Reconciling Projections of Colorado River Streamflow

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Aerial view of Colorado River in Utah.

"Climate Experts Tussle over Details. Public Gets Whiplash," declared a New York Times headline last summer. It's not just the public that has been trying to sort out the numerous and sometimes conflicting predictions of climate-change impacts of recent years. Water managers are wondering which predictions they should use as a basis for water-supply planning. So for the past 18 months, a group of scientists from universities, the National Oceanic and Atmospheric Association (NOAA), and the Bureau of Reclamation has been working to evaluate how and why climate predictions vary. Their work is still in progress, but the goal is to specifically reconcile modeled projections of climate-change-induced reduction in flow of the Colorado River by 2050.

While studies of the potential effect of climate change on Colorado River streamflow have been going on for several decades, disparities in two recent publications, one by Hoerling and Eischeid (2007) and another by Christensen and Lettenmaier (2007), instigated the reconciling effort. Hoerling and Eischeid found a 45 percent reduction in flows at 2050 but Christensen and Lettenmaier predicted only a 5 percent reduction. Another study by Milly and others (2005) split these results with a 20 percent reduction. Cross-study analysis was confounded because each report used a different technique ranging from using raw output from global climate models (Milly and others), to statistical relationships relating temperature and precipitation to streamflow (Hoerling and Eischeid), to a sophisticated high-resolution hydrology "process" model (VIC) driven by downscaled data (Christensen and Lettenmaier).

Scale Matters

The simulations and predictions by Milly and others were made at the global climate model (GCM) scale where a single grid cell is 200 kilometers (km) or more on a side. Hoerling and Eischeid used climate divisions, which vary but are roughly 150 km on a side, while Christensen and Lettenmaier used 12-km boxes. In the current reconciling project, one initial critical finding is that meaningful predictions for the southwestern United States need to account for the highly variable topography and associated changes in climate and hydrology of the Rockies, hence results from earlier studies using coarser resolutions could be much improved.

> *A 10 percent reduction in precipitation would result in a 20 percent decline in runoff in the Upper Colorado Basin.*

In response to these findings, Hoerling and Eischeid now believe their 45-percent runoff reduction from climate divisions overstates the potential losses and they have developed a new high-resolution (4-km) model. The model used by Lettenmaier and a group led by Dan Cayan at Scripps California Applications Program is already at a higher, more topographically sensitive scale. All of these models require high-resolution "gridded" datasets. Such data are currently derived either from downscaling GCM-produced results (for future runoff projections) or from historical datasets built from a spatial analysis of irregularly spaced weather observations (for studying historical runoff sensitivities).

Input Data Matters

The hydrology models that are used to downscale a GCM's result must first be calibrated to produce realistic statistical properties of known, historical runoff. This helps ensure the reliability of a model's sensitivity to future conditions. The goal is for the model to generate the correct 20th-century annual discharge from the Upper Colorado River Basin and a realistic monthly hydrograph—output that is readily verifiable from historical gauge data.

Ideally, all hydroclimate parameters that are responsible for runoff production would also have extensive field observations, permitting the modeler to develop strongly verifiable and empirically constrained parameters that constitute the essential parts of the models' physics. But monitoring at a 4-km scale is neither the current nor the historical reality. Numerous existing datasets have had to rely on sparse and infrequent instrument measurements for even such basic variables as surface temperature and precipitation to depict very high-resolution weather and climate variations in the Upper Colorado.

The situation is more dire for parameters such as vegetation and soil type, soil moisture, wind, and solar radiation, all of which impact evaporation, transpiration, snowmelt, and other key processes. Some of these parameters can be approximated from temperature and precipitation, but even those parameters are not perfectly known. Thus, calibration, while producing correct historical runoff, may not do so for all the correct reasons.

Most of the participating modelers in the reconciling study used one of two sets of 20th century data for model development and calibration. PRISM (Parameter-elevation Regressions on Independent Slopes Model) data, produced by researchers at Oregon State University, yielded estimates of monthly, yearly, and event-based climatic parameters with a spatial resolution of 4 km. (PRISM data production has been discontinued due to lack of funding.) Maurer and others (2002) published a dataset of land surface states and fluxes with a three-hour timestep and spatial resolution of about 12 km. While both datasets are based on direct observations, each requires interpolation for areas lacking weather stations, thus it is not surprising to find significantly different data between them.

