Probability-Based Low Flow Operating Protocol For Appalachian Power Company

Steven Nebiker, P.E.
Water Resources Engineer
811 Mordecai Drive
Raleigh, NC 27604
HydroLogics, Inc.
snebiker@hydrologics.net
919-856-1288 (voice)

Brian J. McCrodden, P.E.
Vice President
HydroLogics, Inc.
bmccrodden@hydrologics.net

Teresa Rogers
Relicensing Manager
American Electric Power
tprogers@aep.com

Abstract:

This paper will describe the development of a probability-based low flow operating protocol for Appalachian Power Company (a division of American Electric Power). The protocol will be included in the relicensing application for the Smith Mountain project, a 636 MW pumped storage project located on the Roanoke River in south-central Virginia.

The technique uses ensemble forecasts (multiple, equally likely forecasts of up to a year in duration) and a basin-wide hydrologic model to develop probability-based triggers, the activation of which lead to specified drought responses. The model simulates an 80-year inflow record to capture as many drought events as possible and assesses the impacts of implementing different trigger strategies on reservoir levels, instream flows, and power generation. The triggers are designed to ensure that the drought response maintains acceptable lake levels while also protecting downstream interests, including maintaining fish habitat and providing recreational flows. The triggers are being developed in an open and collaborative process with stakeholders and, as a consequence, will represent a balance of upstream and downstream impacts during drought. In addition, they have been designed to be activated only as often as the stakeholders and the company find acceptable.

Once a set of triggers is established from the historic simulation of past droughts, these are used in real-time to manage future droughts. If implemented, this risk management approach using probability-based triggers will likely be the first in the nation to be embedded in a hydropower operating license. The presentation will describe the benefits of such an approach as well as the procedural requirements needed to make it work successfully.

Introduction:

The Smith Mountain Project is a pumped storage facility that consists of an upper reservoir (Smith Mountain development) and a lower reservoir (Leesville development). They were built in the early 1960s and have 50 year licenses that are set to expire in 2010. As shown in Figure 1, the project is located in the headwaters of the Roanoke River Basin, which encompasses parts of Virginia and North Carolina as shown below. There are several other reservoirs in the basin, including two owned and operated by the Corps of Engineers (Philpott and Kerr) and two by Dominion-Virginia Power (Gaston and Roanoke Rapids).

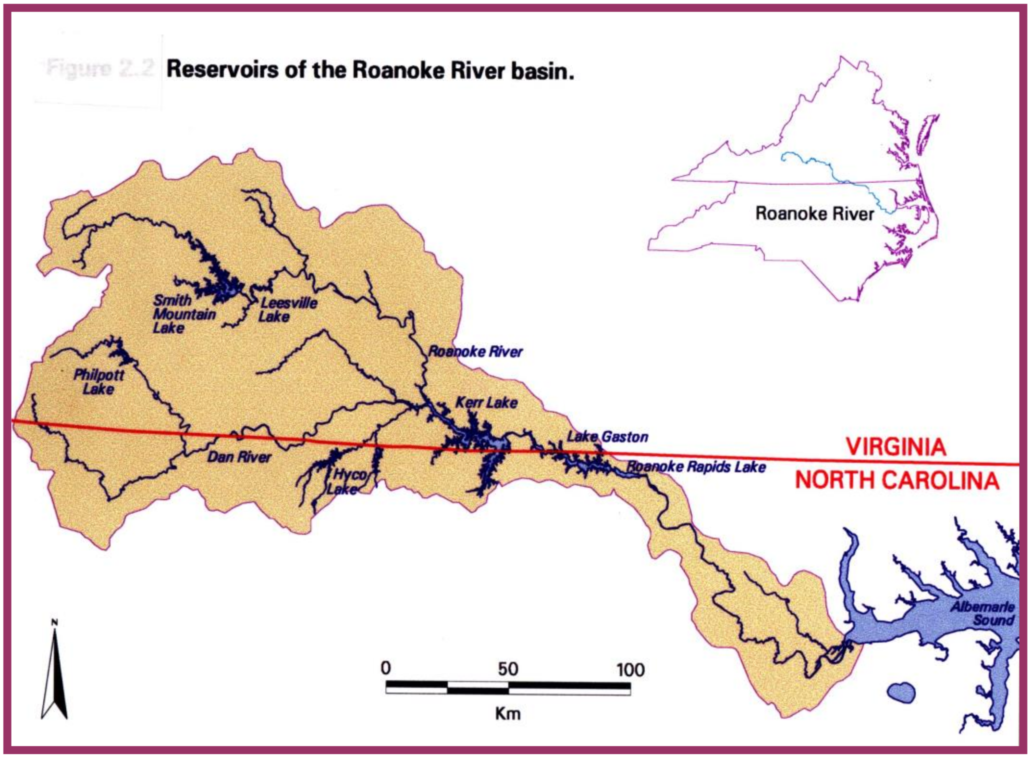

Figure 1: Reservoirs of the Roanoke River Basin

The water that is stored in Smith Mountain Lake first passes through turbines in the Smith Mountain powerhouse to produce electricity and is then discharged into Leesville Lake. Most of this water is retained in Leesville until it is pumped back into Smith Mountain for re-use. A portion of the water in Leesville, however, is released through turbines in the Leesville powerhouse to generate additional electricity and to meet the discharge requirements of the Project's Federal Energy Regulatory Commission (FERC) license.

