AgriLIFE EXTENSION
Texas A&M System

Rainwater Harvesting:
System Planning

Rainwater Harvesting

Rainwater Harvesting: System Planning

Scope

This manual is intended to assist contractors, consultants, individual land owners, and others in planning rainwater harvesting (RWH) systems. RWH systems are diverse, complex, and range in catchment surface area from 25 to more than 1 million square feet. This manual addresses common issues related to catchments that are less than 50,000 square feet and have a storage capacity less than 100,000 gallons. The topics covered address the popular and usual distribution of water for landscapes, pets, wildlife, livestock, and private non-potable and potable in-home rainwater systems. The topic of rainwater that is collected and treated for use in public water systems is mostly avoided in this manual. Some start-up and operational topics are covered in this manual, but more focus is placed on issues of planning and installation. Although we present other rainwater harvesting methods and uses, our focus is on estimating, collection and storage for use in container based systems. Only generalizations on costs are covered.

Inspiration

The authors have engaged in the development of this manual to support their shared vision to protect our planet and our country's resources. All too often, aggressive, financially driven endeavors result in negative impacts on our clean and abundant supply of water. In the next 40 years, the demand for drinking water in the United States will more than double, while currently more than 50 percent of diseased people throughout the world are infected as the result of consuming unclean water. We hope that others learn from this manual and that they will be called to the higher task of implementing rainwater harvesting systems to partially address these issues. President Theodore Roosevelt may best articulate our vision.

> *The nation behaves well if it treats the natural resources as assets which it must turn over to the next generation increased and not impaired in value.*
>
> **Teddy Roosevelt**

Disclaimer

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This manual was reviewed by a panel of experts selected by Extension staff members. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use. Similarly, omission of products or trade names indicates nothing concerning the positions of the authors, reviewers, or the Texas AgriLife Extension Service regarding product effectiveness or applicability.

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Authors

Justin Mechell, Texas AgriLife Extension Service
Billy Kniffen, Texas AgriLife Extension Service
Bruce Lesikar, Texas AgriLife Extension Service
Douglas Kingman, Sam Houston State University
Fouad Jaber, Texas AgriLife Extension Service
Rachel Alexander, Texas AgriLife Extension Service
Brent Clayton, Texas AgriLife Extension Service

Expert Panel Reviewers

Dennis Lye, US EPA
Richard Heinichen, Tank Town
Joe Wheeler, Rain Filters of Texas, LLC
Heather Kinkade-Levario, Forgotten Rain, LLC

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Description of Contents

Chapter 1: Water Concerns

Rainwater harvesting is a technique for providing water to humans that has been used across the planet since the dawn of time. Recent generations have come to take the rainfall for granted. Their primary goal was to treat the runoff as a problem instead of an asset. Understanding the overall water cycle and looking at the effects of rainwater harvesting on the environment help us understand how it can be one of the methods to providing water for our growing demand

Chapter 2: Using Harvested Rainwater

There are many diverse uses for captured rainwater but the impact is the same; water is conserved. Today, most folks install RWH systems as a luxury or to augment their existing supply of water. In the future, however, many U.S. residents will be capturing rainfall to meet their basic drinking water and cooking needs. The U.S. population is forecasted to increase substantially, while our fresh water supply is predicted to decrease. A review of the obvious and less obvious uses of captured rainfall is beneficial to the RWH planner.

Captured rainwater can be used for watering landscape, gardens, and to provide water for pets, wildlife, and livestock. Additionally, rainwater can be filtered, sanitized, and used for non-potable and potable water uses in homes and businesses instead of other sources of water. The process is simple and often less expensive than drilling a well.

Chapter 3: Business Models, Professionalism, and Integrity

The RWH Planning Training Program prepares you to develop a meaningful and positive relationship between you as the planner and your clientele. This portion of the manual is intended to assist you in developing a personal philosophy for planning functional RWH systems that meet or exceed your client's expectations. In your business dealings and negotiations, you will be faced with questions of ethics. You will have the opportunity to demonstrate integrity and earn the respect of your customers. This will result in a prosperous business and you will earn the admiration of your clientele and fellow colleagues within the RWH business community.

Chapter 4: Safety

Safety, whether on-the-job or while interacting with a RWH system, is an important consideration for a RWH planner. General hazard awareness, dangers specific to the installation process, and emergency response are topics that should be discussed with each employee. This chapter does not address the entire breath of hazards and safety issues that a planner may be exposed to at the jobsite; each site is unique. It is suggested that a safety hazard analysis be conducted prior to each installation. This analysis should identify significant hazards and communicate awareness to every employee, site owner, and site visitor. In a case where new or unique hazards are present, such as a crew using a track-hoe to dig a trench for the first time, supervisors should study the potential hazards and communicate these dangers adequately to the crew members.

Chapter 5: Planning

Planning is critical to any major installation project. Proper planning will aid the RWH planner in providing the customer with what they expect in the time frame that they expect.

Chapter 6: Rainfall Data

A RWH planner must be able to accumulate and reasonably interpret precipitation data for a given area in order to estimate storage potential and size RWH system components. There is precipitation data available for nearly every county in the United States. It is provided by each state's climatologist's office. In addition to being able to gather rainfall data, one must also be able to determine characteristics or patterns of precipitation distribution.

Chapter 7: Estimating the Potential for Harvesting Water

Estimating the amount of water that can be harvested in a given area depends on catchment area, rainfall, system efficiency, and a design safety factor. The evaluation or interpretation of each of these essential variables directly effects the planner's estimation. The catchment area and rainfall amounts must be determined accurately. System efficiency relates to spillage, leakage, and losses due to materials. The planner may choose to utilize a design safety factor that provides for the underestimation of the catchment potential so that there is a cushion for the system functionality.

Chapter 8: Estimating Water Usage

RWH planners evaluate each client's water demand needs and desires in order to establish dependable numbers for annual, monthly, and daily water usage. Some RWH systems will supply only a portion of water needs for a client while other systems are required to provide all of a client's water demand. Distribution systems vary and may include all or a combination of the following: drinking water, fountains, irrigation, water gardens, and livestock water.

Chapter 9: Equilibrium for Supply and Demand

Basic economic theorists present the idea that the equilibrium price for a product is determined when product supply equals product demand. The idea is similar for a RWH planner who is attempting to size storage capacity and determine surplus in order to provide an adequate and dependable supply of water to meet the demand needs of the customer. Supply and demand must be compared to best determine storage capacity, surplus, and level of storage. In previous chapters, monthly supply and demand was estimated. This chapter presents an example scenario with accompanying worksheets and graphs are presented to compare demand to supply.

Chapter 10: Roofing, Gutters, and Downspouts

Roofing selection and catchment surface materials must be carefully chosen based on the desired use of the water. Gutters and downspouts are used to convey water from an elevated catchment area like a roof to a storage container in a RWH system. Gutters are installed horizontally and can be level or slightly sloped to increase water flow, although it is recommended that the gutters have some slope. Downspouts are attached to gutters in order to convey runoff from the top of a structure to the ground level or into a storm drainage system. Gutter and downspout systems may be installed or retrofitted to accommodate the needs of a RWH system.

Chapter 11: Debris Filtering and Removal

Animal remains, rodent feces, dust, leaves, sticks and other debris have a history of finding their way from the catchment area into rain storage devices. During a rainfall event, especially the initial downpour, most debris can be prevented from entering the RWH system by the use of screens, coarse filters, settling devices, or first-flush diverters. Preventing contamination is a high priority and is less costly than removing debris from storage tanks or the distribution system with manual labor or expensive filters. The best strategy consists of multiple levels of prevention and should include first removing large-sized items like leaves and sticks and then addressing dust and sediment later in the treatment train. The type and quantity of debris is site-specific and directly related to environmental factors encompassing the catchment area.

Chapter 12: Storage Containers

Since the inception of RWH systems, the most important component has been the storage container used to keep the water safe and secure. Clay pots, animal skins, metal and wooden vessels, and earthen dugouts have been used successfully to store water for human consumption. This chapter addressed the different types of containers and their placement as well as tank connections such as inlets, outlets and overflows.

Chapter 13: Dry vs. Wet Conveyance & Basic Hydraulic Principals

Each RWH system consists of some means of conveying rainwater from the catchment area to the storage container. Because of the piping configuration on some systems, the piping will either remain dry or trap water between rains. These instances are referred to as dry and wet conveyance systems, and there are differences in each that must be considered. The efficient conveyance of water by gravity between system components requires a RWH planner to comprehend basic hydraulic principles. Understanding gains and losses of pressure as water flows through a pipe affords the proper sizing of conveyance piping. Properly sized pipes result in maximizing a RWH system’s functionality and minimizing costs.

Chapter 14: Piping, Fittings, and PVC

The plan of a RWH planner provides a means to convey water from the catchment area to all system components and eventually to the distribution system. Most conveyance systems consist primarily of plastic pipe and utilize gravity to move the water from one location to the next. Choosing the correct pipe is not simple; there are several choices of plastic pipe available and each has specific characteristics and functions.

Chapter 15: Pumps and Controls

Just as the storage tank is the heart of the RWH system, the pump is the most crucial component of a pressured distribution system. A pump provides the pressure required to overcome all system losses and satisfy the end user. Inadequate pressure results in poor performance and a disappointed client. Pumps are sized by performance specifications of a certain flow rate at a given pressure. Pumps are usually either good at producing a high flow rate at a low pressure or a low flow rate at a high pressure. Overall system pressure is affected by changes in elevation and friction losses as water flows through piping, filters, and other components. Understanding a few simple pump operating characteristics can help a RWH planner in determining the correct pump for a given set of circumstances.

Chapter 16: Sanitation

Sanitation is the most important, complicated, and controversial topic related to rainwater. In particular, the question of the client remains, “When is my water safe to drink?” Although rainwater is generally thought to be very safe, water is a great medium for harmful pathogens to survive, prosper, and be transported. History shows us that many of the past disease outbreaks have involved water. Presently, thousands of people die or become very ill each year due to a lack of clean water. However, water is relatively easy to sanitize and, in fact, clean rainwater may be a significant factor in improving drinking water for people across the world. The RWH planner, regardless of applicable or non-applicable regulation for private drinking water systems, is responsible for providing technical performance specifications for sanitation equipment to the client. A client should be informed of the level of protection (or risk) that a treatment strategy affords for a given RWH system.

Chapter 17: Operation and Maintenance

The initial start of a system involves testing whether or not the system works and if each component is performing to manufacturer specifications. The operation and maintenance of a system is the continuous process of checking to see if individual system components are functioning properly, observing storage amount, and monitoring water usage. Routine maintenance and proper upkeep are directly related to water quality for potable water systems. Incorrect or deficient maintenance of equipment results in lower water quality and increased health risks. Regular testing for contaminants is a key determinant of system function. Each system is unique and has its own subtle variations in performance and functionality. A system operator learns these nuances and keeps the system operating at an acceptable level.

Rainwater Harvesting:
System Planning

1. Water Concerns

The goal of this chapter is to engage the RWH system planner in the process of appreciating the impact of RWH systems on the environment. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Describe the rationale and advantages to harvesting rainwater.
2. Identify the major watershed where they reside.
3. Describe a watershed and explain how water moves through it.
4. Describe how activities in the watershed affect water quality in downstream water resources.
5. Explain how rainwater harvesting reduces demand on potable water supplies.

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1. Water Concerns

Why Rainwater Harvesting?

Representatives of the federal government involved with the water supply planning process have determined that the present amounts of available surface and groundwater supplies will not be able to meet future water demand. Water conservation and development of alternative water supplies is necessary to meet our growing demand for fresh water.

Rainwater harvesting is an alternative water supply approach that captures, diverts, and stores rainwater for later use and is available to anyone. Captured rainwater is often used as a potable water source. Another popular use is for attracting and providing water for wildlife, pets, and livestock. Rainwater is also used for landscaping because the water is free of salts and other harmful minerals. Rainwater does not have to be treated with chemicals that have residual influences for most non-potable uses.

Implementing rainwater harvesting techniques directly benefits our country and state by reducing the demand on the municipal and public water supply, along with reducing run-off, erosion, and contamination of surface water (Porter et al., 2008).

According to the United States Environmental Protection Agency (US EPA), 50 to 70 percent of total household water (sanitized water that meets US EPA regulations for Public Drinking Water) is used for landscape irrigation and other outdoor activities (US EPA, 2009). Replacing that water with captured rainwater for landscaping efficiently uses this valuable resource, reduces personal water bills, and decreases the overall demand on public water supplies.

According to the United States Environmental Protection Agency, 50 to 70 percent of total household water (sanitized water that meets US EPA regulations for Public Drinking Water) is used for landscape irrigation and other outdoor activities (US EPA, 2009).

Rainwater harvesting can also help prevent flooding and erosion, turning stormwater problems into water supply assets by slowing runoff and allowing it to soak into the ground. This also helps decrease the contamination of surface water with sediments, fertilizers, and pesticides in rainfall runoff.

Rainwater harvesting can be used in both small-scale residential landscapes and in large-scale landscapes, such as parks, schools, commercial sites, parking lots, and apartment complexes. It can also be used in homes for commodes and clothes washing or, with more filtration and treatment, it can be sanitized enough for all in-home uses. Whether your landscape is large or small, developed or new, the principles described here can help you plan for a rainwater harvesting system.

What are the Advantages of Using Rainwater?

- **Promotes Conservation of Water:** Rainwater harvesting promotes self-sufficiency and appreciation for water as a resource. It also promotes water conservation, while providing an alternative water source.

- **Conserves Energy:** Because the centralized water system is bypassed through the use of rainwater harvesting, this system will conserve energy. Many systems require only a small pump to create water pressure in household pipes and many non-potable systems operate with gravity as the only driving force.

- **Reduces Undesired Stormwater Runoff:** Local erosion and flooding from impervious cover associated with buildings is lessened as a portion of the local rainfall is diverted into collection tanks, leaving less stormwater to manage.

- **Improves quality of Water Supply:** Rainwater is one of the purest sources of water available. Its quality almost always exceeds that of ground or surface water because it does not come into contact with soil or rocks where it can dissolve minerals and salts. Also, captured rainwater will not come into contact with many of the pollutants that are often discharged into local surface waters or contaminated ground water supplies.

- **Supplies Nutrients to Plants:** Rainwater often has a nitrogen content which provides a slight fertilizing effect for plants.

- **Provides Naturally-Soft Water:** Rainwater is considered soft water, and therefore significantly lowers the quantity of detergents and soaps needed for cleaning. Soap scum and hardness deposits do not occur. Water softeners are not necessary with rainwater as it often is with well water. Also, water heaters and pipes are free of the deposits caused by hard water and should last longer, thus saving money.

Your Watershed

Wherever you live and whatever you do, you are in a watershed. What you and others do in the watershed impacts the water quality and quantity of the entire watershed. Understanding your watershed and how water moves through it will give you a better idea of how rainwater harvesting works and how it benefits our environment.

A watershed is an area of land that channels rainfall downhill, above or belowground, to join with the outflow of another watershed or into a marsh, river, lake, or underground aquifer. It includes all surface water groundwater, soils, vegetation, animals, and human activities contained within its area (Figure 1.1).

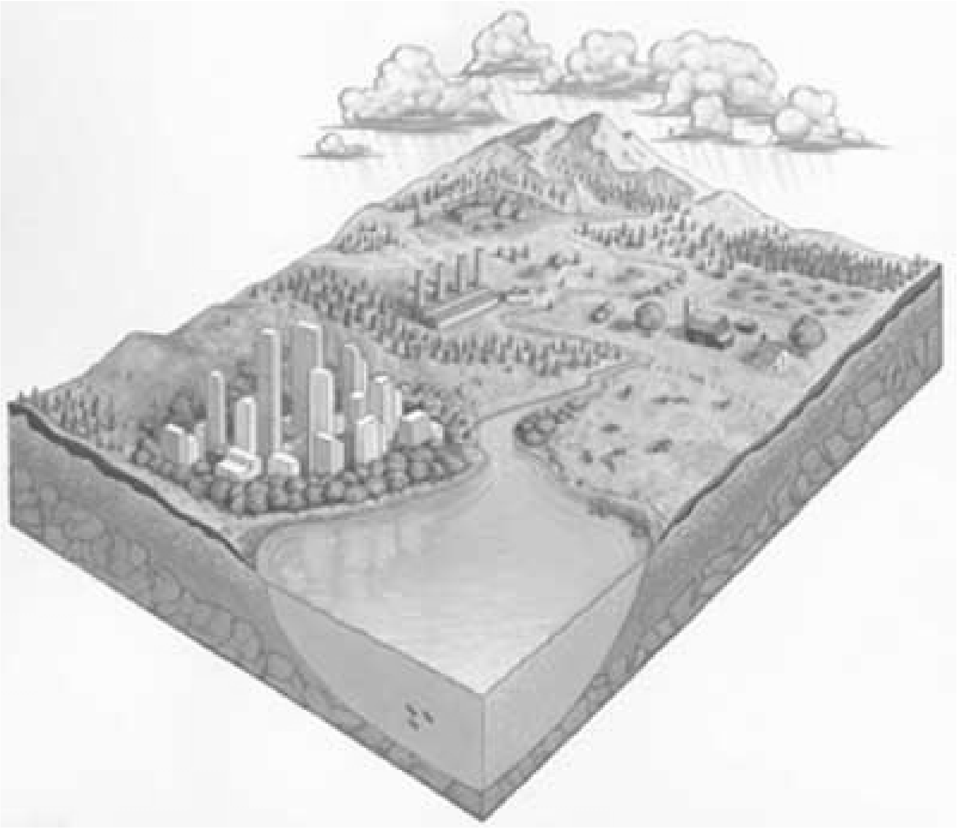

Figure 1.1. A watershed showing multiple land uses (Source: USDA Forest Service).

