EVALUATION OF ENSEMBLE STREAMFLOW PREDICTION FORECASTS FOR THE UPPER KLAMATH RIVER BASIN CONDITIONED ON CLIMATE INDICATORS IN THE UPPER KLAMATH BASIN, OREGON AND CALIFORNIA

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Abstract: The upper Klamath Basin (UKB) is located in south-central Oregon and northeastern California. UKB water managers rely on accurate forecasts of spring and summer streamflow to optimally allocate increasingly limited water supplies for various demands that include irrigation for agriculture, habitat for endangered fisheries, and hydropower production. At the beginning of each month from January through May the Natural Resources Conservation Service (NRCS) estimates the total flow volume expected during the spring and summer months at five locations in the UKB. The NRCS, the Bureau of Reclamation, and the U.S. Geological Survey (USGS) began a collaborative study in 2005 to integrate the USGS's Modular Modeling System (MMS) and Object User Interface Ensemble Streamflow Prediction (ESP) Tool programs into UKB water-supply forecasts. In this paper, the forecast accuracy of the full set of simulated ESP traces are compared with subsets of ESP traces conditioned on climate indicators. In most years, ESP traces conditioned on climate indicator subsets effectively limited the range of the forecast volumes.

INTRODUCTION

On the first day of each month from January through May, the Natural Resources Conservation Service (NRCS) produces streamflow forecasts of the volume of water expected to pass a stream gage or flow into a reservoir during the spring and summer months at five locations in the upper Klamath Basin (UKB): Upper Klamath Lake; Sprague River; Williamson River; Clear Lake; and Gerber Reservoir. The UKB is located in south-central Oregon and northeastern California (Figure 1). The UKB climate is characterized by wet winters and dry summers. Annual high flows occur in the spring because of snowmelt originating in mountainous regions. Approximately 45 percent of the water year runoff (October-September) in the UKB occurs during the months of March through May. Upper Klamath Lake provides most of the necessary water storage in the UKB to help meet water demands during other months of the year.

Accurate streamflow forecasts in the UKB are essential to water managers for optimal allocation of increasingly limited water supplies for various demands that include irrigation for agriculture, habitat for endangered fisheries, and hydropower production. In 2005 the NRCS, Bureau of Reclamation, and the U.S. Geological Survey (USGS) began a collaborative study to integrate the USGS's Precipitation-Runoff Modeling System (PRMS, Leavesley et al., 1983), Modular Modeling System (MMS, Leavesley et al., 1996), and Object User Interface (OUI) Ensemble Streamflow Prediction (ESP) Tool programs into UKB water-supply forecasts.

In this paper the effectiveness of using ESP traces in the Sprague River water-supply forecasts was evaluated by making hypothetical March 1-May 31 ESP forecasts for every year from 1987-2004. The Sprague River Basin stream gage (USGS flow gage 11501000) is located about 5 miles upstream from the mouth of the river, near Chiloquin, Oregon, in the UKB. Simulated flow for the ESP traces was produced using PRMS. A paper in these conference proceedings by Hay et al. (2006) describes the hydrologic model calibration strategy. The forecast accuracy of the full set of simulated ESP traces are compared with subsets of ESP traces conditioned on climate indicators.

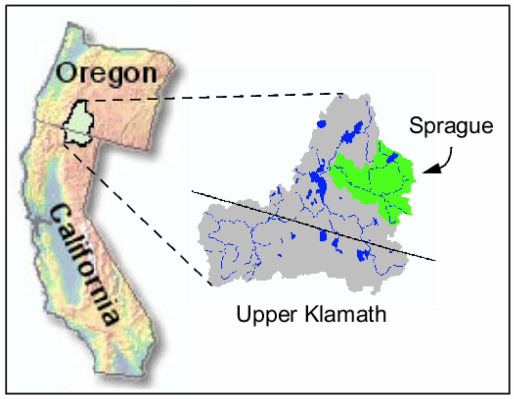

Figure 1. -- Upper Klamath and Sprague River Basins.
[Map reprinted from McCabe and Hay, 2006]

ENSEMBLE STREAMFLOW PREDICTION METHODOLOGY

In ESP forecasting, a multiple set of potential future flow records are simulated to create a range of possible flow scenarios (Day, 1985). In an ESP forecast application, a hydrologic model is used to first simulate real-time flow conditions at a site up to the date and time of the forecast. The pre-forecast period simulation is driven by near recent and real-time climate input data. At the time of the forecast (the present time for the modeler), the hydrologic model is run numerous times to create a set of possible flow records of the forecast period. All the simulated flow records (or traces) have the same simulation starting and ending dates that span the forecast period. The traces are created using the same real-time initial conditions, which include snow, soil moisture, and flow levels on the day of the forecast. However, each trace is simulated using climate input data from a different year in the historical record. Figure 2 shows an example of ESP streamflow prediction traces. In this case, the pre-forecast period is driven with data up until March 1, 2004 (black line). Starting on March 1, ESP traces are simulated based on 1987-2003 meteorological data (colored lines).

