FEASIBILITY STUDY OF BIORETENTION CELLS TO ALLEVIATE STORM WATER RUNOFF AND FLOODING IN MANHATTAN

Submitted To:

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Ron Fehr, City Manager
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Mr. Fehr,

I am delighted to submit my completed formal report, "Feasibility Study of Bioretention Cells to Alleviate Storm Water Runoff and Flooding in Manhattan," that the City Engineer, Brian Johnson, approved on October 10, 2018. This report contains my findings on this topic. The purpose of this report is to prove bioretention cells are a viable option to reduce flooding in Manhattan.

I pursued this research to find a solution to the growing frequency of floods caused by Wildcat Creek. This report covers six main topics: flooding in Manhattan (p.3), characteristics of bioretention cells (p.6), location criteria analysis (p.7), consequences of implementing bioretention cells (p.12), other options (p.18), and governing rules and regulations (p.19). I end my report with several conclusions (p.19) and recommendations (p.20).

Through my research, I proved that bioretention cells reduce runoff, increase time of concentration, and reduce pollution. These benefits reduce the damages caused by flooding, thus saving the City of Manhattan and its residents money. We save more money when we follow the regulations set in place by the Community Rating System through the Federal Emergency Management Agency.

At this point, I recommend we begin designing and constructing a bioretention cell in Sunset Neighborhood Park immediately. I also recommend we continue updating and constructing more storm water management systems as we continue to develop our city.

Please contact me with any questions or comments regarding the information in this report.

Sincerely,

Aubrey Busenitz

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EXECUTIVE SUMMARY

The City of Manhattan is proud to serve the people of Manhattan by providing services and maintaining and developing infrastructure used every day. Our mission is to efficiently deliver services and design infrastructure in a cost effective manner. The safety and quality of life of the local residents is our first priority. To keep Manhattan a safe place to live, we must continue to enhance and develop our storm water infrastructure. Manhattan has seen an increase in floods the past few years. Floods damage property and cost the City of Manhattan money. Runoff also carries pollutants that can contaminate our scarce water supply.

On October 10, 2018, Brian Johnson approved my proposal to research the feasibility of bioretention cells to reduce runoff and flooding for the City of Manhattan. The purpose of this report is to prove bioretention cells are a viable option to reduce flooding in Manhattan. I began this research to find a solution to the growing frequency of floods in Manhattan. My method involved completing four tasks: (1) Research possible locations to introduce bioretention cells; (2) Review research conducted on the efficiency of bioretention cells to reduce runoff; (3) Review financial reports and databases that provide cost estimates of bioretention cells; (4) Research rules and regulations associated with the use of bioretention for storm water management.

Bioretention cells reduce runoff, increase time of concentration, and reduce pollution. They are also cost effective and have a positive net present value. By implementing bioretention cells in the City of Manhattan, we can reduce flooding in Manhattan, thus saving money.

Conclusions

After completing my research, I made eleven conclusions. For a complete list, please see pages 19 and 20. My two main conclusions are the following:

1. Sunset Neighborhood Park is the best location to implement a bioretention cell that is owned by the City of Manhattan.

2. The benefits of bioretention cells outweigh the cost of constructing and maintaining them.

Recommendations

I made four recommendations based on my conclusions and research. For a complete list, please see page 20. My two main recommendations are the following:

1. Begin designing and constructing a bioretention cell in Sunset Neighborhood Park immediately.

2. Continue updating and constructing more storm water management systems as we continue to develop our city.

INTRODUCTION TO DISCUSSION

With safety as our high priority, it is unsettling to consider the number of people displaced by floods. The flash flood that occurred on Labor Day weekend of this year displaced 300 people following the damage to 106 buildings, which includes 381 dwelling units (Richardson & Casanova, 2018). This damage is associated with a high cost. According to Manhattan City Manager Ron Fehr, the flash flood cost a total of $17.2 million in damage; the damage caused to city property was $2.7 million (McNamara, 2018). This recent incident is not an isolated event. Notable floods in 2007, 2010, and 2011 occurred due to excess water from Wildcat Creek. Similarly, there were concerns that the creek would flood in 2015 and 2016 (Richardson & Casanova, 2018). With the recent floods in Manhattan, the City of Manhattan must react quickly to prevent future damages. Problems associated with the recent floods include increased runoff due to urban development, insufficient number of storm water infrastructures in place, increase of polluted water concerns, and focus on large-scale storm mitigation projects.

On October 10, 2018, Brian Johnson approved my proposal to research the feasibility of bioretention cells to reduce runoff and flooding for the City of Manhattan. The purpose of this report is to prove bioretention cells are the best option to reduce flooding in Manhattan. My method involved completing four tasks: (1) Research possible locations to introduce bioretention cells; (2) Review research conducted on the efficiency of bioretention cells to reduce runoff; (3) Review financial reports and databases that provide cost estimates of bioretention cells; (4) Research rules and regulations associated with the use of bioretention for storm water management.

The first part of this report discusses the increased frequency of floods in Manhattan and the problems these floods bring. Next, I compare three locations based on required criteria to determine the best location to implement a bioretention cell. These three locations are Sunset Neighborhood Park, Frank Anneberg Park, and Warner Memorial Park. Then, I describe the main characteristics and components of bioretention cells. Following this, I analyze the consequences of implementing bioretention cells. This section is further broken down into benefits, drawbacks, and cost analysis. Next, I discuss rules and regulations associated with implementing bioretention cells. Lastly, I list my conclusions and recommendations for the City of Manhattan.

Implementing bioretention cells in Manhattan will reduce runoff, increase time of concentration, and reduce pollution for our community. By implementing bioretention cells in the City of Manhattan, we can reduce flooding in Manhattan, thus saving money. I recommend the City of Manhattan begin designing and constructing a bioretention cell in Sunset Neighborhood Park immediately.

DISCUSSION

PROBLEM

Safety and quality of life of the local residents is the City of Manhattan's first priority. To keep Manhattan a safe place to live, we must continue to enhance and develop our storm water infrastructure.

