Incorporating Green Infrastructure into Stormwater Management –

Assessing alternate strategies to address flooding in Port of Spain, Trinidad & Tobago

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Introduction

Climate-related hazards like storms, floods and droughts are the most common disaster related events in the Caribbean region (United Nations, 2016). Warmer global temperatures directly impact the hydrological cycle resulting in higher incidence of intense storms, especially in tropical regions (Kumar, 2012). The region's geographic location combined with current land use practices result in an adverse combination which is partly unavoidable but can still be managed for less disadvantageous results. Additionally, water demand doubles every 20 years, twice as fast as population growth (Lohan, 2008). This calls for a transformation in the way we acquire and use water. The effects of global warming and climate change require multi-disciplinary research especially in the face of global water (im)balances. It is in this context that the issue of flooding needs to be considered holistically with an element of water consciousness.

Large flood events in cities worldwide have heightened concerns about the effect of land use and human development on the landscape's ability to absorb and convey rainfall as it occurs in the urban environment. It is anticipated that by 2050 the urban population will increase by 3 billion people, and any developments to accommodate this increase will result in further changes in the way water is distributed within the hydrological cycle, and in some cases resulting in flood events. Increased variability in weather extremes associated with climate change has added to the incidence of flooding worldwide either because drought conditions result in reducing the infiltration capacity of soils (leading to increased surface runoff when rainfall occurs), or in some regions more intense rainfall events which exceed the capacity of natural and man-made structures to contain runoff.

Floods are natural events. In Trinidad and the rest of the Caribbean, floods sometimes occur when rivers overflow their banks, because of heavy rainfall. Torrential downpours especially during the rainy season is the primary cause of flooding but in urban settings flooding is exacerbated by human activity. Butler and Davies (2004) describe stormwater as “rainwater (or water resulting from any form of precipitation) that has fallen on a built-up area”. They add that “stormwater requires effective drainage to avoid flooding and related issues as stormwater can contain pollutants from rain, the air and catchment surfaces” (Butler & Davies, 2004).

Impermeable surfaces such as roads, paved car parks and roofs, which are characteristic of urban areas, contribute to more significant runoff rates and influence the occurrence, frequency and severity of floods. When rain falls within a watershed these surfaces convey the water rapidly toward a nearby body of water (e.g. river or ocean). Reversely, when surfaces are permeable or contain vegetation, rainwater is infiltrated into the ground or captured and evaporated. Port of Spain, Trinidad is typical of urban centres around the world reaching 100% impermeability for some residential and commercial properties. It is estimated that “an increase in watershed imperviousness of only 10% negatively impacts the receiving streams, lakes, rivers and oceans. Figure 1 shows the effect of imperviousness on the hydrologic cycle. Seventy-five percent imperviousness results in over 55% runoff with less than 15% infiltration. This is significant as drainage infrastructure was developed to remove large volumes of runoff with little consideration to environmental impacts. “As a result, streams that receive stormwater runoff frequently cannot convey the large volumes of water generated during runoff events without significant degradation of the receiving stream (US EPA , 1999).”

Green infrastructure is a method of low impact development (LID). It "differs from conventional approaches to open space because it looks at conservation values and actions in concert with land development, growth management and built infrastructure planning" (Benedict & McMahon, Green Infrastructure: Smart Conservation for the 21st Century, 2001). It integrates vegetation (trees, shrubs, wetland vegetation) with man-made drainage infrastructure and includes structural landscape design features which mimic natural processes to reduce runoff and therefore flooding. This is the definition applied in the paper. Conventional single-purpose gray stormwater infrastructure systems are designed to rapidly move urban stormwater away from the built environment. Green infrastructure on the other hand, reduces and treats stormwater at its source while delivering environmental, social, and economic benefits to urban areas (US Environmental Protection Agency, 2015). Incorporating green infrastructure into urban landscapes offers a number of advantages over traditional, engineered stormwater drainage approaches. The main benefit is to the ecological functioning of the watershed as green infrastructure discourages runoff and encourages infiltration and ground water recharge for access during drier periods. As it relates to flooding, green infrastructure is a form of (rainwater) source control which slows, sinks and spreads water on-site and if applied over multiple sites in a watershed, can potentially reduce the need for larger conveyance-type flood control measures in lowland areas (The Partnership for Water Sustainability in BC, 2014). Green infrastructure techniques such as rain gardens, bio-filters, bio-swales, and infiltration practices are landscaped depressions that collect runoff and manage it through infiltration, evapotranspiration, and biological uptake of nutrients and other pollutants. Porous pavement, planters, tree boxes and rainwater harvesting techniques all contribute to capturing water and reducing runoff.

