Climate variability and climate change, what can we learn from 100 Years of streamflow data?

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Everyone here probably has different questions about changes in hydrology that depend on their location and their interests.

The questions that I set out to investigate were

1) In Missouri watersheds have we seen trends as well as variability?

2) If looking at predictions for the future, what time period should we use for comparison?

I wanted the cleanest signal of streamflow response to climate as possible. At regional scale, Josh couldn't isolate the effects of climate change on hydrology.

The effects of dams, urbanization, etc. on streamflow may dwarf the effects of climate change in your watershed.

However, the effects may be additive, and infrastructure may have been designed based on hydrologic patterns which are no longer present.

We will briefly touch on some climate data

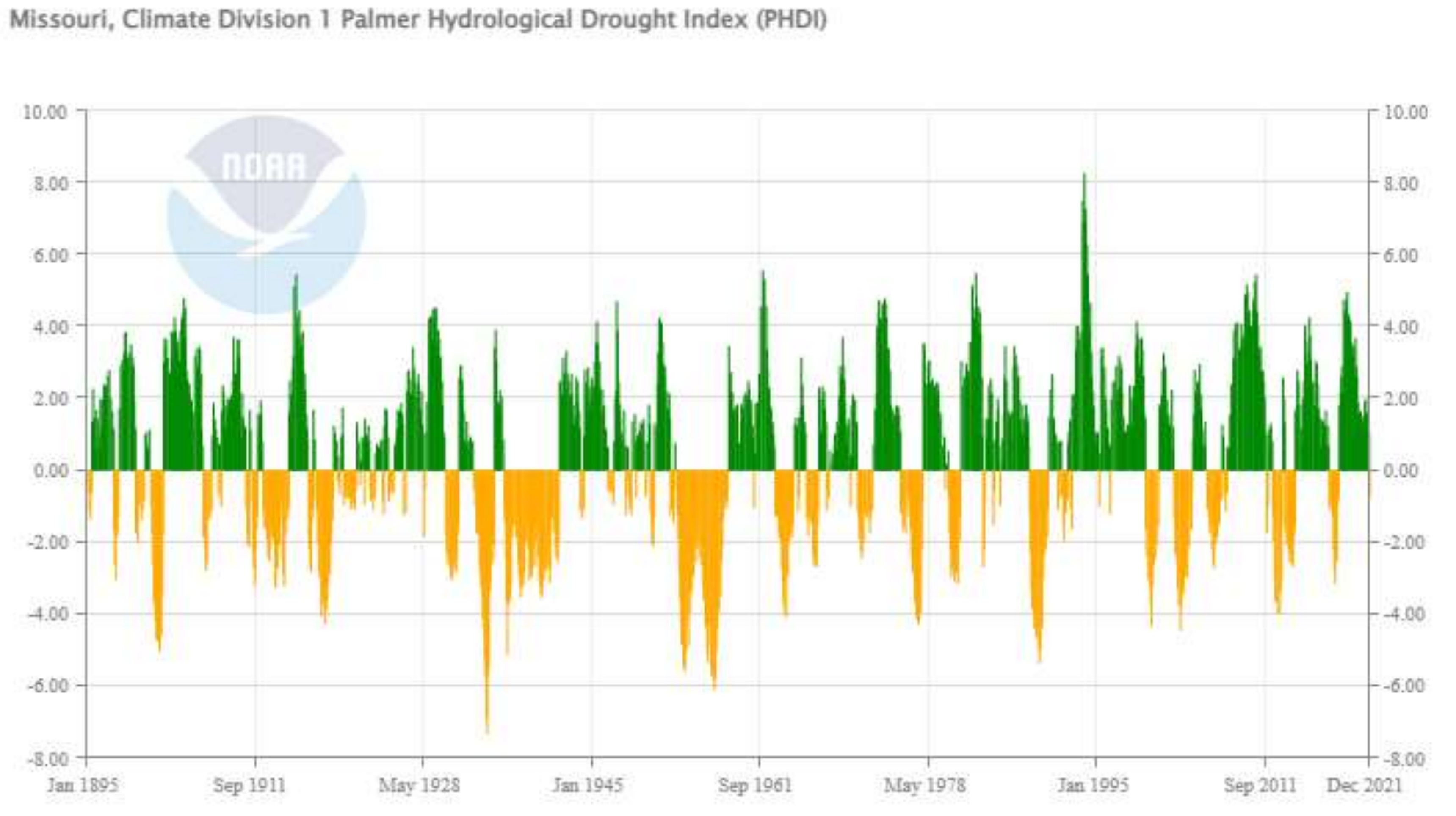
Longer-term climate data are readily available for a variety of geographical polygons. We will use the Climate Divisions, which span the area of most Missouri watersheds

Palmer Hydrologic Drought Index (PHDI)

PHDI is essentially a soil water balance metric that better corresponds to groundwater levels and streamflow than the more familiar Palmer Drought Stress Index

Palmer Classifications

Value	Description
4.0 or more	extremely wet
3.0 to 3.99	very wet
2.0 to 2.99	moderately wet
1.0 to 1.99	slightly wet
0.5 to 0.99	incipient wet spell
0.49 to -0.49	near normal
-0.5 to -0.99	incipient dry spell
-1.0 to -1.99	mild drought
-2.0 to -2.99	moderate drought
-3.0 to -3.99	severe drought
-4.0 or less	extreme drought



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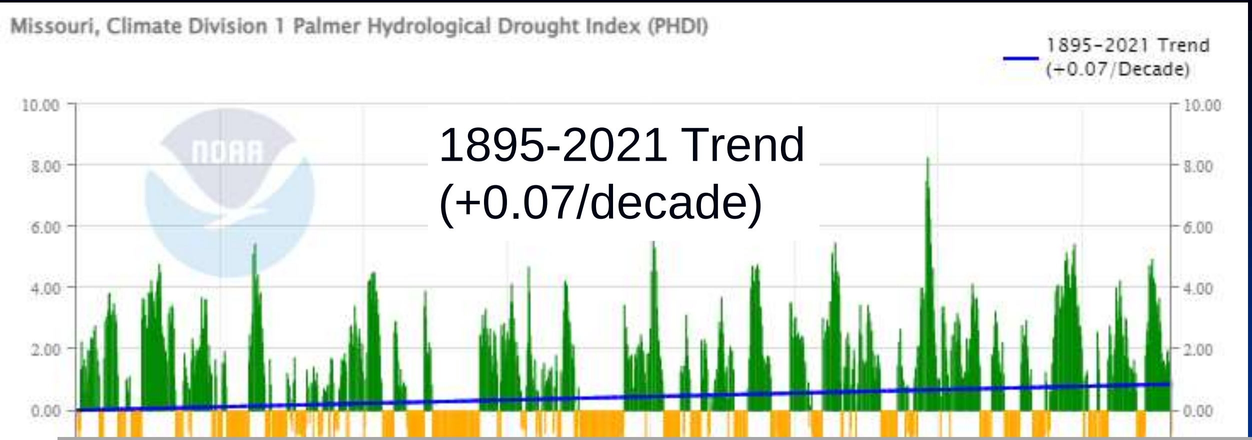
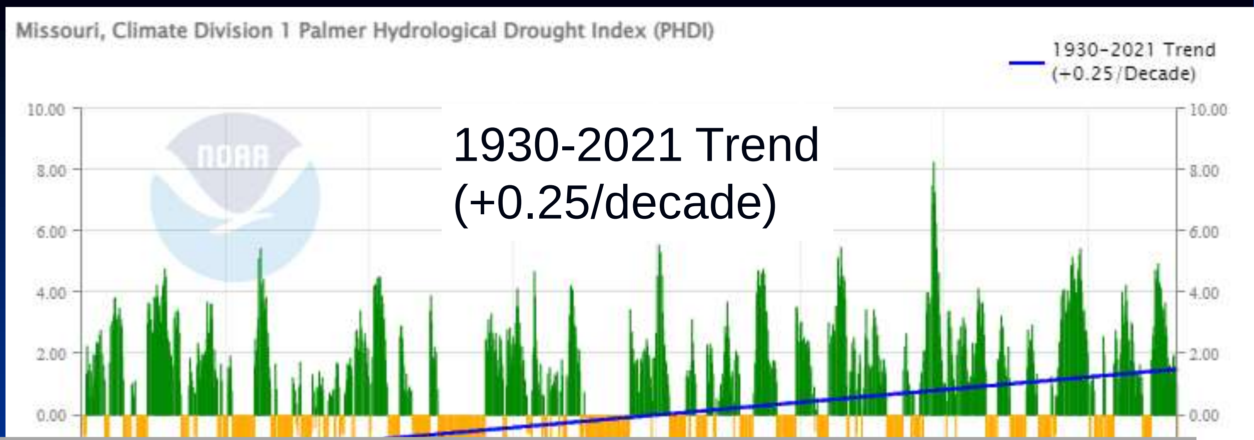
With this much non-uniformly distributed variability, the starting point for a trend analysis matters

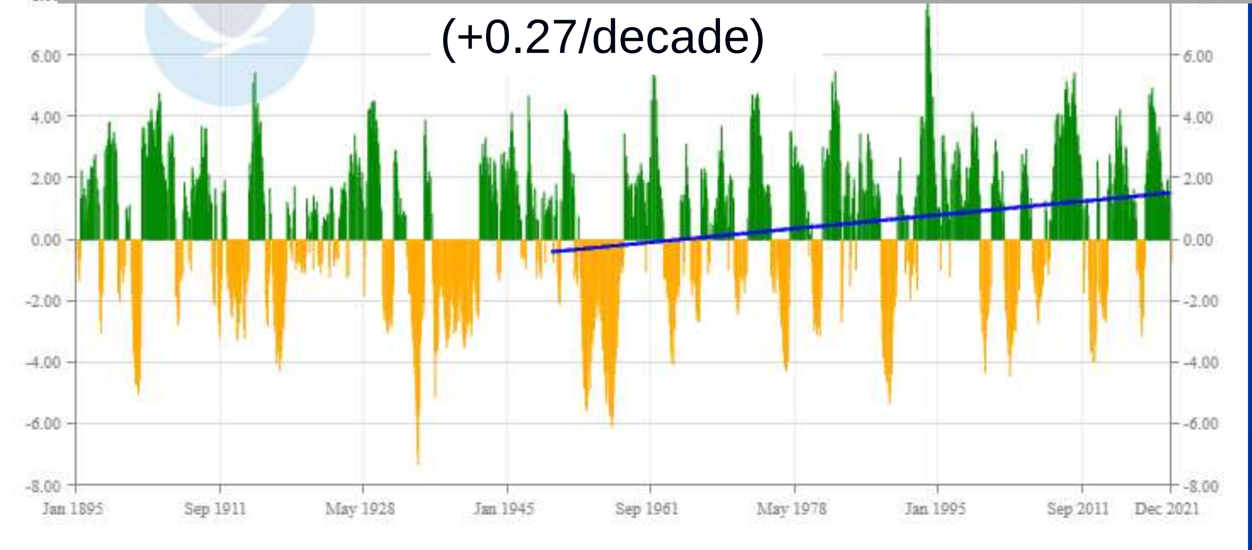


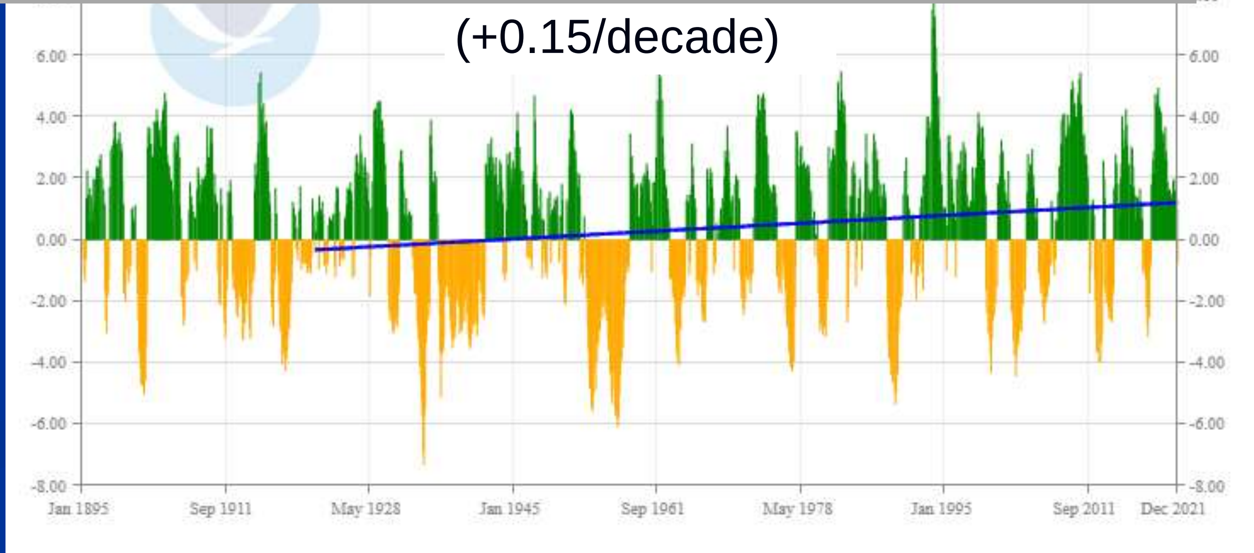


These examples show problems of computing average trends if not all data starts at the same time.

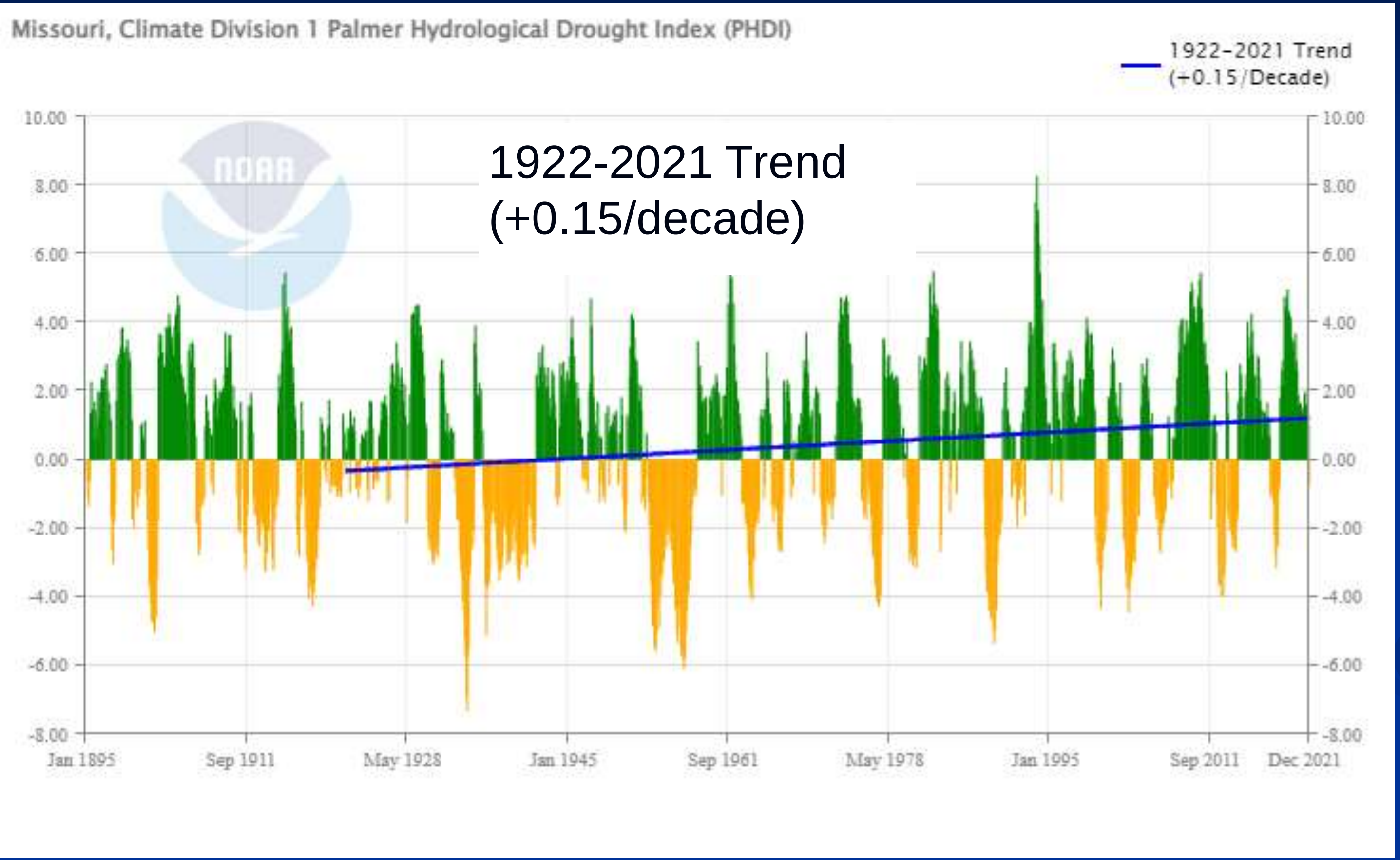
This was not possible with the regional data.