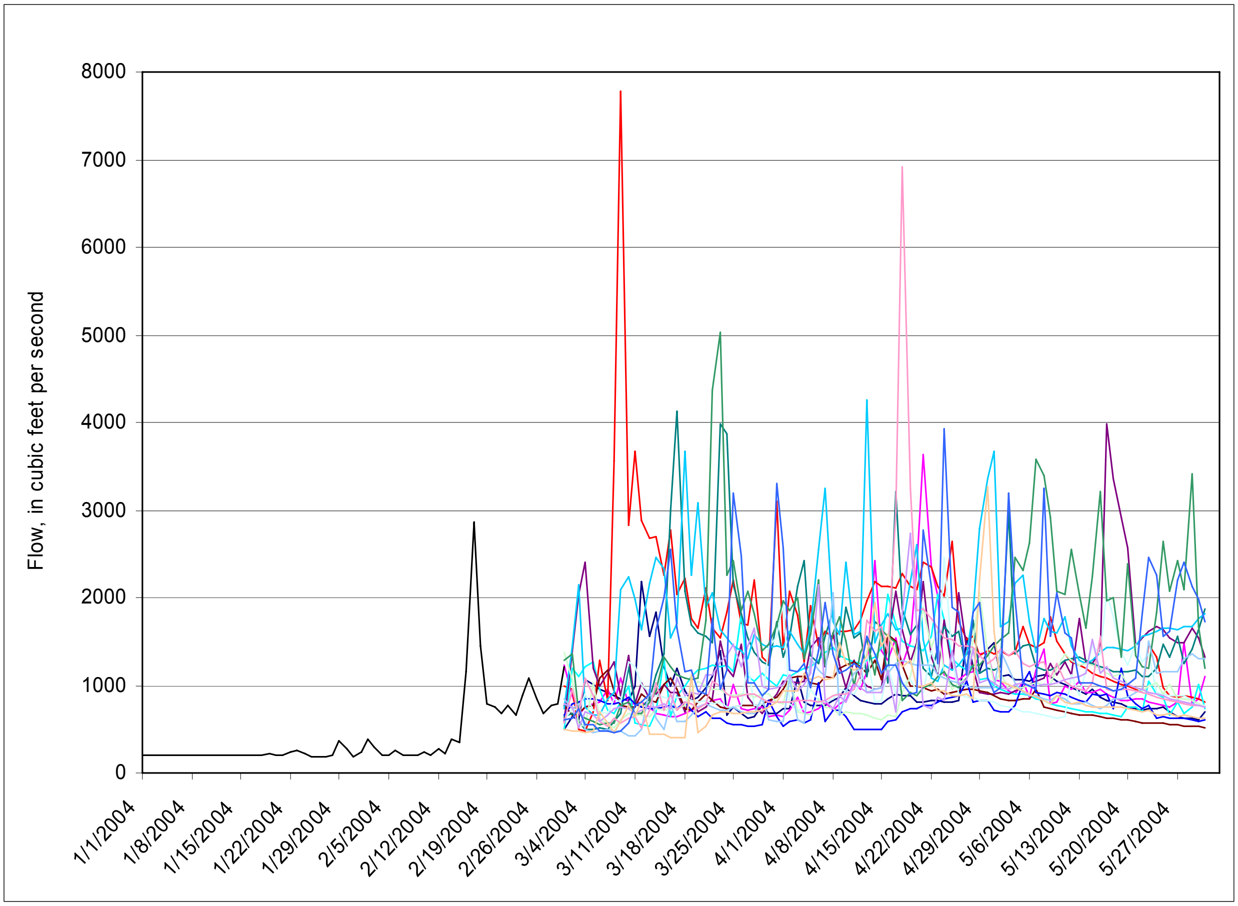

Figure 2.—Ensemble streamflow prediction traces for March 1-May 31, 2004 based on 1987-2003 meteorological data for the Sprague River near Chiloquin, Oregon. The pre-forecast period prior to March 1, 2004 is shown as a single black line, and the traces are shown in colored lines.