Integrating green infrastructure into a stormwater management plan for Port of Spain can not only reduce flooding but can create and enhance recreational spaces for the city's users, while subsequently addressing drought concerns through rainwater re-use strategies and artificial aquifer recharge.

There were several objectives of this study; firstly it aims to investigate current strategies used to address flooding in Port of Spain. Secondly to determine if green infrastructure can be successfully incorporated into a broader stormwater management plan in POS. Finally, the paper attempts to use illustrative examples of how green infrastructure can reduce flooding in Port of Spain.

The diagrammatic representations presented here are utilized as part of the analysis but are not intended to model or provide predictions on the performance of the techniques proposed, as there was insufficient data available to make these assurances; however, it will introduce the option of green infrastructure in becoming an integral part of any future stormwater management strategy and demonstrates the multiple benefits possible from incorporating this technology in the Port of Spain context.

Methodology

The study utilized a combination of personal and email interviews as well published literature. The Inter-American Development Bank (IDB) Flood Alleviation and Drainage Program was examined as it represents the current initiatives being undertaken by the Government of Trinidad and Tobago in their attempts to reduce flooding in the Capital city. Moreover, the current legislative and institutional framework for planning, water and drainage were examined to gain understanding of the support for drainage management and planning in Trinidad.

Renderings and diagrammatic representations of Queens Park Savannah (QPS), Brian Lara Promenade and South Quay were created using Google earth. Design software enhanced photos and other desired features. The renderings created provides a visual representation of green infrastructure at those sites and are intended to initiate community discussion on the possibility of incorporating this technique into the urban landscape.

Study Area

The Republic of Trinidad and Tobago is located at the southern end of the Caribbean archipelago at approximately 11° north of the Equator. The Islands experience a tropical climate with well-defined wet and dry seasons. Average annual rainfall is 1800mm and is concentrated in the wet season.

The City of Port of Spain has served as the capital city of Trinidad since 1757. The landscape is relatively flat and sits at the base of the Northern (mountain) Range extending like a delta fan south towards the coast. The mountain range, mild topography and the coastal location of the City all influence the occurrence of flooding in the city. Additionally, a large section of the outskirts of Port of Spain has been reclaimed and mangroves were removed to facilitate the expansion of the city southward.

The study area is demarcated by the Maraval River and the St. Ann's River to the west and east respectively; north by the foothills of the Northern Range at King George V Park & Queens Park Savannah and south at the coastline. This area represents the majority of the City of Port of Spain but does not represent its official boundaries.

Soils in Port of Spain belong to the Luxisol group which are strongly weathered and consists of fine-textured clay material which is leached to some depth. This soil group is mostly free-draining except where organic content is high (DHI, 2013). Urban soils however rarely follow the sequence and structure of their natural soil groups because they are highly influenced by human activity. They are often “disturbed in portions of the profile. Or perhaps the entire profile may consist of fill (as in the coastal regions of Port of Spain that have been reclaimed) and man is the agent of disturbance” (Craul, 1992). Urban soils are also heavily compacted and unlike soils in the natural environment do not have proper structure and lack organic matter.

Installation of any green infrastructure technique in Port of Spain will require soil enhancement with carefully selected soils.

Map 1: Aerial view of Study Area

Flooding in Port of Spain

Though some observed flood locations are in close proximity to the main river channels and flooding can be attributed to the rivers overflowing their banks, some are thought to be caused by the high degree of impermeability and topography of the city as well as the grid-like street pattern conveying the runoff from roofs and car parks with the streets adopting the role of a paved channels moving water to the lowest point. It has been reported by the Drainage Division that there is a relative absence of underground drainage throughout the city from the Queens Park Savannah south to the Brian Lara Promenade – a distance of approximately 1.6 km through the city from north to south – so streets become part of the drainage system when there is heavy rainfall beyond the capacity of the slipper drains.