Flooding in Manhattan

The flash flood that occurred on Labor Day weekend of this year displaced 300 people following the damage to 106 buildings, which includes 381 dwelling units (Richardson & Casanova, 2018). This damage is associated with a high cost. According to Manhattan City Manager Ron Fehr, the flash flood cost a total of $17.2 million in damage; the damage caused to city property was $2.7 million (McNamara, 2018).

This recent incident is not an isolated event. Notable floods in 2007, 2010, and 2011 occurred due to excess water from Wildcat Creek. Similarly, there were concerns that the creek would flood in 2015 and 2016 (Richardson & Casanova, 2018). With the recent floods in Manhattan, the City of Manhattan must react quickly to prevent future damages. Problems associated with the recent floods in Manhattan that must be addressed include the following:

1) Increased runoff due to urban development.

2) Insufficient number of storm water infrastructures currently in place.

3) Increase of polluted water concerns.

4) Focus only on large-scale storm mitigation projects

Increased Runoff

Manhattan has grown over the past years. The United States Census Bureau reported the population in Manhattan was 52,281 in 2010, and they estimate it grew to 54,832 in 2017 (2018a). This number includes some college students living in Manhattan. According to the Census Bureau, people are counted at their "usual residence," which is the location the person lives or sleeps most of the time (2018b). Thus, college students are counted if they declare Manhattan as their usual residence. To account for the growing population, new residential and commercial buildings have been developed. In 2015, the city of Manhattan had 6,237 acres of residential land already developed. By March 2018, this increased by 277 acres. There are currently plans for this to further increase by 3,566 acres by 2035. This latter number does not include the Blue Township plans for Pottawatomie County (City of Manhattan, 2018b). Over $185 million was invested in commercial development in Manhattan from 2013 to 2017, where 100 million was used to build new buildings. The investment in new buildings has increased by 11.6% from 2013 to 2016 (City of Manhattan, 2018a). Manhattan is growing rapidly, and it will continue to develop in the future.

When rapid urbanization occurs, surface runoff increases. This is currently observable in Manhattan due to the increased development mentioned above. With an increase in new buildings and pavement, there is less ground area for water to infiltrate into the soil. This leads to an increase in runoff that floods streets, homes, and businesses. Research proves that runoff drastically increases with more impervious surfaces. As seen in Figure 1, the percent runoff increases as the impervious surface increases. Current public records for the impervious surface area in Manhattan were not available; however, the NRCS curve-number model makes assumptions for different surface area types. The model suggests commercial and business areas are 85% impervious, residential areas with a 0.25 acre lot size are 38% impervious, and row houses and other residential areas with less than 0.125 acre lot size are 65% impervious (Chin, 2013). As shown in Figure 1, we significantly increase runoff by a factor of 5.5 when we develop pervious land into a business area. Similarly, we triple the previously existing runoff when developing pervious land into residential lots. As long as Manhattan continues to grow and develop, there is a need to find a way to reduce the produced increased runoff.

Precipitation Pie Charts to Show Change for Different Impervious Surfaces

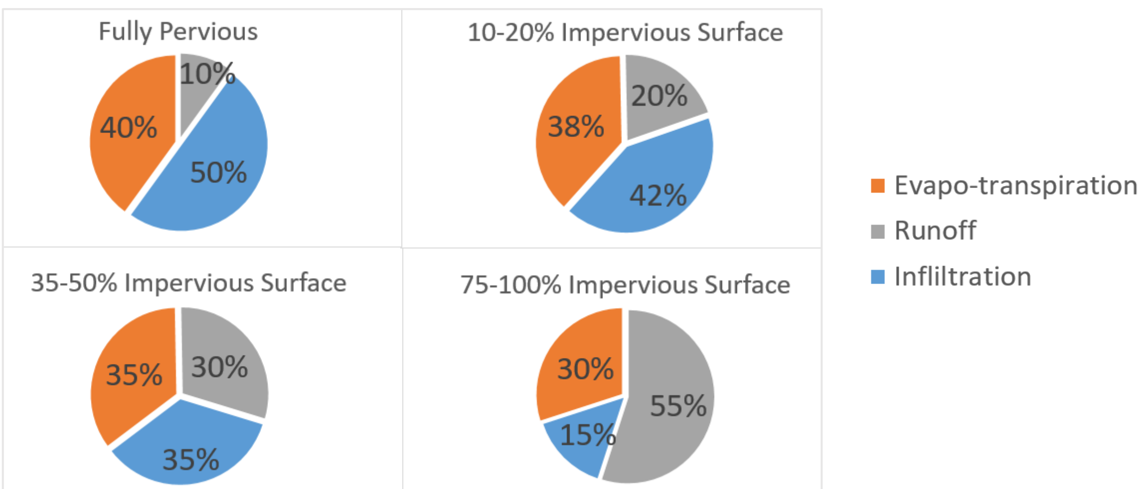

Figure 1: Pie charts showing the percent of precipitation and inflow that becomes runoff, infiltration, and evapotranspiration for different impervious surfaces.
Source: adapted from (Paul & Meyer, 2001)

Insufficient Storm Water Infrastructures

Urban development is a cause of increased flooding in Manhattan. However, Manhattan is also prone to flood risks because it sits in a valley surrounded by the Kansas River, the Big Blue River, and Wildcat Creek. The increased occurrence of floods and Manhattan's flood-prone location prove a need for more storm water mitigation infrastructures. Manhattan has a few locations with storm water mitigation projects including Frank Anneberg Park, Cico Park, and Eureka Valley. However, these locations are not sufficient in alleviating storm water floods. Bunger said the city has not introduced new developments of flood mitigation since 2011 (Richardson & Cassanova, 2018). With the large increase in population mentioned above, it is necessary to match that increase with more flood mitigation projects. The recent flood in

September of this year show the current infrastructures are not sufficient. With the significant increase in urban development in Manhattan, there is also a need for an increased number of storm water infrastructures.

