RESEARCH & DEVELOPMENT

Identifying High-Risk Areas During Precipitation Events in Support of NCDOT Stormwater Quality Monitoring

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16. Abstract

NCDOT's Hydraulics Unit seeks to identify high-risk areas across the state during or soon after the occurrence of heavy precipitation events. Defined by the historical likelihood of obtaining the same precipitation amount within a specified time frame for a given location, these high-risk areas will be highlighted via an alert system and mapping interface for NCDOT employees and contractors to better prioritize and deploy resources to mitigate flooding and runoff.

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EXECUTIVE SUMMARY

The State Climate Office of NC (SCO) and the North Carolina Department of Transportation (NCDOT) have previously partnered on the development of a comprehensive precipitation alert system, which includes a detailed mapping system and rainfall monitoring alert services. This collaborative project has been estimated to save over 110,000 work hours per year, and has won several state and national awards.

This proposal will enhance and leverage that partnership by identifying high-risk areas during or shortly after the occurrence of heavy precipitation events as specified by NCDOT engineers. These high-risk zones will be highlighted on a map interface and/or via an alert, and will be defined by the historical likelihood of obtaining that same precipitation amount within a specified time period at a particular location. For example, one scenario could be: If the precipitation total for the previous 24 hours in Raleigh, NC has historically only occurred once every 25-years, that particular area could be designated as a high-risk region. In addition, a time series plot will display the year-to-date accumulation of rainfall for the current year as compared to the normal (30-year average) year-to-date rainfall accumulation. These additional features will help NCDOT better prioritize and deploy resources for flood and runoff mitigation.

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INTRODUCTION

Monitoring stormwater controls near projects sites is essential to NCDOT operations and required based on water quality permitting guidelines. To comply with these policies, daily rainfall totals have been traditionally measured at each project location. However, substantial effort is involved in the collection of this data and monitoring.

In 2005, the State Climate Office of North Carolina (SCO) at NC State University was funded by NCDOT to develop a web-based alert and monitoring system to visualize radar-based precipitation estimates over the Carolinas, providing the most accurate local-scale precipitation information that is operationally available. The SCO has continued maintenance and developed new enhancements based on user needs since 2006, including text message alerts and precipitation estimates statistics over a drawn polygon area. This heavy rainfall alert system has been estimated to save over 110,000 work hours each year. In addition, the alert system was acknowledged by the NCDOT Continuous Process Improvement in 2008, and was given the bronze award by the National Partnership for Highway Quality in 2010.

This research project built upon the existing alert system infrastructure by incorporating precipitation frequency estimates to better quantify how near real-time events compare with historical occurrences at locations of interest. These efforts will assist NCDOT in identifying high-risk areas for flood and runoff stormwater quality monitoring.

Precipitation frequency estimates were provided by the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 dataset. These data were re-gridded and combined with the gridded precipitation estimates to incorporate storm duration and recurrence intervals. The completed efforts from this project also allow for comparison between the year-to-date rainfall accumulations and the historical normal (30-year average) rainfall amounts over that same time period.

RESULT OF LITERATURE REVIEW

Wootten and Boyles (2014) provide a comprehensive review of radar-based multisensor precipitation estimates (MPE) for use as precipitation estimates in the eastern US, which includes a discussion of the seasonal errors associated with MPE. Additionally, Nelson et al. (2016) provides a detailed description of the process used by the National Weather Service to generate MPE grids, sources of uncertainty and bias, and an assessment of their accuracy compared to surface gauge measurements across the US. Previous engagements with NCDOT users have shown that, while MPE does have errors that have been noted with field use, it is sufficient for the monitoring and alert needs of NCDOT, its contractors, and the NC Division of Water Quality.

The NOAA Atlas 14 dataset consists of precipitation frequency estimates and corresponding 90% confidence intervals for locations across the United States. Bonnin et al. (2007) covers the most recent updates to this data, which includes a summary of the methods used to generate the new estimates, along with selected statistics. Such precipitation frequencies are significant in understanding how extreme rainfall events can influence runoff rates and, by extension, stormwater infrastructure and water quality, as evidenced by Keefer et al (2015). Combining the MPE and precipitation frequency information will help NCDOT plan and assess risks from future rain events.