According to the US EPA, the United States has more than 3.6 million miles of rivers and more than 41 million acres of lakes (US EPA, 2000). Healthy watersheds are vital for a healthy environment. Our watersheds provide water for multiple purposes such as drinking, irrigation of crops, and industry uses. Wildlife, including birds and fish, use the watersheds for food and shelter.

Scientists now recognize the best way to protect our natural resources is to understand and manage them on a watershed basis. Everything that is done in a watershed affects the watershed's system. In the past, most water quality problems were traced to point source pollution which results from the collection of pollutants and their discharge at a defined point.

Examples of point sources include:

- Municipal wastewater treatment discharges.
- Industrial waste discharges.
- Stormwater collection systems.
- Runoff from Intensive Agricultural operations

State and federal environmental agencies typically monitor and regulate point sources, based on quality and quantity standards.

In contrast, nonpoint source pollution comes from sources that are spread out across the landscape. Such pollutants are generally more difficult to isolate and control, yet they have a significant impact on the health of your watershed.

Other examples include:

- Excess fertilizers, herbicides, and insecticides from agricultural lands and residential areas.
- Oil, grease, and toxic chemicals from urban runoff and energy production.
- Sediment from improperly managed construction sites, crop, pasture and forested lands, and eroding streambanks.
- Salt from irrigation practices.
- Acid drainage from abandoned mines.
- Bacteria and nutrients from livestock, pet wastes, and malfunctioning septic systems.
- Atmospheric deposition.

Understanding and learning more about your watershed is the first step in taking action to protect it. To determine what watershed you live in, you can visit *Surf Your Watershed* at http://www.epa.gov/surf. Following is some information that can be gathered to better understand your watershed:

Understanding and learning more about your watershed is the first step in taking action to protect it.

- Sizes, locations, and designated uses of water bodies.
- Impairments to a body of water's use supports.
- Causes of impairment, such as pollutants and habitat limits.
- Water quality attributes: physical, biological, and chemical.
- Categories of nonpoint sources and estimates of their loadings.
- Groundwater quality and sources affecting it.
- Fish and wildlife surveys.
- Maps: topographic, hydrologic, and land use/cover (wetlands, riparian areas, impervious areas).
- Detailed soil surveys.
- Demographic data and growth projections.
- Economic conditions, such as income and employment.
- Threatened and endangered species and their habitat.

The US EPA has endorsed the watershed management approach, defined as a coordinated environmental management framework that focuses public and private efforts on a watershed's highest priority problems.

In the past, such an approach was used more commonly in polluted watersheds or those with limited water supplies, but it can also be proactive, preventing such problems from occurring.

Although large watersheds are usually managed by the local, state, or federal government, landowners throughout an area benefit by becoming familiar with the watershed management process. Information regarding this process can be found in the *Handbook for Developing Watershed Plans to Restore and Protect our Water*. This document can be found at http://www.epa.gov/nps/watershed_handbook.

Rainfall in Your Watershed

The continual movement of rainfall from the water bodies, land, and atmosphere of your watershed is part of the hydrologic cycle.

The hydrologic cycle, found in Figure 1.2, begins with condensation, when water vapor condenses in the atmosphere to form clouds. Clouds release precipitation when the water droplets are too heavy to be held by the atmosphere. The conditions for a specific area determine the presence of clouds and the conditions affecting the formation of water droplets that fall as rain.

When rainfall in the form of precipitation reaches the earth's surface; it infiltrates the soil and becomes soil moisture and groundwater. Rainwater that collects on the surface and becomes runoff enters streams or lakes.

Infiltration occurs when precipitation seeps into the soil. The amount of water that infiltrates the soil varies with the permeability, which is the measure of how easily something flows through a substance.

The more openings in the surface (such as cracks or pores), the more permeable it is and the more infiltration occurs. Infiltrated groundwater recharges aquifers and rivers and moves toward large bodies of water.

Impervious surfaces cause runoff to occur immediately while pervious surfaces cause runoff only after saturation has occurred. These significant increases in runoff have far reaching effects on our neighborhoods and the environment.

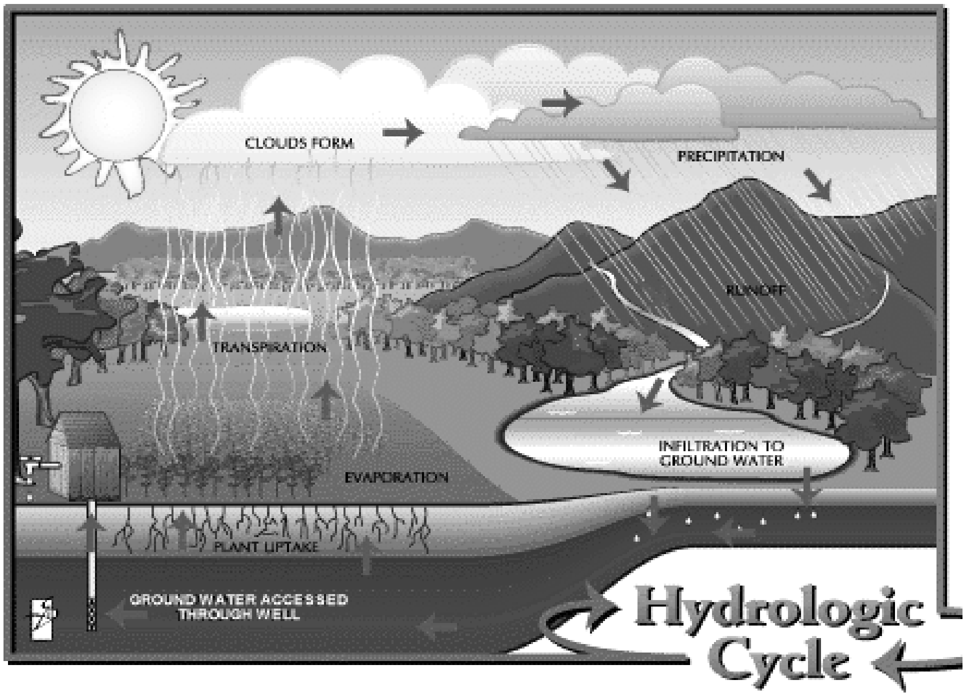

Figure 1.2. The hydrologic cycle (Source: US EPA).

If precipitation occurs faster than it can infiltrate the soil or if the soil is saturated, it becomes runoff. Runoff remains on the surface and flows into streams, rivers, and eventually large bodies such as lakes or the ocean.

Impervious surfaces such as parking lots, driveways, sidewalks, and streets block rainfall and other precipitation from infiltrating naturally into the ground. The water will then run off the surface, which is called stormwater. Movement of this stormwater across the soil causes erosion and could carry and deposit untreated pollutants such as sediment, nutrients and chemicals into surface water.

Water re-enters the atmosphere through evaporation. Sunlight raises the temperature of liquid water on the earth's surface and as the liquid heats, molecules are released, changing it into a gas. Warm air rises up into the atmosphere and becomes the vapor involved in condensation.

Water also re-enters the atmosphere through transpiration. As plants grow water vapor is released to the atmosphere. The quantity of water vapor returning to the atmosphere depends on the age and type of plant, as well as climatic conditions.

Evaporation and transpiration are generally combined and called evapotranspiration. Evapotranspiration can be estimated based on the climatic conditions in your area.

Stormwater in Your Watershed

Rainfall inevitably creates stormwater runoff in your watershed. Implementing a rainwater harvesting system is one way to decrease the amount of stormwater runoff, along with the problems associated with it.

In areas covered by impervious surfaces, water that once had the opportunity to infiltrate and evapotranspire is now running off into our local streams and rivers. Urbanization of native lands is a large contributor to this problem.

A few problems that occur include increased urban flooding, pollution, and decreased groundwater recharge. Runoff frequency and volume have increased due to large impervious surfaces in urban areas. Table 1.1 shows just how much runoff is generated from impervious surfaces during common storm events.

Table 1.1. Accumulated Rainwater Volumes from Common Rainfall Events (Based on a 1000 ft^2 Catchment Area and 100% Collection Efficiency).

Rainfall Depth (in.)	Volume (ft^3)	Volume (gal)
0.5	42	310
1.0	83	620
1.5	125	940
2.0	167	1250
2.5	208	1560
3.0	250	1870

Runoff Quality

The quality of runoff water is directly related to the site's soil, vegetation, and its management. Runoff quality can be degraded when flowing over both agricultural and urban landscapes.

Agricultural Runoff

Agricultural runoff pollutants consist of excess sediment, nutrients, chemicals, and bacteria. The specific use, management, and cover health of the land, along with the time of year will determine the extent to which each of these constituents will be present in the runoff water.

Urban Runoff

In urban areas, increased volumes of runoff flowing over yards, roadways, and parking lots have negative effects on runoff quality. Roadways and parking lots typically have oils, greases, heavy metals, and other chemicals which leak from vehicles onto the surface.

Yards typically contain excess fertilizers, chemicals, animal waste, leaf litter, and grass clippings that can contaminate the runoff. Large runoff events provide optimum transportation of these pollutants from their original location, directly into local streams and rivers. Increased organic matter in stormwater runoff decreases the amount of free oxygen available in water though the natural decaying process.

Groundwater Recharge

The use of a rainwater harvesting system effectively lowers the volume of runoff during storm events. Instead of creating immediate runoff, proper application and use of rainwater provide opportunities for the water to infiltrate the soil. The rate of soil infiltration varies depending on many factors, including type of soil, vegetation, and land use at a particular site. It should be noted that development of land has a dramatic effect on the water movement on a site.

Pre- and post-development infiltration rates are very different (Figure 1.3). After development of a home site, 1,500 to 4,000 square feet are typically covered by an impervious roof. Other areas are covered by driveways, sidewalks, and garages, while the rest is usually landscaped, utilizing trees, bushes, flowers, and turf grass.

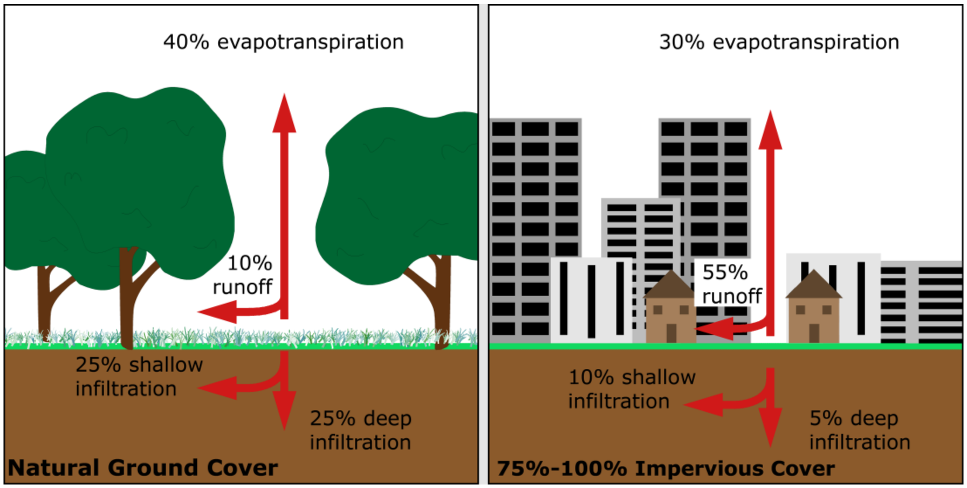

Figure 1.3. Relationship between impervious cover and runoff (Source: US EPA).

Recharge of groundwater systems is a pressing issue in many parts of the southwestern United States. Growing urban populations are straining the groundwater supplies, causing groundwater levels to fall faster than they can be replenished.

Summary

Providing clean drinking water for the next generation and generations to follow is central to the survival of the human species. Too much of the world's population is exposed to disease-causing pathogens that thrive in unclean water. Efficient rain catchment systems can play a significant role in saving lives and improving the health of people across the globe.

Facts and Figures From the US EPA (2009)

Water

- Water is the only substance found on earth in three forms: solid, liquid, and gas.
- A person can live more than a month without food but only about a week without water.
- Sixty-six percent of the human body is water; seventy-five percent of the human brain is water.
- Seventy-five percent of a chicken, eighty percent of a pineapple, and ninety-five percent of a tomato is water.
- A person must consume 2.5 quarts of water per day from drinking and eating to maintain health.
- Water regulates the temperature of the human body, carries nutrients and oxygen to cells, cushions joints, protects organs and tissues, and removes wastes.

Usage

- Manufacturing a car and four tires requires 39,090 gallons.
- Producing one ton of steel requires 62,600 gallons.
- Brewing one barrel of beer requires 1,500 gallons.
- Processing one can of fruit or vegetables requires 9.3 gallons.
- On average, 50 to 70 percent of household water is used outdoors (watering lawns, washing cars).
- The average American uses over 100 gallons per day.
- The average residence uses over 100,000 gallons annually.
- Americans drink more than 1 billion glasses of water per day.

Infrastructure

- The average cost for water supplied to a home in the U.S. is about $2.00 for 1,000 gallons, which equals about 5 gallons for a penny.
- It costs more than $3.5 billion to operate water systems throughout the United States each year.

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Rainwater Harvesting: System Planning

2. Using Harvested Rainwater

The goal of this chapter is to inform the RWH system planner of the numerous potential uses for captured rainwater. Upon completion of this chapter, the participant should be able to accomplish the following objectives.

1. Describe impacts of collecting rainfall.
2. List uses of captured rainfall.

Contents

2. Using Harvested Rainwater

Introduction

There are many uses for captured rainwater but the impact is the same: water is conserved. Today, most people install RWH systems as a luxury or a means by which to augment their existing supply of water. In the future, however, many people will capture rainfall to meet their basic drinking water and cooking needs. The U.S. population is forecasted to increase, while our fresh water supply is predicted to decrease. A review of the obvious and less obvious uses of captured rainfall is beneficial to the planner of a RWH system.

Captured rainwater can be used for watering landscapes and gardens and to provide water for pets, wildlife, and livestock. Additionally, rainwater can be filtered, sanitized, and used for non-potable and potable water in homes and businesses instead of other water sources. The process is simple and often less expensive than drilling a well.

Landscape

Rainwater can be used in a number of ways for landscaping, such as drip irrigation, water features, and raingardens (Figure 2.1). Drip irrigation is most practical when using rainwater for landscape irrigation. It can often be applied by gravity pressure alone or in combination with mechanical equipment.

Rainwater can be used to provide additional water to water features such as fountains and ponds that lose water to evaporation. It can also be used to supply all water needed for relatively smaller water features. Raingardens are depressions in the landscape that collect and store rainwater for a short period of time, thereby allowing it to infiltrate the soil and be utilized by vegetation.

Figure 2.1. Rainwater is the water source for this landscape feature.

Wildlife Watering

Water guzzlers are rainwater collection systems that can be built in remote areas to water wildlife (Figure 2.2). A roof, storage tank, and watering device are all that are needed. Rainfall can be collected off existing barns, sheds, or other covered structures.

Figure 2.2. A water guzzler that supplies water to local wildlife.

Livestock and Pets

Livestock require large quantities of water on a daily basis. Cows and horses can consume 7 to 25 gallons of water per day. The water demand for small herds or individual animals can be met entirely through the collection of rainwater (Figure 2.3).

