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Stormwater Infrastructure and the threat of Climate Change

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Abstract

The purpose of this report is to analyze the modernization of stormwater infrastructure systems and the growing impact of climate change on said systems. Growing population rates and increasing urban settlement are leading to the water demand approaching the water supply capacity. Climate change is the root of several potentially severe issues affecting water resources as well as the rapidly increasing coastal and urban populations including but not limited to rising sea levels and the increasing severity and frequency of storms. Many cities, especially older or low income ones, also may not have adequate systems in place to handle the increased volume of water. As the environment changes at the pace that it is, cities and municipalities must work to adapt new policies and methods to keep their infrastructure up to date and improved if necessary.

Objectives

- Establish the presence of climate change and the stormwater infrastructure it can affect
- Observe how large cities are responding to the effects of climate change
- Analyze how different improvement methods can help mitigate the potential risks
- Analyze the studied results of gray infrastructure versus green infrastructure
- Discuss the economic impact of various improvement methods

Background – Climate Change as a Driving Force

This report will attempt to analyze the effect of climate change on the global environment with special focus on how it will impact existing stormwater infrastructure and what is being done to help mitigate any potential future effects. With global temperatures projected to increase by 4-5 degrees Celsius by 2100, this is an issue that has already begun to rear its head. With those temparature projections, sea levels are expected to rise by nearly 1 cm per year, and it is expected that by 2020 70% of all coastlines will feel the effects of rising sea levels.

As a warmer atmosphere can hold more moisture than a cooler one, the continued increase in global temperatures will lead to changes in precipitation. Since 1900, the average annual precipitation rate has increased by 5% and there have been larger changes observed per region of the United States during the period from 1991-2012 [1].

The increase in water vapor volume in the atmosphere has also led to an increase in frequency for stronger and more severe storms. Figure 1 on the following page shows the increases of precipitation falling in the top 1% of precipitation events from 1958 to 2012. It is projected that the trends shown will continue and that there will be more storms of similar or increasing severity. The extreme change in the Northeast United States is particularly concerning. Is the current infrastructure able to support the expected increase of stormwater volume? [2]

