Analysis of the Impact of Climate Change on Stormwater Design Storms for the State of South Carolina

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ABSTRACT. A warming climate leads to a moister atmosphere and a more rapid hydrologic cycle. As such, many parts of the country are predicted to become wetter with more extreme rainfall events. This paper analyzes rainfall forecasts across the state of South Carolina through 2099 using the data from 134 global climate models. Results show that there is an increasing tendency in both total annual rainfall and design storm intensity. Across the state, the total annual rainfall increase ranged from approximately 1.5-3.3 inches over the forecast period while the 100-year design storm increased by 0.5-1.2 inches depending on location.

INTRODUCTION

Climate change models predict a warmer and moister atmosphere resulting in a more rapid hydrologic cycle and more extreme rainfall events. Stormwater systems, some that are already overloaded, will be stressed even further with increased runoff. Water quality will decrease as sediment runoff and flooding increase.

As a result of current stormwater regulations (DHEC, 2002), which regulates only peak flows and not total runoff, traditional stormwater designs have reduced infiltration, increased total runoff and often require significant downstream storm sewer infrastructure. With increased rainfall due to climate change, these design weaknesses will cause a disproportionate amount of the additional rainfall to directly become runoff. Responsible stormwater management is required to maintain the quality of surface water in a climate that will exhibit increased frequency and intensity of rainfall over time.

This paper presents the results of a detailed analysis of rainfall forecasts based on Global Climate Model (GCM) data archived through the Climate Model Inter-comparison Project – 5 (CMIP5). The data is analyzed to examine the change in annual total rainfall (ATR) and 2, 10, and 100 year 24 hour storm depths between now and the end of the century.

Engineers and regulators will better understand the risk a changing climate will present to stormwater infrastructure as a result of this analysis. That is particularly true for state agencies with regulatory responsibilities for defining stormwater design events such as SC-DHEC and SC-DOT.

The remainder of the paper is structured as follows. The project overview summarizes the main goals of the project and pertinent literature. The sources of data used and the analysis technique are described in the methods section. The results section presents forecasts for the ATR and 2, 10, and 100 year 24 hour storm depths for the entire state of South Carolina. Conclusions and suggestions for future work are presented in the discussion section.

PROJECT OVERVIEW

As an increase of rainfall intensity and frequency is expected, the responsibility of designing stormwater systems to be effective for their entire design life lies on the designing engineer. In a study of water supply vulnerability, GCM predictions were used to predict monthly stream flow to test the impact of climate change on the water supply in Colorado. (Rodriguez, Kaatz, 2009). Downscaling GCMs using Bias Corrected Constructed Analogs (BCCA) provide a higher temporal and spatial resolution (Barsugli, et al, 2009) (Maurer,Hidalgo, 2008). The CA method has improved estimates of precipitation compared to other downscaling methods (Brown, Wilby, 2012). Using multiple GCMs removes the bias that a certain model may have and improves the underestimation of variability (Brekke, et al., 2008). This study uses projected rainfall data from 134 GCMs with daily temporal resolution and $1/8^o$ degree spatial resolution to explore long term trends in rainfall in South Carolina.

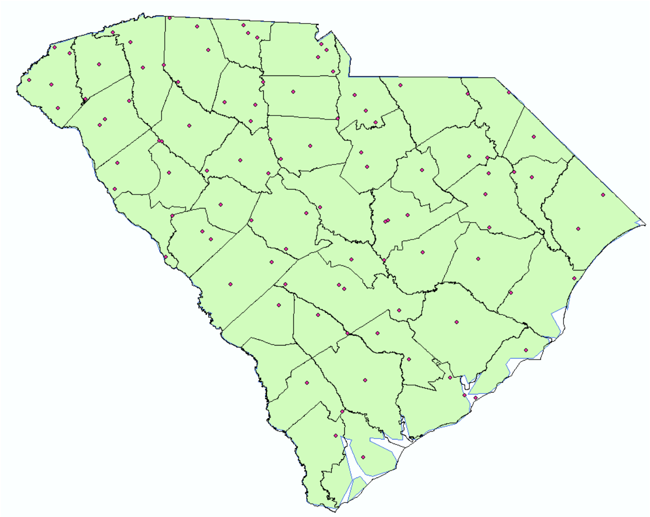

Figure 1 NOAA weather station locations in South Carolina for which observed data was collected and downscaled GCM data was analyzed.

