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Forecast Error Distribution:
A Technique to Quantify the Quality of River Forecasts

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Introduction

How to convey uncertainty in a deterministic (i.e., single-valued) river forecast has always been a challenge for the Missouri Basin River Forecast Center (MBRFC), particularly, to the Weather Forecast Offices (WFOs) it serves. There are many sources for the uncertainty and/or forecast errors. Some of these factors are listed in Table 1. River model input forcings can be key sources of uncertainty and forecast errors, in particular, quantitative precipitation forecasts (QPF).

Table 1. Some Sources of Forecast Error or Uncertainty

Forcings
Forecast Precip (QPF)
Est. Observed Precip (QPE)
Forecast Temperatures (QTF)
Observed Temperatures

Antecedent Conditions
Soil Moisture
Snow Water Equivalent (SWE)

Gages
Rating Curves
Rating Shifts
Backwater Influences
Gage Observation Issues

Model Assumptions
Local Runoff
Uniform Conditions over the basin
State of Precip (solid or liquid)
Evapotranspiration
Routing
Calibration

Forecaster Judgement/Assumptions
Storm placement with basin
Timing

Other
Unforecasted Regulation Changes
Flow/Stage Inputs to model
Levee Failure/overtopping
Dam Failure/overtopping

This analysis does not focus specifically on the impact of QPF on the magnitude of forecast errors – that topic was addressed to a great extent by Meyer et al. (2015). The recommendations from that study, on the duration of QPF to use routinely in river forecasts, were implemented by Central Region river forecast centers the fall of 2015.

Since 1981 the MBRFC has been computing error statistics for the year-round daily forecast points on the Missouri River – from Sioux City, Iowa downstream to St. Charles, Missouri. Previous studies such as Larson and Schwein (2002) and Meyer et al. (2015) have looked at these statistics as a way to measure improvements in forecast quality and skill. These studies were limited to the Missouri River daily forecast points. A post-event review of a particular event can be useful in identifying issues for that particular event. However, it may take several post-event reviews to identify persistent, recurring issues within the model or forecast procedures for a particular location or locations. These earlier studies show why there is a need for verification to show that forecasts in general for the Missouri mainstem have improved over time. However, none of the previous studies provides information that WFOs can use to help quantify the quality of a river forecast for a particular location, and to develop reasonable river forecast expectations.

Common critiques the River Forecast Center (RFC) receive are, “you always over-forecast,” or that, “most of the time the forecast is too low.” Are these perceptions valid observations? If these are valid, how should they be addressed? These questions have been a concern within the RFC, with its WFOs, partners and end users for some time.

Prior to 2001 river forecast centers used locally developed applications for verification. The Missouri Basin RFC performed routine verification on only year-round daily forecast points. In 2001, the 13 river forecast centers were provided with an AWIPS baseline application called Interactive Verification Program (IVP) which allowed for the calculation of an assortment of statistics. It was also at this time that a national requirement to generate verification for every forecast point on a monthly basis was implemented.

In 2015 the Missouri Basin RFC made its first effort to provide WFOs long-term statistics for every forecast point regardless of the type of forecast service provided whether it be a year-round daily, seasonal daily or a flood-only forecast point. These long-term river verification data are available on MBRFC’s pubic website with the same set of statistics being computed for each location. The statistics provided are shown in Table 2. These statistics can be found at https://www.weather.gov/mbrfc/verify.

Table 2. Statistics Available on Missouri Basin RFC’s Long-term Verification Website

Scatter Plot	Mean Error
Sample Size	Root Mean Square Error
Sample Size	Pearson’s Correlation
Mean Absolute Error	Probability of Detection
Mean Absolute Error	Hydrologic False Alarm Rate

While RFC forecasters found this information helpful in understanding the average forecast error and bias, most of the WFOs found it interesting but not useful.

As such a new approach that looks at each location's forecast error distribution was developed in the aim it will have more utility. The new statistical metrics should provide the WFOs with useful information that will allow them to understand the likely error band a particular forecast point has based on past forecast performance.

The Analysis

The Missouri Basin RFC currently provides forecast services for 433 river gage locations. Of these locations, 22 are year-round daily, 37 are seasonal daily, and 374 are flood-only forecast points. Verification of any kind works best when the river gage location has an automated gage that provides continual observational data. Of the 433 locations that MBRFC provides forecast services for, 392 have automated gaging equipment.

Unfortunately, 41 forecast locations in the Missouri Basin RFC domain do not have automated gage data. Some of these locations have only a wire-weight, and/or a staff gage that have to be manually read, and a few forecast points no longer have any type of gage equipment. For gages with only manual data, the value of the forecast distribution may not be as useful or even available. This is due to too small of a sample size and the limited number of forecast and observed data pairs.

For this analysis, all forecast and observed data for forecast points from January 1, 2001 thru September 30, 2018 were used. For the year-round daily and seasonal daily forecast points, data pairs below Forecast Issuance Stage[1] (FIS) were not used. Currently most forecasts have a five-day forecast length (time horizon) and are at a six-hourly time step. Error values (calculated as the forecast minus the observed) were computed for all the data pairs in this time horizon window. For a five-day forecast window, the 20 forecast error values, one for each six-hour time step, were lumped together and then sorted into 13 categories as shown in Table 3. These 13 categories were then combined into six category groups by looking at the absolute value of the error values. Table 4 shows the six groups and qualifier description.

[1] Forecast Issuance Stage as defined in NWS Directive 10-950 as the stage which represents when an RFC begins issuing forecasts for a non-routine forecast point, also known as a "flood-only." This stage is coordinated between a WFO and the RFC. The needs of WFO/RFC partners and other users are considered in determining this stage. Forecast Issuance Stage may be the same stage level as the WFO's Action Stage.

Table 3. Forecast Error Categories

< -10.0	> 0.0 & <= 0.5
>= -10 & < -5.0	> 0.5 & <= 1.0
>= -5.0 & < -2.0	> 1.0 & <= 2.0
>= -2.0 & < =1.0	> 2.0 & <= 5.0
>= -1.0 & < -0.5	> 5.0 & <=10.0
>= 0.5 & < 0.0	> 10.0
= 0.0	

Table 4. Category Group Definitions

very good	between -0.5 & 0 .5
good	between +/-|0.5 & 1.0|
fair	between +/- |1.0 & 2.0|
poor	between +/-| 2.0 & 5.0|
very poor	between +/-|5.0 & 10.0|
extremely poor	greater +/-|10.0|

Of the 433 river forecast points, 401 forecast locations had adequate forecast error data available with a sample size >= 30. For each of these locations, two plots and a summary table were generated. The first plot shown in Table 3 displays the distribution across the 13 categories, where a negative error indicates under-forecasting, a positive error indicates over-forecasting and a zero error value indicates no forecast bias. The second plot shown in Table 4 displays the percentage of values by category grouping. Ideally a forecaster would like to always have forecast errors that fall within the +/- 0.5 foot grouping.

Finally, the totals for how many forecast errors were negative and positive were calculated and the type of overall bias was assigned based on all errors in the 5-day forecast period. If the total number of negative errors was greater than the total number of positive errors and the difference between the two counts was greater than 5%, then it was designated as under-forecast bias. Likewise if the total number of positive errors was greater than the total number of negative errors and the difference between the two counts was greater than 5%, then it was designated as over-forecast bias. If the difference in either case was less than or equal to 5%, then the bias was designated as an equal chance to over- or under-forecast.

About The Examples

Twenty locations were selected across the basin. These 20 examples of forecast error distribution are discussed in the next two sections. The examples cover the different types of forecast service, year-round daily, seasonal daily, and flood-only. Figure 1 shows the location of these forecast points.

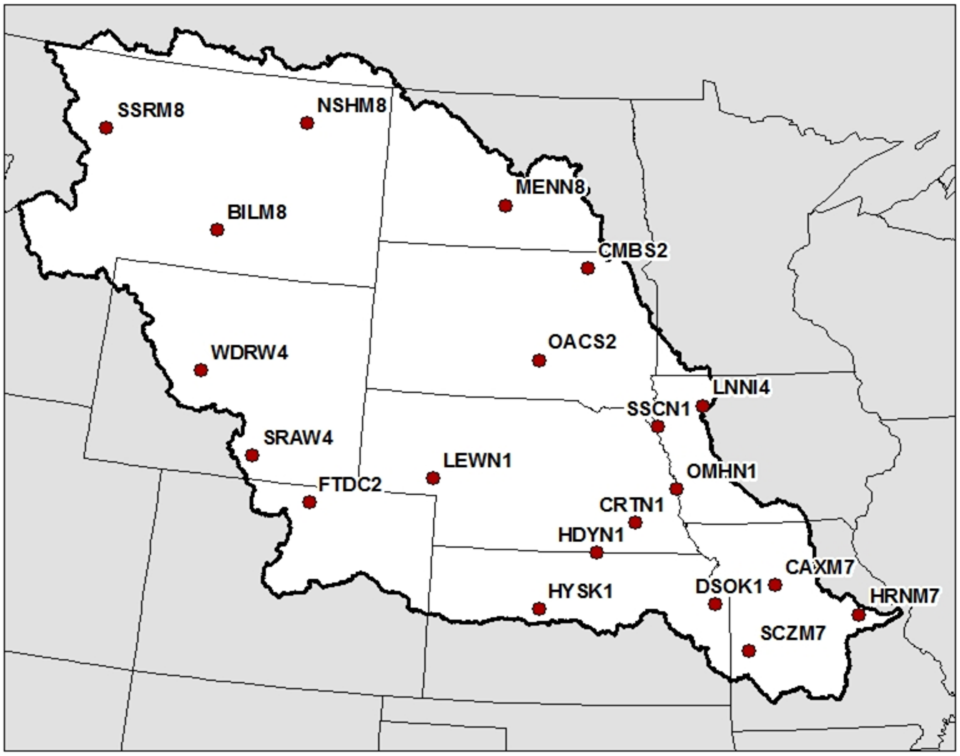


Figure 1. Map of forecast locations used in the examples

For the various forecast distribution examples supplemental location information, such as, flood categories, typical response time, and the hydrologic service area (HSA) office are provided.

What are flood categories? An excerpt from NWS Directive 10-950 “Definitions and General Terminology” is provided in Figure 2.

Flood Categories – terms defined for each forecast point which 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 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 (see Figure 1):

> **Minor Flooding** - minimal or no property damage, but possibly some public threat (e.g., inundation of roads).
>
> **Moderate Flooding** - some inundation of structures and roads near stream. Some evacuations of people and/or transfer of property to higher elevations.
>
> **Major Flooding** - extensive inundation of structures and roads. Significant evacuations of people and/or transfer of property to higher elevations.

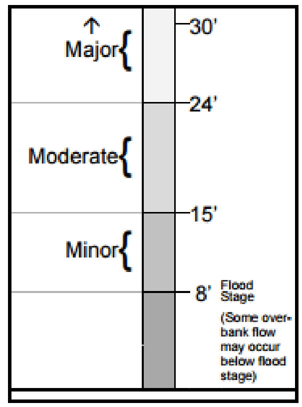


Figure 1. *Stage - flood category relationship.*

Figure 2. Excerpt from NWS Directive 10-950 – Flood Category Definitions

What is response time? As part of the national RFC river forecast verification requirement, every river forecast point has a typical response time qualifier assigned. The three qualifiers are:

Fast – typical time to crest is < 24 hours

Medium – typical time to crest is >=24 hours and < 60 hours

Slow – typical time to crest is >= 60 hours

Year-round Daily/Seasonal Daily Forecast Points

Example 1: Missouri River at Sioux City, IA (SSCN1)

HSA: WFO Sioux Falls, SD
RFC Forecast Group: Missouri Mainstem
Flood Stage: 30.0 ft   Forecast Issuance Stage: 25.0 ft
Moderate Flood Stage: 33.0 ft   Major Flood Stage: 36.0 ft
Response Time: Slow

This gage is located about 79 miles downstream of Gavins Point Dam. There are four tributaries that can impact this location: the James, Vermillion, Big Sioux, and Floyd Rivers. Since the completion of Gavins Point Dam on the Missouri River upstream of Sioux City, this location rarely exceeds flood stage and the strong influence of the dam can be seen by the tight forecast error band. Since the early 1980s, Sioux City has exceeded the flood stage only twice, in 1984 and 2011. It crested below flood stage during the Great Flood of 1993.

Sioux City is close to the perfect forecast error that a RFC forecaster would like to have as the data show in Figure 3. Forecast bias is classified as under-forecast. Nearly 98% of the time the individual forecast errors in the five-day forecast period are always within +/- 0.5 ft and none of the forecast errors is greater than +/- 1 ft.

