Expanding the Tool Kit for Water Management in an Uncertain Climate

***Joel B. Smith**, **Kathleen C. Hallett**, and **Jim Henderson** – Stratus Consulting and **Kenneth M. Strzepek** – University of Colorado*

Typically, water managers size their infrastructure and plan for floods and droughts by looking at extremes in the observed record and adding a margin of safety. Observed runoff records go back to the 1950s or, in many cases, earlier decades. The problem is the recent past may not represent what the future holds. This is because climate was more severe at times before the observed record and the future climate is changing.

Managers Should Look Further Back…and Ahead

There are two arguments warning water managers not to base their water management decisions solely on observed streamflow, temperature, and precipitation records. One argument holds that prior to the 20th century, climate was more variable and severe than the observed record, as demonstrated by "paleoclimate" reconstructions of streamflows from tree rings and other sources. The second, relatively newer argument holds that our current climate is changing rapidly because of increased greenhouse gases in the atmosphere and this may have far-reaching consequences for water resources planning, thus climate model-predicted changes must be considered.

The relevance of using the paleoclimate record to simulate drought was demonstrated in the Severe Sustained Drought study (*Water Resources Bulletin*, 1995) in which streamflow reconstructions from tree rings were used to simulate the impacts of a severe, sustained drought on the Colorado River under current management operations and institutions. Interest in this study was rekindled in recent years when Lake Powell dropped to record low levels in 2002, and storage in Lake Powell from 1998 to 2004 was less than under the severe drought simulation (see *www.hydrosphere.com/publications/SSDRedux.htm*).

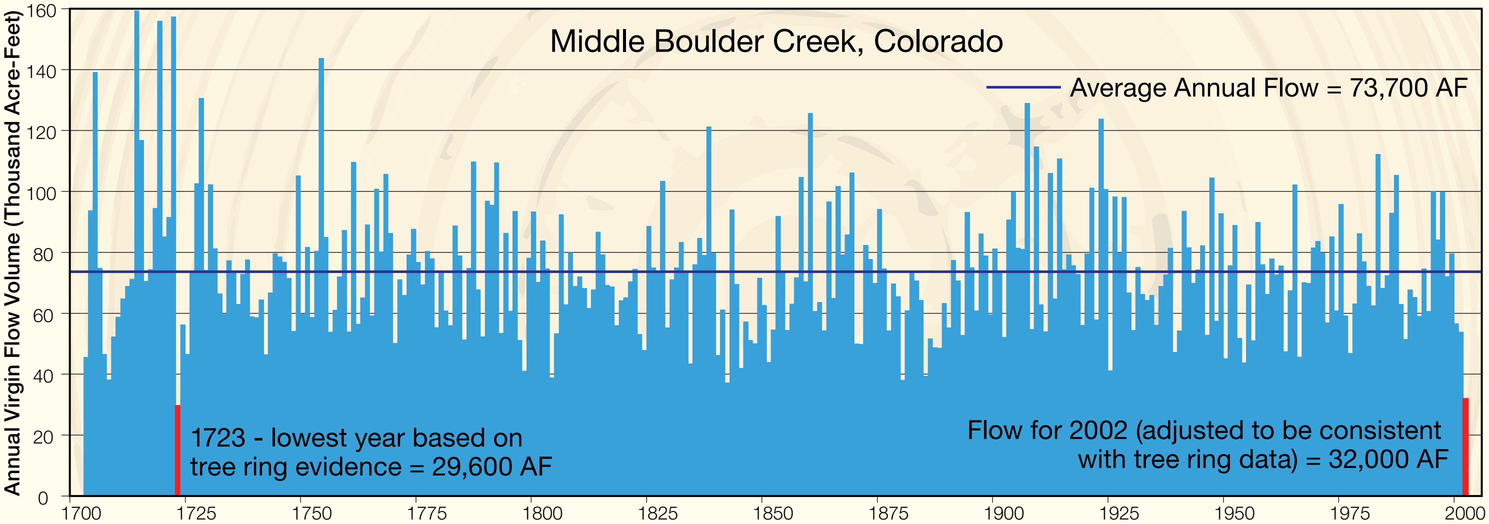
> *Measured streamflow was used in conjunction with reconstructed streamflow to recreate a likely temperature and precipitation record representive of the paleoclimate.*

Looking ahead, greenhouse gases are accumulating in the atmosphere, causing a warming of Earth that will affect global and regional climate patterns. Warming in the Southwest, for example, has already begun and is expected to increase over coming decades, resulting in a snowpack that is smaller and melts earlier (Mote et al., 2005; also see page 26). Warming may also cause changes in precipitation patterns as well, although many aspects of this are uncertain.

