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Analysis of the Sacramento Soil Moisture Accounting Model Using Variations in Precipitation Input

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ABSTRACT

Flooding is a serious risk for areas of the world that are near rivers and streams. The current operational standard in forecasting the conditions of these rivers and streams is the Sacramento Soil Moisture Assimilation model. For that reason, an accuracy analysis of the streamflow forecasts of the lumped version of the model was conducted. Many previous studies have looked at calibration of individual model components and assimilation methods, but basic accuracy and sensitivity analysis also important to consider. Different precipitation data sets were used to determine model sensitivity to precipitation inputs. Analysis was also conducted to see whether or not the sensitivity to times scales would be significant in the simulated streamflow values. Findings can be used for model correction and consideration of model biases as well as providing useful considerations when issuing flood warnings and other types of public communication.

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1. Introduction

Rainfall amounts have a very significant effect on the level and flowrates of rivers and streams all over the planet. In the event of significant rainfall, flooding can occur, causing damages to the surrounding environment, local population, and economy. It is important to be able to look at these rainfall amounts and know how they will affect the nearby streams and rivers. "Streamflow" is a term that represents a given volume of water passing through a point of the stream or river at a given instance of time. This parameter is extremely important when looking at forecasts and is what will be primarily evaluated in this study. Forecasts for parameters such as streamflow, are typically done with hydrologic models. The Sacramento soil moisture Accounting Model (SAC-SMA) is one such model and it is the current operational standard in the National Weather Service River Forecasting centers in the United States. The model is able to accurately simulate streamflow of rivers and streams using multiple parameters such as precipitation received, evaporation, temperature changes, the size of the particular watershed that a given stream or river resides in, and many other factors. Model results are important for relating the forecasts of these events and their governing physical processes with the public. Another important aspect of the model is its applicability for the information that it is using and how well it represents the physical processes used in the calculations (Singh, 1995). The analysis of the model's accuracy is important to validating its continued use in the River Forecasting offices.

There has already been some work in determining the accuracy of hydrologic models, including the SAC-SMA. A complex analysis of each of the components used in the calculations of the model to make sure that it behaves correctly according to the physics that it is based on was done for the eastern part of the United States and found that each model had some kind of parameter that proved to be dominant in the overall calculation of important hydrologic variables such as stream flow and height levels (Herman et. al. 2013). This is important to look at because an inaccurate sensitivity to a particular variable can lead to misleading forecasts that, if used in a briefing or discussion, can negatively affect the public.

Another aspect of hydrologic modeling that needs to be taken into consideration when assessing the accuracy is the data assimilation method. A problematic area for hydrologic models is the areas where the streamflow data is either inaccurate, or nonexistent. Data assimilation helps to get past these problem areas by merging the inaccurate or unreliable data in order to achieve a better representation of the model state (Samuel, 2014). These assimilations lead to more accurate model results and therefore better forecasts. Model analysis using the SAC-SMA was done for area in Ontario, Canada and found that the data assimilation of only soil moisture was lacking in accurate streamflow data, and similarly, the assimilation of only streamflow data had inaccurate soil moisture parameters. When the two were combined, it provided a compensation that made the overall model forecast much more accurate (Samuel et. al. 2014). Another area of data assimilation of the models that has been looked into is the constraints that are applied to it. A weakly constrained data assimilation approach was used with the lumped version of the SAC-SMA in a number of river basins in Texas in an attempt to account for the structural inadequacies in the SAC-SMA and its rainfall runoff estimates. It found that the inclusion of this data assimilation method produced a smaller Root mean square error in the results. It is clear that accuracy analyses such as these are necessary to continue to improve model performance.

One last method that can be used to assess the accuracy of models is the method of verification. The current methods of hydrologic model verification are somewhat out of date, and a newer method of verification should be implemented. The current method of analyzing model output is by essentially applying biases and other error source to the mean of the model output. (Franz and Houge, 2011). This allows for much more inaccuracy than should be allowed. By taking a series of probabilistic streamflow forecasts, then averaging those results, and then applying some other kind of correctional measure, the range of probability in increased by a tremendous amount. A more accurate result could be obtained by instead analyzing which of the outputs has the highest probability, based on observations. (Franz and Houge, 2011).