The Smith Mountain development utilizes a two-foot power pool. This means that when Smith Mountain is generating electricity, i.e., releasing water, Smith Mountain's level can fall up to two feet before Leesville becomes full. Once Leesville is full, power cannot be produced at Smith Mountain until some portion of the water is pumped back to Smith Mountain or released through Leesville dam. There is no set schedule for operating the project. Generation is generally based on the demand for electricity. When the demand for electricity is high, Smith

Mountain will generate. When the demand for electricity is low, water from the lower reservoir is pumped back into the upper reservoir. The operation of the project can change on an hourly basis depending on system demand.

Since the projects were built, there has been considerable development on Smith Mountain Lake. Because of the greater lake level fluctuation, the development on Leesville Lake has not been as pronounced. Development has accelerated in the last 15 years as demand for vacation and retirement homes within proximity to major metropolitan areas has grown.

Appalachian is in the process of renewing its license for another 50 years. As part of this effort, the company undertook two major studies to help formulate how flows should be managed over the term of the next license in order to meet the various demands on the available water resource. These studies include the Instream Flow Needs Study and the Drought/Flood Management Study. The Instream Flow Needs Study utilized PHABSIM to determine the relationship between streamflow and habitat suitability criteria for selected aquatic species and life-stages. The other study, which is the focus of this paper, relies on a hydrologic model of the river basin to understand the competing uses for water now and over the course of the next license period. The model also permits examination of the tradeoffs associated with meeting those uses under different operating protocols. The main issues in the relicensing are lake levels, water supply, and downstream flows for recreation and fish habitat. Power generation is not a significant issue since the company will maintain the ability to pump water back and forth between lakes.

The competition for water use has intensified on the heels of recent drought events. Under its current license, Appalachian is required to release a minimum average weekly discharge of 650 cfs from Leesville. The median inflow to the projects is about 1500 cfs, or about 1 cfs per square mile of drainage area. The current minimum release requirement of 650 cfs means that the projects often spill. However, during the summer months, the 650 cfs minimum release is often higher than the median inflow, causing the lakes to draw down and impacting recreation on the lake. In the last ten years, the company has received numerous variances from the Commonwealth of Virginia to temporarily reduce the minimum release in order to preserve lake levels.

The results of the Instream Flow Study led to recommendations by the Virginia Department of Game and Inland Fisheries (VDGIF) for target flows needed to maintain aquatic habitat for the species of concern. These recommendations are referred to as dry year targets, and are flows that would not produce significant habitat deterioration in even the driest years. As plotted in Figure 2, these targets are much more reflective of the river's natural hydrograph than the year-round 650 cfs minimum release. It should be noted that the target flows are to be measured at Brookneal, which is about 40 miles downstream of Leesville. In most years, the intervening inflows between Leesville and Brookneal are sufficient to meet the targets with the 650 cfs minimum release from Leesville. However, in dry years, intervening inflows can be very low, requiring supplemental releases from the reservoirs that impose additional stress on the lakes. VDGIF also provided flow "floors" for each month. These are flows that are considered to be the absolute minimum acceptable for maintenance of aquatic habitat.