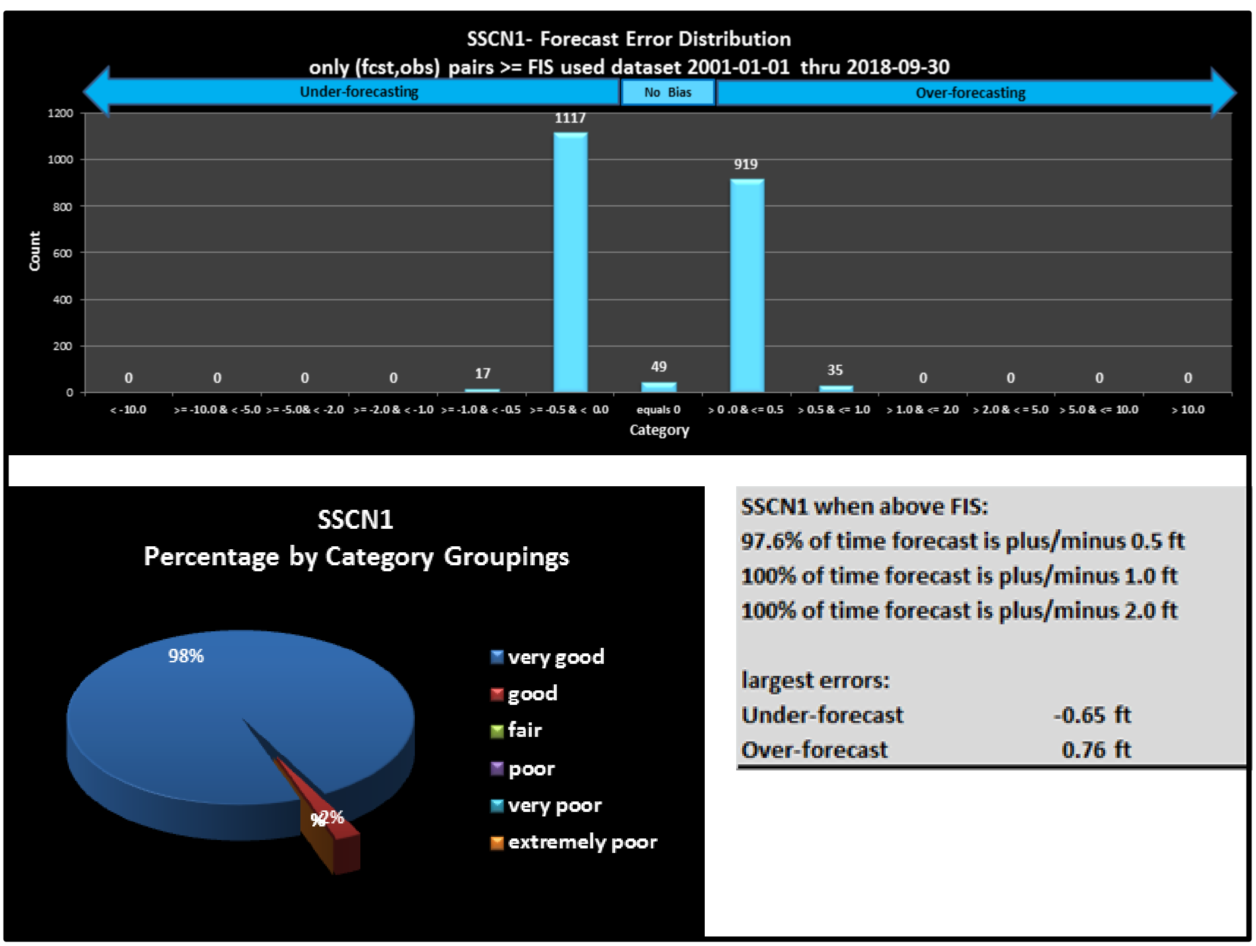


Figure 3. SSCN1 Forecast Error Information

Example 2: Missouri River at Omaha, NE (OMHN1)

HSA: WFO Omaha/Valley, NE
RFC Forecast Group: Missouri Mainstem
Flood Stage: 29.0 ft   Forecast Issuance Stage: 25.0 ft
Moderate Flood Stage: 32.0 ft   Major Flood Stage: 40.0 ft
Response Time: Slow

This gage is located about 116 miles downstream of the Sioux City gage (~195 miles downstream of Gavins Point Dam). In addition to the four tributaries that can impact Sioux City, there are some additional tributaries that can impact Omaha, such as the Little Sioux, Soldier, and Boyer Rivers. While further downstream of Gavins Point Dam, this location rarely has exceeded flood stage since the completion of the dam. Since the early 1980s, Omaha has exceeded the flood stage four times: 1984, 1993, 1996, and 2011.

The forecast error information is shown in Figure 4. Forecast bias for Omaha is classified as under-forecast. There is a larger spread in the errors than example 1, with nearly 80% of the time the individual forecast errors in the five-day forecast period are within +/- 2.0 ft.

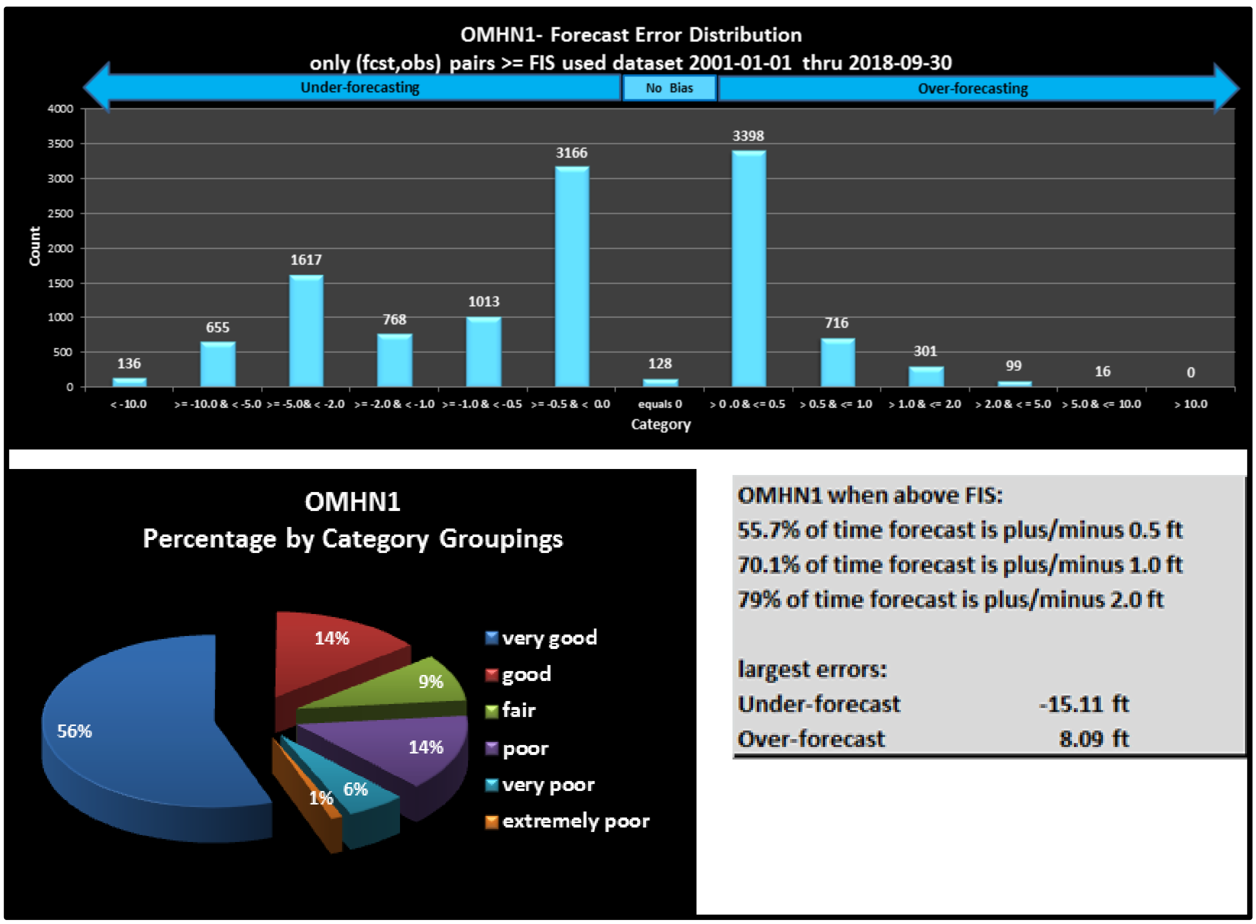


Figure 4. OMHN1 Forecast Error Information

Example 3: Missouri River at Hermann, MO (HRNM7)

HSA: WFO St. Louis, MO
RFC Forecast Group: Missouri Mainstem
Flood Stage: 21.0 ft Forecast Issuance Stage: 19.0 ft
Moderate Flood Stage: 26.0 ft Major Flood Stage: 33.0 ft
Response Time: Slow

This gage is located about 98 miles upstream of the Missouri River's confluence with the Mississippi River. This forecast point is on the lower end of the Missouri River, whereby water from upstream passes through this location. Short-term impacts for this location can be caused from several tributaries, such as the Grand, Chariton, and Gasconade Rivers as well as the releases from the hydropower facility Bagnell Dam on the Osage River. This forecast point on the Missouri River is seldom impacted by backwater from the Mississippi River. The hydropower generation, floodwaters from the Grand, Chariton, Osage, and Gasconade Rivers can all impact the Hermann forecasts.

The forecast error information is shown in Figure 5. Forecast bias for Hermann is classified as under-forecast. There is a much larger spread in the errors particular on the under-forecasting side, with only about 59% of the time the individual forecast errors in the five-day forecast period are within +/- 2.0 ft.

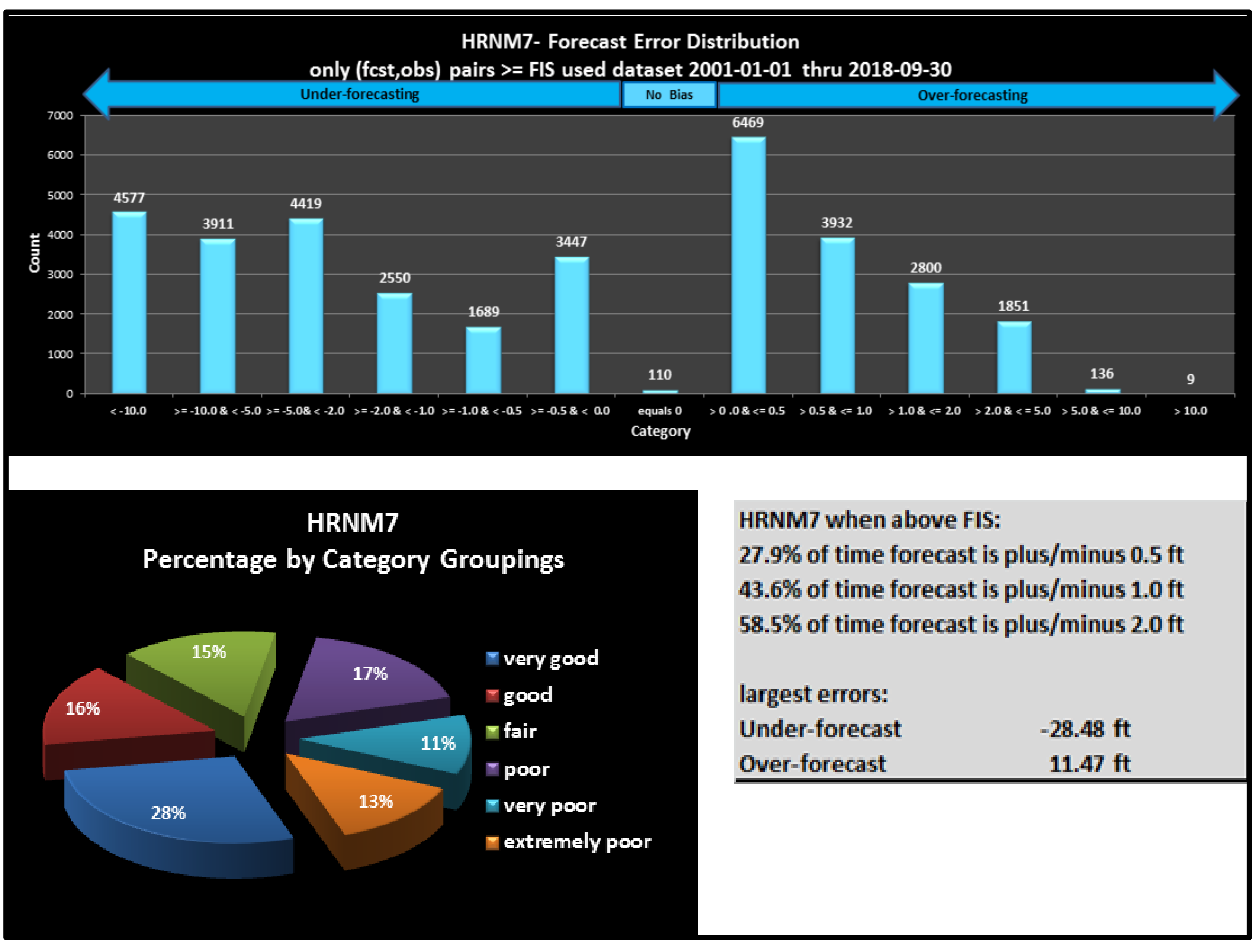


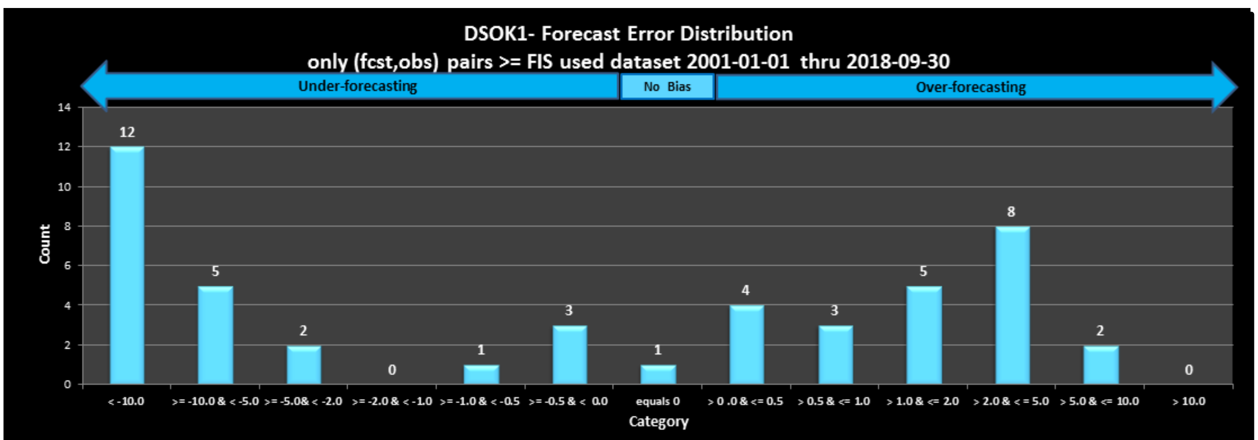
Figure 5. HRNM7 Forecast Error Information