METHODS

The locations of NOAA precipitation measuring stations, Figure 1, were used in the analysis so that the projected rainfall data could be directly compared to historical data. The list of stations was edited to remove duplicate stations (which happened for stations that measured hourly and daily values), stations located outside the projection grid, or stations with region information not specified by NOAA (Bonnin, et al., 2006). BCCA downscaled CMIP5 hydrologic projections were downloaded for each station from an online archive (U.S. Department of Interior, 2014).

After importing the data for each station, the maximum daily values were converted to 24-hour maximum values using

$$Adjusted\ Annual\ Max = Annual\ Max \times t_{24} \times T_{AMS}/T_{PDS}$$

where $t_{24}=1.134$ is the ratio between average daily maxima and average 24-hour maxima. The variable T_{AMS}/T_{PDS} is equal to 1.58 and represents the frequency ratio between an annual maximum series and a partial duration series. Then based on the region associated with each station, each data value (Adjusted Annual Maximum) was multiplied by the Regional Growth Factor (RGF) for the 2-yr, 10-yr and 100-yr return storm frequency. For example, since the station in Clemson, SC (Station ID 38-1770) is assigned to Region 12 by NOAA its RGFs for the 2-,10- and 100-year storm are 0.907, 1.429 and 2.272 respectively (Bonin, et al., 2006). These conversions were made so the calculated values would be directly comparable to current NOAA Precipitation Frequency values.

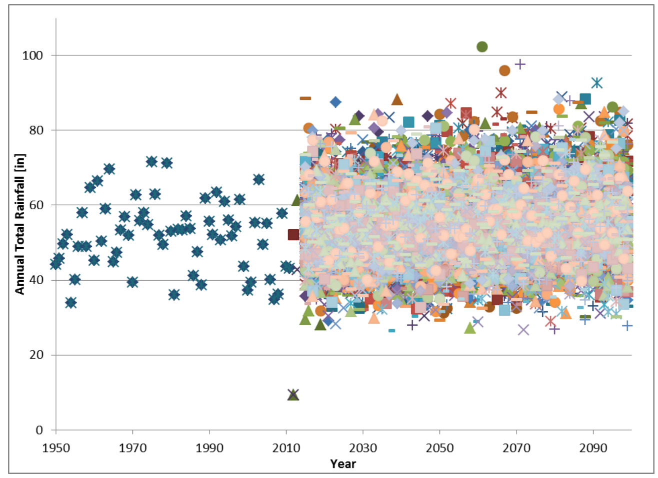

Figure 2 NOAA observed historical annual total rainfall (1948-2011) and predicted annual total rainfall (2015-2099) from 134 different GCMs for Clemson, SC.

RESULTS

Because the analysis presented is location specific, Clemson, SC was chosen as a case study and is represented in many of the figures herein to illustrate a typical location. There are also figures that present similar summarized information for the entire state of South Carolina.

The models used for the rainfall prediction follow the general spread of historical data as seen in Figure 2, which gives confidence in the approach of using multiple models. The yearly average of the models, Figure 3, clearly shows the upward trend in rainfall and a

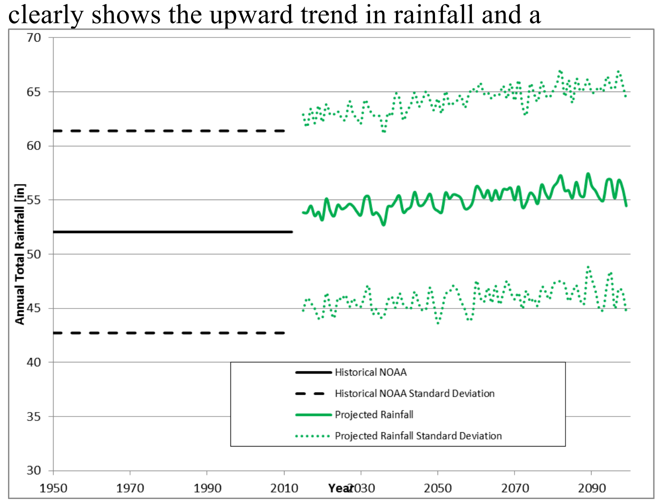

Figure 3 Averaged ATR for Clemson, SC based on NOAA observed data (1950-2011) and projected rainfall for 2015-2099 based on 134 GCMs