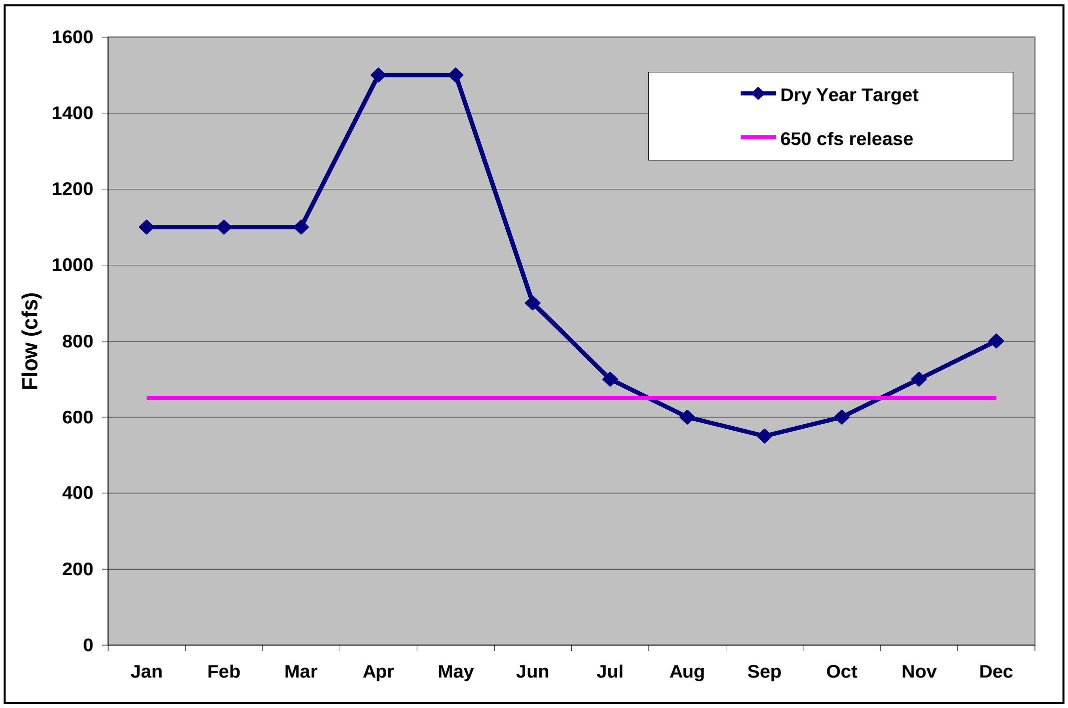

Figure 2: Comparison of Dry Year Targets and Minimum Release

Roanoke River Basin Reservoir Operations Model (RRBROM):

Appalachian retained HydroLogics to develop a hydrologic model of the Smith Mountain projects and to use the model to facilitate development of a low flow protocol. This decision was in part recognition that its basin-specific model (RRBROM) had been successfully applied by a large group of stakeholders in the relicensing of downstream power projects operated by Dominion-Virginia Power.

The RRBROM is an application of HydroLogics' generic mass balance simulation model known as OASIS, which was designed specifically to investigate the interaction between multiple objectives in water allocation decisions. The RRBROM includes all projects in the Roanoke River Basin, with associated operating rules for each, along with various locations where consumptive water use occurs or where streamflow information is of interest. In addition to relicensing, the model is being used to evaluate alternative operating rules for the largest reservoir in the basin (Kerr Reservoir, operated by the Corps of Engineers) to minimize the impacts of prolonged inundation downstream in the expansive flood plain. A schematic from the model is shown in Figure 3.