Figure 2.3. Rainwater is harvested from a barn to water livestock.

Groundwater Recharge

In areas across the country water is being pumped for municipal, agricultural, and industrial uses at rates that exceed the rate by which they can recharge. Many rainwater harvesting systems across the country collect rainwater and direct it to underground temporary storage systems (perforated chambers, washed rock, etc.) that allow the water to infiltrate the soil profile, which then has the opportunity to recharge local aquifers.

Reduce Stormwater Runoff

Passive collection systems redirect a portion of stormwater runoff by allowing the water to settle and infiltrate in depressions called raingardens. The reduction of stormwater leaving individual sites eases the demand on public stormwater drainage systems. It aids in decreasing the potential for urban flooding. Passive collection systems slow the rate of runoff, allowing the water to soak into the ground, recharge soil moisture and groundwater, and provide water for vegetation.

Figure 2.4. Rainwater supplies all the water needs of this home.

Home

Rainwater currently supplies many homes worldwide with an abundant supply of good, soft, safe water to drink and use throughout the home and surrounding property (Figure 2.4). Storage capacity needs to be sufficient to provide several months supply of water. A good filtering and sanitizing system is needed to provide high quality potable water for the home. Rainwater can meet the demands for non-potable water used in commodes and washing machines, thereby reducing the municipal water requirements.

Commercial and Industrial

Rainwater can also be used in commercial and industrial settings, sometimes even for similar uses as in private homes. Rainwater can be used in office buildings and retail stores inside for toilet flushing, plant watering and outside for landscape irrigation. The manufacturing and processing industry can utilize rainwater for cooling equipment and cleaning parts.

Incentives

A number of states, as well as the State of Texas, encourage rainwater harvesting by eliminating the sales tax on collection system supplies (TWDB, 2005). A number of cities in Texas and across the country have also waved permitting fees, offered rebates on tanks, waived property taxes, provided rain barrels, irrigation audits, and low-flow toilets, and set up demonstration sites to help encourage and educate the public on the need to conserve this precious commodity. Other governing bodies support rainwater harvesting to reduce stormwater flows. Check with your local government for more information.

Summary

Captured rainwater has a tremendous potential for meeting both indoor and outdoor water demands. With creative landscaping that is both beautiful and functional, a tremendous amount of water can be saved. We can capture rainfall when and where it lands for immediate use or we can save it for use during droughts. As the nation's population grows, we must become more conscious of ways to conserve water. Capturing rainwater is one tool in this process.

Reference

TWDB. 2005. Texas Manual Rainwater Harvesting. Third Edition. Texas Water Development Board. 2005.

Rainwater Harvesting: System Planning

3. Business Models, Professionalism, and Integrity

The goal of this chapter is to engage the RWH system planner in the process of making ethical choices in order to establish a dependable reputation and build rapport with a client. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Derive a business model for RWH planning.
2. Differentiate between ethical and unethical business practices.
3. Identify strategy to determine customer needs vs. wants.
4. Develop strategy to build rapport with clients.
5. Gain personal respect of client and RWH industry.
6. Provide leadership in RWH industry.

Contents

3. Business Models, Professionalism, and Integrity

Introduction

The RWH Planning and Installation Training Program will prepare you to develop a meaningful and positive relationship between you as the planner and your clientele. This portion of the manual is intended to assist you in developing a personal philosophy for planning and installing functional RWH systems that meet or exceed your client's expectations. In your business dealings and negotiations, you will be faced with situations where your clients' desires may not conform to industry standards or align with practices deemed as protecting public health and the environment. You will have the opportunity to demonstrate integrity and earn the respect of your customers by adhering to these standards in a consistent, professional manner. This will result in a prosperous business and you will earn the admiration of your clientele and fellow colleagues within the RWH business community.

Business Models and RWH Systems Planning

A business model provides a framework and direction for a RWH-related business venture. The model may include a company's purpose, strategies, organizational structures, and operational processes. For example, a business model can address whether or not the business will install potable drinking water systems for commercial use or build raingardens for an individual homeowner. Obviously, planners will have to design their own business model and make necessary alterations, according to market demands.

An example of a simplified business model of a nationally recognized clothing retailer could be:

- Purchase clothing.
- Receive customer order.
- Decorate and modify clothing.
- Assimilate order for retail sale in efficient manner.
- Ensure customer satisfaction.

Although cotton is in the clothing material, the above model does not include growing and harvesting of the cotton prior to the manufacture of the clothing. RWH planners/installers will develop their own model and be prepared to make changes in response to market demands.

The following model was developed as a starting point for individuals interested in RWH systems. This business model is offered for clarification of the roles needed to achieve sustainable rainwater harvesting systems.

- Customer recruitment and marketing
    - Rainwater harvesting awareness
    - Build rapport with potential clients
- Site evaluation
    - Assess catchment possibilities
    - Determine drainage patterns
    - Assess possible placement of system components
- Planning
    - Identify felt, perceived, and actual needs of clients
    - Describe component purpose and function to client
    - Describe and illustrate final appearance to client
    - Determine rainfall patterns
    - Determine water demand
    - Evaluate compliance with federal, state, district, county, city, neighborhood regulations/ordinances
    - Storage and pipe sizing
    - Sanitation requirements
    - Distribution system specification
    - Drawing development
    - Specify construction materials
    - Permitting
    - Specific safety features for public safety
    - Specify accessibility requirements for performing component maintenance
    - Specify and communicate operation and maintenance requirements
    - Communication of system limitations to customer
- Manufacturing
    - Tank manufacturing
    - Assembling packaged treatment systems
    - Constructing control systems
- Installation
    - Locate system components, ancillary equipment
    - Assemble components according to plan
    - Construct a maintainable system
    - Install specified public safety features
    - Permitting inspection
    - Operational startup
    - Coordinate with planner for development of final documentation on system installation

- Operation, maintenance, monitoring and troubleshooting
    - Adjusting operational controls
    - Tank maintenance
    - Collection system maintenance
    - Disinfection system maintenance
    - Roof washer or water diverter maintenance
    - Test water quality
    - Monitor component operation
    - Record operational data
    - Assess function to identify malfunctioning components

A business model should be used to guide and provide structure to a company. RWH planners/installers should consider this listing of potential roles and responsibilities to define their business interests and purpose, along with understanding their role in the industry.

Business Professionalism and Integrity

Credibility, personal respect, and admiration from others are highly valued in today's society. An individual can obtain these accolades by maintaining integrity and adhering to good ethics. Integrity and ethics address the moral duties and obligations that we have within our society and more specifically, the RWH industry. Acceptable behavior, including what is considered right and wrong, is defined within ethics with the goal of achieving maximum good for all people. Each day in the RWH industry, planners/installers are subjected to circumstances that question these attributes. An individual’s response to various situations reveals their commitment to maintaining integrity and good ethics, which could build or weaken their credibility, personal respect, and admiration from others, according to their decisions.

Comparison of Personal Ethics and Law

Generally, society's most important ethical questions evolve into laws that include punishments for offenders as part of the judicial process. The area of personal ethics does not usually include an objective comparison of laws (rules) to one’s actions nor does it result in a structured punishment. Instead, the rules are much less specific and are communicated by word of mouth and by example more so than by written documentation. This is because many of these stated or unstated behavioral norms are based on emotion, religious beliefs, and subjective personal perceptions. Thus, the differences between ethics and laws include structure, formality, and objectivity. Even though ethics are much more vague, they influence our lives as much or perhaps more than any law.

Building Credibility

Credibility is built up within the minds of our peers in the RWH industry and customers by enhancing two elements: believability and dependability. When one demonstrates a level of integrity, honesty, and consistency in one's dealings with others, society acknowledges the pattern. When people with credibility speak, their words carry weight in the minds of listeners. Their words are believed to be true, simply because of who spoke them.

The other element of credibility has to do with being dependable. People in positions of leadership, such as nationally recognized RWH planners/installers, have developed a history of being believable. As a result, their peers in the RWH industry believe what they say and have come to depend upon their input before making decisions. Dependability leads clientele to accept the information being presented; so as a planner, people will accept what you say because of your dependability.

Positional versus Personal Respect

Respect is given to people either because of their position or because they have earned personal respect. Positional respect is a result of the position in and of itself, rather than the character of the person holding that position. For example, a police officer guiding traffic in an intersection holds positional respect. You, as a driver approaching the corner, have never met the police officer. Yet, you carefully follow instructions because of the police officer's position of respect. This type of respect is necessary for the proper and efficient functioning of our society, but it is not the valued type of respect that is necessary to maximize planner-client relationships.

Personal respect, rather than positional, is the goal of an ethical RWH planner. The significant difference between the two is that personal respect must be demonstrated and earned. Our peers and clients observe and keep mental notes of our actions, noticing whether or not we honor good ethics. Gaining the personal respect of clients is far more valuable to the planner than positional respect that might be afforded through regulatory authority.

Leadership in Industry

As part of the responsibility of a RWH planner/installer, individuals have the duty to guide and influence the RWH industry. Part of being a professional is actively participating and obtaining membership in local, state, and national professional associations. Involving oneself in these organizations affords the opportunity to stay abreast of cutting-edge improvements and provide leadership to the RWH industry.
As one provides leadership to the industry, it will result in obtaining admiration from peers through ethical conduct. Gaining this admiration is not for the benefit of our personal egos. It is instead our responsibility to provide the necessary leadership for the entire industry. Leadership also allows us the opportunity to guide the industry toward the betterment for all. Like personal respect, this

benefit from living an ethical life is difficult and time consuming to build, but easily destroyed.

Planners and installers need to function as professionals. This includes knowing the applicable local, state/provincial, and national statutes, codes, laws, and regulations for the industry.

Planners and installers need to function as professionals. This includes knowing the applicable local, state/provincial, and national statutes, codes, laws, and regulations for the industry. If facility owners receive differing answers from planner to the same question, they will become suspicious of the entire industry. As a professional, one must know the correct answer to general questions or you, your business, and the industry will lose credibility.

Planners/installers should compete honestly and lawfully, building their businesses through their own skills and merits. They should avoid any act that might promote their individual interests at the expense of the integrity of the industry and avoid conduct that might discredit the industry. Instead, planners should seek to enhance the reputation of the industry with others by the way they communicate and interact.

Code of Ethics for Planners and Installers

RWH planners/installers should uphold and advance the integrity, honor, and dignity of the RWH industry by adhering to the following code of ethics:

- Hold paramount the safety, health, and welfare of the public in the performance of their professional duties.
- Perform services only in the areas of their competence.
- Behave in an objective and truthful manner.
- Act in professional matters for each employer or client as faithful agents or trustees.
- Avoid conflicts of interest.
- Build their professional reputation on the merit of their services.
- Compete fairly with other contractors and planners.
- Act in such a manner as to uphold and enhance the honor, integrity, and dignity of the RWH industry.
- Provide honest, hard work to employers and clients.
- Protect confidential information.
- Protect the environment.
- Maintain thorough knowledge of applicable federal, state, and local laws and ordinances related to water quality, drinking water standards, and construction techniques and materials.

Planners/installers should compete honestly and lawfully, building their businesses through their own skills and merits.

Summary

RWH planners and installers are in a peculiar time in the development of modern rain catchment and distribution systems. The industry is rapidly changing and increasing in complexity. Demand by consumers is outpacing the supply of available and qualified RWH planners/installers. This predicament leads to the possibility of the installation of under-performing systems that result in customers that are dissatisfied. In past instances involving other industries, bad designs, ineffective devices, and dissatisfied customers have led to negative long-term impacts. Sometimes it takes years for an industry to recuperate losses and regain the respect of the public. In worst cases scenarios, government intervention and regulation can even eliminate an industry. As the RWH industry grows, a code of ethics could serve the industry in a positive way.

Reference

CIDWT. 2009. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Midwest Plan Service, Ames IA.

Rainwater Harvesting:
System Planning

4. Safety

The goal of this chapter is to engage the RWH system planner in the process of appreciating safety issues and preparing for and recognizing hazards. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Recognize major hazards.
2. Respond to safety issues.
3. Protect workers from known hazards.

Contents

4. Safety

Introduction

Safety, whether on the job or while interacting with a RWH system, is an important consideration for a RWH planner. General hazard awareness, dangers specific to the installation process, and emergency response are topics that should be discussed with each employee. This chapter does not address the entire breath of hazards and safety issues that a planner may be exposed to at the jobsite as each site is unique. It is suggested that a safety hazard analysis be conducted prior to each installation. This analysis should identify significant hazards and communicate awareness to every employee, site owner, and site visitor.

Safety and Hazards

Installers working on RWH systems must be aware of and understand the onsite hazards they may encounter in order to minimize the risk of injury. They must avoid personal injury, know first aid basics, identify hazardous situations, and protect visitors. Some common hazards associated with the onsite installation of a RWH system include slips, falls, electrocution, and pinches.

Confined Spaces

There are hazards associated with the installation and presence of aboveground and belowground catchment storage tanks, which are known as confined spaces. Confined spaces have limited entry and exit opportunities, contain known or unknown potential hazards, have poor natural ventilation, and are not designed for continuous human occupancy.

There are two categories of confined spaces: open-top enclosures with depths that restrict the flow of air and enclosures with extremely small openings for entry and exit. Installers should have designated training and equipment regarding confined spaces when they exist. Seek Occupational Safety and Health Administration (OSHA) guidance and applicable certifications. Appropriate action should be taken to prevent children from accessing confined spaces such as locking down lids, closing entryway doors, using ladder guards and fencing around components.

Appropriate action should be taken to prevent children from accessing confined spaces such as locking down lids, closing entryway doors, using ladder guards and fencing around components.

Electrical Shock

Electrical shock is a potential hazard to system installers. Because electrical shock can cause serious injury or death, installers should not attempt to repair electrical equipment unless they are experienced with electrical systems. In all states, installers must be qualified and authorized to work on electrical equipment before attempting to make any repairs or troubleshoot. Depending on the systems, service providers may see 12-volts, 120-volts, and even 240-volts, all of which can cause injury, some even death.

Utility Service Hazards

Utility service lines (natural gas, propane, electrical, water, etc.) are a potential hazard located on most properties. Prior to the installation of a RWH system, the installer should identify the location of every above and belowground utility line. Remember, overhead utility lines are well within the reach of a backhoe's extended bucket.

Utilities such as electrical wiring and natural gas lines installed by the property owner may not be marked by the locator service.

Before digging at a site, underground utility lines should be located. The Underground Service Alert (USA) is a free service available to anyone in the United States. The number is 1(800) 227-2600. Please remember that utilities such as electrical wiring and natural gas lines installed by the property owner may not be marked by the locator service. These local lines may go to an onsite wastewater treatment system, barn, water well, or other facility requiring electricity on the property. Locating these may prove more difficult. A good first step is to talk to the property owner.

Bystanders and Outsiders

In addition to protecting themselves and other crew members, installers should prevent onlookers, visitors, and bystanders from being hurt at the jobsite. The idea and process of utilizing a RWH system is unique to most of the public. Installers should recognize that the novelty of the system will attract curious individuals to the installation site, both during and after working hours. Installers should assume that visitors to the jobsite do not understand, are not familiar with, and are unaware of the hazards associated with the installation of a RWH system and system components.

Installers should take appropriate means to prevent and discourage visitors from falling into an excavated hole, climbing ladders, entering a storage tank, or being trapped by loose or falling construction materials. Ladders, tools, portable machinery, and materials should be placed in a secure area with no reasonable access by the general public. Vehicles, tractors, and other self-propelled equipment left onsite overnight should be locked and parked in an area not to attract visitors, especially children. In some cases, it may be necessary for installers to remove all equipment, materials, and machinery when the workday is completed. Taking these actions also minimizes property theft and damage due to mischief.

Bystanders also include delivery truck drivers and assistants. Onsite job safety management includes being aware of the presence of delivery truck drivers and their assistants. Crewmembers should remain at a safe distance during the unloading of product by a deliverer. Sometimes the unloading of a delivery truck, for example an 18-wheeler with 20-foot joints of PVC pipe, places workers together that are unfamiliar with each other's work habits and aversion to risk taking. All onsite employees and delivery personnel should discuss and understand the unloading process, such as where materials will be offloaded and located on a site.

Chlorine Hazards

In instances where chlorine is used to treat water for contaminants, it is necessary for crewmembers to be familiar with safe handling practices and be able to recognize excessive exposure to chlorine. In low concentrations, chlorine can cause negative health effects such as burning in the eyes, nose and throat, redness in the face, sneezing, and coughing. Higher concentrations and exposure to chlorine causes tightness in throat and chest (pulmonary edema) and can even be fatal.