Polluted Water Concerns

We need to manage storm water more efficiently to reduce runoff. According to the Environmental Protection Agency, "Polluted runoff is one of the greatest threats to clean water in the U.S." (2018a). An increase in runoff can quickly become a serious health concern. Runoff can pick up pollutants as it flows, thus carrying pollutants to locations we retrieve water from for everyday use. Runoff can contain pesticides, bacteria, disease, copper, lead, and zinc, which can be toxic to humans and animals in high concentrations (Gaffield, Goo, Richards, & Jackson, 2003). To protect our water supply and the local wildlife, it is vital to reduce the runoff associated with storm water.

Polluted water also has serious negative environmental effects. For example, runoff carries phosphorus and nitrogen used in pesticides to nearby water sources. An excess of these two nutrients can upset an entire ecosystem by causing excessive algae growth. This alga decreases the availability of dissolved oxygen, thus killing fish and other aquatic life, which can disrupt the populations of organisms that depend on that food supply (Bear, Rintoul, Snyder, Smith-Caldas, Herren, & Horne, 2017).

The Kansas Department of Health and Environment confirmed the River Park Pond near Tuttle Creek had harmful blue-green algal blooms in 2011 (2018). This is a real danger that Manhattan has faced in the past, and has the potential to face again if runoff increases as we continue to build developments. We must find a way to counteract the current and future increases in runoff.

Focus on Large Scale Projects

Bunger said the city is focusing on the possibility of building two dams in Fort Riley (Richardson & Cassanova, 2018). These dams would benefit Fort Riley, Manhattan, and other parts of the county, because they would be located within the Wildcat Creek Watershed. However, Joe File, representative of Wood Group, an engineering consulting company, stated the dams would take five or more years to construct (Richardson, 2018). Although it is important to create a solution to prevent damage from major 100-year storms, like the most recent flood in September, there is a more urgent and time-sensitive need for a solution for 1-year to 25-year storms. These short return period storms are more common, because they have a higher chance of occurring every year. There also needs to be a focus on smaller projects that can reduce runoff during short, high intensity rainfalls.

OBJECTIVES

My research provides the following in this report:

1) A detailed analysis of the efficiency of bioretention cells on alleviating storm water runoff for short return period storms.

2) A comprehensive cost analysis for designing and constructing bioretention cells, as well as the associated maintenance cost.

3) A detailed report of any rules and regulations required for designing and constructing bioretention cells.

4) A recommendation on whether or not the City of Manhattan should implement bio retention cells based on efficiency and cost.

METHOD

To complete the objectives listed above, I completed the following tasks:

1) Research possible locations to introduce bioretention cells.

2) Review research conducted on the efficiency of bioretention cells to reduce runoff.

3) Review financial reports and databases that provide cost estimates of bioretention cells.

4) Research rules and regulations associated with the use of bioretention for storm water management.

SOLUTION

I believe bioretention cells will solve the flooding and pollution problems in Manhattan. I will discuss the characteristics, location criteria, benefits, and drawbacks of bioretention cells.

Characteristics of Bioretention Cells

Bioretention cells are made of many different components and layers including vegetation, bowl, media, internal water storage, and underdrain. Figure 2 labels the parts of a bioretention cell, and how they interact with the water cycle.

Vegetation

The most visible part of bioretention cells are the plants. This vegetation promotes the evapotranspiration of water to the atmosphere. It saves money to select local vegetation for bioretention cells.

Bowl

The top surface layer is the bowl. It contains about 22 to 30 centimeters of ponded water (Winston, Dorsey, & Hunt, 2016). Some of this water will evaporate into the atmosphere.

Media

The next layer is the media filter. The bioretention media layer is about 60 to 120 centimeters thick (Winston, Dorsey, & Hunt, 2016). The media is usually sand, a high permeability soil (Brown, Hunt, & Kennedy, 2009). The media layer removes nitrogen, phosphorus, metals, and other pollutants from water (Brown, Hunt, & Kennedy, 2009).

Internal Water Storage

The internal water storage layer provides more water storage. This water enters the soil through exfiltration (Brown, Hunt, & Kennedy, 2009).

Underdrain

The underdrain is located at the bottom of the bioretention cell within the gravel layer. The underdrain transports water to the storm sewer network (Brown, Hunt, & Kennedy, 2009).

Diagram of Bioretention Cell Labeling its Different Parts

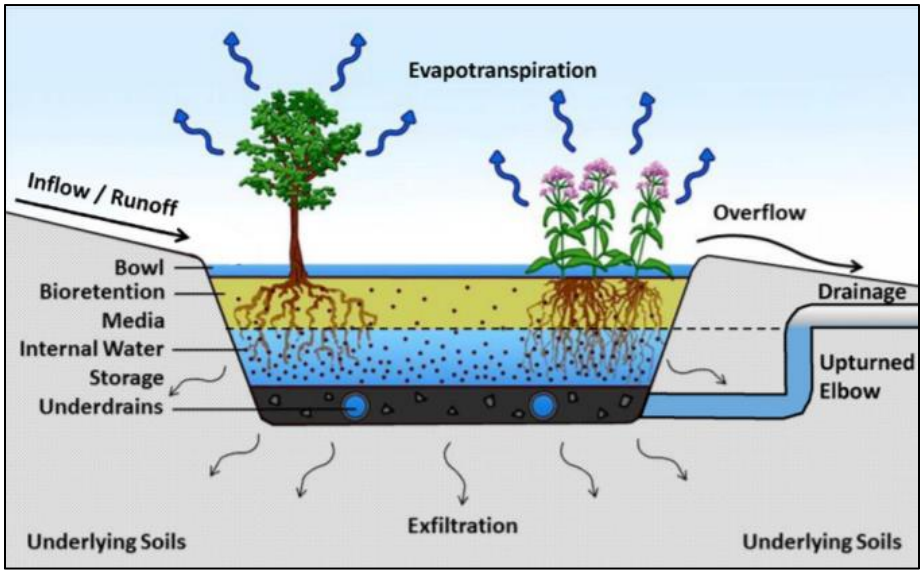

Figure 2: Cross section of a bioretention cell including how the bioretention cell interacts within the water cycle.
Source: (Winston, Dorsey, & Hunt, 2016).

