

# IMPLEMENTATION OF A RAINWATER HARVESTING NETWORK TO MANAGE STORMWATER RUNOFF IN MANHATTAN, KANSAS

by

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A REPORT

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Department of Landscape Architecture and Regional and Community Planning  
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2012

## Abstract

The City of Manhattan, Kansas has been subject to intense flooding in the last couple of years. Areas of the city, within the Wildcat Creek Watershed, have been adversely affected. The City of Manhattan and stakeholders from various walks of life are looking for solutions to alleviate flooding within the area. This Master's Project looks into rainwater harvesting as one of the solutions to help reduce stormwater runoff and contribute to the alleviation of flooding within the Watershed. Rainwater harvesting is increasingly being recognized as an effective way to reduce stormwater runoff. The project explores the potential benefit of using a network of rainwater harvesting elements, namely rain barrels and cisterns supplemented by rain gardens and other infiltration methods to reduce runoff in the City of Manhattan, Kansas.

To assess the benefit of using rainwater harvesting in the City, a neighborhood scale site was chosen and divided into land use types. Three phases were used to assess the impact and implementation of rainwater harvesting. Phase I calculates the volume of runoff generated from each land use type and how much of that runoff can be harvested from the rooftops. The values from the neighborhood scale analysis were then extrapolated to see the impact of rainwater harvesting on a larger scale. Phase II looks at the configuration of a rainwater harvesting system for the structures in each land use type and rainwater reuse options. Finally, Phase III looks at policies, regulations and incentives that can be employed by the City of Manhattan to help encourage rainwater harvesting. This Master's project seeks to educate the City and its residents about the benefits of rainwater harvesting as a stormwater management tool and provide steps towards potentially using rainwater harvesting as a way to reduce runoff, and help alleviate flooding in the Wildcat Creek Watershed.

# Implementation of a Rainwater Harvesting Network to manage Stormwater Runoff in Manhattan, Kansas



Elizabeth Musoke



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SPRING 2012

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Cover Image Source: Minnesota Department of Agriculture, 2011

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To assess the benefit of using rainwater harvesting in the City, a neighborhood scale site was chosen and divided into land use types. Three phases were used to assess the impact and implementation of rainwater harvesting . Phase I calculates the volume of runoff generated from each land use type and how much of that runoff can be harvested from the rooftops. The values from the neighborhood scale analysis were then extrapolated to see the impact of rainwater harvesting on a larger scale. Phase II looks at the configuration of a rainwater harvesting system for the structures in each land use type and rainwater reuse options. Finally, Phase III looks at policies, regulations and incentives that can be employed by the City of Manhattan to help encourage rainwater harvesting. This Master's project seeks to educate the City and its residents about the benefits of rainwater harvesting as a stormwater management tool and provide steps towards potentially using rainwater harvesting as a way to reduce runoff, and help alleviate flooding in the Wildcat Creek Watershed.

*In memory of Milka Musoke*

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# Chapter One

*Dilemma + Thesis of the project*

# Dilemma

The Wildcat Creek Watershed (Figure 1.1) is located in Riley County, Kansas and spans about 99.5 square miles, converging with the city limits of Manhattan, Kansas. The watershed has experienced an increase in flooding events within the city of Manhattan over recent years. According to a document released by the Wildcat Creek Watershed Council, flooding in urban areas of the watershed has increased from a “1 in 20 year occurrence to an almost annual event,” (Wildcat Creek Watershed Council, 2011). Increased urbanization of the area has contributed to major flooding events that are adversely affecting the residents located in the Wildcat Creek Watershed. The Wildcat Creek Watershed Council states that, “Many of the urban residents live in apartments or mobile home parks and are directly impacted by adverse water quality, flooding, and lowered property values,” (Wildcat Creek Watershed Council, 2011).

As an urban planner in training, the work I do is driven by the health, safety and welfare of the people in a community. The Wildcat Creek Watershed Council states that their vision is to “improve the environmental quality of Wildcat Creek to insure the protection of the property and enhancement of the quality of life.” (Wildcat Creek Watershed

Council, 2011). The Wildcat Creek Watershed Master’s Student Group is working together to solve flooding, and issues related to flooding, in the Wildcat Creek Watershed. The way in which we approach these issues and apply possible solutions differ, but we all strive to reach the same goal. My approach to addressing the dilemma is to develop a strategy to reduce the amount of stormwater runoff in urban areas and improve the urban resident’s quality of life within the Wildcat Creek Watershed.

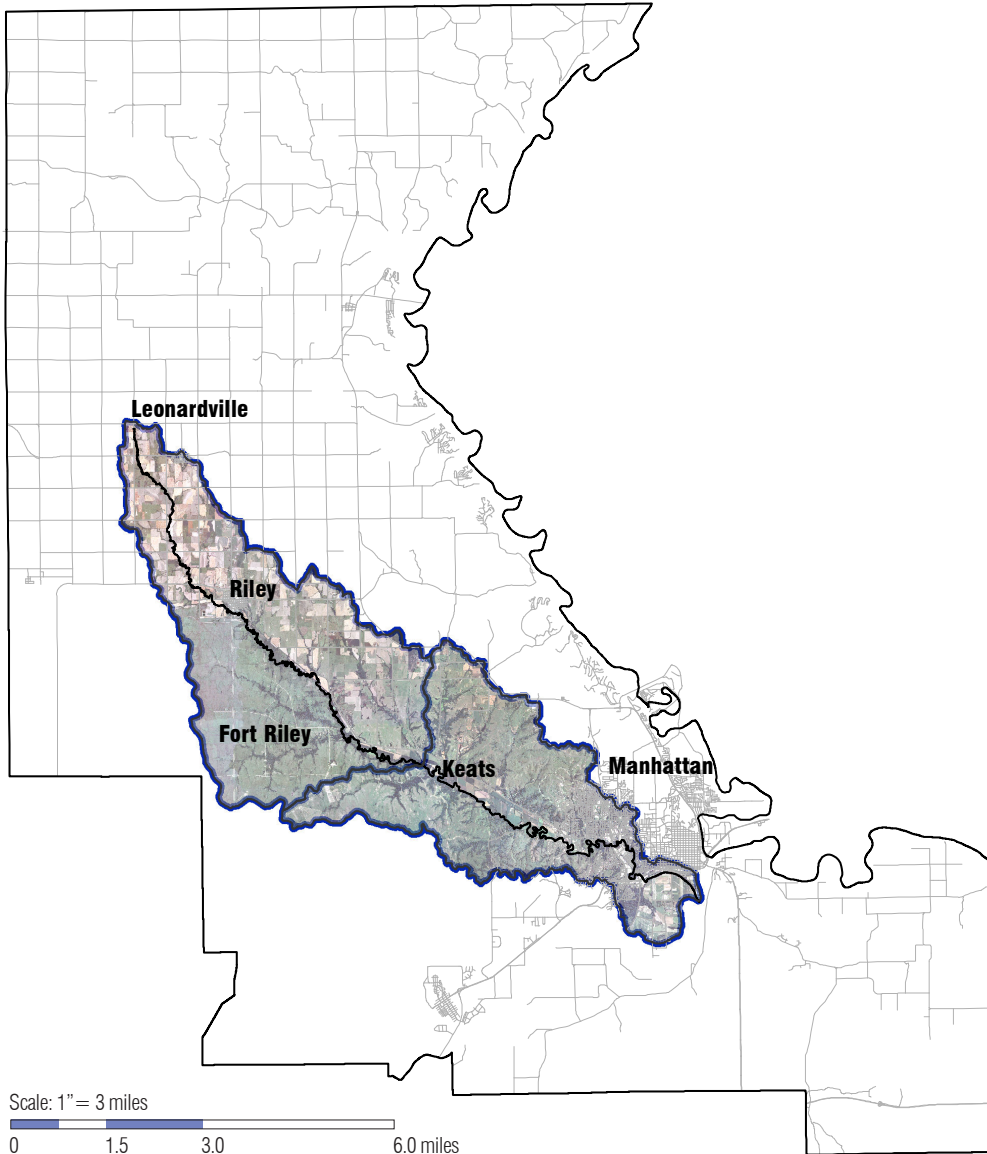
## Thesis

Low Impact Development or LID has been presented as a way to manage stormwater. LID looks into creating decentralized strategies to handle stormwater (U.S. EPA, 2011). I am particularly interested in Rainwater Harvesting (RWH) as a stormwater management tool. Rainwater harvesting is regarded as an effective practice to alleviate stormwater runoff (Kloss, The Municipal Handbook: Rainwater Harvesting Policies, 2008). However, the practice of integrating rainwater harvesting into stormwater management is an underutilized strategy (Foraste & Hirschman, 2009).

The thesis statement of the project is as follows: a rainwater harvesting network, a series of decentralized rainwater harvesting systems, will alleviate stormwater runoff from urbanized areas within the City of Manhattan into the Wildcat Creek Watershed. Rainwater harvesting elements shall capture rainwater and the rainwater shall be reused in order to mitigate the amount of stormwater runoff entering the watershed from precipitation.



Figure 1.1: Boundary of the Wildcat Creek Watershed, located in Riley County, Kansas (Prepared by class LAR 705, 2012)



# Research Question

***Will a network of rainwater harvesting elements reduce stormwater runoff from urban areas into the Wildcat Creek Watershed? If yes, what policies can be in place to allow for a rainwater harvesting network?***

It is apparent in the literature that rainwater harvesting is being recognized as a viable strategy for stormwater management in communities around the United States and the world. EPA's municipal handbook for rainwater harvesting policies states that, "Rainwater harvesting has significant potential to provide environmental and economic benefits by reducing stormwater runoff and conserving potable water..." (Kloss, The Municipal Handbook: Rainwater Harvesting Policies, 2008).

The handbook states that many industrialized countries, such as the United States have not tapped into the potential that rainwater harvesting holds (Kloss, The Municipal Handbook: Rainwater Harvesting Policies, 2008). The proposed question seeks to look into that potential, mentioned in the handbook, and use it to the benefit of the residents of the Wildcat Creek Watershed. The question is explored in three phases.

## **Phase I: Analysis**

This phase answers the first part of the research question: Will a network of rainwater harvesting elements reduce stormwater runoff from urban areas into the Wildcat Creek Watershed? The first part tests the effectiveness of retrofitting sites with rainwater harvesting elements. Knowing the volume of stormwater runoff of each land use type versus the amount of stormwater coming off the structures within the land use type, will determine the amount of runoff that can be collected through rainwater harvesting. The analysis uses the rational method to calculate runoff based on a two year one hour storm event.

## **Phase II: Application**

The second phase addresses how rainwater harvesting can be configured on the site for each of the land use types. Barrel/cistern size, barrel/cistern material, the number of barrels/cisterns needed to capture rainwater from the roof of a structure based on a two year one hour storm event, the cost of the proposed configurations.

## **Phase III: Policy, Regulations and Support Mechanisms**

The third phase specifically addresses the second part of the question: What policies need to be in place to allow for a rainwater harvesting network? The third phase outlines strategies used in other communities to implement rainwater harvesting. Additionally, the third phase delineates policies, regulations and incentives that can be implemented in Manhattan, Kansas.



# Goals and Objectives

The project seeks to plan for the capture and mitigation of stormwater runoff through the use of rain barrels; to establish possible configuration for each land use type on the site and establish possible re-use options. The re-use of collected rainwater drives the effectiveness of rainwater harvesting (Jones, Hunt, & Wright, 2009). The project also explores ways of establishing rainwater harvesting through policy, regulations and incentives. An underlying goal of this project is to educate the community (city officials and the general public) about the benefits of rainwater harvesting. The goals of the project are delineated as follows:

## GOAL 1: CAPTURE + MITIGATE

- Show the reduction of stormwater runoff into the Wildcat Creek Watershed using RWH
  - Determine volume of runoff from each typology
  - Determine total percentage of impervious area
  - Average Rainfall
  - Total Acreage
  - Determine potential volume of rainwater captured from structures

-Determine total catchment area surface for each structure

## GOAL 2: USE + REUSE OF CAPTURED WATER

- Demonstrate the use of RWH in Manhattan, Kansas
  - Provide physical design/integration of rainwater harvesting elements specific to sites in Manhattan, Kansas by typology
  - Establish reuse possibilities within the area
  - Maintain visual integrity of the sites

## GOAL 3: IMPLEMENT THROUGH POLICY

- Develop policy options to support RWH in Manhattan, Kansas (informed by programs in other municipalities)
  - Develop overarching policies that encourage the use of rainwater harvesting
  - Develop financial incentives (Rebates/Discounts/Tax Exemptions)
  - Develop codes/regulations that encourage flexibility in design

or configurations of RWH elements  
-Develop regulations that determine reuse of collected rainwater

## GOAL 4: ENHANCE

- Create community awareness surrounding the importance of RWH/ Promote the use of RWH harvesting in Manhattan, Kansas
  - Choose sites that have high visibility to the community
  - Inform public of the use of rainwater harvesting through signage
  - Educate through the establishment of a rainwater harvesting manual or set of guidelines

# Process Diagram

Figure 1.2 depicts the philosophy and path of this Master's Project. Capturing rainwater can mitigate stormwater runoff; while the re-use of rainwater gives a resident an alternative water supply to utilize while allowing for more rainwater to be captured. Rainwater harvesting enhances both the built environment and the human experience: a double benefit.

To realize this philosophy: How one captures rainwater is defined by exploring the literature on rainwater harvesting. To quantify mitigation, calculations and analyses are needed to determine the volume of rainwater that can be captured. Re-use is pertinent to successful rainwater harvesting; and policy helps aid the success of rainwater harvesting systems. By observing the success of a rainwater harvesting system, the public can be educated, accept rainwater harvesting as a viable solution and change their way of living to incorporate it in their daily lives.

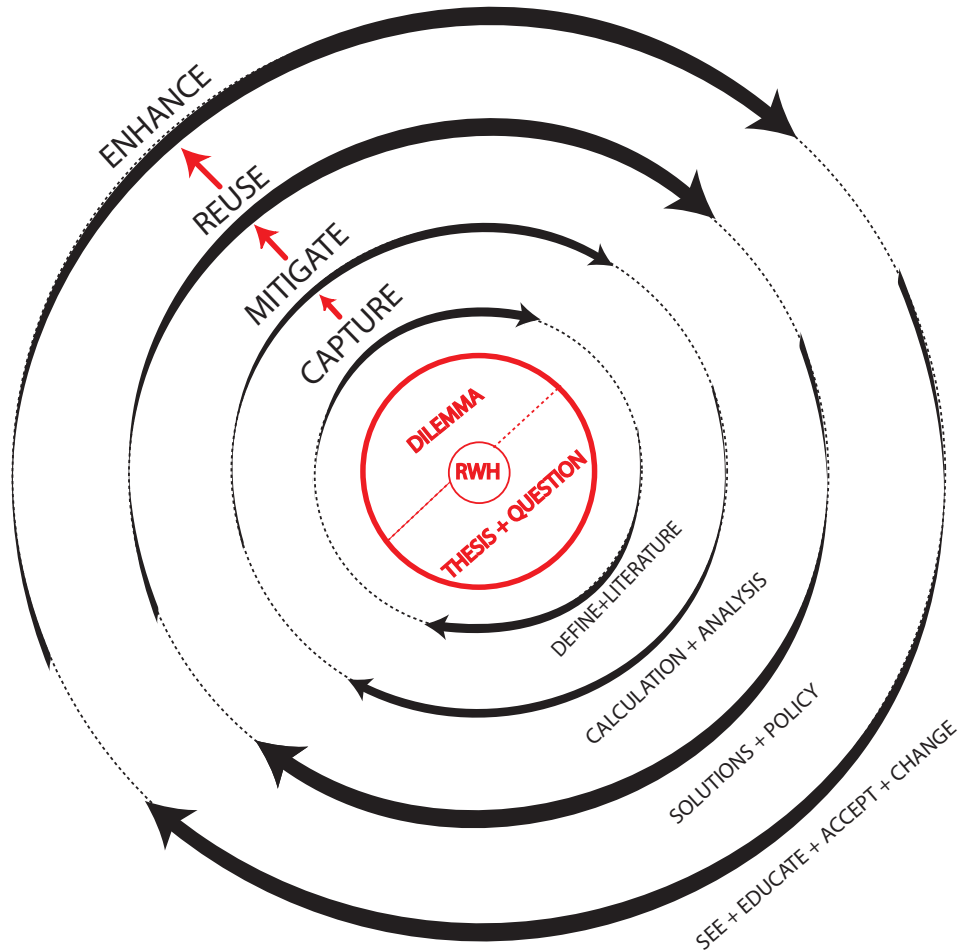


Figure 1.2: Philosophy and Path Diagram

Capture, Mitigate, Reuse, Enhance are words used to describe the philosophy behind the project, while define + literature, calculation + analysis, solutions + policy, and see + educate + accept + change describe the paths used to meet the philosophy (Source: Image by Author)

# Chapter 2

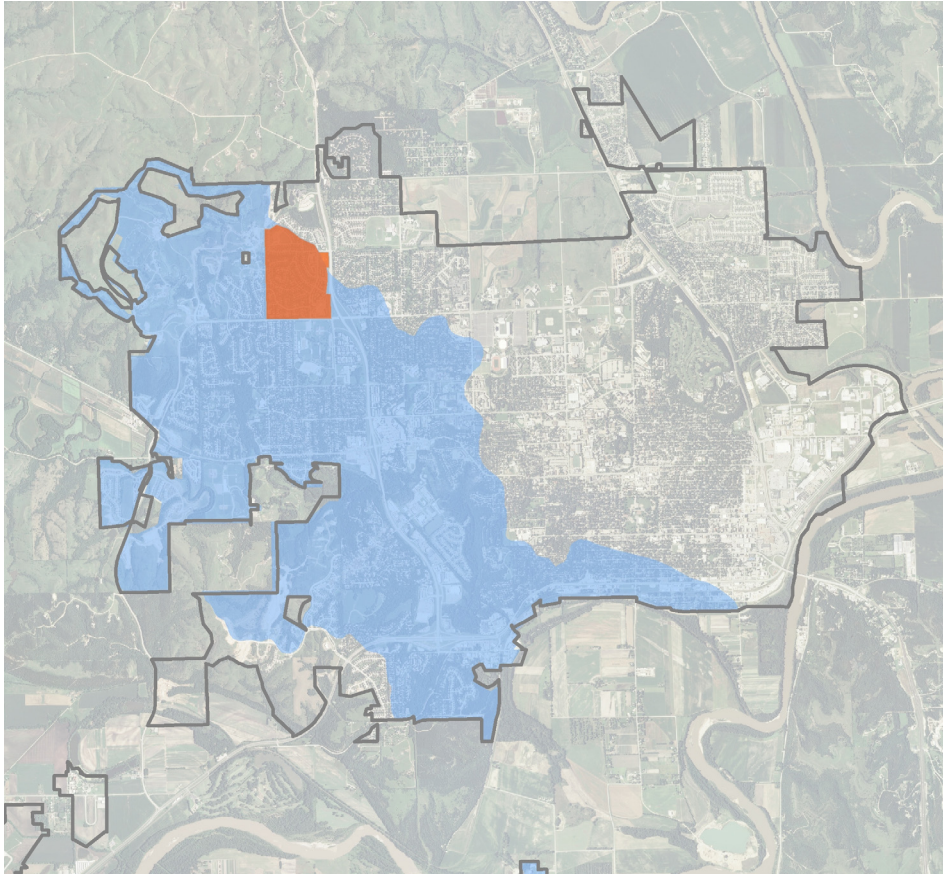
*Literature Review + Case Studies + Site Selection*

## Site Selection

To analyze the effects of the rainwater harvesting network within the City of Manhattan, KS a neighborhood scale site was chosen (Figure 2.1). The site, located in the northern part of the city is flanked by North Seth Child Road to the east and by Kimball Avenue to the south. The west boundary is delineated by the Hudson Nature Trail. The site includes Frank V Bergman Elementary School, single family homes, apartments, First Assembly Church, and a commercial area. The notion of a demonstration site was inspired by a project in California performed by an organization named TreePeople. The project looked at how retrofitting one single family residence with bioswales, rain barrels etc. can mimic the natural function of a watershed to manage stormwater (Ben-Horin, 2007). The demonstration site was used to show how effective the retrofit was and the benefits of retrofitting single family homes on a larger scale. The TreePeople project served two purposes: to reduce runoff and educate the public of the benefits and effectiveness of the previously mentioned retrofits. Further information about TreePeople and the project can be seen in the Precedent Studies section of this Master's project.

The selection of the site was further informed by the WARSSS or Watershed Assessment of River Stability and Sediment Supply (U.S. EPA, 2011). The Wildcat Creek Watershed Master's Student Group conducted the WARSSS assessment and delineated areas of concern. WARSSS is a tool used to evaluate the impact of excess sediment on rivers and streams (U.S. EPA, 2011). The RLA phase, or the Reconnaissance Level Assessment, is the first phase of three in the WARSSS process. The RLA is a quick and qualitative assessment of problem areas. Using the RLA process the student group analyzed the entire watershed. The Wildcat Creek Watershed was first divided into sub-watersheds. Problem areas or "hotspots" were then delineated in each of the sub-watersheds using aerial photography, historical images and topography. The chosen site (shown in Figure 2.1) is located within a sub-watershed that was designated as a problem area.

The site discussed above was also chosen because of the variety of land uses. Each land use has a different way of implementing rainwater harvesting. If the network is replicated throughout the Wildcat Creek Watershed, then the chosen site must show how rainwater harvesting can be implemented on different land uses found within the Watershed.

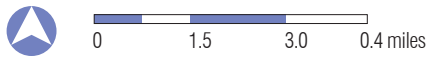


Lastly, the site was selected because of the opportunity for visibility and education. With the site containing a school, church and shopping center the general public, and not just the residents, can see the benefits of rainwater harvesting.

←  
Figure 2.1: Boundaries of the proposed site (Source: Image by Author)

**Legend:**

- Site Boundary
- Area of the City within the Wildcat Creek Watershed
- City of Manhattan Boundary



# Literature Review

The literature review was structured to support the three phases outlined by the research question: Analysis, Application and Policy. The first phase looks at literature that outlines ways to calculate runoff: determining impervious surfaces, defining the catchment area, rainfall intensity, runoff rates, time of concentration etc. The analysis phase also determines the methodology used to calculate runoff without rainwater harvesting retrofits, the size of barrels and the runoff with rainwater harvesting retrofits. Phase II amasses current and past knowledge regarding the use of rainwater harvesting. In other words, exploring the knowledge base in order to understand what makes rainwater harvesting effective. The third phase consists of making rainwater harvesting a reality through policy. In this context policy is a catch-all word that includes: codes and regulations, tax incentives, rebates, education to the public and more.

All three phases are informed by the decision to have a rainwater harvesting program. I have likened the phases to a ripple effect. The decision to have a rainwater harvesting system is likened to the initial drop of water that begins the radiation of the ripples or phases. The phases build off each other and inform each other. The following literature review synthesizes the literature surrounding rainwater harvesting used as a stormwater management tool. Each phase consists of a summary table that synthesizes the key points of each source, and a detailed narrative that expands on the key points. The first table, Table 2.1 summarizes the literature in relation to policy.

