Upper Yellowstone River Surface-Water Supply and Trends

Upper Yellowstone River Workshop
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Chuck Dalby, DNRC Water Resources Helena, MT
406-444-6644) cdalby@mt.gov

Existing and future challenges/threats to water resources

--Rural subdivision development

--Availability of water for competing interests
(irrigation, instream flow, municipal)

--Stream channel alteration and stabilization

--Invasive species

--PKD

--Timber harvest

--Forest fires

--Increasing Recreation use

--Maintenance of water quality

Existing challenges/threats magnified by global warming induced climate changes?

Changes observed in Upper Yellowstone Watershed

Observed Water-Related Changes During the Last Century[142]

Observed Change	Direction of Change	Region Affected
One to four week earlier peak streamflow due to earlier warming-driven snowmelt	Earlier	West and Northeast
Proportion of precipitation falling as snow	Decreasing	West and Northeast
Duration and extent of snow cover	Decreasing	Most of the United States
Mountain snow water equivalent	Decreasing	West
Annual precipitation	Increasing	Most of the United States
Annual precipitation	Decreasing	Southwest
Frequency of heavy precipitation events	Increasing	Most of the United States
Runoff and streamflow	Decreasing	Colorado and Columbia River Basins
Streamflow	Increasing	Most of East
Amount of ice in mountain glaciers	Decreasing	U.S. western mountains, Alaska
Water temperature of lakes and streams	Increasing	Most of the United States
Ice cover on lakes and rivers	Decreasing	Great Lakes and Northeast
Periods of drought	Increasing	Parts of West and East
Salinization of surface waters	Increasing	Florida, Louisiana
Widespread thawing of permafrost	Increasing	Alaska

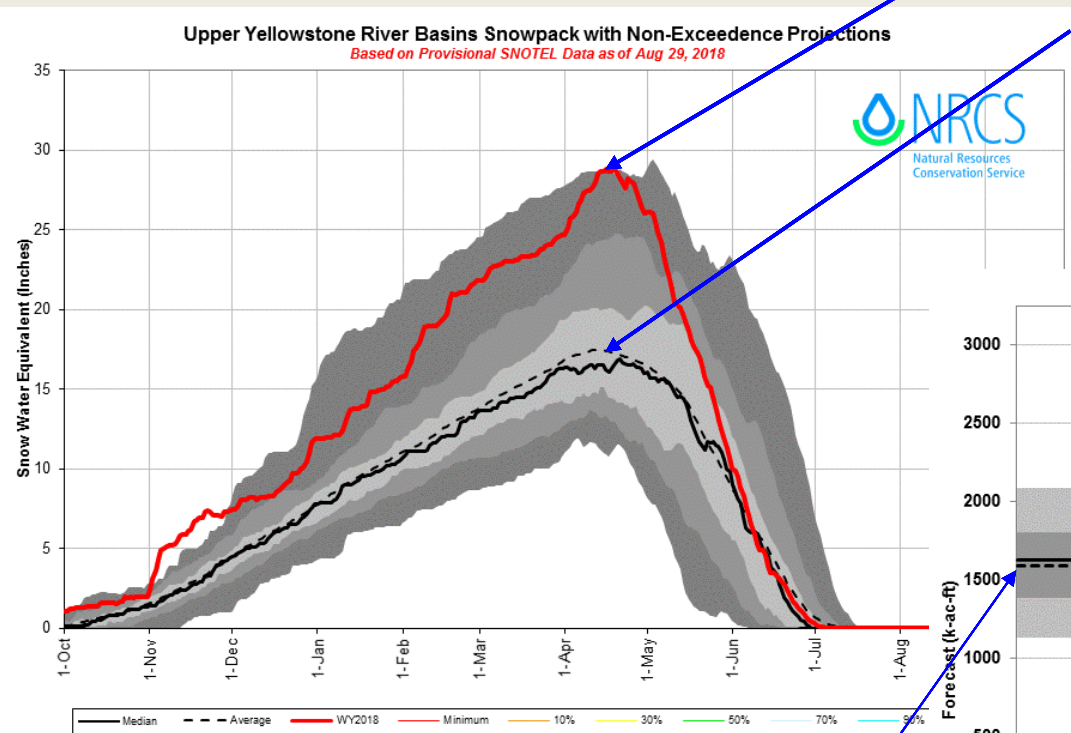
But wait ! How can we have declining snowpack and streamflow with record snowpack and runoff in 2018 ???

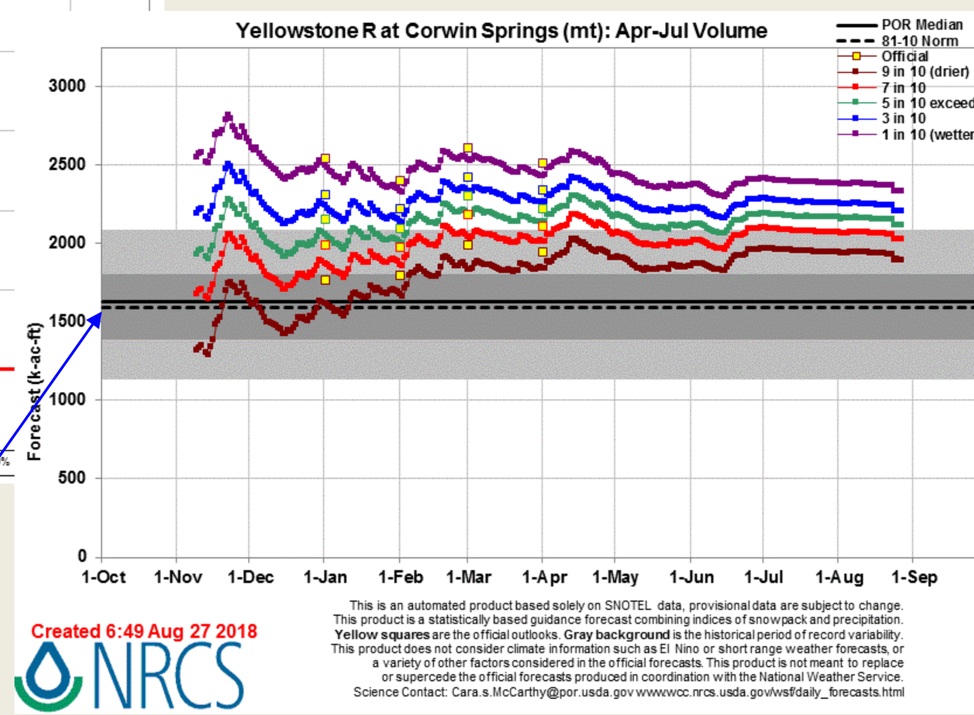
New Snowfall in Billings Breaks Winter Accumulation Record

The mild snowfall that recently covered the Billings area has pushed this winter's total accumulation for the city past the single-season snowfall record.