Ozone Hazards

In instances where ozone is used to treat water for contaminants, it is necessary for crewmembers to be familiar with safe handling practices and be able to recognize exposure to ozone as it has acute toxicity. It is important when utilizing this technology to demonstrate extreme caution. Ozone is a toxic gas that can cause illness if inhaled in significant quantities. Some ozone generators are equipped with ozone monitors and a safety system which shuts down the generator at 0.3 ppm.

Electrical Lockouts and Tagouts

Be aware of lockouts and tagouts. Safe work practices should always be used and be consistent with the nature and extent of the associated hazard. Live parts that have been de-energized but not locked out must be treated as energized. De-energized circuits shall be locked out and tagged. Written procedures shall be kept and made available for inspection. A copy of paragraph (b) of General Industry Standards of Occupational Safety and Health, set by the U.S. Department of Labor, 1910.353, fulfills the requirement for written procedures. This can be found at http://www.osha.gov.

Safe work practices should always be used and be consistent with the nature and extent of the associated hazard.

Lockout and tagout procedures state that the locks and tags must be in place before equipment may be de-energized. Live parts must be disconnected from all electrical sources and stored electrical energy must be released. This may also include the pressurization of the system. The general provisions for lockout and tagout are that live parts must be de-energized unless it is impossible to do so and if safe work practices for working on live parts are mandated.

Locks and tags must be placed together unless the lock cannot be applied. If only a tag is used, an additional safety measure must be used as well. A lock may only be used without a tag if only one item is de-energized, if the lockout period does not extend past the shift, and if exposed employees are familiar with the procedures. A qualified person shall check to see if the equipment is de-energized (if it is over 600 volts) and verify that equipment is safe to energize. Only the person placing the lock shall remove it unless that person is not in the work place and the employer takes certain precautions. Only qualified persons are allowed to work on live, exposed parts.

Engineering Controls

Another means of controlling this hazardous environment is through the use of engineering controls. Engineering controls are those measures that help control the working environment by some physical means. Written procedures, task-specific training, and following proper lockout/tagout procedures ensure safety. These procedures must be documented, and specific training must be provided for employees exposed to electrical hazards.

Use the right tool for the job.

Use the right tool for the job. Hand tools and some specialized tools are designed specifically for use in electrical environments. If you are using a lockout/tagout procedure, check to make sure you are following a permit-to-work procedure as well. This is occasionally used as another level of engineering control.

Summary

Safety on the jobsite is the responsibility of all crewmembers and should be considered when performing all tasks.

References

CIDWT. 2009. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Midwest Plan Service, Ames, IA

Rainwater Harvesting: System Planning

5. Planning Process

The goal of this chapter is to engage the RWH system designer in the process of planning a RWH system. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Determine the most effective order of planning.
2. Determine necessary components of a bid proposal and contract.

Contents

5. Planning Process

Introduction

Planning is critical to any major installation project. Proper planning aids the RWH planner in providing customers with what they expect in the time frame that they expect.

Customer Needs Assessment and Education

The first task in planning a RWH system is to determine the customer's needs and wants. This is an excellent time to do some very basic calculations on rainfall supply and demand to see if expectations can be met. At this time it is also good to share applicable state and local regulations regarding rainwater harvesting.

Another important aspect in the planning process is the education of the client. If the planner can educate the client on the basic principles of rainwater harvesting systems, the client will be able to make more informed decisions. Education of the client will aid in the process by allowing for effective communication between both parties. Educated customers tend to be satisfied customers

Site Evaluation

Once the customer's needs are identified, a site evaluation should be performed. Many times individuals will do site evaluations based on pictures or customer descriptions alone. This is not recommended. The RWH planner needs to go to the specific site where the RWH system is to be installed. Rough sketches should be made and measurements should be taken to determine component locations. Stake out the location of all components to give the customer a visual representation of where the system will be located.

As a professional RWH planner, keep in mind potential hazards or problems that could arise in each component location. Keep in mind operation and maintenance procedures that will need to be completed when evaluating the site.

Prior to final determination of component siting, look beyond the customer's property boundaries. Notice any hazards or problems, such as drainage, that could arise.

Choosing Components

Selecting the correct components for the application and environment help ensure the system performs to its designed standard. Components that are designed to function together should be chosen; incompatible components will cause the system to malfunction.

Sizing Components

Component sizing often comes down to a discussion with the client. Components must be sized for current customer needs and for any future needs. If the cost of increasing component sizes is not an option to meet future demands, design the system in a modular fashion to facilitate expansion and updates in the future. Remember to discuss assumptions used when deciding the size of components with the customer. Incorrect assumptions will cause the system to either under-perform and not meet their needs or over-perform and possibly be cost prohibitive.

Bids and Contracts

After developing a bid and contract, it is advantageous to set up a meeting with the client to convey the proposed timeline for the project, the necessary resources, and a brief description of the final deliverable.

A timeline for the project details the estimated time needed for each phase of construction. Listing the necessary resources allows the client to visualize what products will be used in construction and the equipment and manpower that will be on site for installation. Detailing the characteristics of the project deliverable allow the client to know and understand exactly what is being paid for and when compensation is expected.

Some planners feel it is best to require full compensation upon substantial completion of the project. If this method is used, the contract must explicitly and clearly state what “substantial completion” is.

Exact details of the project deliverables and a timeline should be listed in the bid proposal and contract. Developing a good bid proposal and contract can aid you in protecting yourself legally. The proposal and contract should state exactly what services you will provide at what cost as well as your responsibilities.

Be sure to include the required and recommended water quality testing procedures necessary and detail who is responsible for collecting, processing, and paying for them.

To avoid problems when not working directly with the owner of a new building, at the onset of the contract, it is recommended to file a lien release with the mortgage company or bank. This will not allow the closing to finalize on the building until the planner/installer releases the lien upon payment.

An example bid and contract is included at the end of the chapter.

Installation

Proper installation of each RWH system component is critical to the overall system performance. Problems of upstream components can impact and negatively affect downstream components, possibly jeopardizing the water quality and supply. A thorough inspection of the finalized installation is needed to ensure that no mistakes were made and that all components work properly together.

Testing

Arrangements should be made prior to installation for water quality testing. The appropriate sampling instructions, collection instruments, holding containers, and shipping/delivery procedures should be known in advance of sampling. Proper sampling procedures ensure that water quality samples are valid samples.

Arrangements should be made prior to installation for water quality testing.

Summary

The planning phase of installing a RWH system is often overlooked in order to save time. Proper planning and communication ensures that the customer's and installer's expectations are met and that problems are minimized.

Reference

CIDWT. 2008. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Pilot Test Version 2. March 2008.

Example Bid

RWH Systems
Design Company
Proposal for Rainwater Harvesting System

Site: Bear Creek

Objectives

1. Provide a low-maintenance rainwater system that provides water for irrigation and for potable use.
2. Design the system to be modular so that it can be modified in the future to provide additional potable water.

Scope of Work

Install the materials necessary for a rainwater harvesting system that includes:

- Pre-filtration
- Conveyance Piping
- Tank and fittings

Pump and delivery piping to, can be provided but is not included in the scope of this bid until more information can be determined.

Summary

Based on the initial site visit and the expressed needs of the client, RWH Systems Design Company recommends that a rainwater harvesting system at Bear Creek be sized to accommodate landscape irrigation and future potable use for laundry and toilet flushing. Because of the large metal roof, it is possible to collect a significant amount of water.

Feasibility

Based on the average monthly rainfall in the area the main building can collect and use as much as 40,000 gallons a month.

Recommendations

Due to the size and simplicity of the main building, collection is recommended only from this building. It is also recommended to place the tank in a location that would make it easy to add additional storage in the future if desired.

System Overview

One large tank is the most cost effective and also requires the least maintenance. RWH Systems Design Company recommends a Company Y water tank with a 50,000-gallon capacity. This tank has a 15-year warranty and 75-year life expectancy. The Company Y tank is rated by the NSF for potable water use. The recommended location of the tank is near the main building.

The location behind the main building is ideal because the overflow to the existing drainage is nearby.

For optimal pre-filtration, Gutter guards are recommended on all the gutters. All downspouts will be painted 3-inch PVC. The downspouts are then piped to a collection line that will run from the main building to the tank location and may involve trenching through the yard and sidewalks.

Options

1. Collect from the entire main building and convey rainwater to a 50,000-gallon tank near the barn. This option allows future add-ons and collects the most rainwater possible.
2. This option is similar to the first option except that a larger (75,000-gallon) tank is used. The advantage is that it provides more storage for periods of drought.

Example Bid Continued

RWH Systems
Design Company

QUOTE: Rainwater Harvesting System Option 1

RWH Systems Design
Company
120 Harvest Street
Rain City, Texas 52631
info@rwhsystems.com

Insurance
Precipitation Insurance Co.
#2345578
234 River Street
Waterville, Texas 56789

Date: January 15, 2009
Invoice # 109

Expiration: March 15, 2009

Customer	Address		Phone
Bear Creek	2008 Bear Creek Road, Creek City, Texas		123-456-7891
Salesperson	Job	Payment Terms	Start Date
River Smith	**Tank – Main Building Location**	50% Deposit on 50% Comp	

This quote includes material and labor for installation of the following:

QTY	Item #	Description	Install Total
1	TANK	Water Tank – 50,000 gallon	$25,000
		Base – 6 inch sand pad	$2,500
	FILTRATION		
600ft		Gutter Guards	$2,850
1		Floating Intake Filter	$700
2		6-inch First Flush Diverters	$700
	PIPING		
300		4-inch PVC –Trunk	$4,800
100		6-inch PVC – Trunk	$3,000
30		3-inch PVC – Downspouts, with paint	$1,000
20		6-inch PVC – Overflow	$600
	OTHER		
		TOTAL	$41,150

Quote prepared by: ____
This is an estimate on the items named, subject to the conditions noted below:

*** Exclusions may include:**

- Gutters
- Design work and plans
- Piping from tank to pump
- Pump Enclosure
- Electrical work for pump
- Piping from city main to refill
- Trenching through asphalt/concrete
- Overflow Piping

*Alteration or deviation from the specifications listed above involving extra costs will be executed only upon written request, and will become an extra charge over and above the estimated price.

Example Bid Continued

RWH Systems
Design Company
QUOTE: Rainwater Harvesting System Option 2

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* This quote is valid for 60 days and may require revision until more details can be specified.

RWH Systems Design Company
120 Harvest Street
Rain City, Texas 52631
info@rwhsystems.com

Insurance
Precipitation Insurance Co.
#2345578
234 River Street
Waterville, Texas 56789

Date: January 15, 2009
Invoice # 109

Expiration: March 15, 2009

Customer	Address		Phone
Bear Creek	2008 Bear Creek Road, Creek City, Texas		123-456-7891
Salesperson	Job	Payment Terms	Start Date
River Smith	**Large Tank – Main Building**	50% Deposit on 50% Comp	

This quote includes material and labor for installation of the following:

QTY	Item #	Description	Install Total
1	TANK	Water Tank – 75,000 gallon	$30,000
		Base – 12-inch concrete pad	$5,500
	FILTRATION		
600 ft		Gutter Guard	$2,850
1		Floating Intake Filter	$700
2		6-inch First Flush Diverters	$700
	PIPING		
300		4-inch PVC –Trunk	$4,800
100		6-inch PVC – Trunk	$3,000
30		3-inch PVC – Downspouts, with paint	$1,000
20		6-inch PVC – Overflow	$600
	OTHER		
		TOTAL	$46,150

Quotation prepared by: ______________________________

This is an estimate on the items named, subject to the conditions noted below:

*** Exclusions may include:**

- Gutters
- Design work and plans
- Piping from tank to pump
- Pump Enclosure
- Electrical work for pump
- Piping from city main to refill
- Trenching through asphalt/concrete
- Overflow Piping

*Alteration or deviation from the specifications listed above involving extra costs will be executed only upon written request, and will become an extra charge over and above the estimated price.

* This quote is valid for 60 days and may require revision until more details can be specified.

Example Contract

Components:

RWH SYSTEMS DESIGN COMPANY CONTRACT
Define parties in agreement.
State what terms of the agreement are and what they are in reference to.
State what is expected by each party.

COMPENSATION

Deposit – Material
State payment expectations clearly.

Final Payment
Clearly define when payment is expected to be received.
Define any interest or payment plans that are presented.

PROJECT START AND COMPLETION
State project timeline expectations.
State uncontrollable factors, such as weather, that could extend project completion date.

Termination
Clearly state the conditions under which each party may terminate the signed agreement and contract.

Changes
Clearly state the procedures for each party to change terms of the bid/proposal and agreement and/or contract.

PERMITS
Specify which party is responsible for applying for and adhering to appropriate permits.

AGREEMENT
State any additional terms or conditions of the agreement.

SIGNATURES
Both parties should sign and date the agreement.

I, _____________________________, hereby agree to all above said statements. ___________Date

Client Signature & Title

____ ___________Date

RWH SYSTEMS DESIGN COMPANY Representative

Rainwater Harvesting:
System Planning

6. Rainfall Data

The goal of this chapter is to engage the RWH system planner in the process of evaluating rainfall for a given area by considering annual amount, intensity, and frequency. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Define rainfall amount, intensity, frequency, and return period.
2. Obtain and decipher rainfall data.
3. Discuss trends in monthly rainfall.
4. Recognize rainfall patterns from data.
5. Discuss data regarding duration of days without rainfall.
6. Complete exercises at the end of the chapter.

Contents

6. Rainfall Data

Introduction

A RWH planner must be able to gather and reasonably interpret precipitation data for a given area in order to estimate storage potential and the size of the RWH system components. There is precipitation data available for nearly every county in the United States and is provided by the state's climatology office.

For example, the monthly average rainfall totals for selected Texas cities is available online from the Office of the State Climatologist (http://climate.tamu.edu). For most cities in the U.S., more detailed rainfall data, such as average depth, storm duration, and intensity, is available online from the National Climatic Data Center (http://hurricane.ncdc.noaa.gov/cgi-bin/HPD/HPDStats.pl) and is listed in Appendix A.

In addition to being able to gather rainfall data, one must also be able to determine characteristics or patterns of precipitation distribution. The following aspects of rainfall should be considered:

- Annual amount
- Intensity
- Frequency

Annual amount

The annual amount of rainfall that an area receives is directly related to the available rainfall for harvesting. Ideally, if an area receives 30 inches of annual rainfall, then one should begin the supply estimation based on that annual total. RWH planners should notice that the monthly rainfall depths can vary greatly at a given location (Table A. 8).

The RWH planner should pay careful attention to the varying amounts of precipitation in the given area, along with the different types of precipitation. In the case of College Station, Texas, one can see that February, July, and August are the driest months (Table A.8). Therefore, the RWH planner should take into account these precipitation changes when estimating the size of the RWH system components.

Another aspect to consider is the fact that many portions of the country accumulate precipitation in the form of snow and ice, which means the planner should be familiar with the amount of annual *runoff* in addition to the annual precipitation to gauge the correct size of the components. These examples show the varying factors that should be considered when gathering and analyzing the precipitation data in order to plan and install the correct components for the RWH system.

Many systems in the northern states may also close off the collection system during winter months. This will protect pipes and fittings from breaking due to the expansion of freezing water.

Intensity

Rainfall intensity, measured in inches of rain per hour (iph), is another factor for planners to consider. It can be found with other similar rainfall data. Typically, rainfall intensity is reported in conjunction with duration and return periods.

Rainfall intensity varies greatly across the United States. One of the most striking comparisons can be made between Quillayute, Washington, (101 inches annually) and New Orleans, Louisiana (65 inches annually) (NCDC, 2009). New Orleans has a much higher probability of a 3 iph rainfall event than Washington, which rarely receives above a 1 iph rainfall event. The rainfall intensity of an area may affect the choice of first flush, filtration design, or technique used for the system.

Frequency

The frequency of which rainfall occurs is a vital factor in considering available water for a given site, as it directly impacts the design of the storage and distribution components of the RWH system. In Spokane, it has been known to rain each day for 90 days. In contrast, the rain in New Orleans is much less frequent.

In the planning process, it is necessary to size RWH components like gutters and downspouts based on the probability of the intensity and frequency of rainfall events. This data is provided by climatologists in tables that include location, rainfall intensity, duration of a storm, and return period.

