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The Fault with Asphalt: Towards Absorbent Urban Design in New York City

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The Fault with Asphalt: Towards Absorbent Urban Design in New York City

Scott Brown
Abstract

In the time of metropolises and rapid urbanization, design is instrumental in facilitating a mutualistic relationship between the built urban environment and the surrounding natural processes. This paper addresses the issue of stormwater runoff and identifies design techniques in urban areas used to mitigate the destructive consequences of urbanization related to precipitation and impermeability. With a focus on New York City, this study uses historical and current rainfall data as well as particular case studies to address successful rainwater collection and stormwater mitigation design implementations. To provide an interdisciplinary approach to combating stormwater runoff, the disciplines of environmental history, economics and politics, and related design techniques are discussed to create a more holistic discussion of this urban issue. Chapter 1 explores the urban environment and the particular ecological issue of impermeability within a city while providing quantitative data regarding rainfall and stormwater runoff. Chapter 2 engages the historical account of rainwater management and collection systems globally and then specifically in NYC. In Chapter 3, the economics and policies surrounding stormwater mitigation and rainwater harvesting will be identified and discussed. In Chapter 4, this paper will identify contemporary design techniques and successful strategies to harness rainwater and reduce the amount of stormwater that enters the sewer systems in New York City. Some landscape and building technologies discussed are designed in a way that integrates the structure into the natural environment by adhering to and imitating nature’s own patterns and design. Chapter 5 navigates the practice of domestic rainwater collection and retention in historical, developing, and more developed civilizations to explore collection techniques and reconsider how the developed world values this natural resource. The last section of this paper offers recommendations to mitigate the effects of stormwater runoff with roof and building designs, as well as dealing with fundamentally changing our perspective and attitude towards rain, our forgotten natural resource.

Keywords: rainwater, stormwater, permeability, landscape/architectural design, urban, mitigation, retention, collection
Table of Contents

Introduction

Chapter 1: Rainfall to Runoff: The Numbers

Chapter 2: A Historical Account of Earth’s Lifeblood Turned Hazard

Chapter 3: Regulation for Permeation

Chapter 4: Design to Resign Gray Infrastructure

Chapter 5: The Return to Domestic Harvesting

Chapter 6: For an Absorbent New York

Appendix

Bibliography
Introduction

As water falls from the sky over Black Rock Forest, environmental components such as absorbent vegetation, permeable soil, and natural basins harness and use the water to continue and promote ecological functions and life. Traveling 50 miles southeast, rainwater slides through alleyways and off of rooftops, collecting the pollutants and harmful chemicals of over eight and a half million residents in New York City. Historically, civilizations have worshipped the downpour of water, as the food grows and water basins recharge, communities flourish due to their integration into the hydrological cycle. However, as our population and urban scale have increased dramatically, our connection to the natural world and knowledge of where our natural resources come from has slowly diminished. This disassociation from the environment can be seen in the inharmonious and disagreeable design of buildings and landscapes throughout urban regions. While recently, efforts have been made to give New York City less concrete and more jungle, it is not only the ingenuity of the designer who is responsible for change, but the support of governmental ordinances and economic incentive that will promote a more cohesive urban environment. In the modern metropolis, with the technological advancement of plumbing and distributed water, the gift of rain and its potential benefits are wasted. Additionally, the failure to harness rainwater has created health hazards and economic damage to the urban communities. By addressing rainwater in a similar way to a forest, cities may again harvest the reward of a hydrologically integrated civilization. This paper addresses the potential of urban rainwater collection and the ensuing issues regarding stormwater runoff in the urban region. With a focus on New York City, this paper’s insight into the issues surrounding rain and stormwater can be applied to other urban regions that face similar issues including flood risks, polluted water systems, and drought.
Chapter 1 will provide quantitative data related to concepts of permeability and urban rainfall along with the consequences surrounding stormwater in New York City. Chapter 2 will explore the historical significance of water as well as discuss New York City’s history of stormwater management. Chapter 3 addresses government policy development and economic incentive regarding rainwater collection and stormwater mitigation using Brooklyn Grange, New York as a case study. In chapter 4, successful building and landscape design implementations that function to harness rainwater will be identified while their technologies and communal effects are explored. In chapter 5, the practice of domestic rainwater collection will be studied, with attention paid to historic and developing regions that rely on harnessed rainfall as a primary water source. Lastly in chapter 6, I offer potential political and design recommendations for the continual advancement of the reintegration of New York City’s urban and natural landscape.

Chapter 1: Rainfall to Runoff – The Numbers

The world in which we live is a cyclical system of inputs and outputs that directly influences the quality of life experienced by all of earth’s inhabitants. To humans, the benefits that are obtained from the natural world are known as “ecosystem services” which are then divided into four subsequent categories. Provisioning services are the direct material goods that are reaped from the environment such as food, materials for construction, and freshwater. Regulating services refer to the natural processes that control the quality of natural capital and health of ecosystems, such as trees filtering the air of pollutants and sequestering carbon from the atmosphere in the form of biomass. Additionally, trees absorb precipitation, which protects the quality of soil and adjacent landscapes from erosion and flooding. Similarly, the presence of trees and vegetation promote supporting services, such as wildlife integration to landscapes by
providing habitat and refuge for neighboring biota. Lastly, a cultural service refers to the non-material benefits that are gained from experiencing nature or integrating it into an urban landscape. Services such as these may include recreational enjoyment, improved mental and physical health, and appreciation for the natural world and the welfare it provides.\textsuperscript{1} The focus of this paper on rainfall and stormwater runoff in the urban setting of New York City addresses some of these ecosystem services that have been compromised by this relevant environmental issue.

In the urban environment, impermeable and paved surfaces prevent the percolation of rainwater into the ground, and results in mass quantities of stormwater flowing though streets and picking up pollutants. In many cases, storm drains become overwhelmed from rainfall or clogged by trash, resulting in stagnant bodies of water that can act as disease vectors and insect breeding grounds.\textsuperscript{2} This issue of stormwater runoff and the neglected effort to harness rainwater directly affect the quality of ecosystem services in the urban environment, primarily regulatory and cultural services. The presence of stormwater creates unhealthy living conditions for urban inhabitants, both human and non-human species. When rain falls on the cityscape and the storm drains have been overwhelmed, untreated sewage and stormwater enters adjacent water bodies or pools in low-lying areas within the urban environment. Stagnant water bodies often found in cities after precipitation events are vectors for waterborne diseases and become breeding grounds for insects such as mosquitos which can carry and transfer a variety of diseases. The stormwater that does not enter the sewer system or stay pooled in city streets will find its way to the nearest water body, which in the case of New York City primarily includes the Hudson River, the East

\textsuperscript{2} Ibid., 13.
River and Jamaica Bay. Stormwater entering these water bodies has collected several miles of pollution from agriculture fertilizers, car exhaust, and fecal matter.

Pollution entering New York Harbor and its constituent water bodies make recreation and resource extraction unsafe for human interaction. A study conducted in 2014 by Riverkeeper shows that 3,400 tests taken from 74 sites between New York Harbor and Albany showed that 61% of the sites would not meet the EPA’s criteria for safe recreational waters. These health factors impede the public’s ability to safely enjoy the natural water systems that surround their city, while degrading the environments provisioning services such as the health quality of consumable fish. To exacerbate the issues related to the ecological damage from polluted runoff, the natural landscape systems that could alleviate this degradation have been dismantled in the wake of urbanization and industrialization.

Coastal wetlands including swamps, bogs, and similar areas play a major and unique role as the interface between terrestrial and aquatic ecosystems. Saturated with groundwater, the vegetation in these low-lying areas are adapted to manage large quantities of water. Uniquely, wetlands are able to retain large amounts of sediment and pollutants, ideal areas for natural stormwater treatment. Unfortunately, the increase of urbanization and unnatural infrastructure has destroyed a vast majority of these ecosystems within the last century. Within the New York-New Jersey Harbor Estuary, roughly 85% of the coastal wetlands have been lost, making areas of New York and New Jersey vulnerable to flooding and less equipped to deal with large influxes of polluted stormwater. In a similarly unfortunate research result, over 90% of the freshwater wetlands that once existed within New York City have been drained, paved, and built

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4 New York City Wetlands Strategy, PlaNYC 2012.
By destroying such functional environments within the City, the ecosystem services of these wetlands have also been lost. Particularly, Jamaica Bay, Northern Staten Island, Upper East River, and the Long Island Sound are productive and vitally important wetland systems that are facing rapid ecosystem fragmentation and loss. This degradation has resulted in the loss of wildlife and exacerbated levels of pollution within their adjacent water body. In recent years, New York City has attempted to restore the quality and acreage of coastal and freshwater wetlands within the five boroughs. The restoration project attempts to revitalize degraded wetland areas across 16 different sites including: Meadow Lake, Yellow Bar, Black Wall, and Rulers Bar in Queens; Paerdegat Basin and Calvert Vaux Park in Brooklyn; Inwood Park in Manhattan; Freshkills Park, Pralls Island, Crescent Beach, and Brookfield Landfill in Staten Island; and Pugsley Creek, Soundview Park, Tallapoosa, Turtle Cove, and further upstream along the Bronx River in the Bronx. While the restoration programs continue, this paper will now address some of the further hazards associated with stormwater runoff in the urban environment.