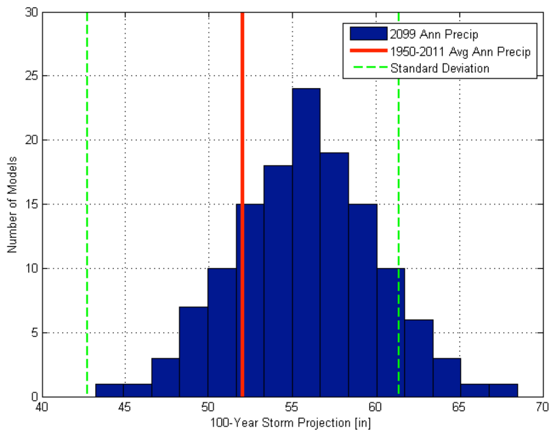

Figure 4: Histogram of the average ATR for Clemson, SC from 2089 to 2099 based on 134 downscaled GCM data sets. The vertical line represents the current average ATR.

comparable spread to the historical data. This increasing trend in ATR was further verified by a histogram of each of the 134 models' predictions of the average ATR in 2089-2099 compared to the current average and standard deviation (Figure 4).

To summarize the difference of current and predicted average ATR over the entire state, a contour map was created (Figure 5). The coastal region, especially Charleston and Horry County, have an increase in ATR of over 3 inches. The upstate and much of the Savannah River Basin exhibit some of the lowest ATR changes predicted by the analysis.

Stormwater design is generally based on the 2 , 10, and 100 year return period storms. Therefore, it is important to see how these design storms change over time, especially in comparison to the current NOAA return

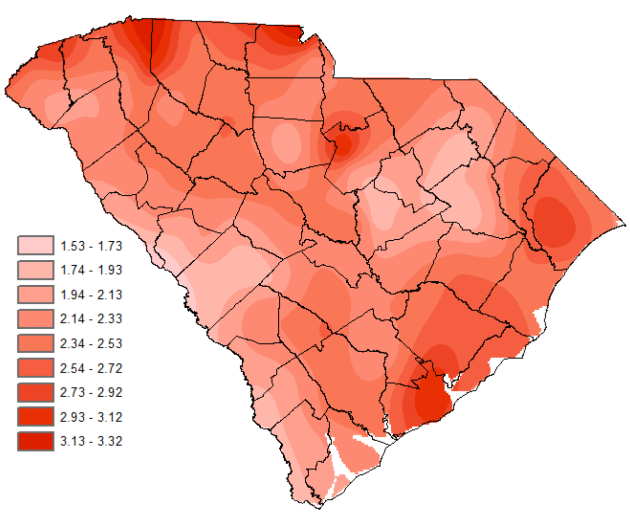

Figure 5 GCM prediction of change in average ATR (inches) over the forecast period (2015-2099) using the last decade of the forecast period

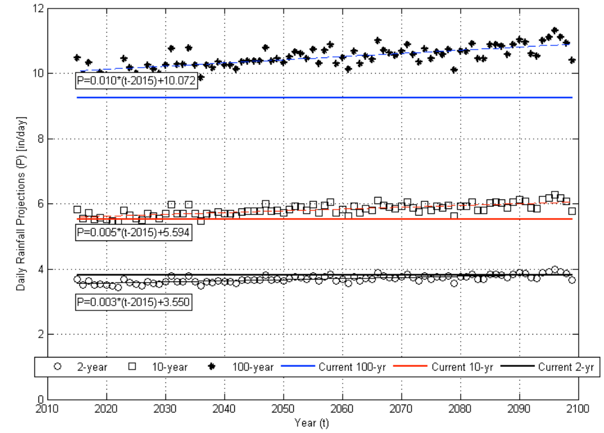

Figure 6 Forecast of 2, 10, and 100 year storm depths versus year based on 134 downscaled GCM data sets.

period data, as seen in Figure 6. Though the 2-year storm does not show significant change for Clemson, SC, the 10-year and especially the 100-year storm have a clear upward trend from the current NOAA value.

