

# FORUM

## Western U.S. Water Supply Forecasting: A Tradition Evolves

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Since 2011, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and three major river forecasting centers of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) have discontinued a long-standing practice of publishing consensus water supply forecasts in western U.S. river basins.

Historically, seasonal runoff forecasts for approximately 700 key locations were developed separately by the two agencies and then coordinated into a single forecast via interagency exchanges. The coordination agreement avoided potential user confusion by providing a single outlook that served as official input to high-stakes water decisions. The shift away from this coordination was driven by a few factors, primarily technological advancement and user interest in more frequent and expanded forecasts.

The waning of the coordination practice motivates this article, which describes the history of this practice, agency forecasting methods, and opportunities and challenges as U.S. water supply forecasting turns a corner. To overcome these challenges and meet these opportunities, the scientific community should participate in the discussions that are currently shaping the future of operational forecasting enterprises.

### *A History of Interagency Coordination*

In the mid-1930s, the USDA Soil Conservation Service (SCS) was charged by a federal mandate to collect monthly snow survey measurements and to issue seasonal (e.g., April–July) water supply forecasts. By 1944, the NWS had joined SCS in independently publishing water supply forecasts for many of the same locations. Both agencies used statistical methods, although the SCS favored the use of snowpack data as predictors, whereas the NWS preferred its own precipitation data. SCS forecasts were initially deterministic, whereas the NWS emphasized a range. Although each agency was the sole forecast provider at distinct locations, disagreements in the dual forecasts in some situations, such as for the severity of a devastating Columbia River flood in 1948, were sources of confusion [Helms *et al.*, 2008].

Early on, forecasters from the two agencies informally and voluntarily coordinated their efforts to provide similar outlook information. Following unsuccessful attempts to establish

a coordination policy in 1955 and 1962, a 1978 agreement determined which agency had primary authority over the forecasts at specific locations. Responsibilities were divided based on constituents' interests (e.g., SCS (now NRCS) supported irrigation planning, and NWS supported flood control) and on the relative performance of each agency's statistical forecasting models. Committees that met regularly until about 2005 developed procedures for allocating new forecast points, renegotiating ownership, and resolving conflicts during the forecasting season.

Since that time and until recently, the coordination procedure was conducted once or twice monthly on a predetermined schedule. Coordination involved several days of negotiation by forecasters from the two agencies before the consensus official forecast could be released. Documentation of the forecasters' exchanges is lacking, although independent forecast values (e.g., the NWS hydrologist's preferred value) were archived in some cases.

### *Technological Progress and User Demands Overtake a Tradition*

As part of the NWS Modernization Program initiated in 1992 and the Advanced Hydrologic Prediction Service initiated in 2002, the NWS augmented its statistical water supply forecast capability by implementing the NWS River Forecast System [Day, 1985]. This system used snow and rainfall-runoff simulation models within the Ensemble Streamflow Prediction (ESP) procedure, in which a sampling of historical weather sequences is used to project watershed conditions ahead into the forecast period. Today, the NWS models are calibrated for more than 6000 streamflow gauges and are capable of both short-term (1- to 10-day) and seasonal forecasting nationally. ESP provides additional information to complement the traditional water supply forecast, such as peak flow probabilities and other statistics that can be derived from an ensemble of daily streamflow predictions.

Although few organized evaluations of the skill of water supply forecasts exist, ESP and statistical forecasts have different strengths and weaknesses. In general, ESPs are thought to have greater potential than statistical methods to predict extreme years and to make predictions at times of year when common statistical predictors of water supply forecasts are not well estimated. ESPs contain bias and spread errors, especially toward the start of snowmelt, when key water allocation decisions are made [e.g., Wood and Schaake,

2008]. Statistical water supply forecasts yield more reliable uncertainty estimates and lower bias. Objective methods exist to address some of the ESP deficiencies, but these have not been implemented comprehensively.

ESP and statistical water supply forecasts traditionally have been prepared only once or twice per month as input to the coordination process via a labor-intensive process in which forecasters scrutinized and, where needed, adjusted inputs and model states (particularly snowpack). When users expressed interest in more frequent updates of water supply forecasts to gauge the effect of weather events occurring between coordination dates, ESPs came to be run on a daily or weekly basis. These more frequent ESP forecasts are made with minimal effort because they rely on model conditions developed as part of routine flood forecasting operations. The NRCS also developed automated daily updating of the statistical forecasts [Pagano *et al.*, 2009]. Each agency's website displayed the new water supply forecast products alongside the official coordinated forecasts for comparison.