Upper Yellowstone 2018 snowpack

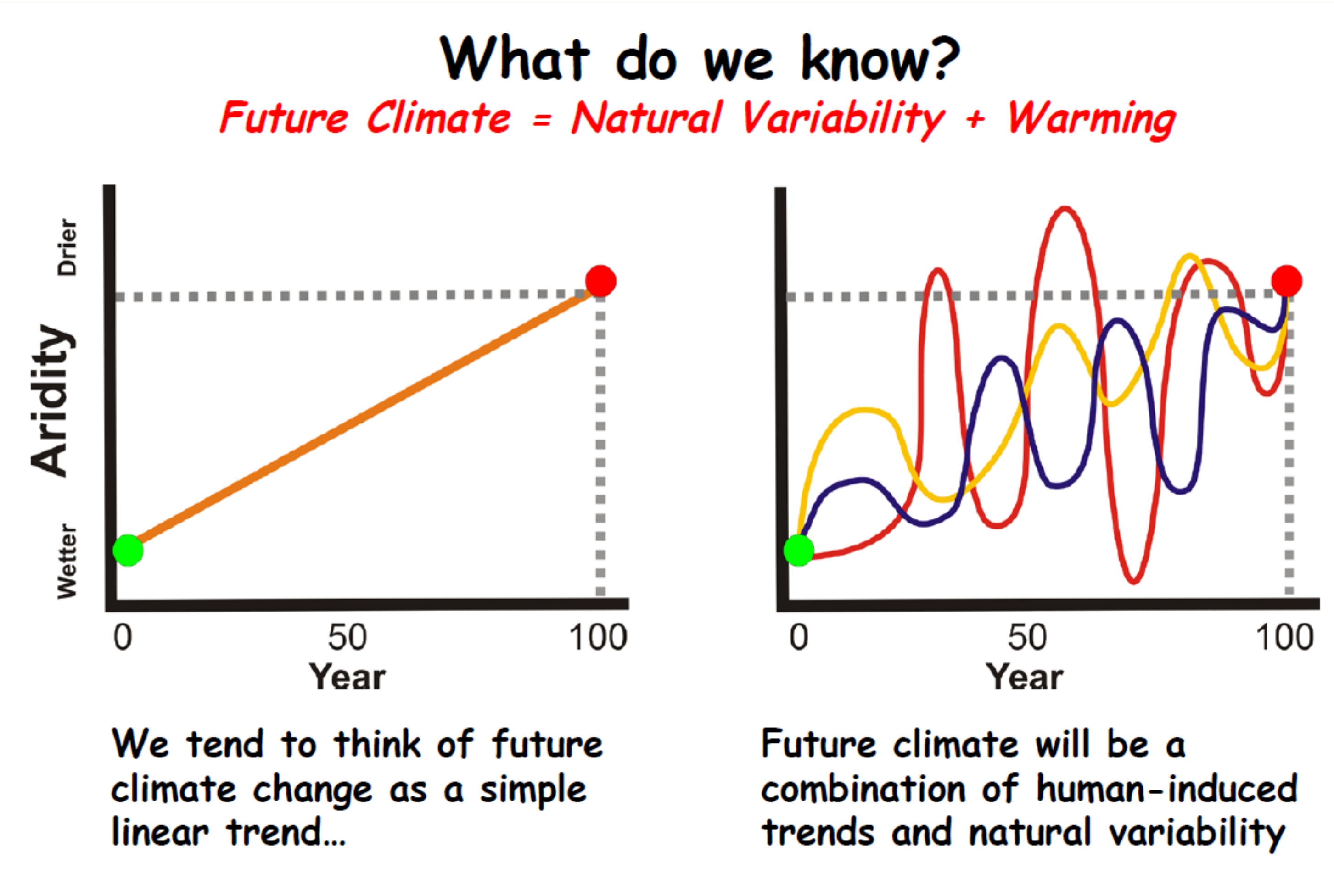
Upper Yellowstone average snowpack





Upper Yellowstone average runoff

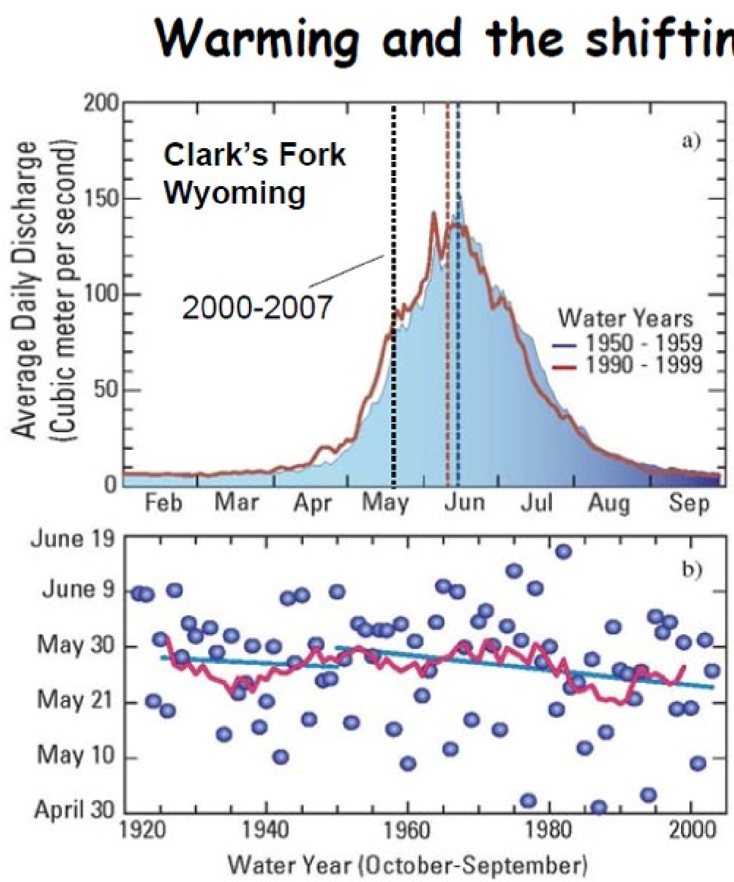
Global heating puts more "energy" into climate system and effects of global warming on snowpack and runoff will be highly variable from year-to-year, but follow general trend



Gray et al. (2006), *Ecology* 87:1124-1130

Potential Effects of global warming on Upper Yellowstone River Streamflow

How might we expect streamflow to change with global warming ?



Consequences:

- Earlier run-off
- Faster run-off
- Diminished late-season flow

Increased year-to-year variability in moisture, temperature and runoff

Courtesy Mike Dettinger, USGS

Upper Yellowstone Surface-Water Supply and Trends

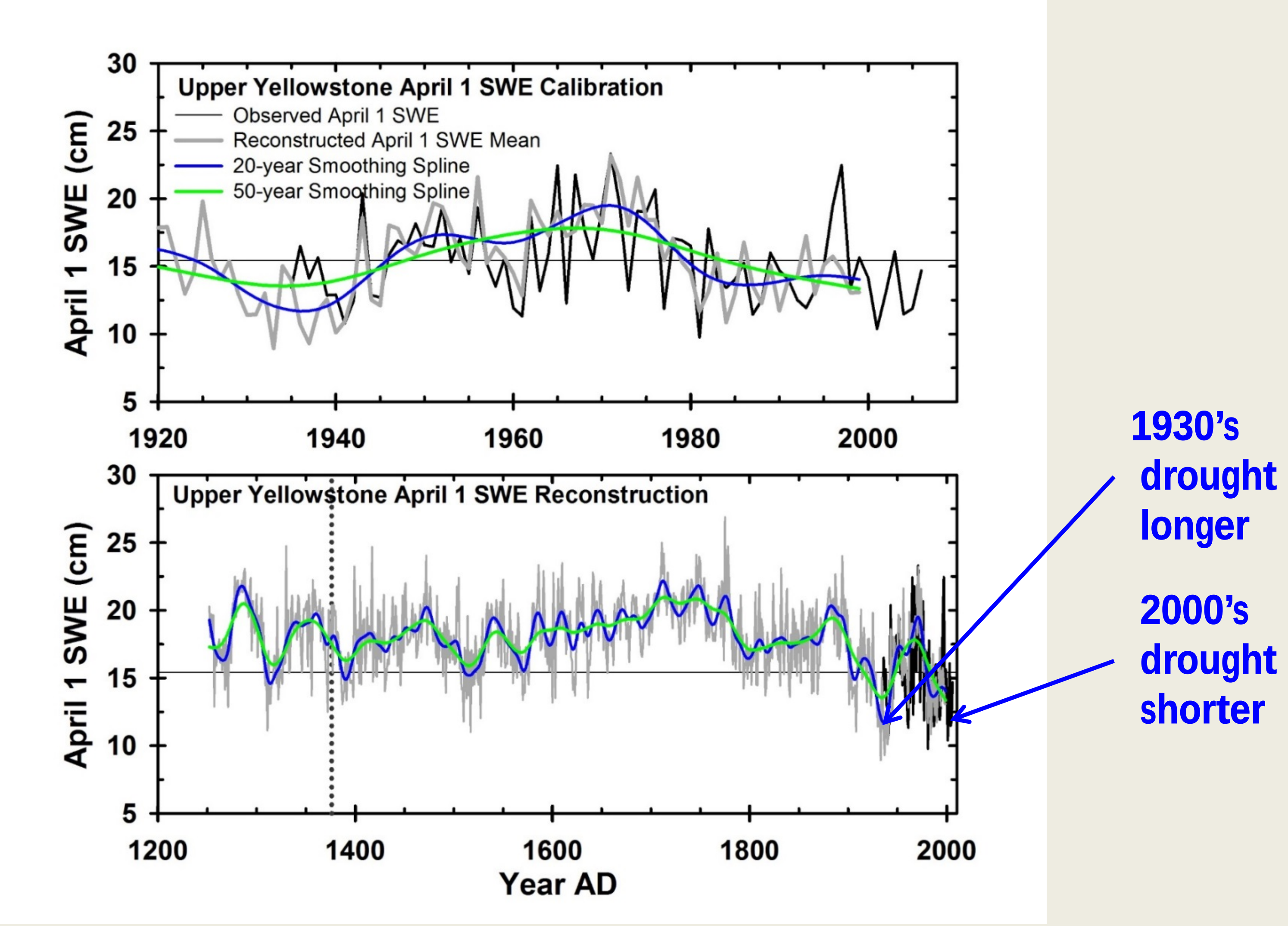
Examined snowpack at Lick Creek NRCS SNOTEL site and streamflow records at Corwin Springs and Livingston (Carter's Bridge) USGS stream gages for changes/trends in:

Snowpack—snowpack size controls runoff volumes—peak flows influenced by snowpack size and temperature
(temperature--controls rate of melt and if it arrives as rain or snow)

Annual flow—total volume of flow moving past stream gage
(sometimes expressed a constant daily rate (cubic-feet-second) that would produce the same volume in 365 days);

