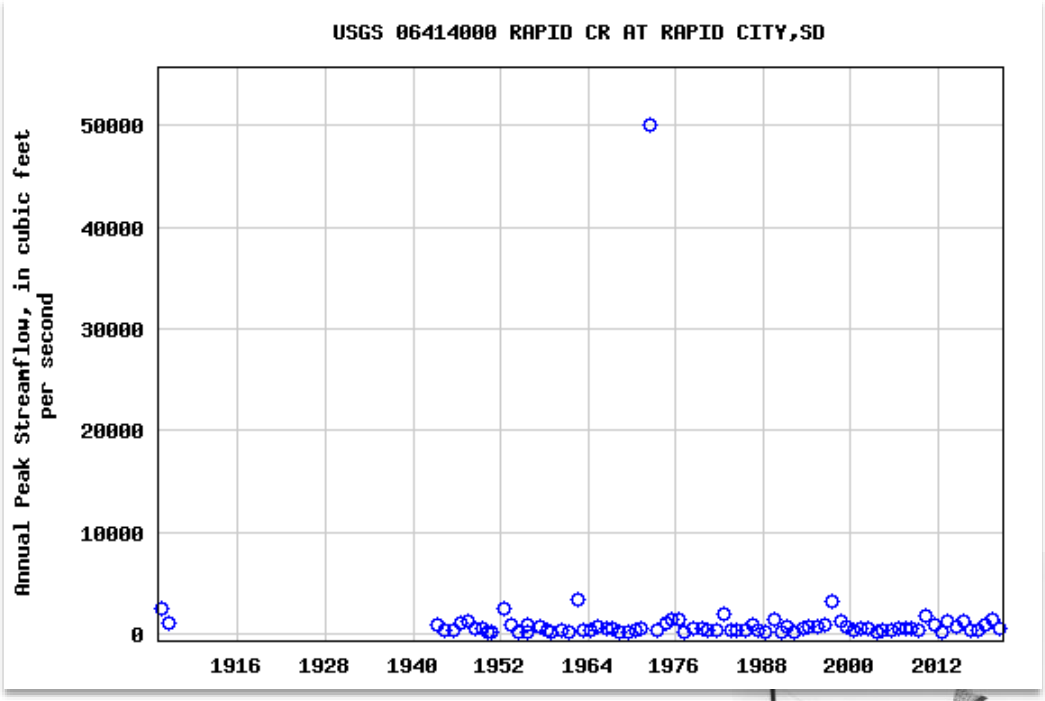
Günter Blöschl, 2022

Floods are threshold responses in a complex system

"…the sheer volume of data cannot be handled, and the required computing power is missing. Therefore, we need to cope with appropriate scale transitions in our model concepts, which is a formidable scientific challenge, and **we need to turn on our brains instead of big computers, which is more exciting anyway**."

Hans-Jörg Vogel (2019), Scale issues in soil hydrology. *Vadose Zone Journal*.


CURIOUSITY
Where thinking transforms into testable conceptual frameworks
READING



An example from Rapid City, SD

Challenge #2:
There are too few observations of extreme floods.

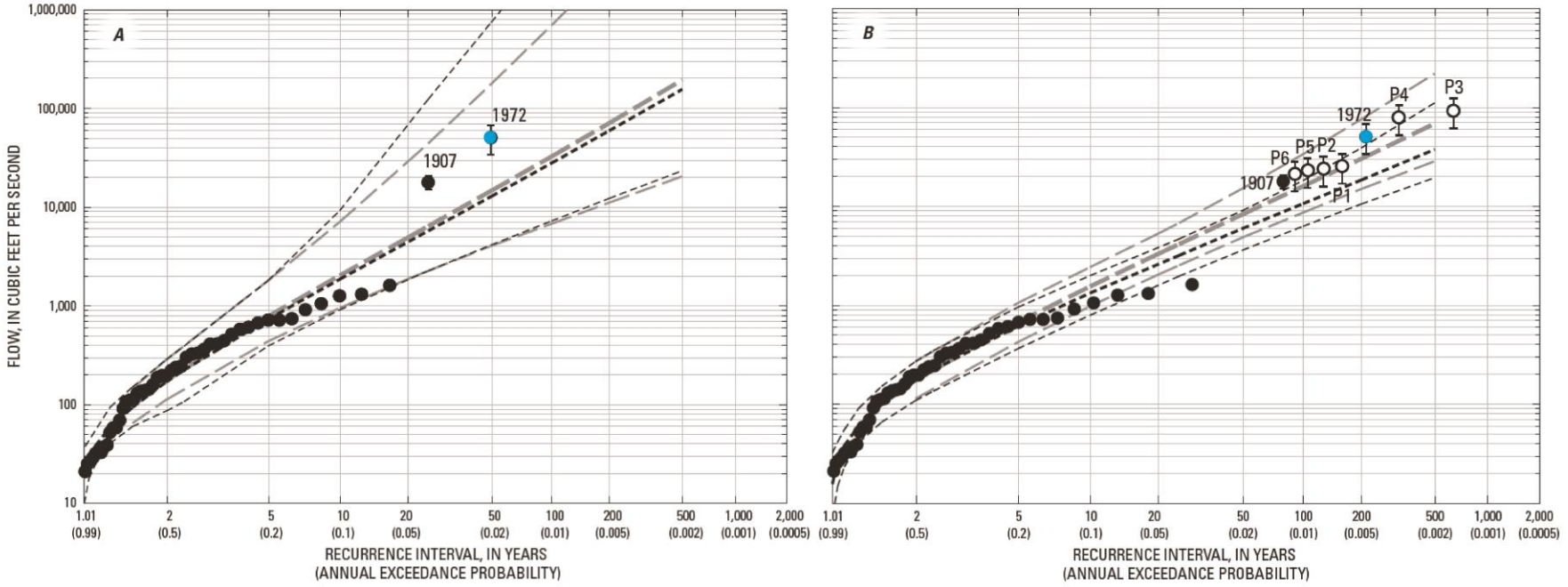
Minnelusa Historical Association, Journey Museum

Flood records are too short to understand extreme floods

FDRG

Natural sedimentary records of flood persist for millennia

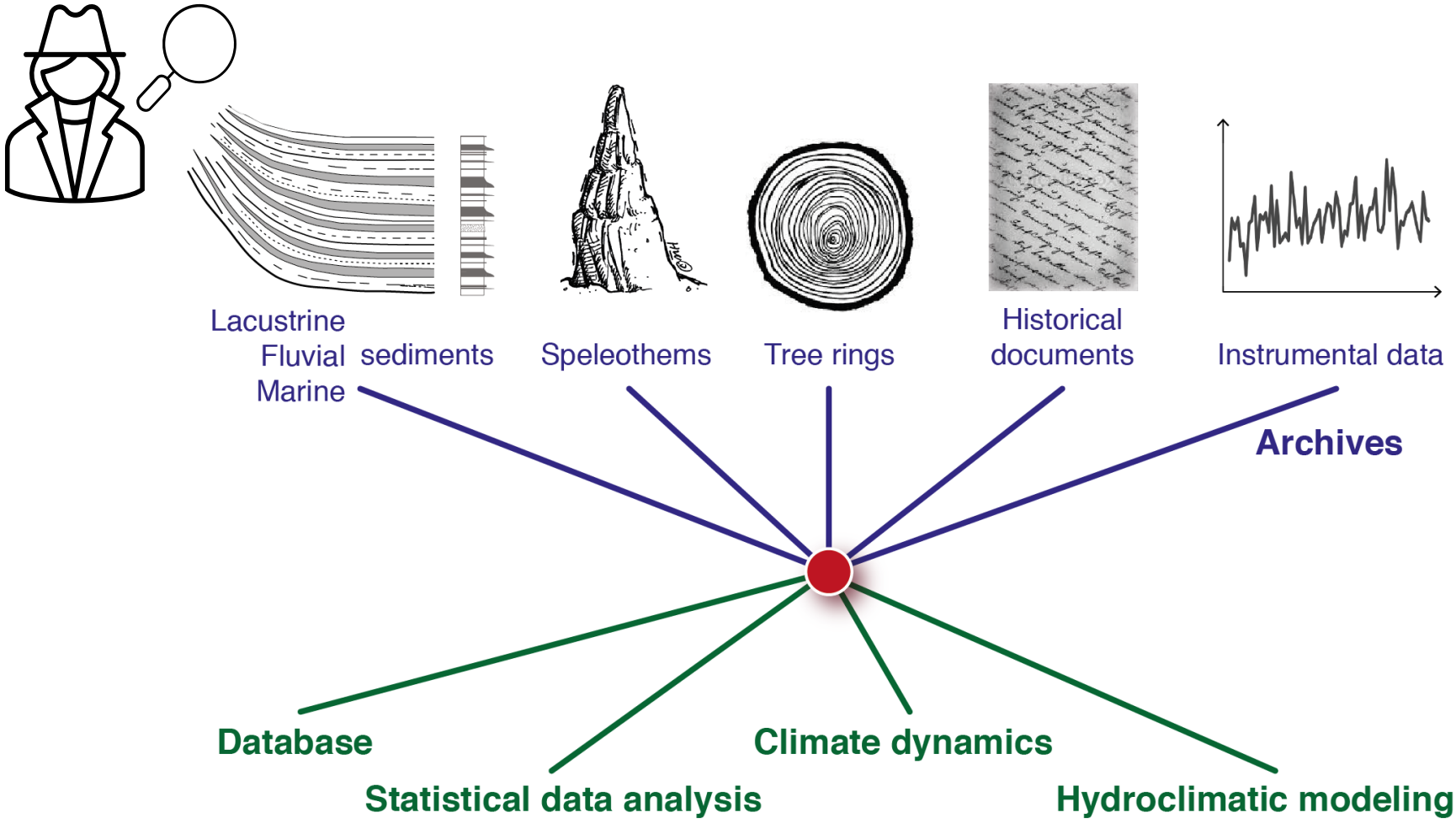
An example from Rapid City, SD – Paleoflood study by Tessa Harden and other (USGS, 2011)



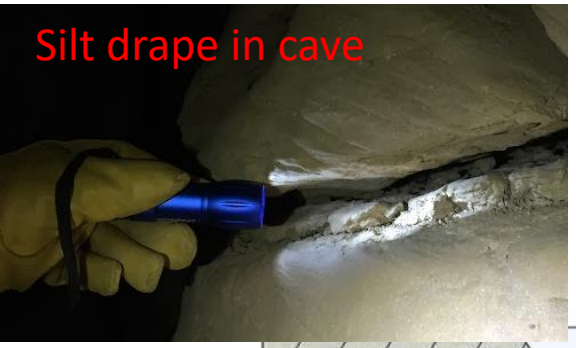
Gauge Data Only → **With Paleoflood Data**