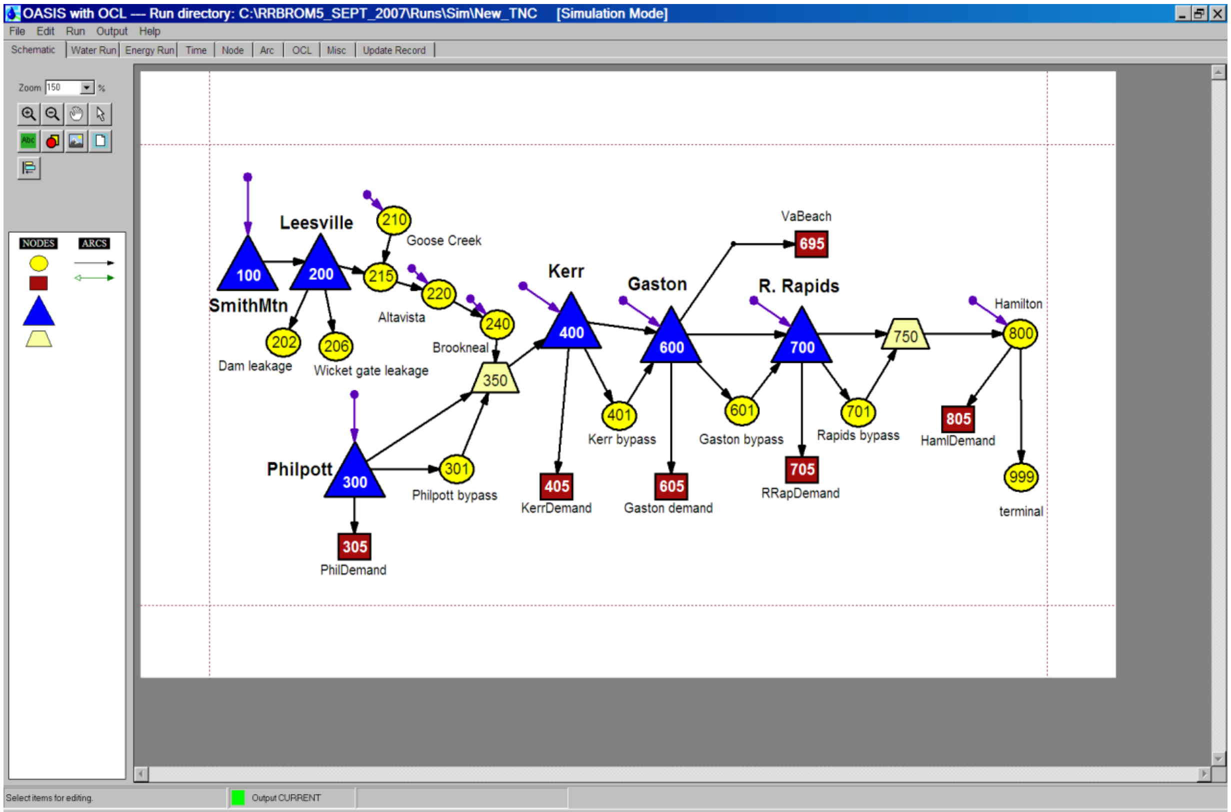

Figure 3: Schematic of the RRBROM

The portion of interest is the upper-left part of the schematic, which shows the Smith Mountain and Leesville reservoirs along with important locations downstream to Brookneal. The purple arrows into various nodes represent unimpaired inflows that are removed of any effect of historical project operation and consumptive uses. The inflow data extend almost 80 years from 1930 to present.

In a relicensing process, the most instructive way to use a simulation model is to run it iteratively for the period of record using one set of facilities, one set of withdrawals corresponding to either current or future demands, and one set of operating policies for each run. By running alternatives for the period of record, the performance of any particular system configuration can be examined over the full range of hydrologic conditions that have occurred during the past 80 years. The OASIS platform enables simulation of ensemble streamflow forecasts (discussed in more detail later) for each week in the historic record, which means probability-based operating rules can be evaluated. Once an alternative has been developed and agreed to, the model can be used in a real-time predictive mode using the current ensemble forecasts to indicate when to take corrective action during a drought. The principal corrective action is cutting back on reservoir releases to preserve lake levels.

Probability-based Triggers:

The critical piece of the low flow operating protocol is the use of probability-based triggers. Probability-based triggers enable flows to be reduced earlier but to a lesser degree than what has occurred during past low inflow periods. This is intended to keep the lake levels and the downstream flows higher for a longer period of time instead of waiting until lake levels drop so low that downstream flows must be reduced more drastically. Probability-based triggers also reduce the chances of taking corrective action prematurely (false alerts) because they account for time of year and the inflows leading up to and projected to occur from that point in time. In other words, a lake that is half full in late fall in this region is not likely to trigger the same response as one in early summer because the inflows in the winter and spring period are higher and thus more likely to refill the lake. Once in restrictions, probability-based triggers have the added advantage of allowing the restrictions to be lifted sooner if wet conditions are projected. For this protocol, the Leesville discharge is to be reduced if the forecasted lake level reaches a predetermined condition. Triggers are activated when the forecasted lake level has an “X” percent chance of reaching a level of “Y” within “Z” weeks.

Probabilistic information about lake levels is derived in the following manner:

- Generate ensemble forecasts (one equally-likely forecast trace for each year in the hydrologic record).
- Simulate each trace using the RRBROM, which produces an estimate of lake level based on each of those years.
- Sort the results to generate a probability distribution of expected outcomes.

This information can be presented graphically. Figure 4 shows the probability distribution of elevations for Smith Lake (adjusted to account for the Leesville elevation) for different time horizons into the future based on a sample forecast using a starting elevation of 791 feet and date of November 1. For example, the plot shows that 12 weeks from November 1, the probability of being at or below 792 feet would be about 30 percent. This forecast is typical of those made in the fall months, when inflows typically rebound in the wetter winter and spring seasons. As a result, the lines shift upward as the time horizon increases, meaning the probability of being below full (795 feet) decreases as the horizon grows. For example, in 4 weeks, there is almost a 60 percent chance of being below 791.5 feet, whereas in 24 weeks there is only a 10 percent chance.