2. Methods

Despite all of these methods used to assess model accuracy, the geographic location of each being as diverse as it is leaves some regions in the dark, with little to no testing specifically for that area. Because of these variations, this study will look at an area of the Midwest United States, which is area prone to severe flooding. Another aspect of these studies that needs to be addressed is considering the variations in precipitation inputs, and how that effects the output of the model. These conditions are what will be analyzed in this study.

a.) Location

The site looked at in this study was the south skunk river at Ames, IA (Figure 1). Areas in Iowa and other parts of the Midwest along major rivers have been known to experience serious flooding in the event of heavy rainfall. By using this site as the test location is it hoped that the results can then be applied to the surrounding areas in order to help mitigate against flooding in the future by having a more accurate model projection of the state of the rivers and streams.

b.) Input data

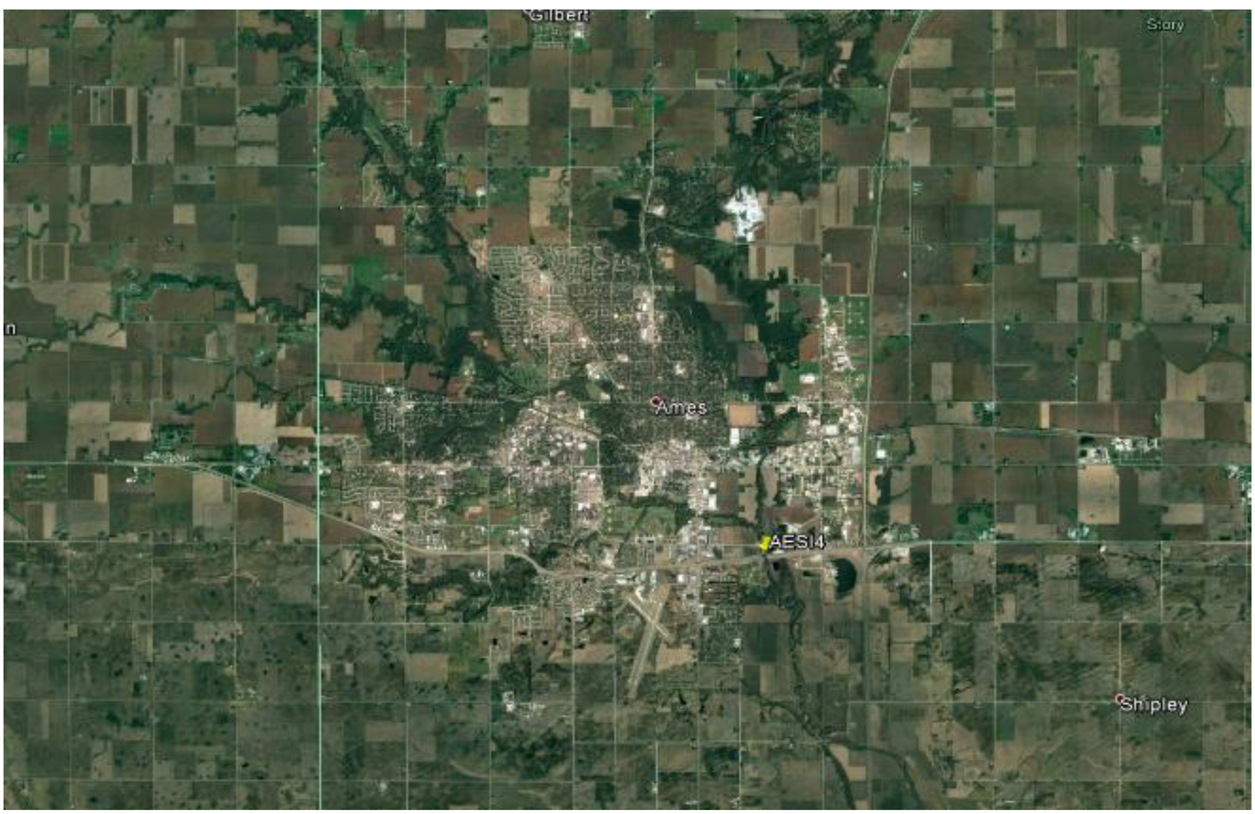


Figure 1: The site looked at was South Skunk River Near Ames, IA. The streamflow data for the site was taken from the USGS stream gage information located at the site marked AES14 and compared with the simulations.