Issues affecting flooding

Apart from rainfall intensity, four main issues that influence flooding in the city of Port of Spain. Firstly, drainage infrastructure in the City is insufficient for the volume of runoff that is generated during intense storm events. Underground drainage infrastructure was constructed in the 1940s and since that time the density and structure of the city has been altered dramatically. The free flow of water is further restricted and its structural integrity compromised in some areas by the installation of water mains within the drainage system. Additionally, officials of the Drainage Division have lamented the absence of grates where underground drains are exposed at the surface, as this leads to solid waste and debris entering the drains further reducing their capacity to contain and move water during a storm event. Insufficient catch pits in the drainage system results in extreme siltation after heavy rainfall events. These issues are compounded by construction activities taking place within the city and on the outskirts higher in the watershed. In fact, construction of high income homes and commercial buildings in the Maraval and St. Ann's areas have been influenced by the expansion of the city northward. DHI identifies the progression of the urban limits higher into the watershed as beginning in the 1980s (2013). They continued that it was also at that time that the city became increasingly densified and therefore increased its level of impermeability within and outside of the city limits (DHI, 2013).

A plan view of Port of Spain reveals a dense network of impermeable surfaces. There is an estimated 80% Impermeability within the city's boundaries, nearing 100% in some sub-areas including the downtown core. (DHI, 2013). There is no benefit to having this degree of imperviousness neither to the users of the city nor to the environment as "impervious surfaces have profound impacts on hydrology, eliminating infiltration and thus increasing dramatically the volume of surface runoff" (Fletcher, Andrieu, & Hamel, 2012).

In Port of Spain, a torrential downpour in the early afternoons can sometimes coincide with high tidal patterns. High tides result in the drainage outfalls that enter into the sea to be submerged; consequently, stormwater has no way to exit the city, and so flooding is strongly influenced by tidal changes ((DHI, 2013). The Inter-governmental Panel on Climate Change (IPCC) estimates that the global mean surface temperature will increase between 2 to 4 ^{o}C by the year 2100 (The CARIBSAVE Partnership for UNDP, 2010). Based on this estimation, sea level in the Caribbean is expected to rise between 1m and 2m in the next 100 years (ibid). The report estimates that with a 1m sea level rise, the urban area in Trinidad will lose 1% of its land base, which can significantly impact the city's port facilities and main transportation networks located within a few meters of the coastline. This sea-level rise projection must also be considered in any stormwater management strategy for Port of Spain as sea level rise will influence flood levels.

Additionally, the city is afflicted with the issue of littering. A June, 2015 newspaper article reporting on floods in the city quoted both the CEO of the Office of Disaster Preparedness and Management (ODPM), Dr. Stephen Ramroop and the Deputy Mayor of Port of Spain, Keron Valentine, as identifying the cause of flash floods being an inundation of litter and garbage on the streets and collecting in the underground drainage systems (Trinidad and Tobago Newsday , 2015). Solutions to littering must also form part of an effective stormwater management plan.

Infrastructure development and planning

Large residential developments and commercial structures have been built within the city limits as well as in surrounding areas over the past 10 – 15 years. These, along with numerous smaller scale projects have affected runoff rates in the city. Though development of the City is encouraged there must be more rigorous focus on adherence to development standards and density.

Traditional methods of flood mitigation must be reviewed with an aim to consider and develop best management practices to address the issue of stormwater. Enhancing urban drainage infrastructure is important but insufficient in addressing flood mitigation. Concretizing, reducing the width and increasing the depth of streams only serve to quickly convey water from higher in the watershed to lowland areas.

If passed as an Act of Parliament, the Planning and Facilitation of Development Bill provides a platform for the orderly development of land, similar to the Town and Country Planning Act before it. In the case of Port of Spain which is already largely covered with buildings and other infrastructure, the use of the proposed Comprehensive Development Plans may provide additional support to the implementation of green infrastructure. Parcels of land may be acquired or available land used to develop green infrastructure for flood management.