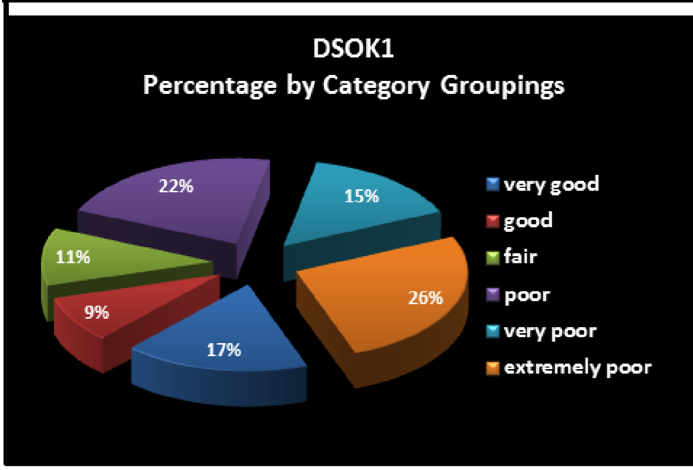
Example 4: Kansas River near De Soto, KS (DSOK1)

HSA: WFO Kansas City/Pleasant Hill, MO
RFC Forecast Group: Kansas
Flood Stage: 26.0 ft Forecast Issuance Stage: 24.0 ft
Moderate Flood Stage: 33.0 ft Major Flood Stage: 36.0 ft
Response Time: Slow

This gage is located about 31 miles upstream of the Kansas River’s confluence with the Missouri River. Several tributaries and dams can influence the river forecasts at this location. While most flooding is due to rain, flooding due to snowmelt, or rain on top of snowmelt can occur.

The forecast error information is shown in Figure 6. Forecast bias for De Soto is classified as an equal chance to over- or under-forecast. There is a much larger spread in the errors with largest errors occurring on the under-forecast side, with only about 37% of the time the individual forecast errors in the five day forecast period are within +/- 2.0 ft. This is likely partly due to the reservoirs in the basin.





DSOK1 when above FIS:
17.4% of time forecast is plus/minus 0.5 ft
26.1% of time forecast is plus/minus 1.0 ft
37% of time forecast is plus/minus 2.0 ft

largest errors:

Under-forecast	**-19.89 ft**
Over-forecast	**6.12 ft**

Figure 6. DSOK1 Forecast Error Information

Example 5: Yellowstone River near Billings, MT (BILM8)

HSA: WFO: Billings, MT
RFC Forecast Group: Yellowstone
Flood Stage: 13.5 ft   Forecast Issuance Stage: 11.5 ft
Moderate Flood Stage: 14.5 ft   Major Flood Stage: 15.5 ft
Response Time: Medium

Daily forecast service is provided during the spring snowmelt season (April thru June) and during the remainder of the year it is a flood-only forecast point. Flooding is most likely to occur due to snowmelt or rain on snowmelt. Several tributaries can impact this forecast point.

The forecast error information is shown in Figure 7. Forecast bias for Billings is classified as over-forecast. The spread of the forecast error distribution is almost shaped like a bell curve with a shift towards over-forecasting. Almost 50% of the time the forecast errors are within +/- 0.5 ft and 90% of the time errors are within +/- 2.0 ft over the five-day forecast period.

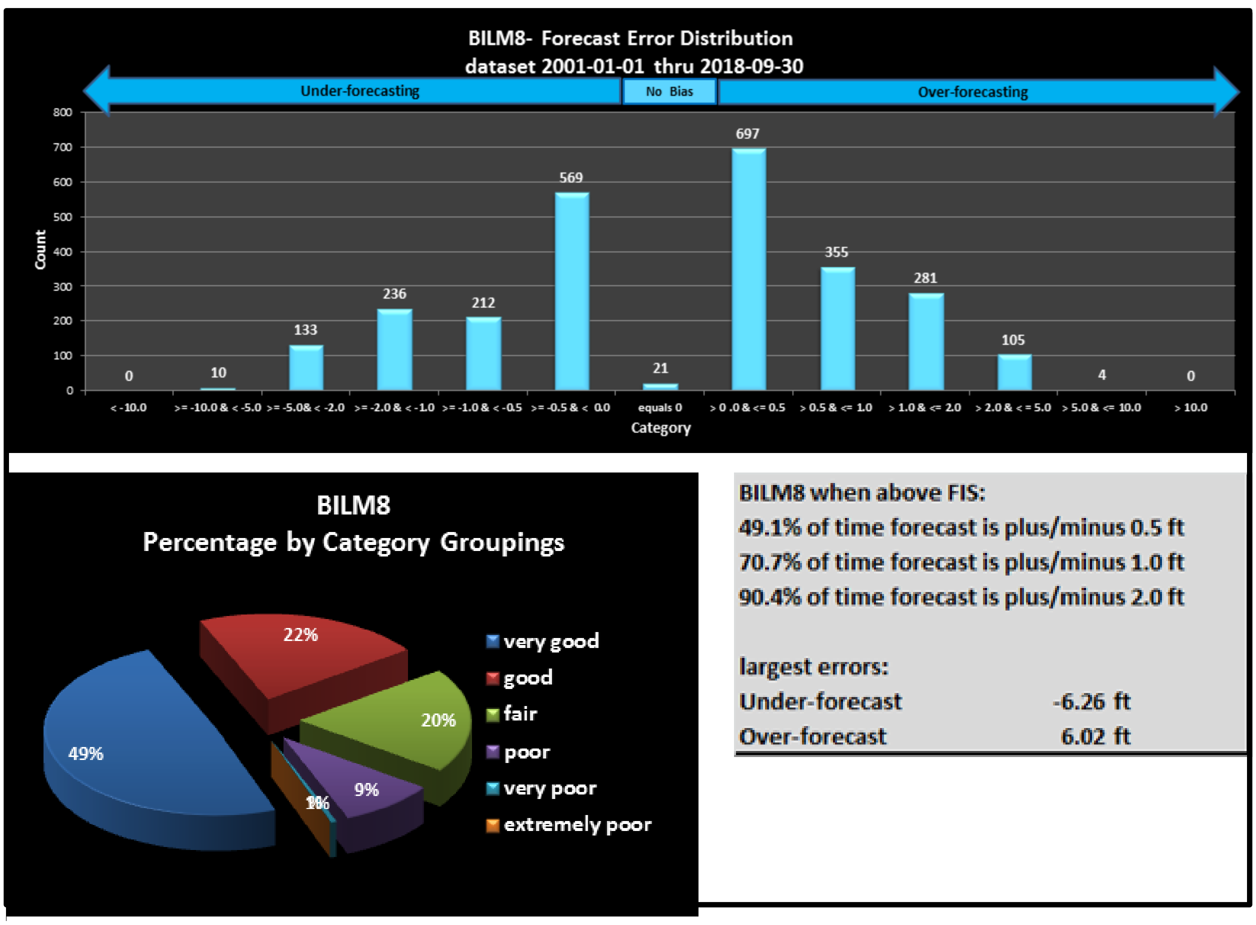


Figure 7. BILM8 Forecast Error Information

Example 6: Milk River at Nashua, MT (NSHM8)

HSA: WFO Glasgow, MT
RFC Forecast Group: Milk
Flood Stage: 20.0 ft   Forecast Issuance Stage: 18.0 ft
Moderate Flood Stage: 28.0 ft   Major Flood Stage: 30.0 ft
Response Time: Slow

Daily forecast service is provided during the spring snowmelt season (April thru June period) and during the remainder of the year it is a flood-only forecast point. While most flooding is due to snowmelt or rain on top of snowmelt, flooding due to just rain can occur. Nashua is the furthest downstream point on the Milk River that is forecast and is about 24 miles upstream of its confluence with the Missouri River. Numerous tributaries such as Beaver Creek and Frenchman Creek can impact the forecasts. Diversions and dams further upstream also can influence the forecast.

The forecast error information is shown in Figure 8. Forecast bias for Nashua is classified as over-forecast. Almost 70% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

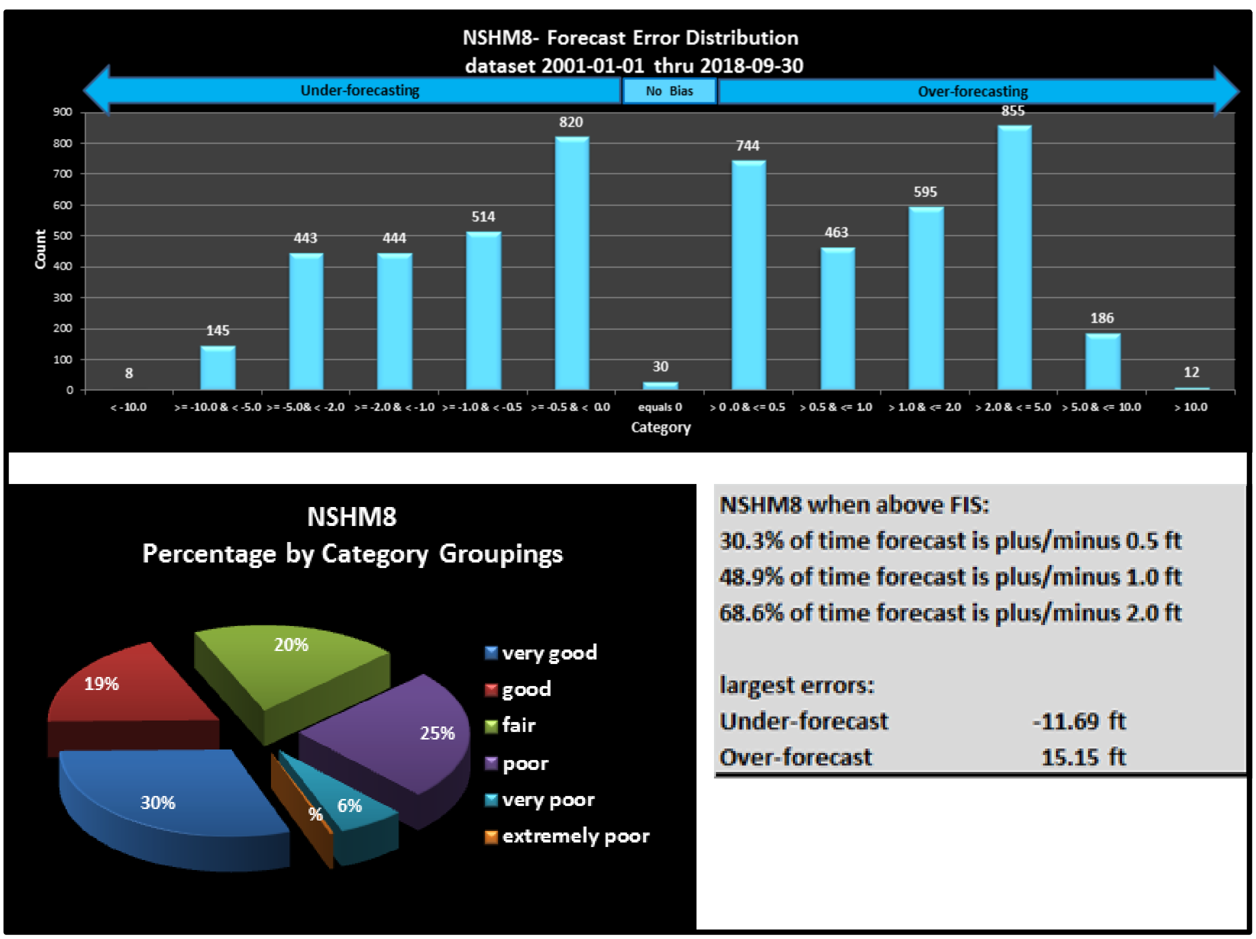


Figure 8. NSHM8 Forecast Error Information

<u>Flood-only Forecast Points</u>

Example 1: Little Sioux River near Linn Grove, IA (LNNI4)

HSA: WFO Sioux Falls, SD

RFC Forecast Group: Siouxs

Flood Stage: 18.0 ft   Forecast Issuance Stage: 17.0 ft

Moderate Flood Stage: 19.5 ft   Major Flood Stage: 21.0 ft

Response Time: Medium

Located about the midpoint of the Little Sioux River (river mile ~139), flooding can occur during any time of the year.