In order to perform an assessment of the accuracy of the model, variations in precipitation input are necessary. Typical runs of the SAC-SMA include a file that contains six hour intervals of precipitation, temperature, and evaporation for the station specified. The baseline precipitation for the file is the mean area precipitation from the national river forecasting center. This particular data was calibrated from observed stage data and observations taken at Automated Surface Observing Stations and Automated Weather Observing Stations (ASOS/AWOS). Hourly precipitation data was obtained from the National Oceanic and Atmospheric Administration's National Climatic Data Center for comparison of not only source, abut also time scale. The data was taken for multiple rainfall events that occurred over Ames, IA from 2003 to 2008. In order to produce a significant amount of simulated streamflow for evaluation, all of these events were required to produce a minimum rainfall amount of 1.5 inches or more. This amount guarantees that at least some measurable amount of streamflow

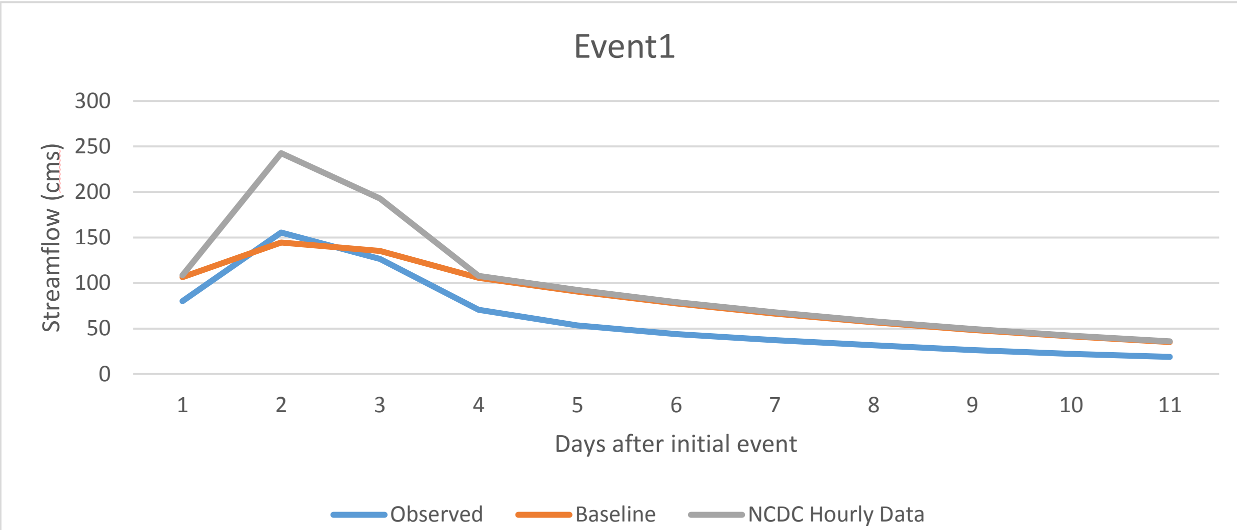
Figure 2: The Data from the NCDC is shown alongside the Mean areal precipitation data to show the adjustments necessary for input of that data into the model. It also shows the differences or similarities in magnitude of the events.