Uncollected rainwater travels over impermeable surfaces collecting the pollution of the densely populated city. During even the most minor of rain events, the sewer system becomes overwhelmed and cannot allow additional water to travel to the treatment plants before being released into adjacent water bodies. In this event, untreated stormwater and in some cases raw sewage, will enter aquatic ecosystems and cause severe environmental harm. Excess nutrients from pesticides and fertilizers can create algal blooms which have a detrimental effect on the marine environment. As excess nutrients feeds and supports the growth of algae which will only be temporarily sustained, decomposing organisms will eat dying algae and consume significant

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5 Ibid. 5.
6 Ibid. 12.
quantities of dissolved oxygen. This effect will create what is known as “dead zones” which are areas within a water body that is unable to support any significant variety of aquatic life. According to the New York State Department of Environmental Conservation, there are at least nine significant freshwater bodies within the New York County that have been tested for high levels of toxicity due to the presence of severe algal blooms every year since 2012. These levels of toxicity can not only be harmful for aquatic biota, but can cause health hazards for urban residents coming into contact with contaminated water with illness ranging from irritated eyes and skin to gastrointestinal disease due to consumption. In addition to the damage caused to the natural environment, excess stormwater can pose threat to human safety.

Aside from degrading the quality of health within the urban environment, excess stormwater is a major safety concern for drivers and pedestrians. On average, there are nearly 6 million car crashes each year across the United States, where over one million of those accidents are caused from adverse weather effects. Interestingly, over 70% of crashes caused by weather happened during or just after a heavy rainstorm. During dry weather, roads build up oils and other hydrocarbons from gasoline and surrounding pollutant factors which then become extremely slick following a rain event. These unsafe factors, along with hydroplaning – the concept of water buildup between the car tires and the road, are reasons for hazard driving conditions and consequential road accidents. While polluted stormwater currently has negative effects on the overall health and safety of the urban environment, designing buildings and

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landscapes to collect and repurpose rainwater not only abates the negative effects of runoff, but optimizes the existing ecosystem services to an urban community.

Figure 1: Landscape Permeability

As rain falls on a natural landscape, the amount of runoff that escapes the immediate surroundings is dependent on the composition of soil and vegetation present. As vegetation becomes denser and soil permeability increases, rainfall will be absorbed by the landscape with less runoff as opposed to a landscape with sparse vegetation and impermeable features. The diagram depicted here illustrates the differences in permeability across varying landscapes. If for example, rainfall was to descend on these particular sites, the more natural and vegetation rich landscapes would be able to retain a majority of that rainfall and produce little runoff. On the other side of the diagram, an urban district that has decimated the native vegetation and replaced

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it with impervious concrete and asphalt, only a small portion of the rainfall is absorbed by the city when the majority is lost as runoff and becomes an environmental hazard.

While the use of impervious materials restricts an urban district’s ability to function as a natural and absorbent landscape, the issue compounds itself as the same materials increase the amount of rain that an urban area receives. The use of heat absorbing materials such as asphalt and the lack of vegetation causes a warming effect around cities also known as the Urban Heat Island Effect. According to climatologists, the temperature differentiation from the city and surrounding landscape can range from six to eight degrees Fahrenheit warmer in cities.\(^\text{10}\) This temperature increase causes the warm city air to rise, which then cools and condenses into rain forming clouds that will fall and soak the area downwind.\(^\text{11}\) According to a 1970’s study known as METROMEX, cities increased cumulative precipitation by 5-25 percent. However, as cities became larger and more studies have been produced, depending on the area there may be up to 60 percent increase in rainfall in urban areas than its adjacent natural landscape.\(^\text{12}\) With the nature of the urban landscape and these quantitative figures in mind, the next section will focus on New York City, the most populous city in the United States.

Covering just over 300 square miles in land area, New York City consists of the five boroughs of Brooklyn, The Bronx, Manhattan, Staten Island, and Queens. Located in the warm humid subtropical climate zone, New York City experiences rainfall nearly every month with exception of snow as the alternative precipitation in the winter months. According to United States climate data from 1961-1990, New York City received an average of 46 inches of rainfall

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\(^\text{11}\) *Innovative & Integrated Stormwater Management*, New York City. 2017

\(^\text{12}\) Ibid. 56.
each year, with May and July as the average wettest months.\textsuperscript{13} To put this annual metric into a more substantial figure, rainfall can be expressed in approximate gallons per year. With the known surface area of approximately 300 square miles for New York City and an annual average downpour of about 46 inches, by converting square miles into inches and multiplying that by 46 inches, an average yearly volume in cubic inches of rainwater can be determined. Once this is calculated, by converting cubic inches into gallons, an approximate average of 238,757,575,757 gallons of rain falls on to New York City annually. Despite this tremendous amount of available water, only a fraction is able to be absorbed or harnessed by the city, where the remaining trillions of gallons go unutilized and cause harm to the city and its residents. According to the NYC Green Infrastructure Program, approximately 72\% of New York City is covered with impermeable surfaces such as asphalt and concrete.\textsuperscript{14} Based on this figure, at least 171,905,454,545 gallons of water are unharnessed annually, and this remaining water is to be collected by the 19\textsuperscript{th} century sewer technology along with any debris it picks up along the way. Water flushes through the streets of NYC, gathering pollutants, overflowing the sewer system to go and pollute adjacent water bodies and create uninhabitable public spaces for urban communities. While these numbers describe a truly incomprehensible amount of water, it is estimated that New York City will see an increase in precipitation in the coming years as an effect of global climate change.


As temperatures warm and the air becomes more prone to holding larger quantities of moisture, New York City will see an increase in the levels of rainfall that it receives on an annual basis. The New York City Panel on Climate Change has put together the graphic above to illustrate the increase in localized rainfall. This issue surrounding impermeability and the use of heat retaining materials is only exacerbated with increased temperatures and increased rainfall.

Figure 2: Predicted Levels of Rainfall in New York City\textsuperscript{15}

In this case, the extensive use of impermeable and heat retaining materials such as concrete and asphalt degrade the urban environment in two compounding ways. As streets are laid with asphalt, the material contributes to localized urban warming creating an increase in precipitation. Consequentially, the urban landscape is now less equipped to deal with large quantities of rainfall that leads to extensive stormwater and the environmental and health issues previously

noted. To further exacerbate this issue, climatologists predict that heavy rainfall from storms will come in less frequent but heavier downpours. This means that sewer infrastructure will be progressively overwhelmed, where the likelihood of combined sewer overflows will increase, and the importance of preemptive absorbance and flood resilience becomes even more crucial to sustain the changing urban environment.

Figure 3: Combined Sewer Overflow Hotspots in New York City\textsuperscript{16}

\textsuperscript{16} Ibid.
While the amount of rain is not necessarily the direct problem to the urban landscape, the existing sewer system is prone to overflowing which leaves untreated water able to pollute the coastlines and contaminate vulnerable districts. New York City experiences on average 54 citywide sewer overflows annually and as much as 70 during wetter years, contributing to an approximate 500 million gallons of polluted sewer discharge weekly.\(^{17}\) Above is a map depicting common sewage overflow hotspots within the five boroughs of New York.

Each borough of New York City varies in their geographical, political, environmental, and demographic characteristics. These components in some respect reflect the quality and quantity of stormwater and sewage overflows that afflict each borough and communities. Therefore, boroughs with more waste, less trash bins, or less storm drain maintenance will experience different levels of disparity caused by polluted runoff. This can perhaps be seen in the more severe sewage overflows in the South Bronx and Northern Queens compared to the more infrequent overflows in Manhattan. Additionally, the age of the infrastructure built to deal with stormwater runoff will play a role in the sewer system’s ability to manage large quantities of runoff. Managing rainfall and stormwater runoff through the use of current and future infrastructure design is how we can control the ecosystem services we obtain regarding this natural resource. As an essential component to life on earth, the implications water has across all ecosystem services is great, but those specific to rainfall will be mentioned here. Provisionally, rainfall recharges underground aquifers and permits life and growth to flora and fauna within the city. As a supporting service, rainfall feeds and affects the water quality of adjacent water bodies, contributing to the health of aquatic life. Lastly, rain can be a magical event in the proper environment affecting moods, promoting inspiration, and even be seen as a spiritual experience.

However, by neglecting rain’s ecological and historic role, we fail to promote these functions and instead degrade them while turning rain from a gift to a nuisance. While rainfall and consequently stormwater are posing as an environmental hazard, taking a look at the history of water and our progression to the modern urban civilization can offer a different outlook for our future as ones who may benefit from the rain.

Chapter 2: A Historical Account of Earth’s Lifeblood Turned Hazard

As astronomers gaze out beyond our solar system searching for extraterrestrial life, a key component to identifying a potentially habitable planet is the presence of water. The life-blood of our planet has promoted the creation and sustained the livelihood for the entire biotic community. While most species are adapted to live in tandem with their local hydrologic cycle, early human civilizations have manipulated and configured water systems to support the growing community and have continued to separate from the surrounding ecological systems.