Paleoflood data provide important context for decision making

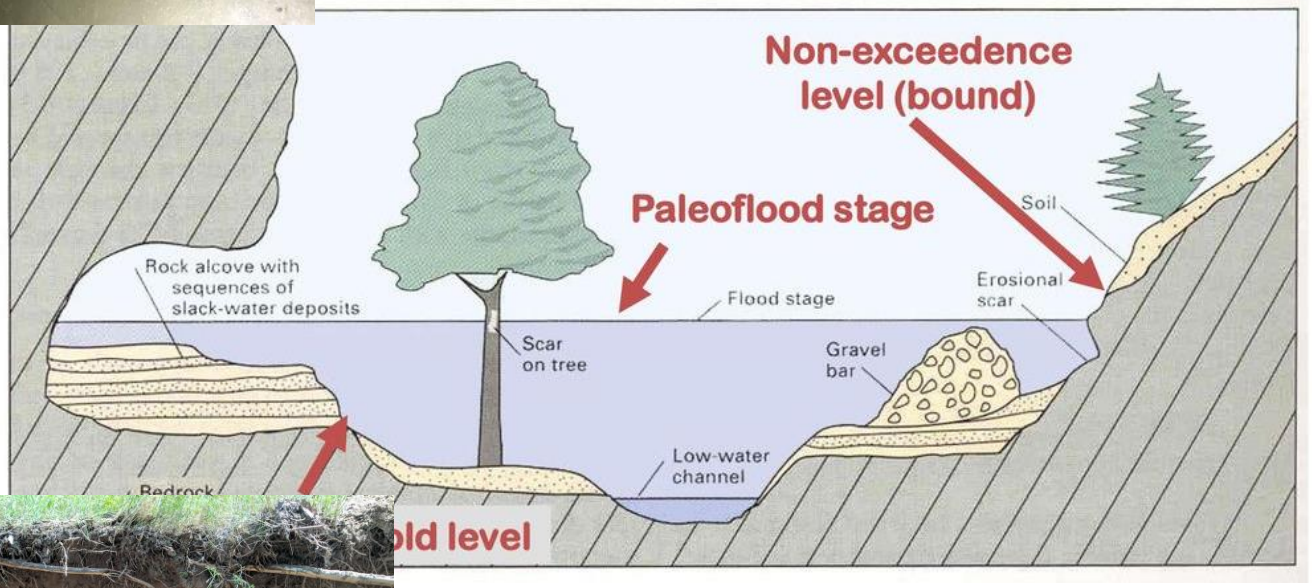
Natural archives in paleoflood hydrology:

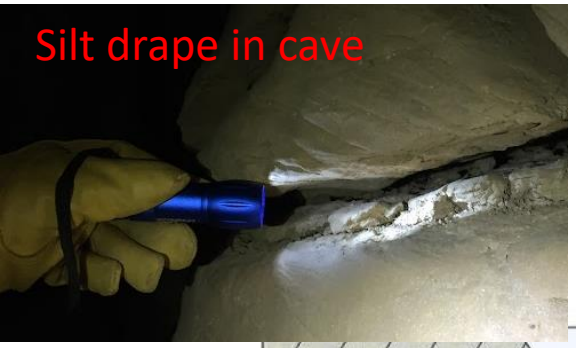


Sources: PAGES, Flood Working Group

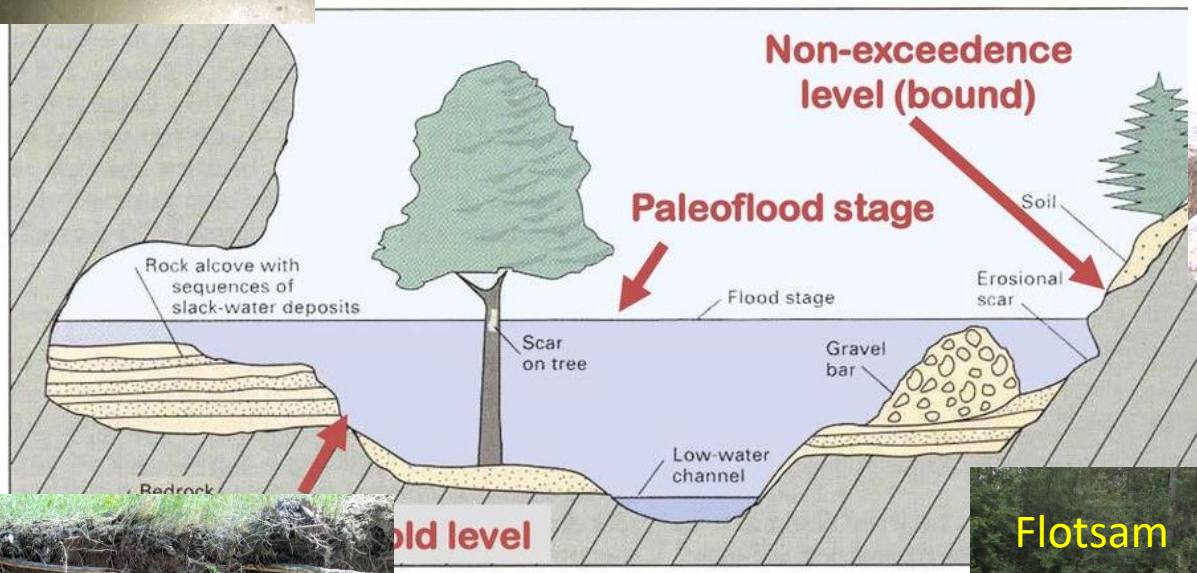


"Minimum Flood Stage"



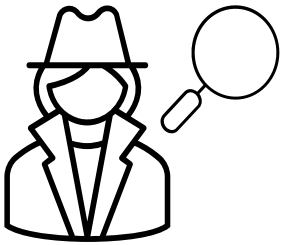


"High water marks"

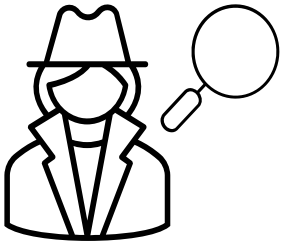


Paleoflood hydrology

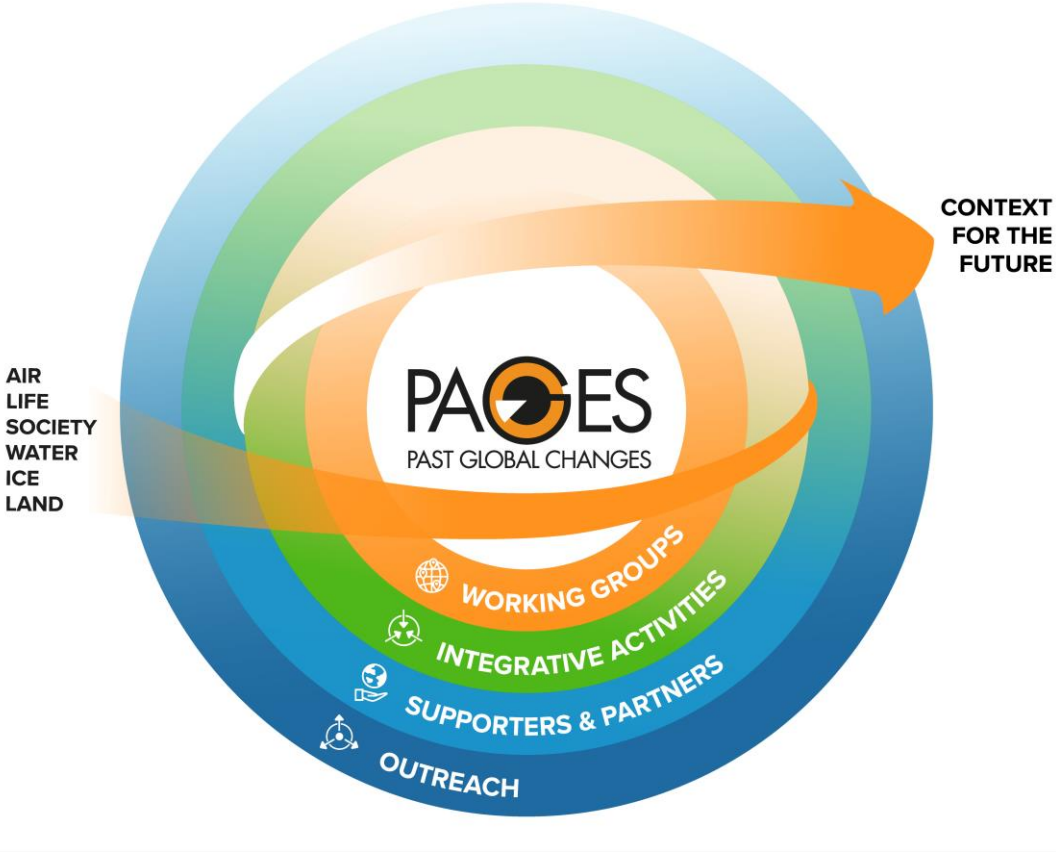
FDRG

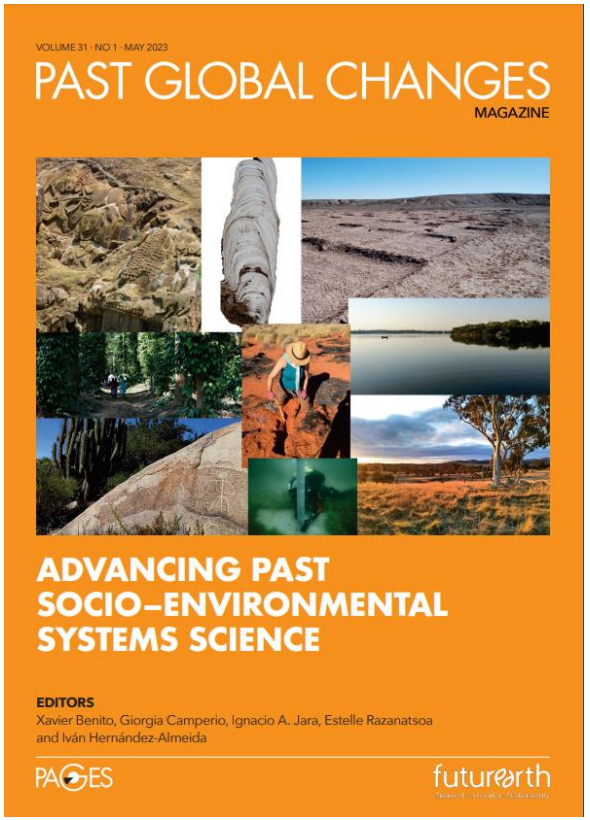


What do you see here?



