Controlling Combined Sewer Overflows with Rainwater Harvesting in Olympia, Washington

by

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Abstract

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Urban development creates impervious surfaces, such as roads, parking lots and rooftops which have significantly altered the movement of water through the environment. Each year, the precipitation that falls on urban areas in the United States results in billions of gallons of stormwater runoff that collects various nonpoint source pollutants from impervious surfaces. Combined sewer systems are designed to collect and convey domestic, commercial, and industrial wastewater as well as stormwater runoff in the same pipes. During heavy precipitation events, stormwater volume has the potential to exceed a wastewater treatment facility's capacity. When this occurs, wastewater and stormwater are diverted from the facility and discharged directly into designated receiving surface waters. This event is called a combined sewer overflow (CSO). CSOs are a major threat to water quality as they are comprised of both raw sewage and stormwater runoff. Rainwater harvesting has the potential to mitigate stormwater runoff and this thesis examines its potential for controlling combined sewer overflows in Olympia, Washington. Rainwater harvesting is defined as the collection, storage and reuse of rainwater. On-site rainwater harvesting systems use cisterns to collect and store volumes of rooftop storm runoff for later use. Approximately six hundred acres of downtown Olympia is served by a combined sewer system. Under normal conditions, treated wastewater is released into Budd Inlet from the Lacey, Olympia, Tumwater, Thurston County (LOTT) Clean Water Alliance owned and operated Budd Inlet Treatment Plant. However, for the first time in over fifteen years, a CSO event occurred from the Plant in the early morning hours of December 3, 2007, releasing approximately 9 million gallons of untreated wastewater into Budd Inlet. Rainwater harvesting systems were modeled onto large-scale buildings (>10,000 ft^2 roof area) served by the combined sewer lines. Daily cistern levels were modeled based on actual precipitation that occurred on and around the 2007 CSO event to determine the volume of precipitation captured in the cisterns and thus prevented from entering the combined sewer lines. Results indicate that approximately 1.22 million gallons and 275,000 gallons would have been captured on December 2 and December 3, 2007, respectively, from the 102 buildings analyzed, indicating a substantial volume of runoff would have been prevented from entering the combined sewer lines, easing pressure on the Budd Inlet Treatment Plant.

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LIST OF ABBREVIATIONS/ACRONYMS

BMP- Best Management Practice

BOD- Biological Oxygen Demand

CSO- Combined Sewer Overflow

CSS- Combined Sewer System

EPA- Environmental Protection Agency

GSI- Green Stormwater Infrastructure

LID- Low Impact Development

MGD- Million Gallons per Day

SSS- Separate Sewer System

SSO- Separate Sewer Overflow

1. INTRODUCTION

Over one hundred million acres of land have been developed in the United States, and development and sprawl are increasing at a faster rate than population growth (Kloss and Calarusse, 2006). Development increases roads, parking lots, and rooftops, collectively known as impervious surfaces. Urban landscapes, with large areas of impervious surfaces, have significantly altered the movement of water through the environment. Not only that, but urban landscapes allow for stormwater to collect a variety of pollution that greatly affects the health of our nation's waters. This nonpoint source pollution is a major source of contamination of our nation's waters (NRDC, 1999).

Each year, the precipitation that falls on urban areas in the United States results in billions of gallons of stormwater runoff and combined sewer overflows (CSOs). CSOs are the result of combined sewer systems (CSSs), which collect and convey storm and wastewater in the same pipes. During heavy precipitation events, stormwater volume has the potential to exceed a wastewater treatment facility's capacity and thus produces a CSO. CSOs are composed of industrial and commercial wastewater, raw sewage and urban stormwater runoff.

Scientific research has determined that CSOs represent a serious threat to water quality (U.S. EPA, 2004; Kloss and Calarusse, 2006; Rochfort, 2000). Mitigation and prevention of increased storm flows and pollutants as a result of urbanization is one of the most challenging areas for water resource managers currently. Reducing runoff decreases the amount of pollution introduced into waterways and relieves the strain on stormwater and wastewater infrastructure.

Conventional stormwater management techniques rely on stormwater Best

Management Practices (BMPs) and often include costly projects constructed to achieve increased storage capacities during high volume precipitation events. However, as population growth and development continues, water authorities are looking for efficient and low-cost stormwater management solutions for managing runoff.

One area of stormwater runoff management currently gaining momentum is low impact development (LID). LID uses engineered, small-scale hydrologic controls to replicate the pre-development hydrologic regime of watersheds through infiltrating, filtering, storing, evaporating and detaining runoff close to its source (PGDER, 1999). One LID method is rainwater harvesting, also known as rainwater catchment or collection. Rainwater harvesting systems use cisterns to collect and store volumes of precipitation, generally from a home or building rooftop. Rainwater harvesting is extensively promoted as an alternative water supply source, however, harvesting systems are seldom solely examined for their ability to control stormwater runoff.

Olympia, Washington was selected as the case study location for 4 main reasons. First, the City borders Budd Inlet, located at the southernmost point of Puget Sound (a unique, valuable, and threatened ecosystem). Second, Olympia is partially served by a combined sewer system. Third, the combined sewer lines are located in the older downtown area which contains concentrated areas of impervious surfaces. Finally, Olympia is subject to high intensity precipitation events, thus elevating the risk for CSO events.

In December 2007, Olympia experienced its first precipitation triggered CSO event in over fifteen years, releasing over nine million gallons of untreated overflow into Budd Inlet. This thesis examines the potential for controlling CSOs with rainwater harvesting systems in Olympia by modeling rainwater harvesting systems onto large-scale buildings served by the combined sewer lines, using the December 2007 CSO event precipitation and then examining the volume of roof runoff potentially prevented from entering the combined sewer lines to determine if the modeled rainwater harvesting systems would have reduced the volume of stormwater runoff that triggered the 2007 CSO event.

2. Stormwater Runoff

Urbanization has greatly affected stormwater runoff. The continued expansion and growing population concentrations in urban areas has put stress not only on our water supply and distribution infrastructure, but has directly and indirectly affected our water supply sources themselves. Stormwater runoff carries with it a myriad of problems, including nonpoint source water pollution and sewer system overflow events. Section 2.1 will review nonpoint source pollution and section 2.2 provides a background on sewer systems, including an in-depth discussion of the two types of sewer systems and their overflow risks, combined sewer systems (CSSs) in 2.2.1 and separate sewer systems (SSSs) in 2.2.2.

2.1 Nonpoint Source Water Pollution

Development rates in the last twenty years have been double the population growth here in the U.S. (Kloss and Calarusse, 2006). Of the 100 million acres of development, impervious surfaces cover over 27 million acres, or 27% (Frazer, 2005).

This means massive displacement and conversion of areas formerly able to capture and assimilate precipitation into impenetrable surfaces. The expected population increase of 25% between the years 2000 and 2025 will add another 68 million acres of development (Beach, 2002).

The landscape vegetation of undeveloped land captures precipitation, allowing it to mostly infiltrate where it falls. In urban and suburban areas, much of the landscape is covered by impervious surfaces, such as rooftops and paved areas. Impervious surfaces alone do not generate pollution. However, impervious surfaces are a critical contributor to the hydrologic changes that degrade waterways, an acute contributing factor of the intensive land uses that do generate pollution, prevent natural pollutant processing through infiltration of precipitation into soil, and provide an effective conveyance system to transport pollutants into storm drains or waterways (Arnold and Gibbons, 1996). Impervious surfaces intensify stormwater runoff, enhance stream channel erosion and diminish groundwater recharge (Stone Jr., 2004).

The U.S. EPA identifies urban stormwater runoff from impervious surfaces a leading threat to water quality (U.S. EPA, 1996). This is because toxic and pathogenic pollutants accumulate on impervious surfaces and are picked up and carried by stormwater, generating what is known as nonpoint source water pollution. These pollutants include sediment; oil, grease, and toxic chemicals from motor vehicles; pesticides and nutrients from lawns, gardens and golf courses; viruses, bacteria and nutrients from pet waste and failing septic systems; heavy metals from roof shingles and motor vehicles; garbage and more (U.S. EPA, 2003). Nonpoint pollution resulting from stormwater runoff has been identified as one of the major causes of the deterioration of the quality of receiving waters (Lee and Bang, 2000).

Nonpoint source water pollution harms fish and wildlife populations, kills native vegetation, pollutes drinking water sources and threatens safety of recreational areas. There is a direct correlation between impervious surface proportion within a watershed and water quality. A number of scientific studies have determined that when watershed imperviousness exceeds 10%, aquatic ecosystem health tends to decline. At 30% impervious surface coverage, the watershed will become critically impaired (Arnold and Gibbons, 1996; Booth and Jackson, 1997; Wang, 2001).

The amount of impervious surfaces in urbanized areas ranges. In residential areas, coverage increases from approximately 10% in low-density subdivisions to over 50% in multi-family communities. In industrial and commercial areas, impervious surface coverage rises above 70% and in regional shopping centers and dense urban areas, impervious coverage is over 90% (Schueler, 2000). In these densely impervious locations, stormwater is often directed into storm drains to be transported to the local sewer system to be treated and discharged into receiving waterways. In fact, most communities rely on a municipal sewage system to deal with stormwater runoff and such systems will be presented next.

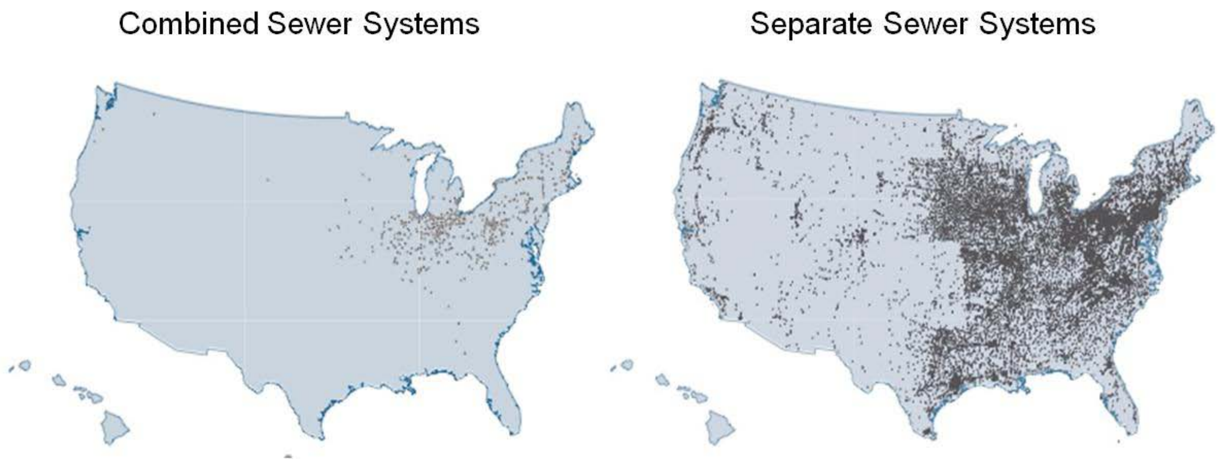
2.2 Sewer Systems

Municipal sewer systems are a considerable and important sector of our nation's infrastructure. Our daily activities generate liquid wastes that without proper treatment and disposal would generate numerous environmental and health issues. Wastewater is any water that has been adversely affected in quality by human influence. Sewage is specifically the subset of wastewater that is contaminated with feces and urine, however, the terms wastewater and sewage are often used interchangeably. To understand the significance of sewer systems, it is important to provide a brief discussion concerning the history of sewer systems and wastewater treatment here in the U.S.

Construction of municipal sewer systems did not start in the U.S. until the 1880s (U.S. EPA, 2004). Before sewer systems, human waste was dumped into privy vaults and cesspools, and stormwater ran into the streets or into surface drains. Rapid urbanization between 1840 and 1880 resulted in increased quantities of wastewater that could not be handled by privy vaults and cesspools. Sewer systems were constructed to protect public health, to address flooding issues as well as to increase community aesthetics.

Municipalities installed sewer systems using two prevailing design options, combined sewer systems (CSSs), where wastewater and stormwater runoff are collected and conveyed in a single pipe system or separate sanitary and storm sewer systems (SSSs), where wastewater and stormwater runoff are collected and conveyed using two separate systems of pipe. Figure 2.1 displays the distribution of the two sewer types and shows that combined sewer systems occur less frequently than separate sewer systems and are more concentrated in the Eastern U.S. However, there are a few located on the West Coast, including one in Olympia, Washington. Both combined and separate sewer systems are designed to overflow storm and/or wastewater. The discharge from both types of sewer systems is called point source water pollution as it is a localized, identifiable source of pollution. These systems will be discussed in detail next in 2.2.1 and 2.2.2.

Figure 2.1 Distribution of Sewer System Types



http://www.epa.gov/npdes/pubs/csossoRTC2004_executive_summary.pdf

As sewer systems were first being constructed in the 1880s, no model sewer systems existed for guiding construction, and engineers were reluctant to experiment with expensive capital works (U.S. EPA, 2004). For municipalities that needed both sanitary and storm sewers, it was less costly to construct CSSs. For municipalities that needed only a wastewater collection system, constructing a SSS was less expensive. Generally, large cities opted to construct CSSs because of the flood prevention offered by combined systems while smaller cities sought separate sanitary and storm sewers (U.S. EPA, 2004).

Sewer systems can be publicly or privately owned, meaning owned and operated by a state or municipality, or a facility whose operator is not the operator of the treatment works, respectively. Municipal sewer systems serve approximately 208 million people in the U.S. and the EPA estimates that publicly-owned sewer systems account for 724,000 miles of sewer pipe while privately-owned sewer systems account for about 500,000 miles of piping to deliver wastewater into these systems (U.S. EPA, 2004). Pipe corrosion occurs in virtually all types of piping systems and over time, susceptibility to corrosion is increased. Leaching occurs, leaks develop and water quality can be degraded. Over two-thirds of the U.S. population depends on hundreds of thousands of miles of piping that is already ageing or will over time.

While the generalized average age of sewer system components is 33 years, components of some systems date back over a century (U.S. EPA, 2004). Not only are these systems aging, but marked variability exists in the current condition of sewer infrastructure, as municipalities have used an array of materials, design and installation practices and maintenance and repair procedures (U.S. EPA, 2004). Population growth will likely contribute additional wastewater to be processed by these variable and ageing municipal sewer systems, adding stress to the already burdened wastewater infrastructure.

Sewer systems are necessary in maintaining the health of our communities and greatly improve local sanitary conditions. However, the age and structural design of both CSSs and SSSs present health concerns for both communities and the natural environment surrounding them. This is because these systems are designed to overflow storm and/or wastewater during specific situations, resulting in separate storm sewer overflows (SSOs) and combined sewer overflows (CSOs). The next two sections will present background and potential risks associated with both SSSs and CSSs.

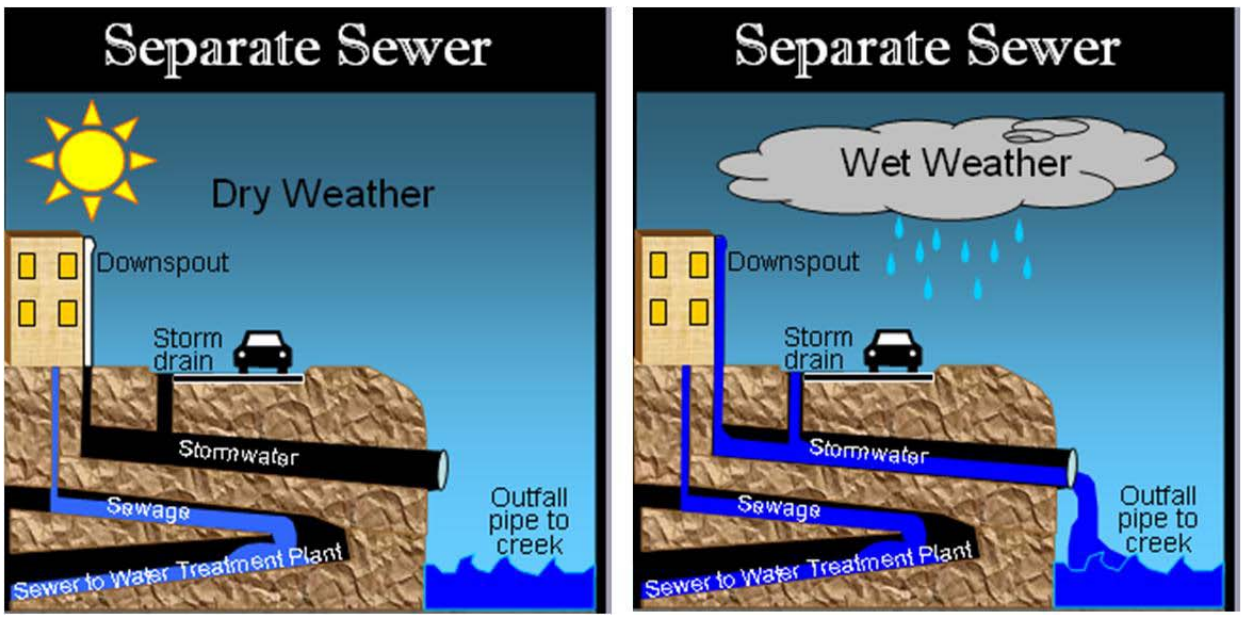
2.2.1 Separate Sewer Systems (SSSs) and Overflows (SSOs)

Separate sewer systems (SSSs), also known as separate sanitary and storm sewer systems are comprised of two sets of pipes that collect and convey domestic, commercial and industrial wastewater mixed with limited amounts of infiltration and inflow[1] to a

[1] Inflow is defined as surface water entering the sewer via means other than groundwater. Inflow is usually the result of precipitation events. Infiltration is defined as groundwater that enters the

treatment plant in one set, while collecting and conveying stormwater runoff directly to surface waters in the other (see Figure 2.2). This is problematic because polluted stormwater runoff is commonly discharged untreated into local water bodies. While the concentration of pollutants in stormwater is generally more dilute than in wastewater, it can still contain significant amounts of pollutants as discussed earlier.

Figure 2.2 Typical Separate Sewer System (SSS) Function during Dry and Wet Weather



http://www.phillyriverinfo.org/CSOLTCPU/Home/images/Sewers%20in%20Dry%20Weather.png

A properly designed, operated and maintained SSS is meant to collect and transport all the sewage that flows into it. However, SSSs are at risk of experiencing sanitary sewer overflows (SSOs). SSOs are partially treated or untreated sewage overflows from a sanitary sewer collection system. While SSOs occur, they occur infrequently and properly maintained SSSs are designed to handle and treat all incoming

sewer, usually through leaky sewer pipes and joints, manholes and service connections (LOTT, 2009).

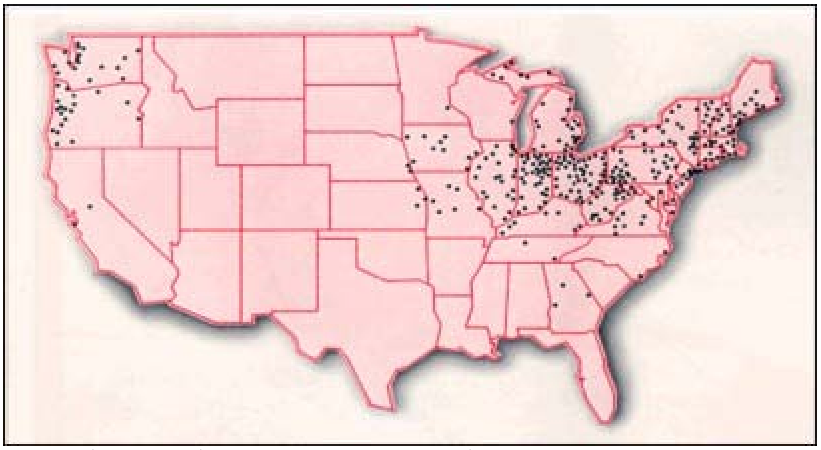
wastewater. Combined sewer systems (CSSs) share wastewater and stormwater runoff in the same piping and are designed to overflow when incoming flow levels exceed the ability of the treatment plant. The focus of this thesis is on combined sewer systems (CSSs) and combined sewer overflows (CSOs), which will be discussed next.

2.2.2 Combined Sewer Systems (CSSs) and Overflows (CSOs)

As sewer systems were first constructed, it was recognized early on that wastewater collection improved local health conditions and often reduced illness. However, by the 1890s, drinking water being drawn downstream from untreated wastewater discharges resulted in major cholera and typhoid outbreaks (U.S. EPA, 2004), and the need to provide wastewater treatment was established. It was clear that although CSSs were efficient means of collecting and conveying storm and wastewater, they also made treatment more difficult because large variation in flows existed between wet and dry weather. Most state and local authorities have not allowed construction of new CSSs since the 1950s (U.S. EPA, 2004).

Approximately 772 communities nationwide contain CSOs, mainly within the Great Lakes, Northeast and Puget Sound regions (see Figure 2.3). Of the 772 communities, approximately 30% have populations greater than 75,000, and the other 70% are small with total service populations of less than 10,000 (U.S. EPA, 2001). Increased stormwater flows generated in urban areas containing CSSs increase the potential for CSO events with increased pollutant concentrations. Also, because most CSSs were designed before 1950, population increases in the following decades have

Figure 2.3 Combined Sewer System (CSS) Locations in the U.S.



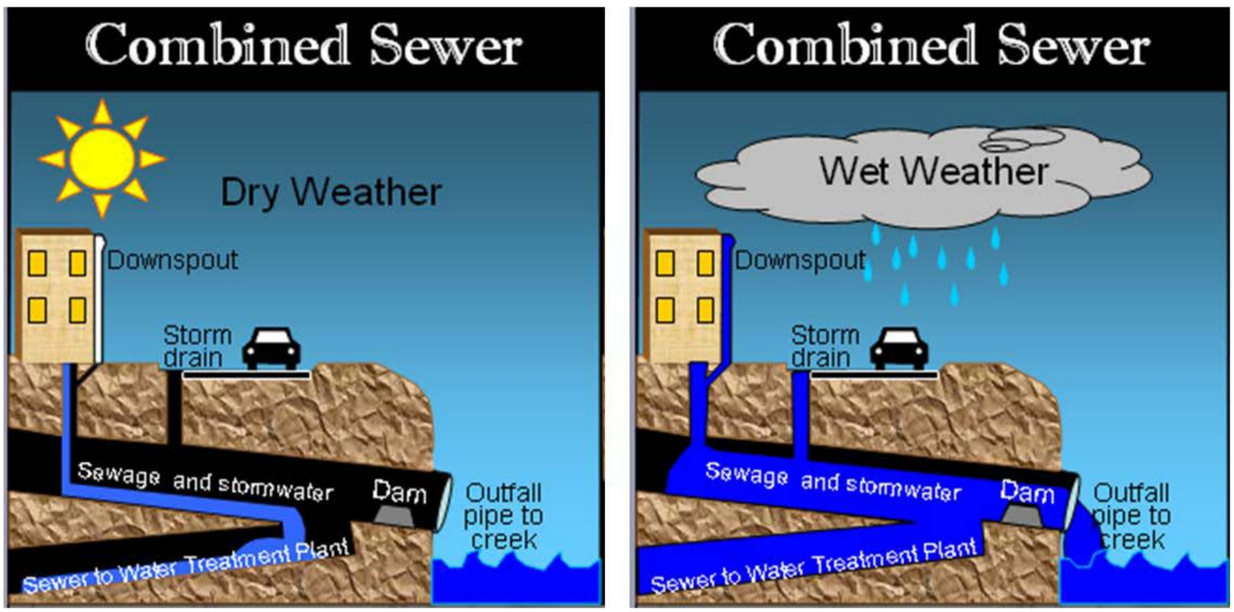
Available from http://cfpub.epa.gov/npdes/cso/demo.cfm?program_id=5

increased dry weather wastewater flows, leaving less capacity available for storm flows.

As mentioned earlier, CSSs are designed to collect and convey domestic, commercial and industrial wastewater as well as stormwater runoff in a single pipe system. Generally, CSSs were designed to carry three to five times the average dry weather flow, giving the pipe system considerable capacity during dry weather. However, during wet weather events, CSSs are designed to overflow, discharging directly to surface waters (rivers, estuaries and coastal waters) when total flows exceed the capacity of the CSS or treatment plant (see Figure 2.4). CSO duration and frequency vary from system to system and from outfall to outfall within a single CSS (U.S. EPA, 2001).

CSOs are composed of commercial and industrial wastewater, raw sewage and stormwater runoff and are significant sources of point source water pollution. The EPA estimates that 850 billion gallons of CSO outfall are discharged into our surface waters each year (Kloss and Calarusse, 2006). CSOs contain substantial amounts of microbial pathogens, oxygen-depleting substances, suspended solids (small particles housing pollutants and pathogens on the surface that remain in suspension in water), toxics (mostly metals and pesticides), and nutrients and floatables (water-borne litter and debris) from both wastewater and stormwater runoff. CSO events are cause for serious public health and water quality concerns.

Figure 2.4 Typical CSS Function during Dry and Wet Weather



http://www.phillyriverinfo.org/CSOLTCPU/Home/images/Sewers%20in%20Wet%20Weather.png

Generally, CSOs are induced during wet weather and overflows during dry weather events are rare and prohibited under federal regulation. Pollutant concentrations of CSO events vary substantially (U.S. EPA, 2004). The relative amounts of domestic, commercial, industrial wastewater and urban stormwater carried by a CSS during storm events are the key operatives of pollutant concentrations associated with CSO discharge.

There are other factors that influence CSO pollutant concentrations. First, pollutants increase on surfaces over long periods of time between wet weather events and the longer duration of time, the higher the pollutant concentrations. Also, the duration of the wet weather event influences pollutant loads, as the early stages of a CSO event (often referred to as the first flush) contain the highest pollutant concentrations. Finally, the intensity and duration of the wet weather event influences pollutant concentrations.

According to the EPA, CSO pollutants impact five general areas: aquatic life support, shellfish harvesting, fish and shellfish consumption, drinking water supply, and water recreation (U.S. EPA, 2004). The following paragraphs will describe these impacts in more detail.

When water provides a suitable habitat for protection and propagation of desirable fish, shellfish and other aquatic organisms, it is designated as aquatic life support (U.S. EPA, 2004). CSOs (and SSOs) contain oxygen-demanding substances that contribute to impaired aquatic life support impairment. CSO pollutants are generally not widespread causes of aquatic life impairment, however several states have experienced diminished aquatic life support capacity within receiving waters of CSO outfall locations (U.S. EPA, 2004).