In ancient civilizations across the globe, the one major feature that was similar across all empires and cultures was the possession and control of freshwater supplies. Present in the civilizations of ancient Rome, China, India, and Mesopotamia, sewer and rainwater harvesting systems became imperative to ensuring public health while securing the possession of water during arid and hot times. Whether for drinking, growing crops, cleaning the home, bathing, or travel, the amount and quality of freshwater a civilization acquired would directly correlate to the well-being of the society. To take a historical case, the Mayan Civilization began around 3000 B.C. and came to its demise around the 9th century due to the lack of integration between the community and the hydrological cycle. As an adjacent freshwater supply sustained the Mayan Civilization and promoted the production of more crops and therefore more people, the ancient
civilization slowly began to see the effects of anthropogenic localized climate change. With a growing society, more homes were to be built using timber from adjacent forests. However, the over harvesting of trees, unknowingly to the Mayan peoples, was having devastating effects on the local hydrological cycle. As trees release water back into the atmosphere through a process called evapotranspiration, the water cycle is continued where clouds form, condense, and fall in the form of rain. Through this process of deforestation for the sake of home building, large expanses of forests were wiped out, causing a lack of water released back into the atmosphere resulting in regionalized drought and the collapse of the historic Mayan peoples.\textsuperscript{18} While the concept of anthropogenic climate change is becoming more evident in the modern context, it is not an issue of drought that this paper addresses but the flooding and stormwater pollution that threatens our modern urban districts. To better understand our lack of integration within the hydrological systems, we may direct our attention to earlier civilizations and the birth of aquatic related infrastructure.

The ancient Roman Empire was one of the first civilizations to actively design and build infrastructure that would drain storm and sewage water away from residential communities. Following the fizzle of the nomadic lifestyle following food and resources, the development of domesticated agriculture allowed communities to settle in one location and build permanent living structures. While the birth of the city promoted economic and technological advancement, the act of residing in one place created both health and environmental hazards for city residents and surrounding ecosystems. Recognizing some of the shortcomings of the city, ancient Rome had become the first civilization to construct a sewer system that would transport city waste and runoff precipitation out of the immediate urban environment. Prior to the development of a waste

removal system, human excrement would simply be disposed of outside on the streets or in communal cesspools that would overflow and pose serious health issues during and after storm events. In an effort to combat this public health hazard, the Roman Empire began to construct their sewage removal system around 800 BC.19

Using clay and a variety of unused pottery components, the Romans had constructed a complex sewage and drainage system that aimed to remove hazardous waste from the inhabited urban environment. Waste from households were transported via clay piping into a communal basin that would then be disposed of into an adjacent water body. Prior to the water being released into the environment, the design of the basin would allow solids to sink to the bottom of the basin before the top layer of water can be released. Once this partially cleaned liquid entered a water body, leftover sludge and solid waste would be used as a fertilizer or simply buried to reduce human exposure.20 Aside from human waste, these clay pipes simultaneously transported excess precipitation to the same basin. Configured throughout flood-prone areas of the city, drain pipes were connected to the clay sewer system, creating the first combined sewer system which transports both human waste and runoff from excess stormwater. While the creation of a subgrade sewer system begins to address the issues related to waste water removal and promoting public health, an ancient technique exists to collect rainfall and more actively get to the root of issues related to rainfall and runoff, the neglected resource.

Before the modern times of indoor plumbing, water was to be fetched from a nearby water body or pulled up from a well and brought to the home. Whether it is carried in baskets, clay pots, or pumped in via hundreds of miles of metal piping, water is an essential component

for everyday life. Ancient civilizations were dependent on nearby water bodies and groundwater aquifers for household purposes and agriculture which required a reliable source to always be available. During times of drought, ancient cities were particularly vulnerable to exhausting their water supply unless they had developed an alternative water collection technique. Prominently practiced in 2000 BC India, China, and Mesopotamia, rainwater harvesting provided water security for urban residents and farmers in order to sustain their communities and families. In the Indus Valley, huge vats were carved out of the bedrock to collect rainfall during precipitation events. During rain event, homes were equipped with rudimentary rainwater harvesting systems on the roofs, able to direct water from the roof and into a basin within the home. During times of drought when domestic water supplies and reservoirs were low, stone channels would lead rainwater from the large vats throughout the city, providing hydration for the urban residents and for the vegetation that fed them. While these exposed reservoirs were appropriate within these climate zones, some drier and hotter climates built vast underground cisterns in order to hold collected water. Built in the 6th century during the Byzantine Empire, the Basilica Cistern in Istanbul is the largest cistern in the world able to store over 100,000 tons of water. Stormwater from the streets were purposefully directed into the subterranean cistern, where water could be passively filtered, and travel through nearly 1,000 meters of aqueduct to be delivered to city inhabitants.

An underground cistern provides the urban residents with a reliable water source that will remain dependable throughout the hot and dry seasons. The Basilica Cistern is a prime example of a sustainable and functional piece of urban infrastructure. Built from recycled column and arches, the Basilica Cistern functioned as a manmade reservoir that served its community in both

historic and modern times. Currently, it functions as an artisanal fishing reservoir for those seeking freshwater carp. Additionally, the ancient cistern now operates as a tourist attraction for travelers interested in observing and exploring this ancient functional and monumental structure. To appreciate the historic practice of rainwater harvesting in ancient civilizations, we now move to discuss the modern metropolis and the issues surrounding infrastructure that have led to the rise of urban ecological concerns regarding impermeability.

Figure 4: The Basilica Cistern in Istanbul

Unlike ancient civilizations, the modern metropolises today hold tens of millions of people each and expand areas of hundreds of square miles. To manipulate the land to be better suited for the automobile, these vast urban districts are made mostly from concrete and asphalt as

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well as other impermeable materials on commercial buildings and homes. However, these ridable and durable materials come at an ecological cost – the lack of permeability. While cities around the globe began implementing their own style of stormwater management, the first modern urban drainage systems dealt with building waste and stormwater runoff in the same system, known as a combined sewer system. This system style consists of basic drainage inlets with piping to transfer excess urban water into a nearby water supply such as a lake or a river. However, the rapid discharge of water into these water bodies caused eroded river banks and polluted the water system creating an unhealthy aquatic ecosystem.  

In the 1970’s, ordinances were passed that required developers to reduce the quantity of peak stormwater discharge by constructing detention basins and other flow control structures in the urban setting. While these implementations abated some of the immediate negative effects of surging stormwater, the concept of infiltration became recognized as a better solution to stormwater. By designing land to allow water infiltration, not only does it decrease the total volume of stormwater in the sewer system, but also allows the groundwater system to be recharged and filtered by the percolation through varying layers of sediment. The acknowledgment of stormwater management practice gave rise to the goal of Low Impact Design in 1990. Low Impact Design sets out to design habitable spaces in which the natural hydrological system is as intact as possible, including areas of infiltration, detention, and consumption. During this time, recognition was given not only to the quantity of stormwater, but to the quality of the runoff as well. In the 1980’s the EPA placed pollutants on the list of stormwater attributes that needed to be controlled. Pollutants such as heavy metals, toxins, bacteria, viruses, and sediment contribute to health risks of both the urban

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26 Ibid.
dwellers and adjacent aquatic life. With this general layout of the evolution of stormwater awareness and management, special consideration to New York City will now be addressed.

First colonized in the 17th century, the city now known as New York quickly became one of the most industrialized and inhabited cities in the world. During the Dutch colonial times in the midst of the 19th century, waste was often deposited in an outhouse or hole behind the home with no official industrial sewer complex. With no system in place to remove waste from city streets, rainfall was the primary means that waste could be washed away into the Hudson and other adjacent water bodies. As the city began to grow, this system was quickly realized to be unsafe for both human and non-human species within the urban and surrounding landscapes. In an interesting historical case in the 16th century, what was later founded to be Manhattan contained a large 48 acre, 60-foot-deep pond called Collect Pond. This pond was fed by an underground spring and provided freshwater for the surrounding inhabitants. However, as urbanization and industrialization continued, buildings were built around the pond which slowly began to deteriorate the quality of the freshwater resource. As adjacent industry began to release pollutants from their infrastructure, stormwater would collect these pollutants and carry them into Collect Pond. By the 18th century, the pond was so filthy that it was unfit for consumption and began to pose as a health hazard by creating stagnant water where mosquitos could breed27. Years later, New York City began building its aqueduct from the Croton watershed which would serve as New York City’s main water supply until the creation of the Delaware/Catskill aqueduct. This historical example displays a transition of incongruity between the city and its inhabitants with the local hydrological system.

27 Ibid.
In 1849, New York City began constructing the sewer system, and laid nearly 70 miles of piping from the years 1750 to 1855. The sewer construction process continued through the 19th century and today nearly 6,600 miles of sewer piping lay beneath the streets of New York City transporting wastewater to 14 sewage treatment plants. As a pioneer of the new age sewer system, most areas of the city are fitted with a combined sewer system in which sanitary and industrial wastewater, rainwater, and street runoff are collected in the same sewers that converge to the treatment plant. In some New York City neighborhoods, stormwater is transported in a separate sewer system where it is directly deposited in local streams, rivers, and bays.

Figure 5: Combined versus Separated Sewer System

The older combined sewer systems as displayed here, are prone to overflowing, where untreated wastewater flows directly into natural water bodies or sits stagnant on the streets within

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29 Ibid.


31 Image from NYC Green Infrastructure Plan
urban communities. In recent years, New York City has dramatically changed the way in which stormwater is managed, with policies and design strategies to detain, absorb, and retain rain and stormwater.

In 2007, New York City Mayor Bloomberg announced his sustainability plan. As part of his campaign to alleviate the negative effects of stormwater, the city committed “to build more Bluebelts and Greenstreets, require green parking lots, incentivize green roofs, and form an Interagency Best Management Practices Task Force.” This initiative opens the door for many opportunities to implement more greenery and functional landscaping to the New York City region in the coming years. The next chapter will outline and discuss some of the policies and economic incentives that have been implemented at the federal and local level in order to further promote rainwater collection and mitigate excess stormwater runoff in the urban environment.