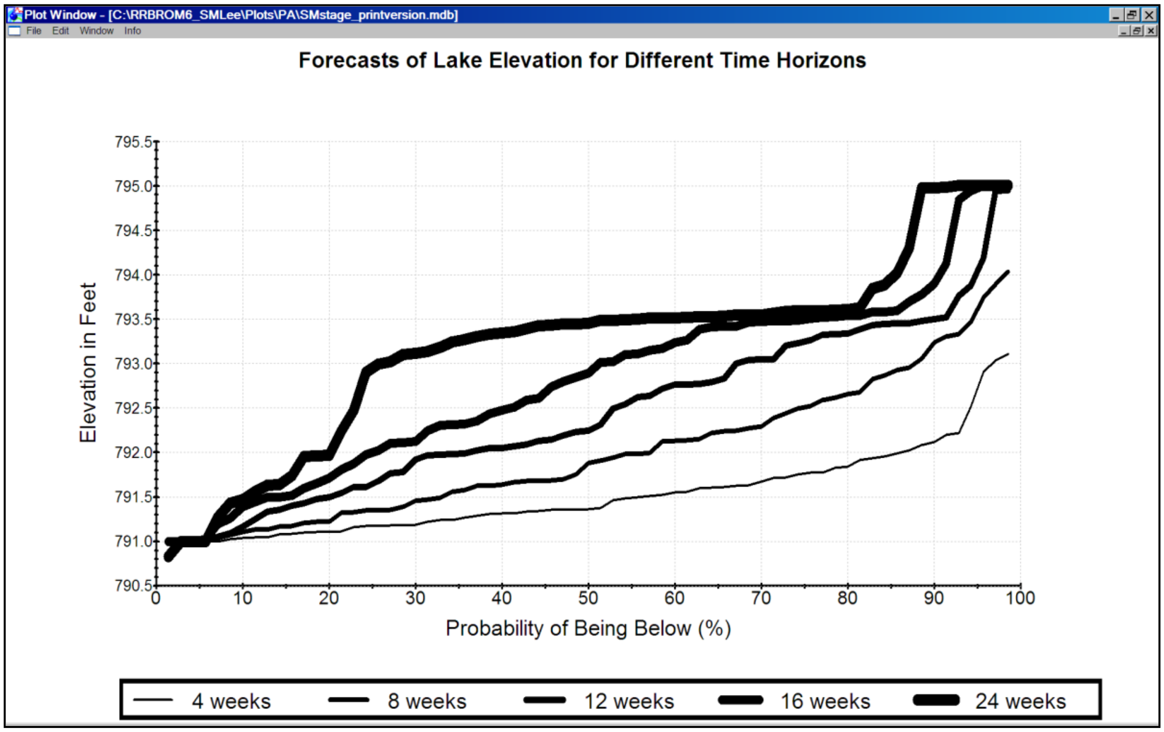

Figure 4: Predicted Lake Levels at Different Times in the Future

Determining when to take corrective action means that a trigger has to be developed that ensures that the drought events are detected in time without being invoked excessively or unnecessarily. These triggers are developed through trial and error by simulating the historic record with the ensemble forecasts.

Conflict Resolution through Interactive Negotiations:

The power and flexibility of the RRBROM tool allowed stakeholders to quickly understand the dynamics of the system and the impacts of proposed changes to the operating protocols, including downstream flow targets and water supply demands.

Early on in the process, the stakeholders endorsed the idea of using probability-based triggers to better manage low flow conditions and to respond proactively to drought events. Appalachian also endorsed the concept given its science-based approach and relative ease of implementation.

Initial runs indicated that multiple triggers would provide sufficient lead time to respond proactively to drought conditions. Each trigger leads to a reduction to downstream flow targets and recreational flow deliveries. Further, results indicated that the triggers would be invoked about once every 3 to 5 years on average, which seemed reasonable to stakeholders who had endured numerous operating variances in the last ten years.

The specific triggers under the latest proposed protocol (HL_8) are as follows:

- Trigger 1: 20% chance of dropping below 790.5 feet in 16 weeks

- Trigger 2: 2% chance of dropping below 790 feet in 10 weeks

A third trigger was added to reduce the impact of multi-year droughts and will be enacted if trigger 2 is in effect and Smith Mountain has not refilled between December and March.

Each of these triggers provides some target flow downstream of the dams as measured at Brookneal. Under normal conditions, the target flow is the dry year target as described earlier in the paper. Under trigger conditions, the target flows provide some reduction to these dry year targets as plotted below. In trigger 1 events, the target flow is 85 percent of the dry year target, or the floor, whichever is higher. In trigger 2 events, the target flow is the floor. In trigger 3 events, the target flow is 70 percent of the dry target, which results in a flow that is below the floor. Trigger 3 events would be infrequent, happening only once every 10 years on average as compared to 3 to 5 years for the trigger 1 and 2 events. Note these targets are guided by concerns over aquatic habitat. Additional requirements are imposed for recreation during the summer period, with cutbacks to the number of days of recreation increasing with trigger event. A summary of the monthly target flows is shown in Figure 5.

