The impact of climate change on established retention ponds – A case study from UWI, St. Augusitne

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Abstract

At the St. Augustine Campus, UWI, a retention pond has been used in the past 30 years to manage storm runoff from the Campus catchment. In the past, from time to time floods were experienced causing inconveniences to staff and students and led to some property losses. Recently a pump was installed to improve the effectiveness of the pond. Although improvements are expected it is not clear how the pond may function in the future under climate change induced precipitation regimes. The aim of this study was to investigate the potential effect of climate change on the efficiency of a retention pond. The study utilised the characteristics of the catchment area, which include land cover, soil condition, infiltration and elevations and intensity duration curves, to create unit hydrographs by the NRCS method. Hydrographs for four historic storms were developed based on the rainfall data. Climate change scenarios that are consistent with projected changes for the southern Caribbean were subsequently incorporated into the developed hydrographs for simulating the performance of the pond under these projected future conditions. Preliminary results suggest that the current pond would fail more often in the future. As it is not practical to change the dimension of the pond, using the pump at an appropriate time during the storm can reduce the incidents of flooding by an appreciable level. These simulations would be used to develop operation rules for the pump. This approach would be useful where detention ponds are to be installed in cases where there is changing infrastructure.

Background

Protecting people, property and the environment from the impacts of flood events has always been a concern for engineers and planners. Despite the development and innovations over the years, there is a significant challenge to design effective urban drainage systems. The impacts on these systems due to climate change and urbanization have been widely acknowledged (Semadeni-Davies *et al* 2008; Huong and Pathirana 2013). A concern in many urban and semi-urban localities, in many parts of the Caribbean, is the increasing failure of established systems that result in localised flooding. This may partly be explained by the increase of 2.05% per decade in extreme precipitation over the past 25 years (Stephenson, Vincent and Allen 2014). Climate change can increase design intensities by 20% to 80% depending on the region (Ekstrom *et al*., 2005; Willems *et al*. 2012). This poses a problem of overloading of current drainage systems that were based on rainfall data for specific return periods derived from historic patterns.

To respond to these challenges, there is a need to design drainage systems that can be upgraded or adapted with minimal cost. Such systems must take into account water quantity (flooding), water quality (pollution) and possible amenity issues. Further, these systems should contribute to sustainable development and improve urban design by balancing the different issues that influence the development of communities. They must be able to function under changing conditions, that is, they must also take into account long term environmental and social factors in decisions about drainage.

Figure 1: Photograph of FERP

One of the structures utilized for managing urban runoff is storm water detention/retention pond which can maintain the outflow from the post-developed basin to a flow similar to that under the pre-developed condition (Park et al 2012; Charlesworth 2010). They are considered to be part of storm-water Best Management Practices for protection from flooding (Maine Department of Environmental Protection 2006) and are now widely used in sustainable urban drainage systems (SUDS) (Ravazzani *et al*., 2014). Typically, they are designed to empty within 6 to 12 hours (City of Austin 2011). Some scientists have attempted to simulate detention ponds using numerical modelling developing appropriate time steps (Jaber and Shulka, 2007; Narayanan *et al*., 2014) while a stochastic search algorithm, a Genetic Algorithm (GA), has been used by Park et al. (2012) to optimize the detention pond design.

The performance of any specific structure will depend on the pond's design, the characteristics of the area contributing runoff to the pond, and the degree of maintenance (Nipper, 2016). Poorly designed ponds or unplanned changes in the catchment can make the ponds ineffective. In some cases existing urban drainage systems can cause problems of flooding, pollution or damage to the environment. For example, the Faculty of Engineering Retention Pond (FERP) (Figure 1) which functions well under average rain storm conditions have been known to exacerbate the flooding problem on the St. Augustine Campus during high intensity rainfalls resulting in the flooding of laboratories and offices.

The FERP was developed after a number of years through the conversion of a small agricultural pond that was used for the irrigation system for vegetation as well as a source of drinking water for animals. The establishment of the university and the new buildings required a number of new drainage systems to remove excess surface runoff on the campus. These systems were then connected to the catchment pond which was subsequently converted to a retention pond. The recent rapid expansion of the St. Augustine campus through the construction of new buildings and car parks within the small catchment reduced its permeability and increased surface water runoff. This reduced opportunities for water to be managed naturally and increased the potential for pollution and localized flooding whenever extreme rainfall events occurred.