Also consider that human perceptions are usually based on the time period of their memories.





1922 is as far back as we can reasonably go with Missouri stream gaging data



Climate Division	PHDI Trend (units/decade)
Northwest	0.15
Northeast	0.18
West Central	0.16
Western Ozark	0.13
Eastern Ozark	0.17
Bootheel	0.12

Across Missouri the PDHI data is showing increasing wetness over the 100 years

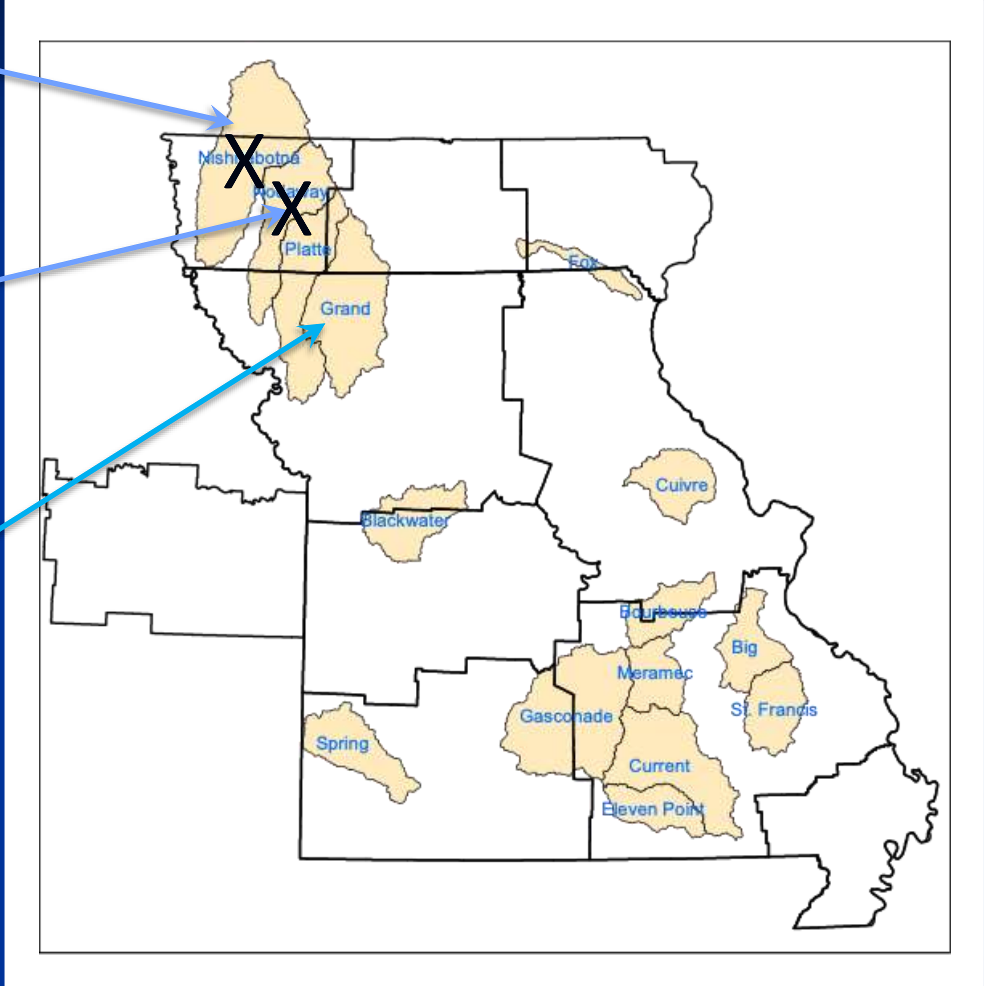
[Climate at a Glance | National Centers for Environmental Information (NCEI) (noaa.gov)]

Climate Divisions overlaid on gaged watersheds with 100 (or almost 100) years of "least-altered" hydrologic data

Not used as much of watershed is in West Central Iowa Climate Division

Not used as attempts to fill time gap with data correlated with downstream gage produced inconsistent results

Watershed used as example for some of data presentation



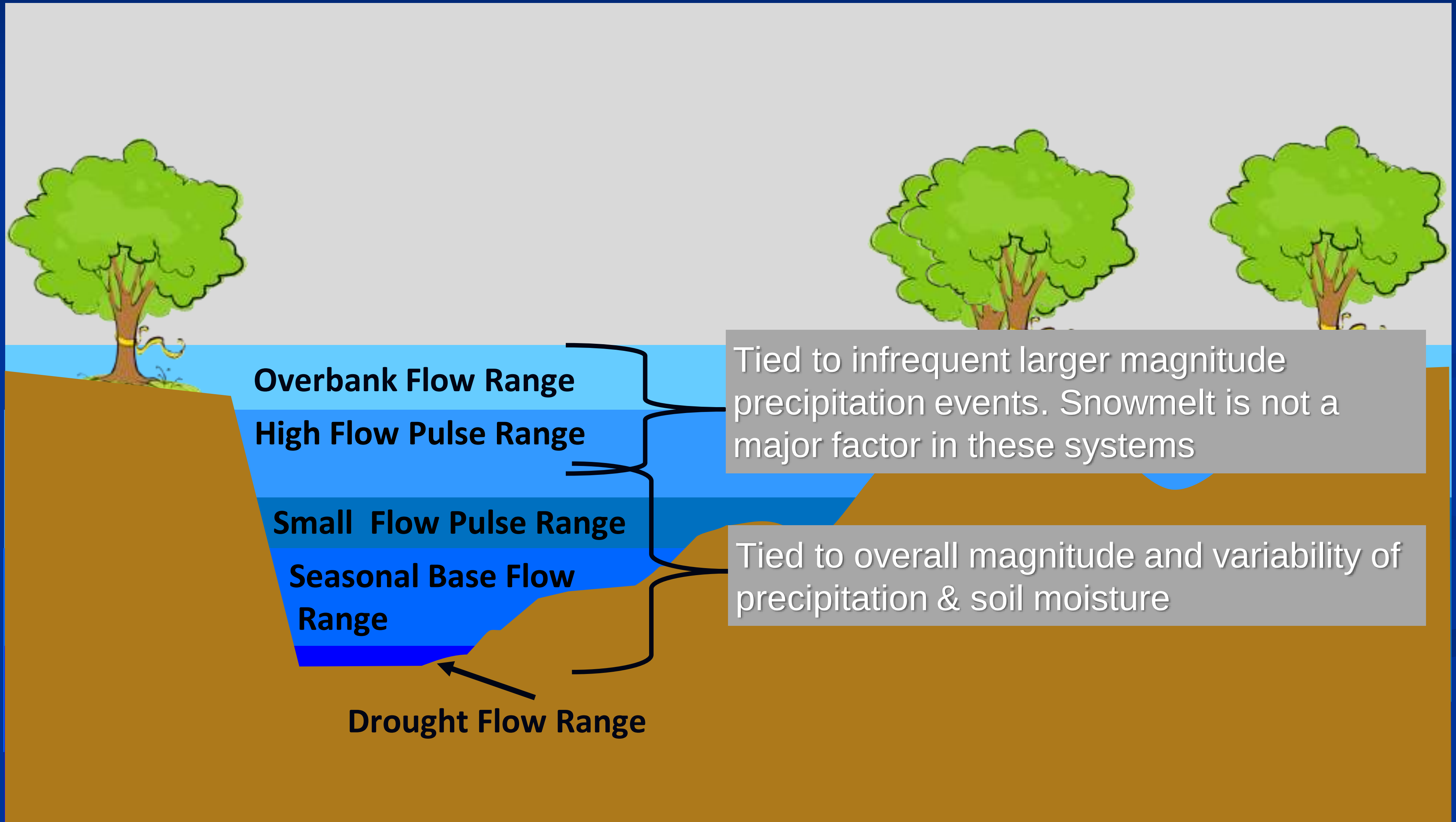
Least-altered = low percentage of urban area, and no major impoundments or withdrawals.

No gage was chosen for the Bootheel due to the extensive hydrologic alterations.

Major channelization in northern watersheds occurred prior to or very early in gaging period.

These 13 gaged watersheds allow the cleanest signal possible of streamflow response to climate over the same 100-year time period. This clean a signal was not possible at the regional level.

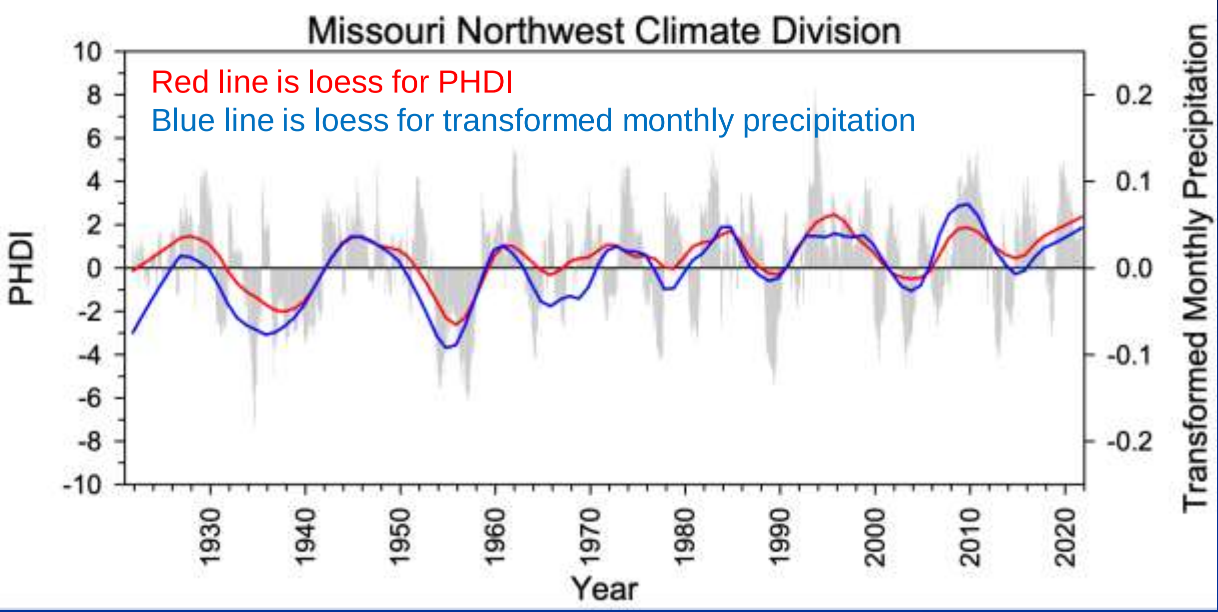
Five Ranges of Flows Drive Important Stream Processes



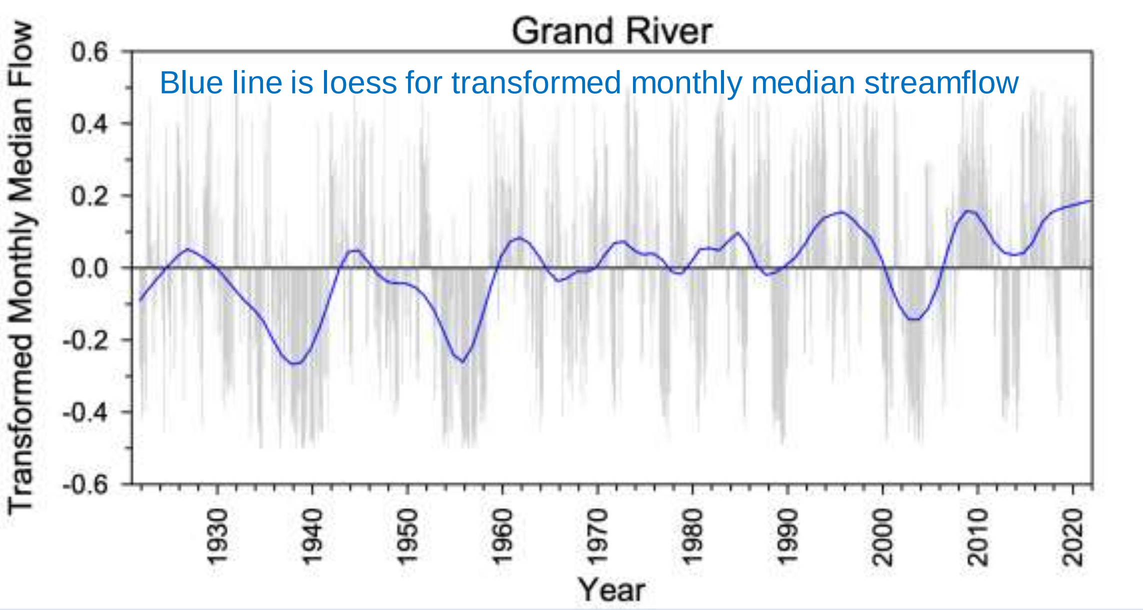
Several metrics in talk used some transformations to account for seasonal variations, but especially to highlight drier (negative numbers) and wetter conditions (positive numbers), which will make easier visual comparisons to the time series data of the PHDI.

Also used some smoothing functions (LOESS) which is a locally weighted regression. The beginning and end of the Loess curves exaggerate the importance of the beginning or ending data points.