The shellfish industry in the U.S. is responsible for supporting thousands of jobs and generating hundreds of millions of dollars for the U.S. economy (NOAA, 1998). Unfortunately, commercial and recreational shellfish harvesting in populated coastal areas has been steadily declining since the 1900s, when outbreaks of typhoid were linked to untreated wastewater (U.S. EPA, 2004). In 1995, more than 33,000 square miles of marine and estuarine water in the contiguous U.S. were classified as shellfish growing waters (NOAA, 1998). These waters were carefully surveyed and classified for harvest to protect public health and ensure safe harvests. Results determined that the primary basis for shellfish harvest restriction was due to concentrations of fecal coliform bacteria associated with human sewage from sewer system outfalls and organic wastes from livestock and wildlife deposited via stormwater runoff. An average of 20% of classified waters are prohibited from harvest annually (NOAA, 1998).

The U.S. population consumes millions of pounds of shellfish annually (NOAA, 1998). Bioaccumulation of the microbial pathogens found in CSO outfall occurs with shellfish grown in contaminated waters. Pathogens can be passed on to humans by eating whole, partially cooked or raw contaminated shellfish (U.S. EPA, 2004). Consuming shellfish contaminated with raw sewage can lead to gastroenteritis in humans, an inflammation of the gastrointestinal tract resulting in acute diarrhea. If untreated, gastroenteritis can be fatal.

Public water supply systems[2] provide drinking water to 90% of Americans (U.S. EPA, 2009). About 65% of the population served by these systems receives water drawn from surface waters (rivers, lakes and reservoirs) while the other 35% drink groundwater. It is possible to contract waterborne diseases from contaminated municipal drinking water and well water. Contamination occurs when sewer system outfalls are located near drinking water intake sources. The EPA identified fifty-nine CSO outfalls located within one mile upstream of a drinking water intake source (U.S. EPA, 2004). Drinking water authorities drawing freshwater near a CSO outfall are aware and in communication with the CSS authorities responsible for outfalls and as such, CSOs generally do not pose a major risk of contamination to most public drinking water intakes.

Each year, millions of people in the U.S. use oceans, rivers, lakes and streams for a variety of recreational activities (U.S. EPA, 2004). Water-based activities, such as

[2] A provision to the public of drinking water with at least fifteen service connections or regularly services at least twenty five individuals

swimming and boating are restricted where CSO discharge occurs. This is because documented cases of gastroenteritis and gastrointestinal illness has been observed from contact with and ingestion of water near wastewater or storm drain outfalls (U.S. EPA, 2004).

The cost for mitigating CSOs nationwide has been estimated at $54.8 billion annually (U.S. EPA, 2008a). CSOs during dry weather are prohibited by law, so the regular events that occur are triggered by stormwater runoff. Stormwater management practices are used to handle and prevent SSOs and CSOs as well as stormwater runoff. Section 3 presents an overview of stormwater management.

3. Stormwater Management

Stormwater management is the practice of managing the quantity and quality of stormwater. Stormwater runoff has been a source of great concern regarding the health of our country's waterways for several decades. Stormwater management in general centers on the use of Best Management Practices (BMPs). Conventional stormwater management is presented in 3.1, including an overview of stormwater BMPs in 3.1.1, CSO control methods in 3.1.2, and general conclusions regarding conventional stormwater management in 3.1.3. An increasingly popular stormwater management methodology is called green stormwater infrastructure (GSI) or low impact development (LID). This methodology uses stormwater BMPs that center on maintaining or restoring the pre-development hydrologic regime of urban and developing watersheds. GSI and LID are presented in 3.2, with a discussion of techniques in 3.2.1 and implementation in various cities in 3.2.2.

3.1 Conventional Stormwater Management

The Clean Water Act was passed in 1972 to protect our nation's waters from pollution and amendments to the Act in 1987 required the EPA to address stormwater runoff in two phases under Section 402, the National Pollution Discharge Elimination System (NPDES) permit program. The NPDES program controls water pollution by supervising point sources that discharge pollutants into waters of the United States, and regulatory monitoring of SSSs and CSSs was implemented in two phases.

Phase I of the NPDES program was issued in 1990 and requires medium and large cities or certain counties with populations of 100,000 or more to obtain NPDES permit coverage for their stormwater discharges. Phase II of the NPDES program was issued in 1999 and requires regulated small sewer systems in urbanized areas, meaning a population density greater than 1,000 people per square mile, to obtain a NPDES permit.

In order to follow the NPDES program requirements, municipalities across the U.S. have developed Best Management Practices (BMPs) for stormwater management. BMPs are commonly used to describe structural or engineered control devices and systems as well as operational or procedural practices designed to retain and/or treat storm runoff. Stormwater management centers around the use of BMPs, and the most commonly applied conventional stormwater management techniques display a reactionary rather than preventative methodology for managing storm runoff. An overview of the three common types of BMPs applied in conventional stormwater management are presented in 3.1 as well as a brief discussion regarding detention ponds, the most commonly applied management practice.

Municipalities containing SSSs are required to develop and implement a stormwater management program to reduce the contamination of stormwater runoff while municipalities containing a CSS are required to implement EPA's determined nine minimum controls and develop long-term CSO control plans, both of which will be discussed in 3.1.2.

Conventional stormwater management has focused on removing stormwater from a site as quickly as possible to reduce on-site flooding. This means predominate implementation of two types of management techniques. First are curb and gutter and piping systems that discharge runoff to the nearest receiving water. Second is implementation of detention type BMPs to reduce peak runoff discharge rates, such as detention ponds (NHDOES, 2008).

3.1.1 Stormwater BMP Overview

The three common types of BMPs are source control, treatment, and flow control. Source control BMPs reduce the exposure of materials to stormwater, therefore reducing the amount of pollutants picked up by storm runoff. Source control BMPs target the activities that produce contaminants and can be divided into two broad categories. The first category includes BMPs dictating planning, design and construction of developments and re-developments to minimize or eliminate adverse impacts. The second category includes education and training to promote awareness of the potential problems associated with stormwater runoff and of specific BMPs to help solve stormwater runoff problems.

Treatment BMPs include facilities that remove pollutants by gravity settling of particulate pollutants, filtration, biological uptake, and soil adsorption (WADOE, 2005). Methods used for runoff treatment facilities include wetpools, biofiltration, oil/water separation, pretreatment, infiltration, filtration, emerging technologies, on-line systems, and design flow[3]. Treatment BMPs can accomplish significant levels of pollutant load reductions if designed and maintained properly.

Flow control BMPs typically control the rate, frequency, and flow duration of stormwater runoff. The need to provide flow control BMPs is dependent on whether a development directly or indirectly discharges to a stream system or a wetland (WADOE, 2005). The purpose of flow control is to store volumes of water that can later be slowly released into the collection system. The volume of storage needed for flow control depends on several factors: the size of the drainage area, the extent of disturbance of the natural vegetation, topography and soils, the proportion of impervious surfaces, and the target release rates, i.e. how rapidly the water is allowed to leave (WADOE, 2005).

Source control BMPs are preferred over treatment BMPs because it is more cost effective to prevent pollutants from entering runoff rather than treating runoff to reduce pollutants. However, detention ponds, a method of flow control, are the most commonly applied stormwater BMP (WADOE, 2005). The function of detention ponds is to manage flows by capturing and detaining stormwater runoff from developed areas and slowly releasing outflow. Unfortunately, the design of some detention ponds prevents groundwater recharge by restricting stormwater to large cement basins, serving as a reactive rather than proactive method for handling stormwater runoff.

[3] See Appendix A for treatment control method definitions

Both CSSs and SSSs implement control methods to prevent overflow events from occurring. However, CSSs are designed to overflow when the treatment system is overwhelmed whereas SSSs are not. This thesis examines the control of CSOs, therefore, I only present methods for CSO control next in 3.1.2.

3.1.2 CSO Control

Historically, CSO prevention was difficult due to an inability to fully quantify CSO impacts on receiving water quality as well as the site-specific variability in the volume, frequency and characteristics of CSO events (U.S. EPA, 1995). The EPA published the CSO Control Policy on April 19, 1994 and sought to reduce negative impacts from CSOs on water quality, aquatic biota, and human health (U.S. EPA, 1994).

As mentioned above, CSOs are subject to NPDES permit requirements. Permits authorizing discharges from CSO outfalls include very strict water quality-based requirements to meet water quality standards (U.S. EPA, 2004). The CSO Control Policy directs implementation and enforcement responsibilities to NPDES authorities.

Currently, the 772 CSO communities have a total of 9,471 outfall locations that are identified and regulated by 828 NPDES permits. CSSs are diverse, varying in configuration, size, age, number and location of outfalls. The CSO Control Policy establishes objectives for CSS communities, including implementation of prescribed nine minimum controls and requiring development of a long-term CSO control plan. The nine minimum controls are as follows:

1. Proper operation and regular maintenance programs for the sewer system;
2. Maximum use of the collection system for storage;
3. Review and modification of pretreatment requirements to assure CSO impacts are minimized;

4. Maximizing flow to the sewage treatment facility for treatment;
5. Prohibition of CSOs during dry weather;
6. Control of solids and floatable materials in CSOs;
7. Pollution prevention;
8. Public notification to ensure that the public receives adequate notification of CSO occurrences and CSO impacts;
9. Monitoring to effectively characterize CSO impacts and the efficacy of CSO controls (U.S. EPA, 2004).

After passing the Control Policy, the EPA expected municipalities to implement the nine minimum controls and to submit appropriate documentation to NPDES authorities as soon as reasonably possible. Of the 828 active CSO permits identified by EPA in July 2004, 94% (777 permits) required implementation of the nine minimum controls (U.S. EPA, 2004).

In addition to implementing the nine minimum controls, EPA and NPDES authorities expect CSO communities to develop and implement a long-term CSO control plan that includes measures for achieving water quality standards set by the Clean Water Act. The plan must evaluate a range of control options, including costs and benefits (the EPA recommend a total nine elements they consider essential for a long-term CSO control plan[4] to direct the selection of an alternative that would achieve water quality objectives compliant with the Clean Water Act (U.S. EPA, 2001). Almost 90% of permits (708 of 828) required development and implementation of a long-term CSO control plan (U.S. EPA, 2004).

For communities developing long-term CSO control plans, municipalities are required to consider significant structural controls. Common CSO control measures

[4] 1) characterization, monitoring and modeling of the CSS; 2) public participation; 3) consideration of sensitive areas; 4) evaluation of alternatives to meet Clean Water Act requirements; 5) evaluate cost and performance considerations; 6) an operational plan; 7) maximization of treatment at the sewer treatment facility; 8) create an implementation schedule; 9) a post-construction compliance monitoring program (U.S. EPA, 2004).

identified by long-term control plans include off-line storage facilities, plant modifications, sewer rehabilitation, disinfection facilities and sewer separation (U.S. EPA, 2004). Off-line storage facilities store wet weather flows in near-surface storage basins, such as tanks and basins or deep tunnels located adjacent to the sewer system (U.S. EPA, 2004). Simple plant modifications, such as changing the physical treatment processes and plant operations during wet weather can result in increased ability to handle wet weather flows. Rehabilitating sewer systems refers to the replacement of structural components that have deteriorated with time. The gradual breakdown of these components allows more groundwater and stormwater to infiltrate into the sewer system (U.S. EPA, 2004). Disinfection is necessary to protect public health from wastewater discharges and facilities hold and treat wastewater before discharging it, although discharge often includes high levels of toxic residual chlorine (U.S. EPA, 2004).

Sewer separation is the most commonly implemented long-term control plan method for CSO control (U.S. EPA, 2004), and is the act of separating combined, single pipe systems into separate sewers for sanitary and storm flows. Separating a CSS contributes to improvements of water quality by reducing or eliminating sanitary discharges to receiving waters (U.S. EPA, 2004). This in turn prevents contact risk with pathogens and impacts to aquatic species. Separating a CSS also relieves regulations associated with CSOs.

However, there are negative impacts associated with sewer separation. These include impacts related to extensive construction, disturbances to residents and businesses, potential disruptions in sewer service, the need for new stormwater discharge controls to maintain positive water quality results, and high costs. Commonly implemented CSO control measures are generally structural and can be very expensive.

Sewer separation can cost as much as $600 per foot of separation (Kloss and Calarusse, 2006). However, costs are highly variable due to the location and layout of existing sewers, the location of other utilities that will have to be avoided during construction, other infrastructure work that may be required, land uses and costs, and the construction method used (U.S. EPA, 1999). Sewer separation costs are increasing over time and many cities have only been able to separate portions of their combined systems due to high costs and physical limitations, such as location within heavy development. The EPA estimates that $63.6 billion (an increase of $13 billion from 2000) is needed to fund established water quality problems associated with CSOs existing as of 2008 or expected to occur in the following 20 years (U.S. EPA, 2008a).

3.1.3 CONVENTIONAL STORMWATER MANAGEMENT CONCLUSIONS

Conventional stormwater management methods, such as the highly implemented detention pond method, have proven to be problematic to downstream waters by altering stream channel morphology[5], reducing groundwater recharge, and increasing frequency and magnitude of floods (NHDOES, 2008). These issues make less water available for drinking water withdrawals and stream base flows.

The downfalls associated with conventional stormwater management are largely due to methods that rely on conveyance efficiency and end-of-pipe treatment. The key to efficient and effective management of stormwater runoff is to simply reduce the volume of runoff generated at the source and maintaining as much of the original site hydrology.

[5] Stream channel morphology includes stream alignment, cross-section geometry and streambed composition

The same applies for CSSs. If CSSs are functioning properly and not experiencing CSO events during dry weather periods, reducing or eliminating inflow from stormwater runoff is the most efficient means of controlling CSO events. Reducing or eliminating inflow also prevents costly infrastructure updates, such as CSS separation. Reducing inflow from storm events is also cost effective by being preventative in nature, therefore reducing treatment costs associated with wastewater flows. Many communities, especially areas containing CSSs have recently shifted focus toward a new methodology for stormwater management. This is called green infrastructure for stormwater management and includes low impact development (LID) technologies for managing storm runoff and will be presented next in 3.2.

3.2 Green Stormwater Infrastructure (GSI) and Low Impact Development (LID)

Green infrastructure is a method of stormwater management that is environmentally sensitive, sustainable, and generally cost-effective (U.S. EPA, 2004). The term green infrastructure refers to a class of stormwater BMPs or management practices that slow, capture, treat, infiltrate and/or store runoff at its source, and include both structural (stormwater capture and treatment) and non-structural (preservation of open space) approaches (LaBadie, 2010). Green infrastructure techniques infiltrate, evapotranspire, capture and reuse stormwater to maintain or restore natural hydrology and can be applied at the site, neighborhood, or regional scale.

The term low impact development (LID) generally refers to development approaches and principles that utilize green infrastructure techniques to create functional drainage systems. Often these two terms are used interchangeably to define a new, comprehensive land planning and engineering design approach with a goal of maintaining and enhancing the pre-development hydrologic regime of urban and developing watersheds (Low Impact Development Center, 2010). I will be referring to this methodology as LID for the purpose of this thesis. Next, LID techniques are presented in 3.2.1 and implementation of LID techniques for stormwater management is discussed in 3.2.2.

3.2.1 LID Techniques

Integrated stormwater management involves the development and implementation of a range of LID and conventional BMPs to improve the quality of urban stormwater runoff before its discharge into the receiving environment. LID techniques are designed to control the timing and volume of storm discharges from impervious surfaces as well as the volume of wastewater (residential, commercial, and industrial) generated within a community (U.S. EPA, 2004). LID principles and applications represent a compelling conceptual shift from a purely structural approach to stormwater management, as LID methods are runoff reduction stormwater BMPs (Puget Sound Action Team, 2005).

On a large scale, protecting and restoring natural landscape features (such as forests, floodplains and wetlands) are significant elements of LID. Preserving these areas simultaneously provides wildlife habitat and recreation opportunities while improving water quality. On a smaller scale, LID techniques can be divided into broad categories such as infiltration practices, filtration practices, and runoff storage practices.

LID infiltration practices are engineered structures or landscape features designed to capture and infiltrate runoff. They are used to reduce both storm runoff volume discharge from a site and to mitigate infrastructure needed to convey, treat, or control runoff (U.S. EPA, 2007). Infiltration practices are also used for groundwater recharge, which is particularly valuable in communities where maintaining drinking water supplies and stream baseflow[6] is of special concern due to limited precipitation or high ratios of water withdrawal to groundwater recharge rates. LID infiltration practices include porous pavement, disconnected downspouts, infiltration planters, and rain gardens, which will be presented briefly below.

LID filtration practices are similar to infiltration practices with the added advantage of providing increased pollutant removal benefits. Rain gardens and infiltration planters can also be categorized as filtration practices because they can provide pollutant removal. Filtration practices treat runoff by filtering it through elements designed to capture pollutants through the process of physically filtering dissolved pollutants. Filtration practices offer many of the same benefits as infiltration, such as reduced storm runoff volume, groundwater recharge, and increased stream baseflow (U.S. EPA, 2007). Rain gardens, infiltration planters, vegetated swales, sidewalk trees and tree planters are examples of filtration LID techniques.

Runoff storage LID practices are beneficial because storm runoff from impervious surfaces can be captured and stored for reuse or gradually infiltrated, evaporated, or used to irrigate plants (U.S. EPA, 2007). Runoff storage practices can reduce the volume of runoff discharged to surface waters, reduce the erosive forces of high storm runoff flows and irrigate landscaping. Runoff storage LID practices include green roofs and rainwater

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[6] Stream baseflow is defined as the sustained flow in a stream channel because of subsurface runoff

harvesting systems. All of the example techniques will be discussed briefly below.

Porous pavement, otherwise known as permeable pavement, offers one solution to managing increased stormwater runoff and decreased water quality associated with transportation related surfaces, such as roads and parking lots. Porous pavement is commonly made up of a matrix of interlocking concrete blocks constructed with voids that allow stormwater to infiltrate through to the underlying soil, which provides groundwater recharge and reduced urban storm flows (Brattebo and Booth, 2003). Permeable pavement is very effective at mitigating storm runoff, however, are not recommended for heavily trafficked areas, such as interstates and highways, as surface durability can be degraded.

Disconnecting downspouts is a simple LID method to prevent storm runoff from entering the sewer system. Downspouts on many homes are connected directly to the local sewer system. Disconnecting downspouts directs roof runoff to drain to lawns and gardens or any form of bioretention, where it can infiltrate into the soil, rather than being transported to the sewer system.

Infiltration planters are containers with open bottoms to allow stormwater to slowly infiltrate into the ground and are only recommended for areas where soil is well drained. They contain a layer of gravel, soil and vegetation, where storm runoff temporarily pools on the topsoil and slowly infiltrates through the planter into the ground. Infiltration planters are variable and can contain a variety of vegetation as well as constructed of many materials, such as wood, stone, brick, concrete and plastic. Planters are commonly located in urbanized areas where space is limited, such as a downtown (LaBadie, 2010).

Rain gardens are natural or dug shallow depressions planted with deep-rooted native plants and grasses designed to capture and soak up stormwater runoff from impervious areas such as sidewalks, walkways and compacted lawns. Stormwater is held in the garden for a short period of time and is allowed to naturally infiltrate into the ground. Although small scale and often implemented at residential homes, rain gardens provide multiple benefits. They absorb, filter and assimilate nonpoint source pollutants before they reach the storm drain, provide habitat for beneficial insects and birds, and increased groundwater recharge (Dussaillant et al., 2005). Rain gardens are also easy to implement as they require less technical expertise to install and maintain than other LID methods.

Vegetated swales, also known as bioswales, are similar to rain gardens in that they are a form of bioretention used to partially treat water quality, control flooding and convey stormwater away from critical infrastructure (UF, 2008). These systems are linear and applied as residential roadside swales, highway medians, and parking lot islands and medians, parallel to roadways. These open-channel drainageways are designed to convey storm runoff and the vegetation treats a portion of the stormwater by absorbing, filtering and assimilating pollutants while well-drained soils enhance site infiltration, recharging groundwater. Vegetated swales are often used as an enhancement of or alternative to traditional stormwater piping (UF, 2008).

Sidewalk trees intercept precipitation and are planted to reduce stormwater runoff and the urban heat island effect as well as improve the urban aesthetic and air quality. Tree boxes are purchased to address spatial issues associated with sidewalk trees, which are often compacted into restrictive spaces. To obtain the full range of potential for street trees, a healthy soil volume is needed and tree boxes are constructed to provide adequate soil space.

Green roofs are roofs with a vegetated surface and substrate and provide multiple ecosystem services in urban areas (Oberndorfer, 2007). Green roofs improve stormwater management by capturing and assimilating precipitation that would otherwise become roof runoff. Green roofs also help regulate building temperatures by providing additional insulation. Green roofs reduce urban heat-island effects[7] by increasing reflection of incoming radiation away from a surface. They also increase urban wildlife habitat by providing a stop for insects as well as resident and migrating birds. Green roofs generally represent a higher monetary investment than other LID techniques, but energy savings and potential credit for reducing greenhouse gas emissions and for stormwater management result in significant savings.

Rainwater harvesting is a dynamic LID technique that not only controls storm runoff but also promotes water conservation by supplying an alternative source of water for non-potable uses such as toilet flushing and landscape irrigation. Described simply, rainwater harvesting uses storage tanks, such as cisterns, to capture runoff, generally from rooftops, which can be used later for non-potable water applications. This thesis examines the ability to control CSO events with rainwater harvesting, therefore, rainwater harvesting is discussed in-depth later in Section 4.

3.2.2 LID Implementation for Stormwater Management (CSO Control)

Many cities nationwide are using LID techniques as advanced components for

[7] An urban heat island is a metropolitan area that is significantly warmer than the surrounding rural areas due to less vegetation, high heat retention from impervious surfaces that absorb sunlight, and increased levels of air pollution

controlling stormwater runoff in urban areas (Hyland and Zuravnsky, 2008). While the consideration of utilizing LID for stormwater management is commonly recognized, the application of LID techniques for CSO control has been limited (U.S. EPA, 2004). Although LID techniques are not currently used as a major combined sewer overflow (CSO) control method in most urban areas, it is being used to complement engineered solutions and has shown capability as part of larger stormwater management programs to reduce the need and sizes of structural controls, such as storage (Hyland and Zuravnsky, 2008; U.S. EPA, 2004). Cities currently using LID to assist in preventing CSOs via stormwater runoff prevention are San Francisco, Philadelphia, Chicago, Portland (Oregon), and Seattle.

San Francisco's total land area is approximately 45 square miles of which almost 80% is composed of impervious surfaces, such as streets, sidewalks, rooftops and parking lots. San Francisco is also one of only two cities in California containing a CSS. Although their CSS currently meets regulatory requirements, wet weather events produce occasional CSOs (Kennedy et al, 2008). As of 2008, the San Francisco Public Utilities Commission (PUC) was developing a long-term sewer system master plan and under that plan requested an analysis of LID techniques for reducing wet weather flows into their CSS. The project team responsible for this task analyzed LID techniques for urban areas and then performed GIS[8] spatial analyses and LID modeling for drawing conclusions. The team examined several LID practices, including green roofs, porous pavement, street

[8] GIS is a geographic information system that captures, stores, analyzes, manages, and presents data that are linked to location

trees and urban forested areas, rainwater harvesting and bioretention methods[9]. The LID model results demonstrated reductions in storm runoff peak flow rates (responsible for triggering CSOs) for all LID practices modeled (Kennedy et al, 2008).

Philadelphia is 135 square miles and is comprised of 56% impervious surface area and is also home to CSS that experiences occasional CSO events (Neukrug et al, 2004). The Philadelphia Water Department (PWD) has standardized LID implementation throughout the city and LID techniques have been utilized since 2006 to control storm runoff. Techniques used by the city include green roofs, rain gardens, vegetated swales, porous pavement, downspout disconnection and rainwater harvesting. The new city policies promoting LID and green infrastructure have drastically reduced CSO inputs and have saved the city millions of dollars (U.S. EPA, 2010a).

Chicago covers approximately 228 square miles and contains a CSS as well as considerable impervious surface areas. The city has adopted a suite of municipal policies that promote decentralized stormwater management and promote the implementation of LID techniques in new construction projects (U.S. EPA, 2010a). The LID techniques utilized in Chicago include green roofs, rain gardens, vegetated swales, porous pavement, downspout disconnection and rainwater harvesting.

Portland, Oregon spans 125 square miles and as home to a CSS has been a leader in implementing sustainable stormwater infrastructure in the form of LID techniques for several decades. The drive to implement LID techniques was generated by the need to control CSO events and the city has pursued several strategies that promote decentralized stormwater management approaches (U.S. EPA, 2010a). Portland building codes require

[9] Bioretention refers to dispersed, small-scale landscape features designed to attenuate and treat stormwater runoff, and includes techniques described in 3.2.1 as filtration and infiltration LID techniques, such as rain gardens, vegetated swales and tree boxes (Kennedy et al, 2008).

on-site stormwater management for all new construction projects and LID techniques used include green roofs, rain gardens, porous pavement, vegetated swales, downspout disconnection and rainwater harvesting. In the future, about 40% of Portland's total CSO control will be managed via LID techniques (Hyland and Zuravnsky, 2008).

The city of Seattle, Washington area is 84 square miles of which approximately one-third is served by a combined sewer system. A majority of Seattle's LID projects are focused on the concept of a natural drainage system that reduces storm flows through retention and infiltration (Hyland and Zuravnsky, 2008). Although Seattle is predominately implementing bioretention and bioinfiltration LID methods, other LID techniques used by Seattle include green roofs, rain gardens, vegetated swales, downspout disconnection and rainwater harvesting.

4. Rainwater Harvesting

The LID technique that is the focus of this thesis is rainwater harvesting. Rainwater harvesting is simply the collection, storage and reuse of rainwater. Although rainwater harvesting literature and research most often focuses on its ability to provide an alternative source of water, rainwater harvesting is a dynamic tool for stormwater management. Unlike the other LID techniques, it simultaneously promotes water and energy conservation while storing stormwater runoff. The focus of this thesis is to examine the capacity of rainwater harvesting to prevent volumes of stormwater runoff from entering a sewer system, specifically CSSs. It is important to discuss rainwater harvesting in depth and the following sections will review several aspects of rainwater harvesting, including a brief introduction in 4.1 and a review of system components in 4.2. Section 4.3 reviews the multiple benefits associated with rainwater harvesting. Finally, 4.4 briefly presents regulations for rainwater harvesting.

4.1 Introduction/Background

Rainwater harvesting is not a new technique and has been practiced for over 4000 years in cultures throughout the world (Kinkade-Levario, 2007). The development of centralized water treatment facilities in the early 1900s to address health concerns led to the discontinuation of rainwater as a primary water source. Rainwater harvesting is currently gaining momentum as an alternative source of water for many areas, especially areas such as the Southwest U.S., where water supplies are diminishing. It is important to provide background information regarding the makeup of a rainwater harvesting system to fully understand how a system operates, which is presented below.

