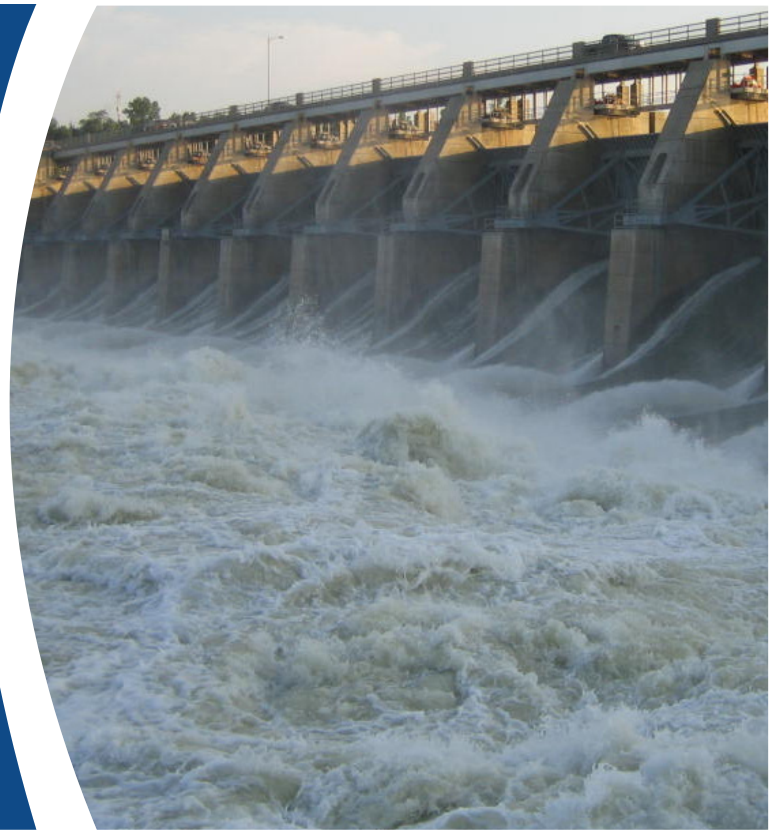
Explaining Hydrologic Extremes in the Upper Missouri River Basin

Background

Nine of the ten largest flood events in the Upper Missouri River Basin (UMRB) since records began in 1898 have occurred since 1970. Dry years have also continued to occur, analogous to low runoff years of the Dustbowl era. As a result, yearly volatility in runoff has become much more extreme since 1970, due mainly to changes in the character of high runoff events.

Researchers from the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado's Cooperative Institute for Research in Environmental Sciences (CIRES) have studied the physical causes for the recent increase of high annual runoff in the UMRB and present their findings in a new assessment report.

