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https://doi.org/10.17077/etd.4nmfqfrh.

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REVIEW AND ANALYSIS OF THE NATIONAL WEATHER SERVICE RIVER FORECASTS FOR THE JUNE 2008 EASTERN IOWA FLOODS

by

Toby John Hunemuller

A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Civil and Environmental Engineering (Water Resources) in the Graduate College of The University of Iowa

December 2010

Thesis Supervisor: Professor Larry Weber

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CERTIFICATE OF APPROVAL

MASTER'S THESIS

This is to certify that the Master's thesis of

Toby John Hunemuller

has been approved by the Examining Committee for the thesis requirement for the Master of Science degree in Civil and Environmental Engineering (Water Resources) at the December 2010 graduation.

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ABSTRACT

The accuracy and quality of river forecasts are dependent on the nature of each flood. Less extreme , more common, floods may afford deviations between the predicted forecast and observed stage because the locals may be prepared, based on past experience to deal with the less extreme flood events. For less frequent, high flow events the flood forecasts and advanced warning time are more critical, because the locals need time to develop emergency response plans.

The National Weather Service River Forecast Centers (NWSRFC) develop the river forecasts and provide them to the National Weather Service Weather Forecast Office (NWS WFO) for dissemination. During flood events the RFC's are tasked with processing the observed data and running, reviewing and modifying the forecast models to provide reasonable river forecasts based on observed conditions and the forecasters' experience.

This thesis will discuss the personal experiences of the author, analyze the components of the National Weather Service river forecasting process, analyze June 2008 river and precipitation forecasts for several eastern Iowa watersheds, and discuss the results of the analysis as well as provide support to current calls to action to support forecast verification through the hindcasting process.

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LIST OF ACRONYMS

ADCP	Acoustic Doppler Current Profiler
AHPS	Advanced Hydrologic Prediction Service
AWIPS	Advanced Weather Interactive Processing System
CHPS	Community of Hydrologic Prediction System
EOC	Emergency Operations Center
ET	Evaportanspiration Rate (Kc)
FAE	Flood Area Engineer
FMAP	Forecast Mean Areal Precipitation
GIS	Geographic Information System
HEC	Hydrologic Engineering Center
HEC-RAS	Hydrologic Engineering Center River Analysis System
HUC	Hydrologic Unit Code
IDOT	Iowa Department of Transportation
MAP	Mean Areal Precipitation
NCRFC	National Weather Service North Central River Forecasting Center
NWS	National Weather Service
NWS RFC	National Weather Service River Forecasting Center
QPE	Qualitative Precipitation Estimate
QPF	Qualitative Precipitation Forecast
RMSE	Root Mean Square Error
SHEF	Standard Hydrologic Exchange File
SSURGO	Soil Survey Geographic
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
WFO	National Weather Service Weather Forecasting Office

INTRODUCTION

The flood of 2008 was a record event in many Iowa communities and resulted in significant flood damage. Ideally emergency response officials have an emergency response plan in place prior to a flood event. Emergency response actions include developing evacuation plans, enacting evacuation notices, disconnecting utilities, relocating belongings, and flood fighting. However, during extreme flooding the typical response plan may be exceeded and decisions need to be made based on river forecast information. The forecast of the projected river stage is a tool to help emergency officials determine what actions are required. Typically volunteers will sandbag around vulnerable structures but production can limited by available materials, labor, and equipment. For these reasons advanced warning is critical to determine the scope of the emergency response measures within the forecast timeframe.

Every flood event is unique and past floods are not always an indication of future events. The flood of 2008 was characterized by day after day of rain resulting in the river forecasts issued higher and higher each day to reflect the precipitation amounts. The constant rain pushed rivers in to unchartered territory and strained everyone involved because the forecasts continued to go up and up.

On the flip side, inflated forecasts can also lead to communities spending precious resources to protect their facilities based on high early forecasts. The forecasts may be revised downward as the event unfolds resulting in the actual flood elevations lower than the action levels for emergency flood fighting. For example, the City of Davenport expended $325,000 to construct 2,900 feet of temporary embankment in July 2010 as the result of an initial forecast of 20-feet which was reduced to a non-threatening 17.6 feet and observed at 17.14 feet (Wellner, 2010)

The US Army Corps of Engineers (USACE) has a team of engineers, Flood Area Engineers (FAE) who are trained to provide technical assistance to communities during high water events. Communities look to their prospective FAE's for information regarding river forecasts and flood fighting plans. The FAE typically utilizes the Rivergages.com or NWS Advanced Hydrologic Prediction Service (AHPS) website to obtain forecast information.

The common thread during flooding is the river forecast. The forecasts are often forgotten or not needed until a flood event occurs. At which time all eyes are on the river forecast and they become an invaluable tool. The river forecasts trigger flood warnings prompting emergency actions. Accuracy and timeliness are the two characteristics that determine the effectiveness of a river forecast. Residents and emergency officials can focus their efforts to designated areas when forecasts have high accuracy and reliability (U.S. Army Corps of Engineers, 1996).

The current river forecasting system has its limitations. The forecast models require many inputs to develop the river forecasts. The inputs have varied spatial and temporal resolution and accuracy which propagates errors throughout the modeling process. It is difficult to conduct a post event forecast validation, as a tool to improve the modeling, because the subjective human inputs that are applied during the forecasting process cannot be duplicated by modeling alone.

Lastly, the users of the forecast information are constrained because they do not see the whole picture when they access the forecast data. The user can access the forecast information from the National Weather Service’s web page (http://water.weather.gov/ahps/). The forecast is a single line calculated to the nearest tenth of a foot for the next four to seven days. The forecasts do not include a confidence interval and as a result the users may develop a false level of confidence with the forecast information because they do not understand the limitations associated with the river forecast.

This research project started out of personal curiosity regarding the river forecasting process. I wanted to know how the "sausage" was made so I could be better equipped to use the forecast information in future high water events. This thesis will document my personal experiences, provide a general overview of the forecast process, and analyze the river forecast and precipitation forecasts from the flood of 2008. The river forecast analysis was designed to evaluate the quality of the river and precipitation forecasts. The research in this thesis is different from other studies because of the in-depth review of the forecasts over a short period of time and as a result provides figures that are not typically produced when evaluating forecasts over a long period of time. The thesis concludes by providing recommendations to improve the information available to the public so the user is well informed and able to react to the event. The research findings support existing calls for action for the continued effort of developing a forecast verification system to improve forecast skill. The findings also reinforce the need to fund research for the continual review of the river forecast modeling system.

CHAPTER 1

PERSONAL EXPERIENCE

I spent nine days in the City of Des Moines during the Iowa Flood of June 2008. I was tasked with manning the Polk County Emergency Operations Center (EOC). I worked with the Polk County Officials to assist in locating resources (pumps, sandbags, etc), provide daily forecast briefings and provide technical assistance. As the flood expanded and resources shuffled to other flood areas, I was responsible for walking the levees to monitor the condition of the levee system around Des Moines.

We saw firsthand what changes in the landscape can do to the river at high flows. A significant change in the river profile was observed, as compared to the 1993 stage, at the Red Rock Remedial Works levee in SE Des Moines. The river was within two to three feet of the top of the levee several days before the crest was expected to occur. The levee protects key infrastructure to the Midwest, the City of Des Moines, and Pleasant Hill. This created an emergency and as a result, equipment and materials had to be located. The Iowa National Guard was called in to sand bag the levee in preparation of the crest. Fortunately, the river overtopped the Highway 65 embankment and the stage did not increase as predicted.

The University of Iowa, Corps of Engineers and Iowa Department of Transportation (IDOT) are wrapping up an analysis of the roadway embankment. The preliminary findings indicate the embankment was an obstruction resulting in the increased stages on the levee. The IDOT has preliminary plans to add two bridges to pass the flow (Darr, 2010). It is probable that there are other structures that have been constructed that are inadvertently altering the river hydraulics. The changes are difficult to capture in the forecast model and can significantly affect the river stages.

We also saw firsthand the effects of a gage providing false information. The Beaver Creek gage spiked about 12 hours before the crest was originally predicted. Due to the timing and impending crest it was difficult to get backup information and verify the actual stage of Beaver Creek before the forecast was completed. As a result the next forecast issued, the morning of the crest, predicted higher stages and the downtown levees could have been overtopped if the higher predicted stage occurred. This prompted a discussion about evacuating the 500-year floodplain within the City of Des Moines. The forecast and evacuation discussion resulted in a call from the Lieutenant Governor of Iowa to find out what was going on. It was a very tense situation while we waited for verified on the ground information to make the next decision. The decision was made to enact the evacuation to err on the side of caution (KCCI News Channel 8, 2008). Fortunately, the USGS was able to get to the site within a few hours and verified the false reading. The NWS Regional Forecast Center (RFC) issued a new forecast later in the day at a lower stage. However, the evacuation notice remained in effect (KCCI News Channel 8, 2008).

During the flood emergency officials anxiously awaited for the revised forecasts to determine the next step. I wondered why it was taking the forecasters so long to provide us the valuable information we needed to make the decisions. Since I was not familiar with the RFC process I couldn't comprehend the variability in forecast elevations and time it took to prepare and review a forecast for the Des Moines River - let alone most of the state of Iowa or the Midwest. As a result of this experience, I wanted to learn more about the processes and inputs that go into a river forecast.

CHAPTER 2

SUMMARY OF NATIONAL WEATHER SERVICE RIVER FORECASTING PROCEDURE

This section is intended to provide a general overview of the forecast process and describe some of the sources of uncertainty. The official river forecasts are generated at one of the National Weather Service River Forecast Centers (NWS RFC). The 2008 Iowa Flood river forecasts were generated by the North Central Regional Forecast Center (NCRFC) located in Chanhassen, Minnesota. The NWS utilizes the Advanced Weather Interactive Processing System (AWIPS) to access and process the data sources and models used to develop the river forecasts. The forecasts are transmitted from the RFC to the local Weather Forecast Office (WFO) in a Standard Hydrologic Exchange File (SHEF). The WFO office uses the forecast to develop flood warnings and uploads the forecasts to the NWS Advance Hydrologic Prediction Service (AHPS) website (http://water.weather.gov/ahps/) (Welles & Sorooshian, 2007). The NWS forecast information as well as USACE forecasts for the flood control reservoirs and locks and dams can be found on the USACE Rivergages website (http://www.rivergages.com).

The RFCs do not develop forecasts for all forecast locations all of the time. Forecast points often coincide with river gage locations. The river forecasts are site specific and some forecasts are triggered by a high river stage. As high water becomes more widespread additional river forecasts are generated for sites that would not normally have a forecast and forecasts may be revised more than one time per day. The increased number of forecasts requires an RFC to have "all hands on deck" for 24-hour operation.

The forecasting procedure is a complex process that requires input from several data sources, as shown in Table 1. The data arrives at the NCRFC in various temporal and spatial scales. The NCRFC performs a quality control analysis of the data before it is used in the forecasting model(s). The NCRFC currently utilizes lumped parameter hydrologic models for the forecasting process. The lumped model utilizes forecast segments, as shown in Figure 1, to determine the hydrologic response and routing of the flows. The forecast segments characterize the basin into the lumped parameters to represent soil conditions, average slope, and uniform precipitation.

The forecaster has the option of choosing from 30 different, locally calibrated models to process the inputs, such as the Sacramento Soil Moisture Accounting Model (National Weather Service Office of Hydrologic Development, 2007), to create the river forecast. The varying hydrologic models are suited for varying types of conditions with respect to antecedent conditions and the seasonal changes that affect precipitation runoff. In short, "The forecasts depend upon imperfect, mathematical descriptions of the physical process governing runoff generation and river routing" (Welles, 2005). The lead

Table 1. Advanced Weather Interactive Processing System data input

Input	Type/use	Scale
Observed Precipitation	Rain gage network	Irregularly spaced at 15 to 25 km (on average)
Observed Precipitation	Weather radar	4km x 4km HRAP grid
Forecast Precipitation	Qualitative Precipitation Forecast (QPF)	Mesoscale - Nationwide based on multiple meteorological forecast models.
Soil data	Initialize hydrologic model	Forecast segments ranging from 200 to 2000 km^2
Rating Curves	Boundary conditions	Various locations along the rivers and streams

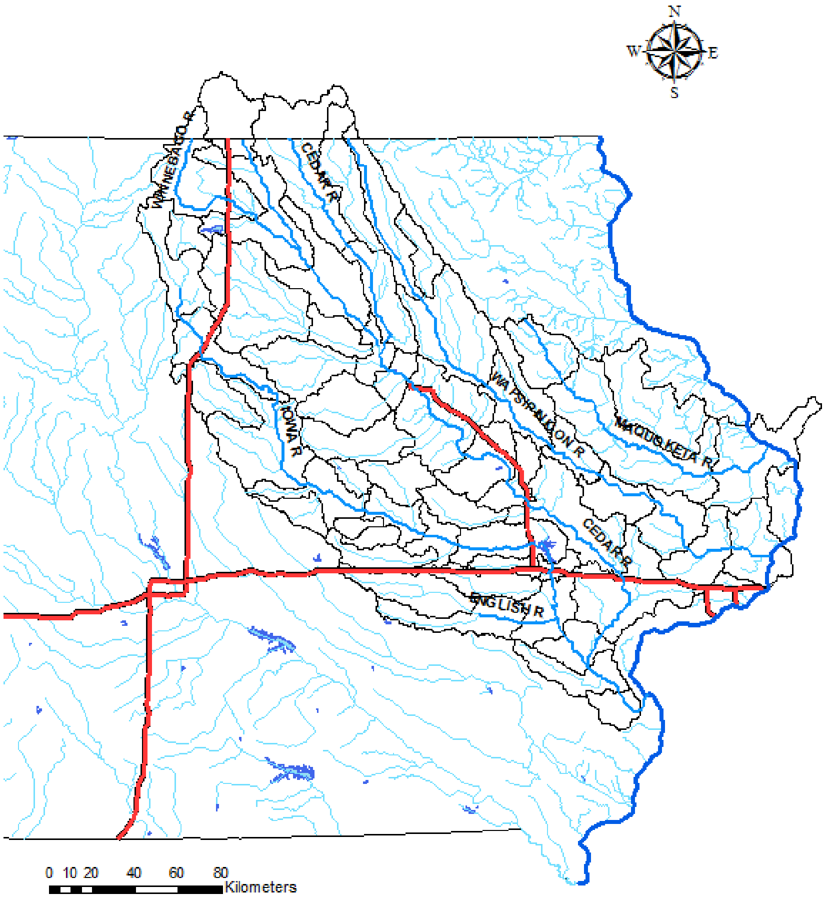


Figure 1. Forecast Validation - Study Forecast Segments. Characteristics such as soil condition, forecast precipitation, and observed precipitation are lumped into a single parameter for the individual forecast segments. The project study area focused on the Cedar, Iowa, Wapsipinicon, Maquoketa and English River watersheds.

forecasters review the predictions and use judgment and experience to issue the official river stage forecast (Mutel, 2010). To date there is not a verification process in place to provide a standard level of confidence to the forecast.

The models currently in operation run the observed and forecast precipitation at a six hour time step which can underestimate the forecast hydrograph depending on the timing and location of the precipitation. For example, a locally intense storm could produce significant runoff within one hour. However, the unit hydrograph for precipitation is based on six hour time steps. As a result the forecaster may need to adjust the unit hydrograph, based on experience, to better simulate the observed conditions.

The forecasters are tasked with trying to predict the results of a very dynamic process to, in the publics' perspective, an exact stage at a river gage location. The observed stage can vary significantly from the forecast stage as the result of several factors. The spatial distribution of observed precipitation may vary from the Forecast Mean Areal Precipitation (FMAP), weather patterns may stall over a particular area, gages can provide false readings and changes in the landscape can affect the amount and timing of the runoff. These factors need to be factored into the river forecast and the uncertainty of the forecasts should be communicated with those using the data. Given the tools they work with the river forecasters do a tremendous job of preparing forecasts during flood events. More effort is needed to refine the model process and reduce the uncertainties associated with the model input parameters.

The National Weather Service is taking steps to improve the modeling procedure by building new models and beginning the transition to the Community of Hydrologic Prediction System (CHPS). CHPS is designed to provide a simpler data infrastructure and improved modeling results. Many USACE Hydrologic Engineering Center (HEC) products will be used to model the watersheds. The RFCs are transitioning to the CHPS system throughout CY 2011 and will be running dual systems until CHPS is tested and ready for full implementation. More information is available at http://www.weather.gov/oh/hrl/chps/. The new process may still be limited by the availability of accurate measured and forecast precipitation information.

CHAPTER 3

SUMMARY OF FACTORS AFFECTING THE NATIONAL WEATHER SERVICE RIVER FORECASTING MODELS

Uncertainty is the crux of any scientific experiment or process and the modeling process used by the RFCs is subject to the normal scrutiny of any scientific process. Simply put the models are designed to simplify the physical process through a series of mathematical equations and relationships (Odoni & Lane, 2010). The models are full of uncertainty, with most of the errors compounding on one another, from input parameters or simplifying the complex physical process to a numeric model. A complex model may not be any more accurate if the inputs and calibration are laden with uncertainty and error. Odini and Lane (2001) identify several constraints of hydrodynamic modeling which are often overlooked and highlighted below.

3.1 Precipitation

Mr. Mike DeWeese from the North Central River Forecast Center shared some valuable information at an office visit in July 2010. Precipitation measured and observed, are the driving inputs in the river forecast models according to Mr. DeWeese. The research community has documented the limitations and errors associated with remote sensed observed precipitation systems. It is common for forecasters to use both radar/satellite and rain gage data. The gage data should be evaluated to verify the distribution, location, spread and shape of the data is appropriate for the project (Hu, 2010).

For example, interpolating rain gage point data to a distributed or lumped coverage area induces errors and biases based methodology for interpolating point data to area coverage. The precipitation measurements are limited by the gage spacing, gage errors, and radar errors (Vasiloff & Sed, 2007). The RFCs process the precipitation data using the Thiessen Polygon technique to determine the mean areal precipitation (MAP) depths for each of the forecast segments. As a result, a single precipitation value is applied to a forecast segment, which can range in size from 200 to 2,000 square kilometers.

The U.S. Army Corps of Engineers has design guidance for flood warning systems (U.S. Army Corps of Engineers, 1996) which references National Weather Service recommendations for determining the number of rain gages in the warning system based on drainage area. The document references a minimum of three gages gages and based on the equation:

$$N = A^{0.33} \quad \text{(N>3)} \tag{1}$$

There are 58 forecast segments as shown in Figure 1 with 75 existing rain gage. The average basin area is approximately 300 square miles. Using equation 1 as a guide there should be approximately 7 gages per forecast segment with a grand total of 400 gages. Increasing gage density may improve the quality of the precipitation data and reduce errors caused by interpolating between gages.

Mr. DeWeese also highlighted the sensitivity of certain forecast segments with respect to precipitation by demonstrating how a variation of few tenths of precipitation resulted in feet of stage change. Basin sensitivity, with respect to precipitation, can be a double edged sword. The sensitivity demonstration highlighted the dependency and impacts of errors in observed precipitation (quantitative precipitation estimates QPE) and quantitative precipitation forecast (QPF) can have a significant impact on the forecast developed by the models.

3.2 Watershed Hydrology

The hydrology in the watersheds are continually changing as the result of varying land uses and development. The watershed is not a static environment thus the modeled hydrology must be periodically verified to match the actual conditions in the watersheds. For example, a significant challenge for river forecasters in the Midwest is predicting and incorporating the hydrologic impacts of agricultural land use and land use changes. Agricultural land use changes are often undocumented and their impacts to the water cycle are uncertain.

At a recent conference, farmers from Minnesota and North Dakota discussed the benefits of tiling their fields. Todd Stanley stated: “We have noticed a big advantage in our tiled land. For instance in 2002 it was the difference between having and not having a crop, since without the tile drainage we would not have been able to get into the fields to plant.” (Hildebrant, 2007) Other statements like: “High water used to worry the heck out of farmers Hughy and Jamey Bland, especially on one flood-prone 900-acre soybean and rice field. But these days, the Corning, Ark., farmers turn on a 24-inch tile flood pump when water inundates the field, and within a few days, the water is out.” (Robinson, 2002).

The State of Iowa has approximately 30 million acres of farmland equating to approximately 85% of the State’s total area (USDA, 2009). Nearly 25-35%, equating to 8 million acres, of Iowa cropland is artificially drained (Zucker & Brown, 1998). Research has shown that the base flow in many Iowa rivers has increased in the second half of the 20th century (Schilling & Libra, 2003). It is difficult to accurately quantify the trends in the flow data because the historic gage data reflects the development of artificial drainage in the landscape over time. There are many theories developed to explain the increase in base river flows. Changes in row crop practices showed some evidence of increasing trends over the last 60 years (Zhang & Schilling, 2006). Changes in base flow trends may also be attributed to the effects of farming land that was once wetland and include switching from small grain and perennial crops (hay, alfalfa, etc) to soy beans and corn. Row crop production in Iowa alone increased by 30 to 40% from 1940 to 2000 (Iowa, 2001).

Schilling and Libra (2003) also discussed the changes in evapotranspiration (ET) as the result of farming once native land and changing crop rotations to rotations dominated by corn and soybeans. Land with native ground cover such as forests and grasses transpire spring, summer and fall. Fallow grasses have ET coefficients (Kc) of 0.85, 0.9, and 0.9 while forests have Kc values of 0.5, 1.10, 0.65 for the three seasons. Corn and soybeans Kc values are lower because the plants do not have significant evapotraspiration, and water uptake, until they are more mature (0, 1.15, and 0.4) for the three seasons.

A study was completed by Schilling and Helmers (2008) that conducted field analysis of flow from agricultural fields and effects to the base flow hydrograph. Tile drains have been shown to reduce surface runoff by increasing rainfall infiltration. However, depending on the watershed characteristics the tiles can either increase or decrease the peak discharge from a watershed (Stillman, Haws, & Govindaraju, 2006).

The effects of agricultural subsurface drainage (field tile) have received considerable attention in the last decade. Tiling has been identified as the source of expedited nitrate transport and as a major contributor to the significant changes in the hydrology of the Midwestern landscape. The impacts of field tile are difficult to estimate because records documenting installation information (spacing, depth, and size) are not kept and the physical effects to the hydrology are not well known.

The World Resources Institute identified a need to study the effects of soil drainage in a 1987 report. The report was a catalyst for soil and drainage scientists develop criteria for soils that required tile and methods to quantify agricultural field tile. Early studies utilized soil data (Soil Survey Geographic (SSURGO) digital soil maps), surface slope data, and low resolution land use data to locate poorly drained soils in areas of agriculture. Early Decision Tree Classification (DTC) GIS scripts were developed to analyze the type of soil (based on classification) and land use to identify land regions that would likely require drainage to sustain crops (Naz, Ale, & Bowling, 2009). The techniques could not distinguish between surface, subsurface, and sub-irrigation drainage practices (Sugg, August 2007).

The improvement of remote sensing techniques has greatly improved the capability of identifying the location and quantity of subsurface drainage. Data collected using infrared remote sensing software has the capability of edge detection filters that can be used for automated feature extraction. Automated extraction has become a reality because the soil in the vicinity of the tile will drain and dry quicker than the surrounding soil. The drier soil has a different fingerprint in the infrared regions of the spectrum than the surrounding moist soil (Naz, Ale, & Bowling, 2009). Timing is critical and it is recommended to collect the imagery approximately two to three days after a one inch rain.

Geographic Information Systems (GIS) algorithms have been developed to estimate the location and density of the tiles at the field scale. Ground truthing the estimated locations can be completed at the field scale but is next to impossible to complete at the watershed level.

A limited number of field studies have been performed to estimate and quantify the physical impacts field tiles have on the hydrology. The studies are performed at the sub-field level and the scalability of the studies are dependent on the tile and soil characteristics of the field. There are several numeric models that have been used to estimate the effects of the soil, water, and tile interaction in subsurface drainage areas. The tiling impacts the river forecast model because the runoff amounts are still largely unknown. More information is needed to quantify the behavior of runoff in agricultural areas. Scaling field scale physical data and numeric models to the watershed level will induce additional errors and biases which are often difficult to quantify.

3.3 Rating Curves

The processes to measure "actual" flow are limited because they are a numeric representations (based on theory) of the physical process which inherently induces uncertainty. River stages are measured continuously using pressure sensors or staff gages and a stage-discharge relationship, known as a rating curve, is used to estimate the flow. The rating curve is developed empirically using coincident direct measurement of river stage and flow at normal river conditions. Odini and Lane (2010) discuss the lack of conformity in rating curves. The rating curves are important and changing boundary conditions in the river forecast models.

Acoustic Doppler Current Profiler (ADCP) is a relatively new technology and can provide near instantaneous measurements, when used correctly, of flow across a river channel to develop the rating curves. ADCP measures the velocity of water by using the Doppler effect to reflect acoustic signals from sediment particles within the water column. The instrument divides the river into depths (bins) and calculates the velocity for a given depth and integrates a flow rate across the river section. The instrument has limited field of measurement due to the transducer depth and blanking distance (USGS, 2009).

The USGS lists some of the common limitations of ADCP which are described below. High sediment concentrations, which are often present during floods, can weaken the signal as it passes through the sediment laden water which can result in erroneous measurements. The instruments also rely on estimates of flow above the transducer to the water surface and along the river edges. It is often not feasible to measure the flow in areas with less than three feet of water depths thus the instrument estimates the edge flows based on operator inputs. Other factors that must be considered when using ADCP are the mounting location of the instrument, selecting a location consisting of uniform flow, the speed at which the boat traverses the river, and the pitch and roll of the boat while taking the measurements.

3.4 Model Calibration/Verification:

The complete river forecast model should be comprised of a hydrologic model to estimate how the water flows in/through the watershed and the hydraulic model which routes the flow in the river channel. The NWS NCRFC typically utilizes a hydrologic model for both the quantity and routing of the flood. NWS hydrologic model documentation was not available. For example, hydrologic models such as HEC-Hydrologic Modeling System (HMS) utilize the continuity and momentum equations to model the precipitation as a reservoir (overland flow). The hydrologic models may be limited depending on the routing model's ability to handle backwater effects, floodplain storage, interaction of channel slope, and subcritical or supercritical flows (USACE, 2000).

In contrast a hydraulic model will utilize channel geometry and roughness characteristics to calculate a continuous water surface profile for a known flow. For example, HEC-River Analysis System (RAS) utilizes an iterative process to solve a one dimensional energy equation to calculate the water surface profile. The momentum equation is used in areas of rapidly varied flows to account for bridges, dams and other channel changes (USACE, 2010). Models are designed to represent the physical process occurring in nature.   The lack of a coupled hydrologic and hydraulic model can be a significant source of uncertainty in the forecast because the channel conditions and capacity are not accounted for in the current hydrologic forecast model as described in the personal experiences examples on page 4.

This chapter discussed many sources of error that are propagated in the river forecast modeling system. The errors are difficult to account for and correct because of the complexity of quantifying the actual value of the quantity being measured. In addition the complex physical process has been reduced to a single value for slope, soil type, and precipitation for a given forecast segment. As a result forecasters must use their professional experience and model calibration information to correct for the errors and uncertainties. Meanwhile the user is largely unaware of the errors and uncertainties involved in the river forecasting process. The next two chapters will focus on the forecast quality for the river and precipitation forecasts.

CHAPTER 4

RIVER FORECAST ANALYSIS

This chapter will focus on the evaluation of the river forecasts utilizing a few different methods including plotting the individual forecasts against the observed stage and computing relative error, bias, accuracy, and forecast warning times.

The soil conditions in Eastern Iowa and the Midwest were saturated following the second wettest winter (2007-2008) on record (National Climate Data Center, 2008). Rivers were swollen as the result of snowmelt and spring rainfall. There was a brief dry period followed by heavy rainfall in early June, as shown in Figure 2, which produced significant flooding. In Iowa 85 of 99 counties were declared disaster areas as the result of the severe flooding. Eastern Iowa was hit especially hard suffering extensive damages (Mutel, 2010).

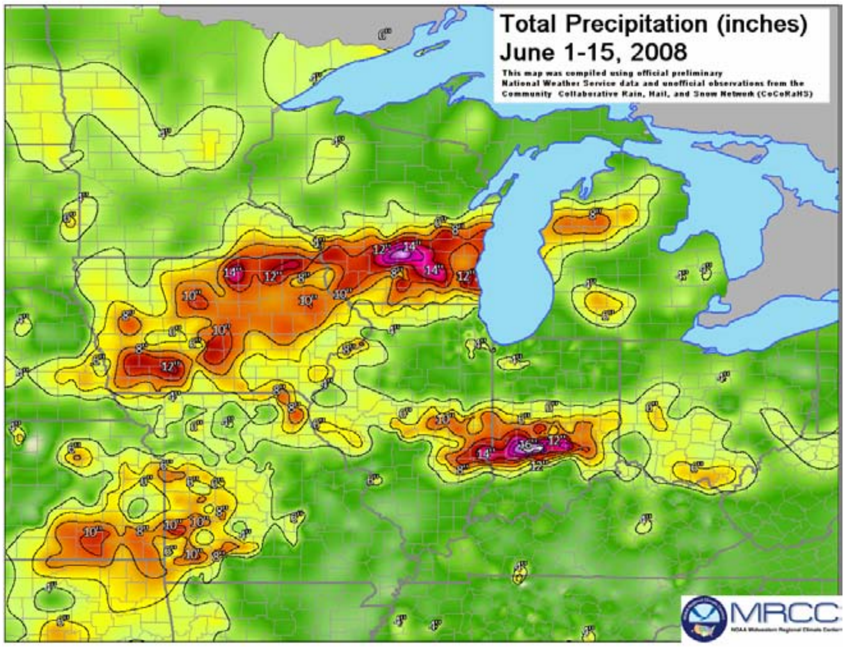


Figure 2. Precipitation total for the period of 1 June to 15 June 2008. (http://www.ncdc.noaa.gov/img/climate/research/2008/jun/june2008precip.png)

The analysis is focused on Eastern Iowa watersheds and primarily the Iowa and Cedar Rivers. Additionally the English, Maquoketa, Wapsipinicon, and Winnebago rivers were evaluated to compare basin response characteristics. River forecasts for the period of June 5 to June 19, 2008 were analyzed with the primary objective to determine flood warning times and investigate the quality (skill) of the river forecasts issued by the National Weather Service North Central River Forecasting Center. The flood warning times were estimated graphically by determining the lead time between the forecast stage and the observed stage. The forecast quality was determined by analyzing the relative forecast error, forecast bias and root mean square error (RMSE).

The study watersheds are shown graphically in Figure 3. The gage identification symbol, river, location, contributing drainage area, and number of issued forecasts are identified in Table 2. River forecasts are issued in 6 hour increments for a total of 7 days. It is important to note that not all of the forecasts were unique. Often times the same forecast was issued in multiple SHEF Files. The study gage locations were organized into three categories based on contributing drainage area to determine relationships between the drainage area and hydrologic response time, forecast quality, and warning times. The three categories: small, medium and large were arbitrarily determined as a basis to capture the differences between small flashy basins, medium basins and larger (main stem) basins. The small contributing areas are classified from 270 to 1,000 square miles, medium sized areas are from 1,000 to 2,800 square miles and large areas are categorized from 2,800 to 13,000 square miles.

4.1 Experimental Design

The first step before conducting the analysis was to determine a method to export the observed and forecast information from the Standard Hydrologic Exchange Format (SHEF) files provided by the NWS NCRFC to Microsoft Excel for analysis. Typical formulas and chart features could be used to analyze the data and prepare figures. The analysis included plotting the time series forecasts with respect to the observed stage, evaluating relative error, bias, and root mean square errors and determining the flood warning lead times. The SHEF file content is shown in Figure 4.

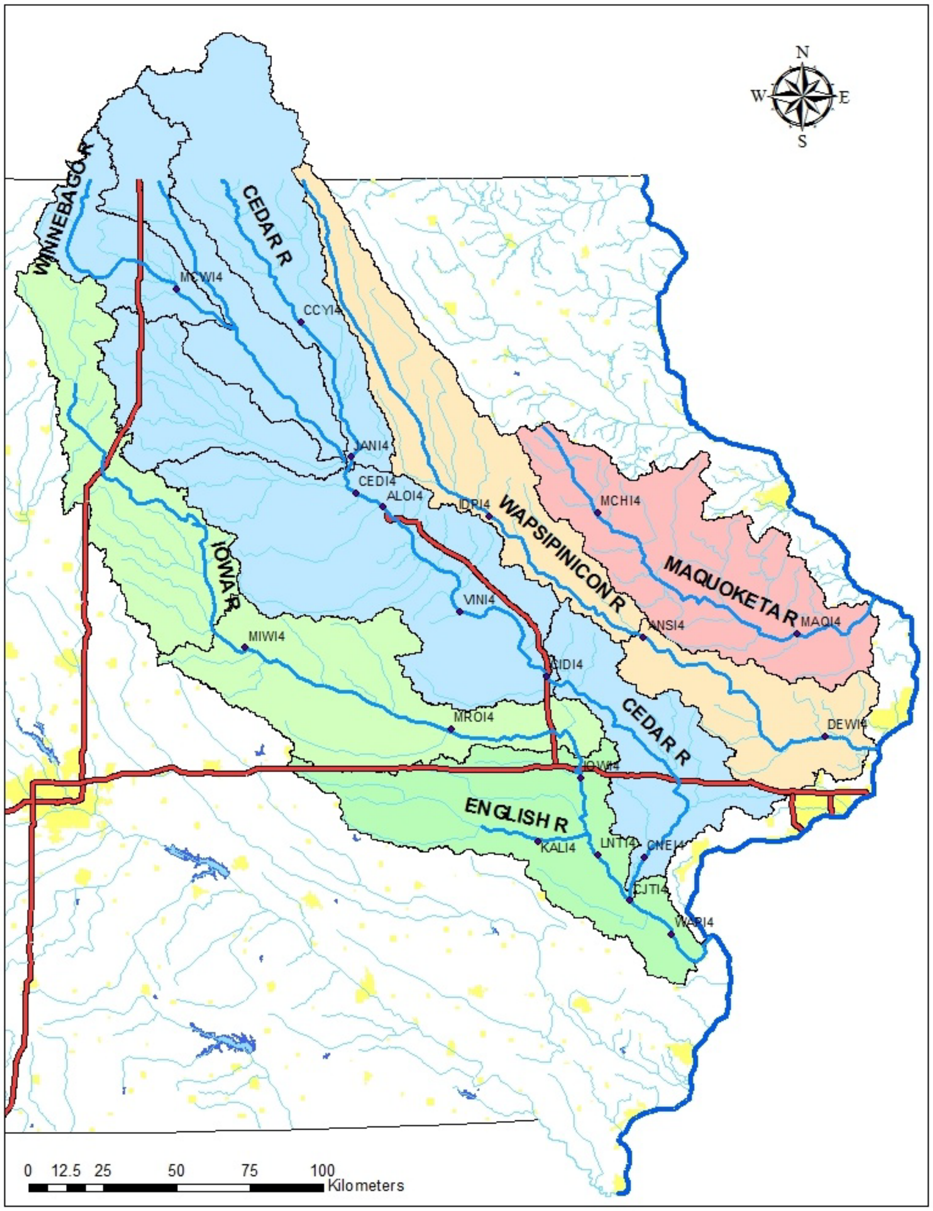


Figure 3. Forecast Validation Study Watersheds. The project study area focused on the Cedar, Iowa, Wapsipinicon, Maquoketa and English River watersheds. The Eastern Iowa watersheds experienced severe flooding during June 2008.

Table 2. Forecast Analysis Gage Sites.

Gage ID	Location	Change in Stage (ft)	Drainage Area mi^2 (km^2)	Issued Forecasts	Category
MCHI4	Maquoketa River - Manchester	12.6	275 (712)	32	Small
MCWI4	Winnebago River - Mason City	13.6	526 (1,362)	47	Small
KALI4	English River - Kalona	11	573 (1,484)	38	Small
IDPI4	Wapsipinicon River - Independence	11.3	1,048 (2,714)	42	Medium
CCYI4	Cedar River - Charles City	18.6	1,054 (2,730)	33	Medium
MIWI4	Iowa River - Marshalltown	7.7	1,532 (3,968)	40	Medium
MAQI4	Maquoketa River - Maquoketa	13.7	1,553 (4,022)	32	Medium
ANSI4	Wapsipinicon River - Anamosa	14.4	1,575 (4,079)	32	Medium
JANI4	Cedar River - Janesville	15.53	1,661 (4,302)	35	Medium
DEWI4	Wapsipinicon River - Dewitt	5.2	2,336 (6,050)	42	Medium
MROI4	Iowa River - Marengo	6.6	2,794 (7,236)	47	Medium
IOWI4	Iowa River - Iowa City	13.1	3,271 (8,472)	55	Large
LNTI4	Iowa River - Lone Tree	10	4,293 (1,1118)	50	Large
CEDI4	Cedar River - Cedar Falls	17.9	4,734 (12,261)	42	Large
ALOI4	Cedar River - Waterloo	18.3	5,146 (13,328)	44	Large
VINI4	Cedar River - Vinton	13	6,040 (15,643)	39	Large
CIDI4	Cedar River - Cedar Rapids	23.6	6,510 (16,860)	43	Large
CNEI4	Cedar River - Conesville	11.5	7,785 (20,162)	41	Large
WAPI4	Iowa River - Wapello	13.9	12,499 (32,371)	68	Large
CJTI4	Iowa River - Columbus Junction	15.4	12,631 (317,602)	60	Large

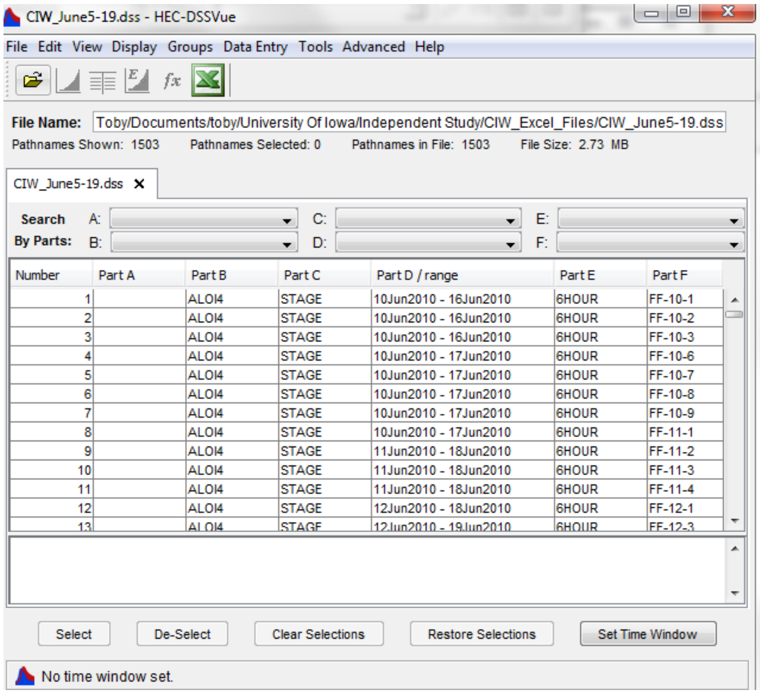
The contents of the SHEF files were viewed and exported using the U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) Data Storage System Visual Utility Engine (HEC-DSSVue) software (Version 2.0, August 2009) for the period of June 5 to June 19, 2008. The HEC-DSSVue user interface is shown in Figure 5. HEC-DSSVue is a database utility software that can be used to view, edit, and manipulate sequential scientific data. The software has a function to import SHEF files for analysis but also has the capability of managing other types of hydrologic data sets (USACE, 2009).

It was not possible to conduct a mass import and export using HEC-DSSVue because HEC-DSSVue would combine the individual SHEF file forecasts into one continuous string of data eliminating the ability to analyze the forecasts individually as shown in Figure 6.

It was determined after coordinating with USACE Rock Island Water Control personnel that the 197 SHEF files had to be imported into HEC-DSSVue one at a time in order to edit the forecast descriptor (Part F) to include a unique identifier. Part F was edited to include the day of the month and the sequential forecast number as a descriptor. For example, the third forecast on June 12th was named FF-12-03. The data was then sorted by gage location using HEC-DSSVue. The selected site was then exported to Microsoft Excel for analysis. The export format from HEC-DSSVue to Microsoft Excel is shown in Table 3. The forecasts are staggered when exported to Microsoft Excel to correspond to the first 6 hour forecast. HEC-DSSVue automatically aligned the first forecast estimate with the time the stage was to occur. This simplified the analysis by not having to manually align the data and introduce the potential for error.

```
: Cedar River  Waterloo - ALOI4
: HSA:DMX   Flood Stage:12.0 FT   Fcst Issuance Stage:8.0 FT
: ------------------------------------------------------------
: CREST 21 - 23 FEET . . . TOP OF RATING CURVE IS 22.5 FEET
: ------------------------------------------------------------
: CREST FORECAST
.A ALOI4  0610 Z DH06/DC06081515/HGIFFX  21.5
:
.E ALOI4 0607 Z DH18/DC06081515/HGIP/DIH06 :6-Hr Obs Stage (ft)
.E1  12.7/ 13.1/ 13.7/ 14.1/
.E ALOI4 0608 Z DH18/DC06081515/HGIFF/DIH06 :6-Hr Fcst Stage (ft)
.E1  15.2/ 16.1/ 16.9/ 18.3/ 19.8/ 20.8/ 21.5/ 21.5/
.E1  21.5/ 21.5/ 21.5/ 21.4/ 21.4/ 21.1/ 20.5/ 19.6/
.E1  18.4/ 17.3/ 16.1/ 15.1/ 14.2/ 13.2/ 12.5/ 11.9/
.E1  11.5/ 11.0/ 10.6/ 10.2/
```

Figure 4. SHEF File Format. The files contains the issue time of forecast, gage ID, crest forecast, previous 24 hours of observed stage and forecast stage information.