4.2 Rainwater Harvesting System Components

There are five fundamental components of a rainwater harvesting systems; 1) a collection surface, 2) a conveyance system, 3) pre-tank treatment 4) water storage, and 5) distribution (Lawson et al, 2009). Please refer to Figure 4.1 for a generalized illustration of a rainwater harvesting system. If harvested rainwater is intended for human consumption, an additional treatment/purification system component would be necessary (TWDB, 2005). Consideration of component interactions when designing a rainwater harvesting system can raise system efficiency and reduce economic costs. The following sections will describe these categories in more detail.

Figure 4.1 Generalized Illustration of a Rainwater Harvesting System

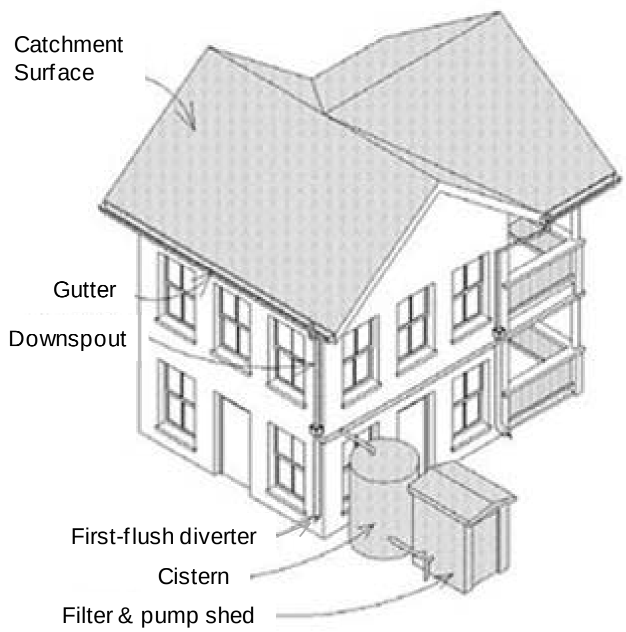

Figure available from The Texas Manual on Rainwater Harvesting, TWDB 2005

4.2.1 Collection Surface

The collection surface is an instrumental component of a harvesting system. The most common collection surface for RWH is a rooftop. Generally, desired roofing for rainwater harvesting is smooth and non-porous, allowing for as much rain collection as possible. It is also important to note the roof pitch, as steep slopes are most desirable for rainwater harvesting as transfer of rainwater to conveyance guttering and downspouts is made simpler. Roofing can consist of several materials, including asphalt shingles, wood shingles, cement tile, terra cotta tile, metal and membrane (Lawson et al, 2009). However, copper roofs or any roofing with lead components should not be used for rainwater harvesting if collected water is intended for human consumption (Lawson et al, 2009). Copper and lead roofing often leach into rainwater falling on them and both lead to serious health risks if consumed over long periods. Popular roofing for RWH are membrane roofs and coated metal roofs due to high associated runoff coefficients[10] during precipitation events (Lawson et al, 2009).

4.2.2 Conveyance System

Gutters and downspouts, also known as the conveyance system, are integral components of a rainwater harvesting system because they capture rainwater from the collection system (rooftop) and convey it to the storage tank or cistern. Popular gutter and downspout materials are galvanized steel, vinyl, half-round PVC, piping, and seamless aluminum (TWDB, 2005). It is important to properly size gutters and downspouts for rooftops with multiple pitches and/or connections, as under-sizing can lead to overflow during high volume precipitation events.

4.2.3 Pre-tank Treatment Components

Directly correlated with the conveyance system are pre-tank treatment components and include leaf screens or leaf guards, first-flush diverters, and pre-tank filters.

Leaf screens or leaf guards are designed to remove debris from the rainwater after it is collected from the rooftop and before it enters the storage tank. Leaf screens or leaf guards cover gutters, generally with fine mesh, and they effectively keep large debris

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[10] A runoff coefficient is defined as the ratio of runoff to precipitation, meaning the ratio of the amount of water that is not absorbed by the surface to the total amount of precipitation that falls during a storm event

from entering gutters during storm events. This reduces excess burden on the filtration system.

During dry periods, rooftops accumulate debris and contaminants. The initial runoff from a roof surface, called the first-flush, generally rinses the roof, leading to cleaner water as the rainfall continues. Sediment, metals and bacteria are reduced as a rain event continues and steady state is generally reached after the first 1 mm of rainfall (Lawson et al, 2009). Diverting about 20 gallons (approximately 1 mm) of rainwater per 1,000 square feet of collection surface is a general rule of thumb for first-flush diversion to ensure harvest of only the cleanest rainwater. The first-flush diverter is a device placed between the gutter and storage tank that discards this initial quantity of rainfall and prevents accumulated rooftop debris and contaminants from entering the storage tanks[11]. The discarded water should then be diverted to a nearby pervious area, ideally a form of bioinfiltration, such as a rain garden or vegetated swale. By discarding the first-flush of water, diverters improve water quality, reduce tank maintenance and protect pumps. Fitting an appropriately sized first-flush diverter is critical to achieving good water quality.

Organic debris that enters the cistern and is stored results in nutrient buildup and low oxygen levels due to decomposition (Lawson et al, 2009). Anaerobic conditions lead to bacterial growth in the tank as well as the potential to develop odors. Pre-tank filters are designed to filter harvested rainwater through a straining action, usually with screen or mesh to eliminate contaminants and small debris. A high quality filter also supplies oxygen to the water during the filtration process (Lawson et al, 2009). The best filter

[11] See Appendix B for additional descriptions and/or illustrations of specific rainwater harvesting components presented in 4.2.3 Pre-tank Treatment Components and 4.2.5 Distribution

material is considered stainless steel because it can withstand all weather conditions, does not rust, keeps its shape, and is self cleaning and drying (Lawson et al, 2009).

Roof washers, a type of pre-tank filter, are placed just ahead of the storage tank and are designed to filter small debris (TWDB, 2005). Roof washers are comprised of a 30 to 50 gallon capacity tank with leaf strainers and a filter that holds water to be filtered before being released into the tank[12]. Roof washers use filters as fine as 30-microns, a filter with pores approximately one-third the diameter of a human hair (TWDB, 2005).

There are also filters on the market that perform both the first-flush and filter straining mechanisms. These modern filters are low-maintenance, needing to be cleaned only twice annually, are designed to last the lifetime of a building, and are efficient at collecting more than 90% of filtered water (Lawson et al, 2009). First flush fine filters are designed to allow the first 5% of rainwater to flow through to be discarded. After discarding the 5% first flush, the fine filter becomes wet and begins filtering fine contaminants before diverting water to a storage tank. There are many filter styles and models to select from,[13] but to ensure filter performance and efficiency, the filter should be sized according to roof area as many are designed to filter variable square footage.

4.2.4 Storage

Cisterns, also referred to as storage tanks, are a central component of rainwater harvesting systems. They are often the most costly feature of a rainwater harvesting system and proper sizing is essential to ensure least cost with maximum storage potential, which will be discussed below. Cisterns can be installed within structures and also above

[12] See Appendix B for additional description and/or illustration of a roof-washer
[13] See Appendix B for additional rainwater harvesting filter illustrations

or below ground, although below ground tanks are generally more expensive to install due to costs associated with excavation and heavier reinforcement (TWDB, 2005).

Tanks or cisterns can be composed of several materials, however, the four most common materials used are plastic, metal, concrete and wood and each of these has advantages and disadvantages. Concrete tanks are very durable while plastic tanks are lightweight, easy to move and clean, durable, and inexpensive. Metal tanks are easy to relocate and both metal and wood tanks are aesthetically pleasing. Cistern material choice will depend on several factors, including geographic location, cistern location (above ground, below ground, inside building or home), local weather patterns, size, and budget.

Cistern costs generally increase with increasing volume and like cistern material, the size is directed by several variables, including local precipitation and precipitation patterns (i.e. dry periods), desired water use from the system, the collection surface area, budget and personal preference. It is important to properly size cistern because over-sizing a cistern results in underutilized cistern volume, translating to a monetary loss. Under-sizing a cistern results in decreased storage capacity, frequent tank overflow (decreased storm runoff control capability), and underutilized water supply from harvesting rainwater. However, properly sized cisterns reduce capital investment while ensuring that water demands are met, making rainwater harvesting an environmentally beneficial and economically viable LID technique.

All cisterns must be equipped with an overflow outlet to prevent backup into gutters and downspouts when cistern volume has reached capacity. The overflow diameter should be at least the same diameter as the inlet pipe and a properly designed overflow can also benefit water quality in the cistern (Lawson et al, 2009). Exactly as with first-flush, cistern overflow should be directed a nearby pervious area, ideally with infiltration capacity. Cisterns should be placed as close to supply and demand points as practical to reduce the distance the water is conveyed.

4.2.5 Distribution

The distribution (or delivery) system is responsible for transporting harvested rainwater from the cistern to the point of end-use in the home or building. Components of the distribution system include calming inlets, pressurized storage tanks, pumps, and float-filters.

Functional rainwater harvesting cisterns collect small amounts of sediments that settle to the bottom of the tank, where higher contaminant concentrations are likely to be found (Gromaire-Mertz et al, 1999). A calming inlet is a device placed at the bottom of the cistern that directs entering water upward to prevent agitation of the settled sediment layer at the bottom of the tank[14]. The calming inlet allows rainwater to enter at the bottom of the tank versus the top. The motion of the calming inlet motion also aerates stored rainwater.

The laws of physics generally require that stored rainwater be distributed with the assistance of a pump and pressure tank to transport water to its intended end use. Standard municipal water pressure is between 40 and 60 pounds per square inch (psi) (TWDB, 2005). Pump systems draw water from the cisterns, pressurize it, and then store the water in a pressure tank until it is needed (TWDB, 2005). Pump systems are designed

[14] See Appendix B for an illustration of a calming inlet

to push water rather than pull it, so it is wise to place the pumps at the same level and as close to the storage tanks as possible. New, on-demand pumps terminate the need for a pressure tank as well as the associated cost and space because they combine the pump and pressure tank function into one device that activates in response to demand.

A floating filter is a device that allows harvested rainwater to enter the pumping system through an elevated uptake point and is attached to the end of the pump's suction hose to draw water from the tank[15]. As mentioned earlier, collected sediment at the bottom of the cistern has elevated concentrations of pollutants, therefore water should not be drawn from the bottom. The cistern surface water also contains increased concentrations of bacteria and also should not be where water is directly drawn from. A floating filter floats on the surface of the cistern water and allows the pump to draw water from the calm, clean water that is in the middle of the tank, generally 10 to 16 inches below the surface.

4.2.6 Additional Treatment For Potable water use

Rainwater harvested solely for outdoor uses does not require additional treatment. However, both potable and non-potable indoor water uses need additional treatment in the form of sediment filtration and disinfection.

A considerable percentage of contaminants found in rainwater is found bound to small sediment particles (Gromaire-Mertz et al, 1999). Sediment filters are designed to remove those remaining small particles, and EPA guidelines for non-potable indoor uses require a sediment filter of 5 microns or less (Kloss, 2008).

[15] See Appendix B for an illustration of a floating filter

There are several forms of disinfection for potable rainwater use, including chlorination, ozonation, reverse osmosis, and ultraviolet light (Lawson et al, 2009). Disinfection methods are best placed after the pressure tank or on-demand pump (TWDB, 2005). Chlorination is an inexpensive disinfection method, however is not always effective at killing all pathogenic contaminants potentially present in harvested rainwater and alters the taste of the water (TWDB, 2005). Ozonation uses ozone to destroy bacteria and viruses, however is less effective at eliminating viruses, but does not leave behind a residual taste. Reverse osmosis mechanically filters bacteria and viruses rather than destroying them, however reverse osmosis units waste large quantities of water and is not the most desirable filtration method for a rainwater harvesting system.

The most popular form of filtration is ultraviolet (UV) light. UV light destroys bacteria and viruses in a non-chemical process, it does not alter the taste of the water and is inexpensive and low-maintenance (Lawson et al, 2009). UV light is only productive on clear water, so it is very important to include a sediment filter if utilizing a UV filtration device. An activated charcoal filter is also recommended for rainwater intended for potable uses. Proper rainwater harvesting system design ensures harvested rainwater is a safe water source. Next, 4.3 examines rainwater harvesting regulations.

4.3 Regulations

There are several barriers to promoting the widespread implementation of rainwater harvesting systems in the U.S. These barriers include lack of regulations and codes, improper pricing of water, and water right doctrines. Each of these will be discussed below.

Rainwater harvesting is largely excluded within regulations and codes here in the U.S. and is not addressed in either the Uniform Plumbing Code (UPC) or the International Plumbing Code (IPC) (Kloss, 2008)[16]. When actually incorporated in the UPC or IPC, guidance for the use of rainwater will be similar to reclaimed water (sewage that is treated to remove solids and other impurities and is purified to a level suitable for controlled non-potable applications) and graywater (wastewater generated from domestic activities such as sinks, showers, and washers that is purified and reused for non-potable water applications), both of which are included in the IPC and UPC. This lack of public policy[17] is restrictive to developing rainwater harvesting. Changing our current codes will be the first step towards widespread rainwater harvesting implementation.

The current price of water here in the U.S. creates little incentive for people to look at alternatives, with the cost of water ranging from $0.70 to $4.00 per thousand gallons and the average being $2.00 per thousand gallons (Kloss, 2008). Water demand is relatively inelastic, so increasing the price of water will not result in an extremely reduced demand. Implementing full pricing of water (which includes external costs such as water treatment and distribution) in the price of water for customers will assist in promoting rainwater harvesting as well as water conservation.

Water rights in the U.S. are dictated by state water laws and consist of two basic doctrines, the riparian doctrine and prior appropriation doctrine (U.S. GAO, 2003). The riparian doctrine is common in the Eastern U.S. while the prior appropriation doctrine is

[16] The UPC is designated as the American National Standard and is a model code developed to govern the installation and inspection of plumbing systems as a means of promoting public health. The IPC is a building code and standard which sets out minimum requirements for plumbing systems in their design and function, and which sets out rules for the acceptances of new plumbing-related technologies.

[17] Public policies are rules, regulations, laws and codes that are developed to ensure public safety and economic activity.

common in the Western U.S. The riparian doctrine links water rights to land ownership and states that if water is on someone's property, it is theirs to use and all other landowners bordering the water will be given equal rights. The prior appropriation doctrine (often referred to as western water rights) instead links water rights to priority and beneficial use. Prior appropriation makes harvesting rainwater difficult as it is capturing rainwater previously appropriated for groundwater recharge and/or surface water recharge. However, many western states, including Washington, allow rainwater harvesting because it is a water conservation practice that can reduce the withdrawal and use of potable water drawn from groundwater and/or surface water sources, therefore making a greater quantity of water available for all. Furthermore, rainwater reused for irrigation purposes would simply mimic rainfall. Next, rainwater harvesting benefits are discussed in depth in 4.4.

4.4 Rainwater Harvesting Benefits

Rainwater harvesting is a powerful tool that can be used to collectively address issues related to water and energy conservation as well as stormwater management. Water shortages are occurring globally and rainwater is being used in many areas as a clean, reliable water source. Rainwater harvesting not only offsets peak water demand periods (generally summer months when irrigation demands are highest), but also reduces high water consumption rates by supplying a safe water source for non-potable water uses. Rainwater harvesting systems collect and store volumes of rainwater, thereby providing stormwater runoff control function as well.

Rainwater harvesting has both upstream and downstream benefits. Upstream (at source) benefits include water conservation, energy conservation, and financial savings. Rainwater harvesting for stormwater management is the downstream (mitigating impact) benefit. This next section will describe the benefits associated with rainwater harvesting in more detail.

4.4.1 Water Conservation

Hoekstra and Hung introduced the water footprint concept in 2002. The water footprint of a nation is defined as the total volume of freshwater that is used to produce the goods and services consumed by the population of that nation (Hoekstra and Chapagain, 2007). Most water use data typically divides consumption information into three categories: domestic water withdrawals, agricultural sector water withdrawals and industrial water withdrawals. However, the water footprint concept incorporates internal and external water footprint analysis within these three categories. An internal water footprint is the volume of water used from domestic water resources while the external water footprint is the volume of water used in other countries to produce goods and services imported and consumed by the people of the country (Hoekstra and Chapagain, 2007).

The size of a water footprint is largely influenced by consumption of food and other agricultural products. The global water footprint is 1240 m^3/capita/year (327,450 gallons/capita/year) average. The U.S. has the largest water footprint, double the global water footprint at 2480 m^3/capita/year (654,900 gallons/capita/year) average, while China's average water footprint is 702 m^3/capita/year (185,380 gallons/capita/year) (Hoekstra and Chapagain, 2007).

Rainwater harvesting is distinct because it is effectually the only stormwater BMP that can also provide an alternative water supply. As population growth continues, U.S. regional water authorities and municipalities must anticipate and secure sufficient water supplies for their customers. All publicly supplied water is treated to potable water (drinking water) standards. In fact, our water delivery infrastructure requires that we use water treated to potable standards for all water applications. However, a significant portion of our per capita water use is applied for non-potable purposes (see Figure 4.2).

Figure 4.2 Percent of Total Water Use that is Non-Potable

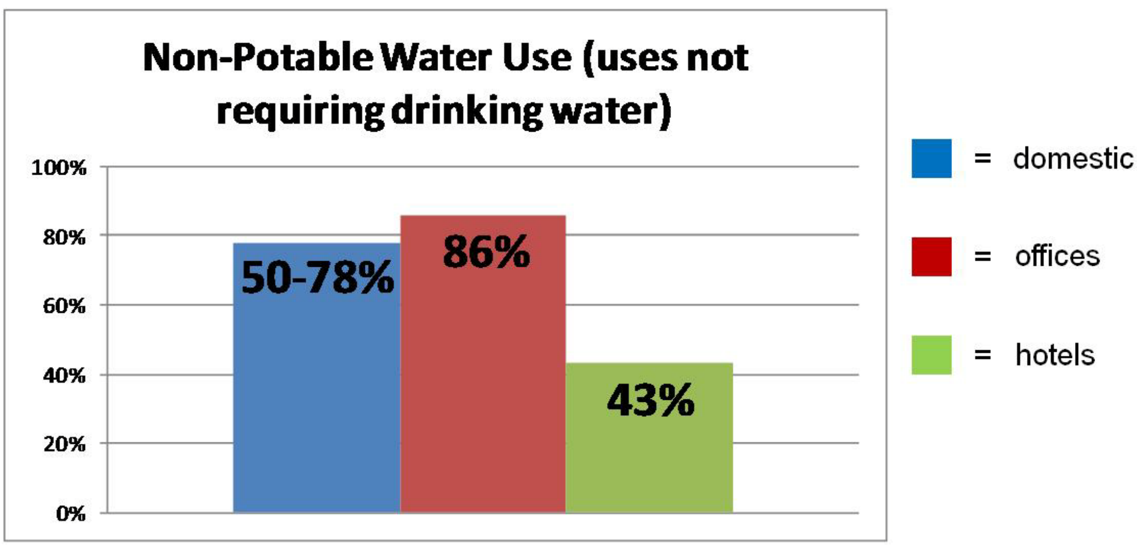


Figure adapted from Foraste and Hirschman, 2009

Non-potable water uses include toilet flushing, vehicle washing, laundry washing, household cleaning and landscape irrigation. Almost 80% of U.S. domestic water demand does not require potable water (Kloss, 2008). When reviewing U.S. household water use, examining indoor and outdoor end uses of water is revealing.

A 1999 study of the 1188 homes in 12 diverse study sites to determine residential (domestic) end uses of water in the U.S. found indoor water use comprises 40.3%

and outdoor water use comprises 58.7% of the total determined average 171.8 gallons per day per home water use (see Figure 4.3) (AWWA, 1999). A large portion of indoor water use is for non-potable applications. A clothes washer and toilet alone account for approximately 50% of indoor home water use and the bathroom is consistently the most water consumptive part of a household (see Figure 4.3).

Figure 4.3 U.S. Mean Daily Per Capita Domestic Water Use

Fixture/EndUse	Avg. gallons per capita per day	Avg. liters per capita per day	Indoor use%	Total use%
Toilet	18.5	70.0	30.9%	10.8%
Clothes washer	15	56.8	25.1%	8.7%
Shower	11.6	43.9	19.4%	6.8%
Faucet	10.9	41.3	18.2%	6.3%
Other domestic	1.6	6.1	2.7%	0.9%
Bath	1.2	4.5	2.0%	0.7%
Dishwasher	1	3.8	1.7%	0.6%
Indoor Total	***59.8***	***226.3***	***100.0%***	***34.8%***
Leak	9.5	36.0	NA	5.5%
Unknown	1.7	6.4	NA	1.0%
Outdoor	100.8	381.5	NA	58.7%
TOTAL	**171.8**	**650.3**	**NA**	**100.0%**

Figure available from AWWA, 1999

As mentioned above, outdoor water use comprises 58.7% of total average home water use. However, outdoor water use is more variable as regional locations and variable property sizes lead to large differences in need for outdoor applications. There is a direct correlation of lot square footage and the percentage of irrigable landscape to the quantity of water used outdoors (AWWA, 1999). Outdoor water use is also dictated by seasonal variability as dominant outdoor water uses are for irrigation, car washing and pool filling. These activities most often occur during warmer and/or drier months, which are highly variable due to climatic variation within the U.S. These periods are commonly referred to as peak demand periods and are problematic when partnered with warmer temperatures and diminishing precipitation events associated with climate change.

Commercial buildings consume a significant portion of our potable water here in the U.S, estimated at 15 trillion gallons of water (USGBC, 2010). Commercial water use includes water for motels, hotels, restaurants, office buildings and other commercial facilities as well as government and public institutions (USGS, 1998). Water use in commercial buildings varies with plumbing fixture type, equipment installed and building function. Regardless of these factors, the restroom plumbing fixtures (toilets, urinals, faucets and showers) account for the majority of building water use (Gilmer and Hughel, 2008). Approximately 60% of total water use in office and administrative buildings is linked to restroom and plumbing fixtures while heating and cooling systems are responsible for the remaining 40% (Gilmer and Hughel, 2008).

The majority of water uses, both domestic and commercial, are for applications that do not require potable water. Rainwater harvesting can supply an alternative non-potable water source that can relieve demand on potable water sources and ease peak demand periods. Rainwater harvesting is an alternative non-potable (and potentially potable) water source that has the ability to relieve demand on potable water supplies, ease peak demand periods, increase water use efficiency and promote water conservation. Next, energy conservation as related to rainwater harvesting will be discussed.

4.4.2 Energy Conservation

Water use and energy use are closely linked. In providing and using water we consume large quantities of energy. The EPA estimates drinking water and wastewater services account for an estimated 3% (56 billion kWh) of total national energy consumption (U.S. EPA, 2010b). Energy is used to withdraw raw water from its source, treat that water and then distribute it (Foraste and Hirschman, 2009). The end uses of this water (further treatment, circulation, heating and cooling) also requires additional energy, however is not included in the drinking and waste water energy consumption estimate (NRDC, 2004).

Estimates of energy required to perform various functions in the water use cycle are wide ranging (Griffiths-Sattenspiel and Wilson, 2009). The existing water-energy nexus research and corresponding literature is focused on California, which transports water over extremely long distances and will realize immediate energy savings through water conservation practices. Therefore, energy consumption per unit of publicly supplied water varies from system to system and region to region as it is dependent on community size and water use priorities (Foraste and Hirschman, 2009).

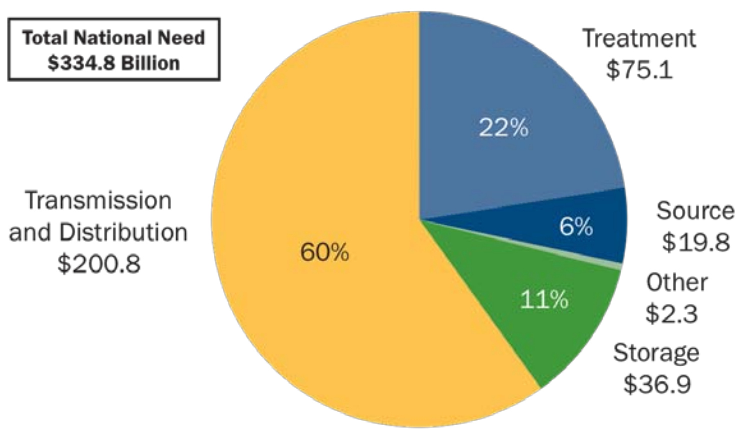
The water-energy nexus depends on several factors. First, the drinking water source and location (energy used for water withdrawals), where more energy is required as distance from source to end use increases. Second, the drinking water utility treatment, meaning treatment level and energy used to achieve that level. Third, community water use (per capita water use and estimated population increases to determine energy used to treat water volume over time scales). Fourth, drinking water utility location (centrally located facility or is water distributed over long distances.)

Increased transportation to and from drinking water utility equates to increased energy used. Fifth and sixth respectively are wastewater utility treatment (increasing standards of treatment require increasing quantities of energy) and wastewater utility location (centrally located facility or is wastewater transported over long distances). Finally, energy used in the water sector depends on whether the community energy source is derived from fossil fuels or renewable energy.

Water supply, use, and disposal are easy to interpret in 3 stages: supply and conveyance, water treatment, and distribution. Most water used in the U.S. is drawn from groundwater aquifers or diverted from surface sources, such as rivers, streams or lakes (NRDC, 2004). Considerable quantities of energy may be needed to create a source of water and transport it to where it will be treated or consumed. From the total energy consumed by public water systems, water distribution accounts for 83%, while supply and conveyance and water treatment account for 10% and 7% respectively (Foraste and Hirschman, 2009), meaning the majority of energy used by public water systems is used to distribute water.

Not only is water distribution the most energy consumptive stage of water supply, use and disposal, but many of the public water supply systems were constructed either around the turn of the 20th century or shortly after the passage of the Clean Water Act in 1972. These systems are now considered outdated and will need costly updates. Water supply and treatment infrastructure includes reservoirs, pump stations, storage tanks, water treatment plants and piping distribution systems (Foraste and Hirschman, 2009) and each of these components represent considerable investments. A 2009 EPA report estimated a $334 billion investment will be needed for repairs and maintenance of municipal water systems for the 20-year period from January 2007 through December 2026 and priority need originates in the transmission and distribution infrastructure (see Figure 4.4) (U.S. EPA, 2009). As rainwater harvesting is a decentralized source of water supply (available on-site), energy consumption associated with water treatment and distribution for municipally supplied water is eliminated for the duration stored rainwater is used.

Figure 4.4 20-Year Monetary Need for Infrastructure Updates by Water Sector (in 2007 dollars)



Available from EPA Report 816-R-09-001, 2009

A large, centralized water system that fails can have a greater negative impact on a community than the failure of small, decentralized systems (Villarreal and Dixon, 2004), such as rainwater harvesting systems. As the water transportation sector represents the category containing the largest need for update and investment, on-site rainwater harvesting also mitigates the need to perform costly updates to our water supply and treatment infrastructure if widespread implementation occurs.