# Phase I: Analysis

Study	Area Investigated	Method	Key Relationship	Findings
Wittenbick Et. Al (2008)	Portland, Oregon	Case Study-Quantitative analysis delineating areas of concern through various criteria	Determining areas that were burdened by excess stormwater runoff	<u>Field Observations:</u> Surface Type, land use, functional descriptions of campus; <u>Field reconnaissance using GPS:</u> Existing drainage patterns, existing storm systems; GIS of impervious surfaces;
U.S. EPA (2000) (LID Lit Review)	United States	Quantitative analysis of urban runoff	Understanding runoff rates in relation to LID techniques	Runoff can be compared by looking at the runoff curve number (CN) pre and post development; curve number based on soil type, land cover, and amount of impervious surfaces. CN number post development should be as close to CN number pre development. Important to maintain Time of Concentration.
Despins (Chapter 1) 2010	Ontario, Canada	Quantitative calculations of catchment area	Understanding how the catchment area of a roof surface is calculated to infer cistern sizing	“Theoretically, for every square meter of roof catchment area, 1 litre of rainwater can be captured per millimeter of rainfall,” (Despin, 2010 p.4). Area of the catchment surface should be as large as possible to increase water savings.

Table 2.1: The content of this summary table is a synthesis of the literature in regards to how what analyses are needed to calculate runoff rates, catchment area size and rain barrel size.

The Oregon Health and Science University (OHSU), located in Portland, Oregon, formulated a Stormwater Management Plan for their campus, using Low Impact Development (LID) techniques. OHSU integrated ecoroofs, bioretention facilities and rainwater harvesting to alleviate the amount of runoff from impervious surfaces. In order to formulate a plan, the University had to understand their site and the hydrologic processes that occurred on campus. With the help of Otak Inc. as a consultant, their main methodology consisted of looking at impervious areas and the quantity and quality of stormwater runoff. The study determined that reducing the size of impervious areas by using LID techniques, like rainwater harvesting, could reduce the amount of stormwater runoff (Wittenbeck, Timmins, & Donnelly, 2008). First, Otak's assessment of the hydrologic processes involved a GIS inventory looking at impervious surfaces. Second, the results were confirmed with a "field reconnaissance" that consisted of field observations. The field reconnaissance included: "surface type, land use and functional descriptions of campus areas" (Wittenbeck, Timmins, & Donnelly, 2008). The field data retrieved from the reconnaissance was vital in determining possible locations for LID infrastructure. This process can be used as a model in the Wildcat Creek Watershed, to identify problem areas through GIS and use field observations to look at land use in relation to areas where rainwater harvesting can be effective.

The U.S. EPA released a document reviewing the literature surrounding the effectiveness of Low Impact Development (LID). When looking at how LID techniques work, the EPA outlined four different ways in which the effectiveness could be evaluated: runoff curve number (CN); time of concentration; retention and detention (U.S. EPA, 2000). The CN value could be an appropriate measure for rainwater harvesting in the Wildcat Creek Watershed study. The CN method "...is used extensively in the analysis of environmental impact and design rainfall-runoff hydrology" (U.S. EPA, 2000). However, even though the method seems geared to looking at the pre-development CN values and the post-development CN values; I think that this method could be translated to the implementation of a rainwater harvesting network within the Wildcat Creek Watershed neighborhood. If used in conjunction with the GIS analysis and field observations conducted for the OHSU stormwater management plan, the CN value could be used to confirm the effectiveness of the proposed rainwater harvesting network.



The U.S. EPA article reviewing the effectiveness of Low Impact Development, also looks at the time of concentration as a way to determine the effectiveness of LID techniques. Time of concentration is described as the "...amount of time it takes for water to travel from the most distant point to the watershed outlet" (U.S. EPA, 2000). Retention and detention of runoff increase the time of concentration. The increase in time of concentration, or the longer it takes water to move from the farthest point to the outlet, is a positive aspect. Ways to increase time of concentration are: "maintaining flow path lengths, increasing surface roughness, detaining flows, minimizing site disturbances, flattening grades in impact areas, disconnecting impervious surfaces and connecting pervious surfaces" (U.S. EPA, 2000). Rainwater harvesting could be effective in detaining flows that are captured from impervious surfaces such as a roof (U.S. EPA, 2000). The time of concentration could be a good indicator of rainwater harvesting's potential to retain and detain runoff.

The Ontario Guidelines for Residential Harvesting Systems looks into collecting runoff from impervious surfaces, in this case roofs. The proposed rainwater harvesting network will look to capture runoff from the roof tops of residential and public areas. Areas where rainwater falls and is collected are known as catchment areas (Despins, 2010). The catchment area is important in determining the amount of water collected off of the rooftop surface which informs the design of a rainwater harvesting system (Despins, 2010). The theory behind the catchment area is described as: "... for every square meter of roof catchment area, 1 Litre of rainwater can be captured per millimetre of rainfall" (Despins, 2010). The catchment area is calculated using the following formula:

$$\text{Catchment Area} = \text{Length} \times \text{Width}$$

Despins (2010) states that rainwater harvesting systems can vary in design; for example, multiple houses may form a single catchment area, feeding to one storage tank or cistern. The size of the catchment area can inform or estimate the expected amount of water needed to be captured and reused; and inform the design.

Phase I of this literature review has described relevant methods that can be used to calculate hydrologic processes in the watershed. What seems to be apparent is that field observation will be necessary to understanding how the site works to supplement any GIS analysis that will take place. Field observation will also be important when looking at the placement of the rainwater harvesting network. Key indicators such as the runoff Curve Number (CN), time of concentration and the size of the catchment area will be important when establishing how effective the rainwater harvesting network can be.

With the calculations taken from Phase I, Phase II explores the literature to find potential configurations of rainwater harvesting elements. A summary of the Phase II's literature can be seen in Table 2.2.

## Phase II: Application

Study	Area Investigated	Method	Key Relationship	Findings
Farahbakhsh, Despina, Leidl (2009)	Canada	Case Study in Canada	Impact of RWH on Stormwater Management	RWH is most effective with other on-site stormwater management elements; End uses for captured rainwater are important to the effectiveness of rainwater harvesting
Reidy (2008)	United States	Cost-Benefit Analysis	Paradigm shift to integrated stormwater management in commercial developments at a minimized cost	Integrating stormwater infrastructure and RWH by using RWH elements within or in between stormwater infrastructure can be cost effective
Jones. Et Al (2009)	Southeastern United States	Case Study of five RWH systems	Reliability of rainwater harvesting techniques in relation to various end uses of the captured water.	Regardless of the different techniques to capture rainwater rate of reuse determined the effectiveness; RWH systems must have an associated end use and thus determine the size of the cistern needed.
Texas Water Development Board (2005)	Texas, United States	Qualitative list of components	Residential and commercial scale rainwater harvesting systems components	Summarizes basic components: catchment surface, gutters, debris catchers, storage, delivery system, treatment;
Forste & Hirschman (2009)	Virginia, United States	Case Study-Quantitative spreadsheet	Show the effectiveness of RWH in comparison to other green practices	The development of a spreadsheet to promote the use of rainwater harvesting
Ben-Horin (2007)	Los Angeles, California	Case Study	RWH effectiveness on a single family home	Cistern system of two 1,800 gallon tanks. Cistern in conjunction with other green infrastructure elements effectively reduced the amount of runoff from the home.
Despins (chapter 6) (2010)	Ontario, Canada	Qualitative guidelines	Implementing rainwater harvesting in residential areas in relation to stormwater management	Lot-level RWH systems used with outflow controls.
Cabell Brand Center (2009)	Virginia, United States	Case Study	Types of rainwater systems by land use	Outlines general guidelines for RWH implementation in residential, industrial, commercial, agricultural etc
Stockholm Environment Institute(2009)	Worldwide	Qualitative assessment	Suggestions of implementing and encouraging rainwater harvesting	Rainfall is a manageable resource; rainwater harvesting is not the silver bullet; RWH is a local intervention; benefit land-poor and land less; policies

Table 2.2: Summary of literature in relation to the application of elements to establish a rainwater harvesting network.

Phase II outlines the knowledge needed to implement a rainwater harvesting program. Essentially, Phase II looks at the best practices in Rainwater Harvesting as a stormwater management tool. The information can be used as a basis to envision what the rainwater harvesting system could consist of.

“Developing capacity for Large-Scale Rainwater Harvesting in Canada” looks at how rainwater harvesting can be used as a stormwater management tool. This article suggests that rainwater harvesting works best in conjunction with other stormwater management elements: “. . .RWH [rainwater harvesting] is most effective when used in combination with other onsite stormwater management techniques to provide some redundant capacity to accommodate overflow” (Farahbakhsh, Despina, & Leidl, 2009). The article also talks about end use capacity of the harvested rainwater. Having various uses for the captured water increases the effectiveness of a rainwater harvesting system (Farahbakhsh, Despina, & Leidl, 2009). By having set end uses for the harvested water, water is continually used allowing the storage unit to collect more (Farahbakhsh, Despina, & Leidl, 2009).

Engineer Philip Reidy wrote a similar philosophy to the Farahbakhsh et al. (2009) article. Reidy discusses using rainwater harvesting in conjunction with conventional stormwater management systems (Reidy, 2008). Reidy states that “Typical implementations. . . involve simply adding harvesting infrastructure into the drainage profile of the required stormwater management systems for the site” (Reidy, 2008). The approach described by Reidy involves combining conventional stormwater infrastructure with tanks to store harvested stormwater runoff. Combining these the two functions, often seen as separate, is more cost effective: “By implementing increasingly cost effective technologies for monitoring and controlling flows within and between stormwater structures, significant cost savings can be achieved as compared to implementing harvesting and stormwater controls in a serial fashion.”

Reidy’s (2008) and Farahbakhsh et al.’s (2009) articles suggest that rainwater harvesting is most effective when it is used with other stormwater management tools and that it is more cost effective to integrate rainwater harvesting with conventional stormwater management rather than having to separate systems.

This point is emphasized by the TreePeople organization that looked into greening a single family home and providing a more efficient stormwater management system for the residence. In this project, two 1800 gallon cisterns are connected to the house to collect runoff from the roof but additionally, runoff was also directed to various depressed areas in the lawn and a vegetated swale (Ben-Horin, 2007). With the rainwater harvesting system plus other elements the single family home was able to capture and retain water from a two-inch storm event (Ben-Horin, 2007). To conclude, rainwater harvesting is indeed effective especially in conjunction with other interventions or existing stormwater management tools.

Despins' discusses the option of combining rainwater harvesting systems with overflow controls to act as a stormwater system (Despins, 2010). Again, the emphasis is on using rainwater harvesting in conjunction with an additional method. Despins states that: "the rainwater tank can be used in place of a holding tank for detention and controlled release" (Despins, 2010). This method used on various lots, in a network, could help the municipal stormwater system cope with excess flows and control runoff more efficiently. Despins' suggestion relates to Phase I and the discussion concerning the time of concentration. Despins' technique can be used to aid the increase of the time of concentration.

A case study of five rainwater harvesting systems was conducted in Southeastern United States. This study looked at the capture of runoff from roofs. The captured water is intended for municipal, non-potable uses. The study states that "In order to better understand the anticipated usage and reliability of rainwater harvesting systems in the southeastern United States, a monitoring study was conducted at five rainwater harvesting systems in North Carolina, measuring cistern water levels and rainfall" (Jones, Hunt, & Wright, 2009). How frequent the systems were used, how much water was used and how the usage of the harvested water were monitored. The results from this study concluded: "Minimal usage of the captured rainwater greatly diminishes runoff volume reduction and economic benefits of rainwater harvesting." Once again, having an expected reuse is vital to the effectiveness of a rainwater harvesting system.

In order to create an effective rainwater harvesting system, Jones, Hunt and Wright (2009) suggest the following:

- Know the anticipated use of the harvested water which thus informs the size of the cistern or barrel; possibly incorporate automatic usage systems.
- Educate users about possible end uses captured water could have.
- Combine infiltration techniques to rainwater harvesting.

(Jones, Hunt, & Wright, 2009)

On another front, the United Nations publication “Rainwater Harvesting: A lifeline for human well-being” looks at rainwater harvesting in various applications. The United Nations outlines different suggestions to consider when applying rainwater harvesting systems. The suggestions include realizing that rainwater harvesting is not the “silver bullet,” it is a “complementary” method that enhances the already existing systems or other alternative systems. The document also suggests that “enabling policies and cost strategies” in addition to “technical know-how and capacity building” are extremely important to implementing a rainwater harvesting system (Stockholm Environment Institute, 2009). Finally, the document states that rainwater harvesting is a local intervention. For rainwater harvesting to work it is important engage in public participation and engage with the stakeholders to discuss the positive and negative impacts of rainwater harvesting and how it can be implemented and/or used with other strategies (Stockholm Environment Institute, 2009).

The next series of articles deal with system components and guidelines specifically oriented at residential and commercial land uses. The Texas Manual on Rainwater Harvesting is penned by the Texas Water Development Board, and describes in detail the attributes one needs to understand about rainwater harvesting. The Texas Development Water Board describes the application of rainwater harvesting in relation to residential and commercial areas.

The manual is relevant to my project, as the study area consists of mostly residential properties with some commercial areas. Rainwater harvesting at small commercial and residential scales consist of six basic components:

- Catchment surface (e.g. a roof)
- Gutters and Downspouts
- Devices to remove debris from the system (leaf screens, first flush diverters)
- Storage tank(s)
- Delivery system
- Water treatment for potable systems

(Texas Water Development Board, 2005)

The manual gives detailed specifications in all of these categories. For example, the section that discusses catchment surfaces looks into different roofing materials and their effects on capturing water. Knowing the information on catchment surfaces, the rainwater harvesting network for the Wildcat Watershed Creek can be tailored to the most common roof materials in the neighborhood. The same can be said for all the other components. That is to say the information presented in this manual can be used to formulate what the best options are for the rainwater harvesting network, unique to Wildcat Creek Watershed.

The second edition of the Virginia Rainwater Harvesting Manual describes rainwater harvesting systems by land use. The Virginia manual describes types of rainwater harvesting system for residential, commercial, industrial, and agricultural land uses. The Virginia manual also describes rainwater harvesting systems for fire suppression and irrigation. Once again, the focus is on residential and commercial applications of rainwater harvesting programs. The Virginia manual suggests that residential uses include non-potable and potable uses, although potable uses are not recommended (The Cabell Brand Center, 2009). The main use of captured rainwater is usually non-potable (The Cabell Brand Center, 2009). The same can be said in commercial establishments. The manual outlines how the components of RWH can be assembled for both land uses (Figure 2.2 and Figure 2.3).

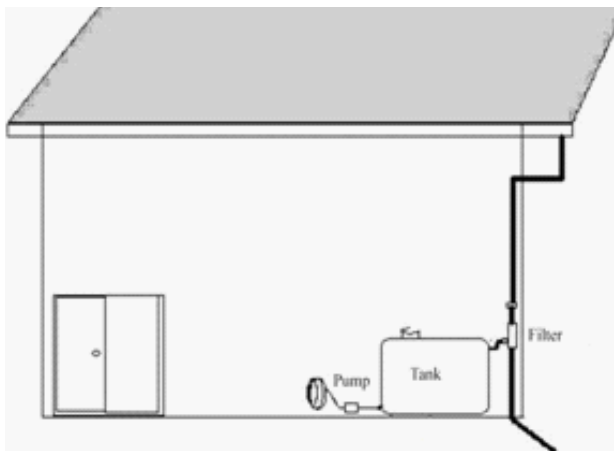


Figure 2.2 (Left): A Rainwater Harvesting system for a small residential home. (The Cabell Brand Center, 2009)

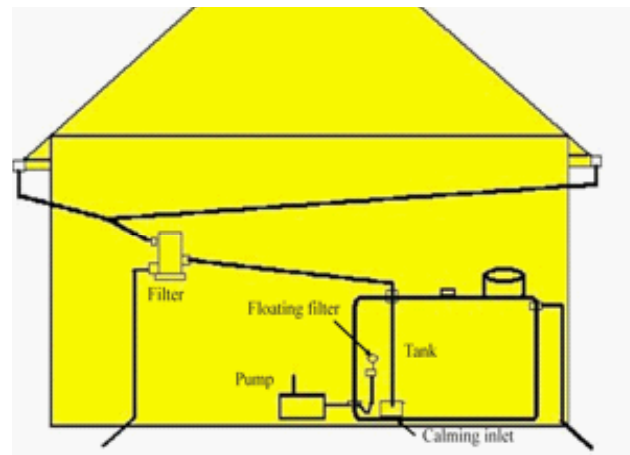


Figure 2.3 (Right): A Rainwater Harvesting system for commercial use or large residential. (The Cabell Brand Center, 2009)

Phase III outlines what the literature discusses about policies, regulations etc. in regards to implementing rainwater harvesting. A summary of the key findings of this phase is shown in Table 2.3.



## Phase III: Policy

Study	Area Investigated	Method	Key Relationship	Findings
Farahbakhsh, Despina, Leidl (2009)	Canada	Case Study in Canada	Overcoming the barriers to implementation using policies	RWH should be looked at as a public benefit instead of a private homeowners benefit; To allow RWH to be effective one needs: (1) Overarching Policy, (2) Regulatory Devices (3) Support Mechanisms
Kloss (2008)	United States	Case Studies	Overview of policies needed to encourage rainwater harvesting	Specific rainwater harvesting codes and regulations are important to encourage use. Incentives will also be extremely important.
Kloss (2008)	United States	Qualitative components and categories of a rainwater harvesting program	Implementation of a Rainwater Harvesting Program	Codes and Regulations; End uses & standards; required system components; permitting; maintenance; rates of reuse
Texas Water Development Board (2005)	Texas, United States	Case Study	Overview of policies that encourage rainwater harvesting in Texas	Tax exemptions; Municipalities offered tax incentives in the form of rebates and discounts; performance contracting for commercial establishments.
Mohd Et. Al (2011)	Malaysia	Case Study	Avenues to encourage rainwater harvesting in Malaysia	Provision of subsidies, tax and cost rebates, rebates, education, guidelines, restricted usage of piped water;
City of Tucson (2008)	Tucson, Arizona	Case Study	Example of an Ordinance mandating rainwater harvesting for new commercial development	Outlines requirements a developer would have to adhere to when integrating RWH in new commercial construction

Table 2.3: Summary table synthesizing the literature relating to policy, incentives and regulations.

As mentioned earlier, the United Nations states that policies and cost subsidies are indeed very important to the implementation of a successful rainwater harvesting program (Stockholm Environment Institute, 2009). Farahbakhsh, Despins and Leidl state that there are three main agents to instigate an effective RWH strategy:

- Overarching Policy
- Regulatory Devices
- Support Mechanisms

(Farahbakhsh, Despins, & Leidl, 2009)

Overarching policy “provides high level direction and sets expectations” (Farahbakhsh, Despins, & Leidl, 2009). Regulatory devices look into “legally binding tools that allow for enforcement” (Farahbakhsh, Despins, & Leidl, 2009). An example provided by the document looks at how the Ontario Building Code was modified to allow for captured rainwater to be used to flush toilets (Farahbakhsh, Despins, & Leidl, 2009). Support Mechanisms are “are aimed at end users and provide information, encouragement and incentives that allow for widespread implementation” (Farahbakhsh, Despins, & Leidl, 2009). Examples of this include education campaigns, manuals, incentives, demonstrations etc (Farahbakhsh, Despins, & Leidl, 2009). This three prong framework is the basis on which policy can be built in order to facilitate implementation of a rainwater harvesting program. Ontario has taken these three prongs and developed a stronger policy for rainwater harvesting.

The U.S. EPA released a document entitled Rainwater Harvesting Policies, part of the Municipal Handbook-Managing Wet Weather with Green Infrastructure. The handbook outlines states that regulations and codes are particularly important to encourage use; incentives will also play a very large role in encouraging rainwater harvesting (Kloss, Rainwater Harvesting Policies, 2008). The handbook concludes that codes and regulations should be in place to primarily manage public health (Kloss, Rainwater Harvesting Policies, 2008). Acceptable uses and treatment of the harvested water should be stipulated (Kloss, Rainwater Harvesting Policies, 2008).

Incentives should be in place to encourage the use of harvested water: “Pricing alternatives such as increasing block rates, which increase the price of water which increase use, create an incentive to conserve potable water” (Kloss, Rainwater Harvesting Policies, 2008). The document states that the cost of water is “underpriced” and with an increase in price of readily available municipal water, the public will be more interested in harvesting and reusing rainwater (Kloss, Rainwater Harvesting Policies, 2008)

The Texas Development Board looks to various financial mechanisms to encourage rainwater harvesting in Texas. Tax exemptions are one of the options mentioned in the Texas Manual; an example would be sales tax being removed from rainwater harvesting supplies and equipment (Texas Water Development Board, 2005). The Texas Manual also looks to financial incentives in the form of rebates and discounts to residents who install rainwater harvesting programs. Performance contracting is used as an incentive for commercial uses. Performance contracting is described as allowing “. . . a facility to finance water and energy saving retrofits with money saved by the reduced utility expenditures made possible by the retrofit” (Texas Water Development Board, 2005). In Malaysia, the government is looking at similar economic practices to encourage rainwater harvesting. Malaysia is looking into: provision of subsidies, tax and cost rebates, education and awareness, guidelines (standardized guidelines for installation), and the restricted use of piped water (Mohd, N.D.). Both the Texas’ and Malaysia’s analysis provided case studies of various municipalities and countries that have implemented the previously discussed policies and incentives.

Tucson, Arizona was the first municipality in the United States to implement a rainwater harvesting ordinance (Reese, 2008). The ordinance required commercial projects to harvest rainwater for use on the landscape: “The new water-saving measure—approved by a unanimous vote by the City Council—mandates that new development meets 50 percent of their landscaping water requirements by capturing rainwater,” (Reese, 2008). As well as water conservation, the ordinance is also recognized to support stormwater management. The City of Tucson’s ordinance can aid in the formulation of policies that could be applied to the City of Manhattan.

## **Summary**

The literature surrounding rainwater harvesting has been presented in three phases: analysis, application and policy. Essentially, analysis, knowledge and policy can be rephrased to: where, what and how. The analysis seeks to find out where the problem areas are; the second phase of knowledge explores the literature to find out what type of rainwater harvesting techniques can be employed to solve the issues in the problem areas identified in phase I; and the third phase looks to phase II to identify the appropriate policies. The phases described, are interconnected and they inform and build off of each other. Important concepts for each phase were derived from the literature and are as follows:

### **Phase I**

- Field observations are an important part of the analysis
- Identifying indicators can aid in measuring the effectiveness of rainwater harvesting elements

### **Phase II**

- Reuse or End Uses of the captured water needs to be specified to ensure the effectiveness of RWH
- Public participation/engagement will be a key force in the wide spread use and implementation of RWH
- Rainwater harvesting strategies work best when used in conjunction with other green infrastructure/stormwater management practices.
- It is important to understand the basic components of a rainwater harvesting system in context to the Wildcat Creek Watershed; the RWH systems must fit in context with the area.

### **Phase III**

- Rainwater harvesting needs to be encouraged through the use of regulations and codes.
- Incentives, tax exemptions, rebates etc. are important to making rainwater harvesting cost effective.

### **Four Principles**

Four main principles were derived from this literature review:

- Rainwater Harvesting (RWH) is more effective using a combination of techniques.
- Public Education/Engagement in the implementation of RWH systems is vital to its success.
- A designated Reuse/End use of the collect rainwater is necessary to the success of the RWH system
- Policy to aid in widespread acceptance and implementation.

These four principles were used to analyze precedent studies.