HYDROLOGIC MODEL

In this study, the hydrologic model PRMS (Leavesley et al., 1983; Leavesley and Stannard, 1995) was applied to the Sprague River. PRMS is a distributed-parameter, physically based watershed model. Distributed-parameter capabilities are provided by partitioning the watershed into hydrologic response units (HRUs). PRMS is conceptualized as a series of hydrologic reservoirs (i.e. impervious zone, soil zone, subsurface, and groundwater). Water moving through these reservoirs interacts to produce runoff. For each HRU, a water balance is computed each day and an energy balance is computed twice each day. The sum of the water balances of all HRUs, weighted by unit area, produces the daily watershed response (i.e. streamflow). For each HRU, PRMS requires daily inputs of precipitation and maximum and minimum temperature.

The calibration of PRMS for the Sprague River Basin is described in this conference proceedings by Hay et al. (2006). In summary, the procedure includes the sequential calibration of simulated: (1) solar radiation, (2) potential evapotranspiration, (3) annual water balance, (4) snow-covered area, and (5) components of daily runoff. This multistep procedure ensures that intermediate model states and fluxes, as well as the annual water balance; components of the daily hydrograph; and snow-covered area are being simulated consistent with measured values. Further details on this strategy for model calibration are described by Hay et al. (in press). A graphical user interface (Luca), introduced in this issue by Umemoto et al. (2006), was used to simplify the application of the multistep calibration process.

CLIMATE INDICATORS

Climate indices have been used in the past to help forecasters choose a subset of years from the historical record to condition their ESP forecast. Hamlet and Lettenmaier (1999) were able to show improvements in Columbia River ESP forecasts by grouping historical meteorological data into six predefined El Nino/Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO) categories. The selection of which years to use in the ESP simulation then was based on the real-time ENSO and PDO conditions of the current year.

Because of the geographic position of the UKB, the relation between ENSO and PDO conditions and UKB streamflow is weak (Kennedy et al., 2005). However, two other climate indicators, (1) the 700-hectoPascal atmospheric height anomaly (700hPa) over northwestern North America (McCabe and Hay, 2006) and (2) the Trans Nino Index (TNI), have shown some relation with UKB streamflow patterns (Kennedy et al., 2005). These indices, described below, are used to define subsets of the ESP traces for each year based on the 700hPa and TNI conditions for that given year.

Atmospheric Height Anomalies McCabe and Hay (2006) describe in these conference proceedings the relation between Sprague River flow and the 700hPa height anomaly over northwestern North America. During years when the mean 700hPa height anomaly over northwestern North America for the months of November through February is negative, total Sprague River flow volume for the following months of March through May is often above the median. Negative atmospheric height anomalies over northwestern North America indicate a reduction of high atmospheric pressure that generally exists over this region during the winter months. Conversely, when the mean November-February 700hPa height anomaly over the Pacific Northwest is positive, the March-May Sprague River flow volume is decreased. This pattern of atmospheric height anomalies indicates an increase of high pressure over northwestern North America. Consequently, there is a deterrence of the flow of atmospheric moisture (and storm systems) into the northwestern U.S., resulting in decreased winter precipitation and subsequently decreased March-May runoff.

Trans Nino Index The TNI is the standardized sea-surface temperature gradient between the Nino 1+2 (longitude range: 90^{o}W-80^{o}W; latitude range: 10^{o}S-0^{o}) and Nino 4 (longitude range: 160^{o}W-150^{o}W; latitude range: 5^{o}S-5^{o}N) regions of the Pacific Ocean (Trenberth and Stepaniak, 2001). Because the original TNI time series is smoothed with a 5-month running average, Kennedy et al. (2005) modified the TNI to make it useable in real-time water supply forecast models. In their analysis they determined that averaged October through December TNI values were significantly correlated (r=0.65) with subsequent April through September Sprague River flow volume. During high flow years in the UKB, the TNI values were generally positive. Conversely, the TNI values were generally negative during low flow years.