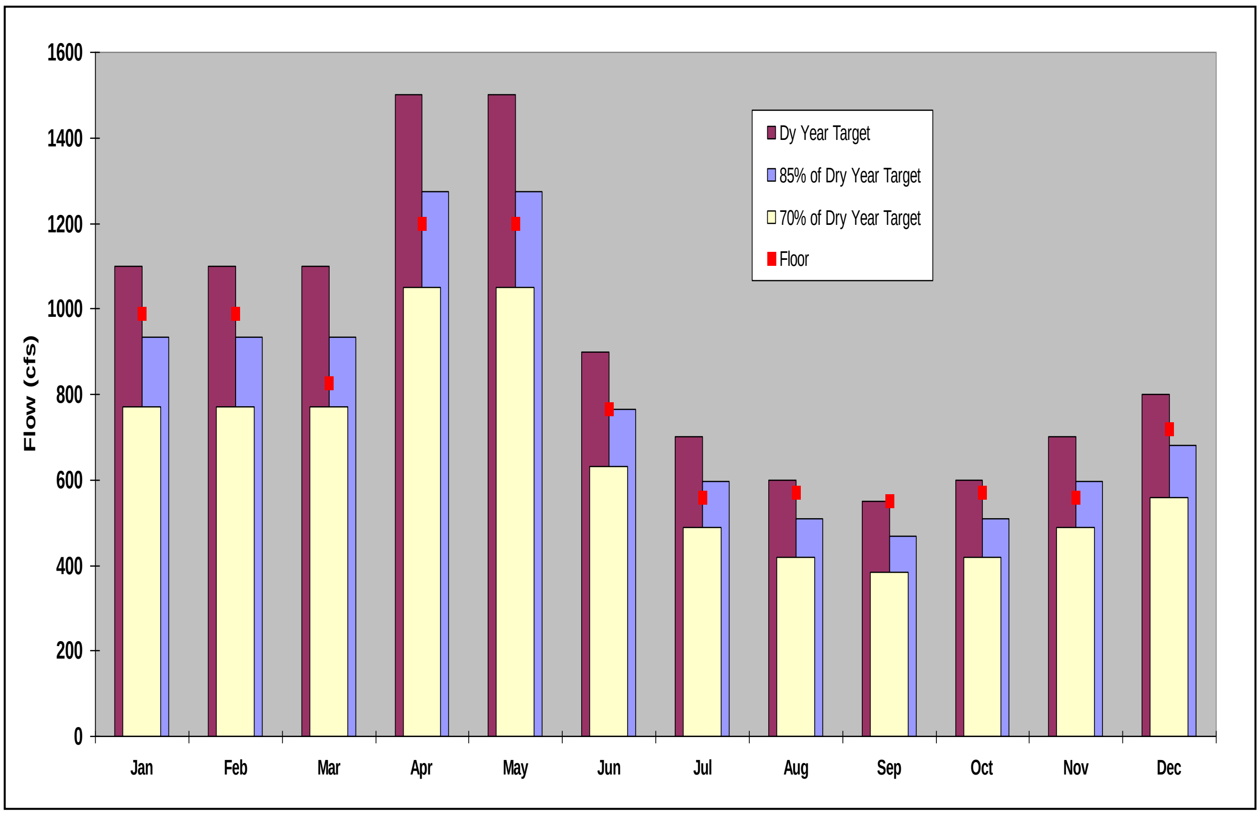

Figure 5: Target flows at Brookneal

The impacts of the proposed protocol on elevations and flows are shown in Figures 6 through 8. Since 1995, when operating data were first readily available, the protocol results in lake levels that would have been close to or higher than actual elevations as shown in Figure 6. [The protocol also includes a 50-year projected net water withdrawal from the lake that is not reflected in the historic elevations, which causes additional drawdown of about 0.3 feet]. In terms of downstream releases, Figure 7 shows that the protocol would provide a lower minimum release from Leesville earlier in the year but would avoid more drastic cutbacks to the release than those experienced in 2001 and 2002, which can negatively impact aquatic habitat. [The historic drops to zero release were maintenance-related]. Despite the lower minimum release, the flows at Brookneal (Figure 8) are similar under the protocol relative to the historical, gaged flows. By accounting for the intervening inflow between Leesville and Brookneal, the Leesville releases can be reduced without violating the Brookneal target flows, thereby reducing drawdown of the lakes.