The 56 billion kWh of energy accounted for in the water and wastewater utilities produces 45 million tons of greenhouse gases (U.S. EPA, 2010b). A highly generalized estimate using the average mix of energy sources results in 1 kWh of energy consumption relative to water infrastructure producing 1.6 pounds of greenhouse gas emissions (U.S. EPA, 2010b). This generalized estimate leads to the conclusion that each U.S. resident is responsible for consuming 182 kWh annually for drinking and wastewater needs, generating approximately 293 pounds of GHG annually. The EPA estimates that $400 million savings nationwide can be realized annually if the water and wastewater utility sector reduces energy use by 10% (U.S. EPA, 2008b). Decreasing potable water demand by 1 million gallons can result in reducing electricity use by nearly 1500 kWh (Kloss, 2008), preventing approximately 2400 pounds of GHG emissions.

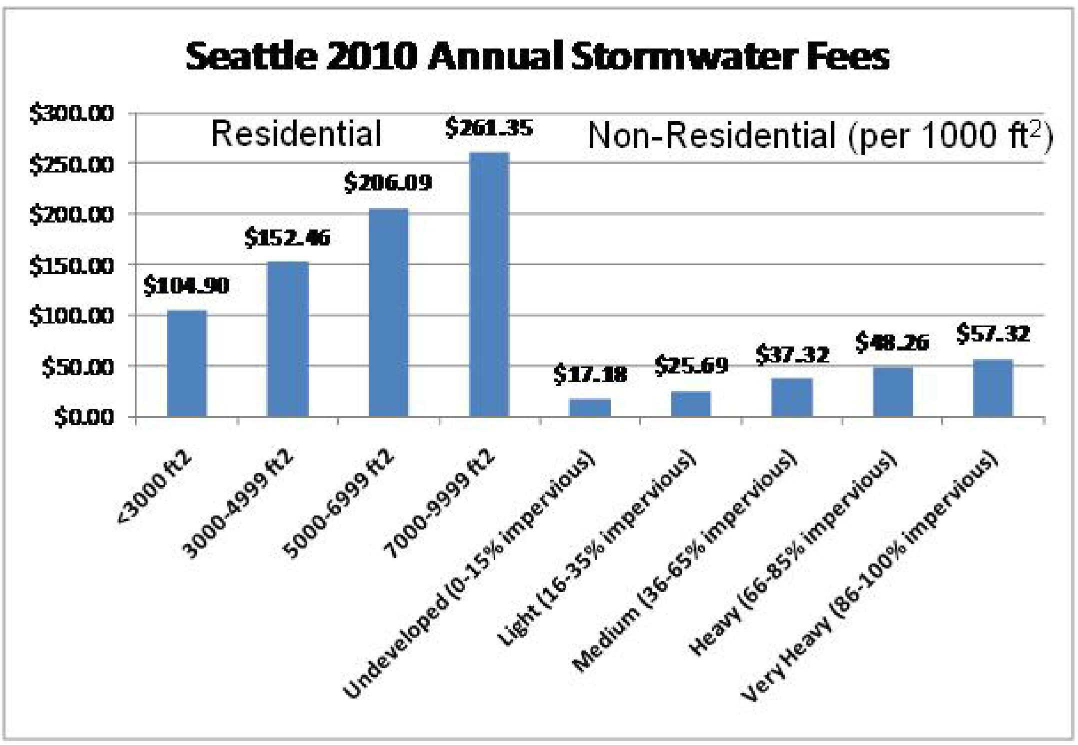
A rainwater harvesting system installed at the King Street Center in Seattle, Washington collects rainwater harvested from the rooftop into three 5400 gallon cisterns. The collected rainwater in this building saves approximately 1.6 million gallons of potable water annually by using collected rainwater for flushing toilets and irrigation purposes (Kinkade-Levario, 2007). One building can make a considerable impact in reducing potable water need and the associated embedded energy in the water transportation sector. Not only do rainwater harvesting systems conserve water and energy, they also represent long-term financial investments, which will be discussed next.

4.4.3 Financial

There is a variety of different rainwater harvesting systems and installation costs for a system are variable. Despite this variety, systems are most economically viable and efficient when incorporated into new construction rather than retrofitting onto an existing structure (Kinkade-Levario, 2007).

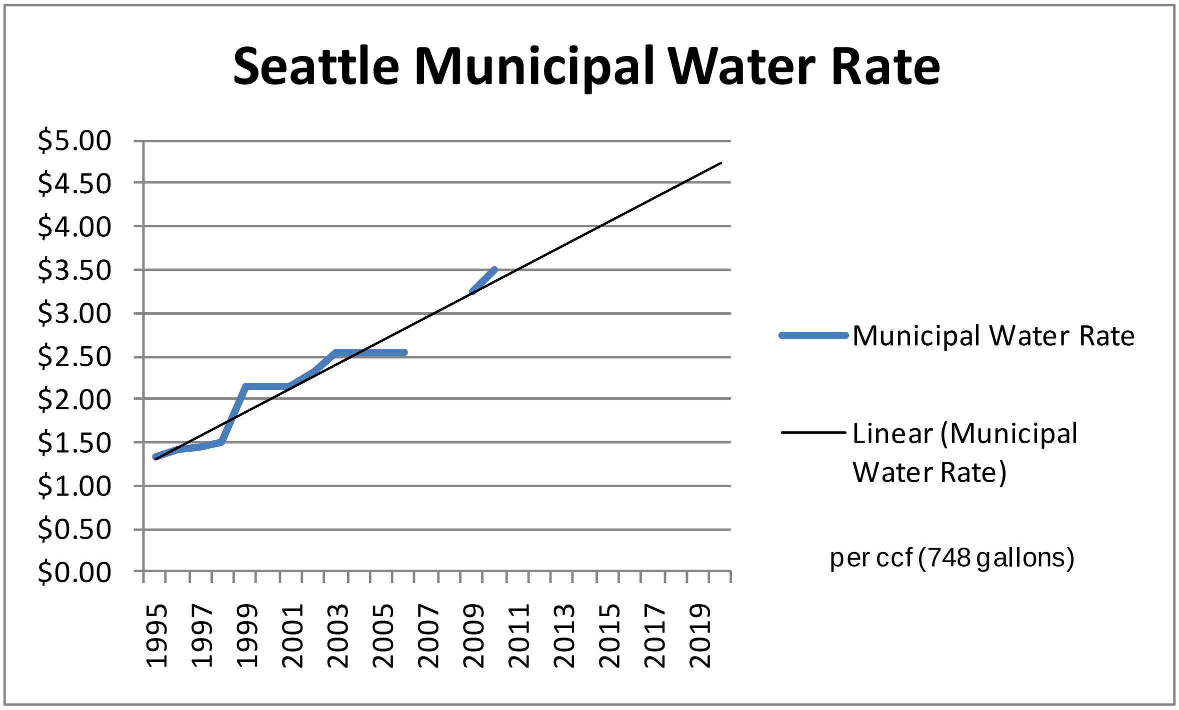
Installing a rainwater harvesting system is a single investment that pays back over its lifetime. Many communities charge increasing (and often substantial) storm runoff fees associated with higher proportions of impervious surfaces on land parcels (see Figure 4.5) (SPU, 2010; City of Tacoma, 2010). These fees can often be discounted by incorporating an approved stormwater BMP, such as a rainwater harvesting system.

Figure 4.5 Example storm runoff fees



Not only are storm runoff fees substantial, but water rates across the nation are rising and are projected to increase exponentially over time with population growth (see Figure 4.6) (SPU, 2010; City of Tacoma, 2010). Owners of rainwater harvesting systems that utilize stored water will realize immediate and direct financial benefits through decreased purchases of municipal water. The payback period for a harvesting system is dependent on system cost as well as discounted site storm runoff fees and decreased municipal water use.

Figure 4.6 Example Water Rate Increases[18]



An example is a rainwater harvesting system installed on Eggleston Laundry in Virginia in 2001. The 34,000 square foot facility paid $30,000 to retrofit for 20,000 gallons storage capacity. The initial predicted return-on-investment was 3 years but after replacing the need for a substantial quantity of municipal water, the payback period was reduced to 12 months (Kinkade-Levario, 2007).

[18] Line breaks due to water rates for all prior years unavailable

4.4.4 Stormwater Management

By collecting and storing volumes of stormwater, a RWH system inherently reduces the volume of stormwater runoff entering a community's storm system. RWH systems designed for large-scale commercial buildings that are highly occupied, such as schools, hospitals and office buildings, have the ability to effectively store large volumes of stormwater that will be utilized on a regular basis, maintaining available storage. The goal of this thesis is to clarify areas of uncertainty regarding the potential of RWH to assist in SWM goals by modeling the performance of RWH systems during high volume precipitation events in Olympia, Washington. It is important to discuss below why Olympia was selected as the case study location.

5. Case Study Selection

The city of Olympia is Washington's state capitol and is located within Thurston County. Olympia is located on the southernmost point of Puget Sound and borders Budd Inlet (see Figure 5.1). Although smaller than its Puget Sound counterparts Seattle and Tacoma, Olympia comprises 16.71 square miles and is home to just over 40,000 residents. Because Olympia is the capitol of Washington, economic activity is primarily derived from state government activity, which provides a stable work force, an engaged and educated community, and a well-supported school system (City of Olympia, 2010a).

Olympia was selected as the case study location for five reasons that will be discussed in the upcoming sections. 5.1 will discuss Olympia's location in that it borders the diverse Puget Sound ecosystem. 5.2 will discuss Olympia land development and

Figure 5.1 Olympia Location

impervious surface coverage. 5.3 will discuss Olympia's precipitation, as high intensity precipitation events are likely while 5.4 will discuss Olympia's sewerage as the city is home to a CSS. Finally, 5.5 will briefly discuss Olympia's role as the state capitol, as there are several large scale government and commercial buildings within the CSS area that remain highly occupied during the week, making RWH system implementation a very attractive option. I will discuss each of the above reasons in detail below.

5.1 Puget Sound

Puget Sound is a unique and valuable ecosystem located in Western Washington (see Figure 5.2). Retreating glaciers carved Puget Sound 11,000 to 15,000 years ago at the end of the last ice age (Puget Sound Partnership, 2010). It is the second largest estuary in the U.S., with over 3000 kilometers of shoreline and fjord-like geomorphology

Figure 5.2 Puget Sound

is unique in the U.S.

Like many coastal ecosystems worldwide, Puget Sound is showing evidence of degradation (Puget Sound Partnership, 2010). Coastal ecosystems both globally and locally are experiencing trends including increasing numbers of imperiled species, disrupted food webs, degraded and/or loss of habitat for many species, and increasing levels of toxic contaminants (Puget Sound Partnership, 2010).

In 2007, the Washington State Legislature enacted Engrossed Substitute House Bill 5372 with the stated goal of restoring the health of Puget Sound by 2020. The responsibility of overseeing and implementing this legislation was given to a newly created state agency, the Puget Sound Partnership. The agency goal is to have Puget Sound considered a "healthy" ecosystem, a self-sustaining system that supports human societies by providing goods and services in the form of energy, food, building materials, water purification, flood and erosion control, as well as providing spiritual enrichment, recreation and aesthetic experiences (Puget Sound Partnership, 2010). Washington is dependent upon Puget Sound to provide goods and services to maintain a high quality of life for residents.

The Puget Sound Partnership is founded on four fundamental beliefs. First, Puget Sound is a national treasure and the life-blood of Washington State. Second, the Puget Sound ecosystem is in serious decline and will likely worsen through time. Third, current activities to protect and restore the Puget Sound ecosystem are fragmented, uncoordinated, and mostly ineffective at the ecosystem scale and fourth, Puget Sound is worth protecting and restoring. The agency further emphasizes that the need for action is urgent as population growth, climate change, and other forces are fundamentally altering

Puget Sound (Puget Sound Partnership, 2010).

The Puget Sound marine nearshore is at the nexus of the aquatic and terrestrial environments and provides habitat for many species. Many of these species are economically important, such as sea grasses, kelp, and forage fish (Puget Sound Partnership, 2010). The nearshore habitat is extremely important in maintaining ecosystem function in Puget Sound because it is created and maintained by processes involving transfers of sediment, nutrients, water and other constituents. It is also the location where substantial human development has occurred.

As mentioned above, Olympia is located on the southernmost point of Puget Sound and borders Budd Inlet. Olympia was established in 1850 and expeditiously developed around the waterfront in the mid-1850s and quickly became a central point for maritime commerce (City of Olympia, 2010c). Budd Inlet was historically a favorite shellfish gathering site for many coastal Native American Salish tribes before European settlement (City of Olympia, 2010a). However, shellfish harvesting for human consumption is currently not recommended because of degraded water quality[19].

Recently, Olympia's growth and subsequent urbanization has aggravated stressors placed on the natural hydrologic system. The next section will discuss Olympia's population growth and link to urban development and increased impervious surfaces.

5.2 OLYMPIA DEVELOPMENT AND IMPERVIOUS SURFACES

Olympia is a naturally aqueous environment that historically contained extensive wetlands and forests. Over the last 150 years, human occupation and activity has

[19] A primary reason behind degraded water quality of Budd Inlet is due to historical sewer system outfall and will be discussed below in 5.4

disturbed the intricate hydrologic cycle that sustains Olympia's natural ecosystem processes (City of Olympia, 2003).

Olympia contains 1.81 square miles of water and Olympia's surface water consists of eight major streams totaling 16 miles in length, four major lakes comprising approximately 430 acres within the city, and about 6 miles of Budd Inlet shoreline (City of Olympia, 2003). These waters along with adjacent landscapes are home to a diverse population of aquatic and terrestrial species that are impacted by anthropogenic activities.

The major trends affecting Olympia's aquatic ecosystems include forest removal, wetland filling, covering land with impervious surfaces, routing creeks below-ground, and allowing toxic substances to multiply, all of which are associated with human activity. The results of these activities include water quality degradation, variable seasonal high and low flows, flooding, streambed alteration and habitat loss, erosion, stream-channel widening, and impediment to fish migration and spawning (City of Olympia, 2003).

As discussed earlier in 2.1, impervious surfaces degrade water quality by replacing natural land covers with new surfaces such as buildings, streets, parking lots, driveways and sidewalks (City of Olympia, 1995). These surfaces do not allow rainwater to infiltrate into the soil, contain nonpoint source pollutants that are collected by storm runoff, and increases the amount of polluted storm runoff entering a watershed's[20] surface water. As little as 10% impervious surface coverage within a watershed has been shown to degrade water quality (City of Olympia, 2003).

The City of Olympia states that urban growth is surpassing science and

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[20] A watershed is a region of land within which water flows down to a specified receiving body, such as a stream, river, lake or ocean

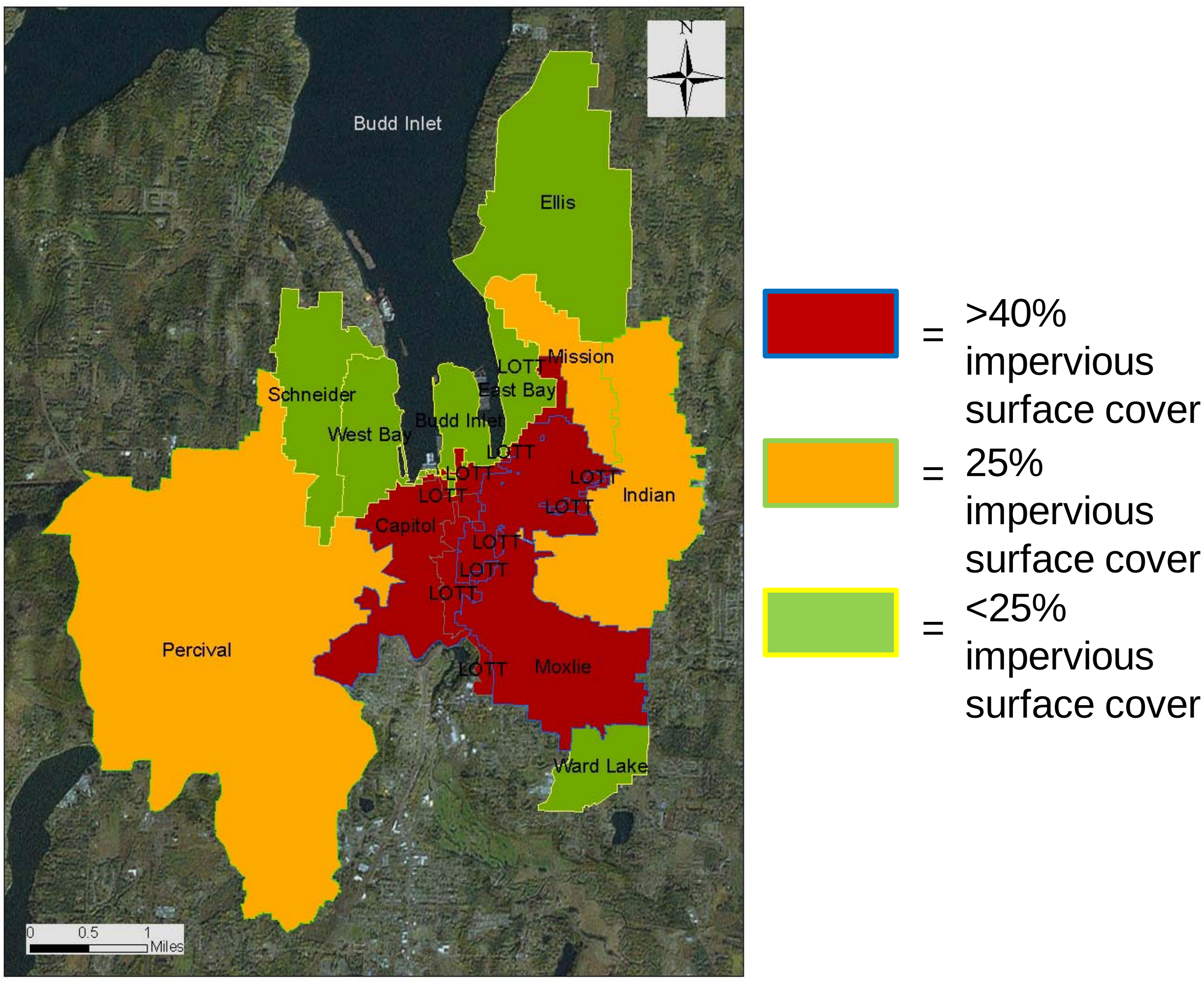
technology's ability to provide solutions for complicated water resource problems characteristic within the urban locale (City of Olympia, 2003). Olympia has experienced one of the highest growth rates in the nation between 1970 and 2000 (City of Olympia, 2003), growing from 23,111 residents in 1970 to 42,000 residents by 2000 (TRPC, 2009). This large population growth period contributed to Olympia's impervious surface area. Olympia is estimated to reach a population of over 79,000 by the year 2025, indicating the importance of protecting water quality from polluted storm runoff generated from impervious surfaces.

Reducing impervious surfaces and mitigating the impacts from impervious surfaces for the purpose of maintaining water quality is a top priority for Olympia because surface water provides 80% of the City's drinking water while the other 20% is drawn from groundwater supplies (City of Olympia, 2010b). By not allowing rainfall to infiltrate into the soil and generating storm runoff, impervious surfaces pollute surface water and deplete groundwater supplies that Olympia depends on for drinking water (City of Olympia, 1995).

Olympia is composed of several drainage basins (see Figure 5.3). As little as 10% impervious surface cover in watersheds/drainage basins has been shown to degrade the health of the aquatic ecosystem. Downtown Olympia houses the most urbanized drainage basins (shown in red) and includes Moxlie Creek basin, containing 47.5% impervious surface cover and Capitol Lake basin, which contains 41.1% impervious cover (TRPC, 2003). Indian, Mission, and Percival Creek basins all contain approximately 25% impervious surface cover, all of which are well above the threshold of cover that degrades aquatic ecosystem health.

Although development and increased impervious surfaces are problematic for any community's watershed health, they are most troublesome for communities that receive high intensity precipitation events, therefore generating large volumes of storm runoff. The next section will discuss Olympia's precipitation patterns to understand the City's storm and surface water patterns.

Figure 5.3 Olympia Drainage Basins[21]



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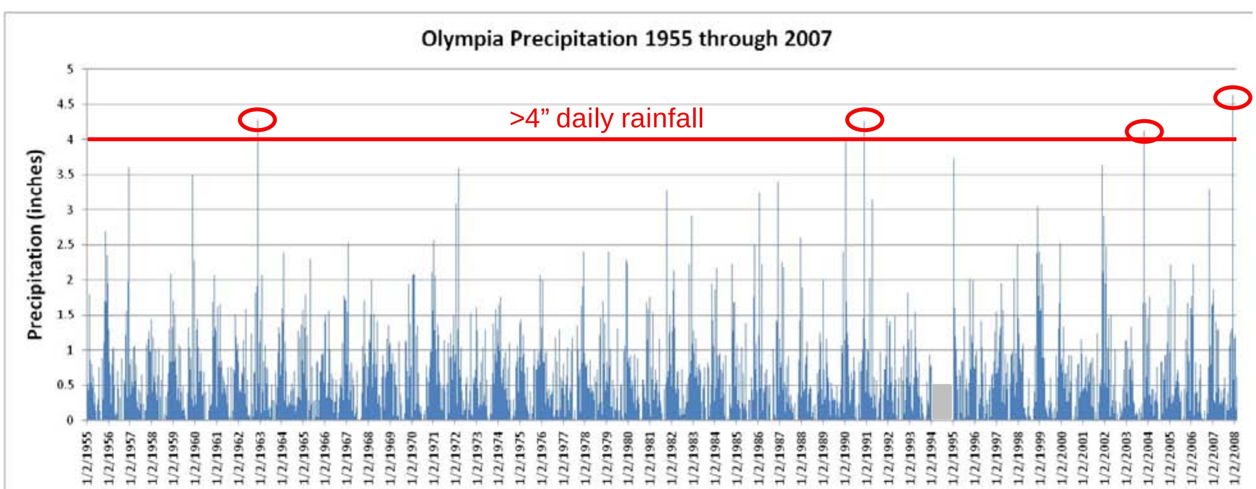
[21]The drainage basins denoted LOTT could not be located within Thurston County data so the presumption is that all water falling in the LOTT basin goes directly to Budd Inlet Treatment Facility, which will be discussed in depth later in 5.4. City and county drainage basin maps indicate that Capitol and Moxlie basins touch boundaries and absorb the mapped LOTT basin and the same for Mission and East Bay basins

5.3 OLYMPIA STORM AND SURFACE WATER

Like most of western Washington, Olympia experiences mild climatic conditions, including sunny summers and wet winters. Olympia receives an average of 51 inches annual rainfall, and while less than other U.S. city's average annual rainfall (i.e. 67 inches in New Orleans, 63 inches in Atlanta and 53 inches in Houston), the rainfall tends to be dispersed over extended temporal periods unlike the other mentioned regions (TRPC, 2009). Olympia is subject to experience high intensity precipitation events (see Figure 5.4) (note the storms where greater than 4 inches of precipitation fell in a single day). Although these events occur only occasionally, climate change is expected to alter precipitation patterns for Olympia (City of Olympia, 2007e). Only one of these very intense precipitation events took place between 1955 and 1990, but between 1990 and 2008, three have occurred.

Figure 5.4 Olympia Rainfall 1955 through 2007[22]



[22] This figure represents Olympia rainfall with a focus on events where over 4" of rain fell in a single day (potential CSO trigger precipitation), thus the focal point is the occurrence of red circles. Please see Appendix D for a larger, more readable precipitation graph.

Climate change is expected to alter Pacific Northwest precipitation by producing a moderate increase from November through January (Salathe et al, 2008) and Olympia specifically will experience increased precipitation over winter months (City of Olympia, 2007e). A statistically significant increase of extreme precipitation events is also predicted to occur (Tebaldi et al, 2006). Warmer ocean temperatures will evaporate greater quantities of moisture and warmer air temperatures are capable of holding more moisture. When this moister air moves over land, more intense precipitation is produced (Tebaldi et al, 2006).

Olympia is likely to experience increased potential for high intensity precipitation events. These events are most problematic in urban areas containing high proportions of impervious surfaces that are also served by a CSS. Olympia is partially served by a CSS and the next section will discuss Olympia's storm and sewer system in detail.

5.4 OLYMPIA SEWER AND STORM SYSTEM

After Olympia's establishment in 1850, the first permanent sewers were installed in 1892 (City of Olympia, 2007d). These first sewer lines were generally short pipes flowing directly into Budd Inlet or Deschutes Waterway that with little planning were extended as the City developed. The Budd Inlet Treatment Plant was originally built in 1949 to manage Olympia's wastewater needs and the plant's outfall was discharged directly into Budd Inlet. Until the mid-1950's, Olympia's sewer lines were combined, carrying both sanitary and storm flows in single pipes that discharged into Budd Inlet. In 1955, the City mandated that future sewer systems in Olympia be separate systems, disconnecting sanitary from storm flows.

Plant discharge has gone through various levels of treatment over the years due to impacts on Budd Inlet aquatic ecosystem health and is monitored by the Washington State Department of Ecology under the NPDES Permit Program.

Primary sewage treatment removes larger floating objects through screening and sedimentation and removes approximately half of suspended solids and significantly reduces biological oxygen demand (BOD). In the early 1950s the Plant treated wastewater at the primary level before releasing outfall into Budd Inlet (LOTT, 2010a). Primary treatment alone is not considered adequate for the protection of the environment or people's health.

Budd Inlet Treatment Facility was upgraded in 1985 to secondary treatment, which relies on processes similar to natural biological decomposition and removes over 90% of suspended solids and BODs. However, this level of treatment does not remove viruses, heavy metals, dissolved minerals or certain chemicals.