This graph shows monthly values of PHDI in the gray for the Northwest Missouri Climate Division. The red line is the loess curve for the PHDI and the blue line is a loess curve for monthly precipitation



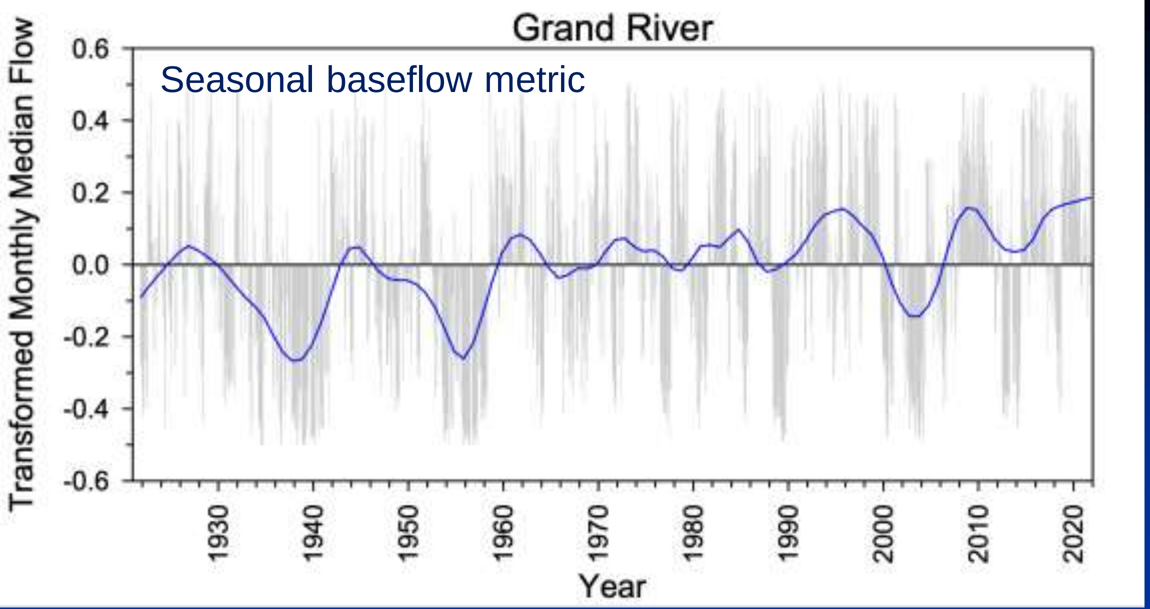
The monthly median data are a good metric for the seasonal baseflow range. The loess curve is visually a good match for that of the PHDI.



All 13 gages showed an overall increase in the transformed monthly medians over the 100-year period.

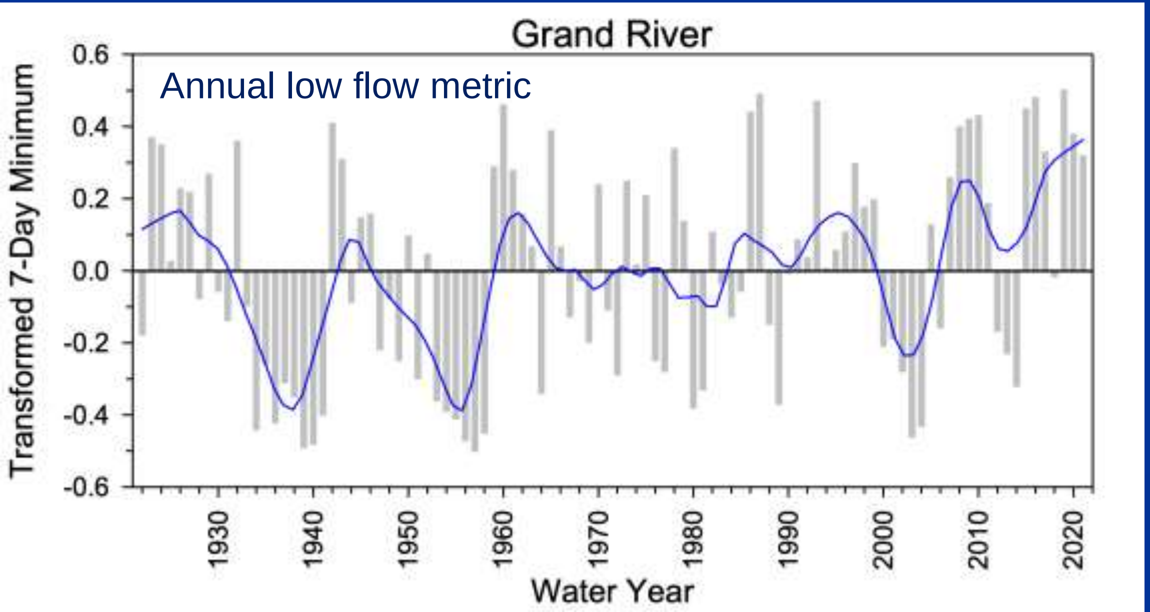
Some of the gages better matched the Climate Division PHDI patterns than did other gages. Presumably, a closer match would be found using PHDI values for the watershed rather than the Climate Division.

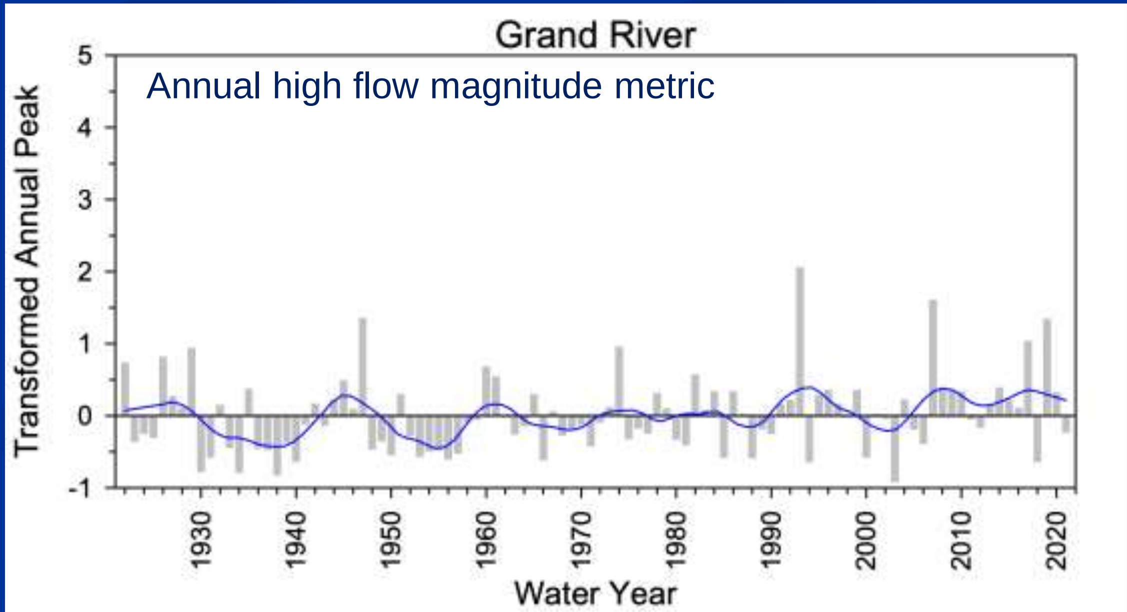
It is easier to consider very low and very high flow conditions on an annual basis rather than monthly



Groundwater Driven

Surface Runoff Driven

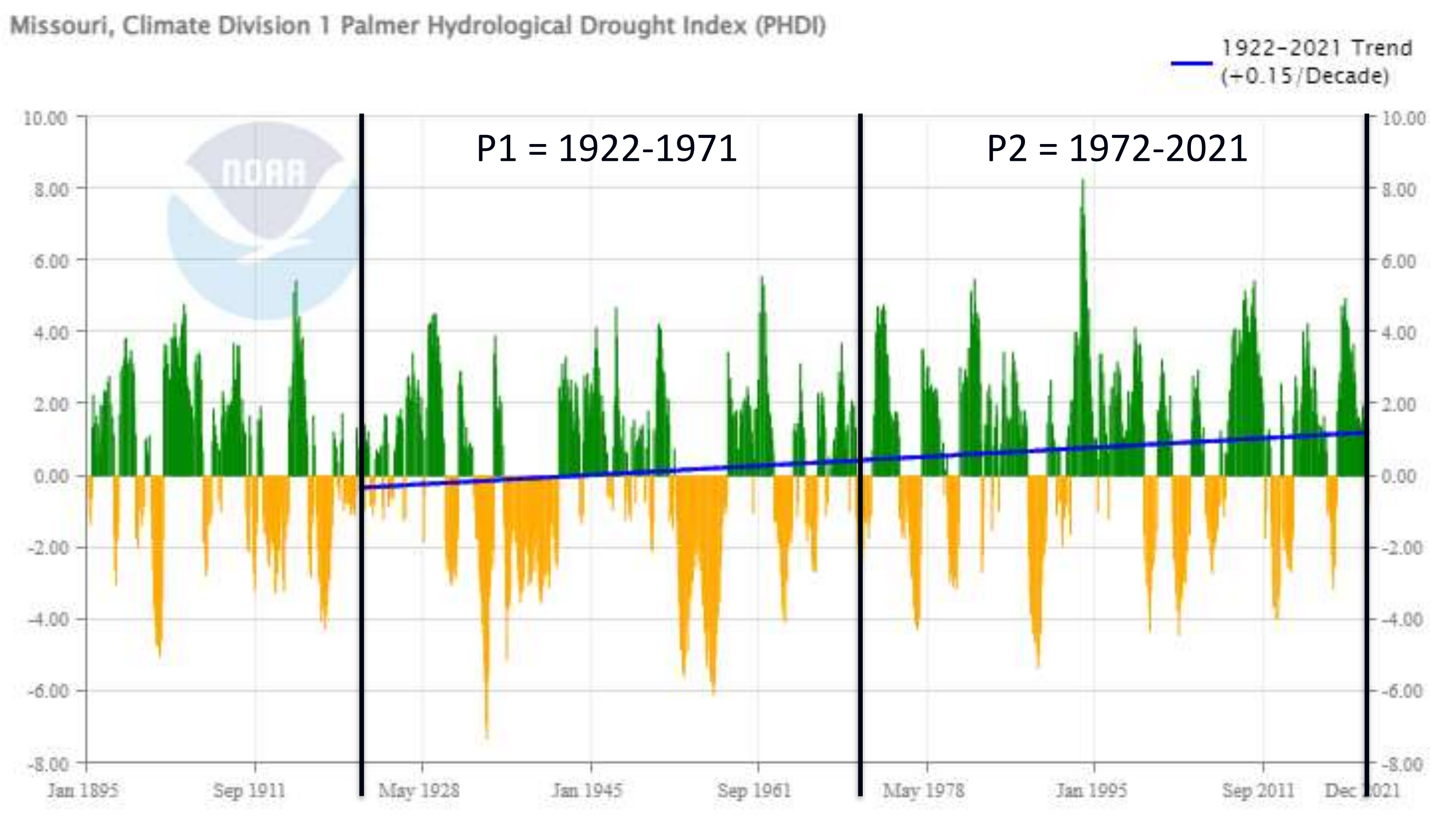




Using only the eye-test, it is apparent that the early portion of the 100-year period is different than the later period for all the flow metrics, whether they reflect flows driven by groundwater discharge or surface runoff.

The trends are different for different flow metrics and for different parts of the state, but in all cases, there is an upward trend with time.

An expedient data exploration is to simply divide the data into two 50-year time blocks: 1922-1971 and 1972-2021 and evaluate differences in metrics across the flow regime. Dividing into 2 time-blocks allows the use of more detailed flow metrics.



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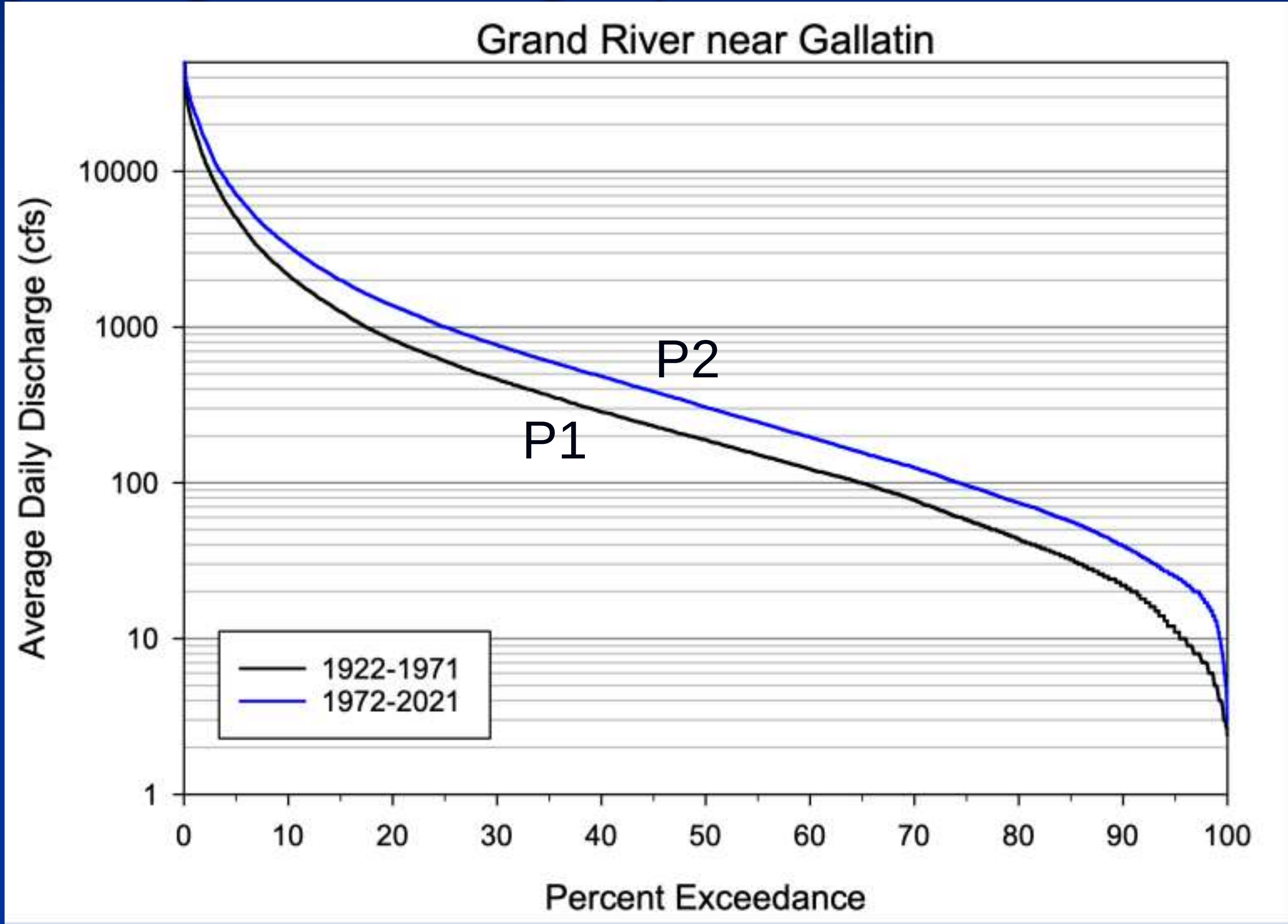
Using the Grand River as an example, we will start with a comparison of flows on an annual basis using flow duration curves. Flow duration curves are created by ranking all average daily discharges and calculating the percent exceedance for each discharge.