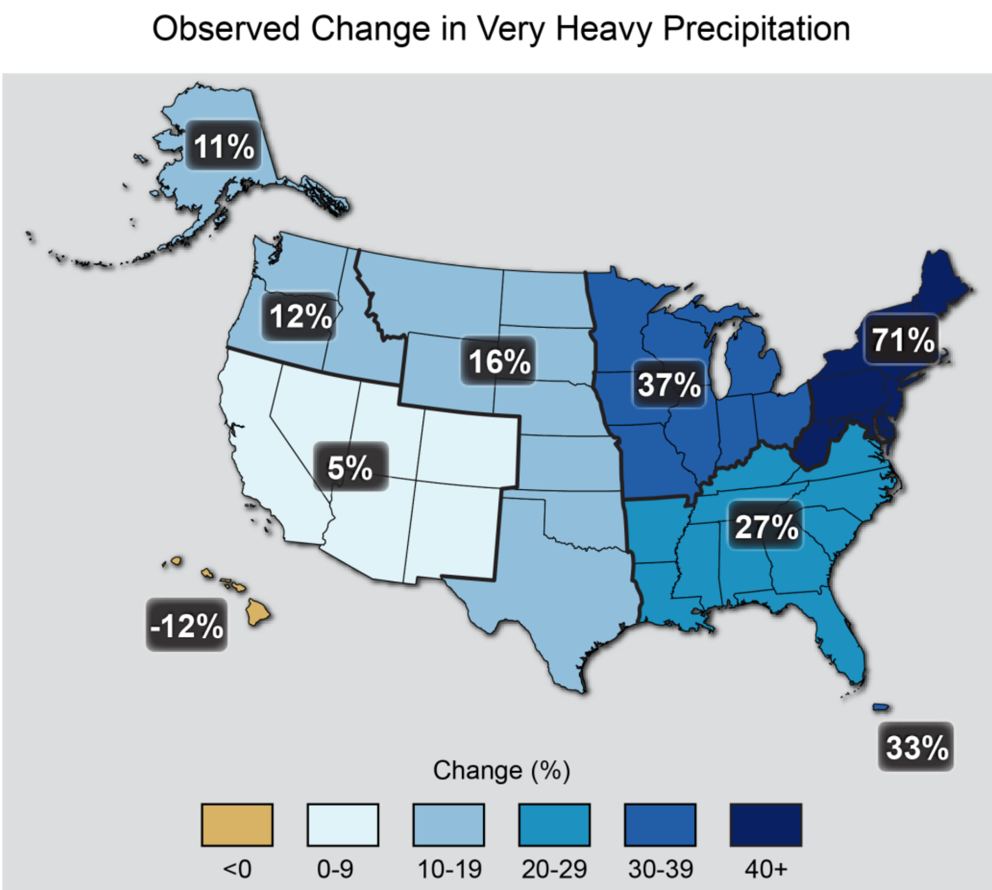

Figure 1: Observed Change in Very Heavy Precipitation [2]

Background – Combined Sewer Overflows

More modern cities and municipalities separate their storm sewer, sanitary sewer, and drinking water supply systems. In these cases, the stormwater drains to local natural bodies of water while the sanitary sewer and drinking water supplies are directed to their respective treatment plants. However, in older cities, the storm and sanitary sewers often drain to the same treatment facility where all the water is treated before it is discharged. If there is a very large volume of precipitation this system can overflow and spill out into the waterways. This is referred to as a Combined Sewer Overflow, or CSO. [3].

Combined Sewer Overflows, or CSOs, became under the control and regulation of the U.S. EPA in 1994. The EPA subsequently developed a set of guidelines for municipalities that would bring CSOs into compliance with the Clean Water Act. These guidelines are referred to as the Nine Minimum Controls [4]. They are as follows [4]:

1. Proper operation and regular maintenance programs for the sewer system and CSO outfalls
2. Maximum use of the collection system for storage
3. Review and modification of pretreatment requirements to ensure that CSO impacts are minimized
4. Maximization of flow to the Publicly Owned Treatment Works (POTW) facility for treatment
5. Elimination of CSOs during dry weather
6. Control of solid and floatable materials in CSOs
7. Pollution prevention programs to reduce contaminants in CSOs
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls

The EPA and research done by the University of Wisconsin-Milwaukee School of Freshwater Science have concluded that the growing effects of climate change will lead to very adverse effects on the state of Stormwater Infrastructure [3].

Case Study I: United States Major City Infrastructure Changes

Boston, MA; Seattle, WA; Philadelphia, PA

Boston Changes

Many cities in North America are taking necessary steps to monitor and preemptively fight the threat that climate change poses. These vary from location to location as there are 772 CSOs in the United States alone [3]. Looking at the previously mentioned Figure 1, it can be seen that the Northeast region is having the largest observed change in very heavy precipitation. As a response, the Massachusetts Water Resources Authority renovated the Deer Island WWTP over a nine year period from 1989-1998. This project involved expansion of the daily treatment capacity from 250 to 350 MGD and raised the plant's overall elevation by 2 feet in order to ensure the facility can operate in accordance with projections until 2050. This renovation and expansion project cost a staggering $3.8 billion over the aforementioned time period [5].

Figure 2 – The renovated Deer Island WWTP

Seattle Changes

While the Pacific Northwest Region does not have nearly the observed change that other regions have, the effects are still being felt and addressed. Seattle WA, a city notorious for its large volume of annual precipitation of 38 inches, developed a software system called RainWatch. This software would record and model the projected rainfall and calculate whether storm drains would need to be monitored or repaired to handle said projections. It also had the capability to increase pumping for drains that were hit with hard storms [3]. This service was discontinued on December 1, 2018 as the city's Department of Public Utilities stopped its support.