<u>Location Criteria Analysis</u>

I determined general criteria for locations best suited for implementation of bioretention cells by reviewing online resources. Next, I chose locations in Manhattan that I thought would meet most of the criteria. I focused on locations currently owned by the City, thus eliminating any cost associated with land ownership. I focused on Warner Memorial Park, Frank Anneberg Park, and Sunset Neighborhood Park as possible locations. The criteria I used to compare these locations are the following:

1. Location within the Wildcat Creek Watershed.
2. Description of the surrounding area.
3. Available room to meet size requirements.
4. Location outside the 100-year flood plain.

Watershed

To reduce the flooding caused by Wildcat Creek, we need to reduce the runoff flowing to the creek. Placing bioretention cells within the Wildcat Creek Watershed would intercept water flowing to the creek and reduce flooding. I delineated the watershed for Wildcat Creek using the StreamStats Program. Figure 3 shows this delineation.

Delineation of Wildcat Creek to Determine if Locations are Within the Watershed

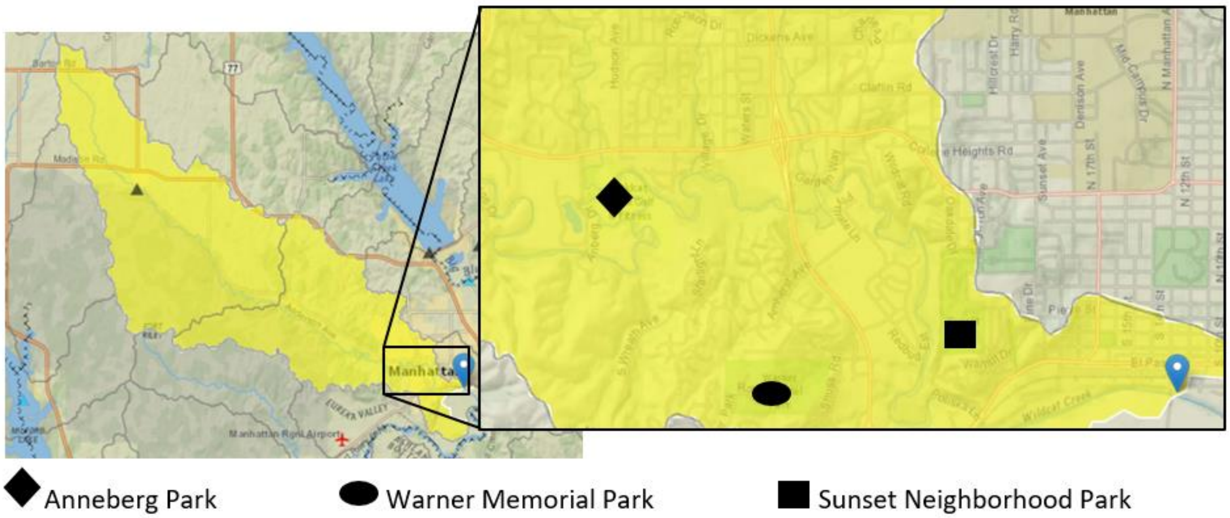

Figure 3: Delineation of Wildcat Creek Watershed zoomed in on the area containing the locations discussed in this report. Source: Adapted from (U.S. Geological Survey, 2016)

Sunset Neighborhood Park

Sunset Neighborhood Park is located in the watershed. Therefore, a bioretention cell located in Sunset Neighborhood Park will intercept water traveling to Wildcat Creek. If less water reaches Wildcat Creek, less flooding will occur.

Frank Anneberg Park

Frank Anneberg Park is located in the watershed. Therefore, a bioretention cell located in Frank Anneberg Park will intercept water traveling to Wildcat Creek. If less water reaches Wildcat Creek, less flooding will occur.

Warner Memorial Park

Warner Memorial Park is located in the watershed. Therefore, a bioretention cell located in Warner Memorial Park will intercept water traveling to Wildcat Creek. If less water reaches Wildcat Creek, less flooding will occur.

Surrounding Area

The surrounding area affects the efficiency of the bioretention cell. The City of Manhattan states that bioretention cells perform well in high traffic areas (2017). High traffic areas are generally more developed, thus producing more runoff. A nearby bioretention cell can intercept this runoff. High traffic areas are also more polluted. The bioretention cell reduces the pollution present in the runoff. Bioretention cells located downhill from the surrounding area will naturally receive more runoff from gravity.

Aerial View of Locations to Show Surrounding Areas

Figure 4: Aerial view of all three locations showing the surrounding area and roads. Source: Google Maps. (2018). [Manhattan, KS], Retrieved November 25, 2018, from https://www.google.com/maps/

Sunset Neighborhood Park

Sunset Neighborhood Park is next to the Sunset Zoo. It is also near the Manhattan High School. As you can see in Figure 4 and 5, there are several roads and parking surrounding the park. It is located downhill from some of these locations. This is a prime location based off the surrounding area.

Frank Anneberg Park

As shown in Figure 4 and 6, Frank Anneberg Park contains roads and parking lots. The park is also located on a slight downhill from Anderson Avenue. This places it downhill from a high traffic road, which is an ideal location.

Warner Memorial Park

As shown in Figure 4 and 7, Warner Memorial Park is has few roads and parking lots in the surrounding area. The roads and paths within the park are gravel or dirt, which have higher permeability than concrete roads. Warner Memorial Park would not provide a lot of runoff for a bioretention cell. The park is also located at a higher elevation than the surrounding area. Thus, Warner Memorial Park is not in an ideal location to receive a high volume of runoff.

Size Requirements

The drainage area contributing to the bioretention cell should be less than four acres and the design area of the bioretention cell should be 1 to 15% of the drainage area (City of Manhattan, 2017). The City of Manhattan also specifies the minimum design area as 15 feet by 40 feet (2017). Bioretention cells occupy a small space, so it is easy to find room to implement them.

