Characterizing Precipitation Forecast Errors for the Folsom Lake Watershed

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BIOGRAPHICAL SKETCH

Theresa Carpenter is a Hydrologic Engineer with the Hydrologic Research Center, joining the Center in September 1998. She received her B.S. (1991) and M.S. (1993) Degrees in Civil Engineering from the University of Iowa. She is actively involved in HRC's hydrologic modeling efforts on several projects covering locations in California, the Mid-Western U.S., Peru, and Central America. Prior to joining HRC, Ms. Carpenter was a Hydraulic Engineer with the U.S. Army Corps of Engineers, Rock Island District. Her main interests are in hydrologic modeling, in particular, the use of distributed hydrologic models and flood forecasting, and in the application of climate information in water resources.

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1. INTRODUCTION

Operation of any given reservoir or system of reservoirs relies on hydrologic forecasts as an important input to operational decision-making. For the Folsom Lake reservoir and watershed, such forecasts are produced by the California-Nevada River Forecast Center (CNRFC), and utilized by the U.S. Bureau of Reclamation, Corps of Engineers and California Department of Water Resources, along with other local utility and community users impacted by the reservoir operation. In collaboration with CNRFC and the Corps of Engineers, a recent effort has been undertaken to examine errors associated with the hydrologic forecasts generated for the Folsom Lake watershed. This effort is complicated by the lack of archives of operational hydrologic forecasts in present-day form covering a wide range of hydrologic response, including significant flow events. Intermittent operational archives of Folsom forecasts exist only for the period: late March 1998 to present. The initial phase of this study, involving analysis of the operational forecasts for this short historical record, has been completed. This paper reports on the results of this analysis, focusing specifically on the analysis of precipitation forecasts from the operational archive spanning the period from 4/1998 through 1/2003. Precipitation forecasts are input to hydrologic models to drive the reservoir inflow forecasts. Errors in these precipitation forecasts for selected events in the operational archive are

characterized in terms of basic statistics for the three forks of the American River that feed Folsom Reservoir.

The data limitation necessitates the development of a system to characterize forecast errors in current CNRFC forecasts and to reproduce "operational" forecasts based on current practices for historical periods with significant events for Folsom Reservoir. To provide the contextual background to the analysis of operational forecast, an overview of this effort to characterize hydrologic forecast errors for Folsom Reservoir is given in the following Section. The resulting reconstructed forecasts can then be used in retrospective studies that facilitate the development of forecast-based pre-release strategies for Folsom reservoir and for other studies examining Folsom Reservoir operation and management (e.g., Carpenter, et al. 2003).

2. OVERVIEW OF FORECAST-ERROR CHARACTERIZATION

The goal of the overall effort is to develop a system for characterizing and *reproducing* the distribution of forecast errors in current CNRFC hydrologic forecasts for the Folsom watershed over a wide range of events. Characterization of the forecast error is complicated in the limited amount of historical forecast data matching the current operational format. If a wealth of the forecast data were available, the analysis would entail probabilistic characterization of the forecast errors for various lead times as described in Carpenter and Georgakakos (2001). That study produced probability distributions and various forecast statistics for 6- to 24-hour lead time operational flow forecasts for the period of record 23 March 1998 to 14 July 2000. The archive of operational forecasts now extends to 31 January 2003; unfortunately, these periods do not include events with large reservoir inflows. Table 1 presents the top ranking inflow events for Folsom Reservoir. The peak inflow within the archival period is approximately 1200 cms,

nearly one-fourth of the highest ranked peak inflow. Thus, it is necessary to characterize the error distributions of the current archived operational forecasts for low to medium-sized inflow events, and utilize that characterization in validation of a system to reproduce "operational" forecasts based on the current methods of generating hydrologic forecasts for significant historical events.

