Drought, Climate Variability & Change, and Potential Impacts on Wyoming's Water Resources

By Dr. Stephen Gray, Wyoming State Climatologist and Director of the University of Wyoming's Water Resources Data Center, with Christina Alvord of Western Water Assessment

"Even the most conservative estimates for regional temperature change would have major consequences for Wyoming's water resources," says Dr. Steven Gray, Wyoming State Climatologist. This article summarizes a series of talks by Dr. Gray, beginning with one presented at an October 2006 workshop co-sponsored by WWA and dedicated to understanding how climate variability and change impact Wyoming's water resources.

Introduction

How vulnerable is Wyoming and the surrounding Intermountain West to climate variability and change? How does climate change contribute to drought? Scientists are interested in the factors that have contributed to water scarcity and caused drought conditions to persist in Wyoming over the past decade. This article addresses what is known about climate change, why Wyoming's water resources are especially vulnerable to climate variability and change, and the relationship between warmer temperatures and water availability. The scientific unknowns about climate change are just as important as areas of scientific consensus, so this article also includes several suggestions for further research.

What do we know about climate change?

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, the earth has warmed approximately 1°F over the past 100 years (IPCC, 2007). An overwhelming majority of climate scientists believe that human activities are a primary driver of this warming, though some disagree on the interactive role of natural factors. Based on regionalized output from leading climate models, the climate of the Upper Colorado River Basin will likely warm anywhere from 2°C to 4°C (3.6°F to 7.2°F) within the next fifty years (IPCC, 2007, Figure 1a). In relation to impacts on Wyoming's water resources, even conservative warming projections will likely have major impacts on regional water supplies. But why would such seemingly small increases in temperature impact Wyoming's water resources? A closer look at regional vulnerabilities to climate variability and change can in part explain the relationship between warmer temperatures and annual water supplies.

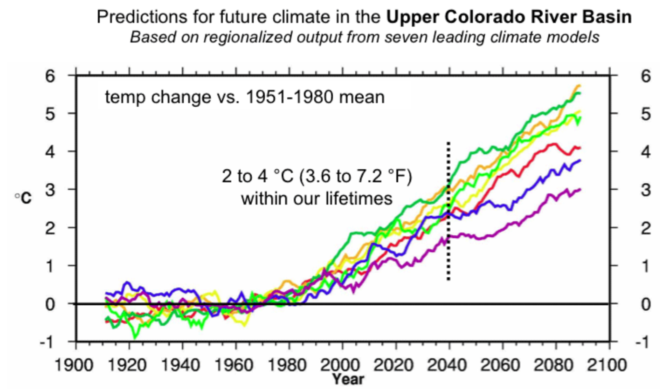

Figure 1a. The IPCC AR4 Report (2007) indicates the Upper Colorado River Basin could warm significantly based on seven different climate models. Even the most conservative warming estimates will have an adverse effect on water supplies for the Upper Colorado River Basin.

Why are Wyoming's water resources vulnerable to climate change?

Wyoming's water resources are sensitive to climate change for several reasons: 1) they are dependent on snowpack; 2) the regional climate is semi-arid; and 3) the geographical features of regional watersheds makes it difficult to capture all available water supplies. Therefore, reduction in average annual snowpack or rapid snowmelt impacts water supplies across the state.

Wyoming relies on runoff from snowpack for annual water supplies; this fact is a primary vulnerability because of the nature of the physical and hydrological processes and the legal framework of western water resources. Snow falls in the mountains in the winter where it is stored as snowpack until it runs off in the spring into streams and reservoirs for use during the rest of the year. So the majority of precipitation falls as snow in the winter, in comparison to watersheds in the east, where precipitation is distributed more evenly throughout the year, regularly replenishing water supplies.

Wyoming's total annual precipitation is also sensitive to climate variability. With an annual average precipitation of 16.84 inches, it is the 5th driest state in the U.S. Wyoming has features of a high altitude desert, and is similar to other warm and dry like New Mexico, Utah, Arizona, and Nevada that have annual average precipitations that do not exceed 15 inches (PRISM Group, Oregon State University, http://www.prismclimate.org). Relatively small changes in precipitation represent a large fraction of the total precipitation.