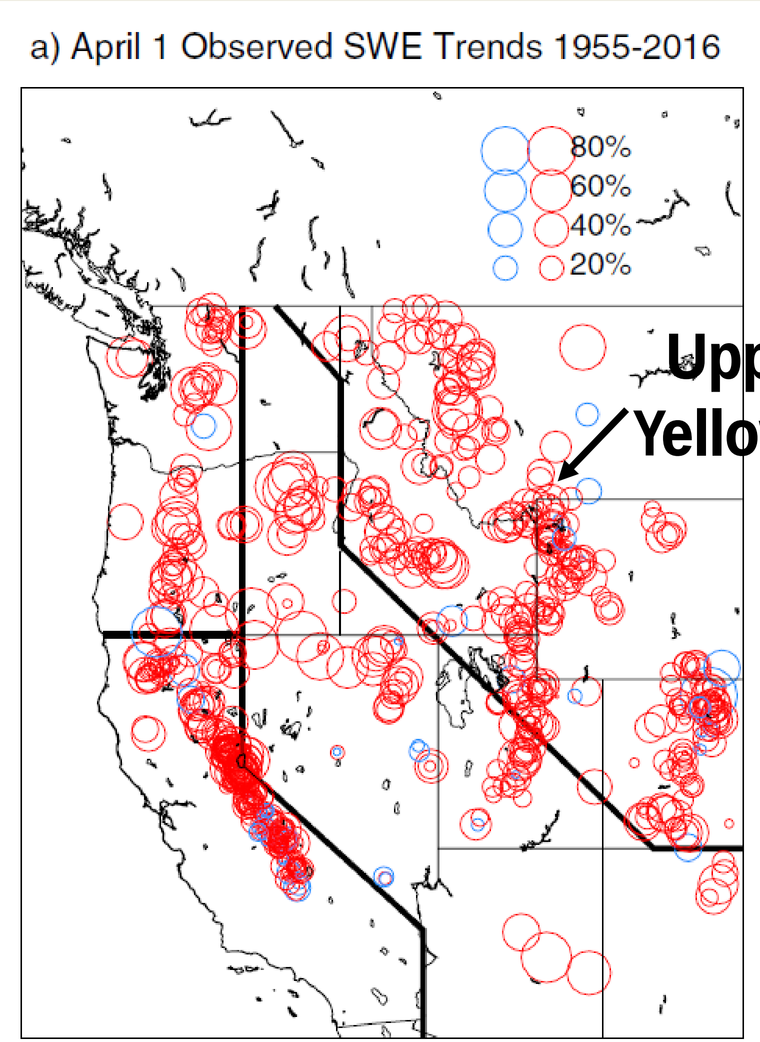
Peak flow – the instantaneous flow that is the largest in a year.

Long-term (1250 to 2004 A.D.) reconstruction of April 1 Snow Water Equivalent (SWE) available from tree-ring Paleo records



Source: Greg Pederson, USGS Bozeman

Recent study shows “dramatic” declines in Western Snowpack



npj | Climate and Atmospheric Science
www.nature.com/npjclimatsci
ARTICLE OPEN

Dramatic declines in snowpack in the western US

Philip W. Mote[1], Sihan Li[2], Dennis P. Lettenmaier[3], Mu Xiao[3] and Ruth Engel[3]

--90 % of snow monitoring sites show declines;

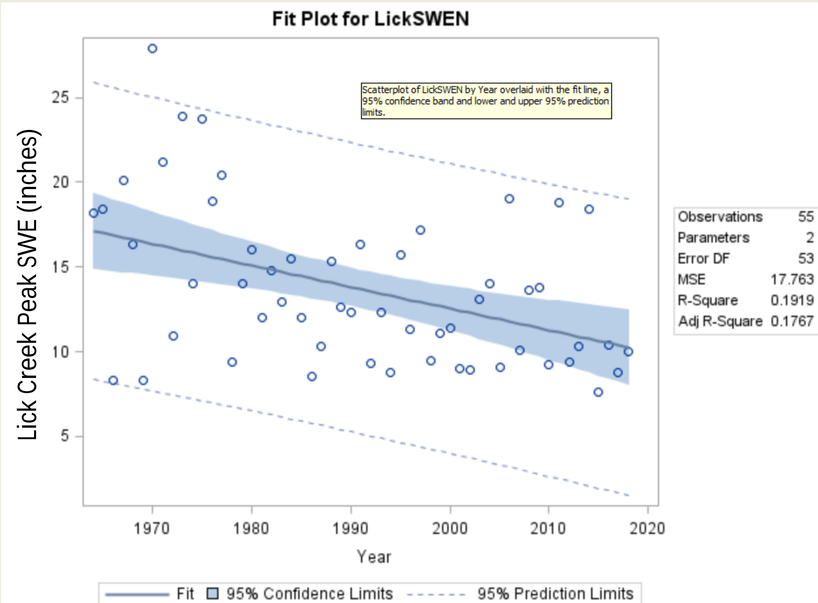
--declining trends across all months, states, and climates;

--averaged across western US, the average decline in April 1 SWE (since 1950) is 15 to 30%.

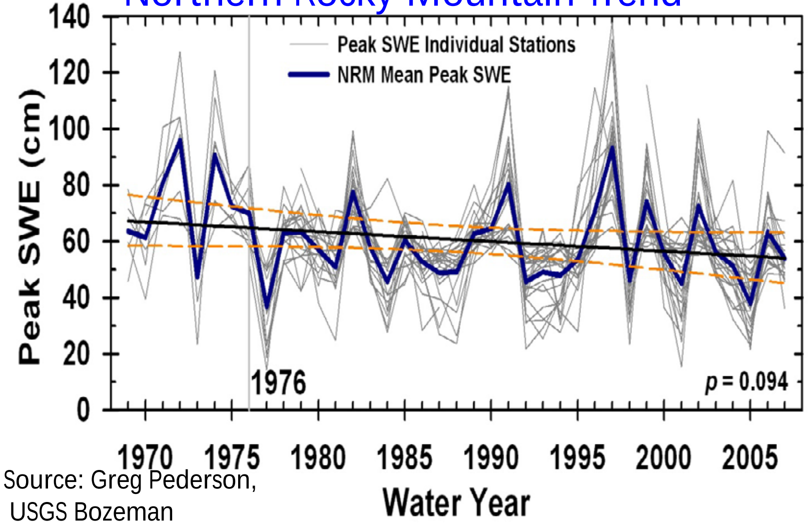
This amounts a total of about 12,160,697 to 24,321,395 acre-feet of water across the western U.S.

(for comparison the average annual runoff of Yellowstone basin near Sidney is about 8 million acre-feet).

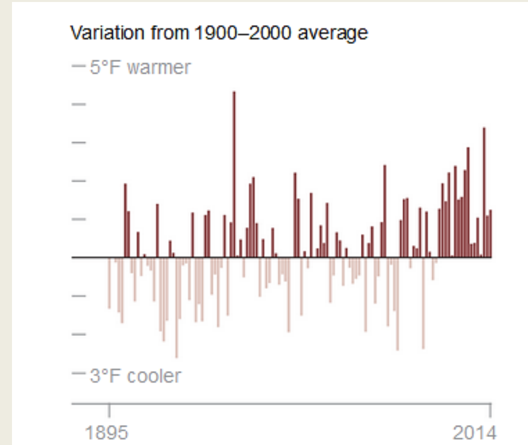
Plot of Lick Creek maximum snow water equivalent (SWE) over 1964 to 2017 indicates **30% decline peak amount of accumulated snow**