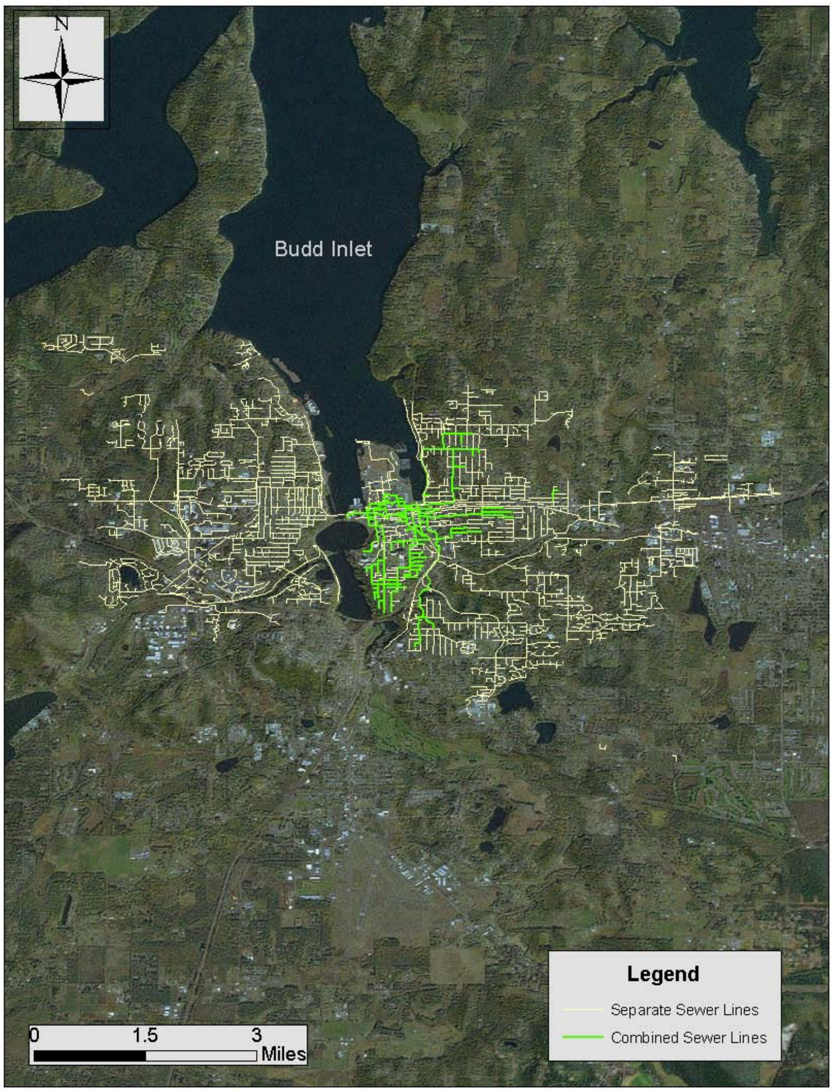
In 1994, upgrades to tertiary treatment processes (advanced level of treatment removing approximately 99% suspended solids and BOD) were incorporated by integrating nitrogen removal and ultraviolet disinfection. In 2004, the Budd Inlet Treatment Plant was further upgraded with the addition of a new Class A reclaimed water[23] sand filter system.

The Budd Inlet Treatment Plant handles storm and wastewater from Olympia as well as from the nearby cities of Lacey and Tumwater as well as the rest of Thurston County, and is owned and operated by the LOTT (Lacey, Olympia, Tumwater, Thurston)

[23] Reclaimed water is former sewage that is treated to remove solids and impurities and purified to a level suitable for further use, such as sustainable landscape irrigation, to recharge groundwater aquifers, or discharge into surface waters.

Alliance. Currently Olympia is primarily served by a conventional sewer system[24] that covers approximately 18 square miles and consists of over 698,000 feet of sewer pipe (LOTT, 2005). Although Olympia's sewer system is primarily a separate sewer system, approximately 600 acres of the downtown area is served by a combined sewer system (see Figure 5.5) (LOTT, 2005).

Figure 5.5 Olympia Sewer Lines

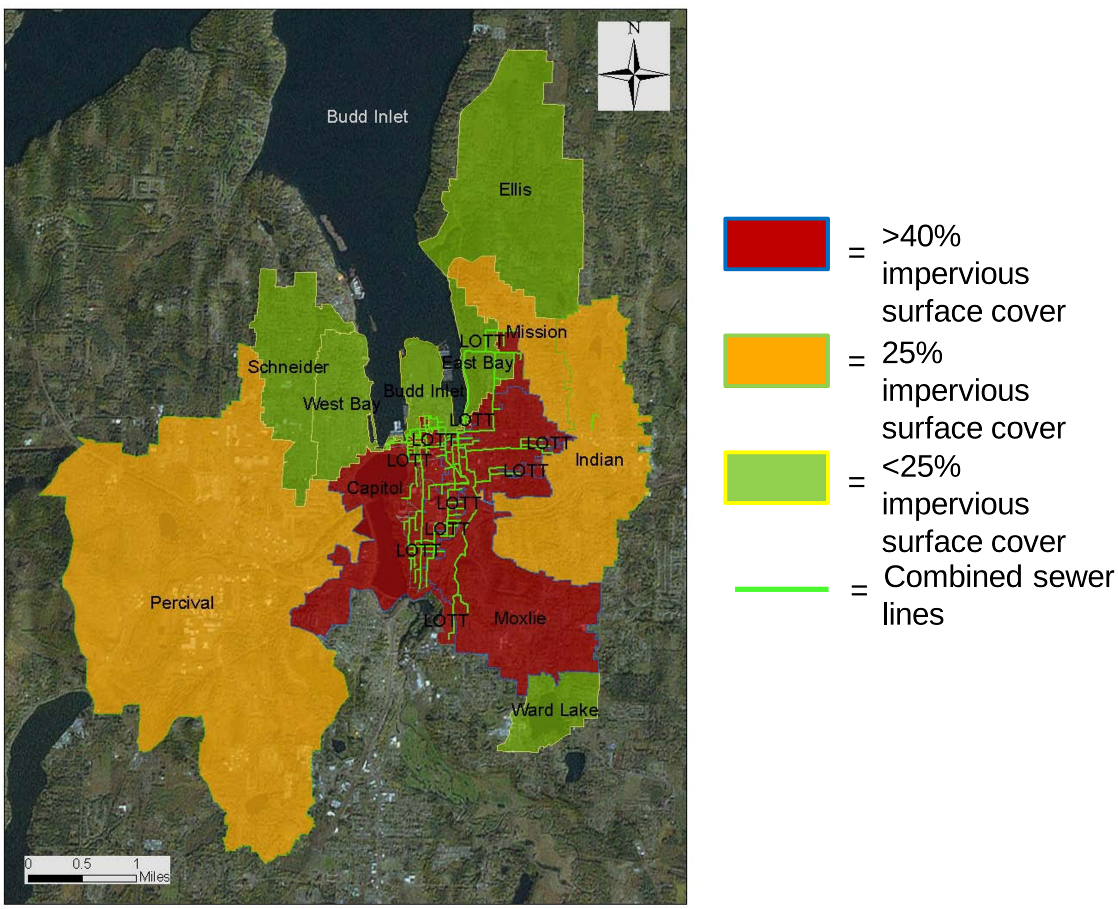


[24] A conventional sewer system is a system that collects municipal wastewater in gravity sewers and conveys it to a central treatment facility before discharge into receiving waters

5.5 Combined Sewer Overflows In Olympia

As discussed above, the most concentrated impervious surfaces are within the Moxlie Creek and Capitol Lake drainage basins, followed by Indian, Mission, and Percival Creek basins. Olympia's combined sewer lines predominately reside within the Moxlie Creek and Capitol drainage basins, and overlap the East Bay and Indian Creek basins as well (see Figure 5.6)[25].

Figure 5.6 Olympia Drainage Basins and Combined sewer lines



[25] As mentioned in footnote 21, the drainage basins denoted LOTT cannot be located within Thurston County or City of Olympia data or maps so the presumption is that all water falling in the LOTT basin goes directly to Budd Inlet Treatment Facility. Careful examination of maps indicates majority of LOTT basin is essentially Capitol and Moxlie basins

This means that the area most at risk for generating large volumes of storm flows to be sent to Budd Inlet Treatment Plant is also the area where there is the least amount of pervious surface to capture and assimilate precipitation.

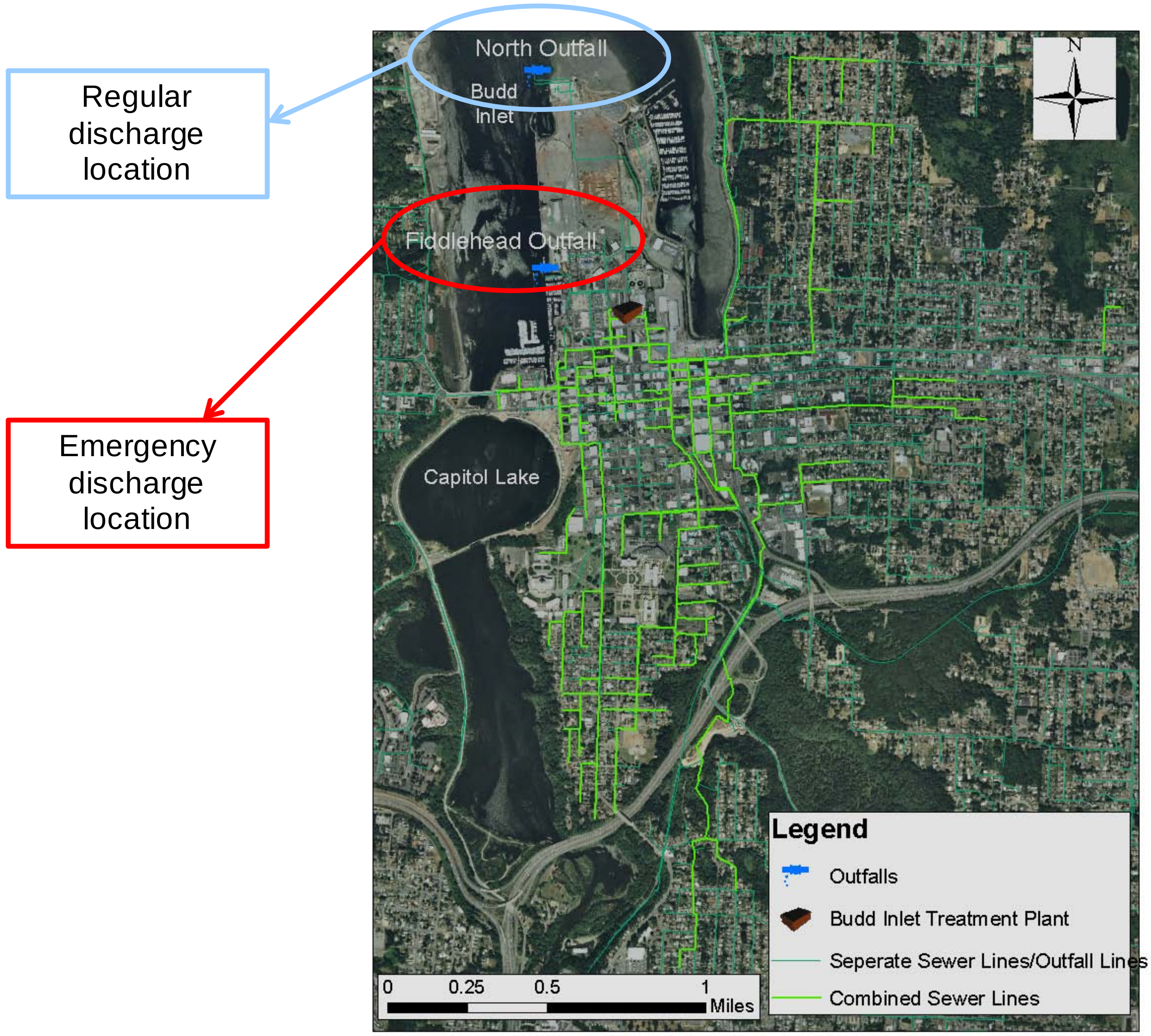
About 10 to 12 million gallons of wastewater flow through the Plant on an average day, however, flows have averaged as high as 22.3 million gallons per day (mgd) during the wettest months. Under normal conditions, treated wastewater is released into Budd Inlet via the North Outfall from the Plant (see Figure 5.7). However, when experiencing high intensity precipitation events, the Budd Inlet Treatment Plant is subject to flow spikes due to the combined sewer area in older downtown Olympia. Approximately 53% of all inflow and infiltration is estimated to come from the combined sewer system area (LOTT, 2005).

A CSO event occurs at the plant when the facility is overwhelmed with excess volume of storm and sewer water (specifically when the equalization basins are full and influent pumps are at capacity[26]) and wastewater is discharged to the emergency Fiddlehead outfall location (see Figure 5.7) (LOTT, 2005). LOTT has experienced only two CSO events between 1991 and 2009, which took place on December 3, 2007 and January 7-8, 2009. Both CSO events occurred due to high intensity precipitation events in which greater than 5 inches of rain fell in a 24-hr period (LOTT, 2009).

My analysis focused on the December 2007 CSO event as it was the first to occur in 16 years. Between 1:00 pm December 2 and 1:00 pm December 3, 5.5 inches of rain fell in Olympia and triggered the event that took place early morning, December 3. Of the 57.5 million gallons of flow that entered the plant for the 24-hour period, 45.74

[26] Equalization basins are used to store peak wastewater flows for later treatment and influent pumps are required to move wastewater to higher elevations (when gravity alone cannot move wastewater).

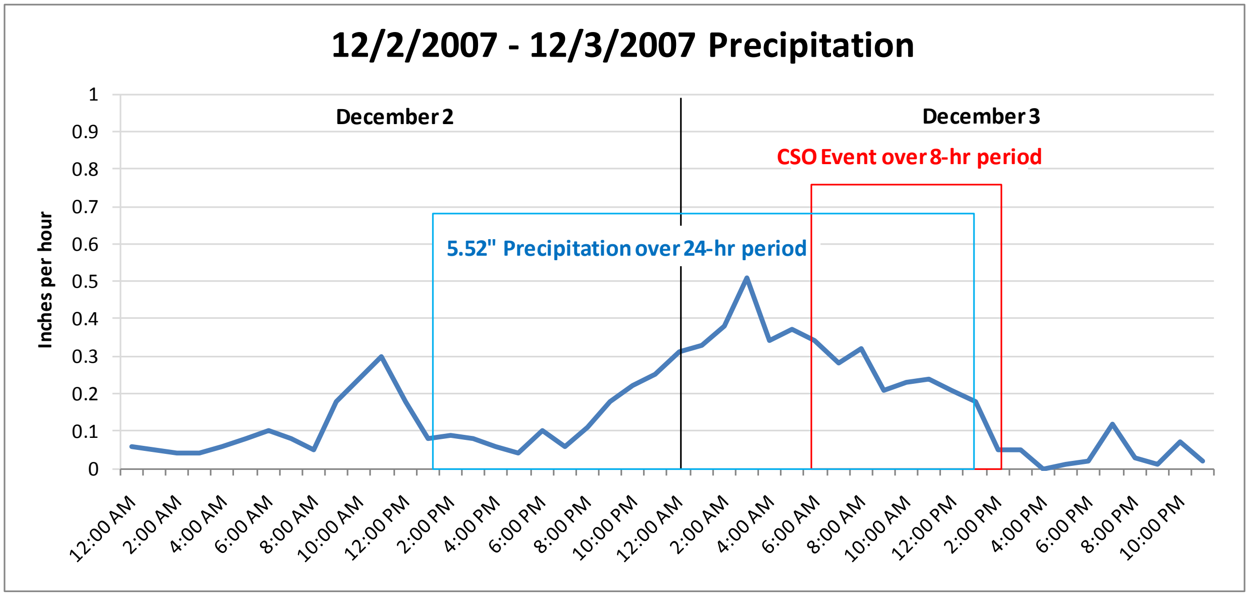
Figure 5.7 Budd Inlet Treatment Plant Outfall Locations



million gallons were fully treated, 2.75 million gallons were partially treated, and 9.01 million gallons were released untreated over an 8-hour period (see Figure 5.8).

The Plant experienced another CSO event January 7-8, 2009 as a result of 5.06 inches of rain that fell between 12:00 am January 7 and 12:00 pm January 8 (LOTT, 2009). The Plant was was forced to divert 1.5 million gallons of screened effluent

Figure 5.8 2007 CSO Event



around the secondary treatment process and blend it with fully treated final effluent. Following the initial diversion, 6.3 million gallons of the blended, disinfected effluent was discharged through the emergency Fiddlehead outfall location. Unlike the 2007 CSO event, the outfall released for this event was all at least partially treated.

LOTT only experiences CSO events during high intensity precipitation events, therefore, reducing inflow into the combined sewer lines in downtown Olympia generated during high intensity precipitation events will relieve pressure on the Budd Inlet Treatment Plant and is a primary objective for preventing CSO events.

The goal of this thesis was to investigate if rainwater harvesting can reduce the volume of stormwater runoff that triggers combined sewer overflow (CSO) events in Olympia. By modeling rainwater harvesting systems onto large-scale buildings served by the combined sewer lines and using the 2007 CSO event precipitation, the additional storm flow storage provided by the harvesting systems during high intensity precipitation events could be evaluated. The next section will present my methods for analysis.

6. Methods and Analysis

I predominately used Geographic Information Systems (GIS) and Microsoft Excel programs to perform my analysis. My methodology included using GIS for a visual analysis and then creating an Excel simulation model to evaluate daily cistern levels on large-scale buildings to determine storage capacity for the 2007 CSO event.

6.1 GIS Analysis

I first mapped Olympia's combined sewer lines with data received by Whitney Bowerman with the City of Olympia (see Figure 6.1), and added a building layer from data available in Evergreen's GIS database to evaluate building vicinities to combined sewer lines (see Figure 6.2).

I then wanted to select large-scale buildings for modeling rainwater harvesting systems, as the larger the roof area, the more potential for runoff prevention. I used the building layer and separated all buildings into four size classes by manually adjusting the properties of the building layer (see Figure 6.3). All buildings smaller than 10,000 ft^2 remained colored lavender.

Figure 6.1 Olympia Combined Sewer Lines

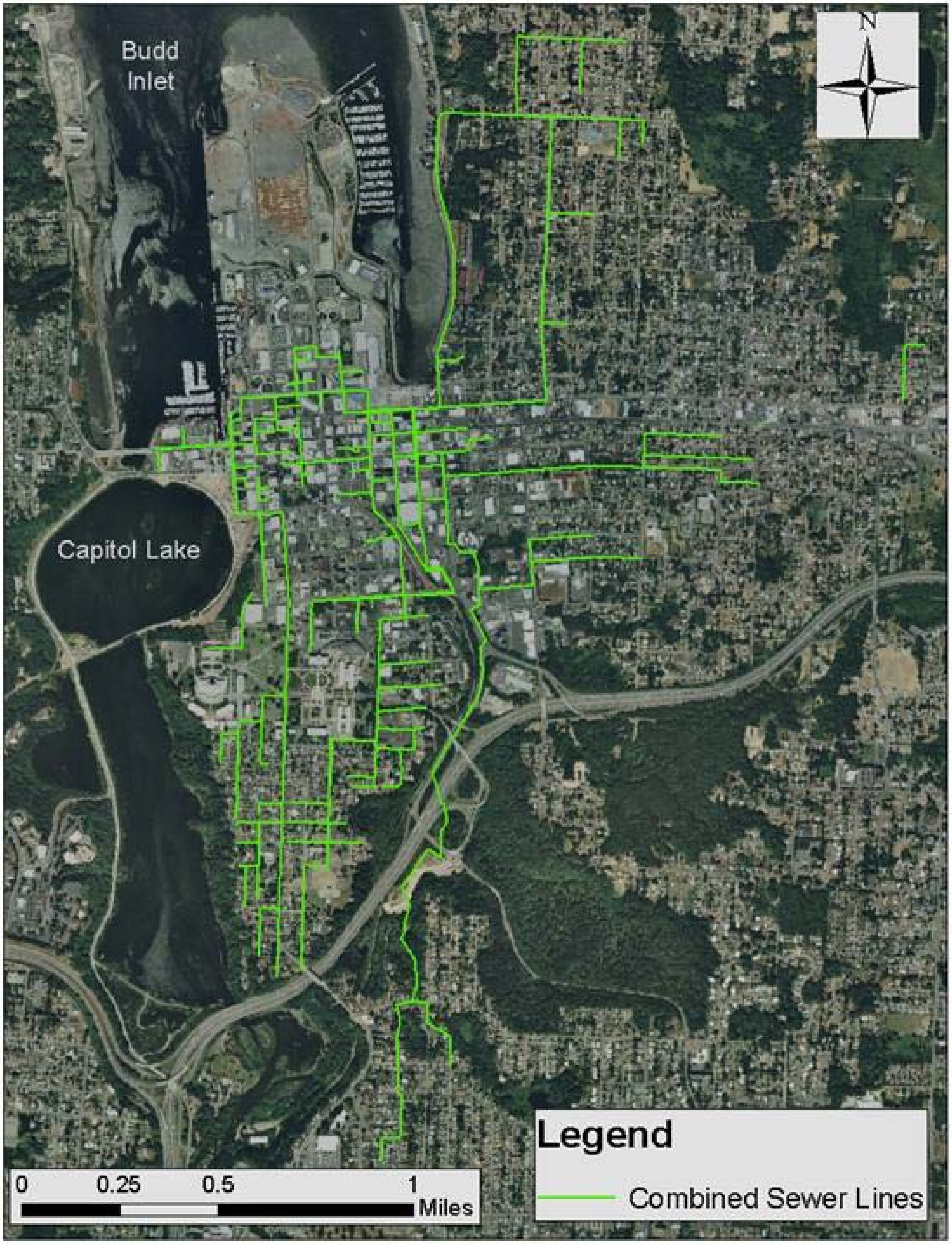


Figure 6.2 Combined Sewer Lines and All Buildings

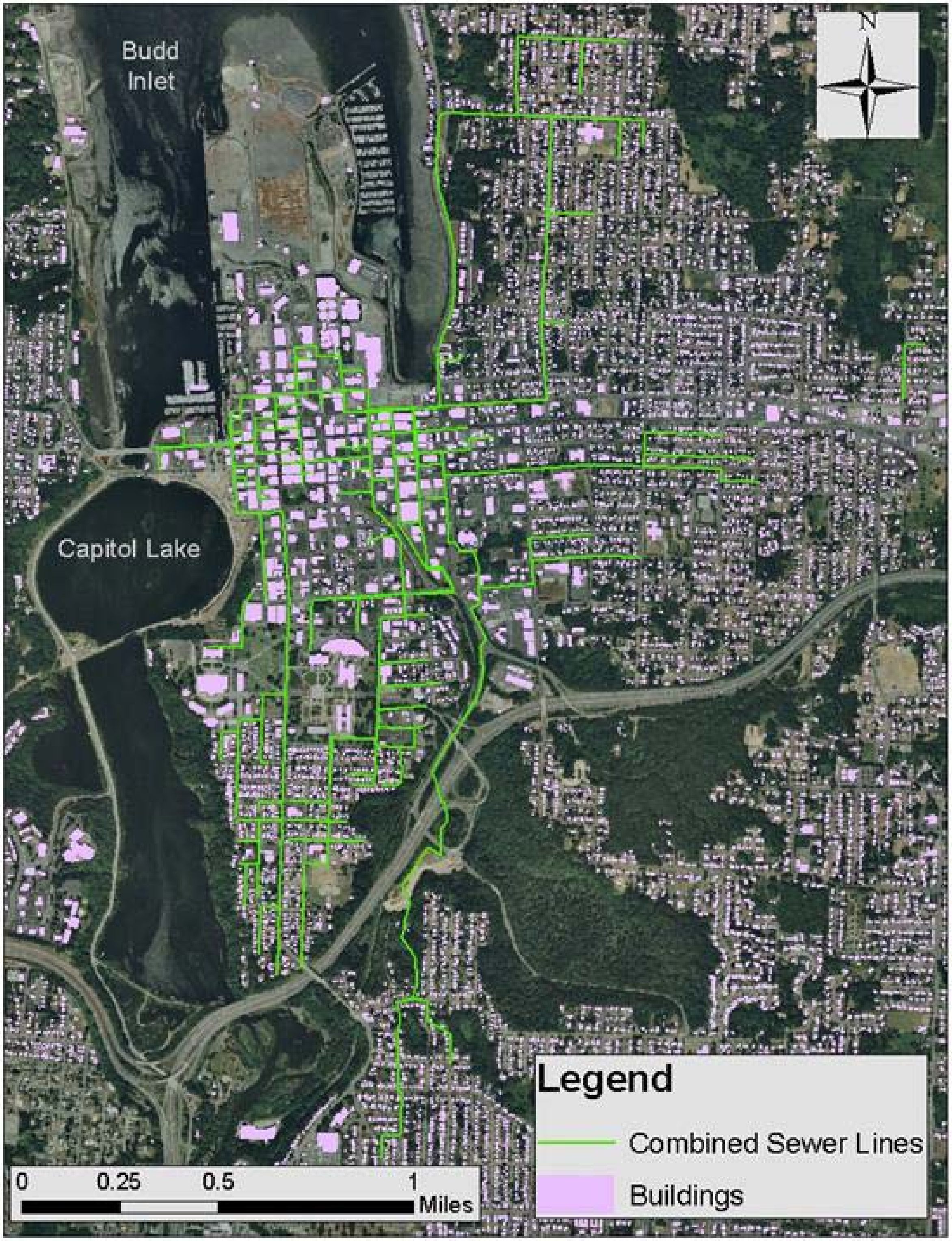
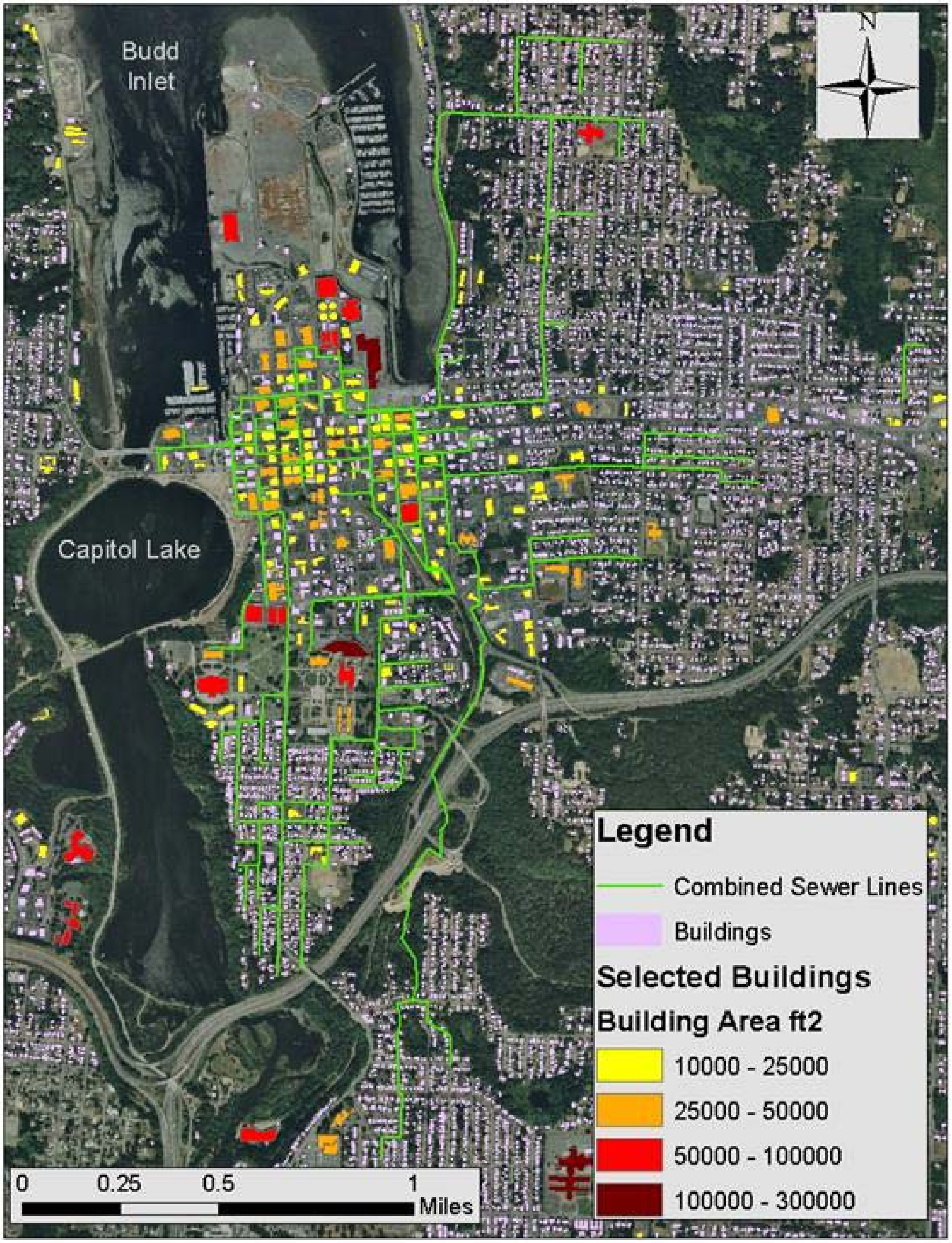
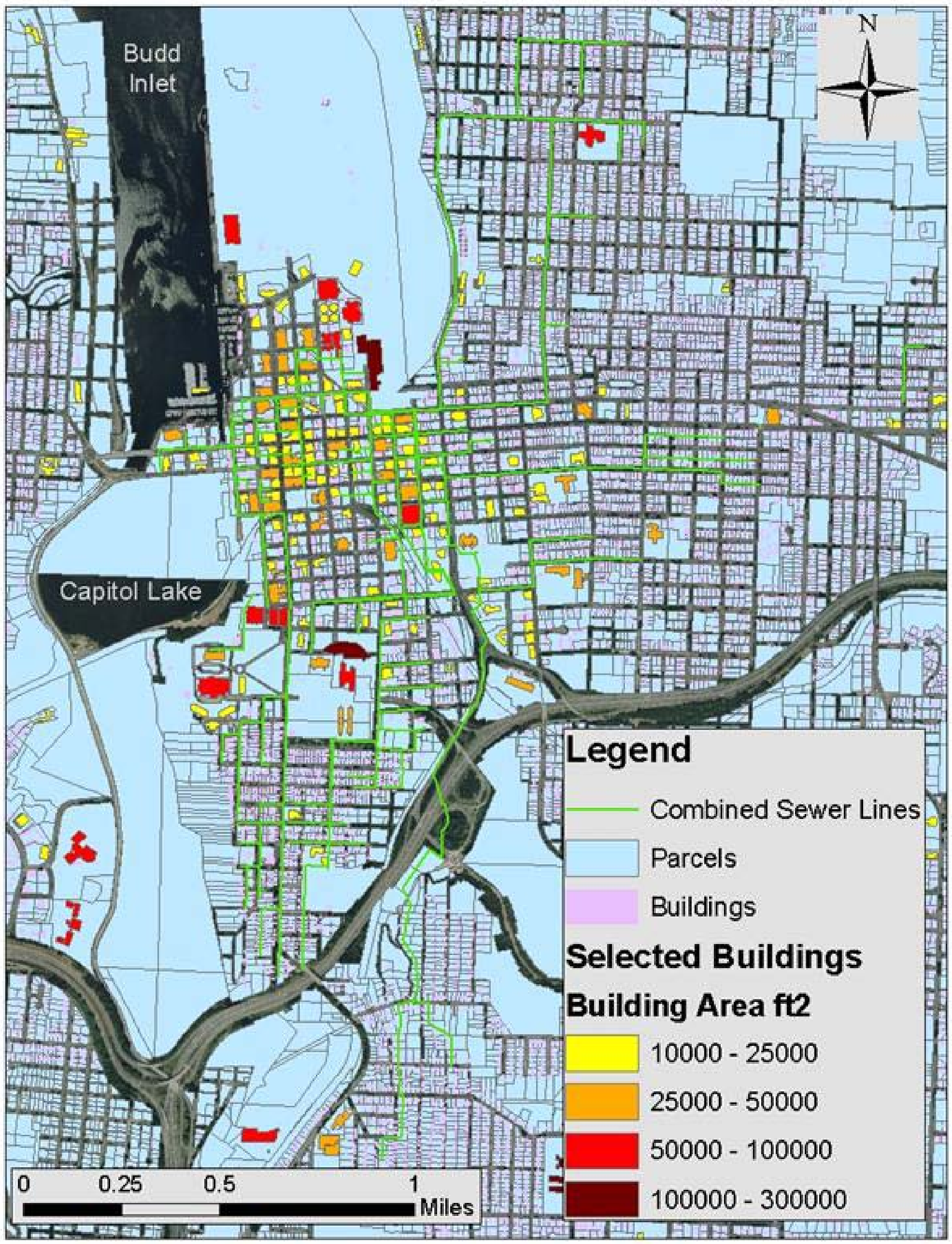


