Brian McCrodden, vice president, and Steven Nebiker, senior project engineer, are with HydroLogics (www.hydrologics.net), Raleigh, N.C. Leslie Carreiro is superintendent of Water Production and Water Quality for the city of Asheville, N.C.

Drought Management

Probability-Based Operating Rules Improve Water Supply Management

Adding excess capacity to prepare for droughts is a common but expensive practice. A risk-based drought plan that incorporates forecasting offers a less expensive and often more reliable alternative.

BY BRIAN McCRODDEN, STEVEN NEBIKER, AND LESLIE CARREIRO

IN RESPONSE TO DROUGHT, population growth, and concerns about climate change, water suppliers have tried to manage and plan for demand by adding excess capacity. The financial and environmental costs of adding capacity, such as reservoirs, have prompted suppliers to consider alternative options, including demand management. In the process, communities are learning that by more intensively managing their water resources, they benefit from sustainably and efficiently managed water supplies.

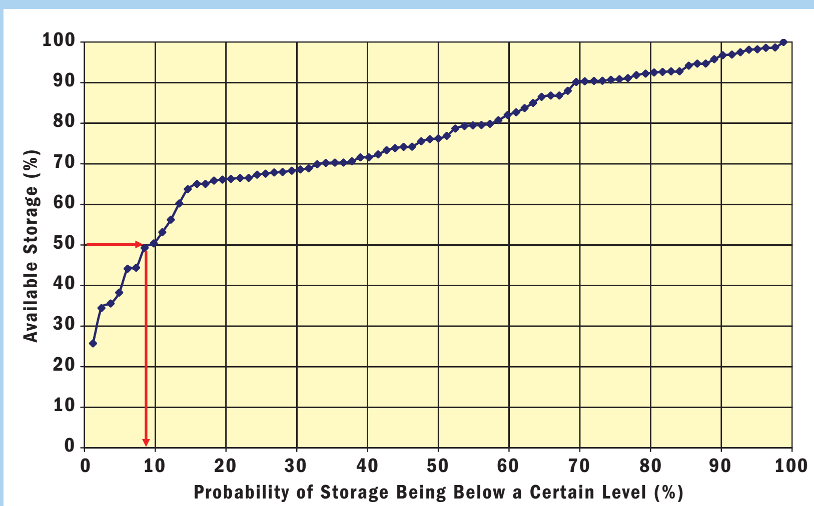
INDUSTRY FOCUS

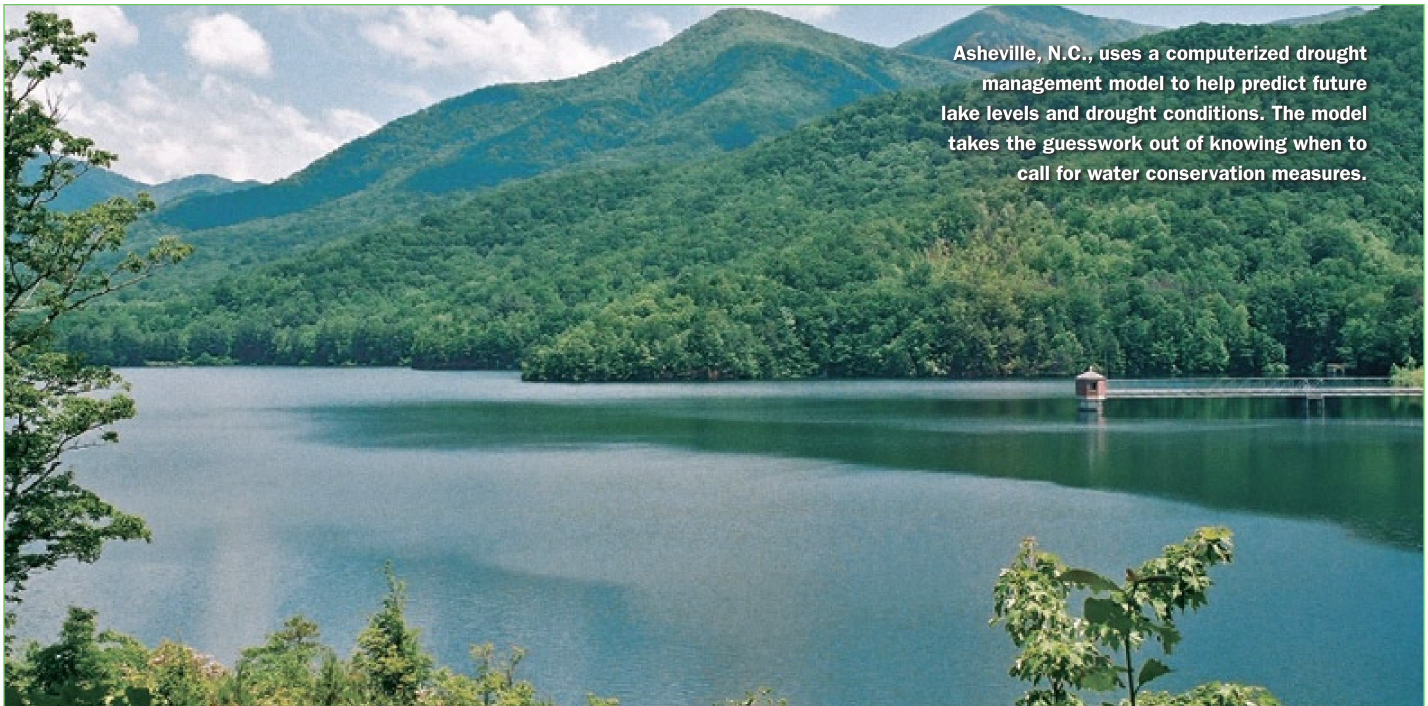
The water business is still driven by supply. Changing the industry's focus to more intensive management has been slow, especially in regions unaccustomed to sustained droughts. The commonly used metrics of "safe yield" and "days of supply remaining" don't adequately capture the risk to a utility, whose primary mission is to ensure a safe, adequate water supply.