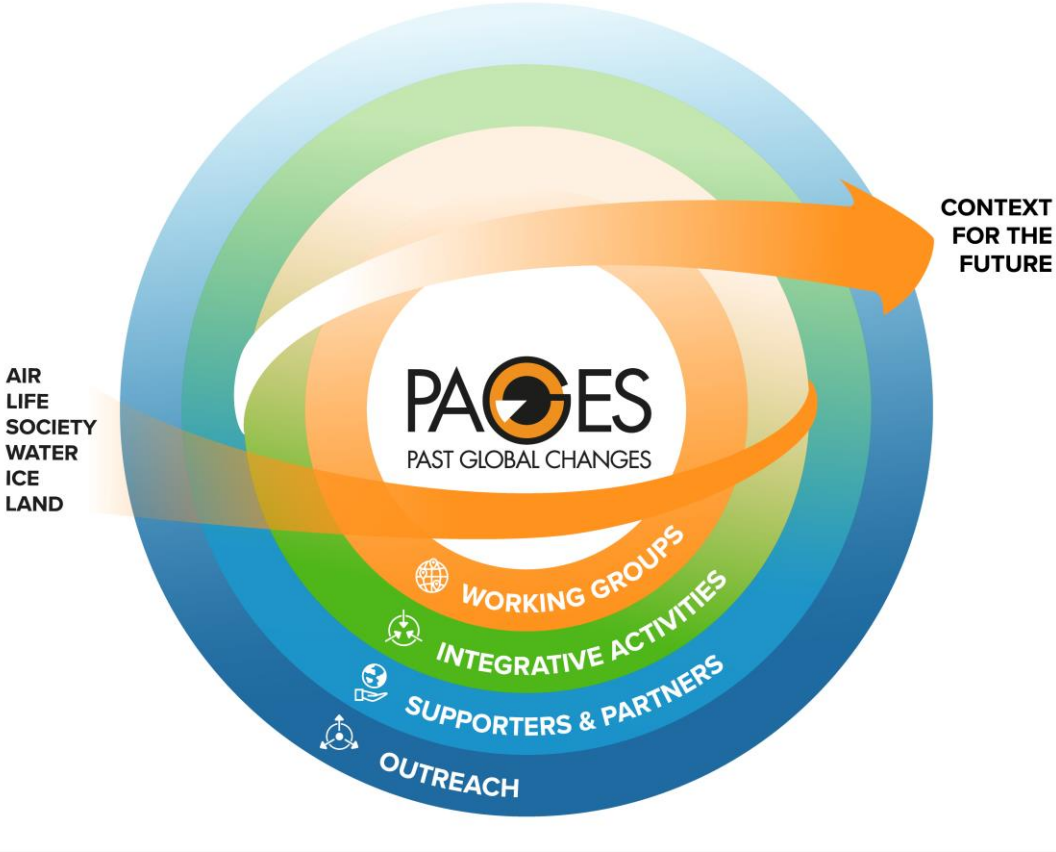
What do you see here?

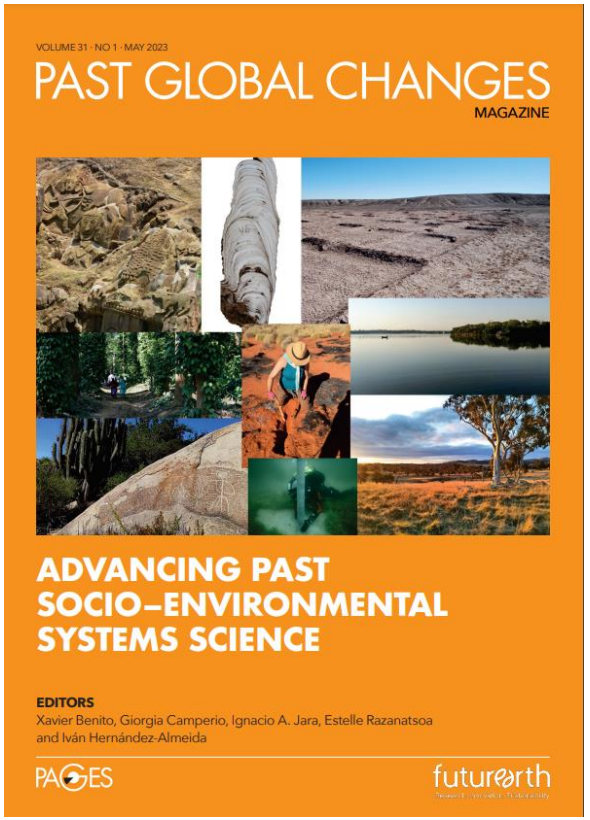




International Paleoflood/ Paleoclimate Groups

FDRG





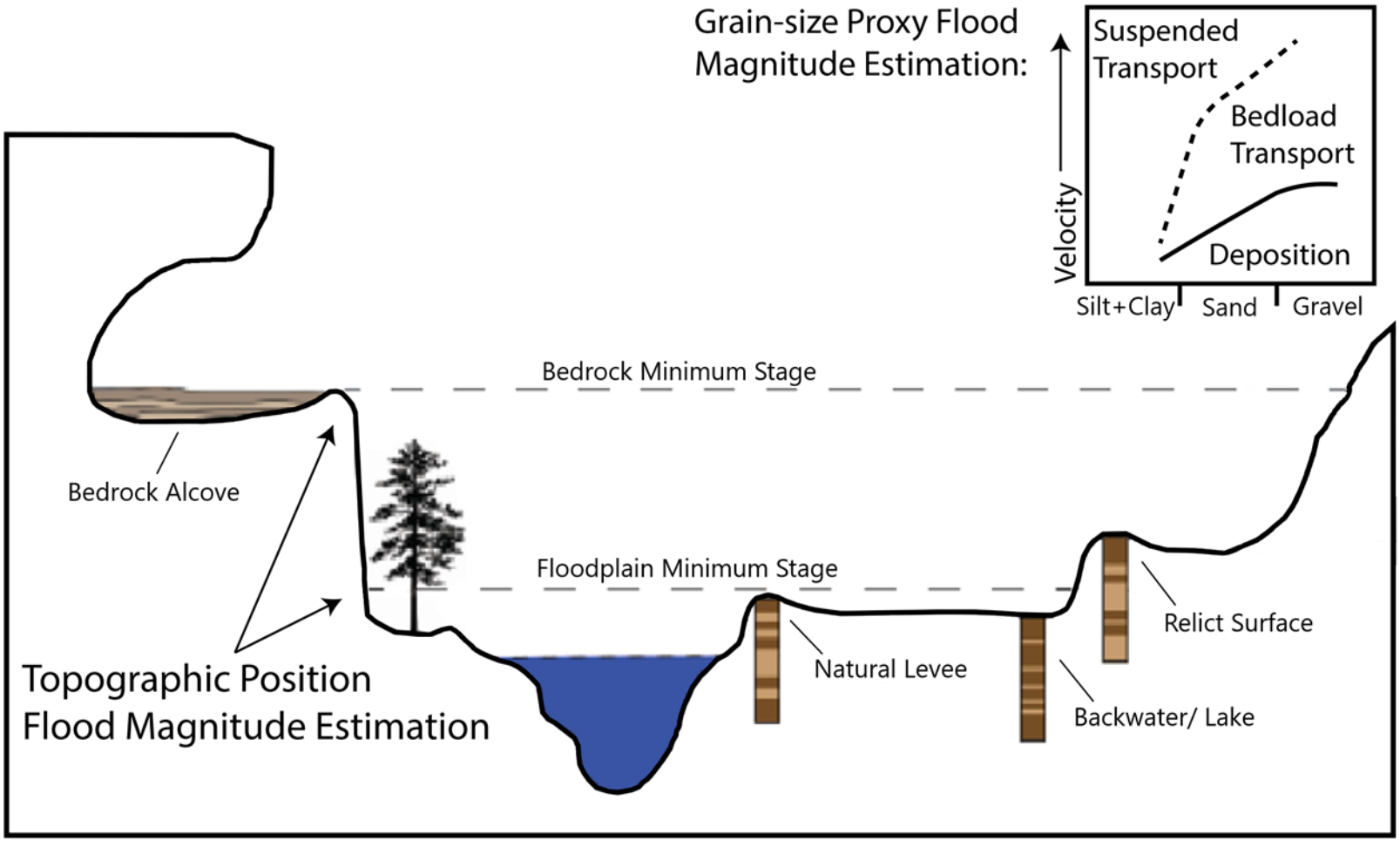
A VERY active paleoflood/climate group working in Spain:

- https://www.floodsresearch.com/
- Museo Nacional de Ciencias Naturales-CSIC in Madrid

International Paleoflood/ Paleoclimate Groups

FDRG

Velocity Particle size

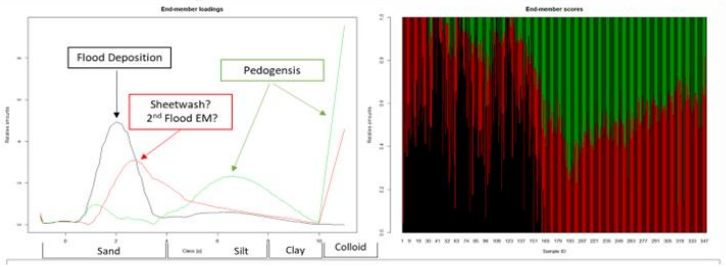


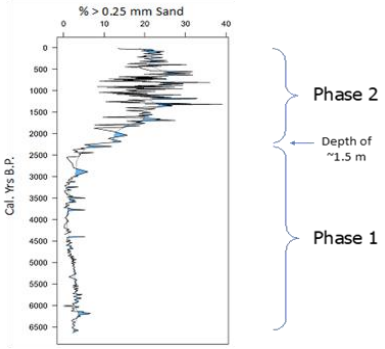
Approach: Discharge Estimation

A New Procedure for Reconstructing Alluvial Paleoflood Hydrologic Data

(1) How do we identify paleofloods?

Grain Size Analysis ----------→ Identify grain size classes associated with floods ----------→ Control for other sources of grain size variability

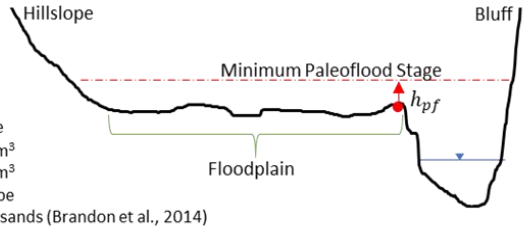




(2) How do we estimate paleoflood stage?