File Name: Toby/Documents/toby/University Of Iowa/Independent Study/CIW_Excel_Files/CIW_June5-19.dss

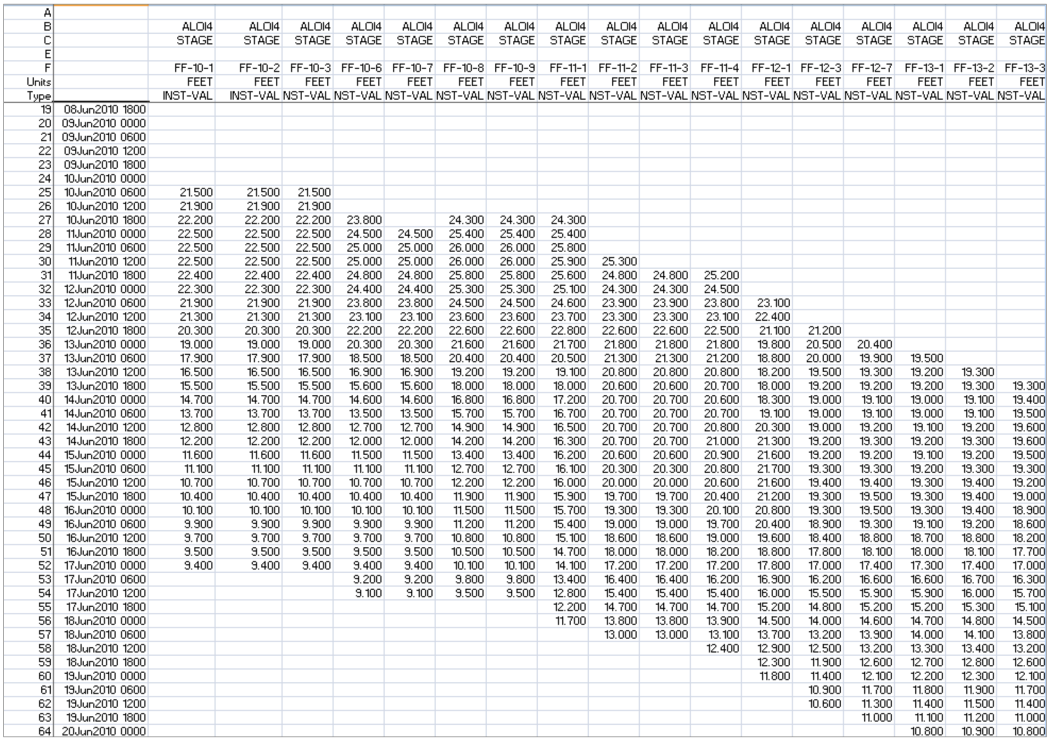
Pathnames Shown: 1503 Pathnames Selected: 0 Pathnames in File: 1503 File Size: 2.73 MB

Number	Part A	Part B	Part C	Part D / range	Part E	Part F
1		ALOI4	STAGE	10Jun2010 - 16Jun2010	6HOUR	FF-10-1
2		ALOI4	STAGE	10Jun2010 - 16Jun2010	6HOUR	FF-10-2
3		ALOI4	STAGE	10Jun2010 - 16Jun2010	6HOUR	FF-10-3
4		ALOI4	STAGE	10Jun2010 - 17Jun2010	6HOUR	FF-10-6
5		ALOI4	STAGE	10Jun2010 - 17Jun2010	6HOUR	FF-10-7
6		ALOI4	STAGE	10Jun2010 - 17Jun2010	6HOUR	FF-10-8
7		ALOI4	STAGE	10Jun2010 - 17Jun2010	6HOUR	FF-10-9
8		ALOI4	STAGE	10Jun2010 - 17Jun2010	6HOUR	FF-11-1
9		ALOI4	STAGE	11Jun2010 - 18Jun2010	6HOUR	FF-11-2
10		ALOI4	STAGE	11Jun2010 - 18Jun2010	6HOUR	FF-11-3
11		ALOI4	STAGE	11Jun2010 - 18Jun2010	6HOUR	FF-11-4
12		ALOI4	STAGE	12Jun2010 - 18Jun2010	6HOUR	FF-12-1
13		ALOI4	STAGE	12Jun2010 - 19Jun2010	6HOUR	FF-12-3

No time window set.

Figure 5. HEC-DSSVue Interface. The interface was used to import, edit Part F to create a unique identifier, and export the Standard Hydrologic Exchange Format (SHEF) file into Microsoft Excel for further analysis.

Table 3. HEC-DSSVue Export Format.



A																		
B		ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4	ALOI4
C		STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE	STAGE
E																		
F		FF-10-1	FF-10-2	FF-10-3	FF-10-6	FF-10-7	FF-10-8	FF-10-9	FF-11-1	FF-11-2	FF-11-3	FF-11-4	FF-12-1	FF-12-3	FF-12-7	FF-13-1	FF-13-2	FF-13-3
Units		FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET	FEET
Type		INST-VAL	INST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL	NST-VAL
19	08Jun2010 1800																	
20	09Jun2010 0000																	
21	09Jun2010 0600																	
22	09Jun2010 1200																	
23	09Jun2010 1800																	
24	10Jun2010 0000																	
25	10Jun2010 0600	21.500	21.500	21.500														
26	10Jun2010 1200	21.900	21.900	21.900														
27	10Jun2010 1800	22.200	22.200	22.200	23.800		24.300	24.300	24.300									
28	11Jun2010 0000	22.500	22.500	22.500	24.500	24.500	25.400	25.400	25.400									
29	11Jun2010 0600	22.500	22.500	22.500	25.000	25.000	26.000	26.000	25.800									
30	11Jun2010 1200	22.500	22.500	22.500	25.000	25.000	26.000	26.000	25.900	25.300								
31	11Jun2010 1800	22.400	22.400	22.400	24.800	24.800	25.800	25.800	25.600	24.800	24.800	25.200						
32	12Jun2010 0000	22.300	22.300	22.300	24.400	24.400	25.300	25.300	25.100	24.300	24.300	24.500						
33	12Jun2010 0600	21.900	21.900	21.900	23.800	23.800	24.500	24.500	24.600	23.900	23.900	23.800	23.100					
34	12Jun2010 1200	21.300	21.300	21.300	23.100	23.100	23.600	23.600	23.700	23.300	23.300	23.100	22.400					
35	12Jun2010 1800	20.300	20.300	20.300	22.200	22.200	22.600	22.600	22.800	22.600	22.600	22.500	21.100	21.200				
36	13Jun2010 0000	19.000	19.000	19.000	20.300	20.300	21.600	21.600	21.700	21.800	21.800	21.800	19.800	20.500	20.400			
37	13Jun2010 0600	17.900	17.900	17.900	18.500	18.500	20.400	20.400	20.500	21.300	21.300	21.200	18.800	20.000	19.900	19.500		
38	13Jun2010 1200	16.500	16.500	16.500	16.900	16.900	19.200	19.200	19.100	20.800	20.800	20.800	18.200	19.500	19.300	19.200	19.300	
39	13Jun2010 1800	15.500	15.500	15.500	15.600	15.600	18.000	18.000	18.000	20.600	20.600	20.700	18.000	19.200	19.200	19.200	19.300	19.300
40	14Jun2010 0000	14.700	14.700	14.700	14.600	14.600	16.800	16.800	17.200	20.700	20.700	20.600	18.300	19.000	19.100	19.000	19.100	19.400
41	14Jun2010 0600	13.700	13.700	13.700	13.500	13.500	15.700	15.700	16.700	20.700	20.700	20.700	19.100	19.000	19.100	19.000	19.100	19.500
42	14Jun2010 1200	12.800	12.800	12.800	12.700	12.700	14.900	14.900	16.500	20.700	20.700	20.800	20.300	19.000	19.200	19.100	19.200	19.600
43	14Jun2010 1800	12.200	12.200	12.200	12.000	12.000	14.200	14.200	16.300	20.700	20.700	21.000	21.300	19.200	19.300	19.200	19.300	19.600
44	15Jun2010 0000	11.600	11.600	11.600	11.500	11.500	13.400	13.400	16.200	20.600	20.600	20.900	21.600	19.200	19.200	19.100	19.200	19.500
45	15Jun2010 0600	11.100	11.100	11.100	11.100	11.100	12.700	12.700	16.100	20.300	20.300	20.800	21.700	19.300	19.300	19.200	19.300	19.300
46	15Jun2010 1200	10.700	10.700	10.700	10.700	10.700	12.200	12.200	16.000	20.000	20.000	20.600	21.600	19.400	19.400	19.300	19.400	19.200
47	15Jun2010 1800	10.400	10.400	10.400	10.400	10.400	11.900	11.900	15.900	19.700	19.700	20.400	21.200	19.300	19.500	19.300	19.400	19.000
48	16Jun2010 0000	10.100	10.100	10.100	10.100	10.100	11.500	11.500	15.700	19.300	19.300	20.100	20.800	19.300	19.500	19.300	19.400	18.900
49	16Jun2010 0600	9.900	9.900	9.900	9.900	9.900	11.200	11.200	15.400	19.000	19.000	19.700	20.400	18.900	19.300	19.100	19.200	18.600
50	16Jun2010 1200	9.700	9.700	9.700	9.700	9.700	10.800	10.800	15.100	18.600	18.600	19.000	19.600	18.400	18.800	18.700	18.800	18.200
51	16Jun2010 1800	9.500	9.500	9.500	9.500	9.500	10.500	10.500	14.700	18.000	18.000	18.200	18.800	17.800	18.100	18.000	18.100	17.700
52	17Jun2010 0000	9.400	9.400	9.400	9.400	9.400	10.100	10.100	14.100	17.200	17.200	17.200	17.800	17.000	17.400	17.300	17.400	17.000
53	17Jun2010 0600				9.200	9.200	9.800	9.800	13.400	16.400	16.400	16.200	16.900	16.200	16.600	16.600	16.700	16.300
54	17Jun2010 1200				9.100	9.100	9.500	9.500	12.800	15.400	15.400	15.400	16.000	15.500	15.900	15.900	16.000	15.700
55	17Jun2010 1800								12.200	14.700	14.700	14.700	15.200	14.800	15.200	15.200	15.300	15.100
56	18Jun2010 0000								11.700	13.800	13.800	13.900	14.500	14.000	14.600	14.700	14.800	14.500
57	18Jun2010 0600									13.000	13.000	13.100	13.700	13.200	13.900	14.000	14.100	13.800
58	18Jun2010 1200											12.400	12.900	12.500	13.200	13.300	13.400	13.200
59	18Jun2010 1800												12.300	11.900	12.600	12.700	12.800	12.600
60	19Jun2010 0000												11.800	11.400	12.100	12.200	12.300	12.100
61	19Jun2010 0600													10.900	11.700	11.800	11.900	11.700
62	19Jun2010 1200													10.600	11.300	11.400	11.500	11.400
63	19Jun2010 1800														11.000	11.100	11.200	11.000
64	20Jun2010 0000															10.800	10.900	10.800

4.2 Forecast Analysis

A figure was created to compare the individual forecasts and observed stage as shown in the Figure 6, Figure 7, and Figure 8. Figure 6 is representative of a typical small watershed, Figure 7 of the medium contributing area, Figure 8 the large contributing drainage area, and Figure 9 large contributing drainage area downstream of the precipitation area. The persistent rainfall continually pushed the forecast upward during the event. The figures show the presence of a base flow recession component, shown by the downward tail, several days into the forecast period. The recession is a result of only including the 24-hour QPF in the river forecast. The figures also highlight the basin response times and characteristics for the three categories. The persistent rainfall continually pushed the forecast upward during the event.

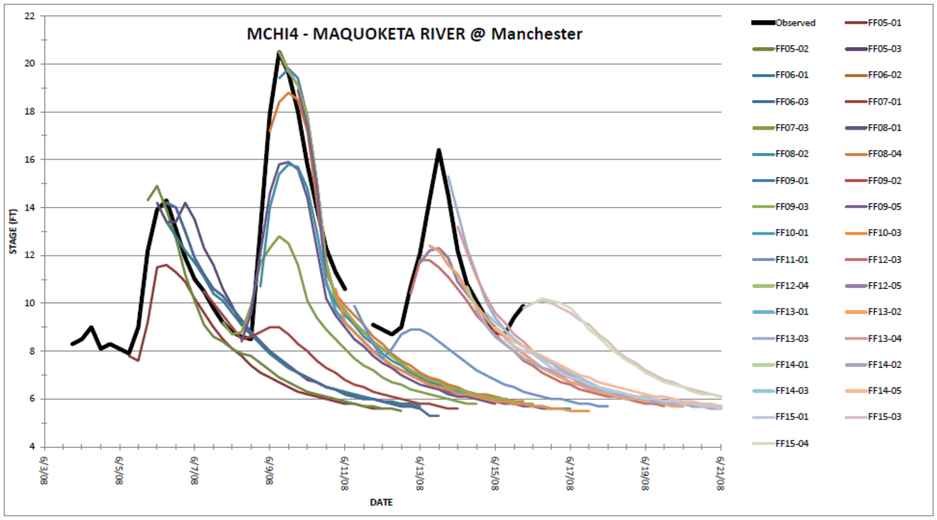


Figure 6. Forecast and observed data for a small drainage area for the Maquoketa River at Manchester (MCHI4) gage. The graph shows the forecast time series with respect to the observed stage. Note the presence of the base flow recession as the result of the forecast including the 24-hour QPF. The small contributing drainage area gages highlight the fast hydrologic response time of the watershed.

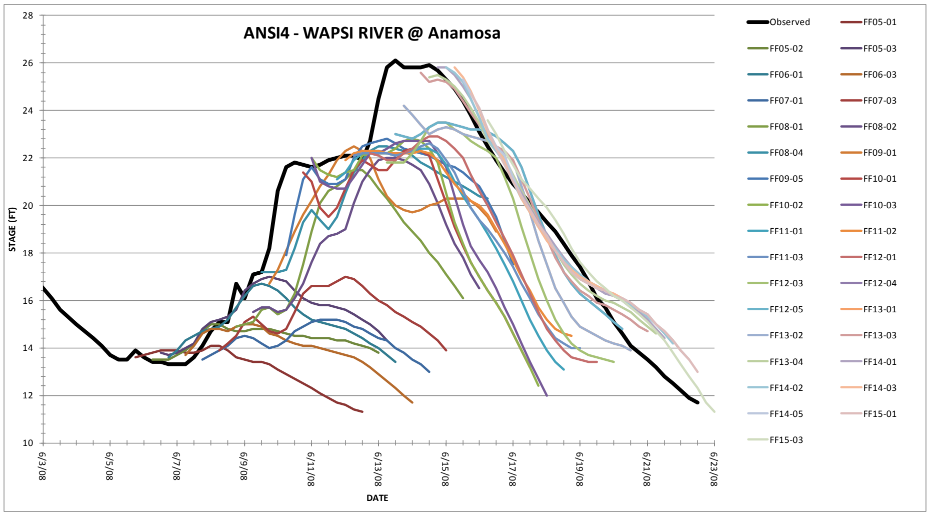


Figure 7. Forecast and observed data for a medium drainage area for the Wapsipinicon River at Anamosa (ANSI4) gage. The graph shows the forecast time series with respect to the observed stage. Note the presence of the base flow recession as the result of the forecast including the 24-hour QPF. Also note the 4 feet of difference between the crest and forecast because the forecasts are unable to keep up with the rising river. The medium contributing drainage area gages show a slightly slower hydrologic response time of the watershed.

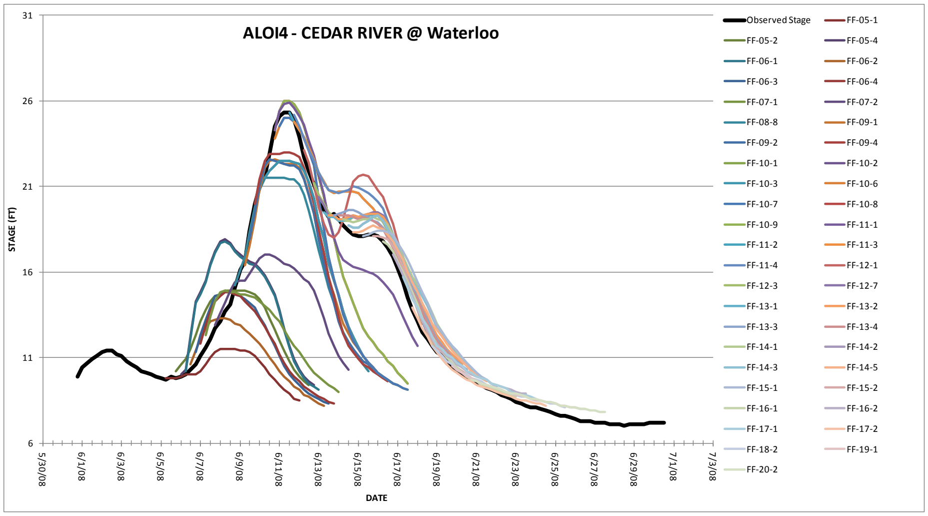


Figure 8. Forecast and observed data for a large drainage area for the Cedar River at Waterloo (ALOI4) gage within the heart of the June 1 to June 15 heavy rainfall totals. The graph shows the forecast time series with respect to the observed stage. Note the presence of the base flow recession as the result of the forecast including the 24-hour QPF. The large contributing drainage areas consistently show a single crest and the slower hydrologic response time of the watershed.

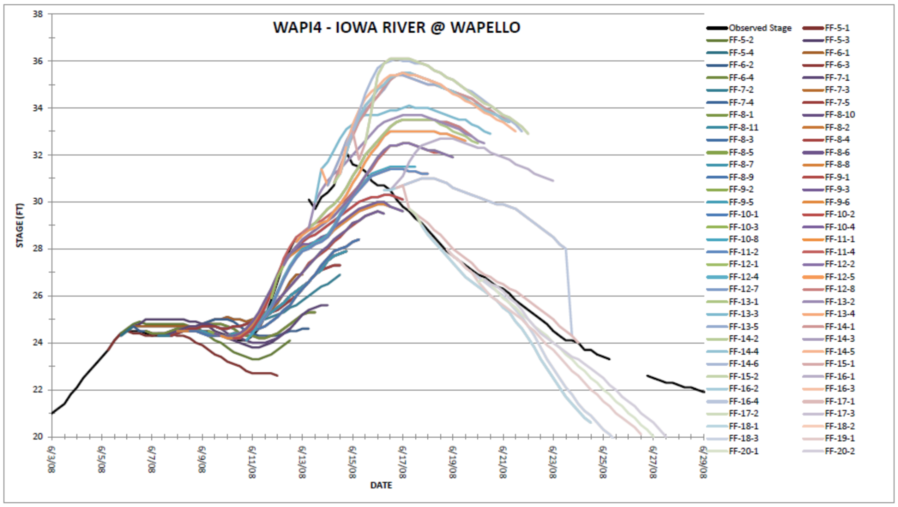


Figure 9. Forecast and observed data for a large contributing drainage area for the Iowa River at Wapello (WAPI4) gage downstream of the high precipitation band as shown in Figure 2. The graph shows the forecast time series with respect to the observed stage. Note the graph does not show the recession forecast and is significantly over predicted despite relatively low precipitation totals.

An observer can gather a lot of information about the June 2008 river forecasts based on the above figures. A few points that stand out are fast hydrologic response times for the small watersheds; the continually increasing forecasts as a result of the nearly two weeks of rainfall; and the individual forecasts had a persistent recession segment approximately 1 to 4 days after the issue date. The recession component of forecast was approximately 1 day after issuance for small watershed and increased to 3 or 4 days for the large contributing drainage area gages. It is the result of only including the 24 hours of forecast precipitation and assuming no additional rainfall for the duration of the 7 day forecast period. The hydrologic response time could be estimated by determining the time from the forecast issuance to the start of the recession portion of the forecast.

Southeast Iowa received a small fraction of the rain that the north central Iowa experienced. One would expect the forecasts to improve in locations of low precipitation. The figures in Appendix A highlight the over prediction, in areas with relatively little precipitation as compared to north central Iowa. For example, the downstream gages of the Iowa River at Lone Tree (LNTI4), Columbus Junction (CJTI4), and Wapello (WAPI4) are significantly over predicted. In contract the forecasts were barely able to keep up with the rising stage at the Conesville (CNEI4) gage on the Cedar River, also located in southeast Iowa.

4.3 Relative Forecast Error (Stage Error)

The next step in the analysis process was to determine the relative error (stage error) of the forecasts for the study gages. Relative error was computed using:

$$\text{Relative Error} = \text{Forecast Stage} - \text{Observed Stage} \qquad (2)$$

Once the relative error table was computed the data were sorted to align the six hour to 7 day errors, refer to Table 4, in order to create relative error plots as shown in Figure 10, Figure 11, Figure 12 and Figure 13 with the remaining figures in Appendix A. The first column on the left is the dependent variable - the Forecast Increment corresponding to the 6-hour increment (days). The remaining six columns are the relative errors for the forecasts issued for June 5 to June 7, 2008. The forecasts were grouped into daily forecasts to simplify the analysis procedure.

Table 4. Relative error data table for the Wapsipinicon River at Anamosa as shown in Figure 11.

Forecast	FF05-01	FF05-02	FF05-03	FF06-01	FF06-03	FF07-01
Increment	6/5/2008	6/5/2008	6/6/2008	6/6/2008	6/6/2008	6/7/2008
0.25	-0.30	0.10	0.40	0.30	0.40	-0.60
0.50	0.10	0.10	0.40	0.60	0.50	-1.00
0.75	0.40	0.20	0.50	1.00	0.50	-1.20
1.00	0.50	0.40	0.70	0.90	0.10	-1.00
1.25	0.60	0.60	0.60	0.60	-0.30	-2.30
1.50	0.60	0.60	0.70	0.10	-0.40	-1.60
1.75	0.50	0.60	0.40	-0.20	-1.80	-2.70
2.00	0.20	0.30	0.10	0.10	-1.10	-3.00
2.25	-0.20	-0.10	0.20	-1.00	-2.10	-4.20
2.50	-0.60	-0.30	-1.10	0.10	-2.30	-6.50
2.75	-1.00	-2.00	0.30	-0.50	-3.60	-7.30
3.00	-1.20	-1.40	-0.40	-0.50	-6.10	-7.10
3.25	-3.10	-2.30	-0.30	-1.60	-7.30	-6.80
3.50	-2.60	-2.40	-1.20	-4.20	-7.60	-6.50
3.75	-3.70	-3.40	-3.70	-5.50	-7.60	-6.50
4.00	-3.80	-5.90	-4.80	-6.10	-7.50	-6.70
4.25	-4.90	-7.00	-5.40	-6.30	-7.70	-6.80
4.50	-7.50	-7.30	-5.60	-6.40	-8.00	-7.00
4.75	-8.70	-7.20	-5.70	-6.60	-8.20	-7.20
5.00	-9.10	-7.20	-5.90	-6.90	-8.40	-7.10
5.25	-9.20	-7.30	-6.10	-7.10	-8.50	-8.10
5.50	-9.30	-7.50	-6.30	-7.30	-8.50	-10.10
5.75	-9.60	-7.70	-6.50	-7.50	-9.50	-11.50
6.00	-10.00	-7.80	-6.70	-7.50	-11.60	-12.10
6.25	-10.30	-7.90	-6.70	-8.50	-13.20	-12.00
6.50	-10.50	-7.80	-7.70	-10.50	-13.80	-12.30
6.75	-10.70	-8.70	-9.80	-12.10	-13.80	-12.50
7.00	-10.60	-10.70	-11.50	-12.70	-14.10	-12.90

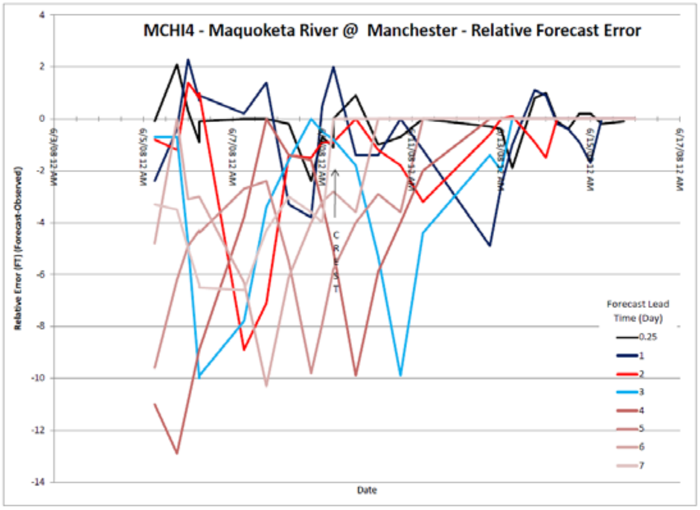


Figure 10. Relative error graph for small drainage area for the Maquoketa River at Manchester (MCHI4) gage. The graph shows the relative error for the forecast issued on a given day. Relative forecast error decreased from day 7 to day 1 which is expected considering the baseline recession shown in Section 4.1. Forecast errors were significantly less after the crest.

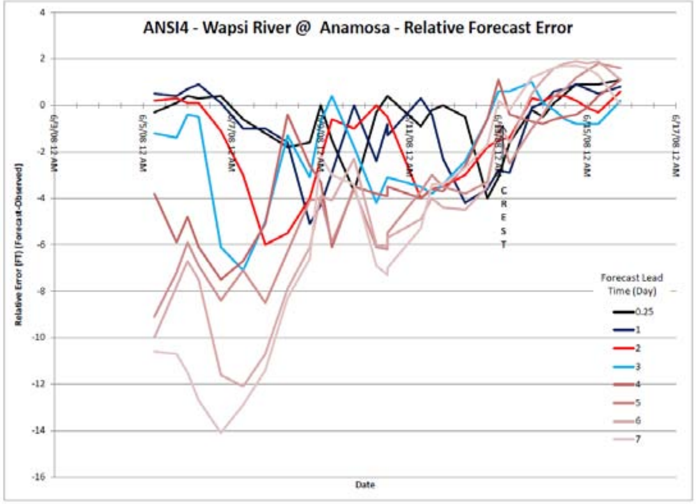


Figure 11. Relative error graph for a medium drainage area for the Wapsipinicon River at Anamosa (ANSI4) gage. The graph shows the relative error for the forecast issued on a given day. Relative forecast error decreased from day 7 to day 1 which is expected considering the baseline recession shown in Section 4.1. Forecast errors were significantly less after the crest.

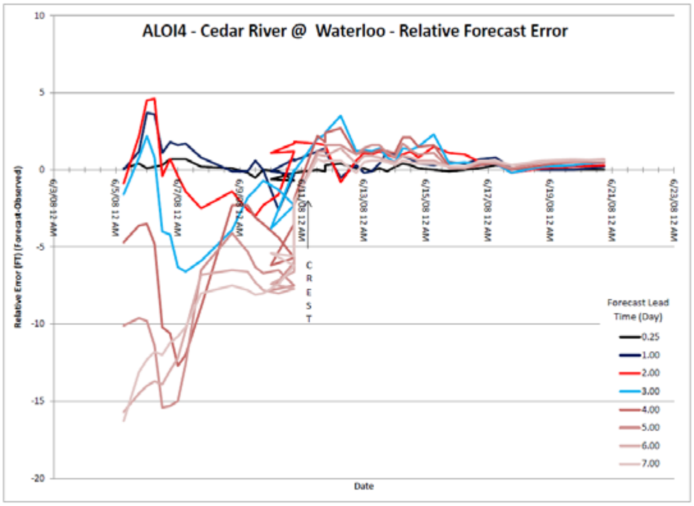


Figure 12. Relative forecast error graph for a large drainage area for the Cedar River at Waterloo (ALOI4) gage. The graph shows the relative error for the forecast issued on a given day. Relative forecast error decreased from day 7 to day 1 which is expected considering the baseline recession shown in Section 4.1. Forecast errors were significantly less after the crest.

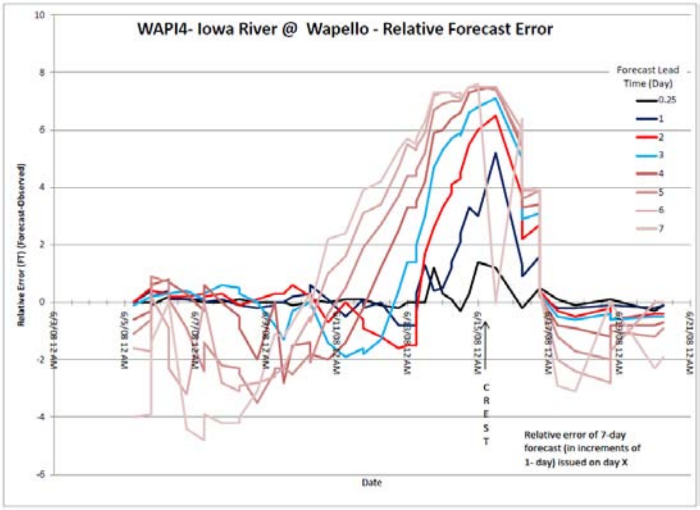


Figure 13. Relative forecast error graph for a large drainage for the Iowa River at Wapello (WAPI4) gage downstream of the high precipitation band. The graph shows the relative error for the forecast issued on a given day. The graph for this location has different characteristics than the other sites. Note the relative error for forecasts issued 5 to 10 days before the crest were underestimated then as the crest approached the forecasts were dramatically over predicted.

The relative forecast error was determined for the first six-hour forecast (0.25 days) and then daily from day 1 to day 7. It is difficult generalize the results using only the figures above but the figures do show a general trend indicating the 7 day forecasts are significantly under estimated and the relative error decreases as the forecast lead time approaches the forecast issue date. Additionally, the small, medium, and large watersheds relative errors are approximately ± 2 feet for the forecast increment of 0.25 day, 1 day and 2 days respectively. This indicates a general improvement in the forecast accuracy for larger watersheds.

The limitations of the current forecast models using only a hydrologic model to route flows. For example, the casual observer may expect the forecasts to be more accurate at farthest downstream gages on the system because there was relatively little precipitation in southeast Iowa resulting in a forecast predicting the routing of the flood wave. However the gage on the Iowa River at Wapello is characterized by the under prediction in the week prior to the crest and significant over prediction in the days prior to the crest as shown in Figure 13.

4.4 Forecast Quality

General trends and conclusions can be inferred from the figures presented in the previous section. However, an empirical analysis of the forecast quality should be completed using bias and accuracy. Forecast bias at different lead times were evaluated using the mean error (ME), computed using the formula (Welles & Sorooshian, 2007):

$$\text{Mean Error} = \text{Average (Forecast Stage - Observed Stage)} \qquad (3)$$

Forecast bias is used as an indicator of systematic errors resulting in consistently under or over estimating the forecast and can be manifested through input or modeling errors (Hashino, Bradley, & Schwartz, 2006).

The accuracy of the forecast at different lead times was evaluated using the root mean square error (RMSE) (Welles & Sorooshian, 2007),

$$\text{RMSE} = \sqrt{(Average(Forecast\ Stage - Observed\ Stage)^2)} \qquad (4)$$

The quality of the forecast can be affected by biases induced by the hydrologic conditions such as snow pack, drought, saturated soil conditions and the variability of the forecasts issued.

The procedure evaluated the three gage contributing sizes to determine if there were any consistencies within each of the categories and trends across the three categories. During a food event emergency officials are generally more concerned forecast accuracy in the time leading up to the crest. For this reason the measures were calculated separately for the rising and falling limbs. The analysis will also determine the approximate forecast lead time that the forecast is within 2 feet of observed using RMSE as the metric.

4.4.1 Small Contributing Drainage Area Gages

The small contributing drainage area group (270 to 1,000 square miles) is characterized by a relatively quick hydrologic response time resulting in flash floods. Flash floods are very difficult to forecast using a 6 hour model time step. The precipitation is spread over a long period of time resulting in a forecast hydrograph that does not match the existing conditions.

The bias and accuracy plots are shown in Figure 14. The figure presents a few interesting points. The Maquoketa River at Manchester (MCHI4) and English River at Kalona (KALI4) appear to have consistent bias and accuracy plots. Based on the figure it appears that the quality of the forecast for the Winnebago River at Mason City (MCWI4) is much better than the other two in the group.

The plots are somewhat misleading for the gage at Mason City because the river rose nearly 13 feet in 18 hours and there were only a few forecasts issued for the rising limb during the event as shown in the figures in Appendix A. After analyzing the raw data, the Mason City gage had some forecasts that significantly underestimated the crest.

There were 19 forecast issued before the crest and the large errors of -10.0 feet were distributed across the forecast lead times of 0.25 and 7 days such that the law of averages skewed the results of bias and accuracy for the period.

The data in Figure 14 also highlights the recession base flow forecast at a lead time of 4 to 7 days. The base flow recession coupled with a short duration flood result in a reduction in bias and improved accuracy toward the end of the forecast period based on the timing of the event more than an improved forecast technique.

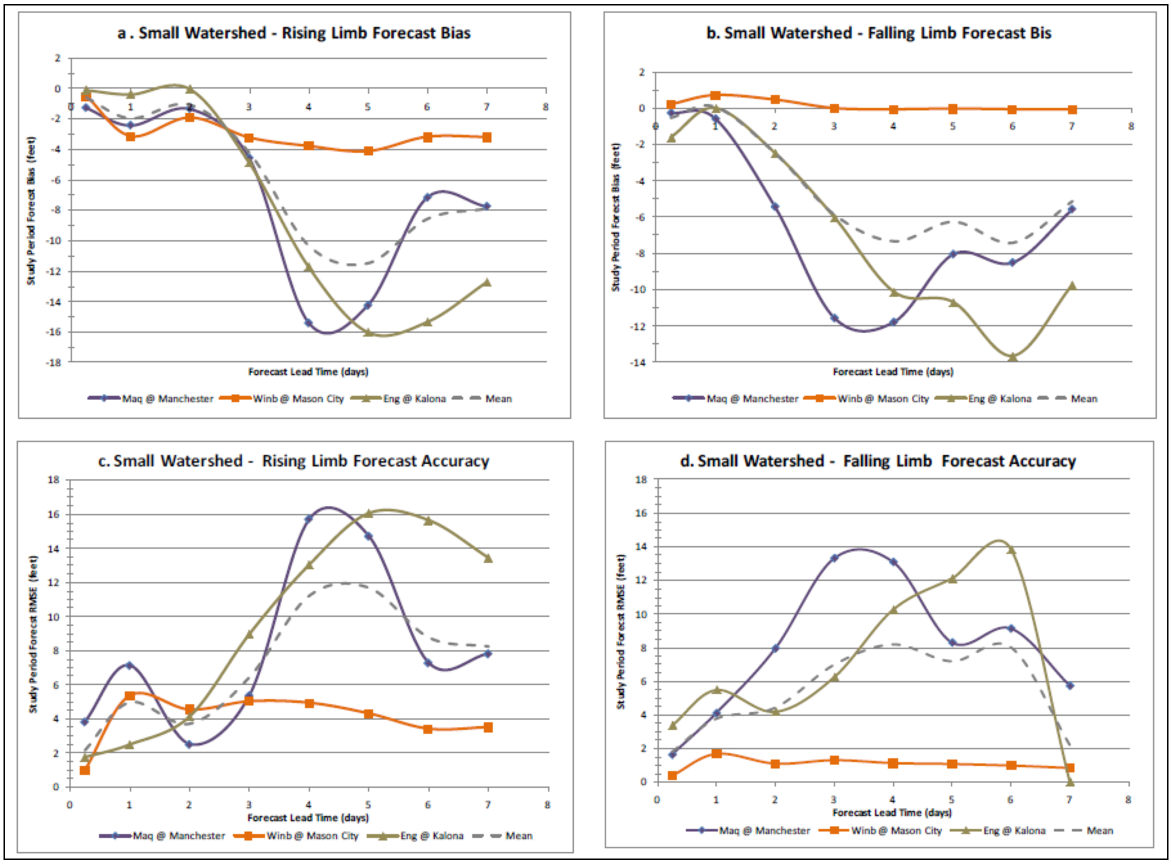
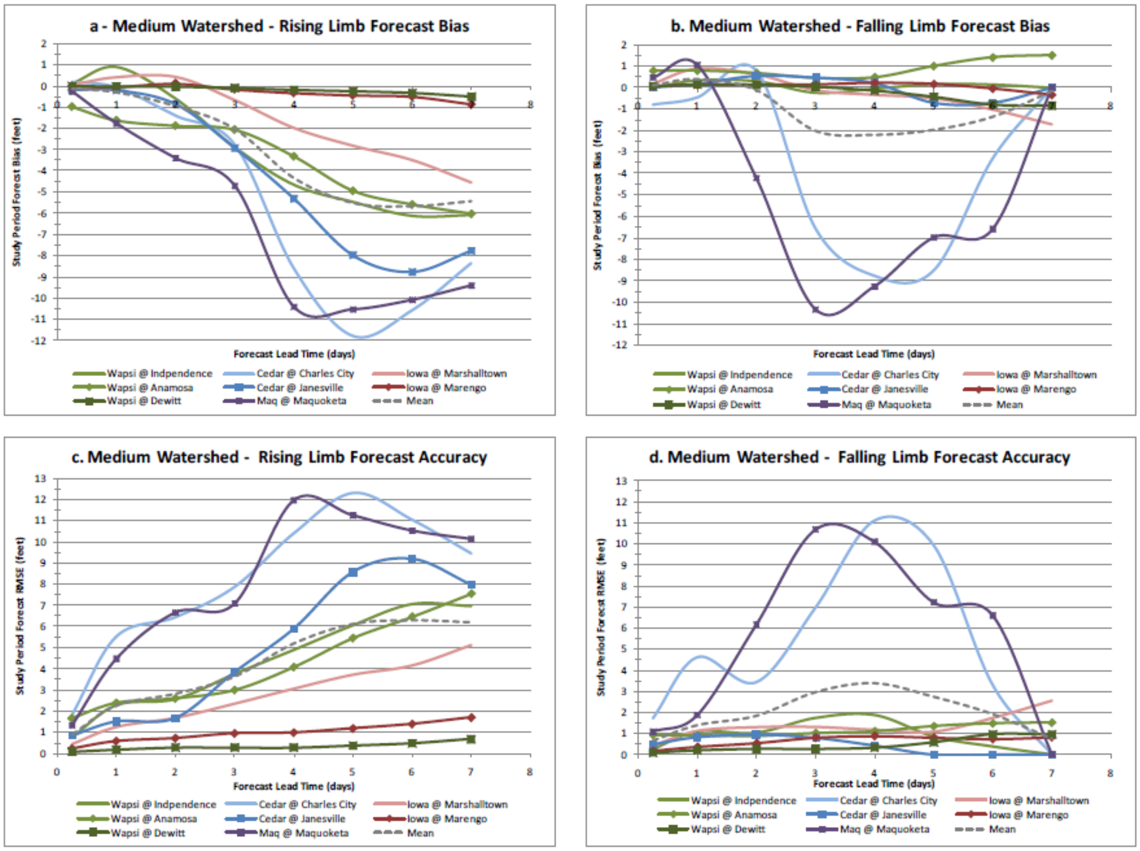


Figure 14. Forecast bias and accuracy graphs for small drainage area gages (270 to 1,000 square miles). The figures show the bias and accuracy of the small watersheds. The watersheds are dominated by flashy events that are difficult to forecast. The Mason City site appears to be abnormally accurate with a low bias as the result of the distribution of the data within the preceding 19 issued forecasts.

4.4.2 Medium Contributing Drainage Area Gages

The medium contributing drainage area group (1,000 to 2,800) square miles is comprised of the entire all three Wapsipinicon sites and the upper two Cedar River and Iowa River study locations. The bias and accuracy plots are shown in Figure 15.


a - Medium Watershed - Rising Limb Forecast Bias

b. Medium Watershed - Falling Limb Forecast Bias

c. Medium Watershed - Rising Limb Forecast Accuracy

d. Medium Watershed - Falling Limb Forecast Accuracy

Figure 15. Forecast bias and accuracy graphs for medium drainage area gages (1,100 to 2,800 square miles). The figures show the improved forecast quality as compared to the small drainage area gages and moving downstream in the respective watershed. The forecast quality before and after have two distinct characteristics. Lastly, the Cedar River forecasts were more biased and had less accuracy than the Iowa River forecasts.