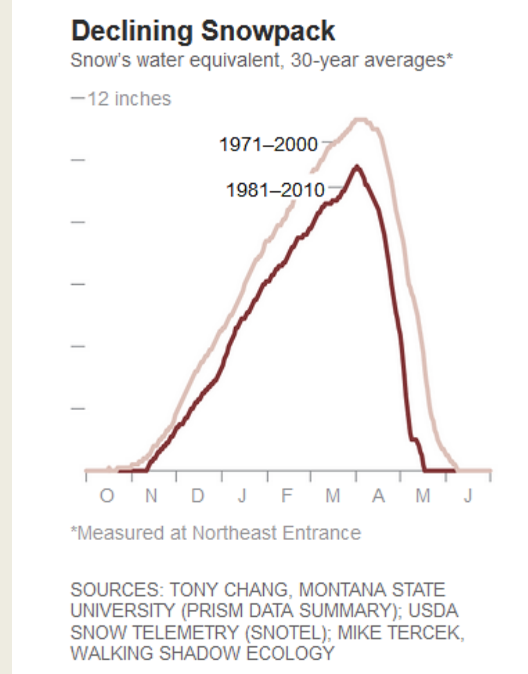


Northern Rocky Mountain Trend



Source: Greg Pederson, USGS Bozeman



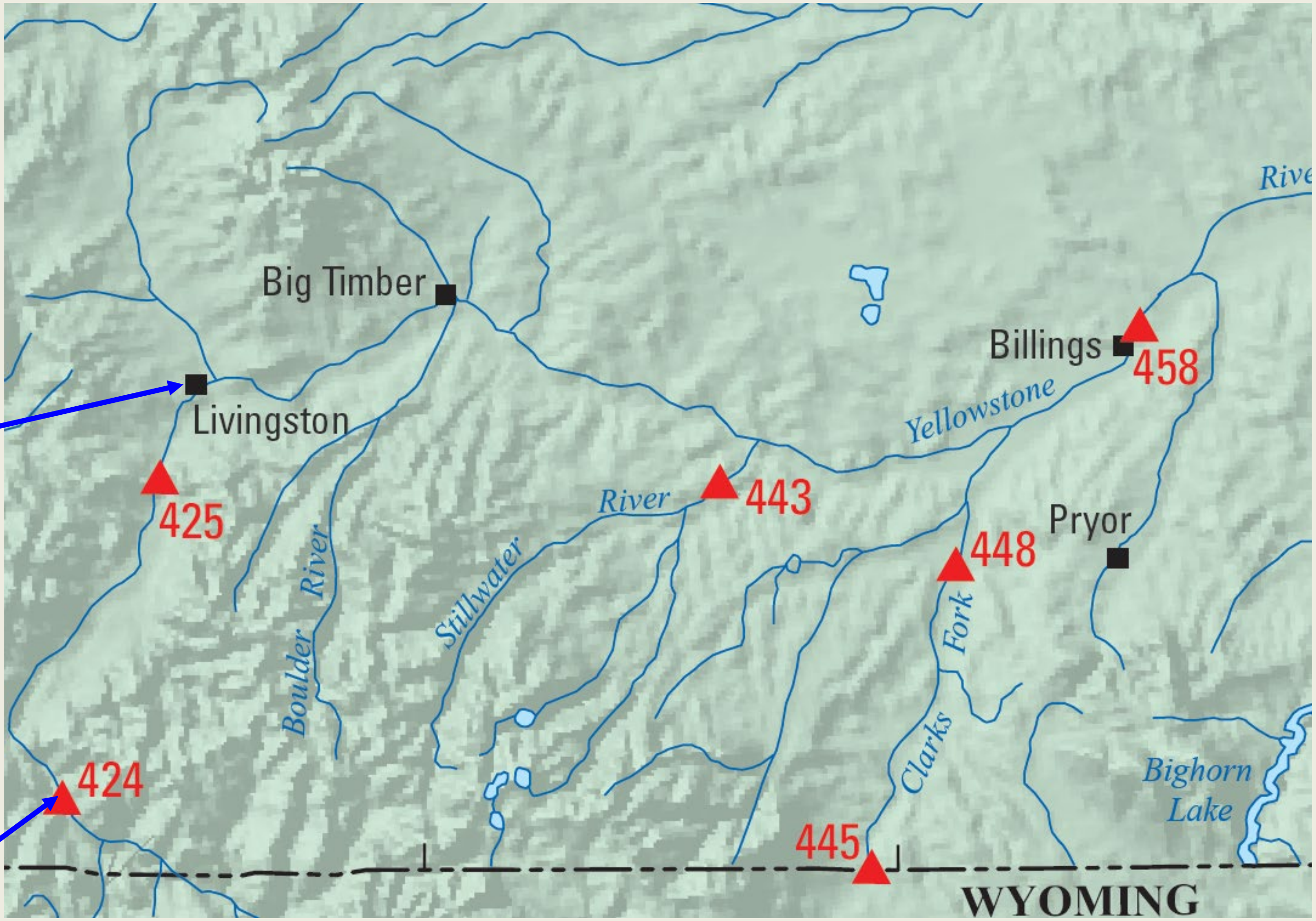


(from National Geographic—courtesy of Mike Tercek)

Location of Upper Yellowstone USGS Stream Gages examined for trends in timing of runoff, annual flow, and peak flow

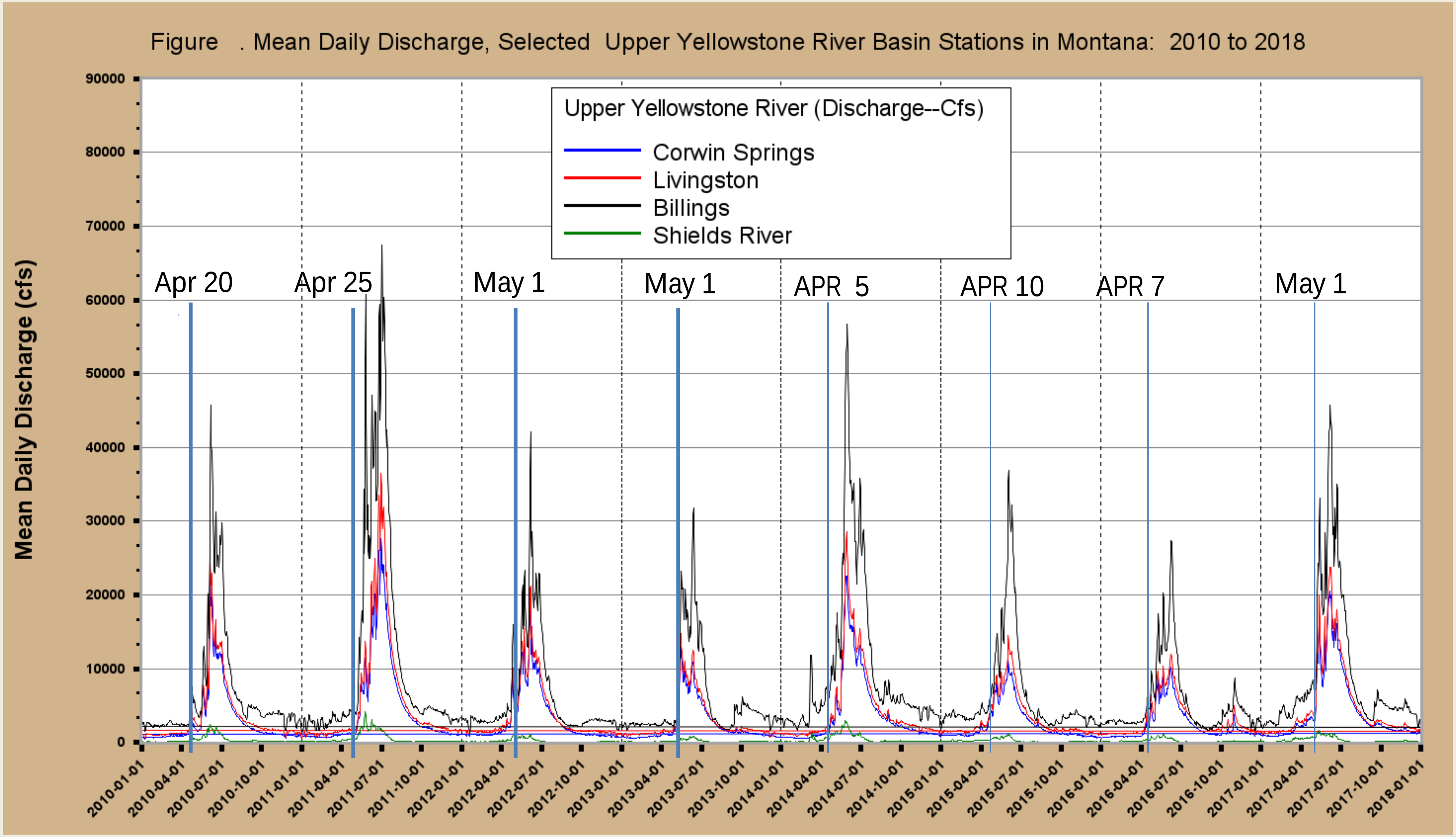
Yellowstone River Near Livingston (Carter's Bridge

Yellowstone River at Corwin Springs



Timing of runoff: is runoff starting earlier ?

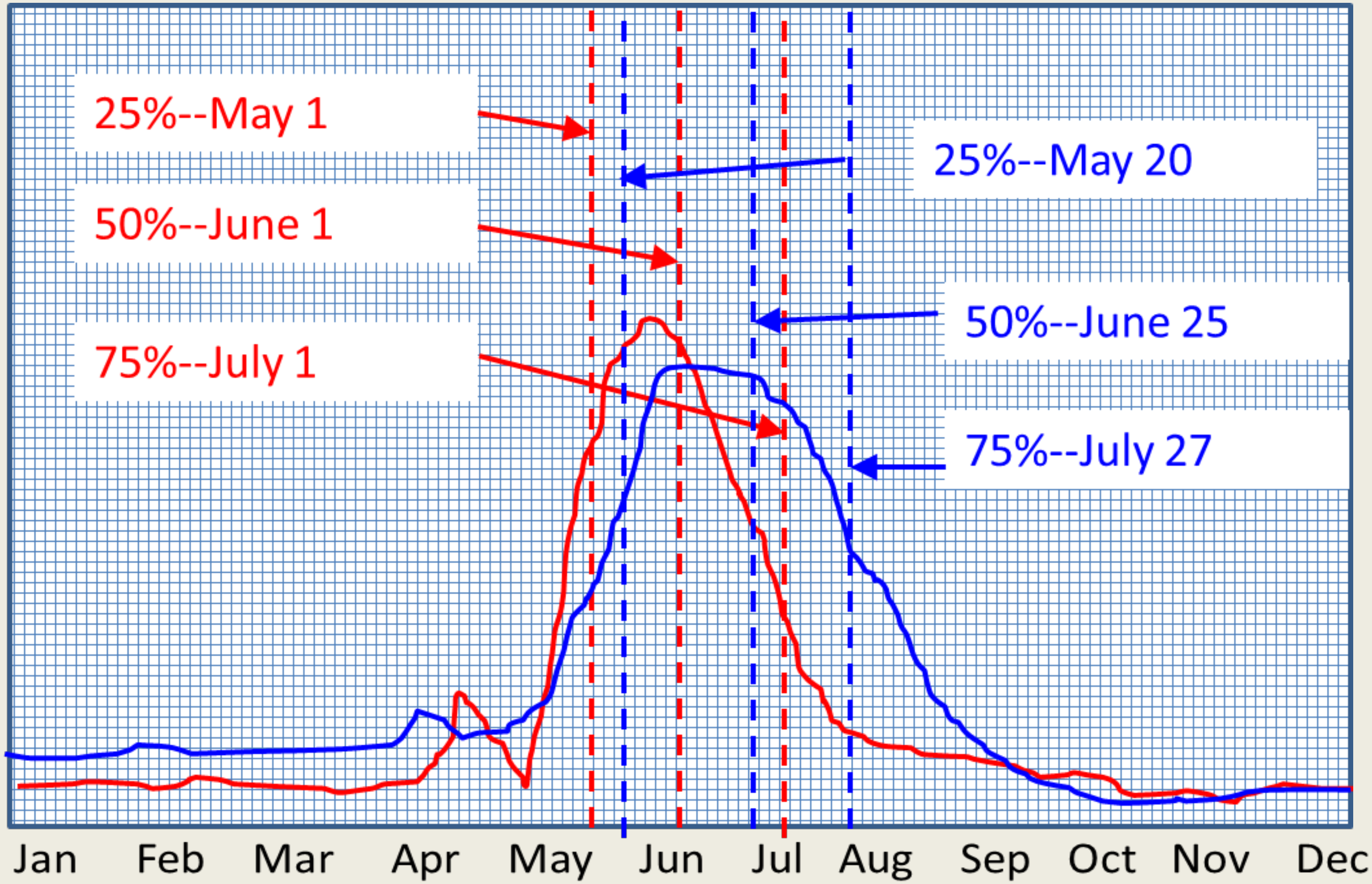
(not clear without better analysis of longer record)