The third vulnerability is the relatively small geographical size of Wyoming watersheds which are the headwaters of the Upper Colorado River, Green River, and the Platte River. The smaller watershed area for these headwater basins limits the total snowpack that may accumulate, and limits the area over which water resources might be captured. The majority of snowpack in Wyoming is concentrated in a relatively small area above 10,000 feet elevation. In the spring, a few hot days can rapidly melt the majority of this winter snowpack. Because of the small watersheds, the runoff may be transported rapidly downstream and out of Wyoming. Thus Wyoming water users may have limited time and opportunity to store water. Another geographic context is that droughts tend to encompass much or all of these watersheds. In larger basins, on the other hand, dry conditions in one sub-region are often offset by average to wet conditions in other locations.

Impact of Warmer Temperatures on Water Supplies

Warmer temperatures exacerbate water supply vulnerabilities by affecting the frequency and behavior of snowfall and snowmelt, and reducing total snowpack amounts. Slight increases in temperature cause precipitation to fall as rain instead of snow and initiates earlier spring snowmelt. In Wyoming, a large fraction of total annual snow falls as "warm snow" (i.e. near the freezing point) in the late spring (April through May). A shift towards more rain-dominated precipitation alters total snowpack amounts and subsequent water resource availability. This is because rain falling on top of snow causes melting, but more importantly, because rain enters ground and surface water supplies almost immediately instead of being preserved as mountain snowpack that gradually melts throughout the spring and summer.

Warmer temperatures causing premature spring snowmelt is characterized by an earlier and steeper shift in streamflow regimes (Dettinger, 2005, Figure 1b.) Spring runoff beginning as early as mid-March leads to increased rates of evaporation and further diminishes late-season flows (NRC, 2007). Earlier timing of spring snowmelt was first observed in the Sierra Nevada mountains in California, and is now being observed elsewhere in the West (Stewart et al., 2004, Figure 1c). While warmer temperatures threaten present and future water supplies, it is also important to incorporate the Paleo record of drought as another component in identifying Wyoming water supply vulnerabilities.

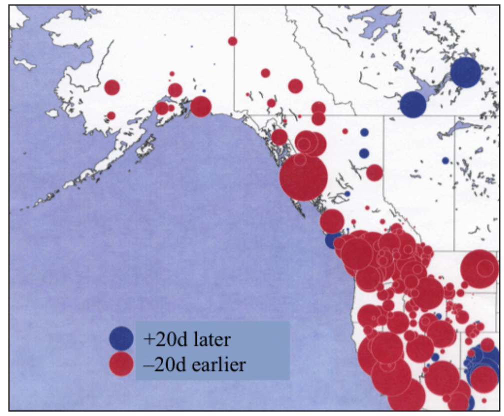

Figure 1c. It is clear that the West, especially in area surrounding the Sierra Nevadas have experienced spring snowmelt upwards of 20 days earlier than averages of spring snowmelt from 1948-2000. Earlier spring snowmelt as a result of warmer temperatures potentially leads to an overall decline in streamflows (Stewart et al., 2004).

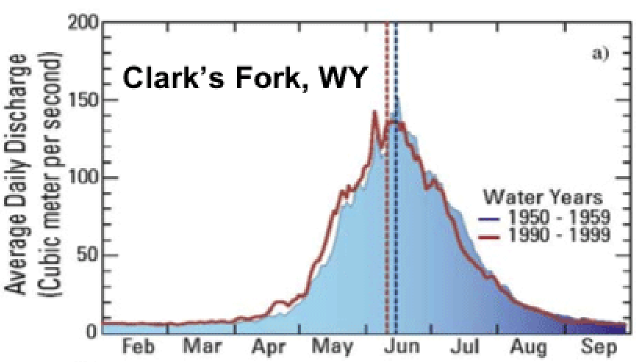

Figure 1b. Increase in temperatures has contributed to earlier peak flows over a long-term average for Clark's Fork, Wyoming (Dettinger, 2005).