Philadelphia Changes

Philadelphia, PA is another city that is making substantial strides to improve its stormwater infrastructure. According to data obtained from the U.S. Census Bureau in 2013 for a study on green infrastructure, the city's sewer system breakdown is as follows: 60% Combined, 40% Separated [6]. In 2011 the city approved a plan called the Green City, Clean Waters Program which allocated $1.2 billion for new green infrastructure over the 25 years from its enactment. This program would convert about one-third of the city's combined sewer to green areas, which the Philadelphia Water Department estimates would lead to an 85% reduction in in stormwater pollution as well as save the city $5.6 billion [6].

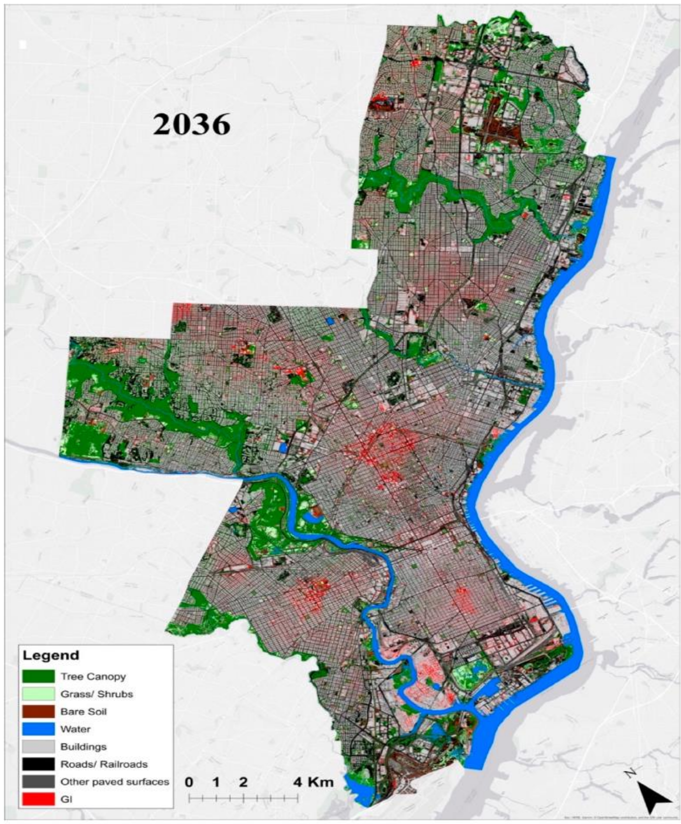

Figure 3 – Projected Site Map of Philadelphia, 2036 [7]

Case Study II: Green Infrastructure and Reducing CSO

Richmond, VA

Background

Combined Sewer Flows are a serious pollution problem for the cities that have them. As the excess, untreated water drains into waterways, it can bring a whole slew of different contaminants from untreated human waste to industrial chemical waste. As the volume and rate of precipitation increases due to climate change, the chance for this to occur also increases.

In order to determine the best way to reduce the amount of CSOs, a comparison of four different stormwater collection systems was applied to an area of Richmond, VA as a part of the Shockoe Creek watershed. This area is depicted below in Figure 4. The four scenarios are as follows [8]:

1. Existing Conditions
2. Gray Infrastructure (Tunnel Storage)
3. Green Free (Free Discharge)
4. Green Control (Added Outlet Controls)