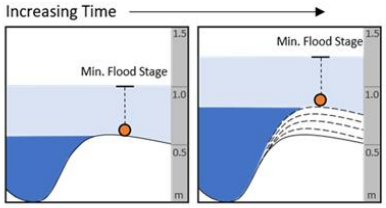
Eq. 1 (Cyr et al., 2015):

$$h_{pf} > \frac{(\rho_s - \rho_w)\theta d90}{\rho_w S}$$

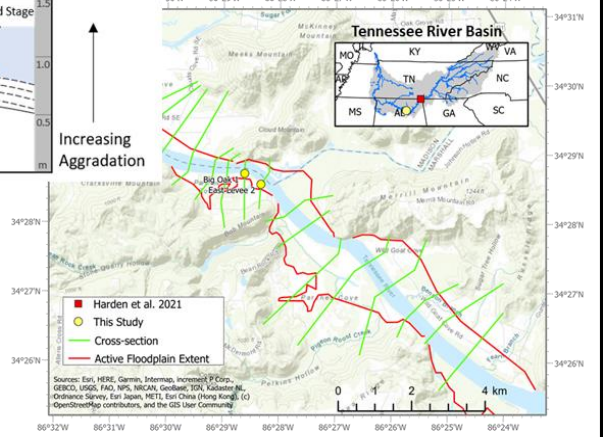


h_{pf} = minimum paleoflood stage
ρ_w = density of water, 1000 kg/m³
ρ_s = density of quartz, 2650 kg/m³
S = longitudinal channel bed slope
θ = 0.047, Shield's parameter of sands (Brandon et al., 2014)

(3) How do we estimate paleoflood discharges?

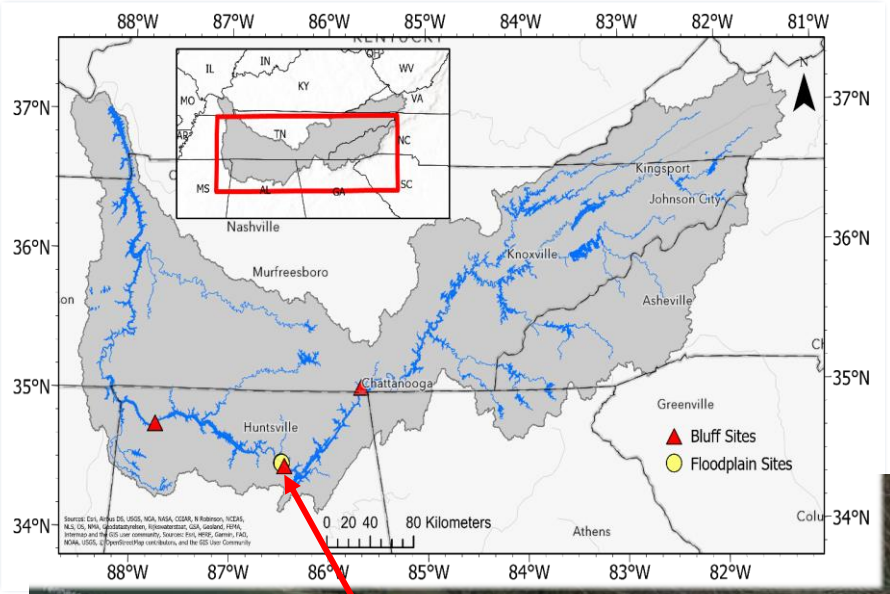


1D hydraulic models with adjusted floodplain elevation



Methods from Lombardi and Davis (2022) *Journal of Hydrology*

Approach: Discharge Estimation


88°W
87°W
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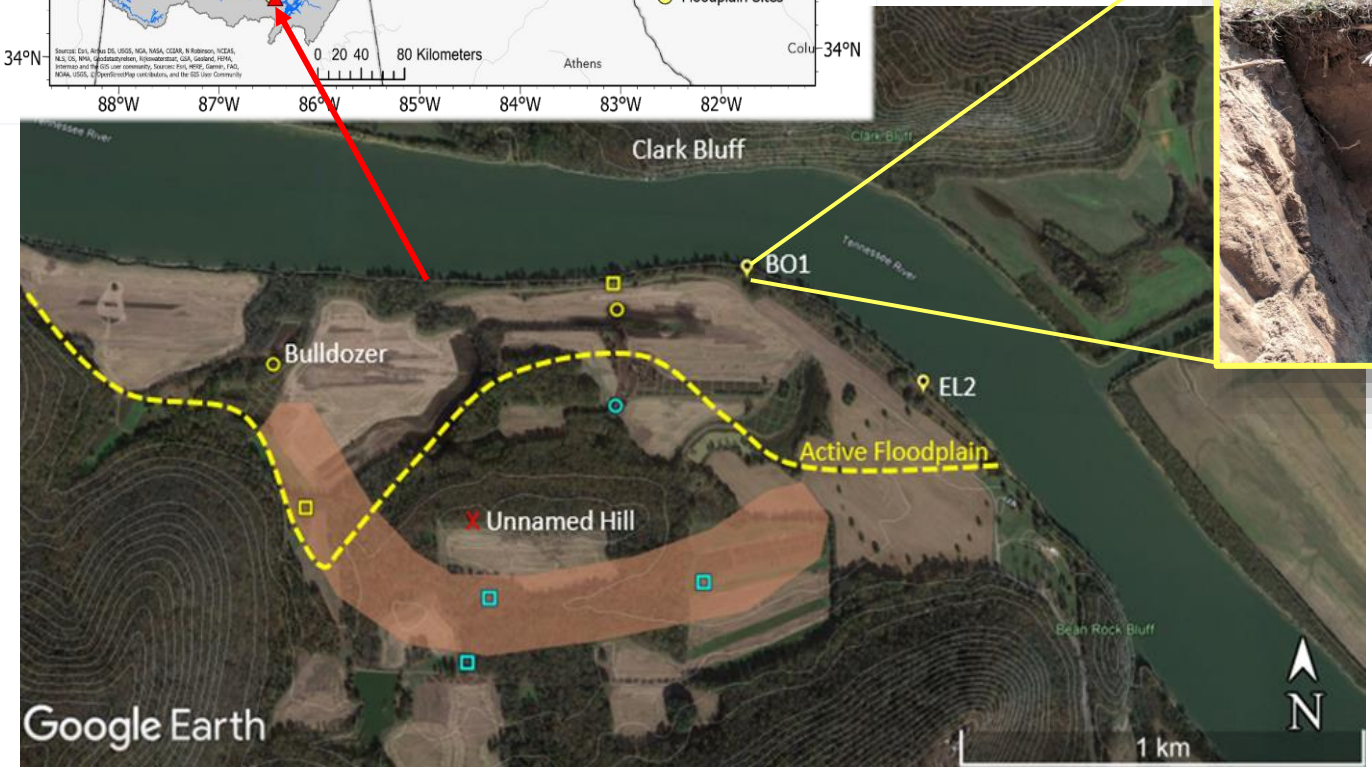
84°W
83°W
82°W
81°W
37°N
36°N
35°N
34°N
IL
IN
KY
WV
VA
MO
TN
NC
MS
AL
GA
SC
Nashville
Murfreesboro
Kingsport
Johnson City
Knoxville
Asheville
Chattanooga
Huntsville
Greenville
Athens
Bluff Sites
Floodplain Sites
0 20 40 80 Kilometers

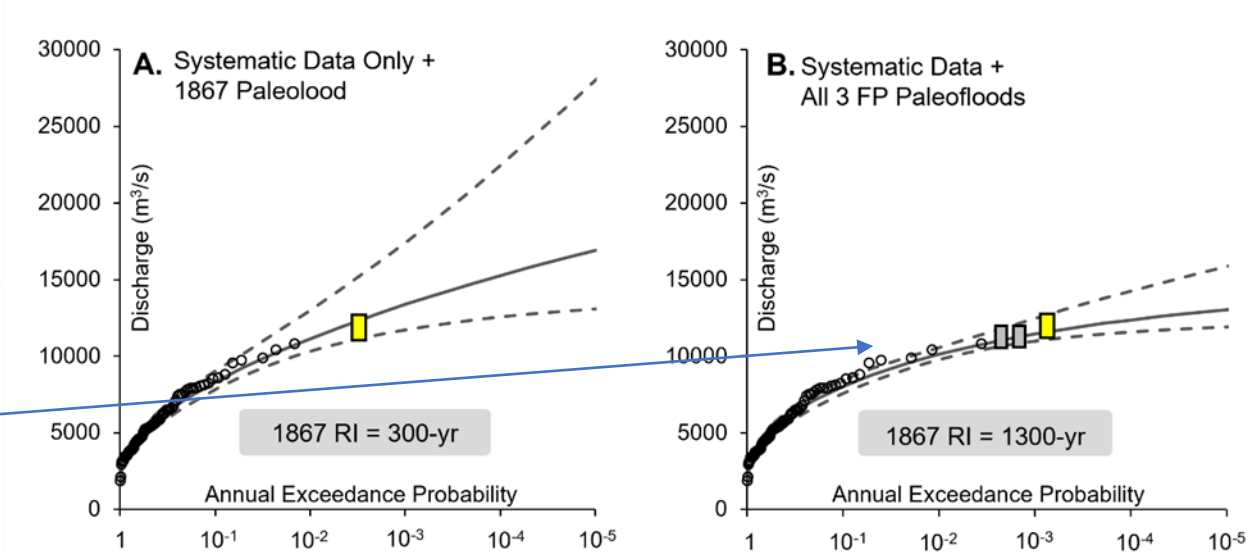

Clark Bluff
BO1
Bulldozer
EL2
Active Floodplain
Unnamed Hill
Bean Rock Bluff
Google Earth
N
1 km

Study Area(s)

We identified 6 additional extreme floods over ~6,000 years in different climates:

Floods during the cooler, wet climate (winter dominant):

- 1867 CE
- 1650 CE
- 1540 CE



Study 1: Improving flood frequency analyses w/ paleo data

We identified <u>6 additional extreme floods over ~6,000 years in different climates</u>:

Floods during the cooler, wet climate (winter dominant):