Return Period

A rainfall return period is based on historical data that does not actually represent a specific period of time. The year designation equals the inverse of the probability that a storm of a particular magnitude (intensity and duration) will occur in a one year time period. Maps displaying the precipitation frequency of storms for the Central and Eastern United States are located in Appendix A. Maps displaying the precipitation frequency of storms for the Western United States can be found online at: http://www.wrcc.dri.edu/pcpnfreq.html.

Table 6.1. Return Period and Probability of Occurrence

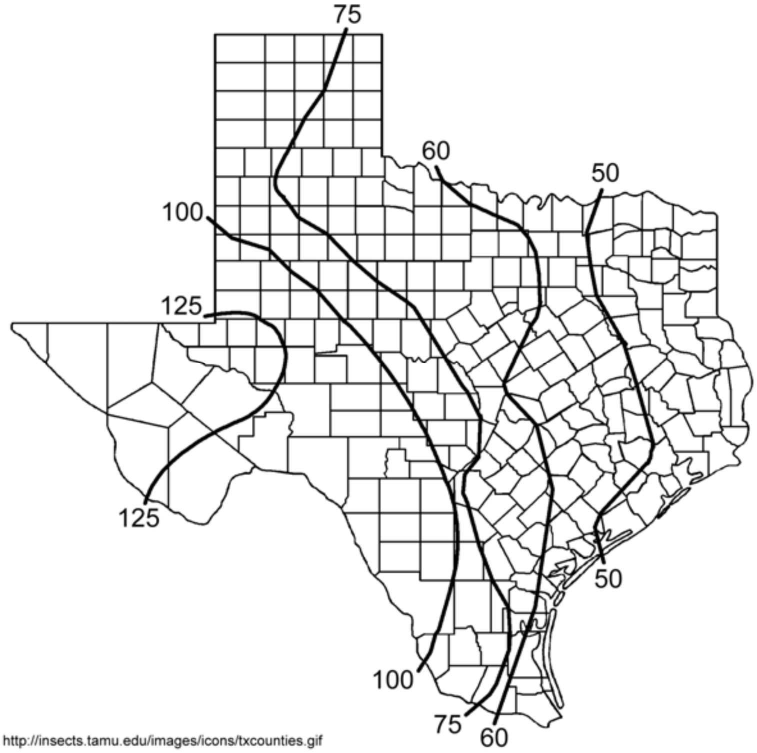
Return Period Years	Probability of Occurrence
2	50%
5	20%
10	10%
15	7%
25	4%
100	1%

For instance, a storm with a 2-year return period has a 50 percent chance of occurring in any one year. A storm with a 10-year return period has a 10 percent chance of occurring in any one year. Table 6.1 details the various return periods and probabilities of occurrence.

Maximum Number of Dry Days

The time interval between rains can be significant (Figure 6.1). Besides reporting rainfall data, climatologists also keep track of dry days, summarized by an average of maximum number of dry days on an annual basis. An example of this interval is in Figure 6.2 on the following page. In semi-arid regions, the interval between rainfalls and the system storage capacity is critical to the successful operation of a RWH system.

Figure 6.1. The dry time between rainfall events can have a significant effect on water supply reservoirs.



http://insects.tamu.edu/images/icons/txcounties.gif

Figure 6.2. Maximum number of dry days observed (derived from Krishna, 2003).

Rainfall Characteristics at two Locations

The following analysis of rainfall characteristics at two locations is helpful in facilitating a discussion about differences in rainfall events. In Table 6.2 below, Quillayute, WA is compared to New Orleans, LA.

Table 6.2. Rainfall characteristics of two locations in U.S.

Location	Annual Rainfall (in)		Intensity		Frequency
Quillayute, WA	100		Low		Frequent
New Orleans, LA	65		High		Moderate

Rainfall Data Recording and Evaluation Sheet

RWH system planner may find it helpful to collect data for a particular area. The following rainfall data sheet could be used (Table 6.3).

Table 6.3. Rainfall Data Recording and Evaluation Sheet

Location	**(city, county, state)**
Intensity	(high/med/low)
Frequency	(frequent/moderate/rare)
Annual Precipitation	(no. inches)
Winter Runoff	(no. inches equivalent)
Return Period	(years, probability, depth)
Max No. Dry Days	(no. of days)
Other	(pertinent characteristics)

Summary

Rainfall events are complicated and a comprehensive review of local rainfall is imperative. Individuals designing a RWH system should retrieve an adequate amount of rainfall data in order to properly size components and meet the customer's needs. Average annual amounts of rainfall and precipitation, rainfall intensity, and frequency of storms should all be considered in assessing the rainfall pattern for a given site. One caveat to rainfall data is the fact that we only have a limited historical perspective on the aforementioned rainfall factors and data used to predict precipitation. In most states, we have collected a little over 100 years of data; some of the data is even questionable. Fortunately, collection and reporting techniques have improved and reliable data has become more accessible via the Internet.

References

Krishna, H. 2003 An overview of rainwater harvesting systems and guidelines in the United States. Proceedings of the first American Rainwater Harvesting Conference; 2003 Aug 21-23, Austin, TX.

NCDC. 2009. National Climate Data Center. http://www.ncdc.noaa.gov/oa/climate/online/ccd/nrmpcp.txt Date accessed: Feb 15,2009.

WRCC. 2009. Western Regional Climate Center. http://www.wrcc.dri.edu/pcpnfreq.html Date accessed: July 2,2009.

Chapter 6 Exercises

Directions: Refer to Table A.8 in the Appendix or other dependable rainfall data to respond to the following questions and statements.

1. What is the depth of the rainfall for month of June for the following locations?
    a. Yakutat, AK ____ inches
    b. Savannah, GA ____ inches
    c. Baton rouge, LA ____ inches
    d. Koror, PC ____ inches
    e. Yakima, WA ____ inches

2. What are the annual rainfall totals for the following locations?
    a. Phoenix, AZ ____ inches
    b. M. Washington, NH ____ inches
    c. Pensacola, FL ____ inches
    d. Indianapolis, IN ____ inches
    e. Corpus Christi, TX ____ inches

3. Identify the three months with the highest rainfall for each city.
    a. Lynchburg, VA ________, ________, ________
    b. Las Vegas, NV ________, ________, ________
    c. Allentown, PA ________, ________, ________

Rainwater Harvesting: System Planning

7. Supply: Estimating the Potential for Harvesting Water

The goal of this chapter is to engage the RWH system planner in the process of determining the potential amount of water that can be collected. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. List the essential variables needed to estimate water supply.
2. Utilize formulae and conversion factors for estimating supply.
3. Explain the differences between catchment footprint and roof area.
4. Identify an appropriate catchment surface runoff coefficient.
5. Choose a meaningful design safety factor.
6. Organize variables in preparation for calculations.
7. Estimate amount of supply on an annual and monthly basis.
8. Estimate supply for a given situation and parameters.
9. Complete exercises at the end of the chapter.

Contents

7. Supply: Estimating the Potential for Harvesting Water

Introduction

Estimating the amount of water that can be harvested in a given area depends on the catchment area, rainfall, system efficiency, and a design safety factor. The interpretation of each of these essential variables directly effects the planner's estimation. The catchment area and rainfall amounts must be determined accurately for the system to work to its fullest potential. System efficiency relates to spillage, leakage, and losses due to materials. The planner may choose to utilize a design safety factor that provides for the underestimation of the catchment potential so that there is a cushion for the system functionality.

At the end of this chapter, you will be able to substitute actual numbers into the following formula. The formula can be used to estimate the water harvesting potential on an annual or monthly basis.

$$\underset{\text{water (gal)}}{\text{Harvested}} = \underset{\text{area (ft}^2\text{)}}{\text{catchment}} \times \underset{\text{(in.)}}{\text{depth}} \times \underset{\substack{\text{conversion}\\\text{factor}}}{.623} \times \underset{\text{coef.}}{\text{runoff}} \times \underset{\text{factor}}{\text{safety}}$$

Simple Estimate

A simple estimate of the number of gallons that can be harvested from a given catchment area from a rainfall event can be determined with the following formula. The total number of gallons harvested is equal to the catchment area (square feet) times the depth of a rainfall (inches) times a conversion factor of 0.623.

$$\underset{\text{water (gal)}}{\text{Harvested}} = \underset{\text{area (ft}^2\text{)}}{\text{catchment}} \times \underset{\text{(in.)}}{\text{depth}} \times \underset{\substack{\text{conversion}\\\text{factor}}}{0.623}$$

Table 7.1 illustrates supply estimates in gallons from rainfall amounts that range from 1 to 15 inches and catchment areas of 2,200, 3,500 and 5,000 square feet. The number of gallons per square foot of catchment area is also provided. Although this formula provides a rough estimate that might be adequate to initiate a discussion with a client, a more comprehensive approach is necessary to provide an adequate estimate.

Table 7.1. Estimated gallons captured.

Rainfall (in.)	Area (ft^2)	Gallons/Square Foot	Total Gallons
1	1,000	0.6	623
3		1.9	1,869
5		3.1	3,115
10		6.2	6,230
15		9.4	9,345
1	3,000	0.6	1,869
3		1.9	5,607
5		3.1	9,345
10		6.2	18,690
15		9.4	28,035
1	5,000	0.6	3,115
3		1.9	9,345
5		3.1	15,575
10		6.2	31,150
15		9.4	46,725

Catchment Area

The catchment area is the location from which water will be collected and must be measured to the nearest square foot. The total roof area is not as important as the footprint of the catchment, which determines the area in which water is collected. Figure 7.1 illustrates the idea of roof footprint. Regardless of the complexity of the angle or shape of the roof, the footprint area is always smaller than the actual area.

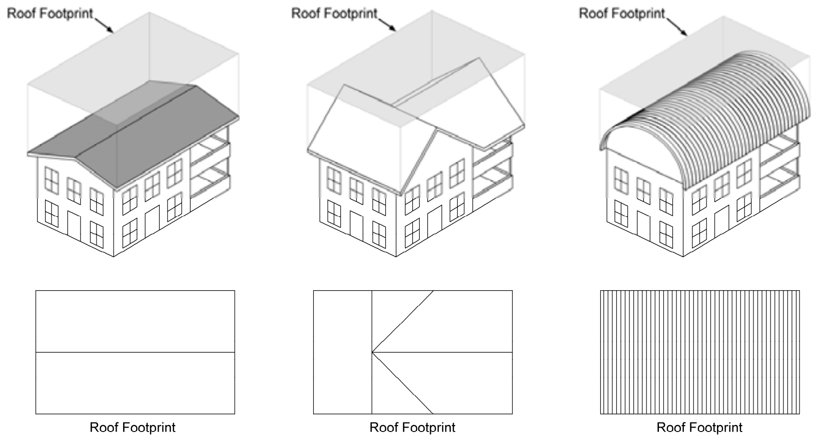


Figure 7.1. Roof catchment footprint versus roof area and shape

It is not the total roof area that is important; it is the footprint of the catchment that will determine the area for which water will be collected.

Catchment Surface Runoff Coefficient

The material and texture of the catchment surface has an effect on the amount of water harvested. A rough and/or absorptive surface conveys less rainwater than a smooth surface. For example, a catchment surface made of grass, soil, rocks, asphalt shingles, or rough concrete will retain some water before it begins to runoff. These surfaces decrease the efficiency of a RWH collection system by allowing infiltration or absorption or facilitating evaporation of the water. In contrast, a smooth metal surface will minimize these losses. In order to compensate for inefficiencies, a catchment surface runoff coefficient is applied to the calculation for supply estimation.

The coefficient has the effect of reducing the estimated total number of gallons collected from a rainfall event. Using the coefficient of 0.75 rather than 0.95 effectively reduces the estimate by 20 percent. Table 7.2 on the next page contains runoff coefficients for specific catchment surface materials. Numbers in the high column should be used when the surface is smoothest and the low coefficient should only be used when the surface is rough. For instance, the coefficient of 0.95 would best represent a catchment surface made of concrete with a smooth, slick finish.

Design Safety Factor

For centuries, design engineers have used a safety factor (known commonly as a fudge factor) to overestimate or underestimate performance in their designs. In the planning process for RWH, a safety factor should be used to underestimate the potential for rainfall catchment. By underestimating the potential, the planner ensures that an adequate supply of water is available. This is critical when a family or business relies solely on rainwater for drinking or irrigation of food crops. The potential for leakage, pluggage, spillage, and other factors that reduce the efficiency of a collection system should be examined when determining a safety factor. A design safety factor that ranges between 0.95 and 0.65 should be considered.

Table 7.2. High and low runoff coefficients for various catchment surfaces. (Haan et al.,1994) & (Waterfall, 1998).

Run-off Coefficients*		
Character of Surface	High	Low
Roof		
Metal, gravel, asphalt shingle	0.95	0.75
Paving		
Concrete, asphalt	0.95	0.70
Brick	0.85	0.70
Gravel	0.70	0.25
Soil		
Flat (2% or less), bare	0.75	0.20
Flat (2% or less), with vegetation	0.60	0.10
Lawns, Sandy Soil		
Flat (2% or less)	0.10	0.05
Average (2% to 7%)	0.15	0.10
Lawns, Heavy Soil		
Flat (2% or less)	0.17	0.13
Average (2% to 7%)	0.22	0.18

Estimating Supply on an Annual Basis

The aforementioned essential variables play a key role in determining a reasonable and dependable supply of water for a given catchment system. Keep in mind the unique factors and circumstances at a site that influence the potential to harvest water. The following formula can be used to estimate the amount of supply on an annual basis. A case scenario is provided to work through this formula.

$$\underset{\text{water (gal)}}{\text{Harvested}} = \underset{\text{area (ft}^2\text{)}}{\text{catchment}} \times \underset{\text{(in.)}}{\text{depth}} \times \underset{\text{conversion factor}}{.623} \times \underset{\text{coef.}}{\text{runoff}} \times \underset{\text{factor}}{\text{safety}}$$

In addition to using the equation above and creating your own spreadsheet to calculate supply, a number of calculators are available on the internet.

For a quick estimate of harvested gallons per square foot per inch of rain, multiply 0.623*Run-off Coefficient*Square Footage.

Case Study: 2,500 ft^2 Home

A local RWH planner has been asked by a client to provide an estimate for the total amount of water that might be harvested each year for a suburban home in St. Louis, Missouri. The footprint of the shingled roof that has gutters and is available for catchment has an area of 2,500 ft^2. A review of the climactic data reveals that St. Louis receives about 38.8 inches of precipitation each year, but only 17.5 inches of that amount is rainfall.

The client only wants to irrigate a garden and landscaping areas, so the spring and summer rains that historically occur in St. Louis will be adequate and timely. The shingled roof is evaluated and assigned a runoff coefficient of 0.95. The safety factor is 0.85 because little spillage is expected and the planner has noticed a trend toward warmer winters and less precipitation in the form of snow.

Harvested water (gal)	=	catchment area (ft^2)	x	depth (in.)	x	.623 conversion factor	x	runoff coef.	x	safety factor
22,000	=	2,500	x	17.5	x	0.623	x	0.95	x	0.85

The total annual catchment potential is determined to be approximately 22,000 gallons. The average number of gallons per square foot of catchment area is 8.8.

Case Study: Retail Store Roof Catchment

A nationally recognized retail conglomerate has asked a RWH planner to install a RWH system. The store manager wants to use the water not only for the horticulture department but also to build an attractive water garden and pond adjacent to the store. The store is located in San Antonio, Texas, and has a useable roof catchment area of 65,000 ft^2. The runoff coefficient for the gravel roof is 0.85. Historically, San Antonio receives 32.9 inches of precipitation each year, most of which is rainfall (NDC, 2009). The planner determined that a safety factor of 0.80 is appropriate because of the evaporation potential on the flat, gravel roof. Following the supply equation presented earlier and multiplying the catchment area, precipitation, conversion factor, run-off coefficient, and the safety factor:

65,000 ft^2 x 32.9 in. x 0.623 x 0.85 x 0.80 = 905,954 gal.

The total annual catchment potential is determined to be approximately 906,000 gallons. The average number of gallons per square foot of catchment area is 13.94.

Estimating Monthly Supply

The previous discussion and two example scenarios predicted the catchment potential on an annual basis. In order to best compare rainfall capture to demand needs, a RWH planner has to predict the catchment potential on a monthly basis. The same formula is used but instead of the annual rainfall depth, the monthly average rainfall depth is utilized. Each month's supply is calculated using the formula. A spreadsheet or chart should be utilized to keep the figures and computations organized. A study of the monthly catchment potential for Key West, Florida, provides a good example.