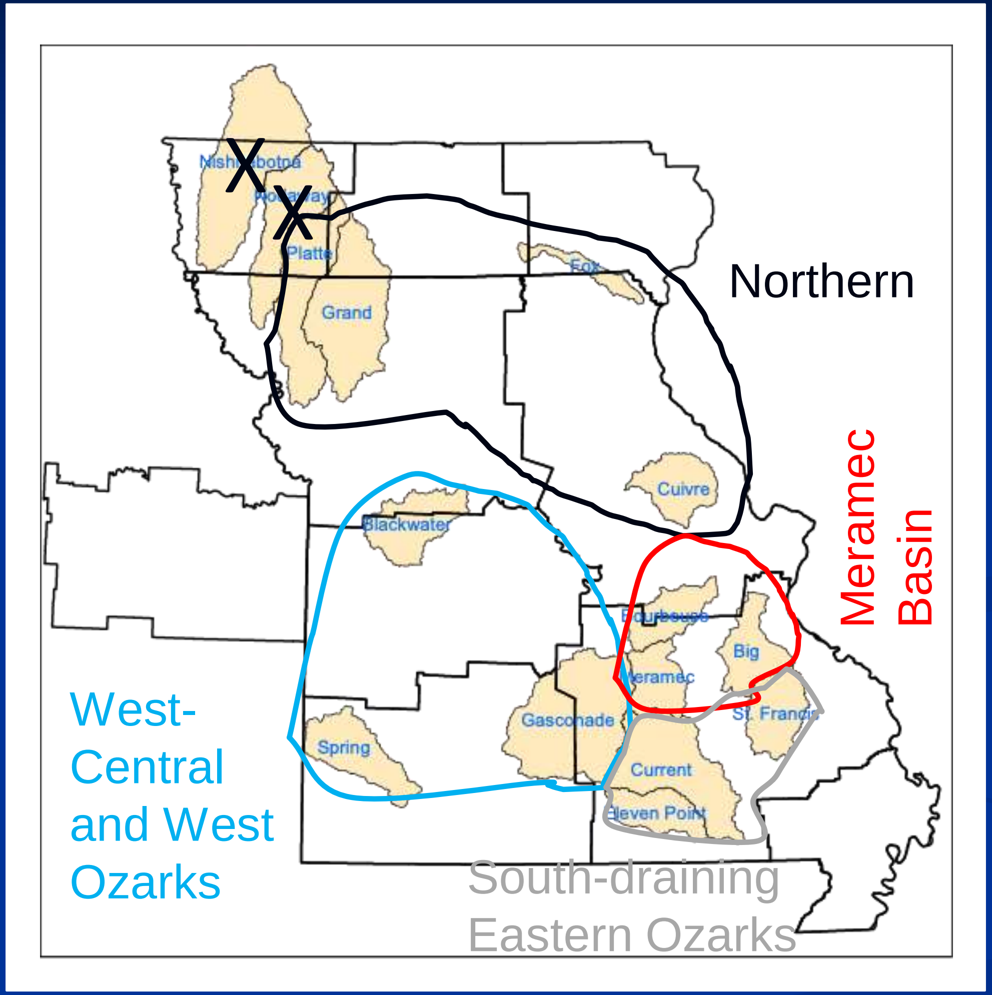


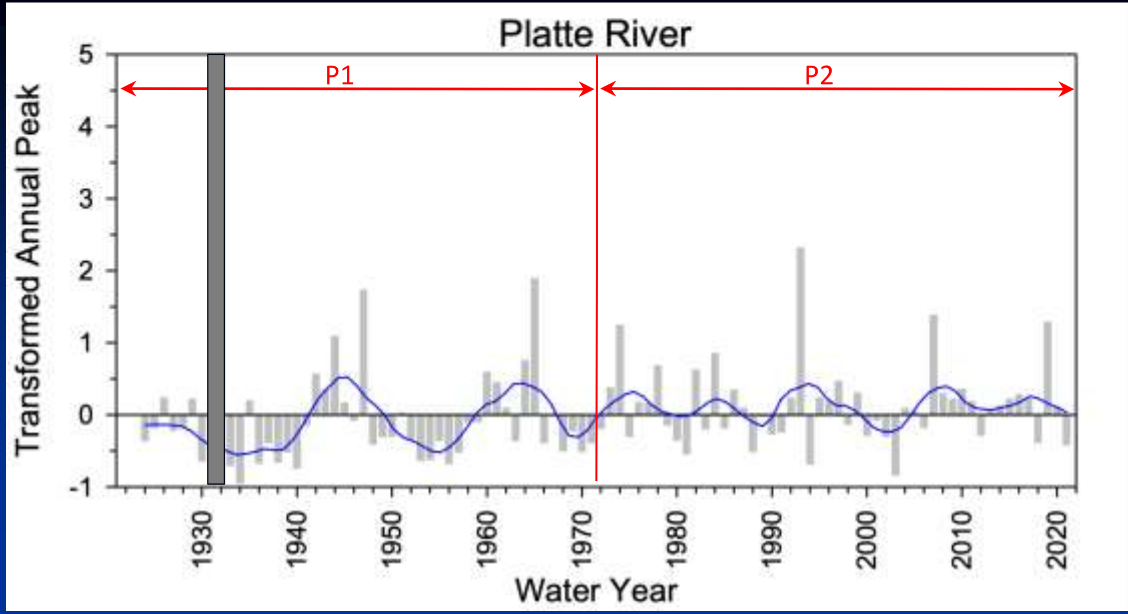
All 13 gages showed increased discharge for the same percent exceedance across the whole range discernible on the graphs. This indicates that both groundwater recharge and surface runoff have increased from P1 to P2.

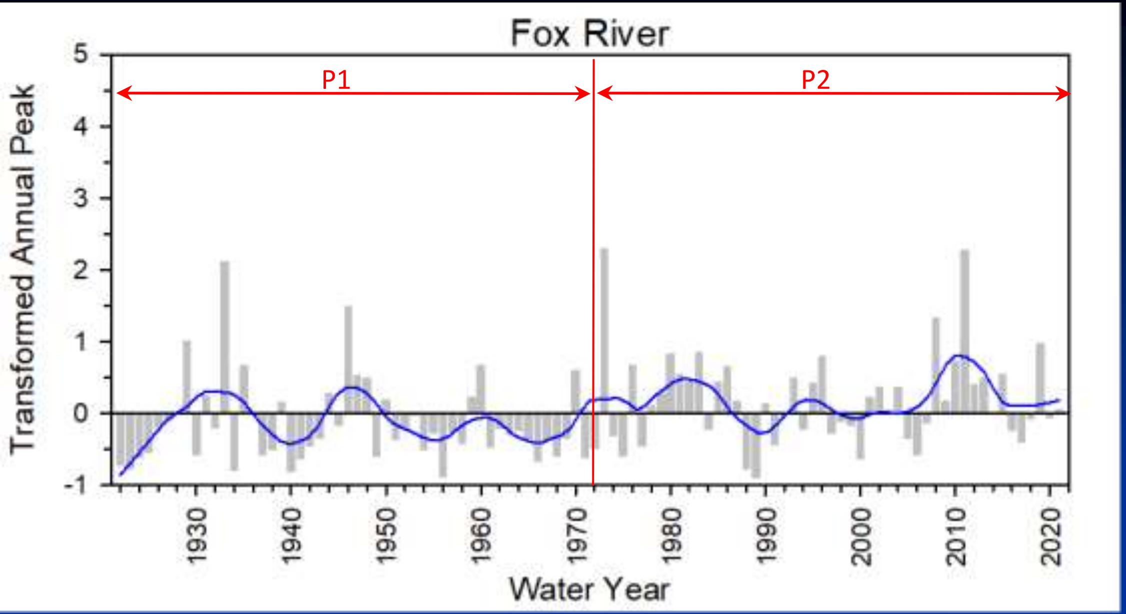
On the annual flow duration curves, there was an apparent convergence between the time periods for the highest flows.

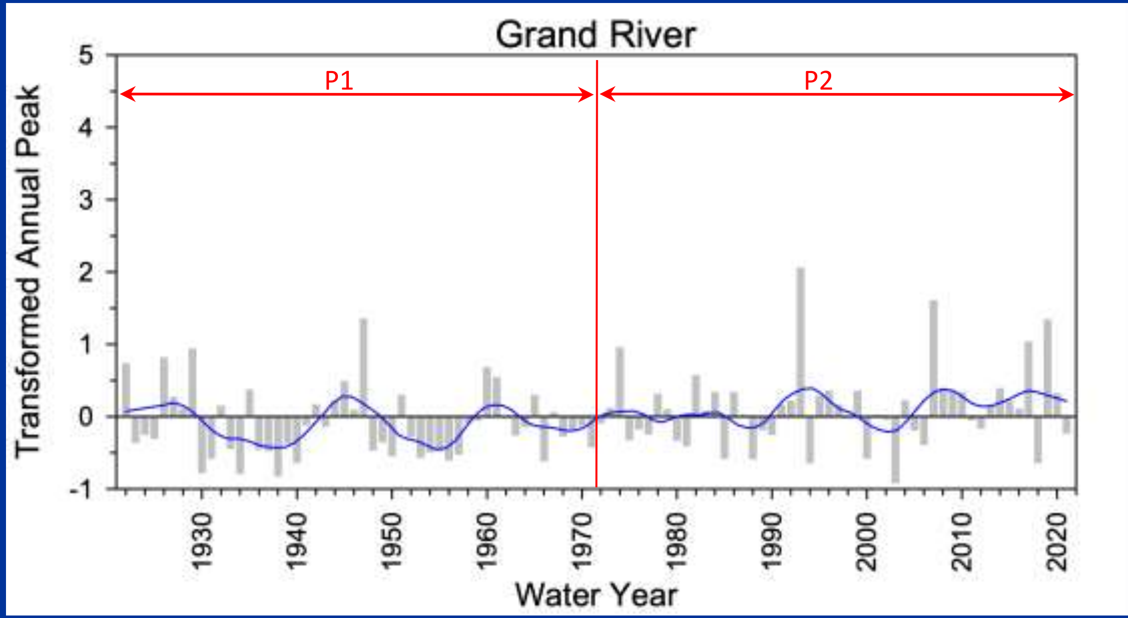
These flows, which are in the Overbank Flow Range, are best analyzed with instantaneous peak data rather than average daily discharge.

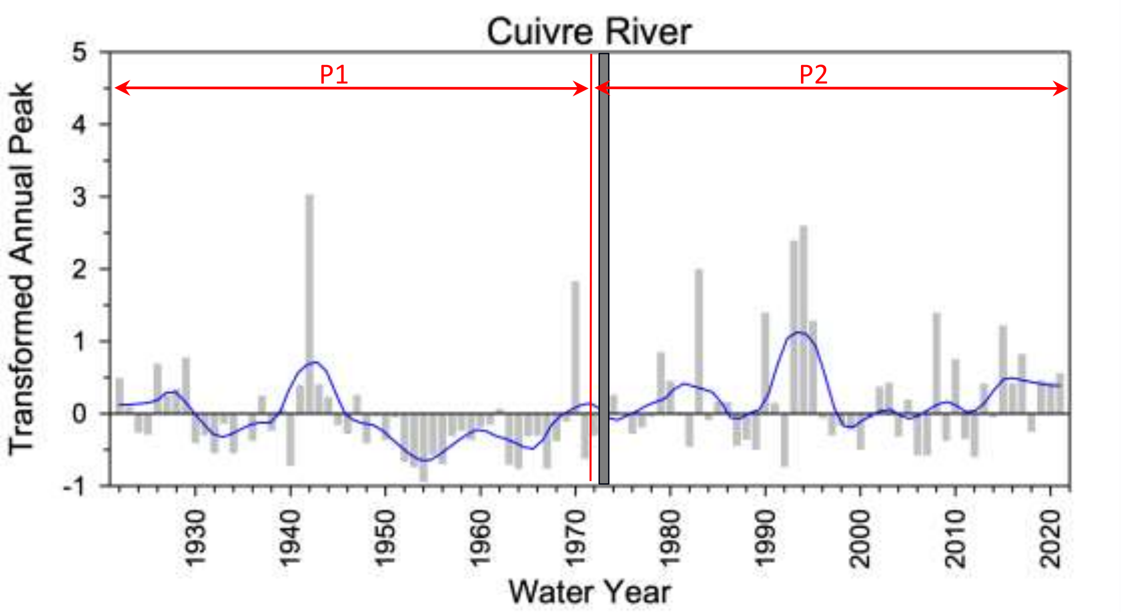
For the overbank flows, we will consider data from all 13 watersheds



