Central Region Technical Attachment
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Project Report: Determining Quantitative Precipitation Forecast Duration to Optimize River Forecast Services

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ABSTRACT

In this paper, the two National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) Central Region River Forecast Centers investigate the errors in quantitative precipitation forecasts (QPF) as well as the impact of QPF on river forecast accuracy in order to determine the optimum number of hours of QPF to use in river forecasts. This study spans 13 months from June 1, 2009 through June 30, 2010. The study was divided into three parts. The first two parts look only at QPF errors using individual 6-hour time step precipitation data, accumulated precipitation data from six hours up to 72 hours, and 24-hour daily precipitation totals out to three days in the analyses. In Part 3, both precipitation and river forecast errors resulting from various QPF durations are analyzed. The methods used in the statistical analysis are hypothesis testing (Student's t-test), error statistics (mean absolute error and mean error), and categorical statistics (probability of detection and hydrologic false alarm ratio).

1. Introduction

Flooding in the United States causes huge economic losses, personal property damage, and human fatalities. The 30-year average annual losses due to flooding from 1983 through 2012 were $8.17 billion in damages and 89 deaths per year (NOAA 2013). The National Weather Service (NWS) is charged with forecasting river levels as part of the NWS mission to protect life and property and enhance the nation's economy. River Forecast Center (RFC) hydrologists use hydrologic models to produce routine, daily forecasts and event-driven flood and water resources forecasts for the nation. These models use a variety of meteorological parameters such as precipitation and air temperature, which can have a strong influence on the accuracy of river forecasts. To further the NWS's mission, there is a continuing need to improve the accuracy and increase the lead-time provided by these forecasts by determining the best input to incorporate into the hydrologic model. One of these variables, quantitative precipitation forecasts (QPF), can increase the lead time of a river forecast and provide earlier warning of a flood. However, the amount, timing and location can be extremely challenging for NWS meteorologists to forecast, particularly as the forecast time period increases.

The purpose of this study was to investigate the errors in QPF as well as the impact of QPF on river forecast accuracy in order to determine the optimum number of hours of QPF to use in those forecasts. The study area encompassed a portion of the Midwest in the NWS Missouri Basin River Forecast Center (MBRFC) and North Central River Forecast Center (NCRFC) areas of responsibility.

Past studies have looked at the effect of QPF on river forecasts (Schwein 1996), the quality of the distribution and quantity of QPF (Cokely and Meyer 1991), and the impact of QPF on river forecasts and flood warnings (Meyer 2003). In 2009, Schwein et al. recommended the number of hours of QPF to use in river forecasts was 24 from September through May (fall, winter, and spring) and 18 from June through August (summer). NWS Central Region management decision was to use 24 hours of QPF year-round as there was concern that changing the QPF duration in summer may be confusing for NWS partners and the general public. With that decision, the RFCs were given the option they could re-evaluate the decision at a later date. The Central Region RFCs revisited the issue with this study and two main goals:

- Evaluate the impact of the various QPF durations on river forecasts (the first study focused solely on precipitation errors but did suggest looking at river forecast errors as a follow-on study)
- Evaluate benefit of longer lead times using newly acquired data with durations out to 72 hours (the first study was limited to 24 hours)

The study was designed to address the above goals by meeting the following objectives:

1. Analyze QPF errors in 6-hour time increments similar to the 2009 study except on a hydrologic forecast basin scale instead of a 4x4 km Hydrologic Rainfall Analysis Project (HRAP) grid, using statistical methods similar to the 2009 study.
2. Analyze QPF errors through the analysis of 6-hour incremental QPF errors, as well as 6–72-hour cumulative QPF errors
3. Identify the optimal number of QPF time periods based upon river forecast verification metrics that balance river forecast lead time with river forecast accuracy.

These three objectives were approached though a three-part methodology. The first part was done similar to the 2009 study looking at positive QPF errors greater than 0.10 inch for each 6-hour time step. The second part expanded on that, using positive and negative errors greater than 0.01 inch for both individual 6-hour increments as well as accumulated errors through 72 hours. Part 3 focused on river forecast errors using forecasts that included QPF time periods from 0 to 72 hours. Conclusions were drawn based on the use of statistical significance testing, quantification of greatest relative change in errors (e.g., increasing error with increasing time periods), and comparisons of probability of detection (POD) with hydrologic false alarm ratio (HFAR) and mean error.

2. Background

There are two RFCs located in the NWS Central Region. The North Central River Forecast Center provides forecasts for the upper Mississippi River Basin (NCRFC), while the Missouri Basin River Forecast Center (MBRFC) forecasts its namesake. Both RFCs are in the Midwestern U.S. and have many hydrometeorological and geological similarities. As a result of the 2009 study, both RFCs began using 24 hours of QPF operationally year-round starting June 1, 2009. Prior to this, the two RFCs had differing local policy with regard to the use of QPF in river forecasts: NCRFC used 24 hours of QPF for the entire year, while MBRFC used 12 hours of QPF from April through September and 24 hours of QPF October through March.

In May 2009, Central Region Headquarters (CRH) and the two RFCs outlined the scope of this follow-up study (see Appendix A). The original design of this study used QPF durations of 0, 6, 12, 18, 24, and 48 hours. Early in the data collection process, based on the recommendation for a QPF durations study in the NWS RFC Verification Team's Final Report (Demargne 2009), the duration of 72 hours of QPF was added.

3. Climate and Hydrologic Summary

The study spanned 13 months from June 1, 2009 through June 30, 2010. In the June 2009 – June 2010 time period, precipitation averaged slightly above normal across the Midwest (as depicted in Figure 1), except for the northern portions of Minnesota, Wisconsin and Michigan. The study period started out with a mix of above- and below-normal precipitation across both the MBRFC and NCRFC. October of 2009 was the wettest on record for much of the region, with two to four times the normal rainfall in most of the study area as shown in Figure 2. September and November 2009 were much drier than normal. Many areas also had the snowiest winters on record from December 2009 to February 2010. Precipitation was more variable across the study area during the first half of 2010 with several wet and dry areas distributed throughout. June of 2010 was another much wetter period for most of the region with 150-300% of normal as shown in Figure 3, breaking several monthly and daily rainfall records across Nebraska through Iowa and Illinois. Additional precipitation maps can be found in Appendix B.

Figure 1. The Midwest as defined by the U.S. Census Bureau

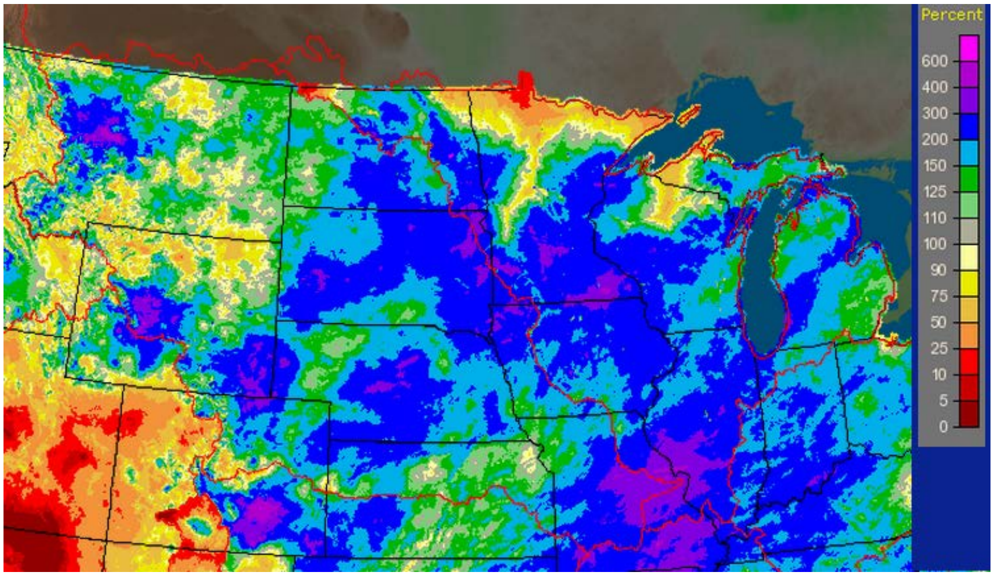

Figure 2. Percent of normal precipitation October 2009

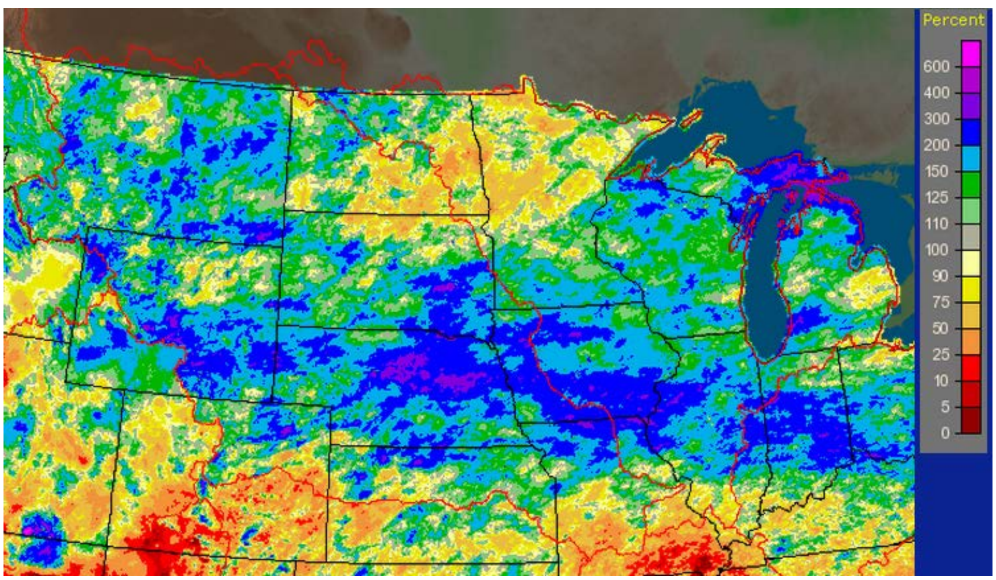

Figure 3. Percent of normal precipitation June 2010

The United States Geological Survey (USGS) historical stream flows for Water Year 2009 (Oct 2008 - Sep 2009) show normal to much higher than normal values for most of the Missouri and Upper Mississippi River basins. For Water Year 2010 (Oct 2009 - Sep 2010), USGS stream flows were also significantly above normal for the majority of Missouri and Upper Mississippi River basins. See Figures 4 and 5 below.

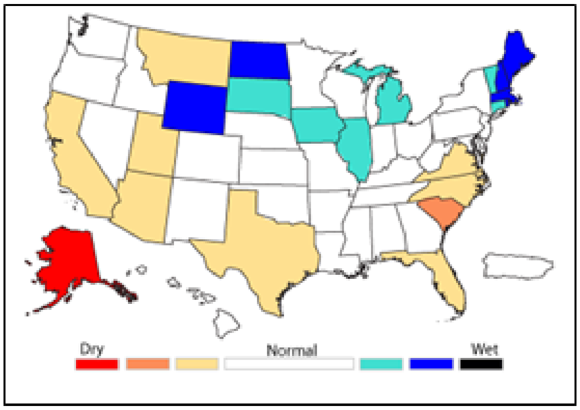

Figure 4. USGS 2009 Water Year streamflow

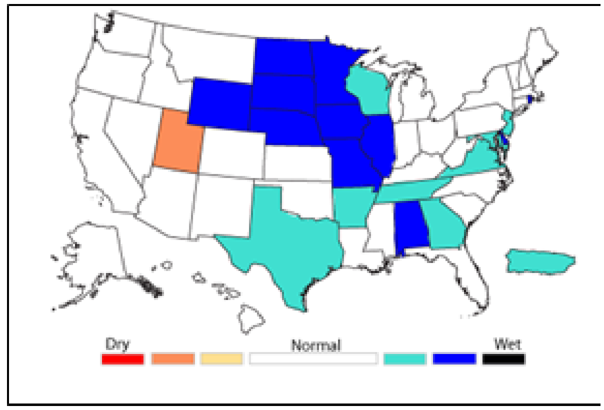

Figure 5. USGS 2010 Water Year streamflow

4. Data Collection and Quality Control

The study was divided into three parts. The first two parts looked only at QPF errors using individual 6-hour time step precipitation data, accumulated precipitation data from six hours up to 72 hours, and 24-hour daily precipitation totals out to three days in the analyses. In Part 3, both precipitation and river forecast errors were analyzed. River forecast basins were selected from a wide geographic area that is representative of the forecast conditions that exist across both RFCs' areas of responsibility. For MBRFC, basins in Colorado, Wyoming, and Montana were excluded due to the mountainous terrain being quite dissimilar from NCRFC's area. To ensure an adequate sample size for Part 3, river forecast points were selected based on the frequency that observations reached forecast issuance stage (FIS) or higher. It should be noted with this sampling constraint, the selected points were not evenly distributed but were concentrated in more hydrologically active geographic regions.

The precipitation data encompassed 1,164 basins in NCRFC's area and 906 basins in MBRFC's area. The morning RFC QPF data for twelve 6-hour time periods were collected for all three parts of this study: 1200-1800, 1800-0000, 0000-0600 and 0600-1200 UTC for Forecast Day 1-3. The QPF data collected were the Hydrometeorological Analysis and Support (HAS) QPF, which is the operational QPF used as input to river forecasts. The observed data collected were a combination of mean areal precipitation (MAP) and multisensory (radar and rain gage) information (MAPX). Observed precipitation estimates used as ground truth in forecast operations vary throughout the year based mainly on weather conditions, such as icing, that can negatively impact radar precipitation estimates. MAP is calculated based on 24-hour precipitation reports and 6-hour synoptic station observations calculated over the basin areas using the Thiessen method (Chow 1964). MAPX is based on 1-hour radar quantitative precipitation estimate (QPE) over an HRAP grid spacing (Fulton 1998) and point-based hourly precipitation observations calculated over the basin areas. MAP and MAPX data were collected in time steps matching the QPF data. The QPF and MAP/MAPX gridded data values were then averaged to the river forecast basin areas with sizes averaging around 300 square miles.

At the time of this study, the CR RFCs did not use more than 24 hours of QPF in their routine forecasts, however, they did create model-driven contingency forecasts that incorporated 72 hours of QPF and produced an ensemble of river forecasts with a range of forecast stage levels in 6-hour time steps over a 5-day period. Besides having a greater number of forecasts to analyze, using these ensemble forecasts in this study had the additional advantage of producing more objective results in that no forecaster modifications to the hydrologic model were incorporated. Rather, errors resulted from changes in model inputs, such as QPF, thereby making QPF-based conclusions easier to cite.

Monitoring scripts were put in place to ensure the precipitation and river stage data were generated and posted to the RFC archive database. As the data had already been reviewed in operations, the main quality control for the precipitation data was ensuring the data successfully posted to the database. For the forecast stage data collected for Part 3, a more detailed review of the data was necessary since it had not been previously reviewed and occasionally, the raw model output would contain erroneous data. This raw model output contained all the forecasts used in this study. When erroneous data were found, they were eliminated from the dataset.

5. Part 1: Precipitation Error Analysis for Individual 6-hour Time Periods

5.1 Methods and Analysis

Similar to the previous QPF optimization study (Schwein et al. 2009), Part 1 analyzed QPF error datasets for each 6-hour period for forecast minus observed (F-O) errors where the forecast was at least 0.10 inch. Statistical means for each time period of QPF errors were tested for significant differences in hopes of finding an obvious break where QPF errors increased significantly from one time period to the next. Due to the extremely large sample sizes, they were reduced to a random five percent sample of each dataset (Hamburg 1977) and then analyzed in a similar manner as the earlier study, by precipitation categories and seasons. While the 2009 study considered geographic regions within the RFCs, the regions in this study were defined by each RFC area as a whole, and then the two areas combined into a single dataset. The seasons were defined as fall (September 1 through November 30), winter (December 1 through the end of February), spring (March 1 through May 31) and summer (June 1 through August 31). Also similar to the earlier study, Part 1 of this study focused on the impact of over-forecasting; under-forecasting (F-O < 0) was not considered. Table 1 shows the sample sizes. Student's t-test for equal means was performed at the alpha=0.05 level for each 6-hour dataset to draw conclusions regarding significant differences between two QPF time periods.

MS Excel 2010 with the Data Analysis toolkit was used to compute the descriptive statistics and Student's t-test. Local computer applications were written to compile the datasets used in the MS Excel spreadsheet (see Appendix C for the dataset specifications).

5.2 Results and Conclusions

Two-tailed Student's t-tests for equal means were conducted on the QPF errors for each forecast period and season on each RFC's dataset separately, followed by the two RFCs' datasets combined. Unlike the 2009 study, significant differences were common within the first 12 or 18 hours. Beyond that, if summer data were extracted from the datasets, results were similar in that they indicated more QPF could be used (no significant differences until later periods). An example of these results is presented in Table 2. The t-test results for Part 1 did not indicate a clear break. Therefore, no conclusion could be drawn as to the optimal QPF duration to use. The remainder of the t-test results can be found in Appendix D.

6. Part 2: Precipitation Error Analysis Accumulated through 72 hours

6.1 Methods and Analysis

This analysis also focused on the precipitation data only, but looked at all the data where the forecast and/or observation was >= 0.01 inch. Datasets were created to accumulate precipitation totals for 6 to 72 hours. In addition to the individual time periods, accumulated precipitation was analyzed in two different ways: a) three 24-hour totals for each forecast day, and b) accumulated values from 6-hour total all the way to 72-hour totals.

The two River Forecast Centers examined both under- and over-forecasting, with forecast precipitation errors <= -0.01 and errors >= 0.01 in the analysis, (i.e. eliminated pairs where the forecast minus observed (F-O) value was zero). The error statistics utilized for the analyses were mean error (ME), mean absolute error (MAE), root mean square error (RMSE), Pearson's correlation (CORR), and the categorical statistics probability of detection (POD) and traditional false alarm ratio (TFAR). The forecast precipitation error statistics were conditioned both by forecast and observed data in the following classes: MIN, 0.01, 0.10, 0.25, 0.50, 1.00, and MAX. The accumulated dataset (6 to 72 hours of QPF) with errors of <= -0.10 and errors >= 0.10 was used in the t-tests. Table 3 provides some descriptive statistics for the accumulated dataset. All three datasets were analyzed by season.

The RFCs used the NWS Interactive Verification Program (IVP) to pair the observed and forecast data values and analyze the precipitation with a variety of statistical metrics. MS Excel 2010 with the Data Analysis toolkit was again used for the Student's t-test and to generate charts .

Local computer applications were written to compile the pairs used by IVP for 1-, 2-, and 3-day precipitation totals, and 6- to 72-hour precipitation totals. The same local applications that were written for Part 1 were used to extract a random five percent dataset for the Student's t-test analysis of the accumulated (6- to 72-hour totals) precipitation dataset.

6.2 Results and Conclusions

While IVP provided a wealth of descriptive statistics (ME, MAE, POD, FAR) in this second part of the study, these statistics did not provide objective conclusive results in determining the optimal QPF duration that should be used routinely in the RFC's river models. Appendix E contains MBRFC results and Appendix F contains NCRFC results. Overall, the error statistics qualitatively showed little change moving forward in time. No clear break was seen where errors became much greater.

The Student's t-test was again used, but this time with the accumulated precipitation errors from 0 to 72 hours of QPF. The test was conducted for each accumulated total and season, on each RFC's dataset separately and then the two RFC datasets combined. Again, due to the large size of the datasets, a random five percent of each dataset was used in the analysis. For most combinations through the accumulating time steps, except for the summer data alone, the p-values were greater than the selected 0.05 alpha level, indicating no significant difference. Similar to Part 1 results, significant differences were shown in the first 12 hours. Example results are presented in Tables 4-6. Student's t-test results for the summer data showed more significant differences with an indicated break in the 36–48-hour time frame. The remainder of the t-test results for Part 2 can be found in Appendix G. Given the results thus far, no conclusion could be drawn as to the optimal QPF duration to use in river forecasts at NCRFC and MBRFC.

Season	1st Period Forecast	2nd Period Forecast	3rd Period Forecast	4th Period Forecast	5th Period Forecast	6th Period Forecast	7th Period Forecast	8th Period Forecast	9th Period Forecast	10th Period Forecast	11th Period Forecast	12th Period Forecast	Total
Mean Areal Precipitation (F-O) Error Sample Size by Season and Forecast Period where Forecast Value > = 0.10													
MBRFC													
Fall	2,488	2,291	2,926	3,234	3,026	2,748	3,332	3,733	3,536	3,015	3,768	3,416	37,513
Winter	1,031	1,235	1,543	1,383	1,372	1,360	1,582	1,678	1,580	1,606	1,345	1,537	17,252
Spring	3,401	3,784	4,238	4,420	3,837	3,835	3,948	3,937	2,875	4,929	4,187	4,679	48,070
Summer	6,274	8,102	8,500	8,898	7,412	7,933	7,865	7,749	5,413	6,527	6,217	6,331	87,221
Sub-Total	13,194	15,412	17,207	17,935	15,647	15,876	16,727	17,097	13,404	16,077	15,517	15,963	190,056
NCRFC													
Fall	2,768	3,352	3,003	2,519	3,017	3,741	3,869	3,457	3,367	3,859	4,167	4,026	41,145
Winter	2,036	1,243	1,391	1,686	2,080	1,585	1,686	1,962	2,021	1,376	1,616	3,211	21,893
Spring	4,116	4,050	3,914	4,246	4,160	3,978	4,278	5,102	5,271	5,139	5,061	4,365	53,680
Summer	11,123	11,344	10,984	11,993	12,650	12,425	12,683	12,450	10,726	9,433	10,261	10,489	136,561
Sub-Total	20,043	19,989	19,292	20,444	21,907	21,729	22,516	22,971	21,385	19,807	21,105	22,091	253,279
RFCs Combined													
Fall	5,256	5,643	5,929	5,753	6,043	6,489	7,201	7,190	6,903	6,874	7,935	7,442	78,658
Winter	3,067	2,478	2,934	3,069	3,452	2,945	3,268	3,640	3,601	2,982	2,961	4,748	39,145
Spring	7,517	7,834	8,152	8,666	7,997	7,813	8,226	9,039	8,146	10,068	9,248	9,044	101,750
Summer	17,397	19,446	19,484	20,891	20,062	20,358	20,548	20,199	16,139	15,960	16,478	16,820	223,782
Total	33,237	35,401	36,499	38,379	37,554	37,605	39,243	40,068	34,789	35,884	36,622	38,054	443,335

Table 1. Sample size of precipitation for part 1 of study

6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
T-test Results for RFCs Combined QPF Errors - Fall, Winter, & Spring Data												
Day 1												
1200 UTC	--	--	--	--	--	--						
1800 UTC	0.080991											
0000 UTC	0.496784	0.316608										
0600 UTC	0.233163	0.509517	0.670752									
Day 2												
1200 UTC	0.63467	0.159098	0.783756	0.42903								
1800 UTC	0.77907	0.123711	0.661876	0.341575	0.846029							
0000 UTC	0.765489	0.106335	0.649236	0.315486	0.83943	0.997267						
0600 UTC	0.00059	0.095844	0.008838	0.014685	0.001226	0.000958	0.000514					
Day 3												
1200 UTC	0.852925	0.034708	0.356637	0.124775	0.460002	0.611197	0.585444	6.52E-05				
1800 UTC	0.367604	0.298587	0.911801	0.707323	0.650617	0.525893	0.501158	0.00356	0.217078			
0000 UTC	2.35E-08	0.000139	2.81E-06	2.33E-06	2.74E-08	2.92E-08	5.32E-09	0.029655	1.82E-10	1.09E-07		
0600 UTC	4.45E-05	0.022376	0.001255	0.001844	8.33E-05	6.93E-05	2.75E-05	0.547351	2.25E-06	0.000278	0.108072	

blue highlights P values that are > 0.05 (not significantly different)

avocado green and blue highlight P values that are > 0.01

Table 2. Student's t-test results with summer removed from datase**t**

Mean Areal Precipitation (F-O) Error Sample Size By Season and Number of Hours Accumulated where abosulute(F-O) >= 0.10												
Number of Hours Accumulated	6	12	18	24	30	36	42	48	54	60	66	72
MBRFC												
Summer	10361	18743	28083	35645	40338	44902	50331	55224	58861	61826	65703	69022
Fall, Winter, & Spring	11414	21550	31360	40988	47748	54053	61674	69126	75148	80125	87038	93588
Sub-Total	21775	40293	59443	76633	88086	98955	112005	124350	134009	141951	152741	162610
NCRFC												
Summer	16442	27348	35290	43275	50082	56230	62171	67855	71722	75265	79280	82399
Fall, Winter, & Spring	14677	25782	34008	42241	50578	59678	68578	76544	83908	92038	99127	106541
Sub-Total	31119	53130	69298	85516	100660	115908	130749	144399	155630	167303	178407	188940
RFCs Combined												
Summer	26803	46091	63373	78920	90420	101132	112502	123079	130583	137091	144983	151421
Fall, Winter, & Spring	26091	47332	65368	83229	98326	113731	130252	145670	159056	172163	186165	200129
Total	52894	93423	128741	162149	188746	214863	242754	268749	289639	309254	331148	351550

Table 3. Sample size of errors for precipitation on Part 2 of study

Part 2 T-test Results for RFCs Combined Accumulated QPF Errors - All Seasons												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--	--	--	--						
12-hr	0.001542											
18-hr	0.029312	0.278289										
24-hr	0.035879	0.237086	0.924364									
30-hr	0.003500	0.742413	0.437356	0.381104								
36-hr	0.001332	0.938026	0.292495	0.248056	0.791933							
42-hr	0.040340	0.178139	0.825475	0.902453	0.301533	0.184221						
48-hr	0.153774	0.042013	0.363601	0.416281	0.082736	0.040666	0.473139					
54-hr	0.154813	0.043533	0.368136	0.420916	0.042592	0.042277	0.478071	0.997158				
60-hr	0.092922	0.071572	0.509100	0.573856	0.135069	0.070942	0.648603	0.784743	0.788787			
66-hr	0.874007	0.000500	0.019155	0.024413	0.001320	0.000362	0.026986	0.137805	0.139369	0.707505		
72-hr	0.392770	4.15074E-06	0.000527	0.000729	1.29736E-05	2.07773E-06	0.000706	0.007862	0.008182	0.002879	0.233380	

[blue]	blue highlights P values that are > 0.05 (not significantly different)
[green][blue]	avocado green and blue highlight P values that are > 0.01

Table 4 Student's t-test summaries for precipitation errors accumulated through 72 hours – all seasons

T-test Results for RFCs Combined Accumulated QPF Errors - Fall, Winter, & Spring												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--	--	--	--	--	--	--	--	--	--
12-hr	0.050760											
18-hr	0.012380	0.632949										
24-hr	0.006500	0.497296	0.837234									
30-hr	0.005594	0.471035	0.804455	0.966713								
36-hr	0.002269	0.218594	0.591289	0.738067	0.768717							
42-hr	0.013040	0.713522	0.886145	0.715985	0.682043	0.471729						
48-hr	4.98774E-05	0.040038	0.096162	0.137628	0.146488	0.240435	0.054878					
54-hr	0.000472	0.150060	0.315917	0.419618	0.441703	0.633410	0.222363	0.472866				
60-hr	0.000297	0.120233	0.261707	0.353640	0.373287	0.550561	0.176763	0.541841	0.906629			
66-hr	2.62286E-05	0.029159	0.072476	0.105839	0.112953	0.192395	0.038526	0.916843	0.400677	0.463510		
72-hr	0.000119	0.075179	0.173644	0.242345	0.257078	0.400889	0.107438	0.702034	0.719598	0.808205	0.616592	

blue highlights P values that are > 0.05 (not significantly different)

avocado green and blue highlight P values that are > 0.01

Table 5. Student's t-test summaries for precipitation errors accumulated through 72 hours – fall, winter, and spring

T-test Results for RFCs Combined Accumulated QPF Errors - Summer only												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--	--	--	--	--	--	--	--	--	--
12-hr	0.011222											
18-hr	0.368774	0.084845										
24-hr	0.515800	0.048426	0.796625									
30-hr	0.101334	0.353907	0.433715	0.300424								
36-hr	0.074231	0.412117	0.355763	0.237864	0.900851							
42-hr	0.452821	0.053881	0.864295	0.926558	0.333535	0.265165						
48-hr	0.168456	2.04935E-05	0.014806	0.031121	0.001175	0.000578	0.021288					
54-hr	0.361228	0.000221	0.054548	0.098847	0.006686	0.003820	0.074744	0.633833				
60-hr	0.459960	0.000358	0.078317	0.137915	0.010252	0.005956	0.106322	0.487064	0.838547			
66-hr	0.000772416	1.11454E-10	5.15142E-06	2.05799E-05	7.3962E-08	1.83548E-08	8.23168E-06	0.031905	0.009814	0.004365		
72-hr	8.09268E-06	2.33287E-14	1.05511E-08	6.13331E-08	5.95959E-11	9.55227E-12	1.68246E-08	0.000822	0.000173	5.15199E-05	0.222179	

blue highlights P values that are > 0.05 (not significantly different)

avocado green and blue highlight P values that are > 0.01

Table 6. Student's t-test summary for precipitation errors accumulated through 72 hours – summer only

7. Part 3: Precipitation and Stage Error Analysis

7.1 Methods and Analysis

Unlike the previous two parts of the study, which looked at the precipitation data only, Part 3 examined the QPF along with the impact the various QPF durations had on the river stage forecasts. Data for all basins and forecast points, both precipitation and stage, were collected for the entire 13-month study period. QPF was analyzed and tested in a similar manner as to Parts 1 and 2. River stage locations used in the analysis were selected based on river forecast point response times (fast, medium and slow), along with the number of events that occurred in the 13-month study period. For this study a minimum of 12 fast (generally time to crest < 24 hours), eight medium (time to crest >= 24 hours and < 60 hours), and four slow (time to crest >= 60 hours) stations were selected from each RFC. Stations were selected based on greatest flood activity, or locations with the highest number of observed flood events. The selections were based on the number of actual observed events. Figure 6 shows the geographic distribution of stations. Examples of sample size for fast-response time locations are shown in Figures 7 and 8. Sample sizes for the medium- and slow-response time locations can be found in Appendix H.

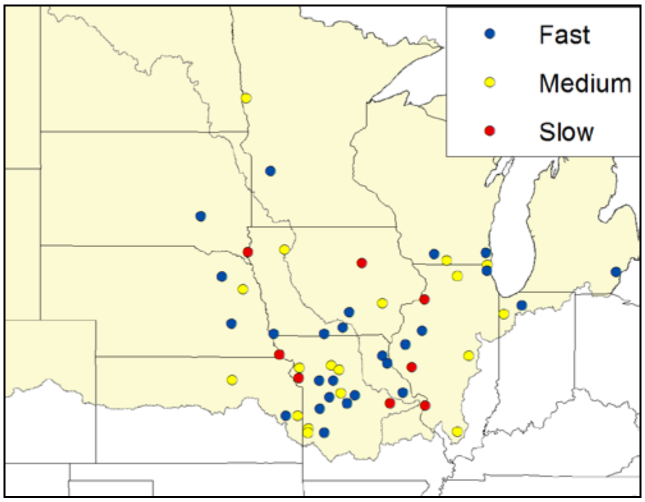

Figure 6. Geographical distribution of forecast points

As the forecast stage and flow variables are not completely independent of each other, the serial correlation nature of the data had to be taken into account for the t-test on river forecasts. To lessen the effects of serial correlation in assessing performance of river forecasts and recognizing that lack of correlation does not imply independence of events, the travel time from headwaters to forecast points was used as a lag between forecast/observation pairs. The longest travel time for fast-, medium- and slow-responding rivers was used for all data points in each category. For the analysis, only forecast observation pairs were used that were separated by at least the following lag times: fast - four days, medium - seven days, and slow - 22 days. While it is recognized that not all correlation can be removed due to the day to day dependency of the numerous parameters input to river forecasts, this method was seen as the best way to remove the majority of it in order to conduct parametric statistical analyses on the river forecast/observation pairs.

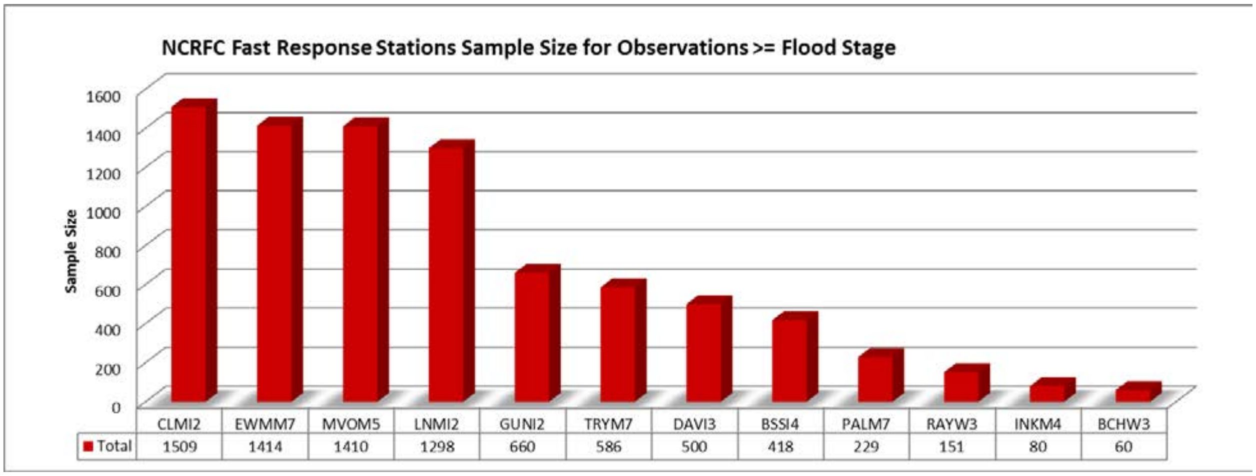

Figure 7. Number of stage pairs greater than or equal flood stage in NCRFC area for fast-response stations

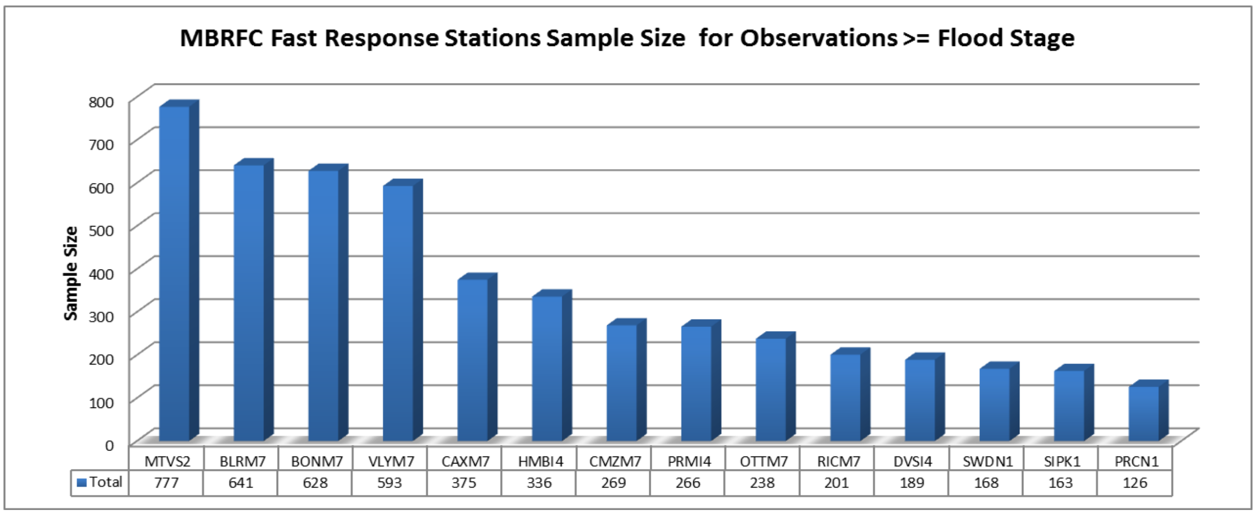

Figure 8. Number of stage pairs greater than or equal to flood stage in MBRFC area for fast-response stations

7.1.1 Student's t-test on Precipitation Data

Unlike the extremely large datasets of Parts 1 and 2, the precipitation dataset for Part 3 focused on data for the basins that feed the fast- and medium-response time locations used in the river stage forecast analysis. Basins for slow-response time locations were not considered as results would be very similar to the analyses in parts 1 and 2. For these t-tests the data were analyzed by season, and whether the forecast minus observed values were less than zero (F-0 < 0), indicating under-forecasting, or greater than zero, (F-O > 0) indicating over-forecasting. The results for both RFCs for this analysis are summarized in Tables 7 and 8. An X in the tables indicates inconclusive. In some instances, a possible "best" QPF duration follows the X. Full t-test results can be found in Appendix I. These results indicate that the optimal QPF time duration for forecasting river stages likely lies in the 24- to 48-hour range.

Fast Response	Under Forecasting			
	Spring	Summer	Fall	Winter
MBRFC	X	X / 48	24	24
NCRFC	48	X	24	24
	Over Forecasting			
	Spring	Summer	Fall	Winter
MBRFC	48	18	X	48
NCRFC	X	X	X	48
	Spring	Summer	Fall	Winter
Conclusions	48	X / 24	24	24-48

Table 7. Precipitation t-test results for fast-response-time locations

Medium Response	Under Forecasting			
	Spring	Summer	Fall	Winter
MBRFC	X	48	24	24
NCRFC	24	X / 6	24	24
	Over Forecasting			
	Spring	Summer	Fall	Winter
MBRFC	48	18	X	24
NCRFC	X / 18	X / 12	24	X / 48
	Spring	Summer	Fall	Winter
Conclusions	24	X	24	24

Table 8. Precipitation t-test results for medium-response-time locations

7.1.2 Student's t-test on River Forecasts

While looking at the t-test on river forecasts, the fast- and medium-response-time locations were analyzed separately for each RFC. The filtered dataset for the slow-response-time rivers was quite limited. Therefore, data for the two RFCs were combined to one dataset. For each response time dataset, the river forecast errors were separated into two groups based on 1) the condition that the *observation* was greater than or equal to flood stage (FS), and 2) the condition that the *forecast* was greater than or equal to FS. These groups were further separated by QPF time periods (0, 6, 12, 18, 24, 48 and 72 hours). Student's t-tests for equal means were performed on the river forecast error datasets in those QPF time periods. An example of the t-test results can be found in Table 9 (blue highlighting indicates no significant difference) and full results are in Appendix I. As with the precipitation analyses in Parts 1 and 2, the results were inconclusive and other methods of analysis were used to determine the optimal QPF duration to incorporate into NCRFC and MBRFC's river models.

Student's t-test for River Stage Forecast Errors Forecasts >= Flood Stage						
QPF hours	0-6 hrs	6-12 hrs	12-18 hrs	18-24 hrs	24-48 hrs	48-72 hrs
RFCs Combined						
Slow	0.738412	0.982778	0.656633	0.964632	0.622351	0.685467
MBRFC						
Medium	0.423603	0.917092	0.593223	0.385964	0.608421	0.6618
Fast	0.05365	0.970936	0.793893	0.39209	0.487353	0.388772
NCRFC						
Medium	0.947471	0.68385	0.694232	0.492518	0.381445	0.84385
Fast	0.384061	0.408543	0.812302	0.64299	0.595445	0.766727

Table 9. Student's t-test results for stage forecast errors

7.1.3 Error and Categorical Statistics

The main analysis developed by the RFCs was to use IVP statistical output to determine the optimal QPF. In addition, the RFCs also computed the percent difference, or relative change, for each statistic. All statistics calculated were combined as a whole, as well as divided by season. One general characteristic common in both RFCs that was also considered in the final conclusions was that the overall river forecast bias for each RFC was low. The scatter plots in Figures 9 and 10 show the river forecasts vs. the corresponding observations and the associated low forecast bias for each RFC. Under-forecasting is indicated below the diagonal, "perfect forecast," line while over-forecasting is plotted above the diagonal. The closer the forecast/observed pair plots to the diagonal, the better the forecast. Since precipitation inputs are one of the strongest drivers of the river model (Linsley et al. 1975), one likely reason for the low bias is the limited amount of QPF used (i.e., 24 hours) in the 1–5-day forecasts.

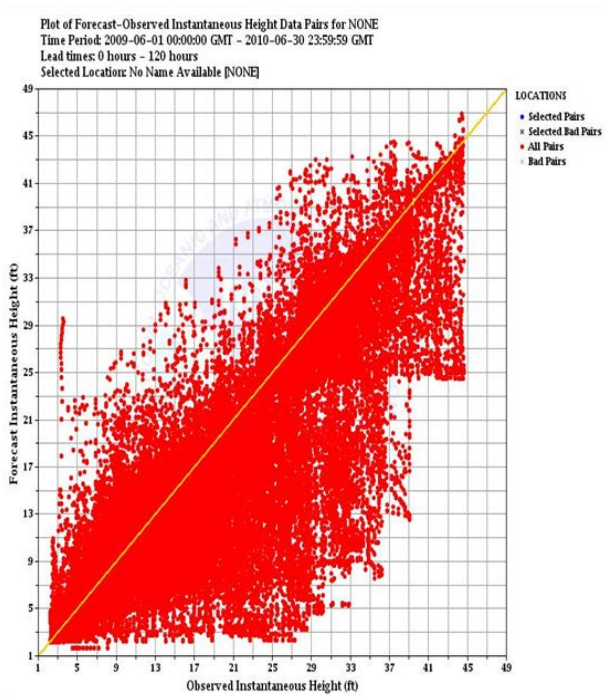

Figure 9. MBRFC scatter plot forecast stage vs. observed stage

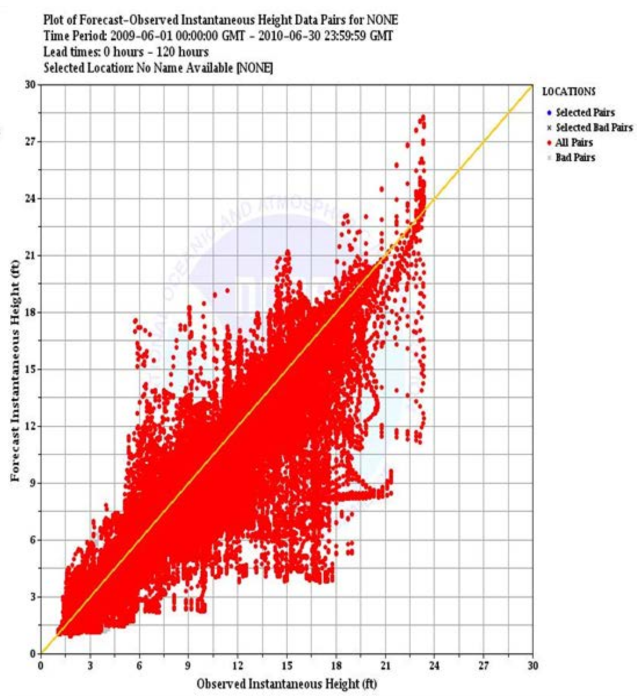

Figure 10. NCRFC scatter plot forecast stage vs. observed stage

The study compared various IVP output for a particular statistic (e.g., MAE, ME), looking at the different QPF durations and computing the relative change of those error statistics from one QPF duration to the next. Plots of HFAR vs. POD by forecast lead-time (1-5 days) and by season were also produced. The analysis used QPF durations of 6, 12, 18, 24, 48, and 72 hours and then 0, 24, 48 and 72 hours in side-by-side comparisons. The second analysis with equal time-period intervals was performed due to concern that unequal time period intervals would adversely skew the conclusions. Examples of the various plots used in this analysis are shown in Figures 11 through 14. Appendix J contains the remainder of the plots. In general, when conditioned on the observation, error statistics decreased with increasing QPF while the opposite was true when conditioned on the forecast (Figures 11 & 13). In the relative change graphs, the annotated number over the bar was the "decision" QPF for that dataset. For results conditioned on the forecast (forecast category), the lesser number in the range of QPF hours (e.g., 24-48 hours of QPF) was used since errors generally increase in time when conditioned on the forecast. The higher number of hours was selected for the ranges in the observed category when errors typically decrease with increasing hours of QPF. Figure 12 shows the greatest change for spring season errors was from 24 to 48 hours, thus, 24 hours was selected. The other seasons suggest using no QPF. However, Figures 13 and 14 show spring and summer to be 24 hours and fall and winter, 48-72 hours. Additional plots can be found in Appendices J and K.

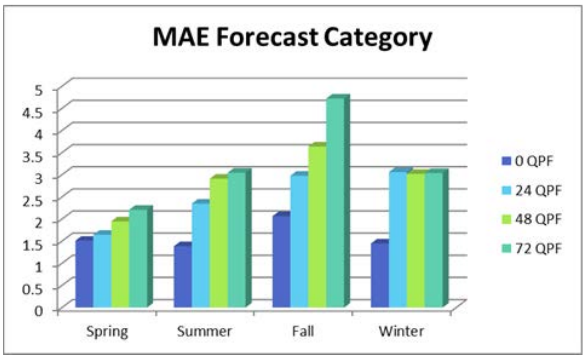

Figure 11. Seasonal mean absolute errors when forecast stage greater than or equal to flood stage for MBRFC fast responders

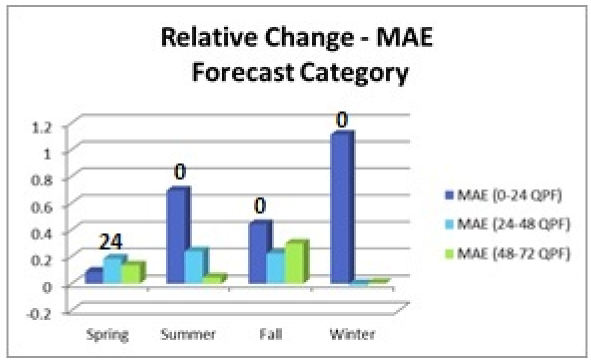

Figure 12. Seasonal MAE relative change when forecast stage greater than or equal to flood stage for MBRFC fast responders

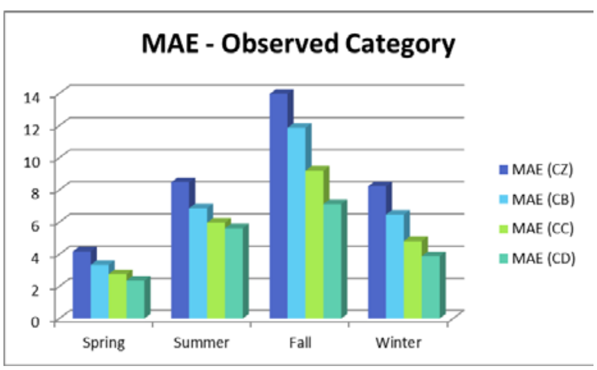

Figure 13. Seasonal mean absolute errors when observed stage greater than or equal to flood stage for MBRFC medium responders

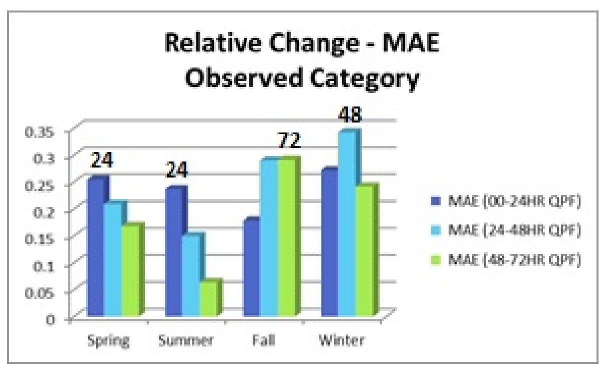

Figure 14. Seasonal MAE relative change when observed stage greater than or equal to flood stage for MBRFC medium responders

The study also examined HFAR vs. POD where the best value of HFAR is 0 and the best value of POD is 1. HFAR had a tendency to worsen (increase towards 1) with increasing QPF while POD improved (increase towards 1). In an attempt to determine a balance between the two, plots of HFAR vs. POD were created. Results for MBRFC (Fig. 15) showed greater increase in POD compared to HFAR in the 0–24- and 0–48-hour range. For example, in Figure 16, notice summer 2009 shows a more significant rise in HFAR compared to little improvement in POD going from 24 to 48-hour QPF, while summer 2010 shows a similar trend but with fewer hours of QPF (12 to 18 hours). Fall shows more rise in HFAR going from 24–48-hour QPF compared to improvements in POD with 0 to 24 hour QPF. Figures 15 and 16 are samples of some of the graphs in Appendices J and K.