Figure 15 shows the reduction in bias and improved accuracy on the Wapsipinicon River for the downstream gages as compared to the upstream gages. The upstream gages at Independence (IDPI4) and Anamosa (ANSI4) have comparable bias and accuracy the farthest downstream gage at Dewitt (DEWI4) shows a marked improvement in reducing bias and increasing accuracy for the analysis period. The two gages on both the Cedar River and Iowa River show the same improvements as the Wapsipinicon when comparing the downstream gages to the upstream gages.

The medium watershed sites also have a longer forecast period with lower bias and improved accuracy. This corresponds to the user having more confidence in days 1 to 3 instead of just the first forecast increment identified with the small drainage area locations. The Cedar River and Maquoketa River proved to be difficult to forecast when comparing them to the bias and accuracy values for the Iowa River sites, above the Coralville Reservoir. Lastly, the forecasts had good quality after the crest because the recession forecast matched the observed stages.

4.4.3 Large Contributing Drainage Area Gages

The large drainage area study gages (2,800 to 13,000 square miles) are represented by the remaining gages on the Cedar River and Iowa River. It is important to note that the Iowa River sites in Figure 15 are below Coralville Reservoir. The lines are color coded by river and with lighter colors used for the upstream gages and darker colors used for the downstream sites. The large drainage area group has higher forecast quality than the previous two as indicated by the tighter grouping of the forecast errors to the zero feet error line.

The Iowa River gage have the highest quality of the group and one could have reasonable confidence in the forecasts for a lead time of up to 3 or 4 days for sites from the Coralville Reservoir to Columbus Junction (CJTI4). As previously mentioned southeast Iowa did not experience the heavy rainfall that was experienced in northeast Iowa. As a result the errors on the Iowa River below the Coralville Reservoir could be related to the hydrologic model using a standard routing technique to route flows downstream combined with changes in the release discharge at the reservoir.

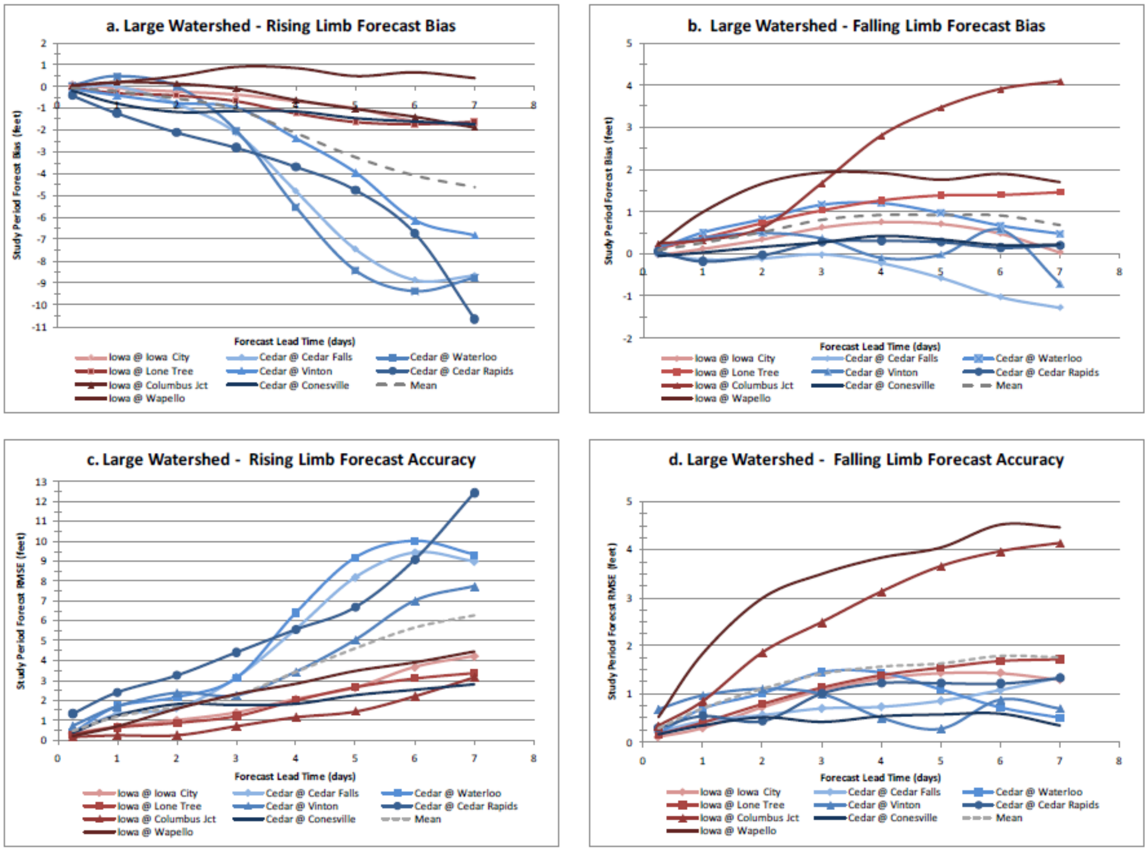


Figure 16. Forecast bias and accuracy graphs for large drainage area gages (2,800 to 13,000 square miles). Rising limb forecast quality is improved as compared to the small and medium contributing drainage area gages. The Cedar River has the lowest forecast quality shown by the higher errors in panels a. and c.

The large contributing drainage area group has a unique characteristic not found in the small and medium groups. The large group is dominated by positive bias in the after crest bias graph shown panel c of Figure 16. The observation is especially true for the Iowa River at Columbus Junction (CJTI4) and Wapello (WAPI4).

The section provided a series of figures of forecast bias and accuracy used to characterize the quality of the forecasts for the study gages as categorized by contributing drainage area. In general the forecast quality improved from the small contributing drainage area gages to the large contributing drainage area gages.

4.5 Forecast Warning Time

The number one question everyone wants to know is "how high and when" because the two questions when combined are related to the forecast warning time. This section will present and discuss a series of figures identifying the warning time patterns for the four gage examples.

The forecast crest date and stage are identified as Stage Max in Part C of the SHEF file. Figure 17 illustrates the relationship between the maximum forecast value and the date at which the crest was forecast to occur with respect to when the forecast was issued. The black line "forecast max value" represents the maximum forecast value of each forecast issued for the site. The green triangles are the "crest forecast" as identified in the Stage Max header in the SHEF file. Crest forecasts were not issued for every river forecast. The relationship between the forecast max value and forecast crest identifies the relative warning time that each site had to prepare for the crest.

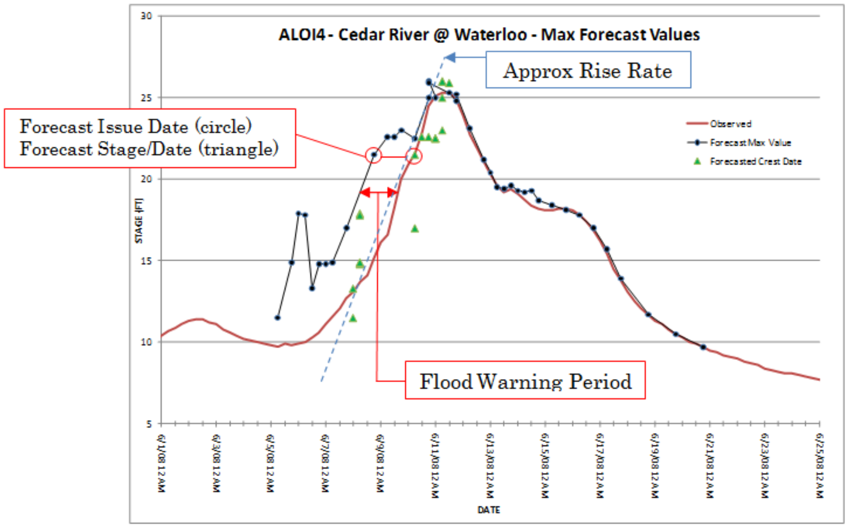


Figure 17. Maximum Forecast and Observed Data. The figure shows the relative flood warning period with respect to the crest forecast date.

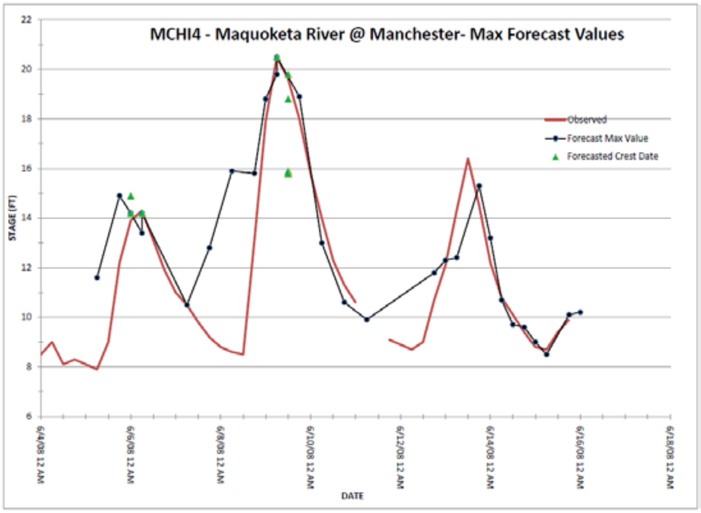


Figure 18. The flood forecast warning lead time graph for Manchester (MCHI4) on the Maquoketa River. The small watershed is dominated by the quick hydrologic response time resulting in flash floods with little to no warning.

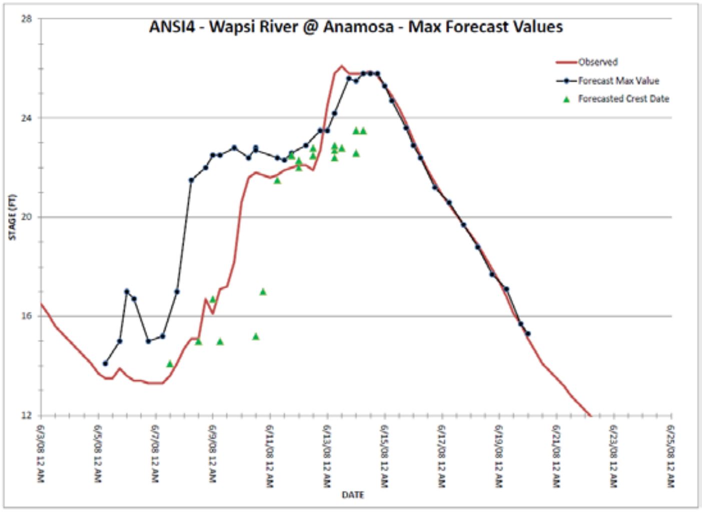


Figure 19. The flood forecast warning lead time graph for Anamosa (ANSI4) on the Wapsipinicon River. The medium watershed has a longer hydrologic response time resulting in slightly longer flood warning time as compared to the small watershed gages. Note the stage increase of approximately 3 feet with relatively no warning in the time immediately preceding the crest.

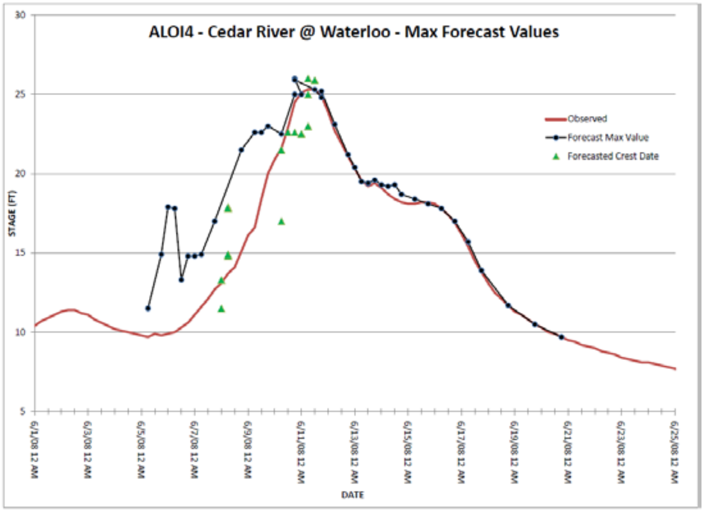


Figure 20. The flood forecast warning lead time graph for Waterloo (ALOI4) on the Cedar River. The large contributing drainage area gage has more warning time than the two smaller categories. However, the site had an increase in stage of 3 feet with relatively no warning in the time immediately preceding the crest.

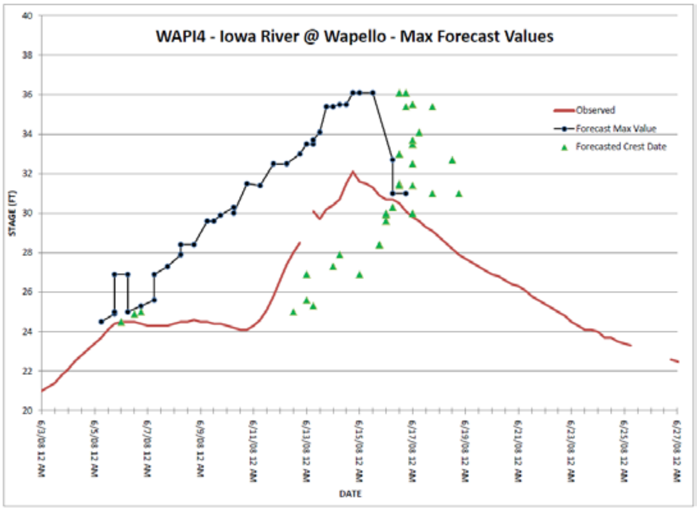


Figure 21. The flood forecast warning lead time graph for Wapello (WAPI4) on the Iowa River. The large contributing drainage area had warning times of 2 to 3 days which is much more warning time than the other sites. The forecasts were over predicted by nearly 4 feet.

Figure 18, Figure 19, Figure 20, and Figure 21 have unique forecast warning time characteristics based largely upon the hydrologic response time of the contributing watershed. The smaller watersheds are dominated by flash floods and have little to no warning time. The medium and large watersheds in general had more warning time for the event. The additional warning time is likely due to the longer time it takes for the water to travel through the watershed to reach the main stem and the opportunity for forecasters to monitor the conditions when making new forecasts.

Accuracy and timeliness are the two characteristics that determine the effectiveness of a river forecast. A forecast that is accurate but not timely is no more effective than a forecast that is timely but inaccurate. Ideally adequate warning time would be provided in advance of the crest. The warning time is needed to allow communities and emergency officials time to implement the emergency response plans which may include sandbagging, installing temporary closures, or evacuation.

Table 5 provides a summary of the warning times and river rise rates for the study gage locations. Rise rate was calculated graphically by drawing a line that fit the rising limb portion of the event and calculating the slope of the line. The first warning time category is the largest warning time, at any time during the flood, when there was more than 18 hours of warning which provides an opportunity to reduce flood damages by 25%. The second category is the time period when there was approximately 6 to 18 hours of warning lead time. The final category is the period of no warning before the crest and may provide a reduction in damages by approximately 10%. The table also shows the change in river stage with virtually no warning.

For example the Cedar River at Waterloo (ALOI4) is shown in Figure 22. Category 1, greatest warning period, is 36 hours because the forecast max value line precedes the observed stage by 36 hours. Category 3, minimal warning period, occurs approximately 24 hours before the crest because the forecast max line is in essence just a few hours ahead of the impending crest. Category 2 was not present at this site because the forecast lead time went from 36 hours to just a few hours as shown by the horizontal portion of the forecast max line on June 9th.

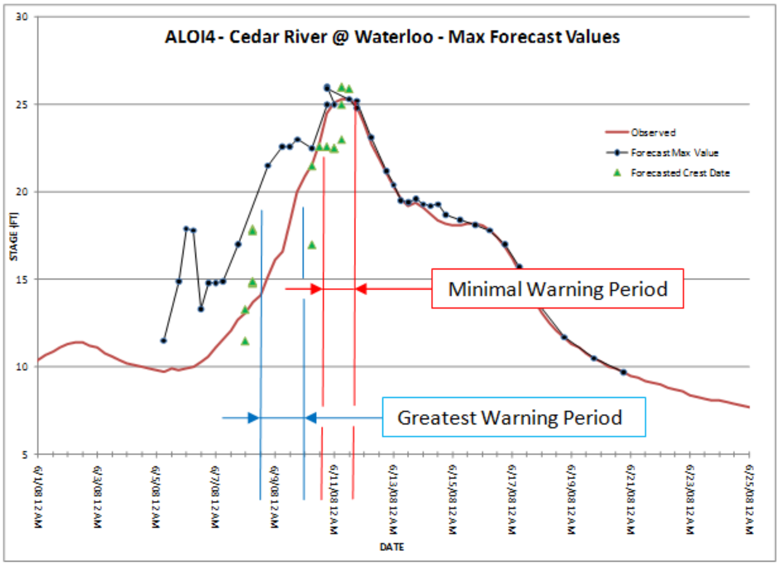


Figure 22. Forecast warning time graph. The figure shows the warning time periods that occurred during the 2008 event. The Cedar River had minimal warning time immediately before the crest as identified in Table 5. Category 1 is 36 hours because the forecast max value line precedes the observed stage by 36 hours. Category 3 occurs approximately 24 hours before the crest because the forecast max line is in essence just a few hours ahead of the impending crest. Category 2 was not present at this site because the forecast lead time went from 36 hours to just a few hours as shown by the horizontal portion of the forecast max line on June 9th.

The Cedar River drainage area gages were plagued with persistent rainfall resulting in lower quality forecasts partially because the river forecasts only include 24 hours of forecast precipitation. The Cedar River has a consistent trend when looking at the figures in Appendix A. The forecast warning times were very small in the 24 to 48 hours immediately preceding the crest with the river stage typically increasing by 3 to 5 feet during that period of time. The reduced warning time is not necessarily the product of a bad forecast because of the timing of the rainfall coinciding with the initial flood wave as a result of rainfall on June 9th in northern Iowa.

Table 5. Warning Time Comparison.

Gage Name	Location	Rise Rate (ft/hr)	1. Greatest Warning Period (>18hrs)	2. Minimal Warning Period (6-18hrs time to crest)	3. No warning Period (<6hrs time to crest)	4. Change in Stage without warning	Notes
MCWI4	Winnebago River - Mason City	0.72	-	-	Entire Event	-	A second crest was forecasted but didn't occur.
CCYI4	Cedar River - Charles City	0.43	-	-	Entire Event	-	Forecasts were issued at the same rate as observed stage
JANI4	Cedar River - Janesville	0.22	24-36hrs until gage out of service	-	24hrs before crest	-	Gage exceeded rating curve - observed crest stage not available.
CEDI4	Cedar River - Cedar Falls	0.15	36hrs	-	24hrs before crest	3ft	
ALOI4	Cedar River - Waterloo	0.16	36hrs	-	24hrs before crest	3ft	
VINI4	Cedar River - Vinton	0.14	54hrs	60hrs before crest	48hrs before crest	4ft	Gage went out of service
CIDI4	Cedar River - Cedar Rapids	0.14	60hrs	60hrs before crest	48hrs before crest	5ft	
CNEI4	Cedar River - Conesville	0.10	84hrs	66hrs before crest	42 hrs before crest	5ft	Crest date was identified and remained constant with stage increasing
MIWI4	Iowa River - Marshalltown	0.09	24-30hrs	-	-	-	Two crests within 1/2 ft and 4 days apart; 2nd crest higher than the first.
MROI4	Iowa River - Marengo	0.04	36hrs (First crest)	-	24hrs before #2 crest	1.5ft	Two crests within 1ft and 2 1/2 days apart
IOWI4	Iowa River - Iowa City	0.06	60-72hrs	-	-	-	

Table 5. Continued

Gage Name	Location	Rise Rate (ft/hr)	1. Largest Warning Lead Time (>18hrs)	2. Minimal Warning 6-18hrs (time to crest)	3. No warning (<6hrs) (time to crest)	Change in Stage without warning	Notes
KALI4	English River - Kalona		-	-	Entire Event	-	Forecast had very little lead time difficult to draw comparisons
LNTI4	Iowa River - Lone Tree	0.05	24hrs	-	60hrs before crest	2 ft	Crest date was identified and remained constant with stage increasing
CJTI4	Iowa River - Columbus Junction	0.10	5 days warning down to 2.5 day warning before crest	-	-	-	Forecast crest 1 day later and 3ft higher than observed crest.
WAPI4	Iowa River - Wapello	0.09	84hrs	-	-	-	Forecast crest 2 days later and 4ft higher than observed crest.
MCHI4	Maquoketa River - Manchester	0.61	-	18hrs before Crest #2	18hrs before crest #2	4ft	3 crests; middle crest was the highest with little advanced warning time.
MAQI4	Maquoketa River - Maquoketa	0.44	-	48hrs before crest #1	18hrs before crest #2	4ft	Crest 1 (31 ft) occurred river dropped to 20 ft then rose to 31.5 ft 52 hours later
IPDI4	Wapsipinicon River - Independence	0.22	36hrs	-	-	-	Forecast crest 1 day later and 1ft higher than observed crest.
ANSI4	Wapsipinicon River - Anamosa	0.11	42hrs	-	48 hrs before crest	-	Forecast was 3ft lower than observed
DEWI4	Wapsipinicon River - Dewitt	0.01	4days	-	60hrs before crest	0.5ft	Forecast anticipated another 0.5ft increase which did not materialize.

The time period categories in Table 5 were developed using typical flood warning preparedness plan components (U.S. Army Corps of Engineers, 1996). The preparedness plans are dependent on the watersheds and stated that streams or tributaries should have approximately 6 to 24 hours of warning time and large river basins require greater than 24 hours to enact emergency response plans, including flood fighting. The time periods also reflect reasonable reductions in flood damage with respect to flood warning time using the Day curve shown in Figure 23. Day's method was developed in the 1970's and is an approximate representation in the reduction of flood damages as a function of the flood warning time (Carsell, Pingel, & Ford, 2004). The maximum reduction in damages is 35%, assuming timely warning dissemination and 100% public response (Scawthorn, 2006).

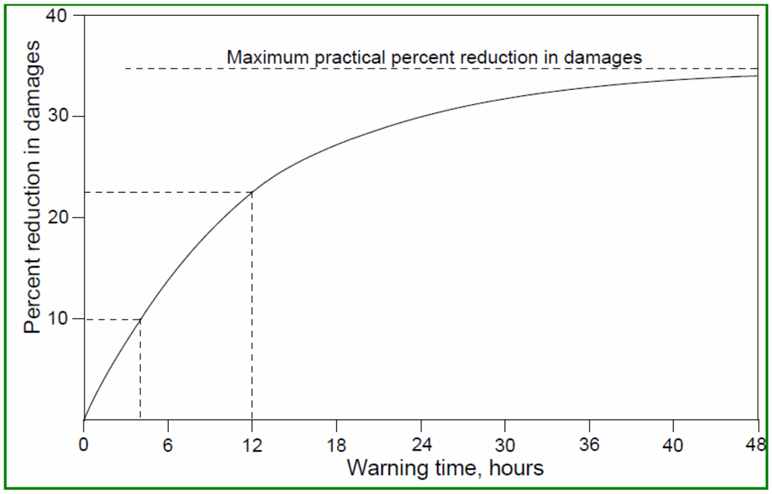


Figure 23. Day Curve. The curve was developed as a tool to assist the formulation of flood warning systems. It is estimated that the maximum reduction of damages as the result of warning times is 35% assuming 100% participation and 48 hours of warning time. Figure courtesy USACE Hydrologic Modeling System Applications Guide (HEC-HMS)

4.6 Discussion of Results

Chapter 4 focused on assessing the forecast quality by analyzing the forecasts and forecast errors in several forms. The SHEF files were imported into HEC-DSSVue and subsequently exported into Microsoft Excel for analysis. Then the forecast series was plotted with the observed stage which revealed a persistent base flow recession in the forecasts. The recession portion of the forecast is the result of only including 24 hours of forecast precipitation in the river forecast.

Next the relative error, bias (mean error) and accuracy (root mean square error) were used to assess the forecast quality of the three contributing drainage area categories small 270 to 1,000 square miles, medium 1,000 to 2,800 square miles and large 2,800 to 13,000 square miles. The locations were divided into categories to determine if there were trends for gages with similar sizes. For example, forecast quality improved from the small contributing drainage area gages to the large contributing drainage area gages. This is likely because as the watershed increases in size the hydrologic response time based on the travel time also increases giving the forecaster a chance to issue new forecasts before the event has passed.

The forecast quality analysis also revealed a tendency to over predict the crest elevations for the lower portion of the Iowa River, past the confluence of the Cedar River. The over prediction may be the product of using a hydrologic model instead of a hydraulic model to route the flood wave downstream.

Lastly, the Max Stage forecast was plotted against the observed stage to determine forecast warning times. As shown above the warning times varied by location and contributing drainage area. The small drainage areas experienced multiple storm based peaks while the medium and large sites were not as flashy resulting in improved warning times until the 24 hours preceding the crest at which time no warning was provided.

Flood warning times increased from north to south. An analysis was completed for the study sites using the information contained in Figure 22 to determine if there were any consistencies or trends in the forecast data. Table 5 provides a general comparison of the advanced warning times at the study sites. Three categorical time periods were developed to provide a basis for comparison between the sites and should not to be construed as times needed for a community to prepare for an event. Each event and each location is unique and the time needed to for local authorities to determine an appropriate course of action will be site specific.

In general the flood warning times increased for the downstream gages on the Cedar, Iowa, Wapsipinicon, and Maquoketa Rivers. The gages along the Cedar River experienced an increase in stage of 3 to 5 feet over the last 24-48 hours prior to the crest. The forecasts were unable to provide advanced warning during this period. The rating curves were exceeded in many instances and created significant uncertainty and challenges in forecasting the flood event.

Above the Coralville Reservoir on the Iowa River, Marshalltown (MIWI4) and Marengo (MROI4) both experienced two separate peaks which were likely caused by locally heavy rain. The Iowa River below Coralville Reservoir, with the exception of Lone Tree (LNTI4), had more warning than the Cedar River. Iowa City had approximately 60 to 72 hours warning during the entire event. Columbus Junction (CJTI4) and Wapello (WAPI4) had between 3.5 and 5 days warning time for the event.

The Maquoketa River at Manchester (MCHI4) and Maquoketa (MAQI4) also had multiple crests. The sites had roughly 18 hours before the second crest where the stage increased by four feet with little warning.

The eastern Iowa Flood of 2008 was the result of persistent rain over the course of nearly two weeks. The forecast analysis techniques presented in this Chapter combine the various sources of error into one quality analysis. Chapter 5 will discuss the precipitation analysis as a component of the river forecast quality.

CHAPTER 5

PRECIPITATION FORECAST ANALYSIS

Precipitation measurements and forecasts are the most significant inputs in the river forecast model as discussed Chapter 3 and Chapter 4. Chapter 4 analyzed the river forecasts from the period of 1 June to 15 June 2008 which identified the consistent recession forecast trend as a result of including only 24 hours of future precipitation in the river forecast. A logical progression of the analysis would be analyzing the quality of the precipitation forecasts in an effort to qualitatively discuss the relationship between precipitation errors and the persistent underestimation of the river forecasts as concluded in Chapter 4. This Chapter will also evaluate the merit of including an additional 24 hours of forecast precipitation (48 hours total) on improving the quality of the river forecast.

The June 2008 flood was the result precipitation totals of 8 to 14 inches of rain for most of the State of Iowa during the period of 1 June to 15 June, as shown in Figure 24, on top of the saturated soil conditions following the second wettest winter (2007-2008) on record (National Climate Data Center, 2008). In Iowa 85 of 99 counties were declared disaster areas as the result of the severe flooding. Eastern Iowa was hit especially hard suffering extensive damages (Mutel, 2010). Maps of daily precipitation accumulations across the United States where periods of heavy rainfall occurred are shown in Figure 25. Figure 27 shows the rainfall accumulation within the upper Cedar River basin based on estimates of the mean areal precipitation for the forecast segments shown in Figure 26. The analysis was conducted on the upper and middle Cedar River basin because of the limited flood warning times discussed in Chapter 4. The forecast segments were divided into two groups for comparison and discussion purposes as shown in Figure 26.

The precipitation analysis evaluated the quality of the Forecast Mean Areal Precipitation (FMAP) with respect to observed Mean Areal Precipitation (MAP) data for the period of 1 June to 15 June, 2008. The data MAP and FMAP files were provided by Mr. Brian Connelly at the NCRFC. Data was not provided for the forecast segment PLOI4 near Palo, IA.

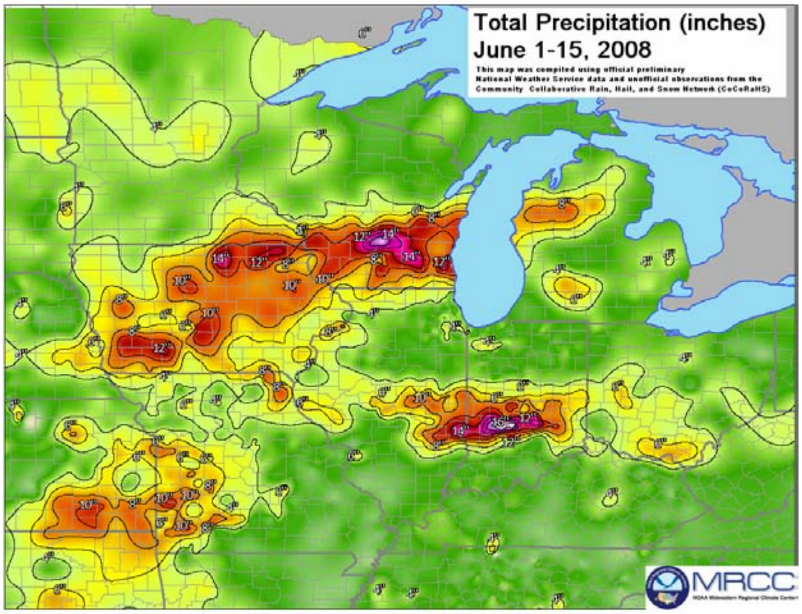


Figure 24. Precipitation total for the period of 1 June to 15 June 2008..
(http://www.ncdc.noaa.gov/img/climate/research/2008/jun/june2008precip.png)

Table 6. Upper-middle Cedar River basin forecast segments included in the precipitation analysis.

NTWI4	CCYI4
MCWI4	IONI4
MBLI4	KSYI4
SHRI4	JANI4
FNHI4	NHRI4
CEDI4	HUDI4
ALOI4	VINI4
DYSI4	CIDI4

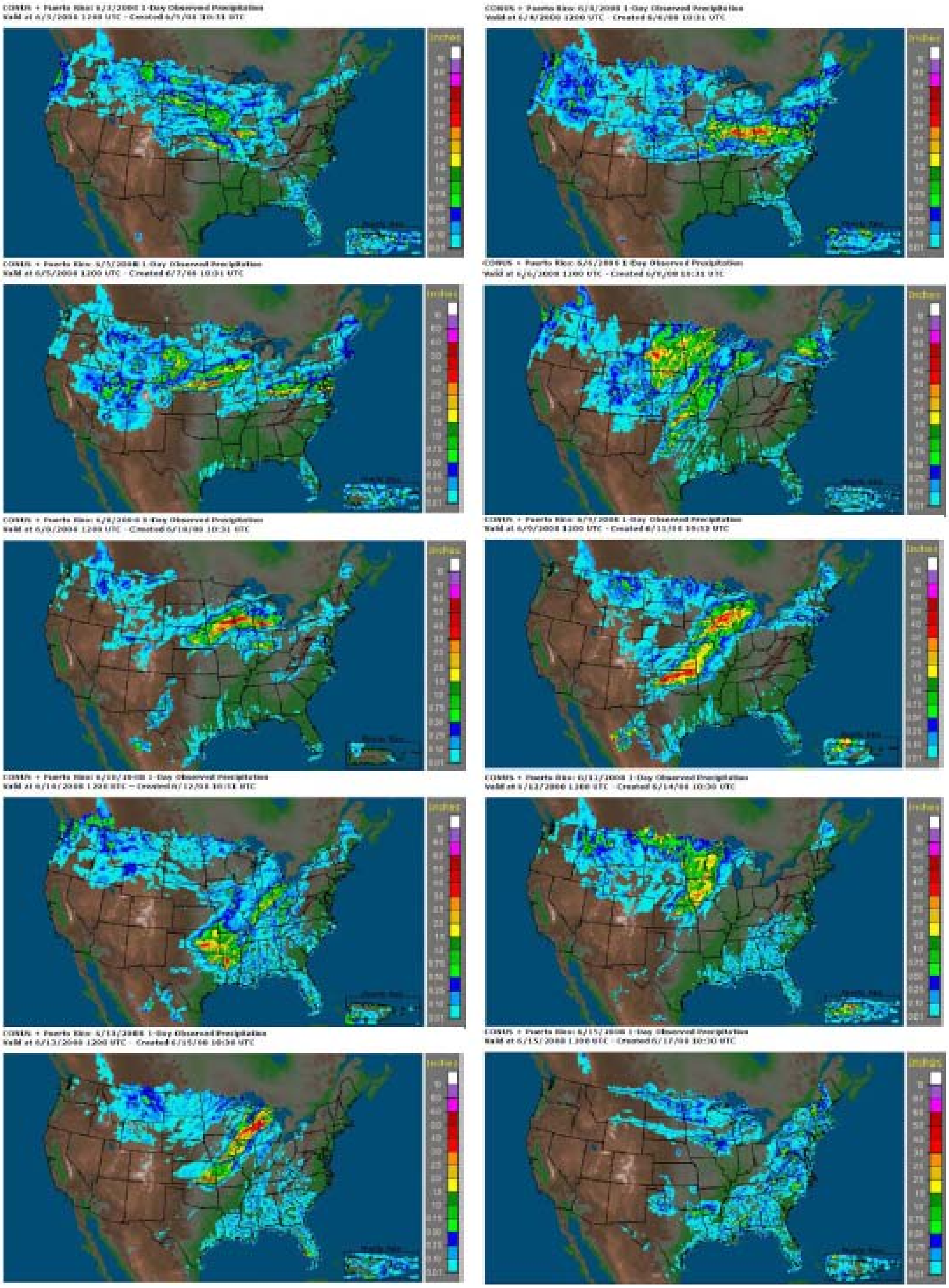


Figure 25. Daily precipitation records for the period of 1 June to 15 June 2008. The convective storms resulted in significant rainfall in the Midwest and Iowa. The days without widespread rainfall were 1 June, 2 June, 7 June, 11 June, and 14 June (not shown in figure).

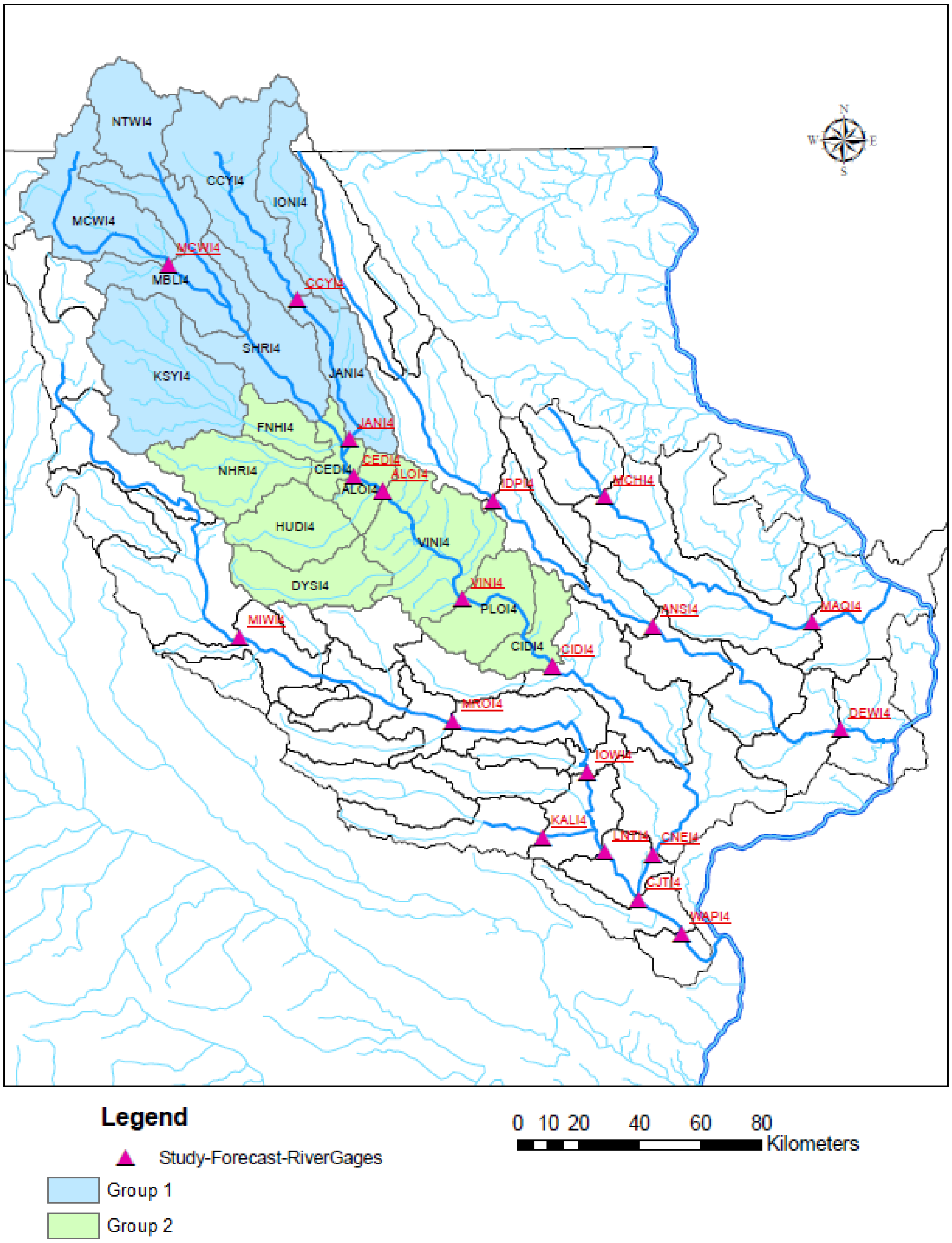


Figure 26. Precipitation forecast analysis forecast segments map. The analysis focused on the upper Cedar River forecast segments. The upper and middle Cedar River basins received an overwhelming amount of rain from 1 to 15 June 2008. The study area was split into two groups by geographic location in order to see if there were geographic characteristics in the quality of the Qualitative Precipitation Forecasts (QPF).

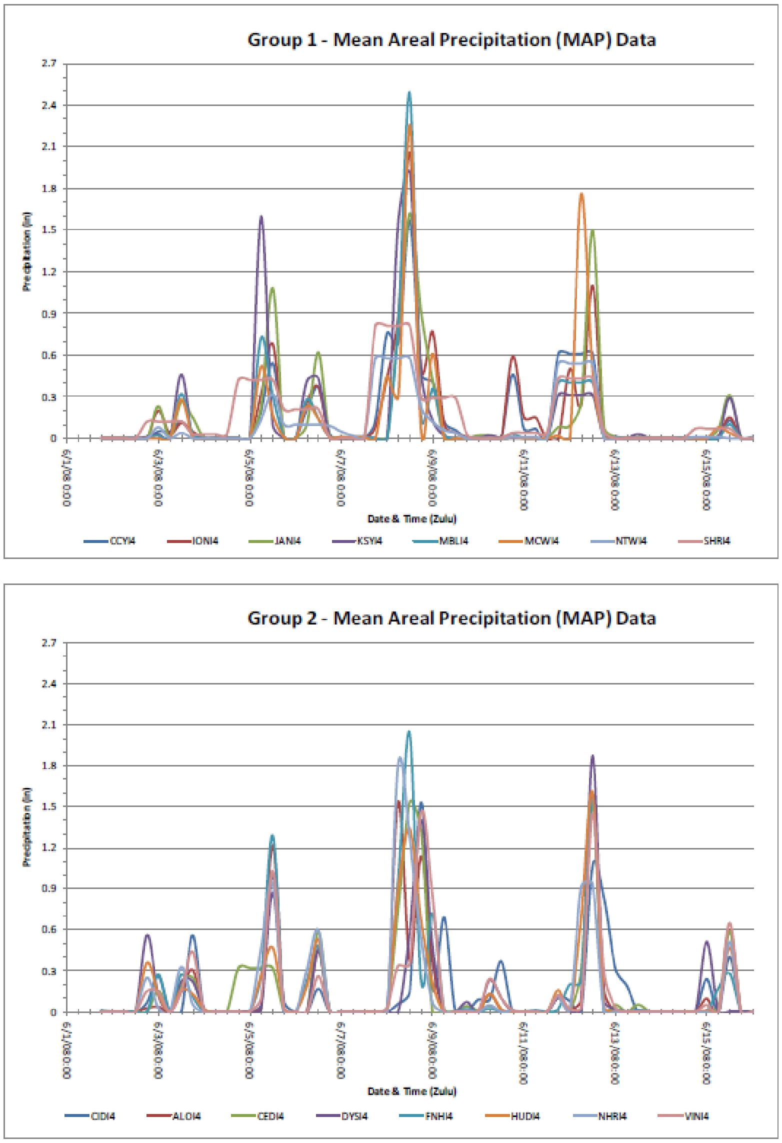


Figure 27. Six hour mean areal precipitation (MAP) totals for the period of 1 June to 15, June 2008. Group 1 consists of the upper Cedar River forecasts segments and Group 2 consists of the middle Cedar River forecast segments. Note the persistent rainfall of 0.5 inches in 10 of the 15 days.