What do we know about the Paleo-Climate Record?

A new 500-year reconstruction of annual streamflows on the Upper Colorado River finds that the amount of water in the Colorado River at Lees Ferry varies dramatically from year to year, often greatly exceeding or falling below the 20th century annual mean of roughly 15.2 million acre feet (Figure 1d, Woodhouse, et al., 2006)[1]. These analyses also show that the long-term annual means over the past 500 years was actually closer to 14.5 million acre feet, and preliminary work suggests that the annual mean over the past 1000 years may have been even lower. Analysis of 25-year annual means for Upper Colorado River stream flows indicate that the past 500 years have been marked by several extended periods of significantly below average streamflows and that, on the whole, the 20th century was a remarkably wet time in the basin's history (Figure 1e).

Areas of Uncertainty and Areas for Further Research

Many aspects of the relationship between warmer temperatures and decreased water supplies are well documented in Wyoming, however changes in regional precipitation, and potential changes in consumptive water uses are still highly speculative. For example, there is little if any conclusive evidence concerning how and to what degree climate change will impact the amount of precipitation falling on sub-regions within the Intermountain West. A recently released report from the National Research Council on the Colorado River reports that temperatures in the region will rise significantly over coming decades based on leading climate model agreement, but do not show any uniformity in regional amount of future precipitation change (NRC, 2007). Model predictions for precipitation change in the Upper Colorado River Basin over the next fifty years range from an increase of 60% to a decrease of more than 20% (Figure 1a).

There is also a pressing need to better understand how climatic variability and change will impact water supplies and demand. More accurate information concerning current and future consumptive uses of water resources for Wyoming and surrounding states could provide both climate scientists and policy makers with a better indication of available water resources and a clearer picture of where water supply vulnerabilities lie. Better estimates of consumptive usees could help answer questions such as, how does water use throughout the year contribute to water scarcity and in what way? Or specifically, how would a predicted 2-3° C

1 Featured in the June 2006 Intermountain West Climate Summary.

rise in summer temperatures, combined with a significant shift from agricultural to municipal use, affect demand? Answering such questions will be a primary challenge in coming years.

Many critical aspects of snowpack variability and snow climatology in Wyoming are still poorly understood. Although the majority of Wyoming's water supplies come from high elevation snowpack, precise runoff contribution by glaciers, permanent snowfields, and low to mid elevation snowpack is not well documented. Low to mid elevation snowpack is potentially the most vulnerable to future warming, but requires research efforts to better understand warming sensitivity. How increased or decreased rates of snowmelt and rainfall affect Wyoming basins is not well understood as well. Further monitoring and assessment efforts are needed to pinpoint regional-specific impacts and vulnerabilities.

In short, Wyoming's water resources are vulnerable to climate change because water supplies are dependent on snowpack, the regional climate is semi-arid, warmer temperatures negatively affect regional water supplies, and the paleo record clearly demonstrates how drought is a natural, defining feature of the regional climate. However, reducing uncertainties associated with regional precipitation forecasts, identifying new relationships between regional water supplies and climate variability and change, and planning for future water use and demand in coming decades are the next steps in assessing regional water supply vulnerabilities.

Sources

Dettinger, M., 2005: Changes in Streamflow Timing in the Western United States in Recent Decades. National Streamflow Information Program (NSIP), USGS Fact Sheet 2005-3018.

IPCC, Working Group I, 2007. Climate Change 2007: The Physical Science Basis: Summary for Policy Makers, available at, http://ipcc-wg1.ucar.edu/wg1/docs/WG1AR4_SPM_Approved_05Feb.pdf.

National Research Council (NRC). 2007. Colorado River Basin Water Management: Evaluating and Adjusting to Hydroclimatic Variability. Committee on the Scientific Bases of Colorado River Bain Water Management Water Science and Technology Board, Washington D.C.: The National Academies Press.