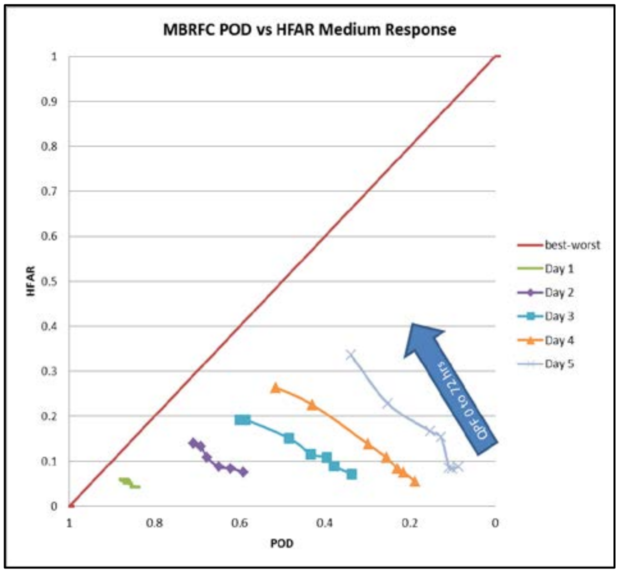

Figure 15. POD vs. HFAR by lead time day in MBRFC area

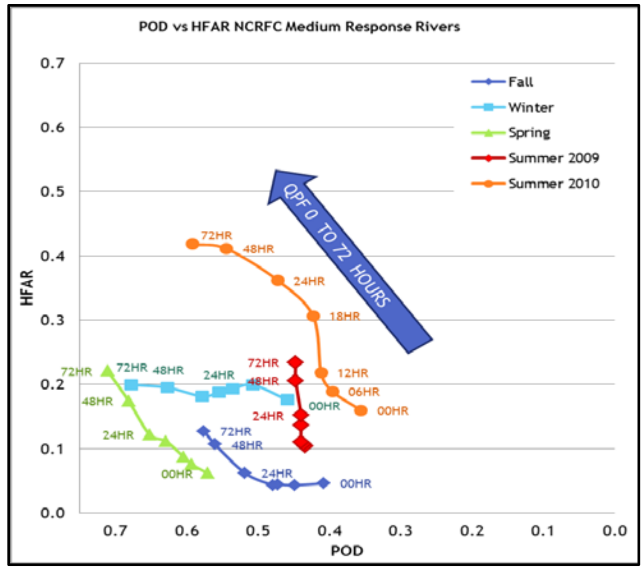

Figure 16. POD vs. HFAR by season for NCRFC area

7.2 MBRFC Results

The conclusions in Table 10 are based on the review of all the data and graphs for part 3. Stage forecast analysis for the various QPF durations can be found in Appendix J. For the MBRFC study area, it appeared the optimal QPF duration was in the range of 24 to 48 hours. During analysis, results were focused on the fast- and medium-response-time locations, because slow-response-time locations were not greatly affected by QPF proximity. That is, as long as it rains somewhere upstream, the water will contribute to the streamflow at the basin outlet.

For QPF durations 0, 6, 12, 18, 24, 48, and 72 hours, the relative change in the error statistics, ME and MAE, were considered. Results tended to indicate using 18-24 hours of QPF, when analyzing by forecast category (conditioned on the forecast). When analyzing by observed category, the data indicated 48–72-hour QPF was best to use. The categorical statistics, POD, again indicated that 48-hour QPF should be used, while HFAR showed 24-hour QPF was the best option.

When evenly distributing the QPF durations to 0, 24, 48, and 72 hours, the relative change from 0–24-hour QPF implied that using some QPF in the river forecasts overwhelmingly confirms the current philosophy on the operational use of QPF in river forecasts. The POD and error statistics by observed category both indicate 24–48-hour QPF being optimal. Conversely, the HFAR and error statistics by observed category show 0–24-hour QPF is optimal.

The study also looked at the POD vs. HFAR plots for fast- and medium-response-time locations, to find a balance between under- and over-forecasting. Fast response time locations indicated using 24-hour QPF, while Medium response time locations favored 48-hour QPF.

Considering…	MBRFC Summary of Conclusions
Considered QPF durations: 0, 6, 12, 18. 24, 48, & 72 hours • MAE by forecast category • ME by forecast category • HFAR • POD • MAE by observed category • ME by observed category	▪ Focused on forecasts above flood stage for fast- and medium-response-time rivers ▪ Considered the raw statistics as well as relative change calculations ▪ Conclusion: optimal QPF duration is 24–48-hour QPF
Considered QPF durations: 0, 24, 48, & 72 hours • MAE by forecast category • ME by forecast category • HFAR • POD • MAE by observed category • ME by observed category	▪ Focused on forecasts above flood stage during study period for Fast, Medium, and Slow response time rivers ▪ Considered the raw statistics as well as relative change calculations ▪ Conclusion: optimal QPF duration is 24–48-hour QPF
Considered QPF durations: 0, 6, 12, 18. 24, 48, & 72 hours • POD vs. HFAR for lead time • POD vs. HFAR for seasons	▪ Focused on forecasts above flood stage for Fast and medium-response-time rivers ▪ Conclusion: optimal QPF duration is 24–48-hour QPF

Table 10. MBRFC Summary of Conclusions

Combining all the methods of analysis, the data indicated there was enough evidence to support using 48-hour QPF in the fall and winter, and 24-hour QPF during the spring and summer. It should be noted there was some evidence to support using 48-hour QPF duration in the spring. However, MBRFC concluded that the optimal QPF duration that should be used routinely in the river model was to continue using 24-hour QPF duration in the spring and summer, and to use a longer QPF duration of 48-hours in the fall and winter.

7.3 NCRFC Results

Similar to MBRFC, error analysis was conducted by conditioning both for observed and forecast categories to determine forecast discrimination and forecast reliability, respectively. Discrimination answers the question of when the observation is above flood stage, or when flooding is occurring, was it forecast? Reliability answers the question, if the forecast was above flood stage, was the observation also above flood stage, or did flooding actually occur?

When conditioned on observations, both ME (bias) and MAE analysis showed a decreasing trend in bias and error with increasing QPF durations as shown in Figures 17-20. Thus, the results clearly indicated an improvement in forecast discrimination when using longer periods of QPF. When conditioned on the forecasts, however, incorporating additional periods of QPF actually increased the error and bias as shown in Figure 18. So adding additional QPF actually decreased forecast reliability.

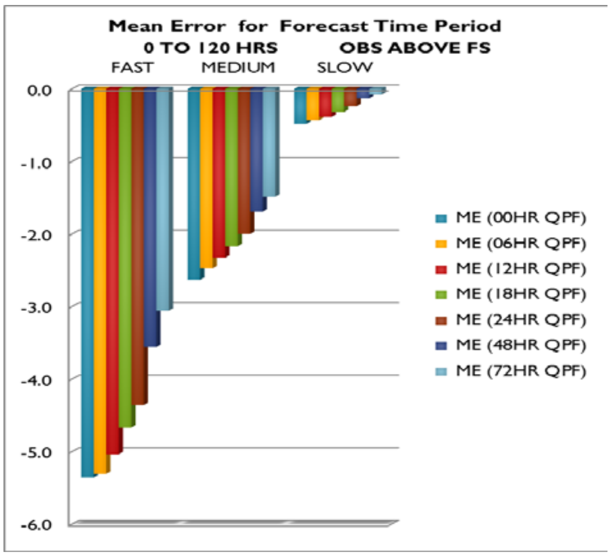

Figure 17. NCRFC ME, by response times, for 5-day forecasts with observations above flood stage

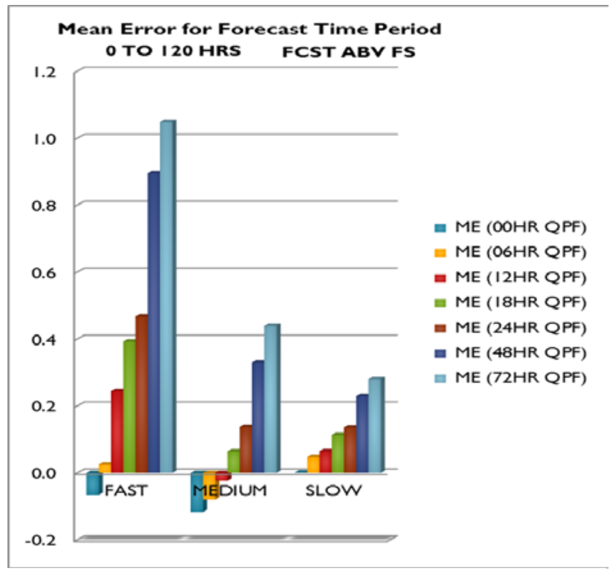

Figure 18. NCRFC ME, by response times, for 5-day forecasts with forecasts above flood stage

When looking at the results conditioned by forecast such as in Figure 20, the seasonal analysis clearly shows that summer exhibits much more bias than the remainder of the year. This seems logical given the climatology of the summer season, which is characterized by highly variable, convective rainfall. Conversely, for the fall and winter seasons when precipitation is predominantly stratiform, one can see relatively minor changes in bias with longer-duration QPF.

When conditioned by observations, the results show that there is a consistent improvement in bias with additional periods of QPF across all seasons (Figure 19).

POD (Fig.21) and HFAR (Fig.22) both increased with longer QPF durations, yielding no obvious optimum QPF duration on initial review. In addition, analysis of the relative change in verification metrics showed no clear breakpoints either. Results of a comparison between POD and HFAR on a seasonal basis, however, indicated a higher summer rate of HFAR vs. POD using additional QPF beyond 24 hours. All comparisons of HFAR and POD during winter showed a greater increase in POD vs. HFAR using 48 and 72 hours of QPF.

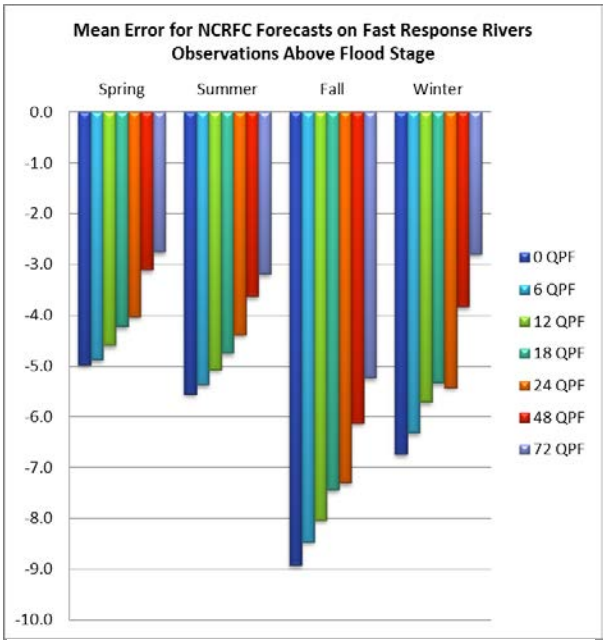

Figure 19. NCRFC Seasonal ME for 5-day forecasts with observations greater than or equal to flood stage

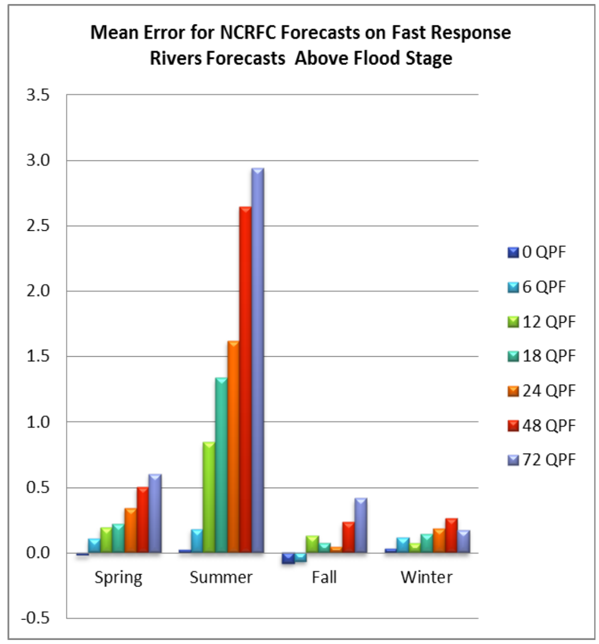

Figure 20. NCRFC Seasonal ME for 5-day forecasts with forecasts greater than or equal to flood stage

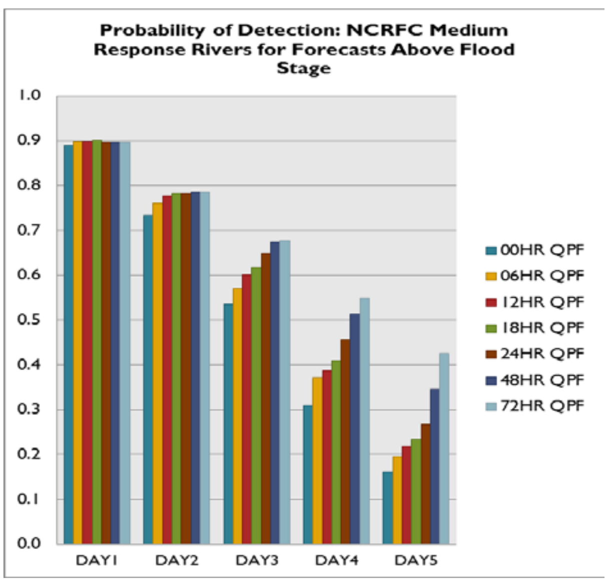

Figure 21. POD for lead times day 1 to 5

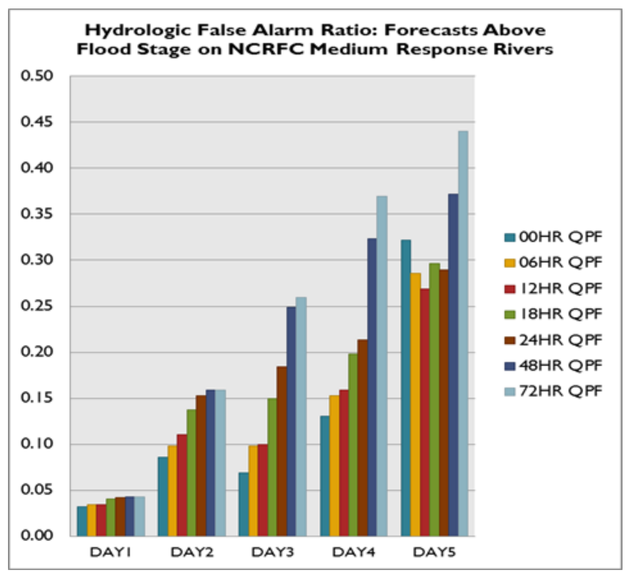

Figure 22. HFAR for lead times day 1 to 5

Comparisons of POD vs. HFAR and mean error vs. POD over day 1 through 5 lead times for fast-, medium-, and slow-response time are shown in Appendix K. Figure 23 demonstrates the results of POD compared to ME on a seasonal basis, with all QPF durations labeled as data points. Trends were examined to determine inflection points indicating where gains could be made without increasing negative effects. For example, the red line representing the summer of 2010 shows an improvement in POD between 18 and 24 hours of QPF. But the trend shows a large increase in ME with no improvement in POD between 24 and 48 hours of QPF.

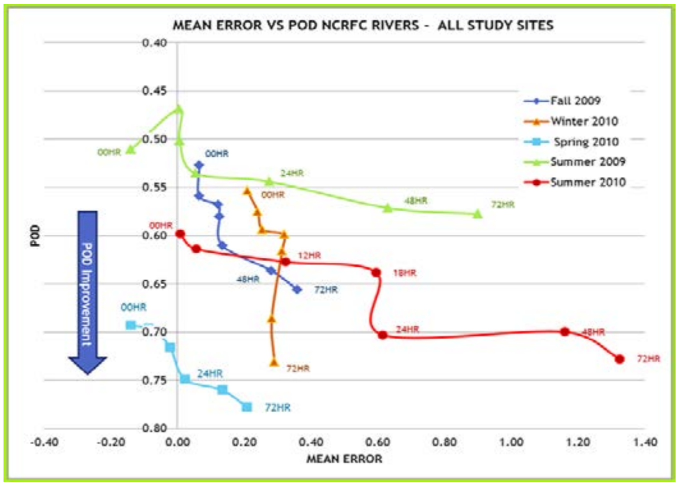

Figure 23. Seasonal Comparison of ME vs. POD for all NCRFC study sites.

Based on the combined results, the NCRFC analysis indicated that there were no consistent results on an annual basis. The subsequent seasonal analysis provided evidence for two recommendations, 24 hours of QPF in spring and summer, and 48-72 hours of QPF in fall and winter. Conclusions for NCRFC are summarized in Table 11.

Considering…	NCRFC Recommendation for best QPF Time Horizon…
POD vs HFAR POD vs ME HFAR vs ME seasonality	• Focus on forecasts above flood stage for fast- and medium-response rivers… • Conclusion: 24 hours QPF spring and summer, 48–72 hour QPF fall and winter
ME vs POD over all lead times MAE vs. POD over all lead times	• Focus on forecasts above flood stage for fast-, medium-, and slow-response rivers and errors over lead times day 1 to 5… • Conclusions: 24-hour QPF for fast and medium response and 24–48-hour QPF for slow response.

Table 11. NCRFC Summary of Conclusions

8. Summary and Recommendations

Each River Forecast Center analyzed river stage forecasts for selected fast-, medium-, and slow-response-time locations for 24-28 forecast points in its area of responsibility. This analysis involved computing several statistics including, but not limited to: mean error and mean absolute error by both observed and forecast conditioning, POD, and HFAR. The two RFCs worked together to arrive at an objective approach to analyze the various plots. The two RFCs found:

- Overall low bias (under-forecasting) for points actively flooding
- For statistics conditioned on forecasts above FS, errors increased with increasing QPF duration (degrading forecast quality)
- For statistics conditioned on observations above FS, errors decreased with increasing QPF duration (improving forecast quality)
- POD increased with increasing QPF time duration (improving forecast quality)
- HFAR increased with increasing QPF time duration (degrading forecast quality)
- Significance testing (Student's t-test) was inconclusive

Analysis of the impact of the various QPF durations on the river stage forecasts indicated there was enough supporting evidence to recommend the following number of hours of QPF be used routinely in the river forecasts at Missouri Basin and North Central River Forecast Centers:

- 24 hours of QPF Spring and Summer (March 1 through August 31)
- 48 hours of QPF Fall and Winter (September 1 through the end of February)

It was further suggested the above dates not be hard-wired but somewhat flexible depending on the conditions at the time. It would also be acceptable to exceed the routine hours of QPF when circumstances warrant, as currently practiced.

9. Lessons Learned

The greatest obstacle that both RFCs encountered in this study was the NWS IVP application performance issues related to memory limitations on the AWIPS system. This constraint, documented in the IVP User's Manual (2007), limited the amount of data that could be processed at one time. Also, due to the complex calculations requested, the batch runs took several hours to complete and were often set up to run overnight. Numerous times the datasets had to be divided into smaller datasets and the results later combined in an MS Excel spreadsheet. Some of the initial statistics considered were eliminated or simplified due to project deadlines, and software and hardware limitations (e.g., computational times exceeding 18 to 24 hours). Another IVP limitation regarded data naming conventions that were not specified in the documentation. These limitations were reported to the IVP software developers for future correction to the software.

10. Acknowledgements

The authors wish to thank Kris Lander (CRH), Jennifer Bushur (MBRFC), and Pedro J. Restrepo (NCRFC) for their significant input and contributions to this manuscript. Julie DeMargne and James Brown provided consultation in water resources verification and statistics, and Hank Herr provided IVP technical expertise. We also appreciate the additional insights from Kevin Werner (CBRFC), Scott Lindsey (APRFC), Tom Adams (formerly of OHRFC), Tony Anderson (ABRFC), and David Welch (LMRFC) concerning QPF, river forecasts and statistics during this study.

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Abbreviations

ABRFC	Arkansas-Red Basin River Forecast Center
APRFC	Alaska-Pacific River Forecast Center
AWIPS	Advanced Weather Interactive Processing System
CBRFC	Colorado Basin River Forecast Center
CRH	Central Region Headquarters
CR	Central Region
FAR	False Alarm Ratio
FIS	Forecast Issuance Stage
FS	Flood Stage
HAS	Hydrometeorological Analysis and Support
HFAR	Hydrologic False Alarm Ratio
HRAP	Hydrologic Rainfall Analysis Project
IVP	Interactive Verification Program
LMRFC	Lower Mississippi River Forecast Center
MAE	Mean Absolute Error
MAP	Mean Areal Precipitation based on rain gage network
MAPX	Mean Areal Precipitation based on radar QPE and hourly gage data
MBRFC	Missouri Basin River Forecast Center
ME	Mean Error
NCRFC	North Central River Forecast Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
NWSRFS	National Weather Service River Forecast System
OFS	Operational Forecast System
OHRFC	Ohio River Forecast Center
POD	Probability of Detection
QPE	Quantitative Precipitation Estimate
QPF	Quantitative Precipitation Forecast
RFC	River Forecast Center
RMSE	Root Mean Square Error
RMSE-SS	Root Mean Square Error Skill Score
TFAR	Traditional False Alarm Ratio (same as FAR)
USGS	United States Geological Survey
WFO	Weather Forecast Office
WPC	Weather Prediction Center

Definitions[1]

Bias - the difference between the mean of the forecasts and the mean of the observations. This could be expressed as a percentage of the mean observation and is also known as overall bias, systematic bias, or unconditional bias. For categorical forecasts, bias (also known as frequency bias) is equal to the total number of events forecast divided by the total number of events observed. With the (2x2) contingency table bias = (a+b)/(a+c). Perfect score: 1.

Contingency Table – is a two-dimensional table that gives the discrete joint distribution of forecasts and observations in terms of cell counts. For dichotomous categorical forecasts, having only two possible outcomes (yes or no), the following (2x2) contingency table can be defined:

2x2 Contingency Table		Event Observed	
		Yes	No
Event Forecast	Yes	a (hits)	b (false alarms)
	No	c (misses)	d (correct negatives)

False Alarm Ratio (FAR) - for categorical forecast, the number of false alarms divided by the total number of events forecast. This is a measure of reliability. With the *(2x2)* contingency table FAR = a/(a+b). Not to be confused with the Probability of False Detection (POFD) (also called False Alarm Ratio), which is conditioned on observations rather than forecasts. Range: 0 to 1. Perfect score: 1.

Hydrologic False Alarm Ratio (HFAR) - The probability that, given a forecast value is within the category, the observed value is below the category (useful when categories represent flood levels).

Traditional False Alarm Ratio (TFAR) - The probability that, given a forecast value is within the category, the observed value is not within the category (either above or below).

Flood Stage (FS) - an established gage height for a given location at which a rise in water surface level begins to impact lives, property or commerce. The issuance of flood (and in some cases flash flood) warnings is linked to flood stage. Not necessarily the same as bankfull stage.

Flood Categories – terms defined for each forecast point that describe or categorize the severity of flood impacts in the corresponding river/stream reach. The severity of flooding at a given stage is not necessarily the same at all locations along a river reach due to varying channel/bank characteristics or the presence of levees on portions of the reach. Therefore, the upper and lower stages for a given flood category are usually associated with water levels corresponding to the most significant flood impacts somewhere in the reach. The flood categories used in the NWS are:

Minor Flooding - minimal or no property damage, but possibly some public threat.

Moderate Flooding - some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations.

[1] Definitions from NWS Directive 10-950 , UCAR-COMET website, USGS website, wikipedia.com, investopedia.com or buzzle.com.

Major Flooding - extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.

Forecast Issuance Stage (FIS) - the stage which, when reached by a rising stream, represents the level where RFCs need to begin issuing forecasts for a non-routine (flood-only) forecast point. This stage is coordinated between WFO and RFC personnel and is not necessarily the same as action or alert stage. The needs of WFO/RFC partners and other users are considered in determining this stage.

Forecast Point - a location along a river or stream for which hydrologic forecast and warning services are provided by a WFO. The observed/forecast stage or discharge for a given forecast point can be assumed to represent conditions in a given reach (see *reach*).

Mean Absolute Error (MAE) - the average of the absolute differences between forecasts and observations. A more robust measure of forecast accuracy than Mean Square Error that is sensitive to large outlier forecast errors. Perfect score: 0. Note: the overbar denotes the mean.

Mean Error (ME) - the average difference between forecasts and observations. Note: it is possible to get a perfect score if there are compensating errors. Perfect score: 0.

Pearson's Correlation Coefficient – is a measure of the linear association between forecasts and observations independent of the mean and variance of the marginal distributions. Perfect score: 1.

Percent Difference/Percentage of Change - Percent difference is calculated as the difference between two values, divided by the average of the two values, expressed in terms of percentage.

Probability of Detection (POD) (or Hit Rate) - for categorical forecast, the number of hits divided by the total number of events observed. This is a measure of discrimination. For the (2x2)**,** contingency table, POD = a/(a+c). Range: 0 to 1. Perfect score: 1.

Probability of False Detection (POFD) (or False Alarm Ratio) - for categorical forecast, the number of false alarms divided by the total number of events observed. A measure of discrimination. For the (2x2) contingency table, POFD = b/(b+d). This is not to be confused with the false alarm ratio (FAR**),** which is conditioned on forecasts rather than observations. Range: 0 to 1. Perfect score: 0.

Reach - a section of river or stream between an upstream and downstream location, for which the stage or flow measured at a point somewhere along the section (e.g., gaging station or forecast point) is representative of conditions in that section of river or stream.

Response Time – for verification purposes, the response time for all forecast points is classified as FAST, MEDIUM or SLOW. These classifications are determined as follows, if rainfall event occurs over the entire area upstream of the forecast point, then:

FAST – flood hydrograph peaks < 24 hours

MEDIUM – flood hydrograph peaks >= 24 hours and < 60 hours

SLOW – flood hydrograph peaks >= 60 hours

Root Mean Square Error (RMSE) – is the square root of the average of the squared differences between forecasts and observations. It puts a greater influence on large errors than smaller errors, which may be good if large errors are especially undesirable, but may also encourage conservative forecasting. Perfect score: 0.

Root Mean Square Error Skill Score (SS-RMSE) - A skill score based on RMSE values. The most commonly used reference forecasts are persistence and climatology.

Sample Size - a numeration of the number of forecasts involved in the calculation of a metric appropriate to the type of forecast (e.g., categorical forecasts should numerate forecasts and observations by categories, etc.)

Scatter Plot – there are several types of scatter plots, the most common presents the forecast values on the y axis and the observed values on the x axis, which are used as a fast way to view the relationship between two variables.. In river forecasting, the two variables are typically the forecast and observed values. The closer the points line up along the positively tilted diagonal line, the greater the positive correlation is between the observed and forecast values.

Serial Correlation – is the relationship between a given variable and itself over various time intervals. Serial correlations are often found in repeating patterns when the level of a variable affects its future level.

Skill Score - a measure of the relative improvement of the forecast over some (usually “low-skilled”) benchmark forecast. Commonly used reference forecasts include climatology, persistence, or output from an earlier version of the forecasting system. In general, skill scores are the percentage difference between verification scores for two sets of forecasts (e.g., operational forecasts versus climatology). Perfect score: 1.

Stage - the level of the water surface of a river or stream relative to an established datum at a given location.

Student’s t-test – a test for determining whether two population means differ significantly. The t-test looks at the t-statistic, t-distribution and degrees of freedom to determine a “p” value (probability) that can be used to determine whether the population means differ.

Uncertainty - is the degree of variability in the observations. This is most simply measured by the variance of the observations. It is an important aspect in the performance of a forecasting system, over which the forecaster has no control.

Water Year - the term U.S. Geological Survey "water year" is defined as the 12-month period October 1, for any given year through September 30, of the following year. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1999 is called the "1999" water year.

Appendix A – Study Scope Document dated May 2009

Optimization of QPF Time Horizons Used in River Forecasts: Part II

Overview:
The proposed QPF study is a continuation of the January 2009 study, *Optimization of QPF Time Horizons Used in River Forecasts.* The goal of this follow on study is to identify the impacts of variable QPF periods on operational forecasts. Conclusions will be based upon the discovery of statistically supportable evidence of optimal QPF at both MBRFC and NCRFC. Both RFC DOHs must agree upon consistent procedure for the data collection and consistent metrics for the study results to be considered supportable evidence. The results of this study will be compared with and used to expand upon the initial *Optimization of QPF Time Horizons Used in River Forecasts* study in the final conclusion.

Study Parameters and Objectives:

Forecast Point and Basin Selection Parameters:

Forecast points and basins will be selected, based upon the following criteria.

- A total of 24 forecast points and contributing basin areas will be selected in each RFC's forecast area. A ratio of 12 fast, 8 medium and 4 slow responding forecast points will be selected in each RFC's forecast area. This ratio is flexible and may be adjusted slightly during basin selection.
- Forecast point selection will occur after the study data collection period has ended, so that the most active forecast points may be studied.
- The forecast points and contributing basin areas that are selected will be used to address all three study objectives.
- The contributing basin area, for the purpose of precipitation analysis, is the basin area defined within the forecast point segment. Area upstream from the forecast point segment will not be included in the contributing basin area.
- The forecast points and contributing basin areas should be selected from the areas established as climate zones in the *Optimization of QPF Time Horizons in River Forecasts* study. Areas in the Rocky Mountains and in Montana will not be included in this study. Basins will be selected from a wide geographic area that is representative of the forecast conditions that exist across the entire RFC area of responsibility; however, the selected points do not need to be evenly distributed across the geographic region. Basins may be concentrated in a more hydrologically active geographic region.

Objectives:

The goal of this follow on study is to identify the impacts of varying QPF periods on operational forecasts. The following three objectives will provide evidence to support the study goal.

(1) Conduct an error analysis similar to the *Optimization of QPF Time Horizons Used in River Forecasts* study, but on a forecast basin scale instead of a 4km grid scale. The error analysis will be conducted on both incremental and cumulative RFC HAS QPF.

General Study Data Collection Parameters

- Data for basin QPF analysis will be extracted from the archive database. A minimum period of 1 year of record will be studied; however, as much record as feasible should be studied by either RFC.
- RFCs will use their standard operational observed precipitation processing methods throughout the study. MBRFC uses MAPX and NCRFC uses MAP during the model run around or before 18 UTC.
- Compute incremental forecast (RFC HAS QPF) and observed (MAPX or MAP) values for daily RFC HAS QPF 12 UTC forecasts in four 6-hour time steps: 1200-1800, 1800-0000, 0000-0600 and 0600-1200 UTC.

- Compute cumulative forecast (RFC HAS QPF) and observed (MAPX or MAP) values for daily RFC HAS QPF 12 UTC forecasts in four 6-hour time steps: 1200-1800 UTC (6 hours), 1200-0000 UTC (12 hours), 1200-0600 UTC (18 hours) and 1200-1200 UTC (24 hours).

General Analysis Procedure and Parameters

- Conduct a one-way ANOVA of cumulative (F-O) positive error and incremental (F-O) positive error consistent with the previous QPF study. This analysis will be done by CRH.
- Records for analysis should include: Season, the UTC period, basin ID, and (F-O) positive error.
- Time series consisting of records for each incremental and cumulative QPF period Forecast – Observed (F-O) positive error > 0.10 inches of QPF.

(2) Determine optimum number of QPF periods, based upon raw RFC HAS QPF forcings applied on a basin scale to RFC runoff zones. The analysis will consider both incremental and cumulative periods of QPF.

General Study Data Collection Parameters

- Data for basin QPF analysis will be extracted from the archive database. A minimum period of 1 year of record will be studied; however, as much record as feasible should be studied by either RFC.
- RFCs will use their standard operational observed precipitation processing methods throughout the study. MBRFC uses MAPX and NCRFC uses MAP during the model run around or before 18 UTC.
- Compute incremental forecast (RFC HAS QPF) and observed (MAPX or MAP) values for daily RFC HAS QPF 12 UTC forecasts in four 6-hour time steps: 1200-1800, 1800-0000, 0000-0600 and 0600-1200 UTC.
- Compute cumulative forecast (RFC HAS QPF) and observed (MAPX or MAP) values for daily RFC HAS QPF 12 UTC forecasts in four 6-hour time steps: 1200-1800 UTC (6 hours), 1200-0000 UTC (12 hours), 1200-0600 UTC (18 hours) and 1200-1200 UTC (24 hours).

General Analysis Procedure and Parameters

- A variety of metrics from the Interactive Verification Program (IVP) will be generated and compared.

(3) Determine the optimum number of QPF periods based upon river forecast verification metrics. The analysis will attempt to identify the optimum number of QPF periods that balances river forecast lead-time with river forecast accuracy.

General Study Data Collection Parameters

- The minimum period of record will be 1 year. Data collection will begin June 2009 and end June 2010 at both RFCs.
- Automatic runs of 0, 6, 12, 18, 24 and 48 hours of QPF will be produced daily at approximately 18 UTC for select RFC basins. The valid date\time of the QPF will begin at 1200 UTC of the current day. The model will be run one time per day around or before 1800 UTC.
- Each model run around or before 1800 UTC run will have a corresponding zero-QPF run to work as a baseline for comparison to QPF-influenced model runs.
- A 7-day forecast and observed time series will be archived and verified. Slow responding basins may require a period greater than 7 days to verify the impact of QPF. Forecast and observed time series will be recorded in the archive database in 6-hour stage intervals through 7 days.
- Carryover values will be set to 5 days prior to the present day.

- Observed rainfall that occurs between 1200 and 1800 UTC of the current day will be ignored and will not replace the QPF forecasted for that time period. NCRFC operations are configured to ingest MAP on a 6-hourly basis and the operational procedures do not overwrite QPF with observed rainfall. MBRFC operational procedures require that MAPX be ingested on an hourly basis. MBRFC cannot modify the MAPX ingest procedure without significant modification of operational processes; consequently, MBRFC will log all occurrences where MAPX exceeds forecast QPF for the model run. Occurrences where MAPX exceeded QPF will be removed from the study data set during the analysis phase.
- MODs will be treated uniformly at both RFCs according to the following methods.
  - A script will be run on the fgroup mod file immediately before the model run has started.
  - If the second date is the current days date at 0600 UTC or later, then the application resets the data to the current day date so that the mod is only applied to time series preceding the current day at 0600 UTC. The mods cannot be easily stopped at 1200 UTC for the current day. The RFCs would have to invest significant resources in the development of a complex script that will handle the task. The 0600 UTC time stamp is a much simpler process that does not require complex script development.
  - The following mods will be adjusted so that no impact occurs on beyond the current day at 0600 UTC: TSCHNG, RRICHNG, ROCHNG, RRIMULT, and ROMULT.
  - Each RFC will operate reservoirs and diversions according to their unique operational practices. Points will be selected to minimize the impacts of reservoirs on the study.

General Analysis Procedure and Parameters

- A variety of metrics will be generated from the Interactive Verification Program (IVP) will be generated and compared. Metrics for river forecasts with QPF will be compared to those without QPF. Verification will be formed on the 6-hour time step for seven day period. Verification will be based up on stage values. Flow will not be verified.
- The general approach will be to analyze trends that show a balance between the optimum numbers of QPF periods required to balance appropriate lead time with river forecast accuracy.
- Inter-compare between fast-, medium- and slow-responding basins for all QPF time periods, for all seasons and identify trends that may indicate declining performance as QPF time horizon increases.

Appendix B – Precipitation percent of normal for June 2009 through June 2010. River Forecast Centers areas of responsibility outlined in red.