The forecast error information is shown in Figure 9. Forecast bias for Linn Grove is classified as under-forecast. About 77% of the time errors are within +/- 0.5 ft and about 98% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

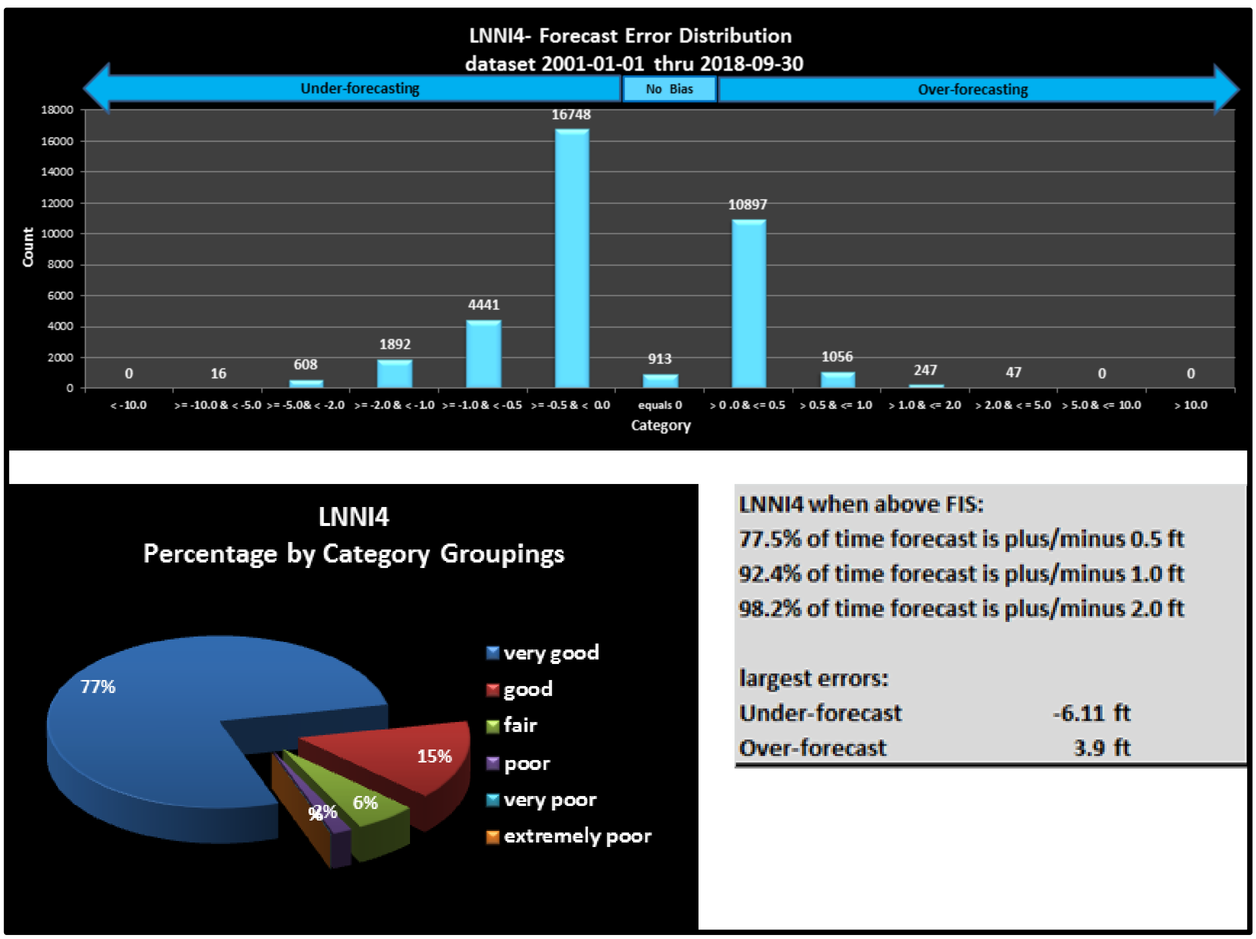


Figure 9. LNNI4 Forecast Error Information

Example 2: Big Blue River near Crete, NE (CRTN1)

HSA: WFO Omaha/Valley, NE
RFC Forecast Group: BigBlue
Flood Stage: 21.0 ft   Forecast Issuance Stage: 19.0 ft
Moderate Flood Stage: 25.0 ft   Major Flood Stage: 29.0 ft
Response Time: Slow

Located in the upper end of the Big Blue River at river mile 167, flooding at this forecast point can occur due to rain, snowmelt or rain on top of snowmelt.

The forecast error information is shown in Figure 10. Forecast bias for Crete is classified as under-forecast. About 62% of the time errors are within +/- 2.0 ft over the five-day forecast period.

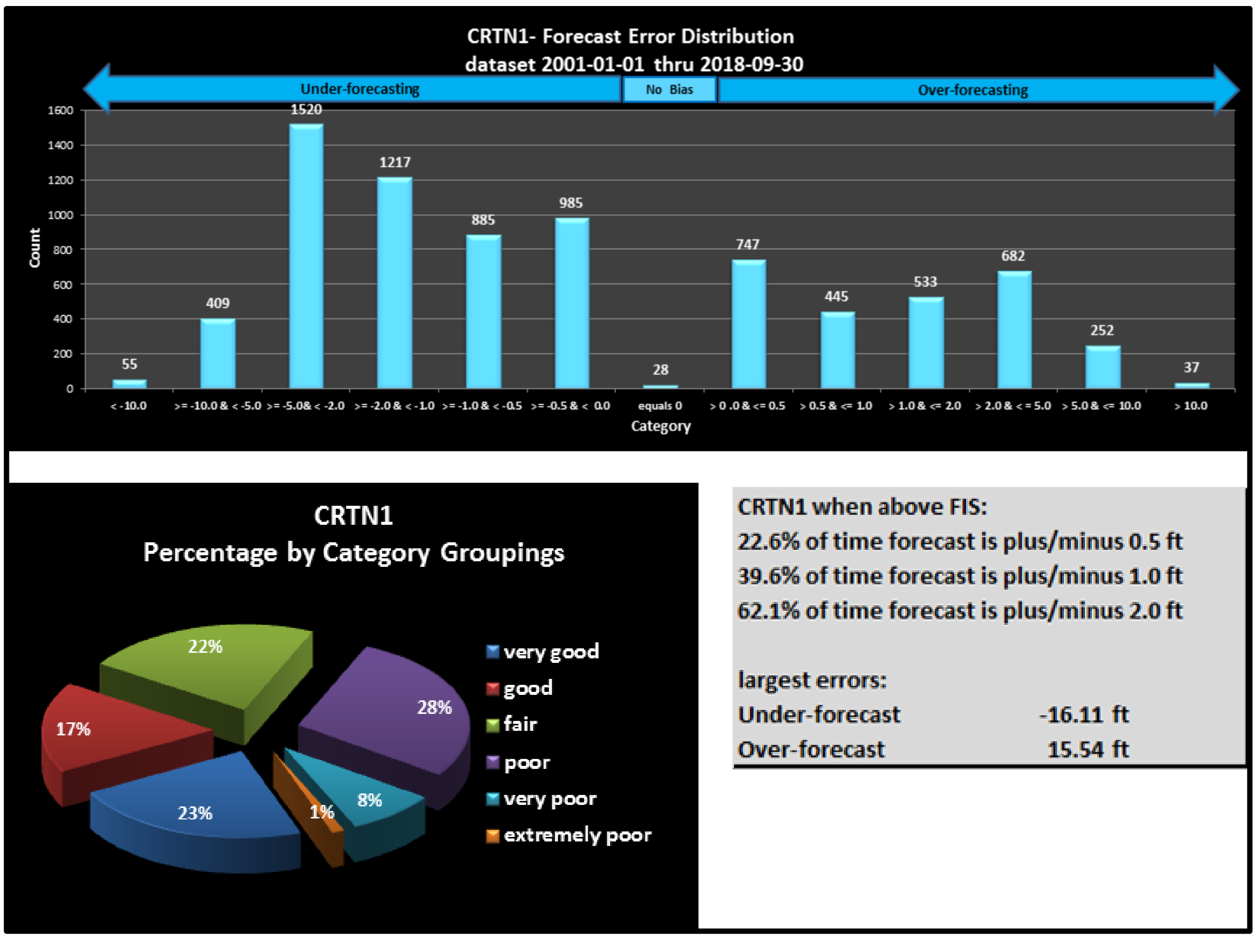


Figure 10. CRTN1 Forecast Error Information

Example 3: Apple Creek near Menoken, ND (MENN8)

HSA: WFO Bismarck, ND
RFC Forecast Group: UpperDakota
Flood Stage: 15.0 ft   Forecast Issuance Stage: 13.0 ft
Moderate Flood Stage: 16.0 ft   Major Flood Stage: 17.0 ft
Response Time: Medium

This forecast point is located just outside of Bismarck, North Dakota. Flooding at this location can be due to snowmelt, rain on top of snowmelt, or rain. The complex hydrology within this basin makes modelling it difficult and forecasting it challenging as well.

The forecast error information is shown in Figure 11. Forecast bias for Menoken is classified as over-forecast. About 7% of the time errors are within +/- 2.0 ft over the five-day forecast period.

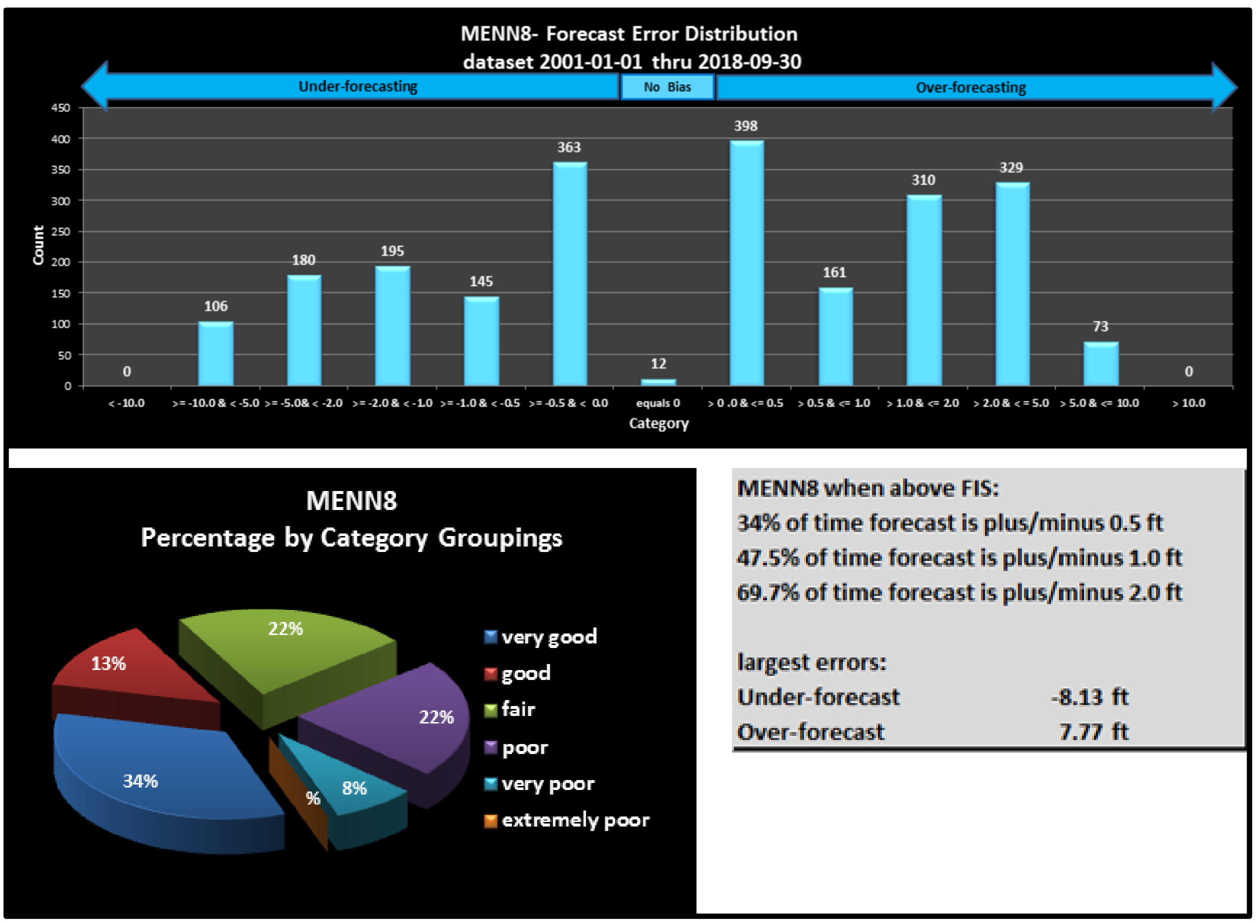


Figure 11. MENN8 Forecast Error Information

Example 4: Wakenda Creek at Carrollton, MO (CAXM7)

HSA: WFO Kansas City/Pleasant Hill, MO
RFC Forecast Group: LowerMoTribs
Flood Stage: 16.0 ft Forecast Issuance Stage: 14.0 ft
Moderate Flood Stage: 19.0 ft Major Flood Stage: 21.0 ft
Response Time: Fast

As with most places within the Missouri basin, flooding can occur any time throughout the year. This forecast point is also susceptible to flash flooding.