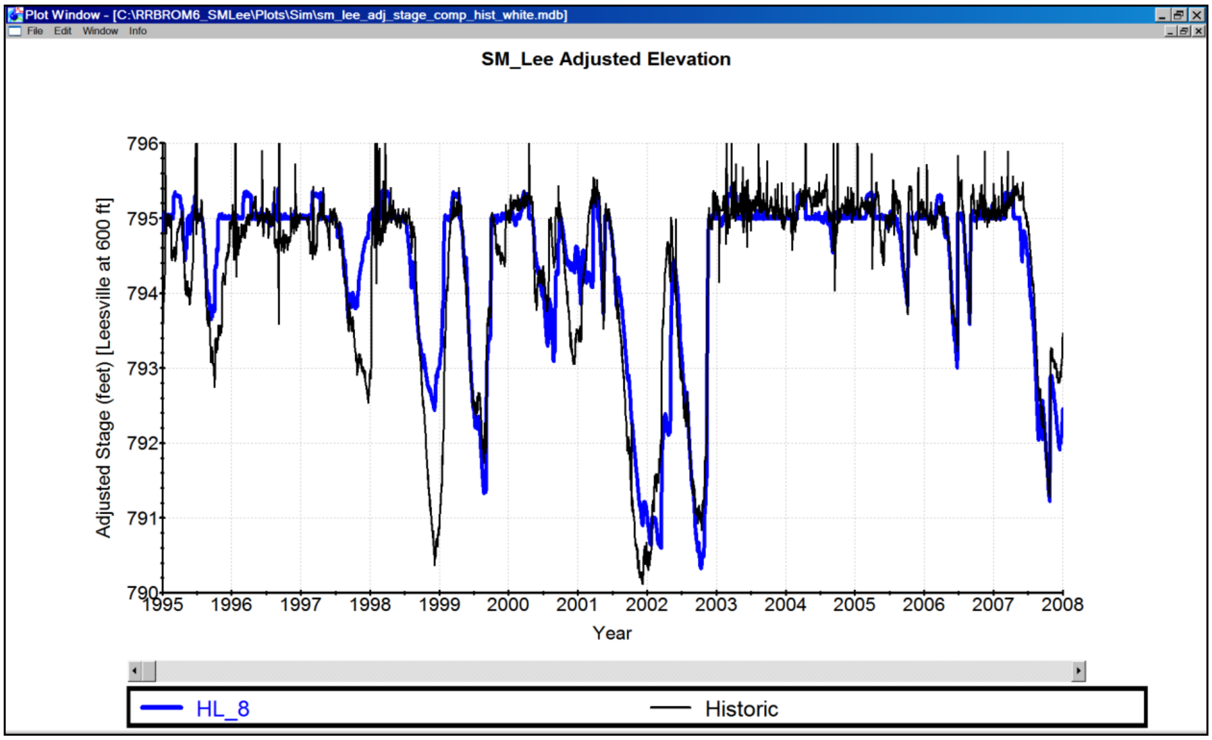

Figure 6: Comparison of Computed and Historic Elevations

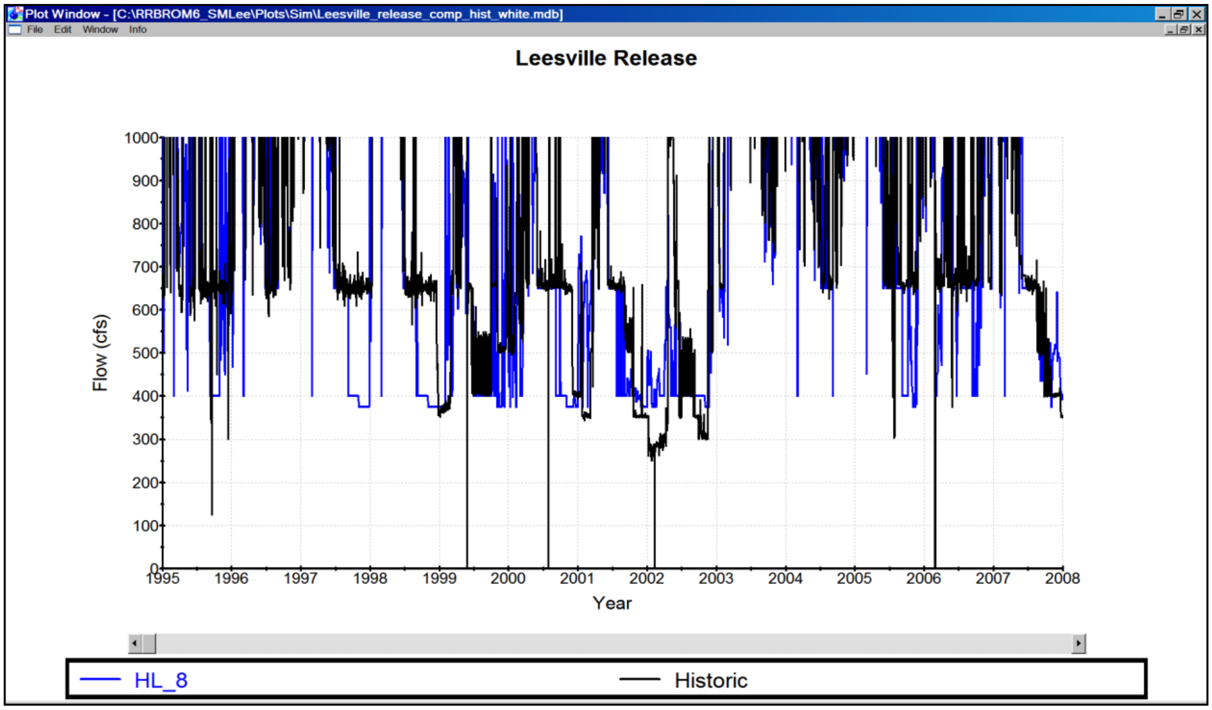

Figure 7: Comparison of Computed and Historic Releases

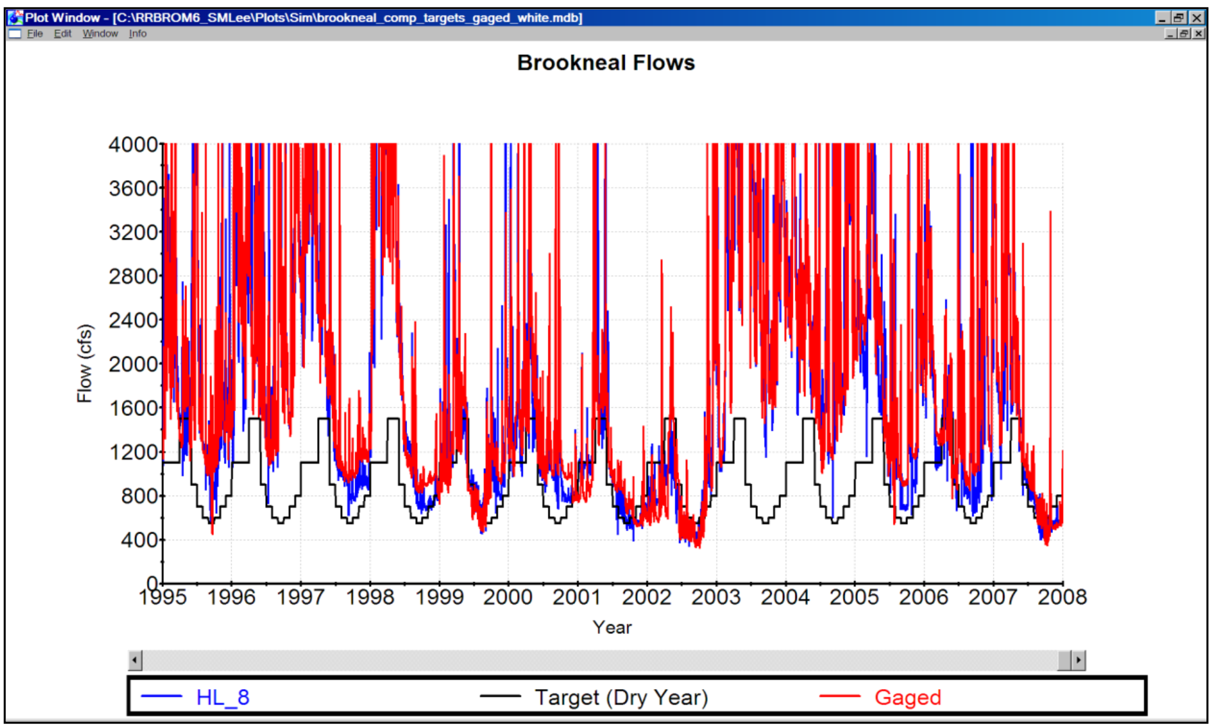

Figure 8: Comparison of Computed and Historic Flows Downstream

As the process went on, the protocols in both normal and low flow conditions received scrutiny from stakeholders concerned about the balance between the main two competing uses: recreation on the lake and recreation downstream on the river. In addition, water suppliers became concerned that if the protocol did not embed future projections of water supply demand, they would have to obtain permits at a later date, which could be much more costly and difficult than trying to obtain these agreements within Appalachian's new FERC permit.

The latest proposal (HL_8) attempts to balance these competing uses, with emphasis on the summer months since most recreation occurs during that time. The proposal has yet to be agreed upon by all stakeholders, and some additional refinements may be sought. At a minimum, embedded in the permit will be a probability-based low flow protocol that will preserve water use during low flow conditions.

Implementation of Low Flow Protocol:

In order to help meet the target flow at Brookneal, Appalachian will rely on some estimate of the intervening inflow between the Leesville dam and Brookneal. The operators will use this information to estimate the amount by which they can reduce the Leesville release to meet the Brookneal target. Since perfect foresight of the inflows is not possible, the target will not always be met from day to day. If the inflow is large enough, it is theoretically possible that the target at Brookneal could be met without any release from Leesville. To support aquatic habitat immediately downstream of the dam, the operators will always be required to release at least 400 cfs (375 cfs in the winter) from Leesville.

