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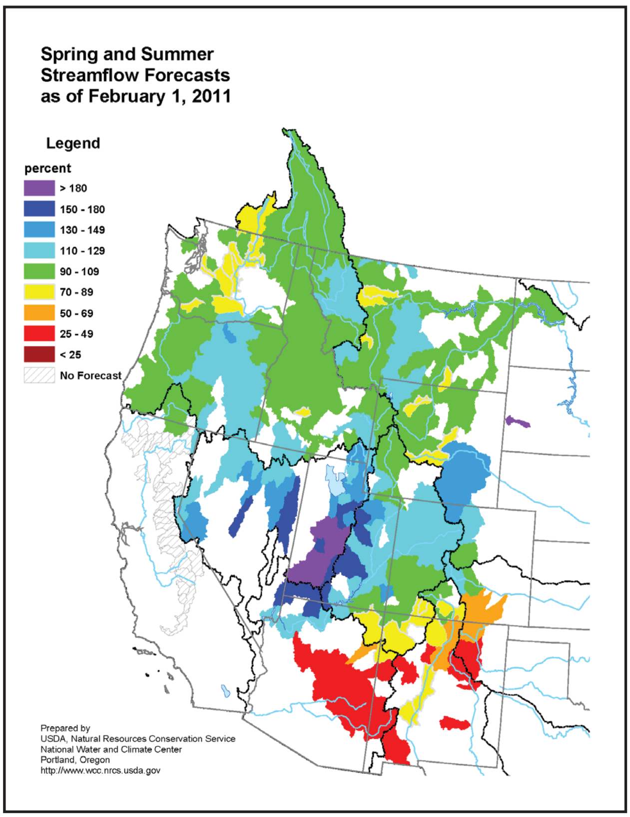
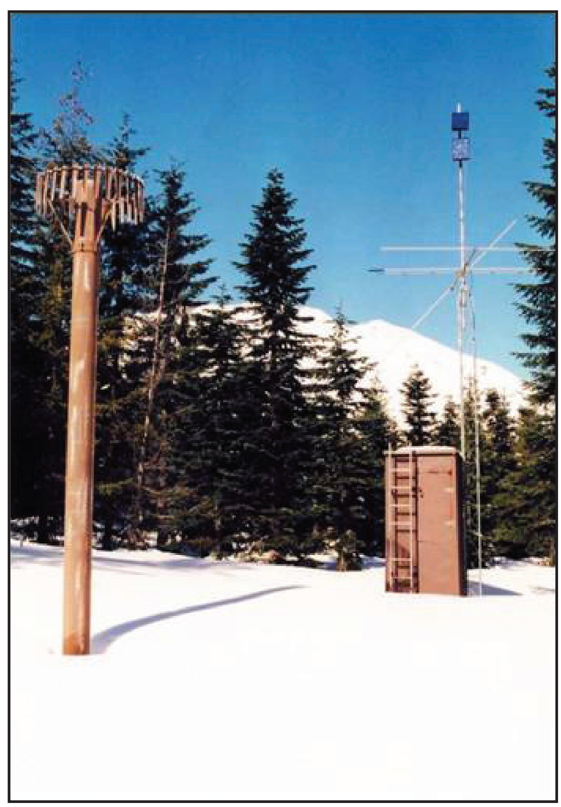
Natural Resources Conservation Service

Part 622 Snow Survey and Water Supply Forecasting
National Engineering Handbook

Chapter 7 Water Supply Forecasting





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Chapter 7 Water Supply Forecasting

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Chapter 7 Water Supply Forecasting