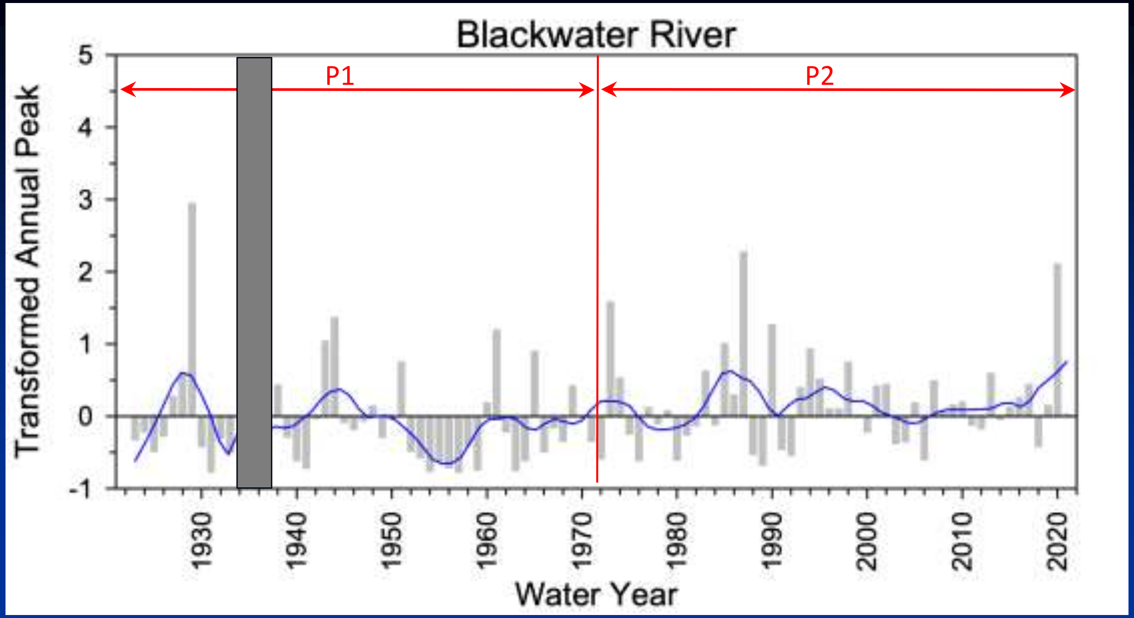




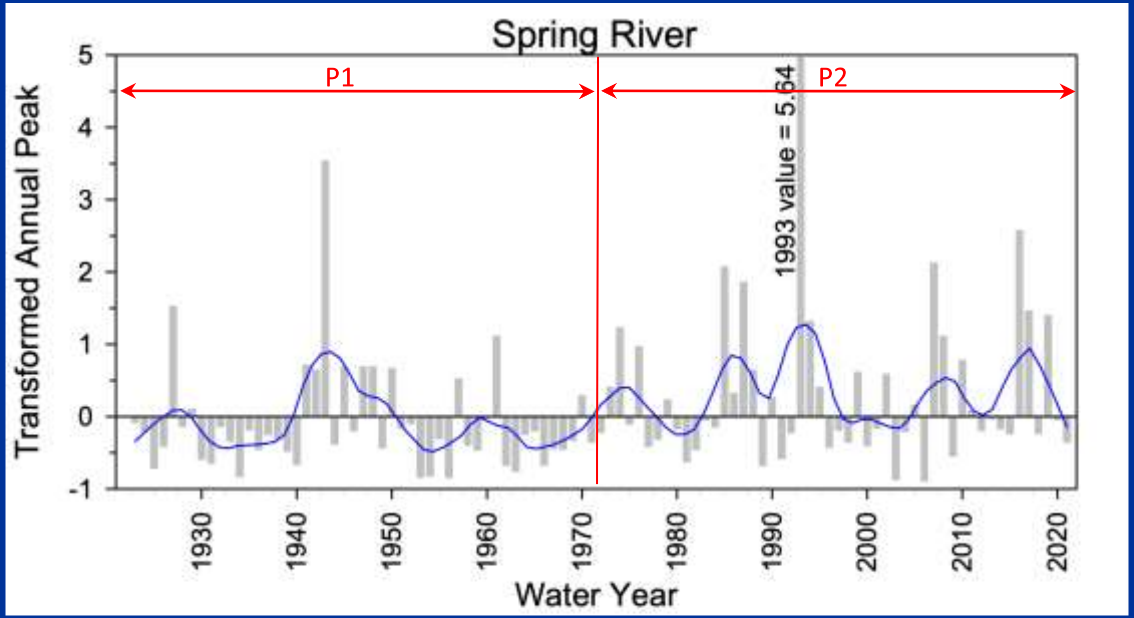


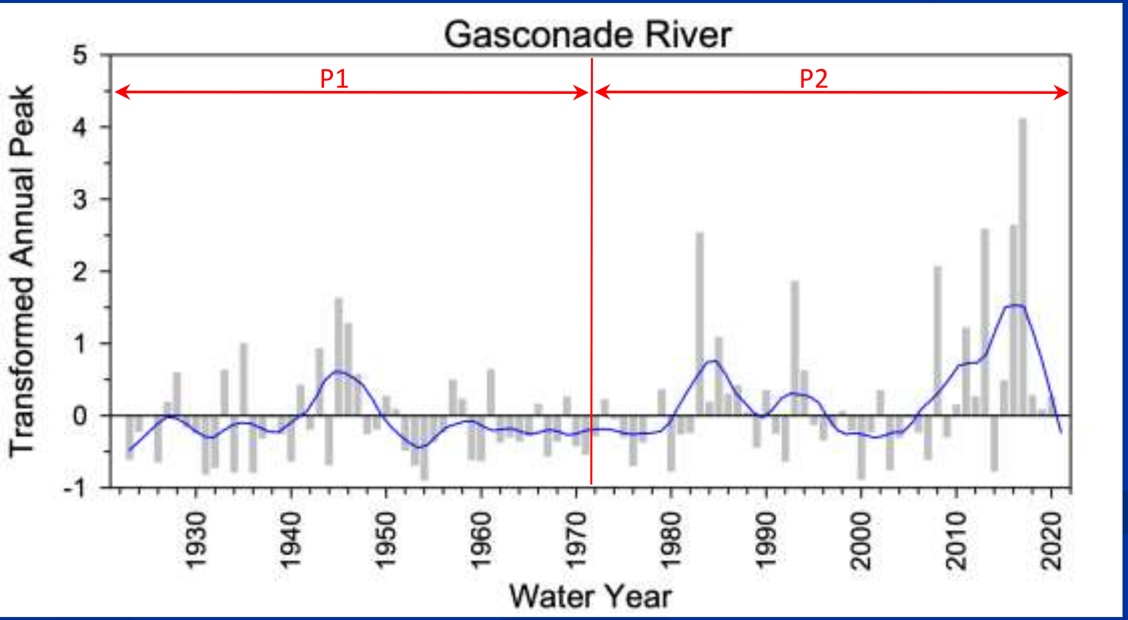


These northern Missouri gages show significant clustering of years with small annual peaks in P1

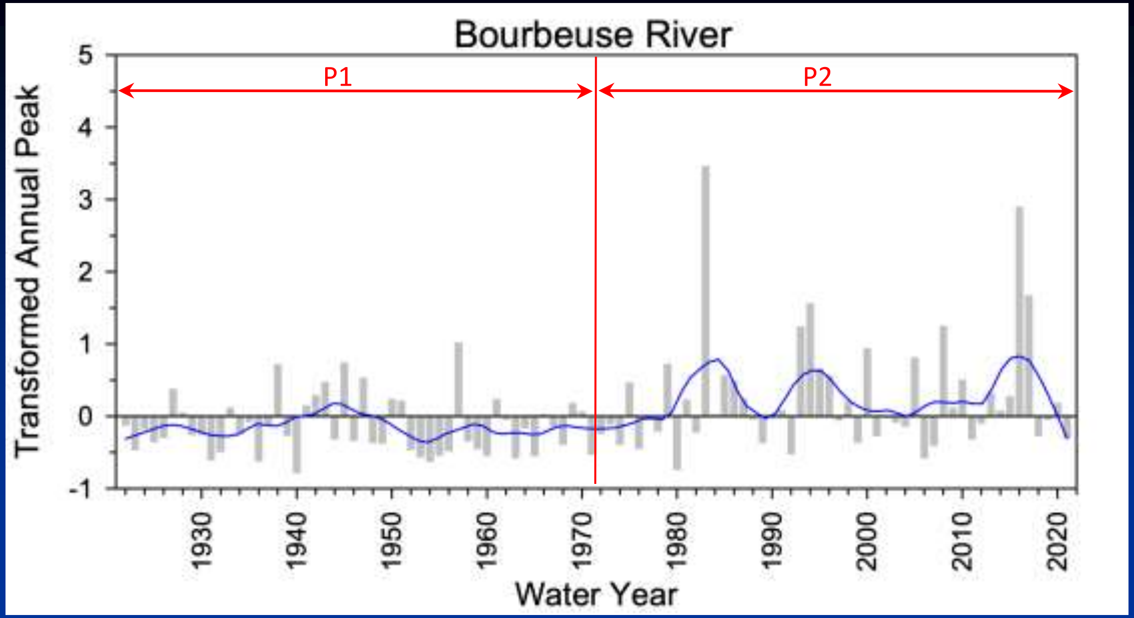


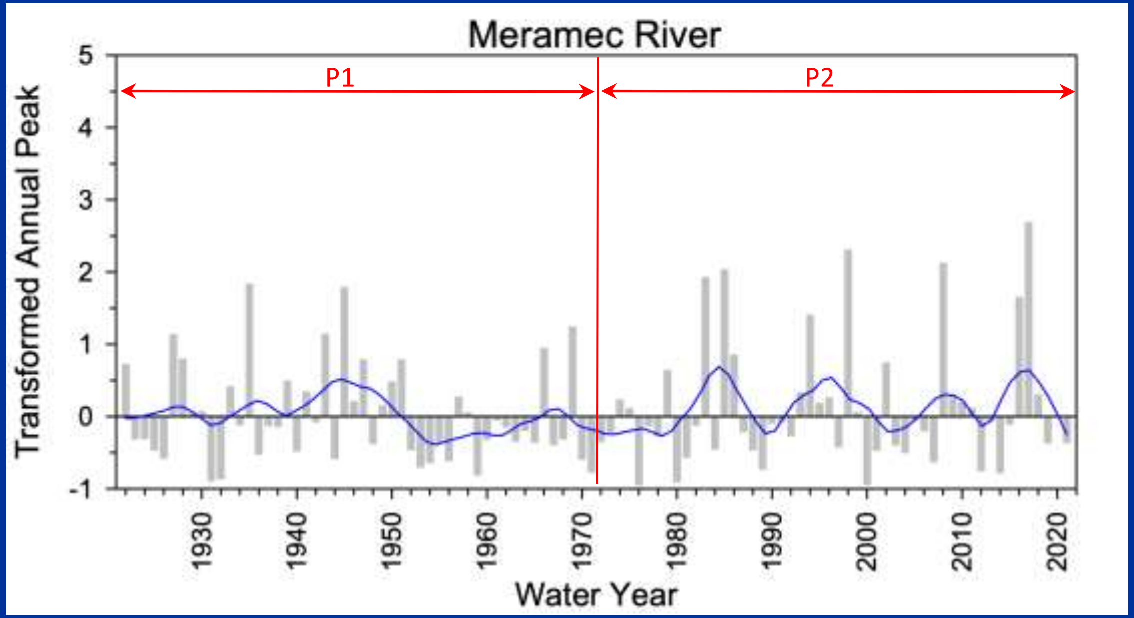
Blackwater data looks like the northern Missouri gages with significant clustering of years with small annual peaks in P1

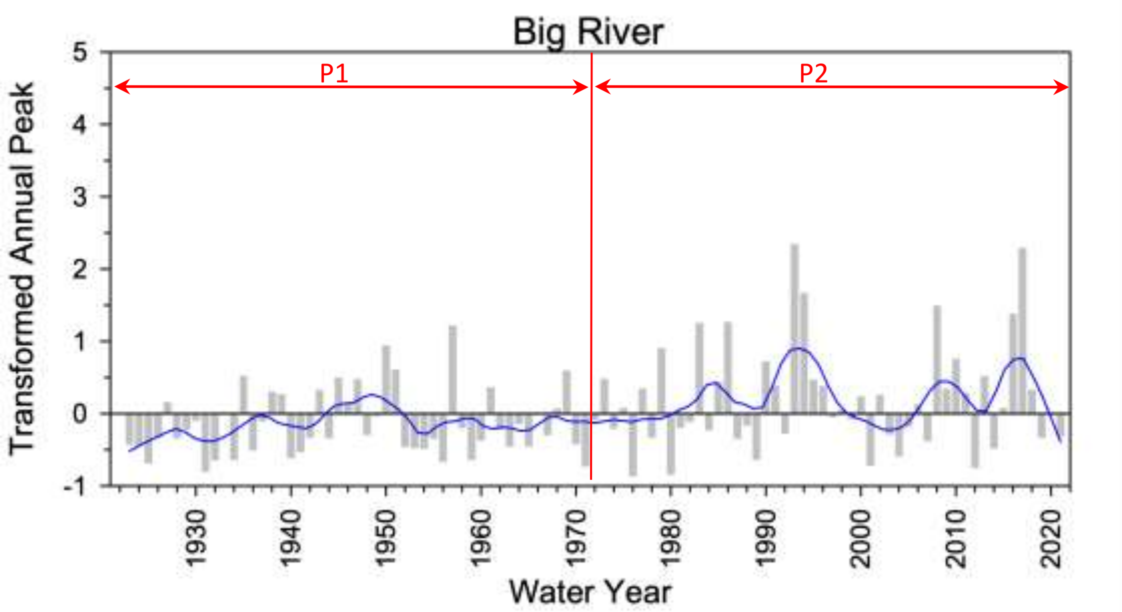




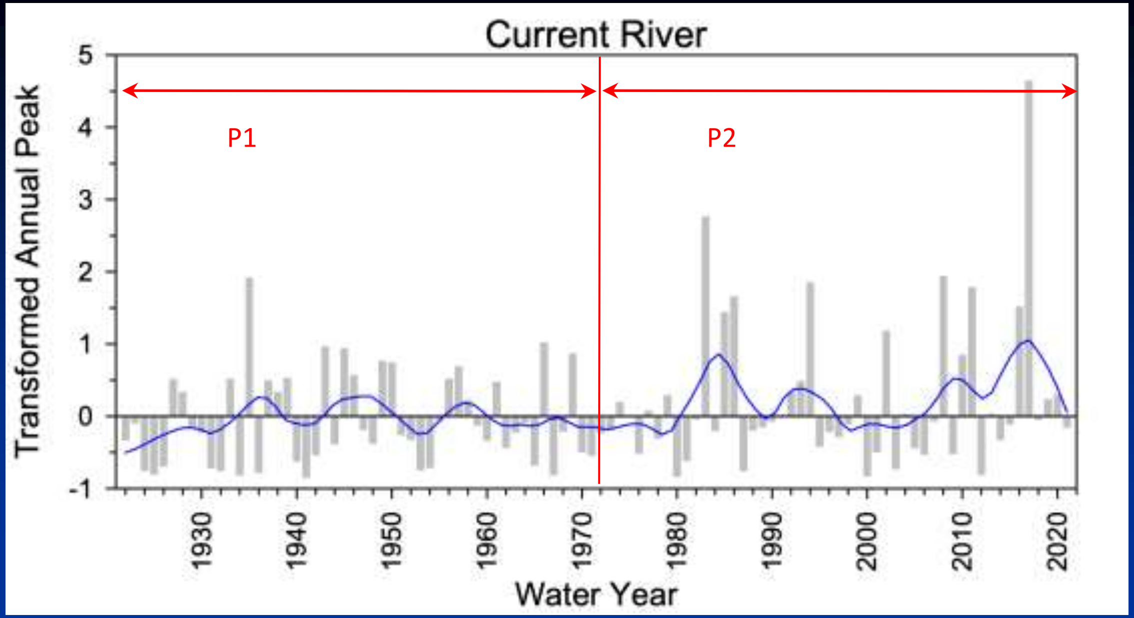
More clustering of high annual events in P2, especially for Spring and Gasconade