# PRECEDENT STUDIES: Methodology

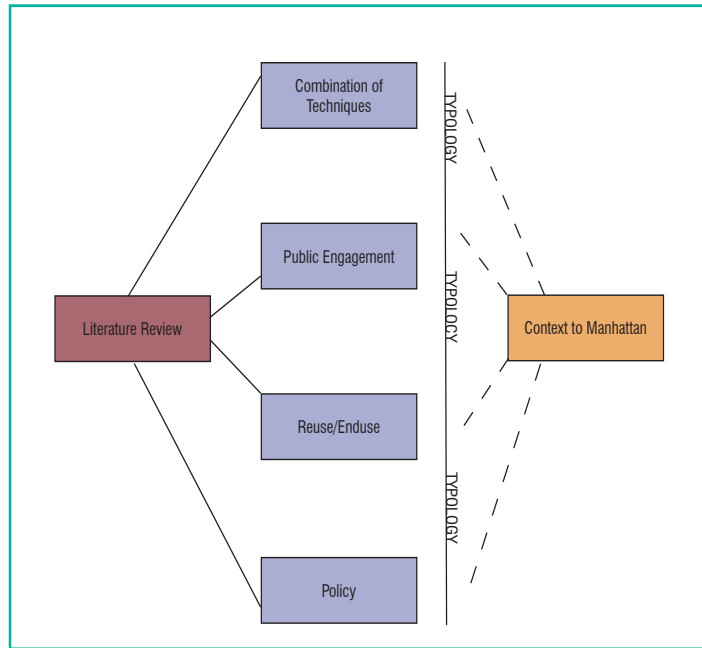
## PROCESS

The literature review revealed four main foci in regards to implementing a rainwater harvesting system, be it on a large scale or small scale. The four main prongs are:

- 1) Rainwater Harvesting (RWH) is more effective using a combination of techniques.
- 2) Public Education/Engagement in the implementation of RWH systems is vital to its success.
- 3) A designated Reuse/End use of the collect rainwater is necessary to the success of the RWH system
- 4) Policy to aid in widespread acceptance and implementation.

These four elements were used to extract information from each case study via a land use typology selected from the proposed study area. The main typologies are single family residential and some commercial. Community buildings were added to the typology, the Site Selection section explains the reasons for this addition. Figure 2.4 shows my thought process of how I came about my methodology.

Figure 2.4: Process Diagram of Precedent Studies



## USE OF PRECEDENTS: KEY FINDINGS

Once the methodology of the precedent studies was established, key points were taken from each case study and related to the context of Manhattan. In summary, the precedents shall be used to inform implementation in terms of integrative uses and partnerships; and inform site selection.

### SITE SELECTION

Previous research has shown that RWH is an underutilized stormwater management tool (Reidy, 2008). The benefits of RWH are not known to the majority of the public. From the precedent studies, cities and non-profit organizations are taking an educational stance to promoting RWH as a positive practice in communities whether it is given a water conservation focus or a stormwater management focus or both, for that matter.

Case Study 2 looks at a demonstration site in South Los Angeles. A non-profit organization in collaboration with other private, non-profit and public organizations came together to retrofit a single family home with a RWH system and other elements to manage stormwater runoff from a 100 year storm event. This demonstration site is open to the public for tours. In 2007, a 100 year storm event was simulated over the house for the public and the media to show the benefits of RWH and other similar systems. The philosophy behind Hall house is to instigate policy change by showing the feasibility of such practices. Hall House was successful in demonstrating the effectiveness of RWH and other strategies, however it falls short in showing the financial feasibility of the implementing such strategies on ones home. The cistern was a major expense (\$25,000) for this project that an ordinary person would not be able to afford (Ben-Horin). The site for the Case Study 1, Audubon Center and Sanctuary, was specifically chosen because of the visibility that the site had with the public. In this case, the Audubon Center and Sanctuary is considered a community, an education center that promotes the appreciation of the outdoors. With large numbers of people attending events and classes at the center, the same people can be educated about the benefits of RWH and related systems. With this example, I found that this demonstration site would only reach a certain segment of the population; a segment that is already conscious about the environment and exclude the population that would need to have this exposure the most.

These case studies changed the perspective on site selection. Site selection will be conscious of the fact that the proposed network of RWH elements also acts as a way to educate and engage as well as reduce runoff; to demonstrate the effectiveness of RWH as a stormwater management tool and encourage the public to implement RWH systems in their homes and businesses. This widespread acceptance of the RWH can instigate change in policy.

### IMPLEMENTATION

All five case studies are informative of how to use a combination of techniques to enhance the effectiveness of RWH. Case Study 2 looks at RWH in addition to vegetated swales, retention grading and a drywell. Case Study 1 looks at a cistern integrated with rain gardens. Case Study 3, Potsdamer Platz, shows large scale integration of cisterns and an artificial urban water body that acts as retention. The scales of integration vary from small (single family) to large (commercial). Case Study 4 looks into how RWH can be implemented in an apartment setting as compared to a single family home represented in Case Study 2. Extra consideration for the position of the cistern must be addressed. There is no set formula to integrate the elements and the integration or use of elements is site specific performing various purposes for the site in question. For example in Case Study 2, the rain gardens acted not only to hold rainwater but preserve the existing native vegetation on the site. Case Study 5 illustrates how the younger generations can benefit from having sustainable practices integrated into their academic lives. Partnerships are key to implementation. Case Study 1 in particular shows the benefits of non-profit organizations collaborating with government agencies and private organizations to implement RWH and other green strategies. The potential for collaboration in Manhattan is high (see Case Study 2).

# CASE STUDY 1: Audubon Center and Sanctuary, Tiburon, California

**Type: Community Building**

## Site Context

This particular project was part of the 10,000 Rain Gardens initiative in California. Two entities Marin Municipal Water District (MMWD) and the Salmon Protection and Watershed Network (SPAWN) worked in conjunction together. 10,000 Rain Gardens seeks to conduct public outreach and education of rainwater harvesting; provide training opportunities; encourage and implement rainwater harvesting projects; grow a water conservation conscious community through rainwater harvesting and other BMP practices; and demonstrate a successful partnership between a government agency MMWD and a non-governmental organization SPAWN. (SPAWN, 2010)

The Audubon Center and Sanctuary (Figure 2.5) is an education center that advocates for the appreciation of the outdoors. The site is located in Richardson Bay, off the coast of northern California, 30 minutes from San Francisco. (SPAWN, 2010)

## RWH Design Strategy

The rainwater harvesting system was designed to accommodate runoff from two sections of the roof. The two sections were named Watershed A and Watershed B. The flow from Watershed A would direct the flows to two rain garden, while Watershed B directs the flows to a 550 gallon cistern and the rain gardens, see Table 8.4 for the rainwater harvesting system's specifications.

### The Cistern

The 550 gallon cistern (Figure 2.7) was placed on leveled ground. The cistern was stabilized by placing it on a foundation with pea gravel laid under it. As with a basic rainwater system, an existing downspout was cut and connected to the cistern. A first flush diverter was also installed. A first flush diverter is acts to direct the initial flow of water from a roof (which can collect debris, insects etc) to a chamber that holds the contaminated water until the end of the storm and is automatically removed from the cistern. (SPAWN, 2010)

### The Rain Gardens

The two rain gardens collect runoff from Watershed B. The upper rain garden is connected to the lower rain garden via a trench (Figure 2.6). Once the water reaches the lower garden, the overflow was directed to a surrounding meadow. (SPAWN, 2010)

## RWH Design Strategy: Diagrams/Images



Figure 2.5: Audubon Center and Sanctuary main building



Figure 2.6: Trench connecting the upper and lower rain gardens



Figure 2.7: 550 Cistern

Watershed A: to rain garden only	315 square feet
Gallons per inch of rain (90% efficiency)	176 gallons
Gallons per year (22-inch avg. rain)	3,885 gallons
Watershed B: to collection tank and rain garden	189 square feet
Gallons per inch of rain (90% efficiency)	105 gallons
Gallons per year (22-inch avg. rain)	2,331 gallons
Rain catchment capacity	550 gallons
Rain garden 1 basin area	35 square feet
Rain garden 2 basin area	65 square feet
Total Rain Gardens design capacity	100 cubic feet
Total materials cost	\$2,975

Table 2.4: Specifications of the System

Image Source: Spwan, 2010

## 1) Integrated RWH Management

In this case study, integrated rainwater harvesting using a cistern and rain gardens benefitted the site (SPAWN, 2010). The rain garden and cistern succeeded in reducing the runoff from the building. The cistern and rain garden complimented each other in that overflow from the cistern was directed to the rain garden. The two rain gardens were integrated to support each other as well to handle overflow.

## 2) Public Education/Engagement

Again this site was chosen with the aim to educate and engage the public. The fact that the building was a community building that educated the public about the outdoors made the Audubon a strategic choice for public education and participation (SPAWN, 2010). Even though the center is heavily visited by the public, it would only attract people already passionate about the environment, and do little to educate those who are not as interested in environmental issues.

## 3) Reuse

With integrated RWH management on the site, the collected water has two functions. The collected water in the cistern is stored in for summer used to establish native plants and used for worm bins. The rain gardens have been constructed to preserve existing shrubs and native grasses. The upper rain garden allows water to infiltrate through the ground via a pipe.

## 4) Policy

The 10, 000 rain gardens document summarized various policy challenges that may be considered, they are listed as followed:

- Setback requirements for tanks from property lines, creeks etc
  - Approval from governing board
  - Building and Plumbing codes
  - Design review
  - Can not disturb (via digging) polluted soils
- (SPAWN, 2010)

## Context to Manhattan, Kansas

This precedent study interested me in several ways. Firstly, the fact that this project among others, were instigated by a collaboration between a governmental agency and non-profit. There has already been an inclination towards this. The Wildcat Creek Watershed Council was formed in 2009, and some members are serving at the City of Manhattan's Wildcat Watershed Working Group. If the entities in Manhattan were to collaborate like SPAWN and MMWD there could be potential to construct demonstration sites like the Audubon Center and instigate change.

The selection of the site was key. If a rainwater harvesting network is to educate and bring awareness of the benefits of RWH in stormwater management, as well as reduce runoff in the watershed, sites where the public frequent will play a major role in this effort. Looking at community buildings within the watershed or other areas that would increase the visibility of rainwater harvesting in the Wildcat Creek Watershed.

# CASE STUDY 2: Hall House, Los Angeles, California

**Type: Residential-Single Family**

## Site Context

Non-profit organization TreePeople has conducted several projects in Los Angeles to promote sustainable growth. The Hall House residence (Figure 2.10) was one such pilot study, where TreePeople in conjunction with various partners, retrofitted a single family home in order to capture and retain on site runoff from a 100 year storm event (Ben-Horin, 2007). In context to its urban watershed, the Hall House is located in the Bollona Creek Watershed (Ben-Horin, 2007). The watershed spans about 130 square miles and includes the majority of the City of Los Angeles, Beverly Hills, West Hollywood and a few other cities. The land use coverage of the watershed is as follows: 64% residential, 8% commercial, 4% industrial and 17% open space.

The Hall House, donated by Mrs. Rozella Hall, is located in a low income neighborhood in South Los Angeles. The house was a craftsman style, wooden frame bungalow. The Hall House is located on a typical 50 ft by 150 ft lot, which amounts to 7,500 square feet. Sixty percent (4,500 square feet) of the lot was impermeable surface. (Ben-Horin, 2007)

## RWH Design Strategy

In order to replicate a naturally functioning watershed, stormwater was managed in two main ways; it was either stored and reused for irrigation or it was directed to the ground for percolation (Ben-Horin, 2007). A vegetated and mulched swale, retention grading, a drywell and a cistern were integrated into the site to replicate a natural watershed to capture and retain runoff (see Figure 2.8). The rainwater harvesting system at the Hall House consists of a two-tank module cistern (Figure 2.11). Each tank holds a volume of 1,800 gallons. The two tanks are connected by a flexible PVC pipe. Each tank is 11 feet tall, with 6 feet above ground and 5 feet below the surface. The cisterns were placed in series along the fence, with the potential for additional cisterns to be placed in series. Runoff is collected from one quadrant of the roof.

The vegetated swale slows the flow of stormwater runoff, as well as filters pollutants from the runoff (Ben-Horin, 2007). TreePeople notes that the swale can be used in any residential setting (Ben-Horin, 2007). Retention grading, or sunken gardens, to hold water and slowly allow it to percolate into permeable areas. Multiple sunken gardens were strategically located around the property. The drywell is a strategy used to capture runoff from the driveway. The water flows into a grated trench where the water is filtered of its pollutants. The runoff is then slowly released into the ground.

## RWH Design Strategy: Diagrams/Images

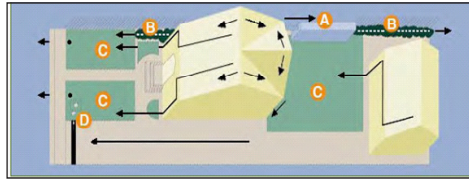


Figure 2.8: The Hall House Rainwater Harvesting System: "The operation of the demonstration site is illustrated in figure 1. Rain falling on the hard surfaces of the site (the roof and pavement) is directed to depressed lawn areas (C), or the cistern (A). Overflow amounts are carried by the vegetated swale (B), which also receives greenwaste (lawn clippings, leaves and twigs) from the site. Water flowing down the driveway toward the street is intercepted by a grated trench drain and diverted to the drywell (D)." (Ben-Horin, 2007)



Figure 2.9: Site chosen in proposed area in Manhattan Kansas for similarities in site layout to the Hall House. The same index of stormwater management elements (as quoted above) are applied to this site in Manhattan.



Figure 2.10: Hall House

Image Source: Ben-Horin, 2007



Figure 2.11: Cisterns at Hall House

## 1) Integrated RWH Management

Treepeople found that utilizing a rainwater harvesting system in conjunction with other elements increased the success of mitigating and reducing the runoff from flood events. "The BMPs are effective in reducing surface runoff, conserving municipal water supplies while maintaining an irrigated landscape, and reducing stormwater runoff and its pollutant load." (Ben-Horin, 2007).

## 2) Public Education/Engagement

The site was used as a demonstration site to encourage the use of rainwater harvesting and swales, drywells. It was built to show the effectiveness of all the elements and to show the public that this is a feasible way to manage urban stormwater runoff, protect the watershed and be replicated. The site was open to homeowners and developers to explore the elements for themselves and learn from the implementation at Hall House in order to replicate it in their own homes or developments (Ben-Horin, 2007). In the spirit of Hall House's mission, I hope to turn this Master's project into an avenue for change by showing the possibility of rainwater harvesting to the public and city officials.

## 3) Reuse

The collected water was used in two separate ways:

- 1) The water percolated through the ground to recharge the aquifer, practically eliminating runoff.
- 2) The water collected in the cistern was used for irrigation of the yard. (Ben-Horin, 2007)

## 4) Policy

According to TreePeople, at the time of this project, Los Angeles' building codes were not conducive to alternative stormwater management techniques. The codes state that runoff should be directed to the street (TreePeople). TreePeople worked within the constraints of the policies of Los Angeles, attaining the necessary permits. However, the main goal of the demonstration site was instigate a change in the city's policy showing the feasibility of rainwater harvesting and other BMPs. At the time of this article, the City of Los Angeles was revising their stormwater management policies and looking to move to the Integrated Resources Plan for wastewater (Ben-Horin, 2007).

## Context to Manhattan, Kansas

Upon inspection of the proposed study area the majority of the predominant land use is residential, with a large number of the residences being single family homes. Hall House is similar to many of the homes found in the proposed study area. Hall House becomes important in that it gives an example of how a typical single family home in Manhattan (Figure 2.9) can be retrofitted with a rainwater harvesting system and other elements and allows us to see how the layout of elements can be laid out on a site.

In regards to policy, Manhattan is similar to Los Angeles, at the time of the document, in that Manhattan has no policies that encourage alternative stormwater management. However, with the success of this project and other efforts, change in policy followed.



# CASE STUDY 3: Potsdamer Platz, Berlin, Germany

Type: Commercial-Large Scale

## Site Context

Potsdamer Platz is considered one of the best examples of large scale rainwater harvesting. The use of Potsdamer Platz attracts people of all different walks of life. The Platz hosts entertainment, office and shopping venues as well as Multi-national corporations like Sony and Daimler Chrysler. When redesigning the space, they found that the soil could not handle large amounts of rainfall and there necessarily became the mother of invention. To cope with precipitation and bad soils, the design team had to come up with an innovative solution (Atelier-Dreiseitl, 2011).

The "urban waterscape" of Potsdamer Platz was designed by Atelier Dreiseitl and Peter Hausdorf. Located in central Berlin, the Platz consists of a collection of 19 buildings, amounting to 48,000 metres squared of roof area. Berlin receives about 21 inches of rain per year (Atelier-Dreiseitl, 2011). About 23,000 cubic metres of captured rainwater is generated by this colossal complex every year.

## RWH Design Strategy

Both green roofs (60% of the roof area is covered in green roofs) and non green roofs alike capture the 21 inches of rain. A lot of this water is directed towards its reuse immediately. In the event of a large rain event, the overflow of runoff is directed to five underground cisterns. Total cistern volume is 2000 cubic metres (approx. 529,000 gallons). (Sustainable Cities, 2011) See Figures 2.12, 2.13 and 2.14.

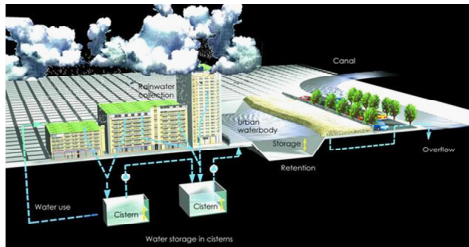


Figure 2.12: Entire Rainwater Harvesting System utilized in Potsdamer Platz (Sustainable Cities, 2011)

## RWH Design Strategy: Diagrams/Images

Figure 2.13: Diagram of the surfaces that collect rainwater and how the rainwater is reused.

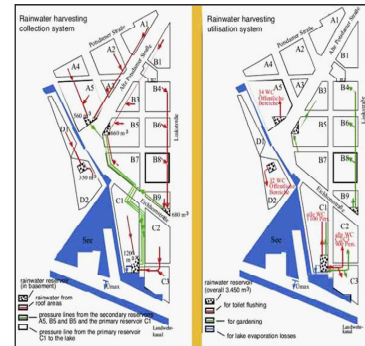
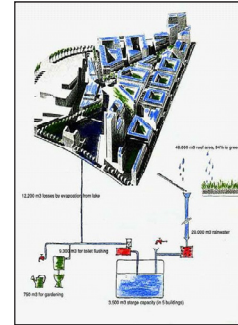


Figure 2.14: Diagram showing where rainwater is collected and how it is utilized.

Image Source: UNEP, 2005

## 1) Integrated RWH Management

A system of green roofs, cisterns and planted purification biotopes were used in conjunction with each other to capture storm runoff. The green roofs and cisterns, captured water from the building level, while the biotopes captured and filtered water that ran along the street. (Sustainable Cities, 2011)

## 2) Public Education/Engagement

Potsdamer Platz is located within a heavily used area of Berlin. The redesign of the Platz has made the area one of the most visited places in Berlin consequently making its visitors aware of stormwater issues, "Urban waterscapes combine sustainable water consumption and recreational areas in such a way that water environment issues become tangible for the city's citizens and visitors." (Sustainable Cities, 2011)

## 3) Reuse

Of the 23,000 cubic metres of collected rainwater:

- 1) 13,000 cubic metres is used for irrigation
  - 2) 10,000 cubic metres is redirected to the interior of the building to flush toilets/urinals and for use by the building's fire extinguishing features.
- (Sustainable Cities, 2011)

## 4) Policy

Germany is at the forefront with policy to encourage RWH within its cities and towns. Germany has enacted a Rain Taxes legislation, "Rain taxes are collected for the amount of impervious surface cover on a property that generates runoff directed to the local storm sewer." (Center for Science and Environment, 2011). So there is an incentive for people to collect rainwater or have more pervious cover. Germany also offers various grants and subsidies enabling residents to take on RWH on their properties. (Center for Science and Environment, 2011)

## Context to Manhattan, Kansas

Even though this is a large scale project, elements of it can still be translated to Manhattan. In terms of policy, Manhattan can emulate Germany in many ways from providing subsidies and grants to encourage rainwater harvesting or the addition of "rain tax" as described earlier, which may be controversial.

Again, visibility of alternative stormwater management tools is extremely important to fostering a citizenry that is well versed and aware of environmental issues concerning stormwater management. It will be important to bring this visibility to Manhattan as to educate the public and city officials alike.

Potsdamer Platz also demonstrates that rainwater harvesting is not just for single family homes or residences, but can be achieved at the commercial scale. Manhattan can use the model of collecting water in underground cisterns in commercial areas and redirecting that to servicing the building or irrigation.

# CASE STUDY 4: Rainwater Harvesting for Multi-storied Residential Apartments

Type: Residential Apartment

## Site Context

The following case study outlines rainwater harvesting strategies for apartment buildings in Dhaka, Bangladesh. The study, by then Master's student Farzana Sultana focuses on formulating guidelines in order to implement rainwater harvesting in urban areas to provide a sustainable water supply. Sultana's thesis looks at how rainwater harvesting can be applied to any residential apartment building (Figure 2.15) in the urban areas of Dhaka. The primary goal of the study was to find out the quantity of rainwater that can be used for domestic water use, with a secondary goal of using a widespread rainwater harvesting to potentially alleviate urban flooding by capturing runoff.

At the time of Sultana's thesis, Bangladesh had released a number of acts and policies that dealt with water pollution and wetland restoration, but hardly any policies dealt with water conservation. With Dhaka receiving about 71 to 80 inches of rainfall, Sultana states that rainwater harvesting would be an effective way to recharge aquifers, provide a sustainable water supply and alleviate storm-water runoff within the city.

## RWH Design Strategy

Sultana's RWH strategy focuses solely on rooftop rainwater harvesting (Figure 2.16). The RWH design strategy focuses implementing rainwater harvesting during construction. The design seeks to combine the following rainwater harvesting elements: Rooftop Catchment area, gutters and downpipes, first flush device, filter chamber, chlorination chamber, dechlorinator, storage tank that can either be underground or overhead and finally a water pump or water supply system. The sizing of the storage tank (Figure 2.17) is crucial in the placement of the tank, as the required size suggests whether it will be overhead or underground (basement) depending on the available area. The storage size was determined in a series of steps:

- Step 1: Determine monthly consumption
- Step 2: Determine Critical Rainfall
- Step 3: Determine total amount of rainwater available in a year
- Step 4: Determine Storage factor, SF
- Step 5: Determine Leakage factor
- Step 6: Calculate storage volume in Gallons
- Step 7: Calculate storage volume in Cubic Feet

## RWH Design Strategy: Diagrams/Images

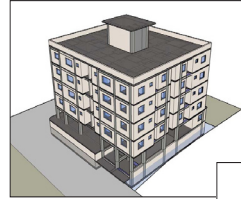


Figure 2.15: Typical multistoried apartment rendering.

Figure 2.16: Rainwater catchment area totalling 6,038.27 square feet, highlighted in blue.

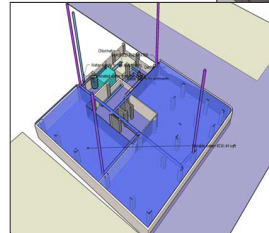


Figure 2.17: Cistern fitted to the basement of the apartment building

Using the steps outlined in the RWH design strategy section, it was found the apartment building shown above with floor heights of 9.33 feet, the appropriate size of the tank would be about 34064.69 cubic feet (or 254821.57 gallons).