Many countries are now treating stormwater as a resource instead of a nuisance and are including green infrastructure requirements in policy because source control techniques have been seen to improve water quality, reduce runoff and provide aesthetic benefit to urban areas.

At its core, urban stormwater management requires a combination of land use planning, engineering, ecological restoration and water resource management professionals to work together to customize solutions for a city. In many jurisdictions it is difficult to get all these skilled professionals in the right combination with incentive to consider shifting from traditional engineering methods to approaches which place a greater emphasis on returning the watershed to its natural water balance.

One challenge to implementation of a stormwater management strategy is the cost associated with execution of such projects. This is especially true in Port of Spain urban areas, as they are extremely densified so land acquisition would be expensive. The increased incidence of flooding in cities however provide an incentive to consider alternative options to existing structural solutions.

Incorporating Green infrastructure into the urban landscape

Flow retardation methods should be considered to address flooding in Port of Spain. Firstly, detention and retention basins can be utilized to capture and store water for short periods or drywells and infiltration basins can remove the water from the surface, and later be utilized for artificial groundwater recharge.

Additionally, rainwater harvesting must be considered on a large scale for commercial and residential properties in Port of Spain to support these green infrastructure options.

Dunn 2010 sites numerous examples of cities which have benefited from supporting green infrastructure strategies. The City of Portland, Oregon reportedly invested $8 million in a program to subsidize the disconnection of downspouts. This, along with other investments specific to green infrastructure improvements, have resulted in keeping 1 billion gallons of stormwater out of combined sewer systems and increasing groundwater recharge. (Dunn, 2010). The City of Seattle, Washington launched the Street Edge Alternative project in 2011; the project decreased impervious surfaces by 11% and reduced stormwater runoff by 99%. The city of Philadelphia incorporated green infrastructure into their planning policy in 2006 and to date are reported to have saved $170 million in flow reduction. In a five year study based on the construction of wetlands in Michigan, the research found "in addition to reducing flows, the wetlands reduced total suspended solids by eighty percent, total phosphorus by seventy, and oxygen depleting substance and heavy metal concentrations by sixty percent"(ibid).

The Greenseams program in the Milwaukee, USA metro area is utilizing constructed wetlands to restore and protect urban streams (Metro, 2002). Wetlands act like nature's sponges ensuring that the destructive effects of floods are mitigated. It is estimated that the area created by the project undertaken by the Metro Group can hold 1.3 billion gallons or approximately 1,970 Olympic-sized swimming pools of water. The project has also been utilized as a community and recreational site. (Metro, 2002).

Sustainable urban afforestation may be considered a green infrastructure technique and it could be utilized in Port of Spain. There has been considerable research into the role of trees in absorbing, transpiring and retaining rainfall. Street trees perform many functions that help to reduce the volume and rate of stormwater runoff entering the drainage system and therefore delaying the onset of peak flows (Metro, 2002). There is need to significantly increase green space in Port of Spain and this can be initiated by increasing tree numbers in the cityscape.

There are a large number of parking lots scattered throughout the city of Port of Spain. During periods of heavy rainfall, stormwater runs off these impermeable surfaces and flows into drains or the street, and becomes a major contributor to runoff. Runoff from carparks are highly polluted with hydrocarbons and pose a threat to receiving environments. If this runoff can be infiltrated at source into a biological medium such as a well-designed bioswale or rain garden which can treat some of the water before it reaches a stream, this is preferred. Installing pervious pavement or diverting runoff to infiltration trenches or bioswales are both commonly used green infrastructure options on parking lots.

Potential opportunities for Implementation of Green (Stormwater) Infrastructure: Example sites

Queens Park Savannah Aquifer Storage and Recovery Area

The 110 hectares that make up the Queens Park Savannah (QPS) serves as a traffic roundabout with a large green space and is a dominant landmark in the city of Port of Spain. The St. Ann's River once flowed through the QPS following the natural topography of the land. It then flowed through the center of the city down Chacon Street but was diverted in 1787 east of the built-up areas to its current location. According to the Water Resource Agency (Division of WASA), the QPS is a major collection point for water within the St. Ann's watershed. There is an opportunity for water to be stored in the QPS to prevent storm drains in the lower portion of the catchment from becoming overwhelmed. Moreover, the QPS's geological composition is suited to water storage and recovery. Ramkhalawan (1999) describes the area as forming alluvial fans at the mouth of the river valleys (Maraval and St. Ann's) with "porous gravel, limestone beds and alluvial deposits consisting of interbedded sand and gravel with boulders and clay". This geology signifies possible recharge capacity in the Savannah to support the existing well field in the QPS.