Sunset Neighborhood Park

Sunset Neighborhood Park is about 10 acres (Loveland, 2018). Part of this area includes a dirt road that runs across the land. There is still a large open area available for use that you can see in Figure 5.

Satellite View of Frank Anneberg Park to Show Available Construction Space

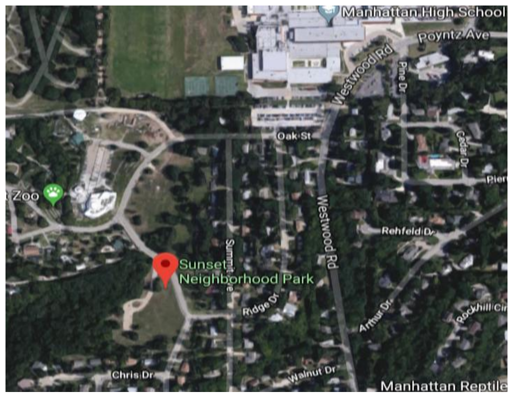

Figure 5: Sunset Neighborhood Park satellite view showing surrounding area and open spaces. Source: Google Maps. (2018). [Sunset Neighborhood Park], Retrieved November 25, 2018, from https://www.google.com/maps/

Frank Anneberg Park

Frank Anneberg Park is about 99 acres (Loveland, 2018). There are sports fields, parking lots, and roads located in the park. Regardless, there is still plenty of room to construct a bioretention cell as Figure 6 shows.

Satellite View of Frank Anneberg Park to Show Available Construction Space

Figure 6: Frank Anneberg Park satellite view showing surrounding area and open spaces. Source: Google Maps. (2018). [Frank Anneberg Park], Retrieved November 25, 2018, from https://www.google.com/maps/

Warner Memorial Park

Warner Memorial Park is about 80 acres (Loveland, 2018). Warner Memorial Park has a few dirt roads and walking paths. There are open grass areas between these roads as shown in Figure 7. There is room for a bioretention cell.

Satellite View of Warner Memorial Park to Show Available Construction Space

Figure 7: Warner Memorial Park satellite view showing surrounding area and open spaces. Source: Google Maps. (2018). [Warner Memorial Park], Retrieved November 25, 2018, from https://www.google.com/maps/

Floodplain

According to the Virginia Water Resources Research Center, bioretention cells should never be located in the 100-year floodplain (2011a). If bioretention cells are located in this floodplain, there is a high chance it will overfill, causing more harm than good.

Sunset Neighborhood Park

According to the City of Manhattan, Sunset Neighborhood Park is not located in the 100-year floodplain (2013).

Frank Anneberg Park

Over half of Frank Anneberg Park is located in the 100-year floodplain (City of Manhattan, 2013). This makes the park a less desirable location for bioretention cells.

Warner Memorial Park

Warner Memorial Park in not located in the 100-year floodplain (City of Manhattan, 2013).

Summary

Sunset Neighborhood Park is the best of the three locations for a bioretention cell. This location meets all the necessary requirements. Table 1 shows the other two locations do not meet one of the gathered criteria. Lower elevations surround Warner Memorial Park and the 100-year floodplain contains Frank Anneberg Park. I recommend implementing a bioretention cell in Sunset Neighborhood Park. I recommend the City of Manhattan research more locations that fulfill the criteria above and implement bioretention cells in these locations. The greater the number of bioretention cells, the greater the impact on the surrounding community.

Table 1: Summary of Location Analysis to Determine Best Location for a Bioretention Cell

Location	In Wildcat Creek Watershed	Meets surrounding area criteria	Available room	Outside 100-year flood plain
Sunset Neighborhood Park	YES	YES	YES	YES
Frank Anneberg Park	YES	YES	YES	NO
Warner Memorial Park	YES	NO	YES	YES

__Consequences of Implementing Bioretention Cells__

I will discuss the benefits, drawbacks, and costs associated with bioretention cells.

Benefits

Bioretention cells provide several benefits to the community. According to the Environmental Protection Agency, "Reducing runoff can help prevent water pollution, reduce flooding, and protect our precious drinking water resources" (2018a).

The goal of green infrastructure is to revert the post-development unit hydrograph back to pre-development values. Figure 8 shows the general unit hydrograph of an area before and after it is developed. Post-development causes increased runoff and reduced time to peak. Bioretention cells can benefit our community by reducing runoff, increasing the time of concentration, and reducing pollution.

Unit hydrographs to Illustrate Development Impacts

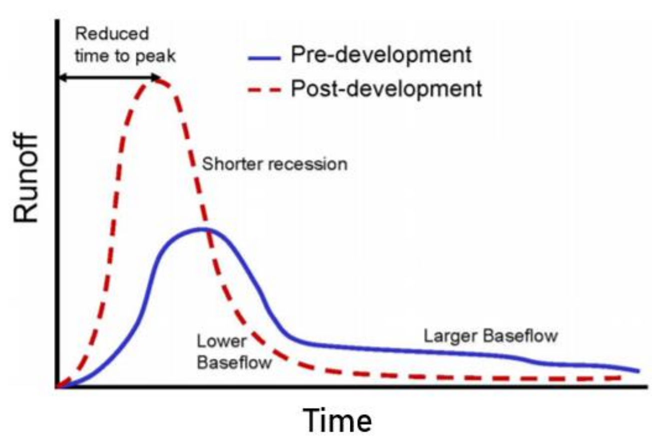

Figure 8: Comparison of unit hydrographs from pre-development and post-development to illustrate the impacts of developed areas. Source: (Liu, Sample, Bell, & Guan, 2014)

Reduced Runoff

Research conducted in Charlotte, North Carolina observed a bioretention cell reduce the peak flow into the cell by at least 96.5% for storms with less than 42 millimeters (1.65 inches) of precipitation (Liu, Sample, Bell, & Guan, 2014). The bioretention cells had a mean peak flow reduction of 99% (Liu, Sample, Bell, & Guan, 2014). Storms of greater precipitation are not as likely to occur in Manhattan. Historically in Manhattan, storms with a greater total precipitation occur at low intensities and long durations. According to the City of Manhattan, 1-year storms with a duration of 14.5 hours or longer will exceed this precipitation (1994). 10-year storms that last longer than 13.8 hours and 100-year storms that last longer than 13 hours will exceed this precipitation (City of Manhattan, 1994). This shows a majority of storms in Manhattan are less than 42 millimeters; thus, I expect bioretention cells in Manhattan to reduce peak runoff into the each cell by at least 96.5% for small to medium sized rain events. When a bioretention cell reduces peak runoff, it reduces the total runoff that would have possibly caused flooding in the area. See Table 2 for park flow reduction and runoff volume reduction results from multiple bioretention cells.