There are various objectives and criteria of drainage systems. There is now general agreement that for drainage systems to be sustainable they should integrate water quality, water quantity, and biodiversity and amenity aspects (Stahre, 2006: Charlesworth, 2010). During the 1990s a wetland system was created within the St Augustine pond and was used by students for biodiversity studies. Based on anecdotal evidence, the small wetland system impacted positively on the water quality. The wetland system within the pond was maintained by the removal of vegetation and sediments every two or three years, at tremendous cost.

Sustaining the wetland meant ensuring that there was sufficient depth of sediments for plant growth. This, however, meant a reduction in effective storage for flood mitigation. Following a number of flooding incidents, the wetland system was removed and in 2015, storage below ground level was restored by the removal of sediments below ground level, and a pumping system was installed for drainage below ground level. This was a single-objective approach intended to improve the performance of the retention pond by addressing only the quantity aspect. The opportunity for multiple disciplinary involvement in the operation of the pond and the biodiversity component was discarded. It is intended that the pump would draw down collected between storm events which would provide increased storage space for the incoming storm. The pumping system has provided increased flexibility and some improvements have been observed. This approach may yet provide a useful way for managing existing detention ponds in urban areas where space for expansion is limited and where future development can compromise design efficiency.

There are many modelling approaches for sustainable drainage systems, however there are still limitations in their ability to mimic the natural response of the devices from a quantity and quality stand point (Zhou 2014). Further, while there have been calls for increased use of detention ponds in Trinidad and Tobago (IDB 2013), little research has been done on the actual performance of detention ponds. The aim of this study is to use hydrological simulations to investigate the performance of the FERP, using representative rainfall data for historic, current and projected future conditions.

Methodology:

Research site

The catchment that feeds the retention pond is approximately 7.5 hectares with the longest water course of 735m and an average slope of 0.0082. The pond is rectangular in shape with dimensions of 30m by 26.5m, has a total storage capacity of 1872m^3 and a maximum depth of 3.7m (Appendix A). An automatic pump was installed with a maximum pump efficiency flow rate of 0.027m^3/s corresponding to a head of 20.73m. The pump is switched on when the depth of water in the pond is 2.2m at the downstream end of the pond.

Using the measurements a relationship between the changes in storage, pond volume, pond depth and pond discharge were developed. Further, the outlet was modelled as a broad-crested weir according to Equation 1 (Appendix BBA). When the flow overtops the outlet structure, water is restricted to a section of about 2m wide above the weir and flow is now modelled as a rectangular orifice plus a broad-crested weir.

The time of concentration was estimated using Kirpich Equation (Kirpich, 1940). Rainfall intensities for the time of concentration were obtained from intensity duration frequency curves available for St. Augustine **(Cooper, 2016).** A runoff curve number which was based on the characteristics of the catchment include soil type (clay loam), land cover and infiltration rate (3.8 mm/hr to 7.7 mm/hr). The respective areas which contribute to the respective land cover were also measured using ArcGIS. This soil was determined to be in Hydrologic Soil Group B. A curve number (CN) of 78 was obtained for the site and used for simulating hydrographs using the Natural Resources Conservation Service (NRCS), formerly Soil Conservative Services Method.

Inflow hydrographs for four historic storms (1994, 2000, 2006 and 2010) were obtained using the NRCS derived 20 minute unit hydrographs with the recorded total rainfall depth for the respective years. The excess rain was obtained by deducting constant rate of abstraction.

A Microsoft Excel programme was developed for the simulations. Simulations for scenarios with different retained volumes in the pond with and without pump use were carried out using the Modified Pul's Method. Outflow hydrographs were generated from the stage-storage and stage-discharge storage relationships (Mays 2004).When the pump is to be used it is switched on when water depth was 2.2m at the downstream end of the pond. Further, scenarios for climate change were performed using the 2.05% annual change in precipitation per decade.