Image Source: Sultana, 2007

## 1) Integrated RWH Management

The case study does not include any other elements such as rain gardens, or swales etc. However, I believe that the apartment building could benefit from other green strategies. For example, the overflow pipe from the system connects back into the drainage system. The drainage from the overflow pipe could potentially flow into a rain garden to aid in aquifer recharge or another use, rather than being placed back into the municipal drainage system.

## 2) Public Education/Engagement

Sultana's thesis advocates for public engagement and education through the involvement and partnership of non-governmental organizations and the local government. Organizations like the Bangladesh Environmental Lawyers Association and others, who are already advocating for a variety of environmental issues can work with communities to educate and encourage the acceptance different environmental initiatives that the government may try to implement.

## 3) Reuse

The case study looks into using the captured rainwater as a supplemental water supply for the residents in urban areas. This means that the proposed reuse options include: drinking water and other general household uses.

## 4) Policy

Policies related to national environmental management, wetland restoration and water pollution are already in force in Bangladesh as a whole. However, policy in regards to rainwater harvesting has not been at the forefront. Sultana suggests tax incentives as a way to encourage rainwater harvesting. The author states that tax incentives for energy conservation could be appropriate for rainwater harvesting. (Sultana, 2007)

## Context to Manhattan, Kansas

As mentioned in Cast Study 2, collaboration between the government and non-profits was seen as a fruitful way to implement rainwater harvesting on a local level. The city of Manhattan can definitely benefit from this. The policy climate of Dhaka is similar to Manhattan, Kansas in that there has not been a major interest in water conservation. Once again the benefit of inter organization collaboration surfaces. Sultana's project proposes partnerships between government and non-governmental organizations in order to promote rainwater harvesting as a form of water conservation and stormwater management.

The study has also highlighted the importance of the barrel or cistern sizes when it comes to apartment buildings. Cisterns and barrels are considerably larger than those used for single family homes and so the placement of the storage tanks may be an issue. Especially in an apartment complex that is already constructed.

# CASE STUDY 5: The Willow School, Gladstone, New Jersey, USA

Type: Community: School

## Site Context

The Willow School is a cutting edge example of integrating sustainability and nature into an educational setting. The school, located in New Jersey fosters ecological appreciation in its students through the built environment (Figure 2.19). Structures on the Willow School property have received both LEED Gold and LEED Platinum Certification (NAIS, 2007).

A comprehensive approach to fostering the importance of nature and responsible living was undertaken in designing The Willow School. The designers looked at everything from building materials, energy efficiency, indoor air quality, plant materials etc. The school also integrates the concept of sustainability in various ways in the school's academic curriculum. (NAIS, 2007)

From a stormwater management stand point, the designers employed a series of elements to reduce storm water runoff leaving the site. A combination of native grasses, reducing impervious surfaces, bio-swaales, rain gardens and rainwater harvesting were incorporated into the site. (NAIS, 2007)

## RWH Design Strategy

The co-founder of the Willow School states that rainwater harvesting addresses both stormwater management and re-use of runoff (Pushard, 2012). Gladstone, New Jersey receives about 40 inches of rain per year. The total roof square footage is about 13,500 sq ft and can potentially capture about 400,000 gallons of rainwater a year (Pushard, 2012). The lower academic building (Figure 2.19) was chosen to harvest rainwater. The main components of the rainwater harvesting system includes:

- One 50,000 gallon underground tank
- One 600 gallon tank in the basement
- One 35 gallon pressure tank
- One pump
- One micron filter
- Ozone Sterilization system (Pushard, 2012)

The 50,000 gallon tank stores the rainwater captured from the roof. Cleaning of the water takes place at this stage before it is transferred to the 600 gallon holding tank. The Ozone sterilization system is used to clean the water, while sediment and debris is removed by a series of filters between the large tank and the holding tank. Overflow of the rainwater is directed to a wetland area (Figure 2.20) on the site. (Pushard, 2012)

## RWH Design Strategy: Diagrams/Images



Figure 2.18: The lower academic building on the Willow School campus

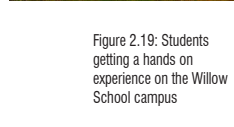


Figure 2.19: Students getting a hands on experience on the Willow School campus



Figure 2.20: Wetlands on the Willow school campus.

Image Sources: 1. The Willow School, 2012; 2. Pushard, 2009; 3. Natural Systems International, 2012

## 1) Integrated RWH Management

As mentioned under the RWH design strategy section, the Willow School integrates a wetland into the rainwater harvesting system design to address overflow. The wetlands are constructed ponds, lined with rubber and filled with rocks. Plants in the wetland are grown hydroponically, meaning that the plants are grown without soil and are fed by the pollutants in the water. (Pushard, 2012).

## 2) Public Education/Engagement

The notion of sustainability is ingrained into every aspect of the school; the students, teachers, and the public who visit this school can not ignore how sustainability has been integrated into this building and how it functions. The Willow School focuses on educating the students about the importance of living sustainably. The younger generation grow up with a sense that living sustainably is the right way to live, or the responsible way to live.

## 3) Reuse

The Willow School's captured rainwater has three main reuses. The rainwater is used for:

- Low flush toilets
- Irrigation of landscaping
- Overflow water is pumped into the ground to recharge after being cleaned by the wetlands.

## 4) Policy

No specific policy initiatives were given for this particular project. However, New Jersey is home to a number of projects that look into green infrastructure as a way to manage storm water. Public Works departments have initiated projects encouraging green initiatives, BMPs, and wetland creation. Different communities across New Jersey have also started rain barrel programs. Interestingly, many of these public works departments partnered with a local watershed action groups to implement initiatives. (Bergstrom, J. & Obropta, n.d.)

## Context to Manhattan, Kansas

Introducing rainwater harvesting at a school setting is an important step to public education. As aforementioned targeting the younger generation as they develop and educating them on what rainwater harvesting is and the benefits, allows them to keep this sustainable practice in their mindset as they get older; hopefully perpetuating the practice.

The Frank V Bergman Elementary school has a catchment area about the same size as the Willow School, and so, similar tank sizes and configuration of the rainwater harvesting system can be used in regards to the Frank V Bergman Elementary school. An important consideration was also derived from this example: with the use of an underground tank, it has to be placed below the frost line of the ground (2 feet) to prevent the water from freezing during the winter months (Pushard, 2012).

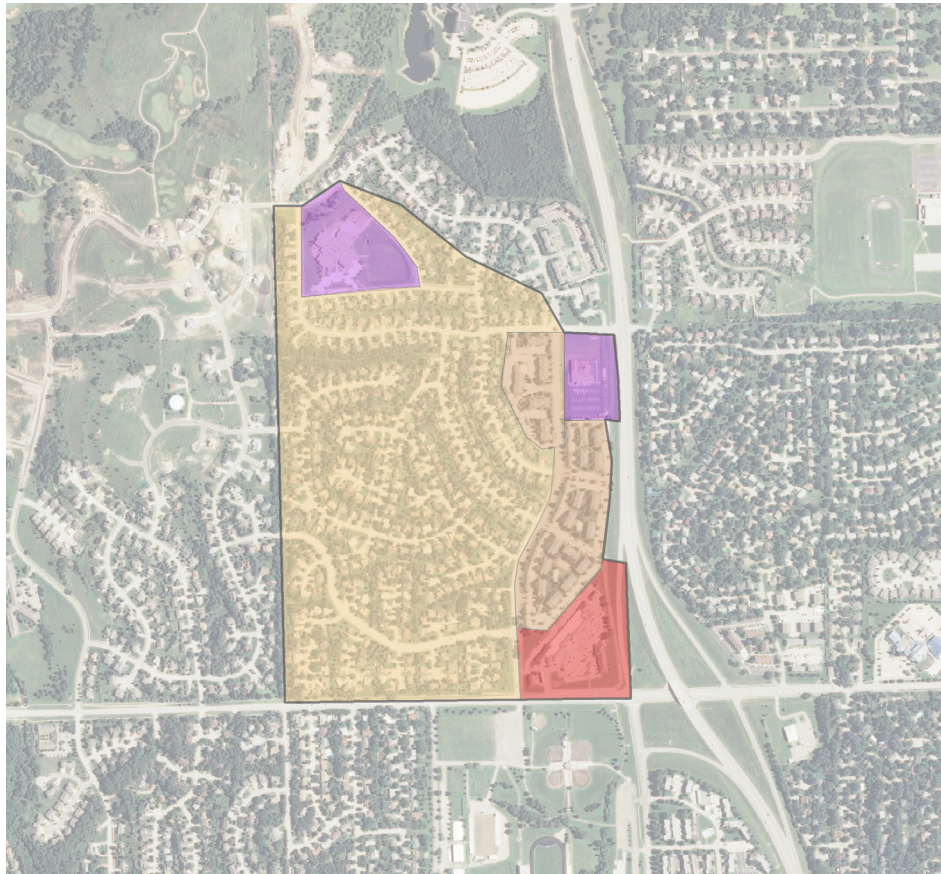
# Chapter 3: Application

*Phase I: Analysis + Calculations*

*Phase II: Application of Rainwater Harvesting Elements*



# Site Selection



The site delineated below (Figure 3.1) is found in the northwestern corner of the City of Manhattan. The site is flanked by Kimball Avenue to the south and North Seth Child Avenue to the west. The East side of the site is delineated by the Hudson Nature Trail. The site was divided into the five land use types: Residential: Single Family; Residential: Apartment; Community: Church (First Assemwblly of God Church); and finally the Commercial land use type that contains business like restaurants and a pharmacy.

← Figure 3.1: Location of proposed site with land use types delineated (Source: Image by Author)

## Legend:

- Residential: Apartment
- Residential: Single Family
- Community: Church and School
- Commercial

# Methodology

## Neighborhood Scale Analysis

The aim of this analysis was to calculate the volume of surface runoff emitted from each land use type and compare the volumes to the potential amount of rainwater that could be collected from the roofs within each land use type. The rational method was used to calculate the volume of runoff for each land use type as well as the potential surface runoff from the structures within each land use type. The rational method is described as:

$$Q = A \times C \times I$$

Whereas,

Q= Discharge (Acre Inches)

A= Area (Acres)

C= Coefficient of Runoff

I= Intensity of Rainfall in (Inches)

The area/acre (A) value of each land use type was determined using the measure tool in ArcGIS. The Coefficient of Runoff (C) was determined using existing values from the American Society of Civil Engineers or ACSE (1969). To determine a more representative runoff coefficient for the site, a weighted average coefficient was used. Finally, the Intensity of Rainfall (I) was determined using a two year one hour storm, which for the City of Manhattan is 1.7 inches. A two year one hour storm event has a 50% chance of occurring in any year.

First, the rational method was used to calculate the total amount of runoff from each land use type. The values are seen in Table 3.1.

Land Use Typology	Total Acreage	Total Surface Runoff (Gallons)
Residential: Single Family	132.85	2,453,075
Residential: Apartments	18.33	533,386
Community: School	9.45	183,194
Community: Church	4.83	131,383
Commercial	9.39	287,531

Table 3.1: Table describing total acreage of land use types and amount of stormwater runoff from each land use type within the selected study site.

Second, the volume of rainwater that could be collected from the roofs in each land use type was calculated. The total amount of rainwater collected from a roof structure was again calculated using the rational method. In this instance, the area value, was the area of the roof, the coefficient value was determined to be 0.85. The coefficient was again determined using the values from the ASCE (1969). ASCE (1969) states that the coefficients for a roof surface fall between 0.75 to 0.95. So the C value for this project was determined by taking the midpoint, which is 0.85. The intensity value remained 1.7 inches.

The Texas Water Board states that structures can collect between 75% and 90% of all rainwater falling on a roof based on the efficiency of the rainwater catchment system (leakages, size of the barrel etc) (Texas Water Development Board, 2005). Thus, once the runoff from each of the structures on the Manhattan neighborhood scale site was calculated, the value was then multiplied by .90 to get the 90% efficiency, by .80 to get the 80% efficiency and so and so forth. A 15 % efficiency was also calculated to observe the effect if even a small amount of rainfall was captured by the roofs.

### **Results by Land Use Type**

The site, located in the north western part of Manhattan was chosen because it included a variety of land uses at a small, neighborhood scale. The site is also located in a problem area of the Wildcat Creek Watershed due to urban development. The site was divided into the following land use types: Residential: Single Family, Residential: Apartment, Community: Church, Community: School and finally Commercial.

#### **Residential: Single Family**

A typical single family home within the designated site was chosen to demonstrate rainwater harvesting. The roof area of this typical single family home is about 1738 sq ft. Using the aforementioned formula to calculate potential rainwater captured, this single family home can collect about 1408 gallons of rainwater at 90% efficiency from a two year one hour rainfall event.



Using this average amount of rainwater captured in the study area, the residential single family land use type can capture about 536, 325 gallons from a two year one hour storm event, which is about 21.9% of the total stormwater runoff through this land use type. On the much lower end, at 15% efficiency, a rainwater harvesting systems can collect about 3.6% of the total stormwater runoff for the entire land use type. 3.6 percent is about 89, 388 gallons from the single family land use type .

### **Residential: Apartments**

The Residential: Apartment typology was split into complexes. The northern complex was delineated as Complex 1 while the apartments that extend south were delineated as Complex 2. Complex 1 can collect about 42, 523 gallons at 90% efficiency and Complex 2 can collect about 85,125 gallons at 90% efficiency from a two hour one year storm event. Thus, in total, both complexes can collect approximately 127, 648 gallons of rainwater, which is about 23.9% of the runoff generated from a two hour one year storm event in the Residential: Apartments land use type. At 15% efficiency both complexes can collect approximately 21,275 gallons from rainwater harvesting, that is about 4% of the total stormwater runoff from the Residential: Apartments land use type.

### **Community: School**

At 90% efficiency, the Frank Bergman's roof catchment area can collect about 43, 697 gallons from a two year one hour storm event. This amount is about 23.9% of the runoff produced by this land use type. At 15% efficiency the school can potentially collect about 7,283 gallons from a two year one hour storm event. This accounts for about 4% of the stormwater runoff produced by this land use type.

### Community: Church

At 90% efficiency, the First Assembly Church roof catchment area can collect about 20,617 gallons. This amount is about 15.7% of the runoff produced by the church property from a two year one hour storm event. With an increased impervious area in comparison to the size of the roof, the amount of water collected is not as much as the other land use types. If the church only collected 15% of the rainfall from the roof, it could possibly capture about 3,436 gallons which is about 2.6% of the total stormwater runoff from the land use type.

### Commercial

The amount of rainwater captured from each of the four structures on the site was calculated. The total amount of rainwater captured from the structures was about 60, 598 gallons at 90% efficiency. This amount is about 21.6% of the total stormwater runoff from the commercial land use type. At 15% efficiency the commercial land use type can capture about 10, 098 gallons which accounts for 3.6% of the total.

The following tables summarize the previous findings. Table 3.2 shows the findings if a rainwater harvesting system could collect 90% of the roof runoff, while Table 3.3 shows the findings if only 15% of the rainwater could be collected.




Table 3.2 (Top): Table describing volume of total stormwater runoff and the amount of stormwater runoff collected through rainwater harvesting at 90% efficiency

Table 3.3 (Bottom): Table describing volume of total stormwater runoff and the amount of stormwater runoff collected through rainwater harvesting at 15% efficiency.

<b>Land Use Type</b>	<b>Volume of Total Stormwater Runoff (Gallons)</b>	<b>Volume of Runoff Captured from Structures (Gallons)</b>	<b>Percentage of Runoff Captured from Total Stormwater Runoff</b>
Residential: Single Family	2,453,075	536,325	21.9
Residential: Apartment	533,386	127,648	23.9
Community: School	183,194	43,697	23.9
Community: Church	131,383	20,617	15.7
Commercial	287,531	60,589	21.1
All Land Use Types	3,588,569	788,876	22.0

<b>Land Use Type</b>	<b>Volume of Total Stormwater Runoff (Gallons)</b>	<b>Volume of Runoff Captured from Structures (Gallons)</b>	<b>Percentage of Runoff Captured from Total Stormwater Runoff</b>
Residential: Single Family	2,453,075	89,388	3.6
Residential: Apartment	533,386	21,275	4.0
Community: School	183,194	7,283	4.0
Community: Church	131,383	3,436	2.6
Commercial	287,531	10,098	3.5
All Land Use Types	3,588,569	131,480	3.7

The total amount of stormwater runoff from all the land used types is 3,588,569 gallons and at 90% efficiency the total amount of rainwater collected from the roofs within the land use types is 788,786 gallons, which is 22% of the total amount of stormwater runoff coming off of the site. At 15% efficiency, rainwater harvesting can capture about 3.7% (131,480 gallons) of the total stormwater runoff. Appendix I contains all the calculations employed for the neighborhood scale analysis.

## **Wildcat Creek Watershed Extrapolation**

The results of the neighborhood scale site analysis were extrapolated from the neighborhood scale site to the portion of the City of Manhattan, Kansas located in the Wildcat Creek Watershed to show the effect of rainwater harvesting if all of the structures within the Wildcat Creek Watershed were to harvest rainwater. The land use types used in the neighborhood scale site analysis include: Residential: Single Family; Residential: Apartment; Community: Church; Community: School and finally the Commercial land use type.

In order to extrapolate the results of the neighborhood analysis to the portion of the city found within the Wildcat Creek Watershed, the first step was to calculate the volume of stormwater runoff being emitted by the land use types throughout the entire city. Using the rational method, the total area where each land use type occurs within the Wildcat Watershed, coefficient for the land use types and rainfall intensity needed to be calculated.

In order to calculate the area of where the land use types are mostly likely to occur, the City of Manhattan Zoning Regulations were used. Zoning is a tool used to describe “. . .the size and use of buildings, where they are located and, in large measure, the density of the city’s diverse neighborhoods,” (NYC Department of City Planning, 2012). That is to say, communities are generally divided into zoning districts based on similar land uses. The City of Manhattan is divided into 22 zoning districts based on land use. The Zoning districts are outlined as follows:

### **Residential**

R-S: Contains Single Family homes and other compatible uses such as schools and churches

R: Contains Single Family homes and other compatible uses such as schools and churches

R-1: Contains Single Family homes and other compatible uses such as schools and churches

R-2: Contains Single Family attached dwelling units other uses also include churches and schools

R-M: Contains Single Family, Two family, and small multi-family homes

R-3: Contains multi-family homes (most apartments occur in this zoning districts)

R-4: This district is similar to R-1 but contains manufactured homes; also contains compatible uses such as schools and churches

R-5: Contains Manufactured and Mobile Homes

### **Commercial**

C-1: Contains banks, professional business offices, government buildings

C-2: Contains retail options in more residential areas

C-3: Contain retail stores in the Aggieville District of the City

C-4: This is the Central Business District of the City on contains a variety of retail options

C-5: Contains accommodations, supplies or services to motorists and other specialized activities

C-6: Contains commercial uses that provide the sale and/or service of heavy equipment

### **Industrial**

I-1: Contains research facilities in an attractive landscaped setting

I-2: Contains manufacturing and research land uses

I-3: Contains uses that conduct manufacturing, processing, assembly and non-retail services

I-4: Contains uses that deal with intensive manufacturing and processing activities

I-5: Contains research, administrative and assembly activities in a setting that is compatible with residential areas.

Light Manufacturing- Service Commercial District (LM-SC): This zoning district contains light manufacturing uses and highway service commercial activities

Planned Unit Development (PUD): PUDs promote flexible development that differs from the zoning regulations. PUDs account for a variety of establishments

University (U): Contains uses associated with Kansas State University

Observing the City of Manhattan's Zoning Regulations and observing where this Master's projects prescribed land use types mostly occurs, the zoning districts were grouped together to find the area of where each land use type occurs:

Developments similar to land use type Residential: Single Family can be found in zoning districts: R, R-S, R-1, R-2, R-M, R-4 and R-5. Land use types Community: Church and Community: School are also mostly found within the same zoning districts as the Residential: Single Family land use type . Developments similar to land use type Residential: Apartment are mostly found in zoning districts R-3 and PUD. While developments similar to land use type Commercial are found in C-1 to C-6, I-1 through I-5. The grouping of zoning districts to represent the land use types are generalizations used to find the approximate acreage where the land use types from the neighborhood analysis can occur. Using ArcGis, the City of Manhattan zoning districts were grouped together as described above and the total area for where the land use types occur was calculated. Figure 3.2 shows the occurrence of the land use types within the Wildcat Creek Watershed

As previously stated, zoning districts R, R-S, R-1, R-2, R-M, R-4 and R-5 represent the Residential: Single Family; Community: Church and Community: School types. Zoning districts R-3 and PUD represent Residential: Apartment land use type and zoning districts C-1 through C-6 and zoning district I-1 through I-5. The acreage for each the groupings representing the land use types found within the Wildcat Creek Watershed are as follows:

Residential Single Family; Community: Church; Community: School- 3789 Acres

Residential: Apartment- 702 Acres

Commercial- 566 Acres

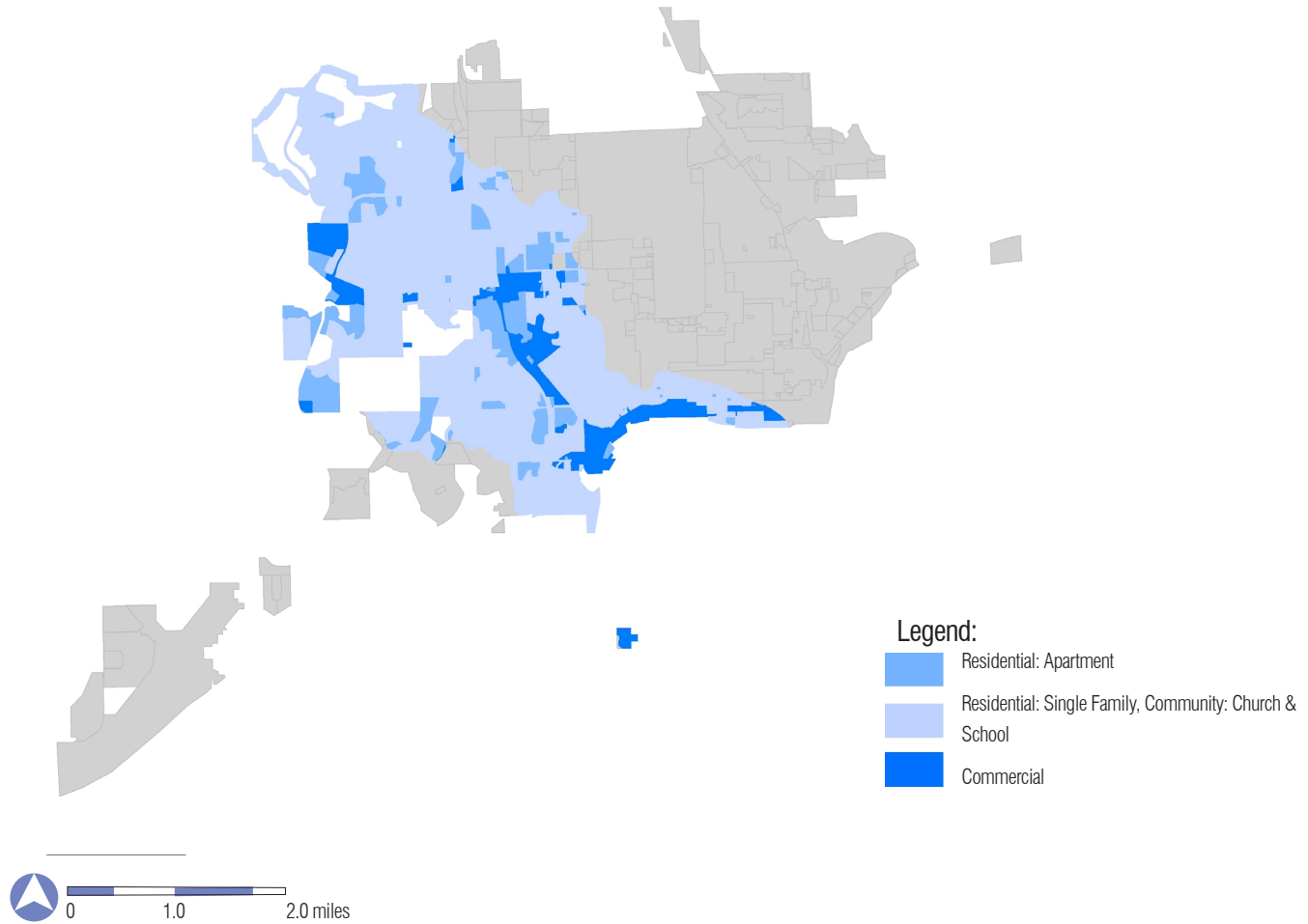


Figure 3.2: Map showing where the land use types occur within the urban portion of the Wildcat Creek Watershed .  
 (Source: map by Author)

Once the area of where the land use types occur was calculated, the Coefficient of Runoff (C) values were determined. The C values from the neighborhood study were used for the Watershed extrapolation. Thus, the C value for Residential: Apartment ranges between .61 and .68. A midpoint between the high and the low C values for the Residential: Apartment land use type was used for citywide the extrapolation. The mid-point C is 0.65. The Commercial land use type C was .67, from the neighborhood analysis and this C value was used for the watershed extrapolation. Since the Residential: Single Family, Community: Church and Community: School land use types occur in the same zoning districts, a weighted average of the coefficients from the neighborhood analysis as used. A weighted average was used because the Residential: Single Family, Community: Church and Community: School are not evenly distributed within the grouped zoning districts and they do not have the same coefficient values. Hence a weighted average was used to represent that the Residential: Single Family is a larger portion of the area, while the Community: Church and Community: School represent a smaller area of the zoning districts grouping. The weighted average coefficient for these three land use types was 0.40. The intensity (I) value remained 1.7 inches for the two year one hour storm event.

