NEIGHBORHOOD LEVEL ANALYSIS OF RAINWATER CATCHMENT IN PORTLAND, OR

by

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Introduction

Resource Consumption of Buildings

Buildings account for the consumption of one-sixth to one-half of the world's physical resources (Brown et al. 1995), both during construction and for maintenance and operation over their lifetimes. Additionally, the built environment produces other negative environmental effects most notably related to water entering and leaving the site. To mitigate the negative influences of the built environment on surrounding ecosystems, non-profit organizations and government agencies have advocated green building practices. The U.S. Green Building Council (USGBC)'s Leadership in Energy and Environmental Design (LEED) certification process for green buildings has become the de facto standard for third-party certification of green buildings in the United States. The LEED scorecard divides green building practices into five key areas: sustainable sites; water efficiency; energy and atmosphere; materials and resources; and indoor environmental quality. (U.S. Green Building Council 2005) This paper will explore stormwater management and to a lesser extent water conservation, two important topics that fall under LEED's sustainable sites area.

The purpose of this paper is to report results of a neighborhood-level rainwater catchment analysis for the City of Portland, with a focus on identifying the total amount of stormwater a neighborhood would divert if all single family residences in a neighborhood used rainwater to supplement municipal water. Key to this study is identifying the ideal cistern size and indoor water use for rainwater to maximize the amount of stormwater diverted from the stormwater system while keeping the cost of the system as low as possible. Important questions to consider are: "How much water is diverted from the stormwater system if each house in a census block group installed a 4500-gallon cistern and used the rainwater for toilet flushing?" "How much water is diverted from the stormwater system if each house used the rainwater for toilet flushing and clothes washing?" A census block group was chosen as a manageable scale to conduct analysis. In 1999 the American Water Works Association (AWWA) commissioned the Residential End Users of Water Study (REUWS), which looked at 100 households for each of the 12 municipal areas in which the study took place. The REUWS served as the basis for water use data for this paper (Meyer et al. 1999). Therefore, this paper was restricted to residential water use and did not look at multifamily households or commercial buildings.

To aid in the assessment of this data a spreadsheet was created that allowed an analysis of specific water use scenarios and cistern sizes. A visual picture of the results of this spreadsheet will allow for the determination of the success rate for rainwater systems for different household water uses and cistern sizes. An analysis will also be presented of percent stormwater diverted from the system if all of the houses in a neighborhood installed specific cistern sizes and water uses. Before this assessment the positives and negatives related to rainwater use will be presented, including an overview of Portland specific concerns and issues.

Definition of terms

Pervious Surfaces

To understand the issues prompting the interest in rainwater catchment systems, terms and key concepts must first be explained. A pervious surface is a surface that can absorb water and is synonymous with soil surfaces, either bare or vegetated. In a natural system

West of the Cascades, rainfall that reaches the ground is absorbed by duff, a thick layer of decomposing organic matter, and organic soils which gradually feed the underlying water table. The groundwater feeds the streams later in the season when the water level drops to the level of the ground water. Thus, the forest naturally processes the rainfall, providing the water needs for the flora and fauna (Booth 1991). During intense storm events, the volume of the water saturates the soils and sends the rainwater over the soil and into the nearest stream. These infrequent events cause a dramatic increase in the volume entering the stream, causing erosion and movement of material in the streams such as boulders and woody debris. After this event, the stream will recover and become replenished and return to a similar state (Booth 1991).

Impervious Surfaces

Impervious surfaces, common in urban environments, will not absorb water. Some examples include concrete, asphalt, metal, and brick. These materials are used to make roads, highways, parking lots, roofs, and sidewalks. An estimated 60% of impervious surfaces are associated with transportation and the remaining 40% related to rooftops (OPWD 1994). As the impervious surface increases, the amount of water leaving a site and entering the nearest stream increases. With the introduction of more impervious cover to the watershed, the frequency of floods to the stream increases and does not allow for the stream to return to its normal non-flood state. The stream is continually impacted by this force of water, which causes erosion of the sides of the channel (channel expansion) and the down-cutting of the stream bed (channel incision). Both of these actions cause an increase in sediments that enter into the stream, decreasing the overall health of the stream, including a reduction in aquatic organisms living in the stream (Booth 1991). As the impervious surface increases the amount of water leaving a site increases. Table 1 shows the difference between forests and other landscapes including suburban lots with respect with where the rainwater goes. Table 1 shows a site in Seattle will annually receive 40.70 inches of precipitation. Annually a suburban residential site will send 9.30 inches of this water off the site as surface runoff, equating to about 20% of the total volume of water falling on the site. A natural forest will only have 0.09 inches of annual precipitation leave the site as surface runoff, or about 1% of the annual precipitation.

Table 1.	Surface Runoff (in)	Interflow (in)	Ground-water (in)	Evapotrans-piration (in)
Land Use				
Forest	0.09	8.46	13.40	18.79
Pasture	0.29	13.26	10.15	17.02
Lawn	0.61	16.72	8.89	14.48
Rural Residential (forest)	1.56	10.81	11.05	17.31
Rural Residential (pasture)	1.64	12.73	9.75	16.60
Suburban Residential	9.30	12.37	6.58	12.44
Multi-family Residential	16.66	8.69	4.62	10.72
Commercial	29.37	2.34	1.24	7.74
Impervious	34.05	0.00	0.00	6.64

Table 1. Precipitation destination in Seattle. This table shows where 40.70 inches of precipitation falling annually in Seattle goes. Note the amount of water which goes to surface runoff, which in the urban environment would be to the stormwater system
(Source: Beyerlein and Brasher 1998, 44).

To illustrate the difference in water handling between the natural and urban systems, the total volume of stormwater runoff of a parking lot is about 16 times more than that produced by an undisturbed/undeveloped meadow of identical size (Schueler 1994). Minimizing the volume and force of rainwater entering from these sources will have a positive effect upon the local streams in the watershed. Figure 1 depicts the relationship between a decrease in pervious surfaces and the amount of runoff leaving a site.

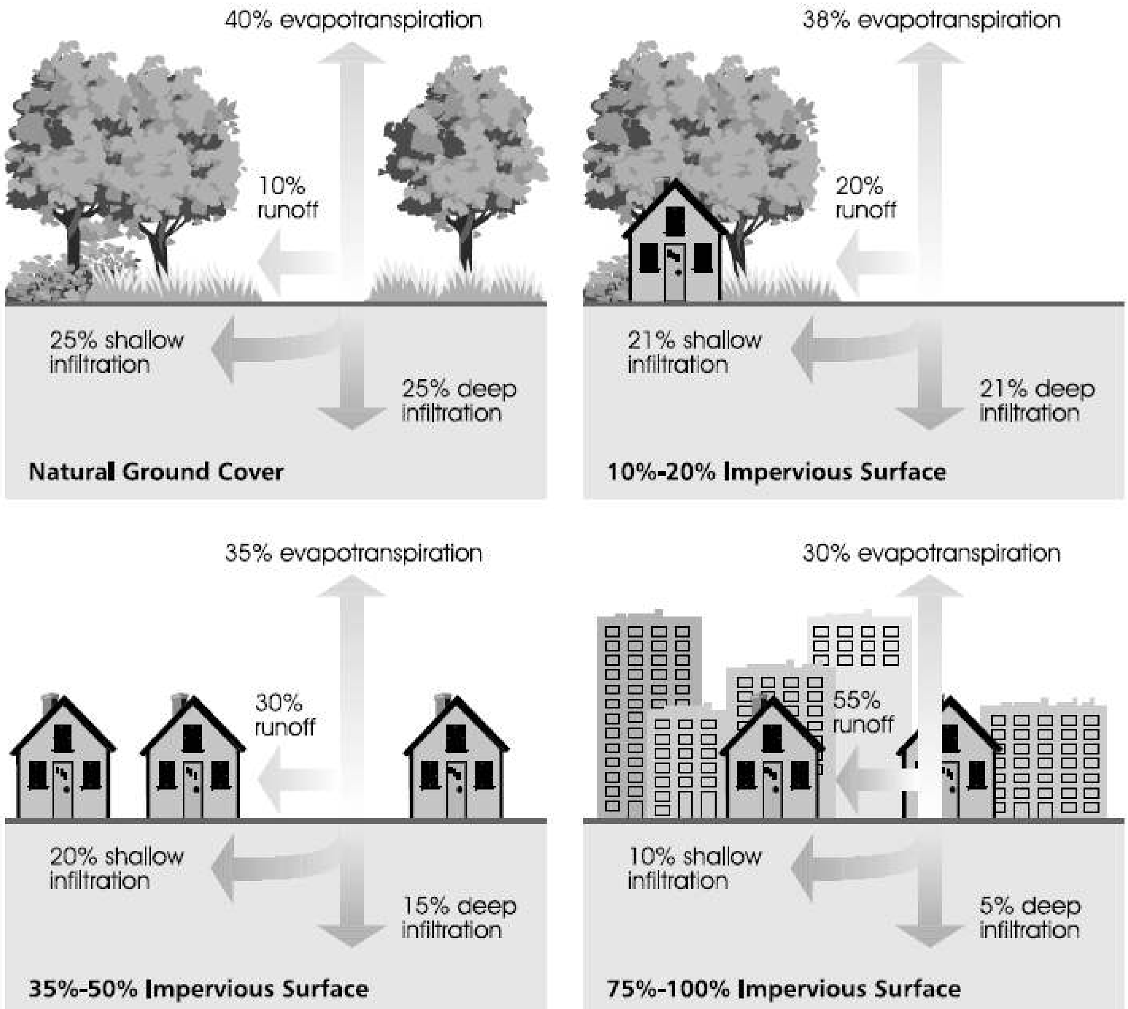


Figure 1. Increase in impervious surface. As the natural ground cover is transformed into impervious surfaces, the amount of runoff leaving the site increases and infiltration decreases (Source: PGCDER 1999, 48).

Stormwater Systems

Stormwater is rainwater that flows across an impervious surface on its way to a natural body of water. Traditional stormwater management design directs stormwater flow from the impervious surfaces to a collection point where the water enters into a large underground pipe. This pipe eventually sends the water to the nearest body of water. This ubiquitous design creates negative effects upon the local environment, including the movement of pollutants picked up off the impervious surfaces and the force of the water leaving the stormwater systems and entering the natural water bodies. In Portland this problem is exacerbated because the sewage and stormwater systems are combined.