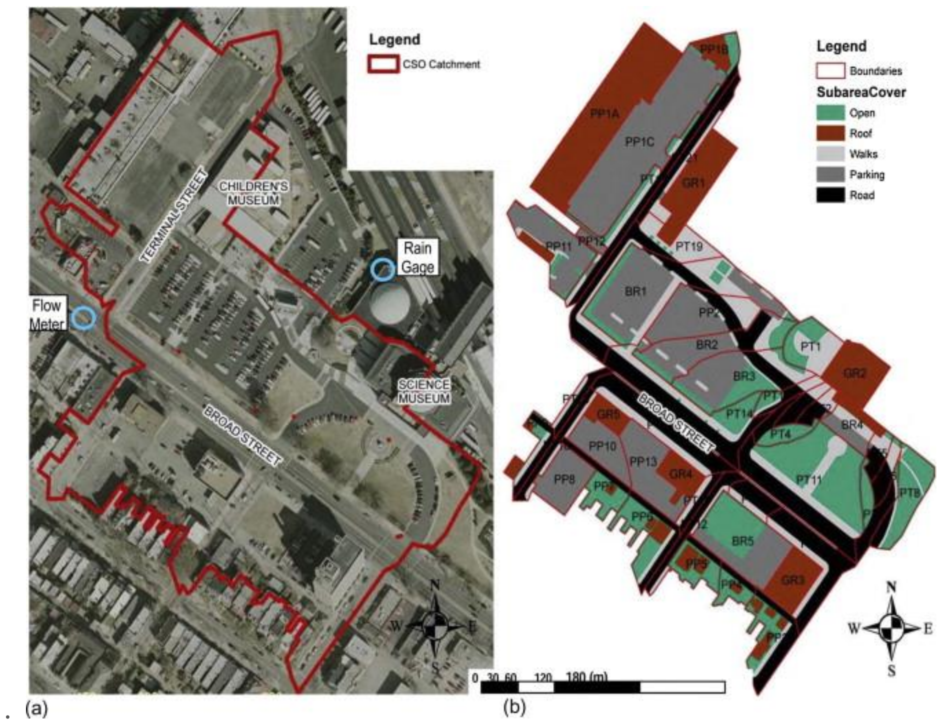

Figure 4 – a) aerial view of study area; b) GIS representation [8]

The four abbreviations seen in figure 4b refer to the green infrastructure methods added to the study area. BR stands for Bioretention, GR stands for Green Roof, PP stands for Porous Pavement, and PT stands for Planter Trenches [8].

Method

The study was conducted using the U.S. EPA's Storm Water Management Model, or SWMM. In order to model flow, data was collected in a 48 cm by 75 cm egg sewer with velocities and depths recorded every 5 minutes. Two specific scenarios were modeled and chosen from historical annual precipitation data collected by the Richmond International Airport National Weather Gage #447201 from August 1948 – December 2010 and mathematically broken down until the 15 minute peak value was determined. From all of this data, scenarios for the 'typical' and 'peak' intensity events were chosen as the years 1978 and 1969, respectively [8].

Scenarios and Results

The 'Typical Intensity' scenario returned the data seen in table 1. The 'Peak Intensity' scenario returned the data seen in table 2.

Parameter	Existing	Gray	Green-free	Green-control
Total discharge (cu.m.)	73,485	73,088	65,471	64,508
Total discharge reduction	–	0.5%	10.9%	12.2%
Maximum outflow (cms)	0.68	0.49	0.33	0.25
Maximum outflow reduction	–	28.3%	51.6%	63.3%
CSO discharge > 0.42 cms (cu.m.)	19,573	1,675	4,820	1,207
Percentage CSO discharge	26.6%	2.3%	6.6%	1.6%
CSO discharge reduction	–	91.4%	75.4%	93.8%
Number of exceedances	124	4	31	5
Duration of exceedances (h)	100.4	5.7	42.0	9.3
Total runoff (cu.m.)	45,752	45,355	22,328	15,986
Total runoff reduction	–	0.9%	51.2%	65.1%

Table 1 - Comparison of overflows and storage provided by all alternatives, 1978 base year [8]

Parameter	Existing	Gray	Green-free	Green-control
Total discharge (cu.m.)	87,870	87,672	79,347	77,931
Total discharge reduction	–	0.2%	9.7%	11.3%
Maximum outflow (cms)	1.34	1.35	1.20	0.93
Maximum outflow reduction	–	−0.8%	10.3%	30.8%
CSO discharge > 0.42 cms (cu.m.)	35,171	11,834	14,442	7,564
Percentage CSO discharge	40.0%	13.5%	18.2%	8.6%
CSO discharge reduction	–	66.4%	58.9%	78.5%
Number of exceedances	95	10	34	15
Duration of exceedances (h)	95.9	19.6	62.0	24.2
Total runoff (cu.m.)	61,634	61,436	34,830	25,584
Total runoff reduction	–	0.3%	43.5%	58.4%