Case Study: Key West, Florida

The rainwater will be collected for an isolated city building with no city water connections available. The catchment is a terracotta roof, and the water will be used for non-potable indoor needs and outdoor irrigation. The variables that need to be determined include: average monthly rainfall (inches), catchment footprint (square feet), runoff coefficient and safety factor.

Table 7.3. Average monthly rainfall data for Key West, Florida. (NCDC, 2009)

Month	Average Monthly Precipitation (in.)
January	2.22
February	1.51
March	1.86
April	2.06
May	3.48
June	4.57
July	3.27
August	5.40
September	5.45
October	4.34
November	2.64
December	2.14

A worksheet is used to facilitate the computations and organize the results. A RWH planner determined that a runoff coefficient of 0.90 and a safety factor of 0.95 are sufficient. The following rainfall data was found for the City of Key West, Florida (Table 7.3) on the NCDC website.

The required variables were put into the Supply Worksheet (Table 7.4). Columns A, B, C, D and E were then multiplied to obtain Column F. Column F represents the estimated catchment potential for each month. The last row in the worksheet reveals the annual catchment potential that was found by summing all of the monthly totals.

The data in column F is valuable because it can be shared with a client and used to compare with monthly and annual demand estimates for a system. Estimating monthly potential catchment helps in identifying rainfall patterns where supply is inadequate. A review of column F may also reveal months where rainfall catchment is in excess of demand.

Table 7.4. Example supply worksheet – estimating monthly catchment potential.

	A	B	C	D	E	F
Month	Monthly Avg. rainfall Key West (inches)	Catchment Footprint (ft^2)	Conversion Factor	Runoff Coefficient	Safety Factor	Multiply Columns A*B*C*D*E Monthly Potential (gallons)
January	2.22	1,800	0.623	0.9	0.95	2,129
February	1.51	1,800	0.623	0.9	0.95	1,448
March	1.86	1,800	0.623	0.9	0.95	1,783
April	2.06	1,800	0.623	0.9	0.95	1,975
May	3.48	1,800	0.623	0.9	0.95	3,337
June	4.57	1,800	0.623	0.9	0.95	4,382
July	3.27	1,800	0.623	0.9	0.95	3,135
August	5.4	1,800	0.623	0.9	0.95	5,178
September	5.45	1,800	0.623	0.9	0.95	5,225
October	4.34	1,800	0.623	0.9	0.95	4,161
November	2.64	1,800	0.623	0.9	0.95	2,531
December	2.14	1,800	0.623	0.9	0.95	2,052
Annual	38.94	1,800	0.623	0.9	0.95	37,336

Summary

A RWH system planner must understand and evaluate the site-specific essential variables in order to estimate potential supply. Meaningful and reasonable numbers for catchment area, rainfall, system efficiency, and design safety factor should be determined. The data and results should be kept in a worksheet and presented to a client in an organized fashion. RWH planners have found that client expectations can be met if the supply is correctly estimated. Rainwater harvesting calculators can be found on several web pages including the Texas Water Development Board and Texas AgriLife Extension Service.

References

Haan, C.T., B.J. Barfield and J.C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press. 1994.

NCDC. 2009. National Climate Data Center. http://www.ncdc.noaa.gov/oa/climate/online/ccd/nrmpcp.txt Date accessed: Feb 15,2009.

Waterfall, P.H. 1998. Harvesting Rainwater for Landscape Use. Arizona Department of Water Resources. 1998.

Chapter 7 Exercises

Directions: Refer to Table 7.1 to respond to the following questions and statements. Remember, the estimations in these exercises are rough estimates only.

1. Nick, a homeowner, reports to Brett, the RWH planner, that his house receives 15 inches of rainfall in the summer months. Brett estimates that Nick has a catchment footprint area of 1,000 square feet. Approximately how many gallons of rainwater could be captured?

   ______________ gallons

2. Bob has a catchment footprint surface area of 3,000 square feet for his range cattle. Approximately how many gallons can he catch for each inch of rainfall?

   ______________ gallons

3. Ricky wants to catch about 15,000 gallons of water during a time when her house gets 5 inches of rainfall. How large of a catchment footprint area is required?

   ______________ square feet

Open-Ended Exercise: Estimation of monthly supply for any chosen location.

Directions: Refer to Table 7.4 as a guide and follow the numbered steps that appear after the spreadsheet. Collect information as required or provided by your instructor to fill in the following spreadsheet to calculate supply on a monthly basis and the annual total. Remember, the estimations in this exercise are rough estimates only.

	A	B	C	D	E	F
Month	Monthly Avg. rainfall (inches)	Catchment Footprint (ft^2)	Conversion Factor	Runoff Coefficient	Safety Factor	Multiply Columns A*B*C*D*E Monthly Potential (gallons)
January			0.623			
February			0.623			
March			0.623			
April			0.623			
May			0.623			
June			0.623			
July			0.623			
August			0.623			
September			0.623			
October			0.623			
November			0.623			
December			0.623			
Annual			0.623			

Steps

1. Build spreadsheet with a computer program or use empty table above.
2. Obtain monthly rainfall averages for given location.
3. Determine catchment footprint area.
4. Determine runoff coefficient from Table 7.2.
5. Determine Safety Factor based on knowledge of the site and discussion in chapter.
6. Obtain monthly catchment potential by multiplying column entries on each row (A*B*C*D*E).
7. Calculate annual catchment amount by multiplying total annual rainfall by totals in last row of columns B, C, D, and E.
8. Double check findings by comparing annual catchment (Step #7) to sum of each month found in Step #6.
9. Review monthly supply amount in column F.
    a. Identify highs and lows
    b. Observe patterns in data
    c. Identify highest 4 months
    d. Identify lowest four months
    e. Identify months where capture potential is zero.

Rainwater Harvesting:
System Planning

8. DEMAND: Estimating Water Usage

The goal of this chapter is to engage the RWH system planner in the process of estimating demand for the user of the RWH system. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. List the essential variables needed to estimate water demand.
2. Assist client in identifying water needs and desires.
3. Obtain and/or assess current demand of client.
4. Obtain ET and PET numbers for a location.
5. Organize variables in preparation for calculations.
6. Utilize ET, PET, and Plant Water Use Coefficient to predict water requirement of specific plants.
7. Convert water requirements in inches depth to demand in gallons.
8. Predict client's monthly and annual demand in gallons for landscaping, turfgrass, livestock, and potable and non-potable water needs.
9. Estimate demand for a given situation and parameters.

Contents

8. Demand: Estimating Water Usage

Introduction

RWH planners should evaluate each client's water demand needs and desires in order to establish dependable numbers for annual, monthly, and daily water usage. Some RWH systems will supply only a portion of water needs for a client while other systems are required to provide all of a client's water demand. Distribution systems vary and may include all or a combination of the following: drinking water, decorative fountains, irrigation systems, water gardens, and livestock watering.

Indoor Demand (Potable/Non-Potable)

Domestic water use in the United States on a per capita basis continues to be reported as the highest in the world. The average American uses over 100 gallons of water per person each day in their homes. (US EPA, 2009)

If a client is using municipal water, meter readings can be recorded and an average daily usage can be more accurately determined. Another alternative is to refer to a source like the Environmental Protection Agency for indoor water use statistics and a water use audit (http://www.epa.gov/watersense/ pubs/indoor.html).

Planners must balance the consideration of water usage by current residents with that of future residents. Assuming the total indoor demand of a three-member family living in a four-bedroom home is 210 gallons per day will likely provide ample water for the family at that time. However, if 10 years from the date of installation, the original family has moved and sold the home to a family of five who regularly hosts friends and family for events, it is likely that the system demand will exceed supply.

Planners should sit down with clients early in the planning process and discuss their current water usage habits, social lifestyle, and property resale considerations to ensure that the client understands that the system has performance limitations.

Planners should sit down with clients early in the planning process and discuss their current water usage habits, social lifestyle, and property resale considerations to ensure that the client understands that the system has performance limitations. At this time, planners should also educate the client on how demand and supply were determined. The client should realize that, while the system was designed with certain safety factors and considerations for drought, precautionary water usage measures should be considered in prolonged periods of drought to protect their water supply.

In the case that a rainwater harvesting system is being installed to only supply water for non-potable uses such as commode flushing and clothes washing, it is necessary to determine the water demand by each device being supplied in the home. Table 8.1 lists the typical amount of water seen in common water usage devices and Figure 8.1 illustrates the breakdown of indoor water demand.

Although it is out of the scope of this manual, readers should be aware that information and data are available on water usage for systems other than individual homes, such as airports, apartments, schools, etc.

Table 8.1. Water usage rates for common fixtures (TWDB, 2005).

Water Using Fixture	Water consumption using conserving fixtures	Assumptions from AWWA* Residential End-Use Study
Ultralow Flush Toilet	1.6 gal/flush	6 flushes/ person/day
Dual Flush Toilet	1 gal/ flush liquids 1.6 gal/ flush solids	6 flushes/ person/day
Showerhead	2.2 gal/min	5 min/ person/day
Bath	50 gal/bath	NA
Faucets	2.2 gal/faucet/min	5 min/ person/day
Clothes washer (front-loading)	18-25 gal/load	2.6 loads/ week
Dishwasher	8 gal/cycle	0.7 cycles/day

*American Water Works Association

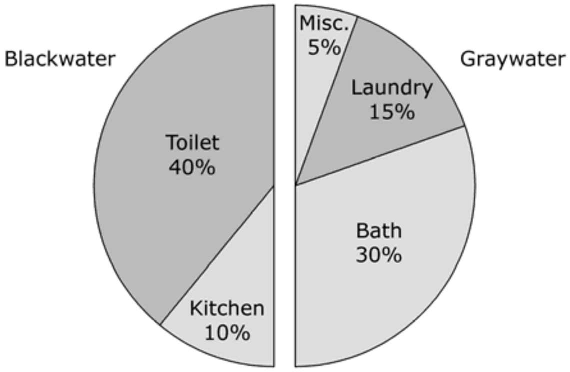


Figure 8.1. Percent composition of typical residential household water use (Lesikar, 2008).

Outdoor Demand

Outdoor demand for water can be much greater than in-home usage. Turf irrigation systems for an average city lot with a 2,500-ft^2 home can use 1,800 gallons each day during the summer months. Livestock and wildlife may require 2 to 25 gallons/head/day all year round (Kniffen, 2007). Drip irrigation and water gardens may utilize water only when it is available from the RWH system.

Existing water demand can be measured but water usage for a landscape or garden is estimated. Irrigation requirements for landscapes, turfgrass, and gardens are based on the crop water requirement (inches) for each type of plant. RWH planners can estimate water demand for irrigation by establishing the crop water requirement and the square footage of the irrigated area.

Supplemental water must be applied when a plant's water use requirement (demand) exceeds the amount of water available from precipitation and irrigation (supply). Water demand by plants, known as the crop water requirement in inches, is determined by the Potential Evapotranspiration number and the Plant Water Use Coefficient.

Evapotranspiration

Evapotranspiration (ET) is a measurement of the total amount of water (inches) needed to grow vegetation. ET is the combined loss of water from the soil and other wet surfaces due to evaporation and plant transpiration (plant uptake and use of water). Each crop, plant in a landscape, or variety of turfgrass has a different water requirement, so each has its own ET number. Besides plant type, climatic factors such as temperature, wind, amount of sunlight, and humidity determine ET.

Table 8.2. Plant Water Use Coefficients (Porter, 2008).

Plant Type	Percentage
Low Water Use (Blue Grama, Desert Willow)	0.20
Medium Water Use (Buffalograss, Bermudagrass)	0.50
High Water Use (St. Augustine, Fescue)	0.75

Potential Evapotranspiration

Because there are hundreds of varieties of cultivated plants throughout the United States, a standard Potential Evapotranspiration (PET) number is available for a local area to use as a reference. A state's climatologist, Cooperative Extension Service, or other entity typically posts PET on a website.

The reference PET is calculated by measuring the water use of a 4-inch-tall, cool season grass with heavy water demands in a deep soil. Because most plants do not use as much water as the cool season grass, the reference PET then must be adjusted for the particular plant types that will be irrigated in order to best estimate water demand.

Plant Water Use Coefficient: Calculating Water Requirement

The water requirements of specific plants can be calculated as a fraction of the PET by using a plant water use coefficient (C). The coefficient varies depending on the type of plant and its stage of growth. Table 8.2 shows coefficients for different plant types. A low-water-use plant requires only 20 percent of PET, but a high-water-use plant requires 75 percent of PET. Drought-sensitive plants require approximately the total PET while drought-tolerant plants may be able to thrive on a fraction of the PET.

The PET is adjusted by being multiplied by the plant coefficient. Because water demand is estimated on a monthly basis, an average PET number for a given month should be used. Table 8.3 shows monthly PET numbers for selected Texas cities.

Table 8.3. Average Monthly Potential Evapotranspiration (PET) for selected Texas Cities (in.) (Texas ET, 2009).

City**	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Austin	2.00	2.66	4.30	5.27	7.55	8.28	8.12	8.20	6.22	4.93	3.08	2.08	62.69
Brownsville	2.57	3.18	4.53	5.31	6.88	7.31	7.59	7.33	5.98	5.16	3.40	2.42	61.66
Dallas	1.80	2.45	4.09	5.15	7.41	8.42	8.76	8.13	6.13	4.49	2.62	1.72	61.17
El Paso	1.30	1.70	4.20	5.60	8.88	9.91	9.24	8.32	7.60	5.20	3.00	1.10	66.05
Houston	2.02	2.71	4.03	5.23	7.48	8.08	7.79	7.78	6.06	4.90	3.06	2.12	61.26
Lubbock	1.20	2.10	4.60	5.40	8.37	9.23	9.06	8.26	6.60	5.00	2.30	1.00	63.12
San Antonio	2.07	2.77	4.40	5.33	7.58	8.21	7.96	8.03	6.19	4.95	3.14	2.15	62.78

**Note: Average evapotranspiration for locations near those listed or for specific time periods may vary from the averages shown

Table 8.4. Worksheet to compute monthly Plant Water Requirement for St. Augustine in Houston, Texas

	A	B	C A*B
Month	PET	Plant Water Use Coefficient	Plant Water Requirement (in.)
01	2.02	0.75	1.5
02	2.71	0.75	2.0
03	4.03	0.75	3.0
04	5.23	0.75	3.9
05	7.48	0.75	5.6
06	8.08	0.75	6.1
07	7.79	0.75	5.8
08	7.78	0.75	5.8
09	6.06	0.75	4.5
10	4.9	0.75	3.7
11	3.06	0.75	2.3
12	2.12	0.75	1.6
Annual	61.26	0.75	45.9

Plant water requirement = PET (in.) x C (plant water use coefficient)

Case Study: St. Augustine Water Requirement

The equation listed on the previous page is used to predict the inches of water needed to irrigate St. Augustine grass in Houston, Texas, on a monthly basis. The following worksheet (Table 8.4) keeps the data organized. The monthly PET data for Houston is entered in Column A and the plant water use coefficient for St. Augustine is 0.75 (Column B). Column C, Plant Water Requirement, is found by multiplying Column A (PET) by Column B (coefficient).

The plant water requirement found in column C of the worksheet is useful information and provides the depth of moisture required on a monthly basis. It does not provide the monthly demand in gallons. In order to compute monthly demand in gallons, one must consider the area that is irrigated. The calculations and worksheet are similar to estimating the catchment potential after a given rainfall depth for a catchment footprint area.

The data in the worksheet (Table 8.5) includes plant water requirement (Column A), area of lawn of turfgrass (Column B), and Conversion Factor (Column C). Multiply columns A, B, and C together to yield the monthly gallons needed to meet the water requirement of St. Augustine grass in Houston, Texas (Column D). This number does not include the consideration of monthly rainfall. The monthly demand that is to be provided by the RWH system should consider both the plant water requirement and available moisture from precipitation.

Table 8.5. Worksheet to calculate plant water requirement in gallons on a monthly basis

	A	B	C	D A*B*C
Month	Plant Water Requirement (in.)	Planted Area (ft^2)	Conversion Factor	Gallons
1	1.5	14,000	0.623	13,083
2	2.0	14,000	0.623	17,444
3	3.0	14,000	0.623	26,166
4	3.9	14,000	0.623	34,016
5	5.6	14,000	0.623	48,843
6	6.1	14,000	0.623	53,204
7	5.8	14,000	0.623	50,588
8	5.8	14,000	0.623	50,588
9	4.5	14,000	0.623	39,249
10	3.7	14,000	0.623	32,271
11	2.3	14,000	0.623	20,061
12	1.6	14,000	0.623	13,955
Annual	45.9	14,000	0.623	400,340

Case Study: Brown Family's Suburban Home

The Brown family has decided to explore the possibility of depending on rainfall to provide all of the family's water needs including drinking, irrigation, and livestock watering. The Browns live near Phoenix, Arizona. There are two adults and two children in their family. The irrigated portion of the lawn is one acre, the garden is 2,500 square feet, and two horses are kept in a small pasture.