Once the stormwater runoff from the land use types was calculated, the amount of rainwater captured from the structures within each land use type was calculated. The neighborhood analysis calculated the percentage of rainwater that could be harvested from the total amount of stormwater runoff for each land use type. The percentage of rainwater harvested from the neighborhood analysis was applied to the watershed extrapolation, assuming that each land use type citywide would collect the same percentage of rainwater harvested at the neighborhood scale. The percentages from the neighborhood analysis represent the percentage captured from a two year one hour storm. The Commercial land use total stormwater runoff was multiplied by 21.6%, the Residential: Apartment citywide stormwater runoff was multiplied by 23.7%; while the Residential: Single Family, Community: Church and Community: School citywide stormwater runoff was multiplied by a weighted average percentage value, since the land use types were combined for the extrapolation. The weighted percentage of rainwater harvested for these three land use types was 24%. The following tables (Table 3.4, Table 3.5 and Table 3.6) show the calculations and results of the extrapolation for each of the land use types.



A (Acres)	3789
C (Average of neighborhood analysis C values)	0.4
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	2577
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>215</b>
Total Volume of stormwater runoff (Gallons)	70,058,057
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>52</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>16,781,349</b>

A (Acres)	702
C (Average of neighborhood analysis C values)	0.65
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	775
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>65</b>
Total Volume of stormwater runoff (Gallons)	21,180,343
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>13</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>4,170,898</b>

A (Acres)	566
C (Average of neighborhood analysis C values)	0.67
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	644
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>54</b>
Total Volume of stormwater runoff (Gallons)	17,595,977
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>12</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>3,776,618</b>

← Table 3.4 (Top): Land containing developments that are similar to Residential: Single Family, Community: School and Community: Church Land Use Types. The table shows the possible volume of water mitigated through rainwater harvesting.

Table 3.5 (Middle): Land containing developments similar to the Residential: Apartment. The table shows the possible volume of water mitigated through rainwater harvesting.

Table 3.6 (Bottom) Land containing developments similar to the Commercial Land Use Type. The table shows the possible volume of water mitigated through rainwater harvesting.

Adding the volumes from Table 3.4 Table 3.5, and Table 3.6 from a two year one hour storm event, the total runoff is **333 Acre Feet within the watershed (~108.5 million gallons)** and from that total runoff, **76 Acre Feet (~ 24.7 million gallons)** can be captured by rainwater harvesting citywide. Calculations for the watershed extrapolation can be seen in Appendix II.

## Citywide Extrapolation

The impact of rainwater harvesting citywide was also calculated. The impact was calculated using the exact methodology for the watershed scale extrapolation. The total area of where the land use types occur citywide was calculated and as well as the weighted coefficient for the Residential: Single Family, Community: Church and Community: School land use types category using the same methodology as described above in the watershed scale extrapolation. Figure 3.3 shows where the land use types occur within the city. The percentage of rainwater harvested for the land use types were again derived from the neighborhood scale analysis. The percentages are based on a two year one hour storm event. The Commercial land use total citywide stormwater runoff was multiplied by 21.6%, the Residential: Apartment citywide stormwater runoff was multiplied by 23.9%; while the Residential: Single Family, Community: Church and Community: School citywide stormwater runoff was multiplied by a weighted average percentage value, since the land use types were combined for the extrapolation. The weighted percentage of rainwater harvested for these three land use types was 24%. The citywide extrapolation excluded the Kansas State University Campus and the Manhattan Regional Airport as they were not similar to any of the land use types explored in this project. Table 3.7, Table 3.8, and Table 3.9 show the calculations and results of the extrapolation for each of the land use types.

Adding the volumes from Table 3.7, Table 3.8, and Table 3.9 from a two year one hour storm event, the total runoff is 693 Acre Feet citywide (~226 million gallons) and from that total runoff, 157 Acre Feet (~ 51 million gallons) can be captured by rainwater harvesting citywide. Rainwater harvesting citywide can capture 22.7% of all stormwater runoff citywide.

### ***Note about the use of the Rational Method***

The rational method is generally applied to areas less than 300 acres (Oregon Department of Transportation, 2005). The extrapolation from the neighborhood analysis to the watershed scale extrapolation and the citywide extrapolation still employ the rational method although the areas are larger than 300 acres. The rational method is still employed to keep the analysis consistent with the neighborhood scale analysis. The extrapolations are based on the findings of the neighborhood scale analysis. With the extrapolated numbers used for estimation purposes only, the numbers cannot be considered for engineering purposes.

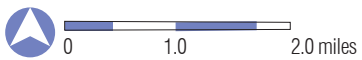
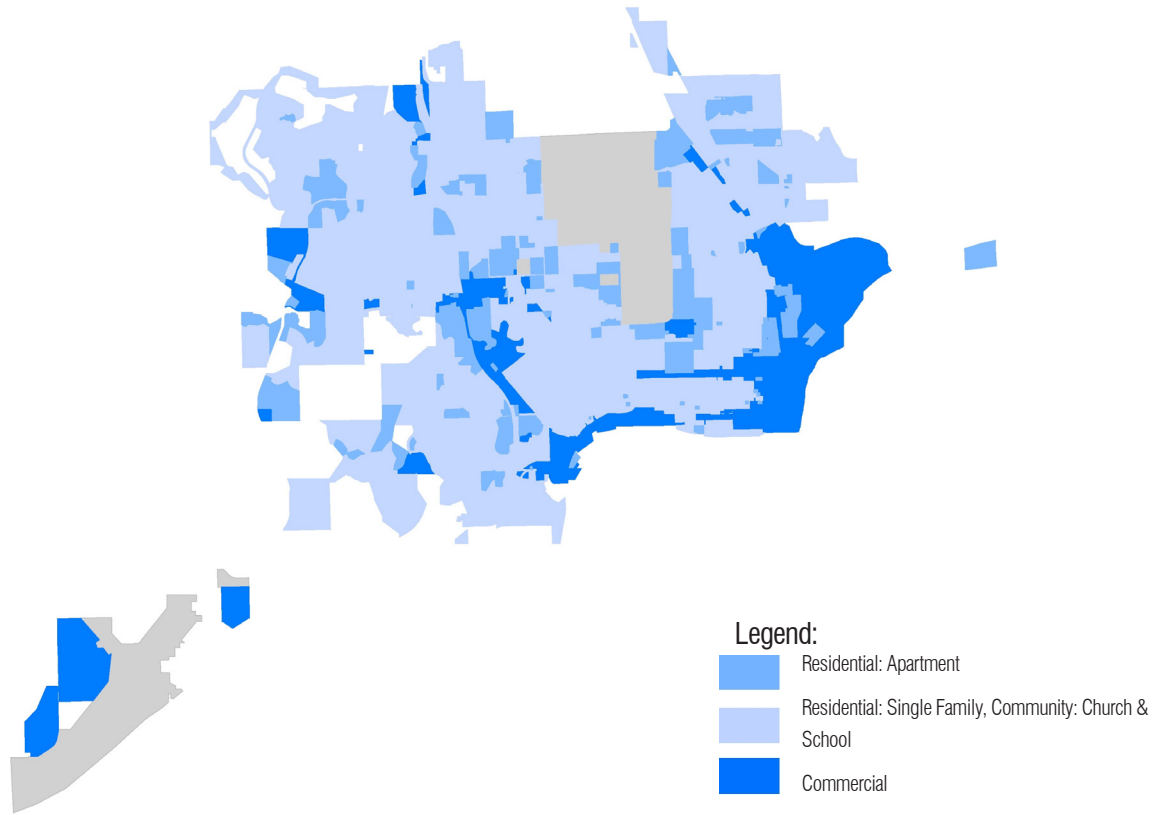


Figure 3.3: Map showing where the land use types occur citywide (Source: Image by Author)

A (Acres)	6803
C (Average of neighborhood analysis C values)	0.4
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	4626
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>386</b>
Total Volume of stormwater runoff (Gallons)	125,778,651
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>93</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>30,141,257</b>

A (Acres)	1416
C (Average of neighborhood analysis C values)	0.65
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	1565
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>130</b>
Total Volume of stormwater runoff (Gallons)	42,360,686
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>26</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>8,406,967</b>

A (Acres)	1869
C (Average of neighborhood analysis C values)	0.67
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	2129
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>177</b>
Total Volume of stormwater runoff (Gallons)	57,675,703
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>38</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>12,486,627</b>

← Table 3.7 (Top): Land containing developments that are similar to Residential: Single Family, Community: School and Community: Church Land Use Types. The table shows the possible volume of water mitigated through rainwater harvesting.

Table 3.8 (Middle): Land containing developments similar to the Residential: Apartment. The table shows the possible volume of water mitigated through rainwater harvesting.

Table 3.9 (Bottom) Land containing developments similar to the Commercial Land Use Type. The table shows the possible volume of water mitigated through rainwater harvesting.

Adding the volumes from Table 3.7, Table 3.8, and Table 3.9 from a two year one hour storm event, the total runoff is **693 Acre Feet citywide (~226 million gallons)** and from that total runoff, **157 Acre Feet (~ 51 million gallons)** can be captured by rainwater harvesting citywide. Calculations for the watershed extrapolation can be seen in Appendix III.

## Program Elements by Land Use Type

After the calculations were conducted, the configuration of a rainwater harvesting system for each typology was analyzed. That is to say, for a single family residential home, how could a rainwater harvesting system be configured on a site? From the precedent studies, TreePeople's configuration of BMPs on a site was effective (Ben-Horin, 2007). Adapting this method and best practices in rainwater harvesting systems from the Virginia Rainwater Harvesting Manual, the configuration of a rainwater harvesting system for each typology was established (The Cabell Brand Center, 2009).

All Rainwater Harvesting systems consist of the same components: the catchment area; the conveyance system; pre-tank treatment; water storage and distribution (Cabell Brand, 2007). The following section outlines the program elements for each typology and diagrams showing possible configurations of rainwater harvesting systems based on the precedent studies and the discussion from articles outlined in the literature review.

### Residential: Single Family

#### Objectives:

- Reduce the amount of stormwater runoff entering the Wildcat Creek Watershed
- Collect rainwater from 90% of the roof structure from a Two year one hour storm event
- Establish reuse options
- Educate homeowners on the benefits of rainwater harvesting

#### Program Elements for Rainwater Harvesting:

- Average amount of volume for a 2 year one hour event
  - 1408 gallons
- Rooftop Catchment Area
  - 90% of the total square footage

- Existing Gutters & Downspouts
- Leaf Screens/First Flush Diverter/Roof Washers (a means of capturing Debris)
- Rain Barrel(s) or Cistern(s)
  - Minimum: Twenty-five 58 gallon barrels
  - Moderate: Three 500 gallon barrels
  - Maximum: One 1500 gallon barrels
  - Cost: \$500to \$1500 per barrel (Plastic, Wood, Metal)
- Delivery System
  - Pressure Tank
    - \$200 to \$1000
  - Pumps for indoor uses
    - Cost: \$585 to \$635 per pump
  - Garden hose for irrigation, outdoor cleaning
- Treatment and Purification components (if used for potable water uses)
- Rain Garden, French drain or Landscaped areas to capture overflow

## **Residential: Apartment**

### **Objectives:**

- Reduce stormwater runoff
- Collect rainwater from 90% of the roof structure from a Two year one hour storm event using barrels or cisterns
- Establish reuse options
- E ducate homeowners on the benefits of rainwater harvesting

### **Program Elements for Rainwater Harvesting System:**

- Average amount of Water to be Captured from a 1” storm event
  - **Complex One:** 8505 gallons
  - **Complex Two:** 5675 gallons
- Rooftop Catchment area
  - 90% of total square footage
- New and Existing Gutters and downpipes
  - Cost for new pipes: \$0.30 to \$12.00 per lineal foot
- First flush device
- Filters
  - Cost: \$100 to \$3000
- Cistern
  - **Complex One:**
    - Minimum: Six 1500 gallon barrels
    - Moderate: Two 5000 gallon barrels
    - Maximum: One 10000 gallon barrel
  - **Complex Two:**
    - Minimum: Four 1500 gallon barrels
    - Moderate: Two 2000 gallon barrels
    - Maximum: One 6000 gallon barrel
  - Cost: Complex 1- \$3150 to \$10000
  - Cost: Complex 2- \$2100 to \$ 6500
- Delivery System
  - Pressure Tank
    - \$200 to \$1000
  - Pumps for indoor uses

Cost: \$585 to \$635 per pump

- Rain garden, french drains or landscaped areas to capture overflow

## Community: School and Church

### Objectives:

- Reduce stormwater runoff
- Collect rainwater from 90% of the roof structure from a Two year one hour storm event using barrels or cisterns
- Establish reuse options
- Educate public and students about the benefits of rainwater harvesting

### Program Elements

- Average amount of Water to be Captured from a 1" storm event:
  - **School:** 43697 gallons
  - **Church:** 20617 gallons
- Rooftop Catchment area
  - 90% of total square footage
- New piping to transport water
  - Cost: \$0.30 to \$12.00 per lineal foot
- First flush device
- Filter
  - Cost: \$100 to \$3000
- Storage tank (underground, overhead, at grade)
  - **School:**
    - Minimum: Five 10000 gallons barrels
    - Moderate: Four 12500 gallons barrels
    - Maximum: Three 15000 gallon barrels
  - Cost: \$17500 to \$45000



- **Church:**
  - Minimum: Four 5500 gallons
  - Modertae: Two 12500 gallons
  - Maximum: Two 30000 gallons
- Cost: \$7700 to \$15000
- Delivery System
  - Pressure Tank
    - Cost: \$200 to \$1000
  - Pumps for indoor uses
    - Cost: \$585 to \$635 per pump
  -
- Signage
- Rain Garden, French drains or landscaped areas for overflow

## Commercial

### Objectives:

- Reduce stormwater runoff
- Collect rainwater from 90% of the roof structure from a Two year one hour storm event using barrels or cisterns
- Establish reuse options
- Educate public and students about the benefits of rainwater harvesting

### Program Elements:

- Average amount of Water to be Captured from a 1” storm event:
  - Building 1: 45134 gallons
  - Building 2: 10558 gallons
  - Building 3: 1818 gallons
  - Building 4: 3079 gallons
- Rooftop Catchment area
- New piping to transport water
  - Cost: \$0.30 to \$12.00 per lineal foot
- First flush device
- Filter (Largest)
- Storage tank (underground or overhead)
  - **Building 1:**
    - Minimum: Five 10000 gallon barrels
    - Moderate: Four 13000 gallon barrels
    - Maximum: One 50000 gallon barrel
  - Cost: \$17500 to \$50000
  - **Building 2:**
    - Minimum: Five 2400 gallon barrels
    - Moderate: Two 5500 gallon barrels
    - Maximum: One 11000 gallon barrel
  - Cost: \$3850 to \$12000
  - **Building 3:**
    - Minimum: Six 330 gallon barrels
    - Moderate: Four 500 gallon barrels
    - Maximum: One 2000 gallon barrel
  - Cost: \$693 to \$2000

- **Building 4:**
  - Minimum: Six 500 gallon barrels
  - Moderate: One 4000 gallon barrels
  - Maximum: One 5000 gallon barrel
- Cost: \$693 to \$2000
- Delivery System
  - Pressure Tank
    - \$200 to \$1000
  - Pumps for indoor uses
    - Cost: \$585 to \$635 per pump
- Signage
- Rain Garden, French drains or landscaped areas overflow

# Configuration Diagrams

The following configuration diagrams (Figure 3.4 to Figure 3.21) depict how rain barrels/cisterns can be placed on a site for each land use type. Three treatment options are prescribed for each of the land use type. The three treatments are Minimum, Moderate and Maximum. The minimum treatment describes the smallest appropriate barrel/cistern size needed to capture the entire amount of rainfall from the structure. The Moderate treatment looks at medium sized barrels/cisterns, while the Maximum treatment describes large sized barrels/cisterns that can be used to capture the total amount of rainfall from a structure's roof. The rainfall amount is calculated using the rational method and is based on a two hour one year storm event. Sizing of the barrels were based on the amount of rainwater runoff from a single structures' roof at 90% efficiency from a two year one hour storm event. The configuration diagrams contain the following information:

- A diagram showing structure and potential barrel placements
- Runoff off from structure (90% efficiency)
- Barrel Type: Size
- Number of Barrels
- Cost per Barrel
- Cost by Configuration for the structure

Following the configuration diagrams, Figures 3.22 to 3.44 depict the variety and barrels available for the various land use types.

## Land Use Type: Residential-Single Family

### MINIMUM

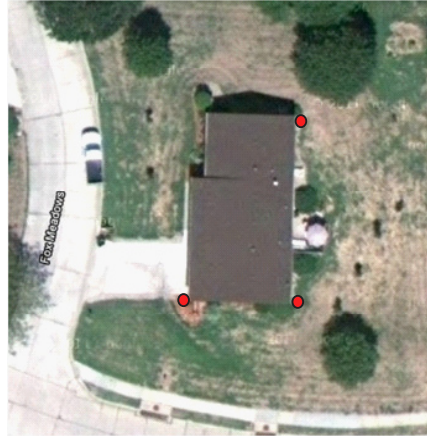
Figure 3.4



Barrel Material: Wood, Plastic, Metal  
Barrel Type: 58 gallons  
Barrel Diameter: 2 ft  
Number of Barrels: 25  
Total Capacity: 1450 gallons  
Cost per Barrel: \$20  
Cost for Configuration: \$500

### MODERATE

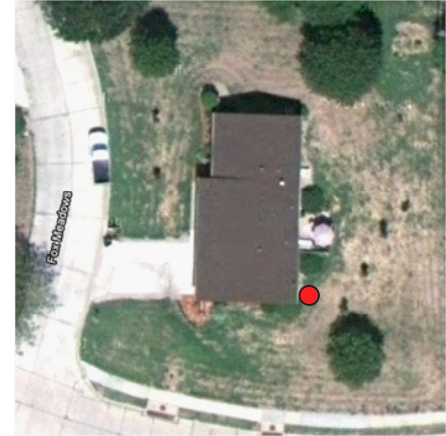
Figure 3.5



Barrel Material: Wood, Plastic, Metal  
Barrel Type: 500 gallons  
Barrel Diameter: 4 ft  
Number of Barrels: 3  
Total Capacity: 1500 gallons  
Cost per Barrel: Free to \$300  
Cost for Configuration: Free to \$1500

### MAXIMUM

Figure 3.6



Barrel Material: Wood, Plastic, Metal  
Barrel Type: 1500 gallons  
Barrel Diameter: 7.75 ft  
Number of Barrels: 1  
Total Capacity: 1500 gallons  
Cost per Barrel: Free to \$300  
Cost for Configuration: Free to \$300

**Runoff from structure: 1408 gallons**

Image Source: Google Maps, 2012

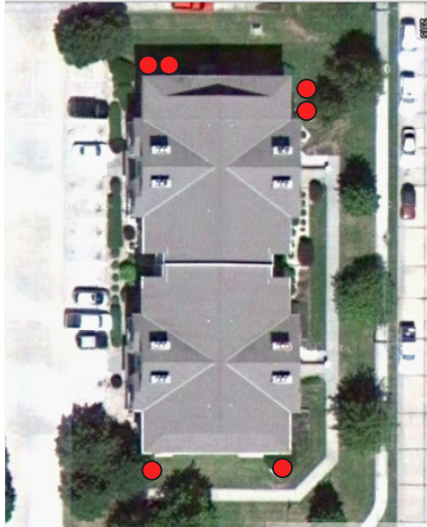
# Land Use Type: Residential-Apartment 1

## MINIMUM

## MODERATE

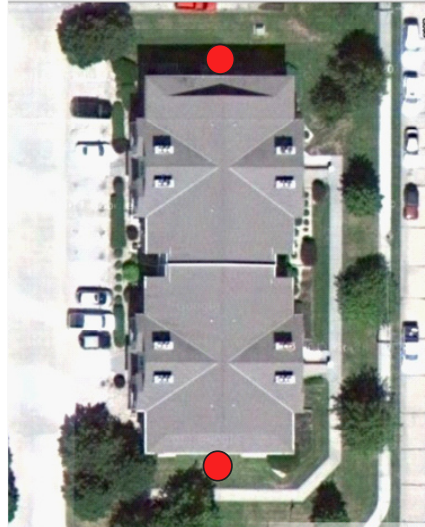
## MAXIMUM

Figure 3.7



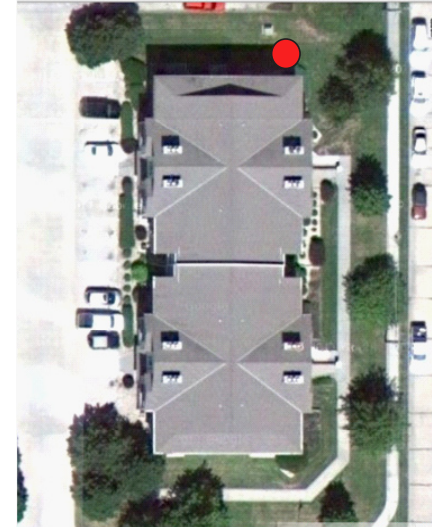
Barrel Material: Polypropylene  
Barrel Type: 1500 gallons  
Barrel Diameter: 7.75 ft  
Number of Barrels: 6  
Total Capacity: 9000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$3150 to \$9000