Chapter 3: Regulation for Permeation

While stormwater abatement promotes significant health and ecological benefits, economic and political logistics must be taken into consideration in order to pursued policy makers and city governments to enact strategy and design methodologies. As a result of rainwater buildup, cityscapes across the nation experience flash flooding that damage residential and commercial property where costs are estimated at $2 billion annually. In New York City with its adjacent natural waterways including the Hudson River and New York Bight, destruction from stormwater does not stop at property damage.

32 Ibid.
As rainfall rolls across impermeable surfaces collecting pollutants from streets and excess nutrient runoff from agricultural, this polluted water supply enters adjacent water systems, affecting the health of aquatic species and consequently can impact health of those who fish in the Hudson River. There are roughly 70 species of fish in the Hudson River, and the Hudson River Sloop Clearwater Incorporated has issued a fish advisory outreach to inform the general public which fish are safe and unsafe to consume. In the Lower Hudson, from Bridge at Catskill to the NYC Battery, there are four species of fish that the Hudson River Sloop Clearwater recommends to never eat due to the buildup of polychlorinated biphenyl (PCB’s) and other toxins including the American eel, Gizzard shad, and the White and Channel catfishes. Additionally, the Hudson River Sloop Clearwater lists ten species of fish that are only recommended to be eaten once a month, with all remaining species recommended to only be consumed up to four times per month. Additionally, recommendations have been made as to who should consume the fish that are regarded as safe to eat. The Hudson River Sloop Clearwater recommends that no child under the age of 15 or any woman of childbearing years should consume any fish from the Hudson River. It is suggested that only men over the age of 15 and elderly women can eat the specified fish that come from the Hudson River as to prevent serious exposure to toxins. Although the water quality of the Hudson River has improved over the past few decades, pollution carried by stormwater runoff continues to compromise a valuable provisioning ecosystem service of the New York City environment. Similarly, stagnant and pollutant holding stormwater runoff that does not find its way to the Hudson River or cannot enter the sewer system create health risks for communities as vectors for waterborne diseases.

Stagnant waters are ideal vectors for a myriad of viruses, pathogens, and accumulated bacteria that pose serious health risks particularly for children, the elderly, and pregnant women. It is estimated that 99 million people in the United States contract intestinal infectious diseases annually, and although many cases go undocumented, medical costs accrue to billions of dollars per year for treatment. Additionally, more than half of these documented waterborne disease outbreaks since 1948 have followed after extreme rainfall.\textsuperscript{35} With the consequences of stormwater runoff recognized, attention will be paid to some of the existing policy frameworks that have influence on current design and infrastructure practice. While there are many policies and documentation that deal with stormwater in New York City including PlaNYC, OneNYC, and documents that deal with gray infrastructure, this section will be focused on design making policy which deals with stormwater mitigation and rainwater harvesting including LEED Certification, the NYC Green Infrastructure Plan, and Grow NYC.

In 1993, the Natural Resource Defense Council headed the development of the United States Green Building Council (USGBC) along with the international accreditation organization Leadership in Energy and Environmental Design (LEED). The LEED organization assesses buildings and neighborhoods with a set of rating systems aimed at assessing the environmental impact of design, construction, operation, and maintenance. The USGBC then assigns a rank of certified, silver, gold, or platinum to the subjected facility based on various environmentally sound components. One area of this assessment includes rainwater management, where points can be obtained through minimizing stormwater runoff that leaves the site. This goal can be attained by designing permeable surfaces throughout the site that allow the infiltration, reuse, and evapotranspiration of rainwater. Additionally, stormwater can be managed with detention

cisterns, that hold stormwater temporarily during heavy storms, or better yet by collecting and reusing rainwater as a supplement or replacement water supply. Besides being environmentally conscious and promoting sustainable development practices, LEED certification offers economic incentive to those who pursue this accreditation.

Dependent on the level of LEED certification acquired and the size of the site, a tax credit is offered to varying development projects. For example, in commercial buildings that are LEED Platinum certified, a tax credit of $6.25/sq.ft. is given for the first 10,000 square feet of the building, $3.25/sq.ft. for the next 40,000 square feet, and $2.00/sq.ft. over the 50,000 square feet marker up to 500,000 square feet. In a residential building that has been awarded LEED Platinum certification, a tax credit of $6.50/sq.ft. is given for up to 2,000 square feet of the building. Additionally, LEED certified sites are eligible to apply for funding sources including grants and loans to encourage sustainable development practices. Furthermore, the Green Infrastructure Grant Program offers private property owners of New York City financial reimbursement for the design and construction of systems that reduce stormwater runoff. Projects that are eligible for this incentive include green roofs and infiltration systems such as rain gardens and permeable pavement.

For green roof projects, reimbursement rates are dependent on the depth of the soil, which correlates to how much rainwater can be absorbed on the roof. The table below depicts the funding rates for varying level of soil depths.

36 Leadership in Energy and Environmental Design, United States Green Building Council. 2015
37 Ibid
Figure 6: Reimbursement Rates for Green Roof Projects

For projects that exceed 20,000 square feet, funding per square foot is calculated using 50% of the rate shown above. To look at a particular case study, Brooklyn Grange, a rooftop garden atop a historic navy shipyard located in Brooklyn, NY grows vegetables in a 10-12” deep soil covering. This massive 65,000 square foot rooftop converts over one million gallons of would-be stormwater into the vegetables that feed the local community. Due to this immense contribution to the management of stormwater, in 2011 Brooklyn Grange received $592,730 in grant funding provided by the Department of Environmental Protection’s Green Infrastructure Stormwater Management program. Additionally, green roofs such as Brooklyn Grange provide further environmental benefits such as air and noise pollution reduction, habitat provision for birds and pollinators, an alternative local food source, and increased beautification of urban design. Grant funding allows organizations such as Brooklyn Grange to pursue environmentally favorable projects while incentivizing future development projects to follow suit. While a single building

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39 Ibid.
can contribute to the goal of abating stormwater runoff and the pollution of adjacent water systems, it is up to the city and local government to instill policies that work to encompass a citywide effort in managing rainwater, the natural resource turned environmental hazard.

In 2010, New York City released the NYC Green Infrastructure Plan which approaches the issue of stormwater by designing and implementing various types of green infrastructure to create a more absorbent citiescape and abate the issue of severe stormwater runoff. According to the NYC Green Infrastructure Plan, traditional approaches to reduce combined sewer overflows include the construction of additional, large infrastructure, but the remaining opportunities for such construction are very expensive and do not provide the sustainability benefits that New Yorkers rightly expect from multi-billion-dollar investments of public funds.\(^{40}\) As opposed to spending over $10 billion constructing large infrastructure built to manage the billions of gallons of stormwater, this alternative approach aims to reduce the amount of stormwater NYC generates and enters the sewer system, while simultaneously implementing greenery back into the urban environment. In 2007 as an addition to PlaNYC, New York City committed to build more pervious surfaces and systems designed to promote the infiltration and detention of rainwater. At the core of the City’s plan is green infrastructure, and the goal to capture the first inch of rainfall over 10% of the impervious areas in the combined sewer watershed in the city.\(^{41}\) By reaching this goal over the next 20 years, New York City will reduce 1.5 billion gallons of stormwater that enters the sewer system annually.\(^{42}\) In order to reduce this amount of runoff, NYC has compiled a Green Infrastructure Task Force to design and build stormwater control systems in existing roadway construction and other public infrastructure programs. In addition to mitigating the

\(^{40}\) NYC Green Infrastructure Plan: A Sustainable Strategy for Clean Waterways. 2015. 36-37.
\(^{41}\) Ibid.
\(^{42}\) Ibid.
amount of runoff that enters the sewer system, efforts have been made in order to reduce the amount of rainfall that turns into runoff by integrating rainwater harvesting systems and policy in New York City.

Rainwater harvesting, according to the National Conference of State Legislatures, is “the act of utilizing a collection system to use rainwater for outdoor uses, plumbing, and in some cases, consumption.” Rainwater harvesting can provide many benefits to both communities and households who participate in system installation. By supplementing or even replacing one’s water supply with captured rainwater, a collection system offers economic incentive to reduce the charge of the utility bill. Additionally, collecting rainwater promotes environmental health and sustains ecosystem services that benefit the urban landscape. By reducing total runoff entering the sewer system, mitigating soil erosion caused by excess runoff, and reducing the usage of piped water from the home, rainwater collection provides a myriad of ecological benefits to the larger urban environment. Whether collected rainfall is used to clean, provide drinking water for animals, or for an irrigation system, there are both economic and environmental benefits that should incentivize both commercial and residential rainwater harvesting.

Currently, the community gardens of New York City are responsible for constructing over 140 rainwater harvesting system across the five boroughs. Collectively, these systems collect over 1.5 million gallons of rainwater a year from rooftops and shaded structures which reduces the demand on the public water supply, mitigates runoff, and provides communities with an alternative source of food. Under the USGBC and their LEED accreditation system,

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commercial buildings such as Brooklyn Grange can receive tax credit and government grants to promote the construction of more sustainable and environmentally conscious infrastructure. Similarly, these types of economic incentives can be given to residential buildings such as The Solaire building in Battery Park. At 375,000 square feet and 27 stories high, The Solaire has integrated a highly sophisticated rainwater capturing system, treating two inches of rainwater to be repurposed throughout the building. Collected in a 10,000-gallon cistern in the basement of the building, rainwater is treated through a sand filter and chlorinated prior to being reused for irrigating two green roofs on the building. Using water efficient technologies and with the supplemental water supply of rainwater, The Solaire building has decreased its water usage by 50% and has earned New York State’s first-ever tax credit for sustainable construction. In order to share the benefits and awareness of rainwater harvesting with the community of New York City, the Department of Environmental Protection began distributing rain barrels in 2008.