5.1 Experimental Design

Measured and forecast precipitation data for hundreds of forecast segments were provided in text files from the NCRFC and needed to be compiled and sorted to the forecast segments included in this study. For each of the 15 segments, daily MAP files consisting of 4 6-hour records and 6-hour FMAP (12z only) files were first imported into Microsoft Excel and saved as individual files by day. The next step was to take the individual daily data and string it together for a continuous data record for the study period. A series of Macros, filters, and sorting procedures were utilized to transform the daily data into a continuous record for each forecast segment for graphing and analysis purposes.

The NWS issues FMAP data every 6 hours. The 00z and 12z FMAPS contain six hour forecast precipitation information for the following three days while the 06z and 18z files contain forecast data for the following two days. The precipitation analysis utilized only the 12z FMAP because they were consistently issued and provided a longer forecast window.

5.2 Relative Error Analysis

The error analysis was completed by subtracting the 6 hour MAP from the FMAP data:

$$\text{Relative Precipitation Error} = \text{Forecast (FMAP)} - \text{Observed (MAP)} \qquad (5)$$

The method would identify under estimated precipitation as negative values similar to the methodology used in the river forecast analysis. The data was plotted, as shown in Figure 28 and was difficult to analyze because the figure is overcrowded as the result of plotting all 6 hour forecast increments. Upon inspection, there is variability between positive and negative errors. However, a trend of under estimating the forecast precipitation is apparent. In order to make the graphs more intuitive, the 6-hour data was summed into 24 hour periods and plotted for increments of 0 to 24 hours, 24 to 48 hours and 48 to 72 hours as shown in Figure 29.

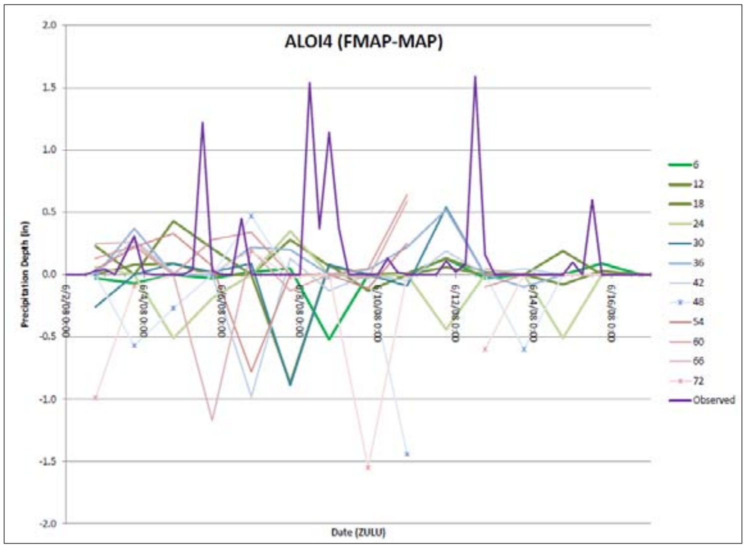


Figure 28. Graph of the 6 hour precipitation in the native format for the ALOI4 forecast segment (Waterloo, IA area). It is difficult to quantify the results because each 6 hour data record is included in the graph. The positive and negative errors are distributed across the 6 hour time periods. The negative errors appear to dominate the positive errors.

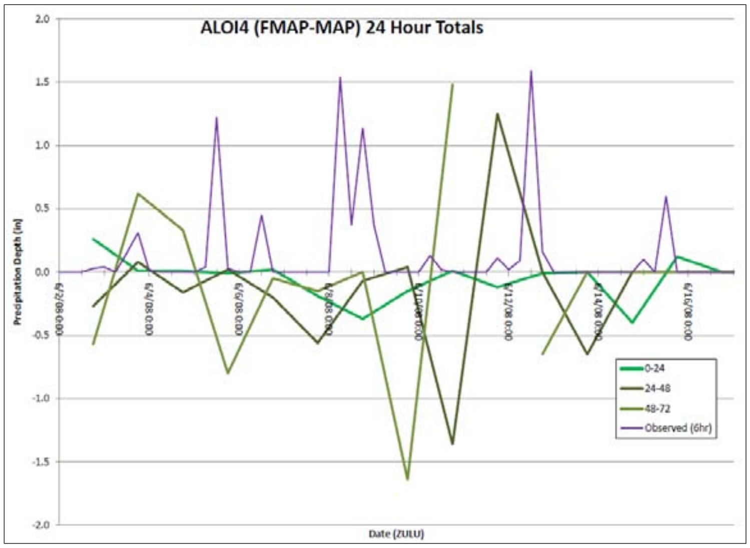


Figure 29. Graph of the 6 hour precipitating information summed into 24 hour increments for the ALOI4 forecast segment (Waterloo, IA area). Note the trend of negative errors which are the result of underestimating the forecast precipitation. It is difficult to correlate the forecast peak to the observed peak without shifting the forecast line to correspond to the time that the forecast was to occur instead of its relatinship to when it was made.

Figure 29 also proved to be difficult to analyze because the forecast increments are based on the time that the forecast was made and not when the precipitation was to occur. The solution was to shift the forecast increments such that the forecast line was aligned to when the precipitation was going to occur resulting in a direct visual comparison of the forecast errors with respect to the observed precipitation. Figure 30 is an example of the graph in final form. The visual analysis can easily be completed from this layout. Appendix B contains all figures for the precipitation analysis.

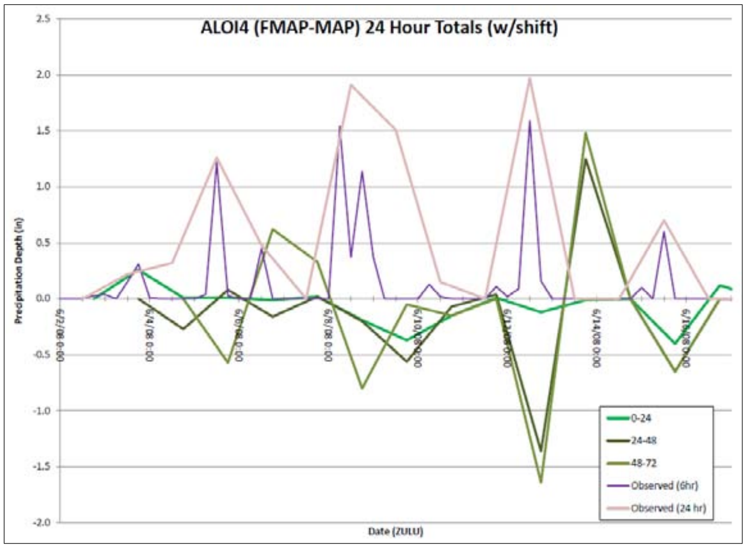


Figure 30. Final precipitation analysis graph with phase shift for the forecast segment ALOI4 (Waterloo, IA area). The forecast time periods are aligned to the date the forecast was to occur for easy comparison of the forecast precipitation with respect to the observed rainfall. Note the consistent under prediction for forecast rainfall.

The precipitation analysis figures in Appendix B shows the consistent under prediction of the actual estimated precipitation on 5 June, 9 June and 12-13 June. The 0 to 24 hour QPF forecast typically under estimated precipitation on average by approximately 0.0 to 0.5 inches and the 24-48 hour and 48 to 72 hour QPF forecasts underestimated on average precipitation by approximately 1.0 to 2.0 inches. The consistent precipitation underestimation provides some reasoning that using an extended precipitation forecast for the river forecast model may not significantly improve the quality of the river forecast.

5.3 Forecast Quality Analysis

General trends and conclusions can be inferred from the figures presented in the previous section. However, an empirical analysis of the forecast quality should be completed using bias and accuracy. Forecast bias was evaluated using the mean error (ME), computed using the formula (Welles & Sorooshian, 2007):

$$\text{Mean Error} = \text{Average (Forecast Stage - Observed Stage)} \qquad (6)$$

Forecast bias is used as an indicator of systematic errors resulting in consistently under or over estimating the forecast and can be manifested through input or modeling errors (Hashino, Bradley, & Schwartz, 2006).

The quality of the forecast was evaluated using the root mean square error (RMSE) (Welles & Sorooshian, 2007), a measure of the forecast accuracy:

$$\text{RMSE} = \sqrt{}(Average(Forecast\ Stage - Observed\ Stage)^2) \qquad (7)$$

Precipitation forecast bias and accuracy charts are shown in Figure 31. The charts show the general trend of negative bias resulting in underestimation of the precipitation forecast and a decrease in quality in the later forecast periods. There is a slight difference in the characteristics of the bias between Group 1 and Group 2. Group 1 has a more decreasing linear trend in bias while Group two has a quick drop in the bias to 48 hours then the bias levels off or decreases slightly. The forecast accuracy charts in Figure 31 are very similar between the two groups of forecast segments.

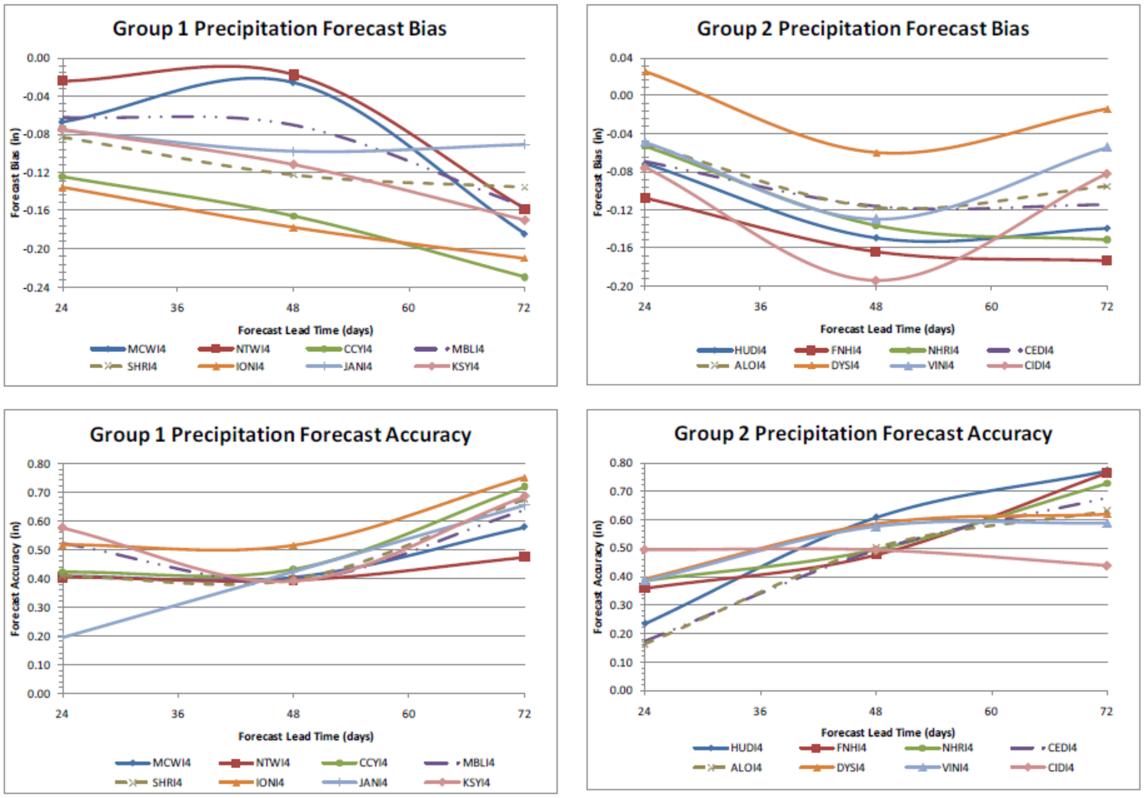


Figure 31. Precipitation forecast bias and accuracy. The general trend of the precipitation forecast figure indicates more negative bias and less accurate forecasts throughout the forecast period.

The values of bias and accuracy shown in Figure 31 show trends but are not the actual values because they are skewed by using all of the records in the analysis. Using the forecast segment ALOI4 as an example there are 12 6-hour forecasts in the 12z file of which 6 were zero precipitation forecasts thus lowering the results of the bias and accuracy calculations.

5.4 Precipitation Analysis Results

The June 2008 flood was the result precipitation totals of 8 to 14 inches of rain for most of the State of Iowa during the period of 1 June to 15 June, as shown in Figure 24 and Figure 25. Analyzing the precipitation forecasts in conjunction with the river forecasts can provide some additional information for the June 2008 flood forecasts. For example, the June 2008 precipitation analysis identified that the rainfall events on the upper Cedar River Basin were typically under estimated, as shown in the Figures in Appendix B. The 5 June, 9 June and 12-13 June QPF forecasts were underestimated for the three forecast lead times of 0 to 24 hours, 24 to 48 hours and 48 to 72 hours. The 0 to 24 hour lead time was the most accurate and was underestimated by approximately 0.0 to 0.5 inches while the longer lead time forecasts of 24 to 48 hours and 48 to 72 hours were underestimated by 1.0 to 2.0 inches for the selected dates.

The precipitation analysis was completed to provide insight to the feasibility of including 36 or 48 hours of forecast precipitation into the river forecast model to improve forecast quality and warning times. However, it is difficult to quantify the effects and provide qualitative impacts of under estimating the precipitation forecast because the modifications made by the river forecaster to the river forecast model. For example, in what was considered the "perfect storm" for Cedar Rapids, heavy precipitation fell in the area on June 13, 2008 as the Cedar River flood crest was arriving. River forecasters did not have the luxury of time to assess how the rivers were reacting to the rainfall to improve the forecasts for the Cedar River because of the dynamic situation of several large rainfall events at different points in the basin and utilizing an extended precipitation forecast would not have greatly improved the river forecasts given the underestimation errors in the 24 to 48 and 48 to 72 hour QPF forecasts.

CHAPTER 6

CONCLUSIONS AND RECOMMMENDATIONS

In the last decade, the National Weather Service has greatly improved the products and information that is available to the public. The forecasters are tasked with trying to model and predict the results of a very dynamic process. The inputs into the river forecast models are many and of variable quality such as: the spatial and temporal distribution and accuracy of observed precipitation measurements, forecast precipitation that deviates from the observed precipitation, river gages that malfunction or provide false readings, river stages that exceed the rating curves, and changes in the landscape that can affect the amount and timing of the runoff.

Every flood event is unique and historic flood events are not always an accurate indication or predictor of how other events will unfold. The flood of 2008 was a record event in many Iowa communities and resulted in significant flood damage. The event was characterized by day after day of rain resulting in the river forecasts issued higher and higher each day to reflect the observed precipitation. The constant rain pushed rivers in to unchartered territory and strained everyone involved.

The river forecast is a tool to help emergency officials determine what actions are required based on the projected stage and advanced warning is critical to determine the scope of the emergency response measures within the forecast timeframe. For these reasons it is important to have a forecast that is accurate and on time.

The river forecasts will be limited by the simplifications and model conditions used to predict flows at the river gage locations. Errors are introduced into the modeling system by the numeric simplifications to the physical process as a result of a lumped parameter hydrologic model and the measurement of observed conditions such as precipitation and flow.

Chapter 4 discussed relative error, bias (mean error) and accuracy (root mean square error) to assess the forecast quality of the contributing drainage areas concluding forecast quality improved from the small contributing drainage area gages to the large contributing drainage area gages. This is likely because as the watershed increases in size the hydrologic response time based on the travel time also increases giving the forecaster a chance to issue new forecasts before the event has passed. The river forecast analysis indicated a decrease in forecast quality after 2 days of forecast lead time which is consistent with the work of Wells et al (Welles & Sorooshian, 2007).

The forecast quality analysis also revealed a tendency to over predict the crest elevations for the lower portion of the Iowa River, past the confluence of the Cedar River. The over prediction may be the product of using a hydrologic model instead of a hydraulic model to route the flood wave downstream.

The warning times varied by location and contributing drainage area. Small drainage areas experienced multiple storm based peaks while medium and large sites were not as flashy resulting in improved warning times until the 24 hours preceding the crest at which time no warning was provided.

In general the flood warning times increased for the downstream gages on the Cedar, Iowa, Wapsipinicon, and Maquoketa Rivers. The gages along the Cedar River experienced an increase in stage of 3 to 5 feet over the last 24-48 hours prior to the crest. The forecasts were unable to provide advanced warning during this period. The rating curves were exceeded in many instances and created significant uncertainty and challenges in forecasting the flood event.

The NWS RFCs issue seven day river forecasts but the forecasts only account for the next 24-hour precipitation forecast. When an event has almost 10-days of rain the river forecasts will continually increase as rain is included in the next 24-hour river forecast window. As noted above, Mr. DeWeese identified that one of the primary drivers in the river forecasting process is the precipitation data.

Chapter 5 analyzed and discussed the precipitation forecasts in conjunction with the river forecasts and identified that the rainfall events on the upper Cedar River Basin were typically under estimated, as shown in the Figures in Appendix B. The 5 June, 9 June and 12-13 June QPF forecasts underestimated rainfall for the three forecast lead times of 0 to 24 hours, 24 to 48 hours and 48 to 72 hours. The 0 to 24 hour lead time was the most accurate and was underestimated by 0.0 to 0.5 inches while the longer lead time forecasts of 24 to 48 hours and 48 to 72 hours were underestimated by 1.0 to 2.0 inches for the selected dates.

River forecasting was further complicated by the distribution of rainfall and timing of the storms with respect to the flood wave. This was considered the perfect storm for Cedar Rapids because the precipitation that fell on June 13, 2008 was now falling on top of the Cedar River flood crest. River forecasters did not have the luxury of time to assess how the rivers were reacting to the rainfall to improve the forecasts for the Cedar River because of the dynamic situation of several large rainfall events at different points in the basin and utilizing an extended precipitation forecast would not have greatly improved the river forecasts given the underestimation errors in the 24 to 48 and 48 to 72 hour QPF forecasts. It is difficult to quantify the effects and provide qualitative impacts of under estimating the precipitation forecast because the modifications made by the river forecaster to the river forecast model.

The results of the river forecast and precipitation analysis support the calls for action to improve the river forecasting system and Qualitative Precipitation Estimates (QPE) and Qualitative Precipitation Forecasts (QPF) as identified by Vasiloff et al (2007) and Wells et al (2007). The river forecasting models rely heavily on precipitation data. Base flow recessions were observed in most forecasts in Chapter 4 because the river forecasts account for only 24 hours of future precipitation. The quality of the river forecast may be limited by the precipitation forecast and the constraints of a hydrologic model to route flows. It is recommended that the flood warning system be updated to take advantage of the advances in computing and modeling technology by incorporating more detailed hydrologic models linked to hydraulic routing models. Lastly the system should account for changes in the landscape that have occurred since the models were originally created.

The National Weather Service is revamping the river forecasting system with the introduction of the CHPS program. However, a one-time static update is not sufficient to continue to model the changing dynamics of the hydrology and hydraulics involved with river forecasting. A one size fits all system may not be adequate and the new system should be designed to accommodate the needs in urban and rural areas by providing hydrologic and hydraulic models. The National Weather Service must be provided adequate funding and resources to continually calibrate and verify the model results. It is vitally important to periodically review the model parameters to account for physical changes occurring in the watershed. Typically models are calibrated to correct for inaccuracies of the physical process (Odoni & Lane, 2010). The academic community has researched and published literature on a wide range of topics that are applicable to the river forecasting process. Implementing a central "flood resources repository" may be necessary to share modeling efforts across multiple organizations and institutions if the NWS is unable to secure the resources needed for an overhaul of the models.

The river forecasts serve an important role to many communities and emergency officials during flooding events. "The value of a forecast is derived from the additional time made for the response effort to reduce damage" (U.S. Army Corps of Engineers, 1996). Officials and residents depend on the river forecast to determine what actions are necessary to react to the event. In essence, the weather forecast provides information on “what” to expect while the river forecast contains the information needed to make decisions on “how” to react. It is probably safe to say that the average person has a general understanding of the uncertainty involved with a 7-day weather forecast. They will use the forecast information to make a general plan by knowing what the weather may be like in the future revising their plans as needed until the day is realized. The public also likely understands that the weather forecast for tomorrow is generally more accurate than 7-days from now. Lastly, the weather person on the local news may state that the forecast is uncertain because of the atmospheric conditions (i.e. the models are not converging). The same basic information is not available or as inherently obvious for a river forecast.

The forecast shown in Figure 32 may appear to be very accurate and precise to the uninformed user because the uncertainty, errors, and biases are not presented in the graph. The hurricane forecasts, as shown in Figure 33 shows some of the uncertainties because the projected path fans out for the forecast period. The more advanced users may have enough knowledge to look at QPF maps and forecast discussion information (www.hpc.ncep.noaa.gov/qpf/qpf2.shtml) to develop some quantitative impacts or uncertainties that may be present in the river forecast with respect to the forecast precipitation information. The QPF “forecast discussion” link contains valuable meteorological forecast information however, the format and content is not presented in layman’s terms. Applying an uncertainty band to the river forecast may provide the additional information needed by the public and emergency officials to react to the river forecast.

The river forecaster will always play an important role in the forecasting process and this document is not intended to diminish their expertise. However, verifying and improving the river forecasts through hindcasting is very difficult because of the subjective corrections made by the forecaster (Demargne & Mullusky, 2009). The forecaster must use their expertise because the current lumped models do not perform well for all events.

The National Weather Service river forecasters are able to provide valuable information, given their resource constraints, during high water events. However the National Weather Service should strive for continued improvement and evolution of the forecasting process. Adequate funding, in conjunction with changes in standard protocol are required to develop standard methods to continually validate and improve the river forecast models through hindcasting procedures. Improvements, such as displaying forecast bounds or river forecast discussions, are needed to better communicate the limitations of the forecasts to the general public. Lastly improving the river forecast modeling system is not enough. The model inputs must also be securitized to validate their accuracy because the most advanced river forecast model will not provide accurate results if the inputs are laden with errors and biases.

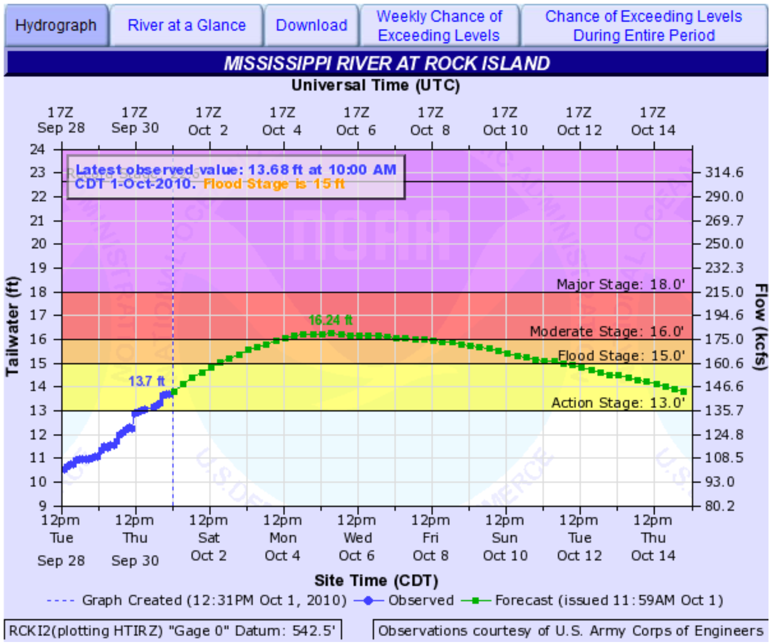


Figure 32. River Forecast as displayed on the National Weather Service Advanced Hydrologic Prediction Service (AHPS) web page. http://water.weather.gov/ahps/

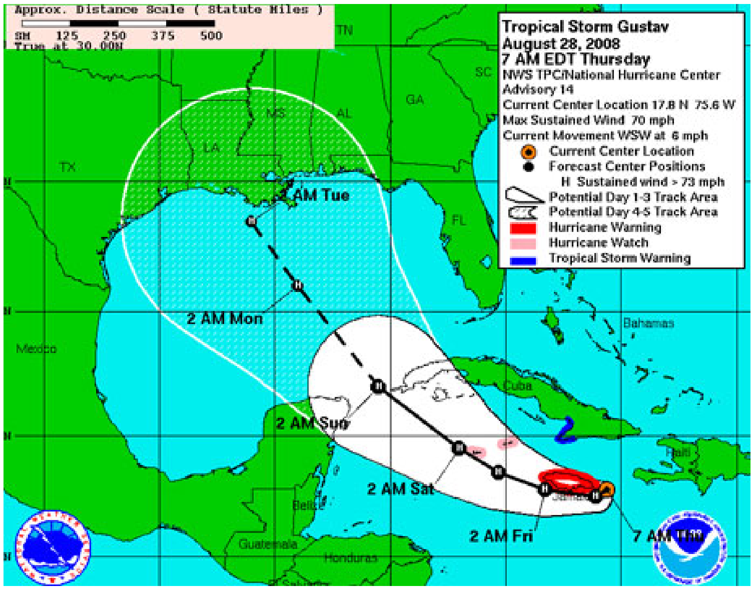


Figure 33. Example hurricane forecast that shows the uncertainty of the forecast trajectory based on the results of the hurricane forecast models.

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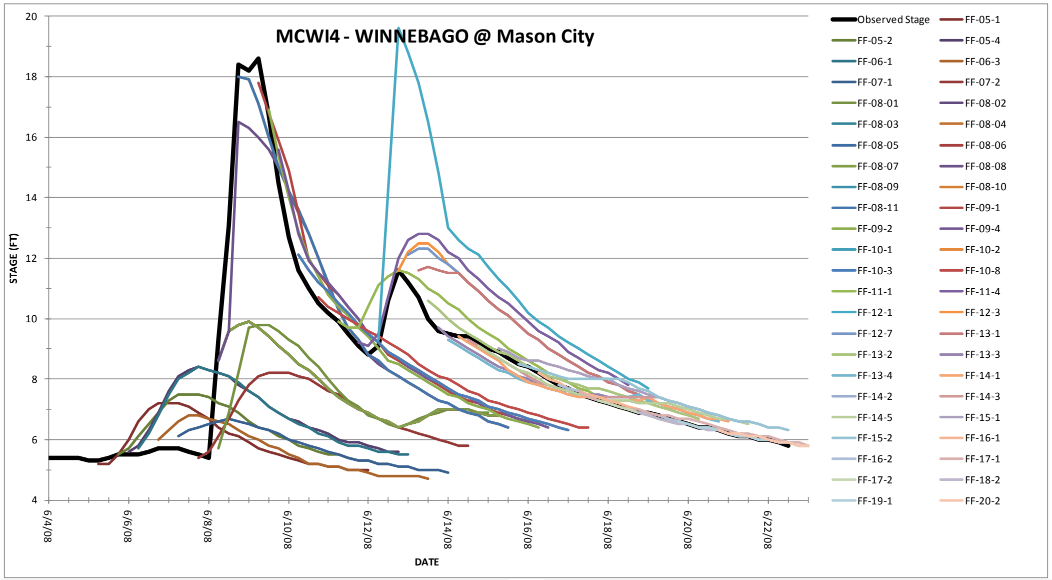
APPENDIX A
RIVER FORECAST ANALYSIS FIGURES


MCWI4 - WINNEBAGO @ Mason City
STAGE (FT)
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12
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6/4/08
6/6/08
6/8/08
6/10/08
6/12/08
6/14/08
6/16/08
6/18/08
6/20/08
6/22/08
Observed Stage
FF-05-1
FF-05-2
FF-05-4
FF-06-1
FF-06-3
FF-07-1
FF-07-2
FF-08-01
FF-08-02
FF-08-03
FF-08-04
FF-08-05
FF-08-06
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FF-08-10
FF-08-11
FF-09-1
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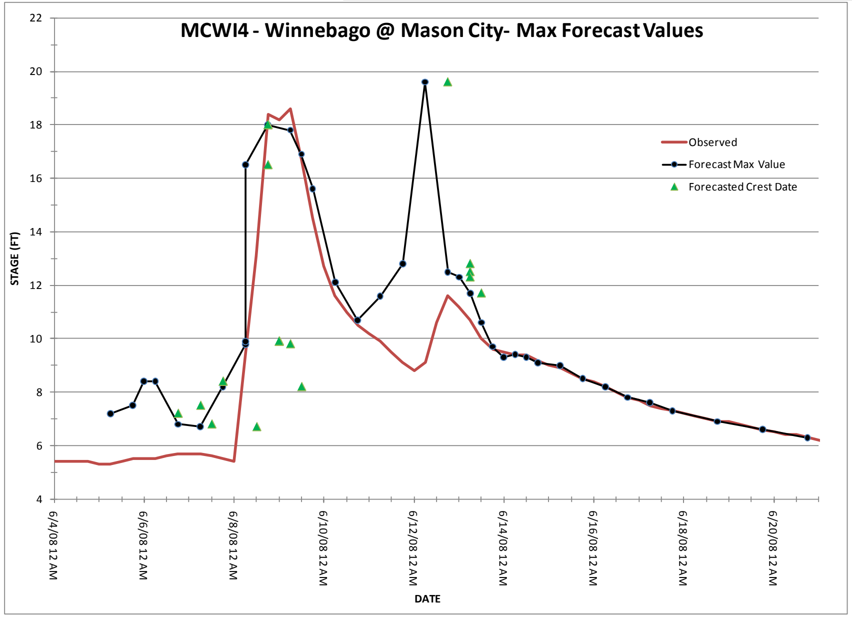
MCWI4 - Winnebago @ Mason City- Max Forecast Values
STAGE (FT)
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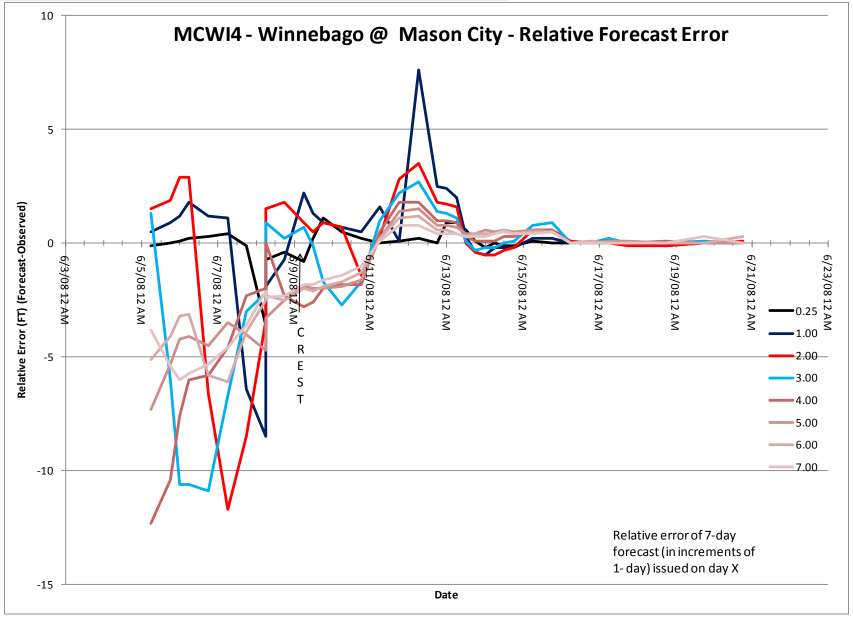
6/4/08 12 AM
6/6/08 12 AM
6/8/08 12 AM
6/10/08 12 AM
6/12/08 12 AM
6/14/08 12 AM
6/16/08 12 AM
6/18/08 12 AM
6/20/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date


MCWI4 - Winnebago @ Mason City - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
10
5
0
-5
-10
-15
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
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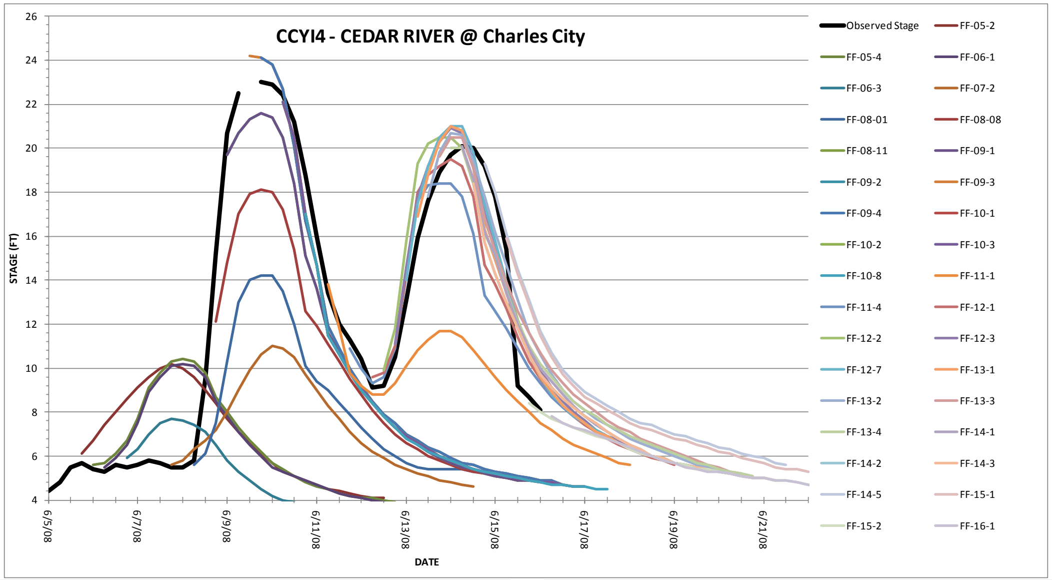
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X


CCYI4 - CEDAR RIVER @ Charles City
STAGE (FT)
DATE
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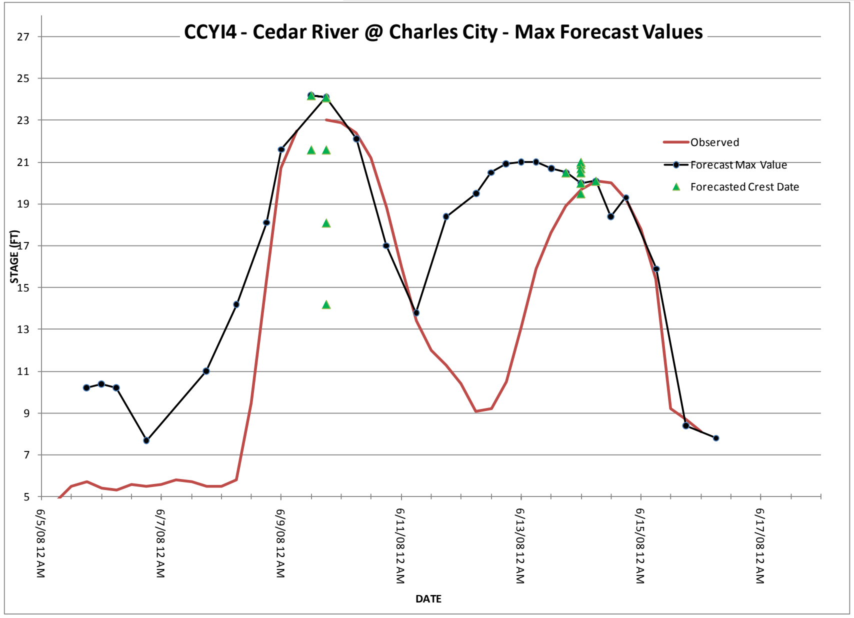
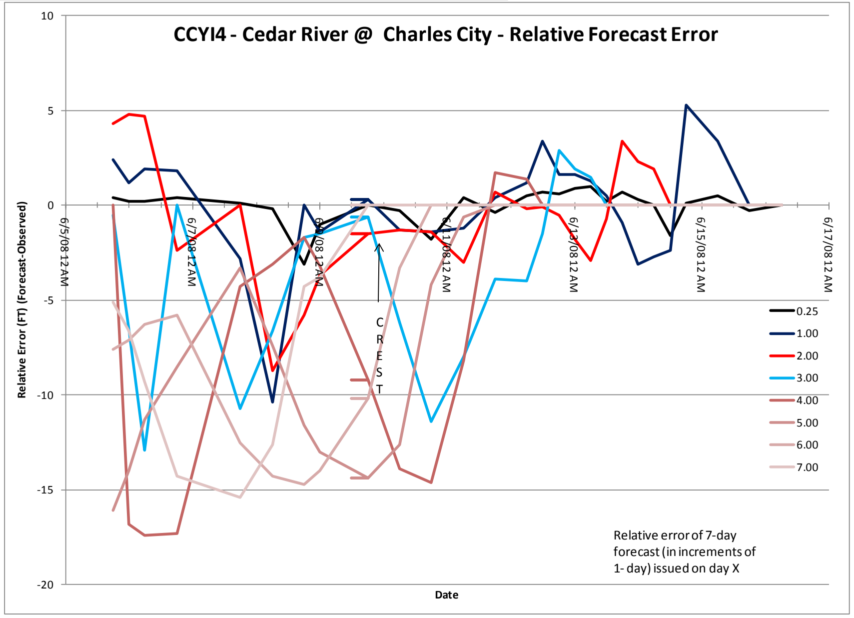
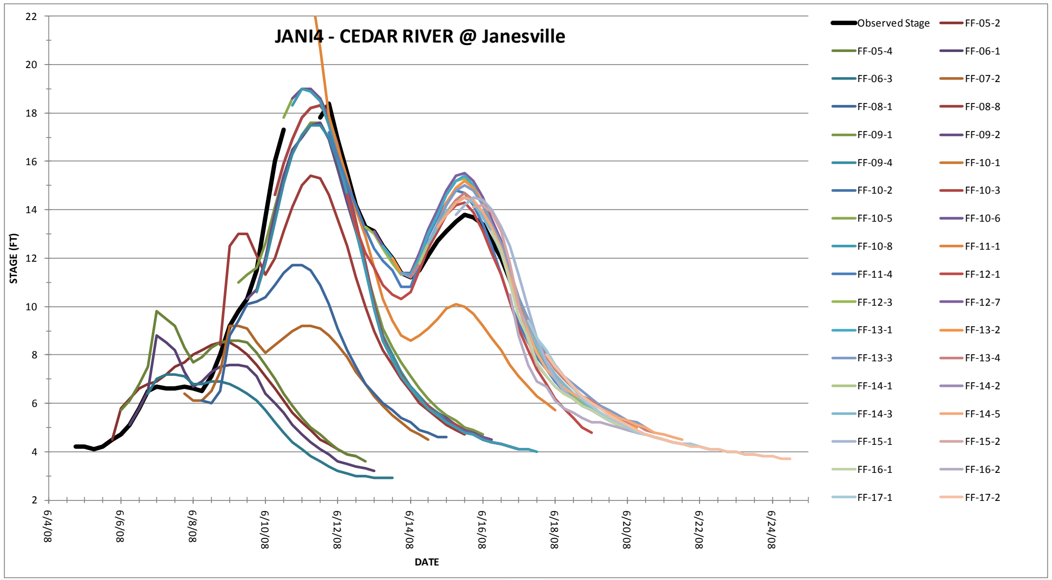
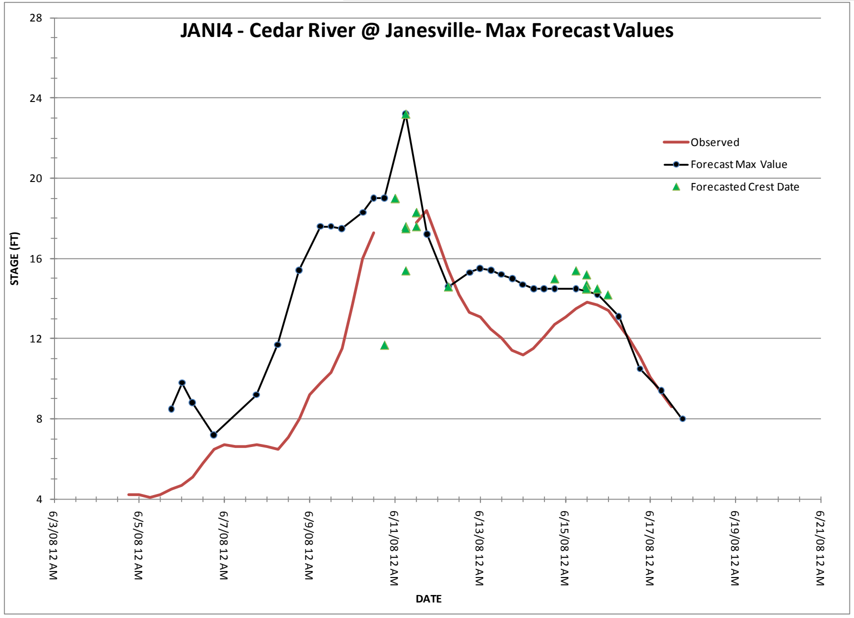
20
18
16
14
12
10
8
6
4
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
Observed Stage
FF-05-2
FF-05-4
FF-06-1
FF-06-3
FF-07-2
FF-08-01
FF-08-08
FF-08-11
FF-09-1
FF-09-2
FF-09-3
FF-09-4
FF-10-1
FF-10-2
FF-10-3
FF-10-8
FF-11-1
FF-11-4
FF-12-1
FF-12-2
FF-12-3
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1