Safe Yield. Safe yield is typically defined as the maximum level of demand that can be sustained in the worst drought over the hydrologic inflow record. Because the length of a record varies, safe yield should be associated with a frequency. In other words, safe yield using a 50-year record means the odds of running out of water in the worst drought year are less than 1 in 50, or 2 percent. Safe yield using a 100-year record means the odds are less than 1 percent. Although risks appear low, utilities will never operate to the safe

Reservoir Storage 12 Weeks in the Future

When drought triggers have been determined, a mathematical model can be used to predict water supply conditions during a drought in real time.





Asheville, N.C., uses a computerized drought management model to help predict future lake levels and drought conditions. The model takes the guesswork out of knowing when to call for water conservation measures.

PHOTOGRAPH: HYDROLOGICS

yield for fear the current drought may be worse than the historic drought on which the safe yield was based. Climate change introduces additional concern that the current drought could be worse than the drought of record. Because running out of water isn't an option, utilities take early corrective actions, such as water restrictions, to preserve system storage.

Remaining Supply. Another common approach to drought management is the days of supply remaining, which assumes only outflow (meeting demand) from the supply source, not inflow. When the days of supply drop below some threshold, demand restrictions are often triggered. Whereas safe yield operation can lead to restrictions being imposed too late—if a drought is worse than the one on which the safe yield was based—the days of supply operation can lead to restrictions being imposed too early. Having only 120 days of supply at the onset of a drought is a lot different from having that much supply at the beginning of a typical high-inflow period.

FORECASTING IS KEY

The key to improved operating efficiency is for a utility to incorporate forecasting into its operating rules to account for seasonal changes, storage levels, and future inflow and demand. The main unknown is future inflow, which can be estimated using ensemble inflow forecasts—one for each year in the historic inflow record, each with the same likelihood of occurring. For example, an inflow forecast for June 1 in the current year would be based on June 1 flows in all previous years. Resulting storage levels at the end of different forecast scenarios (e.g., 8, 12, and 24 weeks into the future) would be based on a repeat of each of those individual inflow traces. A probability distribution can be generated from those results, providing operators with the likelihood of storage being at certain levels at various times in the future.

Because a lack of soil moisture causes droughts to persist, it's important to "condition" forecasts on current watershed conditions. Watersheds act like sponges, so when flows are low, they tend to stay low—even after a rain. Failure to consider current watershed conditions may seriously underestimate the risks of water shortages. Although systems in the Western United States typically condition their forecasts on snowpack, as this heavily influences future flow, most non-snowpack systems don't condition forecasts—if they use forecasts at all. Rather, such systems assume each year's inflow is independent of current watershed conditions.

DEVELOPING DROUGHT TRIGGERS

Drought triggers are the manifestation of efficient water supply operation. The triggers convey when and to what extent corrective action should be taken. Such action typically includes reduced demand, lower minimum releases, and possible activation of backup supplies. Drought triggers in a reservoir-based system usually take the following form:

X% chance of dropping below Y% storage in the next Z weeks

At what probability, however, should an operator take action? Taking action when there's a 30 percent chance of drought compared with only a 5 percent chance may mean the difference between invoking the trigger in time to avoid drastic action later or invoking the trigger unnecessarily. Efficient triggers should