The rain barrel distribution program began in the Jamaica Bay watershed in 2008, giving out 250 barrels to home and building owners. The positive response from the community encouraged the Department of Environmental Protection to expand the rain barrel distribution program in 2009 where over 5,000 rain barrels were distributed to homeowners, schools, and community gardens across the five boroughs of New York City. Rain barrels can provide homeowners with approximately 40% of non-potable water usage during the summer months, as rain barrels are disconnected during the winter months to avoid freezing. In recent years, the rain barrel distribution program has gained popularity and in 2017, over 7,500 barrels were distributed. By raising awareness of the potential benefits that rainwater harvesting brings and by

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implementing policy that provides communities with the resources necessary to collect rainfall, the environmental degradation that results from stormwater runoff can be alleviated while enhancing the ecosystem services provided by rainfall and surrounding water bodies.

To go into more detail of the design strategies implemented in NYC and other successful green infrastructure programs, this next chapter will be devoted to stormwater management design techniques and their compounded benefits to the urban environment and its inhabitants.

Chapter 4: Design to Resign Gray Infrastructure

As opposed to spending billions of dollars reconstructing the NYC sewer systems and building larger and uglier stormwater maintenance facilities, the City turns towards green and blue design techniques to manage rainwater while beautifying the city and educating its inhabitants. By doing so, New York City has gone on the offensive against stormwater. Instead of equipping infrastructure to deal with large amounts of stormwater runoff, the City is working to reduce the amount of runoff that enters the sewer system which ideally can be used for various water demanding projects. These so-called “blue” and “green” infrastructure implementations manage stormwater or rainfall by two means, detention and/or retention operations. In this chapter, while both detention and retention techniques will be explored, attention will be prioritized to those systems that follow the retention methodology as water is encouraged to be reused on site as opposed to directed back to the sewers.

A stormwater management design technique that follows the detention operation is one that collects stormwater or rainwater temporarily and is later released back into the sewer system. During heavy rainfall, the New York City sewer system can be overwhelmed and
overflow with as little as half an inch of rainfall.\textsuperscript{46} Due to the immense area of impervious surfaces over the cityscape including asphalt and concrete on roads, sidewalks, parking lots, and rooftops, storm drains are constantly under pressure to manage millions of gallons of water often unsuccessfully. To alleviate the stress put on the system during heavy storms, detention storage units aid in holding back large quantities of water and reduces the peak flow rate.\textsuperscript{47} Detention storage tanks are typically installed underground, to which runoff is directed, stored, and released back into the system once the storm has diminished and the sewers are able to handle additional water. Detention cisterns such as the one depicted below are popular stormwater mitigation techniques that can be found under NYC parking lots and parks. While this stormwater detention operation lies underneath the landscape, there is a newer and less-well-known detention technique that deals with rainfall directly that goes over everyone’s head.

\textbf{Figure 7: Subgrade Detention Cisterns}\textsuperscript{48}

\textsuperscript{46} Innovative & Integrated Stormwater Management, New York City, 2017.
In dealing with rainfall that collects on the roofs of many buildings, Geosyntec Consultants have designed and implemented Blue Roofs across New York City. A Blue Roof is a method of rainwater detention that uses trays of permeable material such as gravel to allow rainfall to be caught and slowly percolate into an adjacent storm drain thus reducing runoff during peak-flow of rainstorms and alleviating the stress put on the system. The Blue Roof detention technique offers buildings a cost-effective measure to dealing with rainwater detention with the versatility to be installed on nearly any flat roof with additional structural support. Over the last three years, 14 Blue Roofs have been installed atop various schools across New York City offering both commercial and educational facilities a more cost-effective approach to rainwater management than subsurface detention cisterns. Although these detention methodologies alleviate the stress put on the sewer system during heavy rainfall and help reduce sewer overflows, the water they hold inevitably ends up back into the storm drains to a treatment plant. Conversely, stormwater and rainfall retention operations utilize the water from the sky to be reused and never see the underground sewer system.
Away from the urbanized cityscape the issue of stormwater runoff is nearly nonexistent, as rainfall is harnessed for the promotion of biological and geological processes that continue the hydrological cycle that sustains life on our planet. In a forest for example, rainfall is inevitably directed to either three means of use: harnessed by the vegetation to promote their biological processes, absorbed into the soil and percolated down to the water table to replenish the groundwater supply, or become the small amount of runoff that leads to an aquatic ecosystem such as a lake, pond, or ocean by means of a stream or river. Through these processes, rainfall acts to promote the well-being of the natural landscape where the term “stormwater runoff” does not exist. By promoting the methodologies found in a natural system including evapotranspiration, percolation, and strategic runoff direction, our built urban environments may reflect the cyclic functioning processes of that of a forest. Achieving the goal of stormwater mitigation and lessening the consequential environmental and health hazards requires the strategic reintroduction of vegetation and permeable surfaces to vulnerable areas that manage large quantities of rainfall or runoff. In this section regarding contemporary design solutions for stormwater management, the retention operations and their consequential benefits that will be explored are to include green roofs, bioswales, permeable pavements, and retention ponds.

Facing the sky and clouds, the rooftops of New York City are of the first structures to come into contact with rainfall. Before the water is swept through the city streets gathering pollutants, flat roofs prove to be ideal locations to harness water from and return water to the hydrological cycle. A green roof is comprised of various membranes for drainage, on which soil

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can be laid and vegetation can be grown. The image displayed here depicts the necessary layers in order to successfully grow vegetation on a rooftop. With this system, green roofs are able to absorb large quantities of rainfall that is utilized by the vegetation, and then returned to the atmosphere through the process of evapotranspiration where water exits the plants’ leaves in the form of vapor. Besides the economic incentive offered by the Department of Environmental Protection, green roof installations can lower energy costs by cooling the inside of buildings by reducing UV radiation absorption. Additionally, rooftop vegetation offers refuge for aviary species such as birds and pollinators acting as natural resource sinks amidst the lifeless concrete landscape.\textsuperscript{50}

![Green Roof Growing Strata](image)

\textbf{Figure 9: Green Roof Growing Strata}\textsuperscript{51}

The implementation of a green roof to a structure can promote the ecosystem services that are induced following the presence of vegetation. While this essay focuses on the benefits that vegetation can provide in regard to their capacity to absorb rainfall or runoff, the

\textsuperscript{50} Janine Benyus, \textit{Biomimicry: Innovation Inspired by Nature} (Harper Perennial, 2002).

implementation of greenery to any structure aids to filter both air and noise pollution, beautify the cityscape, and combat the effects of the urban heat island effect by cooling the surrounding area. Dependent on the soil depth, green roofs may be fitted with vegetation varying from Sedum – a light perennial succulent grass, to crops including tomatoes, peppers, and even eggplants. In the case of rooftop agriculture, vegetation that is absorbing rainfall is simultaneously providing the urban community with an additional supply of healthy and locally grown produce. While the economic and ecological benefits of green roofs are enticing, vast quantities of vegetation cannot be installed on just any building rooftop. Buildings with flat roofs and strong structural support are required as water saturated soil becomes extremely heavy. While there are some restrictions and complications regarding green roof installations, another means of stormwater retention exists on ground level with fewer limitations.

After a storm, it is typical to see the street sides transform into small rivers, carrying the unharnessed rainfall and myriad of pollutants generated by the city. To take advantage of these urban freshwater rivulets, cities across the country have implemented curbside bioswales or raingardens to collect the water and prevent it from entering the sewer system. Bioswales, such the one displayed here, are pits dug out on sidewalks that are filled with rocky soil and vegetation with an inlet to direct flowing stormwater into the retention system. As bioswales deal with a large influx of water during precipitation events, selected plants for the bioswale must be able to absorb water effectively, thrive in urban environments, and be tolerant to excess water. The bioswale offers a stormwater management approach while simultaneously beautifying the urban landscape as a manicured patch of assorted vegetation and a diverse soil composition. In New York City, the Department of Design and Construction is currently managing the
installation of over 5,000 bioswales across the city.\(^5^2\) According to the Department of Environmental Protection, these bioswales have the capacity to absorb around 8 million gallons of stormwater each year.\(^5^3\) This decrease in water that enters the sewer system reduces the quantity of a sewer overflows while making the City more resilient to flooding.

![Figure 10: A Sidewalk Stormwater Bioswale\(^5^4\)](image)

As vegetative design solutions, both green roofs and bioswales offer additional benefits to the urban landscape and its inhabitants. With the reintroduction of vegetation to the cityscape, surrounding wildlife including bird and insect species are attracted to these vegetated areas and promote beneficial biological processes such as pollination, pest control, and in the unique case of bees, honey production. Additionally, the implementation of green infrastructure such as vegetation aids in reducing both air and noise pollution while combating the effects of the urban heat island phenomenon. While the approach to stormwater abatement can be pursued using

\(^{5^2}\) One New York: A Plan for a Strong and Just City. 2015. 10.
\(^{5^3}\) Ibid.
strategically placed patches of vegetation, it is impossible to ignore New York City’s near 80% of surface impermeability that directly opposes the functionality of the hydrological cycle.