Is runoff starting earlier ?

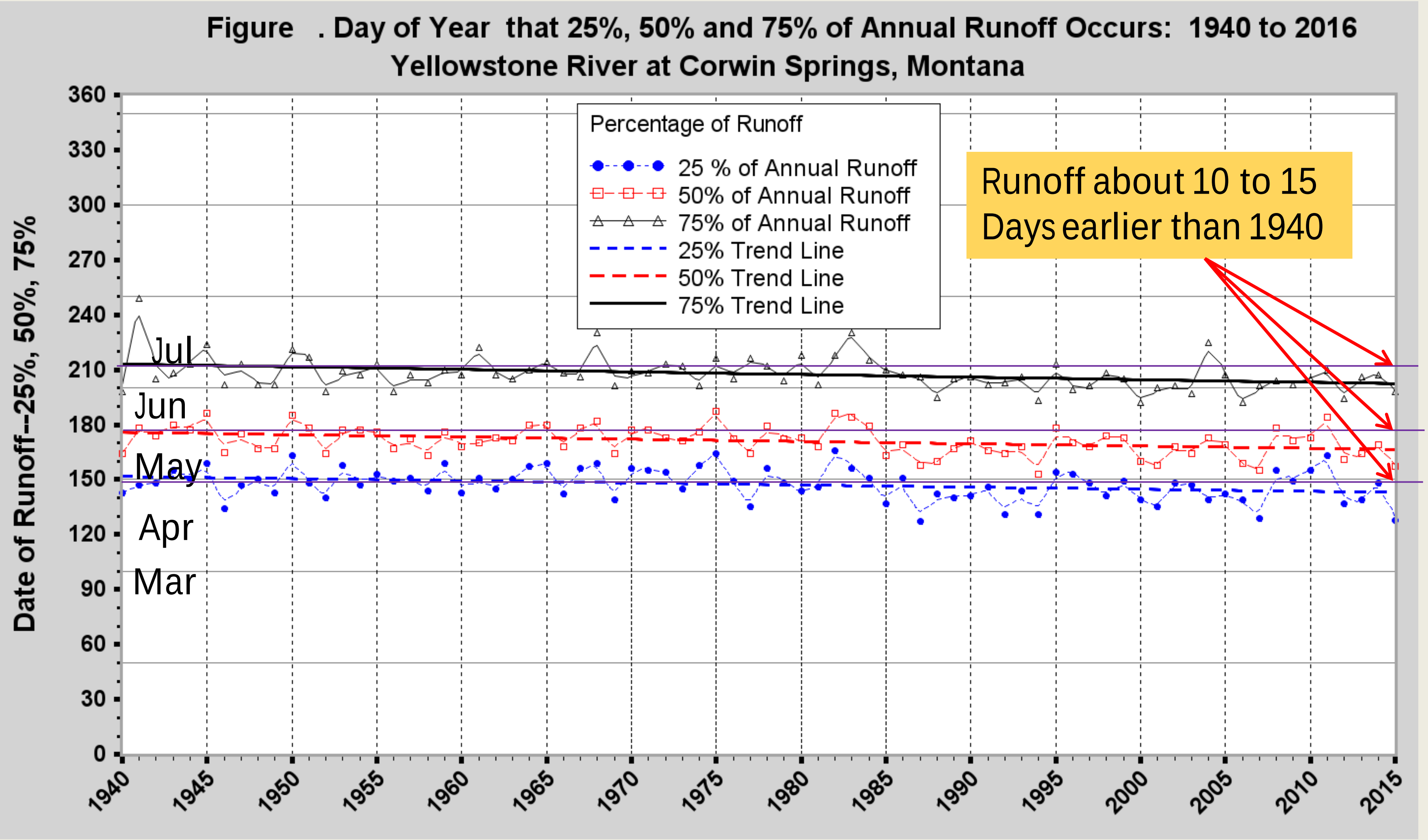
To figure that out:

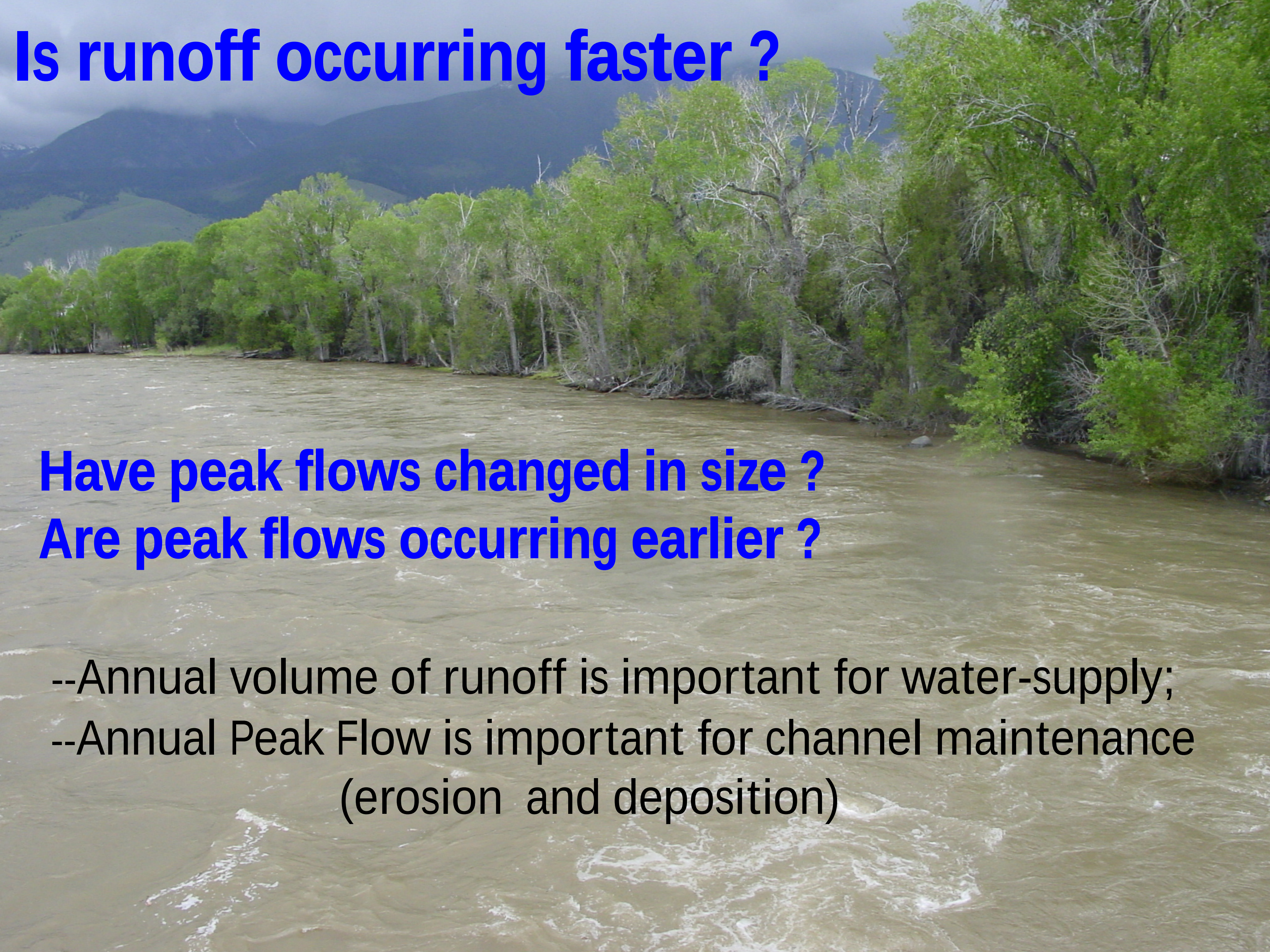
For each year (1940-2016) calculate the date that 25, 50 and 75% of annual runoff occurs ?