Figure 6.3 Selected Large-Scale Buildings



I needed a way to estimate water uses for the buildings. I received a parcel shapefile from Tyle Zuchowski at LOTT which contains water use information for each parcel in Olympia (see Figure 6.4).

Figure 6.4 Olympia Water Use Parcels



The water use provided in the shapefile is the 2008-2009 average gallons per month water use for the winter months November, December, January and February. I made the assumption that parcel water use was generated by the building or buildings that lie within those parcels. I could then use the water use provided in the parcel shapefile to determine a building's water use. The higher a buildings daily water use, the more storage is made available for capturing runoff each day.

In order to find the most effective buildings for rainwater harvesting system placement, I only wanted to look at parcels that contained selected buildings that were served by the combined sewer lines. I first selected buildings that were within 125 feet of the combined sewer lines and then selected parcels that were within 125 feet of the combined sewer lines, but that selected *all* parcels along the combined lines and I only wanted parcels that contained selected buildings. I then reselected parcels that were within 50 feet of the selected buildings to narrow the parcel selection and Figure 6.5 displays the end result.

I determined an estimated water use for each selected building served by the combined sewer lines. For a simple analysis, I only needed to locate the identification number (ID) of each selected building, find the ID of the parcel that contained the building, and then look at the specific water use of that parcel. The easiest way to do this was to label the parcel IDs and building IDs and reference the attribute tables of each to find the building's roof area and the parcel's water use, which I would then record in an Excel spreadsheet, see Figure 6.6 for an example.

Figure 6.5 Selecting Buildings and Parcels Served by the Combined Sewer Lines

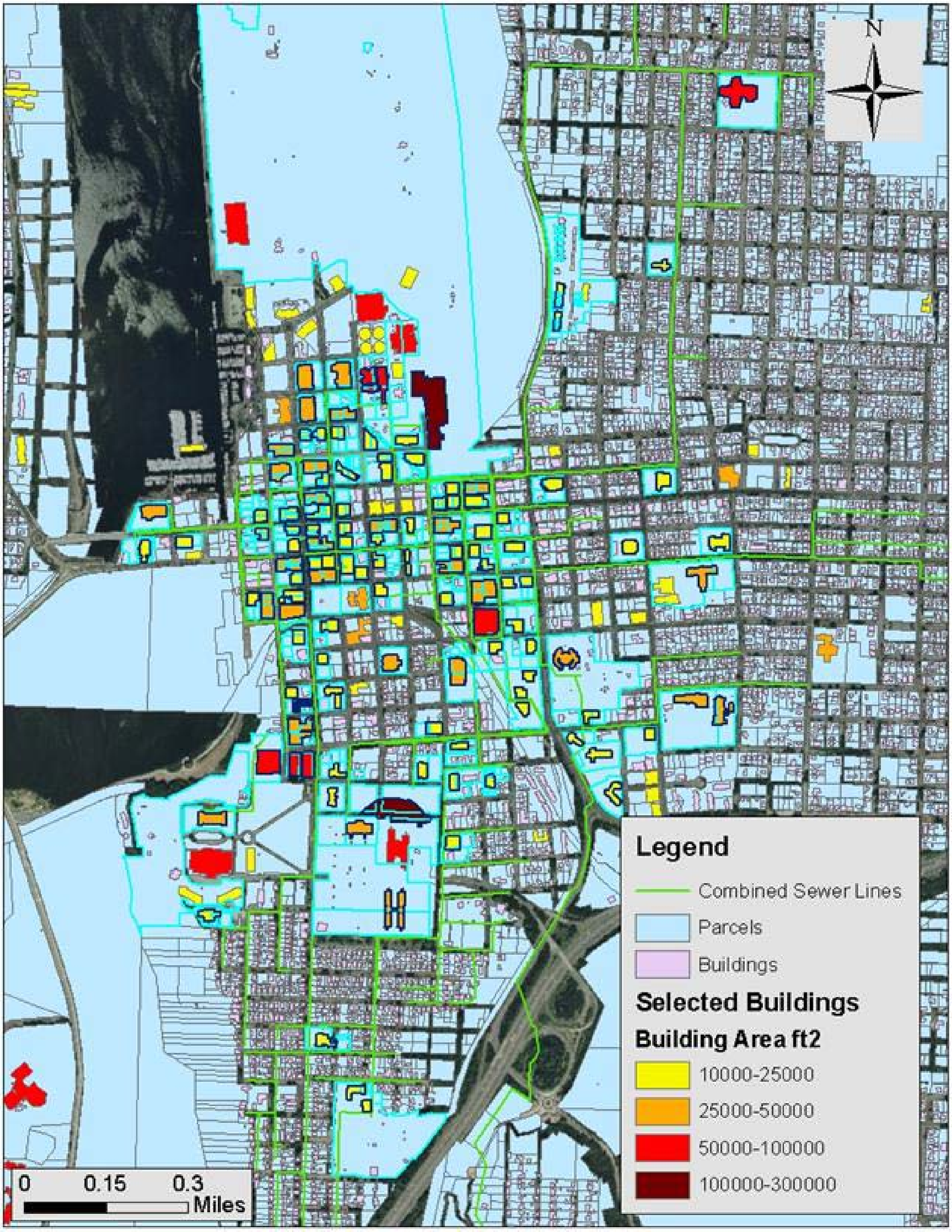
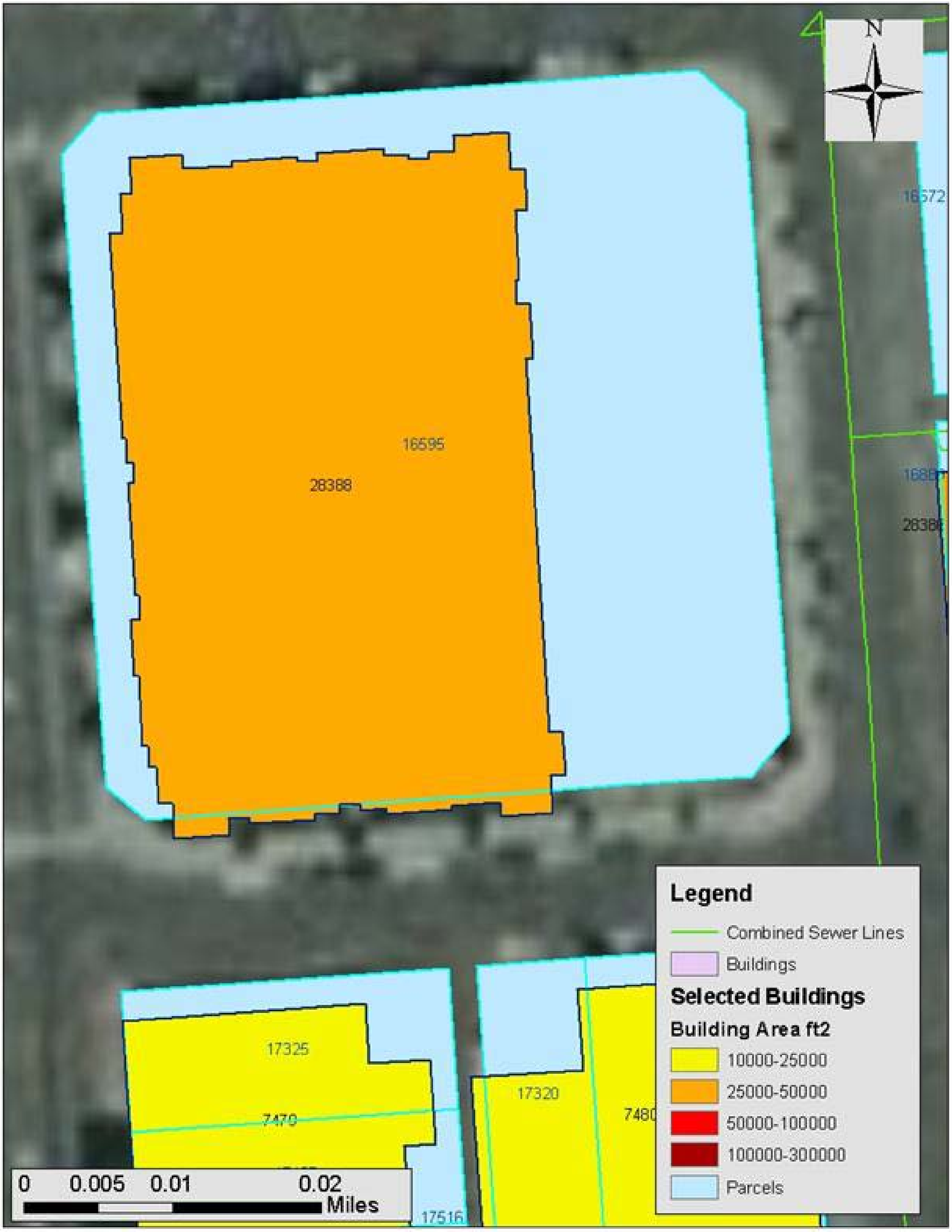


Figure 6.6 One Building per One Parcel



However, I quickly realized that many of my selected buildings did not just reside within one parcel (See Appendix C for building challenge example images). Some buildings overlapped several parcels. When this occurred, I recorded all parcels the building overlapped and summed each parcel's water use to derive a total water use estimate for the building. Others had multiple selected buildings within a single parcel. In a case like this, all three buildings are contributing to parcel water use, so the roof area of all buildings within the parcel were summed to derive a total roof area for analysis.

Other buildings were within a parcel that also contained several very small parcels. In this case, the small parcel water uses were located in the parcel attribute table and were added to total building water use. If my selected building slightly overlapped a parcel that contained a significantly sized unselected building, I eliminated that parcel from the selected building's water use, as I determined that the unselected building was likely the only user of water for that parcel.

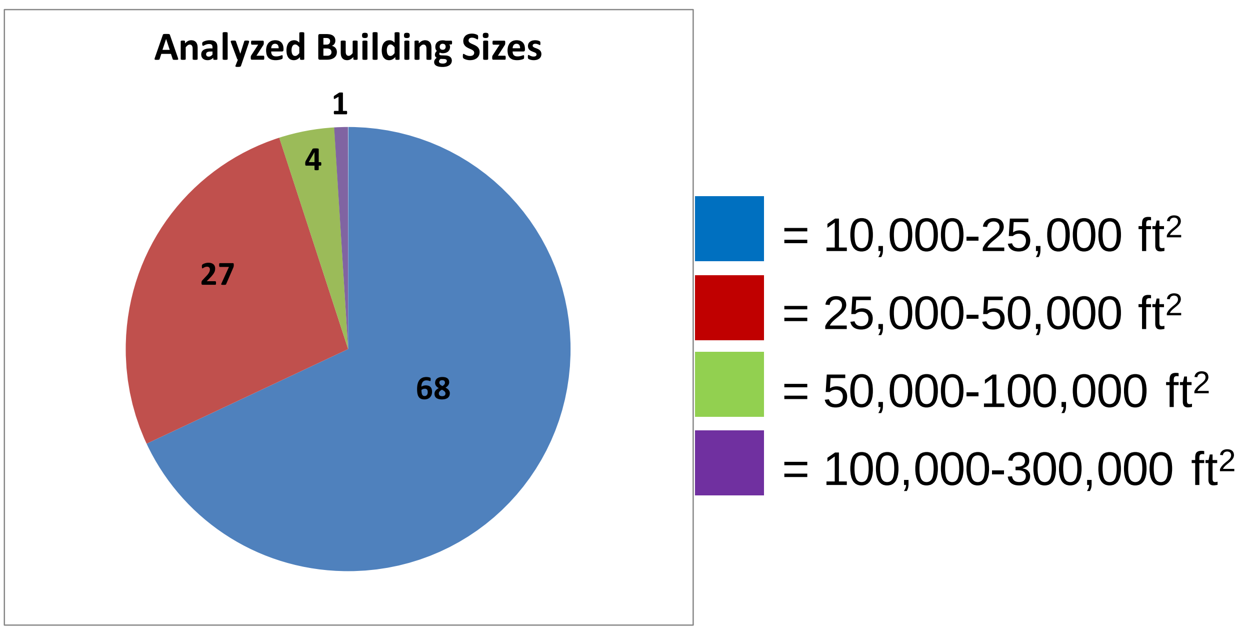
Other selected buildings equally overlapped more than one parcel where one of those parcels included a substantially sized unselected building, but had less than 10,000 ft^2 roof area. In this case, I labeled the building areas and if the building was larger than 1000 ft^2, concluded that the smaller building contributed to water use on that shared parcel. Therefore, I added the square footage of the unselected building to the square footage of the selected building to account for the additional roof area during my analysis. Another case was a selected building that overlapped a parcel that also contained a smaller, unselected building. If the unselected building was smaller than 1000 ft^2, the building was determined to not contribute to parcel water use and square footage was not added to selected building square footage.

6.2 Spreadsheet Simulation Model

After performing the above steps, I then had a spreadsheet containing all selected buildings, the parcels they overlap, the parcel water uses, and the parcel use itself. If the building water use was less than 75 gallons per day water use, the building was not selected for analysis. I also had to physically visit some buildings to determine if they used water and also to verify if some buildings still existed (because the layer was created in 2008). If there were issues with certain buildings, they were not selected for analysis.

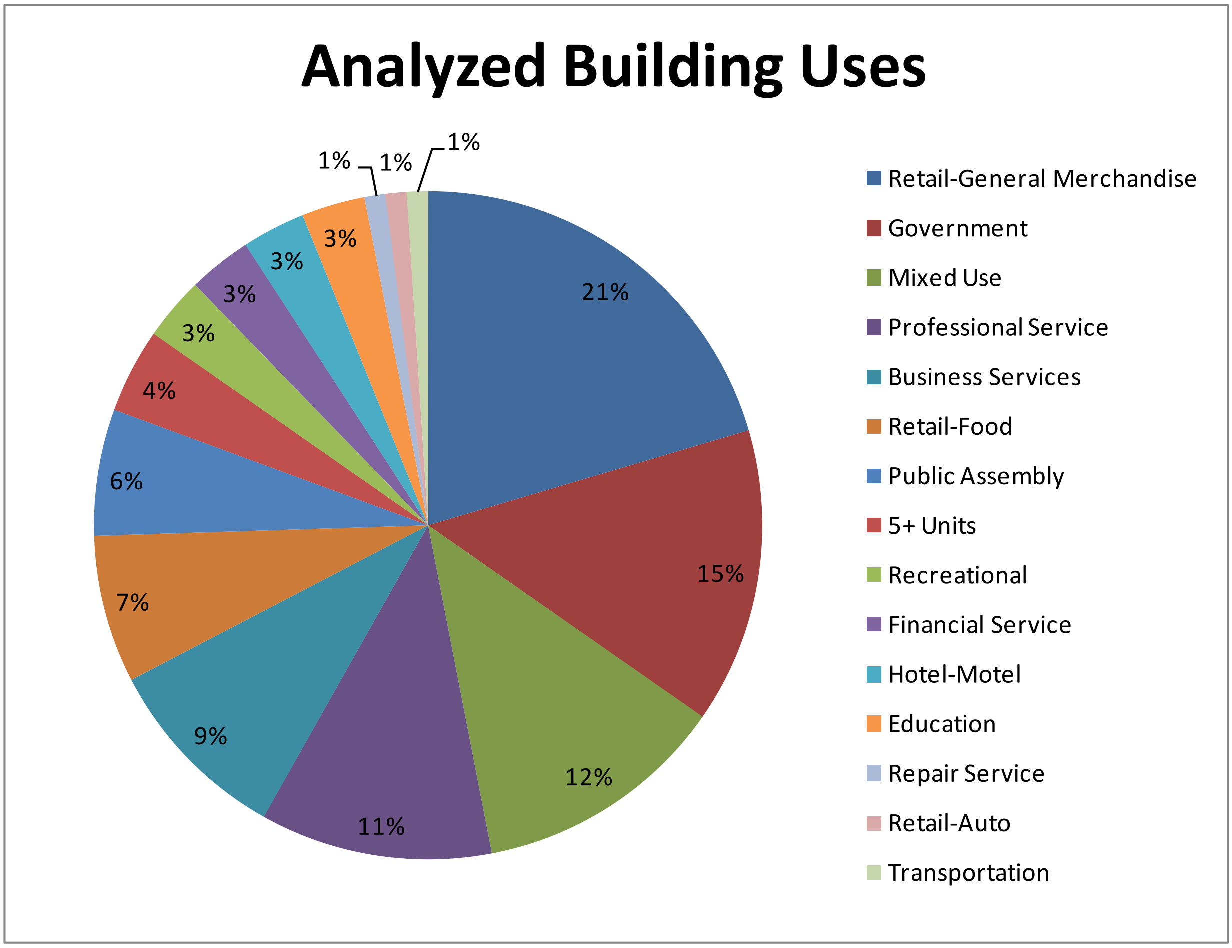
After those eliminations, a total of 102 buildings were selected for analysis. Most buildings were sized between 10,000 and 25,000 ft^2 (see Figure 6.7).

Figure 6.7 Analyzed Building Sizes



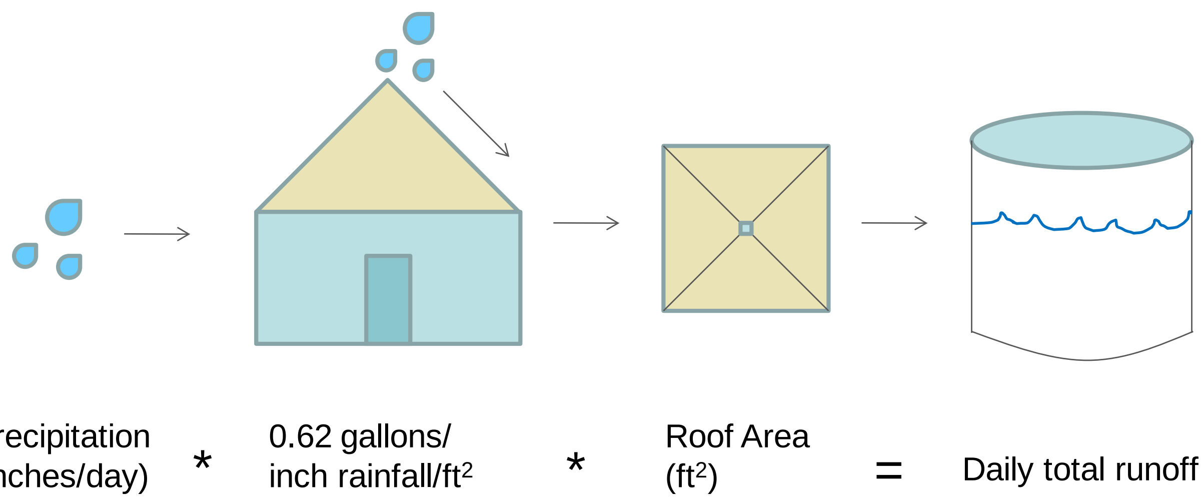
I examined parcel uses and determined the building use from that information. It was important for me to analyze building uses to see what kind of proportion of non-potable water use the building might be using as many commercial buildings have a very high proportion of non-potable water use. General merchandise retail, followed by government and mixed use accounted for almost half of all the analyzed buildings (see Figure 6.8).

Figure 6.8 Analyzed Building Uses



I then examined the roof runoff produced from each building. I used daily precipitation from October 31, 2007 through January 30, 2008. Approximately 0.62 gallons per square foot of collection surface per inch of rainfall can be collected for rainwater harvesting. Therefore, all precipitation was converted to roof runoff using this coefficient. The value then was runoff per square foot, so that was multiplied by the roof area of the building. The result was the total daily roof runoff produced from that building, and this was done for each selected building, see Figure 6.9 for the process.

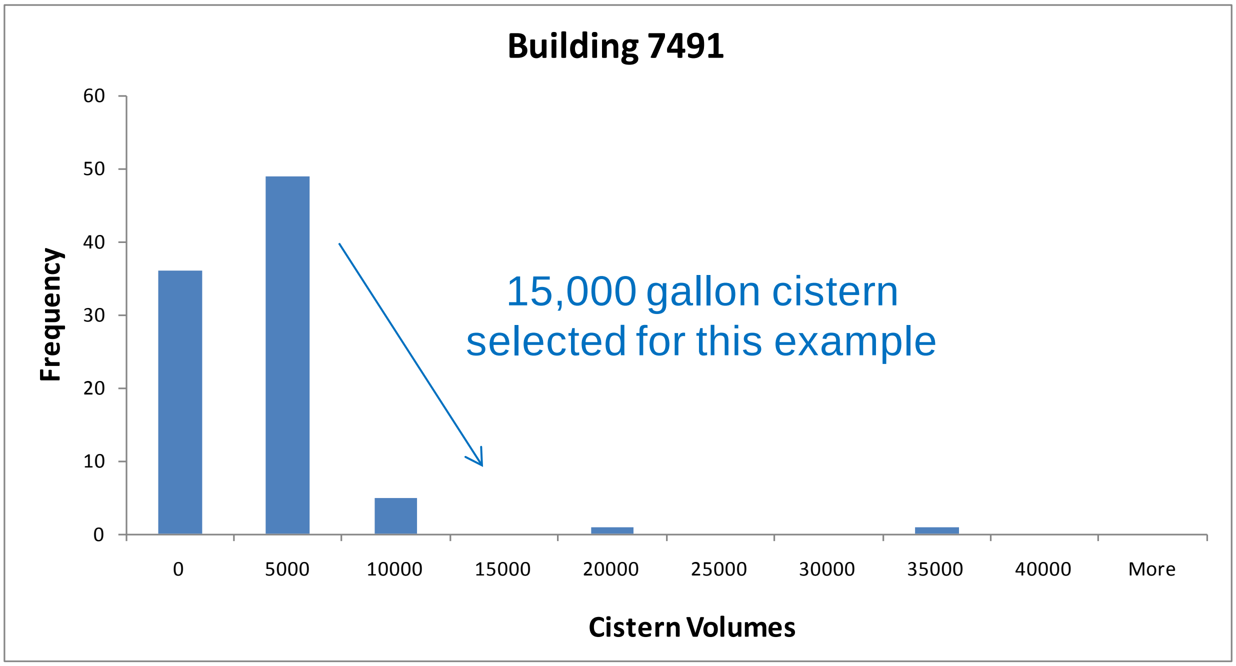
Figure 6.9 Daily Total Runoff Calculations



I then used the daily total roof runoff values to determine an appropriate cistern size for each building. To do this, I generated bin values representing a range of cistern volumes. The bin sizes used were in 5000 gallon increments. I created a histogram based on the daily roof runoff values and the bin sizes. I then determined the cistern size by looking at where the numbers significantly decreased within the bins, see Figure 6.10 on the next page for an example.