It is determined that a per capita consumption of 70 gallons per day is a best estimate of indoor water usage. The cows drink about 25 gallons each per day. The lawn has a plant water coefficient of 0.50 and the garden is estimated at 0.75. Mr. Brown obtains the local average monthly PET amounts as shown in the worksheet (Table 8.6). The total monthly demand is shown in column M. The total annual demand is the sum of column M total at the bottom. The monthly demand for water by the Brown family ranges from 17,241 to 39,264 gallons. The annual demand is found to be 343,700 gallons.

Case Study: Bright Family's Home

The Bright family of 5 has decided to explore the possibility of depending on rainfall to provide water for toilet flushing and clothes washing in the family's new home. The Bright family is building their home near Waco, Texas. The house will be outfitted with ultralow flush toilets that have an average flushing capacity of 1.6 gallons per flush. According to Table 8.1, they need to plan for 30 flushes per day (6 flushes per person per day). The family also has a front-loading clothes washing machine that uses 25 gallons per cycle. They determined that they do more loads of laundry than most families and will assume 4 loads of laundry per week.

Mrs. Bright records the needed figures in a table to calculate the total amount of water they will demand (Table 8.7 and 8.8 at the end of this chapter). The total monthly demand for toilet flushing is shown in column E of Table 8.7 and the annual demand is the last entry. The monthly toilet flushing demand for water by the Bright family ranges from 1,344 to 1,488 gallons. The annual demand is found to be 17,520 gallons for toilet flushing. The annual demand for clothes washing is shown in column D of Table 8.8 and is 5,200 gallons per year. That brings the total annual demand for toilet flushing and clothes washing to 22,720 gallons.

Summary

Estimating demand is vital to providing a functional RWH system for a client. Indoor uses and outdoor needs vary greatly but can be evaluated with a comfortable level of accuracy. Several means exist to confirm indoor usage. Outdoor demand, such as irrigation, can be found by calculating the plant water requirement. By following a process similar to the one used in the case study of the Brown family, helpful data can be accumulated. Monthly and annual demand estimates in gallons provide meaningful information for a client/RWH planner discussion.

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Table 8.6. Worksheet of Brown family monthly demand for water

	A	B	C	D A*B	E A*C	F	G	H	I D*F*H	J E*G*H	K	L	M I+J+K+L
Month	PET	Coefficient garden plants	Coefficient lawn grass	Plant water requirement garden (in.)	Plant water requirement lawn (in.)	Area garden (ft^2)	Area lawn (ft^2)	Conversion	Garden (gal)	Lawn (gal)	Indoor use (gal)	Livestock use (gal)	Total monthly demand (gal)
1	1.1	0.8	0.2	0.9	0.2	2,500	43,560	0.623	1,371	5,970	8,400	1,500	17,241
2	1.5	0.8	0.2	1.2	0.3	2,500	43,560	0.623	1,869	8,141	8,400	1,500	19,910
3	2.2	0.8	0.2	1.8	0.4	2,500	43,560	0.623	2,741	11,941	8,400	1,500	24,582
4	2.9	0.8	0.2	2.3	0.6	2,500	43,560	0.623	3,613	15,740	8,400	1,500	29,253
5	4.1	0.8	0.2	3.3	0.8	2,500	43,560	0.623	5,109	22,253	8,400	1,500	37,262
6	4.4	0.8	0.2	3.5	0.9	2,500	43,560	0.623	5,482	23,881	8,400	1,500	39,264
7	4.3	0.8	0.2	3.4	0.9	2,500	43,560	0.623	5,358	23,339	8,400	1,500	38,596
8	4.3	0.8	0.2	3.4	0.9	2,500	43,560	0.623	5,358	23,339	8,400	1,500	38,596
9	3.3	0.8	0.2	2.6	0.7	2,500	43,560	0.623	4,112	17,911	8,400	1,500	31,923
10	2.7	0.8	0.2	2.2	0.5	2,500	43,560	0.623	3,364	14,654	8,400	1,500	27,919
11	1.7	0.8	0.2	1.4	0.3	2,500	43,560	0.623	2,118	9,227	8,400	1,500	21,245
12	1.2	0.8	0.2	1.0	0.2	2,500	43,560	0.623	1,495	6,513	8,400	1,500	17,908
Annual	33.7	0.8	0.2	27.0	6.7			0.623	41,990	182,909	100,800	18,000	343,700

Table 8.7. Bright family toilet flushing demand worksheet

	A	B	C	D	E A*B*C*D
Month	Days	People	Ultralow flush toilet (gal/flush)	Number of Flushes (flushes/person/day)	Toilet Demand (gallons)
1	31	5	1.6	6	1,488
2	28	5	1.6	6	1,344
3	31	5	1.6	6	1,488
4	30	5	1.6	6	1,440
5	31	5	1.6	6	1,488
6	30	5	1.6	6	1,440
7	31	5	1.6	6	1,488
8	31	5	1.6	6	1,488
9	30	5	1.6	6	1,440
10	31	5	1.6	6	1,488
11	30	5	1.6	6	1,440
12	31	5	1.6	6	1,488
Annual	365	5	1.6	6	17,520

Table 8.8. Bright family clothes washing demand worksheet

A	B	C	D A*B*C
Weeks	Washing Machine Demand (gallons/load)	# of Loads (loads/week)	Washing Machine Demand (gallons/year)
52	25	4	5,200

Exercises

Directions: Determine demand for a selected scenario of your choice or one provided by your instructor on a monthly and annual basis. Use the chapter and the following steps as a guideline.

Steps – Indoor Demand:
1. Determine number of people who use/live in the house.
2. Identify all demand i.e. drinking, clothes washing, toilets, etc…
3. Refer to EPA or other dependable sources to determine daily water use on a per capita basis.
4. Estimate monthly and yearly indoor demand of water in gallons.

Steps – Outdoor Demand:
1. Identify all water uses i.e. livestock watering, raingarden, plant container watering, irrigation, etc….
2. Estimate monthly and yearly outdoor demand of water in gallons.

Steps – Overall Demand:
1. Combine indoor and outdoor demand.
2. Organize data on monthly and yearly basis.
3. Identify low and high months for demand
4. Identify patterns in the data.
5. Identify highest 4 months.
6. Identify lowest 4 months.

Rainwater Harvesting:
System Planning

9. Equilibrium for Supply and Demand:
Sizing Storage Capacity

The goal of this chapter is to engage the RWH system planner in the process of comparing supply to demand in order to determine practical RWH system performance levels in order to size storage capacity. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Describe the concept of equilibrium for a RWH system.
2. Assimilate supply and demand data in a spreadsheet.
3. Utilize spreadsheets to calculate monthly demand, supply, and surplus.
4. Plot (graph) supply and demand curves.
5. Interpret surplus from worksheet and graphs.
6. Devise multiple year demand and supply worksheets.
7. Determine level of risk of inadequate supply.
8. Explain level of risk of inadequate supply to client.
9. Size storage capacity to meet risk level of a client.

Contents

9. Equilibrium for Supply and Demand: Sizing Storage Capacity

Introduction

Basic economic theorists present the idea that the equilibrium price for a product is determined when product supply equals product demand. The idea is similar for a RWH planner who is attempting to size storage capacity and determine surplus in order to provide an adequate and dependable supply of water to meet the demand needs of the customer.

Supply and demand must be compared to best determine storage capacity, surplus, and level of storage. In previous chapters, monthly supply and demand was estimated. The following scenario with accompanying worksheets and graphs is presented to compare demand to supply.

Case Study: 2,100-Square-Foot Home in Topeka, Kansas

A couple with two children live in Topeka, Kansas, and have asked a local RWH planner to estimate the potential rainwater supply and current water demand for their home and large barn.

They plan to irrigate a sizeable garden and attract wild birds with a bubbler in the birdbath. The couple would also like to discontinue using utility water and sanitize a portion of the rainwater for indoor uses such as drinking, bathing, and washing laundry.

Introducing Worksheets, Graphs, and Tabular Data

Table 9.1 on the following page shows the demand/supply with a year one projection of balance in final column (E). Using the per capita 70 gallons per day number with 4 people, the monthly indoor use was found to be 6,300 gallons (Column A).

Monthly outdoor demand ranged from 100 gallons during winter months to as much as 1,700 gallons during a summer month (Column B). Total demand and supply are found in Columns C and D respectively. Column

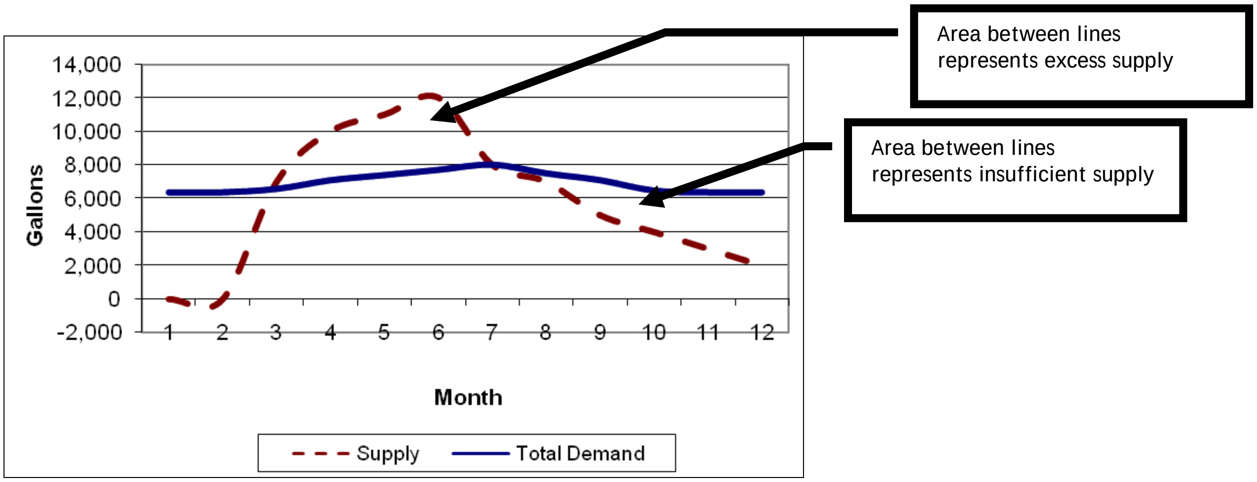
E shows the results of comparing monthly supply to demand and demonstrates insufficient supply 7 out of 12 months.

A review of the annual supply versus demand shows a deficit of 16,500 gallons. Although this formula provides a rough estimate that might be adequate to initiate a discussion with a client, a more comprehensive approach is necessary. In some instances, a client may be overwhelmed or uncomfortable with the idea of reading and interpreting the data in columns C, D, and E in the previous worksheet. For some clients, a graph or plot of the data may be a more effective means of conveying information and evaluating the data. A spreadsheet program, like Excel, provides a means for graphing tabular data and an easy to follow tutorial with step-by-step instructions for those unfamiliar with graphing data.

In this example, the monthly demand and supply data from the worksheet (columns C and D) are graphed in Figure 9.1. The x-axis or bottom scale is the months of the year. The y-axis or scale on the left side is in gallons. December through February are shown as months with zero supply due to the fact that the precipitation will likely be frozen and not effectively collected.

Table 9.1. Supply and demand for 2,100 square foot home in Topeka, Kansas

	A	B	C	D	E
Month	Indoor demand (gal)	Outdoor demand (gal)	Total demand (gal)	Supply (gal)	Year one (gal)
1	6,300	100	6,400	0	-6,400
2	6,300	100	6,400	0	-6400
3	6,300	300	6,600	7,000	400
4	6,300	800	7,100	10,000	2,900
5	6,300	1,100	7,400	11,000	3,600
6	6,300	1,400	7,700	12000	4,300
7	6,300	1,700	8,000	8,000	0
8	6,300	1,200	7,500	7,000	-500
9	6,300	800	7,100	5,000	-2,100
10	6,300	200	6,500	4,000	-2,500
11	6,300	100	6,400	3,000	-3,400
12	6,300	100	6,400	0	-6,400
Annual	75,600	7,900	83,500	67,000	-16,500



Area between lines represents excess supply

Area between lines represents insufficient supply

Figure 9.1. Supply and demand of original scenario for 2,100 square foot home in Topeka, Kansas

The legend identifies the curves by description and assigns a line type. The dashed line shows the supply and the solid line represents the total demand on a monthly basis. The supply for June is 12,000 gallons while the demand for June is only 7,700 gallons.

The area above the solid line and below the dashed line (March through July) represents an excess supply. Insufficient supply can be found when the dashed line falls below the solid line. Such is the case for the months of January, February, and August to December.

The shape of each curve also provides some insights to the amount of change in monthly demand and supply. In this case, the demand is rather flat when compared to the up and down curve of supply. In other words, demand is constant and supply is changing each month. Storage capacity has a major impact on supply and results in a flattening of the supply curve.

Impact of Decreasing Demand and Unlimited Storage

Suppose that the couple determines through meter readings that the indoor demand is only 3,150 gallons per month. In table 9.2, a review of the new monthly data in column E (year one) now shows a supply deficit during only four out of the twelve months and an annual surplus of 21,300 gallons.

Assuming that the entire surplus could be stored, columns F and G indicate that during subsequent years two and three there is ample water each month (Table 9.2). A RWH planner might use these findings to show the couple that with ample storage capacity, their demand can be met with the available supply of rainwater.

Figure 9.2 graphs the demand (Column C) and supply (Column D) from the previous worksheet shows excess supply. The demand curve has shifted farther down and more of the solid line is under the dashed line.

Although the idea of unlimited storage and surplus is impractical, the data and graph easily convey the idea that supply water is plentiful. Considering storage capacity is the next step in the planning process.

As a starting point for calculations, a RWH planner should provide at least enough storage capacity equal to the sum of the 4 highest demand months.

Impact of 8,000-Gallon Storage Capacity

From the results, it is obvious that there is plenty of water, when stored, to supply the family's needs. The following worksheet data results from assuming that an 8,000-gallon capacity tank is used to store water (Table 9.3).

Year two begins with a surplus of 8,000 gallons, a full tank. However, during year three, a deficit of water occurs in January that is not apparent in year two. Graphing the results (Figure 9.3) shows both the supply and the storage amount falling below demand. The year three results will repeat if additional columns are added to the spreadsheet. The 2,000-gallon deficit could be overcome with a 10,000-gallon capacity tank, but in the event of lower than average rainfall, the family might run out of water.

Again, the data in the worksheet shows the inadequate supply, but a graph conveys this idea more easily. The dotted line represents the storage level and is mostly above the solid line of demand. Obviously, the storage is inadequate for January through March.

Storage Capacity and Risk

To minimize the risk of inadequate supply due to long dry periods or over use, a RWH planner should provide at least enough storage capacity equal to the sum of the four highest demand months**.** However, this is only a recommended starting point for calculations. Local environmental patterns and conditions may warrant a different storage capacity.

Access to back up supplies of water can also lessen the needed storage capacity.

In this scenario, the total of the four highest demand months is 18,000 gallons (Table 9.4). Review of available supply and surplus ensures that an 18,000-gallon capacity tank would eventually fill and provide a safeguard during a lower than average rain event. Table 9.4 and Figure 9.4 show the results. In Figure 9.3, the curves for supply and year one and two are not plotted. The simplified graph of year three supply and demand illustrates the cushion of supply due to storage even during the months of January and February. For most months, there are 10,000 gallons or more of water stored.