Returning to the forest analogy, as rain falls on the soil, the water that is not absorbed by plant roots slowly permeates through layer after layer of sediment being naturally filtered until it has reached the water table. This natural process not only prevents large amounts of runoff but replenishes the reserves of earth’s most valuable resource. In sharp contrast, the modern cityscape paved with its asphalt and concrete does not promote groundwater recharge, while simultaneously creating polluted and hazardous water that either lies exposed on the city streets or is led to pollute an adjacent water body. To better emulate the forest’s processes and be in accord with the planet’s natural cycles, a transition to permeable surfaces and pavement must be made in urbanized regions. Permeable pavement such as the example images below, allow stormwater to infiltrate into the underlying soils, promoting pollutant treatment and groundwater recharge.\textsuperscript{55}

![Image of permeable pavements](image)

**Figure 11: Types of Permeable Pavements\textsuperscript{56}**

Since permeable pavements are not as dense as traditional asphalt, the load bearing capacity should be limited to foot traffic and parking lots. Permeable pavements would make

\textsuperscript{55} One New York: A Plan for a Strong and Just City. 2015. 238.

\textsuperscript{56} Photo by Guidelines for the Design and Construction of Stormwater Management Systems, NYC Department of Environmental Protection. 2012.
great replacements of walkable pathways primarily designated for pedestrian foot traffic and non-automotive transportation. Specifically, permeable pavements would make great additions to pathways within parks and other large nature reserves as they perform a functional purpose abating stormwater runoff and allow for more artistic freedom in their design and can enhance the overall aesthetic of the area. With some surfaces not appropriate for permeable paving, the challenge is then turned towards managing the inevitable stormwater in a way that avoids the sewer system and promotes the processes of the hydrological cycle.

Referring back to the natural forest landscape, by following the small amount of stormwater by way of small streams will reveal larger reservoirs such as lakes. With the creation of stormwater retention ponds, cities can be better adapted to handle the runoff from large storms and flooding events. By strategically directing stormwater to a designated area, a city can simultaneously avoid unwanted flooded areas while creating a functional and aesthetically pleasing landscape. Retention ponds such as those depicted below, may promote groundwater recharge, or be maintained as a permanent and functional pond.
Figure 13: Stormwater Retention Pond\textsuperscript{57}

This retention pond directs stormwater runoff into a depressed area with large rocks to denote retention area and promote stormwater infiltration. Stormwater is directed to this landscape by means of subsurface grey infrastructure as well as surface level contouring. The use of large stones slows the water as it moves down into the pond, creating a manageable retention and infiltration area. As an alternative to a temporary water feature which promotes groundwater recharge, a more engineered style of retention ponds consists of a permanent pond which can collect stormwater and is able to direct the overflow to an adjacent water body. With the use of wetland plants, systems such as these are able to filter out many of the pollutants that may be present in runoff before it is released back into a water body. Retention systems such as these ponds are great design implementations to urbanized regions as they perform a useful function while serving as a means of beautification and relief from the city’s concrete and steel. By directing stormwater runoff away from the overwhelmed sewer system into a designated retention area, a permanent pond may offer additional ecological benefits including habitat provision for freshwater aquatic species and birds. Additionally, a pond may offer ecological design strategy such as evaporative cooling during warmer months for residents in a public space. While these design implementations offer strategy to combat the consequences of unharnessed rainfall and runoff within the urban environment, recent research has shown that rainwater collection can offer additional benefits in regard to another essential component of life, the production of food.

In order to provide food for people of all communities, water is the life-giving sustenance that allows the production of produce, grains, meat, dairy, and even clothes. However, the

\textsuperscript{57} Photo by Guidelines for the Design and Construction of Stormwater Management Systems, NYC Department of Environmental Protection. 2012.
development of irrigation is limited by the availability of the surrounding water which usually resides underground. Recent work has shown that current levels of crop production in many parts of the world exceed local freshwater availability, which may be compromised by the increasing large global population and the way in which produce is grown. The current production design of crops includes rows of monocultures, which is easier for the application of herbicides, pesticides, and an irrigation system. However, due to the unnatural state of this operation, rainfall is still lost and is carried to adjacent water bodies or into the groundwater along with all the chemicals applied to the crops. To combat this waste of rainfall, design techniques have been implemented in agricultural environments to harness rainfall over vacant soil and over nearby infrastructure to store water and allow its use during the drier seasons. However, this technique is being used sparsely across all agricultural lands and the issue of water scarcity remains present at the foundation of production for food and other plant-based resources. While this issue is worth mentioning and could be delved into in much greater detail, this paper will now move from discussing urban related issues regarding rainwater collection and stormwater management to the topic of the more intimate, domestic practice of rainwater harvesting both in an out of the urban center.

Chapter 5: The Return to Domestic Harvesting

The growth of early human civilizations and the consequential depletion of water sources necessitated various collection methods of rainwater harvesting. These collection operations included both communal and domestic systems which offer an alternative water source for a community’s inhabitants. As one of the first civilizations to implement rainwater collection into

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their architecture, Ancient Rome has influenced the home design of cultures from around the globe to harvest the gift from the sky.

![Figure 14: Roman Atrium](https://www.daz3d.com/gallery/images/37982/)

By the first and second century B.C.E., Ancient Romans had popularized the *compluvium* which was a rectangular opening in the roof of the home that allowed sunlight, fresh air, and rainwater to enter the home. In order to truly capture the rainwater, Romans built an *impluvium* below the *compluvium* to allow rainwater to pool and slowly channel into an underground cistern. Not only did this atrium offer a private space exposed to the natural elements, but also served as a functional rainfall collection system where water could be used for a number of household purposes. The Roman atrium depicted here illustrates the functional relationship between the *compluvium* and *impluvium* of the Roman household, serving a variety of purposes such as communal gathering, ventilation, evaporative cooling, and rainwater collection. In a time

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where plumbing did not exist, and water was not available on tap, these ancient domestic design methodologies allowed residents to capitalize on natural resources and act as a living component integrated into the landscape continuing the processes of natural cycles; very much similar to the operation of a living plant. Returning to modern times in the developed world, indoor plumbing and access to a seemingly unlimited freshwater supply goes severely unnoticed and underappreciated. When the rain does come, this once cherished resource causes environmental and health hazards due to our present impermeable infrastructure and ecologically inharmonious home design. By looking at parts of the world without these advancements in infrastructure and which rely more intimately on their natural surroundings, we may both recover our appreciation for rainfall and better understand the process of domestic rainwater collection.

Figure 15: Atrium in Rural Zanzibar Home

60 Photo by Self
Off the eastern coast of Tanzania, the Zanzibar archipelago consists of three main islands where the Roman atrium design is utilized in both rural homes and clustered urban dwellings. With a lack of modern infrastructure and a climate consisting of a wet and dry season, many Zanzibaris have implemented the Roman atrium into their homes to create a more comfortable living space while benefiting from nature’s resources. In the more rural homes, the *compluvium* and *impluvium* style atrium is very prominent and more closely resembles the design techniques of the Ancient Romans. In this photograph of rural Zanzibari home, the roof is sloped to direct rainfall into a designated pool where the collected water is used for cleaning, laundry, bathing, and in some cases cooking and drinking once treated. This atrium offers its residents a secluded, open-air space that is used for relaxing, family gatherings, and during the heaviest rains, small children can even be taught to swim in the *impluvium*. While this atrium system functions in a variety of ways for the individual home, the design must be altered to accommodate the population density of the urban hubs of Zanzibar.
Located on the island of Unguja in the Zanzibar archipelago, Stone Town is the largest urban center amongst the islands. The early Omani colonizers brought with them their architectural design with some echoes of the Ancient Roman atrium, but with a different purpose. With a population of over 200,000 inhabitants, Stone Town is mainly comprised of historic apartment-style homes atop street side markets and small shops. Behind the façade of the apartments of Stone Town, the Omani have implemented an atrium which is commonly used in the home country of Oman. In Oman, the atrium was meant to facilitate a central axis to the living complex, while providing the benefits of outside within the privacy of the living community. However, now set in the Zanzibar archipelago away from the arid climate of Oman, this atrium pictured above provides the additional benefit of rainwater harvesting by using rain gutters to direct rainwater into a storage tank that can reused for household tasks. With consideration for climate and the design techniques used by other parts of the world, New York City may be better equipped to not only deal with rainwater but come to appreciate the resource that sustains our planet.

The climate of the northeastern United States varies considerably with four distinct seasons. Due to the significant variation in temperature and type of precipitation throughout the year, it would be unfitting for homes to be built with a section of permanently open roof to collect rainwater. However, with consideration for the climate of the greater New York City region, functional and ecologically harmonious rainwater harvesting systems have been developed in suburban homes as well as the skyscraper apartments of the City.

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61 Photo by Self
Outside the dense and bustling urban hubs, suburban homes offer residents a more privatized lifestyle with the opportunities of big cities not too far away. In many cases, the homes that lie in the suburbs of many big cities are not connected to the main sewer lines that exist beneath the large city complex. Instead, many suburban and most rural households rely on groundwater as the main supply of freshwater. However, as noted in chapters above, waterborne illness has proven to be an issue as groundwater can become contaminated with urban pollutants after a heavy rain event. In order to secure a necessary resource while combating the ecological and health hazard of stormwater runoff, suburban and rural homes can become equipped to benefit from future rain events.