Combined Sewer Systems (CSS's)

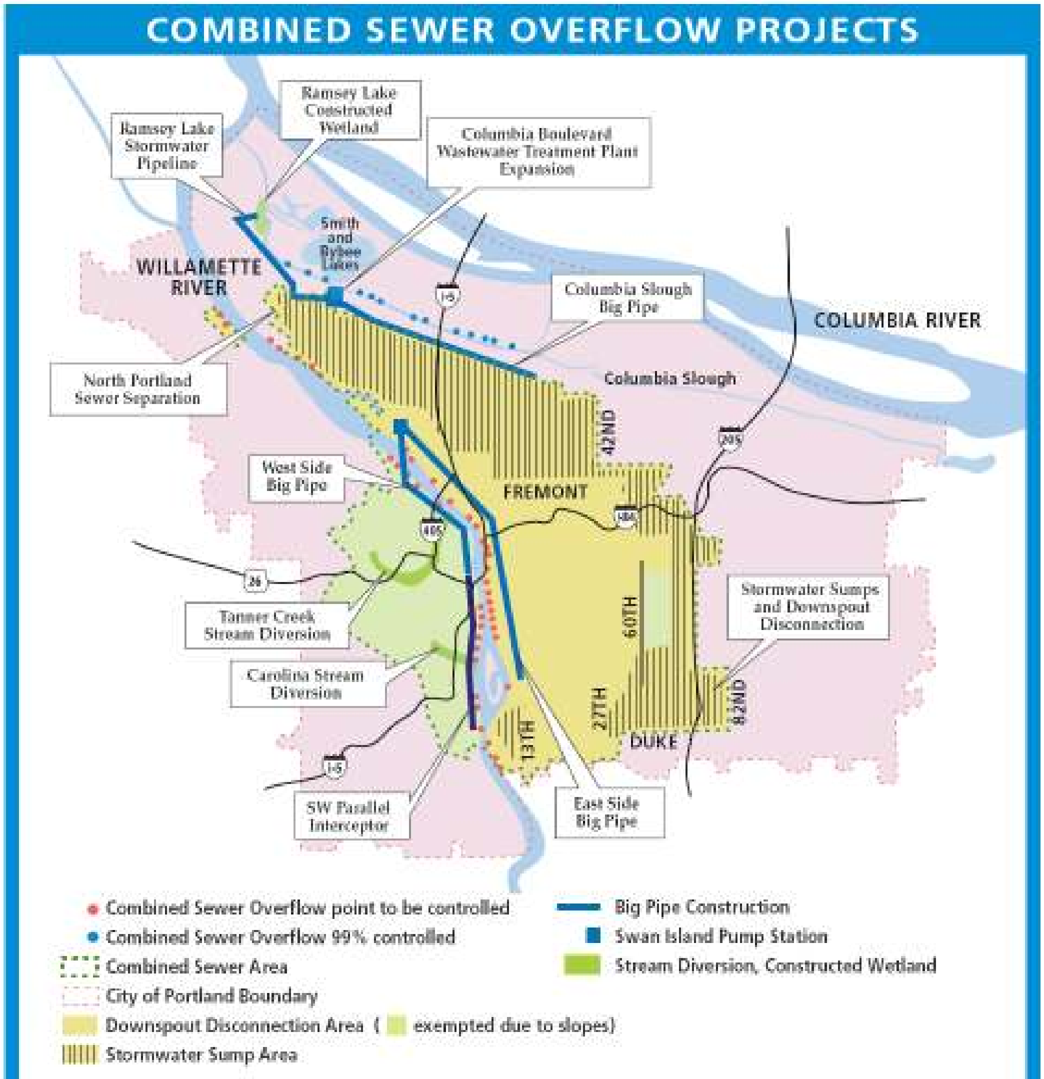
In most of Portland, both the stormwater (water coming off of the roof and the streets) and wastewater (water leaving the household from the toilet, shower drain, sink drains, washing machines and dish washers) enter the same pipe and make up the combined sewer system (CSS). Large pipes take both of these products to waste water treatment plants where the wastewater is treated in a process monitored by the Environmental Protection Agency (EPA) to ensure it meets Clean Water Act (CWA) standards. The treated water is piped into the Columbia River. If the CSS could handle the volume of water at all times, this system would comply with the CWA. Unfortunately, during large storm events the added volume of rainfall overwhelms the wastewater treatment system with the raw sewage and untreated storm water emptied into the Willamette River in Combined Sewer Overflows (CSO's) in violation of the CWA.

According to the City of Portland's website, "In a typical year, sewer overflows pour about 2.8 billion gallons of a mixture of stormwater runoff and raw sewage into the Willamette through 42 outfall pipes. Bacteria in the sewage is a threat to human health." Bacteria and other contaminants in the sewer overflows are also detrimental to steelhead and Chinook salmon, which are listed as threatened under the Endangered Species Act (ESA), along with other aquatic species found in these rivers (City of Portland 2003). The City of Portland is spending 1.4 billion dollars to modify this existing system to deal with the stormwater and wastewater to comply with the CWA (City of Portland 2005a; Garnett 2005). This "Big Pipe" project is installing larger pipes to convey the combined storm and wastewater to the wastewater treatment plants. The result will be that the volume of combined sewage and stormwater now going into the river will be reduced by more than 94% when complete in 2011 (City of Portland 2005b). Figure 2 depicts the programs being pursued to comply with the CWA. With a population of approximately 500,000 adults in Portland, $2000 will need to be paid by each person to pay for the "Big Pipe" project. In Portland the average household size is 2.3 adults (U.S. Census Bureau 2000a). So each household will be expected to pay about $5200 for this project. This would nearly cover the cost of a 1700-gallon underground rainwater catchment system for flushing toilets, washing clothes and irrigation. If the city had given each person $3000 to install a 1500-gal cistern it could have mitigated the stormwater on site and saved the city money while inspiring a local rainwater catchment market.

Explanation of Rainwater

Components of rainwater systems

One way to minimize the water entering the CSS would to be to capture the rainwater coming off roofs and diverting it to indoor and/or outdoor water uses. There are many benefits related to rainwater catchment. In some situations the cost of rainwater catchment is cheaper then drilling wells or connecting to the municipal water supply. Furthermore, rainwater is typically the purest form of water available, specifically in areas where there are no or little industrial emissions. Since the rainwater does not come into contact with minerals in the soil it is often softer than water found in reservoirs or natural



Solutions	Volume Controlled (MG/Year)	%Controlled/Year
Columbia Slough Big Pipe	440	7%
East Side Big Pipe	2100	37%
West Side Big Pipe	730	12%
Cornerstone Projects (Sewer separation, stream diversion, downspout disconnection, sumps)	2400	40%
Total Controlled	5670	96%

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Figure 2. City of Portland Combined Sewer Overflow Projects. These projects are being pursued to increase compliance with the CWA, mitigating the volume of untreated sewer water entering the Columbia and Willamette Rivers (Source: City of Portland 2005c).

water bodies. Rainwater catchment also assists the environment by using water that would otherwise be sent to wastewater treatment plants or into stormwater systems.

The City of Portland is encouraging homeowners to disconnect downspouts from their roofs to minimize the amount of water entering the municipal wastewater system. Instead of just directing the discharged water from their roofs onto their landscape, homeowners can attach rainwater catchment systems and use the captured water for watering their gardens, flushing toilets in their home, or for all of their water uses. Rather than taking water from a distant source, processing it at a central location and transporting it to the building site, rainwater catchment saves energy and reduces the need to install and maintain elaborate municipal water conveyance systems such as piping, pumps and treatment plants.

There are up to six components of a rainwater catchment system.

- the catchment area (roof),
- roof wash system,
- rainwater conveyance system (gutters and downspouts),
- cistern,
- delivery system (pump) and
- water treatment system (filters).

For rainwater harvesting it is best to have a rooftop made of material that allows for the water to flow quickly and efficiently without any of the rainwater sticking to the roof surface. This is termed "collection efficiency" or "runoff coefficient" and takes into account any losses due to leakage, evaporation and overflow (Gould and Petersen-Nissen 1999, 51). Due to many variables, such as overflow and aging of a roof, a runoff of 0.80 is recommended for most roof materials. Asphalt composite roofing, common in Portland, can leach chemicals into the rainwater. Therefore rainwater catchment systems using this type of roof should not use the rainwater for drinking water (TWDB 2005).

Contamination occurs when rainwater falls on roofs and picks up impurities from the roof such as dirt and animal excrement found on the roof. This first flush of water picks up most of the dirt, debris, and contaminants (bird droppings) that accumulate during dry periods (Gould and Petersen-Nissen 1999; TWBD 2005; Wilson 1997). A roof washer or first flush device sends the first several gallons of water from every rain event away from the cistern. By using roof-washing systems, concentrations of metal have been found to be below international guidelines (Lye 1992). To install a rainwater catchment system in Portland the roof washer most conform to the design explained in detail by the permit (POPD 2001).

A rainwater conveyance system is both the gutters on the building and the piping that moves the water from the building to the cistern. Since lead was used in gutter solder for older metal gutters they should be avoided or upgraded. Gutters should have leaf guards installed to minimize the entrance of organic matter into the cistern. The piping entering the residence must be installed to the plumbing code.

To eliminate the breeding of mosquitoes and to keep other animals from getting into the water storage area, it must be covered (Gould and Nissen-Petersen 1999). Typically what are used are barrels with covers or large plastic or cement cisterns. For larger systems it is usually highly encouraged to have a manhole opening to allow a person to enter the cistern to clean the cistern or conduct repairs if necessary. Somewhere in the system an overflow device must be installed to allow excess water to escape. If a cistern is installed above ground it is necessary to ensure the cistern has been made of UV-light-resistant plastic and the plastic is not white or a light color. If the cistern is light in color it will allow light into the cistern that will cause algae growth. Such algae growth will cause unpleasant odors and colors in the rainwater and could potentially clog the discharge valve in the cistern. In Portland for rainwater to be used inside a residence, the cistern must be at least 1500 gallons and the cistern must either be buried or it must be protected by direct sunlight by a shade structure (POPD 2001).

A water delivery system moves the water from the cistern to where it will be used. If the cistern is above ground and the destination of the water is below the cistern, gravity can be used. For every foot gained in height the pounds per square inch (psi) increases by 0.43, or for every 2.31 feet the psi increases by one. Gravity is the easiest method of delivering the water to the source in the home or in the garden; however, if a cistern is to be elevated on a structure to make use of gravity it is necessary to realize one gallon of water weighs 8.35 pounds. Using this information a 500 gallon cistern when full of water weighs 4,175 pounds. Numerous household water appliances such as clothes washers need a specific water pressure to operate. For these reasons pumps are typically used as the delivery system in rainwater catchment systems. Well pumping systems are typically used for rainwater catchment systems, using a pump and a pressure tank to keep the water pressure at a constant level (TWDB 2005).

Water treatment systems are only required by the City of Portland if the rainwater is used for showers, faucets or clothes washing. Such systems are not required for toilets or irrigation water by the City of Portland. A typical water treatment system found in Portland involves a few particulate filters and an ultraviolet (UV) light sterilizer (Errson 2005; TWDB 2005). There are other types of water treatment systems available such as ozone systems and reverse osmosis systems, not as common in Portland (TWDB 2005).

Cost

With all of the water coming off of roofs that could be used for household water use, why are not more people using rainwater? The biggest obstacle to the installation of rainwater catchment systems is the installation cost, which is related to the size of the cistern, and additional equipment, which must be used such as filters and pumps. For a building site with access to a municipal water supply, common in Portland, it might not make economic sense to install a rainwater catchment system. To move water from the Bull Run watershed to Portland requires the use of pumps and extensive infrastructure that must be maintained, costing taxpayer dollars. It is plausible Portland's drinking water does not reflect the full costs and therefore does not allow for a fair comparison of costs and payback for rainwater catchment systems.

Rainwater catchment systems in outlying areas not served by municipal water systems are often cost effective. A rainwater catchment system is often cheaper and more reliable than drilling for water with the additional benefits of softer water and less pollutants (TWDB 2005). If the costs of stormwater infrastructure, the energy costs related to pumping water to the houses and moving stormwater away from the houses, are included in the cost of municipal water supplies, the cost of rainwater catchment systems are comparable to conventional systems (Vishwanath, 2001; Lee et al., 2001).