Figure 3.8



Barrel Material: Polypropylene  
Barrel Type: 5000 gallons  
Barrel Diameter: 11.75 ft  
Number of Barrels: 2  
Total Capacity: 10000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$1750 to \$10000

Figure 3.9



Barrel Material: Polypropylene  
Barrel Type: 10000 gallons  
Barrel Diameter: 11.75 ft  
Number of Barrels: 1  
Total Capacity: 10000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$3500 to \$10000

**Runoff from structure: 8505 gallons**

Image Source: Google Maps, 2012

## Land Use Type: Residential-Apartment 2

### MINIMUM

Figure 3.10



Barrel Material: Polypropylene  
Barrel Type: 1500 gallons  
Barrel Diameter: 7.75 ft  
Number of Barrels: 4  
Total Capacity: 6000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$2100 to \$6000

### MODERATE

Figure 3.11



Barrel Material: Polypropylene  
Barrel Type: 3000 gallons  
Barrel Diameter: 8 ft  
Number of Barrels: 2  
Total Capacity: 6000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$2100 to \$6000

### MAXIMUM

Figure 3.12



Barrel Material: Polypropylene  
Barrel Type: 6500 gallons  
Barrel Diameter: 9.9 ft  
Number of Barrels: 9.9 ft  
Total Capacity: 6500 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$2275 to \$6500

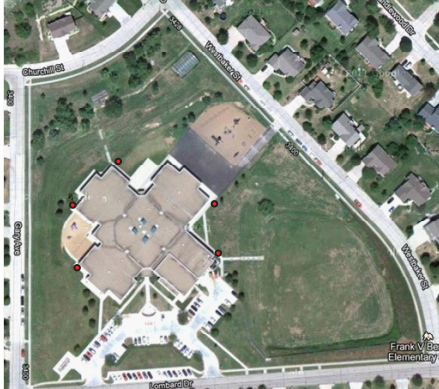
**Runoff from structure: 5675 gallons**

Image Source: Google Maps, 2012

# Land Use Type: Community-School

## MINIMUM

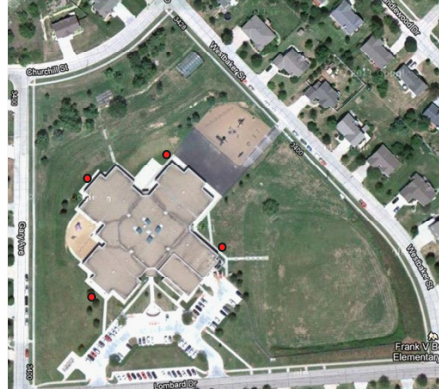
Figure 3.13



Barrel Material: Polypropylene  
Barrel Type: 10000 gallons  
Barrel Diameter: 11.75 ft  
Number of Barrels: 5  
Total Capacity: \$50000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$17500 to \$50000

## MODERATE

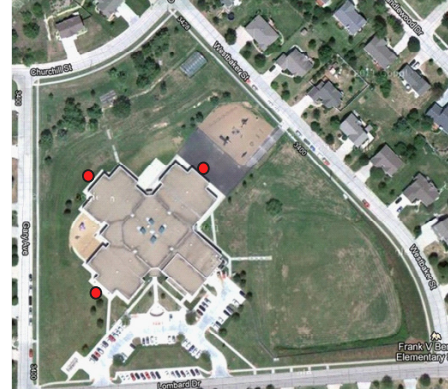
Figure 3.14



Barrel Material: Polypropylene  
Barrel Type: 12500 gallons  
Barrel Diameter: 11.75 ft  
Number of Barrels: 4  
Total Capacity: \$50000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$17500 to \$50000

## MAXIMUM

Figure 3.15



Barrel Material: Polypropylene  
Barrel Type: 15000 gallons  
Barrel Diameter: 11.75 ft  
Number of Barrels: 3  
Total Capacity: 45,000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$15750 to \$45000

**Runoff from structure: 43697 gallons**

Image Source: Google Maps, 2012



# Land Use Type: Community-Church

## MINIMUM

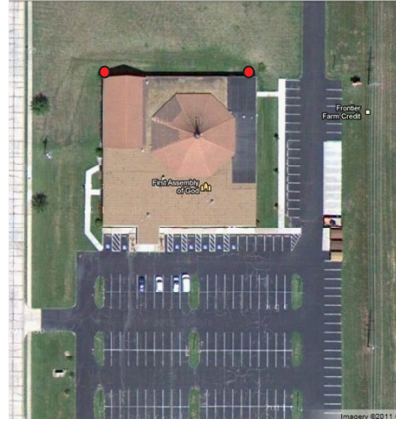
Figure 3.16



Barrel Material: Polypropylene  
Barrel Type: 5500 gallons  
Barrel Diameter: 11 ft  
Number of Barrels: 4  
Total Capacity: 22000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$7700 to \$22000

## MODERATE

Figure 3.17



Barrel Material: Polypropylene  
Barrel Type: 12500 gallons  
Barrel Diameter: 11.8 ft  
Number of Barrels: 2  
Total Capacity: 25000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$8750 to \$25000

## MAXIMUM

Figure 3.18



Barrel Material: Polypropylene  
Barrel Type: 15000 gallons  
Barrel Diameter: 13.75 ft  
Number of Barrels: 2  
Total Capacity: 30000 gallons  
Cost per Barrel: \$0.35 to \$1.00 per gallon  
Cost for Configuration: \$10500 to \$30000

**Runoff from structure: 20617gallons**

Image Source: Google Maps, 2012

# Land Use Type: Commercial

## MINIMUM

Figure 3.19



**Barrel Type: gallons**

1. 10000 (11.74 ft)
2. 2400 (6 ft)
3. 330 (4 ft)
4. 550 (5.53)

**Number of Barrels:**

1. Five
2. Five
3. Six
4. Six

**Total Capacity: gallons**

1. 50000
2. 12000
3. 1980
4. 3300

**Cost of Barrel per gallon:**

1. \$0.35 to \$1.00 per gallon
2. \$0.35 to \$1.00 per gallon
3. \$0.35 to \$1.00 per gallon
4. \$0.35 to \$1.00 per gallon
5. \$0.35 to \$1.00 per gallon

**Cost for Configuration:**

1. \$17500 to \$50000
2. \$4200 to \$12000
3. \$693 to \$1980
4. \$1155 to \$3300

**Runoff from structure: (1) 45134 gallons (2) 10558 gallons (3) 1818 gallons (4) 3079 gallons**

## MODERATE

Figure 3.20



**Barrel Type: gallons**

1. 13000 (12 ft)
2. 5500 (11.5 ft)
3. 500 (4 ft)
4. 1000 (5 ft)

**Number of Barrels:**

1. Four
2. Two
3. Four
4. One

**Total Capacity: gallons**

1. 52000
2. 11000
3. 2000
4. 4000

**Cost of Barrel per gallon:**

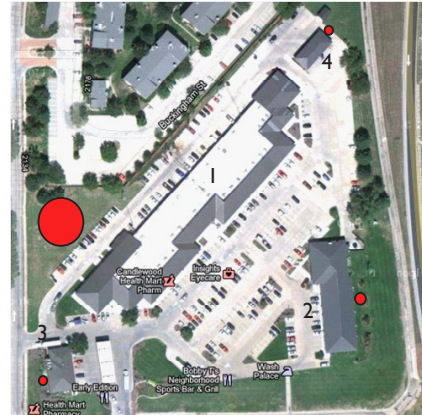
1. \$0.35 to \$1.00 per gallon
2. \$0.35 to \$1.00 per gallon
3. \$0.35 to \$1.00 per gallon
4. \$0.35 to \$1.00 per gallon
5. \$0.35 to \$1.00 per gallon

**Cost for Configuration:**

1. \$18200 to \$52000
2. \$3850 to \$11000
3. \$700 to \$2000
4. \$1400 to \$4000

## MAXIMUM

Figure 3.21



**Barrel Type: gallons**

1. 50000 (68 ft length)\*
2. 11000 (11.75)
3. 2000 (6 ft)
4. 5000 (11.75 ft)

**Number of Barrels:**

1. One
2. One
3. One
4. One

**Total Capacity: gallons**

1. 50000
2. 11000
3. 2000
4. 5000

**Cost of Barrel per gallon:**

1. \$0.50 to \$2.00 per gallon\*
2. \$0.35 to \$1.00 per gallon
3. \$0.35 to \$1.00 per gallon
4. \$0.35 to \$1.00 per gallon
5. \$0.35 to \$1.00 per gallon

**Cost for Configuration:**

1. \$25000 to \$100000
2. \$3850 to \$11000
3. \$700 to \$2000
4. \$1750 to \$5000

**\* Fiberglass Material, all other tanks are polypropylene**

Image Source: Google Maps, 2012

Rainwater Harvesting

## Land Use Type: Residential-Single Family



Figure 3.22 (Top): Single Family home with two 500 gallon cisterns. The image shows that overflow is directed to the lawn. (Containment Solutions, American Rainwater Catchment Association, 2012)



Figure 3.23 (Bottom): Single Family home with one 1500 gallon cistern harvesting rainwater from the roof (Low Impact Development Center, 2007)







Figure 3.24 (Top Left, p.64): Modular rain tanks are also being used to save face and have less of a visula impact on the property. Each modular tank stores 58 gallons of rainwater. (TBJ-INC, 2012)

Figure 3.25 (Bottom Left, p.64): HOGs are a nother from of modular tanks that can be used to store rainwater. The can fit on the side of the house. (Rainwater Hog, 2008)



Figure 3.26 (Right, p. 64): Another image of HOGs showing the slim design. (Rainwater Hog, 2008)

Figure 3.27 (Top): HOGs can also be placed horizontally. The HOGs in this image are being placed along the ground.

In Figure 3.28 (Bottom) Shows the HOGs in the previous image were covered by the deck at this single family home. (Rainwater Hog, 2008)



## Land Use Type: Residential-Apartment



Figure 3.29 (Top): Barrel attached to apartment building using existing downspouts. (Starr, n.d.)

In Figure 3.30 (Bottom left): 1550 gallon cistern that can be used to collect rainwater from the roof tops of larger structures like apartments buildings. (SPAWN, 2010)

Figure 3.31 (Bottom Right): 2500 gallon cistern that can be applied to an apartment setting. (SPAWN, 2010)



## Land Use Type: Community-Church



Figure 3.32 (Left): Two 5250 gallon barrels used to capture rainwater from a larger non-residential structure. (Rainwater Solutions, American Rainwater Catchment Systems Association, 2012)

Figure 3.33 (Right): One 15000 gallon metal cistern, used in a residential setting but can be used for community structures like churches (Rainbank, American Rainwater Catchment Systems Association 2012).

## Land Use Type: Community-School



Figure 3.34 (Top Left) and Figure 3.35 (Bottom Left): Cisterns used in a school setting. This elementary school, Pine Jog Elementary, used a rainwater harvesting system that had the storage capacity of 17000 gallons. The rain cisterns were connected to existing downspouts. o (Raindrops Cisterns, 2010)

Figure 3.36 (Top Right): HOGs can also be used in a larger setting. The Nundah School, located in Australia, used 114 hogs (storage capacity of 5700 gallons) to capture rainwater. (Rainwater Hog, 2008)



## Land Use Type: Commercial



Figure 3.37 (Top): Two 53000 gallons used for this commercial structure. (Innovative Water Solutions, American Rainwater Catchment Systems Association, 2012)

Figure 3.38 (Bottom Left): Close up of one of the 53000 gallon tanks with signage. (Innovative Water Solutions, American Rainwater Catchment Systems Association, 2012)



Figure 3.39 (Bottom Right): Image of the pump system used for the both tanks. (Innovative Water Solutions, American Rainwater Catchment Systems Association, 2012)



Figure 3.40 (Top): Underground tanks can also be employed in commercial structures and other land use types. Figure 3.40 shows a 20000 gallon underground tank used at a CARMAX in Virginia. Underground tanks are helpful when it comes to winter conditions and stop the capture rainwater from freezing. (Sky Harvester, Innovative Water Solutions, American Rainwater Catchment Systems Association, 2012)



Figure 3.41 (Bottom Left): Metal tanks sided covered in wood to add more visual interest to the tank. (ValleyCrest Landscape, 2012)

Figure 3.42 (Bottom Right): Image of 10000 gallon cisterns painted in a southwestern design, to add visual interest. (The Raincatcher Incorporated, 2011)

# Reuse Options

Research conducted during Phase II of the literature review stated that reusing the captured rainwater is vital to the success of a rainwater harvesting system. According to the literature review, "...minimal usage of the captured rainwater greatly diminishes runoff volume reduction and economic benefits of rainwater harvesting," (Jones, Hunt, & Wright, 2009). There are various reuse options that can be employed. The Virginia Manual for Rainwater Harvesting lists the following reuse options:

## Non-potable Demands:

- Building washing/power washing
- Cooling towers
- Fire suppression
- Household cleaning
- Pool/pond filling
- Laundry washing
- Industrial processing
- Toilet flushing
- Landscape irrigation
- Vehicle washing

## Potable Demands:

- Drinking water
- Cooking
- Bathing
- Dish washing

(The Cabell Brand Center, 2009)

Potable demands require extensive water quality regulations in order for the captured rainwater to be at a safe level to ingest. For this Master's project, non-potable reuses are recommended specifically landscape irrigation, household cleaning, toilet flushing, laundry washing and vehicle washing. Non-Potable uses can be implemented without extensive intervention from local government and public health entities to oversee the safety aspects of a system, which takes more time and money. Of the four re-uses mentioned, landscape irrigation can be one of the most effective reuse options. The EPA states that an average American family of four uses about 400 gallons of water a day. (U.S. EPA, 2012). Outdoor usage alone (landscape irrigation) accounts for about 30% of that daily use (U.S. EPA, 2012).

One reuse the Virginia Manual of Rainwater Harvesting did not outline was

simply allowing the captured rainwater to infiltrate into the ground. This can be done to through constructing rain gardens and other infiltration techniques like French Drains. Combining the notion of rainwater harvesting and infiltration can be beneficial. The residents can collect rainwater in the barrels or cisterns and reuse the water for the non-potable demands as discussed earlier, however, if the residents are not using the water and the barrel is full, the water can be directed to a rain garden, french drain or just landscaped areas in the garden where the water can infiltrate into the ground rather than sit in the barrel or cistern.

## **Rain Gardens**

According to the City of Portland, a rain garden is a "...shallow depression that collects rainwater and is often planted with native plants," (City of Portland, 2009). Rain gardens (see Figure 3.43) are effective in capturing overflow from rainwater harvesting systems, or capturing water redirected from a downspout (City of Portland, 2009).



It is important to design a rain garden so that the water captured can be drained within 36 hours of when the water enters the rain garden to prevent water stagnation (City of Portland, 2009). The rain garden should be at least 10% of the roof area rainwater is being captured from. That is to say, if the area of the roof capturing rainwater is 500 square feet then the size of the rain garden should be at least 50 square feet (City of Portland, 2009).

Important aspects to consider when constructing a rain garden are: soil drainage, distance of the rain garden from the structure and slope of the area where the rain garden should be constructed (City of Portland, 2009). The minimum depth of a rain garden should be between 6 and 12 inches, while the rain garden itself should be located at least 10 feet away from the structure it is collecting from (City of Portland, 2009). Overflow or unused captured rainwater can be directed to the rain garden via piping or a garden hose.



Figure 3.43: Rain garden being constructed on a property. (The City of Gresham, Oregon, 2012)

## **French Drains**

A French Drain (Figure 3.44) is simply a trench filled with coarse aggregate (British Columbia, n.d.). The french drain allows stormwater runoff to slowly infiltrate into the ground. Construction of a simple french drain includes digging a trench to a depth between 15 and 20 inches (British Columbia, n.d.). The trench should be about 2 feet wide (HGTV, 2008). The dug channel is first lined with filter fabric, followed by a layer of pea gravel to cover the base. Coarse rock (sized between 1 and 3 inches in diameter) is used to fill the majority of the trench and then a final layer of pea gravel is added to cap of the top of (British Columbia, n.d.). Overflow from the barrels, or unused captured rainwater can be directed to the french drain where it can percolate back into the ground.

## **Lawn or Landscaped Areas**

The City of Portland, Oregon implemented a program called Disconnect the Downspouts. The program essentially encourages infiltration by redirecting rainwater from the downspouts into a lawn or already landscaped areas. The Disconnect

the Downspout program involves cutting the downspout and attaching a flexible elbow and other gutter extensions to direct the flow into the lawn or landscaped areas (Figure 3.45). Splash blocks are used to further ensure the water is directed away from the house and to the designated area where it can infiltrate into the ground. This option is very low maintenance and requires little construction. (City of Portland, 2011)

The City of Portland suggests that the area which the rainwater is draining to be at least 10% of the surface area collecting the rainwater. Aspects to consider include: slope (the City of Portland suggests you do not disconnect the downspouts if the slope is more than 10%); whether the soils on your property have adequate drainage; and finally, water should be discharged at least 6 feet away from the basement structure and 2 feet from the structure's foundation (City of Portland, 2011). Overflow from the barrels or cisterns can be directed to the lawn or landscaped areas; or if there is no current reuse option, the captured rainwater can be routed to these areas as well. This would be a low maintenance option for property owners in Manhattan, Kansas.



← Figure 3.44 (Top): French drain used on a residential site (Ashley, 2010).

Figure 3.45 (Bottom): Two individuals disconnecting the downpouts to flow into the lawn of the residence. (The City of Gresham, Oregon, 2012)



# Chapter 4: Policy

*Phase III: Policy+Regulations+Incentives*

## Policy, Regulations, Incentives

In order to have a successful rainwater harvesting program it is important to have policies, regulation, incentives, etc. to help alleviate the cost of implementation. Cities across the United States have employed various strategies in order to allow rainwater harvesting in their communities. Table 4.1 summarizes efforts cities have undertaken to encourage rainwater harvesting. The table looks at various tools and is guided by the three categories Farahbakhsh, Despin and Leidl (2009) discuss in their journal article “Developing Capacity for Large Scale Rainwater Harvesting in Canada.” The article looks at the following tools: (1) Policy, (2) Regulations, (3) Support Mechanisms (Incentives, Cost subsidies etc). (Farahbakhsh, Despina, & Leidl, 2009).



Table 4.1: Table summarizing policies, regulations and incentives used in various municipalities (continued to next page)

City/State	Tool	Description
Texas	Property Tax Exemptions	A state-wide constitutional amendment in 1993 allowed for property tax exemptions if a commercial structure employed water conservation measures. Rainwater harvesting was considered to be a water conservation strategy. (Texas Water Development Board, 2005)
City of Austin, Texas	Rebate	City of Austin issues a \$30 rebate to all homeowners who purchase a rain barrel. Furthermore, homeowners can also receive up to a \$500 rebate on the cost of implementing a pre-approved rainwater harvesting system. Commercial building owners may be eligible for up to a \$40,000 rebate. (Texas Water Development Board, 2005)
City of San Antonio, Texas	Rebate	Commercial, industrial and institutional entities may receive a 50 percent rebate against the cost of installing a large scale rainwater harvesting system under their Large Scale Retrofit program. (Texas Water Development Board, 2005)
City of Tucson, Arizona	Regulation	The city required that 50% of a commercial property's water used for irrigation must be rainwater. (Kloss, Rainwater Harvesting Policies, 2008)
City of Portland, Oregon	Code	To protect the health of its residents and delineate proper reuse of rainwater, Portland only allows non-potable uses for rainwater in family dwellings. However, Portland does allow for an appeals process if a resident wants to incorporate potable uses into their home. (Kloss, Rainwater Harvesting Policies, 2008)
City of Springfield, Missouri	Rebate	A resident can receive a \$25 rebate by purchasing a rain barrel. The program is sponsored by the City's public works department. (Harvest H2o, 2009)
City of Portland, Oregon	Incentive	The City created the Downspout the Disconnect Program, where the City encourages innovative on-site stormwater management, like redirecting the water from your downspouts into a barrel or green space. The city offers an incentive for the eligible homeowner. (City of Portland, Oregon, 2012).
City of Portland, Oregon	Fee and Fee Discount	The City of Portland enacts a stormwater management fee on all properties. However, a discount is given if one can effectively manages their stormwater on-site. (Kloss, The Municipal Handbook: Rainwater Harvesting Policies, 2008)
City of Los Angeles, California	Policy	The City adopted a Low Impact Development (LID) ordinance that incorporates LID principles and practices into stormwater management within the city which includes rainwater harvesting. (Harvest H2o, 2012)

<b>City/State</b>	<b>Tool</b>	<b>Description</b>
<b>Georgia</b>	<b>Incentive</b>	A recent statewide bill states that a tax credit of \$2500 is available to eligible energy and water efficiency projects. (Harvest H2o, 2012)
<b>Washington</b>	<b>Regulation</b>	Local jurisdictions are required to reduce stormwater management charges by at least 10% if commercial buildings in the state of Washington incorporate rainwater harvesting systems. (Harvest H2o, 2012)
<b>Albuquerque-Bernalillo County, New Mexico</b>	<b>Regulation</b>	The county mandated that new buildings larger than 2,500 sq feet were required to have a cistern and pump, while smaller buildings can incorporate barrels, cisterns or catchment basins. (Kloss, Rainwater Harvesting Policies, 2008)
<b>North Carolina</b>	<b>Incentive (Pending Approval)</b>	A Community Conservation Assistance Program (CCAP) has been developed to provide financial as well as technical and educational help when it comes to landowners implementing stormwater management BMPs on their property. Potentially, landowners could get reimbursed 75% of the average cost of installing the BMP. (Harvest H2o, 2012)
<b>Texas</b>	<b>Incentive: Award</b>	The Texas Water Development Board awards prizes in excellence of rainwater harvesting systems application. The award also functions to educate the public about rainwater harvesting and explore rainwater harvesting technology. (Harvest H2o, 2012)
<b>City of Vancouver, Canada</b>	<b>Subsidies</b>	The City designs and manufactures rain barrels for irrigation. Vancouver subsidizes the cost of barrels by 50%. (City of Vancouver, 2011)
<b>U.S Virgin Islands</b>	<b>Regulation</b>	All new buildings and redesign on existing buildings are required to incorporate “a self-sustaining water supply system,” in the form of a tank, cistern or well. (Harvest H2o, 2012)
<b>Oregon; Ontario, Canada; New Mexico; Virginia; Berkeley, California.</b>	<b>Rainwater Harvesting Guidelines</b>	It is important to also provide rainwater harvesting guidelines to encourage a landowner to consider rainwater harvesting. Landowners can make an informed decision and refer to resources where they can get construction information, pricing, information on rebates and subsidies etc. (Harvest H2o, 2012)
<b>City of Atlanta, Georgia</b>	<b>Regulation</b>	An ordinance was enacted in the City of Atlanta to allow for the potable use of captured rainwater. In my opinion, reducing the restriction of rainwater reuse would encourage landowners to incorporate rainwater harvesting. (Harvest H2o, 2012)

## **Recommendations for Manhattan, Kansas**

As seen in the above table, there are a variety of regulations, incentives and policies. The subsequent discussion recommends a few tools the City of Manhattan can employ to promote rainwater harvesting.