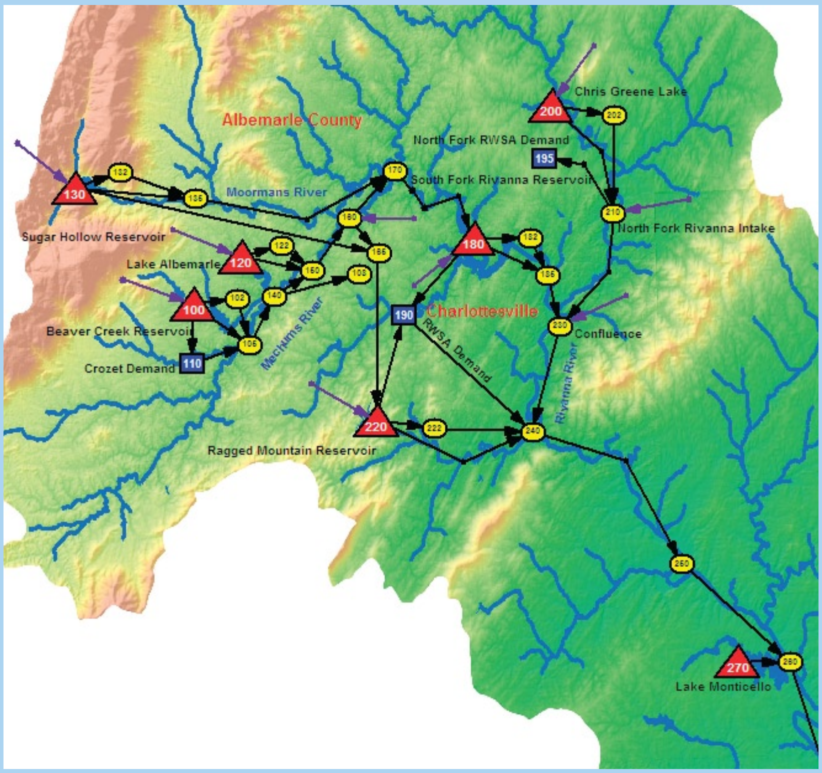
- detect all droughts.
- minimize false alerts, which reduce credibility with the public and reduce utility water sales and revenue.
- be invoked only as often as a utility and public are willing to tolerate.

If a trigger requiring significant demand reductions is invoked once every three years, a community would likely oppose the drought plan because of frequent hardship. Efficient triggers are derived through trial and error by adjusting trigger parameters—probability, storage, and forecast horizon—and using mathematical models to simulate the triggers over the historical inflow record. In this case, inflow forecasts would be generated for each week in the historic record, and the trigger would be invoked if the inflow forecast was inadequate to prevent

This risk management approach has been adopted by several East Coast cities, including Asheville, N.C., and Charlottesville, Va.

Hydrologic Modeling

A model schematic shows the Rivanna Water and Sewer Authority's water supply system in Charlottesville, Va. The wholesaler uses its model to predict the likelihood of future reservoir storage levels and the appropriate timing of drought restrictions.



simulated storage from dropping below a threshold level.

Using the longest possible inflow record captures additional drought information with which to test the triggers. A trigger that worked well in previous droughts increases confidence that it will work well in future droughts, the effects of climate change notwithstanding. An inflow record can be adjusted as necessary and analyses performed to determine how sensitive the triggers are to different climate-change scenarios.

When trigger selection has been finalized, the same mathematical model can be used to predict water supply conditions during a drought in real time. An operator inputs the starting storage and recent inflows, runs the model, and checks the resulting forecast to determine if the trigger has been reached.

For example, as shown in the figure on page 22, if the trigger is based on a 20 percent chance of being below 50 percent storage in 12 weeks and the plot shows less than a 10 percent chance of that occurring, the trigger hasn't been invoked. In the following weeks, the operator would run another forecast as storage level declines and the likelihood of hitting the trigger increases.

REAL-WORLD RISK MANAGEMENT

This risk management approach has been adopted by several East Coast cities, including Asheville, N.C., and Charlottesville, Va. In its last major drought in 1998, Asheville imposed mandatory restrictions and purchased an emergency supply despite demand being 20 percent less than the safe yield. With a risk-based drought plan, the $300,000 emergency supply could have been avoided. In Charlottesville, after significant drought hardships in 2002, the wholesaler successfully used a risk-based plan to navigate recent drought events with minimal disruption to its customers.

With increased confidence that triggers will have their desired effect, managers often reassess capacity expansion plans derived from safe-yield planning, scale back planned expansion, and manage their systems more intensively with forecasts. The city of Rocky Mount, N.C., considered tapping into a large river 35 miles away to avoid repeating 1993 water shortages—the city's worst drought on record at the time. The project would have cost $70 million then. However, since using a risk-based drought plan to reduce demand, lower minimum releases, and tap into often overlooked sources such as quarries, the city has indefinitely postponed the capital project.

DISAPPEARING OBSTACLES

Despite its advantages, probability-based operating rules aren't widely used, partly because of perceived difficulty in communicating the concept of risk to the public and to some extent the computational resources needed to develop forecasts and associated triggers. Many utility managers also believe that large excess capacity is the hallmark of a well-managed system.

With the possibility that droughts could become more frequent because of climate change, and with growing public awareness of the need for more efficient stewardship of water resources, the obstacles to probability-based operating rules are disappearing.