The current hydrologic forecasts consist of reservoir inflow forecasts based on hydrologic modeling of four subcatchments of the American River: three Forks (North, Middle, and South) and the local reservoir drainage. As input to the hydrologic model, forecasts of precipitation (MAP_F) and temperature (MAT_F) are required for the same subcatchments. All of these forecasts must have 6-hour temporal resolution. Again, archives of MAP_F and MAT_F do not exist for extended periods (only an archive of MAP_F has been kept at CNRFC since 2/1997). Therefore to reconstruct historical hydrologic forecasts of reservoir inflows for Folsom Lake, forecasts of MAP_F and MAT_F must also be reconstructed for based on procedures analogous to those currently in use and with 6-hour temporal resolution. This is a multiple year effort to reconstruct historical precipitation and temperature forecasts, use these as input to generate historical hydrologic reservoir inflow forecasts and then to characterize forecasts errors for the range of historical inflow through retrospective analysis.

The initial phase of this effort has included the characterization of precipitation and flow forecasts errors from the existing operational archive and the design of procedures for the reconstruction of precipitation and temperature forecasts. This paper focuses only on the characterization of precipitation forecast errors. The following section discusses the available data from the operational forecast archive used to characterize current forecast errors.

3. OPERATIONAL FORECAST ARCHIVE

In terms of operational 6-hour resolution forecast data, the Hydrologic Research Center (HRC) has an archive of CNRFC hydrologic model operational output for the period 23 March 1998 through 31 January 2003. This is an intermittent record with fairly long periods with no forecasts (e.g., mid-July to November 2000, September through December 2002). It includes a snapshot of the operational model input and forecast output for each forecast preparation time during the historical period (typically, one to four forecasts issued per day although more forecasts were issued during active periods). The database records the precipitation input, potential evaporation input, and streamflow (simulated and observed) for a model simulation period of up to 10 days prior to the forecast preparation time, and forecasts of precipitation, evaporation and streamflow to a maximum of 5 days for the North, South and Middle Fork subcatchments. The precipitation reported is the combination of rain plus snowmelt estimated from snow accumulation and ablation modeling. This dataset was used to examine forecast errors in precipitation and stream flow for events selected from the relatively short record and for forecast lead times from 6- to 120-hours (5 days) with 6-hour resolution. The analysis of precipitation forecast errors is presented in the following section.

4. MAP_F ERROR ANALYSIS

The operational archive dataset provides the basis for a statistical analysis of forecast errors for various forecast lead times to 120-hours and for the three subcatchments. The precipitation input from the simulation period of the forecast archives was used to produce a historical record of "observed" MAP for each subcatchment, where MAP in this analysis represents the subcatchment average precipitation (rain plus snowmelt) based on observed gauge

records of rain and temperature. This record of observed MAP was then used to (a) identify selected events for analysis and (b) compute forecast errors over the selected events.

The selected precipitation events from the archive record (3/1998 through 1/2003) were identified based on a peak observed MAP of 10 mm/6-hr or greater for at least one subcatchment. Table 2 presents a summary of the fifty selected events. The peak MAP listed is an area-weighted average of the three subcatchments. This peak catchment MAP ranges from 5 mm/6-hr to 34 mm/6-hr, with the majority of events having peak MAP in the 10-15mm/6-hr range. For each selected event, a forecast period around the event was identified as beginning approximately five days prior to the event peak and continuing through any significant precipitation following the peak. All forecasts made during this period and for each subcatchment were considered in the precipitation forecast error analysis. When multiple events occurred within short succession (i.e., within the 5-day window before a given peak) with overlapping forecast periods, the forecasts produced during this period were considered only once. Also, for periods with multiple forecasts issued, identical successive forecasts valid for the same forecast preparation time and for a given subcatchment were eliminated in an initial screening.