- 1867 CE
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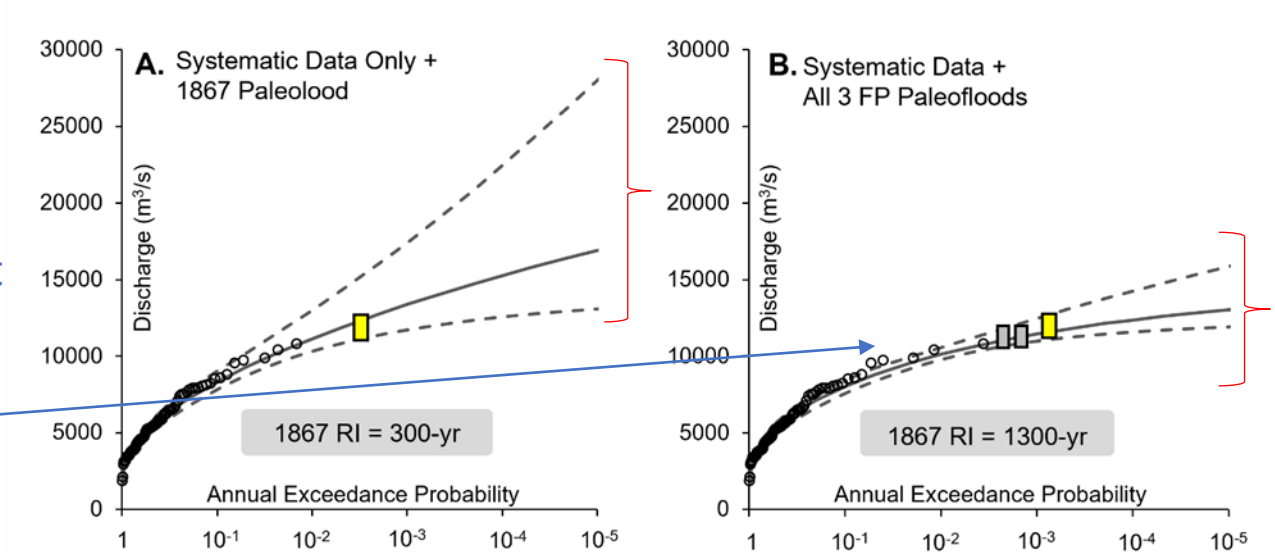
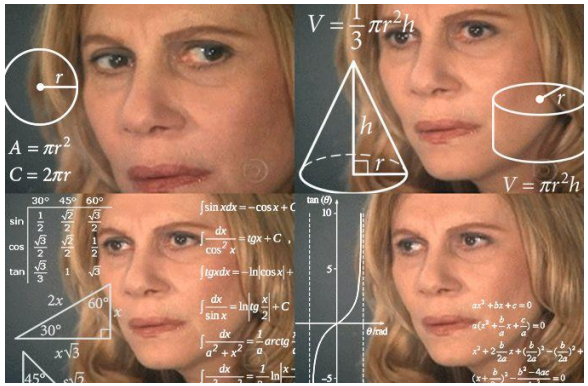


Model uncertainty improved, yay!

But…. Do you notice anything that may prevent this model from accurately representing flood hazard in the future?



Study 1: Improving flood frequency analyses w/ paleo data

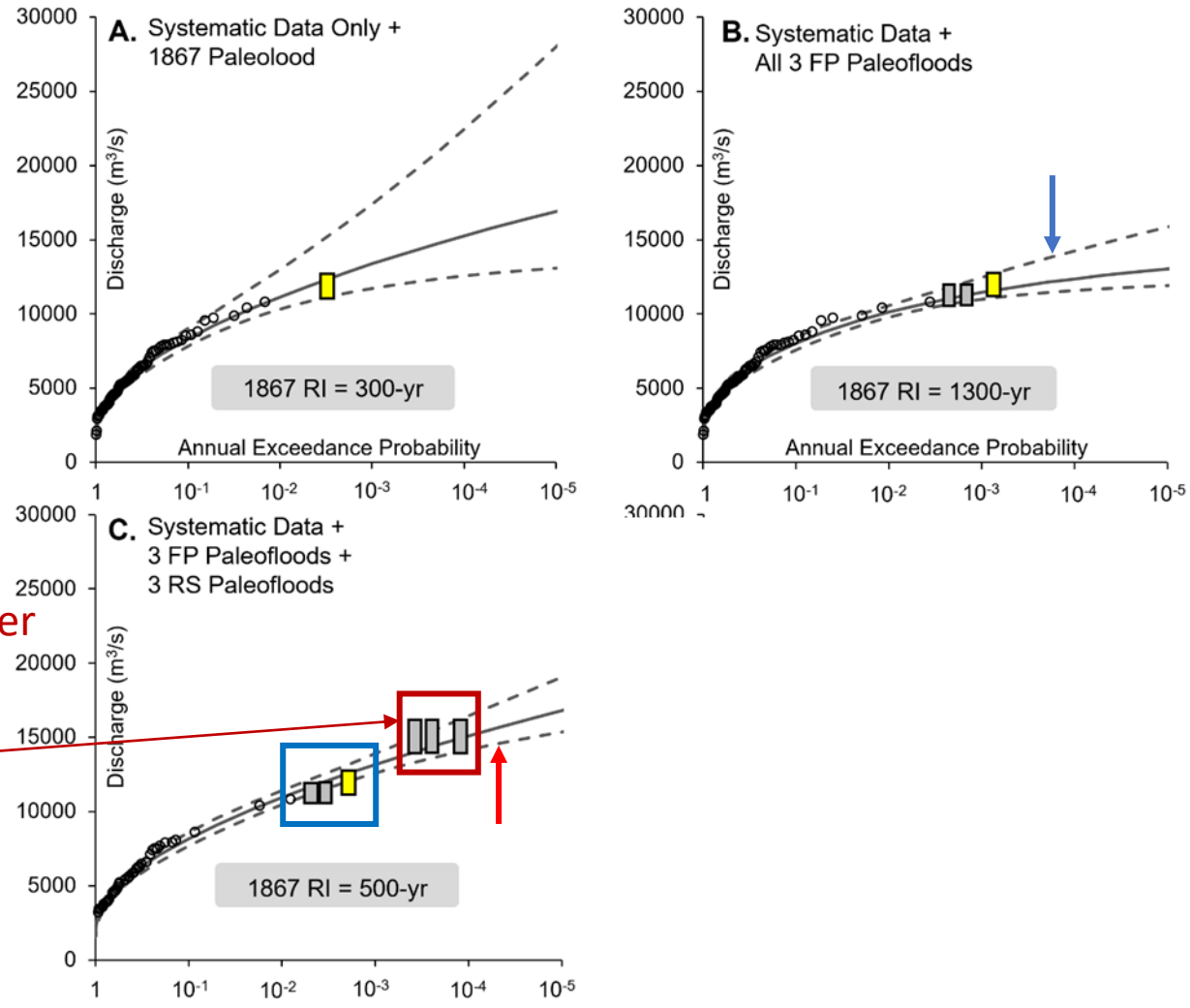
We identified 6 additional extreme floods over ~6,000 years in different climates:

Floods during the cooler, wet climate (winter dominant):

- 1867 CE
- 1650 CE
- 1540 CE

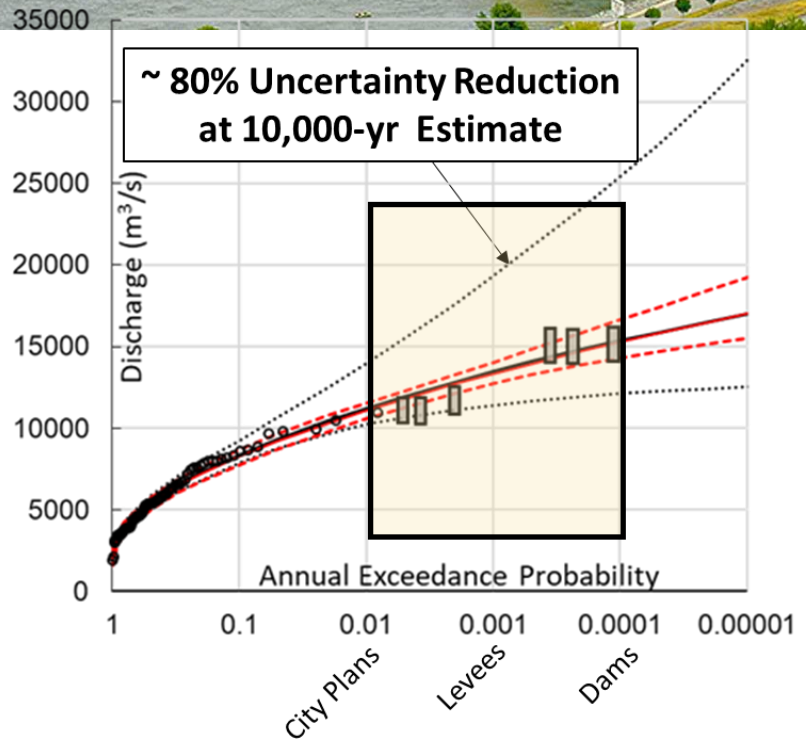
Floods during the warmer, highly variable climate (summer dominant):

- 3200 BCE
- 3500 BCE
- 3700 BCE



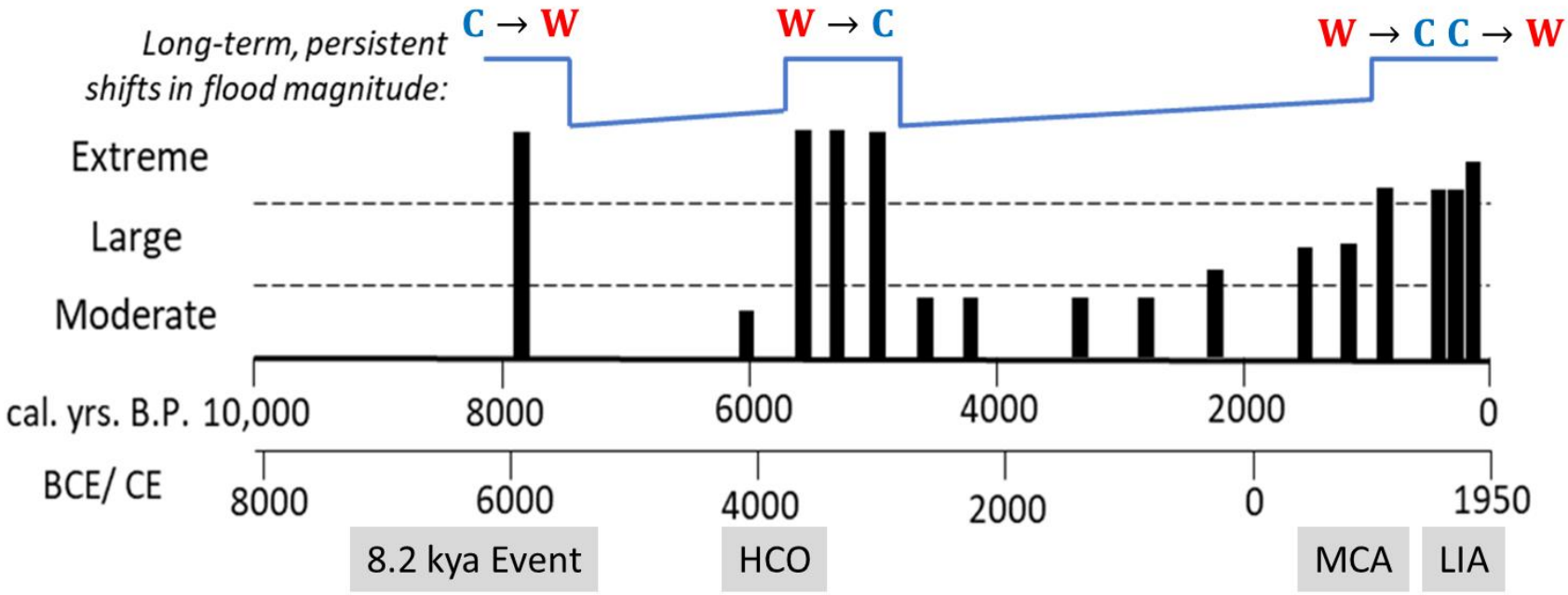
Study 1: Improving flood frequency analyses w/ paleo data

Comparing systematic only FFA (black) to systematic with paleoflood data FFA (red).