The forecast error information is shown in Figure 12. Forecast bias for Carrollton is classified as equal change to over- or under-forecast. About 51% of the time errors are within +/- 2.0 ft over the five-day forecast period.

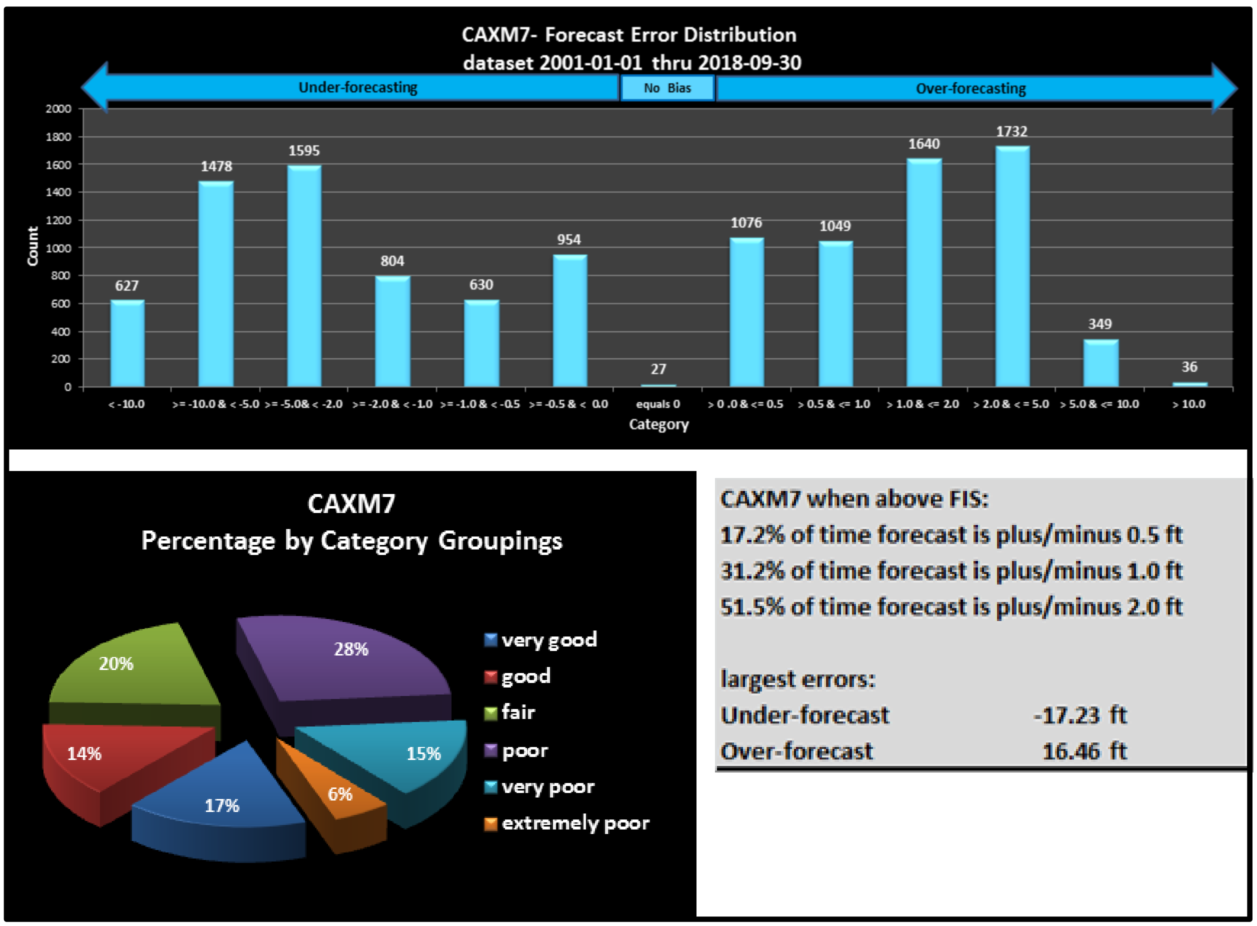


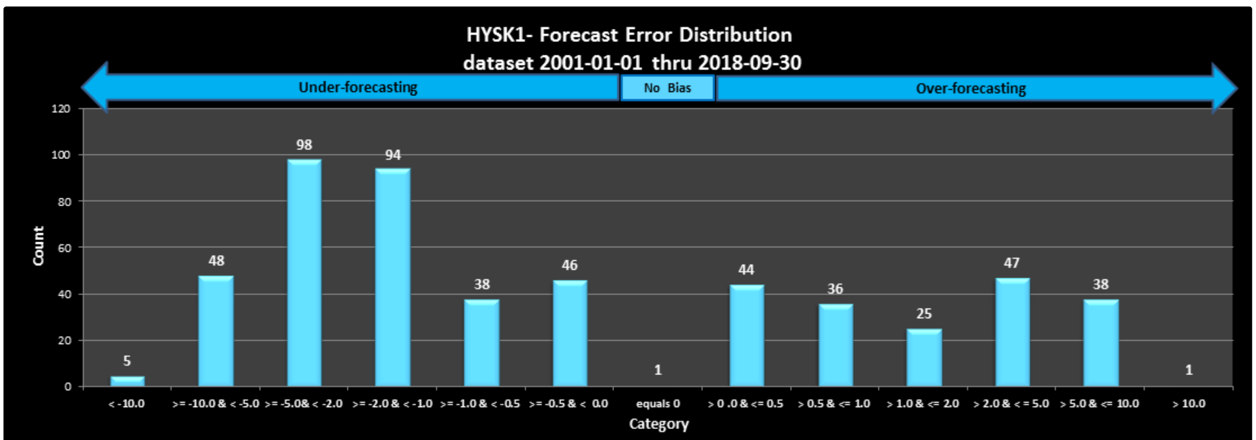
Figure 12. CAXM7 Forecast Error Information

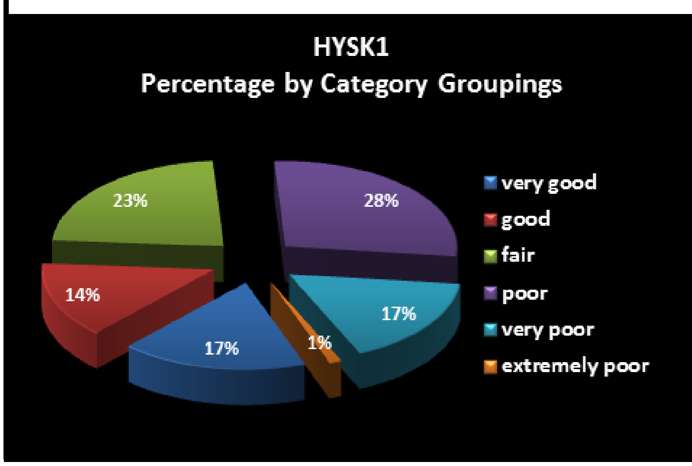
Example 5: Big Creek at Hays, KS (HYSK1)

HSA: WFO Dodge City, KS
RFC Forecast Group: Upper Smoky
Flood Stage: 26.0 ft   Forecast Issuance Stage: 17.0 ft
Moderate Flood Stage: 29.0 ft   Major Flood Stage: 32.0 ft
Response Time: Fast

Like the forecast point in example 4, this location can have flooding due to rain, snowmelt, or rain on top or snowmelt. Flash flooding is also a concern for this forecast point.

The forecast error information is shown in Figure 13. Forecast bias for Hays is classified as under-forecast. About 54% of the time errors are within +/- 2.0 ft over the five-day forecast period.





HYSK1 when above FIS:
17.5% of time forecast is plus/minus 0.5 ft
31.7% of time forecast is plus/minus 1.0 ft
54.5% of time forecast is plus/minus 2.0 ft

largest errors:

Under-forecast	-10.86 ft
Over-forecast	11.02 ft

Figure 13. HYSK1 Forecast Error Information

Example 6: Osage River above Schell City, MO (SCZM7)

HSA: WFO Springfield, MO
RFC Forecast Group: Osage
Flood Stage: 30.0 ft Forecast Issuance Stage: 28.0 ft
Moderate Flood Stage: 35.0 ft Major Flood Stage: 45.0 ft
Response Time: Slow

Waters from several tributaries and the Marias Des Cygnes can impact this location. This location can be heavily influenced by backwater from Harry S. Truman Reservoir.

The forecast error information is shown in Figure 14. Forecast bias for Schell City is classified as under-forecast. About 60% of the time errors are within +/- 2.0 ft over the five-day forecast period.

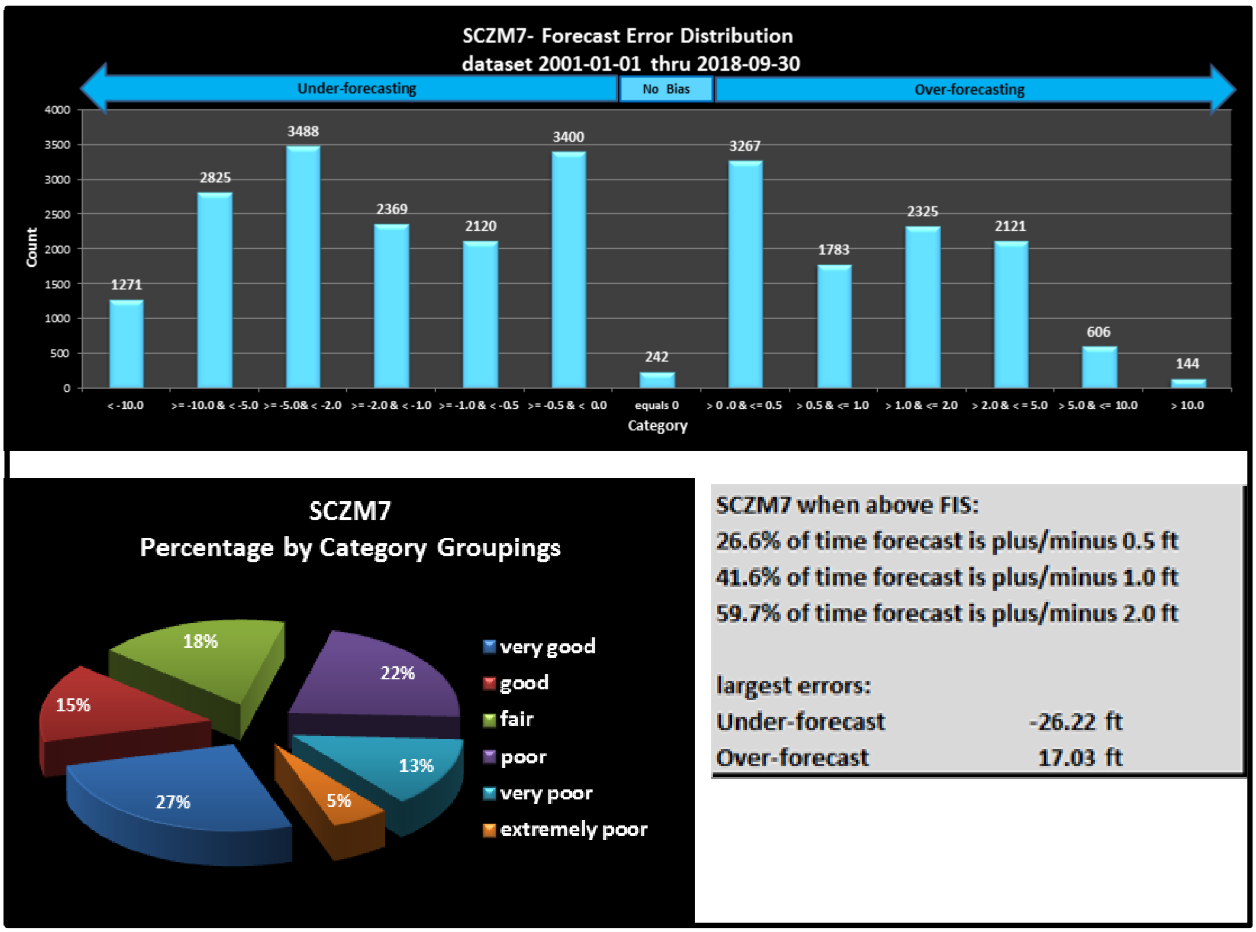


Figure 14. SCZM7 Forecast Error Information

Example 7: North Platte River near Saratoga, WY (SRAW4)

HSA: WFO Cheyenne, WY
RFC Forecast Group: NorthPlatte
Flood Stage: 8.5 ft Forecast Issuance Stage: 7.5 ft
Moderate Flood Stage: 9.5 ft Major Flood Stage: 10.5 ft
Response Time: Fast

Most flooding along this reach of the North Platte River occurs during the spring snowmelt season (April-June period). Flooding is primarily due to snowmelt or rain on top of snowmelt. Numerous homes along the river may start to be impacted when the river exceeds flood stage.