CCYI4 - Cedar River @ Charles City - Max Forecast Values
STAGE (FT)
DATE
27
25
23
21
19
17
15
13
11
9
7
5
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

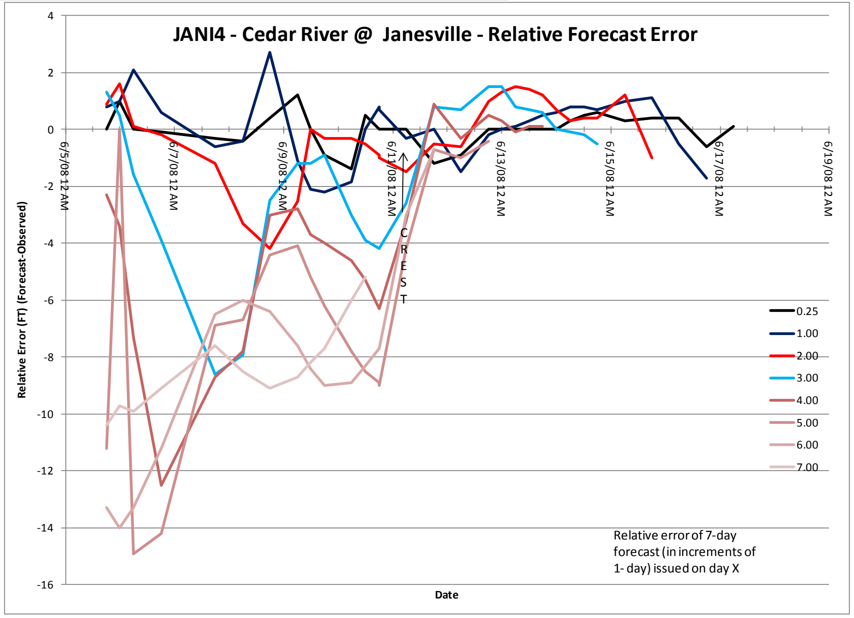

CCYI4 - Cedar River @ Charles City - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
10
5
0
-5
-10
-15
-20
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X



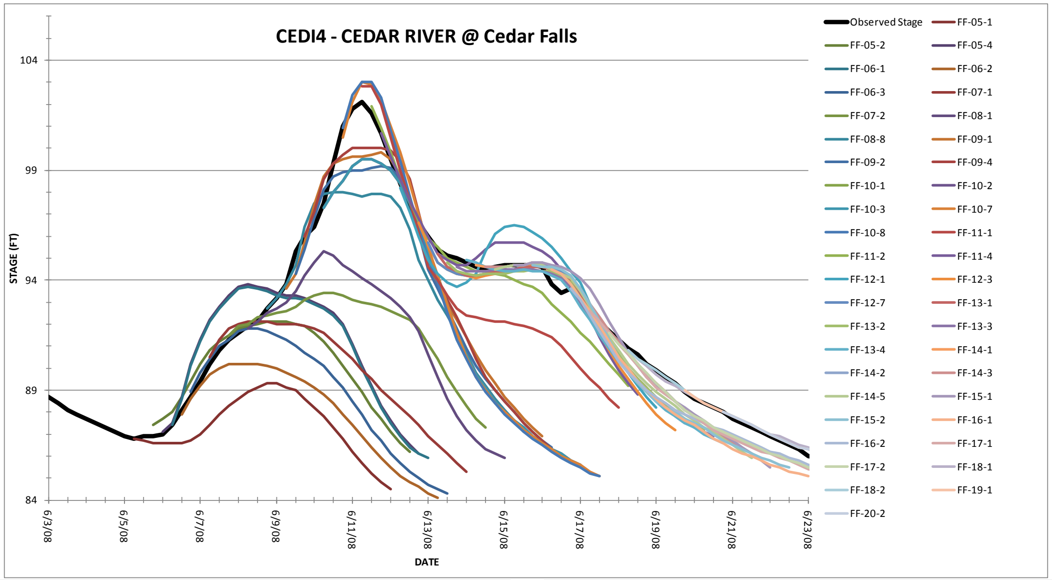
JANI4 - CEDAR RIVER @ Janesville
STAGE (FT)
22
20
18
16
14
12
10
8
6
4
2
6/4/08
6/6/08
6/8/08
6/10/08
6/12/08
6/14/08
6/16/08
6/18/08
6/20/08
6/22/08
6/24/08
DATE
Observed Stage
FF-05-2
FF-05-4
FF-06-1
FF-06-3
FF-07-2
FF-08-1
FF-08-8
FF-09-1
FF-09-2
FF-09-4
FF-10-1
FF-10-2
FF-10-3
FF-10-5
FF-10-6
FF-10-8
FF-11-1
FF-11-4
FF-12-1
FF-12-3
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2

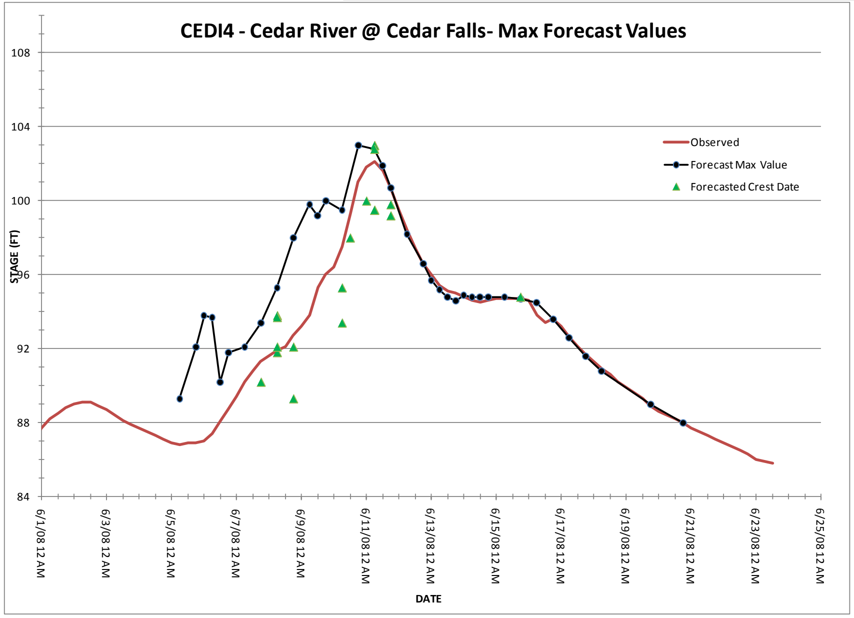


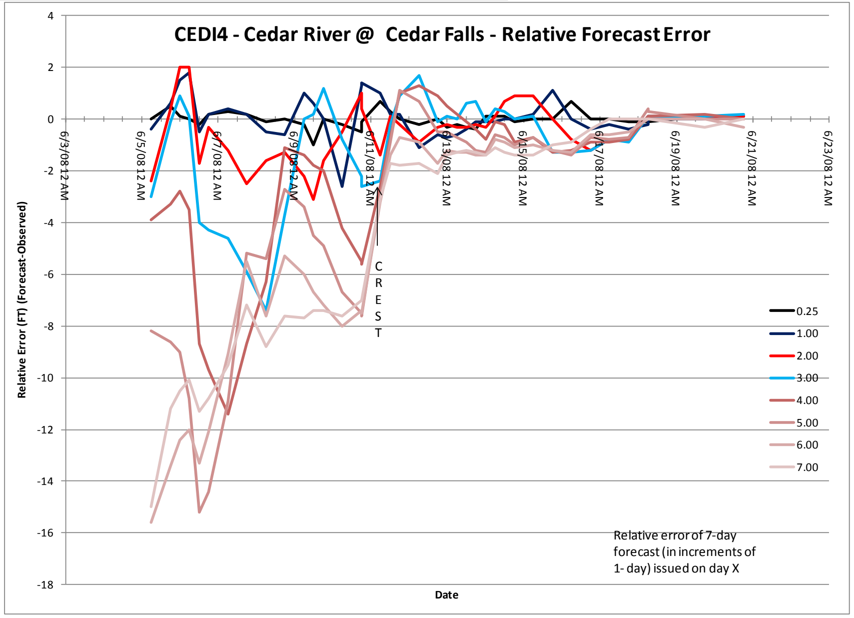
JANI4 - Cedar River @ Janesville- Max Forecast Values
STAGE (FT)
28
24
20
16
12
8
4
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date

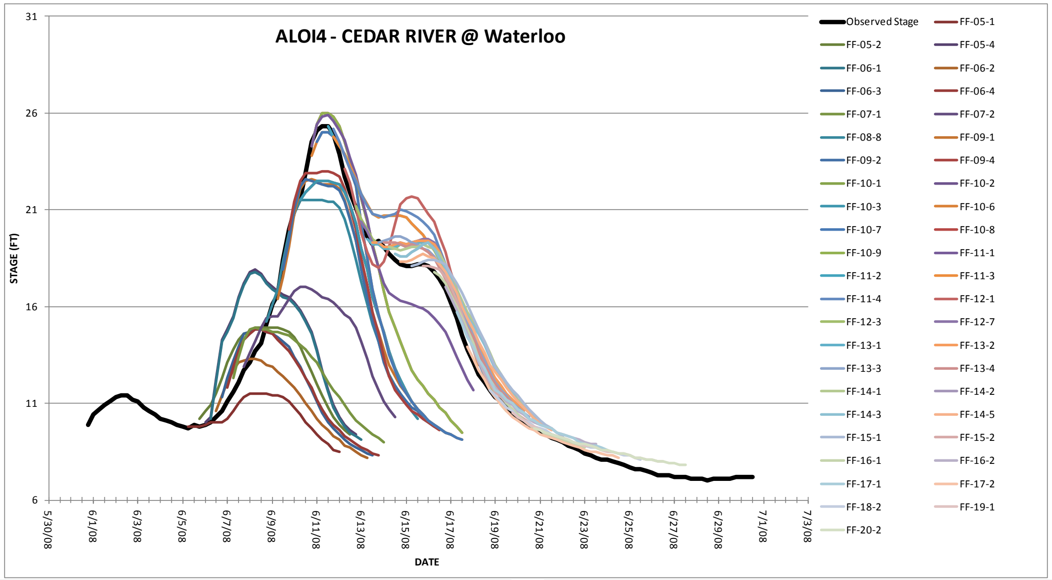


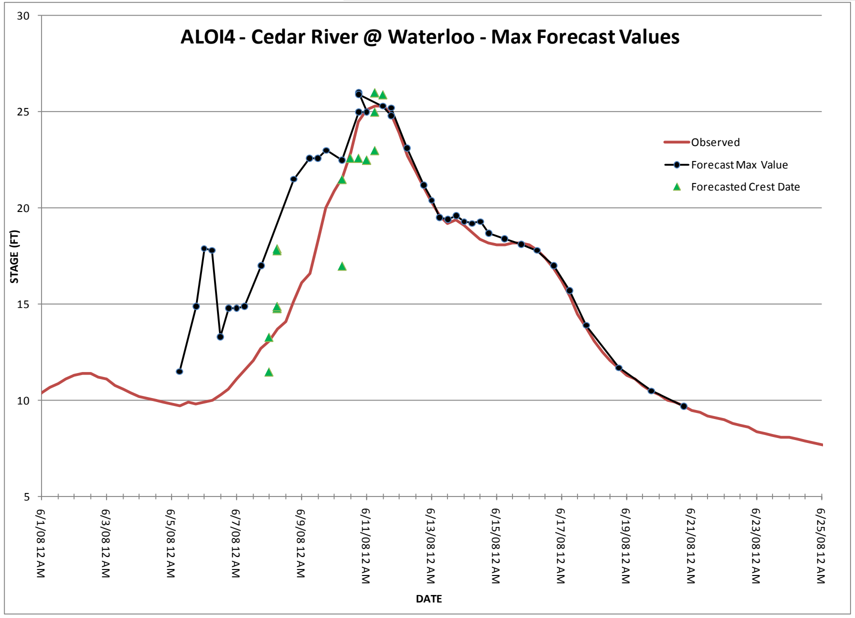
JANI4 - Cedar River @ Janesville - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X
Date

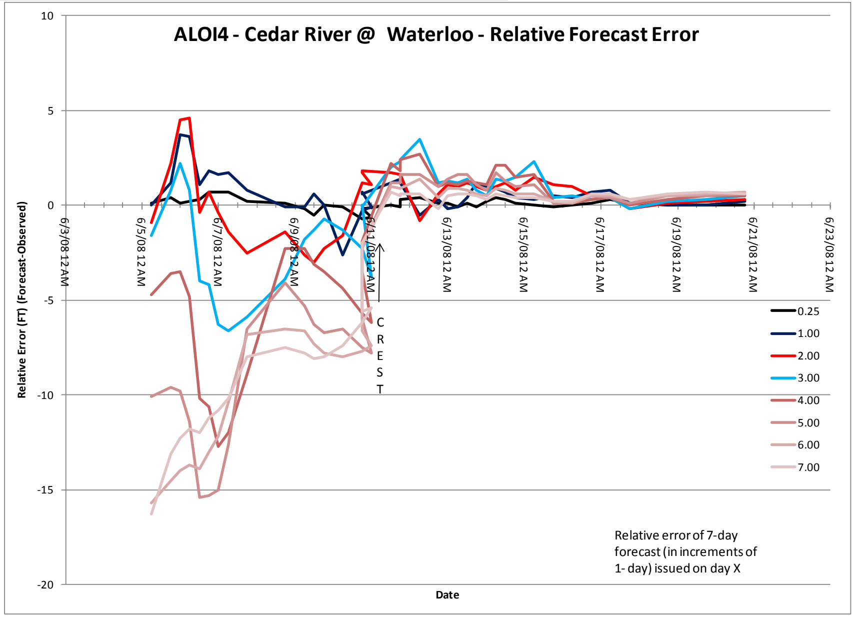

CEDI4 - CEDAR RIVER @ Cedar Falls
STAGE (FT)
104
99
94
89
84
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
DATE
Observed Stage
FF-05-1
FF-05-2
FF-05-4
FF-06-1
FF-06-2
FF-06-3
FF-07-1
FF-07-2
FF-08-1
FF-08-8
FF-09-1
FF-09-2
FF-09-4
FF-10-1
FF-10-2
FF-10-3
FF-10-7
FF-10-8
FF-11-1
FF-11-2
FF-11-4
FF-12-1
FF-12-3
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-1
FF-18-2
FF-19-1
FF-20-2

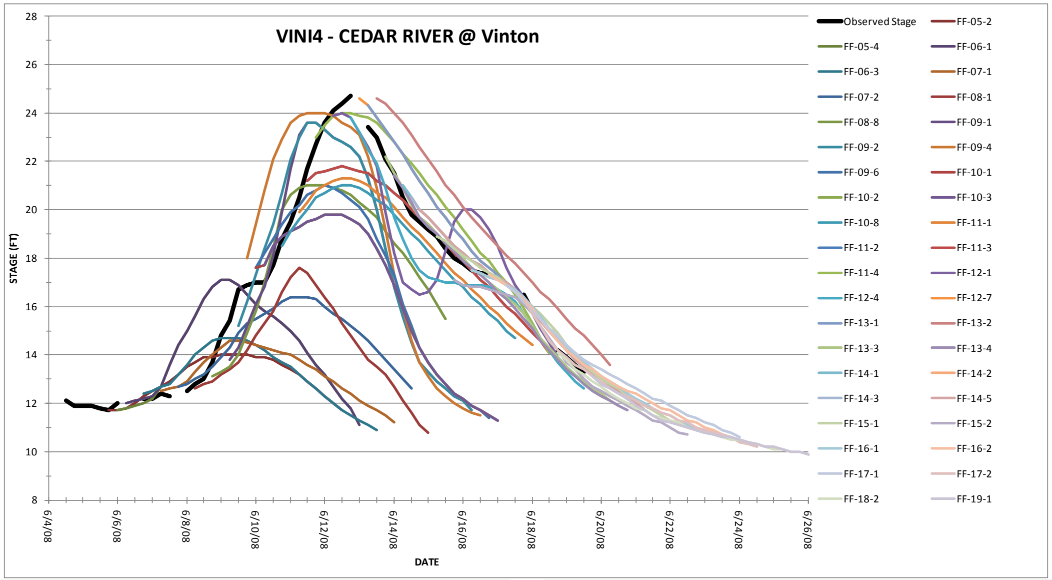

CEDI4 - Cedar River @ Cedar Falls- Max Forecast Values
STAGE (FT)
108
104
100
96
92
88
84
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date

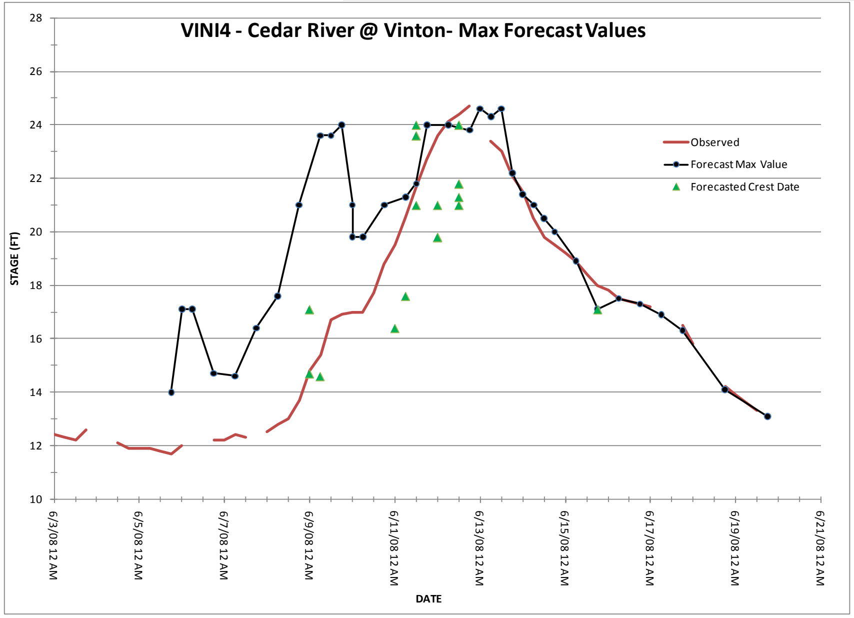

CEDI4 - Cedar River @ Cedar Falls - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
Date
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X

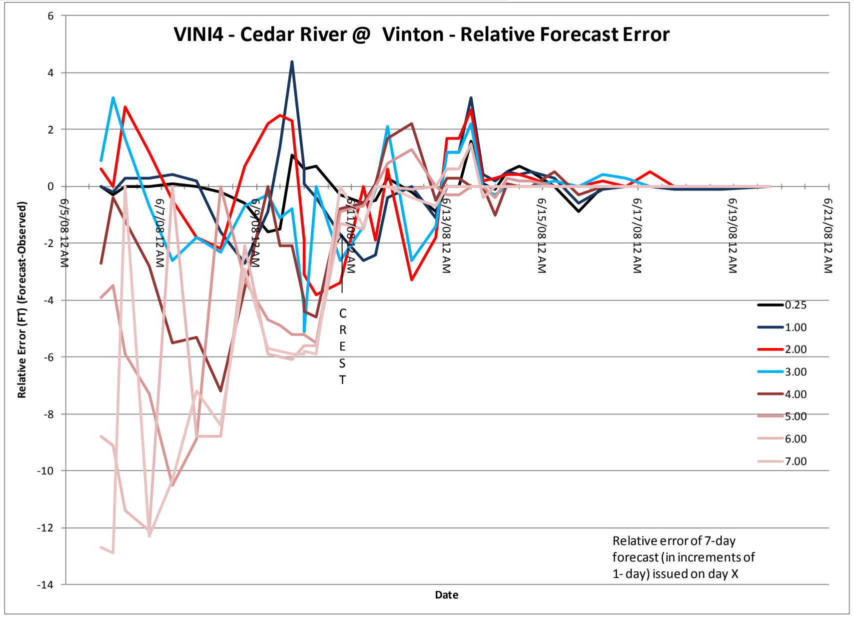

ALOI4 - CEDAR RIVER @ Waterloo
STAGE (FT)
DATE
31
26
21
16
11
6
5/30/08
6/1/08
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
6/27/08
6/29/08
7/1/08
7/3/08
Observed Stage
FF-05-1
FF-05-2
FF-05-4
FF-06-1
FF-06-2
FF-06-3
FF-06-4
FF-07-1
FF-07-2
FF-08-8
FF-09-1
FF-09-2
FF-09-4
FF-10-1
FF-10-2
FF-10-3
FF-10-6
FF-10-7
FF-10-8
FF-10-9
FF-11-1
FF-11-2
FF-11-3
FF-11-4
FF-12-1
FF-12-3
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-2
FF-19-1
FF-20-2

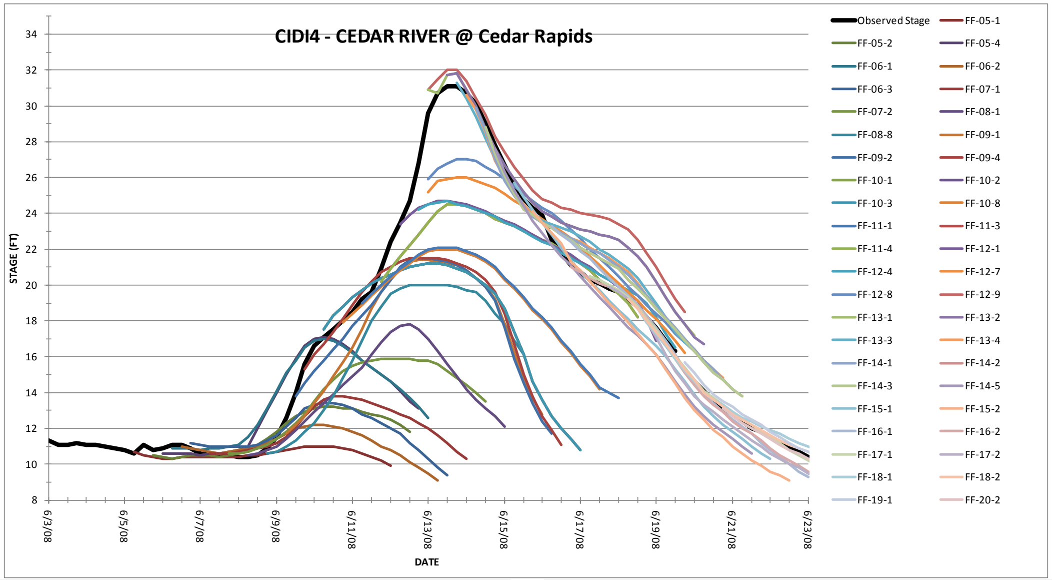

ALOI4 - Cedar River @ Waterloo - Max Forecast Values
STAGE (FT)
DATE
30
25
20
15
10
5
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

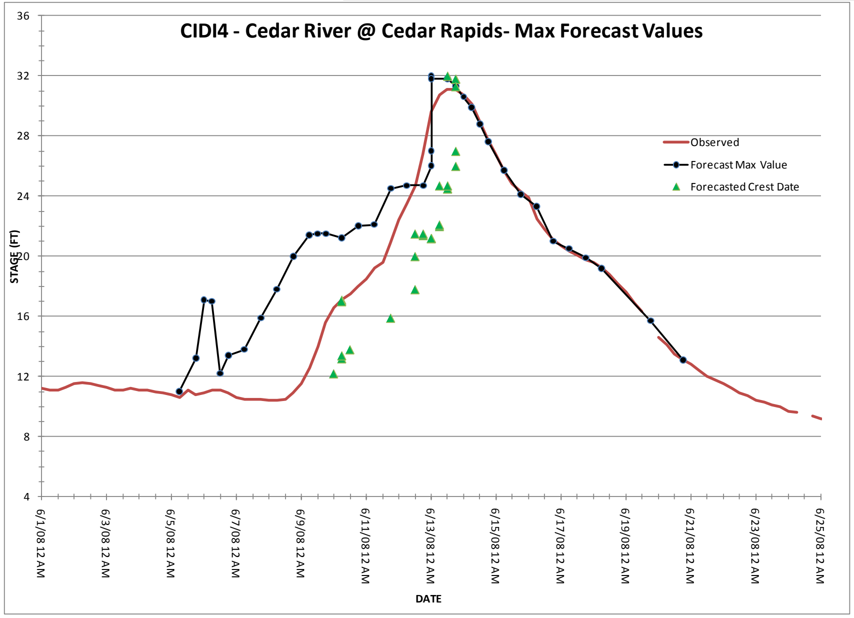

ALOI4 - Cedar River @ Waterloo - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
10
5
0
-5
-10
-15
-20
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X

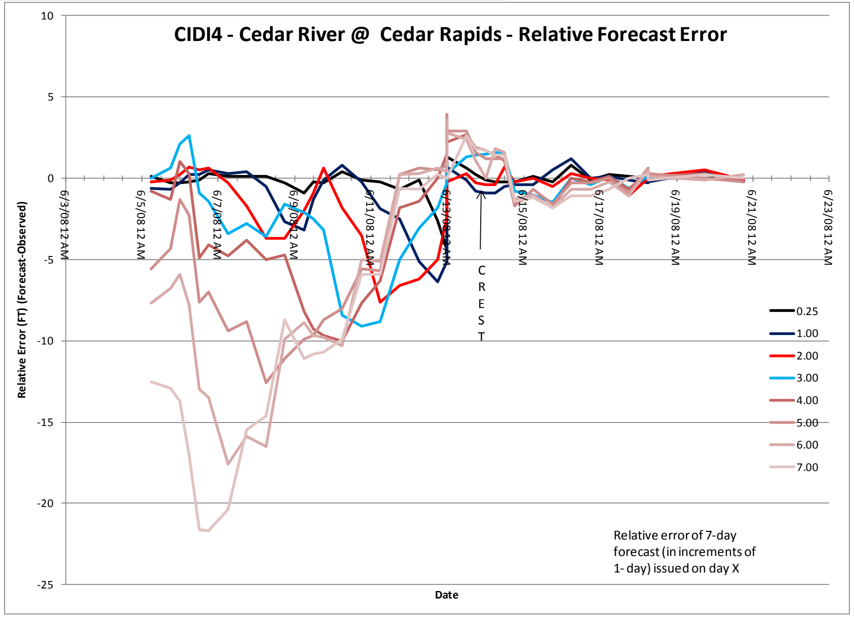

VINI4 - CEDAR RIVER @ Vinton
STAGE (FT)
28
26
24
22
20
18
16
14
12
10
8
6/4/08
6/6/08
6/8/08
6/10/08
6/12/08
6/14/08
6/16/08
6/18/08
6/20/08
6/22/08
6/24/08
6/26/08
DATE
Observed Stage
FF-05-2
FF-05-4
FF-06-1
FF-06-3
FF-07-1
FF-07-2
FF-08-1
FF-08-8
FF-09-1
FF-09-2
FF-09-4
FF-09-6
FF-10-1
FF-10-2
FF-10-3
FF-10-8
FF-11-1
FF-11-2
FF-11-3
FF-11-4
FF-12-1
FF-12-4
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-2
FF-19-1

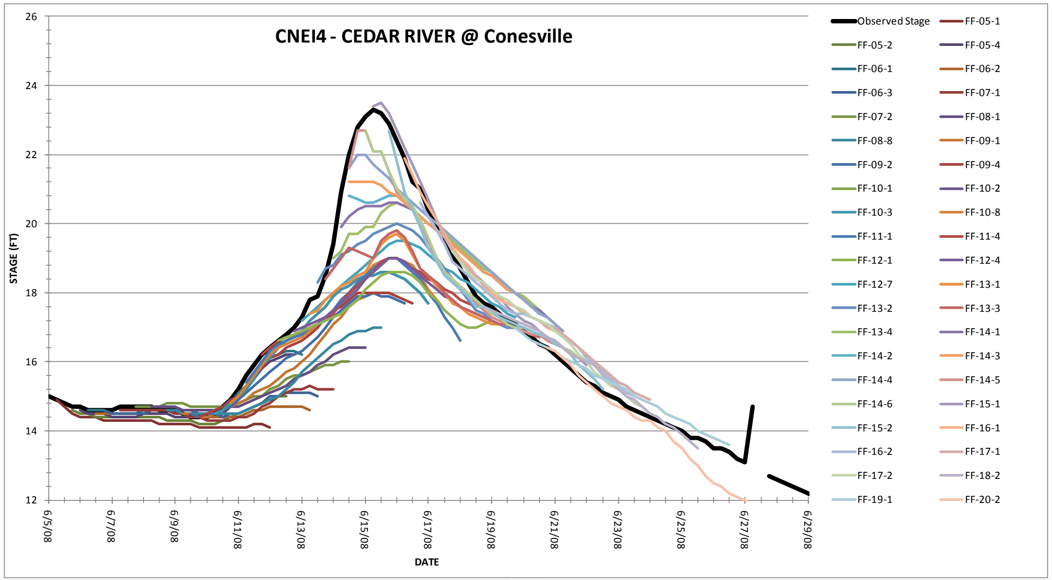

VINI4 - Cedar River @ Vinton- Max Forecast Values
STAGE (FT)
28
26
24
22
20
18
16
14
12
10
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date


VINI4 - Cedar River @ Vinton - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
CREST
Date
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X

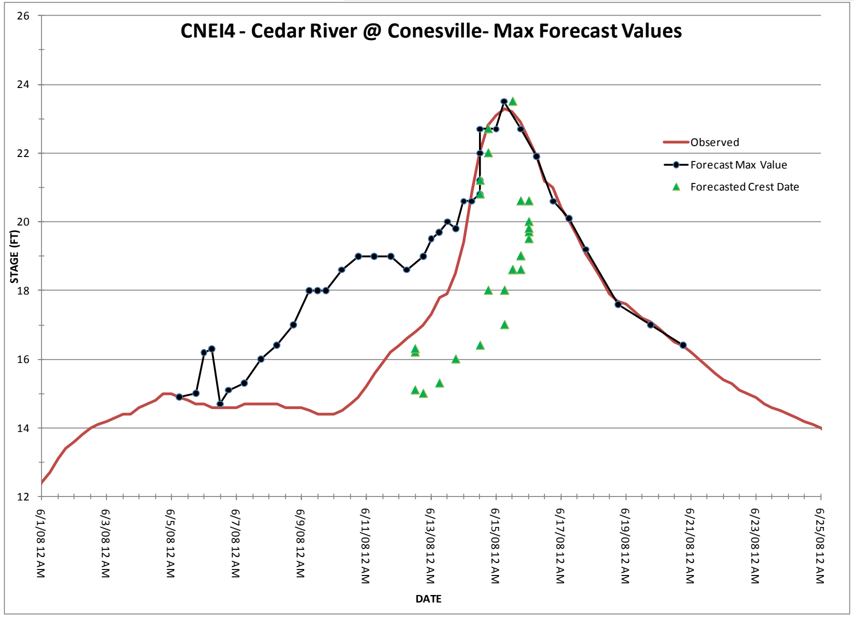

CIDI4 - CEDAR RIVER @ Cedar Rapids
STAGE (FT)
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
DATE
Observed Stage
FF-05-1
FF-05-2
FF-05-4
FF-06-1
FF-06-2
FF-06-3
FF-07-1
FF-07-2
FF-08-1
FF-08-8
FF-09-1
FF-09-2
FF-09-4
FF-10-1
FF-10-2
FF-10-3
FF-10-8
FF-11-1
FF-11-3
FF-11-4
FF-12-1
FF-12-4
FF-12-7
FF-12-8
FF-12-9
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-1
FF-18-2
FF-19-1
FF-20-2


CIDI4 - Cedar River @ Cedar Rapids- Max Forecast Values
STAGE (FT)
36
32
28
24
20
16
12
8
4
Observed
Forecast Max Value
Forecasted Crest Date
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
DATE

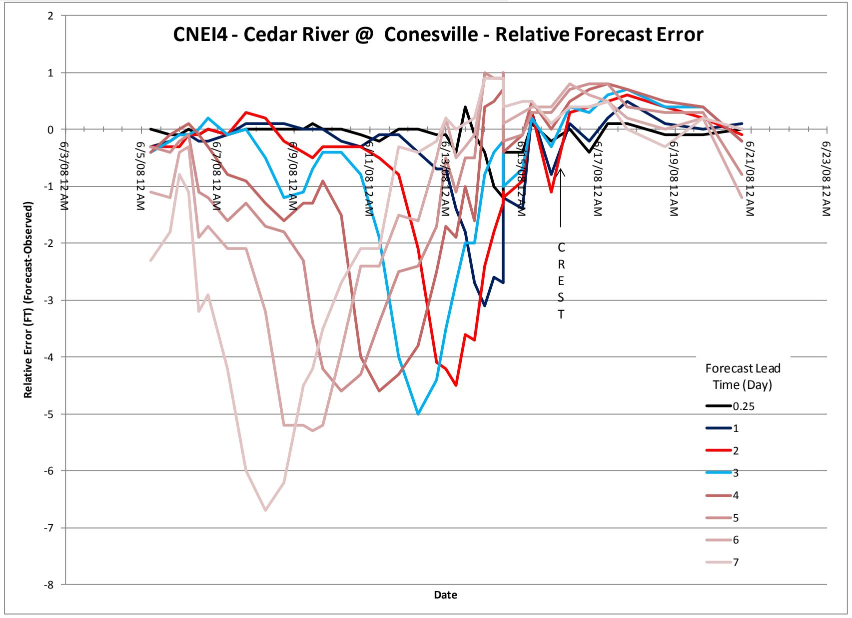

CIDI4 - Cedar River @ Cedar Rapids - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
10
5
0
-5
-10
-15
-20
-25
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
C
R
E
S
T
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day
forecast (in increments of
1- day) issued on day X
Date



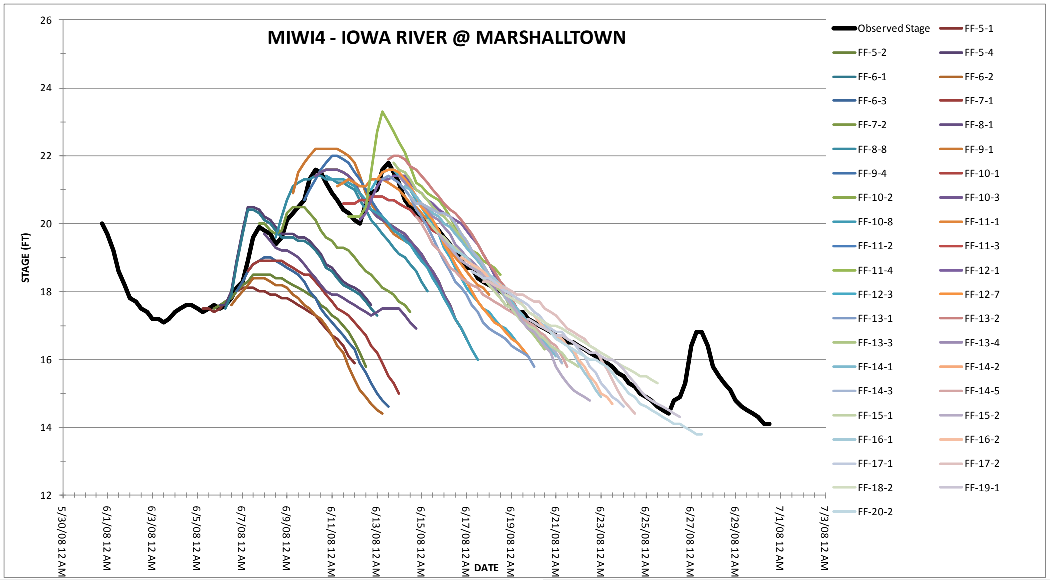
CNEI4 - CEDAR RIVER @ Conesville

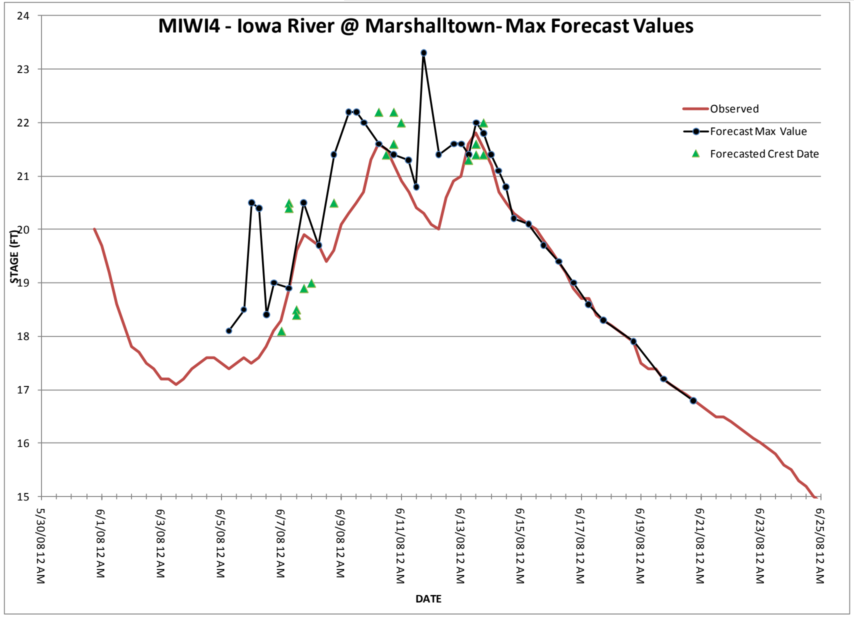


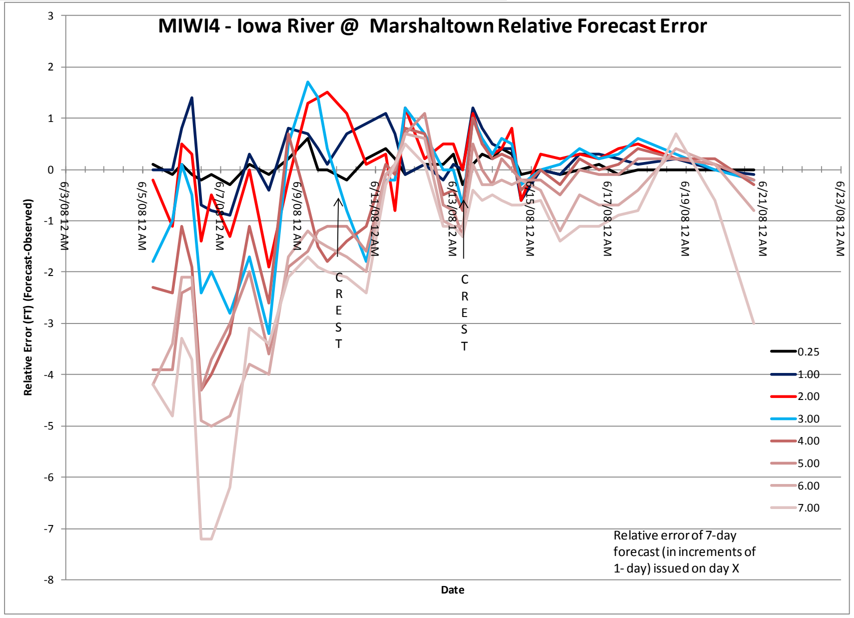
CNEI4 - Cedar River @ Conesville- Max Forecast Values