622.0700 Introduction

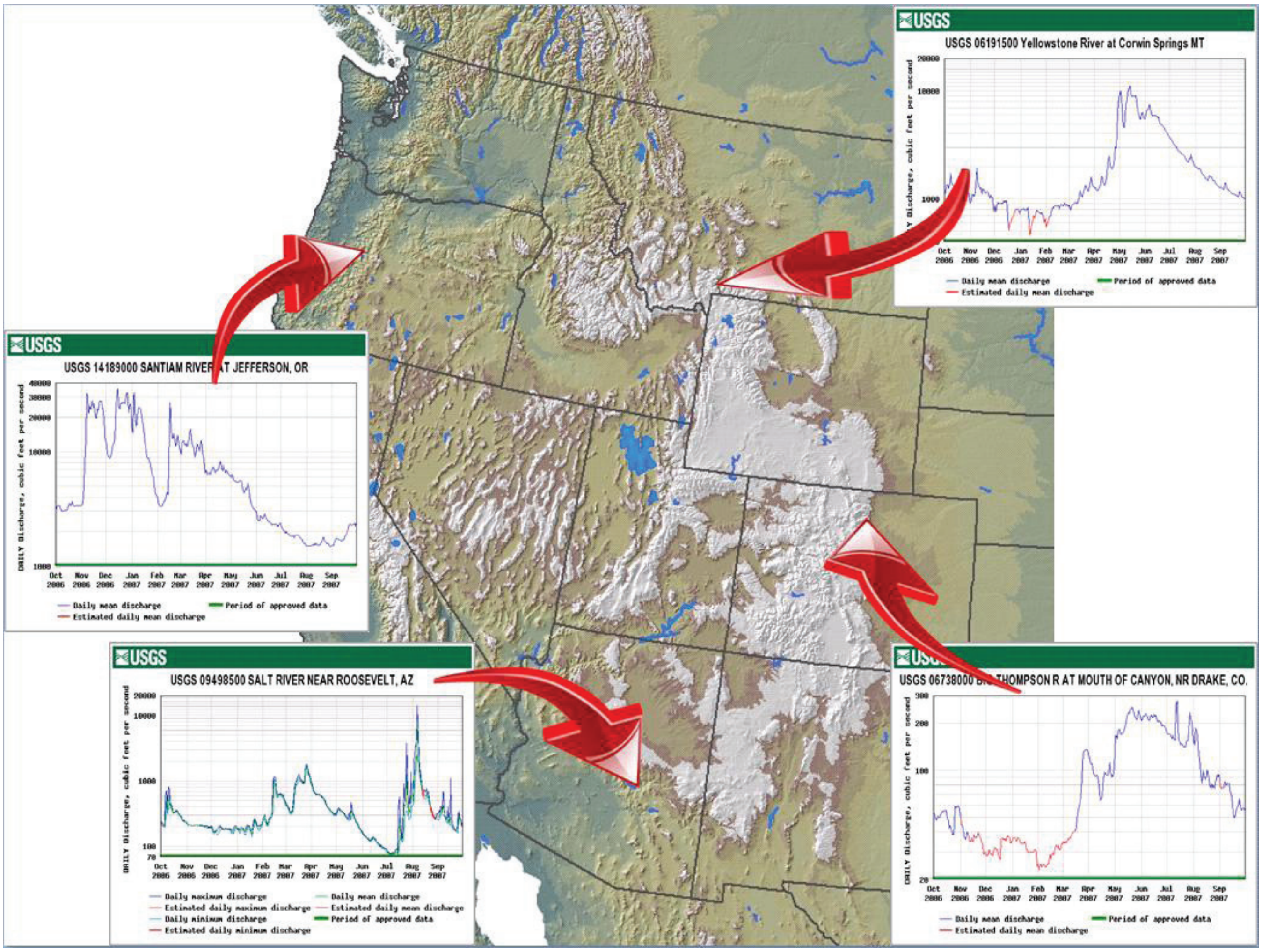
A water supply forecast is a prediction of streamflow volume that flows past a point on a stream during a specified season, typically in the spring and summer. The primary basis of water supply forecasting lies in the fact that most of the annual streamflow in western North America originates as snowfall that has accumulated in the mountains during the winter and early spring. This snowpack serves as a natural reservoir, storing water during the winter and releasing it during the spring and summer snowmelt season. The delay between when the snow accumulates and when it melts makes it possible for hydrologists to use snowpack measurements during the winter to make predictions of snowmelt runoff.

In some areas, however, snowmelt is not a dominant process and, therefore, forecasting is more difficult. For example, winter, spring, and/or summer rainfall can supply a significant amount of the streamflow volume on the west side of the Cascade Mountains, the east slope of the Rocky Mountains, and in parts of the Southwest. Either this rainfall runoff occurs immediately and is not stored in the snowpack, or it occurs after the forecasts are issued and cannot easily be predicted. Hence, forecast uncertainty is higher in these areas than in predominantly snowmelt basins.