Using the observed MAP record and precipitation forecasts (MAP_F) for the valid forecasts, forecast errors were computed as [observation – forecasts] for each of the three subcatchment (corresponding to the North, Middle and South Forks), for an area-weighted catchment average, and for forecast lead times to a maximum of five days in 6-hour increments. The analysis of precipitation forecast errors included the computation of second-moment statistics of observations and forecast errors for each subcatchment and forecast lead-time. These results are presented in Figure 1. The panels of the figure present the mean and standard

deviation of the MAP observations and of the MAP forecast errors for various forecast lead times and for the three subcatchment and basin average. The cyclic appearance in mean observations and standard deviation is due to the use of different averaging periods for each forecast lead time and to the fact that the selected events include one or two significant events that occur preferentially in the afternoon and night hours. Comparison of the observation and forecast error statistics shows that the forecast errors are relatively small. The forecast errors remain within 10% of the mean observations for most forecast lead-times and for each subbasin as shown in Figure 2. The increase in average forecast error during the longer forecast lead times may be influenced by fewer forecasts issued for these longer lead-times. The standard deviations of the forecast errors quickly approach the standard deviation of the observations, generally within a forecast lead-time of 48 hours. In fact, the percent variance explained, also shown in Figure 2, approaches 0 within 24 hours for all subcatchments. For the selected events, the North Fork subcatchment shows the highest mean value and variability of observed MAP, whereas the South Fork subcatchment shows the lowest values of the observed MAP statistics.

The serial correlation of forecast errors for given forecast lead-times with subsequent lead-times was also computed. The serial correlation measures the correlation in errors between one forecast lead-time and another. Figure 3 presents the serial correlation of the 6-hour forecast lead-time with subsequent lead-times out to 72 hours. Clearly the correlation in MAP_F error falls quickly, and approaches zero within 24-hours for all subcatchments. Similarly, Figure 4 presents the serial correlation of the 6-, 12-, 18- and 24-hour forecast lead-time with subsequent lead-times to 72-hours for each of the three forks. Again, the correlation falls quickly, generally within the first 24 hours, for each forecast lead-time and for each subcatchment.

5. SUMMARY AND CONCLUSIONS

This report presents results of a statistical analysis of operational precipitation forecasts for subcatchments of the Folsom Lake watershed and for fifty selected events between 3/1998 and 1/2003. The operational forecasts include forecast time leads from 6- to 120-hours (5 days) in 6-hour increments. Peak catchment-average MAP for the selected events ranged from 5 to 34 mm/6-hr, with only 4 events exceeding 20 mm/6-hr. The mean forecast error over the selected events remains quite low, less than 10% of the mean observations, for the three subcatchments and basin average and for various forecast lead times to a maximum of five days. The variance of the forecast errors approaches the variance of the observed MAP within a forecast lead-time of 48 hours. Similarly, the serial correlation in precipitation forecast errors falls quite quickly for all events. For forecast lead times to 24 hours, the serial correlation falls to near 0 within the subsequent 24 hours. For the short operational archive record, the results indicate that the precipitation forecasts are most useful for forecast lead times to approximately 48 hours.

These are initial results in an effort to characterize current operational forecast errors provided by the California-Nevada River Forecast Center (CNRFC) for Folsom Reservoir. The goal is to characterize the hydrologic forecast errors for Folsom Reservoir over a range of inflow events. The limitation of the existing archive of operational forecasts is the lack of large inflow events in the record, thus necessitating the reconstruction of past hydrologic forecasts for significant historical events. This in turn requires reconstruction of past precipitation and temperature forecasts as input to the hydrologic model currently in use. All forecasts need to be reconstructed based on current operational methods and format (e.g., for subcatchments corresponding to the three Forks of the river and the local reservoir drainage and with 6-hour resolution). The development of a system to reproduce the hydrologic forecast for Folsom

Reservoir is overviewed to provide the contextual background of the precipitation error analysis.

The results of the precipitation analysis from this initial phase will be used to validate the methodology for reconstruction of precipitation forecasts.

6. REFERENCES

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Table 1. Top-ranking inflow events for Folsom Reservoir based on peak inflow.

Rank	Peak Date	Peak Inflow(cms)	Rank based on
			7-day volume
1	1/02/1997	4900	1
2	12/23/1964	4200	3
3	2/17/1986	3400	2
4	1/13/1980	2300	4
5	2/16/1982	2240	6
6	12/20/1981	2230	7
7	3/08/1986	1680	8
8	1/20/1969	1600	10
9	1/21/1970	1570	5
10	3/13/1983	1520	> 10

Table 2. Events selected for analysis of operational precipitation forecast errors.