RESEARCH NEED AND OBJECTIVE

NCDOT needs the ability to identify and classify significant events where heavy rainfall meets or exceeds certain historical rainfall amounts at given locations across the state. The research from this project is expected to continue maximizing efficiency in the efforts spent collecting and monitoring precipitation at NCDOT project sites, and more quickly assess precipitation events that may pose a high risk for flooding and stormwater runoff.

The ability to quickly assess how a recent precipitation event falls within the historical perspective will benefit NCDOT. However, NCDOT does not currently have the capability of making such determinations without putting forth considerable effort toward a more extensive and time-consuming review.

Research into this topic could potentially influence how NCDOT responds to such events as they occur. Thus, our objective is to incorporate precipitation frequency estimates and precipitation normals (30-year averages) into the existing precipitation alert infrastructure and website for heavy rainfall monitoring to meet these NCDOT needs.

GRIDDED DATA ANALYSIS

The National Oceanic and Atmospheric Administration (NOAA) Atlas 14 precipitation frequency estimates for the Ohio River Basin (Volume 2) were downloaded and extracted onto the SCP data servers, as information for

North Carolina was included in this particular dataset. The data include the average precipitation frequency estimate for each storm duration and recurrence interval for each grid point, as well as the 90% confidence intervals. Per recommendations from the Steering Committee meeting, the decision was made to focus on the average precipitation frequency estimates – as opposed to the ranges provided by 90% confidence intervals for the estimates -- to serve as the thresholds that will be met before alerts are sent out. Steering Committee also asked that users have the ability to select not only a given latitude/longitude coordinate when setting up alerts, but also select from pre-defined regions (e.g. counties, HUC12) or generate a custom, user-defined region.

Matching gridded coordinate pairs and associated latitudes and longitudes for the centroid of each MPE grid cell is being stored in our database. Originally, this location information was intended to be used to build SQL relationships that match MPE data with the precipitation frequency estimates for each grid point location in and around North Carolina. However, after receiving clarification from the Steering Committee regarding how locations would be defined (e.g. points, as well as user-defined and pre-defined regions), the decision was made to handle the backend entirely through matrix calculations on a single gridded data file containing all precipitation frequency information for each MPE grid point. This will allow for faster data manipulation when referencing the various user-defined locations.

All relevant NOAA Atlas 14 data were re-projected and re-gridded to match the Hydrologic Rainfall Analysis Project (HRAP) domain and grid (4.7625 km at 60N) of the multi-sensor NCEP Stage IV precipitation estimates (MPE). This step was necessary for preparing the recurrence intervals and return periods needed for the gridded precipitation data calculations across North Carolina. Preliminary evaluation of the re-gridded NOAA Atlas 14 data indicated less than 0.5 km discrepancies in grid cell latitudes and longitudes locations over NC due to differences in spheroids between the projections of both datasets.

Grids of accumulated NCEP Stage IV precipitation were then generated and matched to recurrence interval precipitation amounts to produce grids of recurrence interval exceedances. All grids were created for the full NCEP Stage IV data availability period (2002 to present). SCO evaluated the output to check for errors and ensure data were being stored efficiently. As scripts to generate these grids in a semi-operational setting were developed, updates were run in realtime as soon as new data became available.

Using the Python rasterstats package, polygon averages of gridded precipitation sums were generated for three different polygon groups – the state of North Carolina, all counties in North Carolina, and all HUC 8s in North Carolina – and have been clipped to a masking region for the state. The NOAA Atlas 14 recurrence intervals, re-projected to the HRAP grid, were similarly averaged to the three different polygon types. The precipitation polygon averages were compared to the NOAA Atlas 14 polygon averages to determine the recurrence interval exceedances for each polygon and precipitation duration. Additionally, the maximum gridded recurrence interval exceeded per polygon was also output as a grid. The resulting NetCDF files were grouped by year-month and polygon type and initially contained three variables: the average precipitation over a given polygon for a given period (e.g., 6-hours, 24-hours), the corresponding polygon average recurrence interval exceeded, and the corresponding maximum recurrence interval exceeded. A fourth variable for maximum precipitation over a given polygon for a given period was added later (see under Alert System section below). Polygon statistics are updated each hour, and the historical archive was generated back to the beginning of the MPE record (2002).