Figure 7–1 depicts examples of these different streamflow regimes by showing characteristic hydrographs for four distinct areas. The upper Yellowstone River in Montana (upper right) represents a snowmelt-dominated hydrologic regime. This type of basin is relatively easy to forecast, as snowmelt runoff can be very reliably predicted using snowpack measurements. Spring and summer precipitation is usually small and contributes relatively little to the streamflow volume. The Big Thompson River (lower right) is located on the east side of the Rocky Mountains in the headwaters of the South Platte River in Colorado. Although there is an important snowmelt component, spring and summer precipitation can also add substantially to the streamflow volume. Since spring and summer precipitation cannot be predicted and mostly occurs after streamflow forecasts are issued, this adds a significant amount of uncertainty to streamflow forecasts. The Salt River (lower left) is located in the Southwestern United States in an area of typically ephemeral snowpacks and sometimes intense winter rainfalls. The snowpack that does exist melts much earlier in the year than snowmelt basins farther north and contributes only modestly to streamflow volume. This region also receives considerable precipitation from late summer monsoonal rains that move northward from the Gulf of Mexico, leading to significant streamflow volume. All of these characteristics lead to high streamflow forecast uncertainty in this area. The Santiam River (upper left) is located on the west side of the Cascade Mountains in Oregon in a winter rainfall-dominated area. Snowmelt is only a minor part of the hydrologic regime here. Consequently, most streamflow occurs in winter as rainfall runoff, and snowmelt contributes only a small part to the total streamflow volume. Rainfall cannot be accurately predicted more than a few days in advance and, since there is little storage time lag as with snow, forecast uncertainty is very high in this area. Lastly, although not shown in figure 7–1, forecasting in highly glaciated basins can be difficult due to glacier dynamics not being easily incorporated into standard forecasting models and glacial meltwater production being driven by climatic influences unrelated to or out of phase with annual snowpack accumulation. These examples illustrate the hydrologic diversity throughout the region where NRCS hydrologists prepare water supply forecasts. Although there are some regions that are difficult to forecast due to the hydrologic and climatic characteristics, there are many areas that have good forecast skill due to the dominance of snowmelt in streamflow production.

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) Snow Survey and Water Supply Forecasting Program (hereinafter called the Program) issues water supply forecasts for hundreds of points in the Western United States. The primary forecast product is a seasonal volume for a specified period of months (e.g., April–July). These forecasts are issued near the first of the month between January and June. Mid-month updates are also issued for selected forecast points. In addition, daily guidance forecasts are issued for a subset of forecast points using an automated procedure.

Figure 7–1 Characteristic water year hydrographs for differing hydrologic regimes around the Western United States



The Program also includes some other types of forecasts besides seasonal streamflow volume. These other forecast types include predictions of:

- peak daily flow rate during spring snowmelt season and its date of occurrence
- date the daily flow rate will recede below a given threshold
- maximum lake level rise
- daily flow rate on a given date

These other forecast types are developed and issued to meet user needs and to address specific water management concerns. They provide important additional information useful to water managers, farmers, recreationists, fish biologists, and other interests.

This chapter describes the essential features of water supply forecasting as practiced in the NRCS. The topics are presented in a roughly chronological sequence of activities, from forecasting point establishment, to data gathering, to model development, to operations, and finally to verification. Citations of foundational professional literature and NRCS technical notes are given to provide sources of details on mathematical procedures and other technical information not explicitly described in this chapter.

622.0701 Forecast points

(a) Forecast point establishment

New forecast points are established based on needs brought to the attention of the forecast staff by the State Program staff. When presented with such a request, the hydrologist responsible for that geographic area investigates the data availability and feasibility of producing meaningful forecasts that meet criteria set by the Program. Once this is determined, the point can be added as a forecast point.

The criteria for establishing a forecast point are as follows:

- The forecast point must be located at an identified active streamgaging station.
- If there are upstream reservoirs, diversions, or other water management activities that significantly impact streamflow, these must be identified, and data sources for them must be available (unless it is decided not to correct for these effects and issue forecasts for observed rather than adjusted flow).
- Meteorological and snowpack monitoring stations that are available to provide sufficient input data for forecasting models must be identified.
- At least 10 years of concurrent observed streamflow and hydrometeorological input data must exist.
- The forecast models should meet the minimum skill criterion of having a correlation coefficient of at least 0.3.

Once a forecast point is established, verification should be done each year. In addition, forecast models should be updated at least every 5 years or as often as necessary to reflect data collection and watershed changes.

(b) Forecast point discontinuance

Forecast points must sometimes be discontinued. This is usually due to a streamgage closure, which makes it impossible to verify forecasts or update models. The standard states that if a streamgage is discontinued, a forecast can be produced for up to 5 years after the gage closure, at which time the forecast is discontinued.