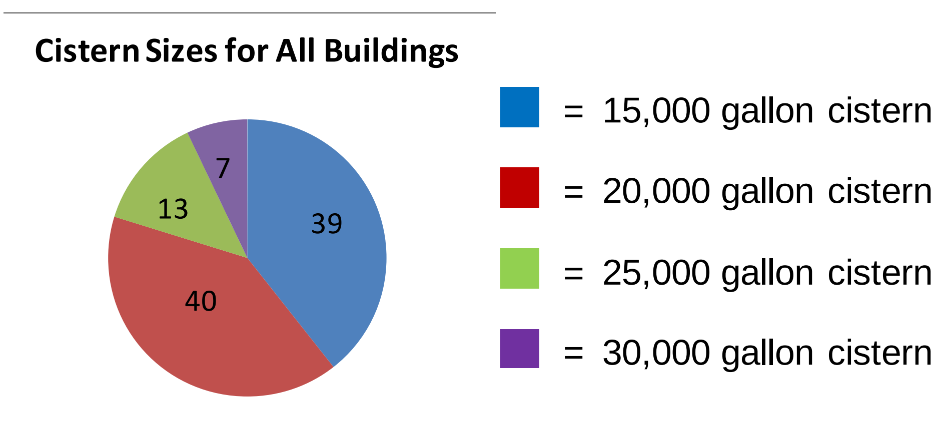
For this example, the roof runoff produced dropped off after 15,000 gallons so I sized the cistern at 15,000 gallons. Although I could have sized the cistern much larger for runoff storage purposes, the general rule is that cisterns cost approximately one dollar

Figure 6.10 Cistern Sizing Analysis



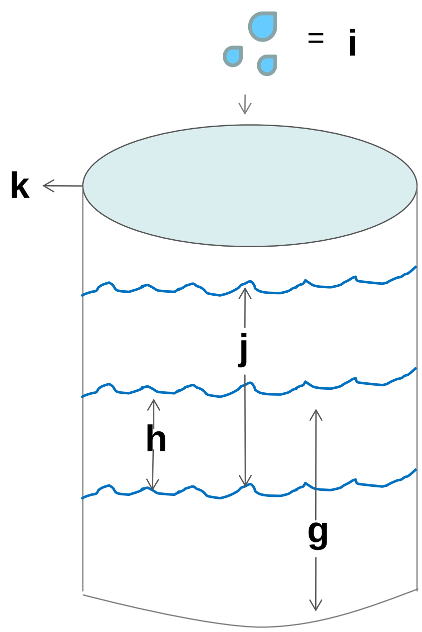
per gallon of storage, so it was important for me to keep the costs accurate and as low as possible while still providing storage for storm runoff. Most cisterns ended up providing between 15,000 and 25,000 gallon storage capacities, although a few of the buildings with larger roof areas were given 30,000 gallon cisterns (see Figure 6.11).

Figure 6.11 Analyzed Building Modeled Cistern Sizes



I next determined daily cistern volumes (or levels). I used IF, THEN logic statements in Excel to create an analysis of daily cistern levels to determine daily capacity available for the time frame between October 31 and January 30 (see Figure 6.12).

Figure 6.12 Daily Cistern Volume Analysis



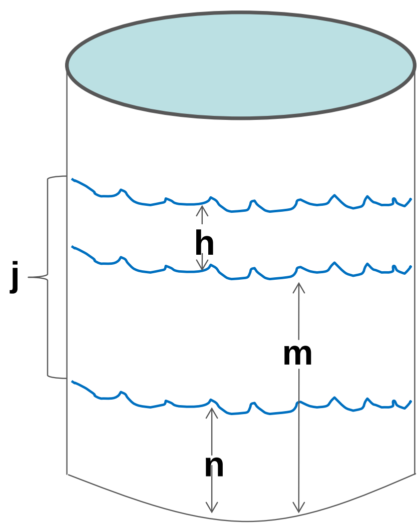
- g = gallons stored at beginning of day
- h = daily water use
- i = inches precipitation
- j = gallons roof runoff
- k = cistern capacity

g-h+j = cistern volume
If (g-h+j)>k, then k
If (g-h+j)<0, then 0

As mentioned earlier, the daily precipitation was converted to gallons roof runoff for each building. The equation to determine daily cistern volume levels is gallons stored at the beginning of the day (g) minus the daily water use (h) plus the gallons roof runoff (j). However, this equation as is would generate negative values and values greater than the cistern storage capacity (k). Negative values occurred if there was no roof runoff and the cistern volume was at a level less than the daily water use while values greater than cistern storage capacity resulted due to high roof runoff (or j) values. Therefore I created logic statements that would prevent these values from occurring. This logic equation was used for each building analysis and generated daily cistern levels for the 3 months I examined.

I then determined the volume of water prevented from becoming runoff each day because it was water stored in the cistern (see Figure 6.13). To do this, another logic

Figure 6.13 Day to Day Volume Stored



- m = cistern volume current day
- n = cistern volume day before
- h = daily water use
- j = gallons roof runoff current day

m-n+h = volume stored

If (m-n+h)>j, then j

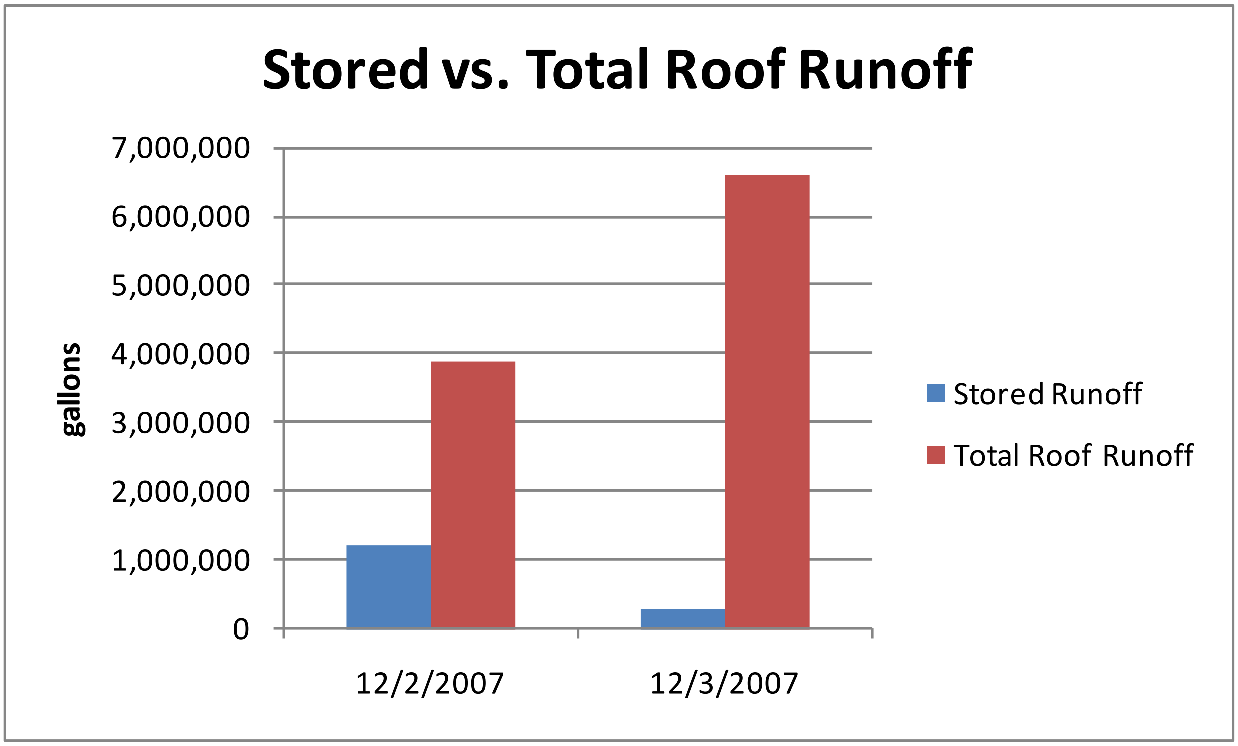
statement was created. The cistern volume the current day (m) minus the cistern volume the day before (n) plus the daily water use (h) determines the quantity of roof runoff stored, thus prevented from becoming runoff sent to the combined sewer lines. However, if the equation generated a value greater than the gallons roof runoff produced the current day (j), than the only volume stored can be the gallons of roof runoff generated that day (j). This logic equation was used for each building and generated daily quantities of gallons roof runoff stored for the period between October 31 and January 30.

7. Results

Approximately 150 acres or 25% of the 600 total acres served by the combined sewer system are buildings. I analyzed and modeled rainwater harvesting systems onto only buildings larger than 10,000 ft^2 that are served by the combined sewer lines, and the roof area of those 102 buildings totaled approximately 53 acres. Therefore, I analyzed approximately 33% of the roof area served by the combined sewer lines and approximately 33% of the buildings served by the combined sewer system are larger than 10,000 ft^2.

A substantial quantity of roof runoff was stored in the modeled cisterns December 2 and 3, 2007 (see Figure 7.1). My model determined that on December 2nd, 1.22 million gallons roof runoff were stored in the modeled cisterns of a total 3.9 million gallons actual estimated runoff produced from the analyzed buildings, meaning approximately one-third or 33% of the total roof runoff that occurred on the 53 acres of analyzed roof area would be stored in the modeled cisterns. On December 3, the model determined 275,000 gallons of runoff were stored in the modeled cisterns of an actual estimated total 6.6 million gallons runoff produced from the analyzed roof area. The modeled quantity stored for December 3 was significantly lower due to most of the cisterns being full from December 2 precipitation.

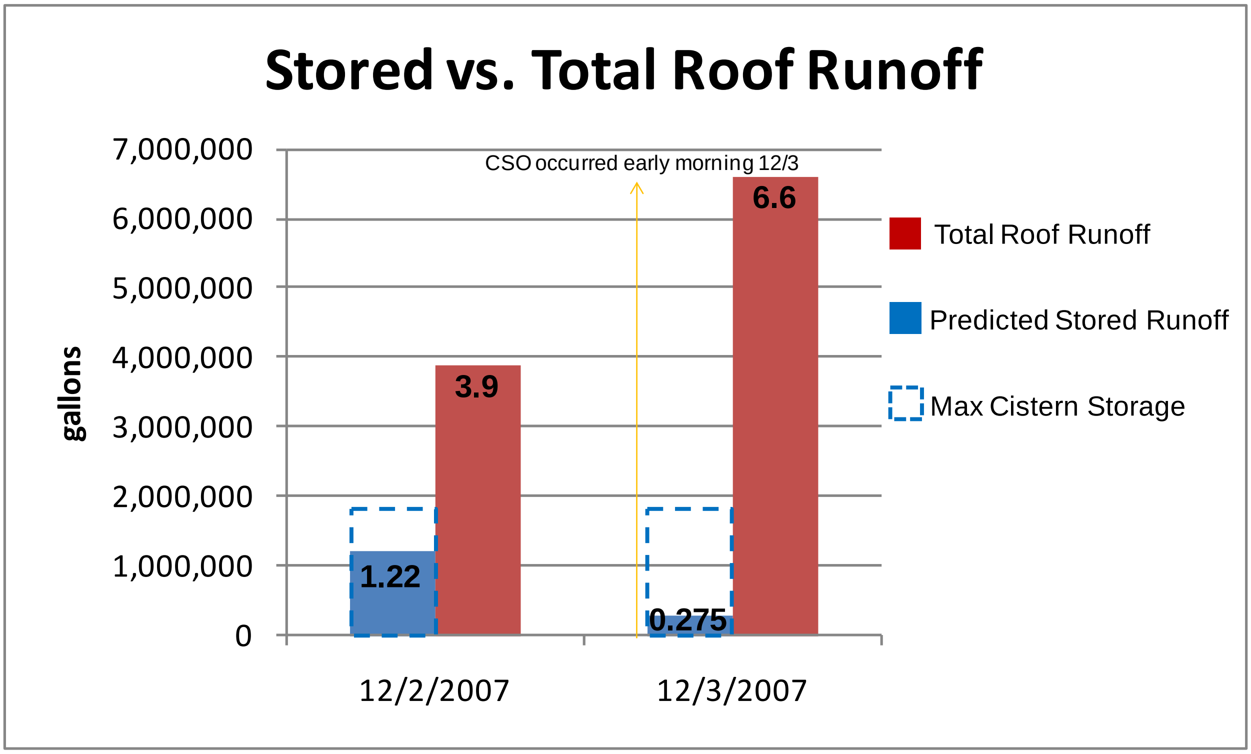
Figure 7.1 Modeled Cistern Storage 12/2/2007-12/3/2007



However, because the CSO event occurred in the early morning hours of December 3, I feel that it was likely triggered by precipitation December 2 and aggravated by continuous heavy precipitation December 3. Therefore, a substantial quantity of roof runoff would be prevented from entering the combined sewer lines prior to the CSO event if the modeled cisterns were actualized. Not only would a substantial quantity of roof runoff be stored in the modeled cisterns, but the early runoff stored on December 2 most likely contained a larger proportion of nonpoint source pollutants than the runoff that occurred late December 2 and early December 3 due to little precipitation occurring the days prior to the CSO event. Thus, by the time the CSO event occurred in the early morning hours of December 3, most of the runoff would essentially be only rainfall containing little (if any) nonpoint source pollutants.

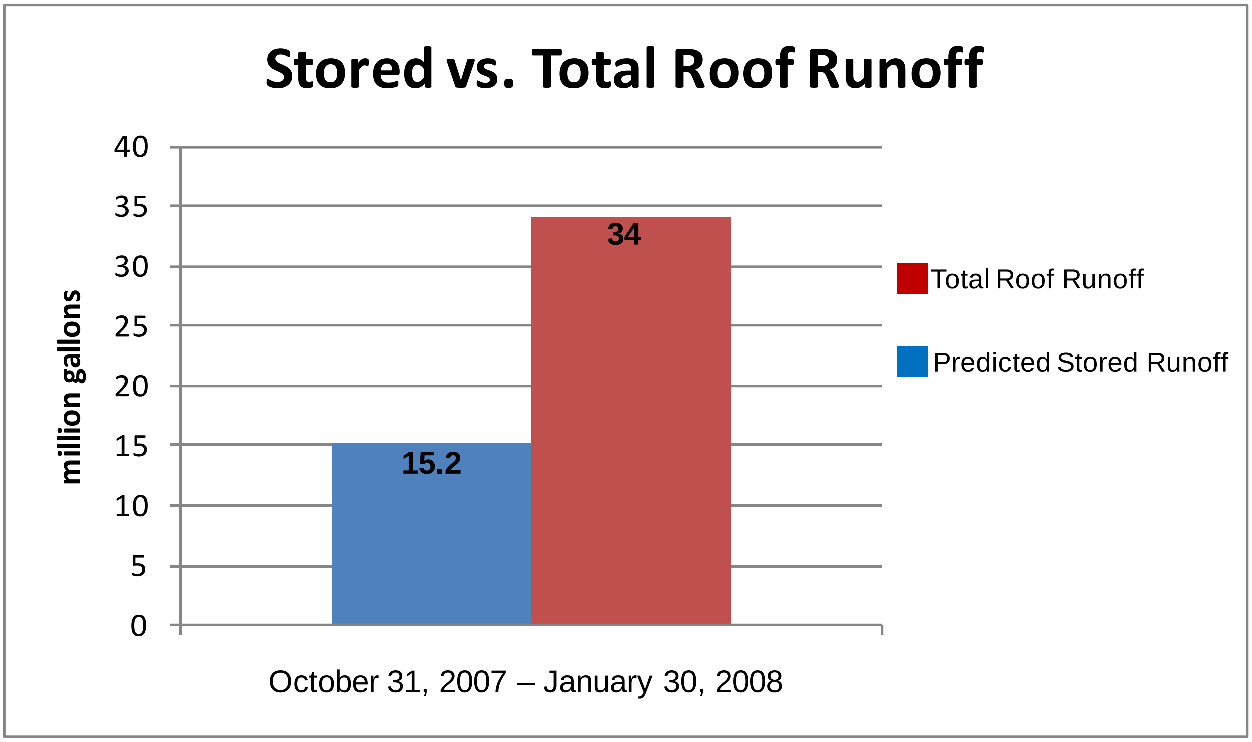
Another important factor is the modeled cisterns provide a total of 1.9 million gallons of storage capacity if they are all empty (see Figure 7.2). If cisterns were implemented, a management option could be to slowly drain cisterns to empty or near empty to greatly increase storage capacity for predicted high intensity precipitation events.

Figure 7.2 Modeled Potential Cistern Storage 12/2/2007-12/3/2007



My primary focus days were December 2 and December 3, 2007. However, the spreadsheet also allowed easy calculation of the total quantity of runoff stored in the modeled cisterns for precipitation that fell on the analyzed buildings October 31, 2007 through January 30, 2008 by summing all analyzed buildings daily volume stored and then summing all buildings daily total roof runoff (see Figure 7.3). An actual estimated total 34 million gallons of roof runoff would have been generated between October 31 and January 30 for the 53 acres of roof area analyzed. With the inclusion of modeled cisterns on the buildings, 15.2 million gallons would be stored for later use in the building. That means almost half of roof runoff from the 102 buildings would be stored and presumably utilized on a regular basis for the time examined.

Figure 7.3 Modeled Cistern Storage October 31, 2007 through January 30, 2008



8. Conclusions

The modeled rainwater harvesting systems on the 102 buildings comprising 53 acres of land cover would reduce the volume of stormwater runoff that triggered the CSO event December 3, thus showing that rainwater harvesting is an effective low impact development solution for providing additional storm runoff storage. The predicted 1.5 million gallons of total runoff stored over December 2 and 3, 2007 was a small proportion compared to the extreme flows received at the Budd Inlet Treatment Plant, so I have to conclude the modeled rainwater harvesting systems would not have prevented the CSO event from occurring. However, the analyzed roof area is only 17% of the total area served by the combined sewer system, indicating additional storage potential.

8.1 Future Plans for Greater Olympia

As discussed earlier, mitigating CSOs can require costly infrastructure updates. Separating combined sewer lines and redirecting stormwater can cost as much as $600 per foot of piping (Kloss and Calarusse, 2006), resulting in multi-million dollar investments.

In the late 1990s as a result of a major inflow and infiltration study as well as a newly created wastewater resource management plan, LOTT and the City of Olympia investigated separation of the downtown combined sewer lines into a separate storm system, and determined the process as not cost-effective.

To handle increased volumes of wastewater, LOTT is planning "just-in-time" construction of several satellite reclaimed water[27] facilities based on population and employment projections to meet future wastewater treatment capacity needs (LOTT, 2010b). Each satellite facility will have the ability to treat one million gallons per day (MGD) and will be expandable for up to 5 MGD (LOTT, 2003). LOTT's second

[27] Reclaimed water is former sewage that is treated to remove solids and impurities and purified to a level suitable for further use, such as sustainable landscape irrigation, to recharge groundwater aquifers, or discharge into surface waters

reclaimed water facility, the Hawks Prairie Reclaimed Water Satellite, cost approximately $35 million and provides 2 MGD of treatment capacity.

8.2 Rainwater Harvesting in Olympia

The modeled rainwater harvesting systems could cost as little as $2.5 million and provide a potential 1.9 million gallons of storage capacity daily (assuming they are all empty) while also promoting water and energy conservation. As mentioned above, LOTTs reclaimed water satellite facilities are designed to treat one million gallons per day at the lowest level. The modeled rainwater harvesting systems with only partial coverage of the CSS area could handle almost 2 million gallons per day at only a fraction of the cost. Also, significant financial savings would be observed by LOTT due to decreased flows to be treated and buildings would save by decreasing municipal water purchases for non-potable water applications.

There are also still 97 acres of smaller-scale buildings with less than 10,000 ft^2 roof area served by the combined sewer lines that were not analyzed. If modeled the same as the large-scale buildings, they could potentially triple roof runoff storage.

8.3 Research Applications

Most rainwater harvesting models that I have encountered use average monthly precipitation to determine the proper sizing of cisterns as they are looking at rainwater harvesting for an alternative water supply. My model is the first that looks at daily cistern levels for stormwater runoff storage, thus having the ability to analyze cistern storage capacity for single storm events. The cistern sizes are also adjustable and can be easily increased or decreased for different storage scenarios. My research is also applicable for any community served by a combined sewer system, and only precipitation quantities, building areas and water uses would need adjustments.

If I had additional time for further research, I would like to model rainwater harvesting systems onto all buildings served by the combined sewer system in Olympia to evaluate total storage potential. In the future, I would like to apply my model to other communities served by a combined sewer system.

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Appendix A-Treatment Control Method Definitions (from WADOE, 2005)

- Wetpools: Wetpools provide runoff treatment by allowing settling of particulates during inactive periods by biological uptake and by vegetative filtration. Wetpools can be single-purpose facilities that only provide runoff treatment or they can also be combined with a detention pond or vault to also provide flow control.
- Biofiltration: Biofiltration uses vegetation in coordination with slow and shallow-depth flow for runoff treatment. As runoff passes through the vegetation, pollutants are removed through the combined effects of filtration, infiltration and settling. These effects are aided by the reduction of the velocity of stormwater as it passes through the biofilter. Biofiltration facilities include swales designed to convey and treat concentrated runoff at shallow depths and slow velocities, and filter strips that are broad areas of vegetation for treating sheet flow runoff.
- Oil/Water Separation: Oil/water separators remove oil floating on the surface of water by using gravity to remove surface and dispersed oil. The two general types of separators include the American Petroleum Institute (API) separators and coalescing plate (CP) separators.
- Pretreatment: There are several methods for pretreatment, however, presettling basins are often used to remove sediment from runoff prior to discharge into other treatment facilities. Pretreatment often must be provided for filtration and infiltration facilities to help protect groundwater or to prevent clogging. Devices can include a pre-settling basin, a wetpond/vault, biofilter, constructed wetland or

an oil/water separator.

- Infiltration: Infiltration refers to the use of the filtration, adsorption, and biological decomposition properties of soils to remove pollutants. Infiltration can provide multiple benefits including pollutant removal, peak flow control, groundwater recharge, and flood control. However, one condition that can limit the use of infiltration is the potential adverse impact of groundwater quality. To adequately address the protection of groundwater when evaluating infiltration it is important to understand the difference between soils that are suitable for runoff treatment and soils only suitable for flow control. Sufficient organic content and sorption capacity to remove pollutants must be present for soils to provide runoff treatment. The use of coarser soils to provide flow control for runoff from pollutant generating surfaces must always be preceded by treatment to protect groundwater quality. Thus, there will be instances when soils are suitable for treatment but not flow control, and vice versa.
- Filtration: A relatively new application of pollutant removal system for stormwater is the use of various media such as sand, perlite, zeolite, and carbon, to remove low levels of total suspended solids (TSS). Specific media such as activated carbon or zeolite can remove hydrocarbons and soluble metals. Filter systems can be configured as basins, trenches or the novel cartridges.
- Emerging Technologies: Emerging technologies are new technologies that have not been evaluated using approved protocols, but for which preliminary data indicate that they may provide a desirable level of stormwater pollutant removal. They have not been evaluated in sufficient detail to be acceptable as stand alone

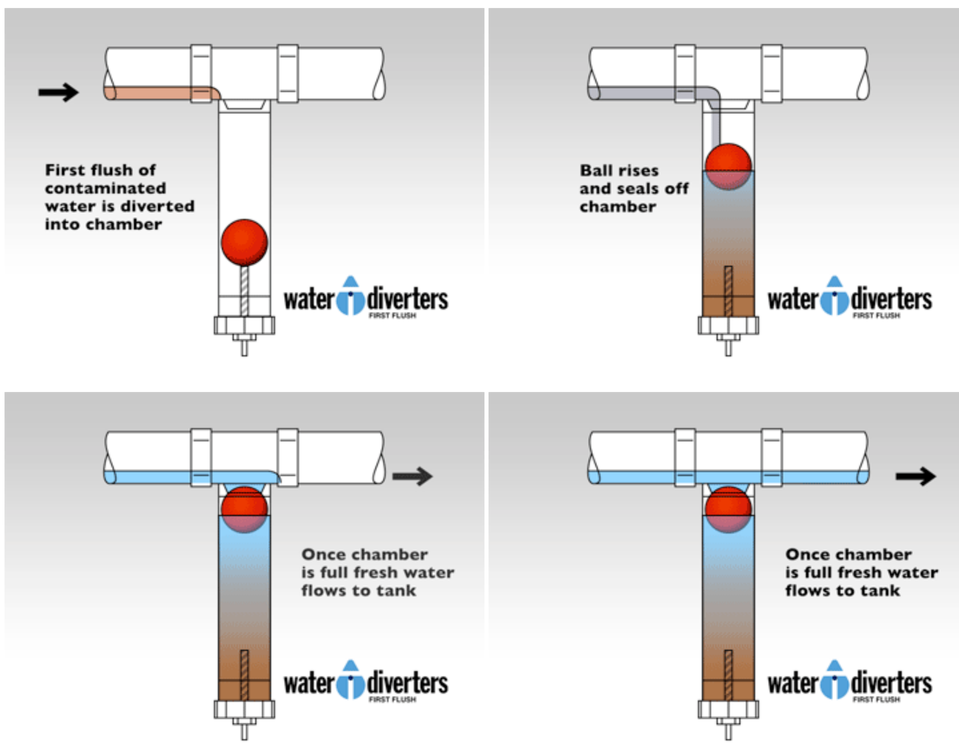
BMPs for general usage in new development or redevelopment situations requiring Basic Treatment. A few emerging technologies are allowed to help remove metals, hydrocarbons, and nutrients. Otherwise, their use is restricted in accordance with their level of development [as explained in Chapter 12]. The recommendations for these emerging technologies will change as we collect more data on their performance. Updated recommendations on their use will be posted on the Ecology website. Meanwhile, emerging technologies can also be used for retrofit situations.