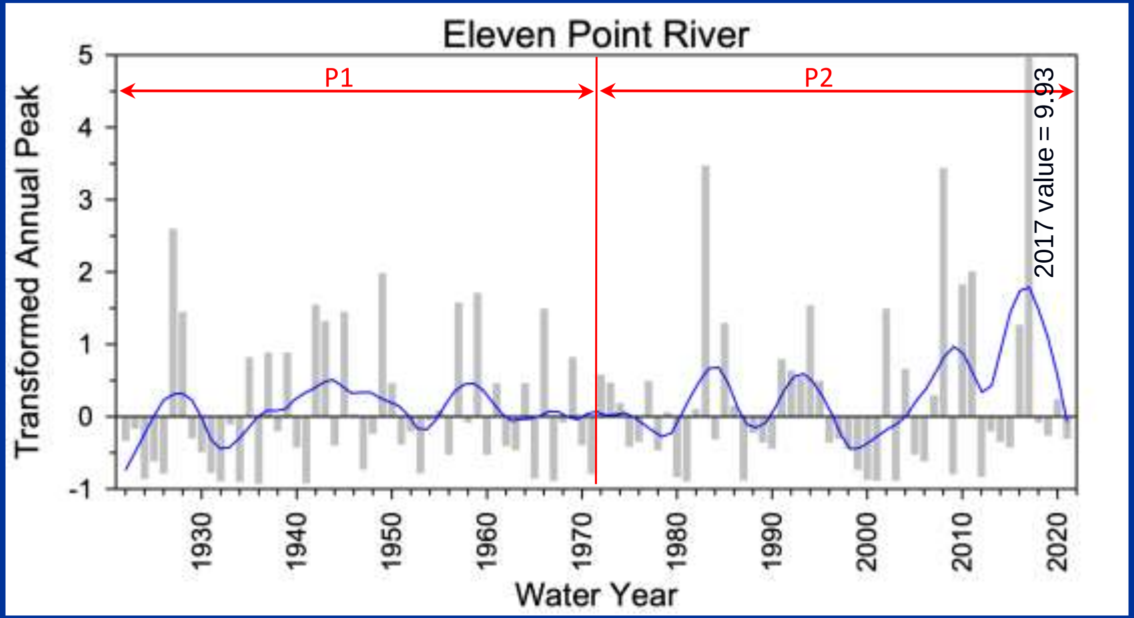


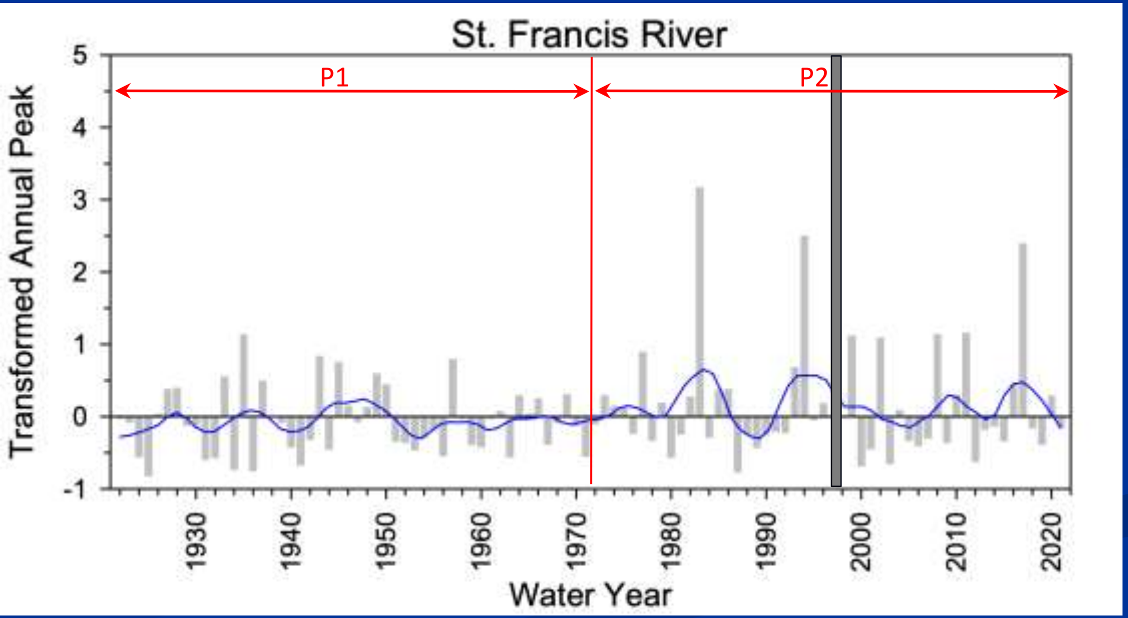




Significant clustering of years with high annual peaks in P2





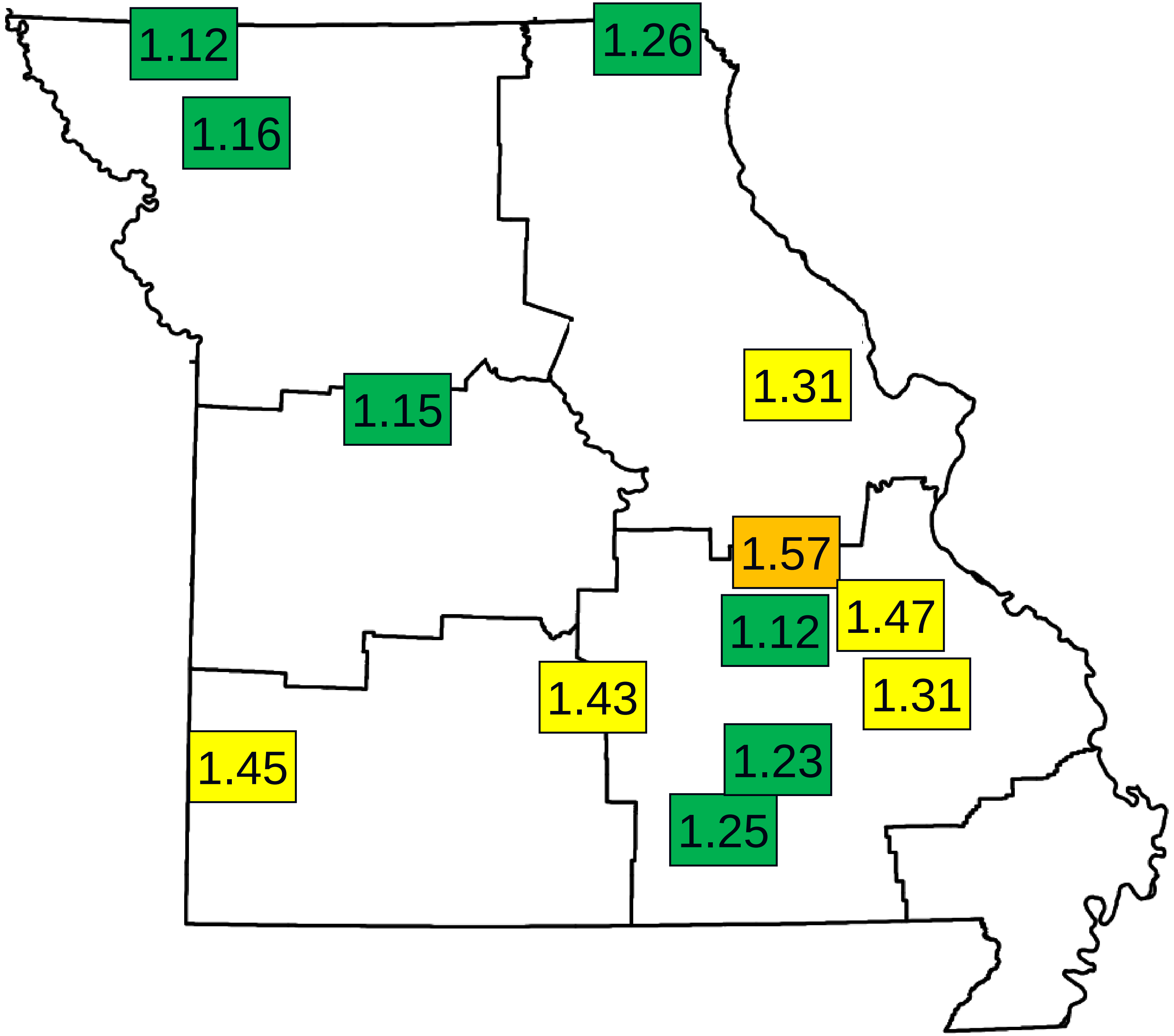


Significant clustering of years with high annual peaks in P2

Flood frequency data are usually computed using this annual maximum series

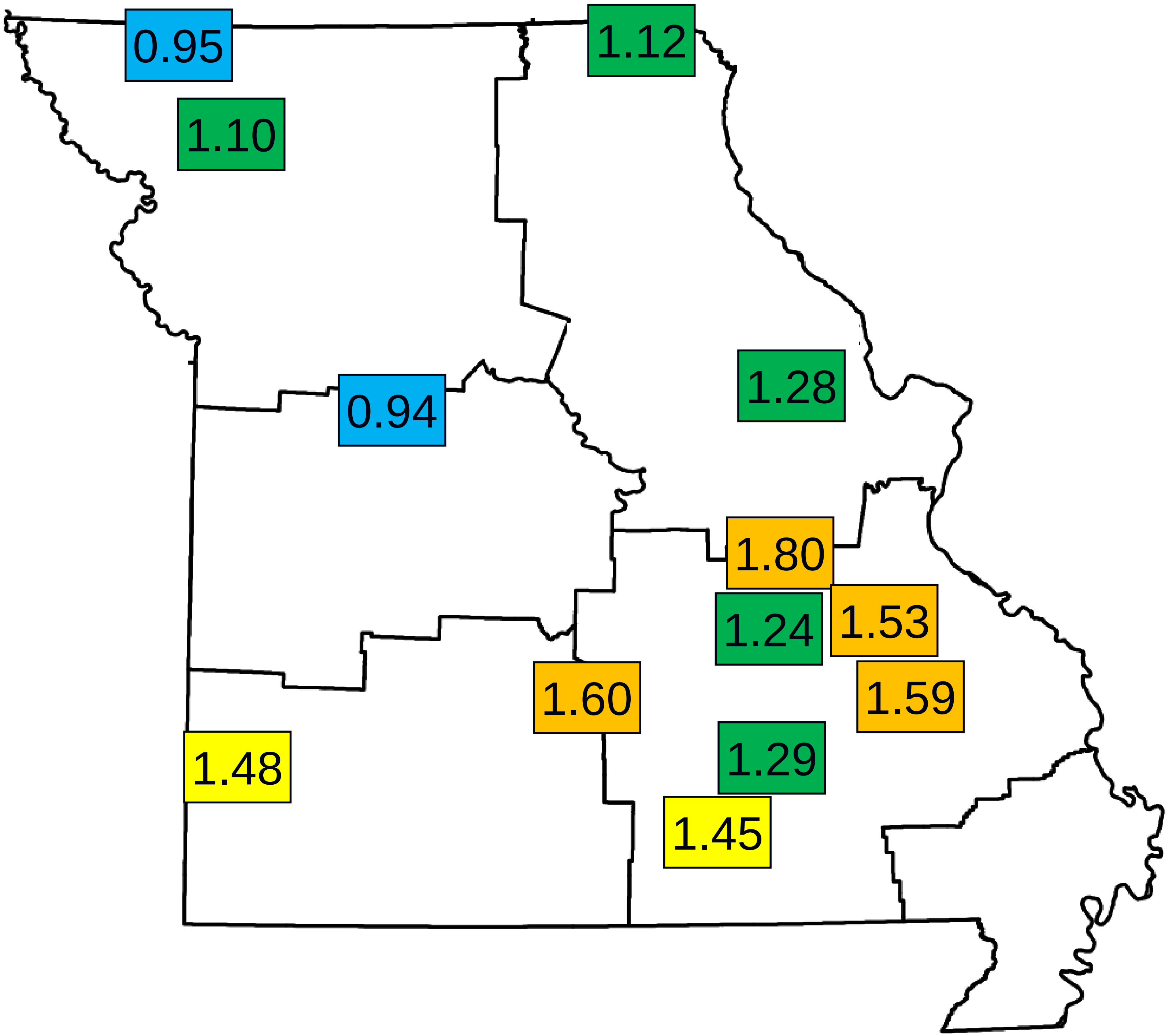
Next, we will look at mapping two commonly computed flood events showing a comparison of the value computed from P2 data divided by that of the P1 data

10-year flood discharge (10% probability every year)



	P2/P1
XXX	0.7-0.89
XXX	0.9-1.09
XXX	1.1-1.29
XXX	1.3-1.49
XXX	1.5-1.99
XXX	>2

100-year flood discharge(1% probability every year)



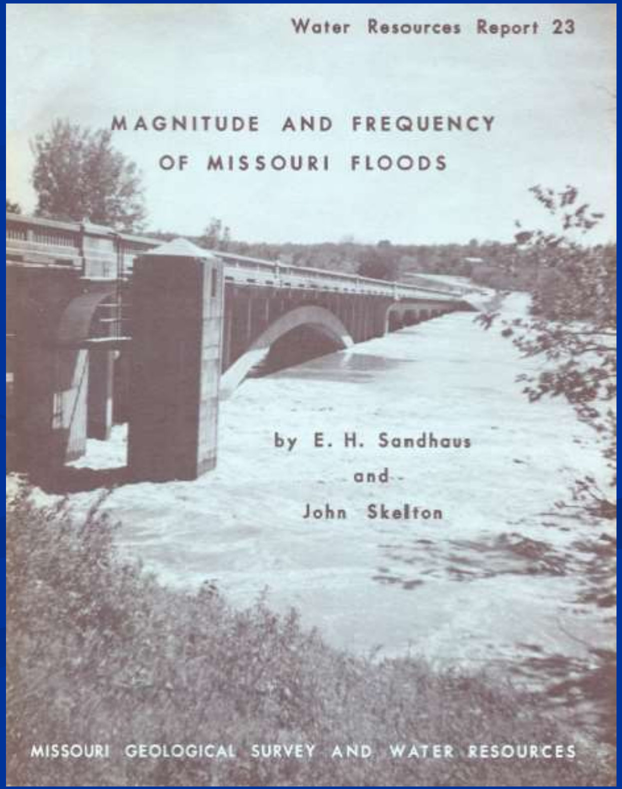
	P2/P1
xxx	0.7-0.89
xxx	0.9-1.09
xxx	1.1-1.29
xxx	1.3-1.49
xxx	1.5-1.99
xxx	>2

The 10-year and 100-year floods impact human infrastructure. Events smaller than the 10-year flood are extremely important for ecological and geomorphic processes and in Missouri streams there can be more than one of these events in many years.

For our gages, we can do Peak over Threshold analyses for:

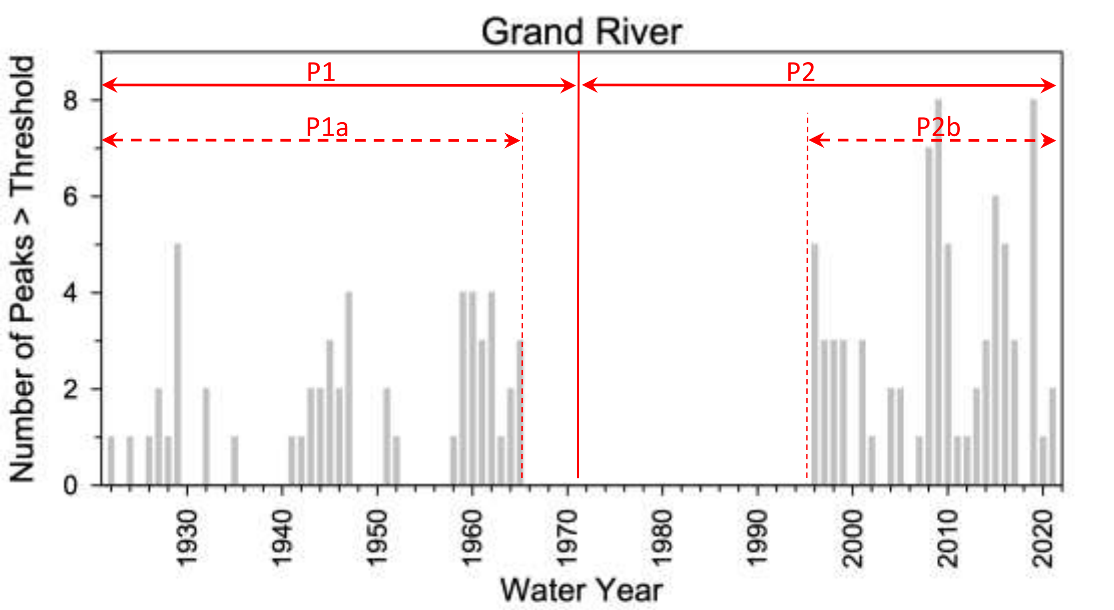
P1a (1922-1965) using data from Sandhous and Skelton (1968)