Agency concerns about the distribution of unofficial forecast products motivated a NRCS/NWS meeting in 2006 to address how best to utilize the agencies' developing abilities. Internally, some forecasters were resistant to releasing the more automated products, which at times did not agree with the official water supply forecasts. The agencies agreed that unofficial forecasts could be distributed, provided they were labeled as "guidance" to avoid confusion with the official forecast. This agreement lasted until 2012, when the two agencies suspended coordination and began maintaining independent products, each retaining an "official" label on some forecasts. In place of the formal coordination practice, each agency's hydrologists are encouraged but not required to collaborate, without a documented definition of what this may entail.

In 2012 the agencies' forecasts typically differed by 5%–10% of average runoff. This disparity is on par with the expected error for critical spring water supply forecasts. Such differences may reintroduce the potential for confusion, e.g., when the forecasts straddle a legally mandated management threshold between distinct water allocation policies, with different benefits and costs for specific users. Some users now appear to rely on one agency's set or the other, whereas other users consider both, depending on their decision framework and institutional allegiance.

### *Changing Forecasts in a Changing World*

There are costs and benefits of having a single official consensus forecast. Ad hoc coordination is a subjective, time-consuming, and nonrepeatable process; delays forecast dissemination; and is not scalable toward expanded forecast services (enhanced and more frequent products). For example, the 2007 Colorado River Interim Operating Agreement requires water managers to operate major reservoirs and allocate water based

on the U.S. Bureau of Reclamation's 2-year monthly reservoir levels prediction study. The study uses NWS monthly ESP forecasts as input for the first year; this type of input is less suitable for coordination than traditional water supply forecasts.

However, coordination serves as a form of peer review, supports user decision rules with unambiguous guidance that can serve as a forecast of record, and may merge the strengths of the two types of forecasting. Fundamental policy issues that originally motivated coordination still remain. Forecasts influence many water management decisions—affecting water rights and usage, markets, and the environment—that now must evolve to accommodate potentially conflicting (but also complementary) forecasts. In February 2013, for example, Kerr Dam managers grappled with an average difference of 17% between the agencies' published forecasts for Montana's Flathead Lake inflow. They were unaccustomed to evaluating management scenarios with multiple uncoordinated forecasts as input, suggesting a need for user education or outreach to accompany such operational shifts.

The evolution of water supply forecasts illustrates the challenges faced by opera-

tional agencies in maintaining traditions (products and procedures) that have been formalized to support the development of decision frameworks within broad user enterprises. Not only can user expectations become formalized (in decision technology, procedure, and laws), but forecasters can configure their internal training, procedures, software, hardware, and related support to deliver the formalized practice with operational reliability.

Forecasting science and technology often progress steadily beyond the existing formalized methods, and today there are clear opportunities to improve current operational river forecasting. These include advances in weather and climate forecasting, hydrologic modeling, communications, computing, verification, and statistical post-processing. Statistical merging approaches such as those now being applied to climate and weather forecasts may provide an objective, science-based avenue back toward a coordinated forecast. Regardless, it is clear that agency efforts to upgrade legacy practices would ideally embrace such science advances while also engaging stakeholders and researchers in an ongoing dialogue about balancing tradition and progress to

meet the evolving information needs of the water community.

### References

- Day, G. (1985), Extended streamflow forecasting using NWSRFS, *J. Water Resour. Plann. Manage.*, *111*(2), 157–170.
- Helms, D., S. E. Phillips, and P. F. Reich (Eds.) (2008), *The History of Snow Survey and Water Supply Forecasting*, *Natl. Bull.* 290-9-6, Natl. Resour. Conserv. Serv., U.S. Dep. of Agric., Washington, D. C.
- Pagano, T. C., D. C. Garen, T. R. Perkins, and P. A. Pasteris (2009), Daily updating of operational statistical seasonal water supply forecasts for the western U.S., *J. Am. Water Resour. Assoc.*, *45*(3), 767–778.
- Wood, A. W., and J. C. Schaake (2008), Correcting errors in streamflow forecast ensemble mean and spread, *J. Hydrometeorol.*, *9*, 132–148.

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