Forecast points should be reviewed periodically to ensure that they are still relevant and are meeting identified user needs. Forecast points may be discontinued if no identified need is being met. Forecast points may also be discontinued if a forecast model update or reanalysis reveals that minimum skill criteria have not been met, even though forecasts have been issued for these points in the past. In such a case, the hydrologist should work with State Program staff to identify other possibilities for addressing user information needs.

(c) Forecast point support

Each Program staff hydrologist is assigned a forecast area. Usually these areas are based on major river basins. Each hydrologist also acts as a liaison to one or more States within the assigned forecast area. This liaison function involves producing that State's forecasts and report files and serving as a contact point for the States to direct various data collection and other issues to the forecasting staff. The liaison function also includes acting as a technical resource and supporting customer education and awareness.

622.0702 Basic data types and usage

The foundation of water supply forecasting is data. The main data source for the Program is the network of mid- to high-elevation snowpack and climate monitoring stations in the snow telemetry (SNOTEL) system. Other data sources commonly used in forecast development are the NRCS manual snow course network, the National Weather Service (NWS) cooperative climate network, and the U.S. Geological Survey (USGS) streamgaging network. The data types usually used in water supply forecasting models are:

- snow water equivalent
- precipitation
- streamflow
- climate teleconnection indices

Other data types that have also sometimes been used or may be used more in the future include: temperature, groundwater levels, and soil water content.

The usage of these data types in forecasting models attempts to index the dominant large-scale hydrologic processes operating to generate spring and summer streamflow. These processes are (in approximate order of occurrence during the year):

- large-scale climate teleconnections (e.g., El Niño) related to future weather and streamflow
- soil water content state in fall going into winter snow accumulation season
- baseflow/groundwater state in fall going into winter snow accumulation season
- precipitation
- accumulation of snowpack in winter
- spring snowmelt
- streamflow response in early spring
- air temperature accelerating or delaying snowmelt as spring progresses

Each data type and the time period covered is intended to index one or more of these processes.

622.0703 Forecasting methodologies

(a) Statistical models

Currently, all NRCS water supply forecasts are produced using statistical models. In the early days of the Program, when computing was much less readily available than it is today, highly simplified statistical relationships were used to make forecasts. Particularly from the mid-1980s onward, however, as computing has developed rapidly, much more sophisticated and computationally intensive statistical techniques have been employed. These techniques are described in the following sections.

(i) Statistical model techniques

In general, statistical models are based on multiple linear regression techniques. Since the early 1990s, principal components regression has been the standard methodology used, based on the procedure developed by Garen (1992). Principal components regression addresses the identifiability problems of regression coefficients when the predictor variables are highly intercorrelated, as is the case for the predictor variables typically used in statistical water supply forecasting models. Principal components analysis is a well-known multivariate statistical technique that summarizes a set of intercorrelated variables into a smaller number of uncorrelated "components," each component being a weighted sum of the original variables. These components can then be used as predictor variables in a multiple regression. Software has been developed by the Program to implement this technique for model development and operational use (Perkins, Pagano, and Garen 2009).

Hydrologists do not necessarily need to be highly familiar with the mathematical details of principal components analysis but do need to understand the general concepts and principles to use the technique properly. This especially has to do with understanding the process of component selection and how to control it. Relevant to this are the variable weightings (eigenvectors) inherent in each component, the process of considering each component in sequence from largest to smallest eigenvalue (i.e., most to least explained variance in the predictor variable set) with no skipping of components, and the standard t-test used to determine the statistical significance of regression coefficients (i.e., whether they are significantly different from zero). These concepts are explained in USDA NRCS (2007b).