Table 2: Peak Flow and Runoff Reduction Results to Prove Bioretention cells Reduce Flooding

Location	Peak Flow Reduction (%)	Runoff Volume Reduction (%)
Nashville, NC	84	63
	92	88
	92	65
	95	89
College Park, MD	44	52
	63	65
Blacksburg, VA	99	97
Silver Spring, MD	83	79

Source: Adapted from (Liu, Sample, Bell, & Guan, 2014)

Increased Time of Concentration

Bioretention cells increase the time to peak flow, causing drainage to revert to the pre-development shape in Figure 7. When the time to peak inflow increases, the time of concentration increases, because time of concentration measures the time to outflow. Therefore, bioretention cells increase the time of concentration. Implementing a bioretention cell in a developed area will increase time of concentration from less than a quarter of an hour to several hours (Liu, Sample, Bell, & Guan, 2014). A longer time of concentration allows more time for infiltration and evapotranspiration. The study observed by Liu, Sample, Bell, and Guan concluded “up to 31% of runoff entering the bioretention cells was lost through exfiltration, and up to 19% was lost to evapotranspiration” (2014). Increasing the time of concentration is important, because it helps reduce the amount of runoff by encouraging more infiltration and evapotranspiration. Time delay is commonly reported to describe time of concentration. Time delay is the ratio of the peak time out and peak time in. Davis calculated the delay ratio for undeveloped to developed land to be approximately equal to six (2008). Thus, Davis set six as the target value for the time delay ratio (2008). Table 3 provides time delay results for various bioretention cells. Most of these bioretention cells exceed the target value, proving bioretention cells can reduce time of concentration.

Table 3: Time Delay Results to Compare Against Target Value

Location	Time Delay ($T_{p(out)}/T_{p(in)}$)
College Park, MD	7.2
	5.8
	22.0
Silver Spring, MD	200.0
Greensboro, NC	200.0
	13.0
Louisburg, NC	4.0
	3.0

Source: Adapted from (Liu, Sample, Bell, & Guan, 2014)

Pollution Control

Bioretention cells reduce water pollution by removing suspended solids, phosphorus, nitrogen, pathogens, and metals. Table 4 provides a summary of research results of pollution removal from several bioretention cells.

Table 4: Water Quality Analysis to Show Pollution Reduction

Location	Total Suspended Solids Reduction (%)	Phosphorus Reduction (%)	Nitrogen Reduction (%)	Coliform Reduction (%)	Zinc Reduction (%)	Copper Reduction (%)	Lead Reduction (%)
Rocky Mount, NC	92	80	72	*	*	*	*
Nashville, NC	84	13	44	*	*	*	*
	89	32	19	*	*	*	*
Lenexa, KS	*	56	*	*	*	*	*
Blacksburg, VA	99	99	99	*	*	*	*
Silver Spring, MD	99	97	100	100	99	96	100
Graham, NC	*	54	63	95	*	*	*
	*	54	58	85	*	*	*
Charlotte, NC	60	32	31	71	60	77	32

*Data is unavailable

Source: Adapted from (Liu, Sample, Bell, & Guan, 2014)

Suspended Solids

Total suspended solid removal occurs by sedimentation and filtration. Sedimentation occurs in the bowl layer of the bioretention cell. Bioretention cells remove total suspended solids by filtration into the media (Liu, Sample, Bell, & Guan, 2014). The soil layers catch the suspended solids as the water infiltrates. A study found a total suspended solids removal ratio of 0.60 for

23 rain events (Liu, Sample, Bell, & Guan, 2014). Another study found 54% to 59% removal of total suspended solids (Liu, Sample, Bell, & Guan, 2014).

High concentration of suspended solids negatively affects aquatic life. Suspended solids blocks sunlight from reaching vegetation under the water, thus upsetting the ecosystem (Murphy, 2007). Removing suspended solids has a positive effect on the environment.

Phosphorus and Nitrogen

Phosphorus treatment includes absorption, filtration, and vegetation uptake. The removal of phosphorus in bioretention cells mainly occurs by adsorption (Liu, Sample, Bell, & Guan, 2014). When water is filtrated in the cell, soil layers retain phosphorus (Liu, Sample, Bell, & Guan, 2014). Once absorbed, vegetation can uptake phosphorus. A study found bioretention cells reduce phosphate concentration by 0.21 to 0.25 milligrams per liter in the bowl layer (Liu, Sample, Bell, & Guan, 2014). Water at the bottom of the cell contained phosphate concentration reduced to 0.03 milligrams per liter (Liu, Sample, Bell, & Guan, 2014).

Excess phosphorus can cause eutrophication, harming ecosystems (Liu, Sample, Bell, & Guan, 2014). Removal of phosphorus reduces the chance of eutrophication.