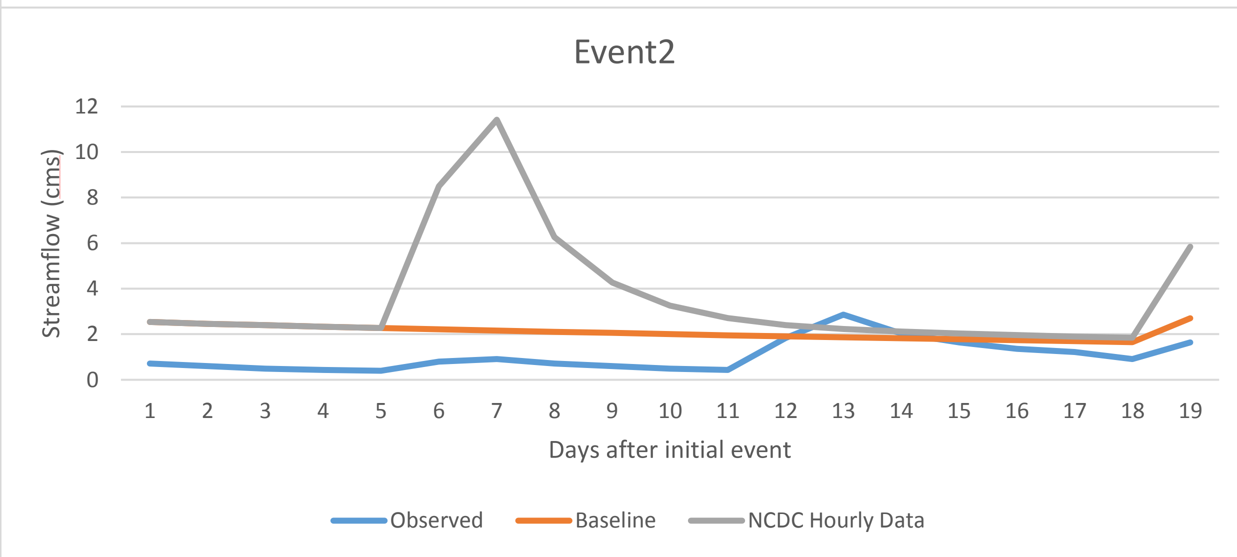
change will take place between the model simulations.

c.) Model analysis

The precipitation data was scaled up form hourly inputs to six-hour time intervals in order to make the input data compatible with the SAC-SMA. (Figure 2). While this means that the one hour intervals will not be resolved in the model simulations, it will generate a difference in the overall amount, assembly a more accurate one than spatially generated data at six hour intervals.

In order to assess the accuracy of the obtained simulated streamflow, observed streamflow data was also taken during and after the duration of each precipitation event from the United States Geological Survey's website to be compared to the simulated streamflow for both of the precipitation data sets. The accuracy of the model forecasts was determined by comparing the accuracy of the intensity of the simulated streamflow with the observed values for each data set across all events. The significance of any time