Where a building is already installed with the existing infrastructure these costs cannot be recouped. However, for structures being built in the city and out of the city away from a municipal water supply, the cost of rainwater catchment systems begins to make economic sense with water use and stormwater generated halved, reducing the cost of the municipal system (Gardner et al., 2001). Using a different economic model for equating future expansion and cost, one study determined rainwater catchment systems would be cheaper for a community than expanding the municipal water supply and stormwater system (Coombes and Kuczera 2003).

Pat Lando, a Portland Landscape Architect specializing in rainwater catchment, installed a 1,700 gallon below-ground system at his southeast Portland house and uses the water for toilet flushing, washing clothes and irrigation. The total cost of the system was $6,600 including permit fees, plumbing costs/fees ($2,000), material costs ($1,830) and excavation ($1,250). For this system, the cost per gallon was $3.88. Figure 3 presents the full price breakdown.

Rainwater Harvesting System Cost Breakdown

Plumbing	$2000
Permit	125
Testing	75
Excavation	1250
Cistern/washer installation	125
Gutters & downspouts	—
Electrical	230
Drill foundation	—
Materials*	1830
Risk-5%	282
Profit-5%	282
Contingency-7%	395
Total	**$6590**

*Materials	
Pump (Grundfos SQ-E)	$500
Pressure tank (Amtrol 2 gal.)	175
Cistern (Norwest)	1050
Filter (Familian PBH420-1.5)	250
Flow control (12 gal.)	30
1" Cylnanoid switch	130
Backflow prevention device	150
PEX tubing	100
PEX fittings	80
Jumbo irrigation box	62

Most materials were purchased at Familian NW and United Pipe.

Figure 3. Rainwater catchment system cost. Chart depicting the cost breakdown for a 1700-gallon below ground cistern in Portland (Source: POSD 2004).

If a cistern is to be placed below ground, the cost increases, since a hole must be dug for the cistern with the connection and overflow for the cistern below ground. Also, a below ground cistern requires a pump to bring the water out of the cistern. The benefit of a below ground cistern is that it does not take up valuable yard space and it will not be exposed to sunlight, since sunlight can break down plastic cisterns over time. When and how much a rainwater catchment system will become empty (failure) will effect the decision to install specific cistern sizes along with the cost associated with the cistern.

Why use rainwater?

Stream Water Quality

As urbanization increases in the Pacific Northwest, the physical, biological and chemical degradation of streams increases, with the most dramatic changes occurring in the early stages of urbanization when the percent of impervious cover is between 5-10% (May et al. 1997). As the impervious cover in a watershed increases so does the volume of stormwater runoff (Schueler 1994). Anadromous fish species, such as salmon & steelhead trout, appear to be most negatively impacted by impervious cover, with biological diversity of the streams dropping off dramatically when the watershed goes above 10% impervious cover (May et al. 1997; Schueler 1994). Figure 4 depicts the direct relationship between an increase in percent impervious cover in a watershed and an increase in stream impact.

Intercepting the rainfall discharged from a roof before it can enter into the CSS positively affects the environment. Currently rainwater is sent into downspouts in the combined sewer system in Portland. This pure, clean water becomes tainted with stormwater off streets and wastewater from toilets and sinks as it is sent to the wastewater treatment plant. It would be more efficient to take this pure water, capture it, filter it and use it in the building and then send it into the combined sewer system after it has been used in the building. This

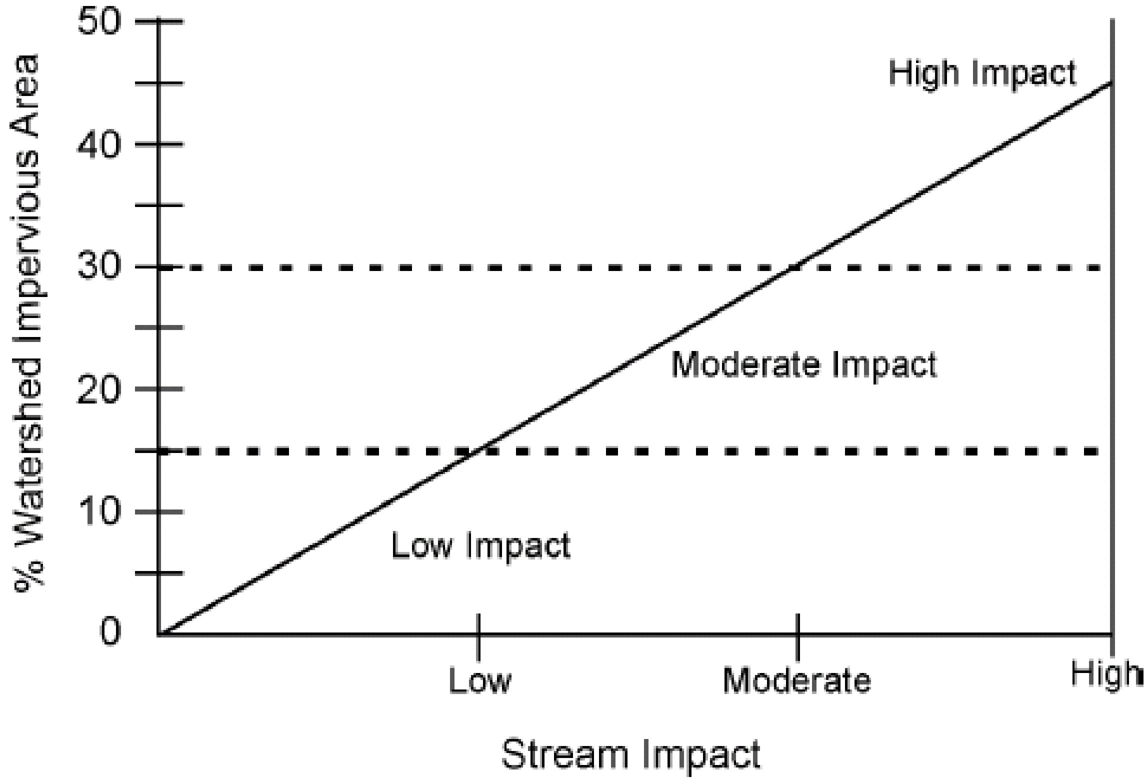

Figure 4. Stream impact from impervious cover. As the percentage of the watershed becomes more impervious, the impact on the streams increases (Source: PGCDER 1999, 29).

is not only an efficient use of rainwater; it also reduces the need to install larger stormwater and drinking water conveyance systems. By using the rainwater to supplement or replace the municipal water in Portland reduces the demand on this community resource.

When a rain event occurs all of the impervious surfaces send the water quickly into the sewer system, where it is often pumped directly into the river. If more buildings used rainwater catchment, one segment of this deluge of water would be collected. As it is used in the building it would slowly enter back into the system. This will assist in minimizing the drastic spikes currently seen in hydrographs for these streams and rivers. The building is now holding onto the rainwater for a period of time and then slowly releasing the water back into the waste treatment system, mimicking what is done in nature with groundwater. Typically a rainwater catchment system has the overflow from the cistern go onto the building site rather then send the overflow into the stormwater system. Not only does this assist with the stormwater problem it also introduces water into the local aquifer. This allows for water to be available for the streams in the summer time and for wells that might use this water (Gardner et al. 2001). Since the majority of rainwater is collected and used, the amount of surface runoff from the overflow is lower than that with the downspout disconnection program.

Reduction of Pollutants

The amount of urban pollutants entering streams adjacent to impervious surfaces is directly related to percent impervious cover of a watershed (Schueler 1994). Parking lots, roads, and rooftops accumulate large amounts of pollutants, which come from numerous sources related to urban development. Thermal pollution can also negatively affect salmon and other aquatic species. In the summer, impervious areas can have a local air and ground temperature 10-12 degrees warmer than nearby fields and forests, which in turn directly influences the degrees of warming of urban streams. In contrast, rainwater in natural systems is not subjected to this additional heating (Schueler 1994).

Potable Water Supply

Precipitation contains very few impurities; it is virtually sodium free and is the softest naturally occurring water available (TWDB 2005). Portland’s municipal water supply collects water from runoff in the Bull Run watershed. As precipitation hits the ground it can pick up minerals, chemicals, bacteria, organic substances and other forms of contamination requiring the City of Portland Water Bureau to filter the water and add large amounts of chlorine to kill the bacteria. In Portland rainwater has 5 milligrams per liter of dissolved minerals, as compared to the City of Portland's water being 18 milligrams per liter (Errson 2005). As a result of fewer dissolved minerals in the water there will be fewer deposits in water heaters and pipes, thereby extending the lifetime of these products (TWDB 2005). This is not only a long-term cost saving, but it also assists the environment by reducing the materials and energy needed to manufacture the replacement for these products. Softer water not only reduces the need to replace piping, it also can significantly reduce the amount of detergents and soaps being washed down pipes into the combined sewer system in Portland.

It has been shown the amount of fecal coliform in a cistern decreases over time and the water quality improves after being in the cistern for a few days, a result of cisterns having a self-disinfection action over time (Gardner et al. 2001). This is because bacteria and pathogens gradually die off during the first few days in storage as long as light and organic matter are excluded from entering the cistern (Gould and Petersen-Nissen 1999). Rainwater is generally bacteriologically safe, and has low mineralization. In a South Australia study, where up to 42% of the population use rainwater as their main source of water, children drinking rainwater from a cistern were found to be less likely to have gastroenteritis than children drinking municipal water (Heyworth, 2001).

Along with a concern with stormwater mitigation there is growing interest in water conservation since it is cheaper to encourage conservation than build an additional dam in the Bull Run watershed or find other alternative water sources (City of Portland 2005d).

Covering 102 square miles and located east of Portland in the Mt. Hood National Forest, the Bull Run Watershed supplies the majority of municipal water in the Greater Portland area. Since this area receives most of its rainfall from October to June, the Bull Run watershed can adequately supply the Greater Portland area during these months. With minimal rainfall in the months of July through September, and the heightened water demand for irrigation, the Bull Run reservoirs are stressed with them occasionally running dry (City of Portland 2005d). Supplemental groundwater is then pumped from the Columbia South Shore Well field (CSSW), which when pumped causes an adjacent pollution plume to flow towards another municipality's water source (Wells et al. 1996). With an increasing population there has been discussion of the necessity to install another dam in the Bull Run Watershed or find alternative water sources. Such construction would cost a significant amount of money, which would be recouped by an increase in taxes or an increase in water rates. Any reduction in the summer water demand will minimize the need for such construction (City of Portland 2005d).

Concerns related to rainwater

Health Hazards

While there are many benefits related to rainwater catchment there are some precautions that must be taken, most of them related to health concerns. In urban areas pollutants such as pesticides, arsenic and lead can be found in the rainwater (TWDB 2005). It is recommended to test the water off an existing roof for toxins before installing a system. Another source of chemical contamination in rainwater is the dissolution of chemicals from sediments in the cisterns and corrosion of the chemicals within the system itself such as the cistern (Gould and Petersen-Nissen 1999). There are several studies showing a higher level of indicator bacteria in untreated rainwater as compared to treated municipal water systems, with documented incidents of salmonella and legionnaires disease from untreated rainwater (Lye 1992). Most of the health concerns related to rainwater are related to bacteria rather than heavy metal contamination. It should be noted that most of the above chemicals and bacteria are found in groundwater and reservoirs that are used as the source for municipal or residential water systems. Most of these health risks are associated with water that is ingested or inhaled (from a shower) and are not a concern for water used for toilet use, clothes washing and irrigation, since ingestion or inhalation of the rainwater does not happen (Lye 1992). Under normal conditions serious chemical contamination of rainwater is rare, with the largest concern usually related to the presence of bacteria. Even this is uncommon if first flush or roof washers are used (Gould and Petersen-Nissen 1999; Lye 1992).