Scripts were also written to parse the gridded and polygon statistics output into usable time series arrays. These scripts require an input location (either latitude/longitude or polygon type and ID), start and end dates, and storm duration (e.g., 6-hours, 24-hours), and output a json array grouped by location and datetime. The output of these scripts will ultimately facilitate integration with the web-based user interface and alert system.

Figure 1: Interface for retrieving past precipitation frequencies depicting two counties in the Coastal Plain that were greatly affected during Hurricane Matthew, resulting in a 100-year recurrence interval for Bladen County.

Location	Storm Duration	Ending Datetime	Maximum Precipitation	Maximum Recurrence Interval Exceeded
Bladen County	24-Hours	2018-09-16 01:00	22.33 inches	1000-Year Storm
Brunswick County	24-Hours	2018-09-14 19:00	23.14 inches	1000-Year Storm
Columbus County	24-Hours	2018-09-16 01:00	22.33 inches	1000-Year Storm
New Hanover County	24-Hours	2018-09-16 07:00	17.84 inches	1000-Year Storm
Pender County	24-Hours	2018-09-16 07:00	17.84 inches	1000-Year Storm

Table 1: Precipitation totals measured by county in Hurricane Florence

To test the underlying capabilities of scripts to parse the gridded and polygon statistics interface that allows NCDOT users to search for past precipitation events and obtain the corresponding NOAA Atlas frequency estimates (Figure 1). Users could select their location type, (counties, NCDOT divisions, HUC 8s, lat/lon coordinates), storm duration, and start/end dates over which to retrieve data. Results were output to a table depicting the locations chosen, ending timestamp for precipitation accumulations, the average and maximum precipitation observed (if polygons were chosen), and the average and maximum recurrence interval that was exceeded (Table 1).

ALERT SYSTEM

A user interface was generated to allow NCDOT employees and contractors to set up precipitation frequency alerts for desired locations (Figure 2). Current functionality allows users to select locations from a list of counties, hydrologic regions, or NCDOT divisions within North Carolina, as well as direct lat/lon coordinate input. Polygon location selections can also be made through a small mapping interface. Other user selections include storm duration, recurrence interval, and alert frequency and method. All submissions for user alert locations were stored in an SQL database table.