Nitrogen treatment includes ammonification, volatilization, nitrification, denitrification, and vegetative uptake. Ammonification breaks down nitrogen compounds, like nitrate, into ammonium. The majority of ammonia in bioretention cells vaporize due to volatilization (Liu, Sample, Bell, & Guan, 2014). Nitrification further reduces nitrogen compounds. Nitrification occurs in saturated water near plant roots (Liu, Sample, Bell, & Guan, 2014). Since bioretention cells contain standing water and vegetation, they are a great location for nitrification to occur. Denitrification converts nitrate to nitrogen gas by soil bacteria (Liu, Sample, Bell, & Guan, 2014). The soil absorbs some of the dissolved nitrogen carried into the bioretention cell. Vegetation uptakes ammonium and nitrate in the soil. The components of bioretention cells clearly play a role in removing nitrogen from the water. Bioretention cells create an environment that promotes the processes that remove nitrogen. Liu, Sample, Bell, and Guan found nitrate removal rates between 13% and 75% based on research from three bioretention sites (2014).

The removal of nitrogen and phosphorus from runoff reduces algae growth in bodies of water. This prevents the destruction of ecosystems as discussed in the problem section.

Pathogens

Bioretention cells remove pathogenic bacteria such as E. coli. The efficiency ratios for the removal of E. coli is 0.70 (Liu, Sample, Bell, & Guan, 2014). Pathogenic bacteria causes infections, so it is important to treat it before it flows into a stream or lake with recreation activity.

Metals

Bioretention cells retain metals on media surface layers (Liu, Sample, Bell, & Guan, 2014). Research suggests “…bioretention appears to be an efficient facility to remove heavy metallic elements from runoff” (Liu, Sample, Bell, & Guan, 2014). One study determined efficiency ratios for copper, zinc, and lead were 0.54, 0.77, and 0.31, respectively (Liu, Sample, Bell, & Guan, 2014). Another bioretention cell removed metal concentrations of 532, 660, and 75 milligrams per kilogram of zinc, lead, and copper, respectively (Liu, Sample, Bell, & Guan, 2014).

Removal of metals is crucial because metals can be toxic to humans and animals if accumulated in high doses.

Drawbacks

Drawbacks of bioretention cells include clogging, treatment of small volumes of water, and public opinion.

According to Wallover, "clogging is the most common failure in a bioretention cell" (2015). Accumulated suspended solids easily clog bioretention cells (City of Manhattan, 2017). This sediment blocks water from infiltrating further into the bioretention cell and can lead to an increase in flooding instead of a decrease. However, maintenance checks exist to prevent excessive clogging. Therefore, keeping up with the determined maintenance schedule is very important.

Since bioretention cells are small and take up little space, they cannot treat large volumes of runoff. Therefore, they do not perform well during large rain events. However, the City of Manhattan is focusing on the possibility of building two dams in Fort Riley (Richardson & Cassanova, 2018). These dams would reduce flooding from large rain events, allowing bioretention cells to cover the runoff from small rain events.

Differing public opinion might be another downfall. There is bound to be public disagreement over the idea of implementing bioretention cells. Some residents will dislike bioretention cells because they personally dislike the way it looks, while others will welcome the idea immediately.

Associated Costs of bioretention cells

The cost of bioretention cells varies greatly depending on the design of the bioretention cell. Barr Engineering compared multiple constructed bioretention cells to determine an average bioretention cell cost based on their research (2011).

Construction Costs

One common method used to determine construction costs is to multiply the water quality volume (WQv) by a determined factor. The water quality volume is the volume of runoff the bioretention cell is designed to treat from a storm (Weiss, Gulliver, & Erickson, 2005). Barr Engineering uses equation 1 to calculate water quality volume (2011).

$$WQv = 43560(0.05 + 0.9I)A/12 \qquad \text{(Equation 1)}$$

I is the impervious fraction and A is the site area. Current public records for the impervious surface area in Manhattan were not available; however, the NRCS curve-number model makes assumptions for different surface area types that can apply to Manhattan. The model suggests residential areas with a 0.25 acre lot size are 38% impervious (Chin, 2013). Since residential housing surrounds Sunset Neighborhood Park, I used 0.38 for I. As stated above under Size Requirements, the sunset neighborhood park area is about 10 acres. I assumed the site area providing runoff to the bioretention cell is about half of the park area, so about 5 acres. I plugged these values into equation 1 and calculated 7,000 cubic feet for the water quality volume for a bioretention cell in Sunset Neighborhood Park.

Barr Engineering estimates the construction cost of bioretention cells to be $15 per cubic foot of water quality volume with a sample standard deviation of $9 (2011). This cost was determined by averaging the cost of 11 constructed bioretention cells. The relatively high standard deviation of $9 shows how much the construction cost varies between projects; the average cost ranges from $6 to $21 per cubic foot of water quality volume with this deviation. It is difficult to determine a precise price without a completed design.

Assuming a water quality volume of 7,000 cubic feet, the average cost of a bioretention cell is about $105,000. The average cost ranges from $42,000 to $147,000.

Maintenance Costs

Barr Engineering used the same method of multiplying the water quality volume by a factor to determine the maintenance cost of bioretention cells (2011). Barr Engineering determined the average annual maintenance cost to be $1.25 per cubic foot of water quality volume with a sample standard deviation of $1.18 (2011). Again, this is a relatively high standard deviation for this average. It shows that the maintenance cost varies between the different projects. The average cost ranges from $0.07 to $2.43. I believe the vegetation affects the maintenance cost the most. Choosing vegetation that requires little attention would save more money long term.

Assuming a water quality volume of 7,000 cubic feet, the average annual cost of maintaining a bioretention cell is about $8,750. The average annual cost ranges from $490 to $17,010.

Cost Benefit Analysis

Nordman, Isely, Isely, and Denning performed a benefit-cost analysis of green and grey infrastructure (2017). They determined how much money reduced runoff and reduced pollution saved. Bioretention cells also increase property values. For pollution, they considered the monetary benefit of removed suspended solids and phosphorus. Agriculture runoff causes an abundance of phosphorus from excess pesticides (Bear et al., 2017). As you know, agriculture lands surround the Manhattan area. Therefore, when a bioretention cell in Manhattan catches more runoff, it removes more phosphorus, and saves more money. After compiling the savings from the benefits of bioretention cells and subtracting construction and maintenance costs, Nordman, Isely, Isely, and Denning calculated a net present value of $1.12 per cubic feet of water quality volume (2017). Assuming a water quality volume of 7,000 cubic feet, the average net present cost of a bioretention cell is about $7,840. A positive net present value means the monetary benefits exceed the implementation and maintenance costs. Therefore, the benefits of bioretention cells outweigh the cost of constructing and maintaining them.