There are many ways in which microbiological organisms can be made harmless in the rainwater catchment process. Sun exposure, sedimentation of particulates, floating of material on the surface of the cistern, and temperature ranges in the cisterns all make the survival of pathogens in the rainwater catchment system minimal (Spink et al., 2003). Most rainwater systems remove water from the bottom of the cistern, usually with a gap to allow for the sediments which are deposited on the bottom of the cistern. The majority of pathogens which could harm humans will either float to the top of the cistern, coagulate and fall to the bottom or will find the colder temperatures near the discharge point of the cistern too cold for survival. Pumps can also cause stress on pathogens and reduce the opportunity for them to survive and reach a person, with the stresses on the pathogen being approximated to the same effect as an autoclave (Spink et al. 2003). Heating rainwater in hot water heaters is another way the pathogens are stressed, reducing their ability to harm humans (Coombes et al. 2004; Spink et al. 2003). Table 2 depicts microbial results of cisterns in various Australian locations.

Location	E. Coli (CFU/100 ml)	Total Coliform (CFU/100 ml)	Pseudomonas Sp. (CFU/100 ml)	Heterotrophic Plate Count (CFU/ml)
Roof runoff at Figtree Place	135	359	59,604	1,362
Maryville rainwater tank	0	18	1673	784
Water surface in tank	**108**	**1050**	**3100**	**1,050**
Medium depth in the tank	**34**	**900**	**780**	**427**
Bottom of the tank	**55**	**862**	**4060**	**1,252**
Cold water tap	**<1**	**200**	**412**	**76**
Hot water tap	**0**	**2**	**<1**	**<1**
Australian Drinking Water Guidelines	0	0	-	-
American Drinking Water Guidelines	0	0	-	200

Table 2. Microbial results of cisterns. Note the hot water tap almost complies with the drinking water guidelines (Source: Coombes et al. 2004, 510).

Another concern with rainwater harvesting is the leaching of chemicals from the roof into the rainwater. It is highly recommended to have the rainwater off of a roof tested to determine what can be expected to come off of the roof since asphalt composite roofs have been shown to leach copper and other potentially hazardous chemicals (Wilson 1997). Chang and Crowley (1993) looked at rainwater coming off of a roof (not going into a cistern) and determined the water quality coming off different types of rooftops was lower than the rainwater falling adjacent to the rooftops. The reason for this decrease in water quality was determined to be from the roof material leaching into the rainwater. Four roof materials were studied: wood shingle, composite shingle, rock and tar and terra cotta, with terra cotta roofs generating the best water quality and wood shingle roofs generating the worst water quality. The water quality from the rooftops decreased with an increase of time between storms and the quality increased with an increase in storm duration, amount of water coming off of the roof and intensity of the storm (Chang and Crowley 1993). If a roof washer had been installed and the water had been allowed to settle the contaminates to the bottom of the cistern it is feasible that the quality of the water would have been increased.

Best Practices in Residential Stormwater Management

Downspout disconnection program

After rain falls on Portland rooftops, the water usually is sent into gutters, flows into downspouts that empty into the combined sewer system. Minimizing the amount of stormwater entering the combined sewer system is the motivation behind the City of Portland's Downspout Disconnect program. This program encourages homeowners to disconnect their downspouts from the CSS and have the water from the roof enter into the soil instead of sending it into the stormdrain. As an incentive, a homeowner receives $53 per downspout they disconnect with a potential for the City of Portland to reduce the stormwater fees by up to 35% based on how many downspouts have been disconnected (City of Portland 2005e). According to Ms. Barbara George, manager of the Downspout Disconnection Program, as of November 2005 47,700 properties have disconnected their downspouts. She went on to say "According to my calculations, 1.1 billion gallons of roof water do not enter the combined sewer each year from these properties. The gallon calculation is based on assumptions of 1600 feet average roof area per property, 36" of annual rainfall (the 60 year average), % of roof disconnected per all the properties, and # gallons per cubic foot of water" (George 2005).

This program is much more progressive than building a bigger pipe to mitigate stormwater issues since it deals with the problem at the source and could minimize the complex infrastructure of pipes required for a conventional stormwater system. The benefit of this program is every downspout disconnected will remove 100% of the stormwater from directly entering the CSS. A shortcoming is that many households cannot disconnect one or more of their downspouts because the discharge could either flood the home's or neighbor's basement. Another concern is that the soil could become saturated and causes the water and some of the soil to flow into the street and then enter into the stormdrain, potentially causing more pollution than if the downspout had just entered into the CSS.

Using rainwater

If the disconnected downspouts first emptied into a cistern and the water was then used in the residence throughout the year, the above-mentioned issues with the downspout disconnection program would be reduced. Collection of the rainwater and use in the residence is a way to address both stormwater and water supply issues, harmonizing a building with its natural system and reducing a building's dependency on external inputs and outputs. Rainwater catchment is becoming more prevalent in the Portland area with the City of Portland's Office of Sustainable Development advocating this technique in its green building program since its inception. A simplified permitting process allowing households to install rainwater catchment systems has been created by the City of Portland. Commercial buildings are beginning to use this technology to reduce stormwater fees and to save money on water bills. American Honda's Distribution Center in Gresham, a LEED Gold rated building, installed a 90,000-gallon cistern to capture rainwater and use it to flush the toilets and irrigate the landscape, partly explaining the $1,400 reduction in annual water costs (City of Portland 2005f).

Rainwater uses in the home

Numerous household water uses do not require drinking water quality water. Rainwater is best suited for toilet flushing, washing clothes, and irrigation since the amount of filtration and concern for chemicals and bacteria in the rainwater is lessened for these water uses. In Portland rainwater can be used for all indoor and outdoor uses; however, additional filtration is required if the water is to be used for ingestion and showering. It is highly inefficient to quickly contaminate potable water by using it to flush human excrement. Similarly it is not necessary to have drinking water quality water when detergents are added to wash clothes. As mentioned earlier, heating of rainwater in hot water heaters makes rainwater bacterilogically safe, suggesting rainwater used in hot water heaters do not require filtration and should be encouraged in rainwater systems (Spinks et al. 2003).

Regulations

In 2001, the City of Portland Office of Planning and Development published the One and Two Family Dwelling Specialty Code 2000 Edition and the Plumbing Specialty Code 2000 Edition (ICC-RES/ 34 #1 and UPC/6/ #2). This code allowed for the use of rainwater harvesting for toilet flushing inside one or two family dwellings with minimal regulatory hurdles. Included in this code are detailed requirements on how to install, maintain and decommission a rainwater catchment system in Portland. Of note are the detailed instructions on how a roofwasher must be designed and installed and the requirement for the cistern to be at least 1500 gallons and either be buried or shaded from direct sunlight by certain permitted structures. Other requirements are the necessity to receive building permits for the shade structure, electrical permits for the pump and plumbing permits for the plumbing into the home (POPD 2001). Other water uses in a residence must have an additional variance and have been approved by the City of Portland (POSD 2004).

Problem Statement

The ways buildings are developed cause numerous detrimental environmental effects, which could be mitigated if natural systems and inputs were mimicked and used. A conventional building needs both a piping system to convey unwanted stormwater away from the site, and piping to bring water to the site from an off-site central water supply. Changing perspectives to regard stormwater off the roof as a resource instead of a nuisance would make a building more self-sufficient by capturing the rainwater and using it in the building, with the water eventually entering back into the system as wastewater. Since rooftops make up to 40% of the impervious surfaces in an urban area, any way the water leaving rooftops can be reduced will assist with stream quality and compliance with the CWA and ESA.

Hypothesis

It is best to mitigate the stormwater problem at the source. Homeowners can substantially reduce the amount of water leaving their property using several different practices including: rainwater catchment, converting impervious surfaces to pervious surfaces (such as ecoroofs and bioswales), and minimizing the amount of new impervious surfaces. This paper will look at intercepting rainwater off residential roofs and storing it in cisterns for indoor use as a way to mitigate stormwater problems in Portland. A large number of residents installing rainwater catchment systems could delay or eliminate the need for future expansions of municipal water supply systems and stormwater/wastewater systems such as the Big Pipe project and the CSSW project along with potential future expansions of the stormwater and water systems. This additional cost saving is rarely looked at when determining the benefit of rainwater catchment systems. Depicting the total amount of stormwater diverted from a large number of houses using rainwater could help to quantify the potential benefits of rainwater harvesting in the city of Portland.

Methodology

Explanation of the spreadsheet

A spreadsheet was generated to determine the water remaining in each household's cistern at the end of each month for an entire year for each water use analyzed. The amount of water diverted from the stormwater system was also determined for each water use and cistern size. This spreadsheet simplifies complex inputs affecting a household's water consumption and potential for supplementing this consumption with rainwater captured from a home's roof. Several constants are used in the spreadsheet to simplify the equation. If each household's water consumption were available it would not be necessary to use the data from the REUWS study. The equation used could be simplified as the following:

Equation 1. Basic equation determining water in cistern.

Y = water collected (limited by cistern size) - water used

A building's size, along with the rainfall pattern, will affect the amount of water falling off the roof with the size of the cistern affecting how much of this rainfall can be captured and stored. How the rainwater is used and the number of residents affects the indoor water usage. Numerous combinations of rainwater uses are possible in a household, including using rainwater for irrigation, using rainwater for toilet flushing, clothes washing and all indoor water uses in a household. Several combinations of these will be reviewed to determine which are most feasible and effective.

To conduct this analysis the building area of a single-family residence was necessary. The source of this spreadsheet was a Metro RLIS shapefile listing site addresses and building area along with numerous other data. This was limited to the single-family residences in the block group studied. From this source data, the spreadsheet was expanded using equations listed below for each month. For a more detailed explanation of this procedure, refer to Appendix A.

Identification of study area

A census block group was chosen for this study because of its manageable scale and specific census data could be used for this and future research. Portland Block Group 2 Census Track 14 was chosen for this study. This block group is located in a dense residential inner Portland neighborhood with the average year of construction 1905. Most of the houses are bungalows with an average size of 1234 ft^2 and an average lot size of 4260 ft^2. Figure 5 depicts the boundaries of the block group. Due to the close proximity of the houses in this neighborhood, it is difficult to disconnect all downspouts on most of the houses, since the discharge could go into neighboring basements. Therefore, in this neighborhood rainwater catchment is a preferable alternative for stormwater mitigation. Due to the small size of the yards if the cisterns were larger than 500 gallons it is expected they would be buried in this neighborhood.

Figure 5. Map of Portland study area, census block group 2, track 14 (Source: author from Metro RLIS data).

Residential Water Use

For this paper it is necessary to determine the daily per person water use, which includes: showers, toilet flushing, washing of clothes, drinking water, dish washing and leaks. Outdoor water use will not be looked at for this study since the amount of stormwater mitigation related to this water use is minimal unless very large cisterns are installed to store the water until the dry summer months. Residential water use rates per person for this paper were derived from the REUWS (Mayer et al. 1999). Two Pacific Northwest cities were included in the study: Seattle, WA and Eugene, Oregon. The average water use for the entire study was 69.3 gallons per capita per day (gpcd), with Seattle conserving more water with an average of 57.1 gpcd (Mayer et al. 1999).