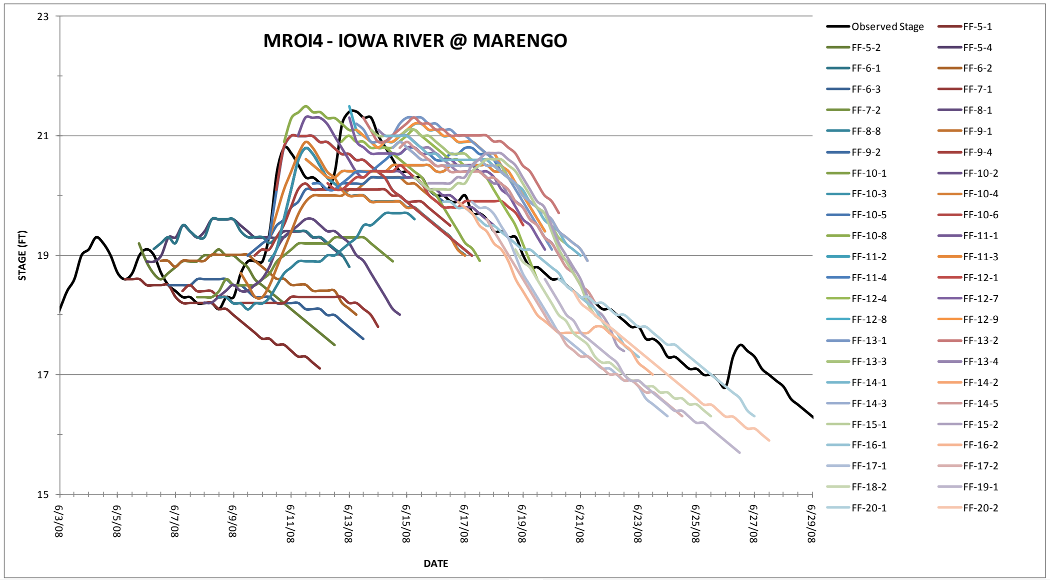


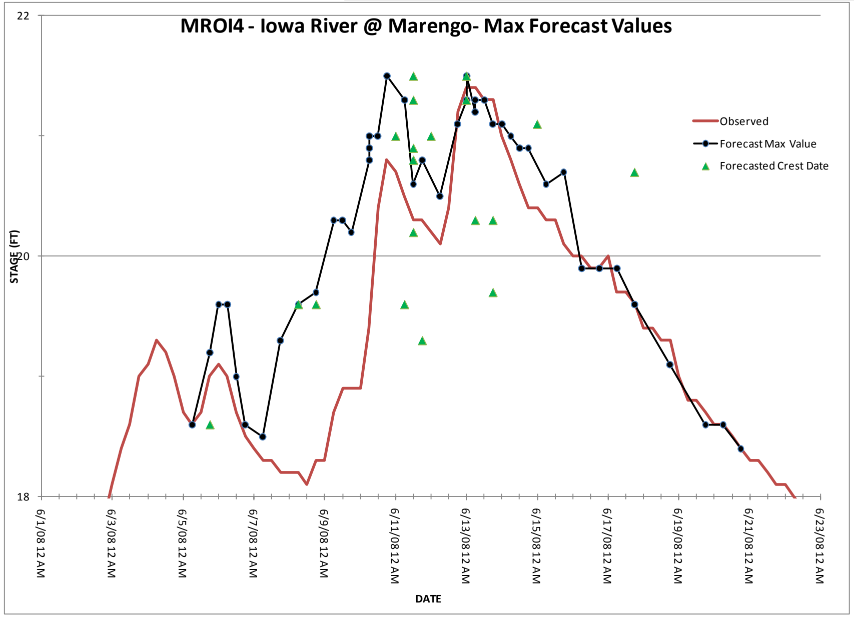
CNEI4 - Cedar River @ Conesville - Relative Forecast Error

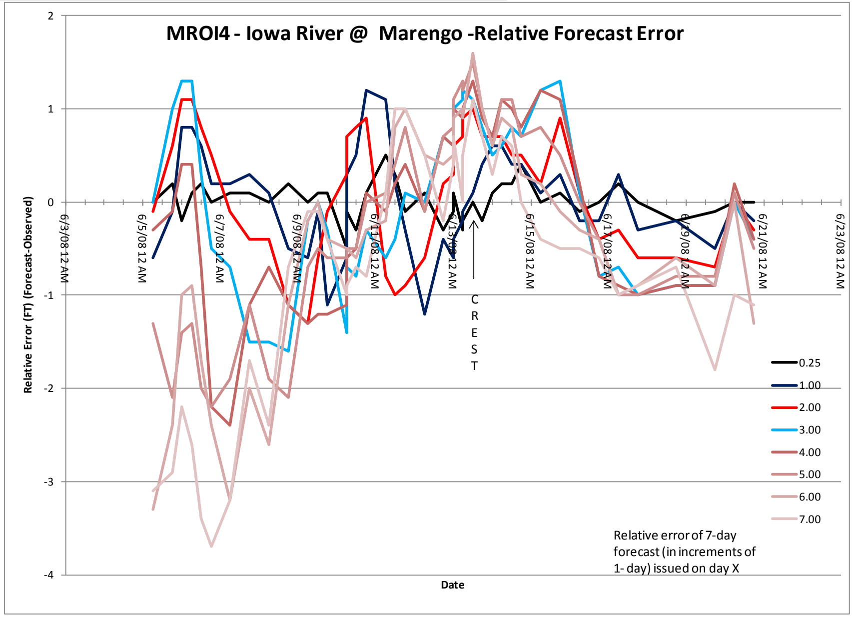

MIWI4 - IOWA RIVER @ MARSHALLTOWN
STAGE (FT)
26
24
22
20
18
16
14
12
5/30/08 12 AM
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
6/29/08 12 AM
7/1/08 12 AM
7/3/08 12 AM
DATE
Observed Stage
FF-5-1
FF-5-2
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-7-1
FF-7-2
FF-8-1
FF-8-8
FF-9-1
FF-9-4
FF-10-1
FF-10-2
FF-10-3
FF-10-8
FF-11-1
FF-11-2
FF-11-3
FF-11-4
FF-12-1
FF-12-3
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-2
FF-19-1
FF-20-2

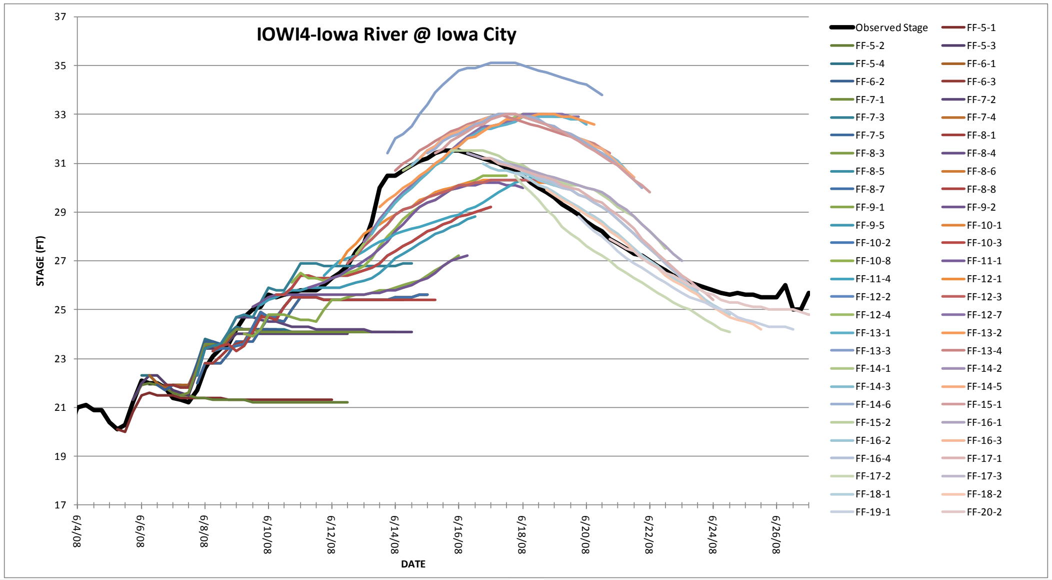

MIWI4 - Iowa River @ Marshalltown- Max Forecast Values
STAGE (FT)
24
23
22
21
20
19
18
17
16
15
Observed
Forecast Max Value
Forecasted Crest Date
5/30/08 12 AM
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
DATE

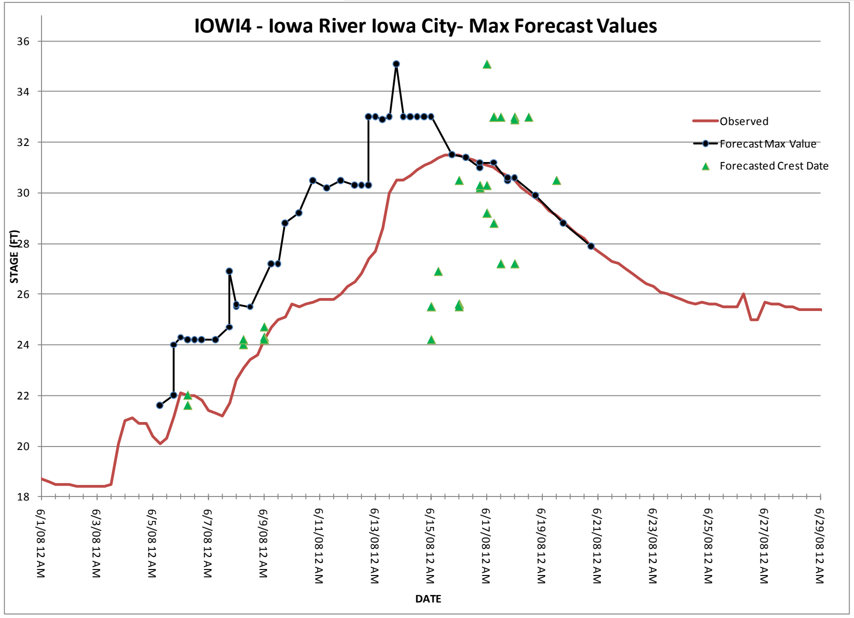

MIWI4 - Iowa River @ Marshaltown Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
CREST
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X
Date

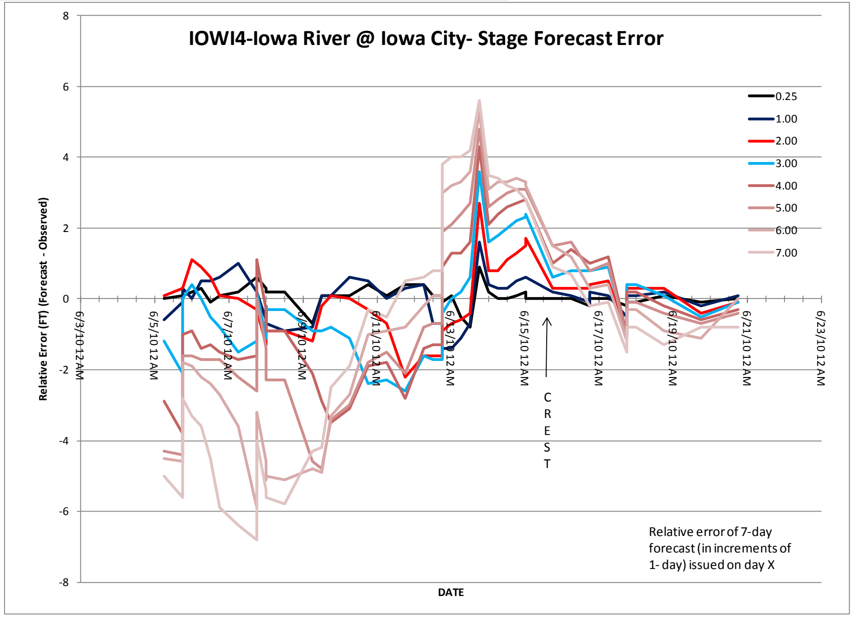

MROI4 - IOWA RIVER @ MARENGO
STAGE (FT)
23
21
19
17
15
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
6/27/08
6/29/08
DATE
Observed Stage
FF-5-1
FF-5-2
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-7-1
FF-7-2
FF-8-1
FF-8-8
FF-9-1
FF-9-2
FF-9-4
FF-10-1
FF-10-2
FF-10-3
FF-10-4
FF-10-5
FF-10-6
FF-10-8
FF-11-1
FF-11-2
FF-11-3
FF-11-4
FF-12-1
FF-12-4
FF-12-7
FF-12-8
FF-12-9
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-18-2
FF-19-1
FF-20-1
FF-20-2

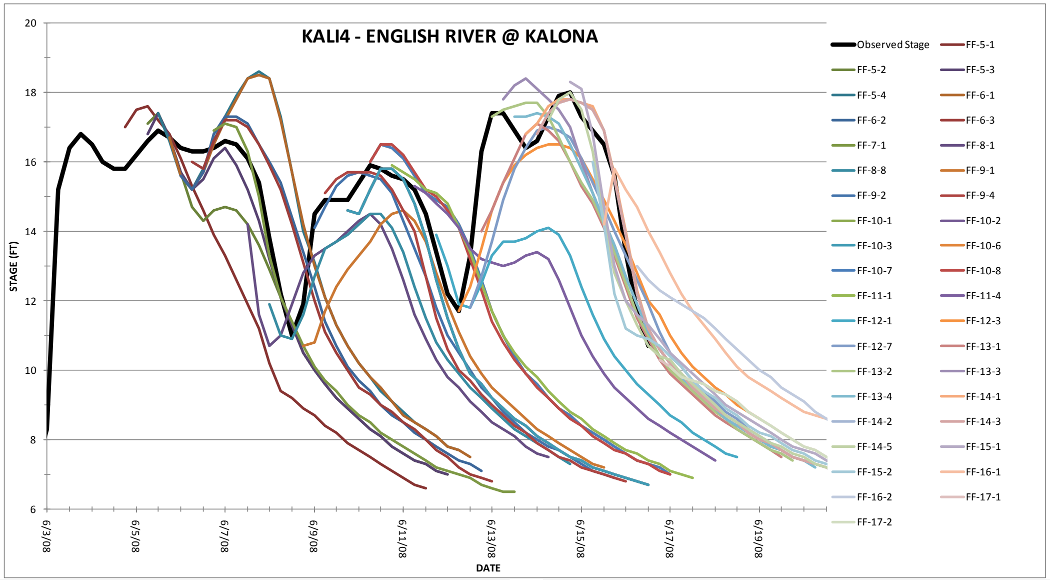

MROI4 - Iowa River @ Marengo- Max Forecast Values
STAGE (FT)
22
20
18
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date


MROI4 - Iowa River @ Marengo -Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
2
1
0
-1
-2
-3
-4
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
C
R
E
S
T
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X
Date

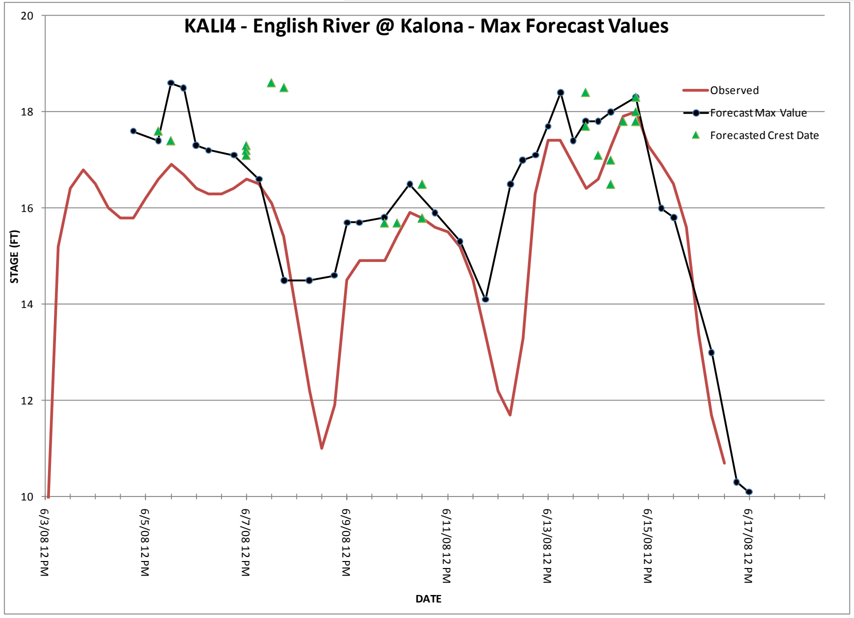

IOWI4-Iowa River @ Iowa City
STAGE (FT)
DATE
37
35
33
31
29
27
25
23
21
19
17
6/4/08
6/6/08
6/8/08
6/10/08
6/12/08
6/14/08
6/16/08
6/18/08
6/20/08
6/22/08
6/24/08
6/26/08
Observed Stage
FF-5-1
FF-5-2
FF-5-3
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-7-1
FF-7-2
FF-7-3
FF-7-4
FF-7-5
FF-8-1
FF-8-3
FF-8-4
FF-8-5
FF-8-6
FF-8-7
FF-8-8
FF-9-1
FF-9-2
FF-9-5
FF-10-1
FF-10-2
FF-10-3
FF-10-8
FF-11-1
FF-11-4
FF-12-1
FF-12-2
FF-12-3
FF-12-4
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-14-6
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-16-3
FF-16-4
FF-17-1
FF-17-2
FF-17-3
FF-18-1
FF-18-2
FF-19-1
FF-20-2


IOWI4 - Iowa River Iowa City- Max Forecast Values
STAGE (FT)
DATE
36
34
32
30
28
26
24
22
20
18
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
6/29/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

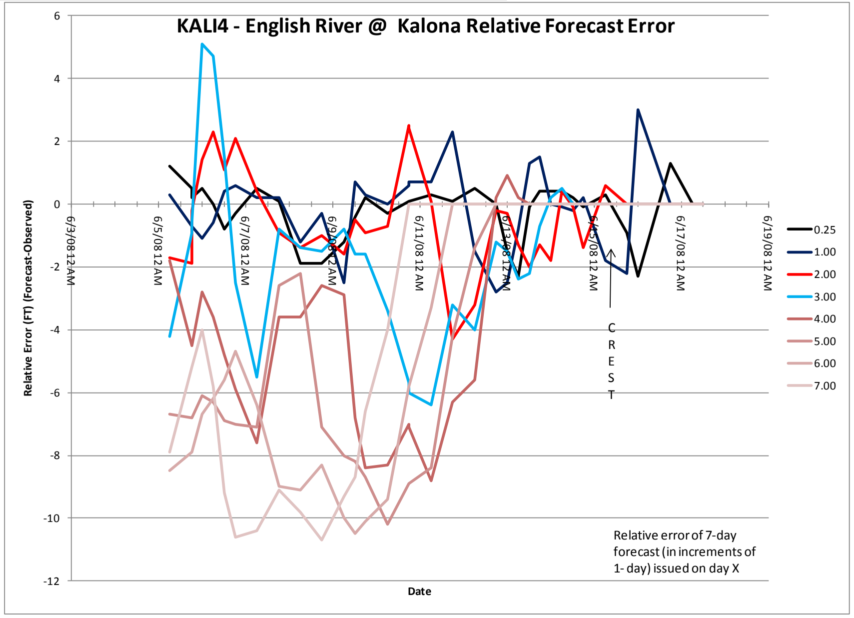

IOWI4-Iowa River @ Iowa City- Stage Forecast Error
Relative Error (FT) (Forecast - Observed)
DATE
8
6
4
2
0
-2
-4
-6
-8
6/3/10 12 AM
6/5/10 12 AM
6/7/10 12 AM
6/9/10 12 AM
6/11/10 12 AM
6/13/10 12 AM
6/15/10 12 AM
6/17/10 12 AM
6/19/10 12 AM
6/21/10 12 AM
6/23/10 12 AM
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
C
R
E
S
T
Relative error of 7-day forecast (in increments of 1- day) issued on day X



KALI4 - ENGLISH RIVER @ KALONA

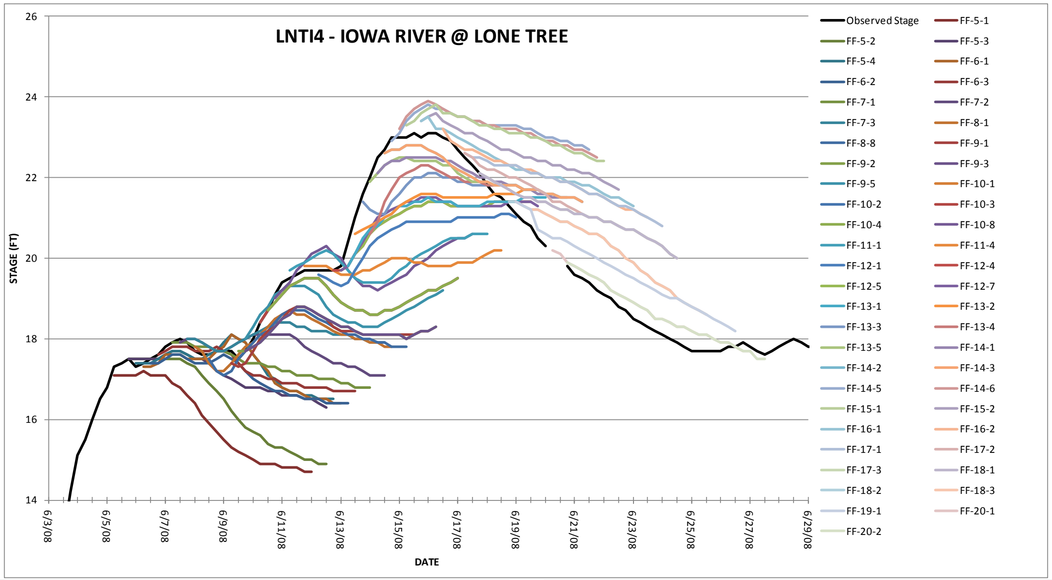


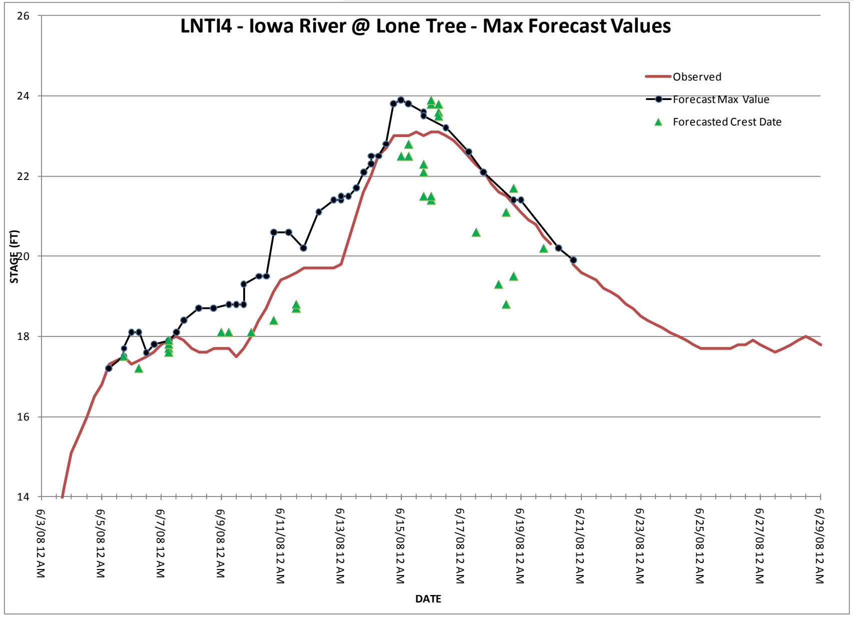
KALI4 - English River @ Kalona - Max Forecast Values

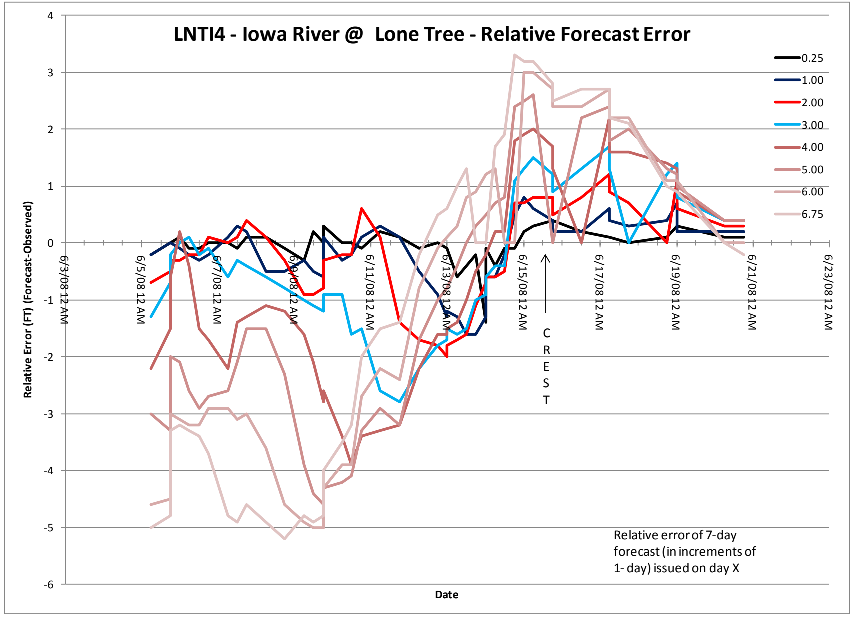


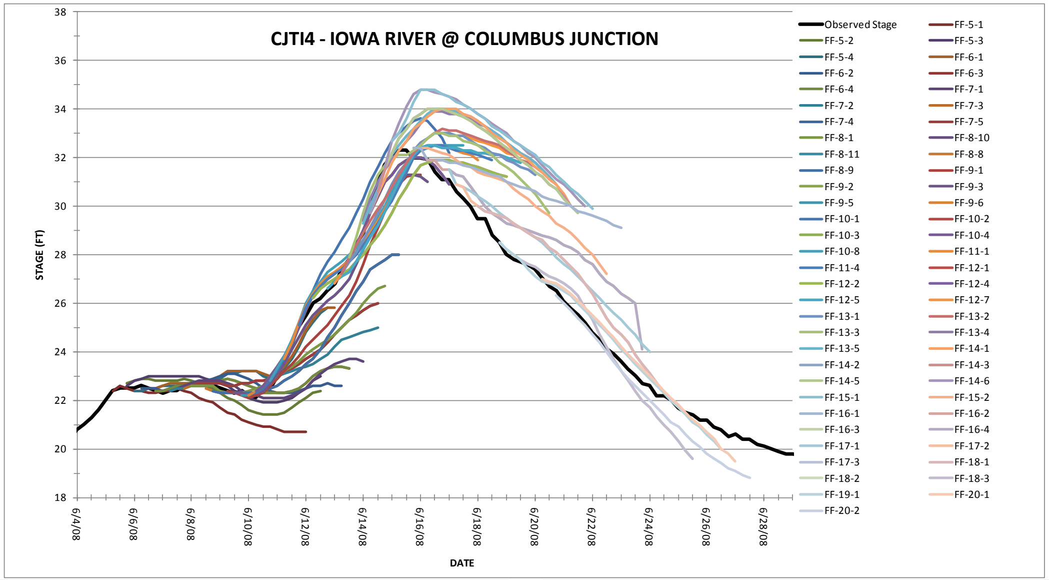
KALI4 - English River @ Kalona Relative Forecast Error

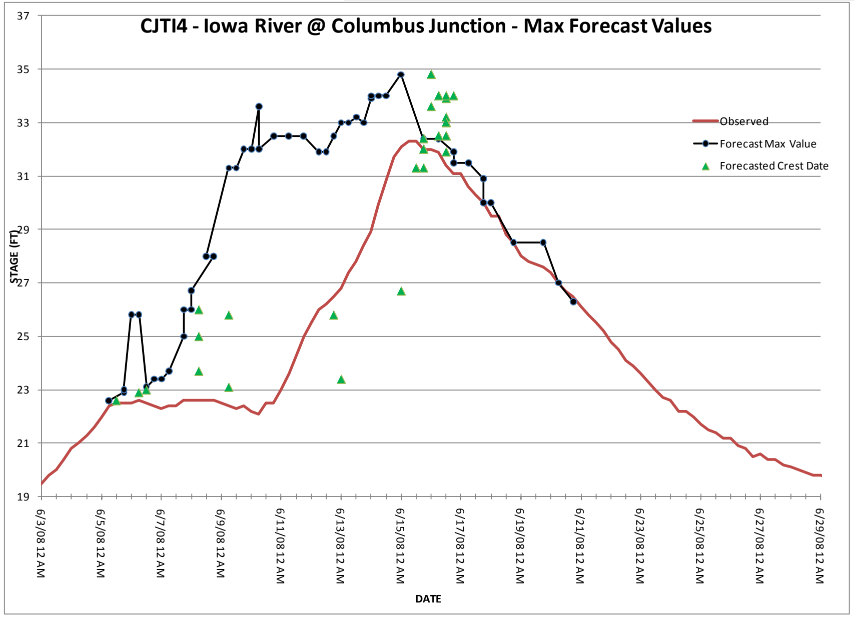
Relative error of 7-day forecast (in increments of 1- day) issued on day X

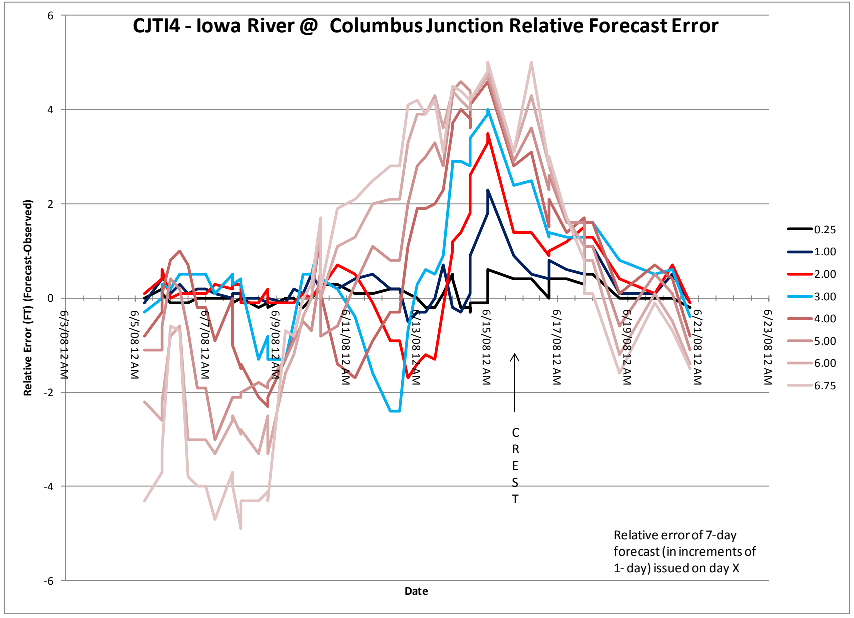

LNTI4 - IOWA RIVER @ LONE TREE
STAGE (FT)
DATE
26
24
22
20
18
16
14
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
6/27/08
6/29/08
Observed Stage
FF-5-1
FF-5-2
FF-5-3
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-7-1
FF-7-2
FF-7-3
FF-8-1
FF-8-8
FF-9-1
FF-9-2
FF-9-3
FF-9-5
FF-10-1
FF-10-2
FF-10-3
FF-10-4
FF-10-8
FF-11-1
FF-11-4
FF-12-1
FF-12-4
FF-12-5
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-13-5
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-14-6
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-17-1
FF-17-2
FF-17-3
FF-18-1
FF-18-2
FF-18-3
FF-19-1
FF-20-1
FF-20-2

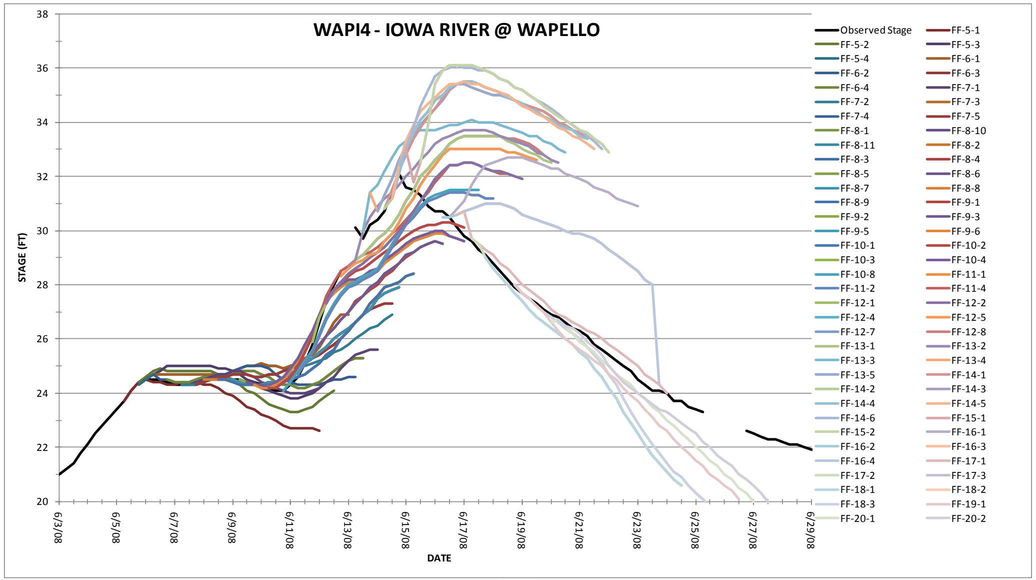

LNTI4 - Iowa River @ Lone Tree - Max Forecast Values
STAGE (FT)
DATE
26
24
22
20
18
16
14
Observed
Forecast Max Value
Forecasted Crest Date
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
6/29/08 12 AM

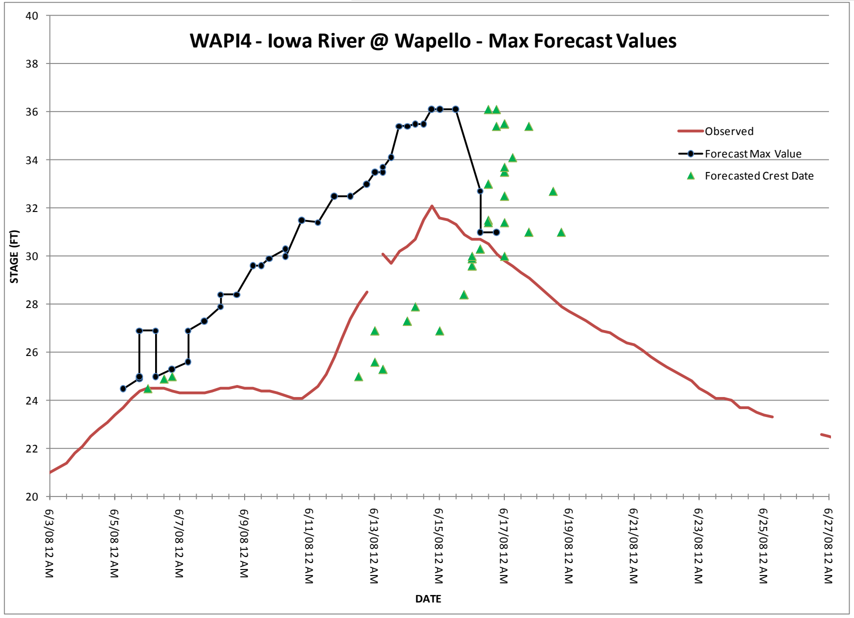

LNTI4 - Iowa River @ Lone Tree - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
4
3
2
1
0
-1
-2
-3
-4
-5
-6
0.25
1.00
2.00
3.00
4.00
5.00
6.00
6.75
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
C R E S T
Relative error of 7-day forecast (in increments of 1- day) issued on day X

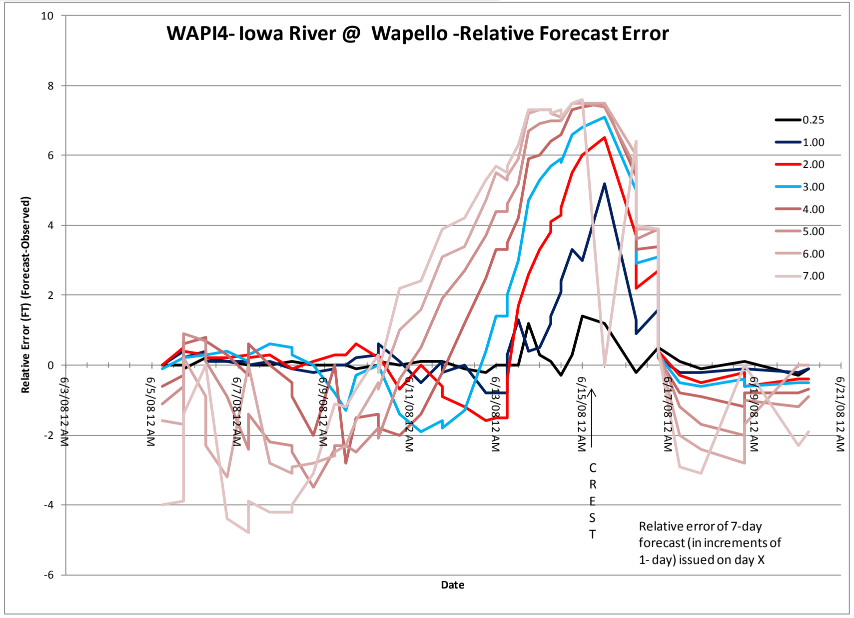

CJTI4 - IOWA RIVER @ COLUMBUS JUNCTION
STAGE (FT)
DATE
38
36
34
32
30
28
26
24
22
20
18
6/4/08
6/6/08
6/8/08
6/10/08
6/12/08
6/14/08
6/16/08
6/18/08
6/20/08
6/22/08
6/24/08
6/26/08
6/28/08
Observed Stage
FF-5-1
FF-5-2
FF-5-3
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-6-4
FF-7-1
FF-7-2
FF-7-3
FF-7-4
FF-7-5
FF-8-1
FF-8-10
FF-8-11
FF-8-8
FF-8-9
FF-9-1
FF-9-2
FF-9-3
FF-9-5
FF-9-6
FF-10-1
FF-10-2
FF-10-3
FF-10-4
FF-10-8
FF-11-1
FF-11-4
FF-12-1
FF-12-2
FF-12-4
FF-12-5
FF-12-7
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-13-5
FF-14-1
FF-14-2
FF-14-3
FF-14-5
FF-14-6
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-16-3
FF-16-4
FF-17-1
FF-17-2
FF-17-3
FF-18-1
FF-18-2
FF-18-3
FF-19-1
FF-20-1
FF-20-2

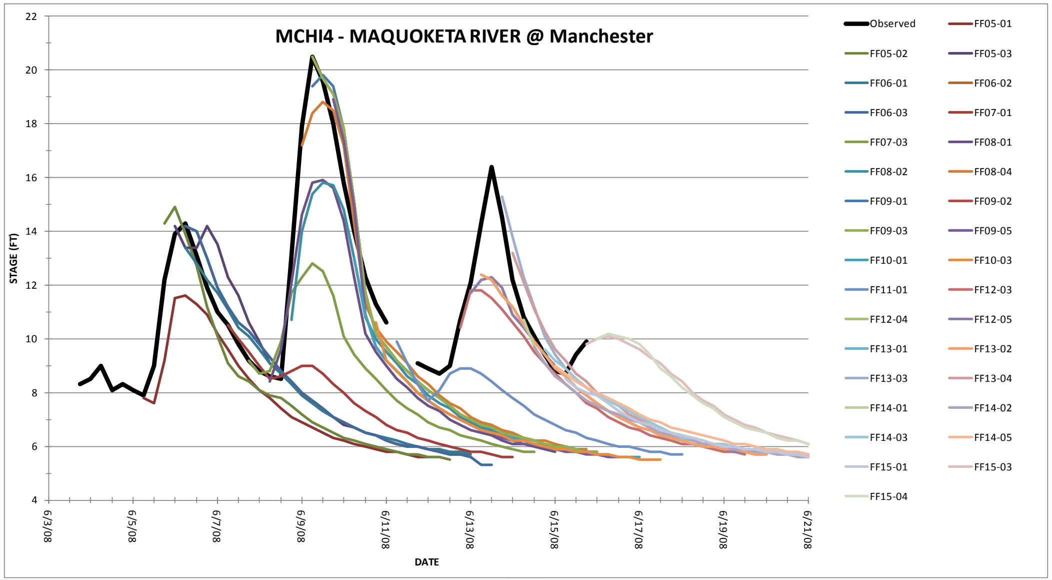

CJTI4 - Iowa River @ Columbus Junction - Max Forecast Values
STAGE (FT)
DATE
37
35
33
31
29
27
25
23
21
19
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
6/29/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