Some important considerations in controlling the number of principal components retained in a model are as follows:

- The critical value of the t-statistic used to test whether regression coefficients for principal components used in the model are significantly different from zero should generally be in the range of 1.2 to 2.5. The hydrologist has some latitude in selecting this value to control how many principal components are retained in the model. Lower critical t values set a less stringent criterion for accepting a principal component as a predictor variable in the model. Therefore, the tendency would be to retain more components. Higher critical t values would make it more difficult for principal components to be retained in the model. A reasonable default value is 1.6. For exact significance levels corresponding to given critical t values, a table of the t distribution can be consulted, which appears in most standard statistics texts.
- Control over the number of principal components retained can be done either by manipulating the critical t statistic or by manually setting how many components to retain in a given model. Control over the number of principal components used in the model is necessary both to ensure the retention of the best number of components to minimize the standard error of the equation and to ensure month-to-month consistency in the set of equations developed for a given forecast point. The equation coefficients and the predictions are significantly affected by the number of principal components used in the model. Undesirable forecast variability from month to month can be introduced by the use of varying numbers of components. There should be reasonable and explainable consistency in the number of principal components used in the monthly sequence of forecast equations for a given forecast point. If the predictor variables used are fairly consistent from month to month, then one would expect the same number of principal components re-

tained by the models. If, however, the variables change by adding or deleting variables (which is, for example, common in the late spring equations), then the number of principal components may change.

Since 2005, a second technique called Z-score regression has also been used (USDA NRCS 2007b; Pagano et al. 2009). This method does not explicitly deal with intercorrelation among predictor variables, but it does provide a way to deal with different record lengths and missing data for predictors (whereas principal components regression requires a serially complete data set). Care must be taken, however, to ensure that all major signals are adequately represented throughout the analysis period; if there is a substantial number of missing years for some predictor variables, the resulting model may be unstable. Although Z-score is not a standard textbook regression method, experience has shown it generally to perform well. In cases of serially complete data, both principal components and Z-score regression give similar forecast results, although the coefficients on the individual predictor variables can be quite different.

These regression techniques have been combined with search algorithms to optimize the selection of time periods and stations and with a leave-one-out jackknife (cross-validation) test for forecast robustness. All of these techniques are described in USDA NRCS (2007b).

(ii) Basin and downstream relational procedures

Two types of statistical models are used: "basin" models and "downstream relational" (frequently called "routed") models. Basin models use basic data types, usually within or near the watershed boundary of the forecast point, to predict streamflow at the basin outlet. Most forecasting procedures are of this type. Downstream relational models take the results from one or more basin models and use these to forecast a downstream point. It is often more convenient and physically meaningful to predict downstream points using the output from upstream basin models rather than creating basin models directly for these downstream points, especially when the additional inflow between upstream and downstream points is minor.

All of the statistical techniques mentioned in the materials cited to this point pertain to the development of basin models. The philosophy, guidelines, and model development procedures described in the following sections are also mostly relevant to basin models.

Downstream relational models are much simpler and more straightforward to develop than basin models. They are essentially an adding up and downstream translation of headwater basin results. The standard technique is first to develop the base linear regression relationship between the upstream basin(s) and the downstream point using historical observed data for the relevant forecast period. Then, jackknife predictions saved from the development of the upstream basin models are passed through this historical relationship to generate predictions for the downstream point. The standard error for the downstream point is calculated from the errors in these predictions. This two-step process preserves the historical relationship between upstream and downstream points while also calculating realistic standard errors for the downstream point based on errors in upstream predictions.

(iii) Statistical model development philosophy and guidelines

There are several basic principles that the hydrologist should keep in mind when developing statistical models so as to ensure the most meaningful application of these models for operational forecasting. These ideas are described in this section.

The overall goal is to develop robust, consistently performing models that can be trusted and relied upon. They should be easily explainable. They should be physically meaningful, statistically valid, and operationally useful.

Standard practices in building and using statistical models include the following:

- Develop separate equations for each monthly forecast issuance, using only those predictor variables known at the time of issuance (this is in contrast to some earlier practices in which future variables were included in equations; this topic is discussed at length in Garen 1992).
- Forecast only the future (this is in contrast to some earlier practices in which the prediction period included both some past as well as some future months). If it is desired to publish a forecast period part of which is in the past (e.g., an April–July volume published in May),

then observed streamflow can be added to the forecast future period; the standard error of the prediction remains the same as that for the future period.

- Use automated, real-time data whenever possible to ensure the availability of input data when needed at forecast time.
- Be aware of the occurrences of large-scale climate phenomena and regimes, such as the El Niño/Southern Oscillation and Pacific Decadal Oscillation. These can be important to consider when selecting periods of record to use in model development and which climate teleconnection indices to use as predictor variables.
- Ensure that there are at least 10 years of data available for developing a statistical model.
- Ensure that, if a forecast model is to be used, it has a correlation coefficient of more than 0.3, which is a rule-of-thumb threshold value indicating useful forecast skill.
- Update models with new data at least every 5 years.
- Perform forecast verification analyses in the fall when the observed streamflow data for the water year become available.