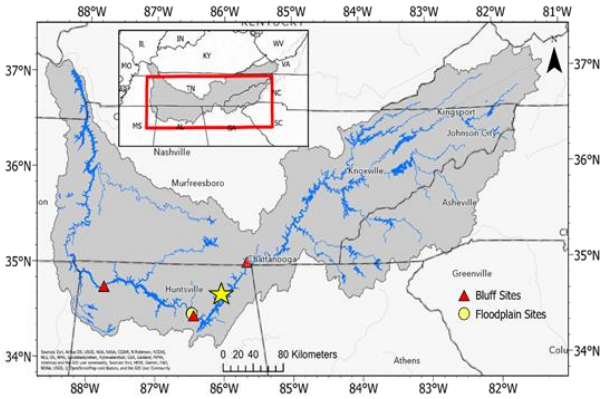
Study 1: Broader Impacts

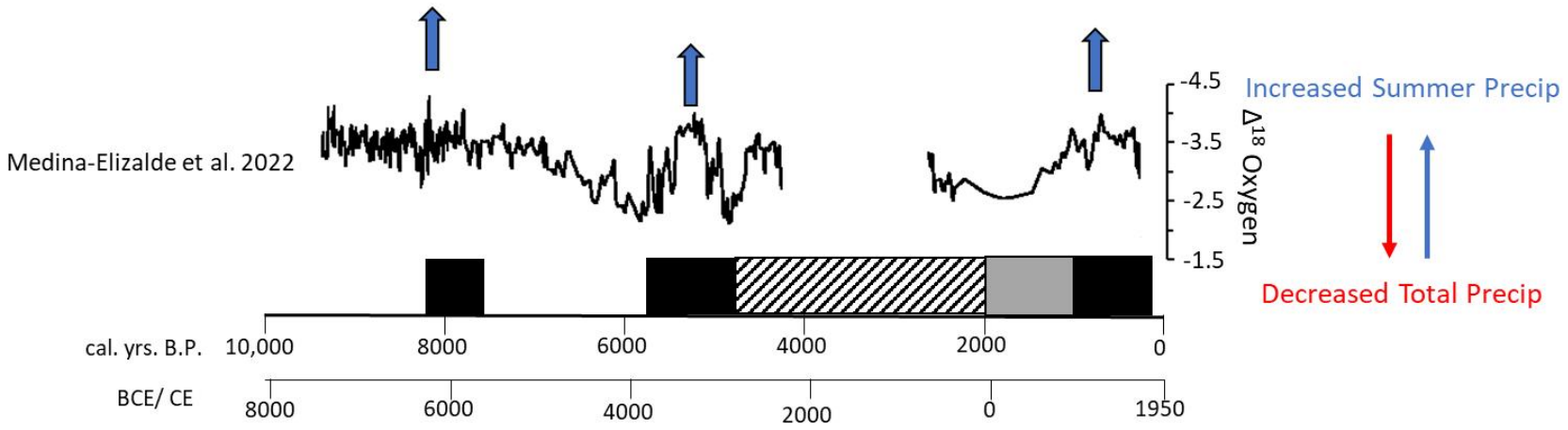
Periods of extreme floods (≥ Q_{100}) from
~7,900 cal yrs BP, 6,000 – 4,900 cal yrs BP, and 1000 – 80 cal yrs BP



Looking to other paleoclimate records in the region we reveal the following patterns:

1. Extreme flood clusters corresponded with periods increased summer precipitation.

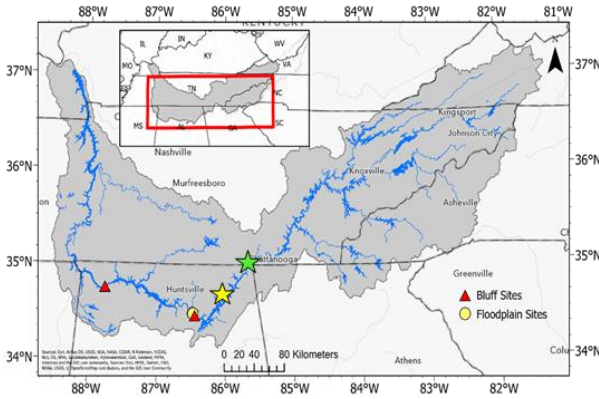




Study 2: Regional flood trends

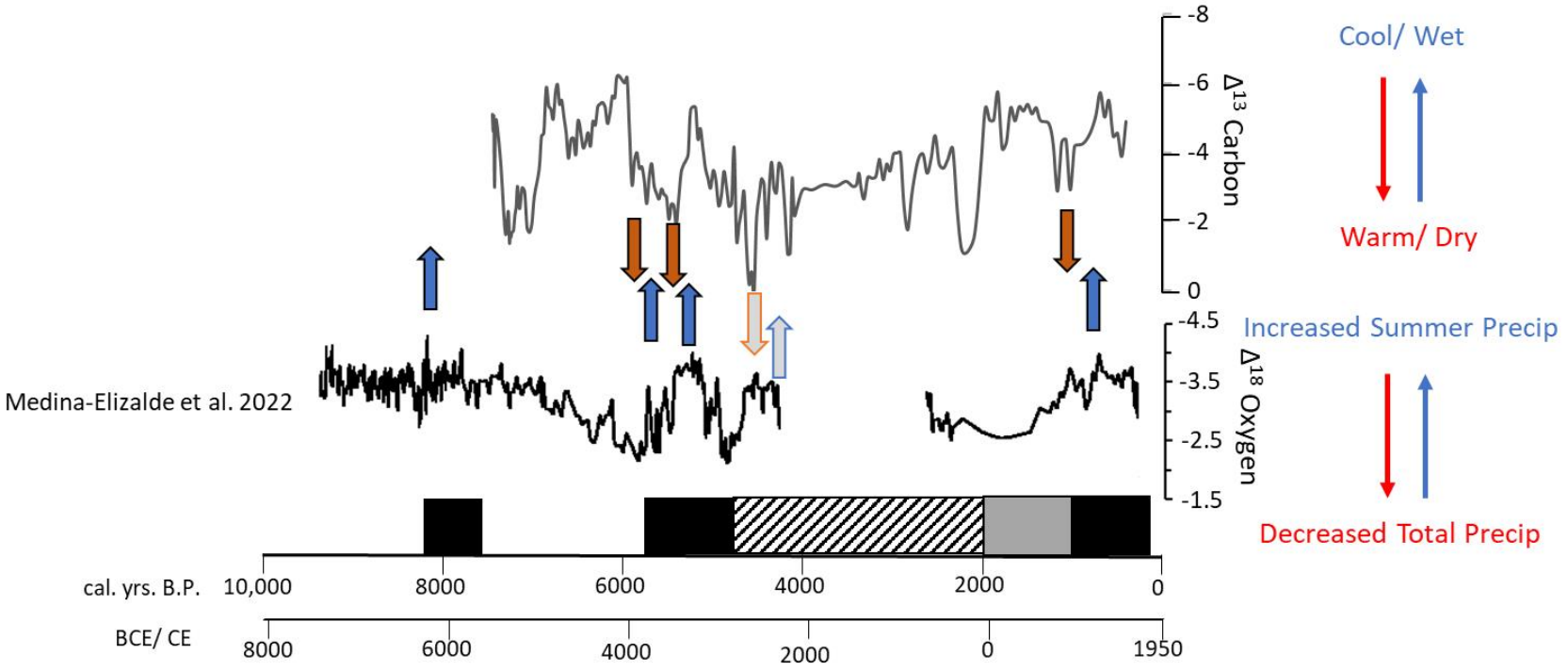
Looking to other paleoclimate records in the region we reveal the following patterns:

1. Extreme flood clusters corresponded with periods increased summer precipitation.
2. Extreme flood clusters were proceeded by extended or severe dry periods.



Driese et al. 2016

Medina-Elizalde et al. 2022



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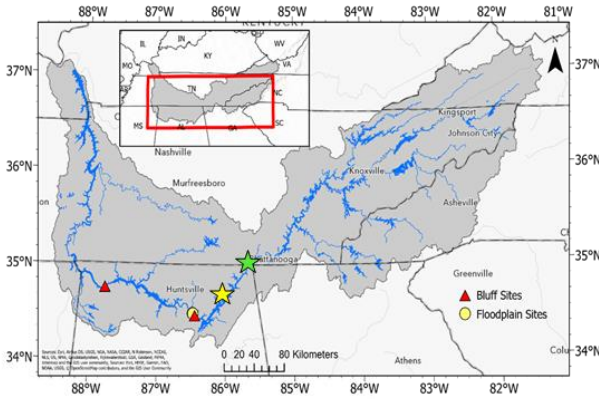
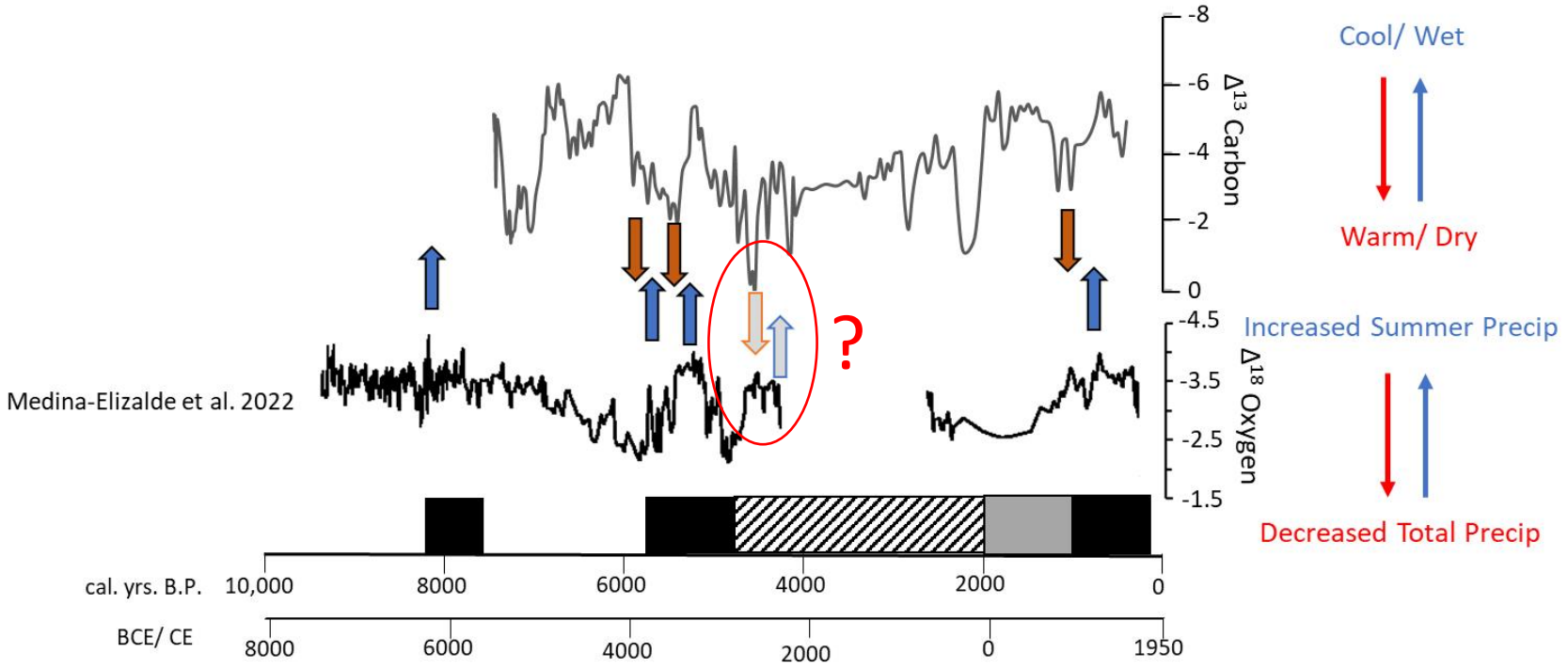