RESULTS

The effectiveness of using ESP in Sprague River water-supply forecasts was evaluated by making hypothetical March 1-May 31 ESP forecasts for every year from 1987 to 2004. Before creating the ESP trace simulations, separate initial conditions were computed for the start of the forecast period (March 1) for every year (18 years, 1987-2004). Running separate 5-year “warm up” simulations created files with initial conditions, each ending on the forecast date (March 1) of each year. Then using the ESP option in MMS, separate sets of forecast period traces (March 1 to May 31) were simulated for 1987-2004 using the March 1 initial condition , excluding the year of each forecast period (17 traces). Subsets of the ESP traces were defined by grouping, for each year, the three ESP traces with 700hPa and TNI values closest to that year.

Figure 3 shows the results, by year, for the ESP analysis. Note that the plots are ranked, from lowest to highest, by the measured March 1 to May 31 flow volume (red line). The blue boxplots show the range of the 17 ESP traces (excluding the simulated-flow volume for that year). The green boxplots show the three ESP traces conditioned on the 700hPa height anomalies that are most similar to that year. The magenta boxplots show the three ESP traces conditioned on the TNI values that are most similar to that year. Note that while the y-axis scales are different, the incremental changes are similar.

In Figure 3, the measured flow volumes (red lines) fall within the range of the 1987-2004 traces (blue boxplots) in every year except 1989, 1995, and 1997 (15 out of 18 years). 1989 and 1995 are relatively high-flow years, and simulated-flow volumes for these years are significantly underestimated.

In general, the subset of ESP traces conditioned on the 700hPa height anomalies (green boxplots) and TNI (magenta boxplots) decrease the range in simulated flow volumes, but the measured flow does not always fall within this reduced range. The measured flow volume falls within the reduced range of the 700hPa subsets 11 out of 18 years. The measured flow volume falls within the reduced range of the TNI subsets 9 out of 18 years.

In addition, when measured flow is less than 50,000 cfs, figure 3 also shows a smaller range in the 1987-2004 ESP traces (Figure 3a-e). The corresponding decrease in the flow volume range associated with the 700hPa and TNI also is significantly reduced.

DISCUSSION AND CONCLUSIONS

This paper presents preliminary results of integrating the USGS Precipitation-Runoff Modeling System (PRMS), Modular Modeling System (MMS), and Object User Interface Ensemble Streamflow Prediction (ESP) Tool programs into UKB water-supply forecasts. Simulated flow volumes from ESP traces were produced for the Sprague River Basin upstream of the USGS streamflow gage (11501000) near Chiloquin, Oregon, using the PRMS hydrologic model. Methods used to calibrate the Sprague River Basin PRMS model are described elsewhere in these conference proceedings by Hay et al. (2006) and Umemoto et al. (2006).