Results and discussions

The relationship between flow and storage for the hydrograph routing simulations was found and shown in Figure 2

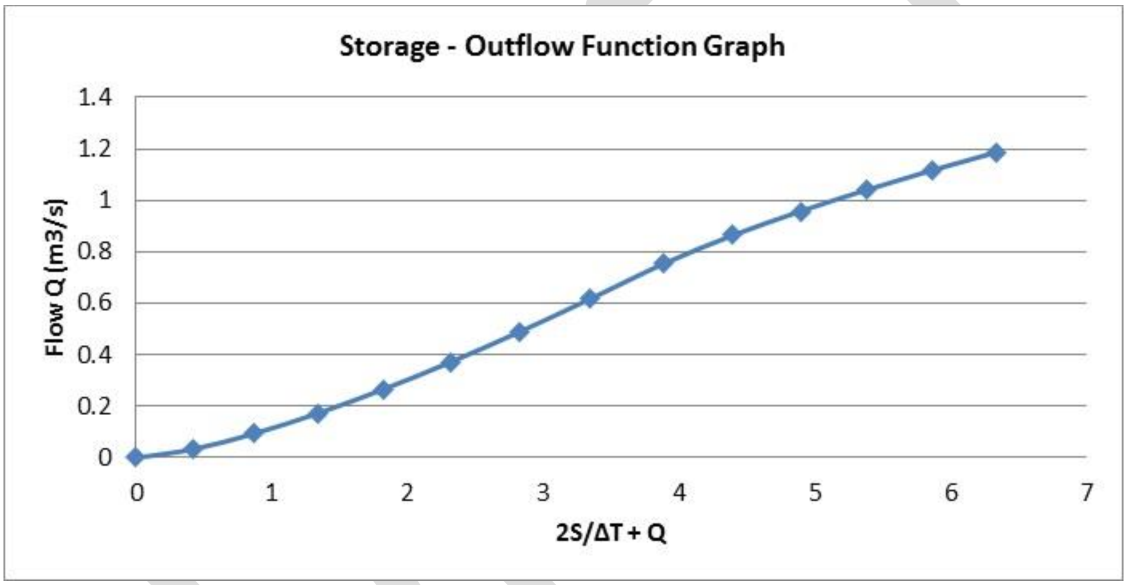

Figure 2: Storage-Outflow Function

The 20 minute unit hydrographs developed for the site is shown in Figure 3. The time of runoff, is realistic, as based on anecdotal information, the flows from storms last for about 40 minutes to an hour after the cessation of storms.