Driese et al. 2016

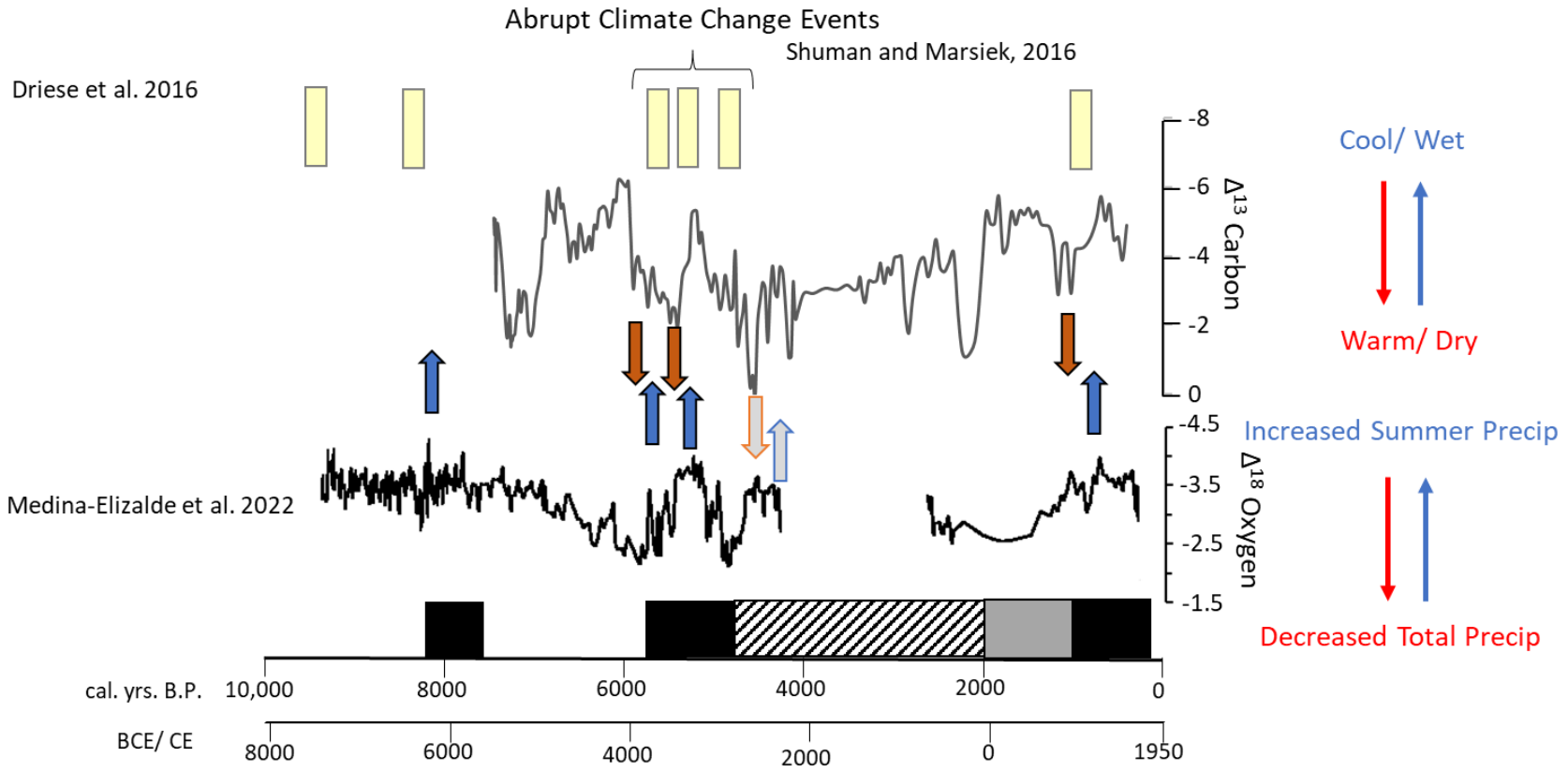
Medina-Elizalde et al. 2022



Study 2: Regional flood trends

Looking to other paleoclimate records in the region we reveal the following patterns:

1. Extreme flood clusters corresponded with periods increased summer precipitation.
2. Extreme flood clusters were proceeded by extended or severe dry periods.
3. Extreme flood clusters were initiated only during very abrupt shifts from dry to wet climate (> 1 sd per 200 yrs)

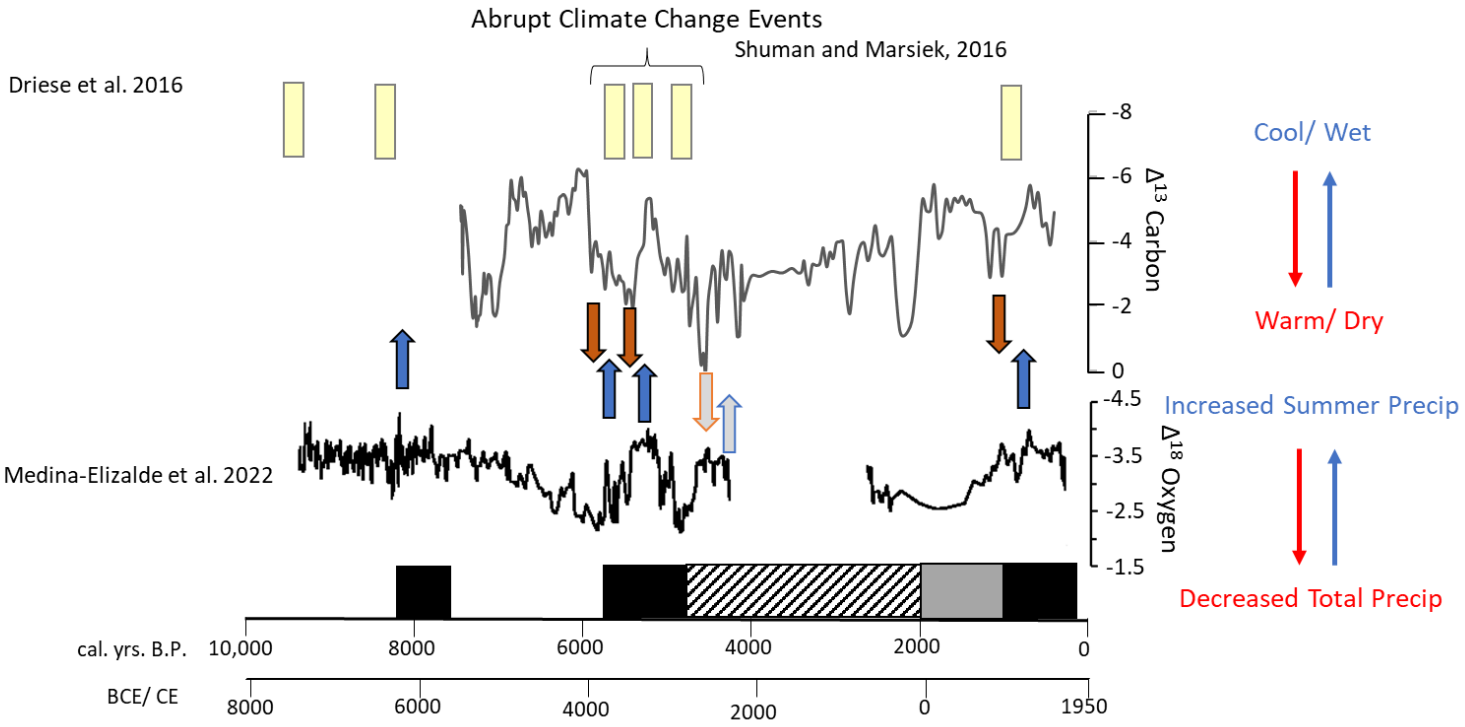


Looking to other paleoclimate records in the region we reveal the following patterns:

Drought alters watershed conditions that reflect low precipitation / flow conditions

Abrupt shifts to warm-season precipitation exceeds geomorphic thresholds

Extreme floods occur and readjust morphology within the watershed; diminishing flood hazard for a period.