(iv) Sequence of tasks for developing a set of statistical models for a forecast point

The general sequence of tasks that the hydrologist will carry out to develop forecast models includes the following steps:

- Determine data sites and predictor variables available. Maps, geographic information system resources, and internet data portals can be used in conjunction with guidance from State Program staff to determine what sites are available within and near a basin and the variables available from each site. This process is also helpful for the hydrologist to obtain familiarity with the geography and hydrology of a basin.
- Select time periods for variables. For snow water equivalent, the current value at the target forecast issuance date is usually used. For other data types that are not inherently accumulated values (as is snow water equivalent), such as precipitation and streamflow, a monthly summation must be selected. This can be determined by physical considerations, or it may be aided by computerized optimization. Generally, these monthly periods should be at least 2 months long (i.e., avoid single month variables). For a given data type, it is preferable to keep the time period the same for all sites.
- Look for “outliers” or unusual observations. Include them if real and can be accommodated without unduly distorting the statistical relationships. A nonlinear transformation (logarithm, square root, cube root) of the dependent variable is often helpful in bringing these unusual values into a range that be handled by the linear statistical model. However, there may be times when the forecast hydrologist’s expert knowledge will dictate when outliers should be excluded from the statistical analysis.
- Look for curvilinear relationships between streamflow and the predictor variables. This is usually seen in areas where low flow is typical, but a few large events can occur. In such regions, a nonlinear transformation can provide a better statistical relationship than a linear model, and it can help prevent negative streamflow predictions in dry years.
- Screen out useless candidate predictor variables before beginning the analysis (i.e., eliminate those predictors with a correlation coefficient with the dependent variable less than approximately 0.3).
- Select a regression methodology. Principal components (the standard technique) or Z-score regression can be used.
- Select predictor variables from the ones available. Automated search algorithms are usually used to initiate the screening process. Final variable selection also includes the hydrologist’s judgment and input from the State Program staff, taking into account considerations of the physical meaningfulness of each variable, the consistency in variable usage from month to month, and local characteristics of data sites. Physical meaningfulness is important to ensure that the equations are understandable and explainable hydrologically. Month-to-month consistency in variable usage is important so that forecast changes during the season reflect hydrometeorological condi-

tions and are not just statistical noise caused by changing predictor variables. Knowledge of local characteristics and idiosyncracies of data sites can be important considerations in including or excluding certain variables.

- Build and store final models.
- Document models and provide this information to the State Program staff so that they can understand the models and provide the data needed to support the operational use of the models.

(b) Simulation models

Another technique to produce water supply forecasts, used to varying degrees by federal agencies and other entities, is hydrologic simulation modeling. Currently, this technique is not being applied operationally in the NRCS, but it is a goal to do so. Using various mathematical constructs, these models attempt to represent the main physical processes affecting the movement of water within a watershed and the generation of streamflow. They operate on a continuous basis using a daily or shorter time step. One advantage claimed for simulation models is that, by explicitly accounting for physical processes, they contain a more complete description of what is happening in the watershed and can potentially make more accurate streamflow predictions, especially under unusual circumstances. It is not yet clear that this claim is necessarily true, at least in comparison to statistical models predicting seasonal streamflow volumes. Perhaps more importantly, however, simulation models can be run year-around and can produce additional outputs besides seasonal streamflow volumes, such as full hydrographs and other hydrograph-based quantities, which can be used to create additional forecast products believed to be desired by water management entities. The disadvantages of simulation models are that they require significantly more input data than statistical models, are more difficult and time consuming to calibrate, require more complex output interpretation, and require more database and software infrastructure. In addition, calibration difficulties can arise and prediction skill can suffer if important physical processes operating in a basin are not well represented in the model, the processes are poorly understood, or there are water management activities that are unmonitored or otherwise interfere with hydrologic responses.

Using simulation models, forecasts are prepared using the ensemble streamflow prediction (ESP) technique in which multiple future streamflow scenarios are generated, each scenario based on the current watershed state and a different historically observed climate input series to represent the forecast period. The ESP technique is described in Leavesley et al. (2010). These streamflow scenarios can then be summarized statistically to obtain forecasts and associated uncertainty of not only seasonal streamflow volumes, but also other hydrologic quantities such as peak flow or date to recede below a threshold flow.