Water efficient person

The efficiency of each piece of hardware, such as faucets and water appliances, along with personal behavior, affects the city water average indoor water use. Irrigation needs relate to the growing season and amount of rainfall occurring during the growing season. The REUWS study discussed the number of households with water efficient appliances and how this reduced the water use. Since residents installing rainwater catchment systems use much less water than people using municipally supplied water (Lye 1992), these households would also be expected to incorporate water efficient practices and behavior since they were willing to spend additional money on a system with a long payback period. These changes could allow for a smaller-sized cistern and allow for more water availability for summer irrigation. With this assumption of willingness to purchase a cistern, the data used in this spreadsheet reflects the water usage for a household only using water efficient devices and water efficient practices. Looking at all water uses in each city and identifying the most efficient water use per city created these numbers, with a water efficient person using 43.6 gcpd. This correlates closely to the water efficient Casa del Agua house in Tucson, AZ water use of 49.4 gcpd. The Casa del Agua was a case study house demonstrating graywater and rainwater use along with water conservation practices (Karpiscak et al. 2001). Figure 6 depicts the average daily water use for a water efficient person. See Appendix B for a more detailed discussion on how the water efficient person's water use was determined.

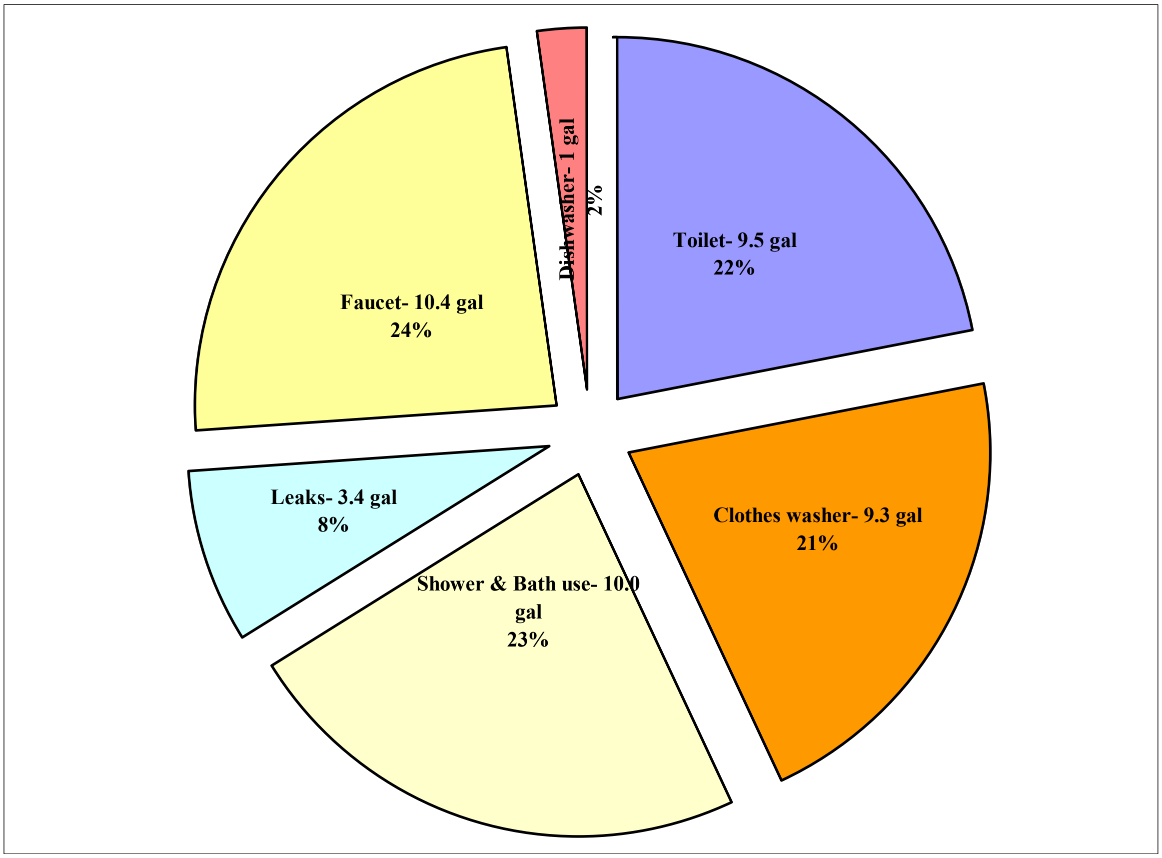

Figure 6. Average water efficient resident's daily indoor water use. The total daily average water use per person is 43.6 gallons. The number next to the water use is the number of gallons used per day, with the second number being the percentage of total water use (Adapted from Mayer et al. 1999).

Calculating Number of Residents

A building's roof size directly impacts the amount of water coming off the roof and the potential rainwater use. This is the supply side of the equation. The demand portion of the equation for indoor water uses is directly related to the number of residents in the house. Subsequently, the number of residents in a household dramatically affects the equation needed to determine the proper cistern size. Since the REUWS data used had water uses based on per person it was necessary to determine the number of residents in each household of this study. To determine this figure, the total area of all residential building footprints was divided by the total number of residents. This produced a figure of one person to 556 ft^2 of building area. For a more detailed explanation on how this was done refer to Appendix C.

Calculating Rainwater Volume

The volume of water generated off of a roof, or supply, is as important as the demand (water use) for water. The quantity of rainwater captured is a function of the amount of water falling on a specific area (rooftop). To determine this, the following equation is used:

Equation 2. Equation determining amount of water coming off of roof.

$$W = R * P * 0.6233 * C$$

Where:
W = Water captured off of roof in a period of time (1 month for this study)
R = Rooftop Area (ft^2) The area is the roof area for each household
P = Average Precipitation (inches per month for this study)
0.6233 = coefficient; a conversion factor to convert the two units of measure, ft^2 and inches to gallons
C = collection efficiency (0.8 used for this study)

For example, a typical home found in Southeast Portland is approximately 25-feet by 50-feet, with a roof area of 1250 ft^2. Using equation 3, an estimated 27,000 gallons of water fall onto this roof every year, with 21,600 gallons of rainwater coming out of the downspouts (as a result of the 80% collection efficiency). That is, a 21,600-gallon cistern would be needed to collect a year's worth of rainwater. If the water is used regularly throughout the year, the size of the cistern can be reduced, since it will be filling up and emptying consistently during the rainy months. The spreadsheet created provides a means for a household to identify combinations of water use and the size cistern to match the water demand to optimize the amount of stormwater diverted. Equation 2 was used every month in the spreadsheet to determine the volume of water generated by the roof.

Calculating water in cistern after use

To determine the water remaining in the cistern every month after using the rainwater, the following equation (Gould and Petersen-Nissen 1999) was used:

Equation 3. Monthly cistern volume after use. Equation used to determine amount of water remaining in the cistern after water is used. In this example the water is used for toilet flushing.

W =MIN(MAX(PM+CM-T,0),C)

Where:
W = Water remaining in the cistern at the end of the month after rainwater is used for monthly toilet flushing.
PM = water leftover from the previous month for toilet use
CM = amount of water captured off the roof for the month
T = amount of water used for flushing toilets for the month
C = capacity of cistern
MAX = if the result of this equation is negative, it will be listed as zero
MIN = makes sure it does not exceed the capacity of the cistern (C).

This equation ensures the amount of water remaining in the cistern does not exceed the cistern size, nor does it let the capacity go below zero. Similar equations were used for the other water use scenarios (indoor water use and toilet and clothes washer use). This equation allows for water coming in from the roof and leaving through water use throughout the month. This equation was also suggested in a presentation at the 2001 International Rainwater Catchment Systems Conference in a presentation entitled "Rainwater Utilization of Quake Disaster Area Rebuilding Programs in Taiwan" (Lee et al. 2001). This equation allows for the cistern to exceed its maximum volume over the month, subtracts the water used, and then makes sure the cistern size has not been exceeded. Although it does have some flaws, it does simply the inputs and outputs while keeping the volume of water in the cistern from exceeding the cistern size or from going negative. Other equations were attempted without success.

Stormwater Diverted Calculation

Since it was difficult to determine how much water was diverted from the stormwater system with Equation 3, a separate worksheet was created to determine the amount of stormwater diverted related to indoor water uses. For months where the cistern has water remaining at the end of the month (where the cistern did not fail), it was determined the rainwater was used to provide the household with all of its water needs for that water use for the month. A simple "countif" equation in Excel was used to determine the months where the monthly cistern water remaining column was positive. From this it was determined how many months succeeded or did not fail. This number of months was multiplied by the 30-day monthly water use for that specific water use in that household to determine how much water was used with rainwater. This total was used since it is conservative and would keep the numbers from becoming inflated. For scenarios where the cistern fails in certain months it is not clear how much/when the cistern fails, so it does not allow for a way to determine how much was diverted from the stormwater in that particular month. Some of the monthly use for that water use is diverted from the cistern, but the exact amount is not easily calculated. The drawback to this analysis is that it does not capture the amount of water diverted from the stormwater system for the months where the cistern might have provided water for some of the month, but at the end of the month it was empty. The results of this analysis will thus be conservative, with the actual amount of stormwater diverted being higher.

Results

Analysis Categories

Three ways rainwater could be used in a residence were analyzed. They were:

1. flushing the toilet
2. flushing the toilet and clothes washing
3. all indoor water use

As can be seen in Figure 6, in this study an average (water efficient) person uses 43.6 gallons of water per person per day with 9.5 gallons associated with toilet flushing (21.8%) and 9.25 gallons associated with clothes washing (21.2%), with a combined water use of 18.75 gpcd or 43% of an average person's daily water use. In this study the scenario where rainwater is used for the toilet could be replaced with the clothes washer since the amount of water these use are about the same.

Cistern sizes greatly affected this study since it limited how much rainfall that could be captured. The cistern sizes chosen for comparison in this study were 110 gallons, 500 gallons, 1500 gallons and 4500 gallons. The 110-gallon size was chosen since it is the size of two 55-gallon rainbarrels combined together, and would be a very cost effective cistern size for a household investigating the feasibility of rainwater catchment. Similarly, a 500-gallon cistern was chosen since it is still an affordable cistern that can provide an impressive amount of stormwater mitigation and does not take up much space on a lot. A 1500-gallon cistern would probably be the maximum above-ground cistern size feasible in the city and it is the minimum size required for the City of Portland Code variance. The 4500-gallon cistern was chosen since it is the maximum cistern size a person would be expected to consider within the Portland area as a result of the tax lot sizes.

Months where there is extensive rainfall will have a higher chance of the cisterns remaining full. Figure 7 depicts the average monthly rainfall for Portland, OR. During the rainy months rainwater catchment can be used to supplement or entirely replace city water for all scenarios. During the dry months from June through September the cisterns become empty since they are not being continuously filled by rainfall. The critical months for % full are June, July, August and September. The month of July is the time when cisterns often run dry (failure). For most of the scenarios the cisterns have water remaining in them in all of the other months, the variation for these scenarios occur during this time. Any rain falling in the summer will be captured by the cistern and used by the households for whatever use the rainwater is directed to. This will reduce stormwater issues in the summer and reduce the demand on the Bull Run watershed.