	Event	Peak MAP	MAP Forecast Period
	2,000	(mm/6-hr)	1/11 11 1 01004001 01104
1	4/23/1998	7.8	4/19 – 4/23
2	5/01 - 02/1998	12.6	4/27 - 5/03
3	5/25/1998	13.3	5/21 - 5/25
4	5/28/1998	13.3	5/24 - 5/29
5	10/24/1998	12.4	10/20 - 10/24
6	11/07/1998	7.3	11/03 – 11/07
7	11/17/1998	10.1	11/12 – 11/17
8	11/22 - 23/1998	15.8	11/17 – 11/23
9	11/27 - 30/1998	14.5	11/23 – 11/30
10	12/03/1998	9.8	11/29 - 12/03
11	1/15 – 20/1999	16.8	1/11 - 1/20
12	1/23/1999	11.1	1/18 – 1/23
13	2/07 – 09/1999	15.4	2/02 - 2/09
14	2/16/1999	19.8	2/12 - 2/18
15	2/20/1999	8.4	2/16 – 2/20
16	2/28 - 3/03/1999	19.8	2/24 - 3/03
17	5/02 – 03/1999	7.1	4/29 - 5/03
18	10/28/1999	32.6	10/23 - 10/28
19	11/07/1999	12.3	11/03 – 11/08
20	11/16/1999	12.3	11/12 – 11/16
21	11/19/1999	14.0	11/15 – 11/19
22	1/11/2000	7.7	1/07 – 1/11
23	1/17 – 19/2000	15.1	1/14 - 1/20
24	1/23 – 24/2000	24.9	1/20 – 1/25
25	1/30/2000	7.5	1/26 – 1/30
26	2/10 - 14/2000	19.6	2/07 - 2/14
27	2/22/2000	9.7	2/18 - 2/23
28	2/26 - 27/2000	17.9	2/23 – 2/27
29	4/13/2000	9.1	4/09 – 4/13
30	4/17/2000	9.2	4/13 – 4/17
31	5/07 - 08/2000	17.0	5/03 - 5/08
32	5/15/2000	7.7	5/11 – 5/15
33	6/09/2000	7.1	6/04 - 6/09
34	11/29/2000	10.7	11/25 – 11/29
35	12/14 - 15/2000	5.1	12/10 - 12/15
36	1/10/2001	10.4	1/06 – 1/10
37	1/23/2001	5.4	1/19 – 1/24
38	2/19 - 24/2001	6.9	2/15 - 2/24
39	3/25/2001	12.3	3/20 - 3/25
40	1/02/2002	12.5	1/01 – 1/03
41	1/26/2002	11.7	1/22 - 1/26
42	2/07/2002	11.3	2/03 - 2/08
43	2/19 - 20/2002	14.2	2/15 - 2/20
44	3/06 - 07/2002	16.0	3/02 - 3/07
45	3/22 - 23/2002	9.3	3/18 - 3/24
46	5/19 - 20/2002	7.8	5/16 - 5/20
47	11/07 - 10/2002	33.7	11/3 – 11/10
48	12/13 - 17/2002	27.5	12/09 - 12/17
49	12/26 - 31/2002	8.0	12/23 - 1/01
50	1/21 - 23/2003	7.1	1/18 – 1/24

