Stormwater Modeling in the Fairfield Run Watershed in Newark, Delaware

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Abstract

Stormwater management is becoming increasingly important as threats of global warming and sea level rise could bring increased flooding and inundation to the state of Delaware. Most stormwater systems are built to handle the water from a 10-year rainfall event. However, older systems may no longer be up to this standard, and retrofitting or new management techniques may be required to handle increased rainfall. The purpose of this research project is to analyze the current stormwater system for the Fairfield watershed in Newark, Delaware by creating a model of the system using the Environmental Protection Agency's Storm Water Management Model and running simulations of rainfall events. Plausible management techniques to reduce runoff and flooding are determined through the use of the model. 2-year, 10-year and 100-year rainfall events are simulated along with actual rainfall events of different scales that have occurred within the last five years. These include Hurricane Irene, Hurricane Sandy and an average day rainfall event. This study concludes that the current stormwater system is not equipped to handle most rainfall events. Flooding at multiple nodes occurs for every simulated storm, but a reduction of impervious surface in the Laird Campus parking lot in the form of a switch from pavement to forest cover would reduce runoff and flooding for storm events.

Background and Justification

When the Christiana Towers were built in 1972, there were no stormwater regulations. During the construction, high sediment concentrations were measured in White Clay Creek as a result of rain washing loose soil from the construction site to the creek. This caused concern among University of Delaware professors. They were assured that sediment runoff was just a side effect of construction and would decrease once construction finished. This, unfortunately, was not the case. A large parking lot was built adjacent to the Christiana Towers and now, 43 years later, White Clay Creek still has very high sediment concentrations. Additionally, the formation of several large gullies has been discovered in the forested areas behind the Christiana Towers and parking lot #6. A few of these are relatively minor, or are being kept in check by trees and rip rap. There is, however, one in particular that begins at the northeastern branch of the lot and is up to 15 ft in parts. It has begun cutting into the lot and crumbling the asphalt to a point where several parking spaces have been roped off. There is a similar situation along the fencing in this branch and at the southernmost point of the lot. In addition to polluting the creek, these gullies are a danger to students and hikers and are costing the University money in terms repair and loss of parking revenue.

Although there may be other factors contributing to the gullying, such as soil type and topography, the main culprit is runoff. The water that runs into the gullies flows into the Fairfield Run, which later connects to White Clay Creek. Therefore, the responsible land area for this runoff is the Fairfield Run Watershed. This watershed extends from the gullies west to New London Road, north to just above Cambridge drive and south to include University Parking Lot #7. These areas receive surface runoff from upper portions of New London Road and residential areas. There is an existing stormwater system in this watershed, but it may not be designed to handle the expected rainfall events.

Objectives

The purpose of this study had two primary objectives. The first was to use the Environmental Protection Agency (EPA) Stormwater Management Model (SWMM) to quantify how the current stormwater system handles precipitation in the Fairfield Run Watershed in Newark, Delaware. The second was to explore how this system may be modified using best management practices to reduce runoff and flooding of nodes.

Methodology

Modeling of the Fairfield Run stormwater system was done using EPA's Storm Water Management Model (SWMM). Previous interns had already created a backdrop showing the system of pipes of nodes as well as overland flow for SWMM. Using SWMM's object toolbar, junctions, outfalls and conduits were drawn over the backdrop. In order to verify the location of nodes, the site was surveyed both in the field and using Google Earth imagery. In some cases, the existence or directions of a pipe was dubious. These were verified by visually examining relevant outfalls or storm drains for the presence of a pipe inlet and the direction of flow. The pipe diameters and node inverts were taken from maps provided by the City of Newark Department of Public Works and Water Resources and were input into the system. Junctions in the middle of the road, between one or more nodes often did not have invert data. In these cases, the junction was determined to have the lowest invert of any nodes it was connected to. Pipe lengths were measured using the scale on the provided map. Slopes were calculated based on invert elevations and pipe length. All pipes were concrete and therefore a Manning's Roughness coefficient of .013 was used.

In order to determine subcatchments for the stormwater system, overland flow was examined in addition to the layout of the pipes and nodes. F01 was divided into two subcatchments, an upper and a lower. F02 is along New London Road and was divided into 4 subcatchments by clumps of pipes and nodes. F05 was split into 3 subcatchments based on the overland flow that runs along the two roads separating the groups of houses. F06, F09 and F12 were split along the Fairfield Run. F10 is one of the parking lots on Laird Campus and were divided based on the branching of pipes. F03, F04, F07 and F08 were small enough to remain whole. This resulted in a total of 23 subcatchments. Percent pervious and impervious for each subcatchment was determined by visually examining the backdrop map for amounts of development like parking lot or pervious cover like grass and forest. A manning's coefficient of

.22 was used for pervious area and .013 for impervious area. The subcatchment slope was found using a LIDAR map. The minimum and maximum elevations were located in each subcatchment and using the distance between these two points a slope was calculated and applied to the entire subcatchment.

Six rain gages were used for the model. Three were design storms based off of 2, 10 and 100 year 24 hour rainfall depths for New Castle County, Delaware. The other three were real storms. Design storm data was taken from the NRCS TR-55, Urban Hydrology for Small Watersheds. Using the NRCS excel sheet for type II distribution, the rainfall depths for each of the design storms was broken into half-hour increments. These increments were then input as a rain gage and attached to the entire watershed. Two of the real storms selected were well known hurricanes that affected New Castle County: Hurricane Sandy and Hurricane Irene. These were entered in DEOS to obtain hourly rainfall depths, which were then put into a rain gauge. The third storm selected was on March 14, 2015. This was chosen because it was representative of normal rainfall events that the watershed experiences. The hourly rainfall depths were also taken from DEOS and put into a rain gage.