622.0704 Forecast operations

(a) Schedule

Official forecasts are produced in the first week of each month from January through June. The schedule for forecast production, which comes from an agreement with the NWS, requires that the process be completed by the fifth working day of the month, although in some areas, forecasts are completed sooner.

Generally, NRCS hydrologists complete their forecast preparation within the first 3 working days of the month. This preparation includes ensuring that all required data are available and of reasonable quality, executing the statistical forecasting models, reviewing the results, and making adjustments if necessary. During the review and adjustment process, the hydrologist may rely on various sources and displays of relevant information, such as tables or maps of snow water equivalent, precipitation, and streamflow data, as well as long-range weather outlooks. Advice and guidance from State Program personnel can also be helpful. Once the hydrologist has finalized the forecast values, they are transmitted to the NWS for coordination.

In some selected basins and in response to special requests, mid-month forecasts are issued. For some forecast points, mid-month forecasts are routinely produced, whereas others are produced only by special request, usually due to critical water management concerns or extreme conditions. In some areas, explicit mid-month forecast models are developed, otherwise mid-month forecasts are generated from the next month's forecasting models, for which the snow water equivalent and precipitation variables have been extrapolated from current observations, based on selected assumptions for the intervening period.

In selected basins, an additional forecast product is routinely generated daily via an automated process. These daily water supply forecasts address a need for frequent forecast updates. To accomplish this, they rely only on readily available automated data, specifically snow water equivalent and precipitation from the SNOTEL network. This forecast product is described in USDA NRCS (2007a) and Pagano et al. (2009). Although these forecasts are generated by a fully automated process, they are comparable in accuracy to the official coordinated forecasts, thereby making them a useful tool for monitoring water supply conditions on a frequent basis. Caution must be taken in using these forecasts for water management decisions, as the input data are not subjected to rigorous quality controls, and weather events can cause these forecasts to have high day-to-day variability.

(b) Forecast coordination with the National Weather Service

The NWS also shares the mission to provide streamflow forecasts to the public for general use. Agreements between the NRCS and NWS established a list that assigned primary responsibility for each forecast point to one or the other agency (or both, in a few cases). In practice, however, both agencies often have forecast procedures for nearly all points. Therefore, coordination between the agencies is required so that both publish the same official forecast numbers for identical forecast points and periods.

Coordination takes different forms depending on the region and the individual offices involved as well as the personalities and specific forecast points involved. Where each agency has its own operational forecast model, coordination usually takes the form of a discussion between the two hydrologists and a joint number agreed upon. In other cases, where only one of the agencies has operational forecast models, coordination simply consists of the exchange of forecast values, each agency providing the values for the forecast points it is responsible for.

622.0705 Forecast dissemination

Snow survey and water supply data and forecasts are disseminated in both tabular and graphical formats through digital and hardcopy media (although with widespread computing and internet availability, some offices no longer produce hardcopy versions). Water supply forecasts and data summaries, usually in the form of monthly bulletins, are created in cooperation with NRCS State offices, which are responsible for distribution to field offices and the water user community. The forecast users include irrigation districts, individuals, municipalities, private and public conservation groups, hydroelectric producers, and local, State, federal, and international water resource managers.

622.0706 Forecast accuracy

(a) Forecast uncertainty interpretation

The uncertainty of any given water supply forecast is represented by the range of five values published for each forecast point and period. These five values correspond to different exceedance probabilities and are calculated based on regression assumptions about the distribution of forecast error. The five values are actually just discrete points on an entire error probability distribution. The standard exceedance probabilities published are 90, 70, 50, 30, and 10 percent. For selected points, 95 and 5 percent are published instead of 90 and 10 percent, respectively.

The flow volume for a given exceedance probability X is to be interpreted as the value for which there is an X percent chance that the actual streamflow volume will exceed this value and a 100–X percent chance that the actual streamflow volume will be less than this value. So, for example, the 90 percent chance of exceedance forecast is the flow for which there is a 90 percent chance that the actual streamflow volume will exceed this value and a 10 percent chance that the actual streamflow volume will be less than this value. The 50 percent chance of exceedance forecast represents the median of the forecast distribution and is the value receiving the most focus in forecast reports and maps and is used most often as the indicator of water supply conditions. The 90 percent chance of exceedance forecast will be the smallest forecast value published, and the 10 percent chance of exceedance forecast will be the largest forecast value published. Note that there is a 20 percent chance that the current year streamflow will fall above or below the range given by the 90 and 10 percent exceedance forecast values.