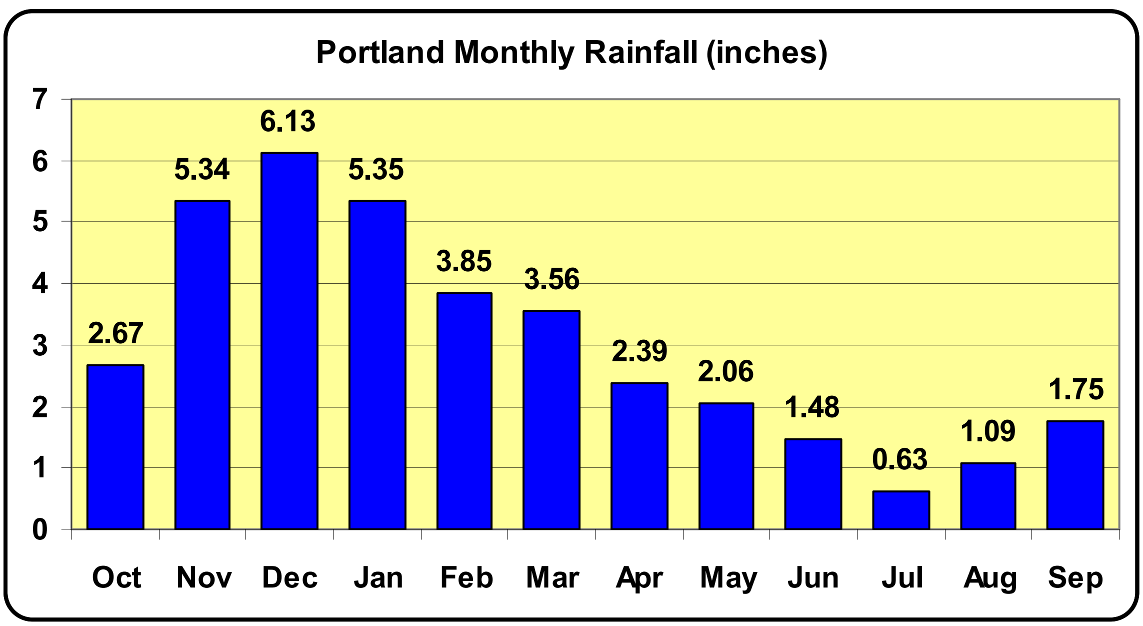

Figure 7. Portland average monthly rainfall (in inches) (Adapted from Department of Meteorology, University of Utah 2005)**.**

Rainwater for all indoor water uses

Figure 8 summarizes the calculated monthly changes to the cistern storage when the rainwater is used for all indoor water uses in the residences studied. All indoor water uses includes the use of water for: showers, clothes washing, toilet flushing, faucet use and leaks. It was expected this water use would have the most incidences of the cisterns becoming empty in the summer since it is the largest use of rainwater. This water use would require filtration of the rainwater.

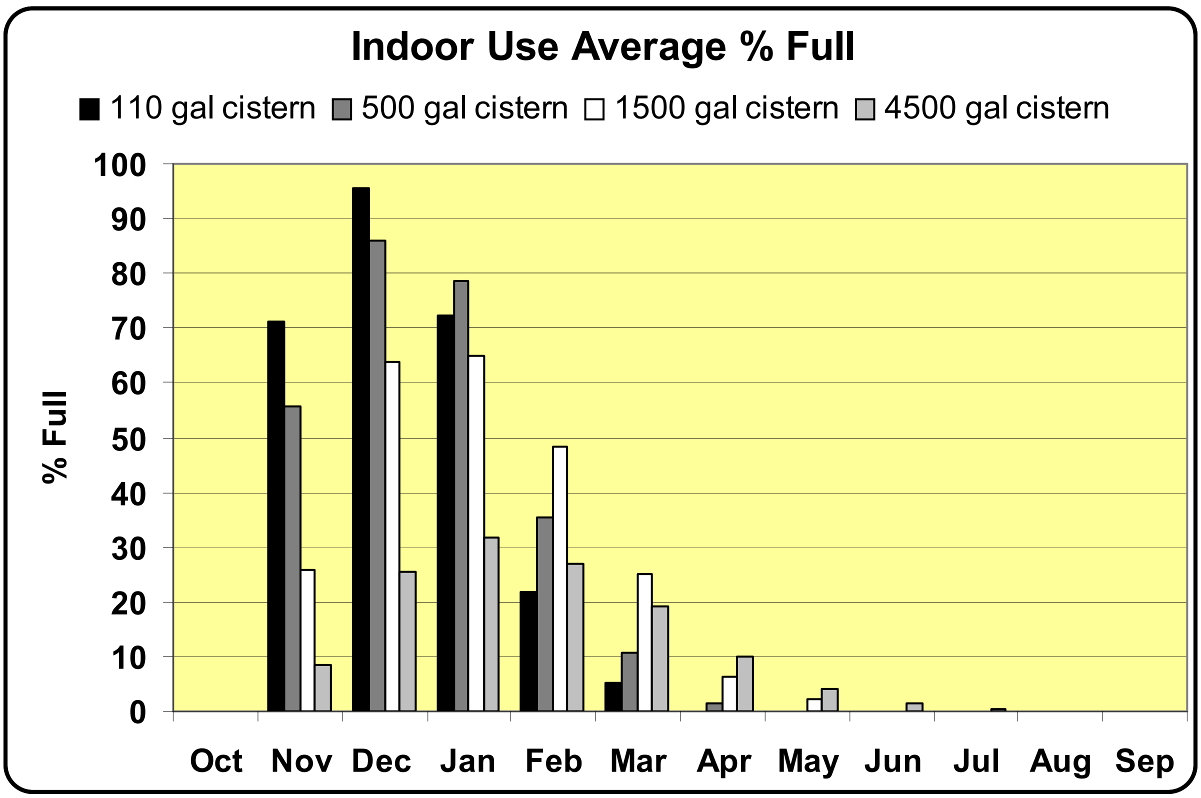

Figure 8. Percent of water remaining in cisterns for all indoor water use. Columns represent the average for all of the residences studied. 100% represents a full cistern at the end of the month while 0% represents an empty cistern. On average all four-cistern sizes will be empty from August through October. All cistern sizes will have water in them from November through March (Source: author's calculations).

All of the cistern sizes have some amount of water remaining in the cistern for the months of November through March, with none of the cisterns having water in them from August through October. The 4500-gallon cistern has the longest stretch of having water remaining, extending from November through July. None of the cisterns ever reach 100% full when the rainwater is used for all indoor water uses. Therefore, the cistern size could be increased to determine if the amount of water in the cisterns could last for the entire year. It is expected a larger cistern in this neighborhood is not feasible due to the small lot sizes.

Rainwater for toilet use

Figure 9 summarizes the calculated monthly changes to the cistern storage when the rainwater is used for flushing toilets in the residences studied. This water use has the least regulatory hurdles in the Portland. For a water efficient person a daily toilet water use is 9.5 gallons and clothes washing water use is 9.3. Therefore, the results from this water use could be easily equated to clothes washing use. Figure 9 clearly shows all of the cistern sizes have some amount of water remaining in the cistern for the entire year, with the 110-gallon cistern approaching empty in July. Therefore, on average, even a 110-gallon cistern will provide enough rainwater for the entire year for a household using an ultra-low-flow toilet (1.6 gpf). Any cistern larger than this is excessive and not necessary for just toilet flushing; however, to be safe it would be wise to increase the cistern size to ensure the cistern does not become empty in the summer. This scenario will positively affect both stormwater issues and water conservation issues since the rainwater is being used in the summer and will reduce the amount of water being removed from the Bull Run watershed. Since toilet flushing is a fifth of the indoor water use in a household, all of this water will be diverted from entering the stormwater system directly as stormwater. It will enter as wastewater, but it would have entered the system otherwise as municipally-supplied water.

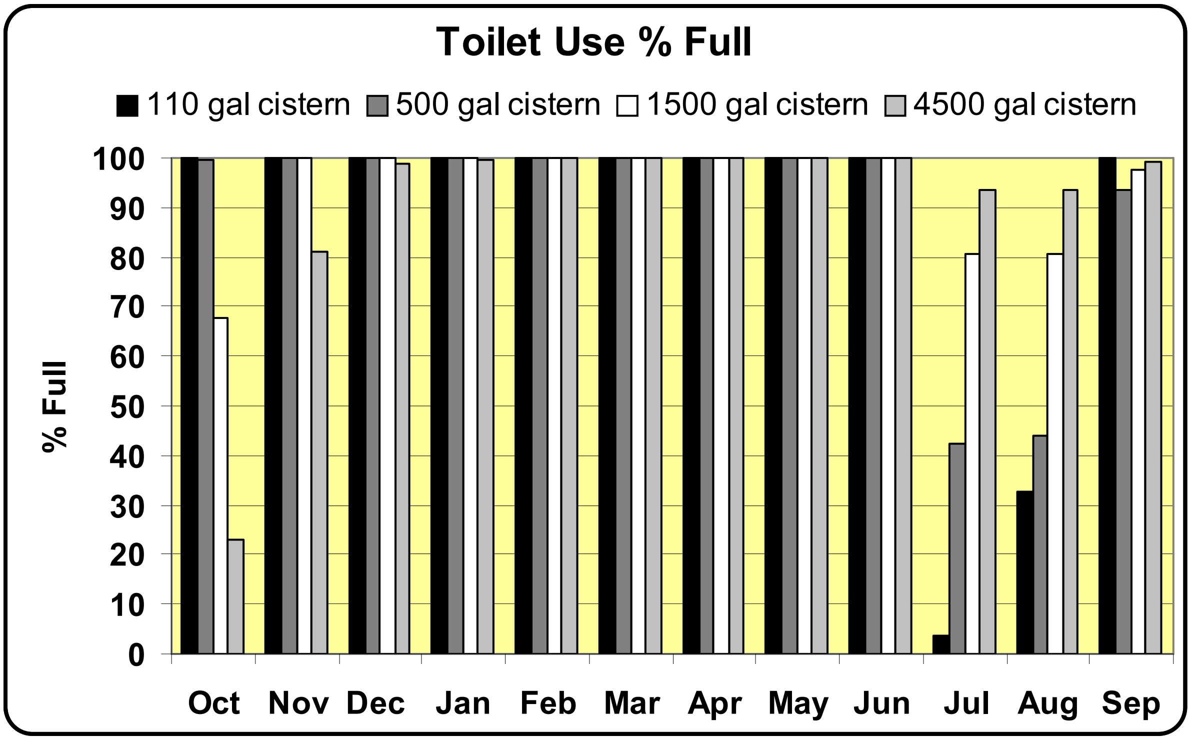

Figure 9. Percent of water remaining in cisterns for toilet flushing. Columns represent the average for all of the residences studied. 100% represents a full cistern at the end of the month while 0% represents an empty cistern. On average all four-cistern sizes will never be empty for the entire year, with all cistern sizes being 100% full with the exception of July, August and September (Source: author's calculations).