The reconciling study found that the verifiable properties of the hydrologic models (such as annual discharge) depend on the input data. Even when a model was calibrated to generate observed historical runoff, the suitability of various calibration procedures could not be verified from the observations because many key hydrologically relevant processes, such as evapotranspiration, are not observed. Lettenmaier's group also investigated data sensitivities related to future climate projections, and how the GCM data were downscaled. They found that different but equally valid downscaling techniques to convert GCM data to 12-km grids for the VIC models yield different datasets. Lettenmaier recently reran his 2007 study with another version of downscaled future data and his results changed from a 5 percent to a 10 percent streamflow reduction by 2050.

Models Matter

The reconciling study has so far focused on hydrology models; climate-model evaluation will come later. These models vary tremendously in how they represent vegetation, soils, transpiration, evaporation, wind, solar energy, and a host of other parameters that are then combined to produce runoff. Add scale and input data into these variables and it's no surprise that runoff results differ.

Perhaps that's not so bad. Because models by definition are representations and cannot mimic reality exactly, scientists can test how the results of different approaches diverge—or not. Agreement within some range provides confidence in a prediction, whereas disagreement merits additional research.

Moving Toward Reconciliation

These initial studies did not produce directly comparable results, yet some agreement among findings emerged. Specifically, the models show similar sensitivity of streamflow to precipitation changes, with a 2:1 ratio of percent change in flow to

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percent change in precipitation using historic data. Hence, a 10 percent reduction in precipitation would result in a 20 percent decline in runoff in the Upper Colorado.

All researchers agree that only high-resolution hydrology models can capture the topographic—and climatic—variability that plays a large part in determining runoff. Approximately 20 percent of the highest portions of the Upper Basin generate nearly 80 percent of the runoff; these areas are all well above 8,000 feet.

A key remaining difference between the hydrology models is a significant difference in runoff sensitivity to temperature changes. Results ranged from 2 percent to almost 9 percent runoff reduction per degree Celsius increase in temperature. With global climate models showing average temperature increases of approximately 2°C by 2050, these results imply runoff reductions ranging from 4 to 18 percent depending on the hydrology model, a very large difference arguing for more study.

What's Ahead

Researchers are unlikely to ever agree on a single prediction for Colorado River streamflow in 2050 but this effort is providing a better understanding of the critical factors affecting changes in the basin and has narrowed the range of projected runoff declines. Current estimates of decline range from approximately 5 percent to 20 percent by 2050. Water managers need to focus on ranges as well as averages of projections and where the greatest certainties and uncertainties lie rather than look for precise values. The reconciling project is helping researchers understand what additional work would help refine predictions and make the models more comparable. In the future, they hope to:

- better understand the role that precipitation in higher elevations of the basin plays in dictating streamflow changes;
- research the sensitivity of hydrology to seasonality: sensitivity to a climatic event (such as drought) may vary depending on the season in which it occurs;
- better quantify the dependence of one year's discharge on the previous year's;
- improve coupling of GCMs and hydrologic models. This will improve understanding of the role of land processes in meteorological forcing to help determine whether aridity ultimately will limit the effects of temperature and precipitation on runoff;
- evaluate the extended set of GCMs to determine which models best represent current climate over the Colorado River Basin and utilize these best models to produce future projections;
- evaluate the extent to which datasets (precipitation, temperature, discharge) determine model results; and finally,
- reach a point where they can compare apples to apples in streamflow projections.

Finally, it is critical to note that beyond 30 to 50 years, future runoff appears to depend significantly on the total emissions of greenhouse gases, with higher emissions leading to more warming and greater reductions in runoff. A substantial uncertainty, and one this study is not designed to answer, is exactly what emissions trajectory will occur. Recent data indicate humans are emitting greenhouse gases at levels higher than assumed likely and the rate of emissions are increasing faster than assumed for the recently released 2007 IPCC studies (Canadell and others, 2007).

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