In order to successfully collect rainfall from any structure, the essential components include a catchment area, a means of conveyance, a storage cistern, dependent on the intended use of rainfall a means of filtration and purification, and finally a distribution mechanism. Fortunately, most homes are equipped with a catchment area - a rooftop, and conveyance instruments - rain gutters, and just require at least a cistern to be able to simply collect rainfall from the rain gutter downspout. Above ground and subterranean are two general types of cisterns that can be used to store rainfall, both having their benefits and shortcomings. Dependent on the property size and layout, one type of cistern may be more beneficial over the other; the general pros and cons of both types of cisterns will be laid out here. Additionally, the size of the roof or catchment area will often determine the size of the cistern as the catchment area directly reflects the amount of rainfall that will be delivered to the storage tank. Above ground cisterns can take up a lot of room if the cistern is of substantial size holding a large quantity of water. Additionally, the water inside the cistern must be shielded from the sun in order to prevent the

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growth of algae and bacteria. On the positive side, an above ground cistern can typically
distribute water to its facility using gravity due to its nature being above ground, therefore not
requiring the use of an electronic pump. In regard to the subterranean rainwater cistern, it takes
much more extensive energy and manpower to excavate a sizeable pit in which the storage tanks
are to be fitted into. However, the below ground cisterns then allow for more space above ground
and are shielded from both the sun and pests more adequately than the above ground tank. Due to
its low position, subterranean cisterns typically necessitate an electric pump to be able to access
the stored rainfall. Additionally, performing maintenance on cisterns that are below ground
require much more labor and energy intensive routines than that of an above ground cistern.
While the pros and cons of the above ground and subterranean cisterns are to be weighed
strategically, the decision is typically guided by the existing layout of the home or facility to best
suit the immediate environment and the intended use of the captured rainfall. As for the rain
gutters, there are typically two types of conveyance systems that transport the rainfall from the
roof to the cisterns.

The two conveyance types are noted as wet systems and dry systems, which refer to the
way in which water is directly emptied into the cistern of a dry system but is conveyed via
underground piping which fills with water in the wet system. A wet system aims to transport
rainfall directly from the rooftop, down into a subterranean pipe, and either pumped into either
an above ground cistern or drained into an underground storage tank. The wet system typically is
more aesthetically pleasing, as transporting pipes are discreet and allow more freedom when
deciding the location of the cistern. However, the wet system can be more expensive, energy
consuming, and may be compromised by breeding mosquitoes due to the nature of the water
filled pipes. In opposition, the dry conveyance systems are directed straight into the cistern,
which requires less piping, maintenance, and net energy. However, conveyance piping is generally visible, and the location of the cistern is typically placed adjacent to the structure which may be aesthetically messy to some. Similar to the cistern, the type of conveyance system chosen will most likely be contingent on the existing site structure and the goals of the water harvesters. Depending on the intended usage of the harnessed rainfall, a filtration and purification technique may be a necessary addition to the system.

Typically, harvested rainwater is used for landscape irrigation, laundry due to its lack of hard minerals from piping, and cleaning. Turning rainfall into a potable supply requires an extensive amount of filtration and purification. Filtration usually entails a slow sediment filter containing sand, activated carbon, and some type of artificial filtering membrane. For purification, ozone is the typical inorganic molecule that can be used to sterilize the water of any bacteria, protists, pathogens, viruses, or protozoans that may be harmful to anyone consuming the water. While this type of purification is only necessary for potable usage of collected rainfall, other uses such as landscaping, cleaning, and laundry require little filtration which may act passively without the use of large energy inputs. Interestingly, there is a method to filter and purify rainfall without the use of chemicals and high energy inputs.

Solar distillation is a method for purifying rainfall suitable for both potable and non-potable usage that is primarily utilized on a small scale. The diagram above illustrates the process of solar distillation. Utilizing the sun’s energy and the process of evaporation, the impurities of the water can be separated from the stilled water passively without the need for external energy inputs. As the sun evaporates the water in the shallow basin, impurities are left behind, and clean water is caught on the underside of the glass or clear plastic which is then

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63 Ibid.
traversed via gravity into a designated trough. This method of combined filtration and purification relies on the earth’s natural processes which can be utilized on a small scale even in the backyard of a home. This style and technique for harnessing rainwater is mainly on an individual basis, where the idea of sharing harnessed rainwater is not a concept that exists. However, in some parts of the world, there is a communal methodology that is practiced which harnesses the water that exists in the air in the form of vapor.

![Solar Energy](#)

**Figure 17: Solar Distillation Illustration**

The practice of fog harvesting can be traced back to precolonial times on the Canary Islands, an archipelago 62 miles offshore Morocco, Africa. This technique can mainly be found in areas that receive little rainfall throughout the year. For example, a town in southern Morocco that resides adjacent to the Anti-Atlas range receives less than 5.2 inches of rainfall a year. Compared to the 45 inches of rainfall New York City gets, this amount of precipitation is not enough in order to sustain an entire community. In order to provide a sufficient amount of water for the community, scientists and designers experimented with different materials and

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64 Ibid.
orientations in order to collect the large amount of fog that rolls through the high elevated Anti-Atlas range. The nets work by being positioned facing the rolling fog banks, the condensation then accumulates on the combined 580 square feet of nylon mesh nets. The now liquified moisture runs down the mesh lining into a trough, which then is funneled via gravity into reservoirs through a vast network of piping collecting 50 liters of potable water per day.\textsuperscript{66} Although skeptical at first, the fog collecting nets have been improved – being able to withstand the high wind speeds of the mountain range and requiring little maintenance that can be done simply. Beginning in 2015, the fog collection system was able to provide potable water into the four different villages. Since then, the square footage of nylon netting has increased to 5,520 square feet and is able to provide clean drinking water to over 800 people in 15 villages which is pumped directly into their home.\textsuperscript{67}

While the main topic of this paper has been to address the issue regarding the harmful effects of stormwater and pollution runoff, the collection of rainfall in order to abate this issue simultaneously secures the most valuable natural resource to life. The Moroccan villages that harness fog from the adjacent mountain range are not concerned with runoff, as their collection source is not in a liquid state. However, regardless of the means by which water is collected whether from the ground, glaciers, or sky, it is a resource that is fundamentally essential to all life and should be recognized as such. To bring this communal mindset into the western culture and modern city living, there must be ways in which this natural resource can open opportunity for a more sustainable and communal urban lifestyle for residential living.

Comprising 63% of New York City’s buildings, apartment complexes consist of a significant percentage of the City’s square footage of rooftop. If utilized and adapted to collect

\begin{itemize}
\item \textsuperscript{66} Ibid.
\item \textsuperscript{67} Ibid.
\end{itemize}
the rainfall over the City, we can not only reduce the stress on New York’s sewer system and alleviate combined sewer overflows, but additionally create a supplemental supply of freshwater for the residential building. As of now, a vast majority of the apartment complexes are equipped with rainwater gutters which direct rooftop water onto the street leading into a storm drain. Although New York City is considered a progressive city in the modern day, we have just begun to comprehend the impacts of the impermeable landscape we have created. Through recent years in both policy and design methodologies, New York City has begun to revert to more ecologically harmonious infrastructure techniques to alleviate sewage overflow. However, by taking notice to parts of the world with a more direct engagement with their environment, we may see to reconfigure our urban landscape to minimize environmental degradation and sustain the natural cycles associated with rainfall.

Chapter 6: For an Absorbent New York

As the urban cityscapes of the United States have become more developed, we have further separated ourselves from the natural environment and from the processes that sustain our health and resources. However, policy and infrastructure development within the last decade has proved an effort to revert our inharmonious landscapes to ones that rekindle our relationship with the natural world to work with local climate and not against it. The goal of this paper is to shed additional light on the urban environmental issues surrounding unutilized rainfall and explore the solutions to mitigate stormwater runoff and sewer overflows in New York City. In regard to the recommendations for future design and policy implementations, I will speak to infrastructure development, domestic adaptations for a wetter world, as well as the application for functional artwork throughout the cityscape of NYC.
The effects of climate change will bring more water to New York City with less frequent storms but heavier rainfall. Infrequent and heavier rainstorms will lead to more sewage overflows and consequential environmental degradation of the surrounding water bodies if rainfall and stormwater are not managed properly. In order to restore and protect the ecosystem services generated and regulated by rainfall, we must give rainfall and stormwater a purpose through green infrastructure instead of reconfiguring our combined sewer system to manage more runoff. Through the use of green infrastructure, we can reestablish ecosystem services that were lost due to impermeable gray infrastructure. These ecosystem services include but are not limited to: promoting groundwater recharge through permeable pavements, natural sediment and pollution filtration through bioswales, habitat restoration through regreening sidewalks, and the aesthetic and health benefits of a cleaner and greener city. While green infrastructure is slowly being implemented in public space and commercial properties through grant and governmental funding, a significant increase of green infrastructure development is pertinent to the well-being of New York city and its residents as the effects of climate change begin to appear. To better fund green infrastructure projects, NYC can look no further than plants themselves for additional funding. As soon as 2019, New York will see to become the eleventh state to pass the legalization of recreational marijuana. In states such as Colorado and California, tax revenues from marijuana are exceeding hundreds of millions of dollars since the pass of the proposition. In New York, sales are estimated to be around $3.1 billion per year, with $1.1 billion of that in New York City alone, with tax revenues generated for New York City projected to be a conservative $336 million per year.\footnote{Scott Stringer, \textit{Estimated Tax Revenue from Marijuana Legalization in New York}, 2015, Accessed December 12, 2018. \url{https://comptroller.nyc.gov/reports/estimated-tax-revenues-from-marijuana-legalization-in-new-york/}} If just 20\% of the tax revenue be used for the development of green
infrastructure, it would provide just over $67 million in annual funding for green development, which would double current annual funding rates.