Urban green spaces need not have one use or function. In the case of the QPS, its main use and function is recreation, while maintaining its historical significance to the people of Trinidad and Tobago, yet most of this space is under-utilized for a significant portion of the calendar year. Green infrastructure solutions can be applied to the QPS; small sections of the Savannah can be used as a stormwater retention and artificial recharge site which can capture, store and recharge water to underground aquifers and increase capacity for supply. At least 10 hectares of land within the interior of the savannah can be converted into a retention pond, specifically designed for aquifer recharge (Figure 5b). Artificial recharge is "a process by which excess surface water is directed into the ground – either by spreading on the surface, or by using recharge wells, or by altering natural conditions to increase infiltration – to replenish an aquifer" (National Research Council, 1994).

Unfortunately, it is often expensive to utilize urban stormwater runoff for artificial recharge because of treatment requirements, therefore cost-benefit analysis of this option would be required determine its feasibility.

In light of climate change predictions, southern parts of the Caribbean are expected to experience higher temperatures and extended dry seasons resulting in water availability challenges. This paper calls for "improved management of water resources and mechanisms to ensure that scare resources are allocated and used in the most efficient and effective manner" (Global Water Partnership, 2014). Desalination is often suggested to address urban water shortages in Caribbean Islands, however this method is both expensive and unsustainable as it utilizes vast amounts of energy; such a system requires 3 to 4 kilowatt hours to produce 1000 litres of fresh water (Deutsche Welle - Environment, 2011). The article continues that no studies have been completed on the effects to marine ecosystems of dumping the waste material/ brine back into the oceans (ibid). If freshwater could be captured and treated, it would come at a much lower cost and is a more environmentally sustainable option to desalination which requires large land area for operation and whose environmental effects are unknown.

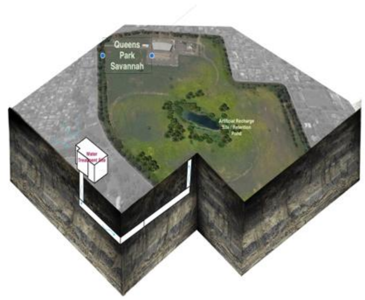

Figure 5a: Image of the QPS showing the St. Ann's river & proposed water treatment area. *Figure 5b: Simplified illustration of proposed aquifer recharge in QPS..*

If stormwater is retained and infiltrated into a system at the QPS, it can serve to increase the city's freshwater supply as well as reduce the volume of water moving downstream. Further research into water volumes at the proposed treatment site (see Figure 2) and water quality out of the St. Ann's river is required to determine the feasibility of utilizing this option; however, there is ample space and great opportunity to build a stormwater detention pond or wetland here which could integrate seamlessly into the existing public green space. A wetland would slow and store runoff while enhancing the aesthetics appeal of the savannah, provide a space for wildlife habitat, offer be an educational demonstration center and other benefits for community involved.

Brian Lara Promenade Bioswales

The location of the Brian Lara Promenade along Independence Square, Port of Spain makes it an excellent potential site to incorporate flood mitigation measures. Moreover, the site already serves as a green space and recreational site and the additional of bioswales will only enhance its current function and aesthetics.

Given that the entire length of Independence Square is flood prone, stormwater could be directed to bioswales (designed as illustrated above) along the length of the Promenade. If stormwater could be temporarily stored here it will result in reduced flows to South Quay. It is not expected that these bioswales can contain all of the runoff south of the QPS, but will require additional support to retain water throughout the city from the use of rainwater harvesting techniques, rain gardens and individual properties working at retaining some water for a few hours after a rainfall event. If this is done, then the bioswales will be much more effective.