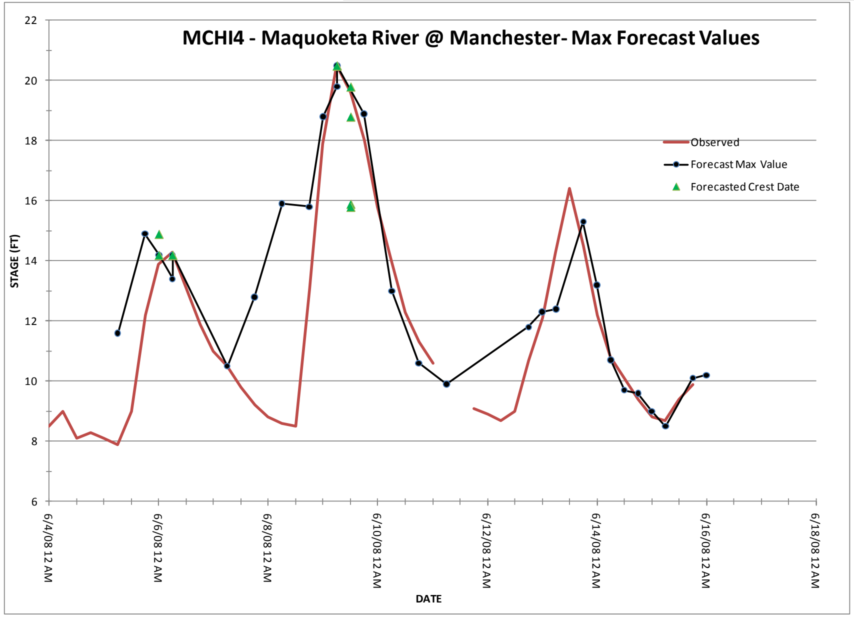

CJTI4 - Iowa River @ Columbus Junction Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
6
4
2
0
-2
-4
-6
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
0.25
1.00
2.00
3.00
4.00
5.00
6.00
6.75
C
R
E
S
T
Relative error of 7-day forecast (in increments of 1- day) issued on day X

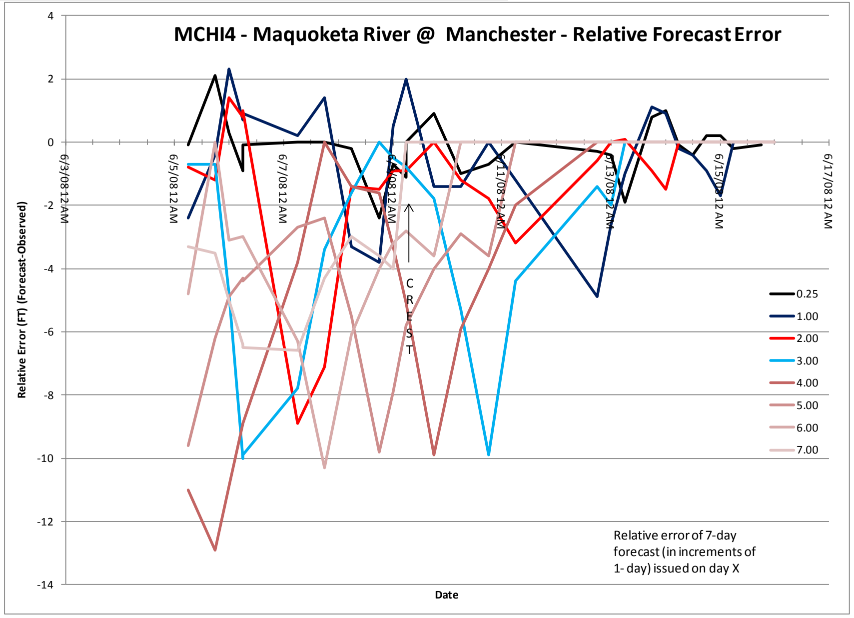

WAPI4 - IOWA RIVER @ WAPELLO
STAGE (FT)
38
36
34
32
30
28
26
24
22
20
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
6/27/08
6/29/08
DATE
Observed Stage
FF-5-1
FF-5-2
FF-5-3
FF-5-4
FF-6-1
FF-6-2
FF-6-3
FF-6-4
FF-7-1
FF-7-2
FF-7-3
FF-7-4
FF-7-5
FF-8-1
FF-8-10
FF-8-11
FF-8-2
FF-8-3
FF-8-4
FF-8-5
FF-8-6
FF-8-7
FF-8-8
FF-8-9
FF-9-1
FF-9-2
FF-9-3
FF-9-5
FF-9-6
FF-10-1
FF-10-2
FF-10-3
FF-10-4
FF-10-8
FF-11-1
FF-11-2
FF-11-4
FF-12-1
FF-12-2
FF-12-4
FF-12-5
FF-12-7
FF-12-8
FF-13-1
FF-13-2
FF-13-3
FF-13-4
FF-13-5
FF-14-1
FF-14-2
FF-14-3
FF-14-4
FF-14-5
FF-14-6
FF-15-1
FF-15-2
FF-16-1
FF-16-2
FF-16-3
FF-16-4
FF-17-1
FF-17-2
FF-17-3
FF-18-1
FF-18-2
FF-18-3
FF-19-1
FF-20-1
FF-20-2

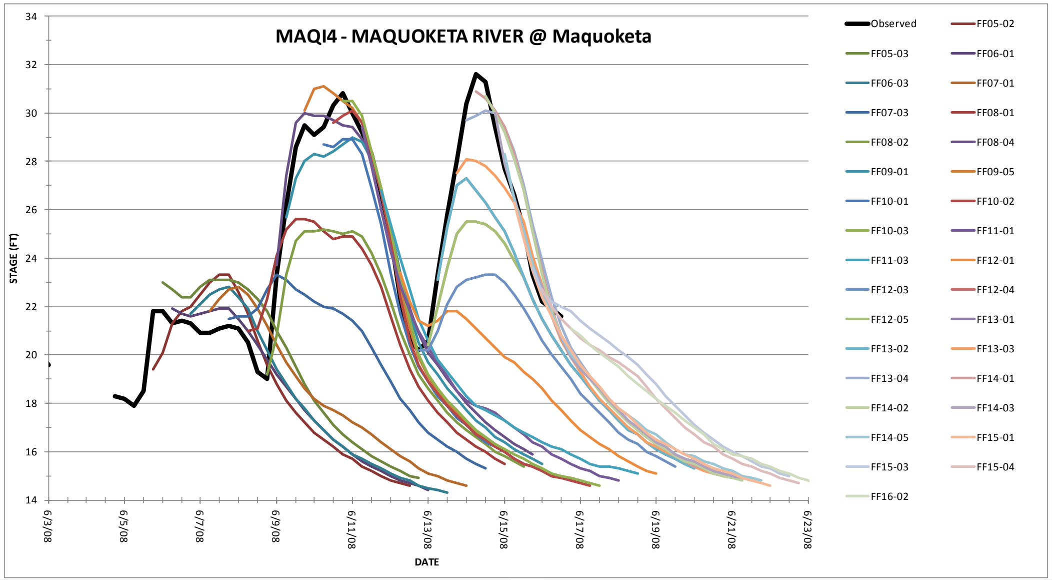

WAPI4 - Iowa River @ Wapello - Max Forecast Values
STAGE (FT)
40
38
36
34
32
30
28
26
24
22
20
Observed
Forecast Max Value
Forecasted Crest Date
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
DATE

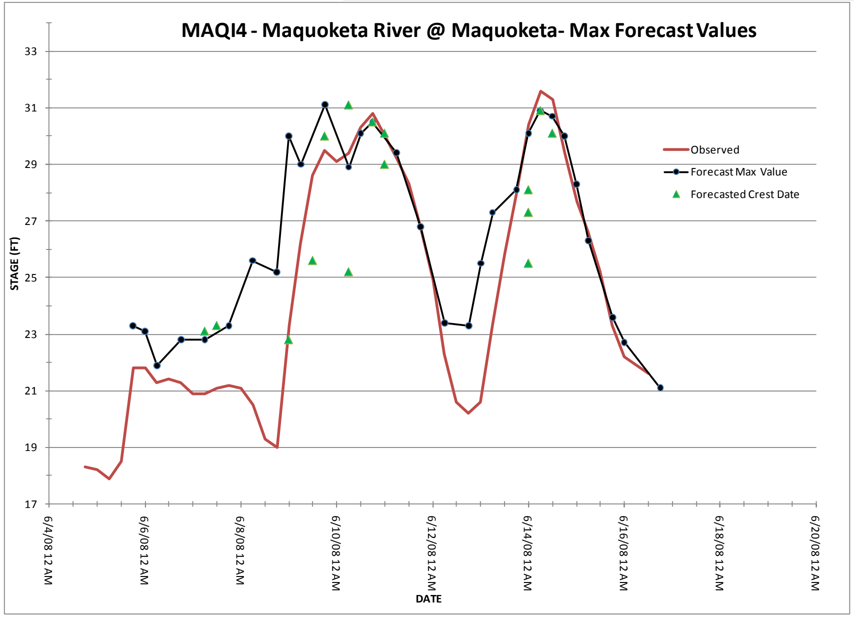

WAPI4- Iowa River @ Wapello -Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
10
8
6
4
2
0
-2
-4
-6
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
C
R
E
S
T
Relative error of 7-day
forecast (in increments of
1- day) issued on day X
Date

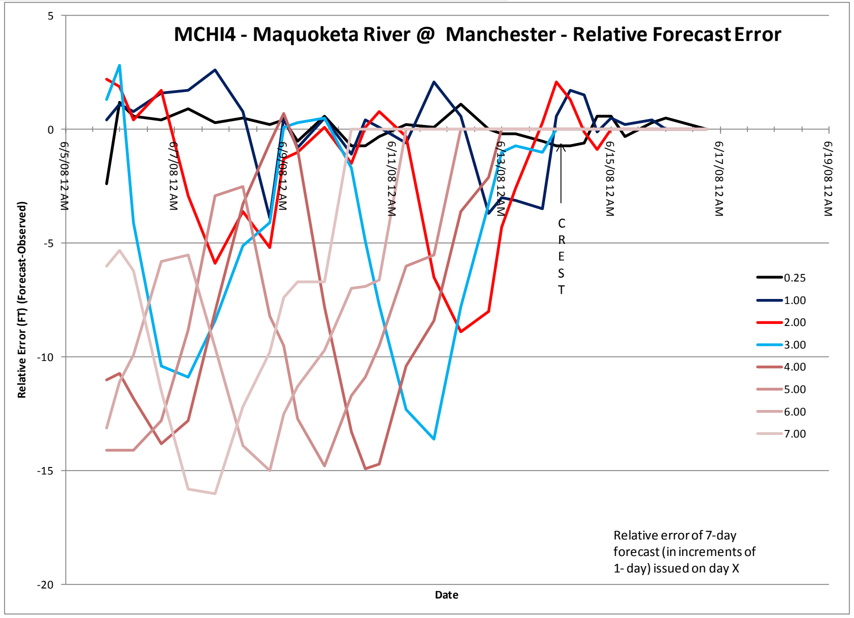

MCHI4 - MAQUOKETA RIVER @ Manchester
STAGE (FT)
22
20
18
16
14
12
10
8
6
4
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
DATE
Observed
FF05-01
FF05-02
FF05-03
FF06-01
FF06-02
FF06-03
FF07-01
FF07-03
FF08-01
FF08-02
FF08-04
FF09-01
FF09-02
FF09-03
FF09-05
FF10-01
FF10-03
FF11-01
FF12-03
FF12-04
FF12-05
FF13-01
FF13-02
FF13-03
FF13-04
FF14-01
FF14-02
FF14-03
FF14-05
FF15-01
FF15-03
FF15-04

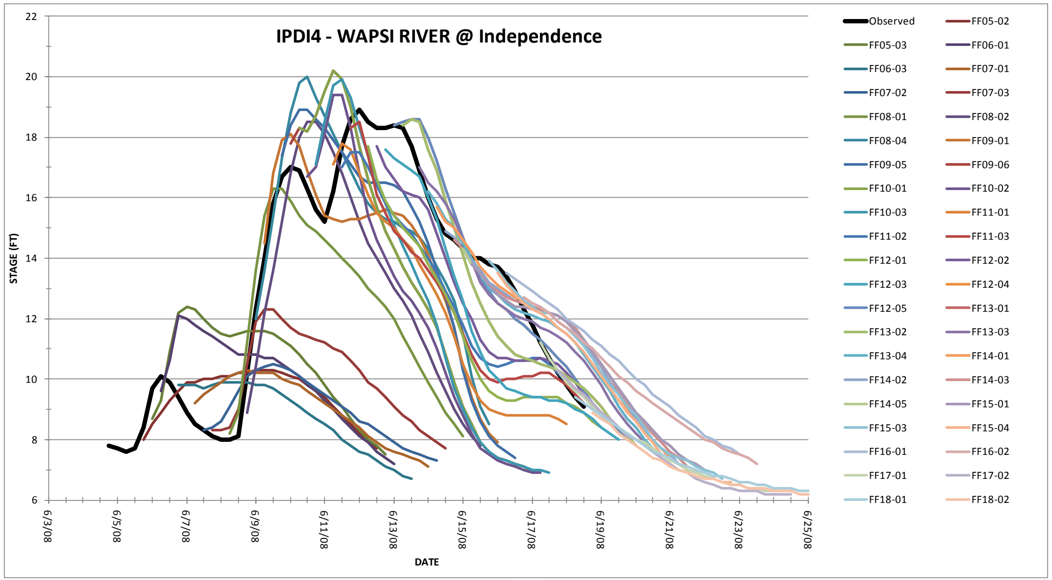

MCHI4 - Maquoketa River @ Manchester- Max Forecast Values
STAGE (FT)
22
20
18
16
14
12
10
8
6
6/4/08 12 AM
6/6/08 12 AM
6/8/08 12 AM
6/10/08 12 AM
6/12/08 12 AM
6/14/08 12 AM
6/16/08 12 AM
6/18/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date


MCHI4 - Maquoketa River @ Manchester - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
4
2
0
-2
-4
-6
-8
-10
-12
-14
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
Date
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X


MAQI4 - MAQUOKETA RIVER @ Maquoketa
STAGE (FT)
34
32
30
28
26
24
22
20
18
16
14
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
DATE
Observed
FF05-02
FF05-03
FF06-01
FF06-03
FF07-01
FF07-03
FF08-01
FF08-02
FF08-04
FF09-01
FF09-05
FF10-01
FF10-02
FF10-03
FF11-01
FF11-03
FF12-01
FF12-03
FF12-04
FF12-05
FF13-01
FF13-02
FF13-03
FF13-04
FF14-01
FF14-02
FF14-03
FF14-05
FF15-01
FF15-03
FF15-04
FF16-02


MAQI4 - Maquoketa River @ Maquoketa- Max Forecast Values
STAGE (FT)
33
31
29
27
25
23
21
19
17
6/4/08 12 AM
6/6/08 12 AM
6/8/08 12 AM
6/10/08 12 AM
6/12/08 12 AM
6/14/08 12 AM
6/16/08 12 AM
6/18/08 12 AM
6/20/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date


MCHI4 - Maquoketa River @ Manchester - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
5
0
-5
-10
-15
-20
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
CREST
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X
Date


IPDI4 - WAPSI RIVER @ Independence
STAGE (FT)
DATE
22
20
18
16
14
12
10
8
6
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
Observed
FF05-02
FF05-03
FF06-01
FF06-03
FF07-01
FF07-02
FF07-03
FF08-01
FF08-02
FF08-04
FF09-01
FF09-05
FF09-06
FF10-01
FF10-02
FF10-03
FF11-01
FF11-02
FF11-03
FF12-01
FF12-02
FF12-03
FF12-04
FF12-05
FF13-01
FF13-02
FF13-03
FF13-04
FF14-01
FF14-02
FF14-03
FF14-05
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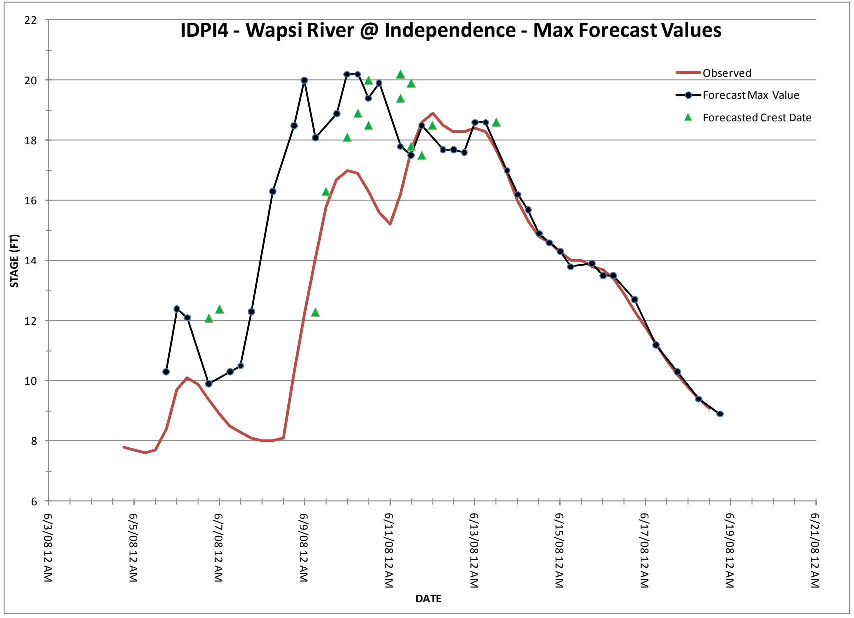
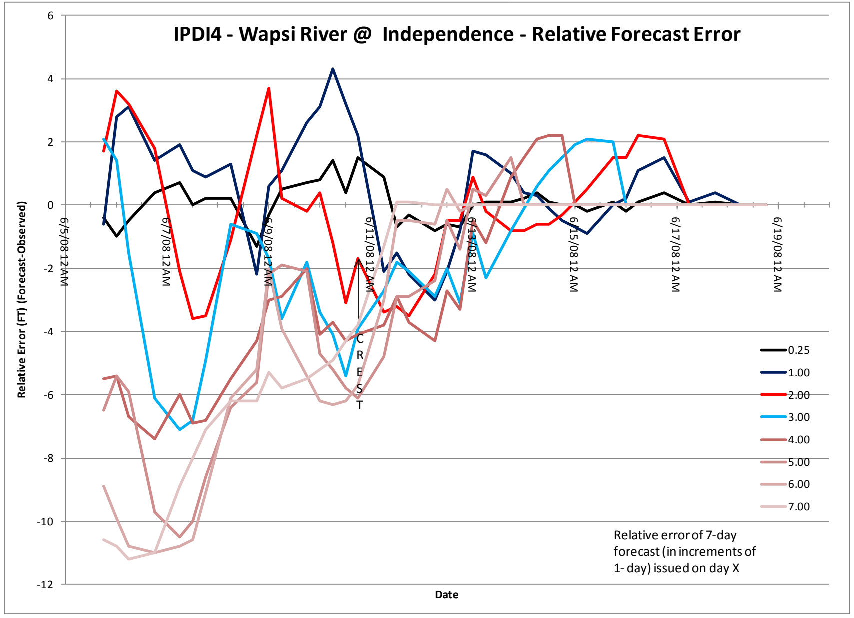
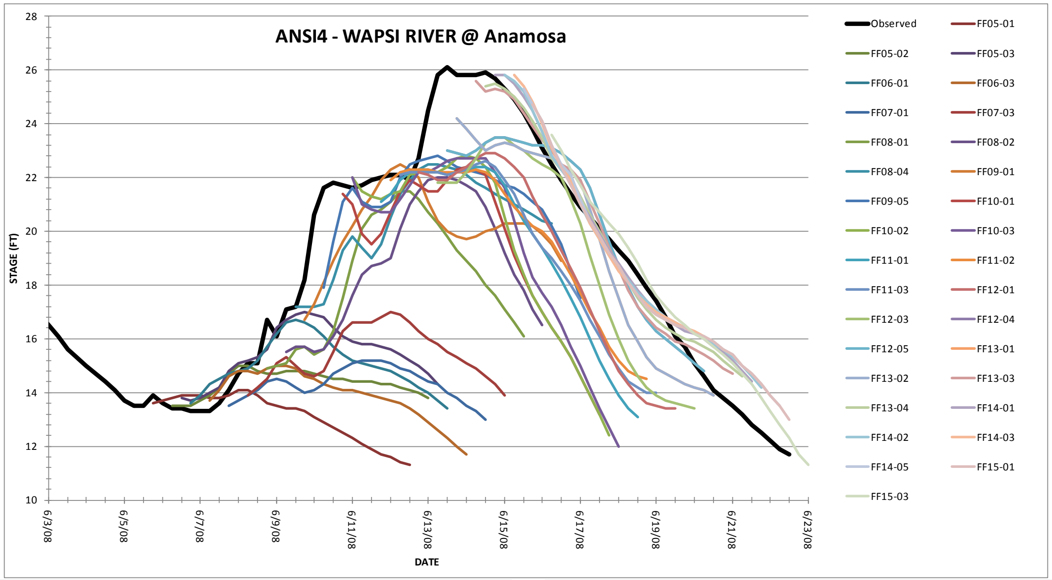
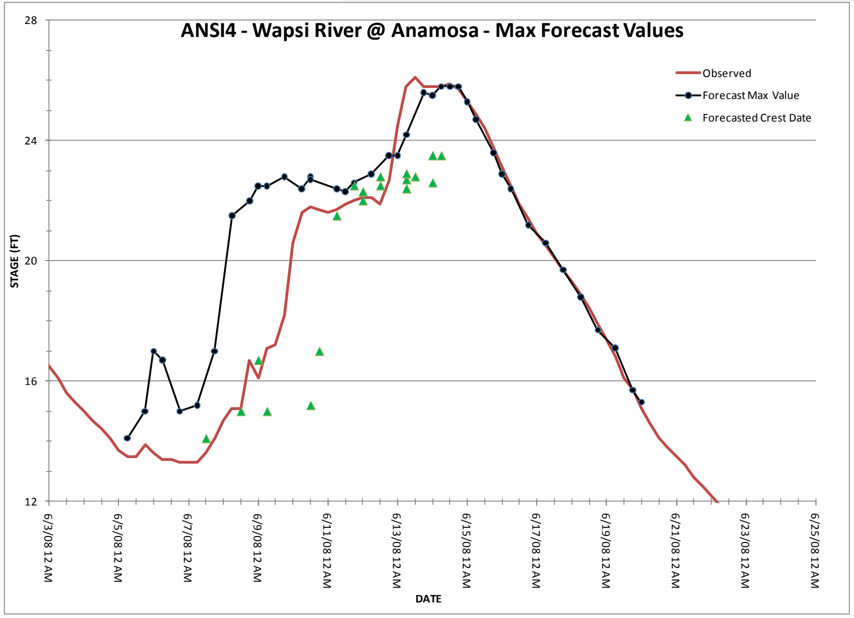
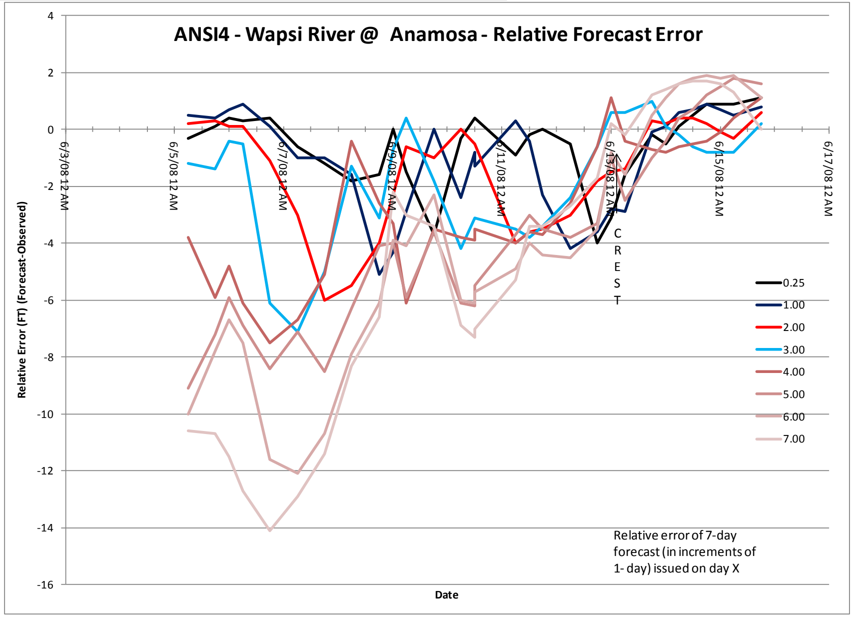
FF15-03
FF15-04
FF16-01
FF16-02
FF17-01
FF17-02
FF18-01
FF18-02

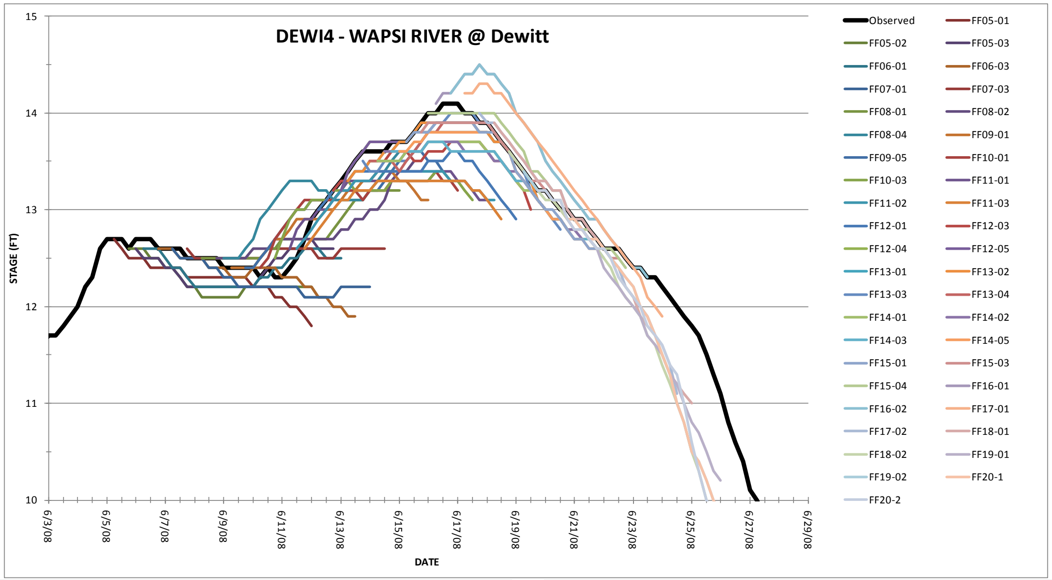

IDPI4 - Wapsi River @ Independence - Max Forecast Values
STAGE (FT)
DATE
22
20
18
16
14
12
10
8
6
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

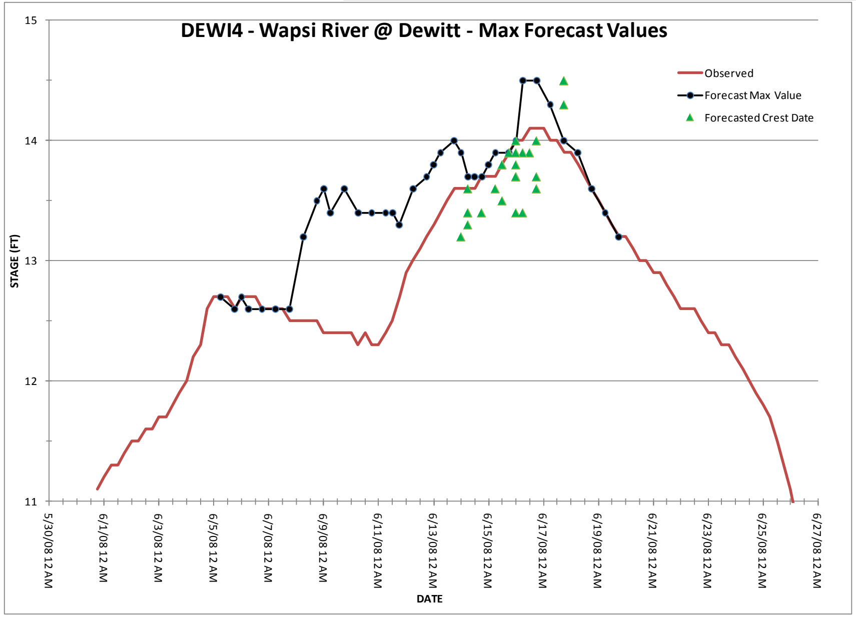

IPDI4 - Wapsi River @ Independence - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
6
4
2
0
-2
-4
-6
-8
-10
-12
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
C
R
E
S
T
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day
forecast (in increments of
1- day) issued on day X

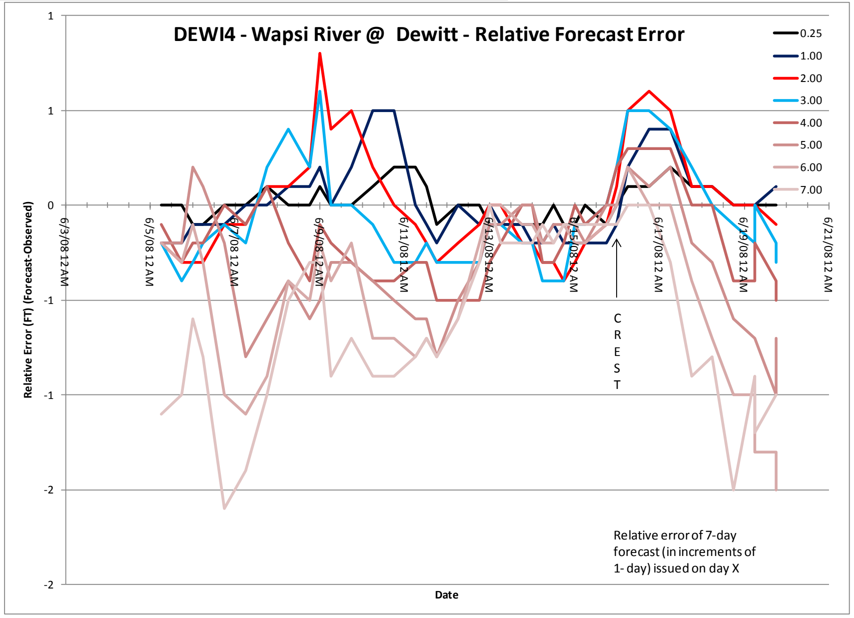

ANSI4 - WAPSI RIVER @ Anamosa
STAGE (FT)
28
26
24
22
20
18
16
14
12
10
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
DATE
Observed
FF05-01
FF05-02
FF05-03
FF06-01
FF06-03
FF07-01
FF07-03
FF08-01
FF08-02
FF08-04
FF09-01
FF09-05
FF10-01
FF10-02
FF10-03
FF11-01
FF11-02
FF11-03
FF12-01
FF12-03
FF12-04
FF12-05
FF13-01
FF13-02
FF13-03
FF13-04
FF14-01
FF14-02
FF14-03
FF14-05
FF15-01
FF15-03


ANSI4 - Wapsi River @ Anamosa - Max Forecast Values
STAGE (FT)
28
24
20
16
12
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
DATE
Observed
Forecast Max Value
Forecasted Crest Date

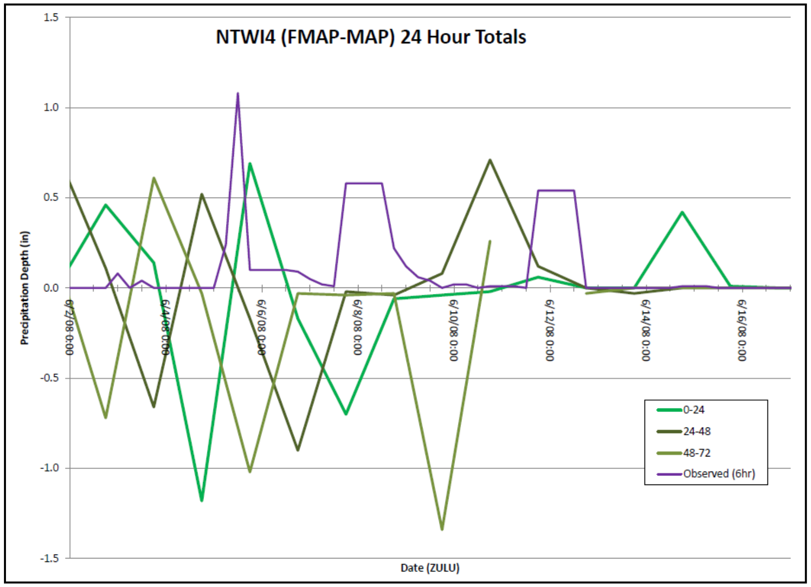

ANSI4 - Wapsi River @ Anamosa - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
C
R
E
S
T
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
Relative error of 7-day forecast (in increments of 1- day) issued on day X
Date

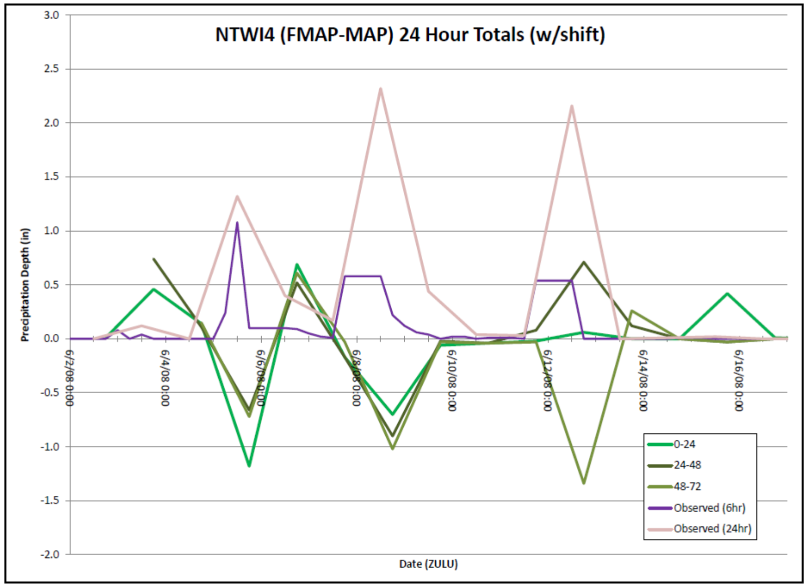

DEWI4 - WAPSI RIVER @ Dewitt
STAGE (FT)
DATE
15
14
13
12
11
10
6/3/08
6/5/08
6/7/08
6/9/08
6/11/08
6/13/08
6/15/08
6/17/08
6/19/08
6/21/08
6/23/08
6/25/08
6/27/08
6/29/08
Observed
FF05-01
FF05-02
FF05-03
FF06-01
FF06-03
FF07-01
FF07-03
FF08-01
FF08-02
FF08-04
FF09-01
FF09-05
FF10-01
FF10-03
FF11-01
FF11-02
FF11-03
FF12-01
FF12-03
FF12-04
FF12-05
FF13-01
FF13-02
FF13-03
FF13-04
FF14-01
FF14-02
FF14-03
FF14-05
FF15-01
FF15-03
FF15-04
FF16-01
FF16-02
FF17-01
FF17-02
FF18-01
FF18-02
FF19-01
FF19-02
FF20-1
FF20-2

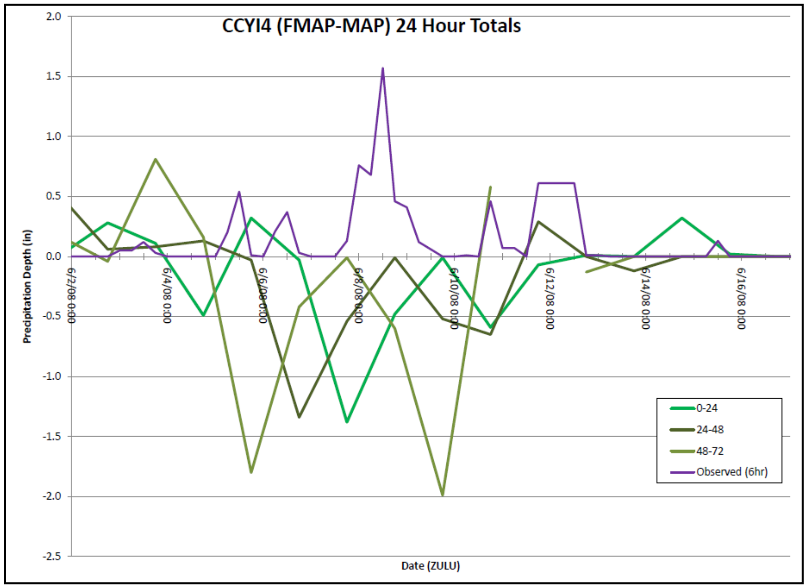

DEWI4 - Wapsi River @ Dewitt - Max Forecast Values
STAGE (FT)
DATE
15
14
13
12
11
5/30/08 12 AM
6/1/08 12 AM
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
6/23/08 12 AM
6/25/08 12 AM
6/27/08 12 AM
Observed
Forecast Max Value
Forecasted Crest Date

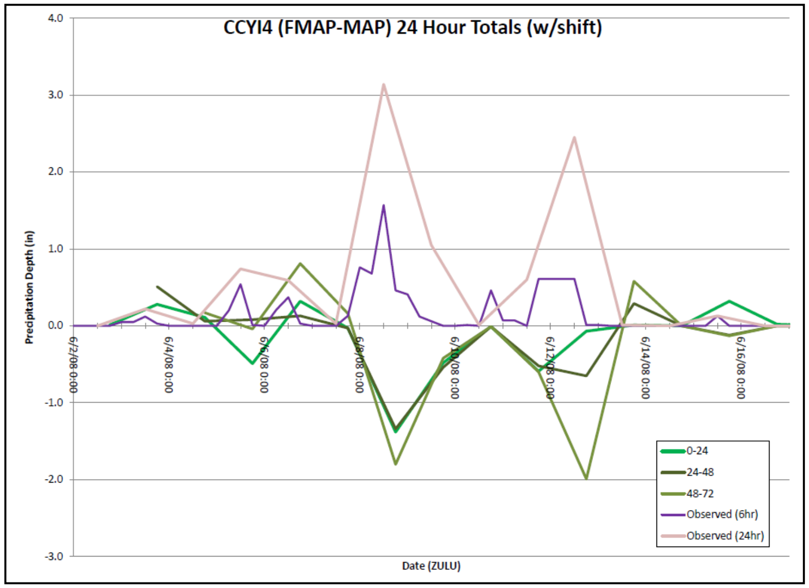

DEWI4 - Wapsi River @ Dewitt - Relative Forecast Error
Relative Error (FT) (Forecast-Observed)
Date
1
1
0
-1
-1
-2
-2
6/3/08 12 AM
6/5/08 12 AM
6/7/08 12 AM
6/9/08 12 AM
6/11/08 12 AM
6/13/08 12 AM
6/15/08 12 AM
6/17/08 12 AM
6/19/08 12 AM
6/21/08 12 AM
0.25
1.00
2.00
3.00
4.00
5.00
6.00
7.00
C
R
E
S
T
Relative error of 7-day forecast (in increments of 1- day) issued on day X

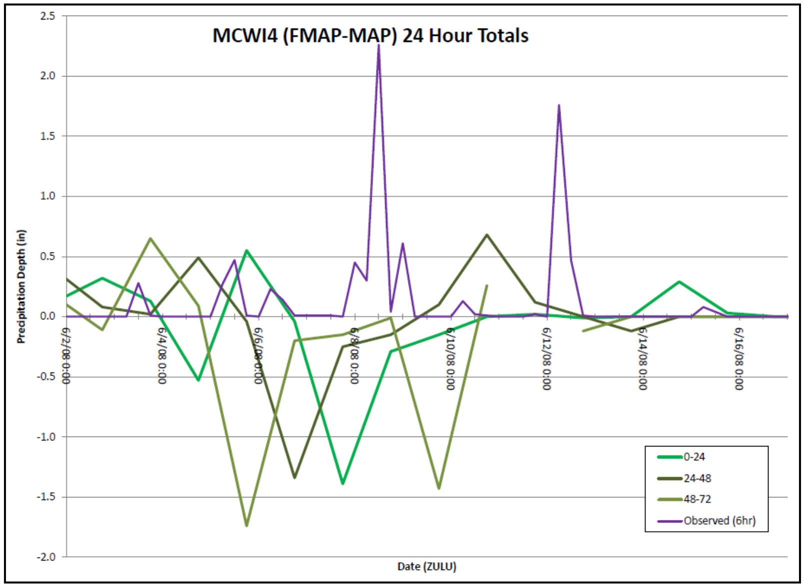
APPENDIX B
PRECIPITATION FORECAST ANALYSIS FIGURES

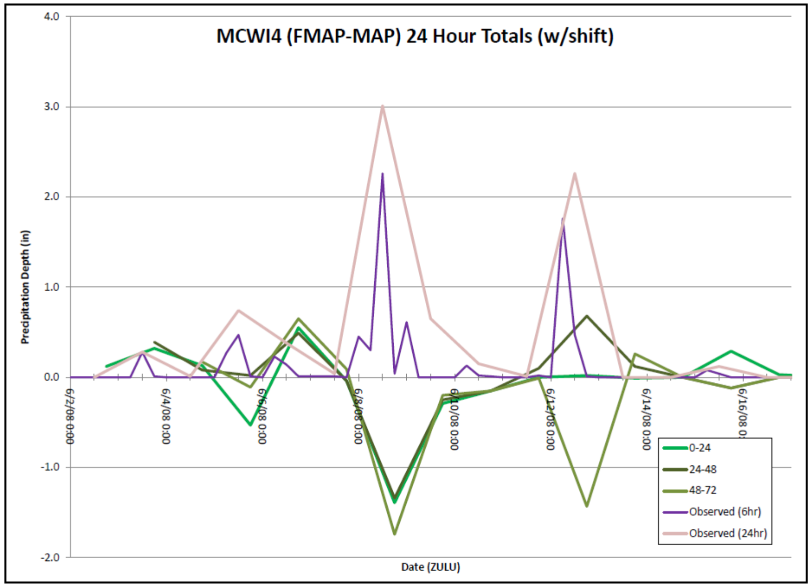

NTWI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

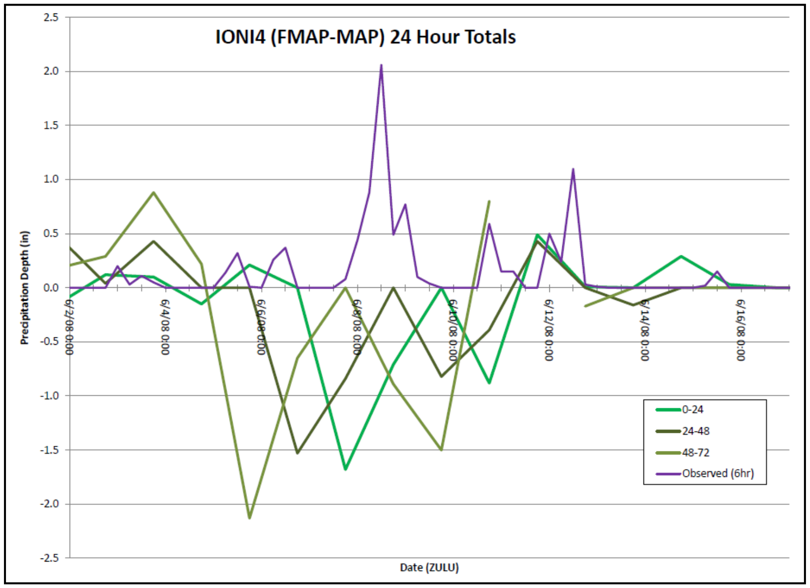

NTWI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)