To regulate stormwater runoff and reduce natural water body pollution and consequential combined sewer overflows, New York City should take on a plan similar to that of our neighboring northeastern city, Philadelphia. With a similar combined sewer system to that New York City, Philadelphia has committed to tackling the issue of stormwater runoff with the implementation of green infrastructure as opposed to refitting their existing sewer system. Over the next 25 years, Philadelphia plans to reduce stormwater runoff by a staggering 85% to be used to promote ecological cycles and ecosystem services. The plan, *Green Cities, Clean Waters* will reduce the amount of combined sewer overflows within the city, minimize pollution entering adjacent water bodies, and enhance the city in terms of its aesthetic and health qualities. New York City can learn from this initiative and create a plan to reduce a significant amount of stormwater runoff with the functionality of green infrastructure. With tax revenue and supplemental government funding, New York City should match Philadelphia and plan to reduce stormwater runoff by 85% over the next 25 years with the use of absorbent design techniques for the cityscape and commercial/residential buildings.

Recently, New York City passed legislation that requires all newly constructed buildings to be fitted either solar panels, green roofing, or micro wind turbines to create more sustainable infrastructure. Recently, Fordham University has fitted the roof of the southern parking-garage structure that covers just over 10,000 square feet with solar panels. Although a great green initiative, Fordham University has neglected to acknowledge a fundamental principle of solar panels –they degenerate from overheating. Interestingly, solar panels function at a maximum efficiency when kept below hot temperatures. However, solar panels generate a lot of heat when
on a rooftop facing the sun and can operate at a lower level of efficiency and become prone to deteriorating sooner. In order to combat this issue with overheating, I recommend placing areas of vegetation among the fast spread of solar panels to cool the surrounding air and allow less solar panels to generate more energy than when they were covering the whole roof. Additionally, sections of green roofing would promote additional ecosystem services including habitat provision for insect and aviary species, the filtration of noise and air pollution, beautification of the Fordham campus, and of course stormwater mitigation. I believe this concept of intermixing solar panels with rooftop vegetation would be extremely beneficial for the efficiency of solar power generation and provide the additional ecosystem services vegetation brings to the urban environment. While green infrastructure should be implemented throughout the City, a large part of this absorbent movement is to involve the urban residents at their homes.

Currently, water usage in apartments of NYC is an expected and uninvolved process. Compounding this level of separation from our natural resource, the apartment buildings themselves do not function harmoniously within the environment by creating additional runoff from the roof as opposed to harnessing it. While there have been efforts in the recent decade to give away rain barrels to homeowners within New York City, there has been insufficient education for installation and maintenance for long term domestic rainwater collection. I recommend providing community members participating in rainwater collection with extensive installation and maintenance information in order to ensure the most amount of rain barrels stay connected to the downspouts of residential buildings. Additionally, I recommend that New York City provide on-call support for residents experiencing issues or damages to the rain barrel or any other aspect of the catchment and storage system. In order to best protect the urban residents and surrounding terrestrial and aquatic ecosystems of New York City from health and
environmental hazards, combined sewage overflows must be reduced to the furthest extent feasible. However, in regard to the rain barrel distribution program, I recommend that the program target specifically to areas that are prone to combine sewer overflows. Looking at the CSO map detailed in Chapter 1, these areas would include the West and South Bronx, North and West Queens, and East Brooklyn. These sewer sheds are most prone to combine sewage overflows and the communities should be targeted by the rain barrel distribution program in order to provide residents with an alternative water supply and maintain resident and environmental health. In addition to these recommendations regarding the rain barrel program, I believe there can be design improvements made to the residential structures of New York City.

Following the design techniques originating from the Roman atrium, I recommend that newly constructed apartment complexes in NYC be designed with an atrium that functions as a communal open space while performing strategic rainwater collection. Not only does design implementation provide residents an open sky with surrounding vegetation and seating but integrates the building into the landscape like a plant – collecting water which can then be reused by the residents for various household purposes. By both reducing the amount of runoff that enters the sewer system while generating an alternative water supply, this design technique works to combat two ecological issues within the urban environment. Although not an issue that directly deals with the environment, this atrium design allows its residents to see and experience a resource that once had so much meaning. By showing a process of harvesting a resource in a meaningful way, we may come to reconsider our relationship with rain and return to a time where rain was appreciated and not a hazard for health and the environment. This idea of rekindling our relationships with the natural world and its resources can reshape our attitudes and actions that affect one another and the surrounding ecosystems. In order to display the potential
that rainfall can provide to urban residents and its role within a natural landscape, I believe it should have its place within the more natural areas of the built environment.

As discussed, mimicking natural systems is the best way to deal with design disintegration between the urban environment and surrounding natural environment. This concept, known as biomimicry, emulates the form of some natural feature that has evolved to adapt to a certain complication that can serve as a guide or template to solve a human problem. In the case of stormwater management, the primary way in which nature deals with rainfall is to collect the majority of it via plant roots or through permeation down into the water table, or form rivulets that lead to larger water bodies where the water can provide life for adjacent wildlife. In order to resurrect these features of a natural ecosystem within the built environment, we must look at the areas of land that are primarily unpaved and can be tweaked to alleviate the stormwater hazard within the visited vicinity. These natural areas include but are not limited to: Central Park, Crotona Park, Prospect Park, Van Cortlandt Park, and Pelham Bay Park. These green and open spaces offer the land, natural landscaping, and foot traffic necessary to deal with influxes of stormwater and create a remarkable scene with its design. Rainwater runoff within these parks and spaces may be directed by small streams on side of walking paths or through cultured plots to a designated water feature. Whether this feature is a larger retention pond or more of an artistic destination, the water that reaches this feature will have been filtered through various sediment paths and vegetation before reaching the final feature. I believe this design implementation will not only be ecological beneficial in reducing environmental and health degradation from runoff, but also be a community inspiration by providing pedestrians with information on the purpose and functionality of the project. In a similar way of enhancing our existing natural areas to be more adapted to handling rainfall and consequential runoff, we must
continue to restore coastal ecosystems that play such a major role for the coastal urban environment.

Coastal wetlands are an essential ecosystem to the coast, and especially important to a coastal city. With the threats of climate change and consequential sea level rise and powerful storms, coastal wetlands act as buffer zones protecting infrastructure from storm surge. Additionally, wetlands’ ability to absorb large amounts of pollutants is the ideal function in order to deal with urban stormwater runoff. As the middle ground between the urban district and the adjacent water bodies, wetlands can function as natural filters to deal with unharvested stormwater before entering into the aquatic ecosystems. While PlaNYC aims to restore wetland areas within New York City, I recommend restoration be targeted to specific areas vulnerable to flooding and prone to combine sewage overflows. These areas include the southeast Bronx and northern Queens surrounding East River and southwestern Brooklyn which are both regions that are afflicted by severe sewage overflow affecting residents and the adjacent water bodies. Additionally, I believe areas of restored wetlands should be interactive and have specific areas that are walkable to the public. Informing and engaging pedestrians is a great way to utilize public space that is additionally serving as a functional component of the landscape. Signage and seating areas are great implementations to this proposed wetland space as involving the public engages the community with nature to learn, appreciate, and hopefully make more sustainable decisions that positively affect the environment. By educating and displaying to the public the issues surrounding uncollected rainwater and unmanaged stormwater, we may better influence individual decision making to make more sustainable choices that acknowledge the importance and value of water.
I believe art has the power to transform the way people think. Being in the field of addressing environmental concerns, I am convinced to believe that art is a means of altering an audience’s mindset of a particular issue by putting it in a different light. The German philosopher Heidegger poses the concept of “enframing” by which humans view the natural world and its resources as static reserves ready to be exploited at our command. The concept of “enframing” is very dangerous to the natural world, as resources that are consumed are not replenished at a sustainable rate and cannot keep up with the capitalistic economy of constant production and consumption that currently exists. To exacerbate this issue of unsustainability, the urban environment has drastically separated itself from the natural cycles that sustain urban life; from the imported food to water piped in to each building, the urban individual’s dependency and awareness of natural operations has diminished. Following the philosophy of Heidegger, I believe that a way to rekindle our appreciation for the natural world and its resources is to display them in front of urban pedestrians in a significant manner. For example, artist Angela Haseltine Pozzi collects trash that has washed ashore on various beaches and transforms it into beautiful marine inspired artwork. Audiences looking at her art actually see the trash in front of them and may change their habits during their next beach trip. In a similar way, by creating artwork that functions to collect rainwater or divert stormwater runoff, a more meaningful connection to rain may be resurrected and influence individual decision making in regard to sustaining this natural resource. To pursue a more mutualistic relationship between ourselves and the abiotic and other biotic communities, we should implement artistic rainwater collection and stormwater redirection systems throughout the cityscape of New York.

New York City is filled with pieces of artwork on city blocks and in public parks. While these are interesting to look at and can even provoke some emotion, rarely is the case that these
artworks are functional. Imagine walking down Canal Street on the first rainy day of the year and seeing that piece of art you never really understood, until now when the rain comes into contact with it. Transforming the rainfall into something visually or auditorily sensational can create a connection with a spectator or passerby that might make them even a little bit excited for the next downpour. Taking this idea one step further, what if this same art structure harnessed rainwater to be stored and later put to use, perhaps for irrigation for an adjacent city garden or pooled in a city plaza for its evaporative cooling properties. In this way, the artwork is revealing to the public the value of rain and how it is involved in everyone’s life. Similarly, its function as harnessing water can be used for a variety of uses that can benefit the urban landscape and its inhabitants. By reconfiguring our urban environment to function within the processes of the hydrological cycle, we may protect the natural systems that sustain us while restoring our relationship as stewards to the environment.
Bibliography