These five values represent the uncertainty inherent in making streamflow predictions at any given forecast point. This uncertainty may include sources such as: unknown future weather conditions, uncertainties associated with the various prediction methodologies, the spatial coverage of the data network in a given basin, hydrologic processes not represented in the forecast model, and data measurement errors.

These five forecasts are given to users to help make risk-based decisions. Users can select the forecast corresponding to the level of risk they are willing to accept to minimize the negative impacts of having more or less water than planned for.

(b) Forecast verification

At the end of each water year and after observed streamflow values have been collected, hydrologists have the opportunity to check the accuracy of their forecasts for the season just completed. This check helps to identify problems with forecast models or physical processes (such as weather events) that are not represented in the model.

The simplest measure of accuracy is just the difference between the median (50% exceedance) forecast and the observed flow volume for each month's forecasts. This difference is often expressed as a percent of observed or long-term average flow. This, however, does not indicate where the forecast falls with respect to the forecast error distribution.

A more meaningful measure in probability terms is to compute the quantile on the forecast probability distribution that corresponds to the observed value. The objective is to identify large forecast errors, ones beyond what one would expect considering the forecast uncertainty, so that, if necessary, model refinements in preparation for the next season can be done.

(c) Forecast accuracy over time

Pagano, Garen, and Sorooshian (2004) give a thorough description of forecast accuracy within a season and over time during the history of the Program. Increases in forecast accuracy from the beginning to the end of a given forecast season that are described in this paper are well known. However, decadal cycles in forecast accuracy are also documented. The speculation is that forecast accuracy may be due, in part, to cycles in climate variability, with higher accuracy during less variable periods and poorer accuracy in higher variability periods. Subsequent work by Pagano and Garen (2005) documents more clearly the cycles in climate variability and persistence, but connections to forecast accuracy remain somewhat ill-defined. Nevertheless, these studies do dispel the idea that there has been a monotonic increase in forecast accuracy over time due to greater data availability and more sophisticated methods being used. They also suggest that it is likely that climate variability plays an important role in forecast accuracy over time.

622.0707 Other products and activities

The items in this section are not water supply forecasts, but they are products and analyses that directly relate to forecasts or are otherwise supported by the Program.

(a) Reservoir operation guides

Most western reservoirs depend on seasonal runoff from snowmelt for all or a portion of their inflow. A Reservoir Operation Guide is a tool that helps managers set outflow rates, based on mandated operational project constraints that enable them to meet storage goals. The technique is principally oriented toward operation and management of reservoirs having less than 100,000 acre-feet of usable capacity and whose primary function is to provide storage for agricultural, municipal, flood control, or recreational interests. NRCS Technical Release (TR) 75 (USDA NRCS 1991) describes the generation of “volume-outflow curves” and “rule curves” that permit managers to use anticipated inflow volume to target outflow rates to reach defined storage levels. The Program provides the inflow volume forecasts used in this procedure and can provide assistance in applying the TR–75 process in developing rule curves.

(b) Surface Water Supply Index

The Surface Water Supply Index (SWSI) was originally developed in Colorado in the early 1980s to be used as a monthly drought index. It was intended to supplement or replace the commonly used Palmer Drought Index in areas where snowmelt-derived streamflow is a major water source for agriculture, a process not represented in the Palmer Index. This original SWSI was based on four basic data types: snow water equivalent, precipitation, streamflow, and reservoir storage. The value of the index was obtained from a combined probability analysis of these data types. The SWSI has become important in some State drought management plans and is used as trigger for State response to drought conditions.

In the early 1990s, a reformulation of the SWSI was suggested by Garen (1993). This reformulation substituted water supply forecasts for the snow water equivalent, precipitation, and streamflow data used in the original SWSI, explaining that the forecasts already integrate these three data types and transform them into a volume of water, commensurate with reservoir storage, to which it is added to form a criterion variable. The probability basis of the original SWSI was retained in the revised version, which allows meaningful comparison of values among river basins on a scale depicting frequency of occurrence.

The Program supports the development and implementation of the revised SWSI in those States that choose to use it.

(c) Research, development, and technical assistance

The Program sponsors and participates in research and development relating to its mission. These projects develop new models, statistical techniques, and products that are incorporated into the Program and made available to the States. The Program also acts as a technical resource for the States, providing advice, special analyses, and assistance in implementing new products or processes.

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