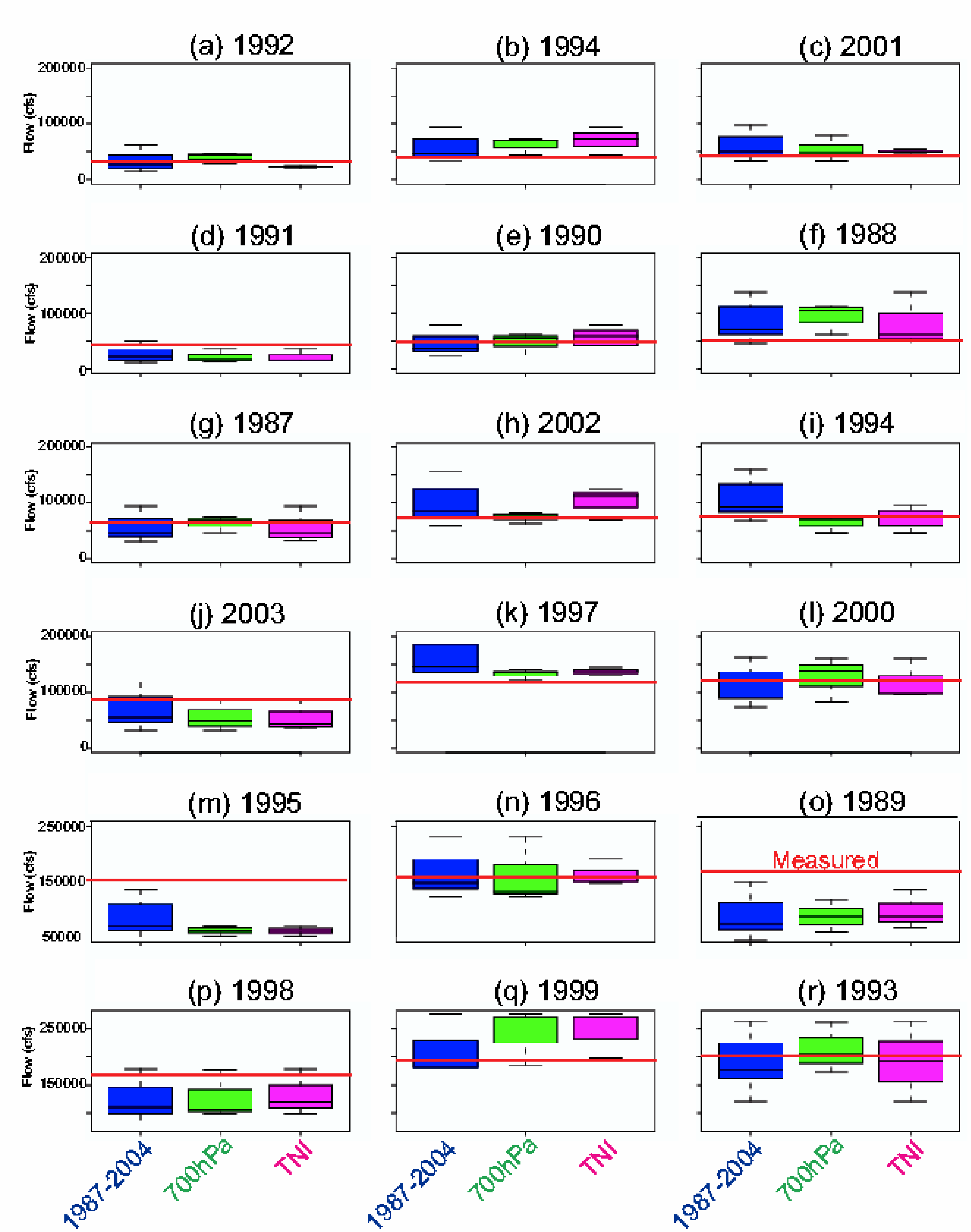

Figure 3.—Boxplots of March-May ESP volumes for the Sprague River by year. Plots are ranked, from lowest to highest flow, by the measured flow volume (red line). Blue boxplots show the range of the ESP traces. Green and magenta boxplots show the three ESP traces

conditioned on the 700hPa height anomalies and TNI values that are most similar to the respective year.

The forecasted March 1-May 31 flow volumes full set of simulated ESP traces was compared with subsets of ESP traces based on two climate indicators: the 700hPa atmospheric height anomaly over the northwestern U.S. and the Trans Nino Index. The 700hPa climate indicator is described in detail in these conference proceedings by McCabe and Hay (2006). In most years, ESP traces conditioned on climate indicator subsets effectively limited the range of the forecast volumes. In addition, ESP trace flow volumes in drier years tended to perform better than in wetter years.

In 15 of the 18 years, the measured flow volume fell within the range of the 1987-2004 ESP traces. However, the measured flow volume fell within the reduced range of the 700hPa and TNI subsets for 11 and 9 years out of the 18 years, respectively. Error in an ESP simulation can be attributed to (1) how well historical climate input data represent the actual climate for the year being forecasted and (2) the quality of the watershed model calibration.

Calibrating a watershed model for the Sprague River Basin and other UKB basins is extremely challenging. This can be attributed in part to the highly complex geology of the region. The measured streamflow record also comes into question. Hay et al. (2006) noted that simulating the daily variation in streamflow for the Sprague River may be unrealistic due to the daily irrigation withdrawals during April-October. These values, reported as monthly totals, were disaggregated to daily values for each month for model calibration. Monthly volumes may also be in question depending on the accuracy of the withdrawal records.

Future work in the UKB will concentrate on developing parameter sets suitable for the current conditions. The parameter set used in this study was developed using a multistep calibration procedure. The procedure (described by Hay et al. (2006)) includes the sequential calibration of simulated (1) solar radiation, (2) potential evapotranspiration, (3) annual water balance, (4) snow-covered area, and (5) components of daily runoff. If forecasted-flow volumes are required, then it may be useful to have subsequent calibrations that produce parameter sets that minimize errors in these flow volumes. In addition, PRMS-model calibrations can be defined to produce parameter sets for low- and high-flow years as well as low and high values for climate conditions. This will significantly increase the number of ESP traces, and supply the forecaster with additional useful information.

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