Example of hydrograph shifted (left) in response to earlier snowmelt.

Is runoff starting earlier at Corwin Springs USGS Gage ?



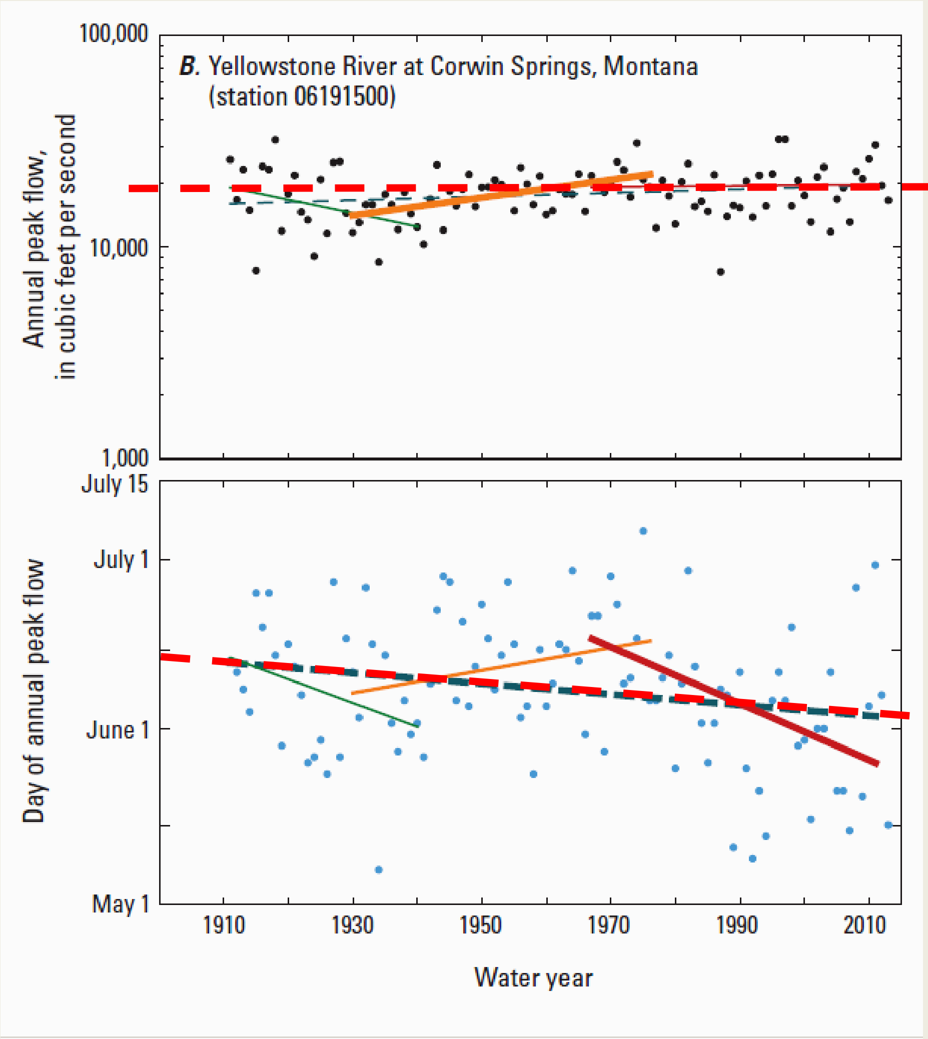


Is runoff occurring faster ?

Have peak flows changed in size ?
Are peak flows occurring earlier ?

--Annual volume of runoff is important for water-supply;
--Annual Peak Flow is important for channel maintenance
(erosion and deposition)

Are peak flows increasing in size or occurring earlier at Corwin Springs USGS Gage ?



Size of peaks
not increasing

Peaks occurring
2 to 3 weeks earlier

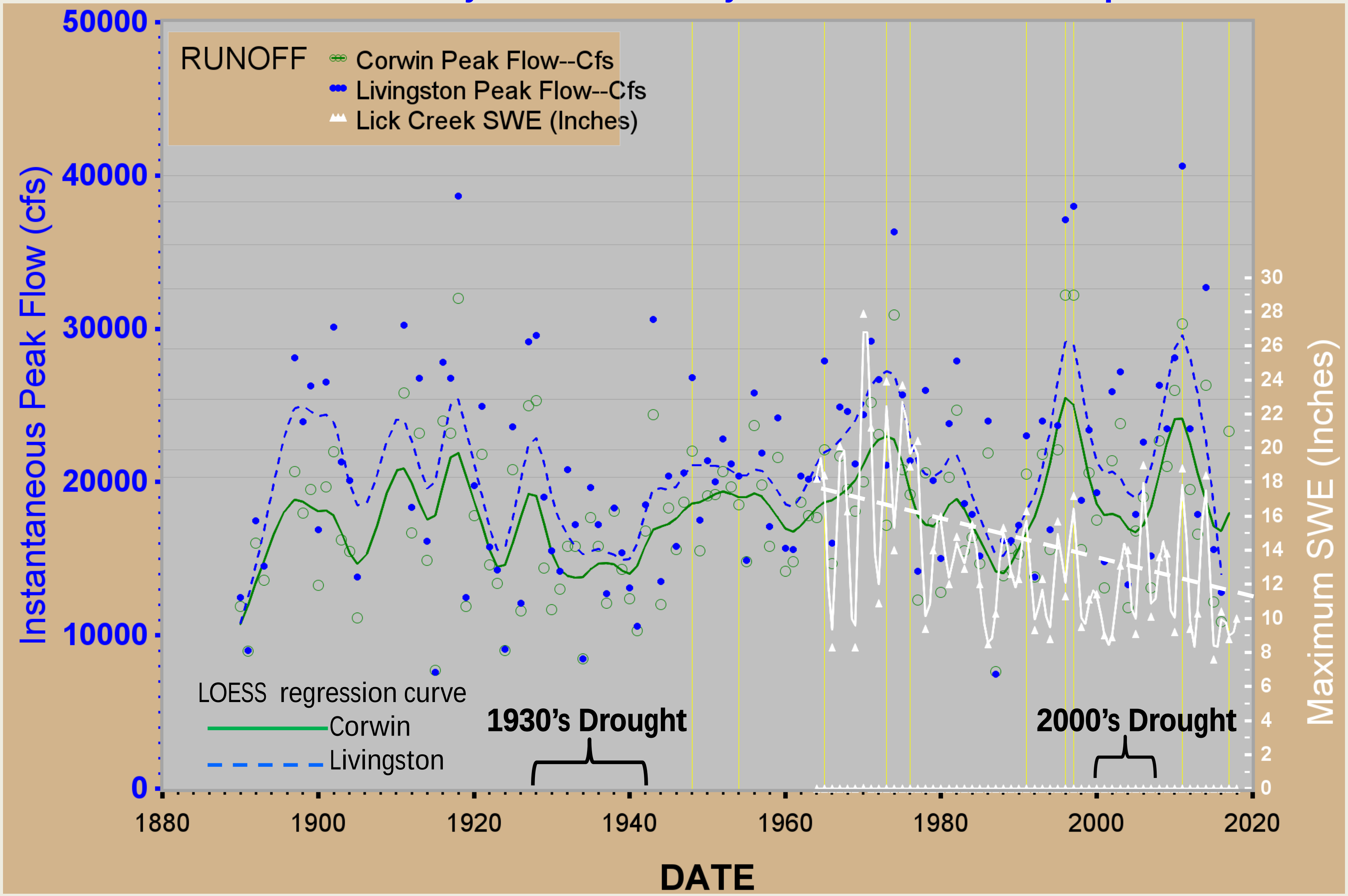
Temporal trends and stationarity in annual peak flow and peak-flow timing for selected long-term streamflow-gaging stations in or near Montana through water year 2011: Chapter B in *Montana StreamStats*

Scientific Investigations Report 2015-5019-B

Prepared in cooperation with the Montana Department of Transportation and Montana Department of Natural Resources and Conservation

By: Steven K. Sando , Peter M. McCarthy , Roy Sando , and DeAnn M. Dutton

Pattern of peak flows shows no trend from 1880 to 2017—but does show annual variability due to natural cycles in climate and snowpack



Are late-season (base-flows) flows diminished ?