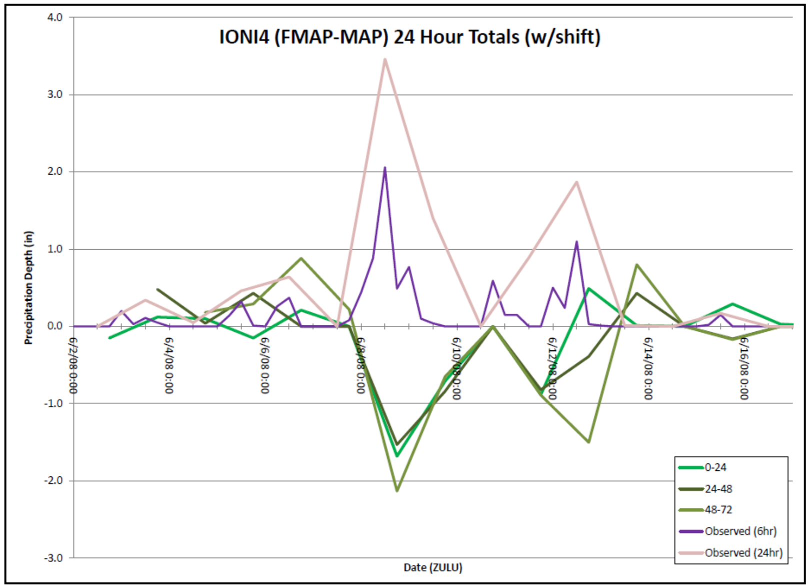

CCYI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

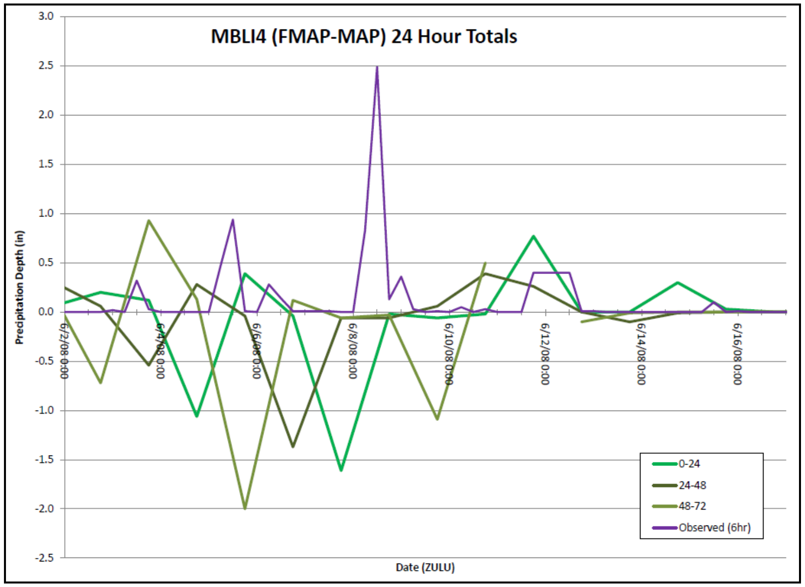

CCYI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)

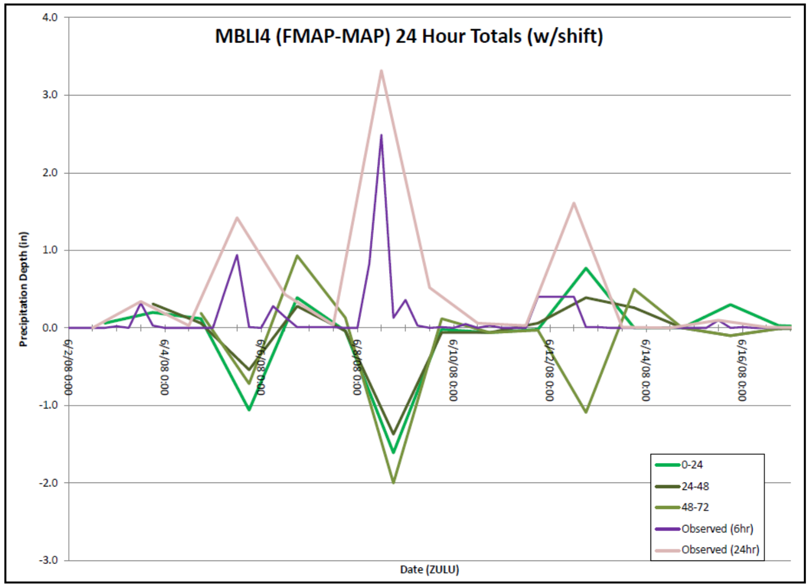

MCWI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

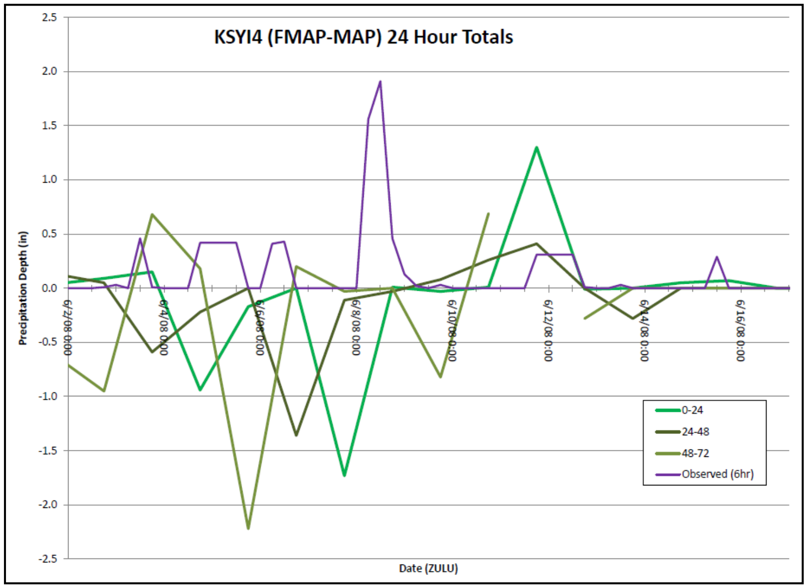

MCWI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)

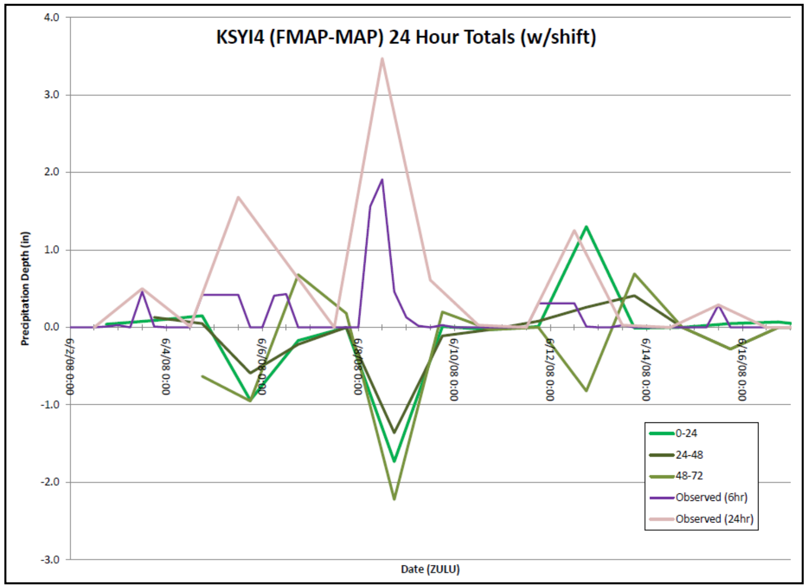

IONI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

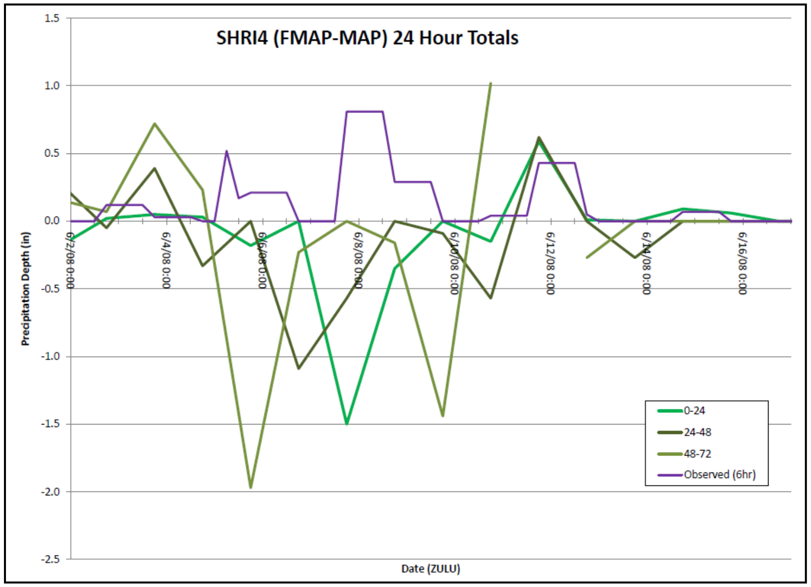

IONI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)

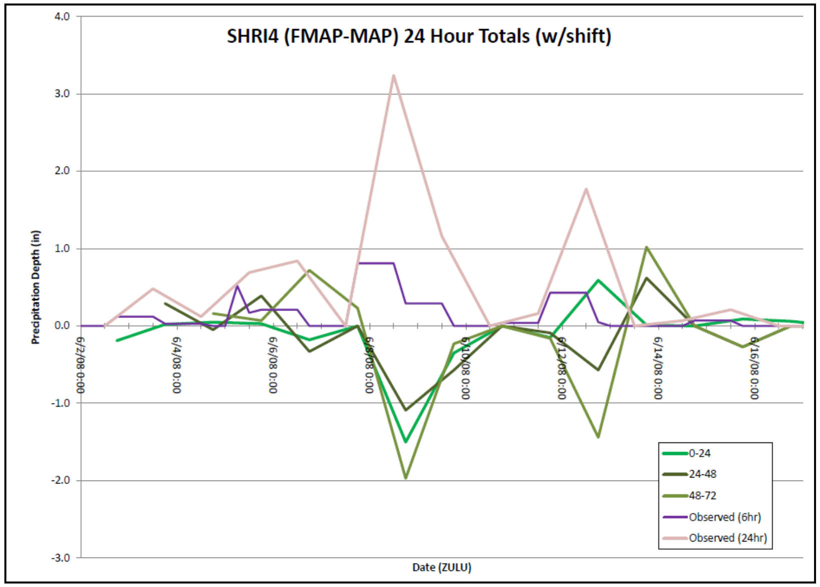

MBLI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

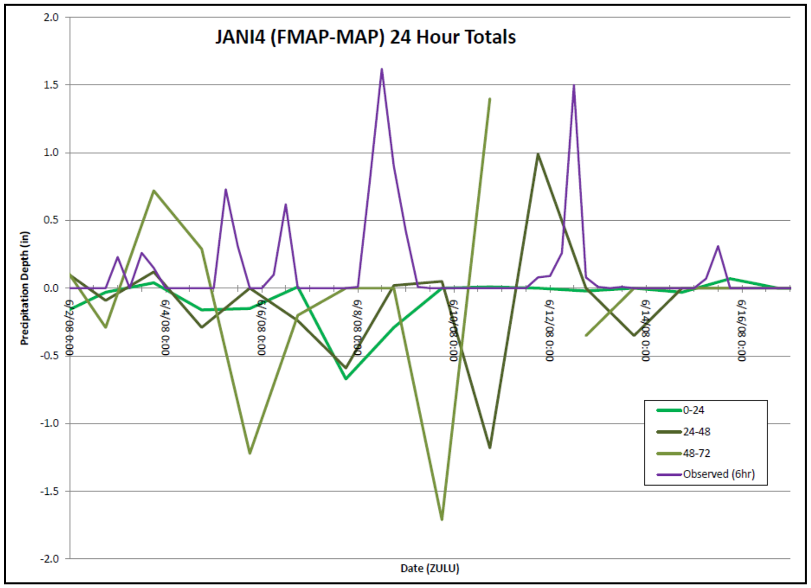

MBLI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)


KSYI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)


KSYI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)


SHRI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)


SHRI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)


JANI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
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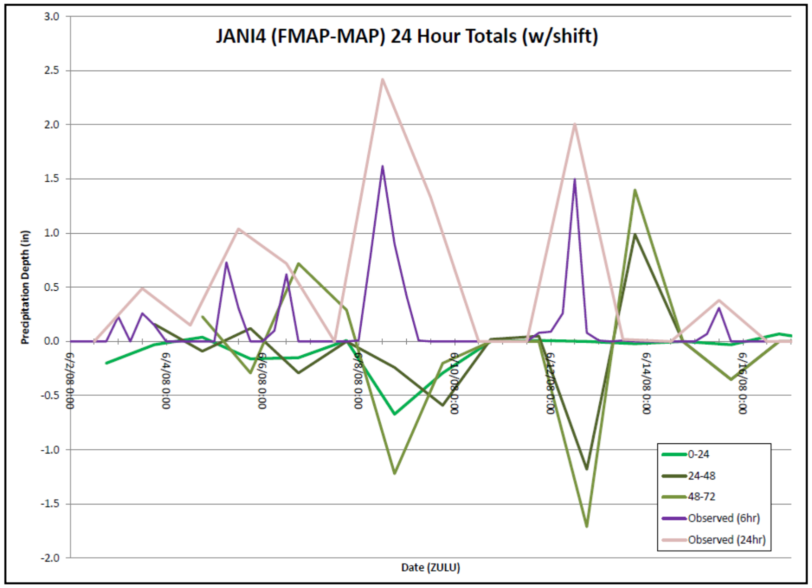
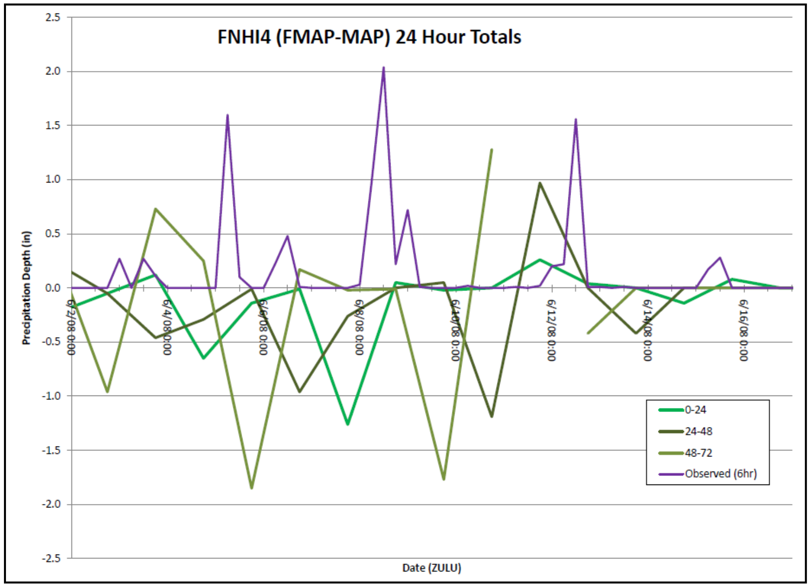
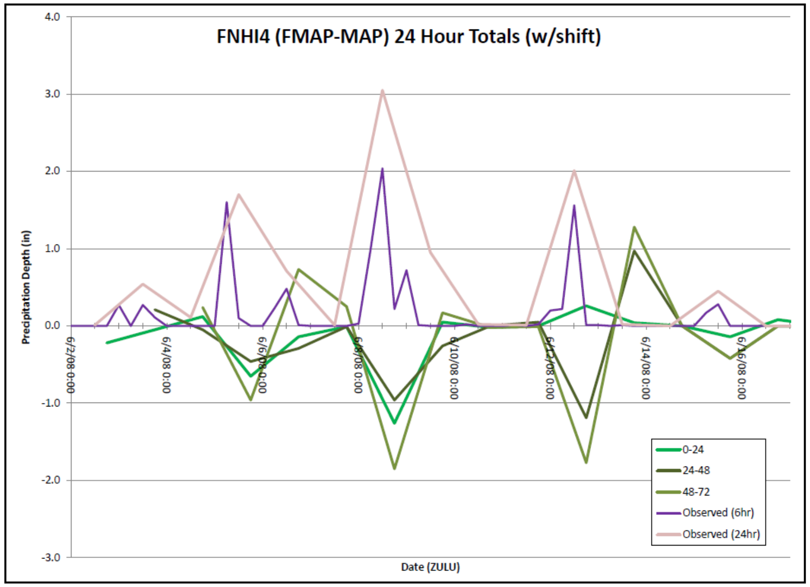
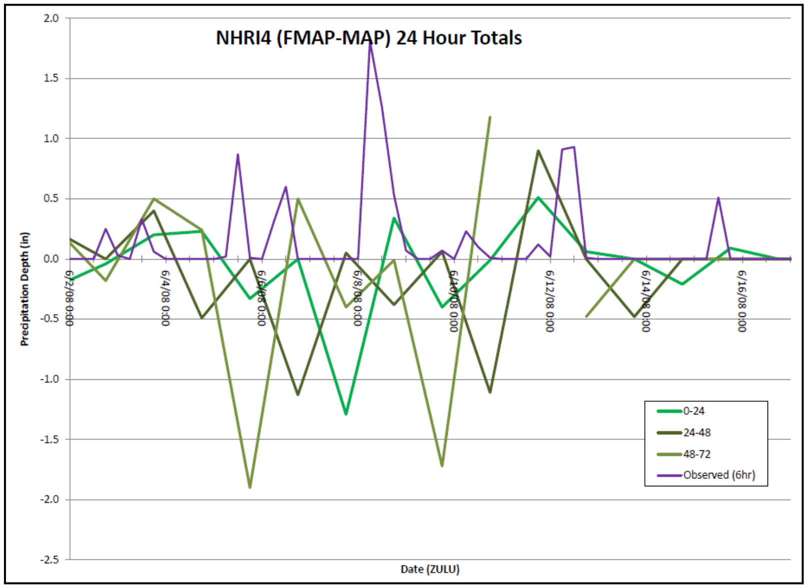
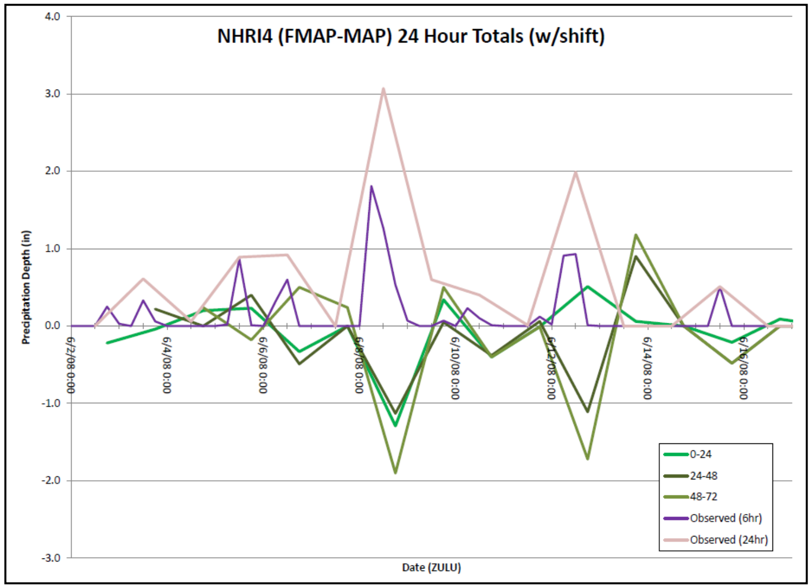
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

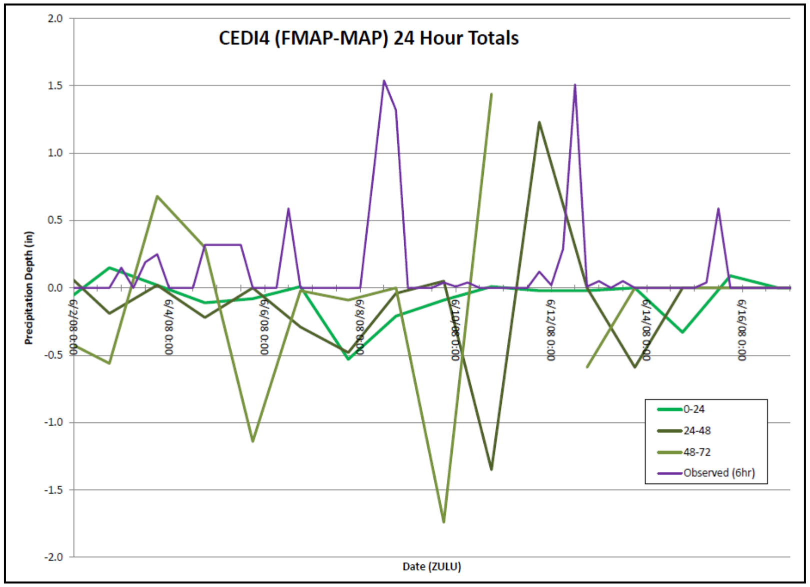

JANI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)

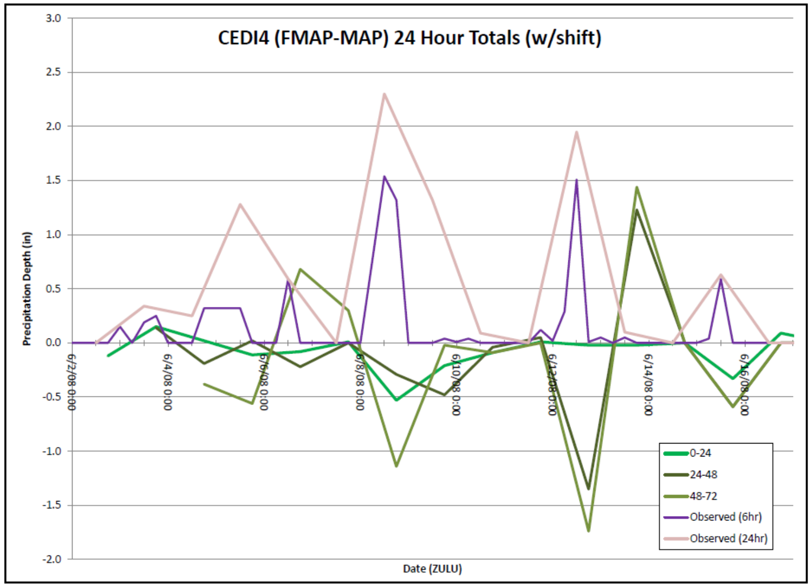

FNHI4 (FMAP-MAP) 24 Hour Totals

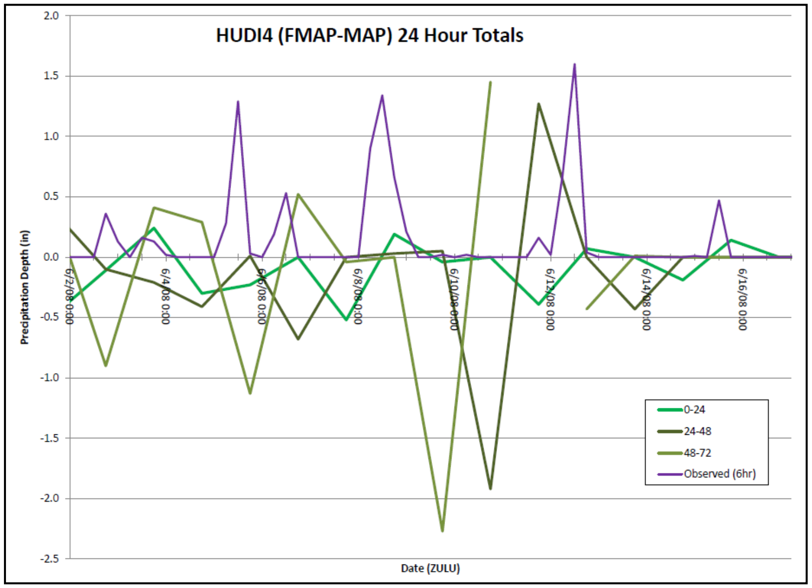

FNHI4 (FMAP-MAP) 24 Hour Totals (w/shift)

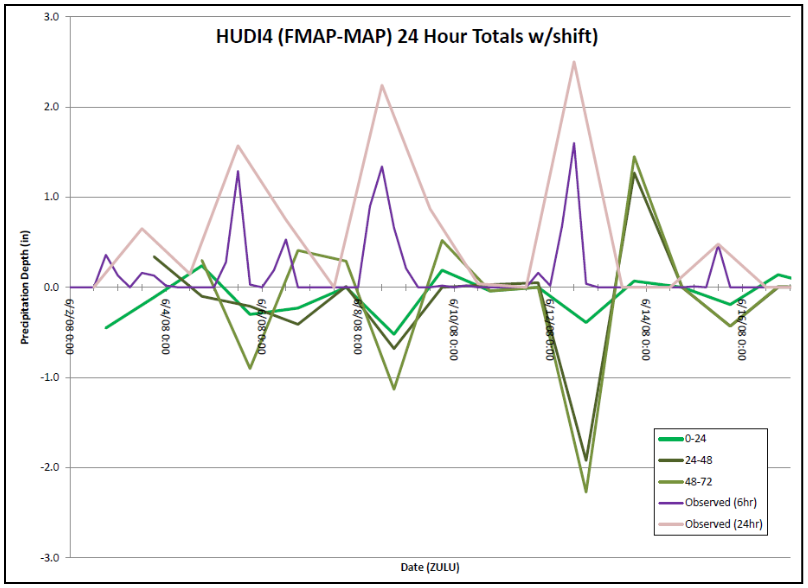

NHRI4 (FMAP-MAP) 24 Hour Totals

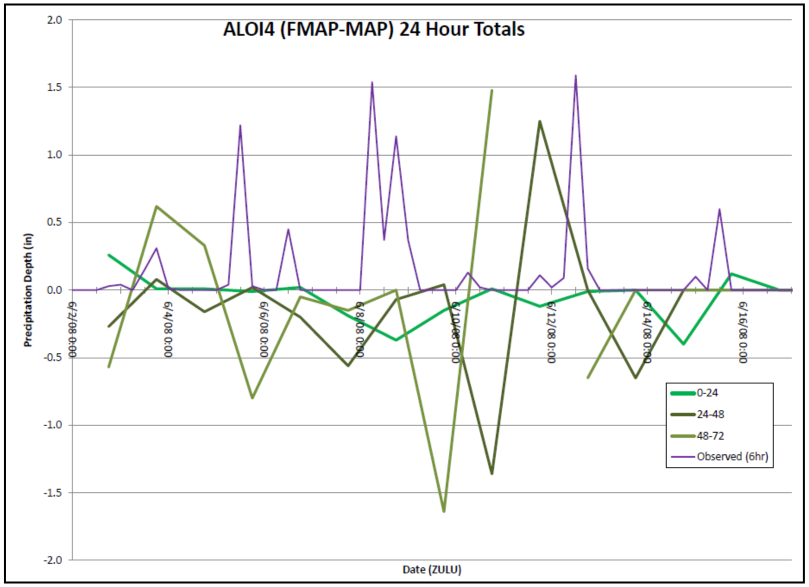

NHRI4 (FMAP-MAP) 24 Hour Totals (w/shift)

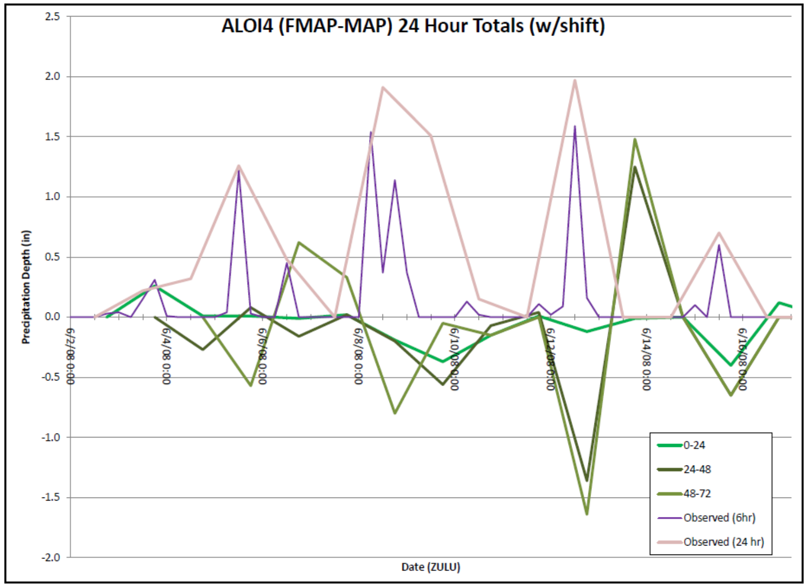

CEDI4 (FMAP-MAP) 24 Hour Totals

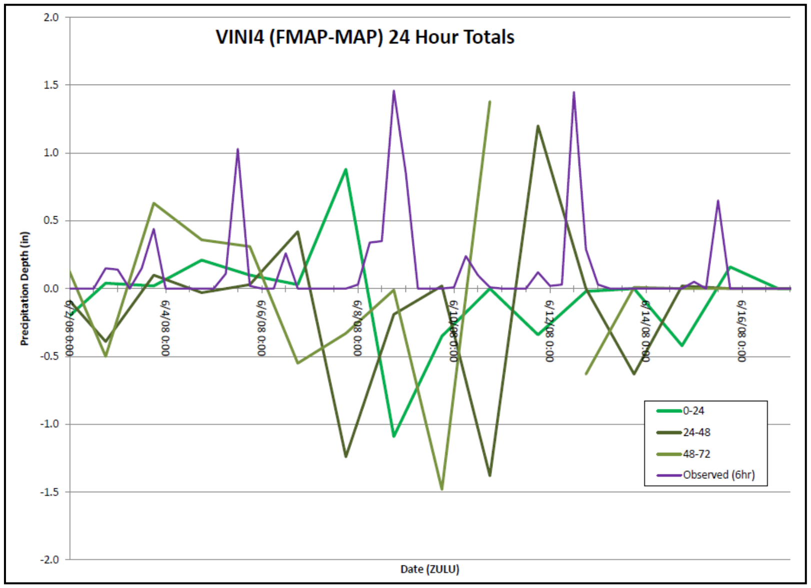

CEDI4 (FMAP-MAP) 24 Hour Totals (w/shift)

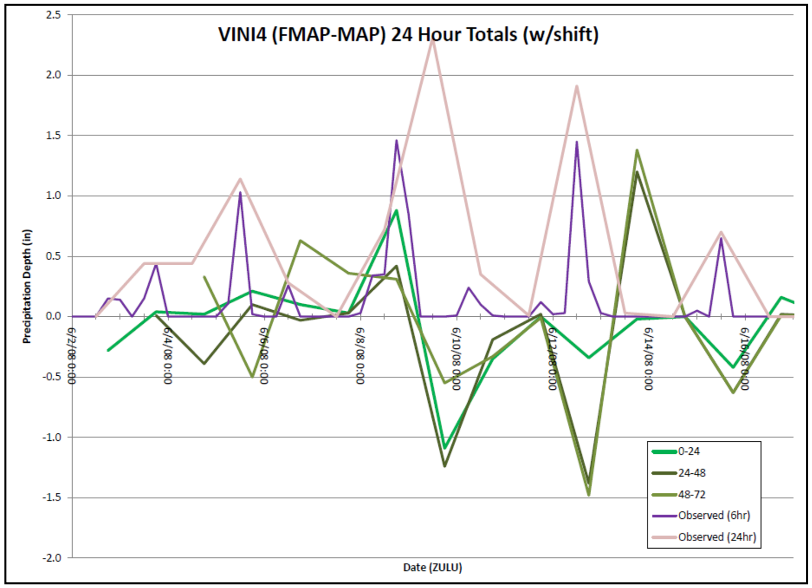

HUDI4 (FMAP-MAP) 24 Hour Totals

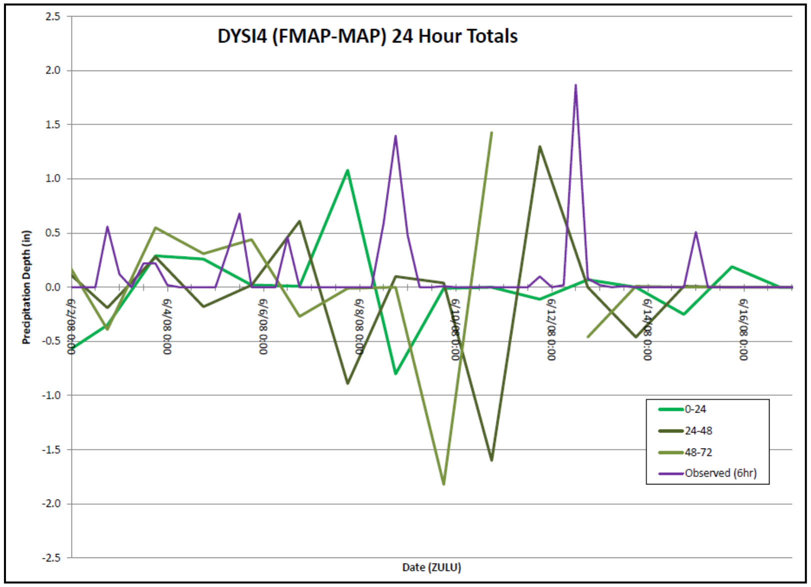

HUDI4 (FMAP-MAP) 24 Hour Totals w/shift

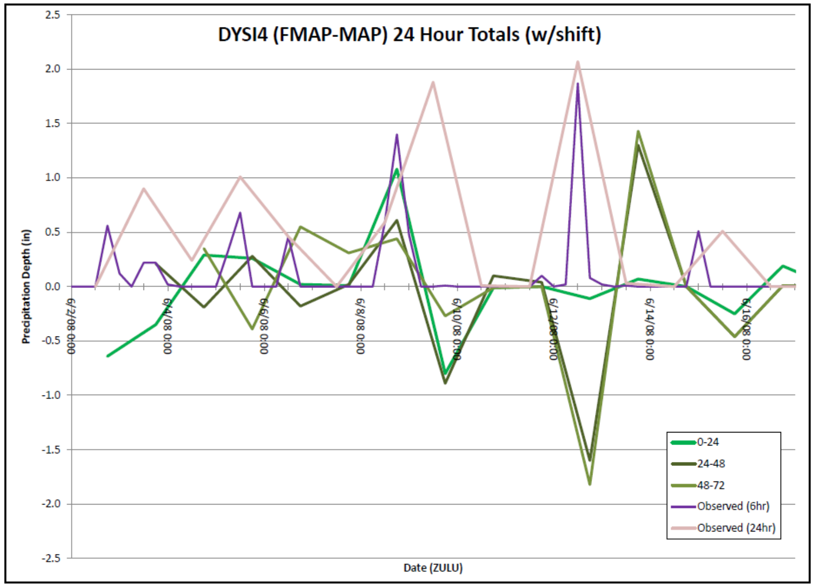

ALOI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)

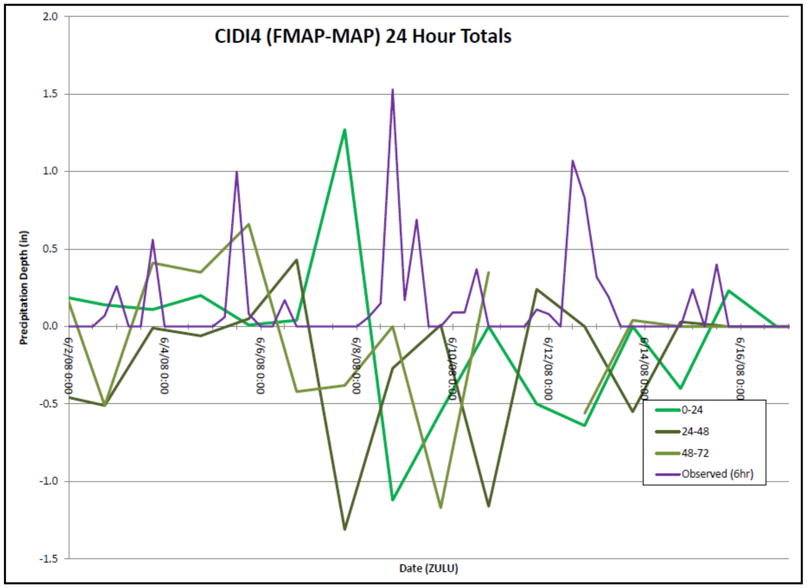

ALOI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24 hr)

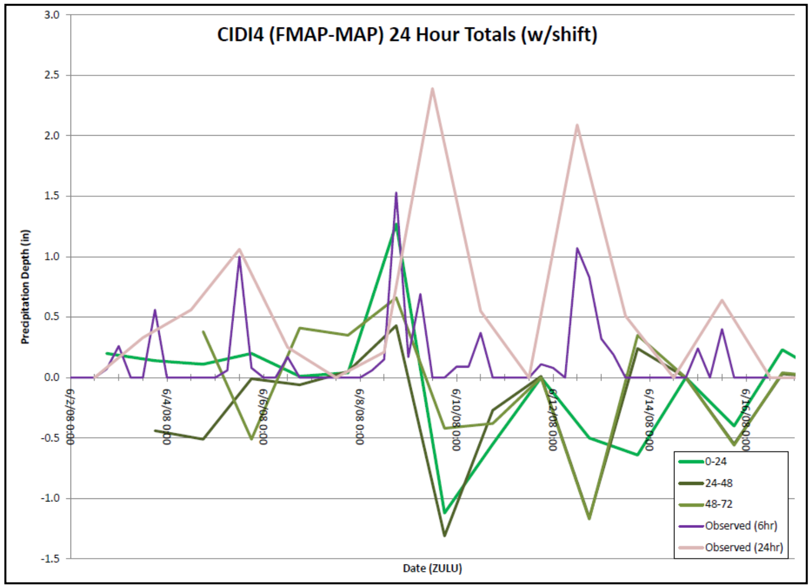

VINI4 (FMAP-MAP) 24 Hour Totals
Precipitation Depth (in)
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)


VINI4 (FMAP-MAP) 24 Hour Totals (w/shift)
Precipitation Depth (in)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
6/2/08 0:00
6/4/08 0:00
6/6/08 0:00
6/8/08 0:00
6/10/08 0:00
6/12/08 0:00
6/14/08 0:00
6/16/08 0:00
Date (ZULU)
0-24
24-48
48-72
Observed (6hr)
Observed (24hr)


DYSI4 (FMAP-MAP) 24 Hour Totals


DYSI4 (FMAP-MAP) 24 Hour Totals (w/shift)


CIDI4 (FMAP-MAP) 24 Hour Totals


CIDI4 (FMAP-MAP) 24 Hour Totals (w/shift)