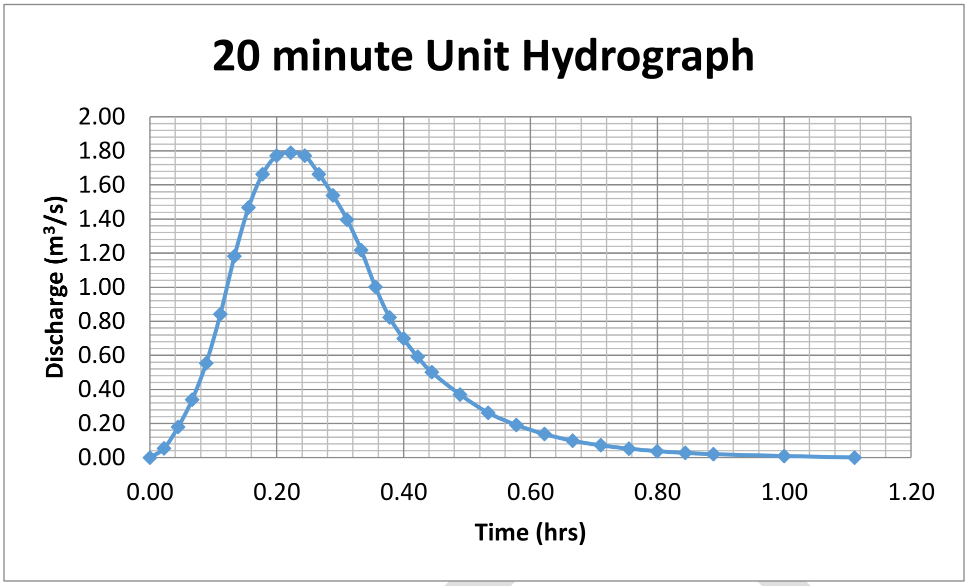

Figure 3 Twenty minute unit hydrograph

The hydrographs simulated based on the 20-minute hydrograph are shown in Figure 4, were generated from the historical rainfall data for the four most intense rainfall events chosen between the periods 1994 to 2010. The simulations were carried out assuming that the FERP was full. Further, most of the rain in these storms fell over a period of approximately one hour duration (see Table 1). Reports of flooding (Photograph 1 in Appendix B) from these events suggest that the 1994 and the 2010 events were more severe and are consistent with the peak flows of the hydrographs generated by the NRCS simulations. It is to be noted that in all four cases the storms lasted for approximately one hour and that the rains were similarly distributed over the period as shown in Table 1. Although there is no data to validate the results, the results are consistent with the cumulative storm rainfall and anecdotal evidence suggests that the floods of 1994 and 2010 were far worse than those of 2000 and 2006.

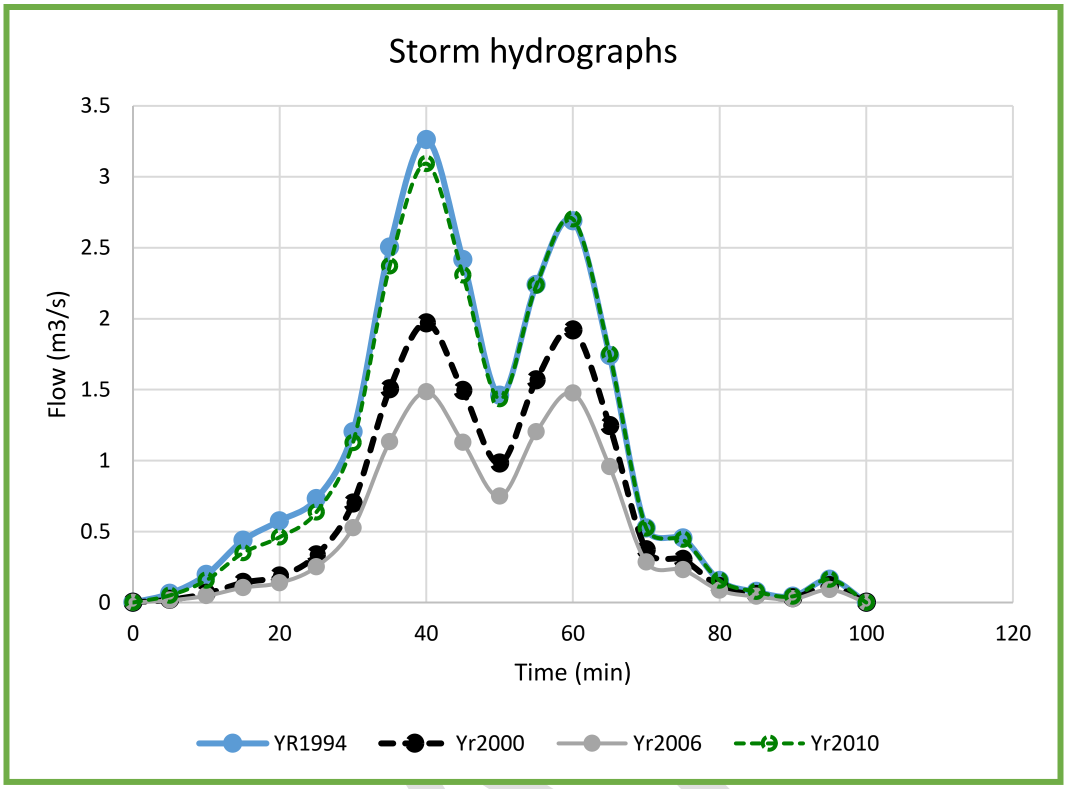

Figure 4: Simulated Storm Hydrograph for historic extreme storms

In the worst case scenario, that is, when the pond is full at the beginning of a storm, the peak flow from the catchment can be reduced by an average of 45%. The storage capacity above the weir retards the incoming flow. As the water in the pond is lowered, the peak flow is further reduced although not significantly. Simulations were carried out for all four storm conditions with scenarios for different conditions of the pond. Figure 5 shows the result for the 1994 storm. When the water in the pond is at the level of the pump, that is when the pond is effectively empty, the peak flow can be reduced by a further 4.4% to about 22%. It was observed that if the pump is activated for cases when the pond is empty and full, there is little improvement by way of further reduction in peak flows.