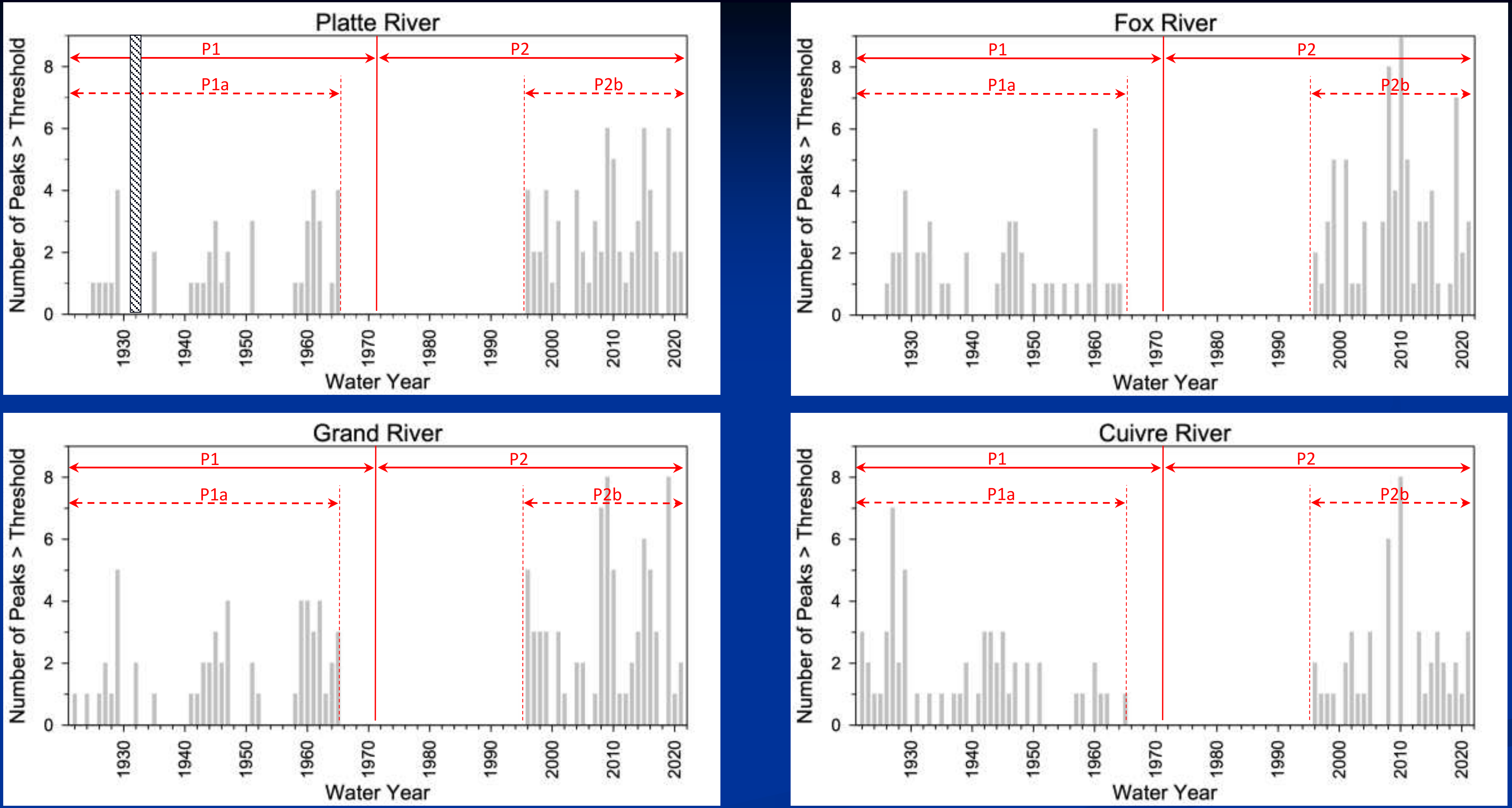
P2b (1996-2021) using 15-minute data retained by USGS since 1996



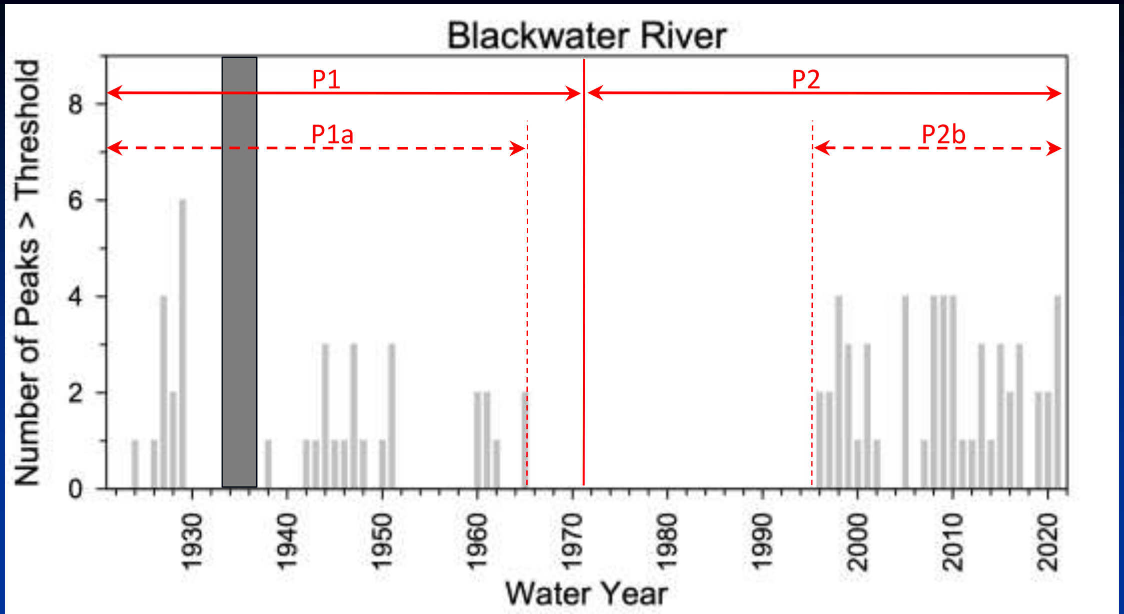
We can plot the Peaks > Threshold for the P1a (44 yrs) and P2b (25 yrs).

The threshold used in the 1968 report limited the options, but for all case, the threshold should be above bankfull.

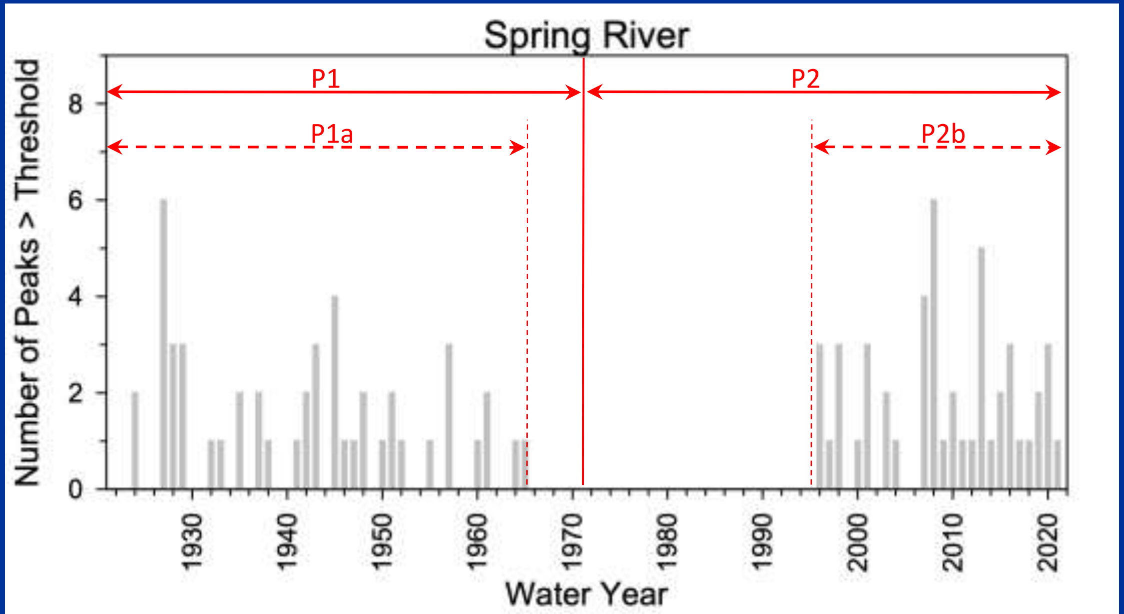


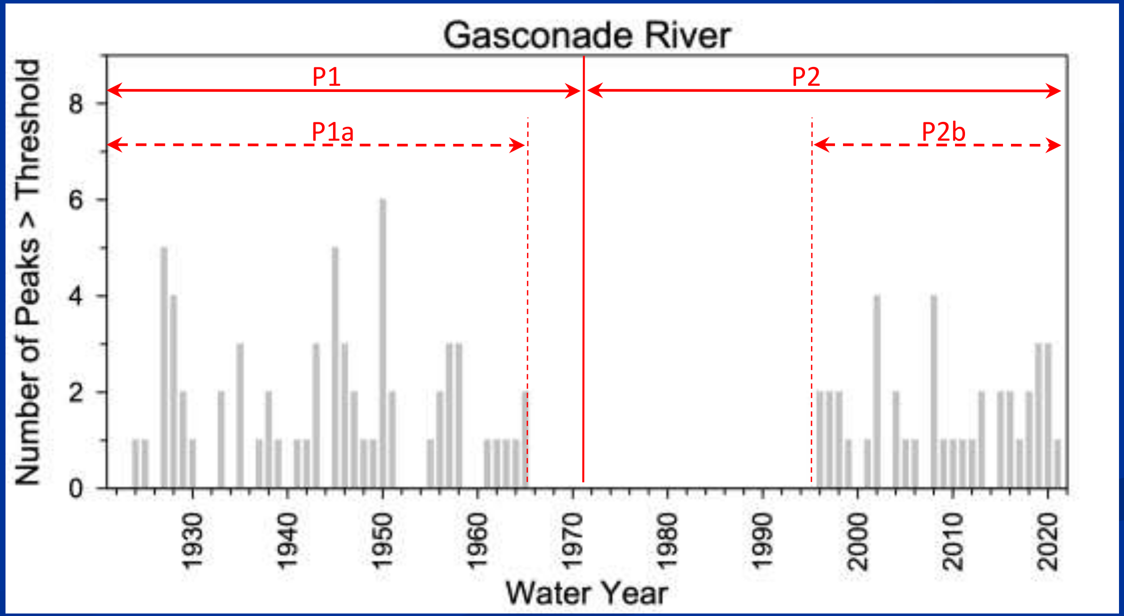


Note more peaks/year and fewer years with no peaks > threshold in P2b

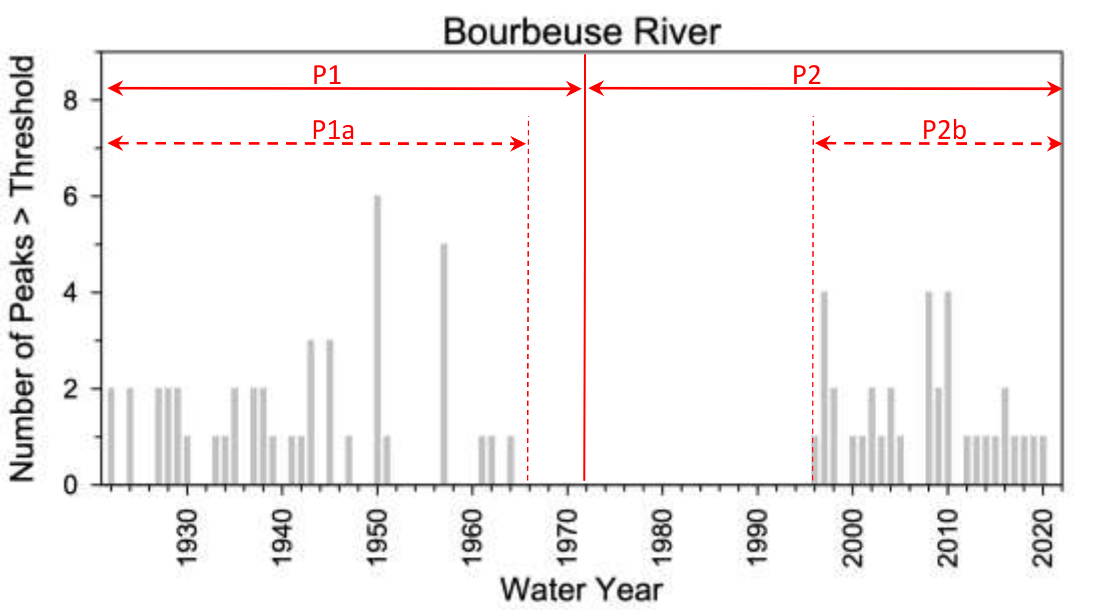


Blackwater is similar to northern Missouri gages with more peaks/year and fewer years with no peaks > threshold in P2b