PRISM Group, Oregon State University, courtesy Chris Daly, http://www.prismclimate.org.

Stewart, I., Cayan, D., and M.D. Dettinger, 2004: Changes in Snowmelt Runoff Timing in Western North America under a 'Business as Usual' Climate Change Scenario. Climatic Change, 62, 217-232.

Woodhouse, C., Gray, S., and D.M. Meko, 2006: Updated streamflow reconstructions for the Upper Colorado River Basin. Water Resources Research, 42. W05415.

On the Web

- For more information on Wyoming water supply vulnerabilities and Paleo streamflow reconstructions on the Colorado River, please contact Steve Gray at sgray8@wyo.edu, or visit the Wyoming State Climatologist homepage at http://www.wrds.uwyo.edu/wrds/wsc/wsc.html.

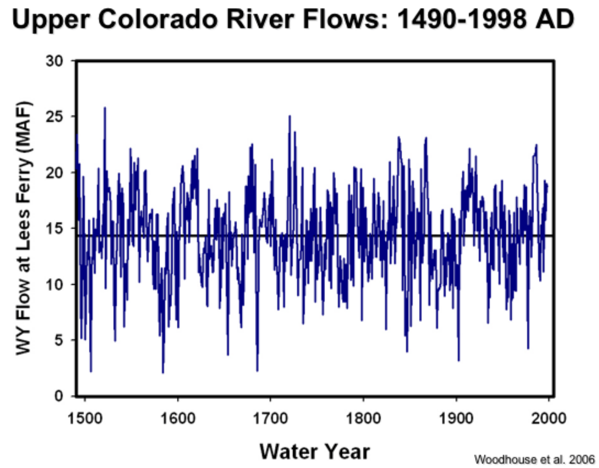

Figure 1d. Graph depicting deviance from 15.2 million acre feet average annual flows for the Colorado River dating back to 1490 A.D. based on historical streamflow reconstructions. Natural variability of Colorado River flows is apparent in this graph (Woodhouse, et al., 2006).

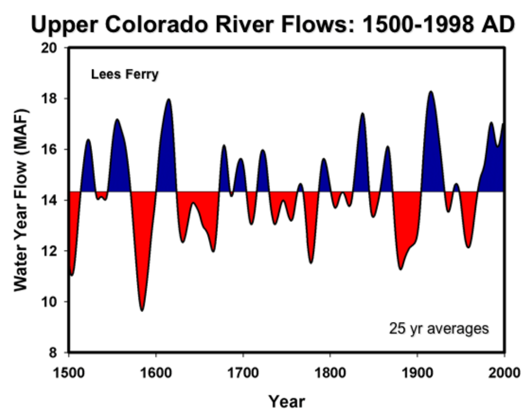

Figure 1e. By examining 25-year averages of flows dating back to 1500 A.D., it is evident that drought is a defining feature of the Colorado River (Woodhouse et al., 2006).

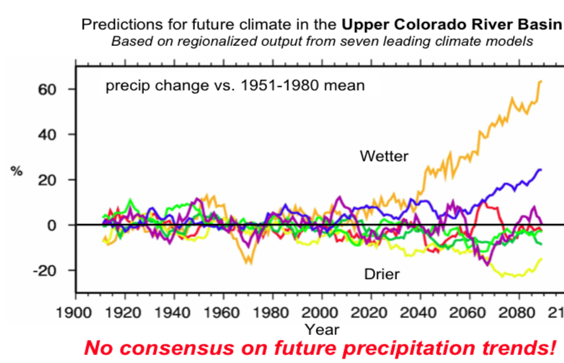

Figure 1f. Climate models used in the IPCC AR4 Report (2007) are not in agreement concerning change in precipitation for the Upper Colorado Region. Wyoming and the Intermountain West are dependent on snow precipitation for water supplies, so further research on regional precipitation projections is necessary for long-term water management and planning.