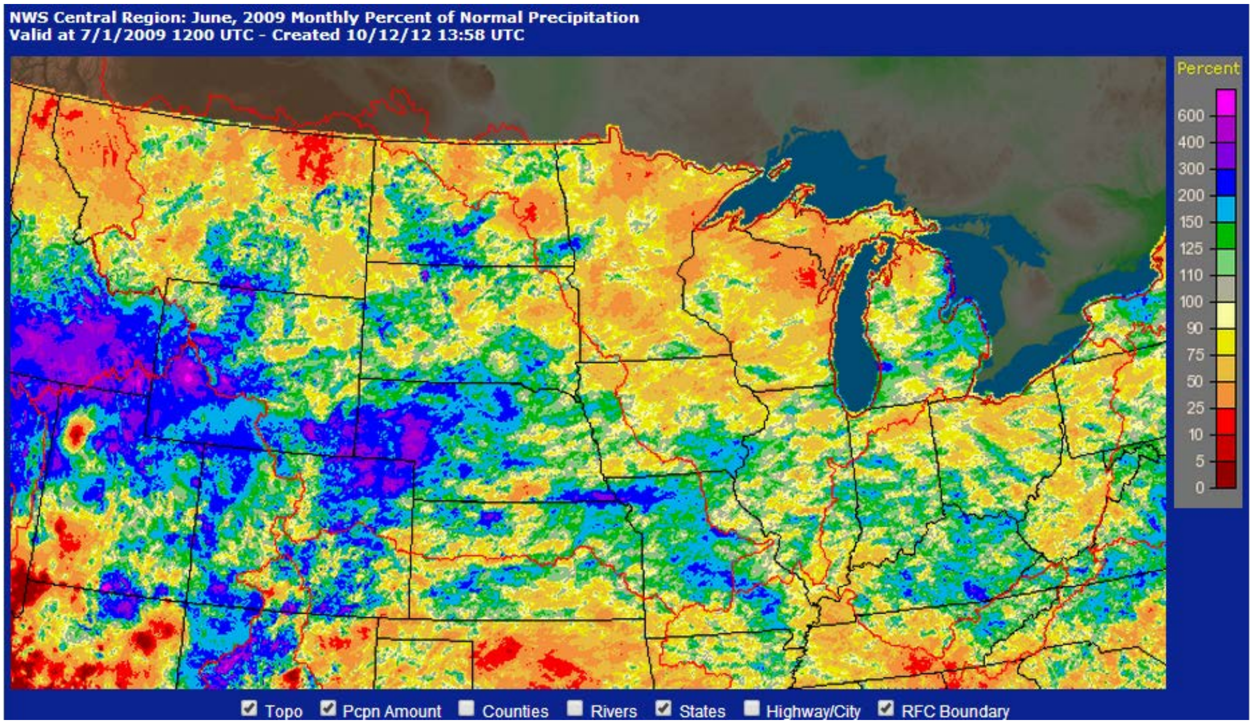


Figure B-1. Percent of normal precipitation for June 2009

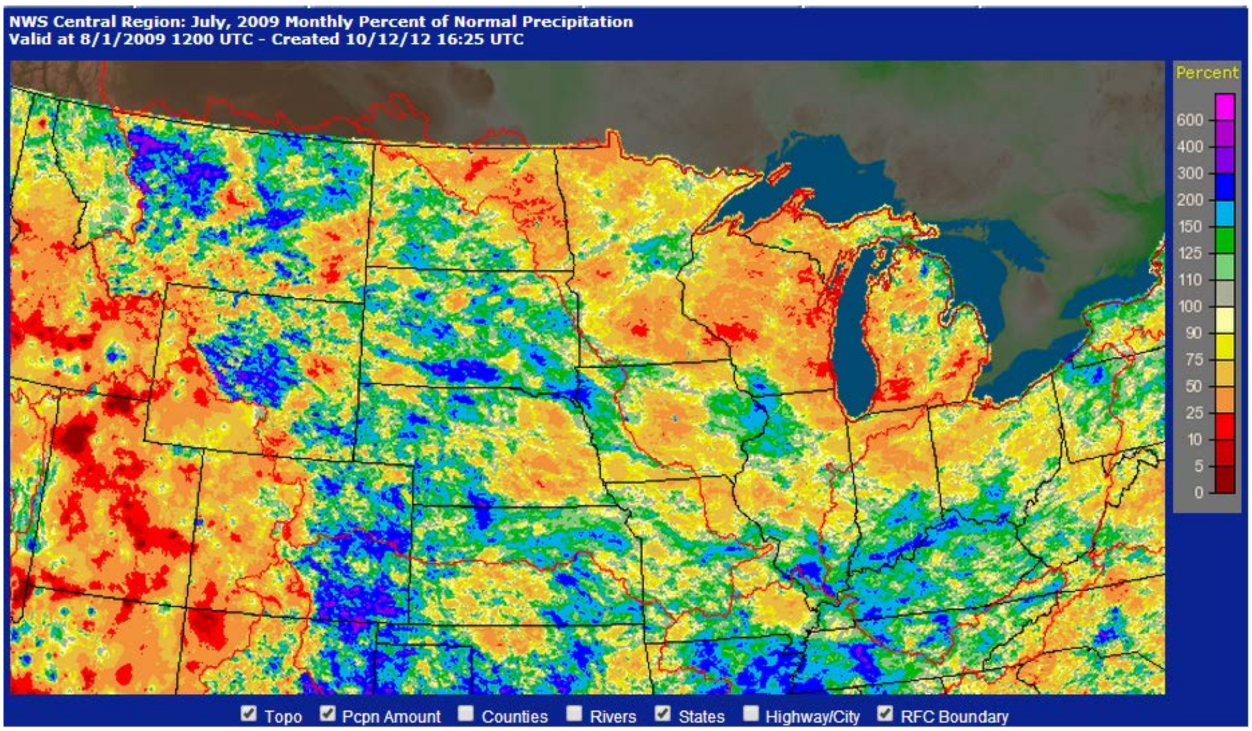


Figure B-2. Percent of normal precipitation for July 2009

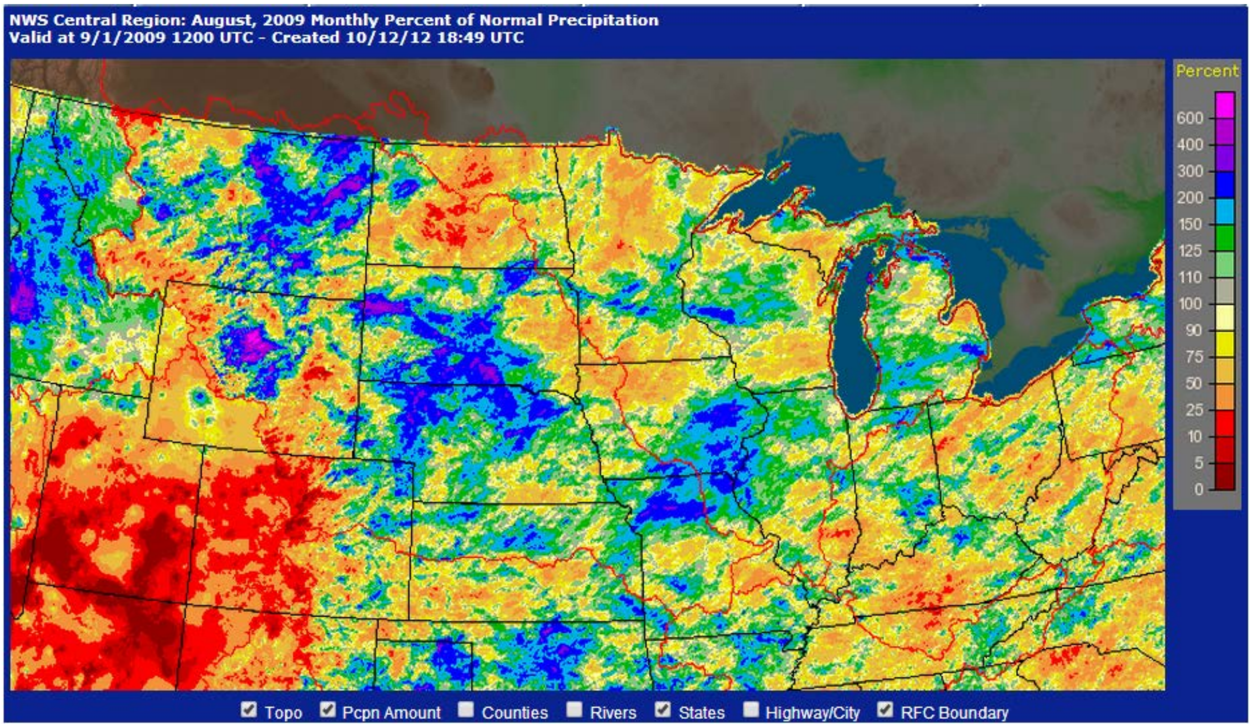


Figure B-3. Percent of normal precipitation for August 2009

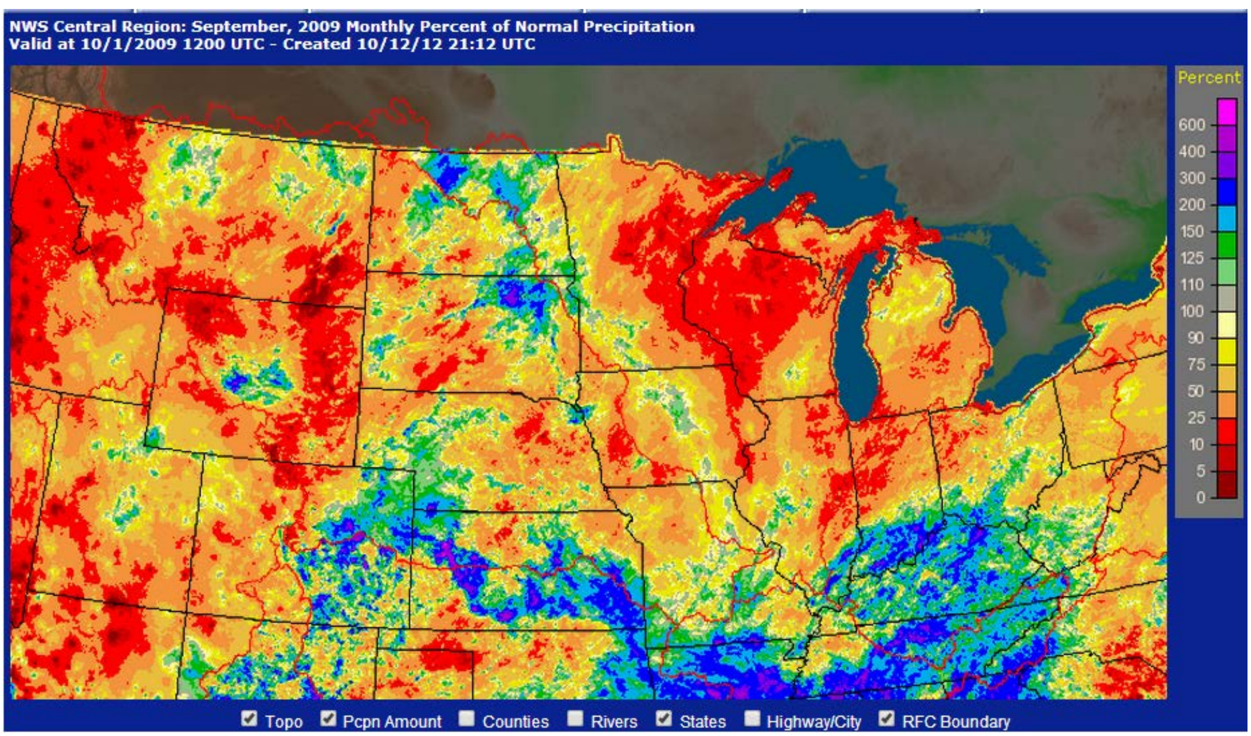


Figure B-4. Percent of normal precipitation for September 2009

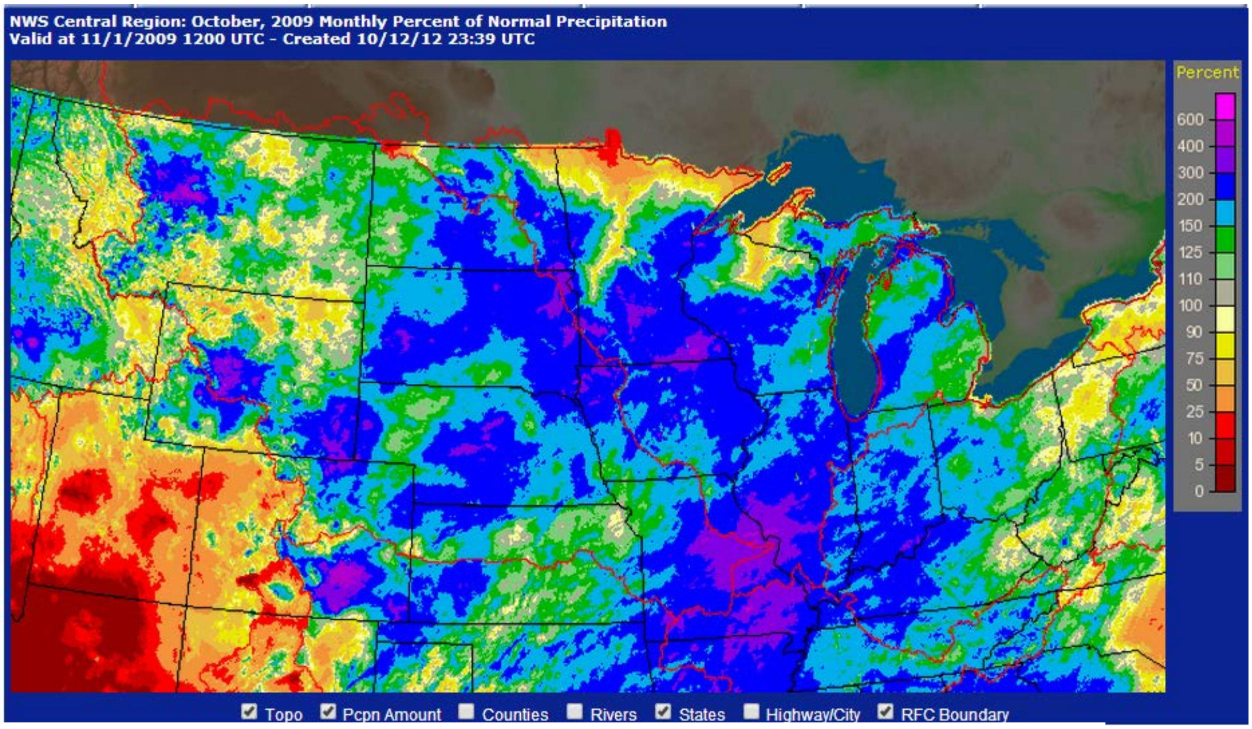


Figure B-5. Percent of normal precipitation for October 2009

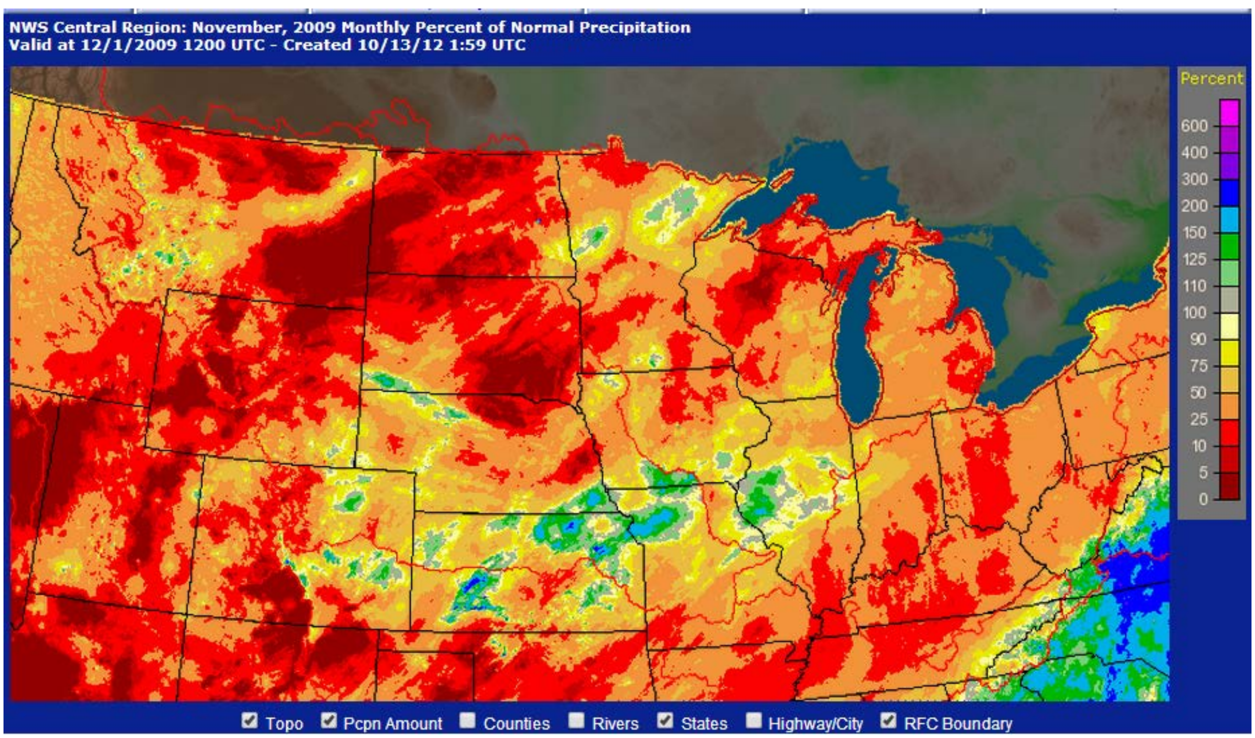


Figure B-6. Percent of normal precipitation for November 2009

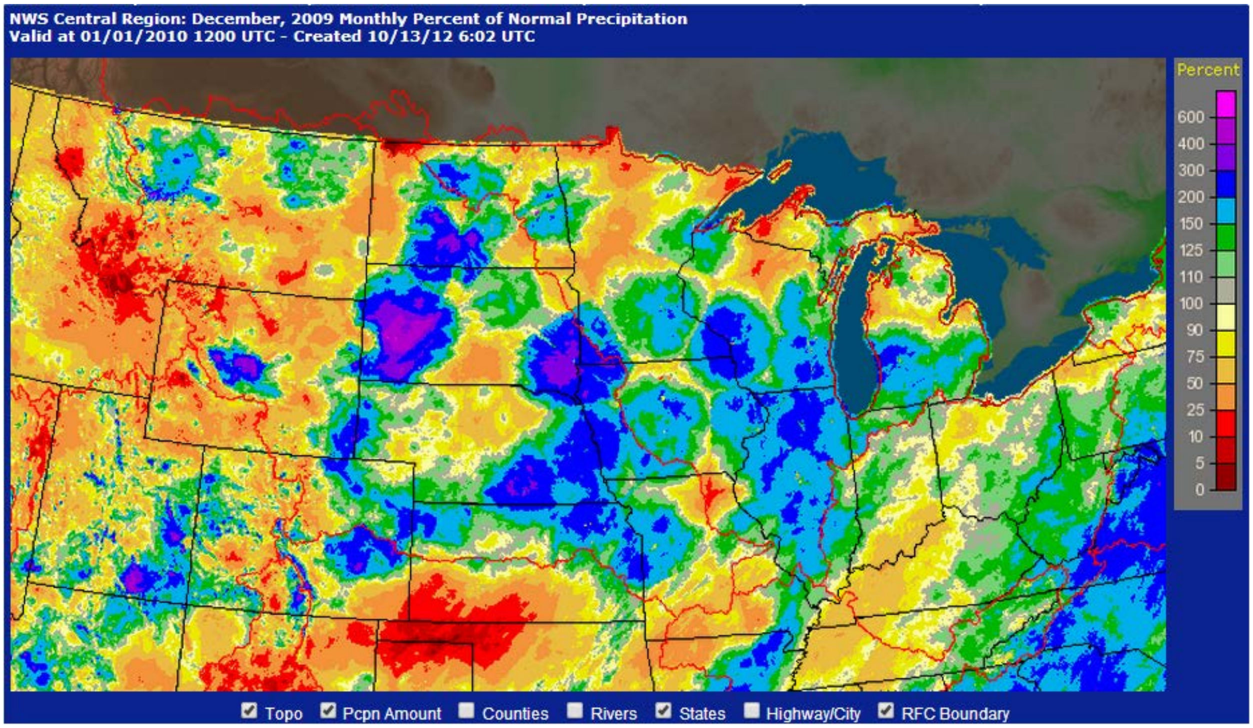


Figure B-7. Percent of normal precipitation for December 2009

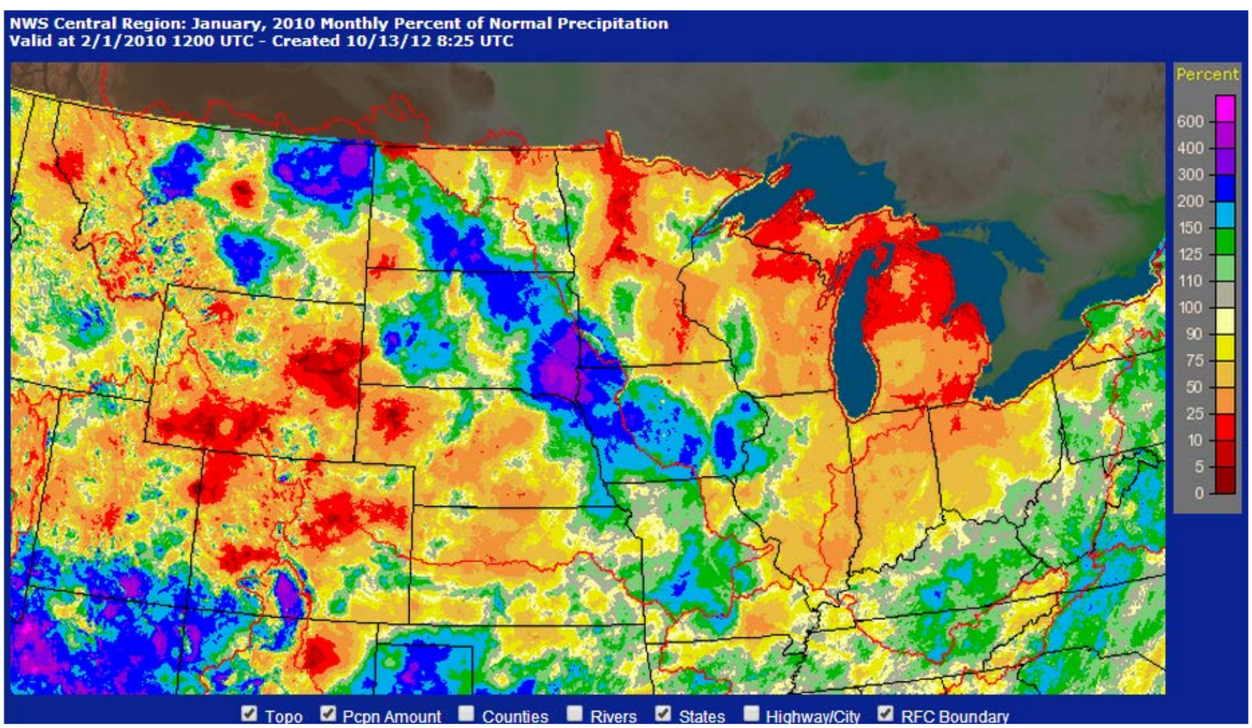


Figure B-8. Percent of normal precipitation for January 2010

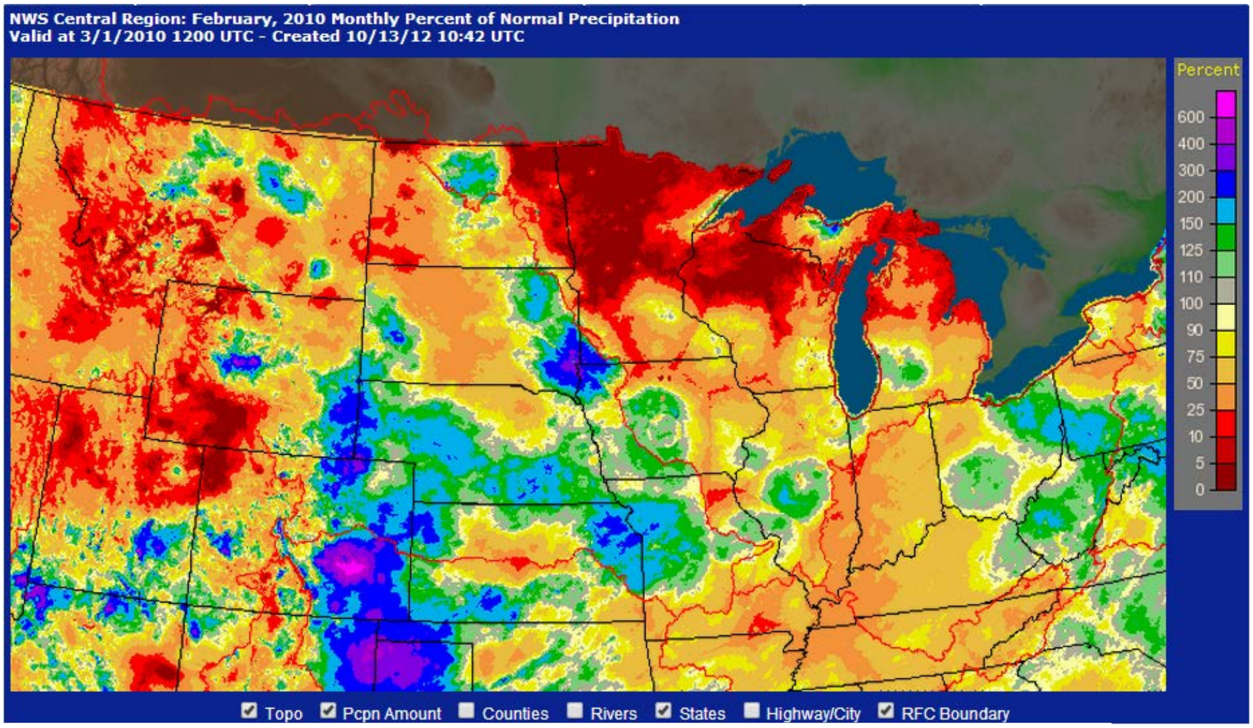


Figure B-9. Percent of normal precipitation for February 2010

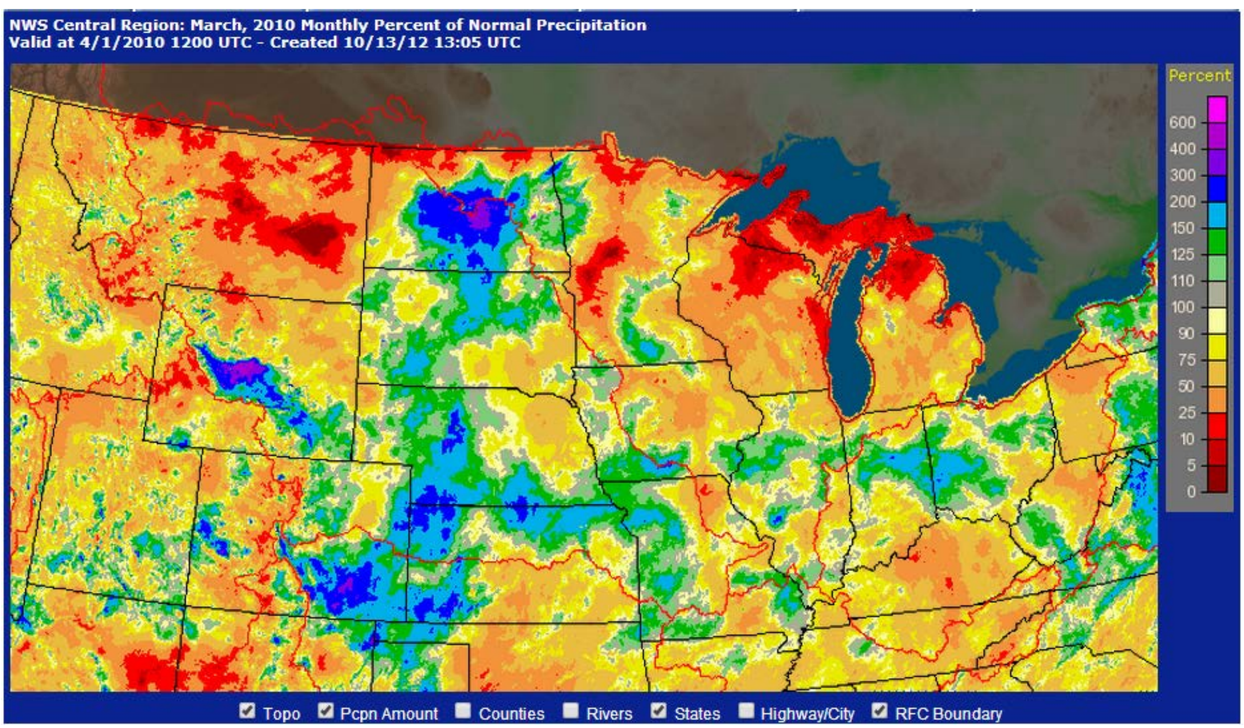


Figure B-10. Percent of normal precipitation for March 2010

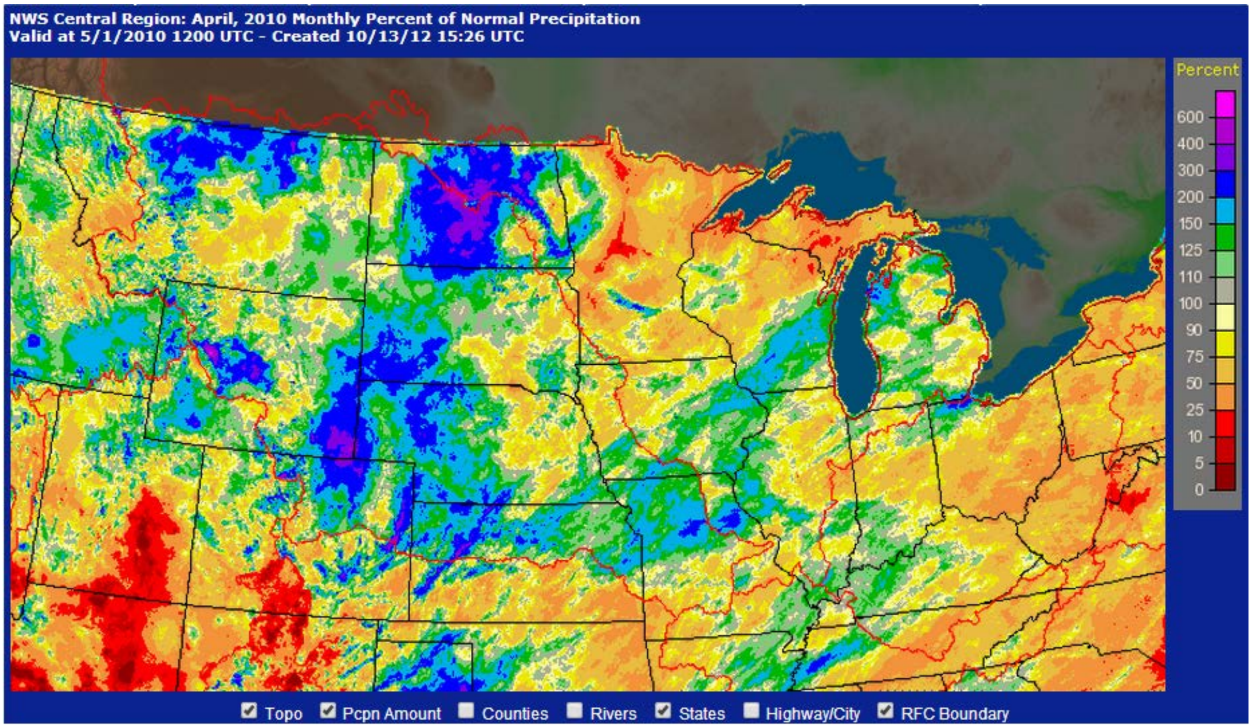


Figure B-11. Percent of normal precipitation for April 2010

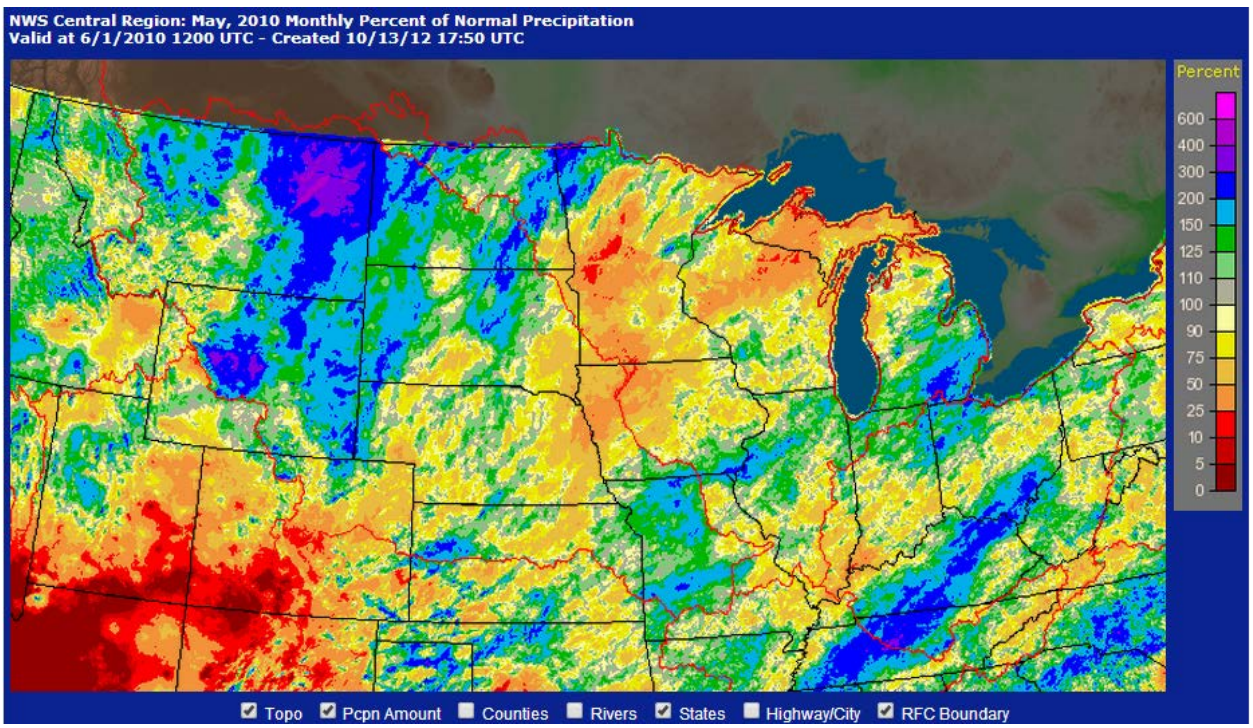


Figure B-12. Percent of normal precipitation for May 2010

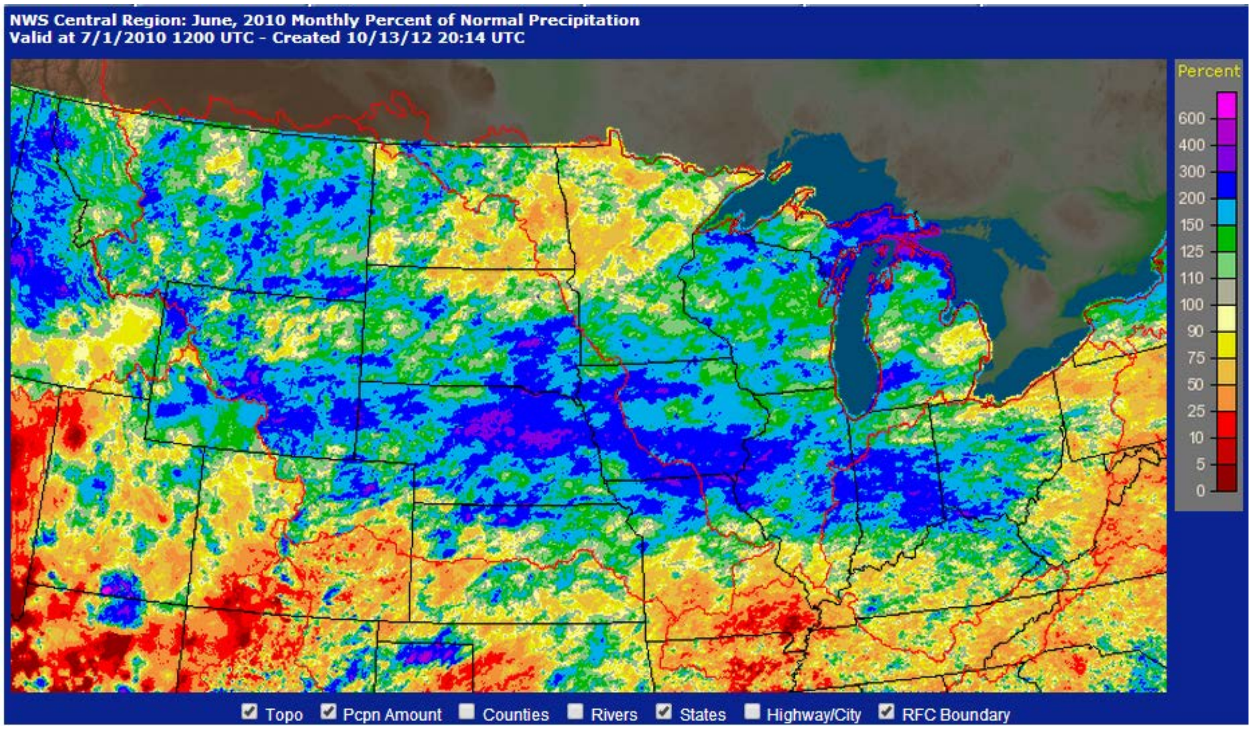


Figure B-13. Percent of normal precipitation for June 2010

Appendix C – Data Specification for Individual 6-hour QPF Values

Format: Comma-delimited fields. Title fields as labeled in table (bold)

Area: All MBRFC and NCRFC basins, except for basins in the following areas should be included: Montana, Wyoming and Colorado

Data Sets:

Data Set 1: Incremental QPF with data for columns: SEASON, TIME, CATEGORY and P_ERROR

Data Set 2: Incremental QPF with all details, columns: MONTH, DAY, YEAR, FORECAST, OBSERVED, F-O, RZONE, F_GRP, SEASON, TIME, CATEGORY and P_ERROR

MONTH: Actual Valid Date (Month) of QPF issued at 1200 UTC

DAY: Actual Valid Date (Day) of Forecast QPF issued at 1200 UTC

YEAR: Actual Valid Date (Year) of Forecast QPF issued at 1200 UTC

FORECAST: RFC QPF value in inches

OBSERVED: Observed MAP or MAPX (depending on RFC) value in inches

F-O: (Forecast – Observed) values in inches (precision to 0.000)

RZONE: Basin ID

F_GRP: Forecast Group ID

SEASON:
- Spring: March - May
- Summer: June - August
- Fall: September - November
- Winter: December - February

TIME: All times originate from the 12 UTC QPF forecast
- Data Set 1: Incremental QPF
  - 12a: 1200 – 1800 UTC Day 1
  - 18a: 1800 – 0000 UTC Day 1
  - 00a: 0000 – 0600 UTC Day 2
  - 06a: 0600 – 1200 UTC Day 2
  - 12b: 1200 – 1800 UTC Day 2
  - 18b: 1800 – 0000 UTC Day 2
  - 00b: 0000 – 0600 UTC Day 3
  - 06b: 0600 – 1200 UTC Day 3

CATEGORY: "Category" column = A, B, C, D, E, and F (based on QPF).
- A: 0.1 >= "QPF" < 0.25
- B: 0.25 >= "QPF" < 0.5
- C: 0.5 >= "QPF" < 1.00
- D: 1.00 >= "QPF" < 2.00

- E: 2.00 >= “QPF” < 3.00
- F: “QPF” >= 3.00

P_ERROR: Positive Error (Forecast – Observed) >= 0.10 inches computed for the specified time period (precision to 0.001)

Appendix D – Part 1 Student's t-tests

T-test Results for NCRFC QPF Errors - Summer Data

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--										--
1800 UTC	0.621728											
0000 UTC	1.17E-09	3.14E-11										
0600 UTC	3.32E-05	2.26E-06	0.027209									
Day 2												
1200 UTC	0.365801	0.142718	2.07E-08	0.000399								
1800 UTC	0.031364	0.094445	2.95E-17	2.53E-11	0.000624							
0000 UTC	0.015837	0.002628	2.69E-05	0.043546	0.101051	3.81E-07						
0600 UTC	3.89E-05	2.94E-06	0.034193	0.955527	0.000444	5.99E-11	0.042385					
Day 3												
1200 UTC	0.414549	0.75113	1.78E-12	2.58E-07	0.063996	0.164035	0.00059	3.73E-07				
1800 UTC	0.002531	0.009125	8.1E-19	6.66E-13	2.39E-05	0.213198	1.03E-08	1.6E-12	0.017068			
0000 UTC	0.285336	0.560986	4.45E-13	7.87E-08	0.034155	0.280657	0.000227	1.19E-07	0.782284	0.035998		
0600 UTC	0.432068	0.195209	9.25E-08	0.000799	0.957281	0.002625	0.118714	0.000849	0.101436	0.000146	0.059785	

Table D-1. NCRFC Student's t-test summary for individual 6-hr precipitation errors - summer only

T-test Results for NCRFC QPF Errors - Fall, Winter, & Spring Data

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--	--									
1800 UTC	0.043573											
0000 UTC	0.55542	0.217237										
0600 UTC	0.056503	0.878261	0.265617									
Day 2												
1200 UTC	0.873127	0.058607	0.647043	0.075744								
1800 UTC	0.892355	0.029168	0.474111	0.038085	0.763499							
0000 UTC	0.160659	0.488431	0.522862	0.583648	0.207023	0.116949						
0600 UTC	0.000808	0.219851	0.015822	0.159247	0.001224	0.0004	0.046522					
Day 3												
1200 UTC	0.683309	0.088692	0.797428	0.113998	0.80443	0.575866	0.294116	0.002176				
1800 UTC	0.510543	0.135455	0.960902	0.172483	0.617747	0.413298	0.412658	0.004182	0.798874			
0000 UTC	0.073825	0.615002	0.366625	0.731067	0.101162	0.047445	0.798987	0.059354	0.156425	0.242146		
0600 UTC	0.858884	0.050859	0.641943	0.066193	0.991691	0.743549	0.191036	0.000829	0.802744	0.60691	0.086417	

Table D-2. NCRFC Student's t-test summary for individual 6-hr precipitation errors - fall, winter, & spring

T-test Results for MBRFC QPF Errors - Summer Data												
6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day 3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--	--									
1800 UTC	0.759512											
0000 UTC	1.25E-06	3.98E-08										
0600 UTC	7.02E-09	8.94E-11	0.348825									
Day 2												
1200 UTC	0.022187	0.005966	0.015769	0.000862								
1800 UTC	0.484993	0.654312	4.82E-09	7.90E-12	0.001887							
0000 UTC	9.19E-05	6.70E-06	0.351774	0.061668	0.132449	1.12E-06						
0600 UTC	2.07E-05	1.63E-06	0.769657	0.236405	0.045212	2.98E-07	0.554827					
Day 3												
1200 UTC	0.503802	0.307811	4.93E-05	6.29E-07	0.113381	0.164242	0.001669	0.000395				
1800 UTC	0.10597	0.133599	1.33E-10	1.80E-13	0.000138	0.271741	4.02E-08	1.20E-08	0.026501			
0000 UTC	0.932527	0.700023	3.57E-06	2.71E-08	0.032208	0.447614	0.0002	4.52E-05	0.571728	0.101697		
0600 UTC	0.938436	0.697092	1.98E-06	1.22E-08	0.027415	0.436146	0.000132	2.98E-05	0.554322	0.091909	0.992209	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table D-3. MBRFC Student's t-test summary for individual 6-hr precipitation errors – summer only

T-test Results for MBRFC QPF Errors - Fall, Winter, & Spring Data												
6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day 3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--	--									
1800 UTC	0.539763											
0000 UTC	0.50257	0.17328										
0600 UTC	0.836179	0.628967	0.311018									
Day 2												
1200 UTC	0.304727	0.085481	0.685003	0.155159								
1800 UTC	0.933615	0.586067	0.433324	0.905291	0.250399							
0000 UTC	0.475658	0.928443	0.135609	0.551291	0.063215	0.518053						
0600 UTC	0.175832	0.465606	0.025853	0.183717	0.009411	0.192181	0.514386					
Day 3												
1200 UTC	0.993763	0.518576	0.464268	0.829827	0.26508	0.935574	0.450762	0.149079				
1800 UTC	0.219809	0.5307	0.041733	0.238698	0.016946	0.240103	0.582259	0.941257	0.193837			
0000 UTC	0.000147	0.001032	2.09E-06	5.74E-05	4.45E-07	0.000143	0.001128	0.006238	6.37E-05	0.006982		
0600 UTC	2.84E-05	0.000239	2.14E-07	7.93E-06	4E-08	2.62E-05	0.000256	0.001705	1E-05	0.002051	0.74052	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table D-4. MBRFC t-test summary for individual 6-hr precipitation errors – fall, winter, & spring

T-test Results for RFCs Combined QPF Errors. Summer data only												
6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day 3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--	--									
1800 UTC	0.123078											
0000 UTC	6.56E-07	5.42E-11										
0600 UTC	2.09E-11	2.54E-16	0.048544									
Day 2												
1200 UTC	0.012048	2.6E-05	0.005778	2.91E-06								
1800 UTC	0.011377	0.357987	1.03E-14	1.33E-20	5.26E-08							
0000 UTC	0.003635	4.66E-06	0.021404	2.36E-05	0.647155	6.58E-09						
0600 UTC	4.74E-06	7.9E-10	0.709096	0.020234	0.018568	2.87E-13	0.057257					
Day 3												
1200 UTC	0.058017	0.767499	1.72E-12	4.16E-18	2.6E-06	0.512796	3.92E-07	3.38E-11				
1800 UTC	0.001686	0.099103	6.1E-16	7.92E-22	3.4E-09	0.386891	4.17E-10	1.73E-14	0.149137			
0000 UTC	0.160149	0.890867	1.4E-10	7.74E-16	5.06E-05	0.287657	9.48E-06	1.91E-09	0.66095	0.074894		
0600 UTC	0.06859	0.000512	0.000751	1.66E-07	0.489251	3.47E-06	0.257371	0.003016	8.53E-05	2.61E-07	0.000883	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table D-5. RFCs datasets combined, Student's t-test summary for individual 6-hr precipitation errors – summer only

T-test Results for RFCs Combined QPF Errors. Fall, Winter & Spring data only												
6-hour Forecast Begin Time	Day 1 1200 UTC	Day 1 1800 UTC	Day 1 0000 UTC	Day 1 0600 UTC	Day 2 1200 UTC	Day 2 1800 UTC	Day 2 0000 UTC	Day 2 0600 UTC	Day 3 1200 UTC	Day 3 1800 UTC	Day 3 0000 UTC	Day 3 0600 UTC
Day 1												
1200 UTC	--	--	--									
1800 UTC	0.012365											
0000 UTC	0.042709	0.652631										
0600 UTC	0.022609	0.689487	0.934854									
Day 2												
1200 UTC	0.87116	0.018489	0.060166	0.033881								
1800 UTC	0.265672	0.131608	0.30575	0.23061	0.341895							
0000 UTC	0.019837	0.738063	0.885649	0.946119	0.029837	0.208563						
0600 UTC	1.26E-07	0.005322	0.001303	0.000867	2.58E-07	1.14E-05	0.001141					
Day 3												
1200 UTC	0.362364	0.078657	0.20614	0.142281	0.45739	0.81189	0.12723	2.92E-06				
1800 UTC	0.127703	0.236305	0.489912	0.399917	0.17462	0.69646	0.365657	3.56E-05	0.518178			
0000 UTC	2.88E-06	0.06241	0.019079	0.01476	5.96E-06	0.000264	0.018603	0.236426	6.94E-05	0.000806		
0600 UTC	2.54E-06	0.043051	0.013009	0.010023	5.11E-06	0.000196	0.012623	0.359408	5.5E-05	0.000582	0.801009	

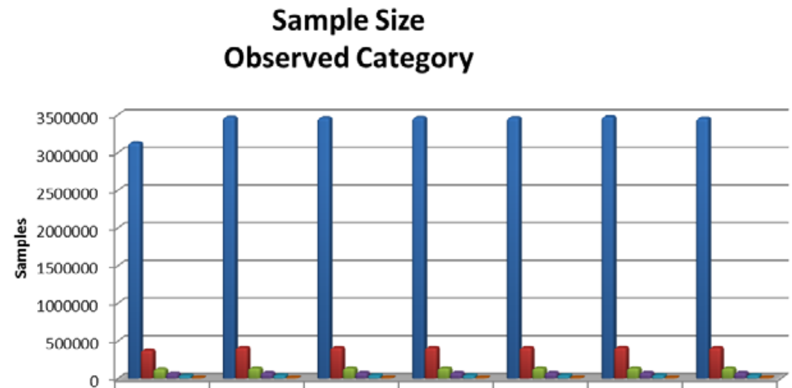
blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table D-6. RFCs datasets combined, Student's t-test summary for individual 6-hr precipitation errors – fall, winter, & spring

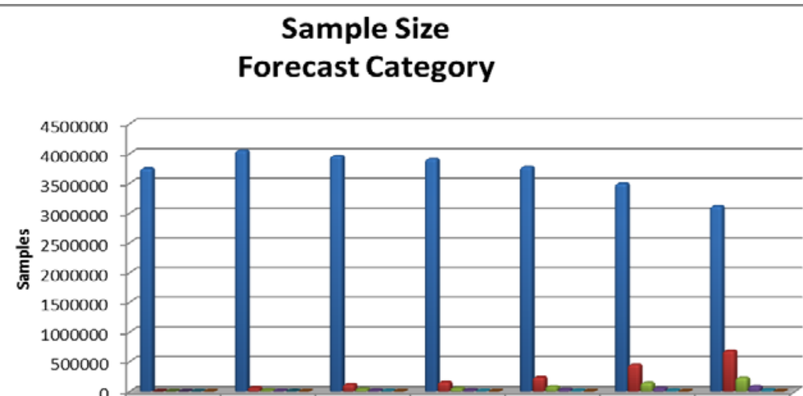
Appendix – Part 2 MBRFC IVP Statistics

<u>Individual 6-hour Time Step Dataset</u>



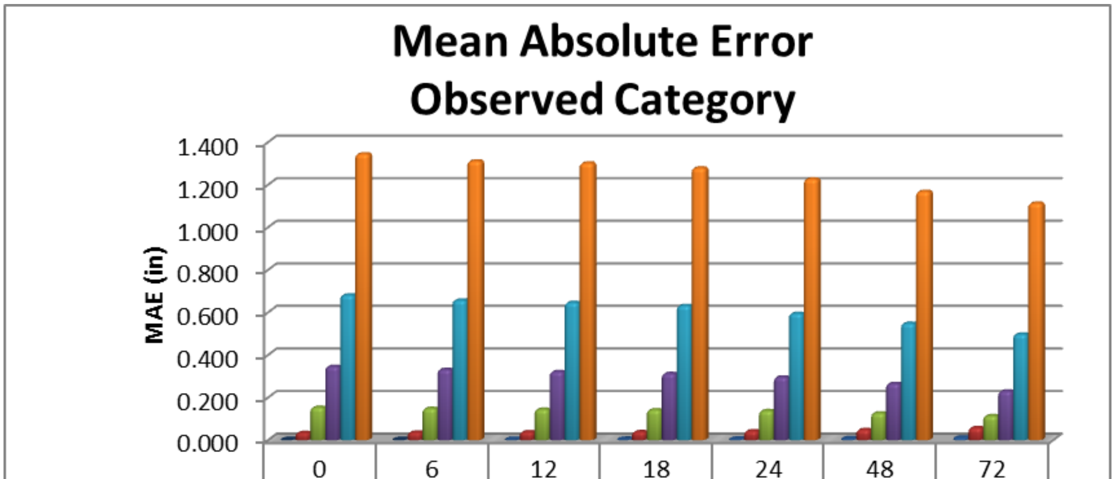
	0	6	12	18	24	48	72
< 0.01	3127727	3465905	3458756	3462375	3460308	3473189	3454793
>= 0.01 - 0.10	376183	411123	410097	410104	410372	413087	410294
>= 0.10 - 0.25	128334	142114	141765	141886	141802	142769	142072
>= 0.25 - 0.50	67549	76763	76481	76655	76494	77109	76846
>= 0.50 - 1.00	37053	43013	42914	43030	42874	43343	43229
>= 1.00	10148	11894	11873	11937	11860	12019	12055

Figure E-1. Sample size of precipitation errors conditioned on observed precipitation in defined ranges



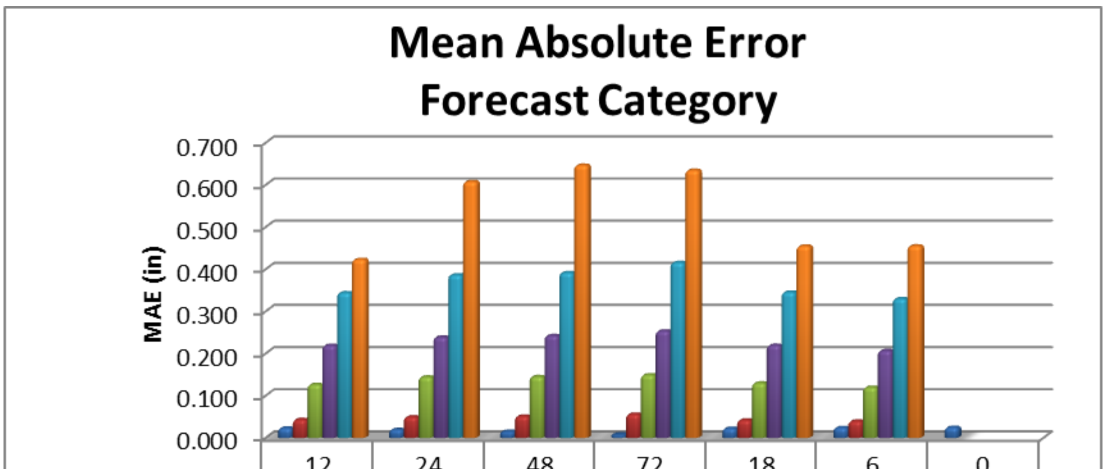
	0	6	12	18	24	48	72
< 0.01	3746994	4053911	3956769	3904080	3772947	3494871	3118120
>= 0.01 - 0.10	0	63483	123552	160982	241826	448197	682282
>= 0.10 - 0.25	0	21779	41601	54076	84193	146289	229514
>= 0.25 - 0.50	0	8843	16111	21442	34119	55655	86104
>= 0.50 - 1.00	0	2582	3580	5016	9731	15177	21917
>= 1.00	0	214	273	391	894	1327	1352

Figure E-2. Sample size of precipitation errors sorted conditioned on forecast precipitation in defined ranges



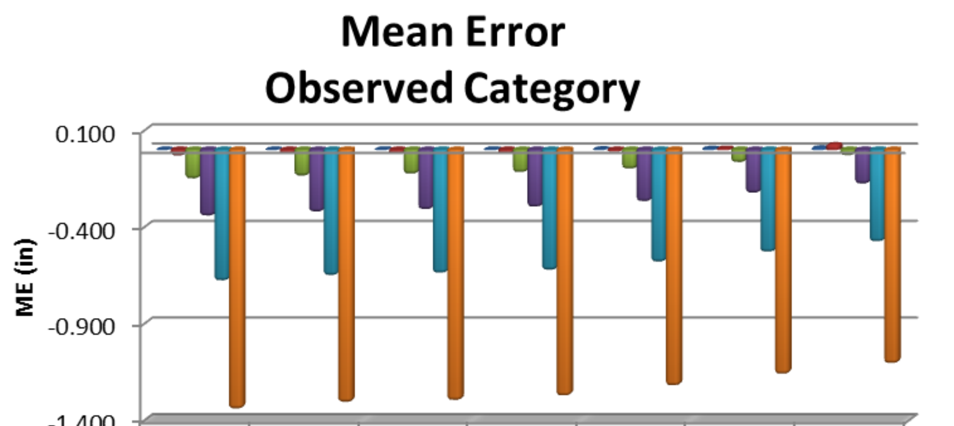
	0	6	12	18	24	48	72
< 0.01	0.000	0.001	0.001	0.002	0.003	0.006	0.010
>= 0.01 - 0.10	0.035	0.037	0.039	0.040	0.044	0.050	0.060
>= 0.10 - 0.25	0.155	0.150	0.146	0.144	0.140	0.129	0.116
>= 0.25 - 0.50	0.347	0.333	0.323	0.314	0.297	0.267	0.232
>= 0.50 - 1.00	0.683	0.659	0.647	0.633	0.596	0.550	0.499
>= 1.00	1.346	1.312	1.303	1.280	1.228	1.169	1.114

Figure E-3. Mean absolute error conditioned on observed precipitation in defined ranges