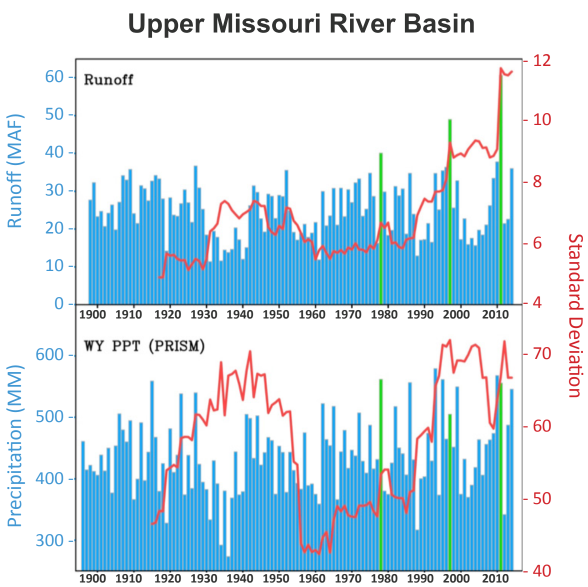


Major Findings

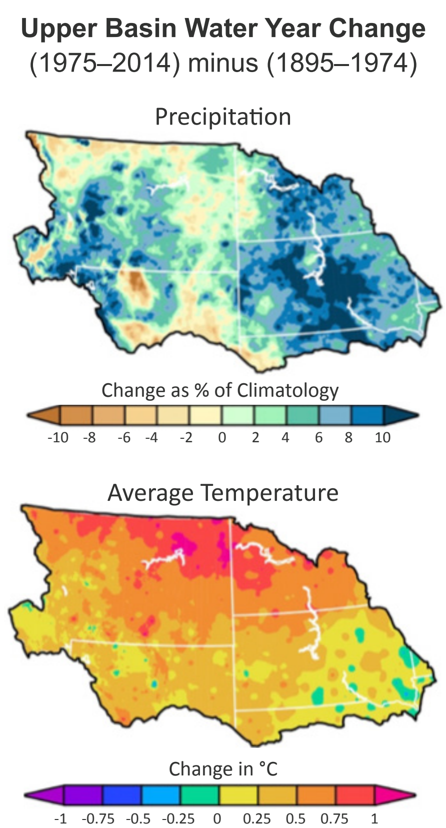
The increased frequency of high annual runoff events in the last 40-year period, as measured by naturalized runoff at Sioux City, Iowa, resulted mainly from the land surface response to increased precipitation falling over the UMRB. Runoff production was shown to be especially sensitive to two features of observed meteorological changes during 1975-2014 (relative to 1895-1974):

- A seasonal wetting that saw the largest percentage increases (+12%) occur during the cold season (October-March).
- A regional wetting that saw the strongest wet trends occur over South Dakota and the eastern one-third of the upper basin (up to +20%).

Using historical meteorological data and land surface models, the report paints a picture of an upper basin that is inefficient at converting annual precipitation to runoff. A runoff coefficient of only about 8% indicates that less than 1/10th of the annual precipitation falling over the upper basin is realized as runoff at Sioux City, Iowa. This low runoff efficiency is unique compared to other parts of the country, where for example runoff efficiencies can be as high as 50% or greater in the humid East and Pacific Northwest. UMRB efficiency is higher in the cold season, and thus the greater increase in precipitation at that time of year led to an amplified runoff response. Land model experiments demonstrate an acute runoff sensitivity to soil moisture conditions over eastern portions of the upper basin, especially in the reach from Gavins Point to Sioux City. Higher soil moisture conditions due to wetting in the last 40 years over that mostly unregulated sub-basin have appreciably enhanced its contribution to the upper basin's overall runoff production.



Time series of water-year (1 October-30 September) UMRB runoff (million acre-feet) above Sioux City, Iowa for 1898-2014 (top), and water-year precipitation average for the upper basin above Sioux City (mm; bottom). Green bars highlight the three highest runoff years in the record. A measure of the year-to-year volatility is shown in the red curves that plot standard deviation of water-year values for 20-yr moving windows. Runoff at Sioux City from USACE; precipitation is PRISM.



The observed change in water-year (1 October-30 September) precipitation (% of climatology, top), and average surface air temperature (°C, bottom). Changes are calculated by differencing the 40-yr average (1975-2014) from the 80-yr average (1895-1974). Data source is PRISM.

Conclusions

The report demonstrates a strong physical connection between the increased frequency of high annual runoff events in the UMRB and the increase in precipitation falling over the upper basin. Each of the nine highest annual runoff years since 1975 were abnormally wet years. A concentration of wetting during the cold season has been key, leading to higher soil moisture conditions that further acted to increase efficiency in runoff production. The upper basin has warmed, which may have slightly reduced runoff efficiency, though this effect has been far eclipsed by the increased precipitation.

The cause for these changes in meteorological conditions was also briefly explored in the report. Most of the magnitude in observed precipitation increases, and hence much of the runoff increases, occurred via natural variations in the region's climate. The warming trend, by contrast, was consistent with an emergent signal of human-induced climate change.

Wetter and warmer conditions in the UMRB are anticipated in the future due to human-induced climate change. Under an aggressive emissions scenario, the upper basin is expected to warm by about 6°C by the end of the 21st century. It is currently unclear whether the impact of such unprecedented warming on future upper basin runoff will dominate over precipitation changes, or even over the typical natural precipitation variability. Further investigation is required on how annual runoff efficiency will change and whether year-to-year runoff volatility will increase.

In the immediate future, runoff variations including extreme high and low runoff years, will continue to be dominated by natural variability in the upper basin. The report indicates that predictions of such variability will benefit from improved soil moisture monitoring, whose antecedent land surface states were found to correlate with subsequent annual runoff. However, the direct effects of precipitation will continue to prevail in driving runoff variability. Overall, improved outlooks for annual runoff and likelihood of flooding will benefit most substantively from improvements in precipitation predictions at monthly, seasonal and longer time scales.

For more information, contact:

Ben.Livneh@colorado.edu, or
Martin.Hoerling@noaa.gov
NOAA Earth System Research Laboratory
325 Broadway, Boulder, Colorado 80305

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