The forecast error information is shown in Figure 15. Forecast bias for Saratoga is classified as over-forecast. About 82% of the time errors are within +/- 0.5 ft, about 96% of the time the forecast errors are within +/- 1.0 ft over the five-day forecast period.

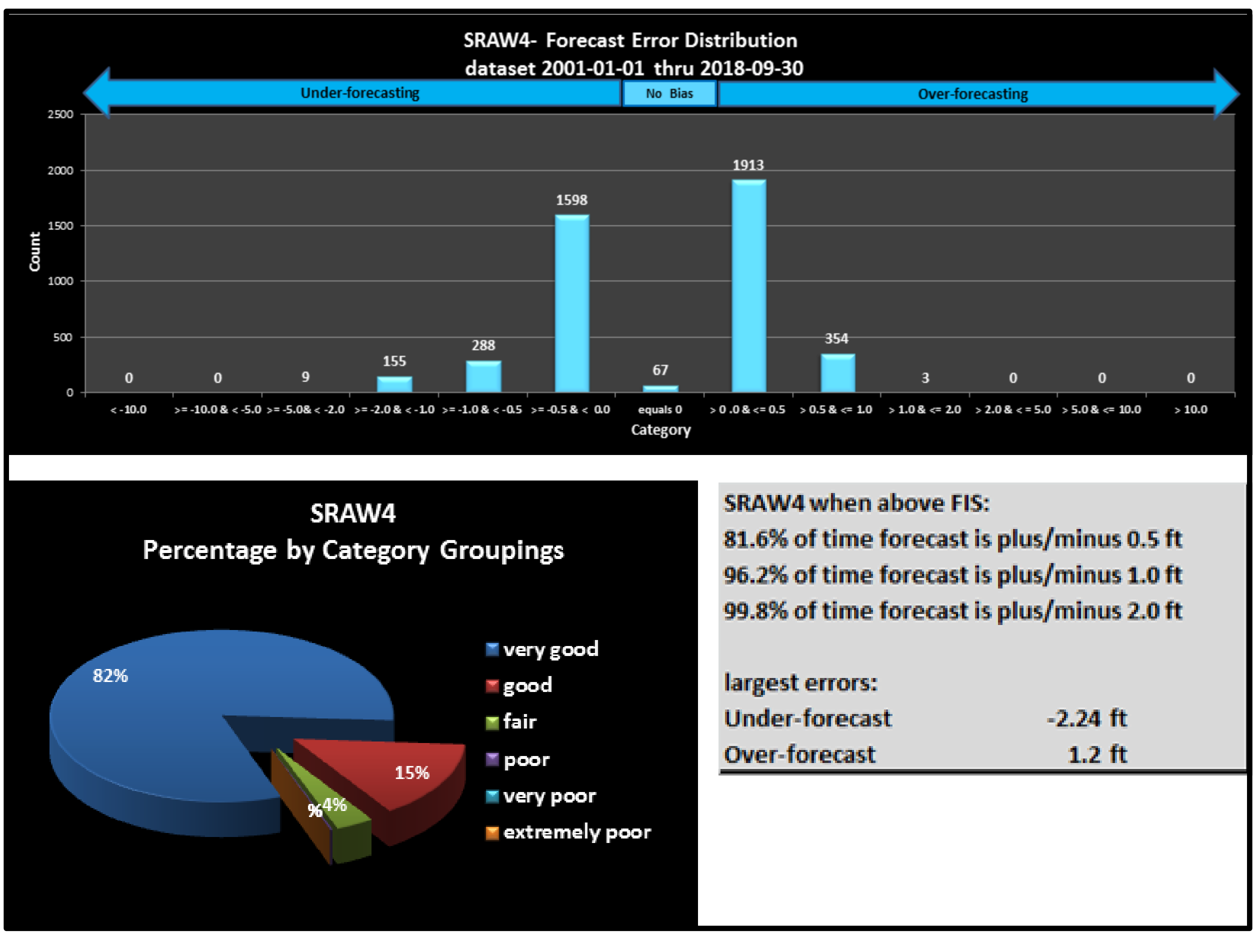


Figure 15. SRA Forecast Error Information

Example 8: North Platte River near Lewellen, NE (LEWN1)

HSA: WFO North Platte, NE
RFC Forecast Group: NorthPlatte
Flood Stage: 7.5 ft   Forecast Issuance Stage: 6.5 ft
Moderate Flood Stage: 8.5 ft   Major Flood Stage: 9.5 ft
Response Time: Slow

In the winter this location is often impacted by ice jams. In addition to flooding due to ice jams, flooding can occur due to rain only, snowmelt or rain on snowmelt. There are several reservoirs upstream as well as multiple diversions and returns along the North Platte that can also impact forecasts.

The forecast error information is shown in Figure 16. Forecast bias for Lewellen is classified as an equal chance to over- or under-forecast. About 91% of the time errors are within +/- 0.5 ft and about 98% of the time the forecast errors are within +/- 1.0 ft over the five-day forecast period.

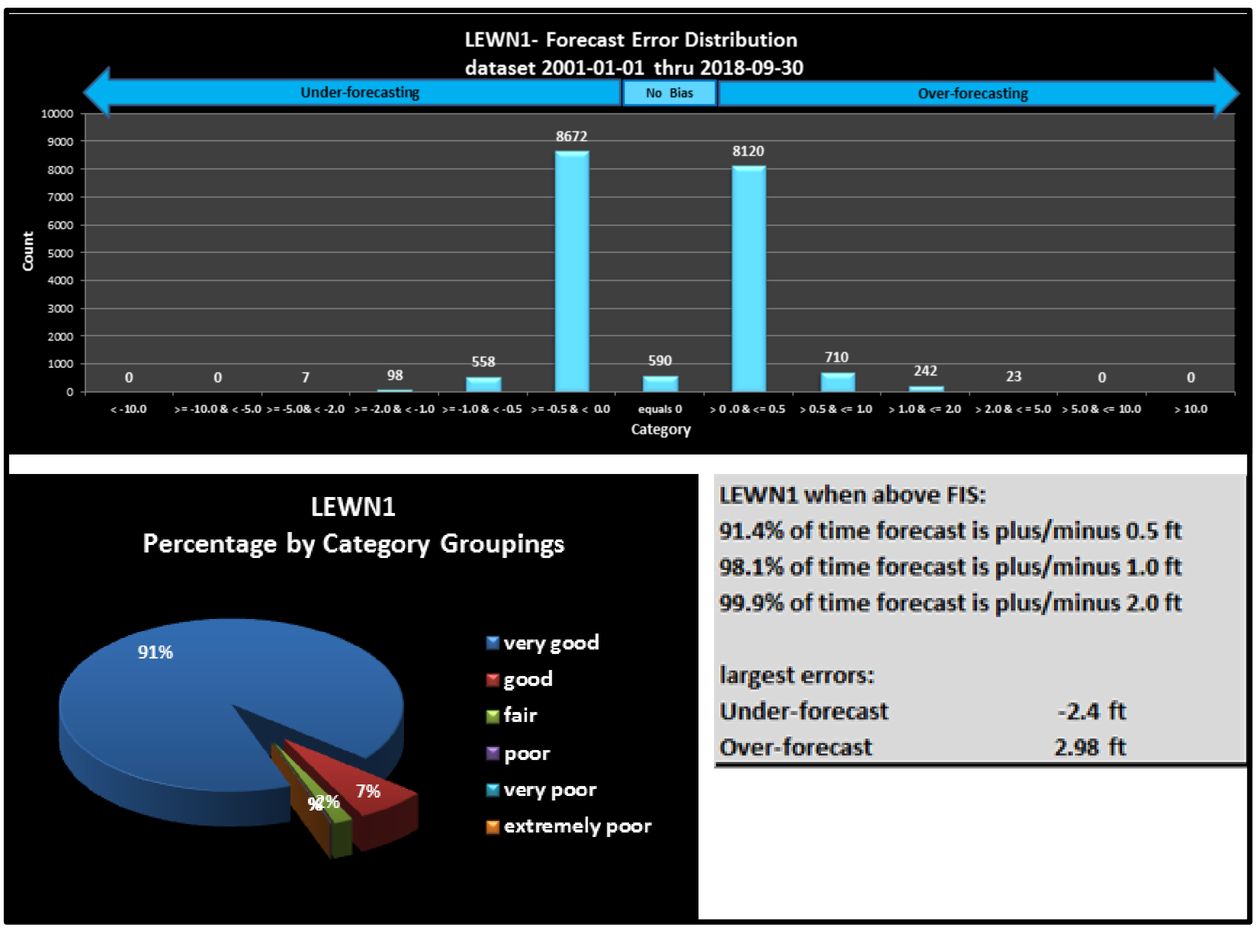


Figure 16. LEWN1 Forecast Error Information

Example 9: Cache La Poudre River near Fort Collins, CO (FTDC2)

HSA: WFO Denver/Boulder, CO
RFC Forecast Group: SouthPlatte
Flood Stage: 7.5 ft   Forecast Issuance Stage: 6.0 ft
Moderate Flood Stage: 9.0 ft   Major Flood Stage: 10.5 ft
Response Time: Fast

As with many locations in the Rocky Mountains and its foothills, this location is prone to flash flooding. Flooding can occur due to rain, snowmelt or rain on top of snowmelt.

The forecast error information is shown in Figure 17. Forecast bias for Fort Collins is classified as under-forecast. About 72% of the time errors are within +/- 0.5 ft and about 98% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

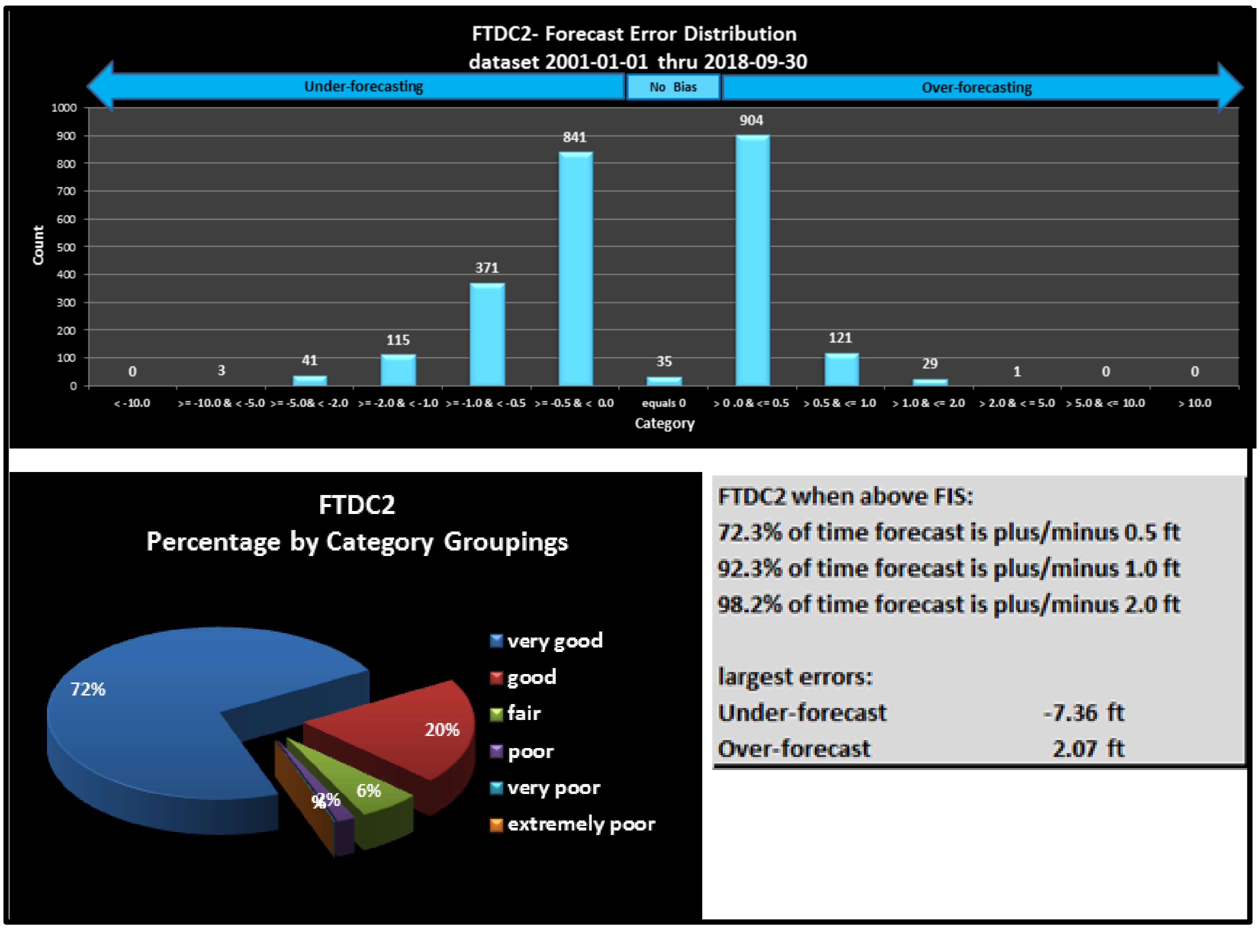


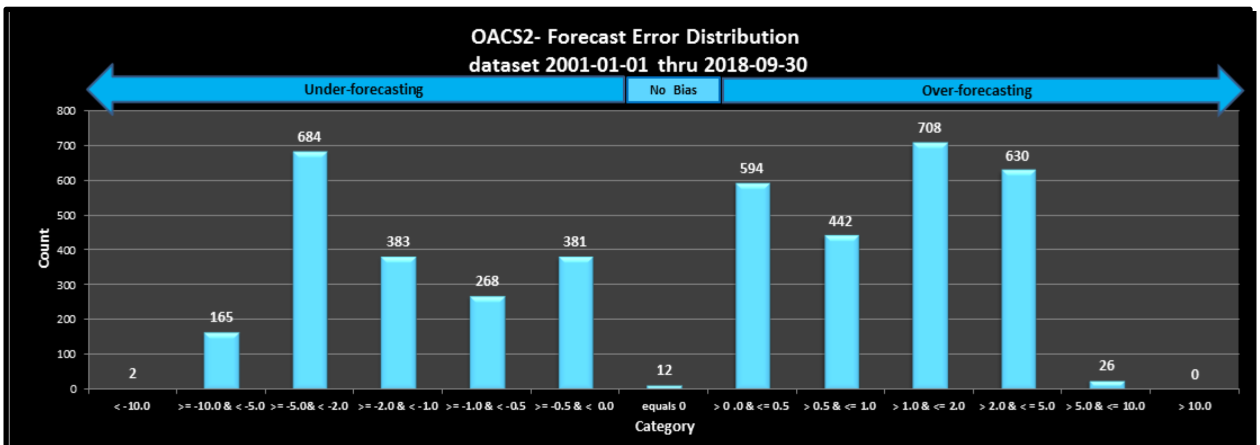
Figure 17. FTDC2 Forecast Error Information