Study 2: Regional flood trends

British Colombia, Canada 2021

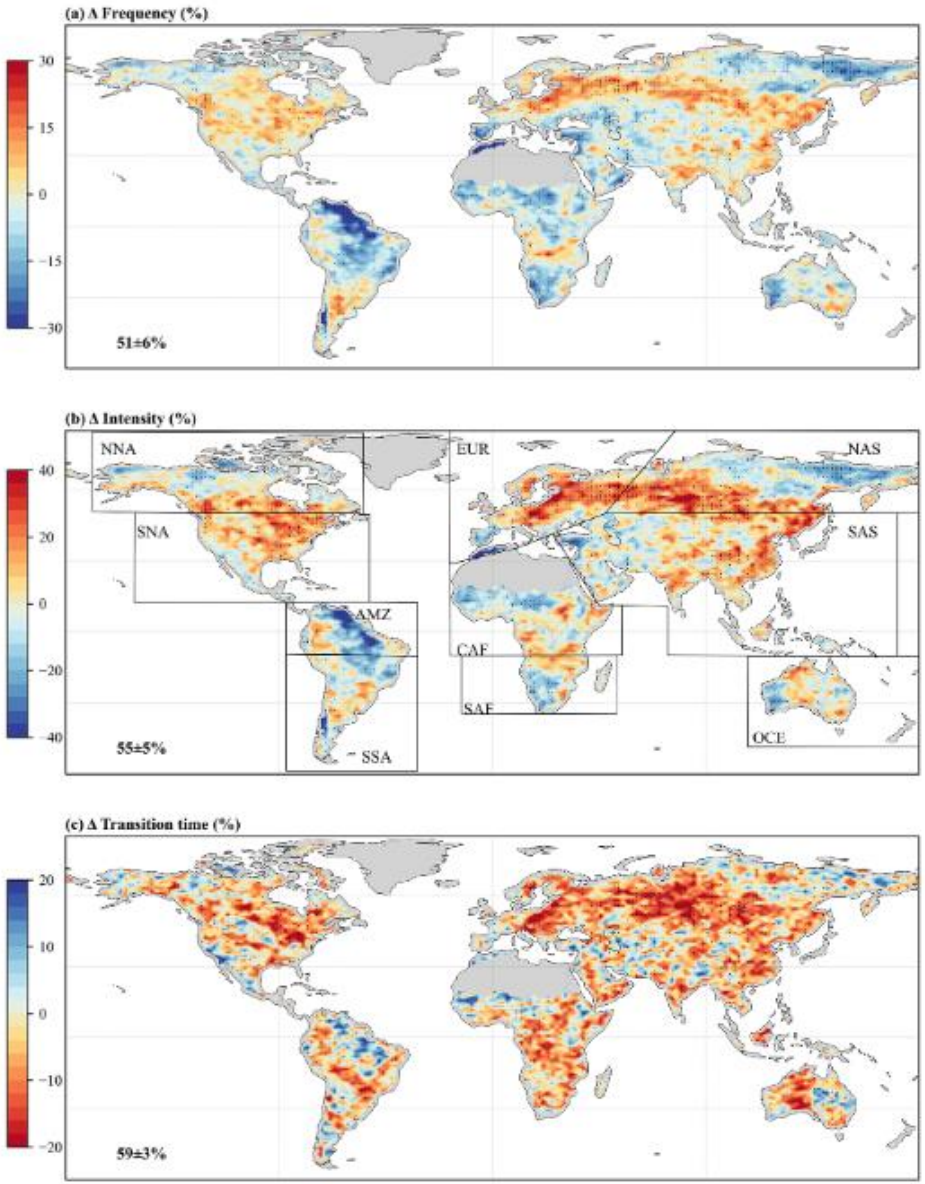
Image: Don Mackinnon/ AFP via Getty Images.

California, USA 2017

Image: Josh Edelson via Getty Images.

“Deficit to Deluge”

Future Changes in Dry to Wet Transitions:

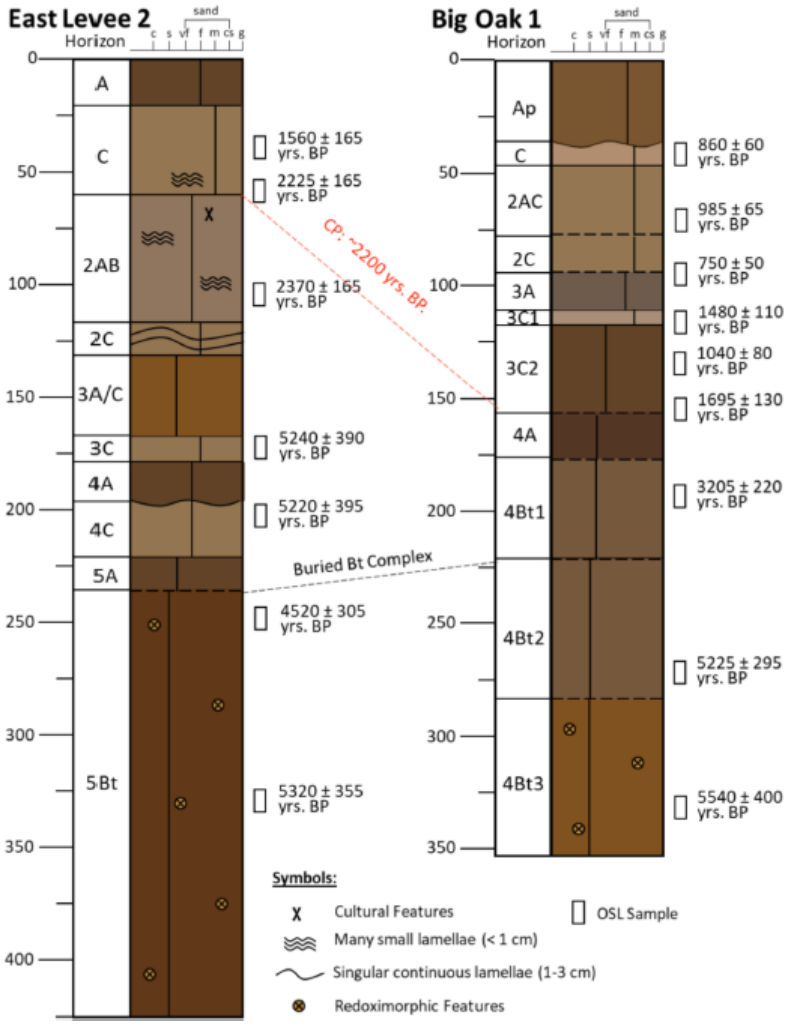


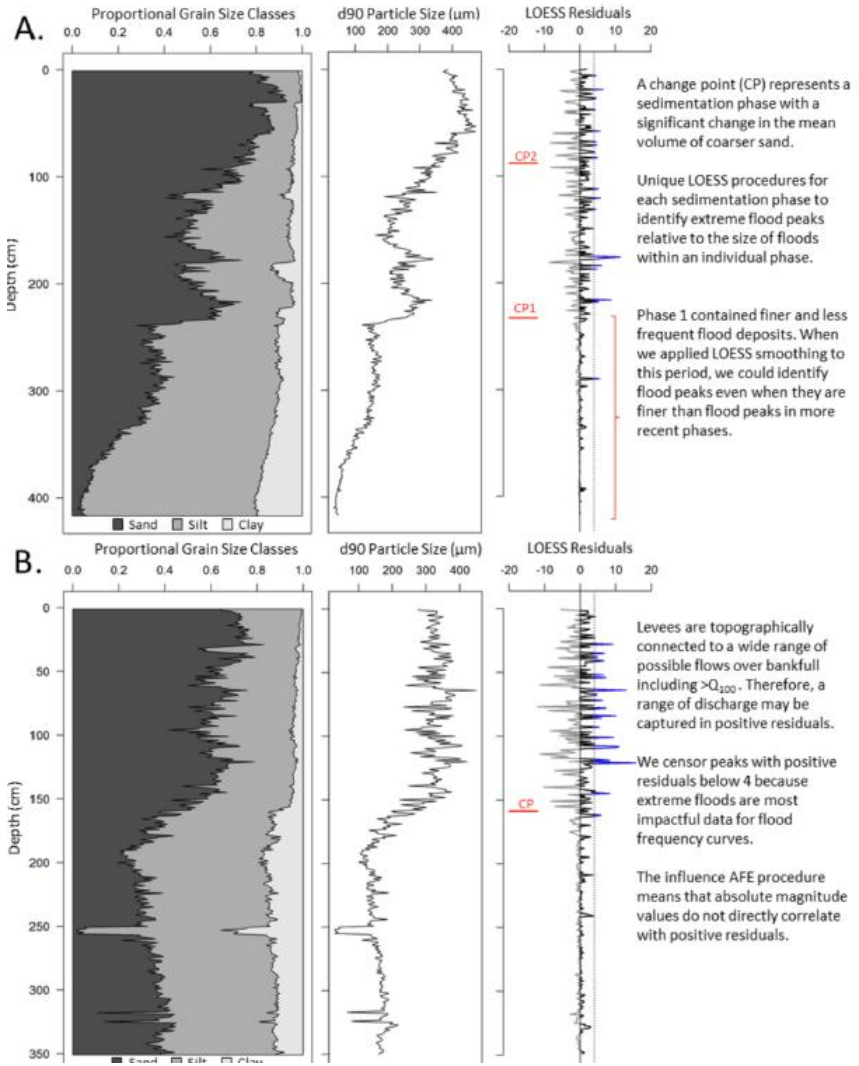
Three-fifths of the world is projected to experience accelerated dry to wet transitions during the next century (Chen and Wang, 2022).

Our findings indicate urgent needs to:

- Evaluate the risk of compound drought/ flood hazards
- Incorporate concepts of geomorphic thresholds into flood risk assessment
- Identify ways to manage rivers in ways that allow system to re-adjust to increases in precipitation variability

Source: Chen and Wang (2022) *Geophysical Research Letters*


East Levee 2
Horizon
sand
c s vf f m cs g
A
C
2AB
2C
3A/C
3C
4A
4C
5A
5Bt
1560 ± 165 yrs. BP
2225 ± 165 yrs. BP
2370 ± 165 yrs. BP
5240 ± 390 yrs. BP
5220 ± 395 yrs. BP
4520 ± 305 yrs. BP
5320 ± 355 yrs. BP
CP: ~2200 yrs. BP
Buried Bt Complex
Big Oak 1
Horizon
sand
c s vf f m cs g
Ap
C
2AC
2C
3A
3C1
3C2
4A
4Bt1
4Bt2
4Bt3
860 ± 60 yrs. BP
985 ± 65 yrs. BP
750 ± 50 yrs. BP
1480 ± 110 yrs. BP
1040 ± 80 yrs. BP
1695 ± 130 yrs. BP
3205 ± 220 yrs. BP
5225 ± 295 yrs. BP
5540 ± 400 yrs. BP
Symbols:
Cultural Features
Many small lamellae (< 1 cm)
Singular continuous lamellae (1-3 cm)
Redoximorphic Features
OSL Sample


A.
Proportional Grain Size Classes
d90 Particle Size (µm)
LOESS Residuals
Depth (cm)
Sand
Silt
Clay
CP2
CP1
B.
Proportional Grain Size Classes
d90 Particle Size (µm)
LOESS Residuals
Depth (cm)
CP
A change point (CP) represents a sedimentation phase with a significant change in the mean volume of coarser sand.
Unique LOESS procedures for each sedimentation phase to identify extreme flood peaks relative to the size of floods within an individual phase.
Phase 1 contained finer and less frequent flood deposits. When we applied LOESS smoothing to this period, we could identify flood peaks even when they are finer than flood peaks in more recent phases.
Levees are topographically connected to a wide range of possible flows over bankfull including >Q100. Therefore, a range of discharge may be captured in positive residuals.
We censor peaks with positive residuals below 4 because extreme floods are most impactful data for flood frequency curves.
The influence AFE procedure means that absolute magnitude values do not directly correlate with positive residuals.

We identified 6 additional extreme floods over ~6,000 years in different climates:

Floods during the cooler, wet climate (winter dominant):

- 1867 CE
- 1650 CE
- 1540 CE

Floods during the warmer, highly variable climate (summer dominant):

- 3200 BCE
- 3500 BCE
- 3700 BCE