### **Rebates and Other Incentives**

The Wildcat Creek Watershed Council is a group of Manhattan residents that came together to address the issues of the Wildcat Creek Watershed, “The general vision of the group is to improve the environmental quality of Wildcat Creek to insure the protection of the property and enhancement of the quality of life,” (Wildcat Creek Watershed Council, 2011). The Council, through the direction of Rod Harms, currently provides 58 gallon rain barrels for the cheap price of \$32. However, a number of cities use rebates as a way to encourage rainwater harvesting. The cities of Austin, Texas; San Antonio, Texas and Springfield, Missouri are outlined in the table above but they are only a small fraction of the amount of cities that offer rebates to offset the price of implementing a rainwater harvesting system.

In addition to subsidizing the cost of barrels, the City of Manhattan could also offer monetary rebates to residents who choose to incorporate a rainwater harvesting system on their property. In Manhattan’s context, a possible rebate procedure could be if a resident buys two or more of the Council’s \$32 barrels, a rebate or discount amount could be given. The residents should also be able to get a rebate if they purchase a rain barrel from another source.

Incentive programs like North Carolina’s Community Conservation Assistance Program can be a valuable incentive to allow people to implement rainwater harvesting on their properties (Harvest H2o, 2012). The proposed program provides technical assistance to residents wanting to implement green practices on their properties and a reimbursement program of up to 75% of the cost to implement a green strategy on their property.

The City of Manhattan, could offer a reimbursement up to a certain percentage if property owners (residential and commercial) decide to establish a rainwater harvesting system and integrate infiltration techniques to support the rainwater harvesting system.

Another incentive that has been used in Portland, Oregon and in Germany is the reduction of a stormwater utility fee if green practices are present on the property. The City of Manhattan could offer a decrease in stormwater utility rates if a property owner implements rainwater harvesting.

### **Regulations: Ordinances designed to encourage rainwater harvesting**

Incentives are important for property owners so that the cost of rainwater harvesting can be somewhat alleviated and thus they are more encouraged to take part in the practice. However, some City's have taken charge in the form of regulations in order for change to occur. The City of Manhattan can design ordinances that require rainwater harvesting to be utilized. Two examples are seen below.

#### **City of Portland, Oregon: Disconnect the Downspouts**

Between 1995 and 1996, the Disconnect the Downspouts program was enacted by the City of Portland to reduce the amount of stormwater entering the Combined Sewer System. The program had two main goals: (i) reduce the volume of stormwater entering the combined sewer system, and (ii) promote citizen participation and engagement (Environmental Services, 2008). Portland divided the city into mandatory areas, where the downspouts needed to be disconnected and flows directed away from the sewer system, and voluntary areas where residents could choose whether or not they wanted to disconnect the downspouts (Environmental Services, 2008). The mandatory areas were designated by the Director of Environmental Services under the following set criteria:

“6.1.1 amount of stormwater flow which must be diverted according to the CSO Management Plan, Amended Stipulation and Final Order, project design memoranda or plans for adequately conveying or managing flow within combined sewer basins,  
6.1.2 amount of time available to achieve necessary stormwater flow removal based on system modeling, design, and capacity needs,  
6.1.3 feasibility of implementing programs which represent a significant dollar savings over other alternate plans to reduce CSOs,  
6.1.4 ability to reduce costs of conveyance to other parts of the sewer system for treatment where sewer basins are in remote areas at the end of interceptors making capture and conveyance of CSOs costly,  
6.1.5 differing soil and geographic conditions affecting water percolation into the soil and groundwater,  
6.1.6 importance of severely reducing or eliminating CSOs in sensitive areas such as City parks or natural areas,  
6.1.7 the sizes of major conveyance and storage facilities which are designed dependent upon a certain rate of stormwater removed from the combined sewer system”

(Environmental Services, 2008)

Even though, the city had a mandatory aspect to the program, they still offered incentives. The incentive part of the program was structured as follows: the residents would receive a one time incentive per disconnected downspout that met the program standards. Incentives were provided if the residents disconnected their downspouts by themselves or if community groups (authorized by the Director of Environmental Services) offered free services to disconnect downspouts and help property owners. The City, however, also contracted stormwater professionals to assist residents who requested help. The services from the stormwater professionals were also free. Downspout Disconnection staff were authorized to inspect disconnected downspouts to ensure safety and consistency with the standards. Through this process, the City sought to engage the citizens, community groups and professionals and promote partnerships between the groups as well as build awareness.

As previously mentioned, the City reimbursed property owners a one-time incentive for disconnecting a downspout. The City stipulated that the disconnected downspouts had to be in coherence with the program standards. The reimbursement rates are as follows in Table 4.2.

Reimbursement per eligible downspout:	Minimum	Maximum
Supplies	Unit Cost	\$25
Labor	Unit Cost	\$13
Landscaping and Miscellaneous	Unit Cost	\$15

← Table 4.2: Reimbursement values used in the Downspout Disconnection Program

The City of Manhattan could implement a similar program but with rainwater harvesting. Manhattan can designate mandatory target areas where stormwater runoff is adversely affecting the function of the Wildcat Creek Watershed. The mandatory target areas will be delineated using set criteria. Inviting community groups, organizations and professional companies to help with the installment of rainwater harvesting systems can be beneficial. Rod Harms, a member of the Wildcat Creek Watershed Working Group has began providing the city with rain barrels and has enlisted the help of students from Kansas State University and other groups and organizations. This already established network can be a good starting point for the City to build a program around this present framework.

### **City of Tucson, Arizona**

In 2003, the City of Tucson Arizona became the first city to require commercial developers to harvest rainwater on their properties (Reese, 2008). The ordinance states that 50% of the water used for irrigation purposes should be rainwater (Reese, 2008). The ordinance required that a rainwater harvesting plan be submitted at the same time of the landscape plan. The rainwater harvesting plan must contain the following aspects:

1. An estimated volume of water needed to meet the needs of the landscaping.
2. An implementation plan of a proposed rainwater harvesting system that meets the requirements of the appropriate development standards.
3. Show provisions for on-site water metering.

(City of Tucson, Arizona, 2008)

The City of Tucson stipulates that within three years of the certificate of occupancy, the development must provide 50% of its landscape irrigation needs from captured rainwater. The Downspout Disconnection Program in Portland is helpful for residential properties, while Tucson's Rainwater Harvesting ordinance is tailored for larger developments.

The City of Manhattan, can use Tucson's ordinance to develop standards to mandate rainwater harvesting in future developments or existing areas. As mentioned earlier, the City of Manhattan could designate a mandatory target area set on valid criteria and require through a written ordinance that rainwater harvesting be employed to alleviate the adverse affects stormwater runoff is having on the environment, specifically the Wildcat Creek Watershed.

### **City of Manhattan, Kansas: A Outline of a Rainwater Harvesting Ordinance**

The following ordinance outline draws from the Tucson Rainwater Harvesting Ordinance (City of Tuscon, Arizona, 2008) and the Disconnect the Downspouts Program in Portland, Oregon (Environmental Services, 2008). The ordinance also looked at the City of Manhattan, Kansas' draft ordinance to amend the code of ordinances to add a narrative relating to the prevention of pollution of stormwater runoff (City of Manhattan, 2007). The ordinance should be coupled with a rainwater harvesting manual or a rainwater harvesting guidelines document that residents can refer to.



# Ordinance No. \_\_\_\_

**AN ORDINANCE AMENDING CHAPTER 8 OF THE CODE OF ORDINANCES OF THE CITY OF MANHATTAN, KANSAS; BY ADDING A NEW ARTICLE, XVII, RAINWATER HARVESTING REQUIREMENTS, SECTIONS 8-352 THROUGH SECTIONS 8-353, RELATING TO THE MANDATORY USE OF RAINWATER HARVESTING SYSTEMS ON ALL EXISTING PROPERTIES AND FUTURE DEVELOPMENTS WITHIN THE WILDCAT CREEK WATERSHED AND VOLUNTARY USE OF RAINWATER HARVESTING ON EXISTING PROPERTIES AND FUTURE DEVELOPMENTS WITHIN THE REMAINING AREAS OF THE CORPORATE LIMITS OF THE CITY.**

WHEREAS, the City of Manhattan (the “City”) has experienced increased flooding events within the Wildcat Creek Watershed in the past years, specifically June 2011; and

WHEREAS, the City has experienced adverse damage in the form of property loss, environmental degradation and loss of water quality do the flooding events associated with the Wildcat Creek Watershed; and

WHEREAS, rainwater harvesting is an effective method to reduce the amount of urban stormwater runoff entering the Wildcat Creek Watershed; and

WHEREAS, rainwater harvesting is an effective method to promote infiltration to aid in ground water recharge; and

WHEREAS, the City has limited provisions promoting and encouraging the use of rainwater harvesting.

**NOW THEREFORE, BE IT ORDAINED THAT BY THE GOVERNING BODY OF THE CITY OF MANHATTAN, KANSAS:**

**Section 1.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding the Article XVII Sections. 8-352 to Sections. 8-353 to Chapter 8, to read as follows:

Article XVII: Rainwater Harvesting Requirements

**Section 2.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-352 to read as follows:

**Sec. 8-352. Administration and Applicability**

- a) The director of public works shall adhere to, implement and enforce the stipulations of this article. (The city must appoint an administrator, in this ordinance the director of public works is given administrative authority)
- b) The article shall be applied mandatorily to existing properties and future developments within the Wildcat Creek Watershed, while existing properties and future developments outside of the Wildcat Creek boundary can elect to adhere to the provisions of this article.

**Section 3.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-353 to read as follows:

**Sec. 8-353. Definitions**

The following words used within Article XVII are defined as follows:

**Rainwater** means fallen water in any form of precipitation

**Stormwater Runoff** refers to runoff from rainwater

**Rainwater Harvesting System** refers to the collection of rainwater from a catchment area (roof), which is then conveyed to a storage unit (barrel or cistern) and distributed for other uses.

**Captured Rainwater** rainwater that has flowed into a barrel or cistern

**Properties and Future Developments** refers to structures that are either inhabited or where business is conducted.

**Section 4.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-354 to read as follows:

**Sec. 8-354. General Intent of Rainwater Harvesting**

A. The goal of Rainwater Harvesting is to:

1. Reduce the volume of stormwater runoff entering the Wildcat Creek Watershed as a means of reducing flooding potential.
2. Promote the reuse of rainwater in the various forms delineated within Article XVII Sec. 8-356.
3. Promote and encourage rainwater water harvesting as a form of water conservation.
4. Encourage infiltration of captured rainwater to aid in groundwater recharge

**Section 5.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-355 and 8-356 to read as follows:

**Sec. 8-355. General Standards of Rainwater Harvesting**

A. All existing properties and future developments within the Wildcat Creek Watershed Boundary shall include a rainwater harvesting system. (The city will have to consider the fairness of this action, rainwater harvesting could be enforced citywide)

1. Existing properties shall be required to collect 90% from a two year one hour storm event of the rainwater that falls upon the roof(s) of the structure(s) effective May 1, 2017.
2. Future developments submitting plans after May 1, 2015 shall be required to incorporate rainwater harvesting systems into the development. These developments are required to collect 90% of the rainwater that falls upon the roof of the developments.

B. Properties and future developments outside the boundary of the Wildcat Creek Watershed can elect to incorporate a rainwater harvesting system.

1. If elected, properties and future developments shall be required to collect 90% of the rainwater that falls upon the roof(s) of the structure(s).

C. A rainwater harvesting system shall consist of the following:

1. A catchment surface (e.g. the roof)
2. A conveyance system (gutters, downspouts, other piping)
3. A storage unit (barrels or cisterns)
4. A distribution system (a means of removing the rainwater from the barrel for use e.g. a hose, pipe, soil drain, etc.)

D. The rainwater harvesting system shall be sized to hold 90% from a two year one hour storm event of the rainwater that falls upon a catchment surface.

### **Sec. 8-356. Reuse Standards of Rainwater Harvesting**

A. Captured rainwater shall have non-potable uses. Potable use of captured rainwater is prohibited. The following uses are encouraged:

1. Building washing/power washing
2. Cooling towers
3. Fire suppression
4. Household cleaning
5. Pool/pond filling
6. Laundry washing
7. Industrial processing

8. Toilet flushing
9. Landscape irrigation
10. Vehicle washing

(Introduce safety standards for storing rainwater for reuse. Also refer to a rainwater harvesting manual/guidelines for information on reuse)

B. Captured rainwater shall not be permitted to flow into the municipal sewer system of the city. Captured rainwater shall be permitted to flow into the following:

1. Rain gardens
2. French drains
3. Landscaped areas
4. Vegetated Swales

Other infiltration techniques that encourage infiltration shall be also be accepted.

(Refer to a rainwater harvesting manual/guidelines for information on infiltration techniques)

**Section 6.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-357 to read as follows:

### **Sec. 8-357. Reimbursements**

A. All properties implementing a rainwater harvesting system, meeting the 90% efficiency standard, shall receive a one-time monetary reimbursement of up to 75% of the total cost of constructing a rainwater harvesting system.

B. All properties implementing a rainwater harvesting system, meeting the 90% efficiency standard, shall have a reduced stormwater utility fee.

C. Reimbursements and reduced stormwater utility fees shall be approved and authorized by the Director of Public Works.

(The amount of reimbursements and other incentive measures will have to be discussed. As well as who will authorize reimbursments and how they are distributed)

**Section 6.** That the Code of Ordinances of the City of Manhattan, Kansas, is hereby amended by adding new Sec. 8-358 to read as follows:

**Sec. 8-358. Violation**

- A. Failure to implement a rainwater harvesting system on existing properties and future developments shall constitute a violation of Chapter 8 Article XVII of the Code of Ordinances and deemed unlawful.
- B. Any violation shall be punishable as provided in Article I, Section 1-7 of the Code of Ordinances.

The above ordinance is by no means complete, but rather an outline of what a rainwater harvesting ordinance for the City of Manhattan, Kansas would contain. The ordinance is written as an amendment of City of Manhattan's Codes of Ordinances, specifically Chapter 8: Buildings and Building Regulations, which is similar to where the City of Tucson's Rainwater Harvesting Ordinance is located. The ordinance establishes mandatory rainwater harvesting areas, namely properties within the Wildcat Creek Watershed; and voluntary rainwater harvesting areas, namely properties outside of the Wildcat Creek Watershed. The recommendation to have mandatory areas can come across as unfair, and may be more favorable to enact the ordinance citywide. However, as stated earlier the City of Portland designated mandatory areas for their disconnect the downspouts program based on set criteria. The ordinance outlines the general intent of rainwater harvesting, general standards for rainwater harvesting, permitted reuse standards, reimbursements and incentives and finally a section for those in violation. The ordinance should be coupled with a rainwater harvesting manual or rainwater harvesting guidelines that address how to put together a rainwater harvesting system for different land uses (residential vs. commercial). The manual or guidelines should also describe barrel sizes, materials, and estimated costs. A detailed section on how to reuse rainwater including infiltration techniques would be imperative to the success of the rainwater harvesting program.

# Chapter 5: Conclusion

# Conclusion

The Wildcat Creek Watershed, located in Riley County, Kansas has been subject to major flooding events in the past years. A large portion of the City of Manhattan, Kansas lies within the Wildcat Creek Watershed. In June 2011, a major flooding event adversely affected the City of Manhattan and its residents. More flooding events are expected to occur in the coming years, "Flooding in the urban portions of the watershed has increased from a 1 in 20 year occurrence to almost an annual event," (Wildcat Creek Watershed Council, 2011). The Wildcat Creek Watershed Council states that increased development in the urban portion of the watershed has led to "...substantial erosion, impaired water quality, endangered aquatic species and caused property damage and habitat loss," (Wildcat Creek Watershed Council, 2011)

This Master's Project proposes the use of rainwater harvesting as a way to reduce the amount of stormwater runoff entering the Wildcat Creek Watershed from urban areas. A small neighborhood scale site within the Wildcat Creek Watershed was chosen to show the impact of rainwater harvesting on the reduction of stormwater runoff. The site is located in the northwestern corner of the City. The site was divided into land use types: Residential: Single Family; Residential:

Apartment; Community: Church; Community: School; and finally Commercial to show the application of rainwater harvesting in different land use settings. The volume of stormwater runoff was calculated using the rational method, where:

$$Q \text{ (Discharge)} = A \text{ (Area in Acres)} \times C \text{ (Runoff Coefficient)} \times I \text{ (Rainfall Intensity in Inches)}$$

The calculations were based on a two year one hour storm event. For the region the amount of rainfall based on a two year one hour storm event is 1.7 inches; thus the rainfall intensity (I) was taken as 1.7 inches. The results of the calculations show that from the entire site about 22% of stormwater runoff can be captured from rainwater harvesting alone (at 90% efficiency). The results were then extrapolated to show the impact on the watershed and citywide.

## Recommendations: Further Research

The findings of this project show the potential of rainwater harvesting in the City of Manhattan. Rainwater harvesting alone can have a slight, but beneficial impact on the reduction of stormwater runoff from urban areas within the watershed. It should be used in conjunction with other techniques to increase the effectiveness of reducing stormwater runoff. Additional research can

inform how rainwater harvesting can be used in combination with other stormwater reduction techniques.

More site specific details are needed to get a more accurate picture of the amount of rainfall runoff from the roofs of the structures in each land use type. This can be attained by looking at the roofing materials and the pitch of the roof. Site specific details are also needed to determine the best placement of the rain barrels and cisterns, to provide more accurate configurations of rainwater harvesting systems.

An alternative method to the rational method should be used for extrapolating the stormwater runoff for the urban portion within the watershed and the citywide extrapolation, in order to get more applicable numbers for engineering use. (American Society of Civil Engineers, 1969)



## **Recommendations to the City**

This master's project is intended to show the benefits of implementing a network of rainwater harvesting elements to alleviate stormwater runoff and encourage the reuse of collected rainwater and infiltration. The information contained in this document can be the starting point of implementing a rainwater harvesting program within the city.

A pilot study in the proposed site could be a way to test how rainwater harvesting implementation could work on a neighborhood scale, after which it can be broadened to other areas and in the long run, the entire city. A pilot study could help the city understand the needs of implementing harvesting as a stormwater management tool. The study would help the city understand the needs of implementing a rainwater harvesting program, promote awareness, and allow for community and stakeholder participation before policy is shaped. A pilot study can also help the city understand how to formulate incentives, subsidies, rebates etc. With the Wildcat Creek Watershed Council already distributing rain barrels and promoting rainwater harvesting, the City of Manhattan has the opportunity to develop rainwater harvesting as a stormwater management tool in collaboration with this community organization.

## **Recommendations to the General Public**

The information found in this master's project can be used on an individual level as a starting point to build a rainwater harvesting system. Homeowners and business owners can build off the information found in this document, particularly, calculating how much water one can capture from a roof, what is needed to construct a rainwater harvesting system, possible barrel sizes and configurations, and finally, cost estimation.

As aforementioned rainwater harvesting is a part of the solution to alleviating flooding with the Wildcat Creek Watershed. Rainwater harvesting is one of the solutions proposed by the Wildcat Creek Watershed Master's Student Group. To see other proposals to alleviate flooding and manage stormwater within the Wildcat Creek Watershed use the following link:

<https://krex.k-state.edu/dspace/handle/2097/13605>

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# **Appendix I: Rainwater Harvesting Calculations**

# Land Use Type: Residential-Single Family

## 2 Year 1 Hour Storm

Volume (Q)=A x C x I (Land Use Type)	
Area (Acres)	132.85
Coefficient	0.40
Intensity	1.7
Q (Acre Inches)	90.34
Q (Acre Feet)	7.53
Q (Gallons)	2453074.72

Volume (Q)=A x C x I (Single Site)	
Area	0.24
Coefficient (Weighted)	0.45
Intensity	1.7
Q (Acre Inches)	0.18
Q (Acre Feet)	0.02
Q (Gallons)	5018.11

## Roof Collection

Area	0.04
Coefficient (Weighted)	0.85
Intensity	1.7
Q (Acre Inches)	0.06
Q (Acre Feet)	0.005
Q (Gallons)	1564

Efficiency	90%	80%	75%	15%
	1408	1251	1173	235

## Notes

C Values were derived using standard C values used in general stormwater calculations. The C values in this spreadsheet were derived from the American Society of Civil Engineers (American Society of Civil Engineers, 1969).

A weighted average C value was calculated for the single site. See Table "Weighted Single Family C"

The C value for the roof was derived from the American Society of Civil Engineers (1969). Typical C values for a roof are between 0.75 and 0.95. A middle value, 0.85 was used for the roof coefficient value.

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

Total Rainwater Captured by  
Harvesting for entire Land Use  
Type (90% efficiency)  
536325

Total Rainwater Captured by  
Harvesting for entire Land Use  
Type (15% efficiency)  
89388

Treatment	Barrel Size	Number of Barrels	Capacity
Minimum	58*	25	1450
Minimum	300	5	1500
Moderate	500	3	1500
Maximum	1500	1	1500

To get the volume of rainwater for the entire land use type at 90% efficiency and 15%; 1408 was multiplied by 381 (for 90% efficiency) and 235 was multiplied by 381 (for 15% efficiency). 381 is the the amount of single family homes within the Residential:Single Family homes land ues type.

Barrels are sized to hold the volume of water if the rainwater harvesting system collected rainwater at 90% efficiency.

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com)

\* Barrel size given by the Wildcat Creek Watershed Council

## Residential-Single Family Weighted Coefficient Calculation

### Weighted Coefficient Value Calculations for a single site of the Land Use Type Residential: Single Family

To find the weighted C value, the percentage of surface types (lawn, roof, driveway) to the total acreage of the site was calculated. The "Area/Total Single Site Acreage" is multiplied by the typical Coefficient value for each surface derived from the American Society of Civil Engineers (1969) to get the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the Weighted Coefficient.

#### Single Site

	Roof	Driveway	Lawn	Total Acreage of Single Site
Area (Acres)	0.04	0.03	0.17	0.24

	Area/Total of single Site Acreage	Coefficient	Area/Total Acreage*Coefficient
Roof	0.17	0.85	0.14
Parking	0.12	0.85	0.10
Lawn	0.72	0.30	0.21
	<b>Weighted Coefficient</b>		<b>0.45</b>
	(Sum of Area/Total Acreage*Coefficient)		

# Land Use Type: Residential-Apartment

## 2 Year 1 Hour Storm

Volume (Q)=A x C x I		Complex 1
Area	4.89	
Coefficient (Weighted)	0.68	
Intensity	1.70	
Q (Acre Inches)	5.65	
Q (Acre Feet)	0.47	
Q (Gallons)	153476.02	

Volume (Q)=A x C x I		Complex 2
Area	13.49	
Coefficient (Weighted)	0.61	
Intensity	1.70	
Q (Acre Inches)	13.99	
Q (Acre Feet)	1.17	
Q (Gallons)	379910.18	

Roof Collection		Complex 1
Area	0.24	
Coefficient	0.85	
Intensity	1.70	
Q (Acre Inches)	0.35	
Q (Acre Feet)	0.03	
Q (Gallons)	9449.69	

Roof Collection		Complex 2
Area	0.16	
Coefficient	0.85	
Intensity	1.70	
Q (Acre Inches)	0.23	
Q (Acre Feet)	0.02	
Q (Gallons)	6305.54	

## Notes

C Values were derived using standard C values used in stormwater calculations. The C values in this spreadsheet were derived from the American Society of Civil Engineers (American Society of Civil Engineers, 1969). A weighted C value was used for the both the apartment complexes. See Table "Weighted Apartment C"

The C value for the roof was derived from the American Society of Civil Engineers (1969). Typical C values for a roof are between 0.75 and 0.95. A middle value, 0.85 was used for the roof coefficient value.