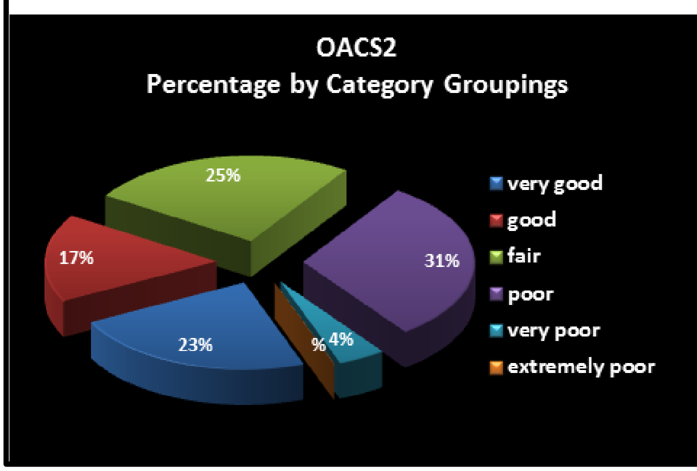
Example 10: White River near Oacoma, SD (OACS2)

HSA: WFO Rapid City, SD
RFC Forecast Group: LowerDakota
Flood Stage: 15.0 ft   Forecast Issuance Stage: 13.0 ft
Moderate Flood Stage: 20.0 ft   Major Flood Stage: 25.0 ft
Response Time: Slow

The USGS gage on the White River, Oacoma is located about 2 miles upstream from where the river enters Lake Francis Case (Fort Randall Dam). Flooding can be due to ice jamming, snowmelt, rain on top of snowmelt, or rain only. The biggest floods have been due to a combination of ice jamming, snowmelt, and rain in late winter/early spring.

The forecast error information is shown in Figure 18. Forecast bias for Oacoma is classified as over-forecast. About 65% of the time forecast errors are within +/- 2.0 ft over the five-day forecast period.





OACS2 when above FIS:
23% of time forecast is plus/minus 0.5 ft
39.5% of time forecast is plus/minus 1.0 ft
64.9% of time forecast is plus/minus 2.0 ft

largest errors:

Under-forecast	-11.34 ft
Over-forecast	6.83 ft

Figure 18. OACS2 Forecast Error Information

Example 11: James River near Columbia, SD (CMBS2)

HSA: WFO Aberdeen, SD
RFC Forecast Group: James
Flood Stage: 13.0 ft Forecast Issuance Stage: 12.5 ft
Moderate Flood Stage: 16.0 ft Major Flood Stage: 18.0 ft
Response Time: Slow

This location can be impacted by releases from upstream reservoirs and can often be in backwater due to high flows from the Elm River tributary that enters the James River just downstream of the gage. In addition, the extremely flat gradient of the James River can also impact forecasts. Runoff response can be impacted by whether the basin is in a dry or wet period, that is, if the many potholes and sloughs throughout the basin are empty or full. Flooding can occur due to rain, snowmelt, or rain on top of snowmelt.

The forecast error information is shown in Figure 19. Forecast bias for Columbia is classified as under-forecast. About 63% of the time errors are within +/- 0.5 ft and about 85% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

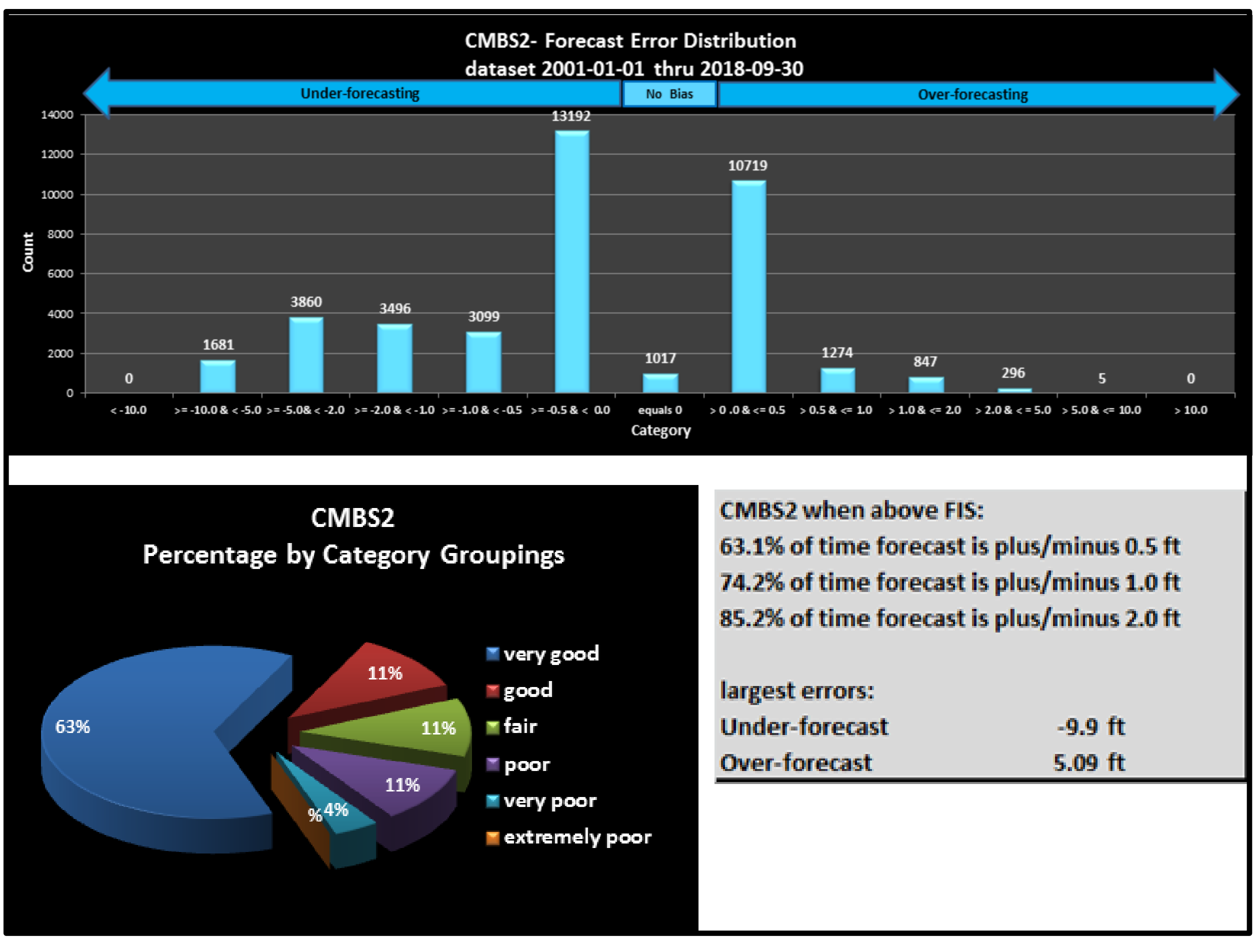


Figure 19. CMBS2 Forecast Error Information

Example 12: Republican River near Hardy, NE (HDYN1)

HSA: WFO Hastings, NE
RFC Forecast Group: LowerRepublican
Flood Stage: 11.0 ft   Forecast Issuance Stage: 9.0 ft
Moderate Flood Stage: 14.0 ft   Major Flood Stage: 15.0 ft
Response Time: Slow

Most flooding that occurs is due to rain although flooding due to snowmelt or rain on snowmelt can occur. Upstream diversions and reservoirs can impact these forecasts at this location.

The forecast error information is shown in Figure 20. Forecast bias for Hardy is classified as under-forecast. About 88% of the time errors are within +/- 2.0 ft over the five-day forecast period.

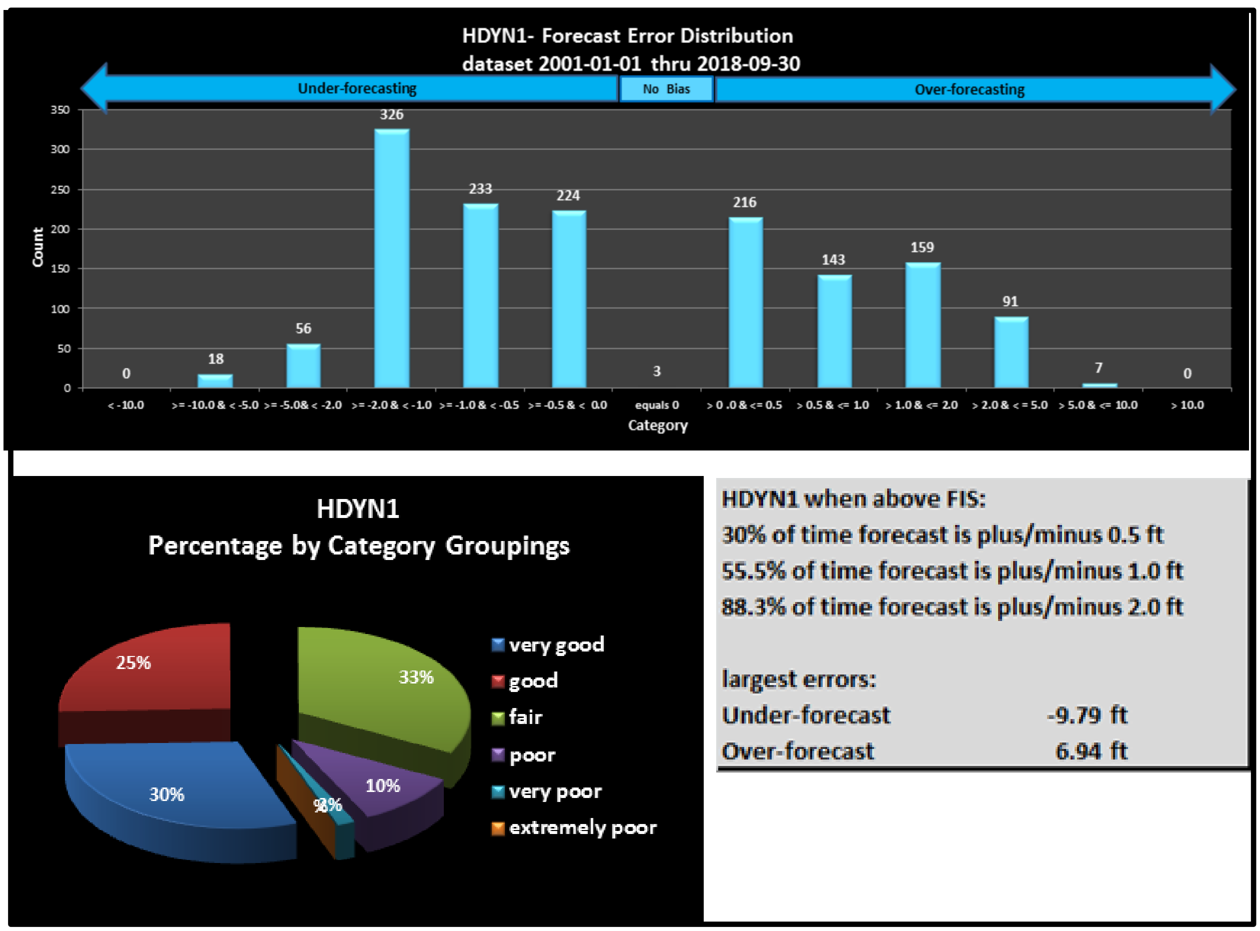


Figure 20. HDYN1 Forecast Error Information

<u>Example 13: Sun River near Simms, MT (SSRM8)</u>

HSA: WFO Great Falls, MT
RFC Forecast Group: UpperMissouri
Flood Stage: 7.5 ft Forecast Issuance Stage: 6.0 ft
Moderate Flood Stage: 10.0 ft Major Flood Stage: 12.0 ft
Response Time: Medium

Flooding is most likely to occur during the spring snowmelt season (April-June). This forecast point is downstream of Gibson Dam, off-river reservoirs, and diversions and these can all impact forecasts for this location. Flooding is primarily due to snowmelt or rain on top of snowmelt.