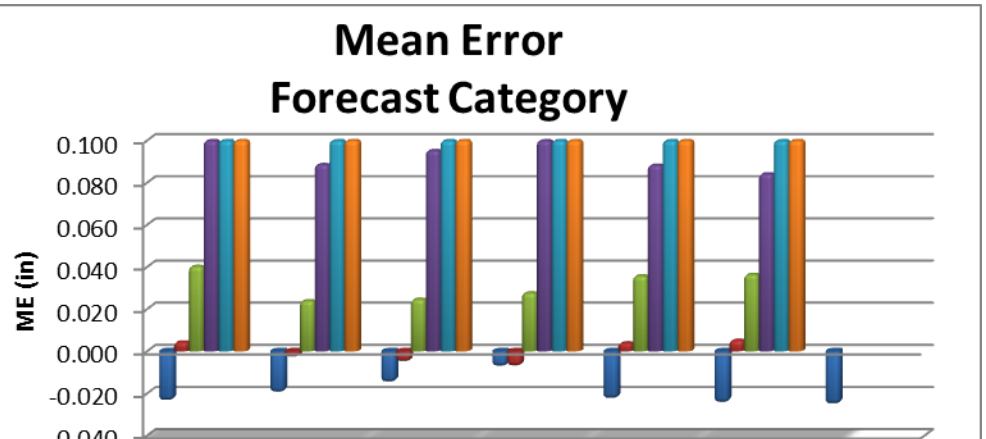
	12	24	48	72	18	6	0
< 0.01	0.024	0.020	0.015	0.008	0.023	0.025	0.025
>= 0.01 - 0.10	0.044	0.050	0.052	0.057	0.043	0.040	
>= 0.10 - 0.25	0.127	0.145	0.146	0.150	0.131	0.120	
>= 0.25 - 0.50	0.220	0.239	0.243	0.254	0.220	0.207	
>= 0.50 - 1.00	0.345	0.387	0.392	0.416	0.346	0.331	
>= 1.00	0.424	0.608	0.647	0.635	0.455	0.456	

Figure E-4. Mean absolute error conditioned on forecast precipitation in defined ranges



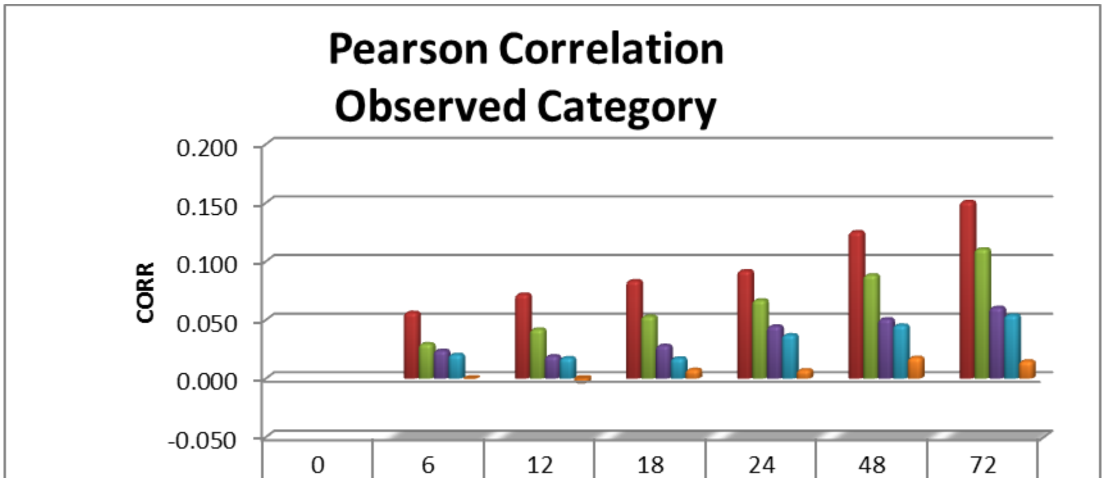
	0	6	12	18	24	48	72
< 0.01	0.000	0.001	0.001	0.002	0.003	0.006	0.010
>= 0.01 - 0.10	-0.035	-0.028	-0.022	-0.019	-0.010	0.008	0.030
>= 0.10 - 0.25	-0.155	-0.141	-0.130	-0.122	-0.104	-0.071	-0.033
>= 0.25 - 0.50	-0.347	-0.327	-0.314	-0.301	-0.273	-0.229	-0.182
>= 0.50 - 1.00	-0.683	-0.655	-0.643	-0.628	-0.585	-0.534	-0.481
>= 1.00	-1.346	-1.312	-1.302	-1.278	-1.226	-1.166	-1.111

Figure E-5. Mean error conditioned on observed precipitation in defined ranges



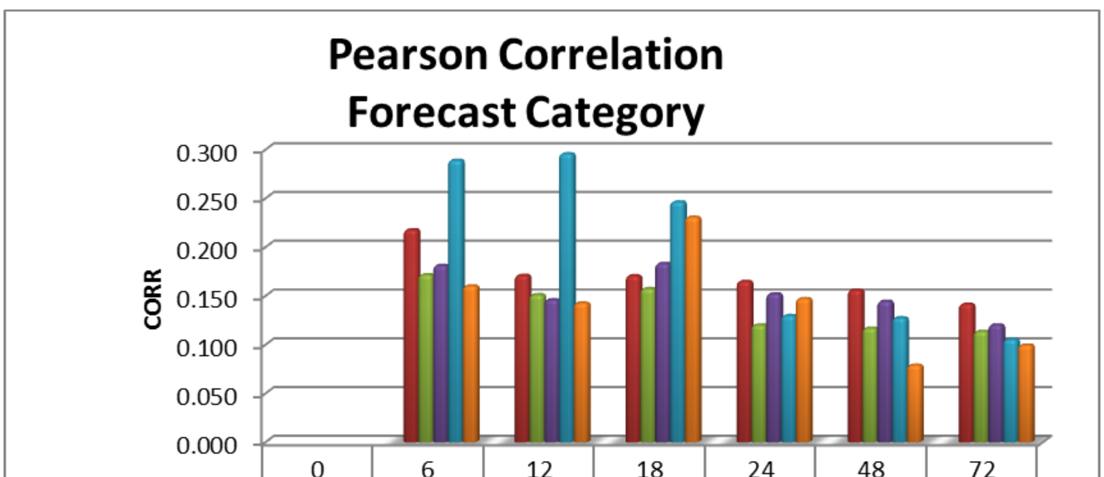
	12	24	48	72	18	6	0
< 0.01	-0.024	-0.020	-0.015	-0.008	-0.023	-0.025	-0.025
>= 0.01 - 0.10	0.004	-0.003	-0.005	-0.007	0.004	0.005	
>= 0.10 - 0.25	0.040	0.024	0.025	0.028	0.036	0.036	
>= 0.25 - 0.50	0.102	0.089	0.095	0.114	0.088	0.084	
>= 0.50 - 1.00	0.173	0.217	0.236	0.281	0.159	0.118	
>= 1.00	0.179	0.478	0.519	0.497	0.214	0.159	

Figure E-6. Mean error conditioned on forecast precipitation in defined ranges



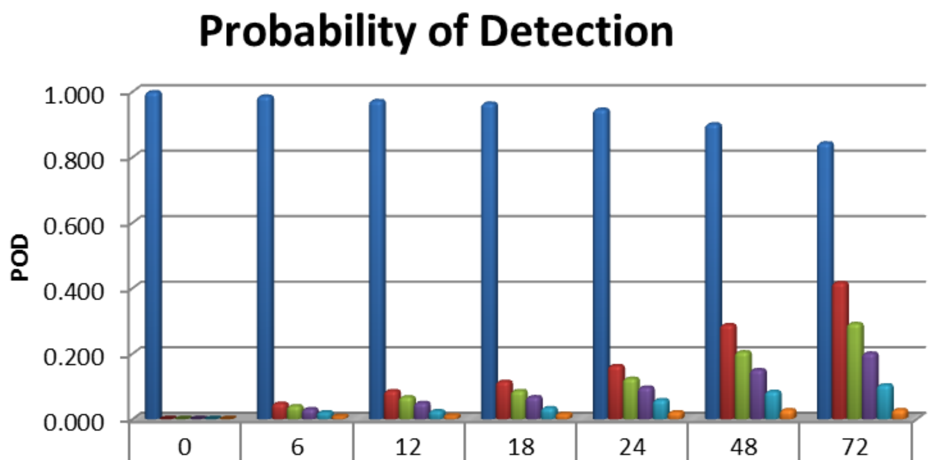
	0	6	12	18	24	48	72
< 0.01							
>= 0.01 - 0.10		0.057	0.072	0.084	0.092	0.125	0.151
>= 0.10 - 0.25		0.030	0.042	0.053	0.067	0.089	0.111
>= 0.25 - 0.50		0.024	0.020	0.029	0.045	0.051	0.061
>= 0.50 - 1.00		0.021	0.018	0.018	0.038	0.046	0.054
>= 1.00		0.000	-0.005	0.008	0.008	0.018	0.015

Figure E-7. Pearson correlation conditioned on observed precipitation in defined ranges



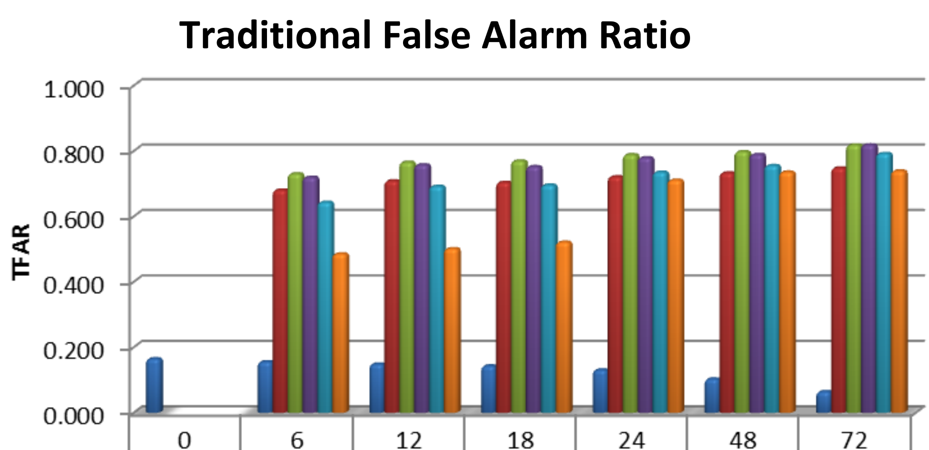
	0	6	12	18	24	48	72
< 0.01							
>= 0.01 - 0.10		0.218	0.171	0.171	0.165	0.156	0.142
>= 0.10 - 0.25		0.172	0.151	0.158	0.120	0.117	0.114
>= 0.25 - 0.50		0.181	0.146	0.183	0.152	0.145	0.120
>= 0.50 - 1.00		0.289	0.296	0.247	0.130	0.128	0.106
>= 1.00		0.160	0.143	0.231	0.147	0.079	0.100

Figure E-8. Pearson correlation conditioned on forecast precipitation in defined ranges



	0	6	12	18	24	48	72
< 0.01	1.000	0.987	0.973	0.965	0.947	0.902	0.844
>= 0.01 - 0.10	0.000	0.049	0.088	0.116	0.164	0.289	0.418
>= 0.10 - 0.25	0.000	0.041	0.069	0.088	0.125	0.206	0.292
>= 0.25 - 0.50	0.000	0.032	0.051	0.069	0.098	0.152	0.202
>= 0.50 - 1.00	0.000	0.021	0.026	0.035	0.060	0.085	0.105
>= 1.00	0.000	0.009	0.011	0.016	0.022	0.029	0.029

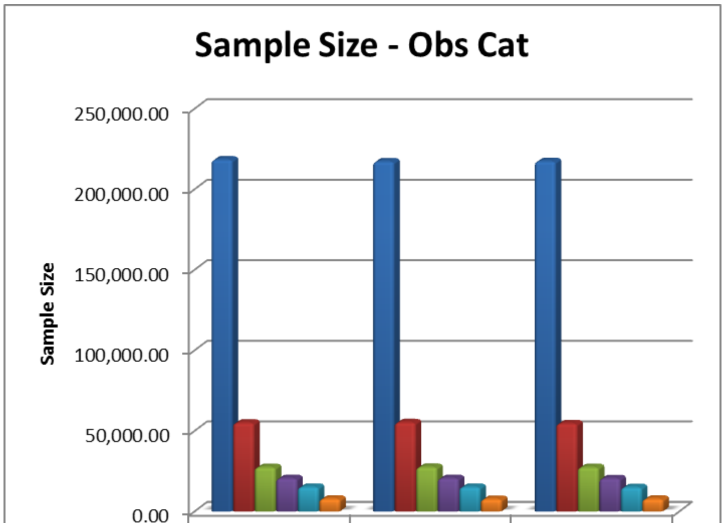
Figure E-9. Probability of detection in defined ranges



	0	6	12	18	24	48	72
< 0.01	0.165	0.156	0.149	0.144	0.131	0.104	0.065
>= 0.01 - 0.10		0.681	0.709	0.705	0.722	0.734	0.749
>= 0.10 - 0.25		0.731	0.766	0.770	0.789	0.799	0.819
>= 0.25 - 0.50		0.720	0.758	0.753	0.780	0.790	0.819
>= 0.50 - 1.00		0.644	0.692	0.696	0.736	0.756	0.793
>= 1.00		0.486	0.502	0.522	0.711	0.736	0.740

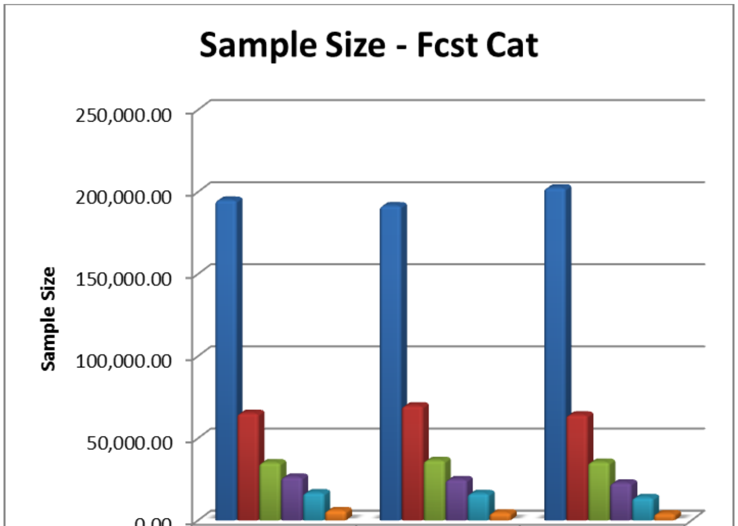
Figure E-10. Traditional false alarm ratio in defined ranges

Three 24-hour Daily Totals Dataset



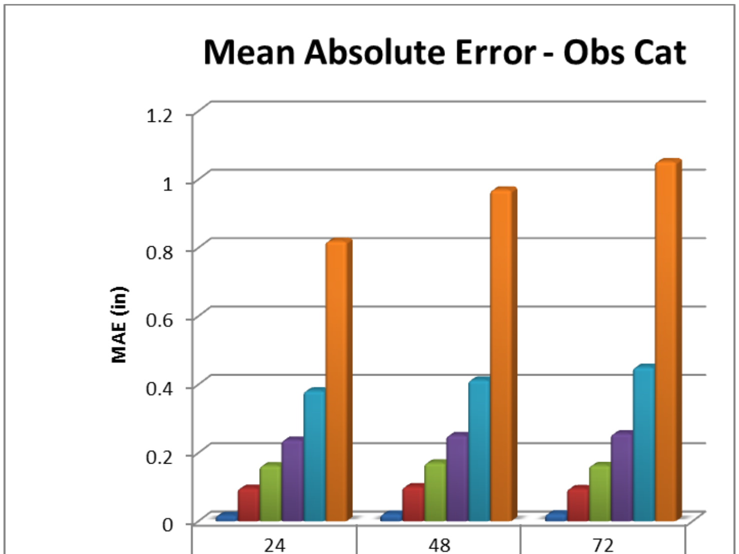
	24	48	72
< 0.01	218,452.00	217,281.00	217,423.00
>= 0.01 - 0.10	55,110.00	55,364.00	54,676.00
>= 0.10 - 0.25	27,486.00	27,622.00	27,493.00
>= 0.25 - 0.50	20,622.00	20,686.00	20,581.00
>= 0.50 - 1.00	15,271.00	15,248.00	15,054.00
>= 1.00	7,904.00	7,751.00	7,832.00

Figure E-11. Sample size of precipitation errors conditioned on observed precipitation in defined ranges



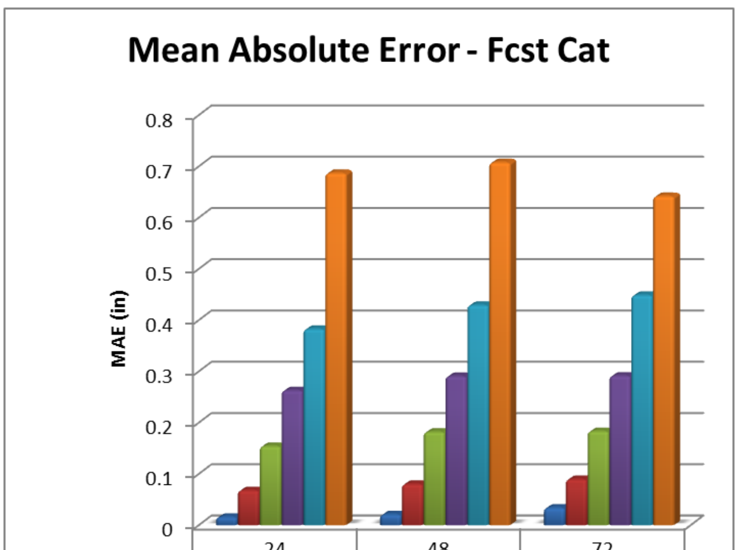
	24	48	72
< 0.01	195,052.00	191,623.00	202,492.00
>= 0.01 - 0.10	65,261.00	69,779.00	64,251.00
>= 0.10 - 0.25	35,163.00	36,573.00	35,506.00
>= 0.25 - 0.50	26,423.00	24,928.00	22,815.00
>= 0.50 - 1.00	16,868.00	16,400.00	13,963.00
>= 1.00	6,078.00	4,649.00	4,032.00

Figure E-12. Sample size of precipitation errors conditioned on forecast precipitation in defined ranges



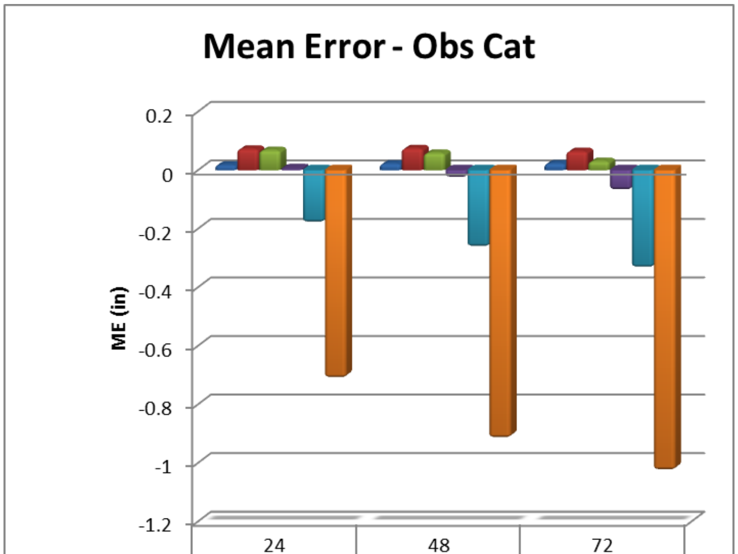
	24	48	72
< 0.01	0.016591	0.021074	0.021731
>= 0.01 - 0.10	0.096859	0.101268	0.095839
>= 0.10 - 0.25	0.162888	0.170965	0.163487
>= 0.25 - 0.50	0.237881	0.251305	0.256404
>= 0.50 - 1.00	0.381739	0.413374	0.450933
>= 1.00	0.81958	0.969831	1.052489

Figure E-13. Mean absolute error conditioned on observed precipitation in defined ranges



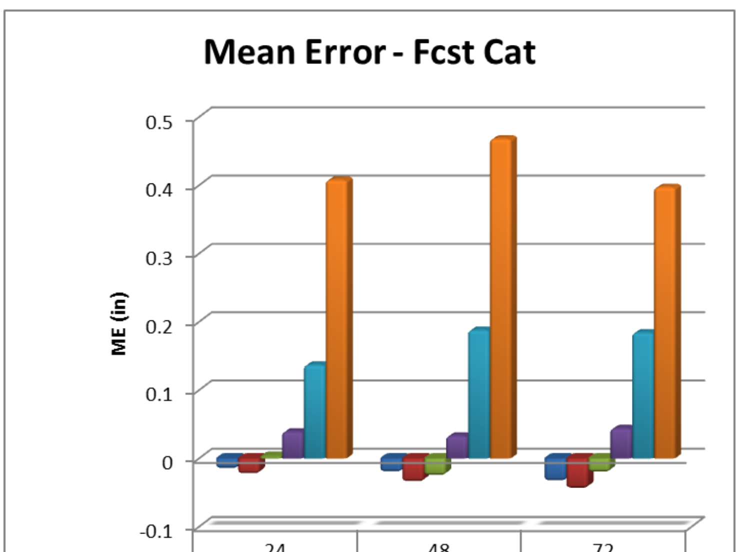
	24	48	72
< 0.01	0.01629	0.021165	0.034344
>= 0.01 - 0.10	0.068262	0.080471	0.089923
>= 0.10 - 0.25	0.154439	0.18224	0.183602
>= 0.25 - 0.50	0.263191	0.290923	0.291813
>= 0.50 - 1.00	0.382893	0.429701	0.449074
>= 1.00	0.687182	0.708028	0.64213

Figure E-14. Mean absolute error conditioned on forecast precipitation in defined rages



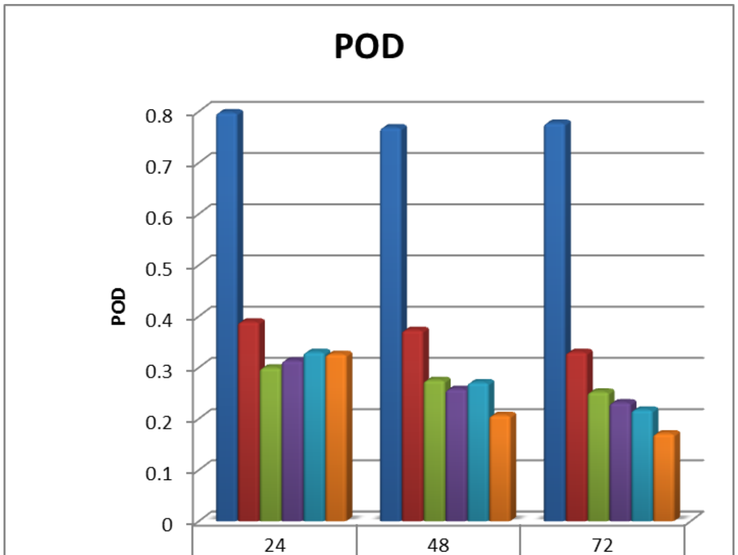
	24	48	72
< 0.01	0.016591	0.021074	0.021731
>= 0.01 - 0.10	0.072798	0.074457	0.064597
>= 0.10 - 0.25	0.067971	0.058719	0.030589
>= 0.25 - 0.50	0.005133	-0.028365	-0.070521
>= 0.50 - 1.00	-0.181006	-0.26432	-0.335296
>= 1.00	-0.711936	-0.916891	-1.026896

Figure E-15. Mean error conditioned on observed precipitation in defined ranges



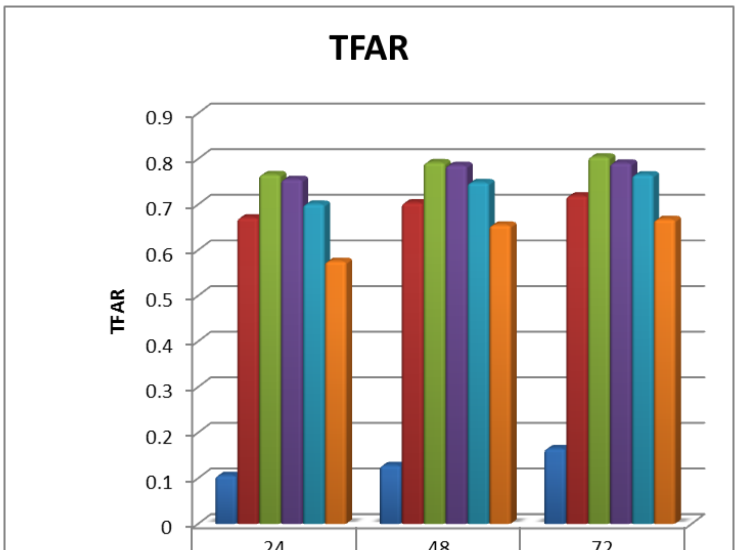
	24	48	72
< 0.01	-0.01629	-0.021165	-0.034344
>= 0.01 - 0.10	-0.023809	-0.035374	-0.045252
>= 0.10 - 0.25	0.003607	-0.026304	-0.021492
>= 0.25 - 0.50	0.039165	0.033147	0.044103
>= 0.50 - 1.00	0.136915	0.187984	0.18429
>= 1.00	0.407899	0.468109	0.397254

Figure E-16. Mean error conditioned on forecast precipitation in defined ranges



	24	48	72
< 0.01	0.79796	0.768641	0.777434
>= 0.01 - 0.10	0.389421	0.373167	0.330017
>= 0.10 - 0.25	0.299643	0.275396	0.252501
>= 0.25 - 0.50	0.313452	0.257952	0.231524
>= 0.50 - 1.00	0.330168	0.270724	0.21755
>= 1.00	0.326164	0.206812	0.171093

Figure E-17. Probability of detection in defined ranges



	24	48	72
< 0.01	0.10631	0.12844	0.165241
>= 0.01 - 0.10	0.671151	0.703922	0.719164
>= 0.10 - 0.25	0.765777	0.792005	0.804484
>= 0.25 - 0.50	0.755365	0.785944	0.791146
>= 0.50 - 1.00	0.701091	0.748293	0.765452
>= 1.00	0.575847	0.655195	0.667659

Figure E-18. Traditional false alarm ratio in defined ranges

Accumulated Precipitation Dataset

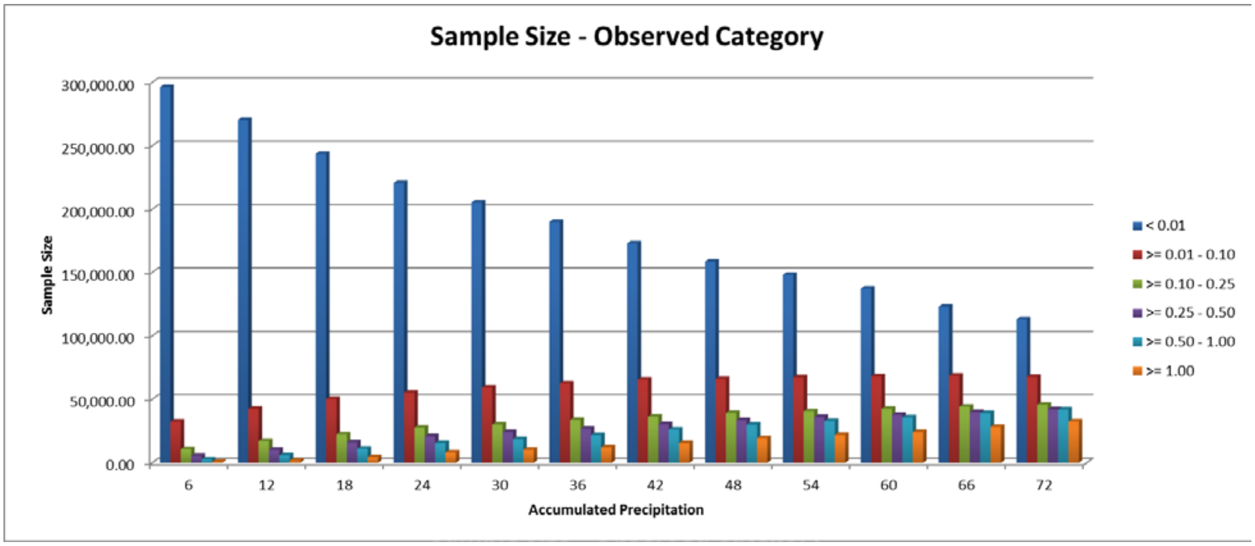


Figure E-19. Sample size of errors for precipitation accumulations through 72 hours conditioned on observed precipitation in defined ranges

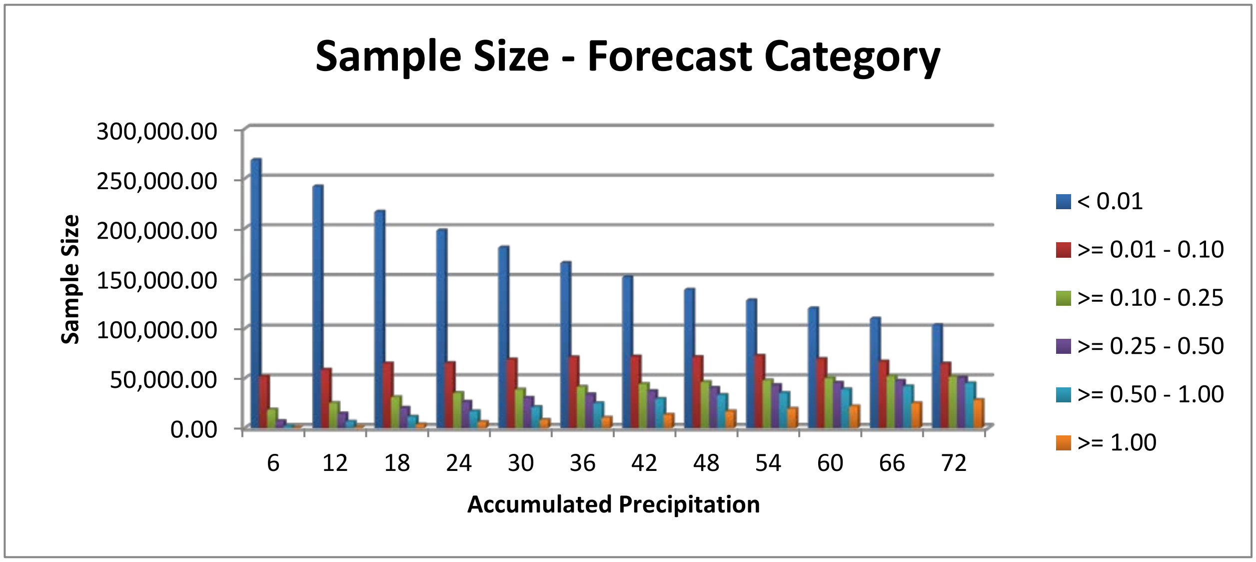
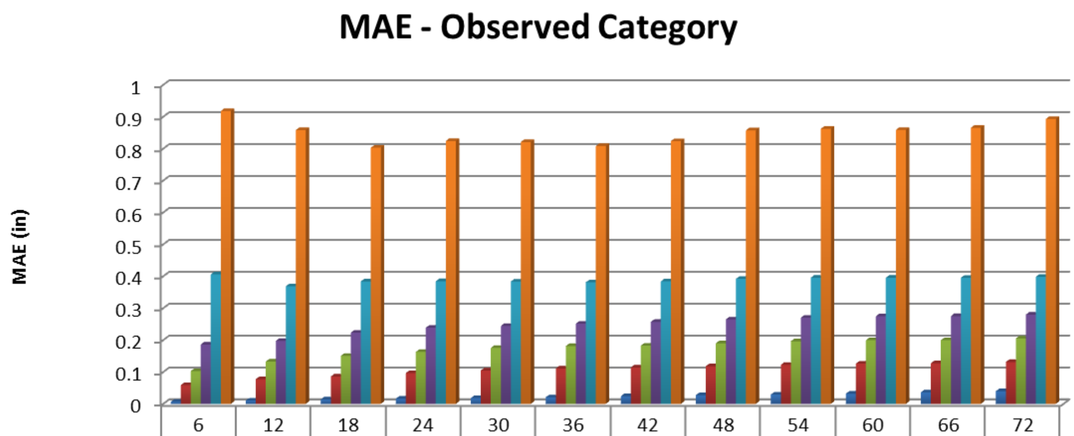


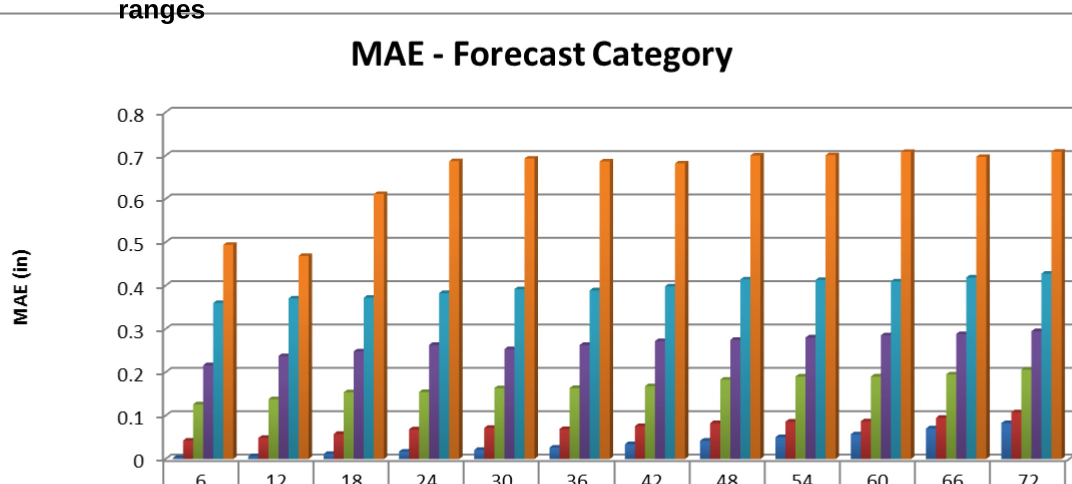
Figure E-20. Sample size of errors for precipitation accumulations through 72 hours conditioned on forecast precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	0.00649	0.01066	0.01416	0.01643	0.01835	0.02097	0.02429	0.02745	0.02948	0.03209	0.03625	0.03983
>= 0.01 - 0.10	0.05899	0.07754	0.0859	0.09663	0.10493	0.11112	0.11412	0.11813	0.1224	0.12621	0.1275	0.13126
>= 0.10 - 0.25	0.10304	0.13282	0.15043	0.16283	0.17544	0.18126	0.1826	0.18993	0.19634	0.19964	0.19954	0.20516
>= 0.25 - 0.50	0.18612	0.19751	0.22306	0.23868	0.24423	0.25144	0.25706	0.26473	0.27023	0.27471	0.27517	0.28002
>= 0.50 - 1.00	0.40614	0.36837	0.38385	0.38453	0.38338	0.38098	0.38409	0.39183	0.3957	0.39542	0.39536	0.39847
>= 1.00	0.91786	0.85824	0.80294	0.82388	0.82083	0.80827	0.82362	0.85732	0.86228	0.85852	0.86535	0.89319

Accumulated Precipitation

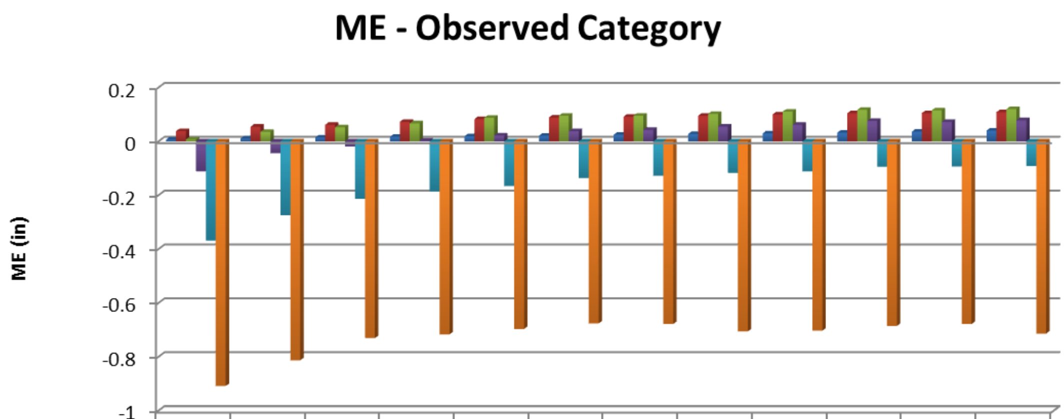
Figure E-21. Mean absolute error conditioned on observed precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	0.00306	0.00645	0.01163	0.01726	0.02109	0.02648	0.03408	0.04224	0.05026	0.05692	0.07052	0.08281
>= 0.01 - 0.10	0.04248	0.04877	0.05782	0.06834	0.07188	0.06922	0.07601	0.08284	0.08622	0.08699	0.09526	0.10775
>= 0.10 - 0.25	0.12614	0.13785	0.15386	0.15454	0.16355	0.16371	0.16805	0.18309	0.19041	0.19026	0.19521	0.20653
>= 0.25 - 0.50	0.21627	0.23755	0.2485	0.26325	0.25348	0.26317	0.27218	0.27495	0.28043	0.28553	0.28838	0.29506
>= 0.50 - 1.00	0.3599	0.37057	0.37225	0.38289	0.39199	0.38915	0.39826	0.41424	0.41315	0.4097	0.41864	0.42778
>= 1.00	0.49404	0.46854	0.6114	0.68718	0.69327	0.68663	0.68198	0.70022	0.70129	0.70861	0.69727	0.70896

Accumulated Precipitation

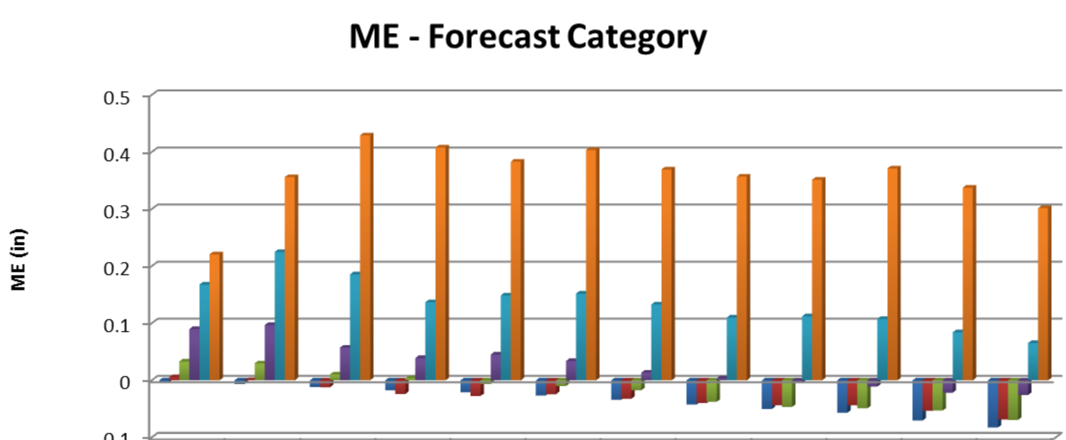
Figure E-22. Mean absolute error conditioned on forecast precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	0.00649	0.01066	0.01416	0.01643	0.01835	0.02097	0.02429	0.02745	0.02948	0.03209	0.03625	0.03983
>= 0.01 - 0.10	0.03772	0.05444	0.06144	0.07236	0.08227	0.08849	0.09114	0.0949	0.09989	0.10409	0.10485	0.10814
>= 0.10 - 0.25	0.00676	0.03518	0.05222	0.06682	0.08727	0.09513	0.09493	0.10116	0.10994	0.11655	0.11523	0.11939
>= 0.25 - 0.50	-0.1113	-0.0438	-0.0195	0.00284	0.02144	0.03738	0.04276	0.05491	0.06154	0.07576	0.07242	0.07822
>= 0.50 - 1.00	-0.3685	-0.2748	-0.2133	-0.1856	-0.1662	-0.1359	-0.1283	-0.1171	-0.1118	-0.0942	-0.0932	-0.0921
>= 1.00	-0.9089	-0.8133	-0.7308	-0.717	-0.6969	-0.6764	-0.6783	-0.7061	-0.7031	-0.6853	-0.6786	-0.7139

Accumulated Precipitation

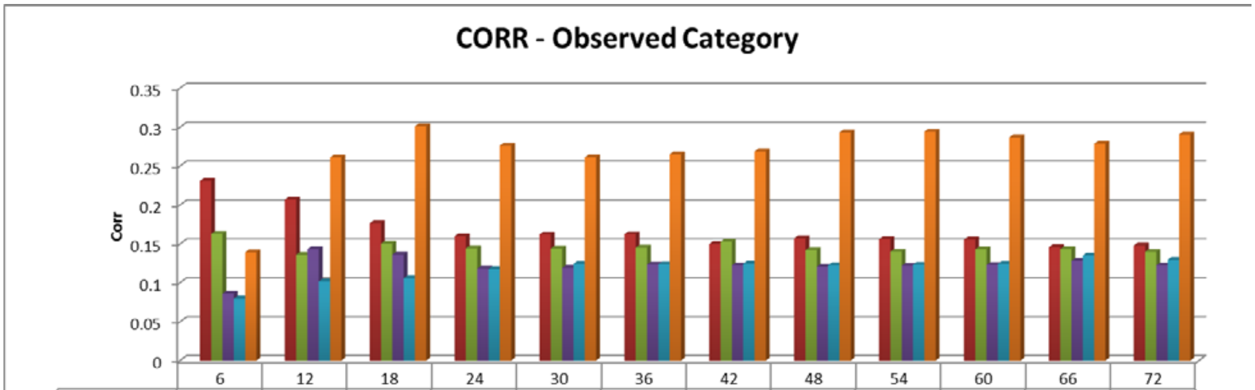
Figure E-23. Mean error conditioned on observed precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	-0.0031	-0.0065	-0.0116	-0.0173	-0.0211	-0.0265	-0.0341	-0.0422	-0.0503	-0.0569	-0.0705	-0.0828
>= 0.01 - 0.10	0.00549	0.00051	-0.0121	-0.0239	-0.0273	-0.0243	-0.0325	-0.0399	-0.0437	-0.0438	-0.0535	-0.0684
>= 0.10 - 0.25	0.03311	0.02987	0.01037	0.0035	-0.0066	-0.0098	-0.0173	-0.0378	-0.0467	-0.0491	-0.0531	-0.0693
>= 0.25 - 0.50	0.08992	0.09686	0.0574	0.03909	0.04526	0.03398	0.01361	0.00357	-0.0048	-0.0108	-0.0217	-0.0258
>= 0.50 - 1.00	0.16778	0.22499	0.18569	0.13692	0.14873	0.15203	0.13305	0.11001	0.11216	0.10764	0.08417	0.06541
>= 1.00	0.22075	0.35614	0.42924	0.4079	0.38323	0.40362	0.36955	0.35701	0.35151	0.37127	0.33753	0.30176

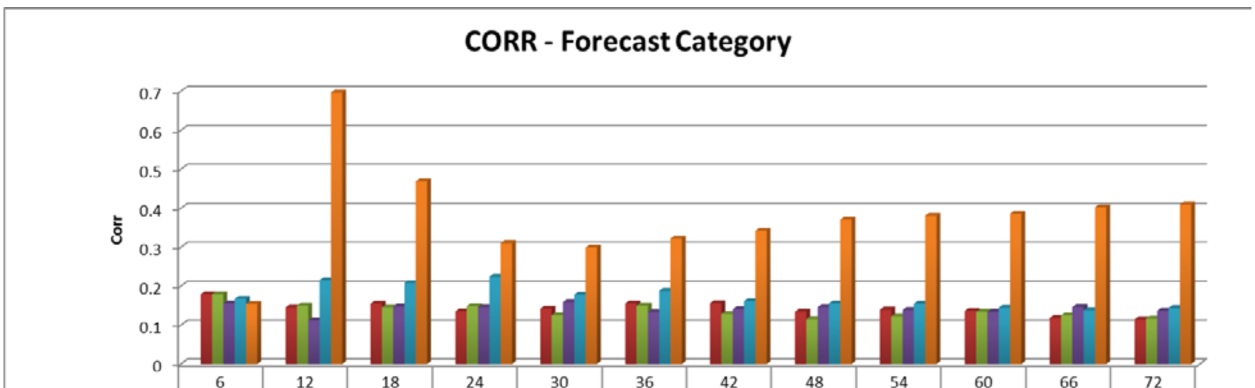
Accumulated Precipitation

Figure E-24. Mean error conditioned on forecast precipitation in defined ranges



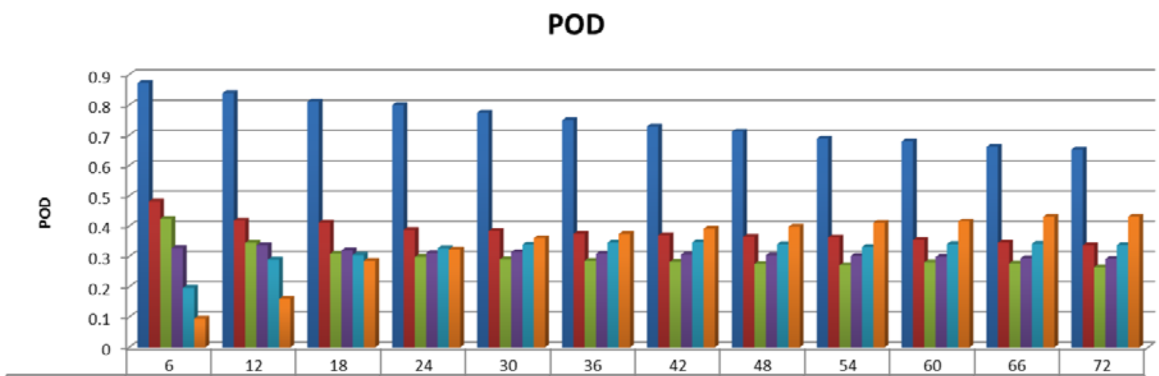
	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01												
>= 0.01 - 0.10	0.230705	0.206996	0.17628	0.15966	0.161945	0.162308	0.149918	0.156931	0.15583	0.155311	0.145778	0.148052
>= 0.10 - 0.25	0.162872	0.135828	0.150337	0.144573	0.144206	0.145258	0.152758	0.14204	0.13994	0.143167	0.143426	0.139652
>= 0.25 - 0.50	0.086341	0.143326	0.136123	0.118149	0.119	0.12352	0.122486	0.120546	0.121843	0.123011	0.128353	0.122382
>= 0.50 - 1.00	0.079504	0.101554	0.105797	0.117646	0.124376	0.123855	0.12468	0.122548	0.123311	0.12425	0.134952	0.129677
>= 1.00	0.139211	0.261082	0.301239	0.276114	0.261223	0.265082	0.268744	0.293045	0.294062	0.286733	0.278615	0.290423