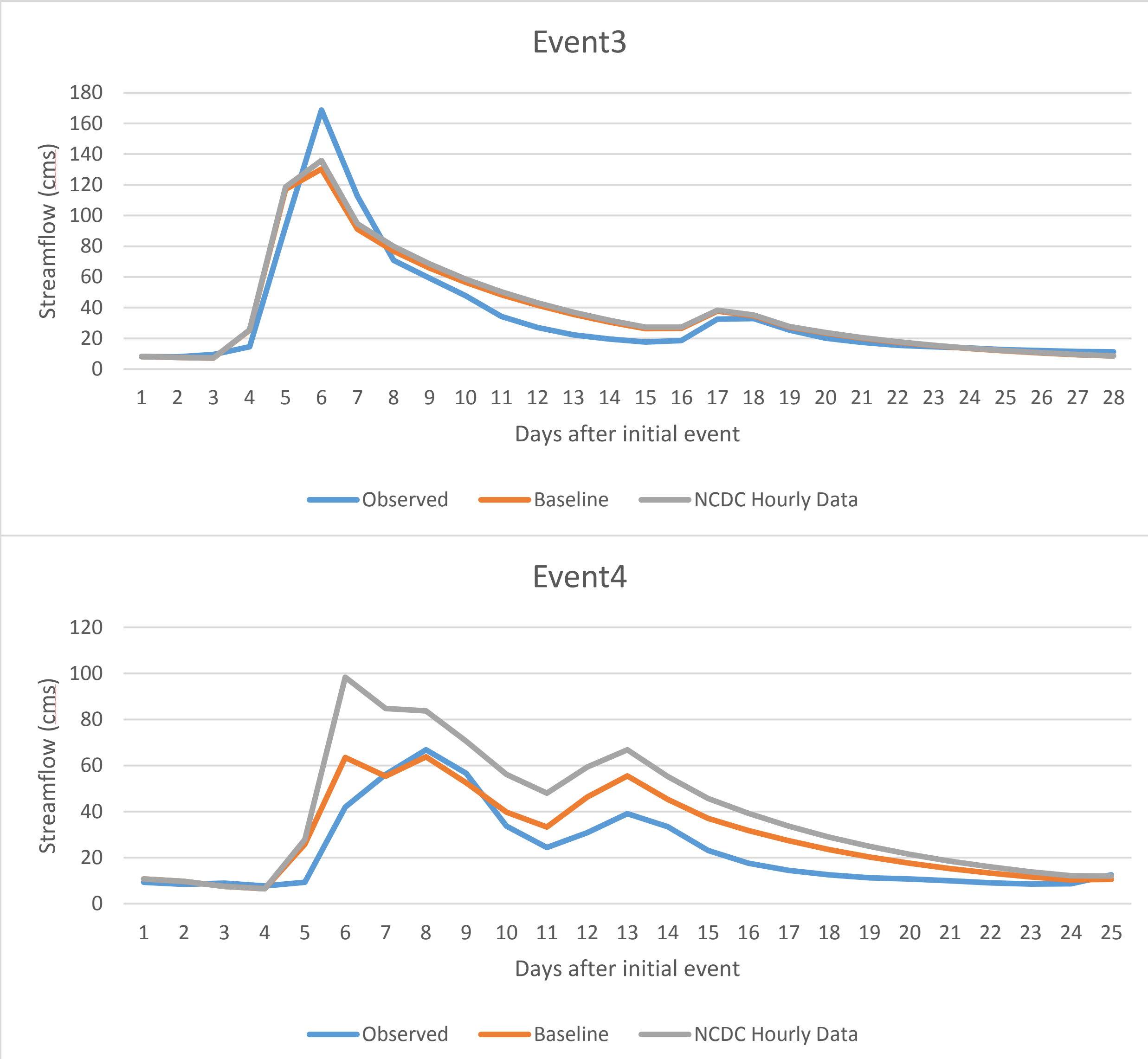


Figure 3: the four above plots are the results of the two different precipitation input shown alongside the observed values for the time period of each of the events. The time interval begins the day of the precipitation event and continues in daily intervals in order to observe the effects of the changes in input.

related parameters were also noted. Dependencies were also looked at for the time required after the input change for the state to return to approximate normal conditions.

3. Results

The output of the model results for the events was compared with the baseline simulated values and the observed values. (Figure 3). Statistical analysis was also done for both the baseline precipitation vales and the hourly event data and compared to the observed values (Figure 4). Resulting R-squared values and root mean square error values were also calculated (Table 1).