These arguments for basing water resources planning on additional information besides the observed record are typically presented separately. This may be because the techniques for estimating each type of change — paleoclimate reconstructions for pre-observed climate and climate models for future climate change — do not mesh easily with each other. However, it is possible to combine both data sets, as a team lead by Stratus Consulting working in concert with the city of Boulder, Colorado, is doing. Although the process is still underway, when complete, it will allow the city to examine potential effects of long-term change in climate imposed on a reconstruction of paleoclimate variability.

Laying the Past Onto the Future

The National Oceanographic and Atmospheric Administration's (NOAA)



Variability in streamflow reconstructed from tree-ring data for Middle Boulder Creek shows the 2002 drought was comparable to the lowest flow in the 300-year record (from Hydrosphere Inc.).

Office of Global Programs awarded a grant to Stratus Consulting to work with the city of Boulder to examine the city's vulnerability to long-term climate change and climate variability. The grant builds on an earlier study Boulder undertook with Hydrosphere Inc. to examine the city's vulnerability to a repeat of a 300-year record of climate variability (see figure, below left). That record was based on a reconstruction of streamflow in Middle Boulder Creek developed by Connie Woodhouse of NOAA's National Climatic Data Center using data from a tree-ring chronology. Hydrosphere found that the city could cope with the variability indicated in the 300-year record. They also examined a 15 percent reduction in runoff, arbitrarily selected to simulate the effects of climate change, and found such a reduction would cause problems.

Building on this analysis, Stratus Consulting (with Hydrosphere, the University of Colorado, NOAA, and the National Center for Atmospheric Research) is examining how Boulder could cope with the combination of the climate variability indicated by the paleo record and greenhouse gas-induced climate change.

The potential effects of climate change on water resources are typically examined by estimating change in runoff using output from climate models. Changes in meteorological variables such as precipitation and temperature from the models are combined with an observed record to feed into hydrologic models. The difficulty in applying the reconstructed streamflow record is that the prehistoric changes in temperature and precipitation are not obvious. The reconstruction only gives streamflow. Of course, streamflow can be used directly in management models to assess how an exact repeat of the paleoclimate record can affect water management. What is not so clear is how to combine change in climate and the paleoclimate record.

We worked with Balaji Rajagopalan of the University of Colorado to devise a technique to use observed (measured)

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streamflow with reconstructed streamflow to recreate a likely temperature and precipitation record to represent the paleoclimate record. Our goal was to develop a new reconstruction of streamflows that was similar to the tree-ring-derived reconstruction in terms of: 1) duration, 2) average streamflow, and 3) overall frequency of extreme flows.

Our approach was to select several years from the observed record in which the annual streamflow closely matched that of a single year in a 400-year reconstructed streamflow record developed by Woodhouse. From this subset of years, we used a random selection process, placing the greatest weight on the closest match, but allowing for some variability, to determine the "selected" year from the observed record that would serve as the analog for the particular year from the paleo record. The process was repeated for each year of the paleo record.

The result is an ensemble of data from the observed record that approximates the volume of total annual streamflow and variability of the paleo record, but that contains temperature and precipitation data which can be used to approximately recreate paleoclimate conditions.

The monthly temperature and precipitation values will next be used as input parameters for the Snowmelt-Runoff (SRM; Martinec et al., 1994) and WATBAL (Rosenzweig et al., 2004) models to produce new "modeled" streamflows for Boulder Creek. SRM simulates and forecasts daily streamflow in mountainous basins where snowmelt is a major runoff component, and WATBAL is an integrated water balance model developed for climate change impact assessment of river basin runoff. Changes in temperature and precipitation from climate models for the central Rocky Mountains will be combined with the new paleoclimate temperature and precipitation data set. This will produce estimates of the conditions that would be experienced under a warmer climate with changes in average precipitation, but also one with more variability than in the recent record.

This approach will allow water managers to use the paleoclimate record and climate change models jointly to evaluate the risks from both climate change and climate variability together, providing an improved tool for water resources planning. In other words, water managers can examine what would happen if past droughts happen again, but this time under warmer conditions consistent with climate change.

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What To Do?

Trends that have natural origins may well reverse themselves, but if they are driven by manmade influences on the climate system, streamflow timing may continue to change. If present trends continue, the natural reservoirs provided by western snowfields will become progressively less useful for water-resources management, flood risks may change in unpredictable ways, and many mountain landscapes will experience increasingly severe summer-drought conditions.

Given the potential for large impacts of climate change on water resources, water management policies that promote flexibility and resilience will be needed to accommodate potential warming impacts, although they remain uncertain. Equally important, continued and enhanced streamflow monitoring and analysis of western snow-fed rivers will be needed to determine the precise natural and human-induced causes, and the likely future, of these western streamflow-timing trends.

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