Table 2 - Comparison of overflows and storage provided by all alternatives, 1969 intense year [8]

It is clear from the above data that each method was an improvement on the existing infrastructure. All of the methods led to reductions in total discharge, CSO discharge, CSO exceedances and total runoff. The gray infrastructure method leads to the greatest reduction in duration and frequency of CSO exceedances, so this method is the best choice to reduce the total amount of CSOs.

In reducing the overall effect of climate change, the most effective option would be a combination of methods. Although the gray infrastructure method is most effective at reducing the effects of CSOs, both of the green infrastructure methods are effective at reducing the discharge, runoff, and outflow of water from aquifers.

Case Study III: Climate Change and SWM in Asian Cities

Bangkok, Thailand; Tokyo, Japan; Hanoi, Vietnam

Background

The global population is at approximately 7.7 billion as of April 2019. Not only is the population expanding rapidly, but more and more are living in or moving to cities. This is a phenomenon known as urbanization. The U.N expects that by 2020, 68% of the global population will be located in urban areas [9]. As the population becomes denser and denser, water demand will increase, which will in turn lead to increasing water scarcity.

As urbanization becomes more prevalent, the amount of impervious surface will as well. Impervious surfaces are defined as artificial surfaces that do not allow liquid (in this case stormwater runoff) to pass through them. These can include asphalt, concrete, stone, and compacted soils. The increased amount of precipitation combined with the increase in paved surfaces can lead to larger amounts of water flowing into existing natural bodies of water and the deposit of minerals and pollutants from the various surfaces. In extreme cases, this can lead to floods and increased erosion along the natural water bodies [10].

Cities in Japan and Thailand have designed their stormwater management infrastructure with the aim to control the flow of the water for their on utilization. Controlling in this manner allows for municipal and commercial use of the stormwater while also preventing flooding and other potential disasters from affecting the city by diverting the unused water towards forests, farmland, and other natural areas. In Vietnam there is a greater focus on infiltration, with stormwater infrastructure improvements dedicated to increase the amount of water in aquifers [10].

Improvements

Tokyo is one of the largest cities in the world with a population of over 9 million in the city alone. By including the Greater Tokyo Area, that number increases to 36 million. With an annual precipitation of 1530 mm or 60.23 inches there are a lot of concerns about flooding and water demand. To combat this the city has constructed a very large system of underground tunnels and storage tanks known as the G-Cans project in order to divert stormwater from the city in a much quicker manner. Construction on the G-Cans project began in 1992 and was completed in 2009 at a cost of $2 billion. Built to withstand a once in 200 years flood, this system involves 6.5 kilometers (4 miles) of tunnels, 78 pumps, and 5 containment silos that are 65 meters deep with a diameter of 32 meters [11]. On a much smaller scale is the artificial infiltration system that not only helps control stormwater but also recharge the aquifers that supply water to the city. This system can be seen in figure 5 below.

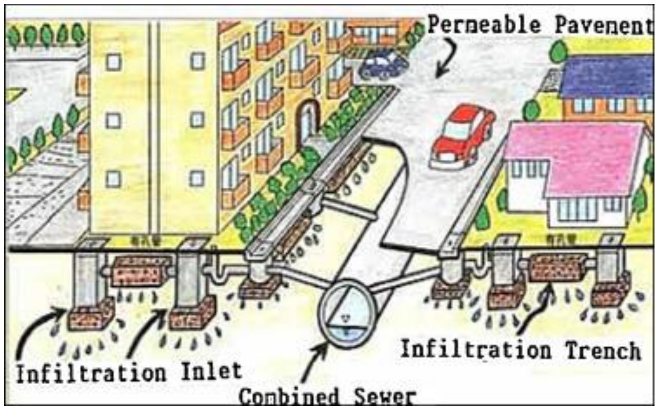

Figure 5 – Tokyo's Infiltration System [10]