Before testing all the rain gages, one was applied to the watershed and the model was run to test for any errors. Several errors occurred in the first run. However for the most part they were that some of the conduits had adverse slopes. This was fixed by ensuring that the conduit had been drawn in the right order, in the direction of flow and secondly that the inflow invert had a higher elevation than the outflow invert. Once all errors were fixed, the model was run for each of the six rain gages. Node flooding and surcharging was noted for each event, as well as runoff depth. The SWMM time series tool was used to create hydrographs of precipitation and runoff and the animation tool was used to view changes in flooding and runoff over the length of the storms.

Lastly, an attempt was made to improve the flooding and runoff with the model. In this scenario about 30% of the parking lot in subcatchments 7,8 and 10 was converted back to forest cover. In order to do this, the percent impervious and pervious ground cover were changed for each of these subcatchments. A manning's roughness coefficient of .013 was still used for impervious area and .22 for pervious area. The model was then run with the different storms again and the results were graphed and analyzed to see what effect increased pervious cover would have.

Results

After creating the stormwater model, running simulations and performing various analyses, results were gathered, and a few key conclusions were drawn. The first of these is that the existing stormwater system is not currently equipped to handle the water from storm events. When a 2-year storm simulation was run, there were five nodes that experienced flooding in the system, and the total flood volume was 151,000 gallons. The results increased with the greater design storms, as seven nodes flooded in a 10-year storm simulation and twelve nodes flooded in a 100-year design storm simulation. The total flood volumes were 300,000 and 674,000, respectively. These results can be seen in Figure 1.

Storm Event	Total Precipitation (in)	Nodes Flooded	Total Flood Volume (gal)
2-year Design Storm	3.20	5	151,000
10-year Design Storm	4.80	7	300,000
100-year Design Storm	8.00	12	674,000
March 14, 2015 Storm	1.10	2	5,000
Hurricane Sandy	4.52	4	494,000
Hurricane Irene	6.23	7	1,020,000
10-year (North Campus Reforested)	4.80	7	279,000

Figure 1. Quantitative data gathered from SWMM model simulations

In addition to modeling design storm events, simulations were run to recreate actual storm events. An average rainy day that occurred on March 14, 2015 was first simulated. The results showed that two nodes were flooded, and the total flood volume was 5,000 gallons. Next, Hurricane Sandy was modeled. Four nodes flooded, and the total flood volume was

494,000 gallons. Finally, a simulation was run for Hurricane Irene, resulting in seven flooded nodes and 1,020,000 gallons of water for the total flood volume (Figure 1).

The next part of this project involved simulating a potential management strategy to reduce runoff and flooding. A reduction in impervious surface by means of conversion to forested land in subcatchments F07, F08, F10A, F10B and F10C was simulated, and results were collected. In F07, the percentage of impervious surface was reduced by 25%, and in F08, the percentage was reduced by 45%. In F10A, F10B and F10C, the percentage of impervious surface was reduced by 20%, 10% and 20%, respectively. The model was run with these updated settings, and the results were compared to a 10-year storm under normal conditions. It was found that seven nodes still flooded, but the total flood volume was reduced to 279,000 gallons. A simulation of Hurricane Sandy with the proposed conditions was also run to compare runoff. The results comparing those conditions to normal conditions can be seen in Figure 2. The final results of this showed that a 30.4% increase in forest cover in the Laird Campus parking lot would have resulted in a 30.3% reduction in runoff during Hurricane Sandy.

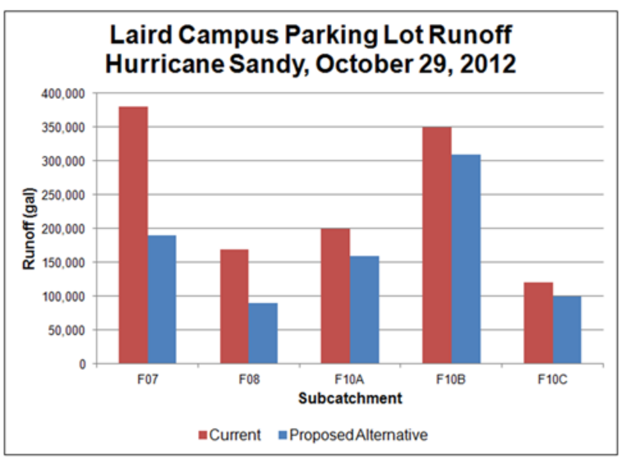

Figure 2. Runoff (gallons) caused by Hurricane Sandy compared to the theoretical runoff with a reforestation management strategy implemented

Conclusions and Project Implications

At a minimum, stormwater systems are designed to withstand flooding during 10-year design storm events. Fairfield Run's current stormwater system does not perform to this standard. The current system floods during much more frequent 2-year storms, and flooding increases significantly as storms become more intense. These flooding problems contribute to runoff, erosion, and pollution of White Clay Creek, a source of drinking water for Newark residents. Using the Environmental Protection Agency's Stormwater Management Model, it was determined that a 30.4% increase in forest cover in the Laird Campus parking lot would have decreased runoff by 30.3% during Hurricane Sandy. A reforested surface would decrease runoff in all future storms as well.

SWMM may be used to explore other best management practices for reducing stormwater levels in the Fairfield Run watershed. By running alternate simulations and exploring these options, recommendations may be made to the City of Newark and the University of Delaware for improving stormwater management.

References

City of Newark Department of Public Works and Water Resources

Delaware Environmental Observation System

University of Delaware Water Resources Agency

USDA Natural Resources Conservation Service, Soil Survey