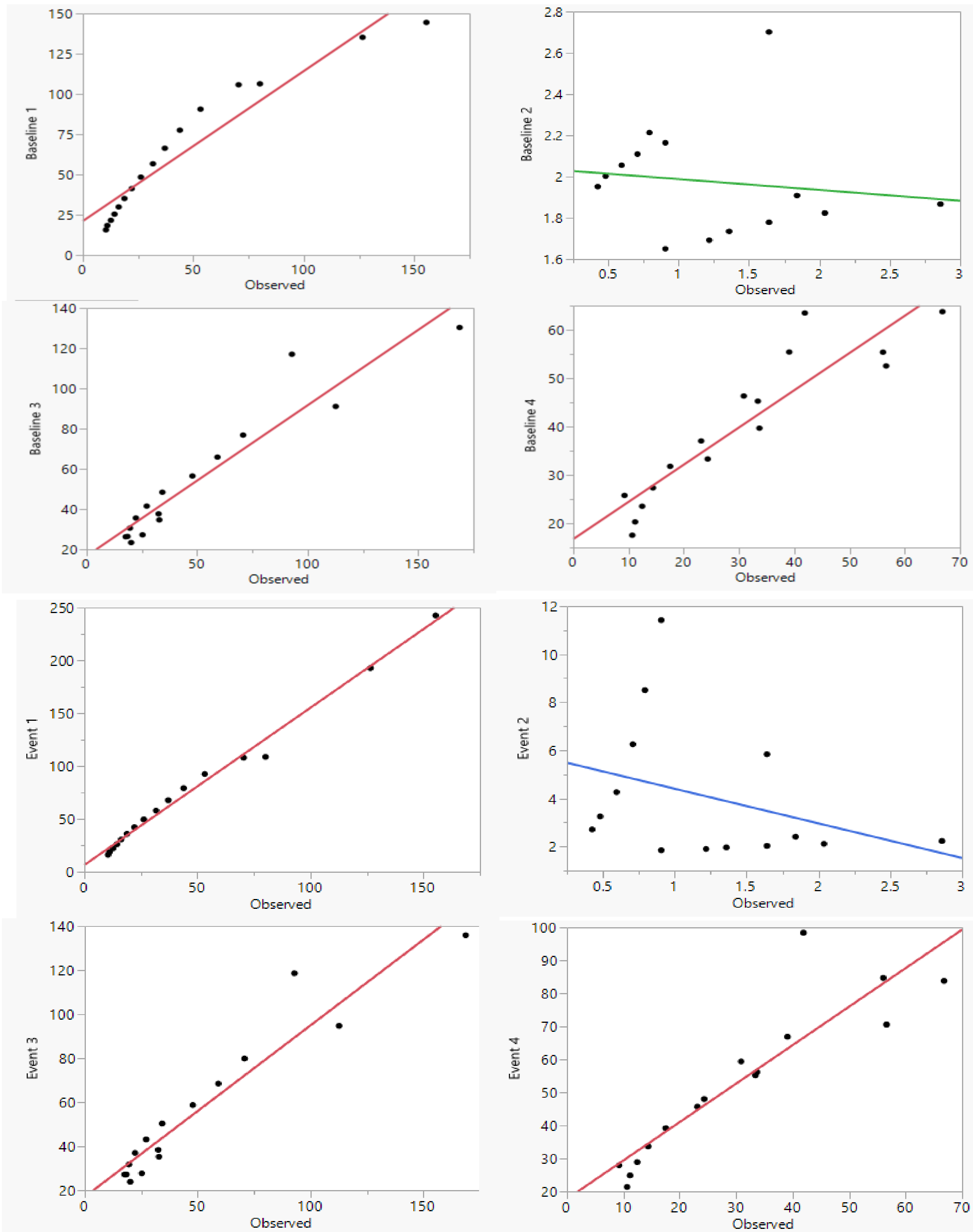


Figure 4: Shown are the values of the event simulated streamflow and the baseline streamflow against the observed values. The R-squared values as well as the root mean square error for all of these comparisons are located on Table 1.

Table 1: The values of R-Squared and the root mean square error are shown for each of the baseline and event comparisons with the observed streamflow.

	R Squared	Root Mean Square Error
Baseline 1	0.90	13.10
Event 1	0.99	06.42
Baseline 2	0.01	00.28
Event2	0.11	02.87
Baseline 3	0.90	10.65
Event 3	0.91	10.53
Baseline 4	0.84	6.21
Event 4	0.81	10.36

The initial analysis of the results show that the model has a moderate sensitivity to precipitation inputs. All of the analyzed events show significant increases in relative streamflow when the adjusted hourly values exceed that of the baseline values. This increase appears to be relative to the precipitation increase, as cases where the baseline data did not deviate much from the event precipitation showed little difference in simulated streamflow values.