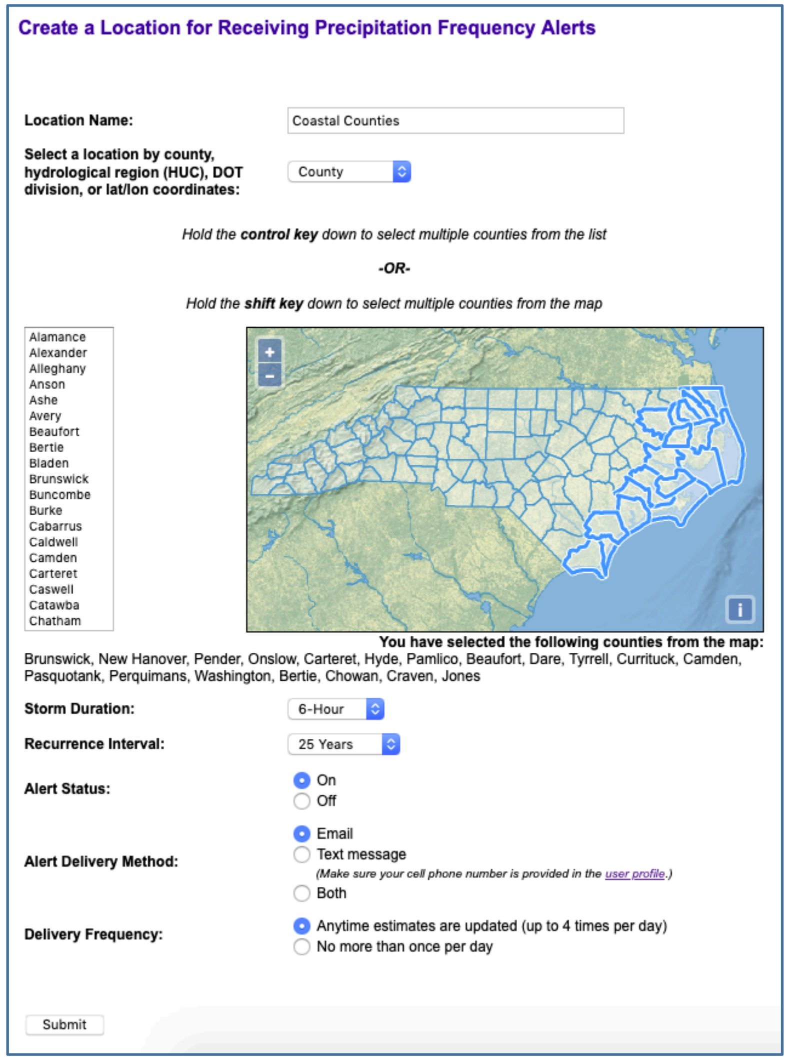
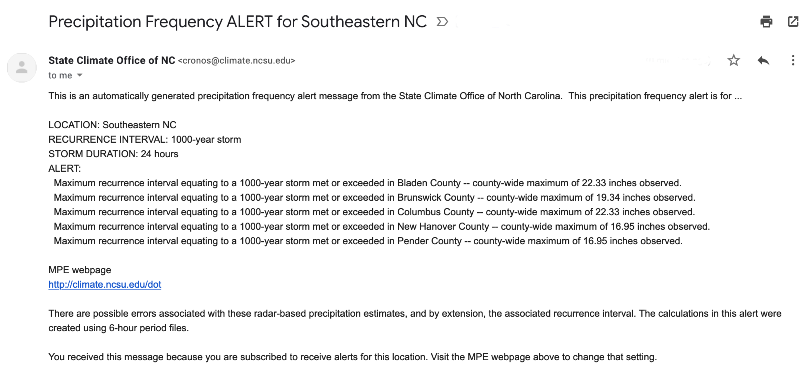


Figure 2: Interface for setting up a precipitation frequency alert for user's desire location(s), storm duration, and recurrence interval.

Scripts were then generated to parse through the database table of user-specified precipitation frequency locations every 6 hours after new MPE data was uploaded to SCO servers, to check whether the precipitation frequency thresholds set up by NCDOT users were met or exceeded. If the specified threshold was met for any of a user's chosen locations, they were alerted via email and/or text message (Figures 3 and 4) with information specific to which location was affected, and by how much the threshold was exceeded.



Precipitation Frequency ALERT for Southeastern NC

State Climate Office of NC <cronos@climate.ncsu.edu>
to me

This is an automatically generated precipitation frequency alert message from the State Climate Office of North Carolina. This precipitation frequency alert is for ...

LOCATION: Southeastern NC
RECURRENCE INTERVAL: 1000-year storm
STORM DURATION: 24 hours
ALERT:
Maximum recurrence interval equating to a 1000-year storm met or exceeded in Bladen County -- county-wide maximum of 22.33 inches observed.
Maximum recurrence interval equating to a 1000-year storm met or exceeded in Brunswick County -- county-wide maximum of 19.34 inches observed.
Maximum recurrence interval equating to a 1000-year storm met or exceeded in Columbus County -- county-wide maximum of 22.33 inches observed.
Maximum recurrence interval equating to a 1000-year storm met or exceeded in New Hanover County -- county-wide maximum of 16.95 inches observed.
Maximum recurrence interval equating to a 1000-year storm met or exceeded in Pender County -- county-wide maximum of 16.95 inches observed.

MPE webpage
http://climate.ncsu.edu/dot

There are possible errors associated with these radar-based precipitation estimates, and by extension, the associated recurrence interval. The calculations in this alert were created using 6-hour period files.

You received this message because you are subscribed to receive alerts for this location. Visit the MPE webpage above to change that setting.