Rainwater for toilet and clothes washer use

Figure 10 summarizes the calculated monthly changes to the cistern storage when the rainwater is used for toilet flushing and clothes washing in the residences studied. These two water uses account for 43% of a water efficient person's daily water use or 18.8 gallons per day. Toilet use would not require any treatment of the water, but water for the clothes washer would need to be filtered. Figure 10 estimates all of the cistern sizes will have some amount of water remaining for the months of September through June. The 1500 and 4500-gallon cisterns never become empty while the 110-gallon cistern is empty in July and August,

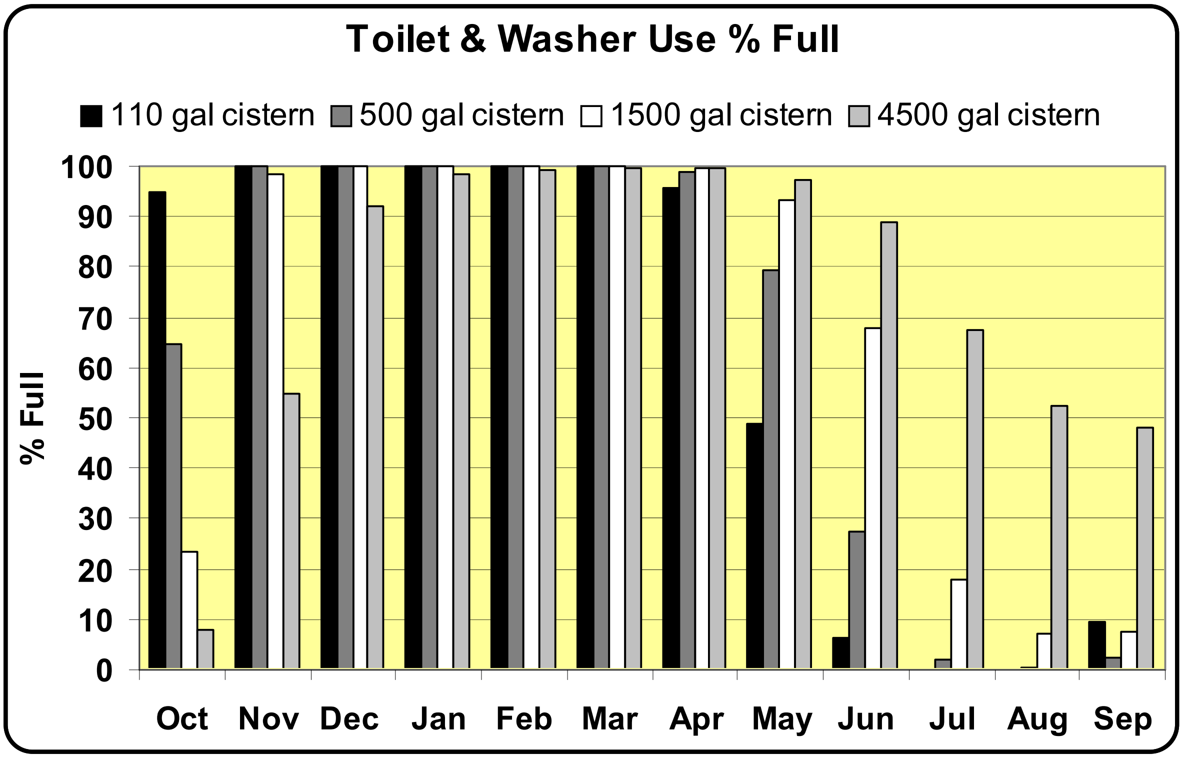

Figure 10. Percent of water remaining in cisterns for toilet and washer use. Columns represent the average for all of the residences studied. 100% represents a full cistern at the end of the month while 0% represents an empty cistern. All cistern sizes will have water in them from September through June (Source: author's calculations).

and the 500-gallon cistern is empty in August. Therefore, the ideal cistern size to mitigate both stormwater and the water supply limitations in the summer would be the 1500-gallon cistern since, it is the smallest size cistern studied which has water remaining in the cistern for the entire year. The 1500 and 4500-gallon cisterns will lessen demand on the Bull Run watershed since the water is being used in the summer for some houses. More than 40% of the water use in a water efficient household could be taken care of by a 1500-gallon cistern for the entire year. Both of these water uses do not require the water to be drinking water quality. This water will be diverted from entering the stormwater system directly as stormwater and will enter as wastewater. In addition, rather than having come from the municipally-supplied water, it come from outside and thereby reduces demand on the municipal supply.

Stormwater Diverted

Identifying the total amount of stormwater a neighborhood could divert out of the storm-sewer system if rainwater was used is helpful in justifying the installation of such systems in the city. It is a quantifiable metric that helps to determine if a large amount of water is diverted from the stormwater system. This diversion could alleviate the need to expand on a stormwater system, with all of the extensive costs related to such an expansion. Furthermore, it allows a macro-level assessment of rainwater as a stormwater diversion strategy, which could potentially encourage developing areas to install rainwater catchment systems instead of extensive stormwater systems. A municipality should determine the costs of a municipally-supplied water source, including the costs of the large storage system, pumps, filtration, and underground infrastructure related to such a system. Furthermore, the cost savings related to installing a smaller, or even no, stormwater system, should be included in the calculation when comparing this to the cost of installing a rainwater catchment system at each new building.

Figure 11 illustrates that no matter which water use or cistern size is chosen, the percentage of stormwater diverted from the CSS from residential rooftops will be at least 30%, and could be as large as 68%. This is an impressive quantity of stormwater removed from the CSS with the installation of a relatively cheap and simple system. It is interesting to note the stormwater diverted for toilet flushing changes very little for each of the cistern sizes, with a 110-gallon cistern having about the same effect on the stormwater volume discharged

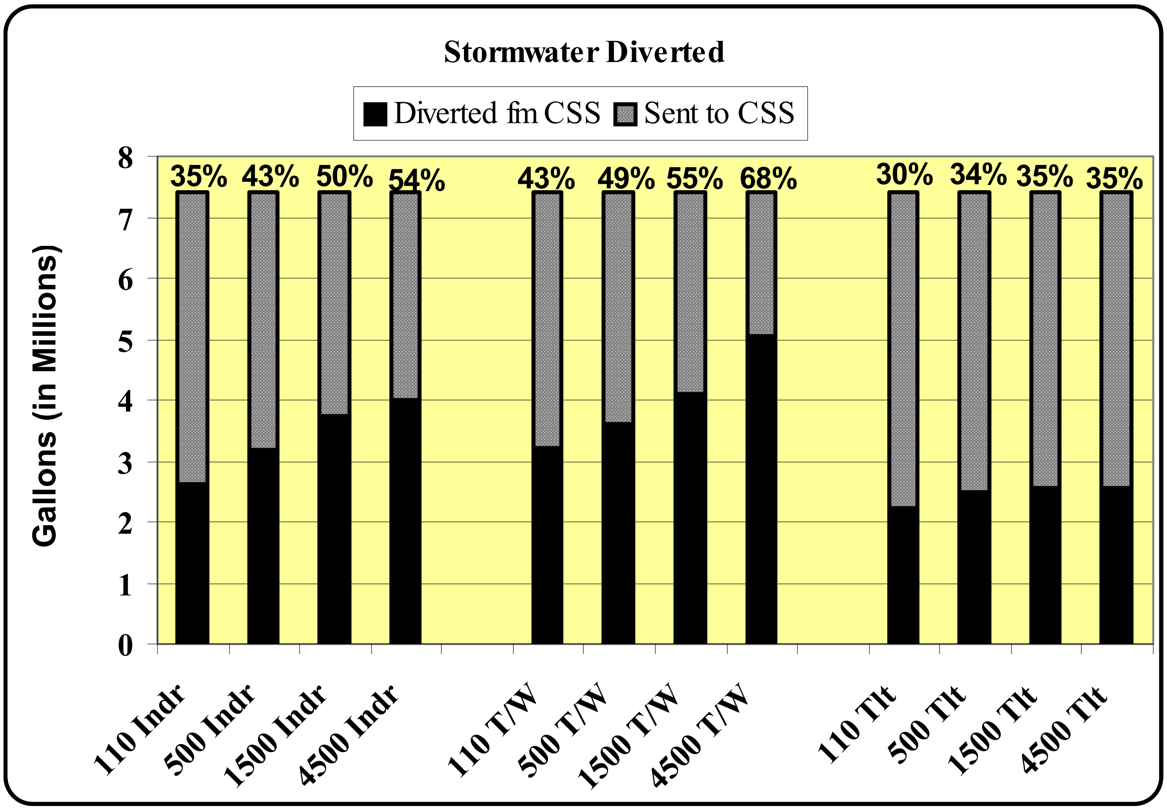

Figure 11. Rainwater diverted from the Combined Sewer System. Total amount of water (in millions of gallons) diverted from the CSS if all of the houses in the study (317) used rainwater. The number on the bottom axis refers to the cistern size. Indr indicates the rainwater is used for all indoor water uses, T/W indicates rainwater is used for toilet flushing and clothes washing and Tlt indicates the rainwater is used for toilet flushing. The percentage listed above each column is the percentage of stormwater diverted from the CSS by using rainwater for the use listed (Source: author's calculations).

as a 4,500-gallon cistern, diverting around 2 million gallons of stormwater from the stormwater system or about 30% of the stormwater leaving all of the households in this study. The reason for this is that all of the cisterns sizes are 100% full during the same months, with none of the cistern sizes failing throughout the entire year. A variation for the percentage of stormwater diverted occurs when rainwater is used for all indoor water uses and toilet and clothes washer use. This occurs since there is variation between the numbers of months the cistern fails for the different cistern sizes.

Conclusion

Discussion

All of the figures with graphs depict the fact that rainwater catchment used for some type of indoor water use will reduce a household's effect on the stormwater system and water supply, no matter the cistern size. Many of the scenarios have the cisterns becoming empty in the summer when there is very little rainfall, which is to be expected with Portland's rainfall regime. The graphs created from the spreadsheets show the combined results of rainwater catchment for numerous variables including roof size, and number of persons in a household. These calculations apply to the entire study area, not individual residences. This allowed for identifying situations in which all scenarios are expected to have enough water for specific months. This analysis also identified scenarios with more variability where water would be still available in the cistern for some households and empty for others. It is in these months and situations where more in-depth analysis could be done in the Portland area with real water data from specific households.

This paper presents arguments for the use of rainwater catchment as a proactive way to mitigate numerous impacts of the built environment. The benefits related to rainwater catchment will hopefully outweigh the costs associated with such practices. This paper demonstrates such a large-scale analysis does allow for viewing trends and generalities that are not available when just specific households are analyzed.

The graphs showed many interactions related to water use and cistern size. As is to be expected, a larger cistern allowed for more water uses and fewer instances of the cisterns becoming empty. Notable, many of the cisterns remained full, implying a smaller-size cistern could be used for some uses or more water uses could be added to maximize cistern benefits. The possible combinations of water use and cistern size are quite extensive. One of the most surprising results of the study was the toilet scenario, with a 110-gallon cistern for all three of the water use scenarios. For at least five months of the year the 110-gallon cistern was large enough to work successfully for all of the houses and water use scenarios, diverting up to 35% of the stormwater being discharged from a typical house. Often a small-size cistern is assumed to not be large enough to have any positive environmental effect. This analysis indicates that this is not a valid assumption. If rainwater is used to flush toilets alone, the 110-gallon cistern will work for the entire year, diverting 30% of the stormwater in a year.