The overall accuracy of the simulated streamflow values didn't seem to matter when comparing the precipitation inputs. If one of the inputs resulted in in values that were higher than the observed, the other type of precipitation input data would only show that to a higher degree. This contradicts what was expected, which is to say that the event data, which was taken at a higher interval, would make the model predictions more accurate, even if only slightly so. When looking at the two types of precipitation input, the event precipitation seemed to be overall more less accurate then the baseline values.

Another aspect of the precipitation input sensitivity is its time-dependence. For three of the events analyzed, the hourly and baseline precipitation simulated streamflow values rapidly return to near identical values shortly after the precipitation event. This raises an interesting question as to whether the model can accurately account for the long term effects of precipitation input changes. This time intensive similarity is one that can be useful when considering which information to use in the forecast that are submitted to the public. If it is known that one particular data set will more accurately simulate the streamflow, then it should be used for that aspect, even if the intensity or magnitude of the streamflow may be too high or too low.

The most notable of the events is event number two. The change in precipitation input caused the model to produce and extremely unprecedented increase in the streamflow value when compared to the other events. When compared to event four, both the precipitation inputs were increased by approximately the same magnitude This behavior can be explained by the initial state of the river at the time of the event. The streamflow values were extremely low at that time, meaning that even the smallest change in precipitation input would result in exponentially large increases in streamflow.

4. Conclusion

Flooding in rivers and streams is something that will continue to threaten the surrounding areas, and methods of evaluating these potential risks must be put under scrutiny. An accuracy assessment of the SAC-SMA has shown us that variations in precipitation inputs can have a number of effects on the resulting simulated outputs.

The difference in the precipitation inputs will be reflected in the simulated streamflow by increasing or decreasing relative to the magnitude of the input change. The initial conditions of the streamflow are also very important to consider when changing the inputs, as was seen in case two.

As this model in continuing to be used by the River Forecasting centers, these results are important to consider when deciding how accurate the model will simulate any anticipated precipitation. It is also important when considering any watches or warnings that need to be issued to the public.

5. Acknowledgements

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6. References

Franz, Kristie J. and Hogue, T. S., "Evaluating uncertainty estimates in hydrologic models: borrowing measures from the forecast verification community" (2011). *Geological and Atmospheric Sciences Publications.* Paper 70. http://lib.dr.iastate.edu/ge_at_pubs/70

Herman, J. D., Reed, P. M., & Wagener, T. (2013). Time-varying sensitivity analysis clarifies the effects of watershed model formulation on model behavior. *Water Resources Research Water Resour. Res., 49*(3), 1400-1414. doi:10.1002/wrcr.20124

Lee, H., Seo, D., & Noh, S. J. (2016). A weakly-constrained data assimilation approach to address rainfall-runoff model structural inadequacy in streamflow prediction. *Journal of Hydrology*. doi:10.1016/j.jhydrol.2016.09.009

NCDC, 2016: U.S. Hourly Precipitation Data – Hourly precipitation for Iowa. Accessed 01 November 2016 [Available online at http://www.ncdc.noaa.gov/IPS/hpd/hpd.html]

Samuel, J., Coulibaly, P., Dumedah, G., & Moradkhani, H. (2014). Assessing model state and forecasts variation in hydrologic data assimilation. *Journal of Hydrology*, *513*, 127-141. doi:10.1016/j.jhydrol.2014.03.048

Singh, V. P. (1995). The NWS Forecast system - Catchment Modeling. In R. J. Burnash (Ed.), *Computer models of watershed hydrology* (pp. 311-366). Highlands Ranch, CO: Water Resources Publications.

USGS, USGS Current Water Data for Iowa. (n.d.). Accessed 01 November 2016. [Available online at http://waterdata.usgs.gov/ia/nwis/rt]