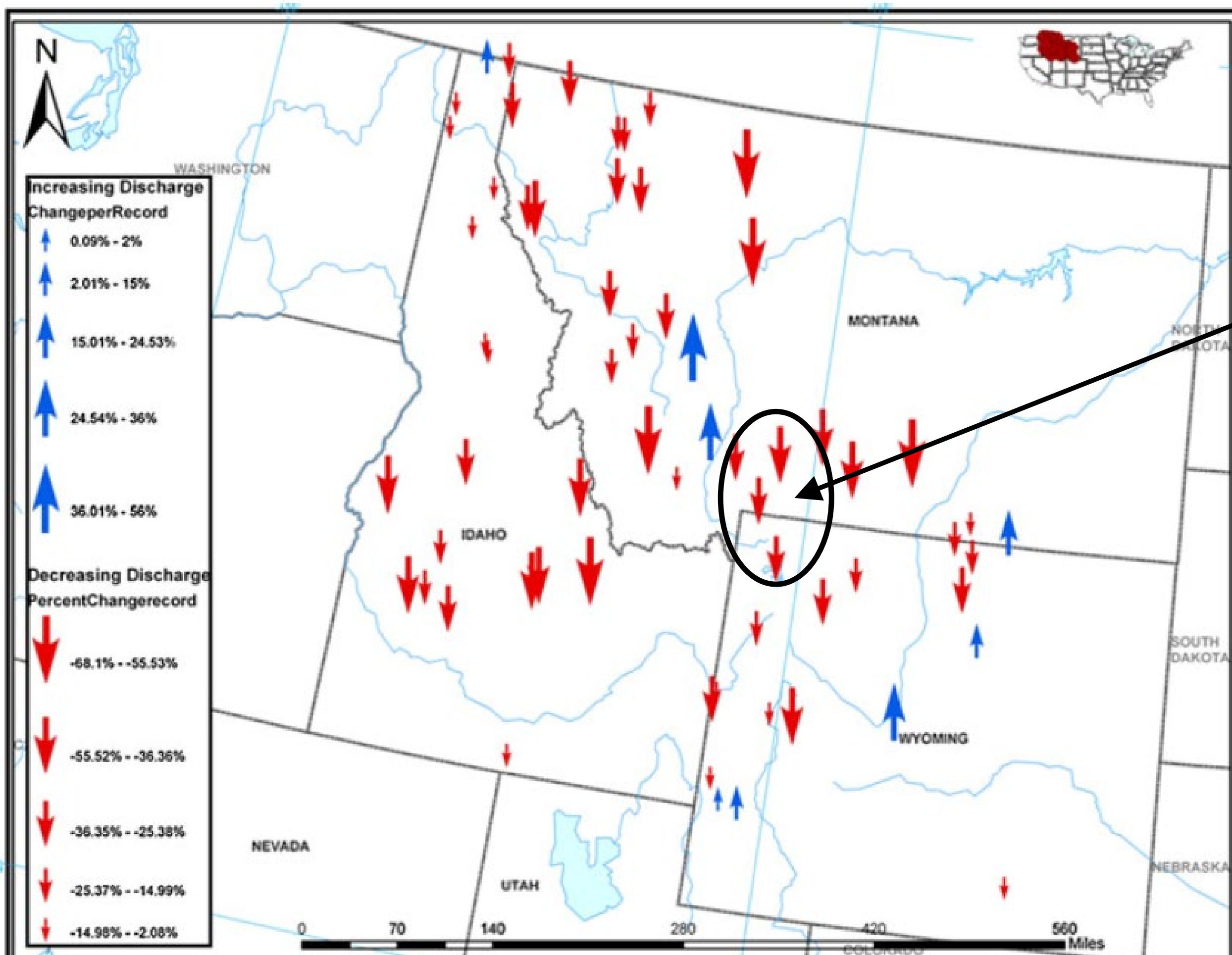


Fig. 5 Amount and type of normalized discharge change per record across the Central Rockies. The downward pointing red arrows signify a decreasing slope and the upward pointing blue arrows signify an increasing slope. The Larger the arrow the larger the discharge change at each gauging station. This figure shows a decreasing trend across the study area with very few positive slopes

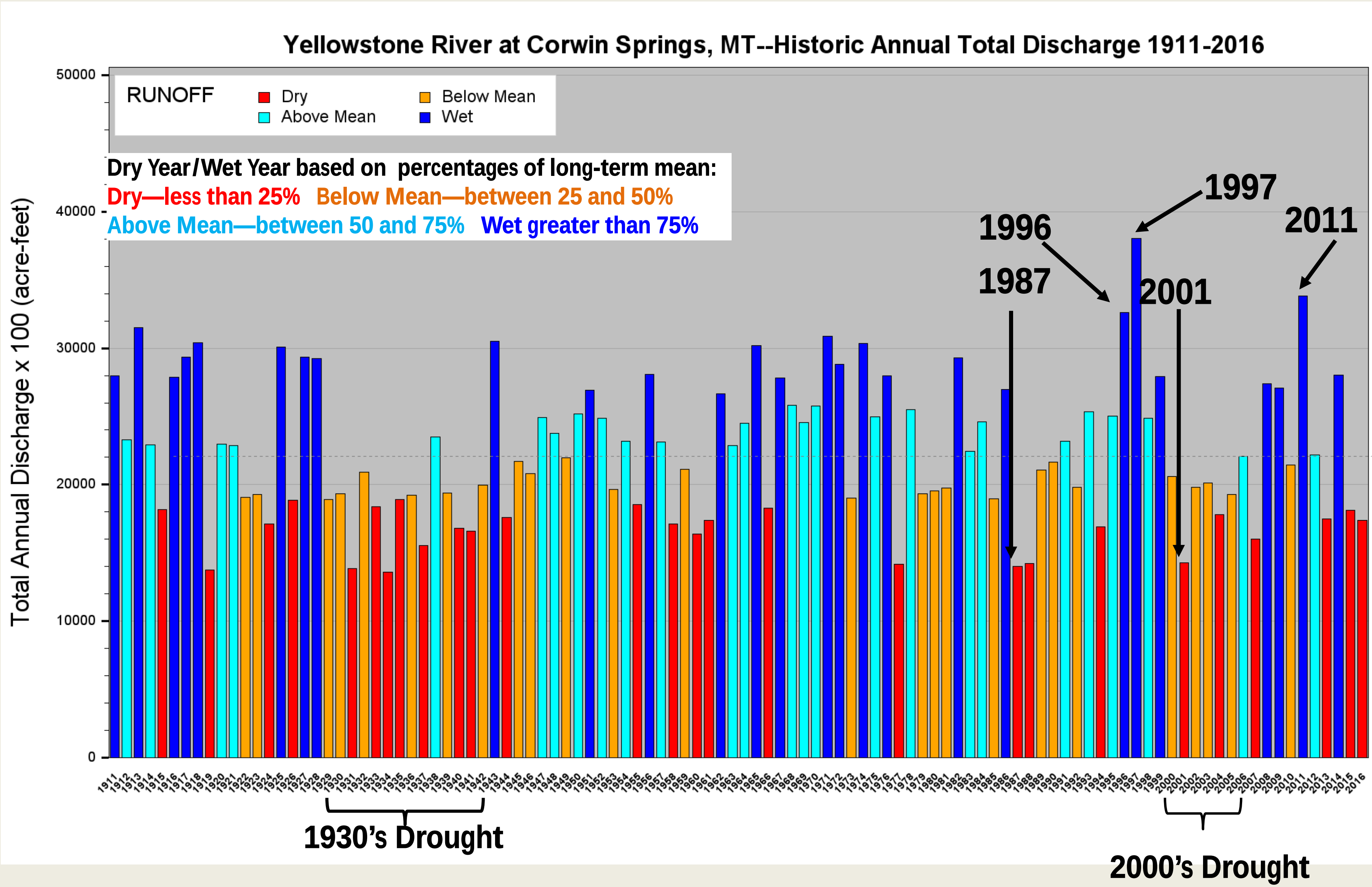
25 to 35% Decline in August Streamflow

Climatic Change (2012) 112:997–1014
DOI 10.1007/s10584-011-0235-1

Impacts of climate change on August stream discharge in the Central-Rocky Mountains