Efficiency (Complex 1)	90%	80%	75%	15%
	8505	7560	7087	1417

90% Total Rainwater Captured  
by Harvesting for Complex 1  
42524

15% Total Rainwater Captured  
by Harvesting for Complex 1  
7087

Efficiency (Complex 2)	90%	80%	75%	15%
	5675	5044	4729	946

Total Rainwater Captured by  
Harvesting for Complex 2 (90%  
efficiency)  
85125

15% Total Rainwater Captured  
by Harvesting for Complex 2  
(15% efficiency)  
14187

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

To get the volume of rainwater for complex 1 at 90% efficiency and 15%; 8505 was multiplied by 5, the number of apartment structures to Complex 1 (for 90% efficiency) and 1417 was multiplied by 5, the number of apartment structures for Complex 2 (for 15% efficiency).

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

To get the volume of rainwater for complex 2 at 90% efficiency and 15%; 5675 was multiplied by 15, the number of apartment structures in Complex 2 (for 90% efficiency) and 946 was multiplied by 15 the number of structures in complex (for 15% efficiency).

Total Rainwater Captured by Harvesting for entire Land Use Type (90% efficiency)

**127648**

Total Rainwater Captured by Harvesting for entire Land Use Type (15% efficiency)

**21275**

Treatment- Complex 1	Barrel Size	Number of	
		Barrels	Capacity
Minimum	1500	6	9000
Moderate	5000	2	10000
Maximum	10000	1	10000

Treatment- Complex 2	Barrel Size	Number of	
		Barrels	Capacity
Minimum	1500	4	6000
Moderate	3000	2	6000
Maximum	6500	1	6500

Added 90% Total for Complex 1 and 90% Total for Complex 2 to get total rainwater captured for the land use type if each structure collects 90% of rainwater falling upon the roof.

Added 15% Total for Complex 1 and 15% Total for Complex 2 to get total rainwater captured for the entire land use type if each structure collects 15% of rainwater falling upon the roof.

Barrels are sized to hold the volume of water if the rainwater harvesting system collected rainwater at 90% efficiency.

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com)



## Residential-Apartment Weighted Coefficient Calculation

### Weighted Coefficient Value Calculations for a single site of the Land Use Type Residential: Apartment

To find a weighted C value, the percentage of surface types (lawn, roof, driveway) to the total acreage of the site was calculated. The "Area/Total Single Site Acreage" is multiplied by the typical Coefficient value for that surface derived from the American Society of Civil Engineers (1969) to get the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the Weighted Coefficient. This process was repeated for both complexes.

Site: Complex 1

	Roof	Parking	Lawn	Total Acreage of Complex 1
Area (Acres)	1.21	2.19	1.50	4.89

	Area/Total Acreage Complex 1	Coefficient	Area/Total Acreage*Coefficient
Roof	0.2467	0.85	0.21
Parking	0.4470	0.85	0.38
Lawn	0.3063	0.3	0.09
	<b>Weighted Coefficient</b>		<b>0.68</b>
	(Sum of Area/Total Acreage*Coefficient)		

Site: Complex 2

	Roof	Parking	Lawn	Total Acreage Complex 2
Area	2.41	5.31	5.77	13.49

	Area/Total Acreage Complex 2	Coefficient	Area/Total Acreage*Coefficient
Roof	0.18	0.85	0.15
Parking	0.39	0.85	0.33
Lawn	0.43	0.3	0.13
	<b>Weighted Coefficient</b>		<b>0.61</b>
	(Sum of Area/Total Acreage*Coefficient)		

# Land Use Type: Community-School

## 2 Year 1 Hour Storm

Volume (Q)=A x C x I (Land Use Type)

Area	9.45
Coefficient (Weighted)	0.42
Intensity	1.70
Q (Acre Inches)	6.75
Q (Acre Feet)	0.56
Q (Gallons)	183193.67

### Roof Collection

Area	1.24
Coefficient (Weighted)	0.85
Intensity	1.70
Q (Acre Inches)	1.79
Q (Acre Feet)	0.15
Q (Gallons)	48551.86

Efficiency	90%	80%	75%	15%
	43697	38841	36414	7283

## Notes

C Values were derived using standard C values used in stormwater calculations. The C values in this spreadsheet were derived from the American Society of Civil Engineers (American Society of Civil Engineers, 1969). A weighted coefficient was calculated for the site, see Table "Weighted School C."

The C value for the roof was derived from the American Society of Civil Engineers (1969). Typical C values for a roof are between 0.75 and 0.95. A middle value, 0.85 was used for the roof coefficient value.

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

Total Rainwater Captured  
by Harvesting for entire  
Land Use Type (90%  
efficiency)  
**43697**

Total Rainwater Captured  
by Harvesting for entire  
Land Use Type (15%  
efficiency)  
**7283**

Treatment	Barrel Size	Number of	
		Barrels	Capacity
Minimum	10000	5	50000
Moderate	12500	4	50000
Maximum	15000	3	45000

Barrels are sized to hold the volume of water if the rainwater harvesting system collected rainwater at 90% efficiency.

## Community- School Weighted Coefficient Calculation

**Weighted Coefficient Value Calculations for a single site of the Land Use Type Community: School** To find a weighted C value, the percentage of surface types (lawn, roof, driveway) to the total acreage of the site was calculated. The "Area/Total Single Site Acreage" is multiplied by the typical C value derived for that surface from the American Society of Civil Engineers (1969) to get the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

School Site				
	Roof	Green Space	Parking	Total Acreage of School Site
Area (Acres)	1.24	7.41	0.80	9.45

	Area/Total Acreage	Coefficient	Area/Total Acreage*Coefficient
Roof	0.13	0.85	0.11
Green Space	0.78	0.30	0.24
Parking	0.08	0.85	0.07
		<b>Weighted Coefficient</b>	<b>0.42</b>
		Sum of Area/Total Acreage*Coefficient	

# Land Use Type: Community-Church

## 2 Year 1 Hour Storm

Volume (Q)=A x C x I	(Land Use Type)
Area	4.82
Coefficient (Weighted)	0.59
Intensity	1.70
Q (Acre Inches)	4.84
Q (Acre Feet)	0.40
Q (Gallons)	131383.30

## Roof Collection

Area	0.58
Coefficient	0.85
Intensity	1.70
Q (Acre Inches)	0.84
Q (Acre Feet)	0.07
Q (Gallons)	22907.35

Efficiency	90%	80%	75%	15%
	20617	18326	17181	3436

## Notes

C Values were derived using standard C values used in stormwater calculations. The C values in this spreadsheet were derived from the American Society of Civil Engineers (American Society of Civil Engineers, 1969). A weighted coefficient was calculated for the site, see Table "Weighted Church C."

The C value for the roof was derived from the American Society of Civil Engineers (1969). Typical C values for a roof are between 0.75 and 0.95. A middle value, 0.85 was used for the roof coefficient

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

Total Rainwater Captured  
by Harvesting for entire  
Land Use Type (90%  
efficiency)

**20617**

Total Rainwater Captured  
by Harvesting for entire  
Land Use Type (15%  
efficiency)

**3436**

Treatment	Barrel Size	Number of Barrels	Capacity
Minimum	5500	4	22000
Moderate	12500	2	25000
Maximum	15000	2	30000

Barrels are sized to hold the volume of water if the rainwater harvesting system collected rainwater at 90% efficiency.

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com)

## Community-Church Weighted Coefficient Calculation

**Weighted Coefficient Value Calculations for a single site of the Land Use Type Community: Church** To find a weighted C value, the percentage of surface types (lawn, roof, driveway) to the total acreage of the site was calculated. The "Area/Total Single Site Acreage" is multiplied by the typical C value derived for that surface from the American Society of Civil Engineers (1969) to get the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Church Site				
	Roof	Green Space	Parking	Total Acreage of Church Site
Area	0.58	2.29	1.96	4.82

	Area/Total Acreage	Coefficient	Area/Total Acreage*Coefficient
Roof	0.12	0.85	0.10
Green Space	0.47	0.30	0.14
Parking	0.41	0.85	0.34
		<b>Weighted Coefficient</b>	<b>0.59</b>
		(Sum of Area/Total Acreage*Coefficient)	

# Land Use Type: Commercial

## 2 Year 1 Hour Storm

Volume (Q)=A x C x I	(Land Use Type)
Area	9.30
Coefficient (Weighted)	0.67
Intensity	1.70
Q (Acre Inches)	10.59
Q (Acre Feet)	0.88
Q (Gallons)	287531.30

### Roof Collection (1)

Area	1.28
Coefficient (Weighted)	0.85
Intensity	1.70
Q (Acre Inches)	1.85
Q (Acre Feet)	0.15
Q (Gallons)	50148.53

### Roof Collection (2)

Area	0.30
Coefficient (Weighted)	0.85
Intensity	1.70
Q (Acre Inches)	0.43
Q (Acre Feet)	0.04
Q (Gallons)	11730.65

### Roof Collection (3)

Area	0.05
Coefficient (Weighted)	0.85
Intensity	1.70
Q (Acre Inches)	0.08
Q (Acre Feet)	0.01
Q (Gallons)	2020.28

## Notes

C Values were derived using standard C values used in stormwater calculations. The C values in this spreadsheet were derived from the American Society of Civil Engineers (American Society of Civil Engineers, 1969). A weighted coefficient was calculated for the site, see Table "Weighted Commercial C."

The C value for the roof was derived from the American Society of Civil Engineers (1969). Typical C values for a roof are between 0.75 and 0.95. A middle value, 0.85 was used for the roof coefficient



<b>Roof Collection (4)</b>	
Area	0.09
Coefficient (Weighted)	0.85
Intensity	1.70
Q (Acre Inches)	0.13
Q (Acre Feet)	0.01
Q (Gallons)	3421.44

<b>Efficiency Roof 1</b>	<b>90%</b>	<b>80%</b>	<b>75%</b>	<b>15%</b>
	45134	40119	37611	7522
<b>Efficiency Roof 2</b>	<b>90%</b>	<b>80%</b>	<b>75%</b>	<b>15%</b>
	10558	9385	8798	1760
<b>Efficiency Roof 3</b>	<b>90%</b>	<b>80%</b>	<b>75%</b>	<b>15%</b>
	1818	1616	1515	303
<b>Efficiency Roof 4</b>	<b>90%</b>	<b>80%</b>	<b>75%</b>	<b>15%</b>
	3079	2737	2566	513

Efficiency was determined by multiply the Q(gallons) value by 90%, 80%, 75% and 15%. Efficiency is defined by the percentage of rainwater a rainwater harvesting system can capture.

**Total Rainwater Captured by Harvesting for entire Land Use Type (90% efficiency)**  
**60589**

**Total Rainwater Captured by Harvesting for entire Land Use Type (15% efficiency)**  
**10098**

Treatment-Roof 1	Barrel Size	Number of Barrels	Capacity
Minimum	10000	5	50000
Moderate	13000	4	52000
Maximum	50000	1	50000

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com) and [www.bhtank.com](http://www.bhtank.com)

Treatment- Roof 2	Barrel Size	Number of Barrels	Capacity
Minimum	2400	5	12000
Moderate	5500	2	11000
Maximum	11000	1	11000

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com)

Treatment- Roof 3	Barrel Size	Number of Barrels	Capacity
Minimum	330	6	1980
Moderate	500	4	2000
Maximum	2000	1	2000

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com) and [www.water-storage-tank.com](http://www.water-storage-tank.com)

Treatment- Roof 4	Barrel Size	Number of Barrels	Capacity
Minimum	550	6	3300
Moderate	1000	4	4000
Maximum	5000	1	5000

Barrel sizes from [www.plastic-mart.com](http://www.plastic-mart.com)

## Commercial Weighted Coefficient Calculation

**Weighted Coefficient Value Calculations for a single site of the Land Use Type Commercial** To find a weighted C value to the percentage of surface types (lawn, roof, driveway) to the total acreage of the site was calculated. The roof area for all the buildings was aggregated to get a single roof area. The "Area/Total Single Site Acreage" is multiplied by the typical C value for that surface derived from the American Society of Civil Engineers (1969) to get the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Commercial Site								
	Roof 1	Roof 2	Roof 3	Roof 4	Roof 5	Green Space	Parking	Total Acreage of Commercial Site
Area	1.28	0.30	0.05	0.05	0.09	3.11	4.42	9.30

	Area/Total Acreage	Coefficient	Area/Total Acreage*Coefficient
All Roofs	0.19	0.85	0.16
Green Space	0.33	0.3	0.10
Parking	0.48	0.85	0.40
	<b>Weighted Coefficient</b>		<b>0.67</b>
	(Sum of Area/Total Acreage*Coefficient)		

# **Appendix II: Wildcat Creek Watershed Extrapolation**

# Wildcat Creek Watershed Extrapolation Results

## 2 Hour 1 Year Storm Event Extrapolation

All C, LM-SC, All I	
Area	565.71
Coefficient (Weighted)	0.67
Intensity	1.70
Q (Acre Inches)	644.34
Q (Acre Feet)	53.69
Q (Gallons)	17595977.14
<b>Captured Rainwater (Acre Feet)</b>	<b>11.60</b>
	<b>3,776,618 gallons</b>

R, R-2, R-1, R-4, R-5, R-M, R-S	
Area	3789.45
Coefficient (Weighted)	0.40
Intensity	1.70
Q (Acre Inches)	2576.82
Q (Acre Feet)	214.74
Q (Gallons)	70058057.14
<b>Captured Rainwater (Acre Feet)</b>	<b>51.54</b>
	<b>16,781,349 gallons</b>

## Notes

Area of land containing developments similar to the Commercial Land Use Type within

Q Value was multiplied by 21.6% (percentage of rainwater captured for the Commercial land use type in the neighborhood analysis)

Area of land containing developments that are similar to Residential: Single Family,

Q Value was multiplied by 24% (weighted percentage of rainwater captured for the Single Family, Church, School land use types in the neighborhood analysis)

<b>R3, PUD</b>	
Area	701.52
Coefficient (Weighted)	0.65
Intensity	1.70
Q (Acre Inches)	775.18
Q (Acre Feet)	64.60
Q (Gallons)	21180342.85
<b>Captured Rainwater (Acre Feet)</b>	<b>12.79</b>
	<b>4,170,898 gallons</b>

Area of land containing developments similar to the Residential: Apartment within the The Coefficient used for this citywide extrapolation for the Residential: Apartment land use type was derived from finding the mid-point of the coefficient values of complex 1 and complex 2 in the neighborhood scale analysis.

Q Value was multiplied by 19.8% (weighted percentage of rainwater captured for the Apartment land use types in the neighborhood analysis)

<b>Results of Extrapolation</b>	
Total Stormwater Runoff within the urban portion of the Wildcat Creek Watershed	333 108,508,526 gallons
Total Stormwater Runoff captured by rainwater harvesting from th urban portion of the Wildcat Creek Watershed	75.9 24,732,123 gallons
Percentage of total stormwater runoff of rainwater water harvested from structures with the urban portion of the Wildcat Creek Watershed	22.8

## Weighted Coefficient Calculations used in Extrapolation

### Weighted Coefficient Value for Residential: Single Family; Community: School and Church grouping

To find a weighted C value to represent the grouped land use types, the percentage of each land use type acreage within the grouped category was calculated. The coefficient for each land use type derived from the neighborhood scale analysis was multiplied by the percentage of the land use type acreage to get the value in the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Land Use Type	Acres
Schools	73.47
Churches	59.14
Single Family	4924.06
Total of Acreage of Land Use Types	5057

	Area/Total Acreage	Coefficient derived from neighborhood scale analysis	Area/Total Acreage*Coefficient
Single Family	0.97	0.40	0.39
Church	0.01	0.59	0.01
School	0.01	0.42	0.01
		<b>Weighted Coefficient</b>	<b>0.40</b>
		(Sum of Area/Total Acreage*Coefficient)	

## Weighted Percentage Calculations used in Extrapolation

### Weighted Percentage Value of rainwater harvesting captured for Residential: Single Family; Community: School and Church grouping

To find out the amount of rainwater the grouped land use types can possible harvest, the percentage of each land use type acreage within the grouped category was calculated. The percentage of captured rainwater for each land use type derived from the neighborhood scale analysis was multiplied by the percentage to get the value in the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Land Use Type	Acres
Single Family	4924.06
Churches	59.14
Schools	73.47
Total of Acreage of Land Use Types	5057

	Area/Total Acreage	Percent of Rainwater Harvested derived from neighborhood scale analysis	Acreage*Percent of Rainwater Harvested
Single Family	0.97	0.24	0.23
Church	0.01	0.16	0.00
School	0.01	0.22	0.00
<b>Weighted Percentage of Rainwater Harvested</b>			<b>0.24</b>
(Sum of Area/Total Acreage*Coefficient)			



## Summary Tables

### Land containing developments similar to the Commercial Land Use Type

A (Acres)	566
C (Average of neighborhood analysis C values)	0.67
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	644
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>54</b>
Total Volume of stormwater runoff (Gallons)	17,595,977
Volume Rainwater harvesting from Structures (Acre Feet)	12
Volume Rainwater harvesting from Structures (gallons)	3,776,618

### Land containing developments that are similar to Residential: Single Family, Community: School and Community: Church Land Use Types

A (Acres)	3789
C (Average of neighborhood analysis C values)	0.4
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	2577
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>215</b>
Total Volume of stormwater runoff (Gallons)	70,058,057
Volume Rainwater harvesting from Structures (Acre Feet)	52
Volume Rainwater harvesting from Structures (gallons)	16,781,349

### Land containing developments similar to the Residential: Apartment

A (Acres)	702
C (Average of neighborhood analysis C values)	0.65
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	775
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>65</b>
Total Volume of stormwater runoff (Gallons)	21,180,343
Volume Rainwater harvesting from Structures (Acre Feet)	13
Volume Rainwater harvesting from Structures (gallons)	4,170,898

# Appendix III: Citywide Extrapolation

# Citywide Extrapolation Results

## 2 Hour 1 Year Storm Event Extrapolation

### All C, LM-SC, All I

Area	1869.05
Coefficient	0.67
Intensity	1.70
Q (Acre Inches)	2128.85
Q (Acre Feet)	177.40
Q (Gallons)	57675703.00
<b>Captured Rainwater (Acre Feet)</b>	<b>38.32</b>
	<b>12,486,627 gallons</b>

Area of land containing developments similar to the Commerical Land Use Type within

### R, R-2, R-1, R-4, R-5, R-M, R-S

Area	6803.28
Coefficient (Weighted)	0.40
Intensity	1.70
Q (Acre Inches)	4626.23
Q (Acre Feet)	385.52
Q (Gallons)	125778651.42
<b>Captured Rainwater (Acre Feet)</b>	<b>92.52</b>
	<b>30,141,257 gallons</b>

Area of land containing developments that are similar to Residential: Single Family, Community: Church and Community: School Land Use Types within the City of

<b>R3, PUD</b>	
Area	1416.41
Coefficient	0.65
Intensity	1.70
Q (Acre Inches)	1565.13
Q (Acre Feet)	130.43
Q (Gallons)	42360686.00
<b>Captured Rainwater (Acre Feet)</b>	<b>25.82</b>
	<b>8,406,967 gallons</b>

Excluded from extrapolation: KSU Campus and Airport

<b>Results of Citywide Extrapolation</b>	
Total Stormwater Runoff Citywide	693 232,332,069 gallons
Total Stormwater Runoff captured by rainwater harvesting from structures Citywide	157 50,832,823 gallons
Percentage of total stormwater runoff of rainwater water harvested from structures Citywide	22.7

Area of land containing developments similar to the Residential: Apartment within the

The Coefficient used for this citywide extrapolation for the Residential: Apartment land use type was derived from finding the mid-point of the coefficient values of complex 1 and complex 2 in the neighborhood scale analysis.

## Weighted Coefficient Calculations used in Extrapolation

### Weighted Coefficient Value for Residential: Single Family; Community: School and Church grouping

To find a weighted C value to represent the grouped land use types, the percentage of each land use type acreage within the grouped category was calculated. The coefficient for each land use type derived from the neighborhood scale analysis was multiplied by the percentage of the land use type acreage to get the value in the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Land Use Type	Acres
Schools	182.29
Churches	88.01
Single Family	6532.70
Total of Acreage of Land Use Types	6803

	Area/Total Acreage	Coefficient derived from neighborhood scale analysis	Area/Total Acreage*Coefficient
Single Family	0.96	0.40	0.38
Church	0.01	0.59	0.01
School	0.03	0.42	0.01
		<b>Weighted Coefficient</b>	<b>0.40</b>
		(Sum of Area/Total Acreage*Coefficient)	

## Weighted Percentage Calculations used in Extrapolation

### Weighted Percentage Value of rainwater harvesting captured for Residential: Single Family; Community: School and Church grouping

To find out the amount of rainwater the grouped land use types can possible harvest, the percentage of each land use type acreage within the grouped category was calculated. The percentage of captured rainwater for each land use type derived from the neighborhood scale analysis was multiplied by the percentage to get the value in the "Area/Total Acreage \* Coefficient" column. The values within the "Area/Total Acreage \* Coefficient" were totaled to get the weighted coefficient.

Land Use Type	Acres
Schools	182.29
Churches	88.01
Single Family	6532.70
Total of Acreage of Land Use Types	6803

	Area/Total Acreage	Percent of Rainwater Harvested derived from neighborhood scale analysis	Area/Total Acreage*Percent of Rainwater Harvested
Single Family	0.96	0.24	0.23
Church	0.01	0.16	0.00
School	0.03	0.22	0.01
<b>Weighted Percentage of Rainwater Harvesting</b>			<b>0.24</b>
(Sum of Area/Total Acreage*Coefficient)			

## Summary Tables

### Land containing developments that are similar to Residential: Single Family, Community: School and Community: Church Land Use Types

A (Acres)	6803
C (Average of neighborhood analysis C values)	0.4
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	4626
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>386</b>
Total Volume of stormwater runoff (Gallons)	125,778,651
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>93</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>30,141,257</b>

### Land containing developments similar to the Residential: Apartment

A (Acres)	1416
C (Average of neighborhood analysis C values)	0.65
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	1565
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>130</b>
Total Volume of stormwater runoff (Gallons)	42,360,686
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>26</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>8,406,967</b>

### Land containing developments similar to the Commercial Land Use Type

A (Acres)	1869
C (Average of neighborhood analysis C values)	0.67
I (1.7 inches)	1.7
Total Volume of stormwater runoff (Acre Inches)	2129
<b>Total Volume of stormwater runoff (Acre Feet)</b>	<b>177</b>
Total Volume of stormwater runoff (Gallons)	57,675,703
<b>Volume Rainwater harvesting from Structures (Acre Feet)</b>	<b>38</b>
<b>Volume Rainwater harvesting from Structures (gallons)</b>	<b>12,486,627</b>