Since the 110-gallon cistern is the size of two 55-gallon rainbarrels, another added benefit of this cistern size is the ability to easily expand the cistern size after the household is inspired by initial success. One study stated "once a portion of the roof is covered for harvesting, consumers notice rooftop rainwater going to 'waste' from other areas and are motivated to invest in capturing all rooftop water" (Vishwanath 2001). If a homeowner installed an 110-gallon rainwater system (currently not to code) for flushing toilets and washing clothes, the cost of such a system would be $1000 if a pump were needed, and $300 if gravity were used instead of a pump.

Although a 110-gallon cistern will work for most scenarios, the cistern size that succeeds for the most months for all water use scenarios is the 4500-gallon cistern. This would be difficult to install in most Portland residences due to the size of such a cistern. The most ideal cistern size for saving money and water use would be the 1500-gallon cistern for toilet and clothes washer use. This cistern would succeed for almost the same number of months as the 4500 size, but it would cost less and have a better chance of fitting in an urban lot (either above or below ground). Using a 1500-gallon cistern for toilet and clothes washing diverts 55% of the stormwater coming off a roof away from the stormwater system while reducing the strain on the municipal water supply. For this study of 317 houses, this equates to diverting 4.1 million gallons of stormwater per year, thereby saving 4.1 million gallons from being withdrawn from the Bull Run watershed (based on an average house diverting 13,000 gallons per year). In Portland 146,000 residential households use the municipal water supply (City of Portland 2005g). It is assumed this number refers to single and multifamily residences. If 146,000 is multiplied by 13,000 it equates to about 1.9 billion gallons of rainwater could be diverted from the CSS and saved from being drained from the Bull Run water supply every year.

Advantages to the spreadsheet analysis

This analysis created a spreadsheet, which can be used to assess a household's rainwater use success for different sized cisterns, and water uses. This spreadsheet can be used again to look at other neighborhoods in Portland, or with minimal modifications to the data it could be used for analyzing other neighborhoods in other cities. The spreadsheet can also be used to look at individual households to attempt to assess the ideal rainwater harvesting water use and cistern size with minimal additional data entry. All that is needed is the number of people in the household and the building footprint.

It would be surmised indoor water use would divert the most amount of stormwater; however, Figure 11 indicates that rainwater used for toilet and clothes washer use will divert the most amount of stormwater. The design of the stormwater-diverted equation appears to be affecting this result. This analysis only counted when the cistern did not fail at the end of the month. If the cistern failed, even on the 29^{th} day of a 30-day month, it was calculated that the stormwater off of the house was not diverted from the system. This allowed such water uses, which always have water in the cistern at the end of the month, such as the toilet and clothes washer water use, to have more successes and therefore have more stormwater diverted. The smallest number of failures of the cistern occurs with the toilet and clothes washer use. The largest number of failures occurs with the indoor water use. If the calculation could be modified to fully calculate the amount of rainwater used in a month it could more accurately show the amount of stormwater diverted.

Most papers discussing how to predict the ideal cistern size encourage the analysis to be very conservative to make sure the household will have enough water in all years, including drought years. This was not a major concern here, since the study took place in Portland where, if the cistern ran out, municipal water supply could be tapped to supply the necessary water. However, a degree of conservation was introduced by the runoff coefficient that was used. The runoff coefficient used in this study was 0.80, where another source suggested an asphalt composite roof could have a runoff coefficient of 0.90 (TWDB 2005). By using this lower runoff coefficient the amount of water entering into the cistern is diminished.

Industries requiring large quantities of pure water, such as computer microchip manufacturers and photographic processors, should be attracted to the purity of rainwater. Since Portland has several large microchip manufactures requiring an extensive amount of water, rainwater catchment by these corporations would greatly reduce the demand for water from the Bull Run watershed and dramatically reducing the stormwater leaving these large facilities.

Future recommendations

Further modifications to the spreadsheet would allow for a more realistic assessment of rainwater use and stormwater diversion. In the future it is recommended several households installing rainwater catchment systems are studied before the cistern is installed and again after the installation of the system. This will provide baseline water use and then indicate if there is a reduction in water use as speculated. Also, it would create real numbers to place into this spreadsheet rather than numbers gathered from the REUWS.

The Rainwater Harvesting Guide by the Texas Water Development Board states the runoff coefficient for asphalt composite roofs is 0.90 (TWDB 2005). In this study 0.80 was used to remain conservative. In the future the spreadsheet should be modified to allow for easy modification of the runoff coefficient. Currently the only way to change this is to change each monthly calculation of water collected off the roof. In the future having these equations referring back to a column with a place to change this number would make it easier to modify the runoff coefficient.

The equation used as the basis of this study is a good way to analyze rainwater harvesting by taking the water remaining in the cistern and adding the rainfall in and then subtracting the water used in the month. The benefit is that it simplifies the water system analysis. The drawback to this equation is that it is optimistic, since it allows for potentially more water into the cistern than what it can hold and it then subtracts the water used. Only after this is done is the limit of the cistern size used. Determining the actual amount of stormwater diverted from the system would help to identify exact numbers related to the benefits of each cistern size. Currently, the analysis is unable to show the total benefits of such scenarios as indoor water use since this water use will fail half way through a month.

Modifying this analysis will increase the quality of the numbers related to the amount of stormwater diverted.

It is not clear if this model could be easily translated to another part of the country since it is designed to have wet winters and four months of dry summers. More specifically, it assumes you will only irrigate from June-September. It would have to be analyzed to determine if it could work in a different climate. It is expected that a rainwater catchment system could be smaller and more successful in areas where there is a shorter period between rain events. Areas of the United States like the Northeast, Midwest and Southeast would be expected to be able to have a smaller cistern and less failures since the periods between rain events are short, especially when water use increases related to irrigation in the summer.

One use of this analysis in the future for another neighborhood would be to identify areas where the soil in a specific area cannot absorb the runoff from disconnected downspouts. Residences in these areas might be best suited to install rainwater catchment systems, since at least a portion of the stormwater will both be kept from entering the CSS, and kept off the non-absorbent soil. Another use for this spreadsheet in the future would be in expanding municipalities that are looking for alternatives to the standard way of dealing with water supply and stormwater mitigation. If houses were to use rainwater for some or all of the water uses, the size of the water main and water supply could be reduced. Also, the size and, potentially, the maintenance schedule for the stormwater system, could be reduced. These are ways in which the municipality could not only reduce the environmental effect of new buildings but also potentially save money.

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Appendix A: Base information for spreadsheet

A small sampling of residences was desired to keep the analysis manageable. To do this a U.S. Census Bureau blockgroup in the author's neighborhood was chosen by typing in the authors address on the U.S. Census Bureau website. This identified the blockgroup as Census Block Group 2, Tract 14 Multnomah County, Oregon (U.S. Census Bureau 2000b). A well-defined neighborhood was desired which could provide some good data and still had a small number of households to study. In Arcview the RLIS 2000 census blockgroup shapefile, bkgrp.shp, was opened. The above blockgroup was highlighted in the bkgrp shapefile. The MultTL1100 shapefile, which has the desired taxlot information including the square footage of the buildings on the tax lots, was then opened. The Theme "Select by theme" button was pulled down "Select the features of the active theme (MultTL1100) which "intersect" "Bkgrp.shp" This highlighted all of the polygons of the MultTL1100 shapefile which intersected the Block Group 2, Census Tract 14. This was exported into a dbf which was then opened in excel. This excel spreadsheet was the basis for this paper.

As mentioned above the MultTTL1100 shapefile had many desired attributes. The attributes (now columns in excel) that were kept for this paper were: Area, TLID, RNO, Owneraddr, siteaddr, bldgsqft, yearbuilt, and landuse. After the intersection tool was conducted there were a total of 420 polygons from this shapefile in this blockgroup, which equated with 420 rows in the spreadsheet. These rows were then sorted by landuse type. The five types of landuse found in the spreadsheet were: SFR, MFR, VAC, COM and IND. Looking at the map of this blockgroup along with knowledge of the neighborhood, it was determined these stood for single-family residence, multifamily residence, vacant, commercial and industrial. All of the rows that did not have the SFR landuse were removed from the spreadsheet since this study looked at residential water uses, based on data from the REUWS. There were at total of 317 rows remaining in the spreadsheet. This did not agree with the 2000 census, which had 364 one unit, detached residences in this blockgroup. It is surmised the difference between the two is due to the fact that some of the taxlots listed as MFR landuse in the shapefile are actually called one unit, detached by the census.

The Owneraddr was kept in the spreadsheet if in the future there was a desire to determine which households were owner occupied and which households were rentals. This information would help determine which households might be interested in the installation of a cistern. It is surmised an owner of a rental property would not be as interested in installing a cistern as an owner occupied household.

The bldgsqft column was the total building footprint area on the ground. It was not the area of the interior living spaces. This was subtracted from the total area of the tax lot (Column A) to produce the nonroof area. In the future this area could be used to determine the irrigable area of a property. Such information might be useful when determining the amount of irrigation water necessary to irrigate the irrigable area. For each month the equations mentioned in the paper for rainfall coming off the roof and water remaining in each cistern was conducted for each of the 317 residences in this study. For each month the previous month water remaining was added into the amount of water captured by the month for the present month and subtracted by the monthly water use.

Appendix B: Estimation of number of residents

A formula to determine the number of individuals in a house was created by taking the total residential building square footage, which was derived from summing the building square footage from all taxlots zoned SFR and MFR, with the result being 553,632. This was then divided by the number of residents in the block group (995) to determine the ratio for building ft^2 and number of persons in a house, with the result being 556 ft^2. In the spreadsheet the building area was divided by 556 ft^2 and rounded to get the number of residents in each residence of this study. According to the 2000 U.S. Census data, the average number of residents per household in the Portland block group 2, census track 14 is 2.06, with the City of Portland average being 2.6 residents per household (U.S. Census Bureau 2000a; U.S. Census Bureau 2000b). In the spreadsheet created, the average number of residents in each single-family residence is 2.16, which is close to the results of Census.

Appendix C: Daily water use of water efficient person

Clothes washers

The REUWS stated 75% of clothes washer load sizes were between 25 and 50 gallons per load. The new horizontal axis washing machines use between 20 and 25 gallons per wash. For the water efficient home, 25 gallons per load was used. For the REUWS the average wash size was 40.9 gallons (Meyer et al. 1999). The average number of loads of laundry per capita per day was 0.37. Multiplying 40.9 gallons by 0.37 equals 15.1. The REUWS study states the mean daily per capita clothes washer usage was 15.0 gpcd. Therefore, to find how much water a water efficient household would use 25 gallons must be multiplied by 0.37, which is 9.25 gcpd. This was used in this study's spreadsheet.

Leaks

The results of all of the cities studied determined the average gallons leaked per day per person is 9.5 gpcd. The city with the lowest rate leak rate is Boulder with 3.4 gpcd. This is the number to be used for daily leaks in a water efficient household.

Faucets

Aerators can be installed on most faucets to make it more water efficient. Currently, the most common water efficient aerator is a 1.5-gallon per minute (gpm) aerator. In the REUWS Seattle's faucets minutes per capita are 6.9, which was also the lowest number of all of the cities in the REUWS. Therefore, multiplying 6.9 by 1.5 is 10.4 gpcd for water efficient faucet use and was used in the determination for a water efficient household.

Dishwashers

The average dishwasher water use for the average study was 1.0 gcpd. This number was used for the water efficient household water use.

Total

Totaling all of the above water efficient water uses provides an average daily water use per capita per day of 43.6 gallons. This number was used in the spreadsheet for the daily water use per person.