Figure E-25. Pearson correlation conditioned on observed precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01												
>= 0.01 - 0.10	0.179412	0.145654	0.154906	0.135572	0.142329	0.15538	0.156252	0.134763	0.139934	0.136871	0.118122	0.114498
>= 0.10 - 0.25	0.179644	0.150055	0.145679	0.148704	0.124993	0.150101	0.128377	0.115171	0.121983	0.134456	0.12457	0.11641
>= 0.25 - 0.50	0.155648	0.112137	0.147911	0.145917	0.158624	0.133712	0.141069	0.146132	0.139036	0.134622	0.146404	0.137222
>= 0.50 - 1.00	0.167722	0.215445	0.207829	0.224269	0.178313	0.188186	0.161369	0.155621	0.154824	0.144944	0.138781	0.144144
>= 1.00	0.154144	0.696673	0.468476	0.309892	0.299161	0.321855	0.342171	0.370875	0.380811	0.385843	0.402727	0.409913

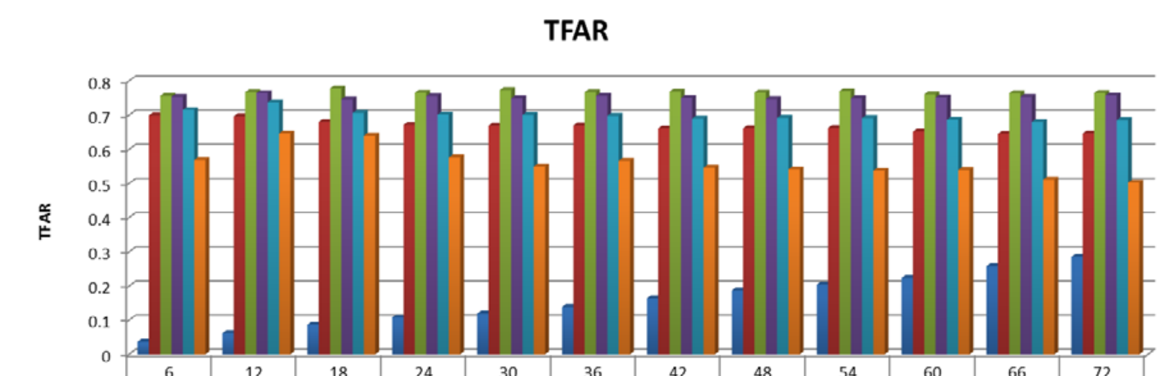
Figure E-26. Pearson correlation conditioned on forecast precipitation in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	0.87304	0.839296	0.81194	0.799774	0.775342	0.749008	0.729313	0.712267	0.689121	0.680049	0.662441	0.652924
>= 0.01 - 0.10	0.48197	0.41838	0.411985	0.388002	0.384247	0.375044	0.370609	0.36519	0.363487	0.35427	0.345582	0.33692
>= 0.10 - 0.25	0.424654	0.344631	0.308587	0.298071	0.290598	0.286134	0.282151	0.275822	0.271302	0.280854	0.277594	0.264116
>= 0.25 - 0.50	0.328027	0.336768	0.320319	0.311533	0.314431	0.308475	0.306034	0.303944	0.301763	0.298322	0.29414	0.291943
>= 0.50 - 1.00	0.196241	0.289524	0.304933	0.327233	0.339401	0.345333	0.346721	0.340704	0.331809	0.34111	0.341992	0.337372
>= 1.00	0.09488	0.159659	0.286132	0.323951	0.360347	0.374606	0.391459	0.398072	0.411251	0.415745	0.431266	0.431363

Accumulated Precipitation

Figure E-27. Probability of detection in defined ranges



	6	12	18	24	30	36	42	48	54	60	66	72
< 0.01	0.037063	0.062564	0.086613	0.108173	0.119194	0.138688	0.164615	0.187091	0.204557	0.223225	0.258154	0.285666
>= 0.01 - 0.10	0.699129	0.696695	0.680738	0.671296	0.668965	0.669654	0.661296	0.66162	0.662509	0.651847	0.645169	0.646631
>= 0.10 - 0.25	0.756091	0.767183	0.778441	0.76579	0.773413	0.767533	0.768982	0.766145	0.770238	0.760923	0.764097	0.764697
>= 0.25 - 0.50	0.753454	0.76435	0.746339	0.755374	0.748829	0.755861	0.749818	0.746902	0.748918	0.751863	0.753392	0.757121
>= 0.50 - 1.00	0.715376	0.737847	0.706147	0.701091	0.700367	0.697856	0.690161	0.691846	0.69123	0.686674	0.680794	0.685693
>= 1.00	0.568493	0.646541	0.640497	0.575847	0.550043	0.566462	0.546244	0.541246	0.537231	0.539387	0.51129	0.502613

Accumulated Precipitation

Figure E-28. Traditional false alarm ratio in defined ranges

Appendix F. Part 2 NCRFC QPF Error and Categorical Statistics

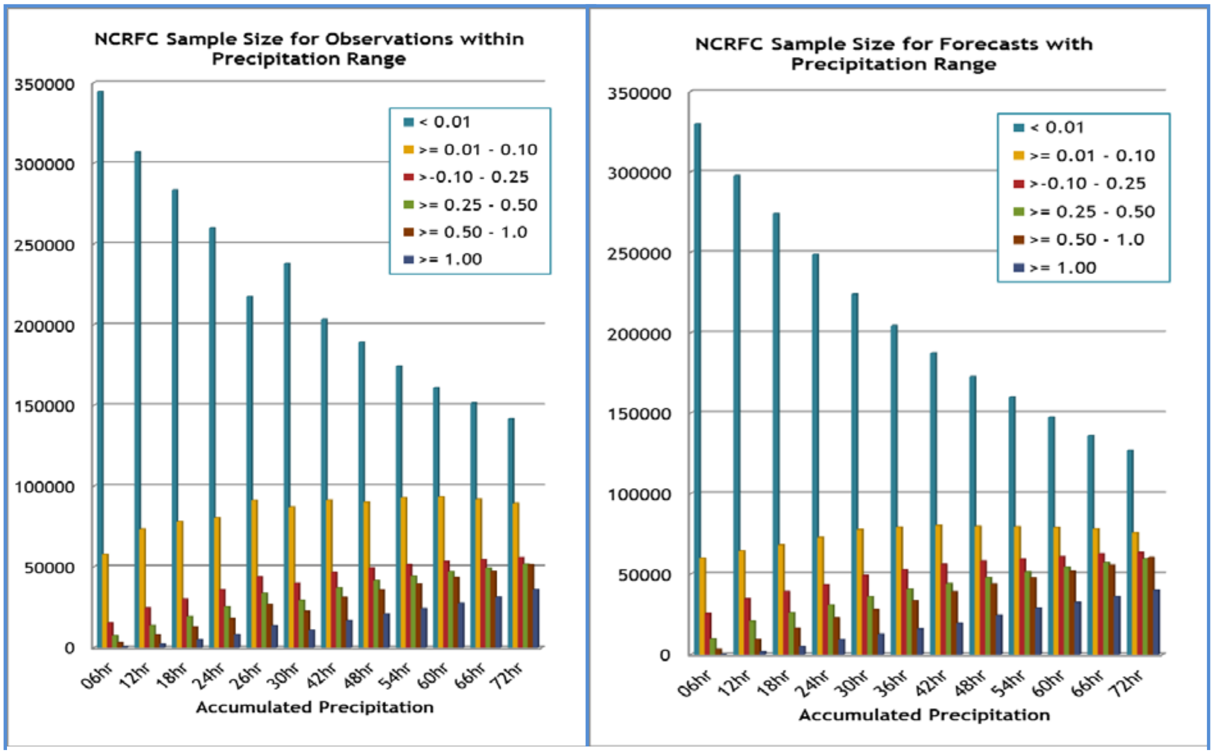
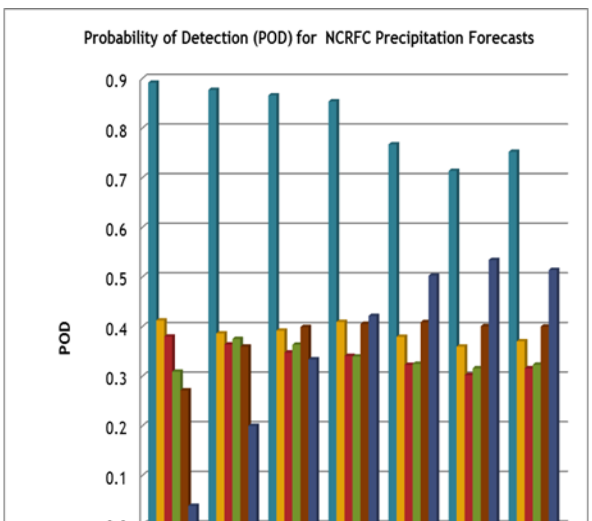


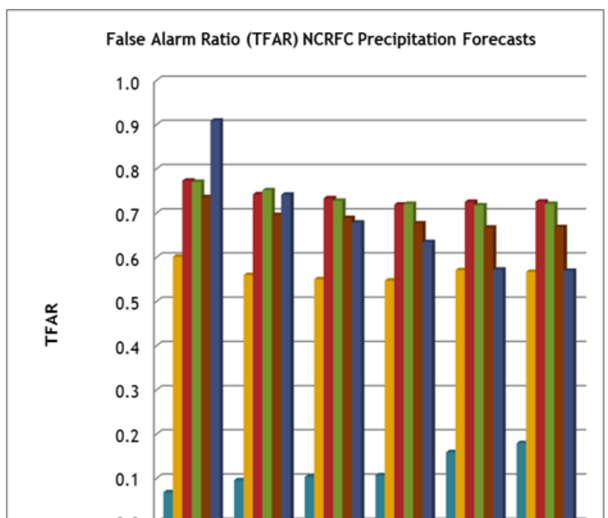
Figure F-1. Sample size for NCRFC QPF within each observed and forecast precipitation



	6	12	18	24	48	66	72
< 0.1	0.892	0.877	0.866	0.854	0.767	0.714	0.752
>= 0.01 - 0.10	0.412	0.386	0.392	0.410	0.380	0.360	0.370
>= 0.10 - 0.25	0.380	0.364	0.348	0.341	0.323	0.302	0.316
>= 0.25 - 0.50	0.309	0.375	0.364	0.340	0.325	0.316	0.323
>= 0.50 - 1.00	0.272	0.360	0.399	0.406	0.409	0.401	0.400
>= 1.00	0.039	0.200	0.334	0.422	0.503	0.534	0.514

Accumulated Precipitation over 0 to 72 hours

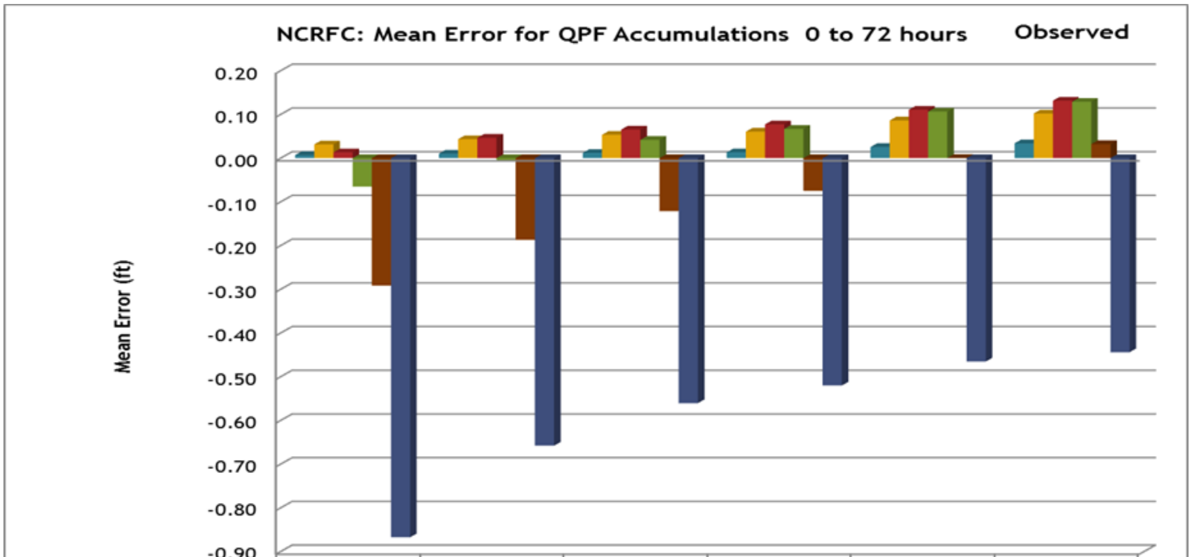
Figure F-2. POD for NCRFC QPF



	6	12	18	24	48	72
< 0.01	0.069	0.096	0.104	0.107	0.159	0.180
>= 0.01 - 0.10	0.601	0.560	0.550	0.547	0.571	0.567
>=0.10 - 0.25	0.773	0.743	0.734	0.719	0.726	0.726
>= 0.25 - 0.50	0.771	0.752	0.728	0.721	0.718	0.721
>= 0.50 - 1.00	0.736	0.696	0.689	0.677	0.667	0.668
>= 1.00	0.909	0.742	0.679	0.635	0.572	0.570

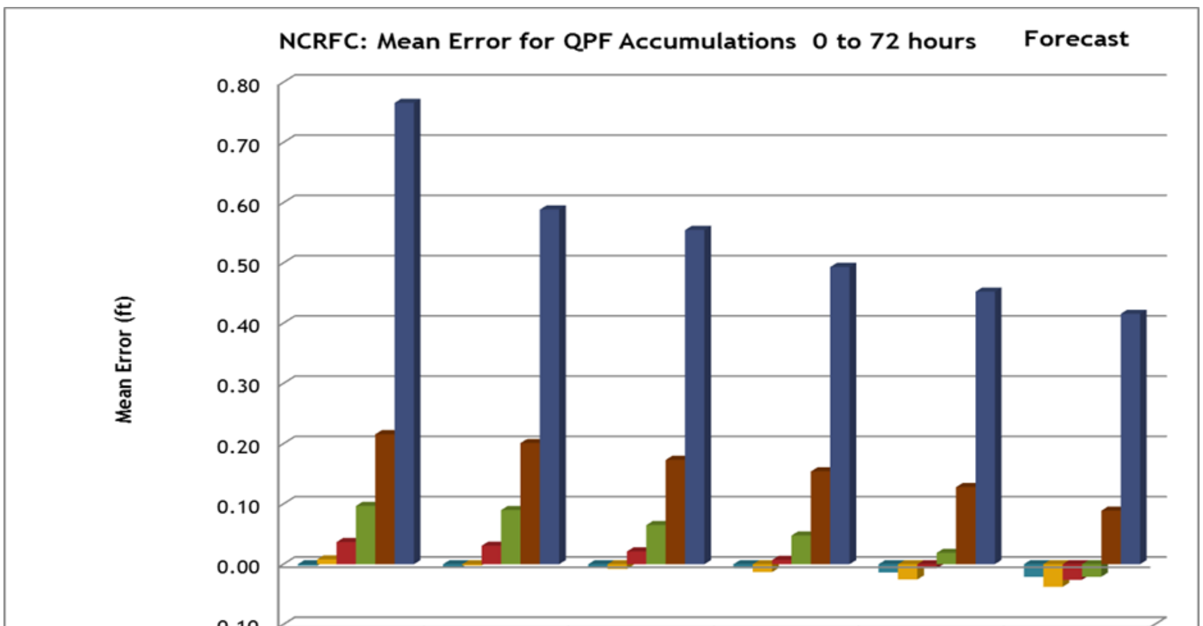
Accumulated Precipitation over 0 to 72 hours

Figure F-3. TFAR for NCRFC QPF



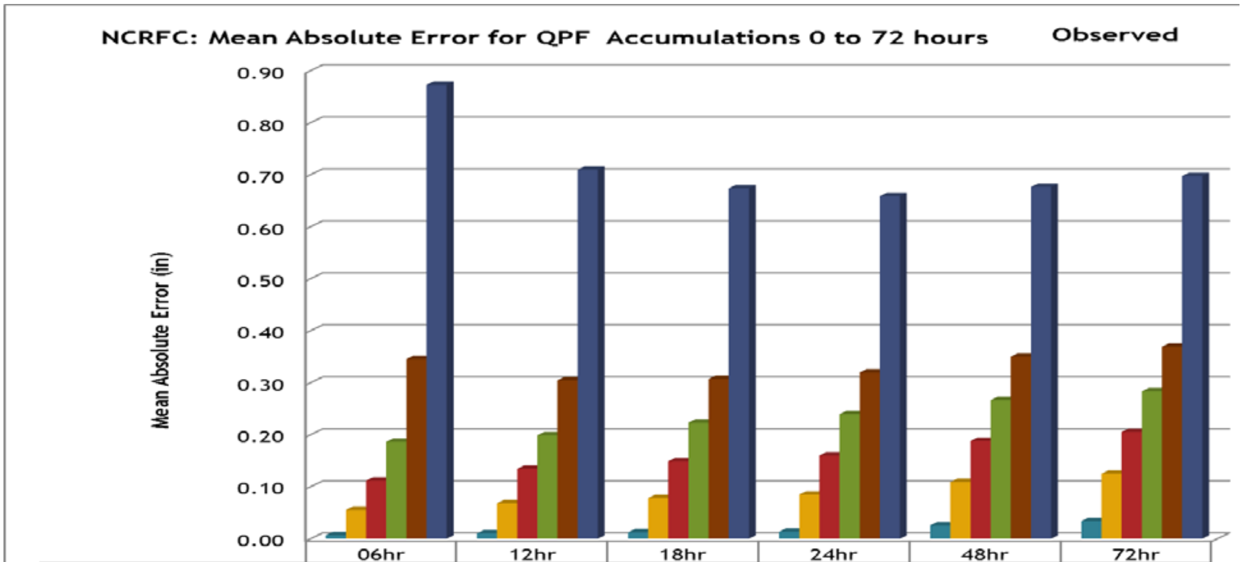
	06hr	12hr	18hr	24hr	48hr	72hr
ME (0 to 0.01)	0.007	0.010	0.012	0.013	0.026	0.034
ME (0.01 to 0.10)	0.031	0.043	0.053	0.061	0.086	0.102
ME (0.10 to 0.25)	0.013	0.047	0.065	0.077	0.111	0.131
ME (0.25 to 0.50)	-0.065	-0.006	0.042	0.067	0.106	0.129
ME (0.50 to 1.0)	-0.292	-0.187	-0.121	-0.075	0.000	0.032
ME (1.0 and Above)	-0.867	-0.658	-0.561	-0.520	-0.466	-0.444

Figure F-4. Mean error NCRFC QPF conditioned on observed precipitation in defined ranges



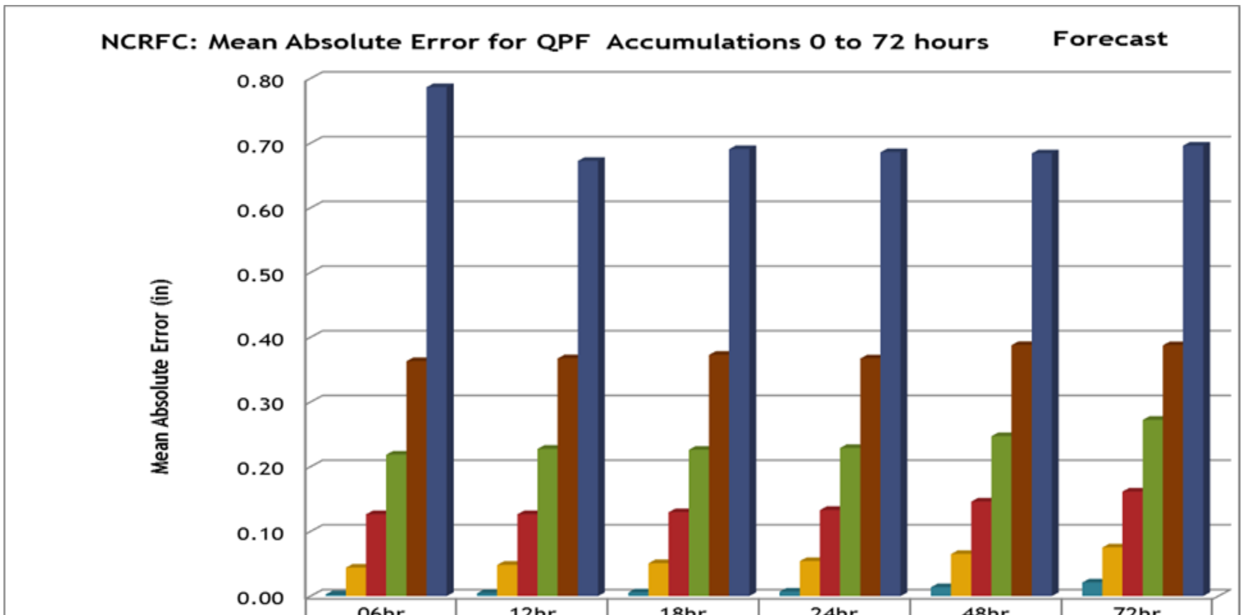
	06hr	12hr	18hr	24hr	48hr	72hr
ME (0 to 0.01)	-0.003	-0.004	-0.006	-0.007	-0.014	-0.021
ME (0.01 to 0.10)	0.008	-0.002	-0.008	-0.013	-0.025	-0.038
ME (0.10 to 0.25)	0.037	0.031	0.021	0.007	-0.007	-0.026
ME (0.25 to 0.50)	0.097	0.090	0.065	0.048	0.019	-0.021
ME (0.50 to 1.0)	0.216	0.201	0.173	0.154	0.128	0.089
ME (1.0 and Above)	0.766	0.589	0.555	0.493	0.452	0.416

Figure F-5. Mean error NCRFC QPF conditioned on forecast precipitation in defined ranges



	06hr	12hr	18hr	24hr	48hr	72hr
MAE (0 to 0.01)	0.007	0.010	0.012	0.013	0.026	0.034
MAE (0.01 to 0.10)	0.055	0.068	0.078	0.085	0.109	0.125
MAE (0.10 to 0.25)	0.112	0.134	0.149	0.160	0.188	0.205
MAE (0.25 to 0.50)	0.186	0.199	0.223	0.239	0.266	0.283
MAE (0.50 to 1.0)	0.345	0.305	0.307	0.319	0.350	0.369
MAE (1.0 and Above)	0.873	0.710	0.674	0.659	0.677	0.697

Figure F-6. NCRFC mean absolute error conditioned on observed precipitation in defined ranges



	06hr	12hr	18hr	24hr	48hr	72hr
MAE (0 to 0.01)	0.003	0.004	0.006	0.007	0.014	0.021
MAE (0.01 to 0.10)	0.044	0.048	0.051	0.054	0.065	0.075
MAE (0.10 to 0.25)	0.126	0.126	0.130	0.133	0.146	0.162
MAE (0.25 to 0.50)	0.219	0.227	0.226	0.229	0.247	0.272
MAE (0.50 to 1.0)	0.363	0.367	0.373	0.367	0.388	0.388
MAE (1.0 and Above)	0.786	0.673	0.691	0.686	0.684	0.696

Figure F-7. NCRFC mean absolute error conditioned on forecast precipitation in defined ranges

Appendix G – Part 2 Student's t-tests

Accumumlated Precipitation Datasets

Part 2 T-test Results for MBRFC Accumulated QPF Errors - All Seasons											
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.044537											
18-hr	0.517338	0.129799										
24-hr	0.085189	0.563329	0.253983									
30-hr	0.232838	0.329477	0.554327	0.603837								
36-hr	0.783106	0.042587	0.656905	0.083423	0.279696							
42-hr	0.910497	0.013396	0.377332	0.024635	0.123732	0.646341						
48-hr	0.096431	3.1974E-05	0.009263	2.83E-05	0.000945	0.023157	0.067124					
54-hr	0.212742	0.000201	0.031876	0.000229	0.004491	0.073542	0.179458	0.619237				
60-hr	0.381901	0.000793	0.080242	0.001054	0.014401	0.171914	0.364689	0.334113	0.643663			
66-hr	0.037677	2.8112E-06	0.001970	1.48E-06	0.000125	0.005372	0.019490	0.652517	0.334888	0.145360		
72-hr	0.000824	9.2568E-10	5.95E-06	8.28E-11	9.82E-08	1.77E-05	0.000118	0.054826	0.014156	0.002844	0.132713	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-1. MBRFC Student's t-test summary for accumulated precipitation errors – all seasons

T-test Results for MBRFC Accumulated QPF Errors - Fall, Winter, & Spring												
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.462967											
18-hr	0.452782	0.971451										
24-hr	0.006502	0.058309	0.030420									
30-hr	0.049088	0.232726	0.178825	0.407835								
36-hr	0.130218	0.473864	0.408978	0.185019	0.576379							
42-hr	0.082326	0.345800	0.282263	0.296684	0.756432	0.796545						
48-hr	0.031847	0.170864	0.123472	0.645849	0.852823	0.449518	0.613808					
54-hr	0.000542	0.006724	0.002523	0.201735	0.090773	0.021241	0.039646	0.127575				
60-hr	0.009070	0.066937	0.039756	0.917751	0.492290	0.199719	0.300403	0.614612	0.293922			
66-hr	0.002298	0.022316	0.010633	0.480216	0.228889	0.070479	0.119220	0.304177	0.607297	0.590038		
72-hr	0.010386	0.075649	0.045486	0.996700	0.541776	0.220381	0.339802	0.672073	0.247597	0.928229	0.522410	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-2. MBRFC t-test summary for accumulated precipitation errors – fall, winter, & spring

T-test Results for MBRFC Accumulated QPF Errors - Summer only												
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.044765											
18-hr	0.805472	0.049648										
24-hr	0.368241	0.000908	0.202523									
30-hr	0.969851	0.018203	0.747004	0.325612								
36-hr	0.382967	0.000746	0.208951	0.957946	0.337719							
42-hr	0.115095	2.7404E-05	0.041040	0.460325	0.077045	0.415523						
48-hr	8.1E-05	6.3236E-12	3.13E-06	0.000635	7.89E-06	0.000366	0.005457					
54-hr	7.35E-06	6.0379E-14	1.37E-07	5.62E-05	3.53E-07	2.75E-05	0.000650	0.539798				
60-hr	0.000645	1.9389E-10	4.09E-05	0.004909	0.000101	0.003173	0.032480	0.476852	0.178797			
66-hr	5.92E-08	4.4545E-18	2.28E-10	3.48E-07	5.74E-10	1.19E-07	6.68E-06	0.101606	0.310113	0.015855		
72-hr	1.44E-11	1.4114E-24	4.33E-15	3.62E-11	9.25E-15	6.73E-12	1.22E-09	0.001505	0.010678	6.41E-05	0.118395	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-3. MBRFC t-test summary for accumulated precipitation errors – summer only

blue highlights P values that are >0.05 (not significantly different)

green and blue highlights P values that are >0.01 (not significantly different)

T-test Results for NCRFC Accumulated QPF Errors - All Seasons												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.432668											
18-hr	0.052169	0.210483										
24-hr	0.029463	0.129599	0.776186									
30-hr	0.004188	0.024727	0.323617	0.492951								
36-hr	1.31E-05	0.000121	0.012031	0.030262	0.139611							
42-hr	0.003704	0.023000	0.330812	0.508399	0.963066	0.115064						
48-hr	0.000431	0.003383	0.113975	0.212319	0.597203	0.305988	0.550263					
54-hr	0.000654	0.004845	0.133707	0.239708	0.637512	0.295078	0.592145	0.961096				
60-hr	0.00578	0.034884	0.434852	0.640791	0.79518	0.066412	0.825981	0.403486	0.441211			
66-hr	0.022277	0.111676	0.797947	0.959881	0.42852	0.015996	0.440608	0.145642	0.183001	0.573506		
72-hr	0.041968	0.188047	0.986253	0.750222	0.28658	0.006946	0.291328	0.086996	0.105417	0.391255	0.769066	

Table G-4. NCRFC Student's t-test summary for accumulated precipitation errors – all seasons

blue highlights P values that are >0.05 (not significantly different)

green and blue highlights P values that are >0.01 (not significantly different)

T-test Results for NCRFC Accumulated QPF Errors - Fall, Winter, & Spring												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr		--	--									
12-hr	0.074569											
18-hr	0.006166	0.305202										
24-hr	0.230760	0.502926	0.084180									
30-hr	0.080976	0.911903	0.235590	0.557939								
36-hr	0.004631	0.277881	0.977855	0.070165	0.209104							
42-hr	0.137043	0.647604	0.113576	0.795015	0.718900	0.094616						
48-hr	0.001699	0.164051	0.755116	0.032004	0.112741	0.768451	0.042307					
54-hr	0.377479	0.251714	0.021517	0.663000	0.278630	0.015696	0.452908	0.005037				
60-hr	0.061409	0.952868	0.231459	0.497303	0.951636	0.202590	0.655044	0.102969	0.222997			
66-hr	0.017033	0.601015	0.550478	0.203890	0.500491	0.515021	0.277265	0.324702	0.062398	0.511977		
72-hr	0.012337	0.519126	0.631803	0.161699	0.421756	0.596785	0.220448	0.389115	0.044479	0.426667	0.893607	

Table G-5. NCRFC t-test summary for accumulated precipitation errors – fall, winter, & spring

blue highlights P values that are >0.05 (not significantly different)

green and blue highlights P values that are >0.01 (not significantly different)

T-test Results for NCRFC Accumulated QPF Errors - Summer only												
Number of accumlated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.178105											
18-hr	0.627738	0.396258										
24-hr	0.050596	0.474750	0.136669									
30-hr	0.013933	0.214153	0.045944	0.617829								
36-hr	0.000304	0.016187	0.001689	0.118542	0.296712							
42-hr	0.004067	0.098112	0.016186	0.382541	0.714778	0.495465						
48-hr	0.193997	0.291251	0.064080	0.776189	0.811634	0.178741	0.530715					
54-hr	2.64E-05	0.002305	0.000181	0.028636	0.092894	0.492339	0.180653	0.044823				
60-hr	0.010932	0.192803	0.038336	0.591950	0.979954	0.296934	0.727146	0.786402	0.089795			
66-hr	0.146834	0.887922	0.334885	0.571067	0.279028	0.027124	0.138462	0.373212	0.004451	0.244793		
72-hr	0.304048	0.768620	0.588226	0.330955	0.137526	0.008751	0.058884	0.188735	0.001180	0.121452	0.671502	

Table G-6. NCRFC t-test summary for accumulated precipitation errors – summer only

Part 2 T-test Results for RFCs Combined Accumulated QPF Errors - All Seasons												
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.001542											
18-hr	0.029312	0.278289										
24-hr	0.035879	0.237086	0.924364									
30-hr	0.003500	0.742413	0.437356	0.381104								
36-hr	0.001332	0.938026	0.292495	0.248056	0.791933							
42-hr	0.040340	0.178139	0.825475	0.902453	0.301533	0.184221						
48-hr	0.153774	0.042013	0.363601	0.416281	0.082736	0.040666	0.473139					
54-hr	0.154813	0.043533	0.368136	0.420916	0.042592	0.042277	0.478071	0.997158				
60-hr	0.092922	0.071572	0.509100	0.573856	0.135069	0.070942	0.648603	0.784743	0.788787			
66-hr	0.874007	0.000500	0.019155	0.024413	0.001320	0.000362	0.026986	0.137805	0.139369	0.707505		
72-hr	0.392770	4.151E-06	0.000527	0.000729	1.297E-05	2.078E-06	0.000706	0.007862	0.008182	0.002879	0.233380	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-7. RFCs' data combined - Student's t-test summary for accumulated precipitation errors for all seasons

T-test Results for RFCs Combined Accumulated QPF Errors - Fall, Winter, & Spring												
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.050760											
18-hr	0.012380	0.632949										
24-hr	0.006500	0.497296	0.837234									
30-hr	0.005594	0.471035	0.804455	0.966713								
36-hr	0.002269	0.218594	0.591289	0.738067	0.768717							
42-hr	0.013040	0.713522	0.886145	0.715985	0.682043	0.471729						
48-hr	4.9877E-05	0.040038	0.096162	0.137628	0.146488	0.240435	0.054878					
54-hr	0.000472	0.150060	0.315917	0.419618	0.441703	0.633410	0.222363	0.472866				
60-hr	0.000297	0.120233	0.261707	0.353640	0.373287	0.550561	0.176763	0.541841	0.906629			
66-hr	2.6229E-05	0.029159	0.072476	0.105839	0.112953	0.192395	0.038526	0.916843	0.400677	0.463510		
72-hr	0.000119	0.075179	0.173644	0.242345	0.257078	0.400889	0.107438	0.702034	0.719598	0.808205	0.616592	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-8. RFCs' data combined t-test summary for accumulated precipitation errors – fall, winter, & spring

T-test Results for RFCs Combined Accumulated QPF Errors - Summer only												
Number of accumulated hours	6-hr	12-hr	18-hr	24-hr	30-hr	36-hr	42-hr	48-hr	54-hr	60-hr	66-hr	72-hr
6-hr	--	--	--									
12-hr	0.011222											
18-hr	0.368774	0.084845										
24-hr	0.515800	0.048426	0.796625									
30-hr	0.101334	0.353907	0.433715	0.300424								
36-hr	0.074231	0.412117	0.355763	0.237864	0.900851							
42-hr	0.452821	0.053881	0.864295	0.926558	0.333535	0.265165						
48-hr	0.168456	2.049E-05	0.014806	0.031121	0.001175	0.000578	0.021288					
54-hr	0.361228	0.000221	0.054548	0.098847	0.006686	0.003820	0.074744	0.633833				
60-hr	0.459960	0.000358	0.078317	0.137915	0.010252	0.005956	0.106322	0.487064	0.838547			
66-hr	0.00077242	1.115E-10	5.1514E-06	2.058E-05	7.396E-08	1.835E-08	8.232E-06	0.031905	0.009814	0.004365		
72-hr	8.0927E-06	2.333E-14	1.0551E-08	6.1333E-08	5.96E-11	9.552E-12	1.682E-08	0.000822	0.000173	5.152E-05	0.222179	

blue highlights P values that are > 0.05 (not significantly different)

green and blue highlights P values that are > 0.01 (not significantly different)

Table G-9. RFCs' data combined t-test summary for accumulated precipitation errors – summer only

Appendix H – Part 3 Station Selection: Forecast Point Selection for Fast, Medium and Slow Response Times

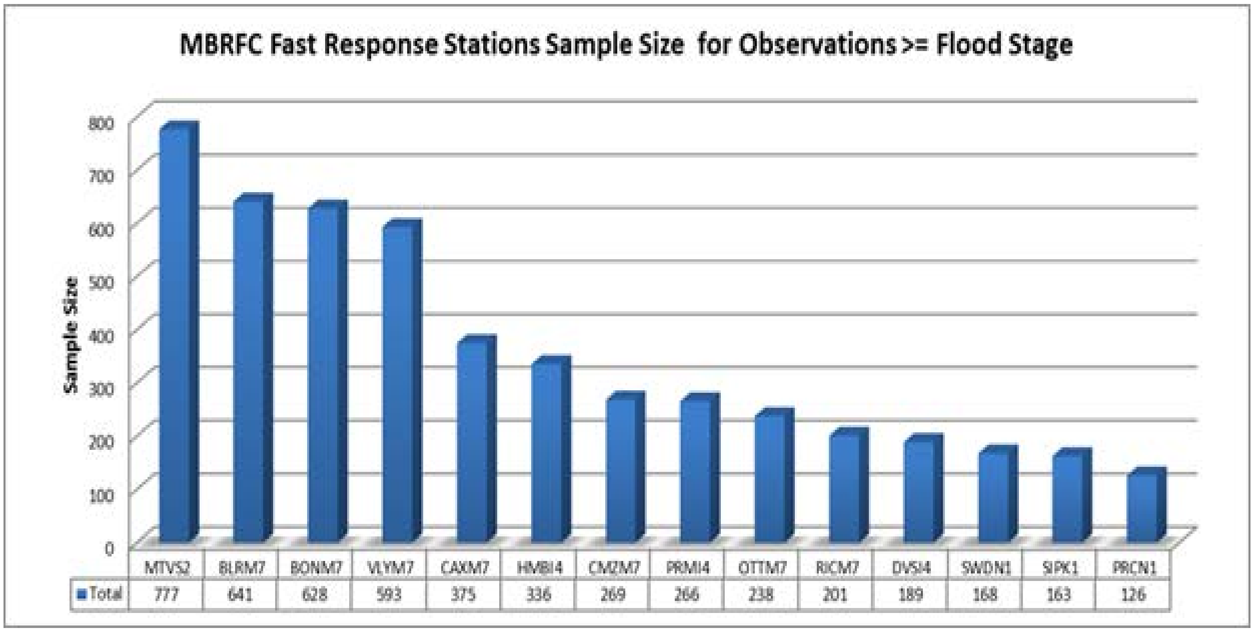


Figure H-1. Fast-response time locations - number of stages greater than or equal to flood stage in MBRFC area

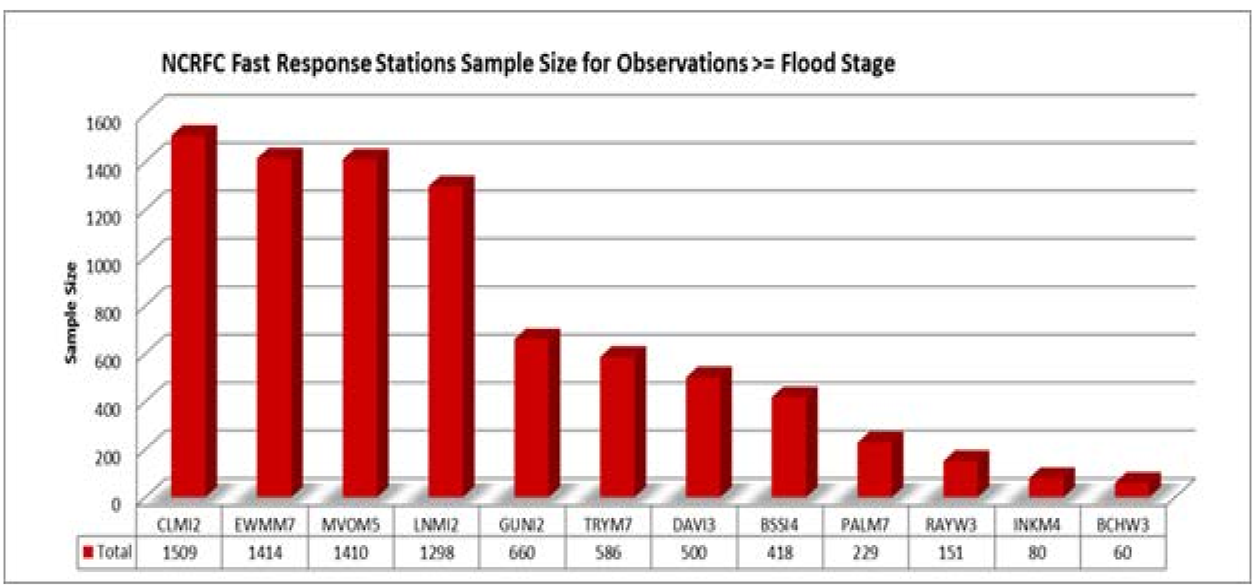


Figure H-2. Fast-response time locations = number of stages greater than or equal to flood stage in NCRFC area

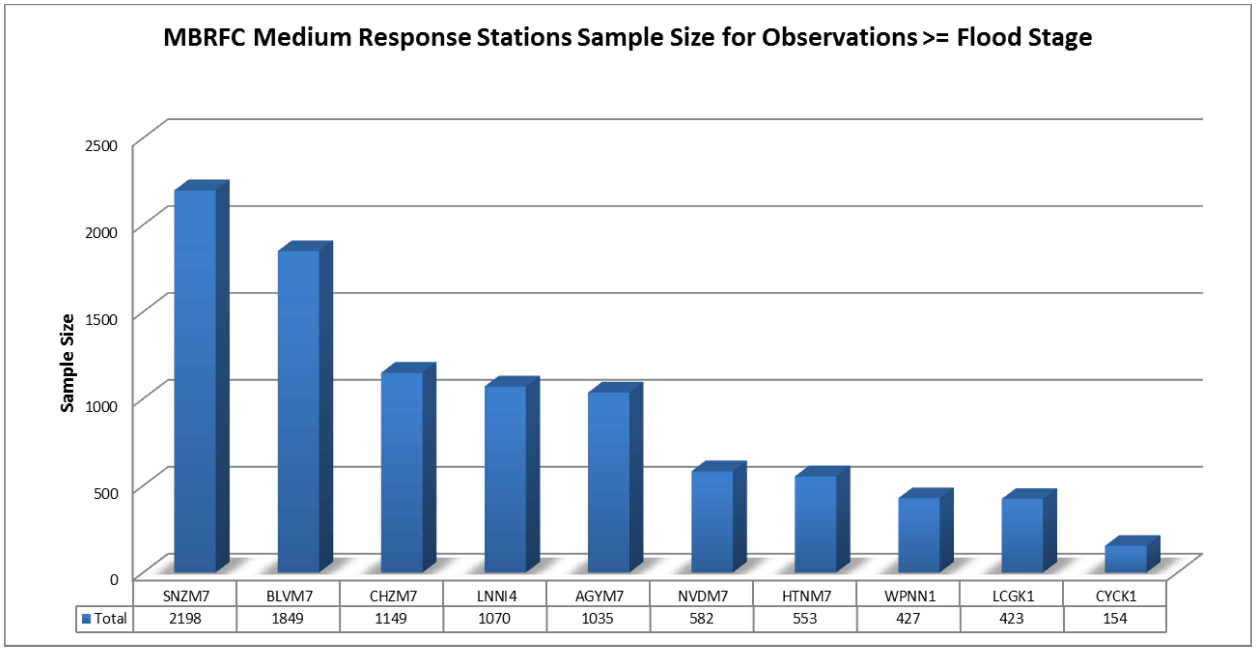


Figure H-3. Medium-response time locations - number of stages greater than or equal to flood stage in MBRFC area

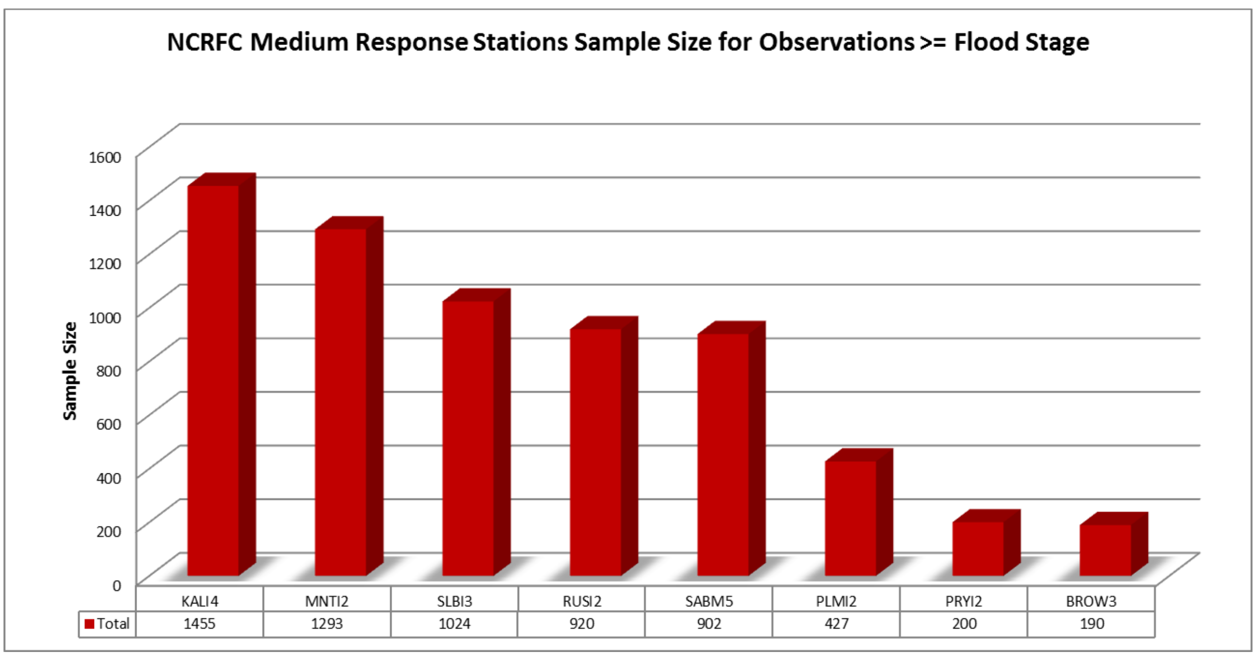


Figure H-4. Medium-response time locations - number of stages greater than or equal to flood stage in NCRFC area

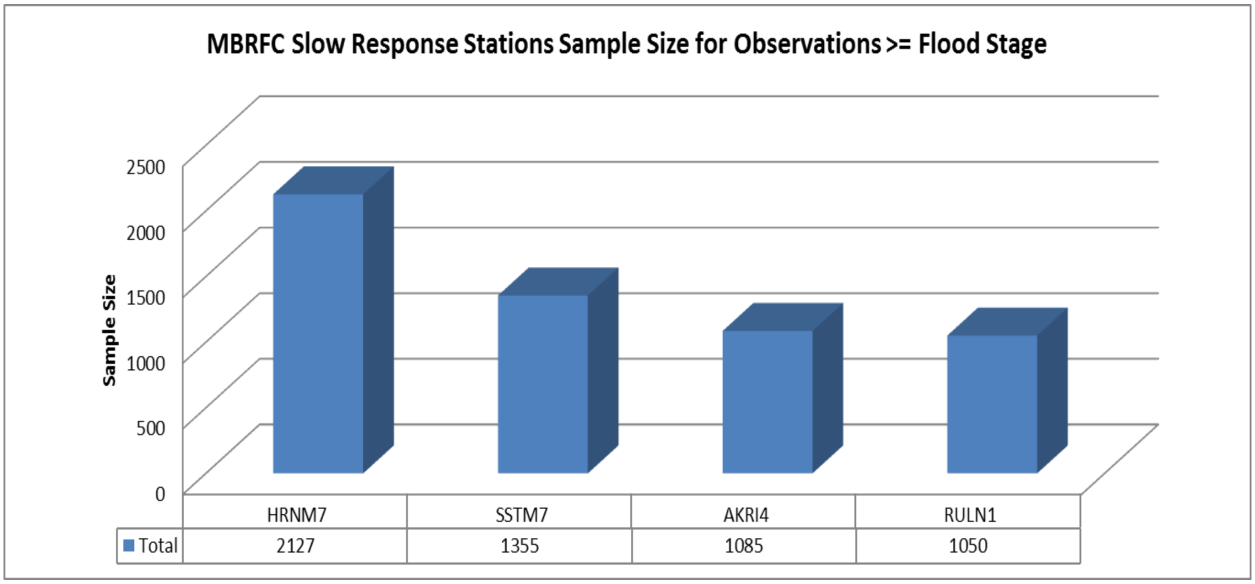


Figure H-5. Slow-response time locations - number of stages greater than or equal to flood stage in MBRFC area

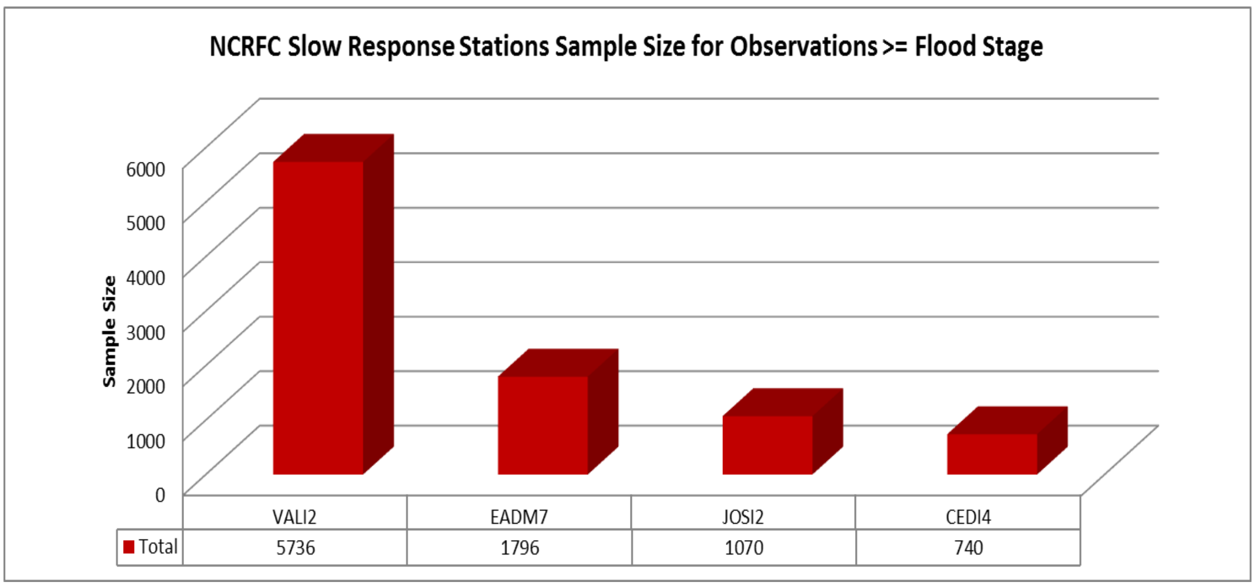


Figure H-6. Slow-response time locations - number of stages greater than or equal to flood stage in NCRFC area

Appendix I – Part 3 Student's t-tests

<u>Precipitation Student's t-test results for fast- and medium-response time stations</u>

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-1. Fall precipitation Student's t-test results for MBRFC fast responders

		T-test Fall Fast Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.757804	0.802451	0.393977	0.258242	0.000852	7.62E-09
6 QPF			0.586007	0.257448	0.160961	0.000377	2.75E-09
12 QPF				0.557005	0.389132	0.002548	6.23E-08
18 QPF					0.780328	0.014709	1.29E-06
24 QPF						0.031912	5.82E-06
48 QPF							0.0166
72 QPF							
		T-test Fall Fast Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.760225	0.822765	0.808926	0.861277	0.550314
12 QPF				0.504003	0.908744	0.495894	0.764969
18 QPF					0.508557	0.914395	0.18606
24 QPF						0.480585	0.573354
48 QPF							0.080814
72 QPF							

Table I-2. Winter precipitation Student's t-test results for MBRFC fast responders

		T-test Winter Fast Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.52832	0.136433	0.041563	0.004248	2.1E-07	3.86E-18
6 QPF			0.424037	0.189412	0.037988	1.76E-05	2.95E-14
12 QPF				0.607342	0.203115	0.000446	9.05E-12
18 QPF					0.449912	0.002659	2.75E-10
24 QPF						0.022794	2.15E-08
48 QPF							0.001115
72 QPF							
		T-test Winter Fast Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.681034	0.334141	0.280104	0.67995	0.644814
12 QPF				0.505128	0.416667	0.926454	0.196138
18 QPF					0.893415	0.278908	0.007768
24 QPF						0.165005	0.001379
48 QPF							0.028483
72 QPF							

The yellow shaded area in the following tables indicates $P < 0.05$, i.e., data are significantly different.