Bangkok, the capital city of Thailand, is facing its own stormwater issues due to the layout of the city itself. As about 30% of the city land is used for agriculture, the city is taking a slightly different approach than that of Tokyo. The Bangkok Metropolitan Administration (or BMA) has been implementing surface level control methods including retention ponds and rainwater harvesting systems. Vegetation is also being planted and used for the infiltration benefits that it can provide and the government is working to expand its underground system to include a large tank system that would drain the excess into the Gulf of Thailand [10].

Hanoi, Vietnam is facing similar issues to that of Bangkok. Hanoi is at a greater risk of flooding due to its location right next to the Red River as well as the many lakes within the city itself. While the surface methods of capturing stormwater are the same methods being used in Bangkok, the rainwater harvesting and surface runoff drainage systems are decentralized and incorporated into the city itself. This allows any excess to quickly and easily be collected and diverted into streams and lakes throughout the city or into rainwater storage tanks, similar to figure 8 [10].

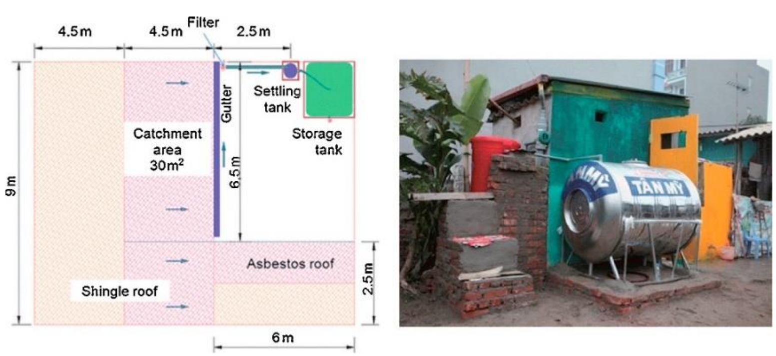

Figure 6 – Rainwater harvesting tank in Hanoi [10]

Analysis and Conclusions

Despite the uncertainty surrounding climate change, the effects are already being felt all around the globe. It is interesting to note that based on the studies observed in this report, the methods being used to combat the rising stormwater issues are very similar all over the world. The data observed in the Richmond, Virginia model suggests that gray infrastructure is most effective and preventing CSOs and pollution that can follow as a result of the overflow, while the use of green infrastructure is effective at reducing the surface runoff and discharge.

This data is consistent with the methods being utilized in Tokyo, Bangkok, and Hanoi. Gray infrastructure in Tokyo is being utilized to prevent flooding and other damaging events, while updated infiltration systems are being deployed in all three cities in order to best serve the demands of each respective city. It can be concluded that in order to most effectively combat the effects of climate change on stormwater, there must be a concentrated effort to improve existing infrastructure when possible and build new gray or green infrastructure depending on specific needs.

Plenty of questions remain around the economic impact of infrastructure improvements. The information regarding the improvements in Philadelphia and Tokyo suggests that these improvements will come at a great economic cost; Philadelphia is investing $1.2 billion over a 25 year span in order to achieve their goals and Tokyo spent $2 billion over a 17 year period on their G-Cans project. The Massachusetts Water Resources Authority spent more than both of these projects combined, $3.8 billion, on their nine year renovation of the Deer Island WWTP. These costs are only for the construction and implementation of the infrastructure improvements and do not take into account cost of upkeep and training relevant to the improvements. With the costs being as high as they are it may be difficult for many cities, especially lower-income ones, to allocate the funding that may be required for necessary improvements. This is a complex issue without a clear option for immediate relief, and as such it will take a concentrated effort to overcome.

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