- On-line Systems: Most treatment facilities can be designed as "On-line" systems with flows above the water quality design flow or volume simply passing through the facility with lesser or no pollutant removal efficiency. However, it is desirable to restrict flows to treatment facilities and bypass the remaining higher flows around them. These are called "Off-line" systems. An example of an on-line system is a wetpool that maintains a permanent pool of water for runoff treatment purposes.
- Design Flow: Design criteria for treatment facilities are assigned to achieve the applicable performance goal at the water quality design flow rate (e.g., 80% TSS removal)

Appendix B-Additional Descriptions and/or Illustrations of Specific Rainwater Harvesting Components

- First-flush diverter

  First-flush diverters come in various designs but all perform the same general function: to discard the first-flush of water from the rooftop as it is considered the most contaminated. Below are a series of illustrations depicting the basic funtion of a first-flush diverter.



Images courtesy of www.rainharvest.com

* <u>Roof washer</u>

  Roof washers are designed to filter small debris from the rooftop. Below left is an illustration of a box style roof washer. They are effective, however, modern filters are replacing the need for roof washers by combining first-flush and filter straining mechanisms into one device. Below right compares older, roof washer style filters with a modern filter.

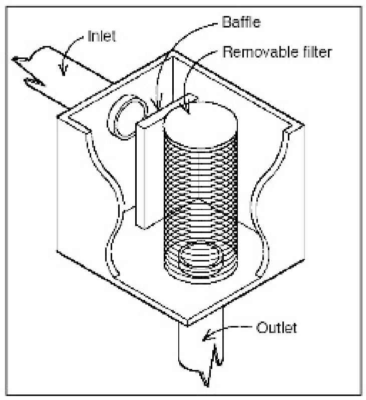


Image courtesy of TWDB, 2005 Image courtesy of LaBranche et al, 2007

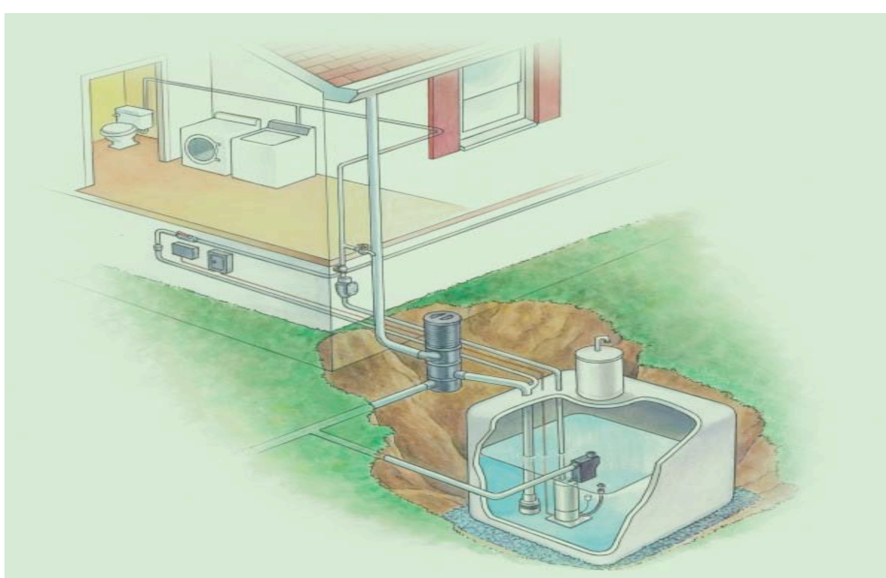
* <u>Rainwater Harvesting Filters</u>

  There are several designs and styles of rainwater harvesting system filters with a range of purposes (roof area capture abilities) and prices. Below are two images depicting various filter styles[28]. Below those are three illustrations of an example modern rainwater harvesting filter and what it would look like installed.

[28] For above left figure, numbers provide additional information. 1: Incoming rainwater; 2: Larger debris is removed; 3: Pre-filtered water flows over a secondary fine filter sieve; 4: Cleaned water flows to the cistern; 5: Dirty water is discarded

Image courtesy of www.starkenvironmental.com

Image courtesy of LaBranche et al, 2007



All above images courtesy of www.rainwaterharvestingstore.com/filters

- <u>Calming Inlet</u>

  A calming inlet allows incoming rainwater to enter from the bottom of the tank and directs water upward so as not to disturb fine particles at the cistern bottom. Below is an illustration of an example calming inlet, however, again there are many different styles on the market.

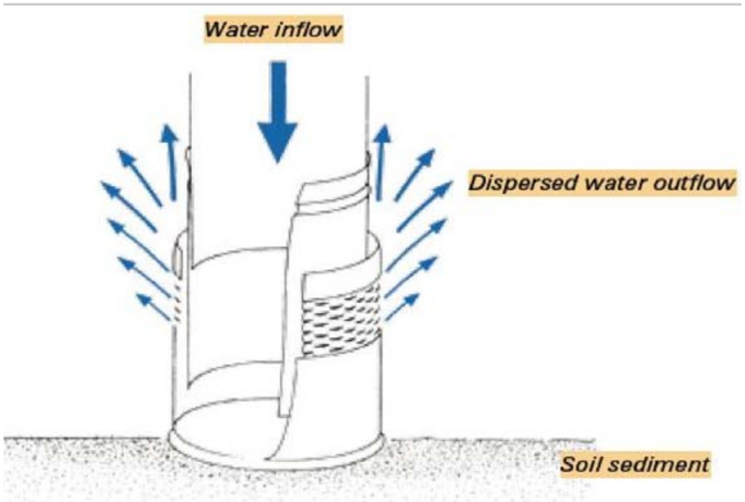


Image courtesy of Lawson et al, 2009

- Floating filter

Floating filters are important for drawing the cleanest water from the cistern (generally from10 to 16 inches below the surface). An air-filled ball suspends the floating inlet filter and allows for connection of the floating inlet to a pump or section line. Below are illustrations.

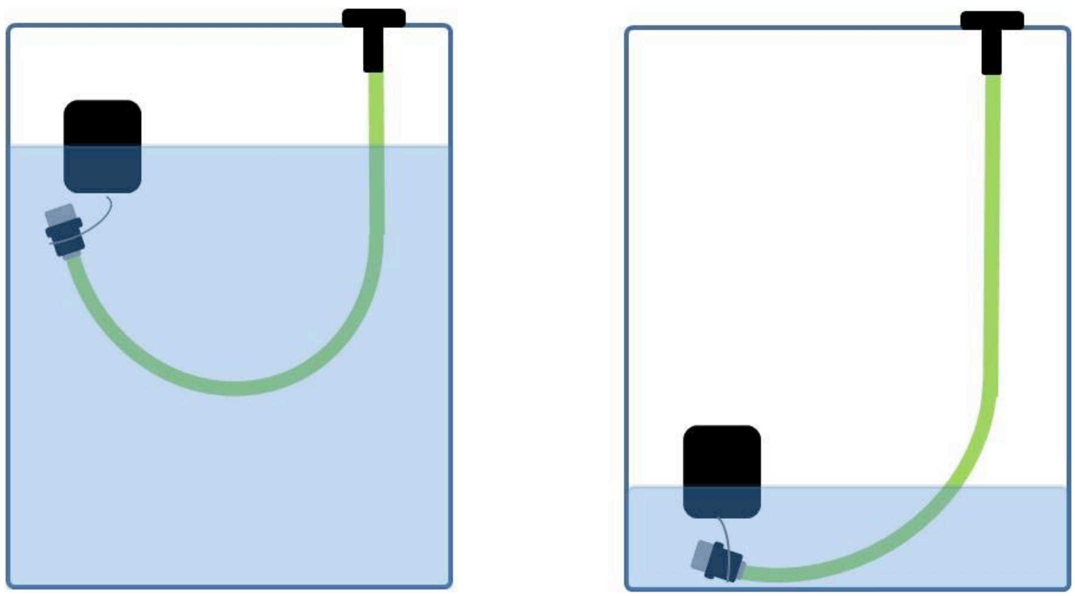
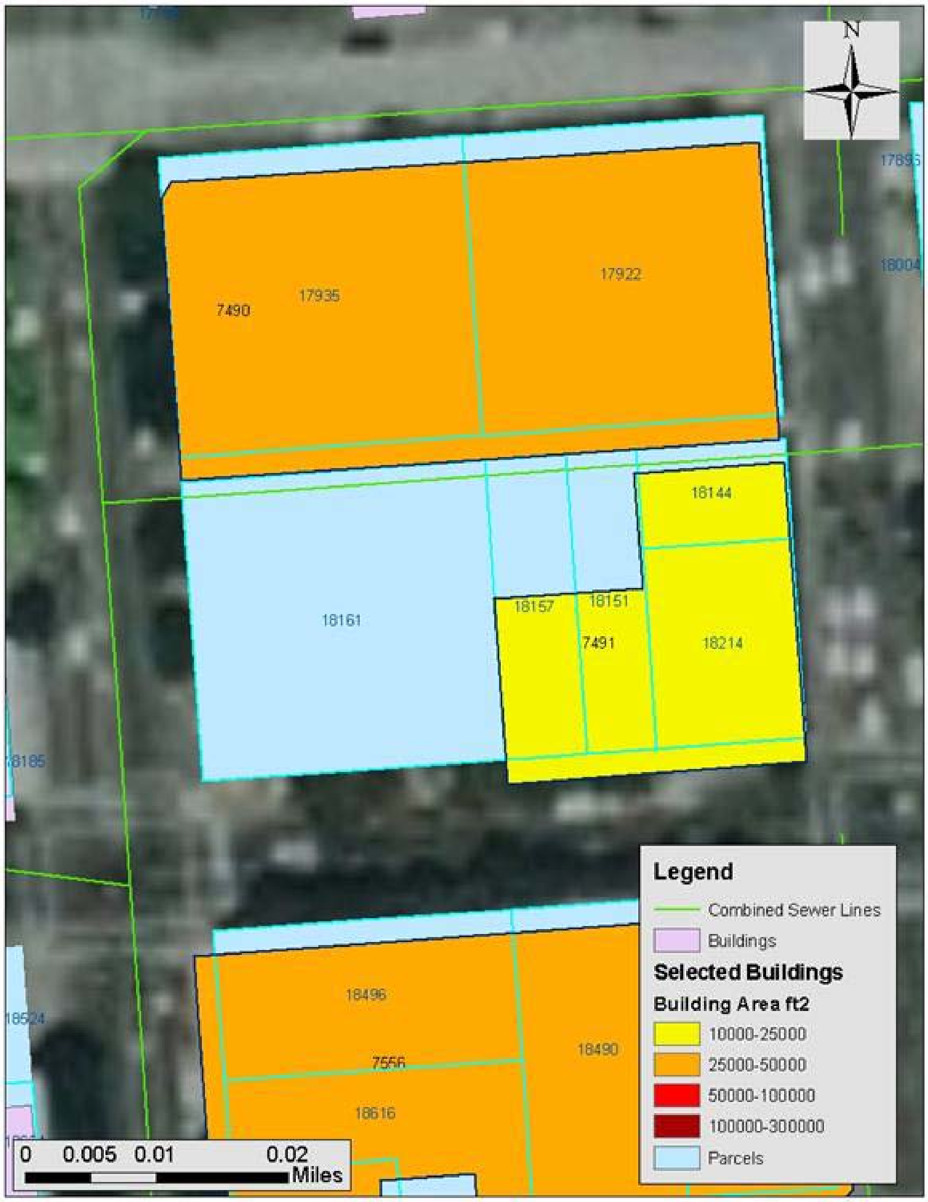


Image courtesy of http://www.beingwater.com/rainwater

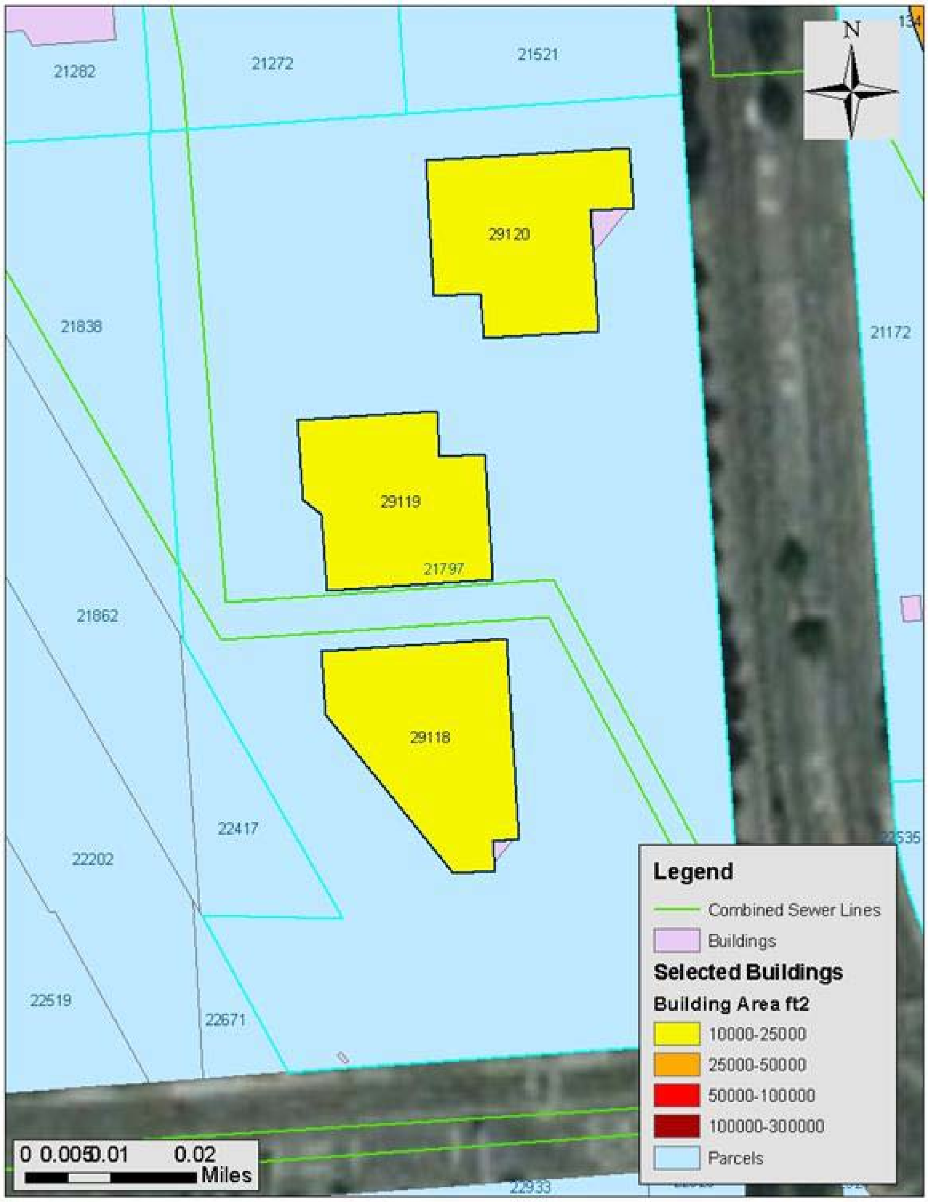
Images courtesy of www.starkenvironmental.com

Appendix C-Building Challenge Examples

a) One Building-Multiple Parcels

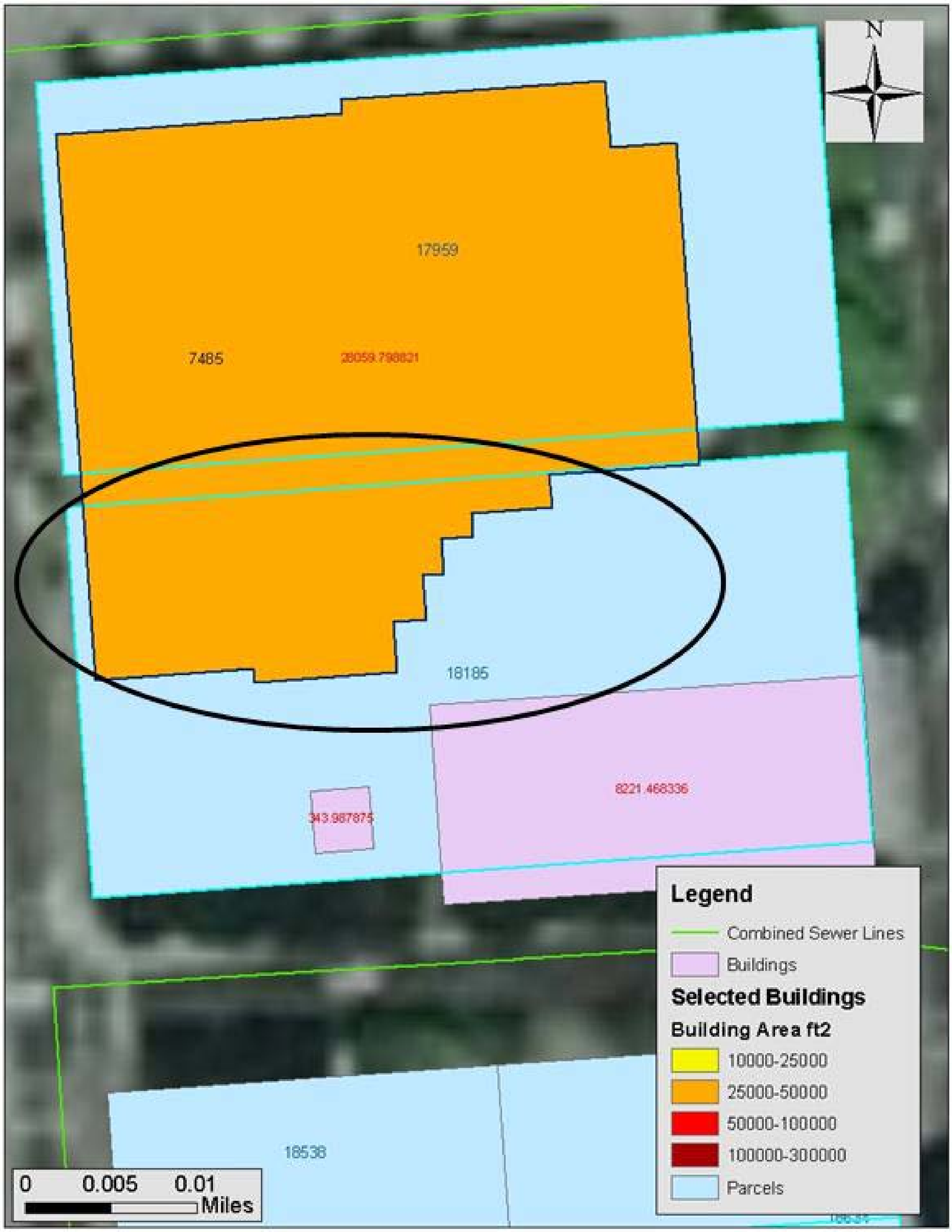


b) Multiple Buildings-One Parcel

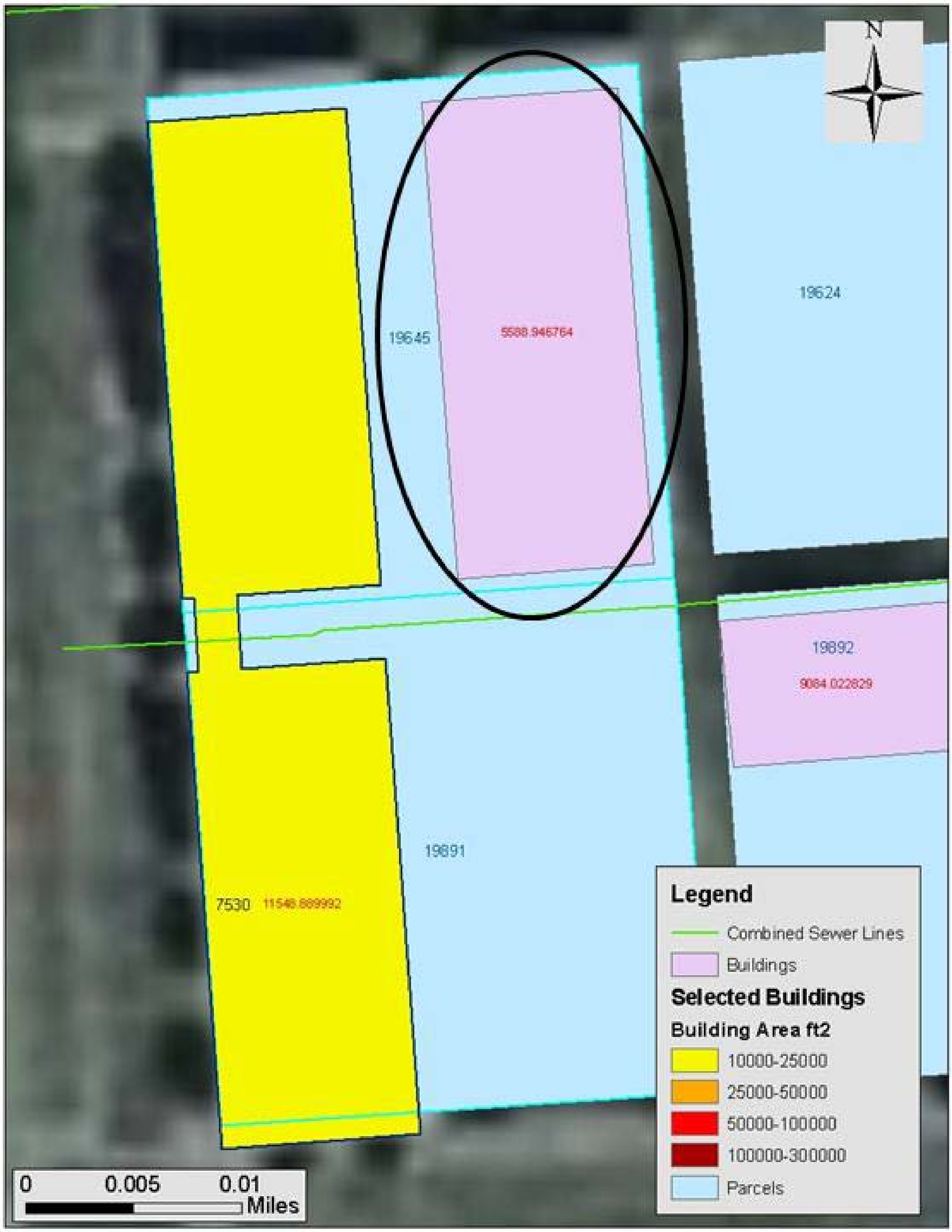


c) Multiple small parcels within one large parcel

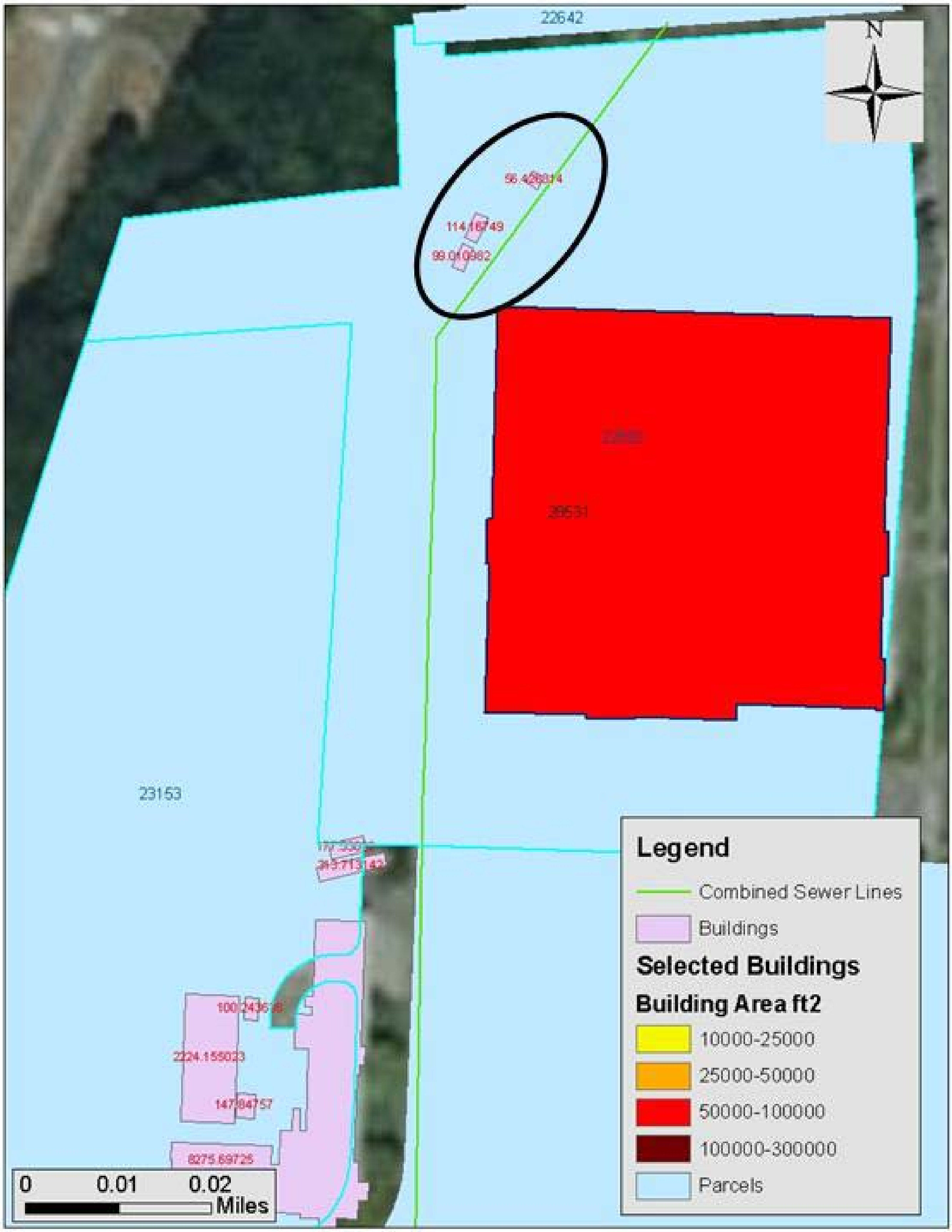
d) Selected building small parcel overlap



e) Shared parcel-significantly sized unselected building



f) Shared parcel-insignificantly sized unselected building



APPENDIX D- ENLARGED OLYMPIA PRECIPITATION CHART