Table I-3. Spring precipitation Student's t-test results for MBRFC fast responders

		T-test Spring Fast Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.424665	0.624194	0.618003	0.334838	0.171809	0.066266
6 QPF			0.78322	0.794109	0.855648	0.549476	0.275779
12 QPF				0.990482	0.655434	0.397506	0.187097
18 QPF					0.666204	0.406853	0.193259
24 QPF						0.679246	0.366376
48 QPF							0.62218
72 QPF							
		T-test Spring Fast Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.65456	0.091104	0.137288	0.014923	3.1E-05
12 QPF				0.128268	0.203256	0.011966	1.38E-06
18 QPF					0.721137	0.379227	0.000743
24 QPF						0.17026	3.68E-05
48 QPF							0.002447
72 QPF							

Table I-4. Summer precipitation Student's t-test results for MBRFC fast responders

		T-test Summer Fast Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.437147	0.802698	0.594499	0.525301	0.241725	0.08915
6 QPF			0.595165	0.805392	0.902281	0.053501	0.013783
12 QPF				0.775809	0.693184	0.155435	0.050829
18 QPF					0.90683	0.090314	0.026031
24 QPF						0.076969	0.022034
48 QPF							0.605516
72 QPF							
		T-test Summer Fast Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.046011	0.583458	1.51E-05	0.019124	0.047799
12 QPF				0.058369	4.13E-17	3.38E-11	6.83E-10
18 QPF					1.25E-10	2.15E-05	0.000171
24 QPF						0.000288	2.14E-05
48 QPF							0.421351
72 QPF							

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-5. Fall precipitation Student's t-test results for NCRFC fast responders

		T-test Fall Fast Responders NCRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.79496	0.56923	0.263112	0.11891	0.003308	3.69E-06
6 QPF			0.759139	0.394972	0.198418	0.000797	1.47E-05
12 QPF				0.587305	0.328609	0.019065	5.69E-05
18 QPF					0.664476	0.070844	0.000472
24 QPF						0.168202	0.002105
48 QPF							0.002105
72 QPF							
		T-test Fall Fast Responders NCRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.572416	0.155389	0.077004	0.010378	0.088997
12 QPF				0.247038	0.092288	0.133349	0.103152
18 QPF					0.564787	0.804726	0.706478
24 QPF						0.643777	0.718181
48 QPF							0.858417
72 QPF							

Table I-6. Winter precipitation Student's t-test results for NCRFC fast responders

		T-test Winter Fast Responders NCRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.923802	0.380985	0.148542	0.055964	1.34E-05	6.17E-13
6 QPF			0.439579	0.181338	0.072007	2.48E-05	2.07E-17
12 QPF				0.570271	0.302186	0.000555	4.09E-10
18 QPF					0.643355	0.004053	1.65E-08
24 QPF						0.016061	0.006948
48 QPF							0.006948
72 QPF							
		T-test Winter Fast Responders NCRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.160321	0.310788	0.477853	0.90387	0.516858
12 QPF				0.568626	0.308229	0.023043	0.001836
18 QPF					0.647517	0.077718	0.00775
24 QPF						0.183586	0.023975
48 QPF							0.338
72 QPF							

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-7. Spring precipitation Student's t-test results for NCRFC fast responders

	T-test Spring Fast Responders NCRFC Underforecasting						
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.867182	0.970169	0.48019	0.156563	0.156563	2.92E-05
6 QPF			0.898853	0.898853	0.394267	0.119388	1.93E-05
12 QPF				0.469959	0.154135	1.93E-05	0.187097
18 QPF					0.383765	0.484765	0.000587
24 QPF						1	0.005465
48 QPF							0.005465
72 QPF							

	T-test Spring Fast Responders NCRFC Overforecasting						
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.865605	0.479318	0.562938	0.562938	0.625129
12 QPF				0.28543	0.33892	0.33891	0.347246
18 QPF					0.831023	0.831023	0.648326
24 QPF							0.810824
48 QPF							0.810824
72 QPF							

Table I-8. Summer precipitation Student's t-test results for NCRFC fast responders

	T-test Summer Fast Responders NCRFC Underforecasting						
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.939949	0.001853	0.990116	0.715992	0.780599	0.057444
6 QPF			0.951353	0.951833	0.776045	0.837955	0.068681
12 QPF				0.958024	0.69405	0.755988	0.057572
18 QPF					0.733348	979,493	0.063739
24 QPF						0.938391	0.116354
48 QPF							0.111849
72 QPF							

	T-test Summer Fast Responders NCRFC Overforecasting						
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.571539	0.182313	0.038321	0.07634	0.389118
12 QPF				0.010621	0.000281	0.000424	0.025594
18 QPF					0.319638	0.63938	0.33899
24 QPF						0.459006	0.020145
48 QPF							0.037485
72 QPF							

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-9. Fall precipitation Student's t-test results for MBRFC medium responders

		T-test Fall Medium Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.422568	0.862932	0.141179	0.024072	1.52E-11	7.06E-26
6 QPF			0.344279	0.027409	0.003002	2.13E-13	3.13E-28
12 QPF				0.206982	0.042881	1.6E-10	6.12E-24
18 QPF					0.445579	3.03E-07	1.02E-18
24 QPF						1.35E-05	6.82E-16
48 QPF							0.000144
72 QPF							

		T-test Fall Medium Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.929062	0.618833	0.782528	0.991594	0.63684
12 QPF				0.448772	0.81868	0.899007	0.617231
18 QPF					0.206752	0.344517	0.069205
24 QPF						0.585025	0.711495
48 QPF							0.216344
72 QPF							

Table I-10. Winter precipitation Student's t-test results for MBRFC medium responders

		T-test Winter Medium Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.061356	0.000388	5.61E-05	4.68E-08	5.34E-30	5.25E-81
6 QPF			0.115148	0.04084	0.000731	1.95E-19	3.75E-60
12 QPF				0.630184	0.071647	8.77E-14	1.38E-49
18 QPF					0.191317	4.13E-12	5.39E-46
24 QPF						1.35E-08	8.22E-39
48 QPF							3.13E-13
72 QPF							

		T-test Winter Medium Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.791468	0.624454	0.076308	0.001147	1.17E-08
12 QPF				0.781205	0.045276	3.33E-05	1.4E-14
18 QPF					0.050792	6.65E-06	1.99E-18
24 QPF						0.014152	3.82E-12
48 QPF							6.77E-08
72 QPF							

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-11. Spring precipitation Student's t-test results for MBRFC medium responders

		T-test Spring Medium Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.353473	0.851474	0.105993	0.137984	0.12329	0.121287
6 QPF			0.500077	0.511403	0.583579	0.515158	0.48221
12 QPF				0.189777	0.232033	0.20501	0.19631
18 QPF					0.922354	0.973308	0.910798
24 QPF						0.900585	0.842484
48 QPF							0.939298
72 QPF							

		T-test Spring Medium Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.285225	0.309149	0.263715	0.144098	2.91E-05
12 QPF				0.888883	0.942503	0.773354	0.000205
18 QPF					0.932657	0.610836	8.14E-06
24 QPF						0.646579	1.25E-06
48 QPF							3.94E-07
72 QPF							

Table I-12. Summer precipitation Student's t-test results for MBRFC medium responders

		T-test Summer Medium Responders MBRFC					
			Underforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		1.6E-05	0.001055	0.007712	1.24E-05	1.35E-05	0.472766
6 QPF			0.296254	0.09112	0.868352	0.868713	8.67E-07
12 QPF				0.524133	0.237207	0.239398	9.21E-05
18 QPF					0.070176	0.071526	0.0009
24 QPF						0.999699	6.88E-07
48 QPF							7.67E-07
72 QPF							

		T-test Summer Medium Responders MBRFC					
			Overforecasting				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.495445	0.044775	1.83E-30	6.77E-30	5.73E-26
12 QPF				0.08704	2.19E-44	3.87E-46	2.49E-43
18 QPF					1.03E-34	1.62E-35	5.58E-32
24 QPF						0.383567	0.001823
48 QPF							0.015456
72 QPF							

The yellow shaded area in the following tables indicates P< 0.05, i.e., data are significantly different.

Table I-13. Fall precipitation Student's t-test results for NCRFC medium responders

		T-test Fall Medium Responders NCRFC					
			Under forecasting Fall				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.822359	0.520463	0.071446	0.010198	1.59557E-06	5.42562E-13
6 QPF			0.676146	0.117125	0.019965	5.61302E-06	4.01486E-12
12 QPF				0.257666	0.059851	4.70375E-05	1.22559E-10
18 QPF					0.450775	0.003037898	8.81886E-08
24 QPF						0.026672081	4.10593E-06
48 QPF							0.017300966
72 QPF							

		T-test Fall Medium Responders NCRFC					
			Over forecasting - Fall				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.748893	0.446148	0.127491	0.030937235	0.017364289
12 QPF				0.590062	0.139941	0.018916286	0.007117653
18 QPF					0.304065	0.057990659	0.024403749
24 QPF						0.548123445	0.411000791
48 QPF							0.811158005
72 QPF							

Table I-14. Winter precipitation Student's t-test results for NCRFC medium responders

		T-test Winter Medium Responders NCRFC					
			Under forecasting Winter				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.810341	0.576928219	0.656489528	0.00191329	2.48668E-11	3.30806E-31
6 QPF			0.751612512	0.165651142	0.004578866	1.88406E-10	2.30381E-29
12 QPF				0.287723271	0.012452942	1.85638E-09	2.18067E-27
18 QPF					0.154447678	0.011896781	2.18529E-22
24 QPF						0.000391601	5.71305E-17
48 QPF							2.2071E-06
72 QPF							

		T-test Winter Medium Responders NCRFC					
			Over forecasting - Winter				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.393059908	0.239444931	0.187944553	0.492951678	0.815614011
12 QPF				0.775244825	0.670882468	0.680561623	0.30974094
18 QPF					0.876137272	0.343718797	0.076166586
24 QPF						0.209738395	0.026607234
48 QPF							0.297082572
72 QPF							

The yellow shaded area in the following tables indicates $P < 0.05$, i.e., data are significantly different.

Table I-15. Spring precipitation Student's t-test results for NCRFC medium responders

		T-test Spring Medium Responders NCRFC					
			Under forecasting Spring				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.978803	0.803554	0.65649	0.141875	0.002348088	6.33874E-07
6 QPF			0.826967	0.680601	0.156305	0.003013364	1.09591E-06
12 QPF				0.846475	0.234435	0.006325149	3.75055E-06
18 QPF					0.325221	0.011896781	1.11358E-05
24 QPF						0.117079656	0.000515447
48 QPF							0.060083959
72 QPF							

		T-test Spring Medium Responders NCRFC					
			Over forecasting - Spring				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.463412	0.441102	0.098726	0.060627559	0.080434888
12 QPF				0.068067	0.002686	0.000335354	0.000372241
18 QPF					0.306387	0.207764377	0.27922807
24 QPF						0.925437203	0.860030791
48 QPF							0.715478427
72 QPF							

Table I-16. Summer precipitation Student's t-test results for NCRFC medium responders

		T-test Summer Medium Responders NCRFC					
			Under forecasting Summer				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF		0.935255	5.27139E-10	1.24634E-09	1.19418E-09	8.57872E-12	3.51305E-13
6 QPF			1.29846E-09	2.94357E-09	2.77575E-09	2.13433E-11	8.81227E-13
12 QPF				0.948959316	0.98284947	0.291501298	0.076439353
18 QPF					0.933051169	0.268718373	0.069411292
24 QPF						0.309778256	0.084814614
48 QPF							0.469471341
72 QPF							

		T-test Summer Medium Responders NCRFC					
			Over forecasting - Summer				
	0 QPF	6 QPF	12 QPF	18 QPF	24 QPF	48 QPF	72 QPF
0 QPF							
6 QPF			0.980688272	0.051151919	0.009642464	0.026867708	0.094217514
12 QPF				0.015992714	0.001069571	0.00298378	0.022722052
18 QPF					0.454025431	0.979460046	0.41403464
24 QPF						0.354258274	0.056870638
48 QPF							0.196494578
72 QPF							

Stage Forecasts Student's t-test results

Tables I-17 and I-18 show results that in all cases indicate no significant differences.

Student's t-test for River Stage Forecst Errors Forecasts >= FS						
	no QPF to 6-hr QPF	6-hr QPF to 12-hr QPF	12-hr QPF to 18-hr QPF	18-hr QPF to 24-hr QPF	24-hr QPF to 48-hr QPF	48-hr QPF to 72-hr QPF
RFCs Combined						
Slow	0.7384	0.9828	0.6566	0.9646	0.6224	0.6855
MBRFC						
Medium	0.423603	0.9171	0.5932	0.3860	0.6084	0.6618
Fast	0.0537	0.9709	0.7939	0.3921	0.4874	0.3888
NCRFC						
Medium	0.9475	0.6839	0.6942	0.4925	0.3814	0.8439
Fast	0.3841	0.4085	0.8123	0.6430	0.5954	0.7667

Table I-17. Student's t-test summary by forecast category

Student's t-test for River Stage Forecst Errors Observations >= FS						
	no QPF to 6-hr QPF	6-hr QPF to 12-hr QPF	12-hr QPF to 18-hr QPF	18-hr QPF to 24-hr QPF	24-hr QPF to 48-hr QPF	48-hr QPF to 72-hr QPF
RFCs Combined						
Slow	0.7758	0.9767	0.8922	0.5969	0.3067	0.7061
MBRFC						
Medium	0.798078	0.6680	0.9397	0.8928	0.5253	0.5396
Fast	0.5597	0.7765	0.7404	0.9513	0.6073	0.6609
NCRFC						
Medium	0.9776	0.9661	0.9593	0.9034	0.8519	0.9208
Fast	0.9753	0.9837	0.9365	0.9779	0.7476	0.5128

Table I-18. Student's t-test summary by observed category

Appendix J – Part 3 MBRFC Results

Approach 1 – using QPFs of 0, 6, 12, 18, 24, 48, and 72 hour

Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data				QPF Selected based on Relative Change			
~ Less QPF	MAE Forecast Cat	6	12	0	0	24	18	48	48
	ME Forecast Cat	18	0	12	0	24	12	48	24
	HFAR	0	12	0	0	24	18	24	24
~ More QPF	POD	72	72	72	72	72	48	12	12
	MAE Observed Cat	72	72	72	72	72	48	48	48
	ME Observed Cat	72	72	72	72	72	48	72	48
Conclusions		24	24	24	18	48	24	48	24

Table J-1. Summary of stage forecast analysis by season using QPFs of 0, 6, 12, 18, 24, 48, and 72 hour for fast-response stations

Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data				QPF Selected based on Relative Change			
~ Less QPF	MAE Forecast Cat	0	0	0	0	48	18	24	X
	ME Forecast Cat	72	24	0	0	24	X	24	24
	HFAR	6	0	0	0	24	18	24	24
~ More QPF	POD	72	72	72	72	48	48	48	48
	MAE Observed Cat	72	72	72	72	48	48	72	48
	ME Observed Cat	72	72	72	72	48	48	72	48
Conclusions		24	24	18	18	48	24	48	48

Table J-2. Summary of stage forecast analysis by season using QPFs of 0, 6, 12, 18, 24, 48, and 72 hour QPF for medium-response stations

Fast-Response Stations

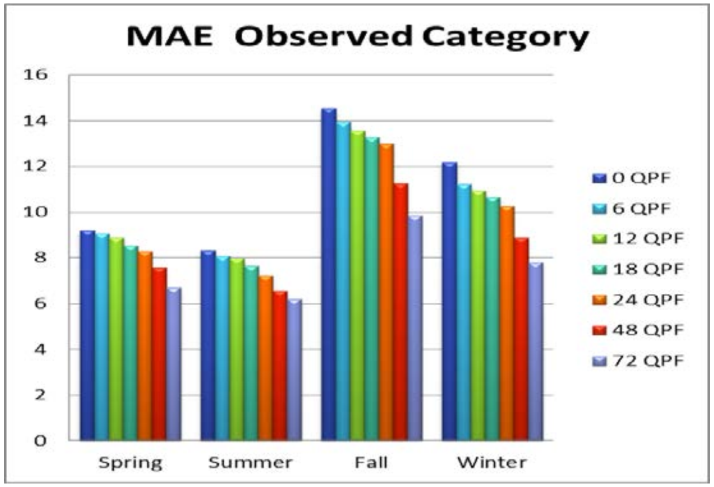


Figure J-1. Seasonal mean absolute errors when observed stage greater than or equal to flood stage for fast responders

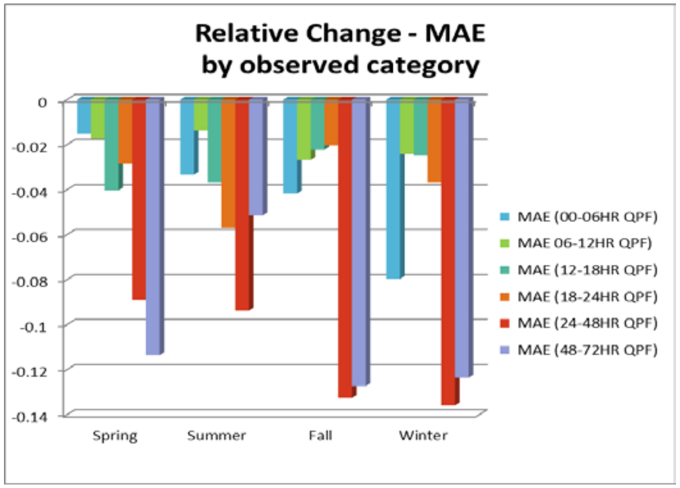


Figure J-2. Seasonal MAE relative change when observed stage greater than or equal to flood stage for fast responders

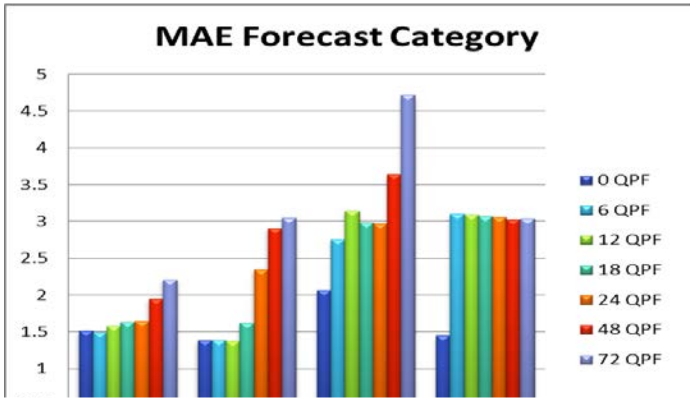


Figure J-3. Seasonal mean absolute errors when forecast stage greater than or equal to flood stage for fast responders

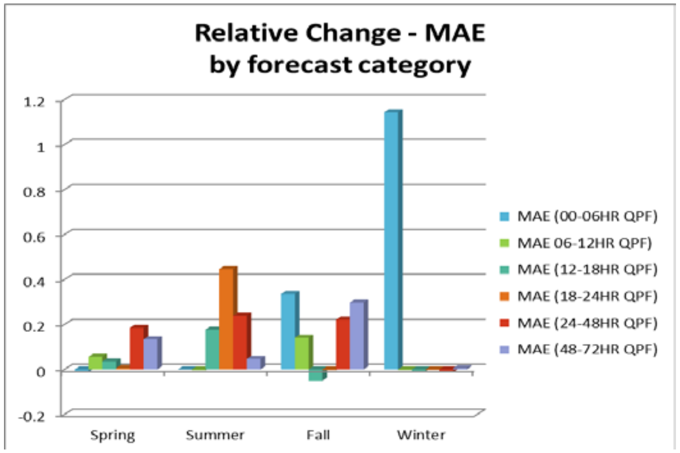


Figure J-4. Seasonal MAE relative change when forecast stage greater than or equal to flood stage for fast responders

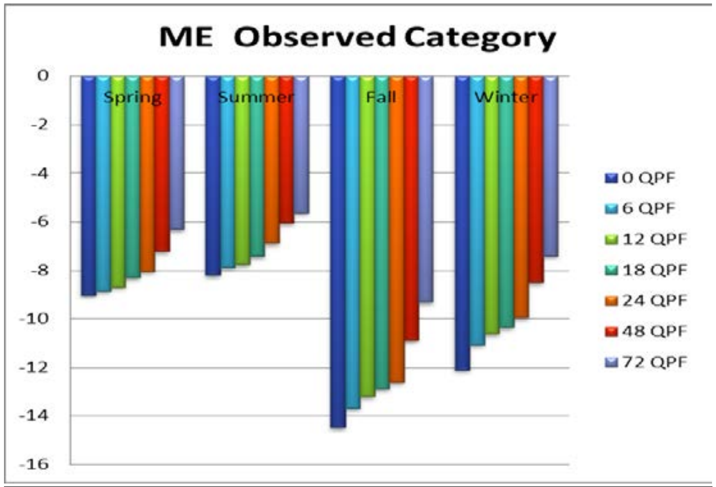


Figure J-5. Seasonal mean errors when observed stage greater than or equal to flood stage for fast responders

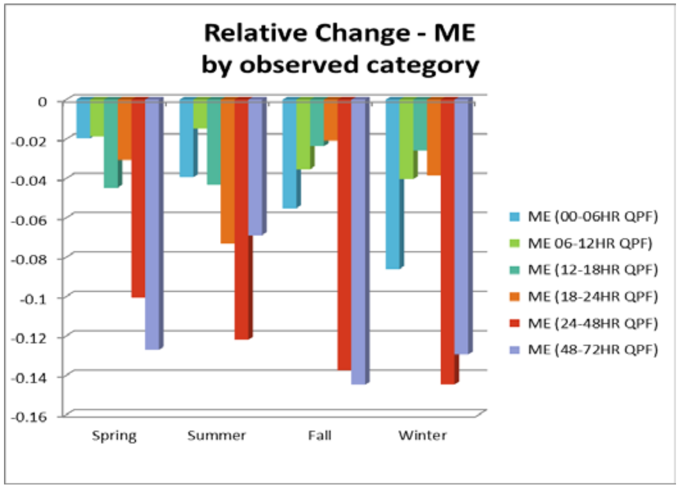


Figure J-6. Seasonal ME relative change when observed stage greater than or equal to flood stage for fast responders

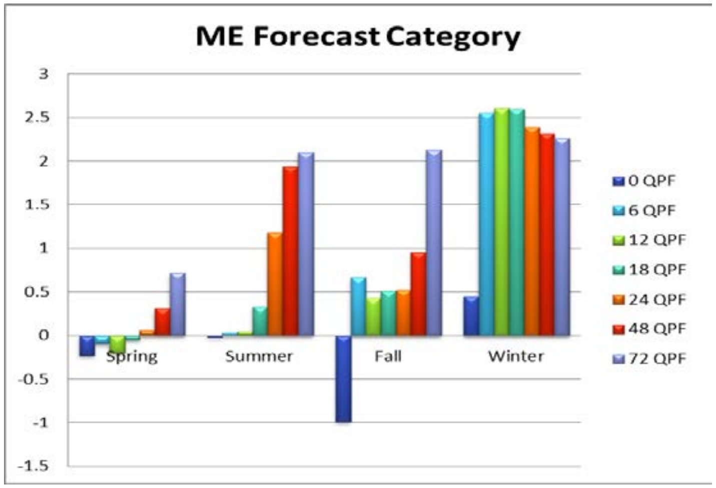


Figure J-7. Seasonal mean errors when forecast stage greater than or equal to flood stage for fast responders

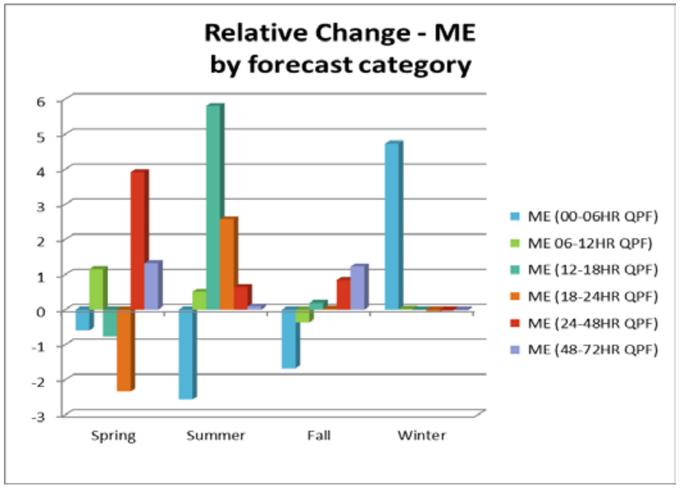


Figure J-8. Season ME relative change when forecast stage greater than or equal to flood stage for fast responders

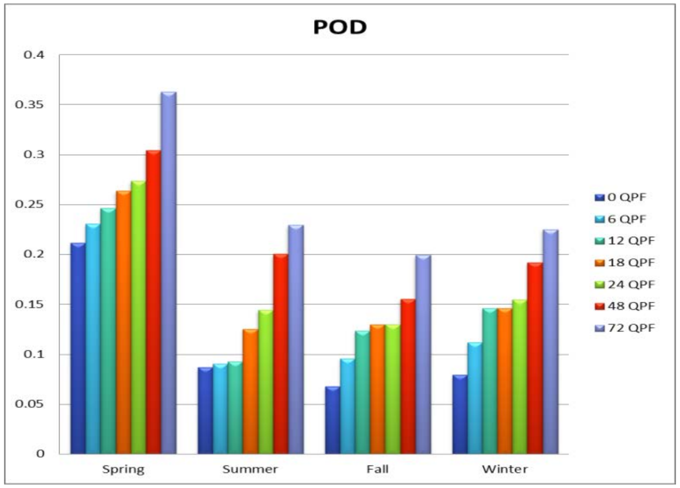


Figure J-9. Seasonal probability of detection for fast responders

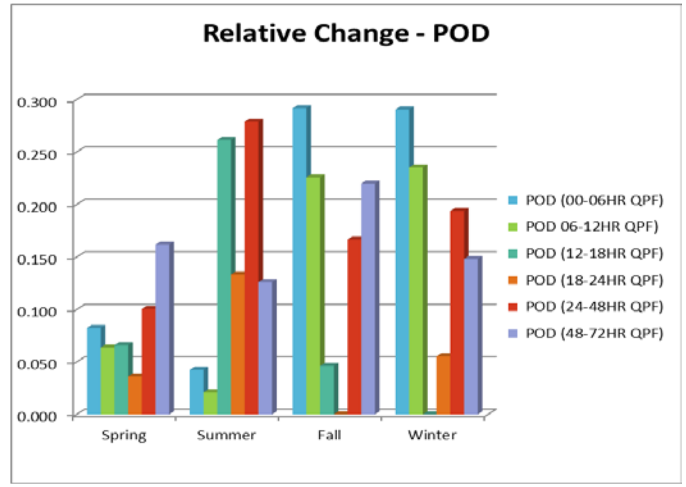


Figure J-10. Seasonal POD relative change for fast responders

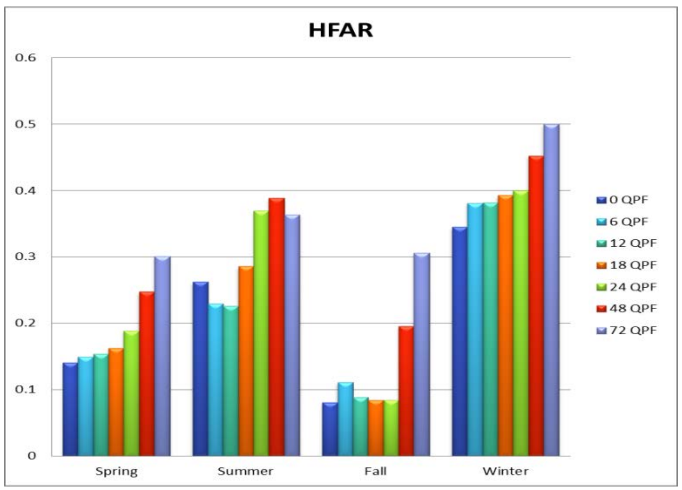


Figure J-11. Seasonal hydrologic false alarm ratio for fast responders

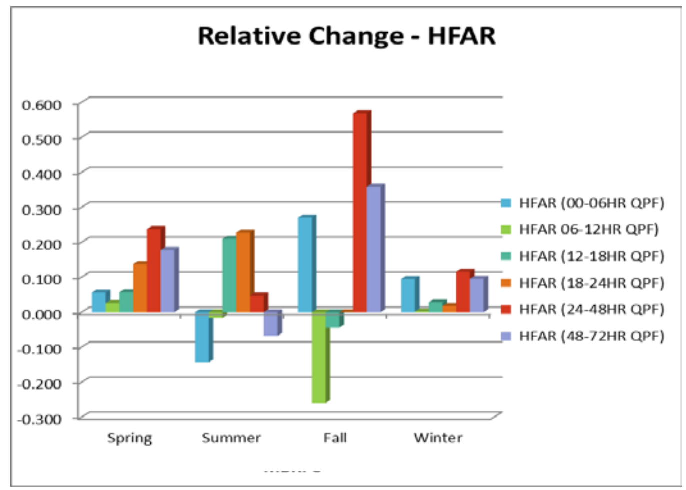


Figure J-12. Seasonal HFAR relative change for fast responders

Medium-Response Stations

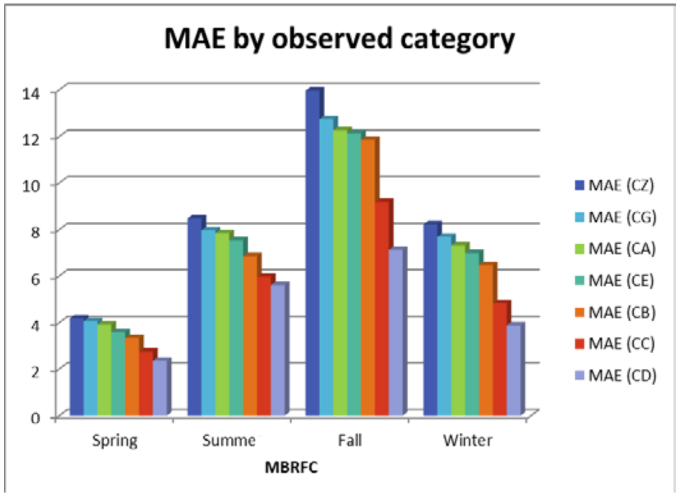


Figure J-13. Seasonal mean absolute errors when observed stage greater than or equal to flood stage for medium responders

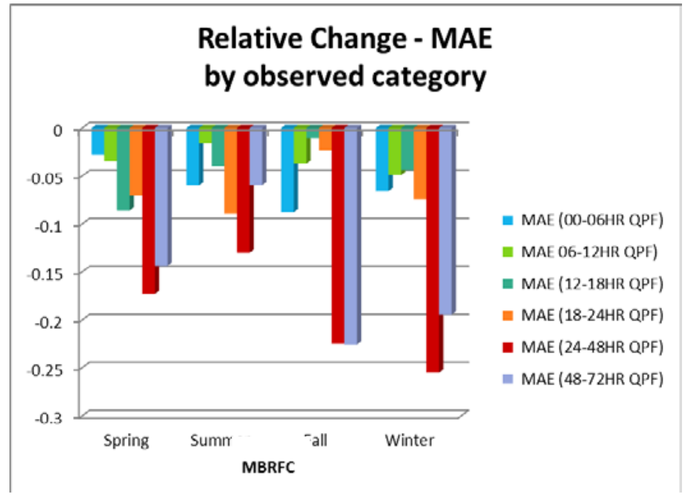


Figure J-14. Seasonal MAE relative change when observed stage greater than or equal to flood stage for medium responders

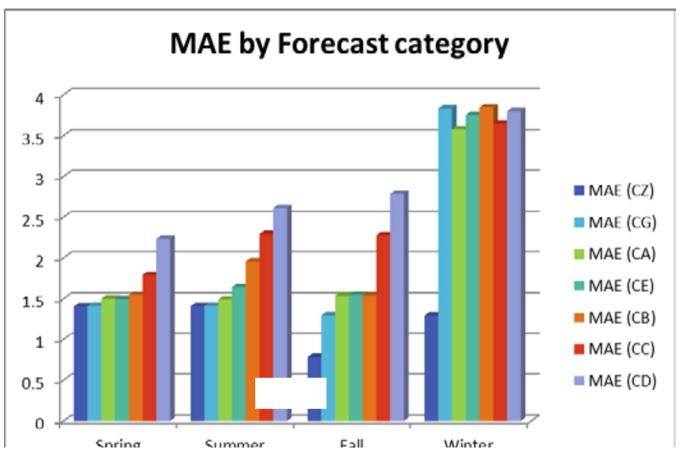


Figure J-15. Seasonal mean absolute errors when forecast stage greater than or equal to flood stage for medium responders

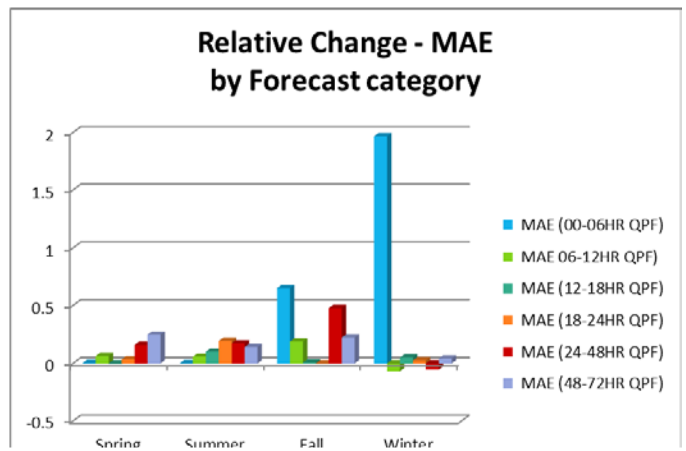


Figure J-16. Seasonal MAE relative change when forecast stage greater than or equal to flood stage for medium responders

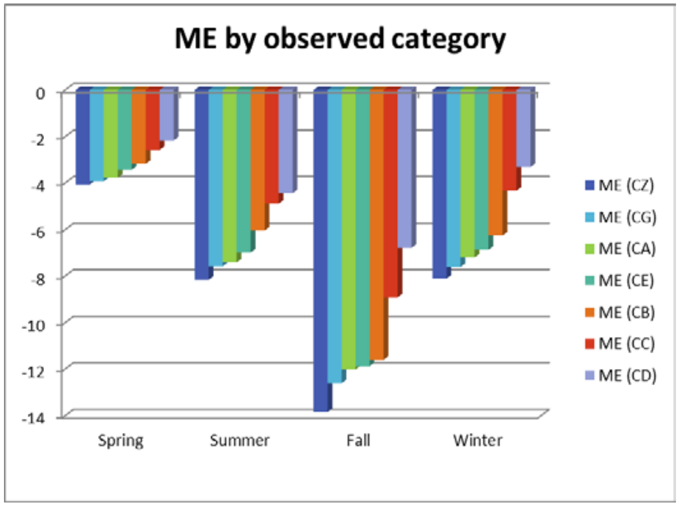


Figure J-17. Seasonal mean errors when observed stage greater than or equal to flood stage for medium responders

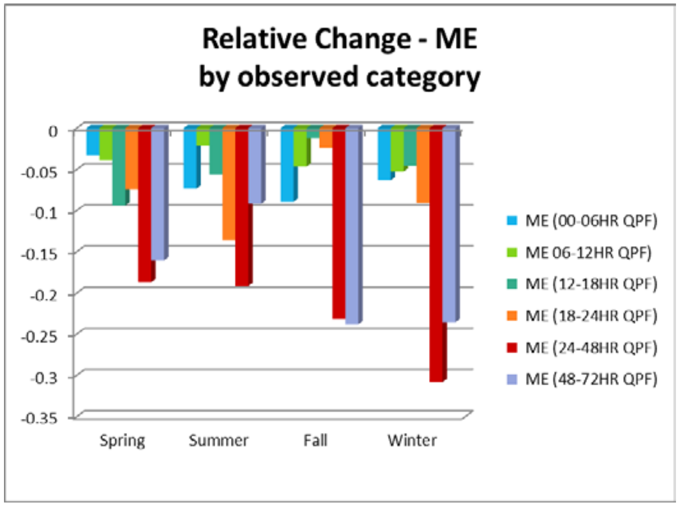


Figure J-18. Seasonal ME relative change when observed stage greater than or equal to flood stage for medium responders

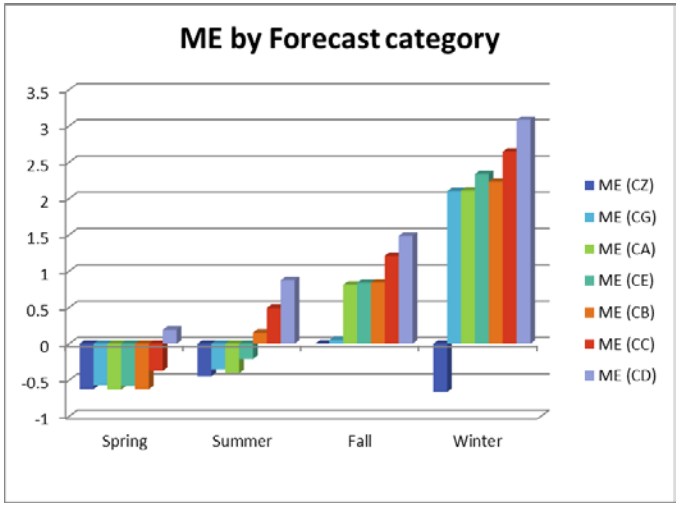


Figure J-19. Seasonal mean errors when forecast stage greater than or equal to flood stage for medium responders

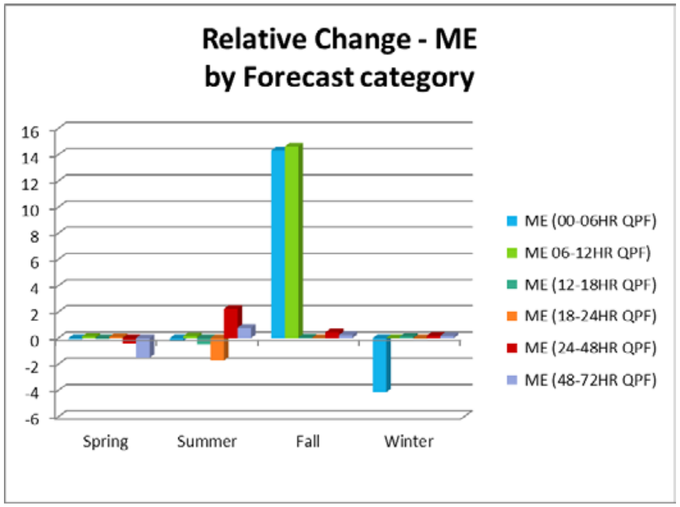


Figure J-20. Seasonal ME relative change when forecast stage greater than or equal to flood stage for medium responders

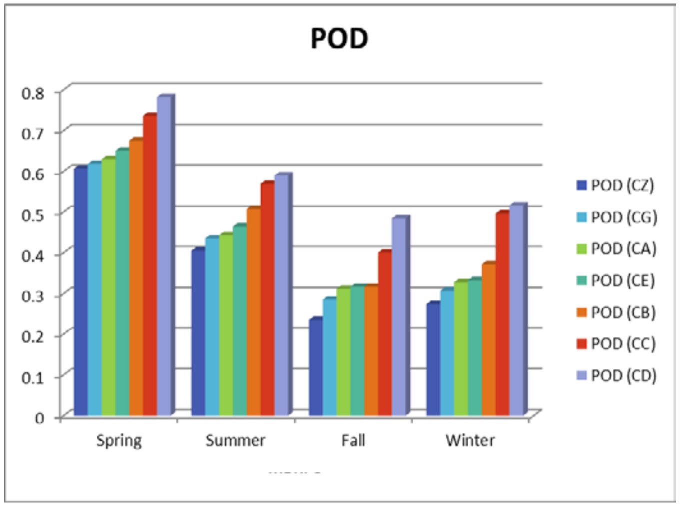


Figure J-21. Seasonal probability of detection for medium responders

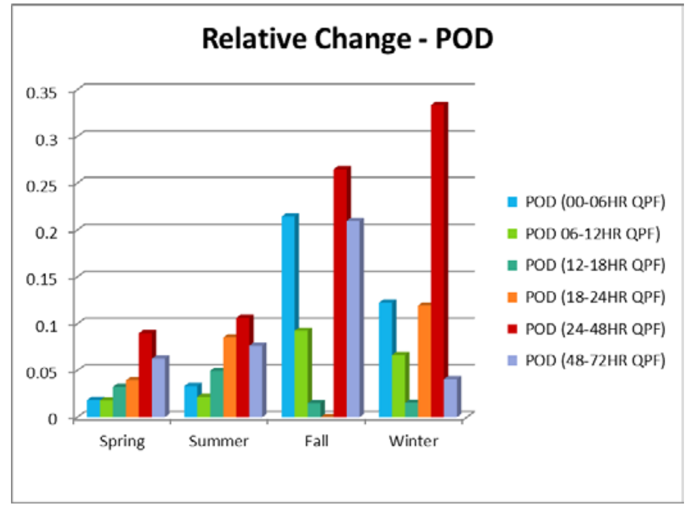


Figure J-22. Seasonal POD relative change for medium responders

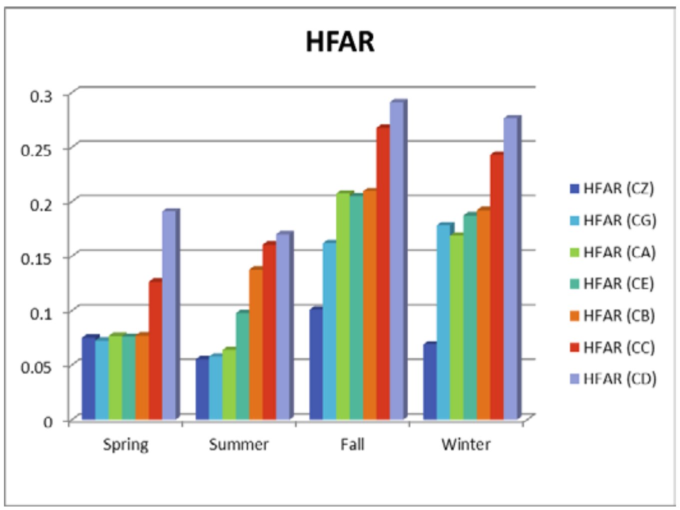


Figure J-23. Seasonal hydrologic false alarm ratio for medium responders

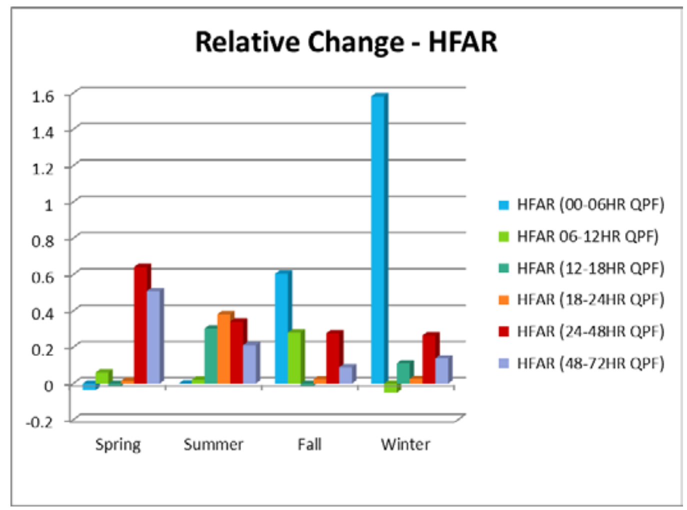


Figure J-24. Seasonal HFAR relative change for medium responders

Approach 2 – using QPFs of 0, 24, 48, and 72 hour

Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data				QPF Selected based on Relative Change			
~ Less QPF	MAE Forecast Cat	0	0	0	0	24	0	0	0
	ME Forecast Cat	24	0	24	0	24	0	0	0
	HFAR	0	0	0	0	0	0	0	0
~ More QPF	POD	72	72	72	72	24	24	24	24
	MAE Observed Cat	72	72	72	72	72	24	48	24
	ME Observed Cat	72	72	72	72	72	24	48	24
Conclusions		48	48	48	48	48	24	48	24