Year	1994	2000	2006	2010
Total rain (mm)	127	82	86	110
Distribution of rain as a (%) over 20 min periods ($1^{st}/2^{nd}/3^{rd}$)	30/45/25	31/42/26	31/41/28	31/43/25
Inflow peak flows	3.26	1.97	1.48	3.09
Reduction in peak flow with pond full (%)	51	42	37	50
Reduction in peak flow (0.99m)	51.9	42.2	41.3	51.2
Reduction in peak flow (0.38m)	54.5	48	50.0	52.2
Reduction with pond empty (surface at level of pump)	55.2	51	59	54
Pond at pump level and pump activated	55.9	51.0	59.0	54.4

When allowances are made for climate change, for a 25 year storm, the peak flow would be reduced by 32% in 2030 and 34% by 2050. Further, for an increase of 15% to 20% in total precipitation and precipitation intensity or the four historic storms, it was found that the average reduction in peak flows was 48% compared to 45% under current conditions. However, this enhanced reduction in the future does not tell the whole story, since, the reduction relative to current reduced peak flows indicates that the effectiveness of the pond would be slightly diminished since the future reduced peak flows would be about 5.2% higher than present. This effect which can result in an increased likelihood of flooding can be mitigated by proper use of the pumping system.

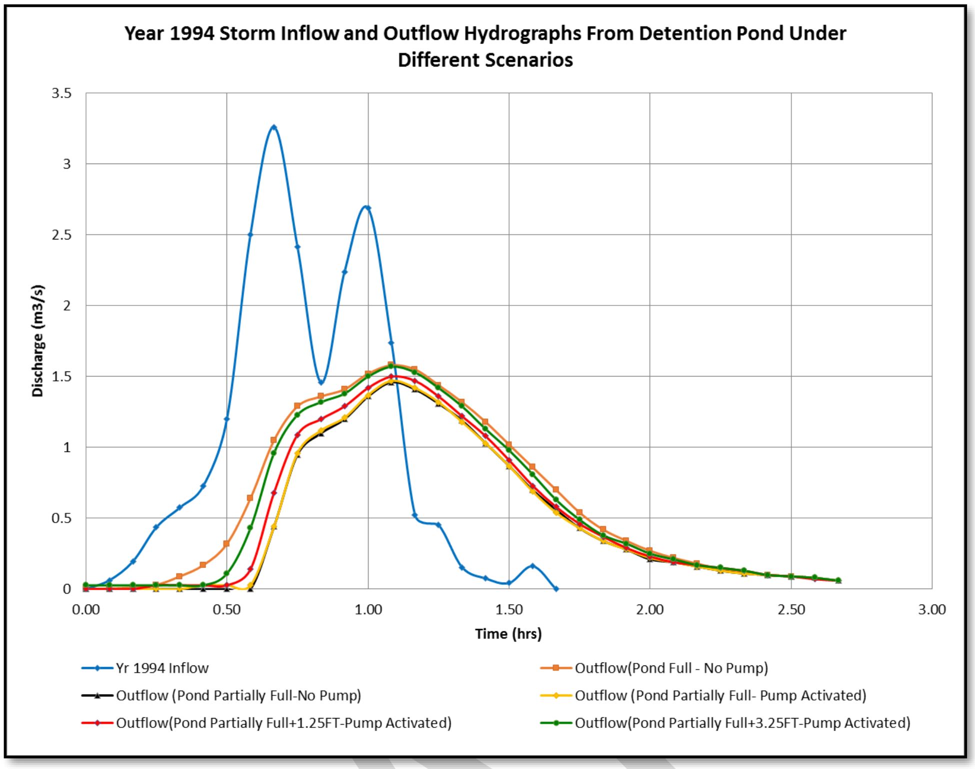

Figure 5: Simulated performance of the FERP for various scenarios.

Conclusions and recommendations

A short-coming of this research is that there are no actual flow data with which to validate the simulation. Notwithstanding, the results demonstrate what is possible under varying scenarios. The most important condition in operating the pond with a pump activated is when the pond is empty. Hence the pump is most useful in emptying the pond after a storm.

An increase in precipitation totals and intensity of up to 20% would increase the peak flow under the detention pond operation by only 5.2%. This could be controlled by the use of pump.

The pond would continue to be effective in the future if a pump system is used to reduce the effect of increased peak flows.