Figure 6a: Section of Brian Lara Promenade Figure 6b: Rendering showing BLP bioswales and enhanced tree cover

Figure 6a shows a section of the Brian Lara Promenade (BLP) at intersection of St. Vincent Street & Independence Square. The grassed areas are lawn that are not well maintained, the path is constructed of concrete pavers. Figure 6b is an enhanced image of the same site. The grassed areas have been replaced by bioswales which include salt-water resistant plants. The bioswales are constructed with various materials including different sizes of sand and stones to encourage infiltration. Given that bioswales are not as effective during high storm flows, other strategies such as large scale disconnection of stormwater pipes as part of a rainwater harvesting strategy north of this site should support these bioswales. Parking lots must also retain their stormwater on site and littering in the street must be drastically reduced. Proper bioswales construction and maintenance are required to to derive complete benefit from this technique (ABC, 2016).

Downtown - South Quay Wetland

Figure 7a: South Quay.

Figure 7b. Illustration of proposed changes to detention pond at South Quay.

Figure 7a is a diagrammatical representation of the current uses of the site at South Quay. This site was acquired in 2007 by the Trinidad and Tobago Housing Development Corporation and cleared for the construction of the Eastbridge housing development. It consists of 4 separate parcels of land along the South Quay causeway. Eastbridge would have required extensive and costly infrastructural upgrade to alleviate flooding as the site experiences intense flooding because of its proximity to the St. Ann's river and low-lying topography. Since the Eastbridge project was shelved, part of the site was hurriedly constructed into a detention pond in 2011 to alleviate flooding at that time, the rest of the site is essentially un-used except as a footpath for access to communities north and south of the site.

Figure 7b shows potential re-purposing of this site. The detention pond should remain; be extended a few meters toward the river channel (St. Ann's River). This extension would serve to connect the river to the detention area in times of high stream flows. The now expanded detention pond can be further amended to create a wetland. These alterations to the site can result in reduced flooding in South Quay. This proposal prohibits access to persons currently using the footpath on the vacant lot so elevated platforms are proposed to allow movement across the pond and over the 4-lane causeway. Additionally, as part of the final development plans for the entire site, soil enhancement strategies should be introduced to increase infiltration. Bio-swales, rain-gardens and other green infrastructure and low impact development strategies should be actively pursued whenever the site is developed in the future.

CONCLUSION

Flooding in Port of Spain is a multi-faceted problem that cannot be solved without a detailed plan. The city has expanded without considerations for the hydrological systems within it and this has led to flooding. Traditional conveyance methods and drainage infrastructure are necessary for urban systems but they only represent part of the solution. To target the issue of flooding in the city of Port of Spain, alternative options must also be considered. Green (stormwater) infrastructure has been used as a “cost effective, resilient approach to managing wet-weather impacts while providing community benefits” (US Environmental Protection Agency, 2015) in other urban centers. Several potential sites have been identified as opportunities for implementing pilot projects in Port of Spain with emphasis on data collection, community outreach, education and feedback.

The complex nature and physical structure of the study area requires a combination of traditional drainage infrastructure as well as green infrastructure techniques to impact flooding. In the three examples described for potential installation, additional support to retain water at source (utilizing rain gardens, rainwater harvesting, permeable paving etc.)

is essential to success as these sites and techniques are insufficient to significantly reduce the volume of runoff generated by development within and outside of the City of Port of Spain. The three sites proposed are all state-owned and the state can initiate these strategies without the need for land acquisition, however consultation with related stakeholders is required.

There is need for legislative and institutional reform to support stormwater management initiatives in Port of Spain. This support must emanate from the highest level of government and across all levels of governance coupled with concerted efforts at collaboration between and among agencies responsible for stormwater planning and management. In light of predictions which identify sea-level rise, floods and drought as climate change realities for the Caribbean region, it is imperative that Port of Spain thrive to focus on solutions which mitigate against these climate risks. There is need to improve channels of communication between the different silos responsible for stormwater management to address the issue of flooding utilizing an integrated watershed management approach.

This study has revealed that there is currently growing support for innovative solutions to address flooding among a wide range of stakeholders including businesses, public sector organizations, NGO's, academics and other interest groups. This interest should be harnessed and supported to arrive at the most comprehensive solution to flooding in the city. A cost-benefit analysis of installing green infrastructure should be compared to short and medium term traditional drainage infrastructure options in future research.

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