Table J-3. Summary of stage forecast analysis by season using QPFs of 0-, 24-, 48-, and 72-hour QPF – fast-response stations

Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data				QPF Selected based on Relative Change			
~ Less QPF	MAE Forecast Cat	0	0	0	48	24	0	48	48
	ME Forecast Cat	24	0	48	24	X	X	48	48
	HFAR	0	0	0	48	0	0	48	48
~ More QPF	POD	72	72	72	72	24	24	72	24
	MAE Observed Cat	72	72	72	72	24	24	72	24
	ME Observed Cat	72	72	72	72	24	24	72	24
Conclusions		48	48	48	48	24	24	72	48

Table J-4. Summary of stage forecast analysis by season using QPFs of 0, 24, 48, and 72 hour – medium-response stations

Fast Response Plots

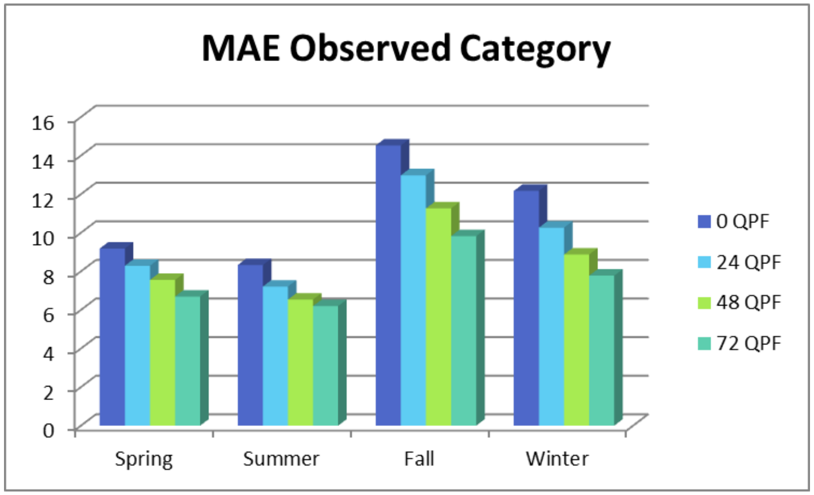


Figure J-25. Seasonal mean absolute errors when observed stage greater than or equal to flood stage fast responders

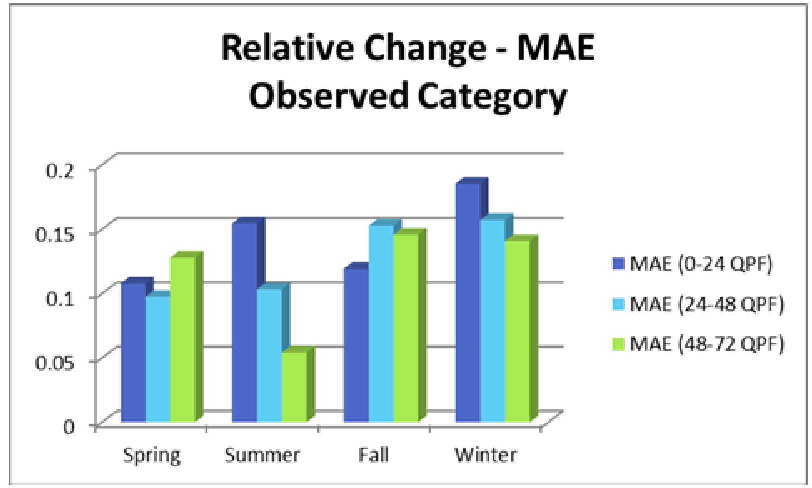


Figure J-26. Seasonal MAE relative change for observed stage greater than or equal to flood stage for fast responders

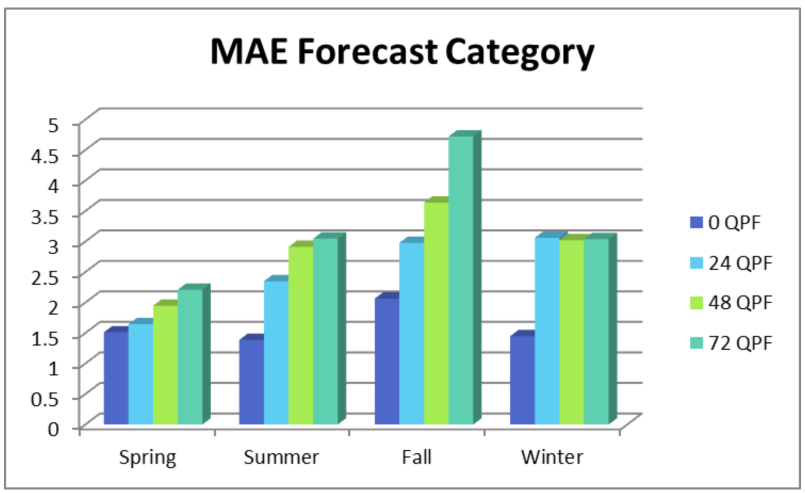


Figure J-27. Seasonal mean absolute errors when forecast stage greater than or equal to flood stage for fast responders

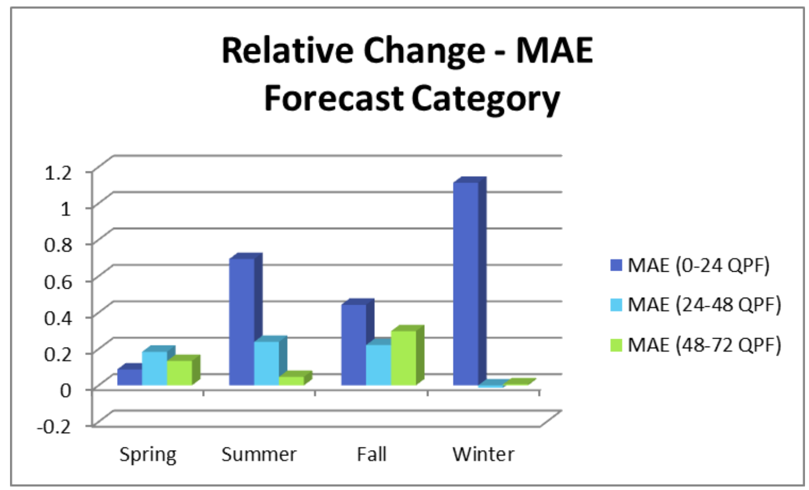
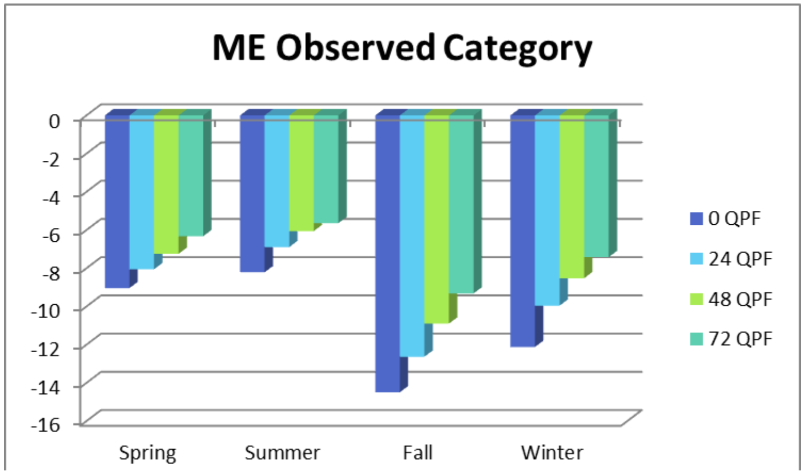


Figure J-28. Seasonal MAE relative change for forecast stage greater than or equal to flood stage for fast responders



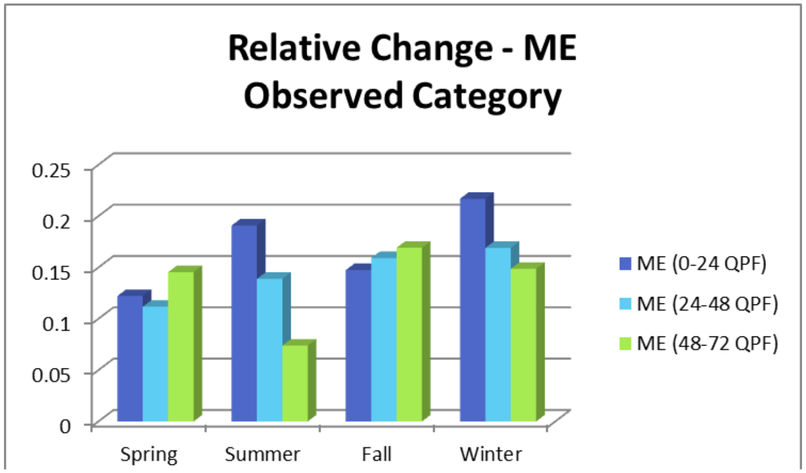
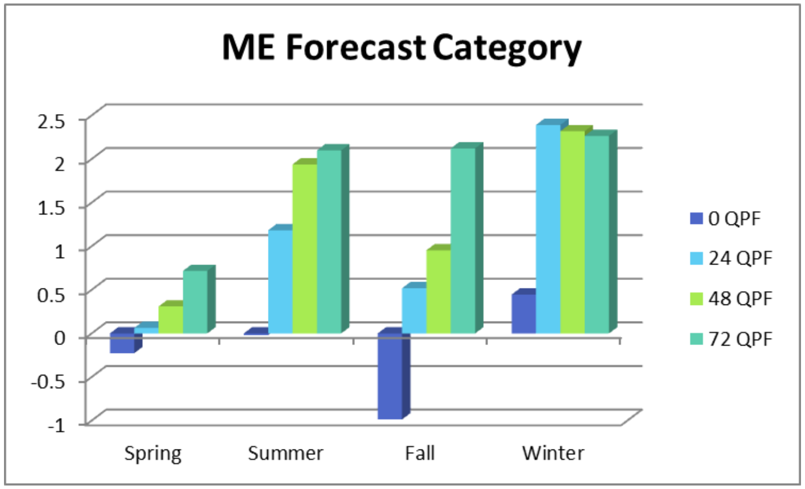


Figure J-29. Seasonal mean errors when observed stage greater than or equal to flood stage for fast responders

Figure J-30. Seasonal ME relative change when observed stage greater than or equal to flood stage for fast responders



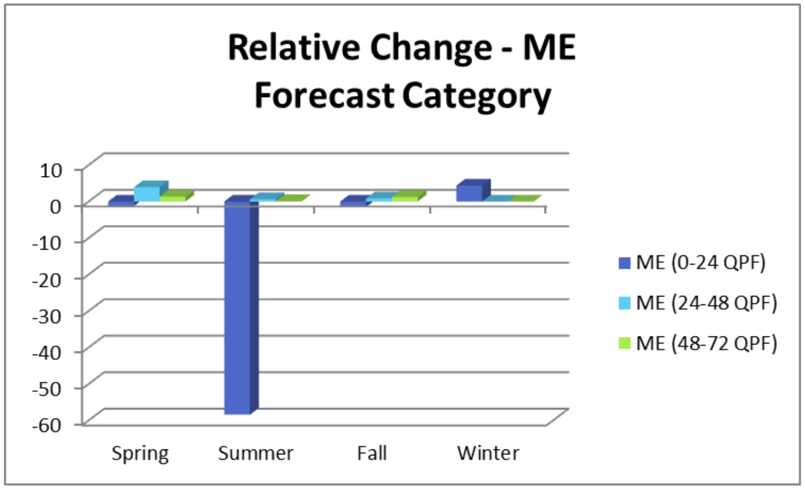


Figure J-31. Seasonal mean errors when forecast stage greater than or equal to flood stage for fast responders

Figure J-32. Seasonal ME relative change when forecast stage greater than or equal to flood stage for fast responders

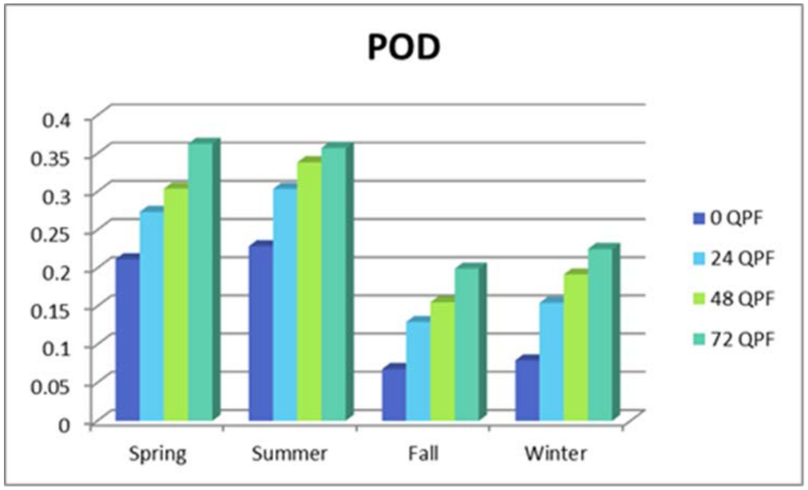


Figure J-33. Seasonal probability of detection for fast responders

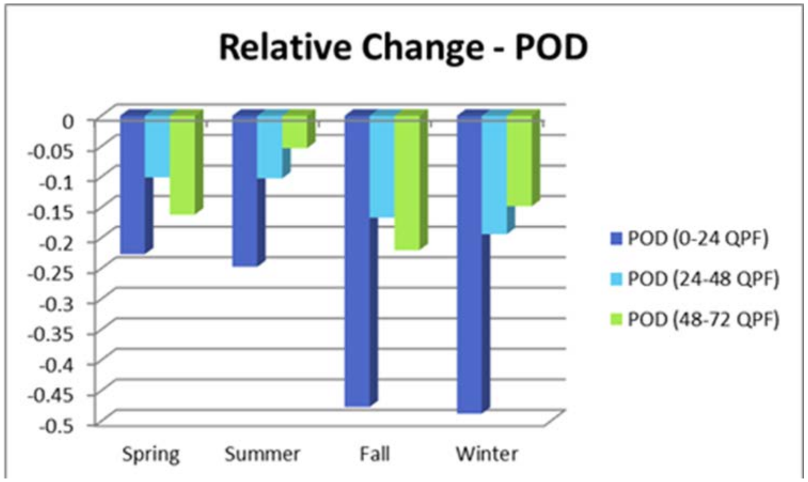


Figure J-34. Seasonal POD relative change for fast responders

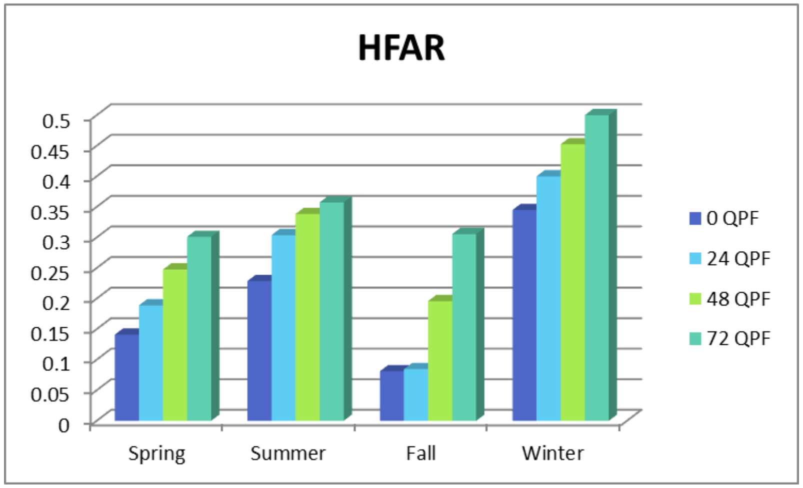


Figure J-35. Seasonal hydrologic false alarm ratio for fast responders

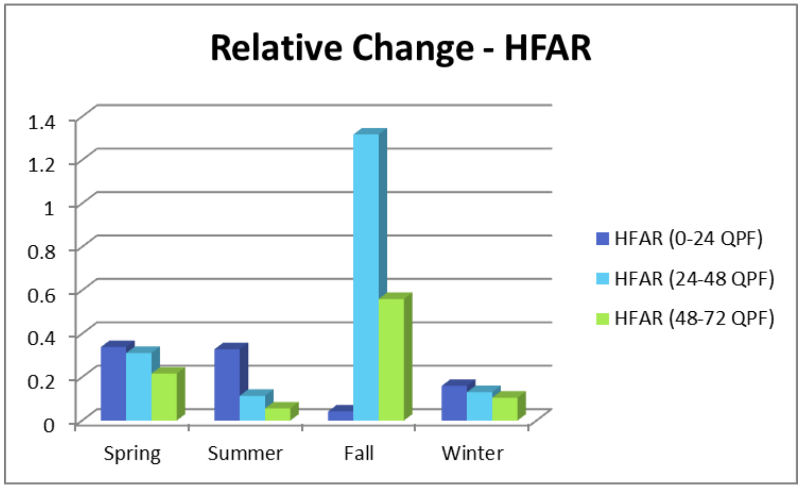


Figure J-36. Seasonal HFAR relative change for fast responders

Medium Response Stations

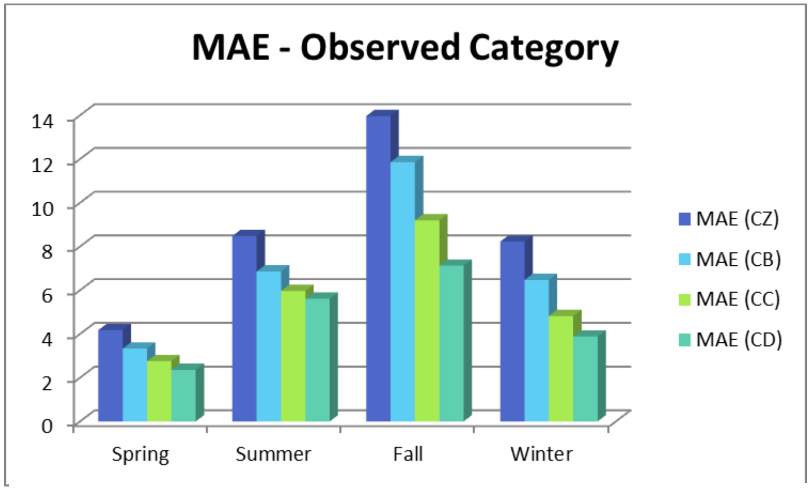


Figure J-37. Seasonal mean absolute errors when observed stage greater than or equal to flood stage for medium responders

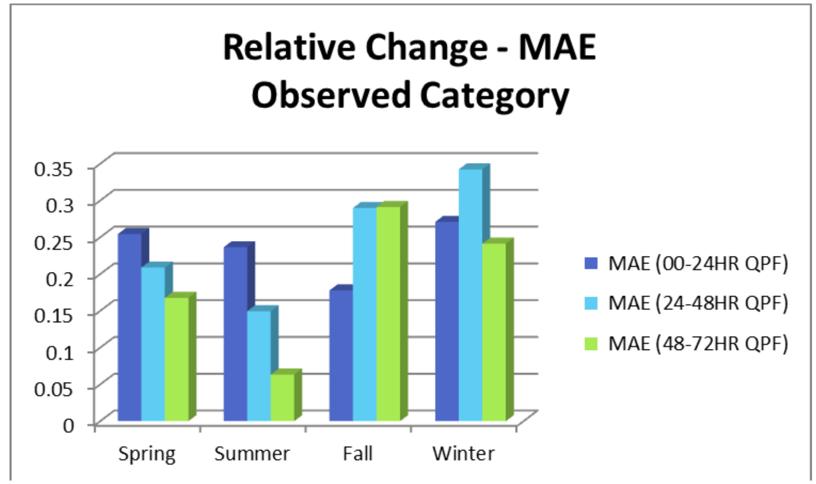


Figure J-38. Seasonal MAE relative change when observed stage greater than or equal to flood stage for medium responders

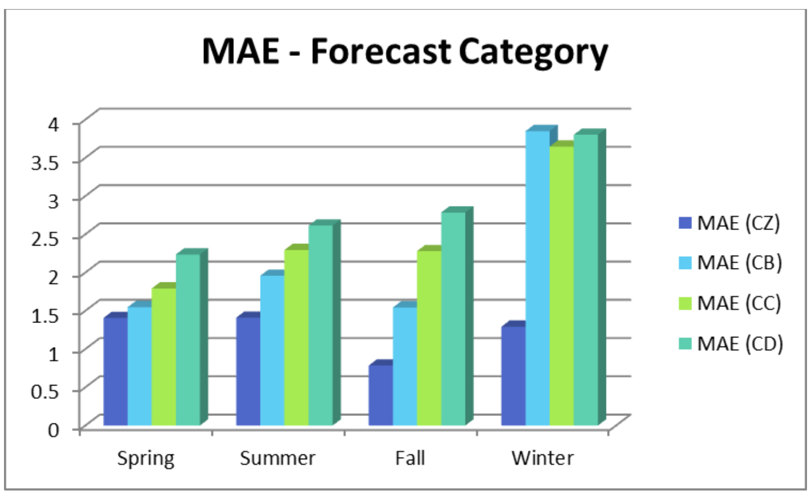


Figure J-39. Seasonal mean absolute errors when forecast stage greater than or equal to flood stage for medium responders

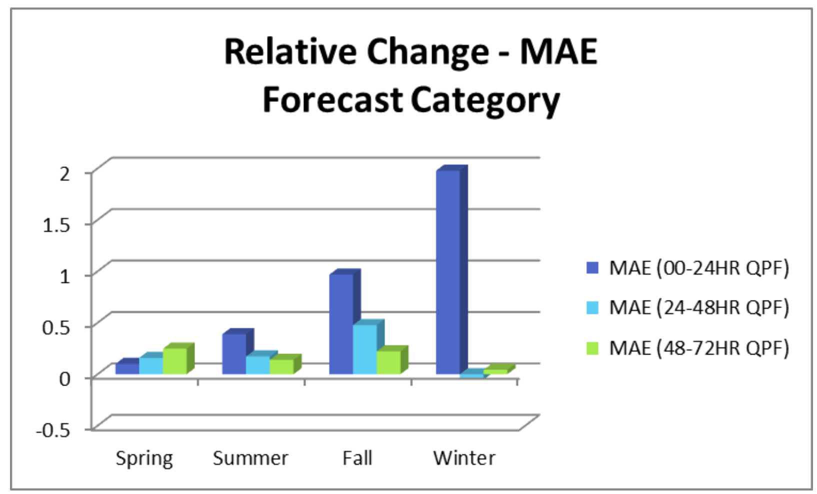


Figure J-40. Seasonal MAE relative change when forecast stage greater than or equal to flood stage for medium responders

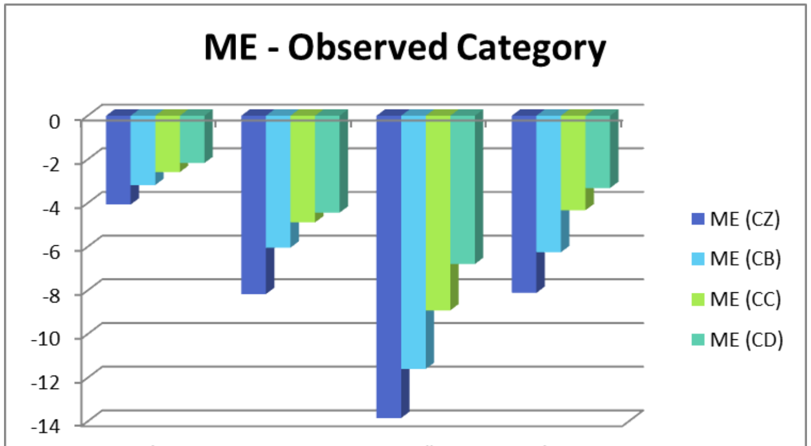


Figure J-41. Seasonal mean errors when observed stage greater than or equal to flood stage for medium responders

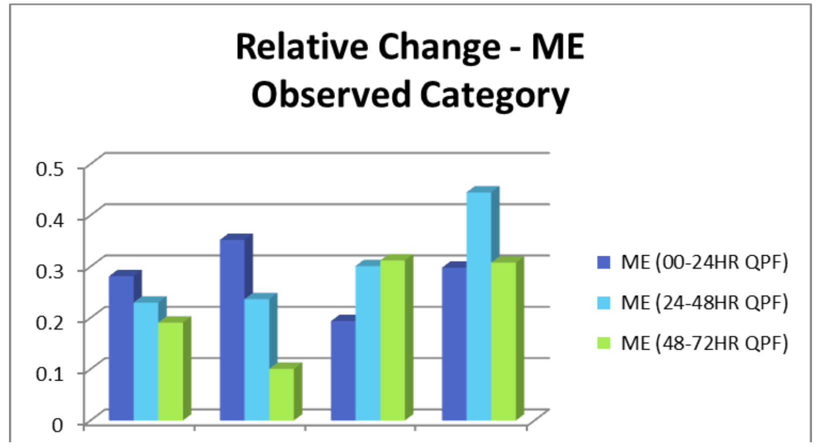


Figure J-42. Seasonal ME relative change when observed stage greater than or equal to flood stage for medium responders

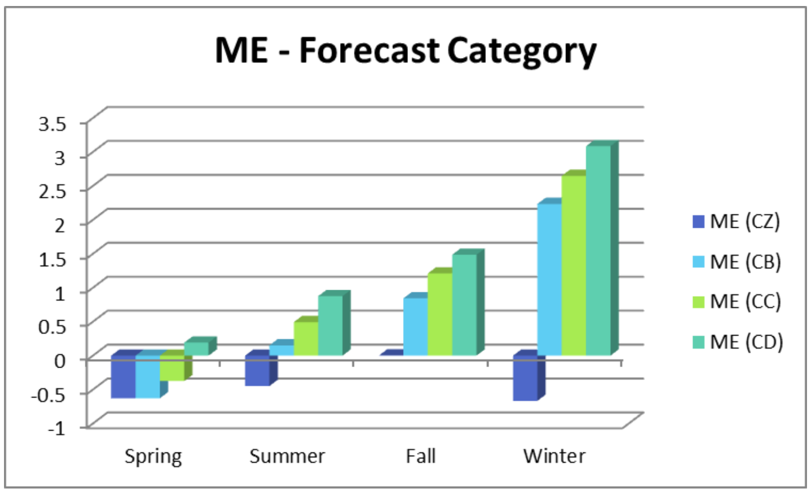


Figure J-43. Seasonal mean errors when forecast stage greater than or equal to flood stage for medium responders

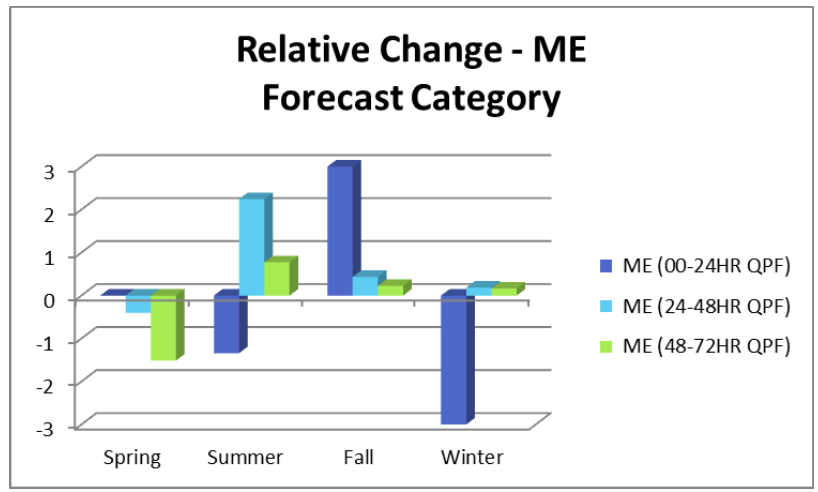


Figure J-44. Seasonal ME relative change when forecast stage greater than or equal to flood stage for medium responders

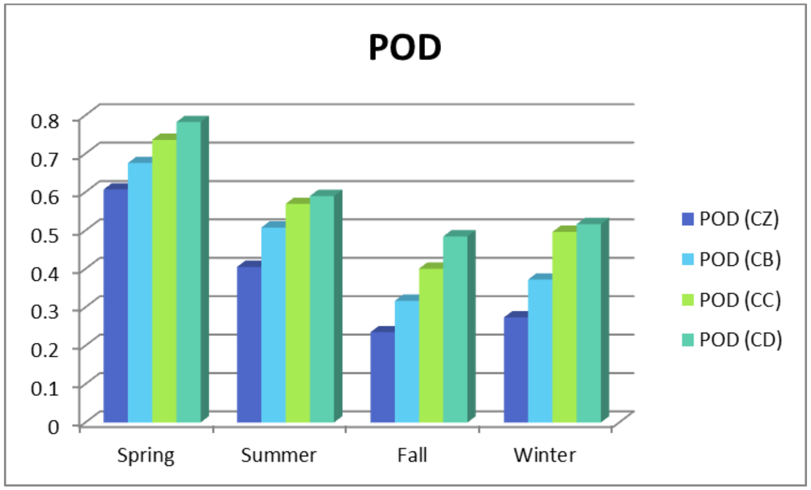


Figure J-45. Seasonal probability of detection for medium responders

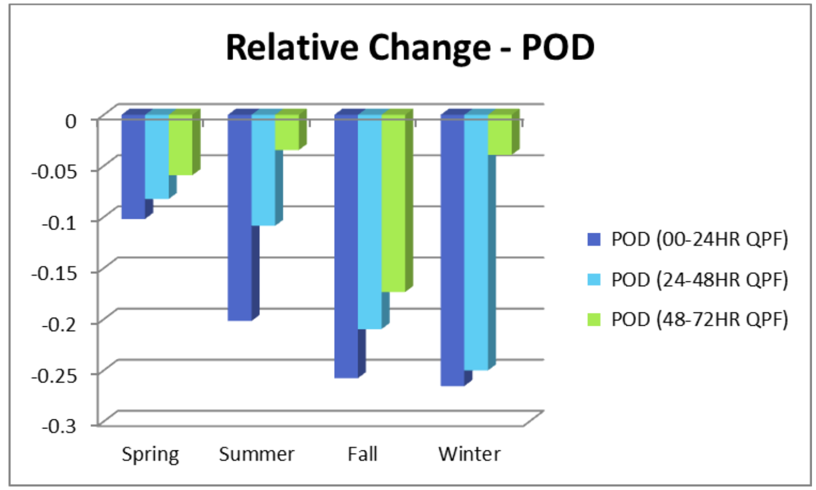


Figure J-46. Seasonal POD relative change for medium responders

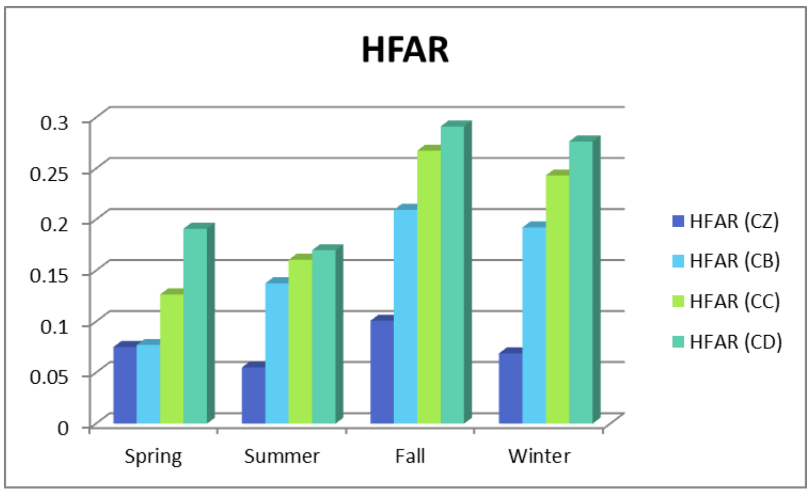


Figure J-47. Seasonal hydrologic false alarm ratio for medium responders

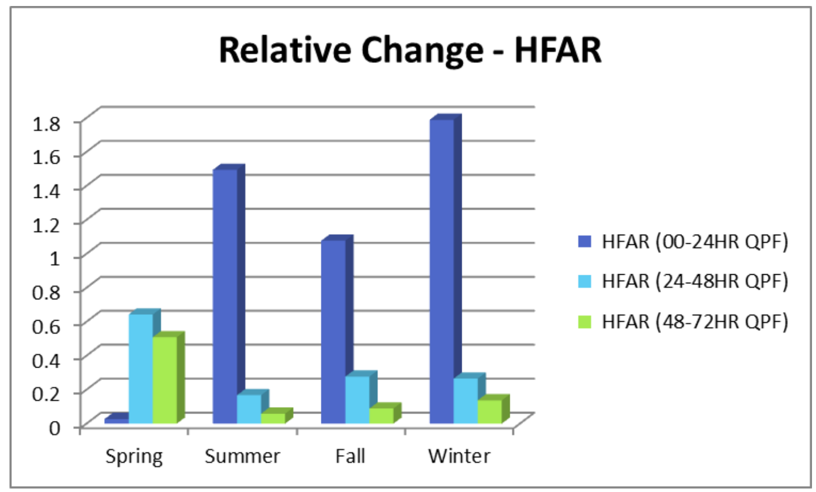


Figure J-48. Seasonal HFAR relative change for medium responders

Approach 3 – POD vs. HFAR Plots

QPF Selected based on HFAR vs POD lead-time plots Considered 0-, 6-, 12-, 18-, 24-, 48-, and 72-hr QPFs	
Forecast Point Response Time Category	
Fast	24
Medium	48
Slow	Not Calculated
Conclusions	48

Table J-5. Summary of stage forecast analysis by season based on HFAR vs. POD lead-time plots for durations of 0-, 6-, 12-, 18-, 24-, 48-, and 72-hour QPF

Forecast Point Response Time Category	Spring	Summer	Fall	Winter
	QPF Selected based on HFAR vs POD seasonal plots Considered 0-, 6-, 12-, 18-, 24-, 48-, and 72-hr QPFs			
Fast	48	24	48	12
Medium	72	72	24	24
Slow	24	72	18	24
Conclusions	48	48	24	24

Table J-6. Summary of stage forecast analysis by season based on HFAR vs. POD lead-time plots for durations of 0-, 6-, 12-, 18-, 24-, 48-, and 72-hour QPF

Lead-Time Plots

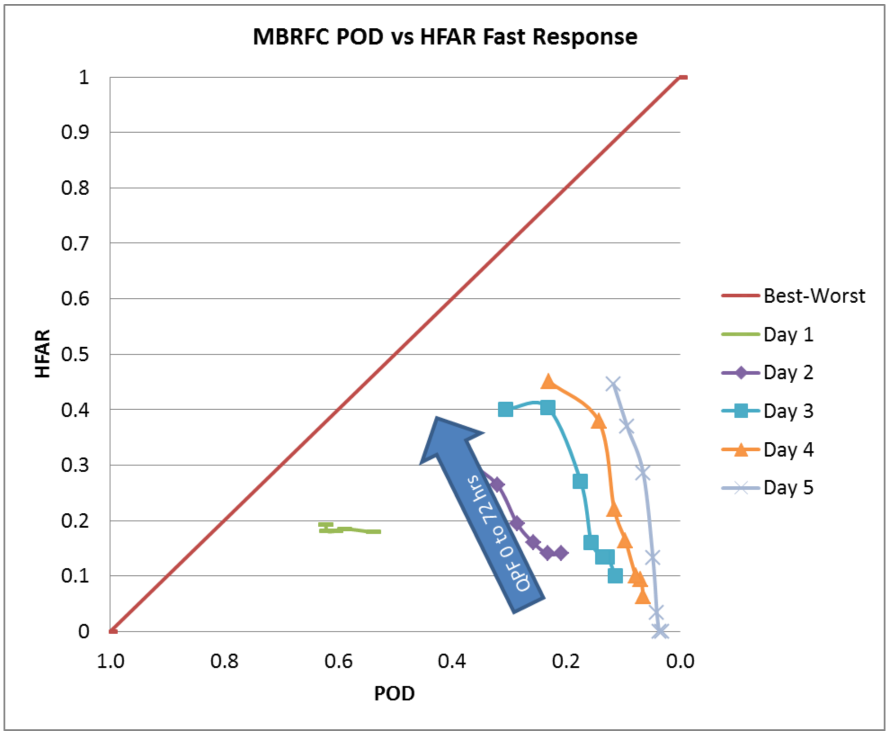


Figure J-49. POD vs. HFAR by lead time for fast responders

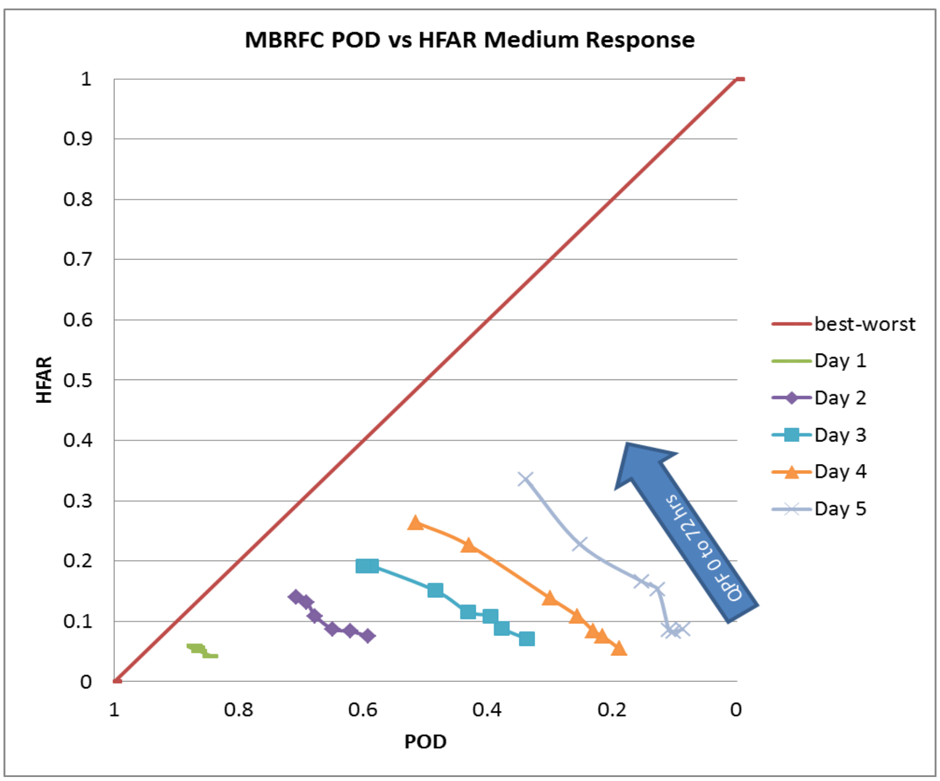


Figure J-50. POD vs. HFAR by lead time for medium responders

Seasons Plots

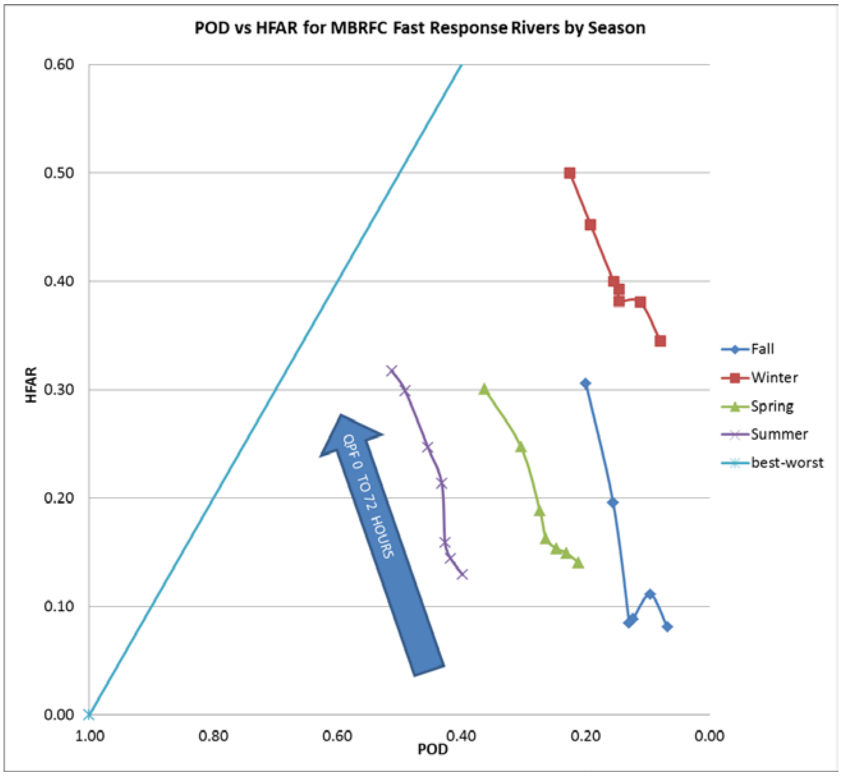


Figure J-51. POD vs. HFAR by seasons for fast responders

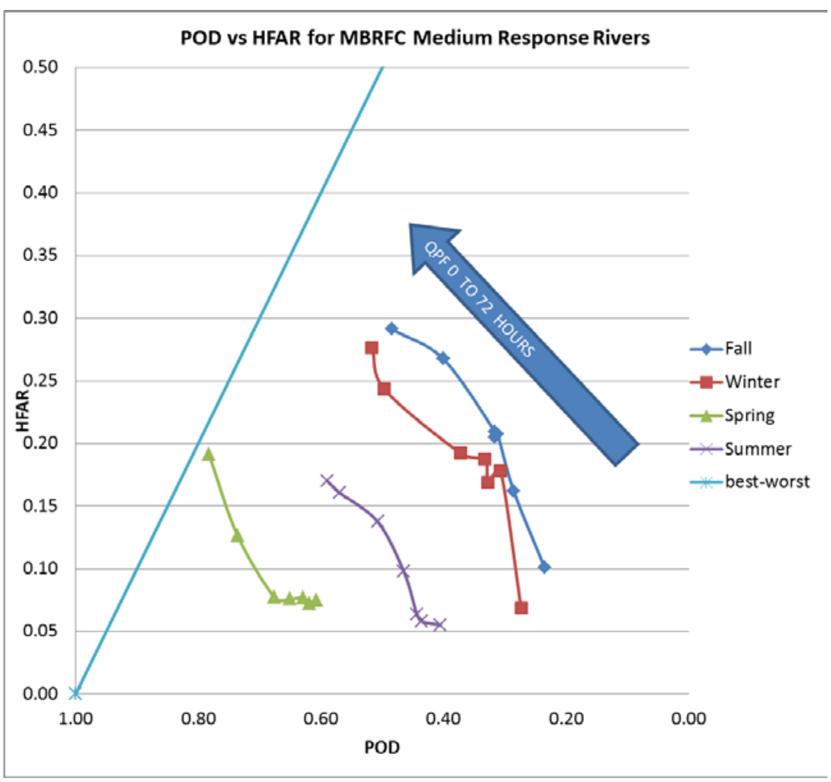


Figure J-52. POD vs. HFAR by seasons for ,edium responders

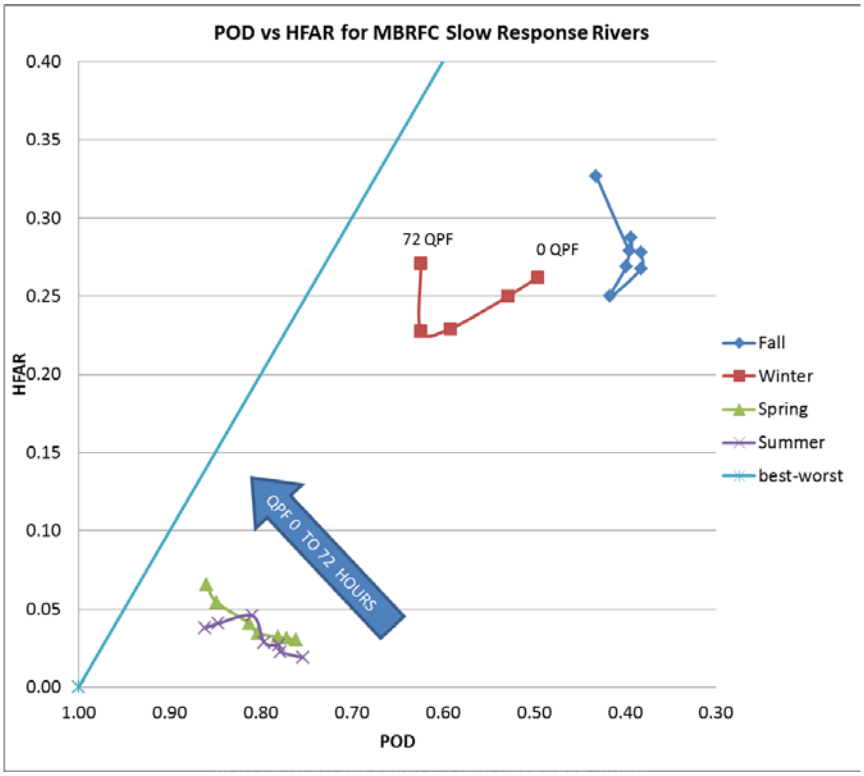
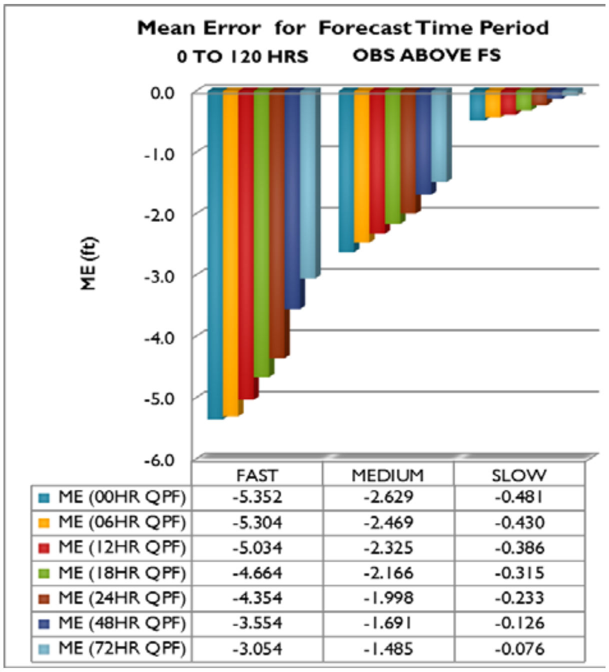