If the pump is activated when the pond is close to full or full, the peak of the outflow could increase negating the purpose of the presence of the pump.

The research should be continued to determine the best operating condition for the pump, particularly where there are multiple storms over a short period.

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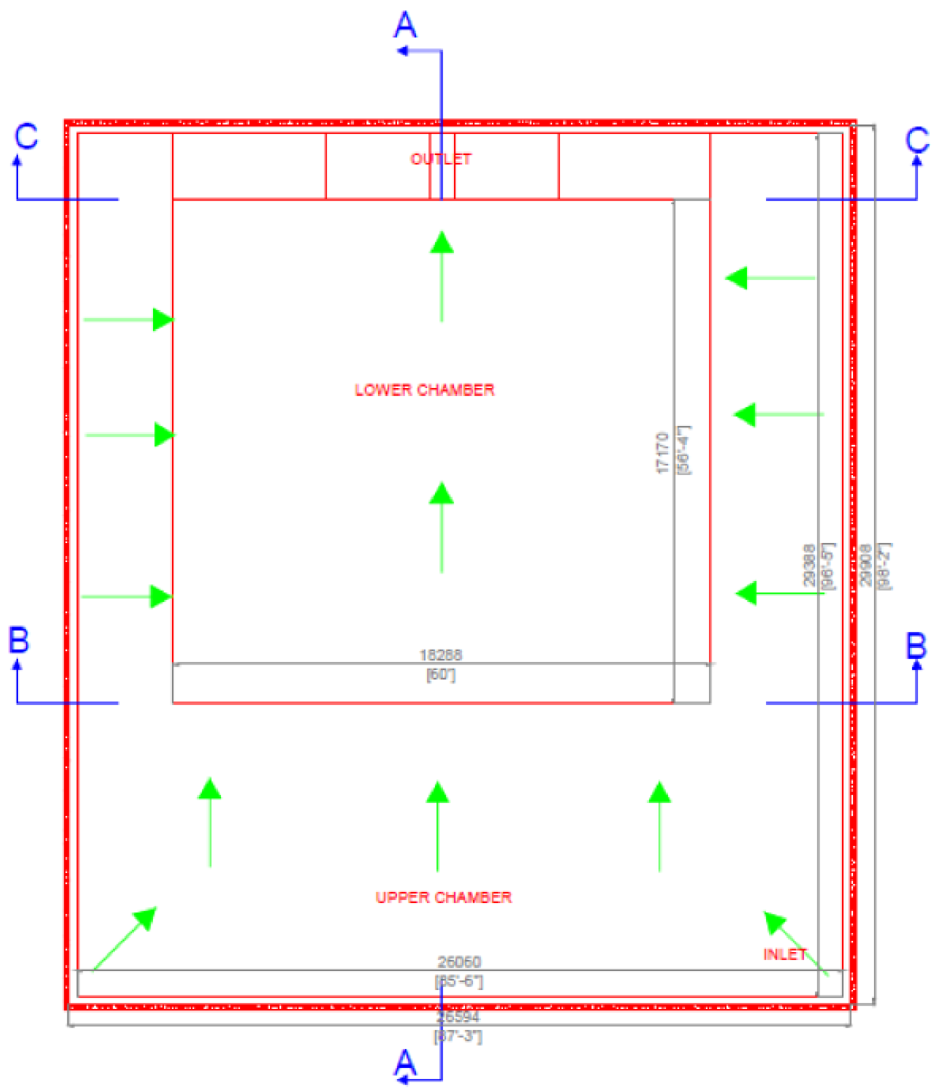
Appendix A: Sketch of pond



Appendix B

$$Q - \frac{2}{3} C_d .B.\sqrt{2g}(H)^{\frac{2}{3}} \text{ Equation 1}$$

$$Q = \frac{2}{3} C_d B.\sqrt{2g}(H_2^{\frac{3}{2}} - H_1^{\frac{3}{2}}) \text{ Equation 2}$$

Where Q (m3) is the flow rate over the weir

C^d is the discharge coefficient

H (m) is the head over the weir from the weir crest

B (m) is the width of the contracted rectangle or the width of the channel suppressed

'g' is the acceleration of gravity (9.81m/s^2)

Photograph A: Flooding in the Engineering Faculty