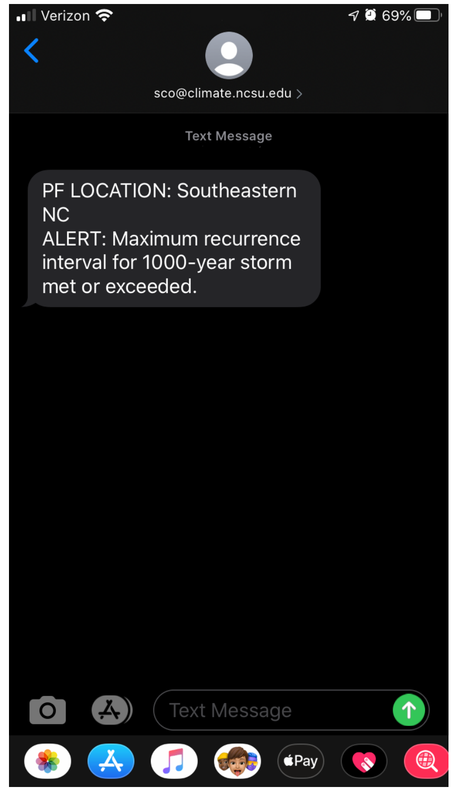


Figure 3 and Figure 4: E-mail and text precipitation frequency alerts

Upon initial testing, SCO researchers discovered that some users may not receive alerts depending on the format in which their cell number has been stored. This issue applied not only to the alert system developed for precipitation frequencies, but for the NCDOT precipitation alert system in operations since 2006. A solution was implemented to address the discrepancy with both systems.

In addition, when viewing email and text messaging output after the alert system became operational, output values of precipitation and recurrence intervals did not seem to coincide. Upon investigating, SCO researchers found that while all polygon statistics were calculated correctly, the initial absence of the maximum precipitation value for each polygon gave the appearance of a discrepancy when compared to the calculated maximum recurrence interval in the messaging output. Polygon statistics were re-generated historically to incorporate the additional maximum precipitation variable, and alert-related scripts were updated accordingly.

MAPPING INTERFACE AND YEAR-TO-DATE ACCUMULATIONS

Work began on the development of a new mapping interface for the NCDOT website to include additional capabilities to display recent MPE grids in terms of the recurrence interval exceeded based on a storm duration of interest. SCO scientists explored ways to make the map more mobile-friendly, with the idea of designing the framework so the year-to-date precipitation accumulation as compared to historical normal could be easily integrated with the map.

In year two of the project, it became clear that the skills needed to generate the map were better suited for experts in data visualization and analyses. The State Climate Office is looking forward to partnering with SAS on generating the final map in another project, with the SCO serving as the data stewards and climate experts.

CONCLUSIONS AND RECOMMENDATIONS

The SCO would suggest expanding upon the existing gridded data analysis for the HUC 8 level to other hydrologic regions down to the HUC 12 level, as well as the ability for creating user-generated polygons. It is highly recommended to implement the calculation of weighted precipitation frequency estimates, as the 4.7625 km size of the MPE grid cells could result in little to no data points for smaller polygons.

In addition, the development of a precipitation frequency climatology for North Carolina would be very beneficial for NCDOT operations and planning. Such a climatology would include returning all instances across the state where specified recurrence interval thresholds were met, regardless of the storm duration.

IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

The generation of gridded datasets that place recent rainfall events in a historical perspective are of great use to NCDOT in regards to stormwater management, as higher precipitation amounts could pose a risk to existing infrastructure that may not be designed to withstand the resulting flooding. The alert system that taps into these underlying datasets is essential to NCDOT operations, as it notifies employees and contractors in a timely manner regarding whether or not a recent event may have adverse impacts on a given structure.

These products would be most especially beneficial to NCDOT's Hydraulics Unit. This division is responsible for ensuring that transportation structures such as bridges and culverts are properly designed of sufficient size and capability so that natural flooding is not exacerbated, and make certain that existing structures can withstand the flood level it was designed for without interrupting travel.

Training is needed to instruct NCDOT employees and contractors in setting up precipitation frequency locations and thresholds, as well as in understanding the output from the email and text alerts. A basic overview of precipitation frequencies should also be included in the training, so as to avoid misinterpretation of the product results.

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