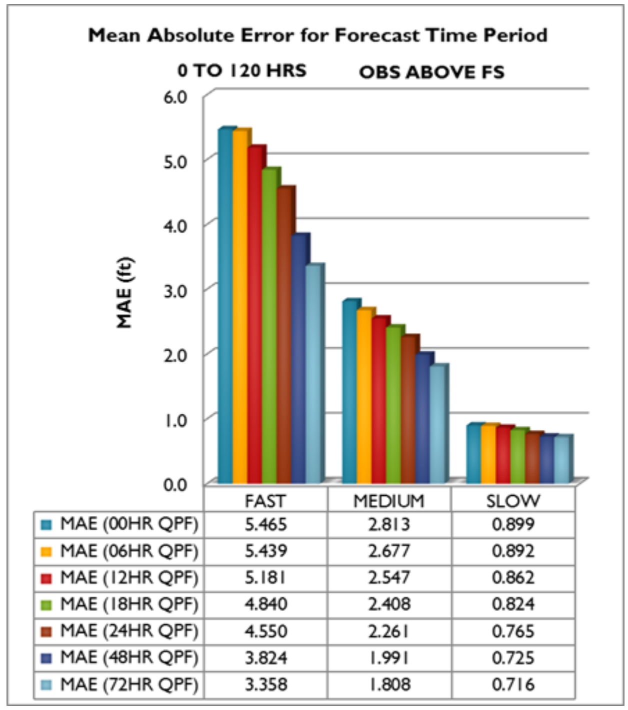
Figure J-53. POD vs. HFAR by seasons for slow responders

Appendix K – Part 3 NCRFC Results



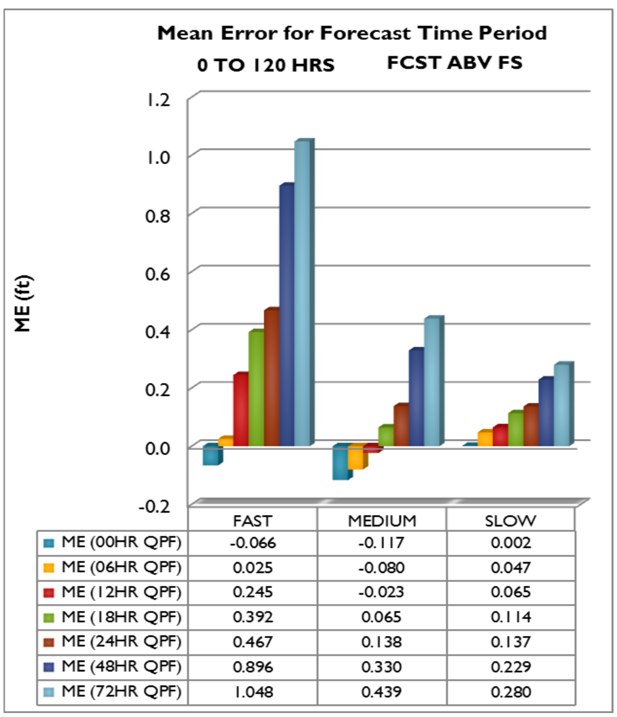
	FAST	MEDIUM	SLOW
ME (00HR QPF)	-5.352	-2.629	-0.481
ME (06HR QPF)	-5.304	-2.469	-0.430
ME (12HR QPF)	-5.034	-2.325	-0.386
ME (18HR QPF)	-4.664	-2.166	-0.315
ME (24HR QPF)	-4.354	-1.998	-0.233
ME (48HR QPF)	-3.554	-1.691	-0.126
ME (72HR QPF)	-3.054	-1.485	-0.076

Figure K-1. Mean error for 5-day forecasts conditioned on observations >= flood stage



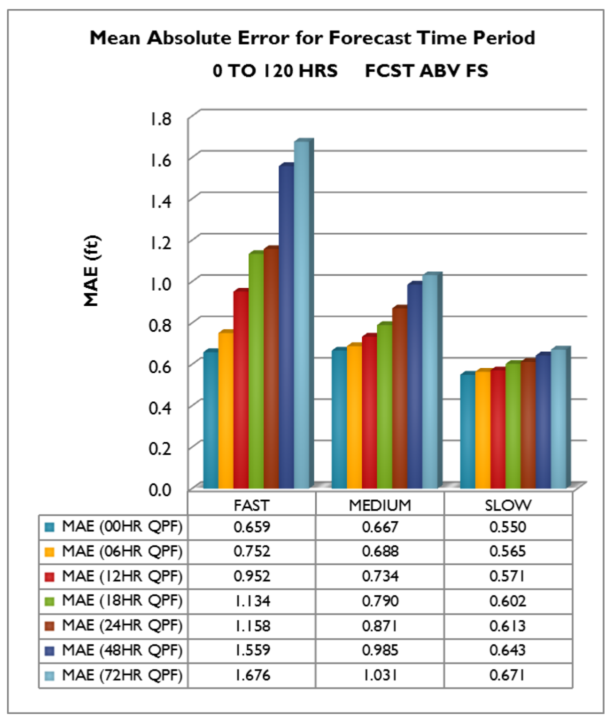
	FAST	MEDIUM	SLOW
MAE (00HR QPF)	5.465	2.813	0.899
MAE (06HR QPF)	5.439	2.677	0.892
MAE (12HR QPF)	5.181	2.547	0.862
MAE (18HR QPF)	4.840	2.408	0.824
MAE (24HR QPF)	4.550	2.261	0.765
MAE (48HR QPF)	3.824	1.991	0.725
MAE (72HR QPF)	3.358	1.808	0.716

Figure K-2. Mean absolute error for 5-day forecasts conditioned on observations >= flood stage



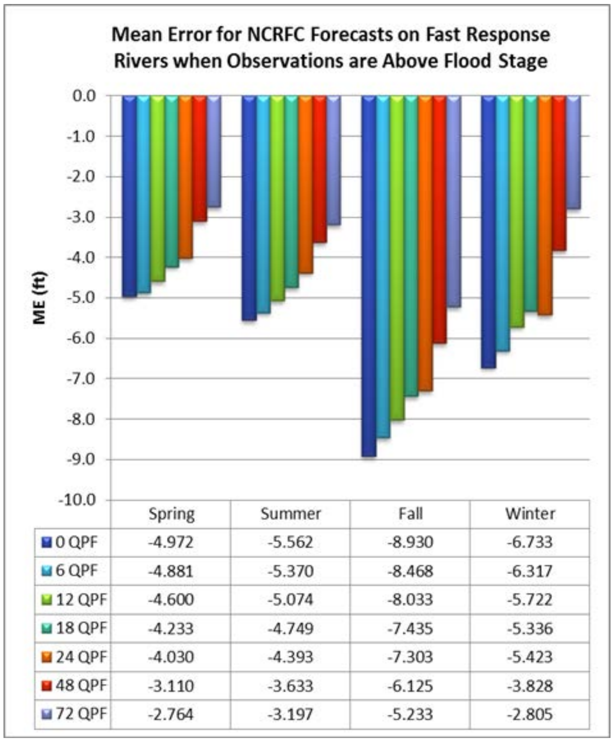
	FAST	MEDIUM	SLOW
ME (00HR QPF)	-0.066	-0.117	0.002
ME (06HR QPF)	0.025	-0.080	0.047
ME (12HR QPF)	0.245	-0.023	0.065
ME (18HR QPF)	0.392	0.065	0.114
ME (24HR QPF)	0.467	0.138	0.137
ME (48HR QPF)	0.896	0.330	0.229
ME (72HR QPF)	1.048	0.439	0.280

Figure K-3. Mean error for 5-day forecasts conditioned on forecast stages >= flood stage



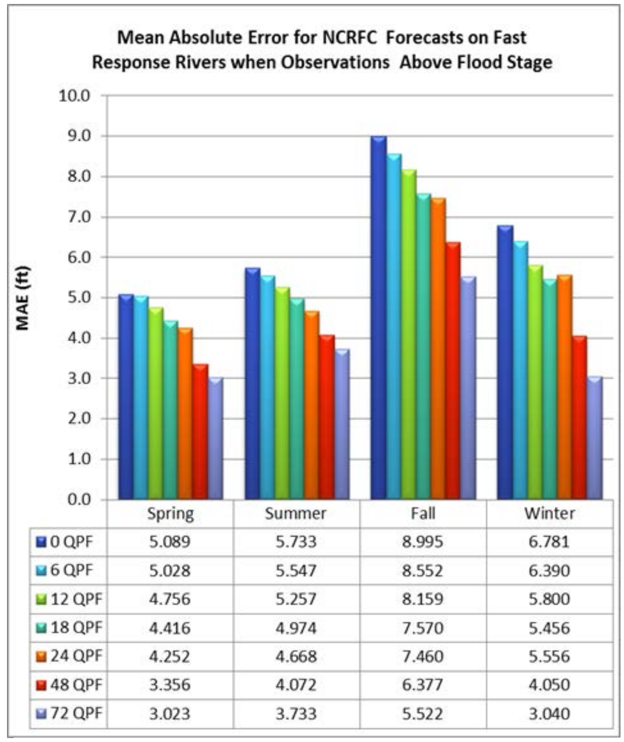
	FAST	MEDIUM	SLOW
MAE (00HR QPF)	0.659	0.667	0.550
MAE (06HR QPF)	0.752	0.688	0.565
MAE (12HR QPF)	0.952	0.734	0.571
MAE (18HR QPF)	1.134	0.790	0.602
MAE (24HR QPF)	1.158	0.871	0.613
MAE (48HR QPF)	1.559	0.985	0.643
MAE (72HR QPF)	1.676	1.031	0.671

Figure K-4. Mean absolute error for 5-day forecasts conditioned on forecast stages >= flood stage



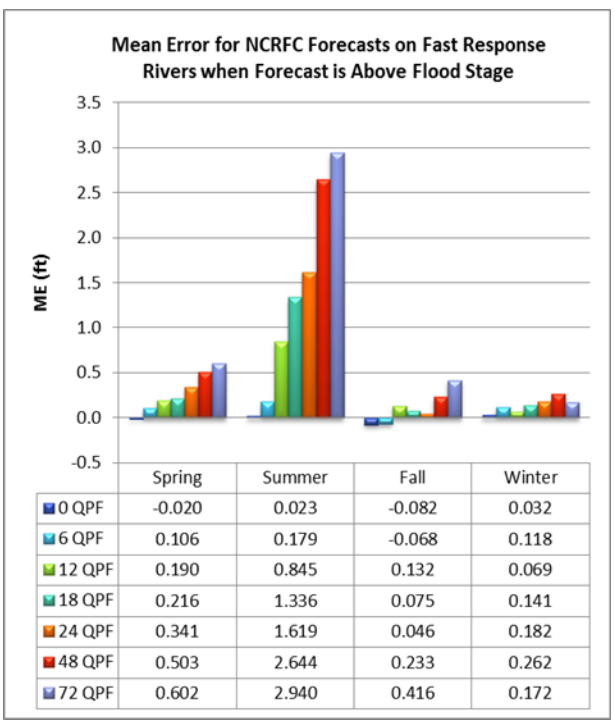
	Spring	Summer	Fall	Winter
0 QPF	-4.972	-5.562	-8.930	-6.733
6 QPF	-4.881	-5.370	-8.468	-6.317
12 QPF	-4.600	-5.074	-8.033	-5.722
18 QPF	-4.233	-4.749	-7.435	-5.336
24 QPF	-4.030	-4.393	-7.303	-5.423
48 QPF	-3.110	-3.633	-6.125	-3.828
72 QPF	-2.764	-3.197	-5.233	-2.805

Figure K-5. Seasonal mean error for fast responders conditioned on observations >= flood stage



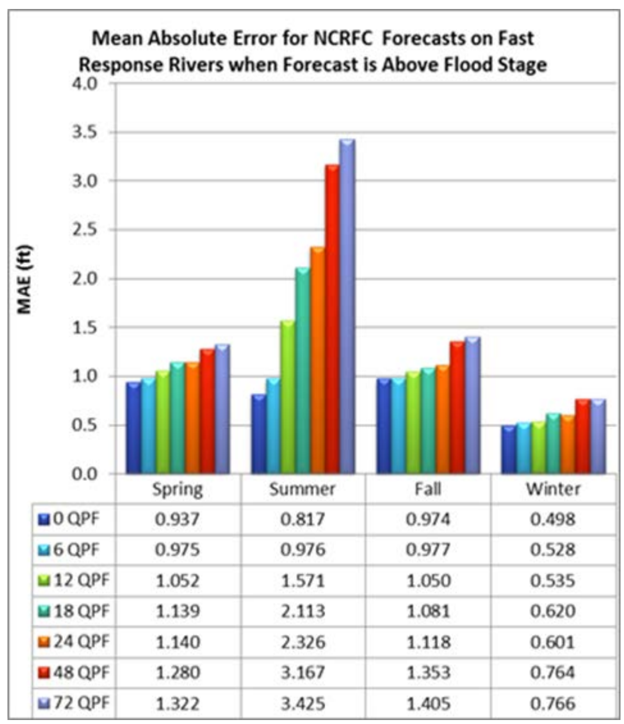
	Spring	Summer	Fall	Winter
0 QPF	5.089	5.733	8.995	6.781
6 QPF	5.028	5.547	8.552	6.390
12 QPF	4.756	5.257	8.159	5.800
18 QPF	4.416	4.974	7.570	5.456
24 QPF	4.252	4.668	7.460	5.556
48 QPF	3.356	4.072	6.377	4.050
72 QPF	3.023	3.733	5.522	3.040

Figure K-6. Seasonal mean absolute error for fast responders conditioned on observations >= flood stage



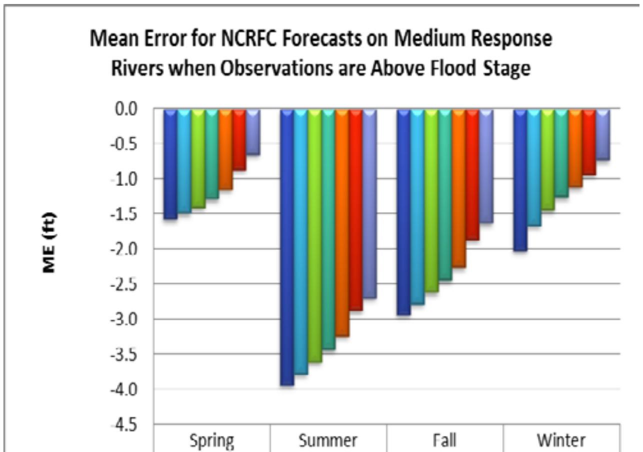
	Spring	Summer	Fall	Winter
0 QPF	-0.020	0.023	-0.082	0.032
6 QPF	0.106	0.179	-0.068	0.118
12 QPF	0.190	0.845	0.132	0.069
18 QPF	0.216	1.336	0.075	0.141
24 QPF	0.341	1.619	0.046	0.182
48 QPF	0.503	2.644	0.233	0.262
72 QPF	0.602	2.940	0.416	0.172

Figure K-7. Seasonal mean error for fast responders conditioned on forecast stage >= flood stage



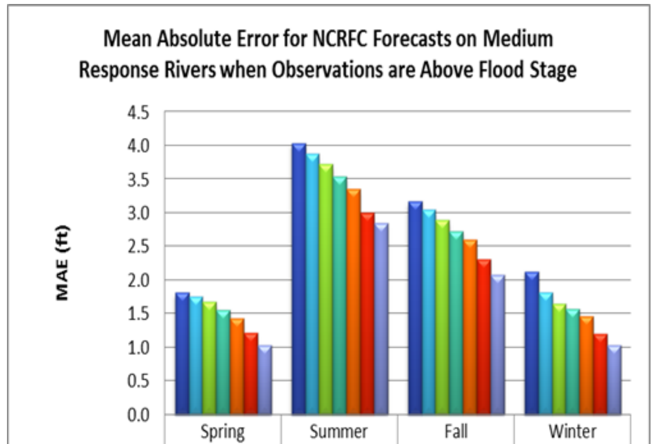
	Spring	Summer	Fall	Winter
0 QPF	0.937	0.817	0.974	0.498
6 QPF	0.975	0.976	0.977	0.528
12 QPF	1.052	1.571	1.050	0.535
18 QPF	1.139	2.113	1.081	0.620
24 QPF	1.140	2.326	1.118	0.601
48 QPF	1.280	3.167	1.353	0.764
72 QPF	1.322	3.425	1.405	0.766

Figure K-8. Seasonal mean absolute error for fast responders conditioned on forecast stage >= flood stage



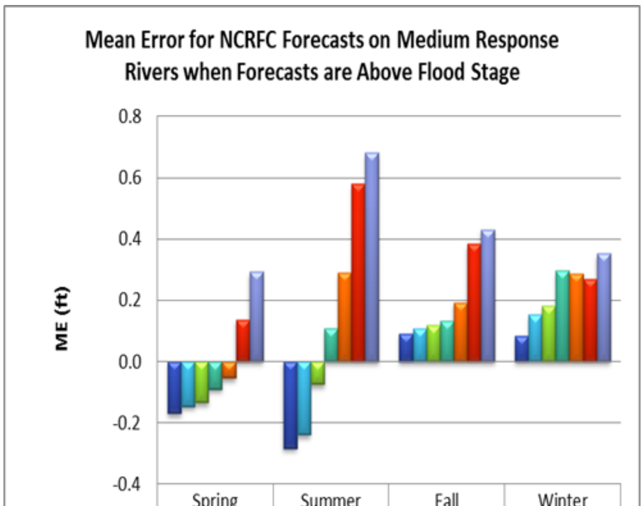
	Spring	Summer	Fall	Winter
ME 0hr QPF	-1.568	-3.930	-2.932	-2.018
ME 6 hr QPF	-1.482	-3.771	-2.775	-1.662
ME 12 hr QPF	-1.403	-3.603	-2.608	-1.436
ME 18 hr QPF	-1.283	-3.421	-2.438	-1.251
ME 24 hr QPF	-1.147	-3.230	-2.250	-1.105
ME 48 hr QPF	-0.855	-2.865	-1.856	-0.927
ME 72 hr QPF	-0.641	-2.689	-1.622	-0.719

Figure K-9. Seasonal mean error for medium responders conditioned on observations >= flood stage



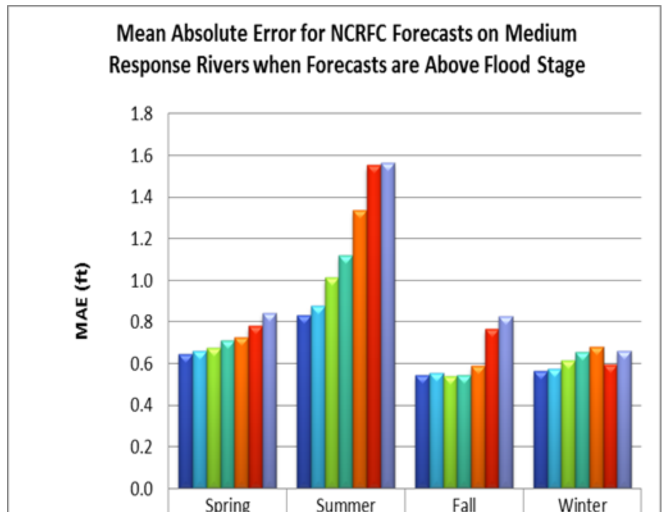
	Spring	Summer	Fall	Winter
MAE 0hr QPF	1.816	4.037	3.167	2.133
MAE 6 hr QPF	1.753	3.886	3.045	1.824
MAE 12 hr QPF	1.679	3.723	2.893	1.657
MAE 18 hr QPF	1.562	3.545	2.735	1.579
MAE 24 hr QPF	1.433	3.359	2.605	1.468
MAE 48 hr QPF	1.213	3.007	2.314	1.205
MAE 72 hr QPF	1.031	2.844	2.086	1.038

Figure K-10. Seasonal mean absolute error for medium responders conditioned on observations >= flood stage



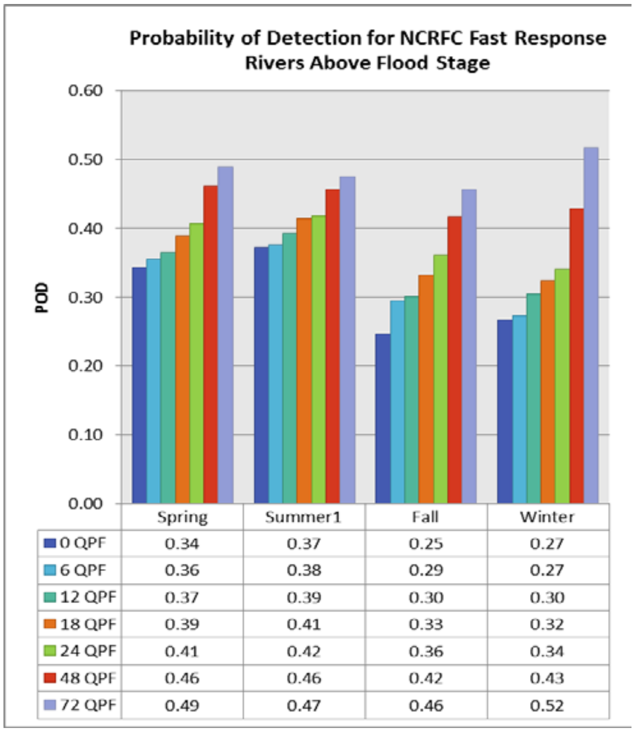
	Spring	Summer	Fall	Winter
ME 0hr QPF	-0.169	-0.284	0.092	0.084
ME 6 hr QPF	-0.146	-0.240	0.107	0.152
ME 12 hr QPF	-0.135	-0.074	0.120	0.182
ME 18 hr QPF	-0.090	0.110	0.132	0.295
ME 24 hr QPF	-0.055	0.291	0.194	0.287
ME 48 hr QPF	0.136	0.579	0.383	0.269
ME 72 hr QPF	0.292	0.680	0.432	0.352

Figure K11. Seasonal mean error for medium responders conditioned on forecast stage >= flood stage



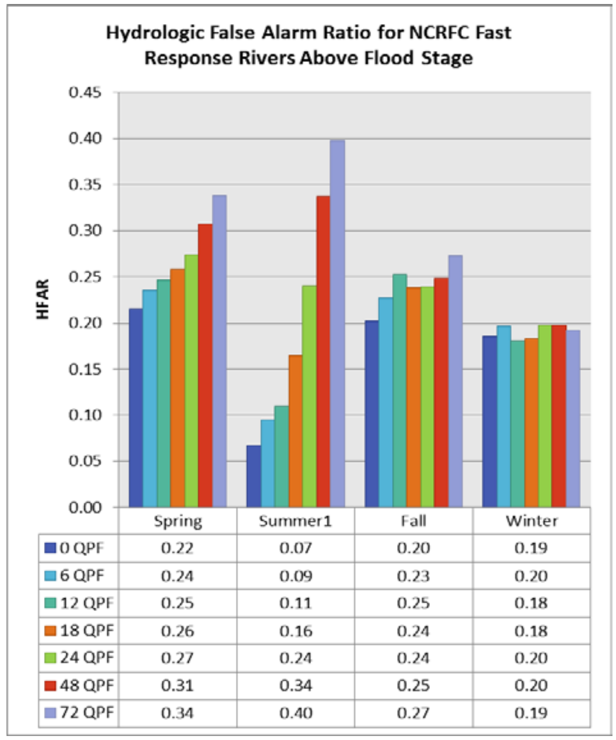
	Spring	Summer	Fall	Winter
MAE 0hr QPF	0.646	0.833	0.547	0.564
MAE 6 hr QPF	0.663	0.880	0.555	0.574
MAE 12 hr QPF	0.677	1.014	0.542	0.614
MAE 18 hr QPF	0.714	1.122	0.544	0.654
MAE 24 hr QPF	0.727	1.338	0.588	0.680
MAE 48 hr QPF	0.781	1.553	0.768	0.594
MAE 72 hr QPF	0.844	1.566	0.826	0.662

Figure K-12. Seasonal mean error for medium responders conditioned on forecast stage >= flood stage



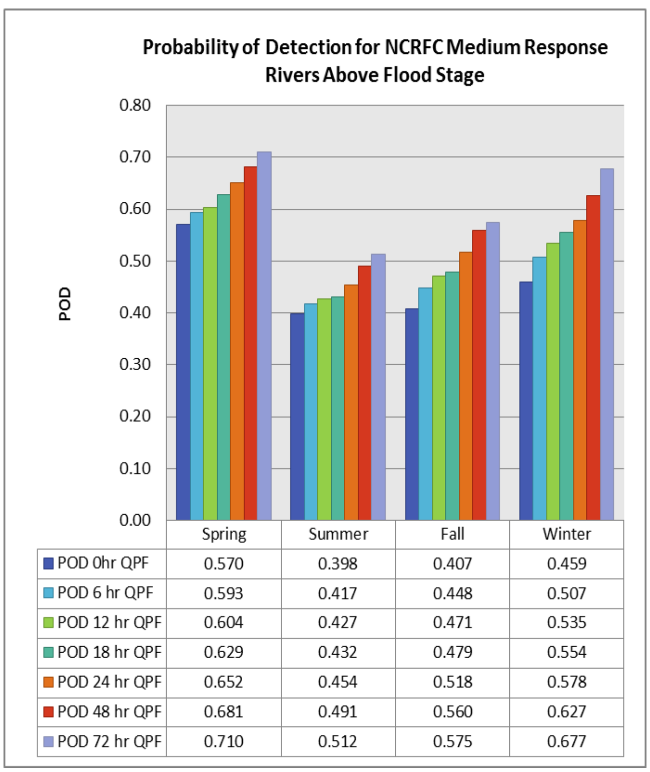
	Spring	Summer1	Fall	Winter
0 QPF	0.34	0.37	0.25	0.27
6 QPF	0.36	0.38	0.29	0.27
12 QPF	0.37	0.39	0.30	0.30
18 QPF	0.39	0.41	0.33	0.32
24 QPF	0.41	0.42	0.36	0.34
48 QPF	0.46	0.46	0.42	0.43
72 QPF	0.49	0.47	0.46	0.52

Figure K-13. Seasonal POD for fast responders



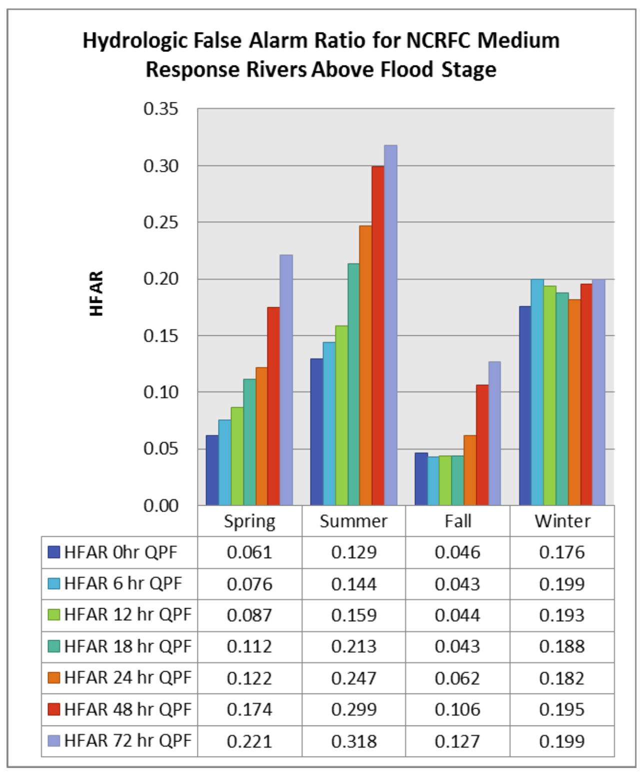
	Spring	Summer1	Fall	Winter
0 QPF	0.22	0.07	0.20	0.19
6 QPF	0.24	0.09	0.23	0.20
12 QPF	0.25	0.11	0.25	0.18
18 QPF	0.26	0.16	0.24	0.18
24 QPF	0.27	0.24	0.24	0.20
48 QPF	0.31	0.34	0.25	0.20
72 QPF	0.34	0.40	0.27	0.19

Figure K-14. Seasonal HFAR for fast responders



	Spring	Summer	Fall	Winter
POD 0hr QPF	0.570	0.398	0.407	0.459
POD 6 hr QPF	0.593	0.417	0.448	0.507
POD 12 hr QPF	0.604	0.427	0.471	0.535
POD 18 hr QPF	0.629	0.432	0.479	0.554
POD 24 hr QPF	0.652	0.454	0.518	0.578
POD 48 hr QPF	0.681	0.491	0.560	0.627
POD 72 hr QPF	0.710	0.512	0.575	0.677

Figure K-15. Seasonal POD for medium responders



	Spring	Summer	Fall	Winter
HFAR 0hr QPF	0.061	0.129	0.046	0.176
HFAR 6 hr QPF	0.076	0.144	0.043	0.199
HFAR 12 hr QPF	0.087	0.159	0.044	0.193
HFAR 18 hr QPF	0.112	0.213	0.043	0.188
HFAR 24 hr QPF	0.122	0.247	0.062	0.182
HFAR 48 hr QPF	0.174	0.299	0.106	0.195
HFAR 72 hr QPF	0.221	0.318	0.127	0.199

Figure K-16. Seasonal HFAR for medium responders

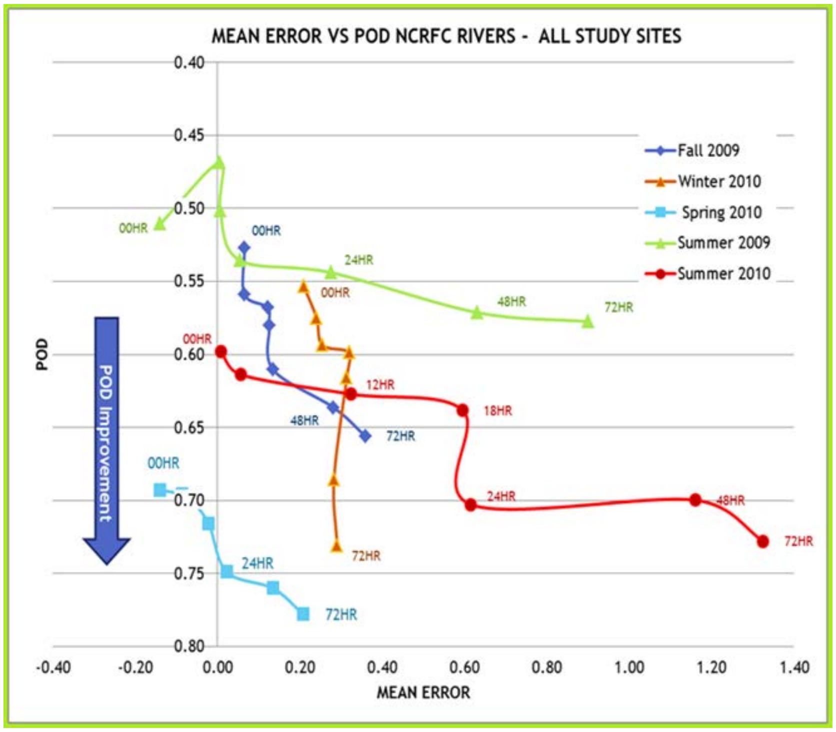


Figure K-17. HFAR vs mean error by seasons for all response time stations combined

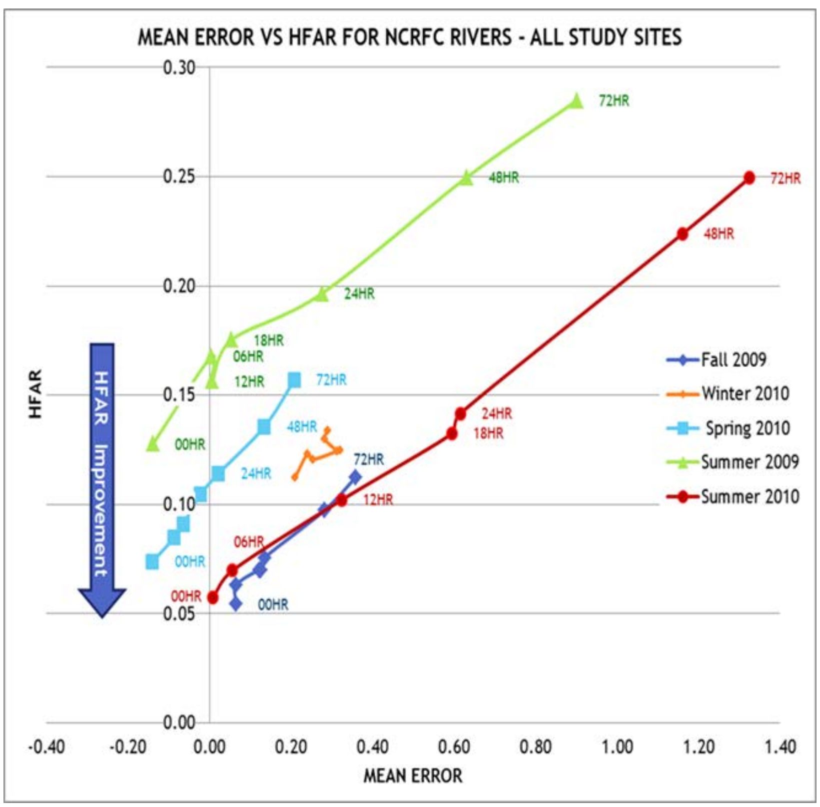


Figure K-18. HFAR vs mean error by seasons for all response time stations combined

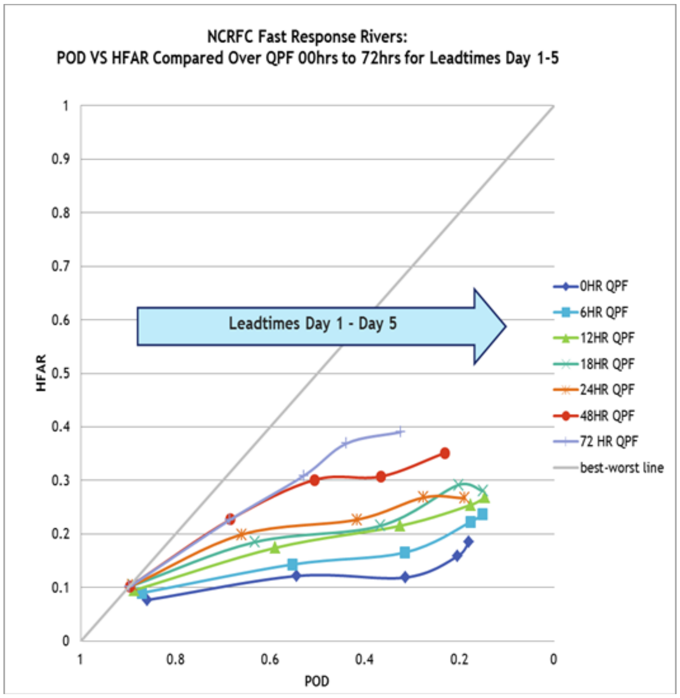


Figure K-19. POD vs HFAR by lead time for fast responders

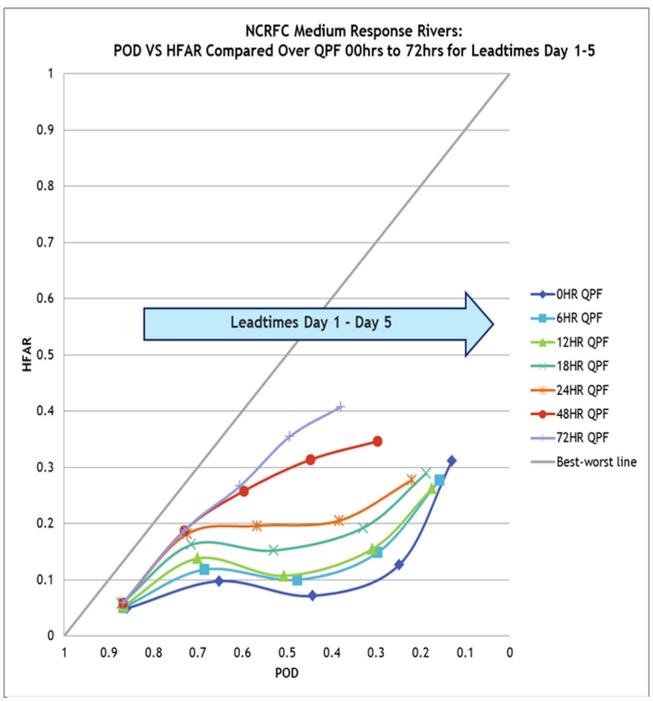


Figure K-20. POD vs HFAR by lead time medium responders

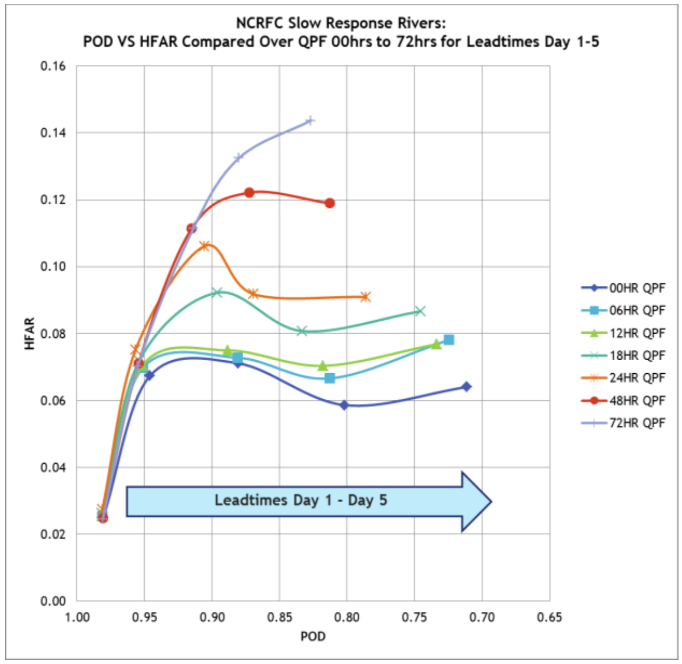


Figure K-21. POD vs HFAR by lead time for slow responders

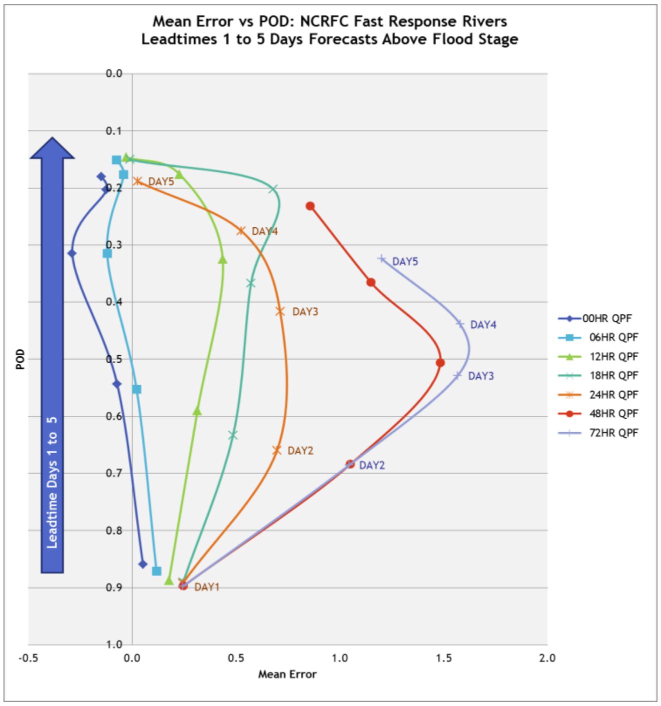


Figure K-22. Mean error vs. POD for fast responders over day 1-5 lead times

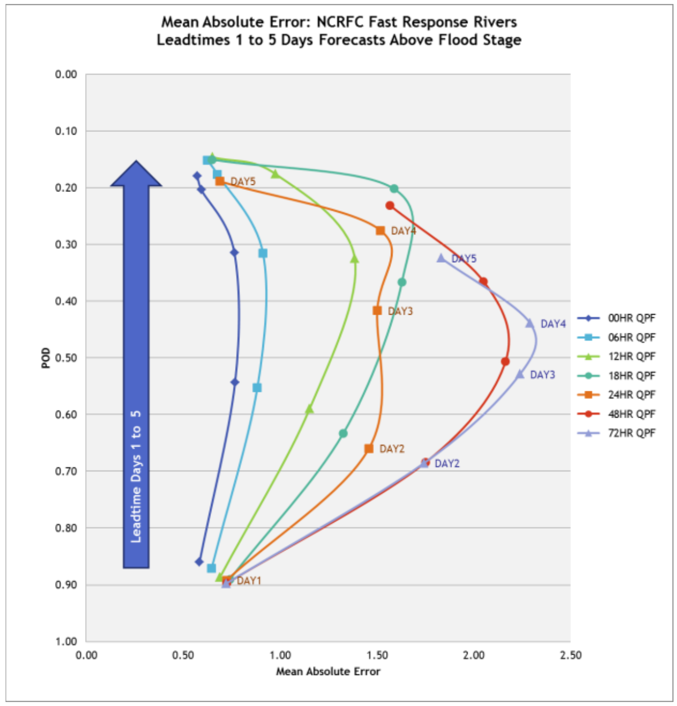


Figure K-23. Mean absolute error vs. POD for fast responders over day 1-5 lead times

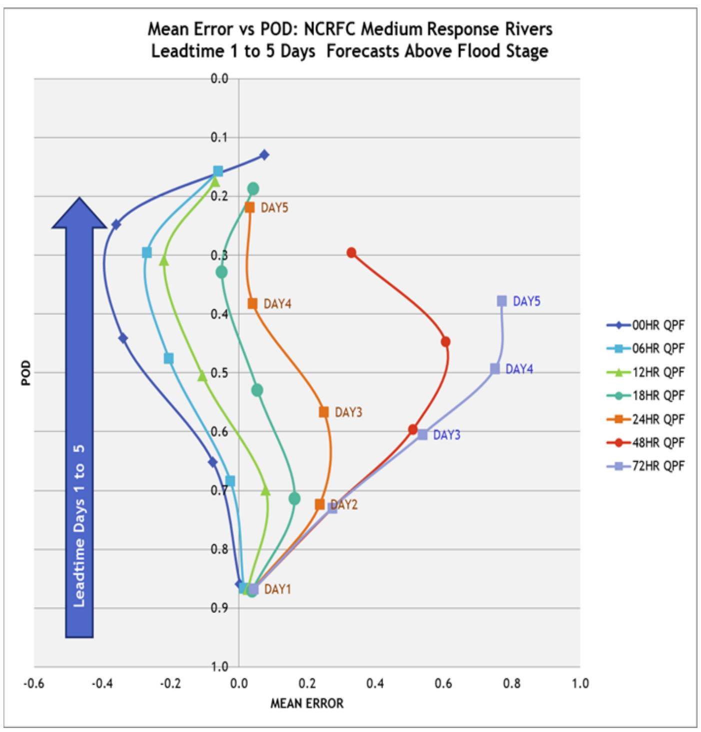


Figure K-24. Mean error vs. POD for medium responders over day 1-5 lead times

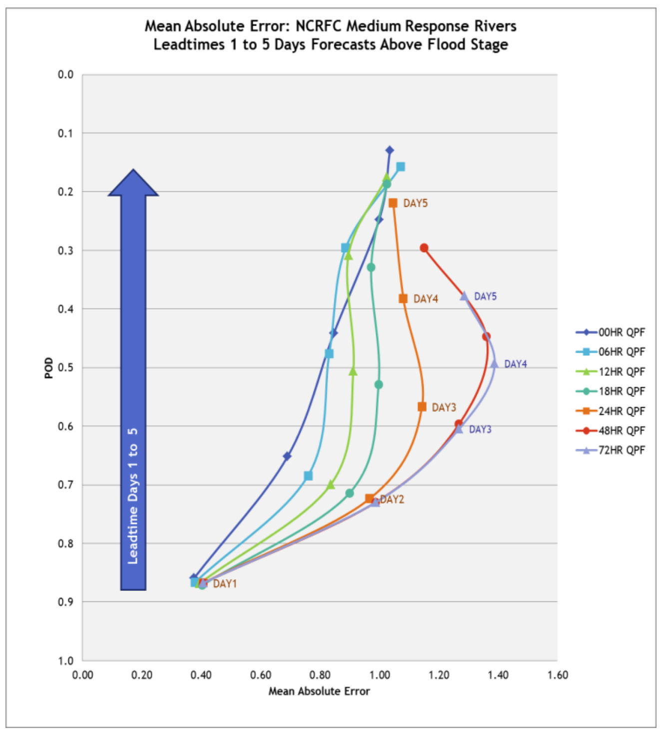


Figure K-25. Mean absolute error vs. POD for medium responders over day 1-5 lead times

NCRFC FAST RESPONSE RIVERS Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data			
~ Less QPF	MAE Forecast Above FS	0	0	0	0
	ME Forecast Above Fs	0	0	24	0
	HFAR	0	0	0	12
~ More QPF	POD	72	72	72	72
	MAE Observed Above FS	72	72	72	72
	ME Observed Above FS	72	72	72	72

Table K-1. Summary of NCRFC results for fast-response rivers

NCRFC MEDIUM RESPONSE RIVERS Statistics: Considering when Forecasts / Observations Above Flood Stage		Spring	Summer	Fall	Winter
		QPF Selected based on Raw Data			
~ Less QPF	MAE Forecast Above FS	0	0	0	0
	ME Forecast Above Fs	24	12	0	0
	HFAR	0	0	6	0
~ More QPF	POD	72	72	72	72
	MAE Observed Above FS	72	72	72	72
	ME Observed Above FS	72	72	72	72

Table K-2. Summary of NCRFC results for medium-response rivers

Appendix L – Additional References and Other Studies

Additional References

Herr, H., August 2007, NWS OHD, "IVP Batch Program User's Manual for Verification" available at http://www.nws.noaa.gov/oh/hrl/verification/ob8/VerificationBatch.pdf

Herr, H., August 2007, NWS OHD, "IVP Batch Program User's Manual for Pairing" available at http://www.nws.noaa.gov/oh/hrl/verification/ob8/PairingBatch.pdf

NWS, National RFC Verification Team, January 2009, Interim Report available at http://www.nws.noaa.gov/ohd/rfcdev/docs/NWS-Verification-Team_interim_report_Jan09.pdf

Other Studies

Larson, L. W. and N. O. Schwein, 2001: A Statistical Evaluation of Mainstem Forecasting Errors for the Missouri and Mississippi Rivers, *AMS Journal*, 7 pp.

Schwein, N. O., 2000: A Methodology for Determining River Forecasting Skill using Monthly Cumulative Distribution Functions of Mean Daily Flow, *NOAA Technical Memorandum NWS CR-117*, 45 pp. Available at http://www.crh.noaa.gov/crh/?n=tm-117