Other Options

Other low impact design solutions, including retention basins and impermeable sidewalks, alleviate flooding. However, I believe they are not the best option for Manhattan.

Detention Basins

Detention basins are similar to bioretention cells, except detention basins maintain a higher level of water on the surface than bioretention cells. Detention basins pose a greater safety risk to the public due to the thicker layer of water. The steep slopes and lack of suitable safety rails make it difficult for someone to get out of the basin if he/she fell in (Jones, Guo, Urbonas, & Pittinger, 2018). Detention basins require a larger land area and hold more water than bioretention cells (L. Marston, personal communication, November 28, 2018). This makes it more difficult to find an unused area that we can transform into a detention basin. L. Marston also stated that detention basins are less aesthetically appealing to the public (personal communication, November 28, 2018). Barr Engineering estimates small detention basins cost $145 per cubic foot of water quality volume. Detention basins will have a greater water quality volume because they are able to treat more water than bioretention cells. Therefore, with a higher cost per water quality volume and a greater water quality volume, I expect detention basins to cost significantly more than bioretention cells. Bioretention cells are a better option than detention basins because they are cheaper and safer.

Permeable Pavement

Permeable pavement is an alternative to impermeable pavement and has some of the same benefits as bioretention cells. “Permeable pavements are alternative paving surfaces that allow storm water runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated” (Virginia Water Resources Research Center, 2011b). Similar to bioretention cells, permeable pavements are also prone to clogging from sediments (Brown & Hunt, 2012).

Construction of permeable pavements requires excavating more soil than constructing traditional pavement. Permeable pavements require more depth beneath the surface layer to provide room for undrains and other layers to promote infiltration (Virginia Water Resources Research Center, 2011b). Since we would need to excavate more soil and place more parts, the construction time of permeable pavement is greater than regular pavement. The public is less likely to like the construction of permeable pavements than bioretention cells due to the inconvenience. Permeable pavement requires closing roads and sidewalks until construction is complete, but bioretention cell construction is unlikely to cause road closures. Permeable pavements are not as strong as traditional impermeable pavement, so they cannot be in high traffic areas (Virginia Water Resources Research Center, 2011b). Therefore, it is limited in where we can construct it.

Barr Engineering estimates that permeable pavement costs $16 per cubic foot of water quality volume (2011). The company does not have data on the maintenance costs, but since permeable pavements are prone to clogging, I expect the maintenance costs to be similar to that of bioretention cells. Maintenance for permeable pavement might be a little less than for bioretention cells, because permeable pavement does not have vegetation to maintain. Bioretention cells are the better option because permeable pavements have more limitations than bioretention cells.

No Action

Another alternative would be to spend no money on storm water management by doing nothing. However, as I previously explained in the problem section, flooding in Manhattan is a growing problem that is only going to get worse as we continue to develop our city. Doing nothing is not an option for the City of Manhattan. We must take action now to protect our city from future floods.

<u>Governing Rules and Regulations</u>

There are no local or state laws and regulations for storm water mitigation, however there are national laws and regulations put in place to protect natural resources, including water. I will discuss the Clean Water Act and the Community Rating System.

Clean Water Act

They City of Manhattan is responsible for following the regulations put in place by the Clean Water Act. The Clean Water Act prohibits the discharge of polluted water without a National Pollutant Discharge Elimination System (NPDES) permit (Environmental Protection Agency, 2018b). This permit has specifications on what can be discharged and how much (Environmental Protection Agency, 2018b). Further information on how to obtain a NPDES permit and the regulations put in place by the Clean Water Act is available online at http://epa.gov.

Federal Emergency Management Agency

Manhattan is a class 8 community within the Community Rating System (CRS) through the Federal Emergency Management Agency (FEMA) (FEMA, 2018). Property owners in a class 8 community receives a 10% flood insurance reduction (FEMA, 2018). To maintain this rank, the city must meet certain qualifications and follow regulations put in place. This is a huge incentive for the City of Manhattan to keep up with flood mitigation as the city continues to develop. This also provides an incentive to encourage community involvement in implementing bioretention cells around the city.

Maintaining the CRS rank or striving to reach the next highest rank serves as the regulations the city must abide by to continue receiving the flood insurance reduction. This serves as a motivator for the entire community to come together to reduce our impact on flooding. Following the regulations associated with storm water management financially benefits residents while protecting the surrounding ecosystem.

Further information on FEMA's CRS is available online at https://www.fema.gov.

CONCLUSIONS

Based on my findings from this report, I made the following conclusions:

1. Sunset Neighborhood Park is the best location to implement a bioretention cell that is owned by the City of Manhattan.

2. Bioretention cells reduce runoff and flooding.

3. Bioretention cells increase time of concentration.

4. Bioretention cells reduce pollution in runoff.

5. The cost of bioretention cells varies widely based on size and design parameters of the cell.

6. The benefits of bioretention cells outweigh the cost of constructing and maintaining them.

7. Detention basins cost more than bioretention cells.

8. Permeable pavements have more construction limitations than bioretention cells.

9. Bioretention cells are the best storm water management option for the City of Manhattan.

10. They City of Manhattan is responsible for following the regulations put in place by the Clean Water Act.

11. The Community Rating System provides a huge incentive for the City of Manhattan to keep up with flood mitigation as the city continues to develop.

RECOMMENDATIONS

I recommend the City of Manhattan pursue the following actions:

1. Begin designing and constructing a bioretention cell in Sunset Neighborhood Park immediately.

2. Inform the public of the Community Rating System incentives to encourage business and landowners to implement bioretention cells on their property.

3. Continue updating and constructing more storm water management systems as we continue to develop our city.

4. Create a regulation requiring property owners construct storm water mitigation systems when they develop land.

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