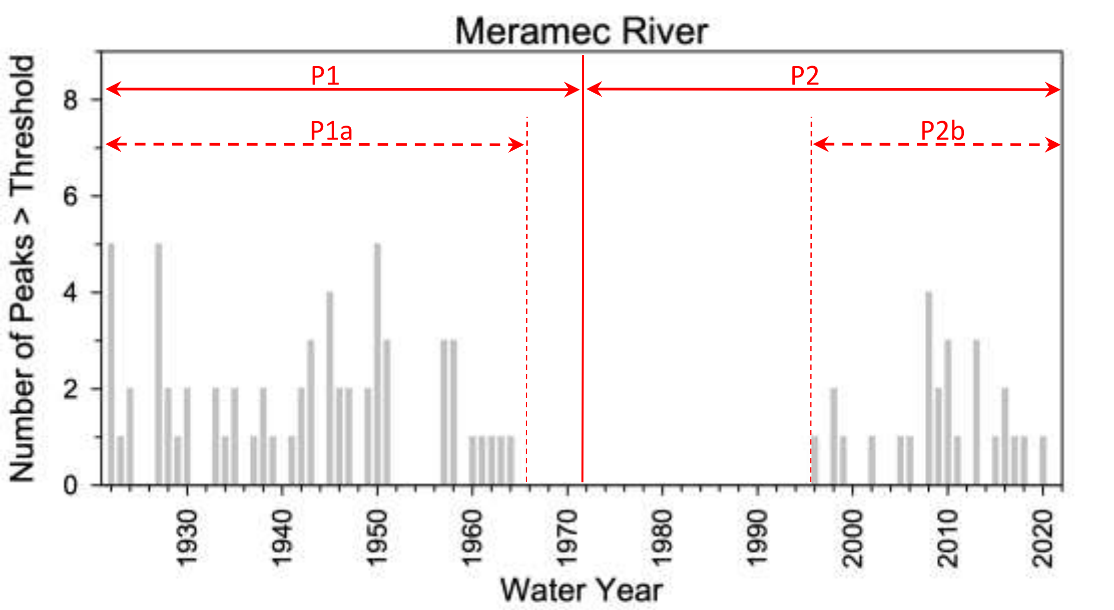


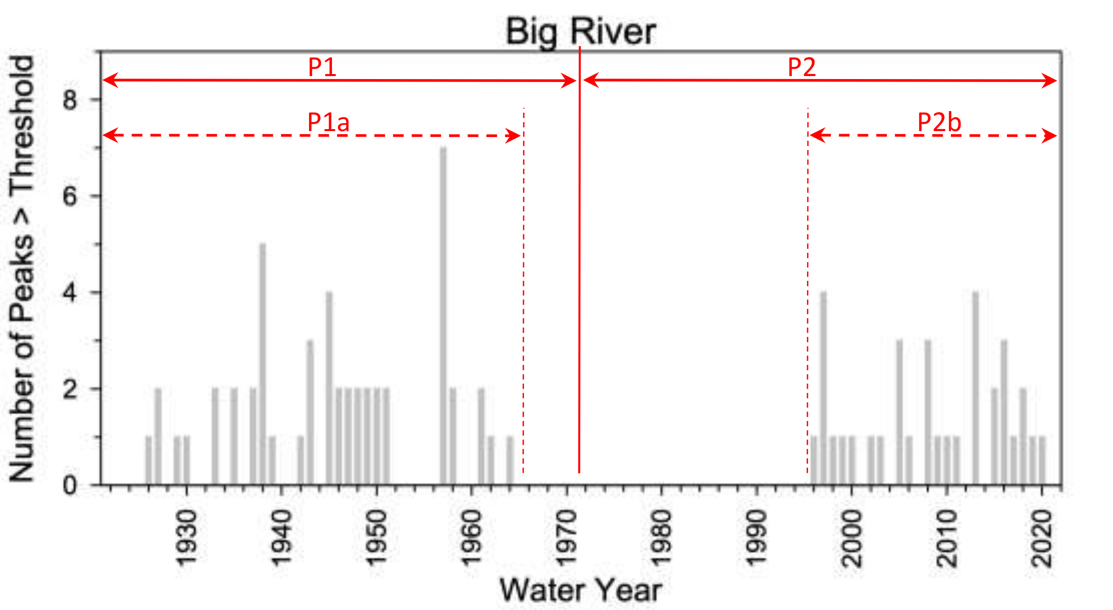


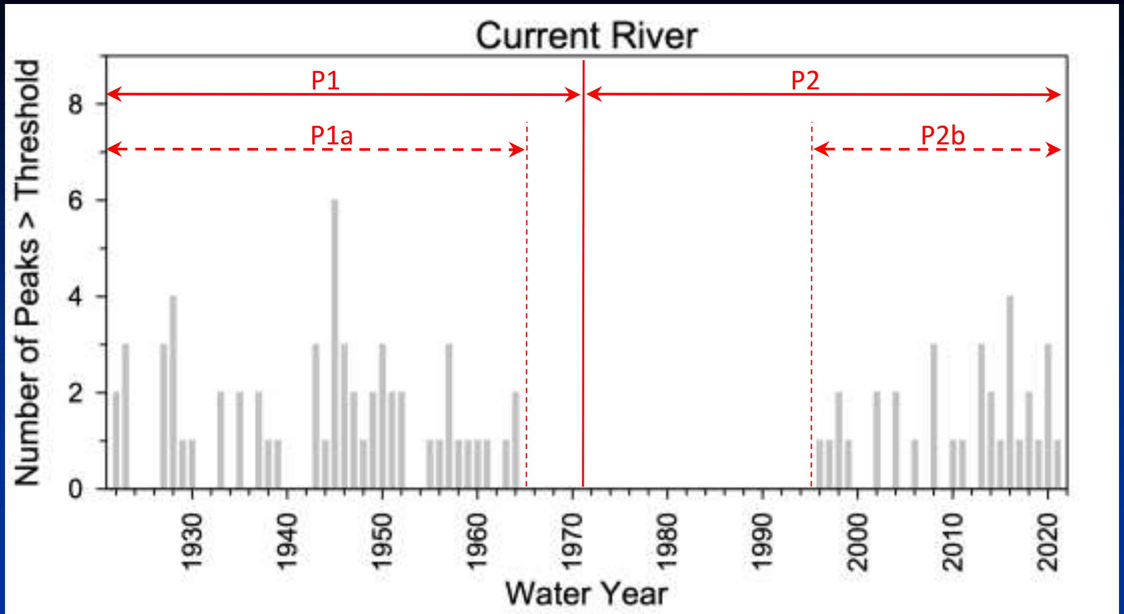
Differences between P1a and P2b are less visually distinct for Spring and Gasconade

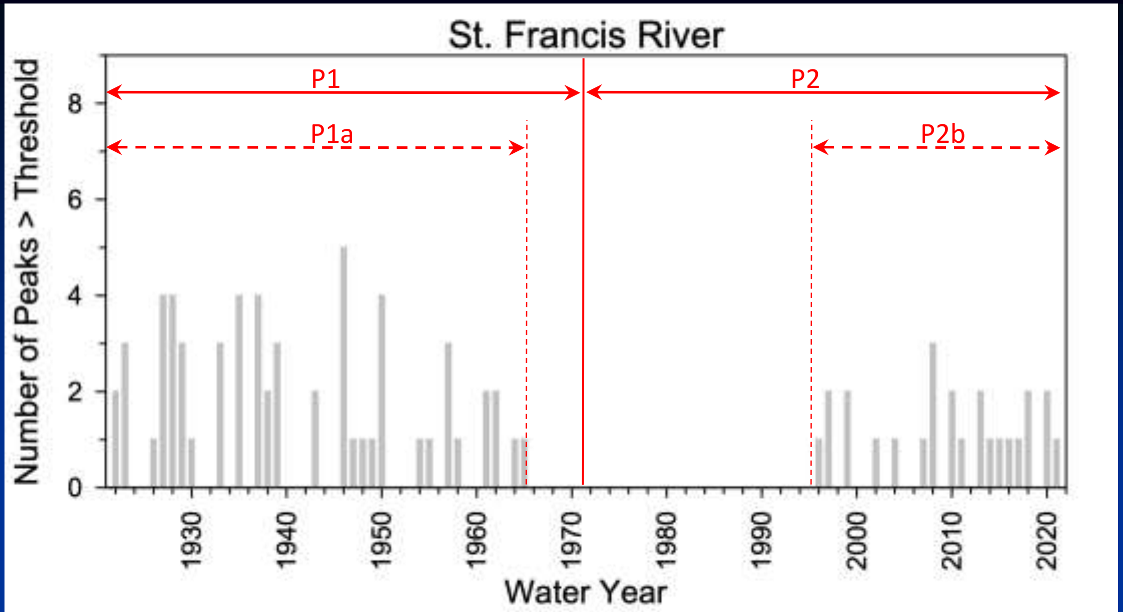


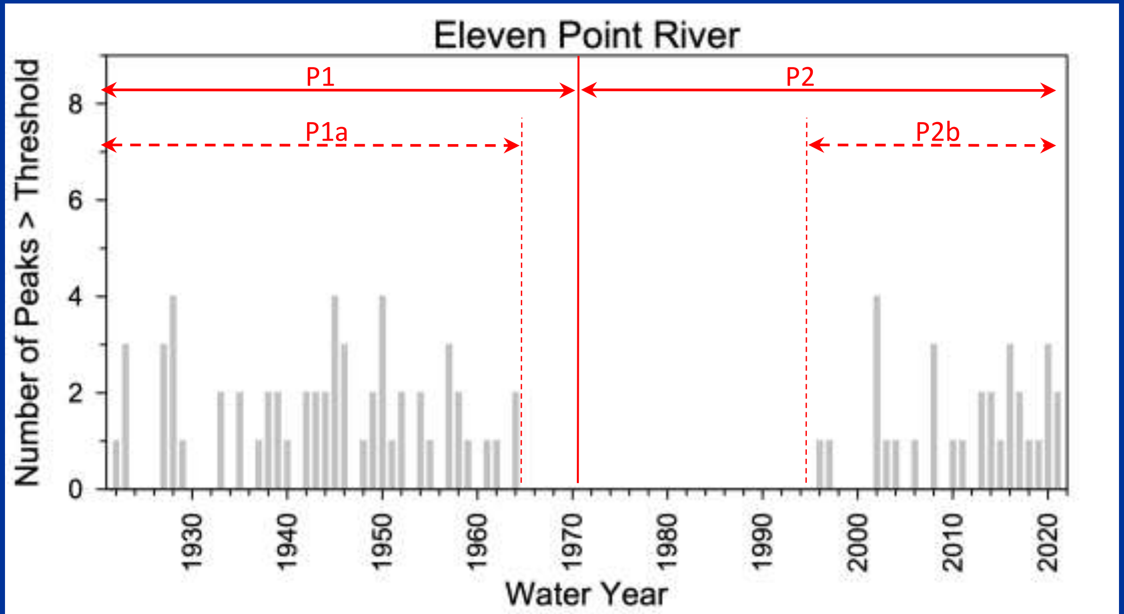
Differences between P1 and P2 are less visually distinct for these Meramec Basin gages than for northern Missouri gages







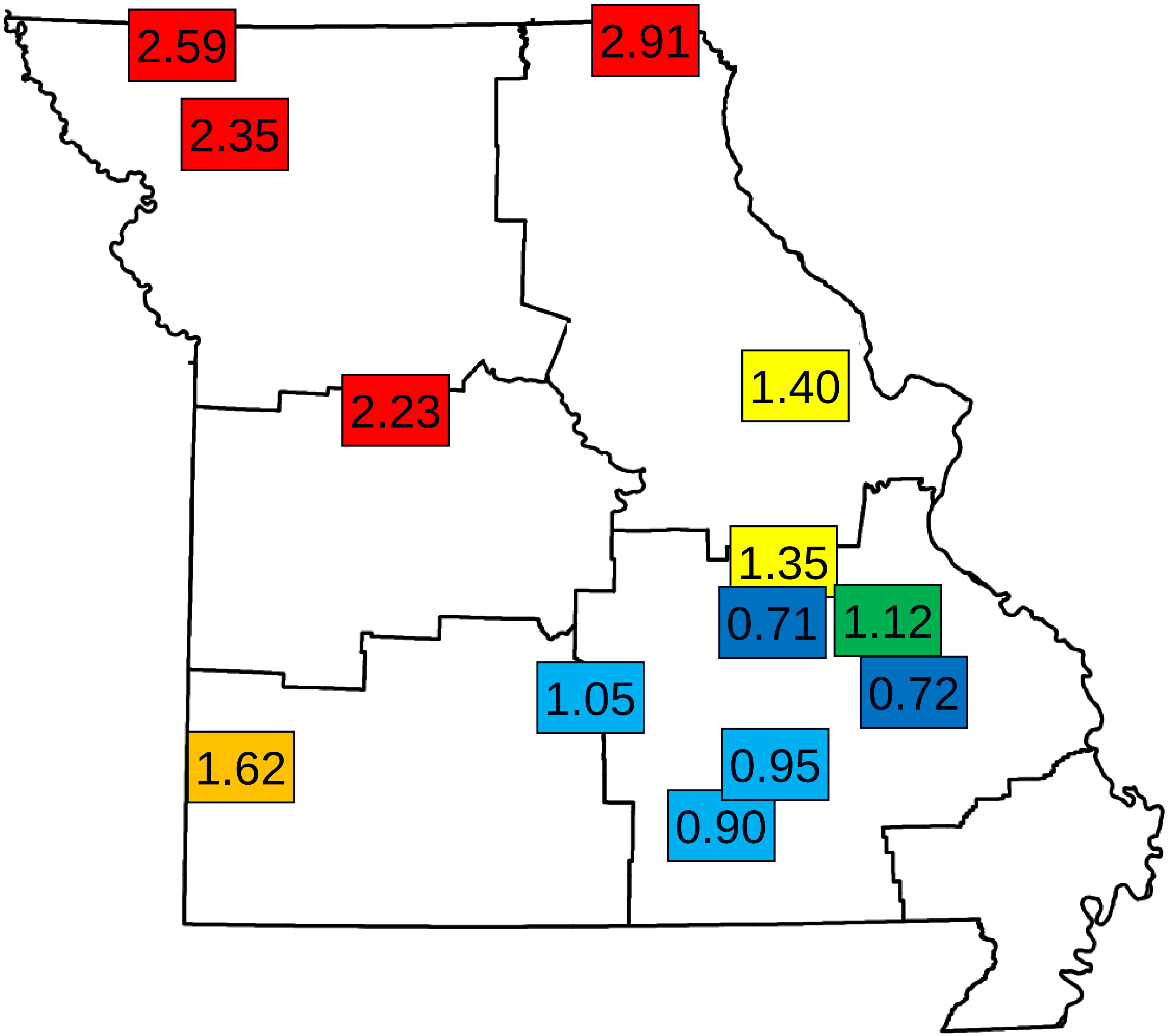




These south draining Ozark watersheds show decreased peaks/year in P2b

Next, we will look at mapping two commonly computed flood events showing a comparison of the value computed from P2b data divided by that of the P1a data

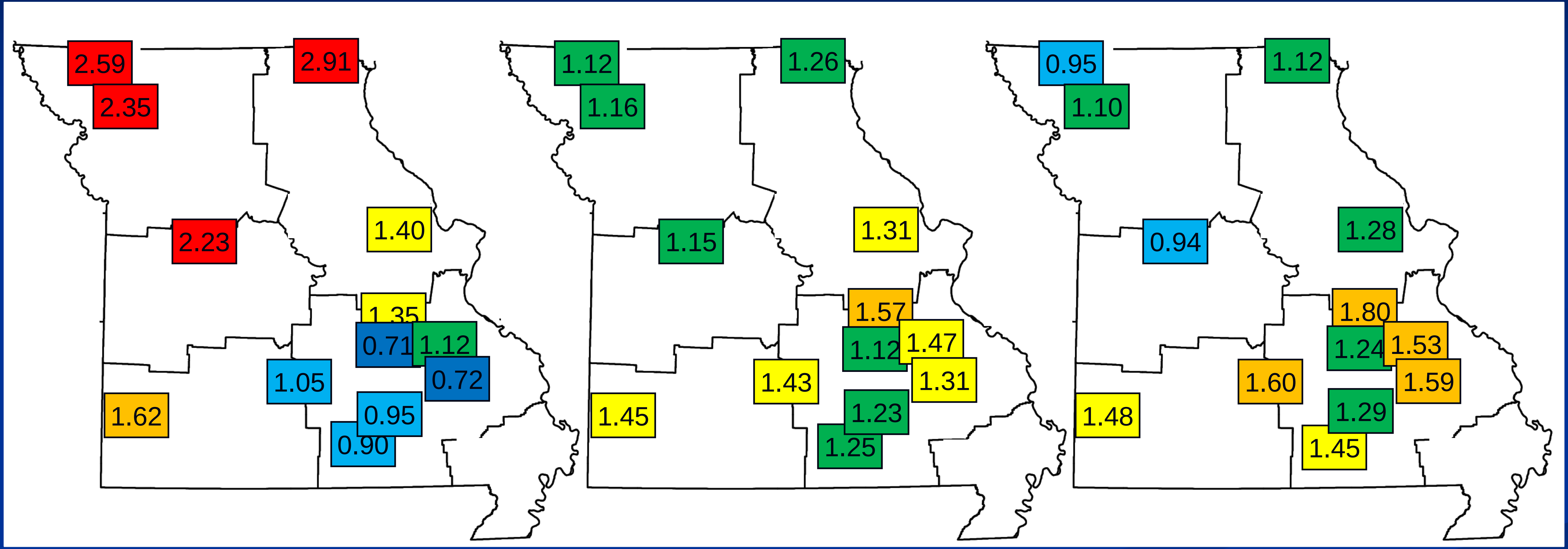
Peaks over threshold per year



	P2b/P1a
XXX	0.7-0.89
XXX	0.9-1.09
XXX	1.1-1.29
XXX	1.3-1.49
XXX	1.5-1.99
XXX	>2

The overbank portion of the flow regime has changed between the time blocks,

but not uniformly



Peaks over threshold per year 10-year flood 100-year flood

Summary

- When looking at 100 years of precipitation, PHDI, or flow data, there has been an overall trend towards wetter conditions in Missouri
- There are upwards trends in groundwater discharge and surface runoff
- The non-uniform changes in the runoff portion of the flow regime are consistent with shifts not only in overall wetness, but also to possible changes in the magnitude, intensity, and/or duration of larger rainfall events.

What time period of flow data should be used?

Climatologists update precipitation statistics every 10 years and use 30 years of data

Hydrologists want as long a period of record as possible to reduce uncertainty for predicting high flow and low flow metrics. But this only works if period has variability but not trends.

Will the hydrology of the future be more like the hydrology of the past, the hydrology of the present, or something different?

What time period of flow data should be used?

One option is to use the period that is most appropriate for the risk being considered. Risk is a function of both the probability and the consequences.

Where does your risk come from?

- Drought
- Infrastructure damage
- Frequent small floods

Remember that hydrologic change may bring new opportunities as well as new risks.

Take-away: Know how the hydrology in your watershed has been altered by climate as well as other anthropogenic changes

USACE also operates the Pomona, Melvern, and Hillsdale Reservoirs in Marais des Cygnes watershed

Upstream of us here at this hotel there are 6 flood control dams and downstream is a hydroelectric dam.

By Kmusser - Self-made, based on USGS data., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=4389913

Take-away: The hydrology presentations have shown changes, not forecasts

- Are your efforts at planning and operations keeping up with changes that have occurred?
- What are you going to do to be ready to adapt to future changes?
- Water is a shared resource, so you cannot adapt independently
- How are you going to engage, advocate, and collaborate with other water users?