Figure 7 shows that this prediction of an increasing design storm depth is consistent among the 134 climate models used. The overwhelming majority of these models predict some increase in storm depth with the most extreme being nearly a three inch increase in Clemson, SC.

To examine the predicted change in 100 year storm depth over the forecast period the slope of the trend line of 100 year depths was multiplied by the length of the GCM time series (84 years) for each station. The resulting contour plot (Figure 8) therefore represents the projected increase in depth, not the difference between the current 100 year depth and the projected 100 year depth for 2099. It is interesting to note that the areas

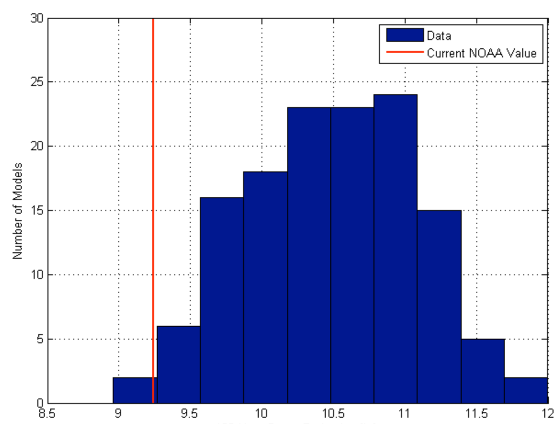

Figure 7 Histogram of the Clemson, SC 100-year design storm depths based on 134 downscaled GCM data sets from 2015 to 2099.

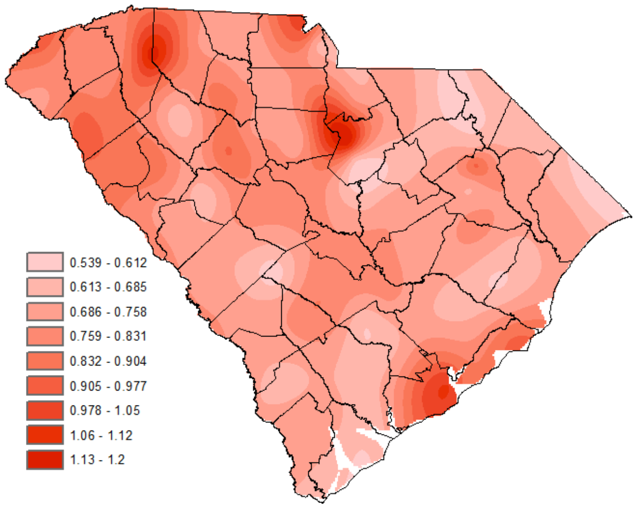

Figure 8 GCM prediction of change in 100 year design storm depth (inches) over the forecast period.

where the 100-year design storm has the greatest increase do not always correspond to the areas that were projected to experience a larger increase in ATR (Figure 5).

DISCUSSION

A detailed analysis of the projected change in rainfall patterns in South Carolina has been conducted using BCCA downscaled GCM data from CMIP5. The GCM data show that average total annual rainfall will increase across the state over the remainder of the century. However, the increase is not uniform across the state with coastal regions predicted to have greater increases than most of the state. The Savannah River Basin is predicted to have below average growth in average annual total rainfall compared to the rest of the state.

The analysis also shows that the 2-, 10-, and 100-year design storm depths increase across the state. For example, the 100-year design storm depth is projected to increase between 0.5 and 1.2 inches by the end of the century.

The projected increases in both average annual total rainfall and design storm depths have the potential to stress existing stormwater infrastructure. The increases may also require regulatory agencies to re-visit their published design storm depths.

One possible approach to mitigating the impact of these changes is to require new developments (and re-developments and retro-fits) to more closely replicate the predevelopment site hydrology. This could be done through the use of low impact development (LID) best management practices (BMP) to encourage infiltration and on-site runoff management. Such an approach has the potential to make new development more resilient to the projected changes in rainfall patterns.

The research team is currently undertaking a series of case studies to investigate the increase in resiliency that can be achieved through the use of LID/BMP on new developments.

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