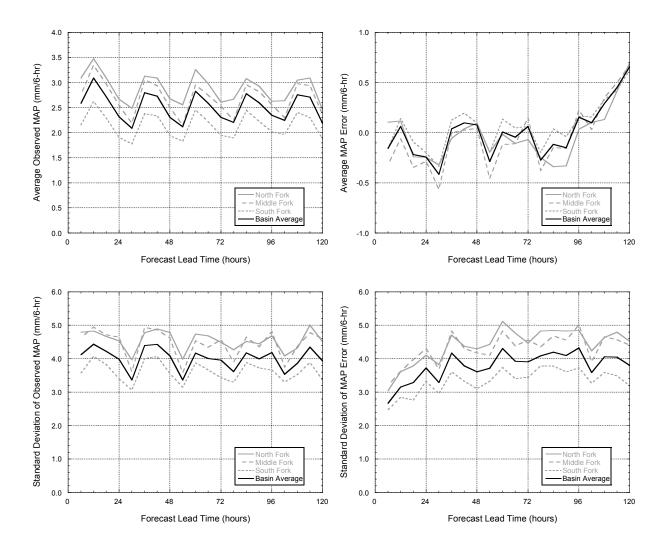


Figure 1. Statistics of MAP observations and forecast errors for various forecast lead-times to a maximum of 5 days. Panels show: (a) observed mean, (b) mean error, (c) standard deviation of observations, and (d) standard deviation of forecast errors.

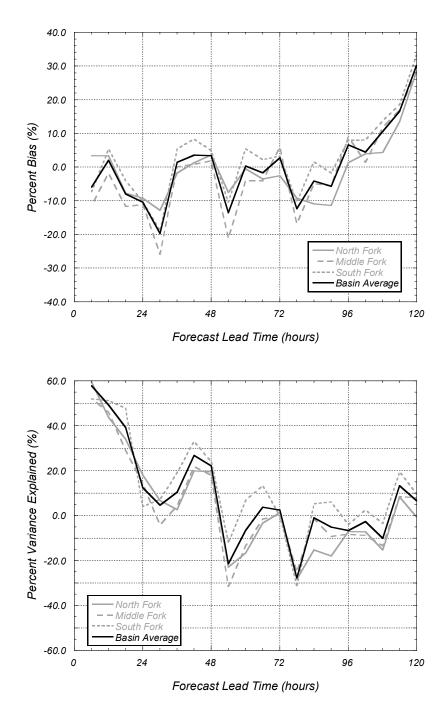


Figure 2. Percent bias in average forecast MAP error (top panel) and percent variance explained by forecast MAP (lower panel) for various forecast lead times to a maximum of five days.

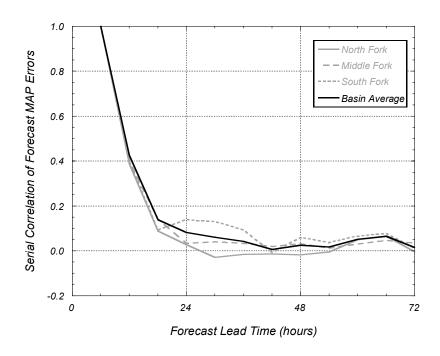


Figure 3. Serial correlation of forecast MAP errors for the 6-hour forecast lead time with subsequent lead times to 72-hours for all sub-basins.

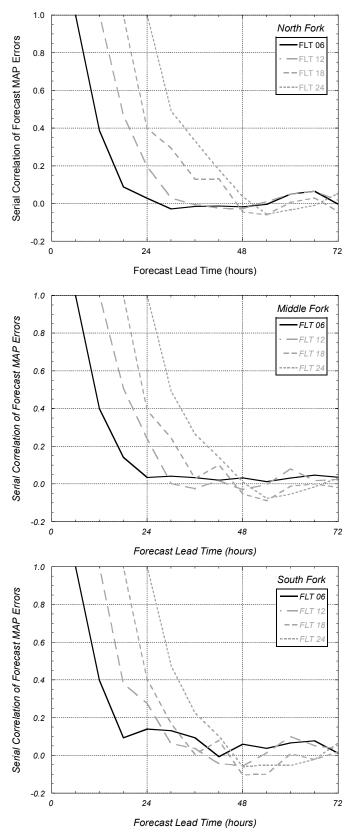


Figure 4. Serial correlation of forecast MAP errors for the 6-, 12-, 18- and 24-hour forecast lead times with subsequent lead times to 72-hours for each of the three sub-basins.