Jason C. Leppi · Thomas H. DeLuca · Solomon W. Harrar · Steven W. Running

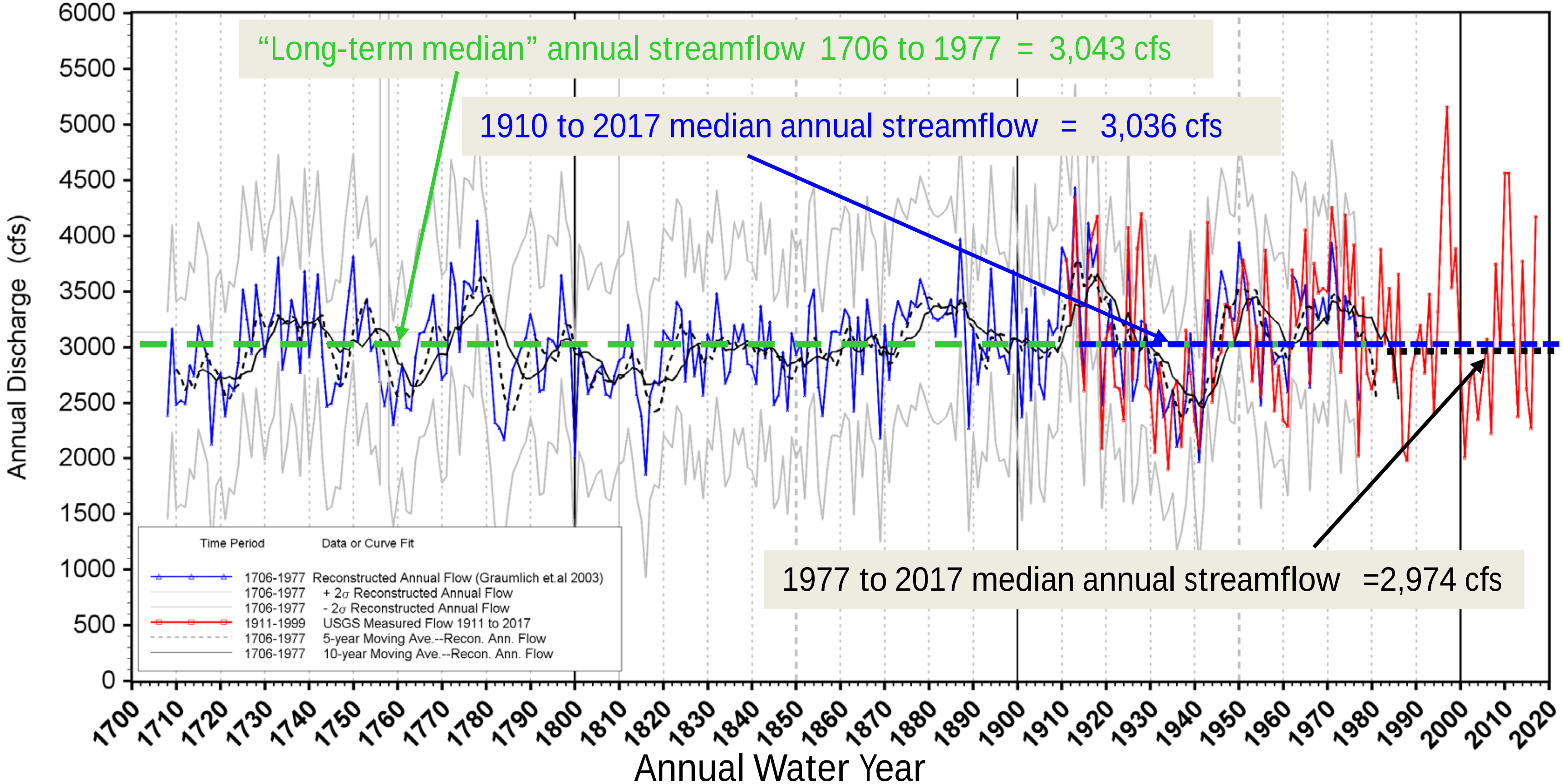
Corwin Springs—Annual volume of runoff in sequence 1911 to 2016



Tree-ring re-constructed annual runoff (Graumlich and others, 2003) for Yellowstone River at Corwin Springs suggests no long-term trend in annual streamflow, with recent years close to the long-term median, but highly variable.

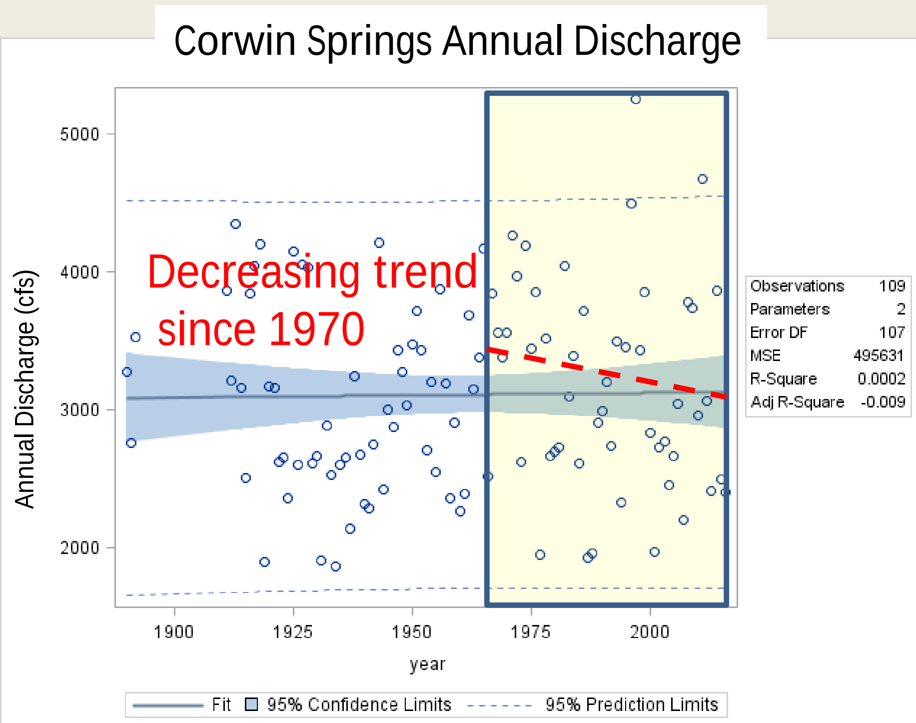
Figure . Annual Runoff -- Yellowstone River near Corwin Springs, Montana (U.S. Geological Survey Station 06191500)

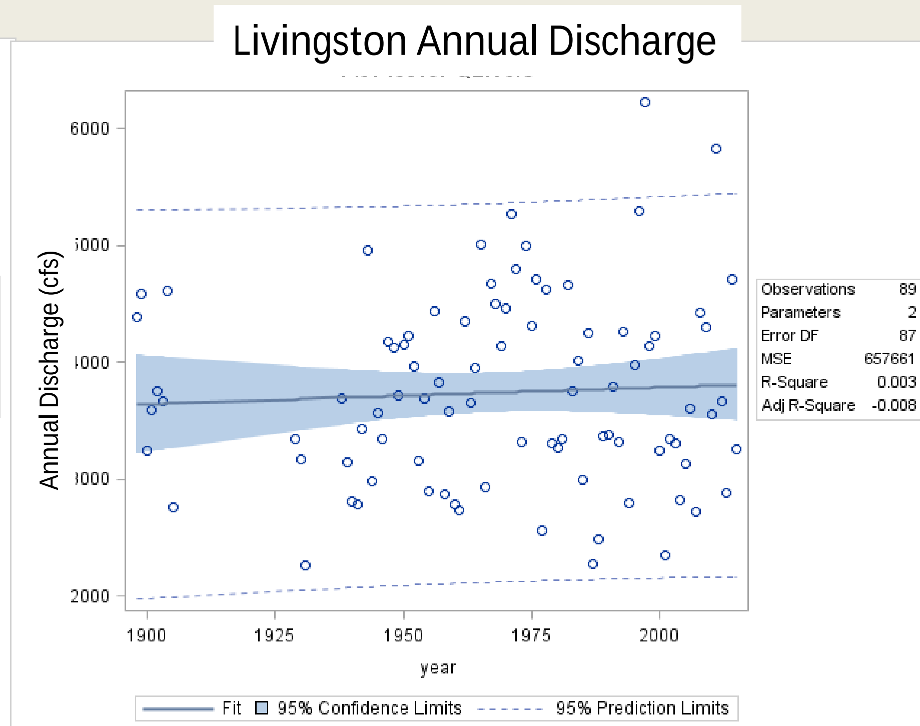
Tree-Ring Reconstructed Annual Runoff (1706 to 1977) and Measured Annual Runoff (1911-2017) by Water Year



Flow reconstruction by Graumlich et.al. 2003 (Upper Yellowstone River flow and teleconnections with Pacfic Basin climate variability during the past three centuries(Climatic Change 59:245-262).
Annual streamflow 1706-1977 reconstructed by Graumlich et.al. (2003) using upper Yellowstone tree-ring width chronologies and extra-regional climate parameters.
Data Source: Reconstructed Annual Flow, -2 and + 2 Standard Deviation of Flow, and USGS Measured Flow = Graumlich, L.J., et.al., Upper Yellowstone River Flow Reconstruction International Tree-Ring Data Bank. IGBP PAGES/World Data Center for Climatology, Data Contribution Series #2002-074. NOAA/NGDC Paleoclimatology Program, Boulder CO, USA.
Five and ten-year moving averages computed from retrieved data. (DNRC Water Resources Division, Helena, MT.)

Graphs of annual discharge over time *suggest* lack of long-term trend or declining trend at Corwin Springs– *depending* on length of streamflow record analyzed





TRENDS in STREAMFLOW and SNOWPACK—CONCLUSIONS

Global-warming induced climate change has significantly affected Upper Yellowstone snowpack and streamflow over the past 50 years.

- Snowpack in the Upper Yellowstone Watershed has declined by about 30% since 1950 and is melting 5 to 15 days earlier.
- Runoff at Corwin Springs is starting 10 to 15 days earlier than 1940.
- No trend in peak flows at Corwin Springs; peaks occurring 2 to 3 weeks earlier.
- Late season “base flow” has declined 25 to 35% in Upper Yellowstone
- Annual volume of water is highly variable since 1700 and shows multi- year wet and dry cycles; existence of trend depends on time period examined; decreasing trend of about 15% from 1975-2016

What do these changing climate conditions mean for Upper Yellowstone Water Uses ?

--Increasing variability in year-to-year water supply with higher highs and lower lows (2011 or 2018 runoff could be followed by extended drought);

-Increasing variability in irrigation water supply and length of growing season;

--Aquatic ecosystems will be more stressed by elevated water temperature and changes in the pattern of runoff;

--Competition for existing uses of water (for example irrigation and instream flow) is likely to increase;

--Get used to smoky summers.

Key Message: Cooperation among all water users will be increasingly important. Framework for doing this is an effective Drought Management Plan.