The forecast error information is shown in Figure 21. Forecast bias for Simms is classified as over-forecast. About 55% of the time errors are within +/- 0.5 ft and about 93% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

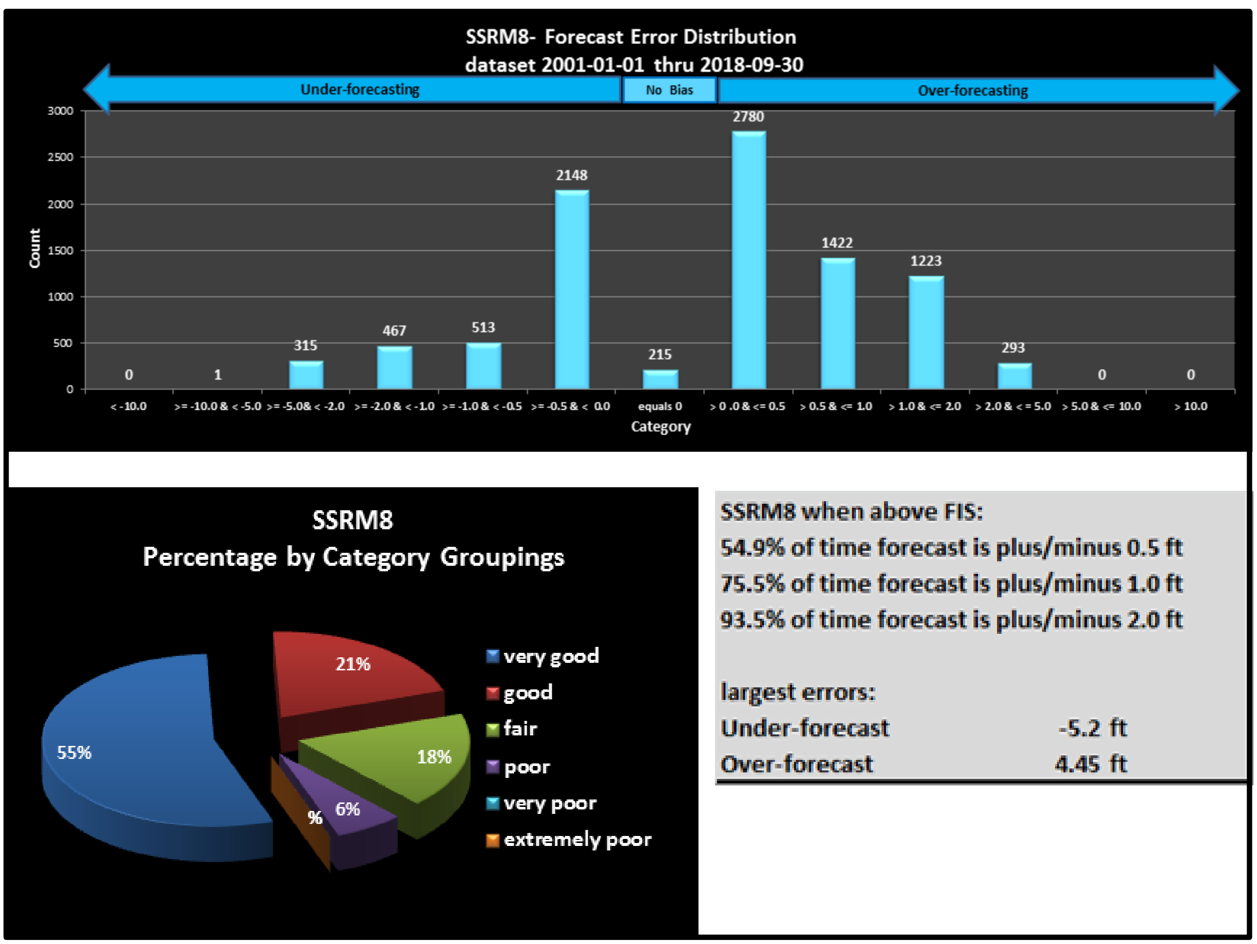


Figure 21. SSRM8 Forecast Error Information

Example 14: Wind River near Riverton, WY (WDRW4)

HSA: WFO Riverton, WY
RFC Forecast Group: Bighorn
Flood Stage: 9.0 ft Forecast Issuance Stage: 8.0 ft
Moderate Flood Stage: 11.0 ft Major Flood Stage: 12.0 ft
Response Time: Medium

Flooding is most likely to occur during the spring snowmelt season (April - June period). Forecasts can be impacted by reservoirs and diversions that are upstream of the river gage.

The forecast error information is shown in Figure 22. Forecast bias for Riverton is classified as over-forecast. About 52% of the time errors are within +/- 0.5 ft and about 95% of the time the forecast errors are within +/- 2.0 ft over the five-day forecast period.

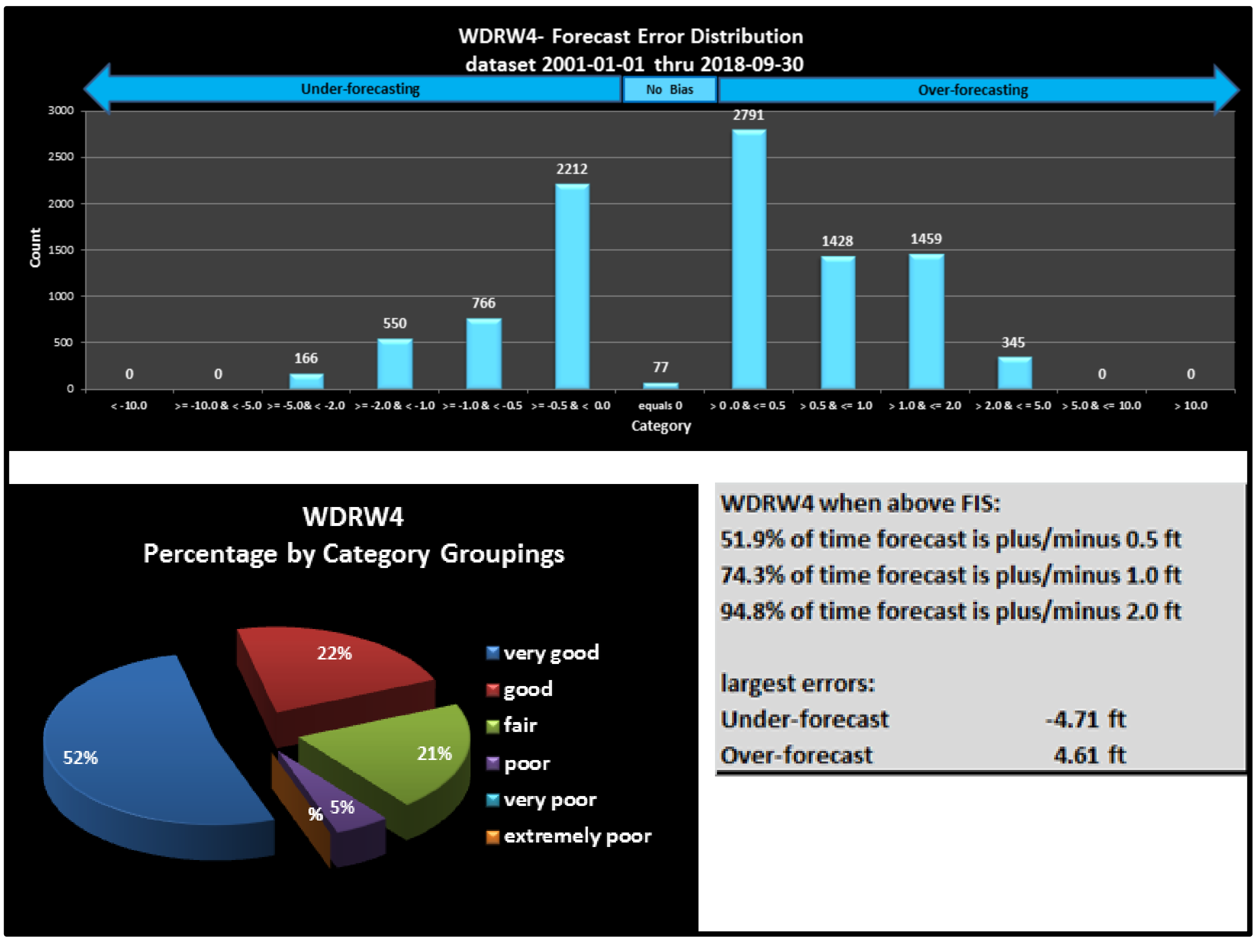


Figure 22. WDRW4 Forecast Error Information

Overview of All Forecast Points

For the 401 forecast points where adequate forecast error data were available, the error information shows that the RFC is more likely to under-forecast for 223 locations, over-forecast for 128 locations, and has an equal chance of over- or under-forecast for 50 locations.

Based on the three response times, and looking at overall forecast bias, as shown in Figure 23, when the bias is equal chance of over- or under-forecasting, the response time of a particular forecast point has little impact. For over-forecast bias there is some impact – with over-forecasting decreasing as the response time moves from fast to slow. The impact of response time is most noticeable when the locations have an under-forecast bias – locations where the response time is fast are more likely to be under-forecast.

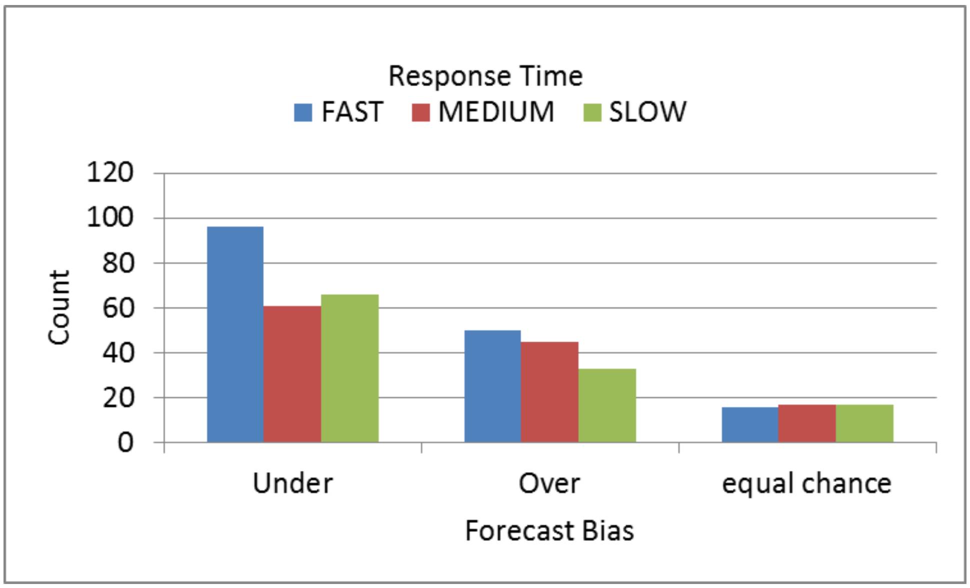


Figure 23. Forecast Bias and Response Time

Summary

The plots and information for all 401 forecast points have been integrated into the long-term verification webpages. These plots should help WFOs to better understand the likely size of forecast error that may occur at individual forecast points so that they can have more confidence in the likely error band and reasonable expectations about the accuracy of a river forecast. This should also help WFOs to provide important decision support information to emergency managers and other users. As this paper shows, each forecast point is unique and is affected by a variety of issues. The plots and data provided also show forecast tendency at each forecast point location. Do forecasts tend to be high or low or are they clustered around the "very good" category? Plots also show if forecasting errors are well distributed. On major flood events, do forecasts tend to have an under- or over-forecast bias? This forecast error information helps verify whether perceptions about a particular forecast point location are valid.

At the RFC, this forecast error information can be used in three ways. First, the RFC forecaster can use this information when evaluating their own forecasts. Second, the information is another tool that the RFC can also consider when prioritizing calibration and re-calibration and other model development/improvement efforts on the forecast points/groups that have the largest forecast bias issues. Finally, since these data will be updated yearly to include the past years' flood events – it gives the RFC a way to track whether changes made to the model are improving the forecasting bias and skill at individual forecast point locations.

At WFOs, the forecasters will now have this information available for most forecast points. This will give them an extra piece of information when providing decision support services. It will help address concerns locals may have about the uncertainty in the river forecast. The WFOs will now have documented analysis and information on nearly every river forecast point in their areas of responsibility. This will help them provide the best hydrologic service possible.

Future efforts will be focused to enhance the display and communication of expectation statistics to better depict the accuracy of RFC forecasts for decision support activities of first responders, NWS partners, other decision makers and the general public. This will be done through graphically applying expectation bounds for each forecast time horizon around routine river and flood forecast hydrographs, and the redesigning and reorganizing of Missouri Basin RFC web services.

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