Appalachian will then use its licensed copy of the RRBROM in a real-time forecasting mode to determine when to invoke the triggers during drought events. The operators will input the starting lake level and update the inflows to the projects through the forecast date, and then run the model to generate a probability distribution of lake levels over the forecast horizon associated with the trigger. If the probability of reaching the associated trigger lake level is high enough, the trigger will be invoked and minimum releases from Leesville reduced. For trigger 1, that means the probability of dropping below 790.5 feet in the next 16 weeks is at least 20 percent.

The stakeholders agreed that the protocol would be reviewed every five years and adjusted as necessary to ensure a balanced approach to low flow management, particularly in future drought events that could be worse than those in the historic record.

Authors

Steven R. Nebiker is a Water Resources Engineer for HydroLogics, Inc. and is responsible for the modeling and evaluation of hydropower operating protocols, both for relicensing and day-to-day dispatch. He also is involved in drought management planning and the mitigation of water supply risk.

Brian J. McCrodden, Vice President and Business Manager of HydroLogics, Inc., has expertise in the integrated management and operation of water resources systems. He has overseen the development of large basin-wide hydrologic models like the one used for the Roanoke River Basin and has worked closely with hydropower companies, state and federal agencies, and environmental groups to assess the tradeoffs of various water management strategies and develop operating rules that enhance system performance.

Teresa P. Rogers is the Environmental and Regulatory Affairs Supervisor for American Electric Power, and is responsible for overseeing the relicensing process for Appalachian Power's Smith Mountain Project.