Table 9.2 Supply and demand with decreased demand and unlimited storage for 2,100 square foot home in Topeka, Kansas

	A	B	C	D	E	F	G
Month	Indoor Demand (gal)	Outdoor Demand (gal)	Total Demand (gal)	Supply (gal)	Year One (gal)	Year Two (gal)	Year Three (gal)
					surplus 0	surplus 21,300	surplus 42,600
1	3,150	100	3,250	0	-3,250	18,050	39,350
2	3,150	100	3,250	0	-3,250	14,800	36,100
3	3,150	300	3,450	7,000	3,550	18,350	39,650
4	3,150	800	3,950	10,000	6,050	24,400	45,700
5	3,150	1,100	4,250	11,000	6,750	31,150	52,450
6	3,150	1,400	4,550	12,000	7,450	38,600	59,900
7	3,150	1,700	4,850	8,000	3,150	41,750	63,050
8	3,150	1,200	4,350	7,000	2,650	44,400	65,700
9	3,150	800	3,950	5,000	1,050	45,450	66,750
10	3,150	200	3,350	4,000	650	46,100	67,400
11	3,150	100	3,250	3,000	-250	45,850	67,150
12	3,150	100	3,250	0	-3,250	42,600	63,900
Annual	37,800	7,900	45,700	67,000	21,300		

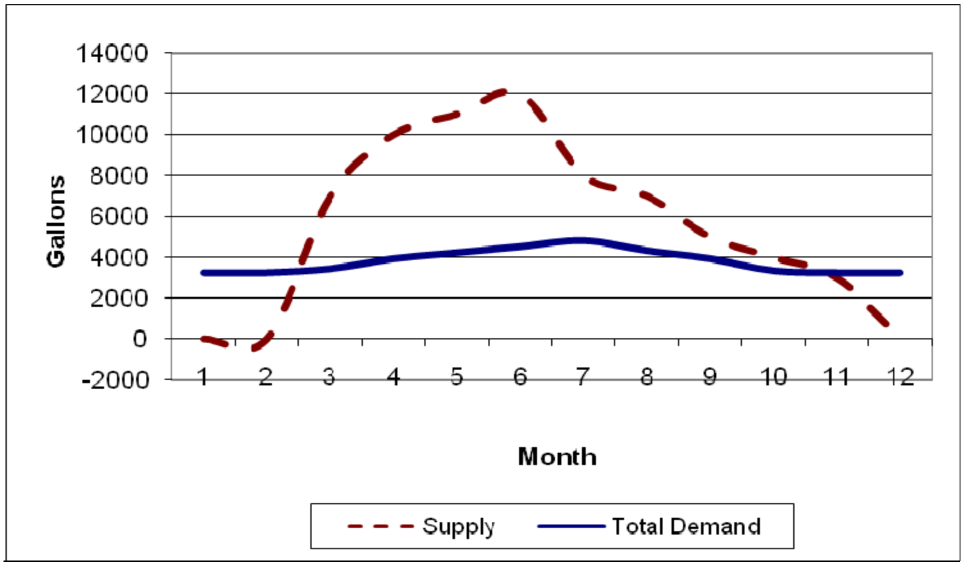


Figure 9.2. Supply and demand after decrease in demand for 2,100 square foot home in Topeka, Kansas.

Table 9.3. Supply and demand with 8,000-gallon storage capacity for 2,100 square foot home in Topeka, Kansas.

	A	B	C	D	E	F	G
Month	Indoor Demand (gal)	Outdoor Demand (gal)	Total Demand (gal)	Supply (gal)	Year One (gal)	Year Two (gal)	Year Three (gal)
					surplus 0	surplus 8,000	surplus 4,500
1	3,150	100	3,250	0	-3,250	4,750	1,250
2	3,150	100	3,250	0	-3,250	1,500	-2,000
3	3,150	300	3,450	7,000	3,550	5,050	1,550
4	3,150	800	3,950	10,000	6,050	8,000	7,600
5	3,150	1,100	4,250	11,000	6,750	8,000	8,000
6	3,150	1,400	4,550	12,000	7,450	8,000	8,000
7	3,150	1,700	4,850	8,000	3,150	8,000	8,000
8	3,150	1,200	4,350	7,000	2,650	8,000	8,000
9	3,150	800	3,950	5,000	1,050	8,000	8,000
10	3,150	200	3,350	4,000	650	8,000	8,000
11	3,150	100	3,250	3,000	-250	7,750	7,750
12	3,150	100	3,250	0	-3,250	4,500	4,500
Annual	37,800	7,900	45,700	67,000	21,300		

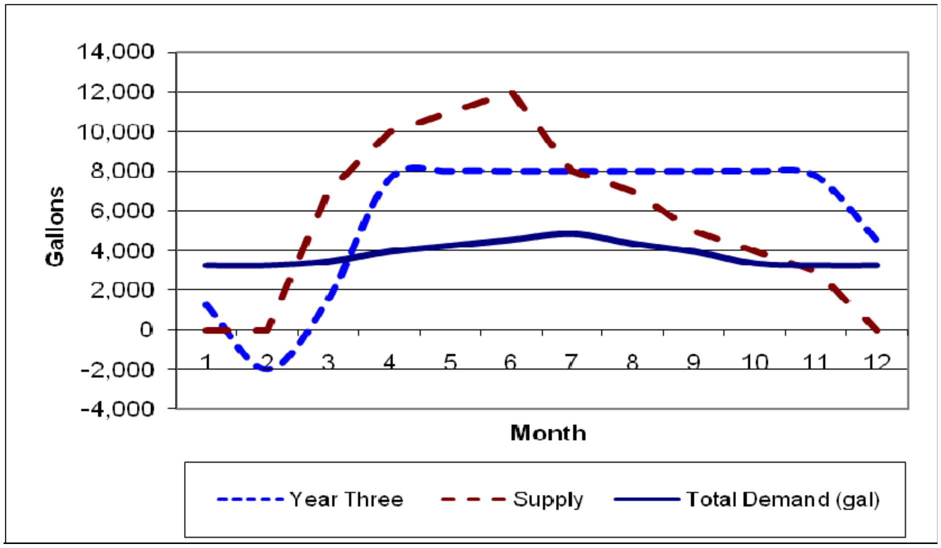


Figure 9.3. Supply, demand, and storage volume during year three for 2,100 square foot home in Topeka, Kansas.

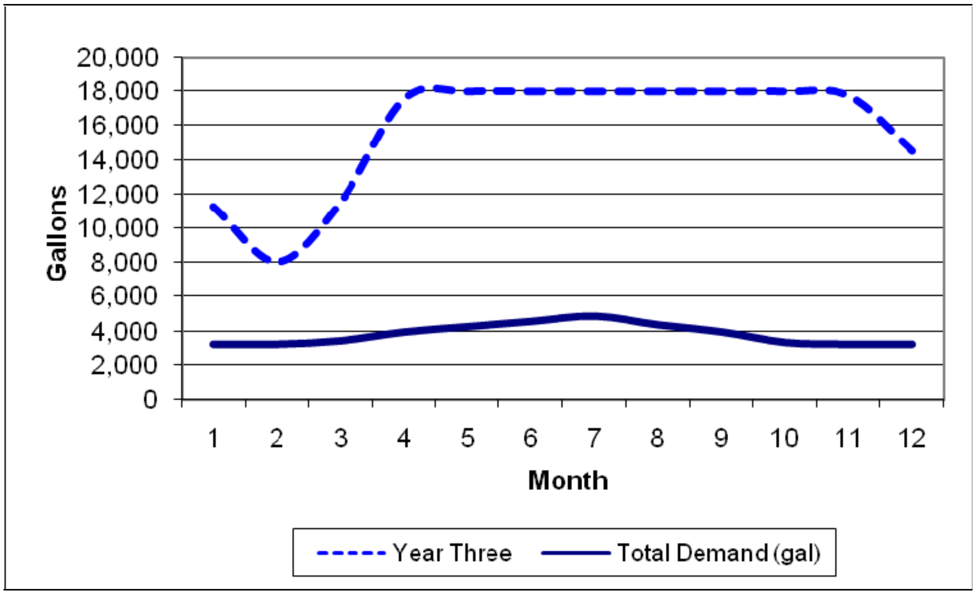


Figure 9.4. Supply and demand volumes of year three for 2,100 square foot home in Topeka, Kansas.

Table 9.4 Supply and demand with 18,000-gallon storage capacity for 2,100 square foot home in Topeka, Kansas

	A	B	C	D	E	F	G
Month	Indoor Demand (gal)	Outdoor Demand (gal)	Total Demand (gal)	Supply (gal)	Year One (gal)	Year Two (gal)	Year Three (gal)
					surplus 0	surplus 18,000	surplus 14,500
1	3,150	100	3,250	0	-3,250	14,750	11,250
2	3,150	100	3,250	0	-3,250	11,500	8,000
3	3,150	300	3,450	7,000	3,550	15,050	11,550
4	3,150	800	3,950	10,000	6,050	18,000	17,600
5	3,150	1,100	4,250	11,000	6,750	18,000	18,000
6	3,150	1,400	4,550	12,000	7,450	18,000	18,000
7	3,150	1,700	4,850	8,000	3,150	18,000	18,000
8	3,150	1,200	4,350	7,000	2,650	18,000	18,000
9	3,150	800	3,950	5,000	1,050	18,000	18,000
10	3,150	200	3,350	4,000	650	18,000	18,000
11	3,150	100	3,250	3,000	-250	17,750	17,750
12	3,150	100	3,250	0	-3,250	14,500	14,500
Annual	37,800	7,900	45,700	69,000	21,300		

Summary

The previous spreadsheets exhibit trends in rainfall supply and distribution demand that might not otherwise be seen or predicted during a more simple review and discussion with a customer. It is recommended that a RWH planner estimate supply and demand for at least a three-year interval in order to identify all trends and especially an interval of insufficient supply.

The process to compare supply to demand is tedious, but it is a necessary responsibility of the RWH planner. The reward for determining insufficient supply and residual is being able to ensure a manageable level of risk that meets a client's expectations. Costs are lowest as a result of choosing proper storage capacity.

Exercises – Comparing supply to demand and estimating storage capacity

In previous exercises from the supply and demand chapters, participants completed estimations on a monthly basis. Let's compare your finings with the intent to determine storage capacity.

1) Fill in the chart to show supply and demand in gallons.

Month	Total Demand (gal)	Total Supply (gal)	Balance
Jan			
Feb			
Mar			
Apr			
May			
Jun			
Jul			
Aug			
Sep			
Oct			
Nov			
Dec			
Annual			

2) Determine difference(s) between Supply and Demand on a monthly basis. Extra supply should be indicated as a positive balance. Indicate negative balance (insufficient amount of water) by placing parentheses around the gallons in the "Balance" column.

3) What month, if any, is the largest deficit?

4) How many gallons is the highest negative balance?

5) Determine how much storage is required to meet/exceed demand.
    a. Choose storage amount
    b. Look at end of year surplus
    c. Expand worksheet to included 3 or more years
    d. Adjust storage until desired supply is maintained

Rainwater Harvesting:
System Planning

10. Roofing, Gutters, and Downspouts

The goal of this chapter is to engage the RWH system planner in the process of choosing a roofing material as well as, modifying, and installing gutters and downspouts. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Choose appropriate roofing material for rainwater collection.
2. Describe function of a gutter, downspout and conveyance piping in a RWH system.
3. Consider aesthetic desires of customer regarding gutters and downspouts.
4. Label major components of a gutter.
5. Evaluate existing gutter and downspout for use with proposed RWH system.
6. Utilize the Uniform Plumbing Code to size gutters and downspouts based on roof area and rainfall intensity.
7. Install gutters and downspouts.
8. Identify a flow reducing transition in a gutter/downspout system.
9. Recognize an unsightly gutter and downspout piping or transition.

Contents

10. Roofing, Gutters, and Downspouts

Introduction

Roofing and catchment surface materials must be carefully chosen based on the desired use of the water. Gutters and downspouts are used to convey water from an elevated catchment area like a roof to a storage container in a RWH system. Gutters are installed horizontally and can be level or slightly sloped, which is recommended in order to increase water flow. Downspouts are attached to gutters which then convey runoff from the top of a structure to the ground level or into a storm drainage system. Gutter and downspout systems may be installed or retrofitted to accommodate the needs of a RWH system.

Roofing, gutters, and downspouts should be smooth, the correct size, durable, attractive, and well suited for the buildings on which they are used. Besides the Uniform Plumbing Code (UPC), local building codes often specify gutter sizing and installation requirements. Special considerations such as rainfall, snow loading, aesthetics, and roof construction materials may be addressed in local codes. One should consult a company representative specializing in gutter and downspout design and installation for product advice.

Roofing Selection and Catchment Surface Materials

For non-potable water systems, almost any hard or impervious roof surface material may be utilized to collect water. RWH systems designed for indoor use should be able to remove unwanted foreign material that could be present in water collected from parking areas, locations with excessive overhanging vegetation, and areas adjacent to sources of airborne pollution. Catchment systems that collect water for human drinking should be made of non-toxic materials.

For non-potable water systems, almost any hard or impervious surface material may be utilized to collect water.

Choose RWH system components wisely. Some materials may leach harmful chemicals and substances into the collected water. Wood or cedar shake roofing may retain moisture between rainfall events allowing for biological growth.

NSF International has approved certain coating to be applied to catchment surfaces designed for potable systems. This list can be found at the NSF International website under Protocol P151, "Health Effects from Rainwater Catchment System Components."

When potable water is desired, slick catchment surfaces should be used as this will decrease the amount of dust and other airborne pollutants that could stick to the surface. The slick surface also aids in the natural cleaning of the surface during the initial rainfall.

It is important that the selected roof design does not allow water to pool for prolonged periods of time. Ideally, the surface should dry quickly and completely after rainfall events. Limiting standing water or wet spots on catchment surfaces decreases opportunity for biological growth that can degrade the water quality.

Gutter and Downspout Selection and Installation

There are some general guidelines (Porter, 2008) for selecting and installing gutters and downspouts for a RWH system. In some cases, a RWH planner prefers to minimize the number of downspouts to facilitate water conveyance, which is adequate so long as the gutter is large enough to accommodate the higher flow rate.

RWH systems that supply water for drinking should not utilize gutters or downspouts made of zinc, copper, or organic materials such as wood or bamboo. If copper is used, it should be painted on the inside with NSF-approved paint. General guidelines for selecting and installing gutters include:

- Select gutters at least 5 inches wide.
- Select gutters made from galvanized steel (29-gauge minimum) or aluminum (.025-inch minimum).
- Rounded-bottom gutters are preferred to decrease debris buildup
- Slope sectional gutters $^{1}/_{16}$-inch per 1 foot of gutter to enhance flow.
- Slope seamless gutters $^{1}/_{16}$-inch per 10 feet (Figure 10.1).
- Use expansion joints at connections for straight runs exceeding 40 feet.
- Keep the front of the gutter ½-inch lower than the back (Figure 10.2)
- Provide gutter hangers at least every 3 feet (every foot in areas of heavy snow load) (Figure 10.3).
- Utilize external gutter hangers where possible.
- Select elbows with 45-, 60-, 75-, or 90-degree angles, as needed.

When sizing gutters and downspouts it is recommended to follow the Uniform Plumbing Code unless local rules and regulations specify otherwise.

Sizing Gutters and Downspouts

Sizing gutters and downspouts is critical for the efficient conveyance of water and minimizing losses. When sizing gutters and downspouts it is recommended to follow the Uniform Plumbing Code unless local rules and regulations specify otherwise. The UPC requires that gutters and downspouts be sized for a specific location to accommodate a 60-minute duration storm with a return period of 100 years (Table C.6).

RWH planner should also refer to local rainfall data or construction codes to determine if a rainfall intensity number (Table C.6) other than what appears in the UPC should be used. Conferring with reputable gutter and downspout installers about a given area would also help in determining an appropriate rainfall intensity number.

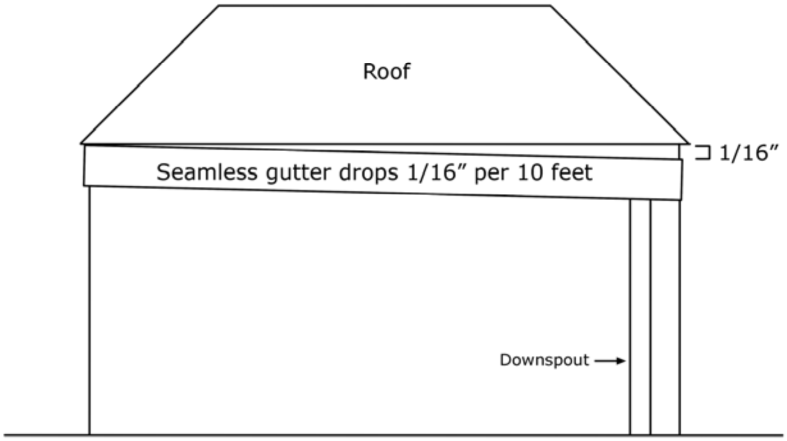


Figure 10.1. Diagram of seamless gutter sloping 1/16” per 10 ft.

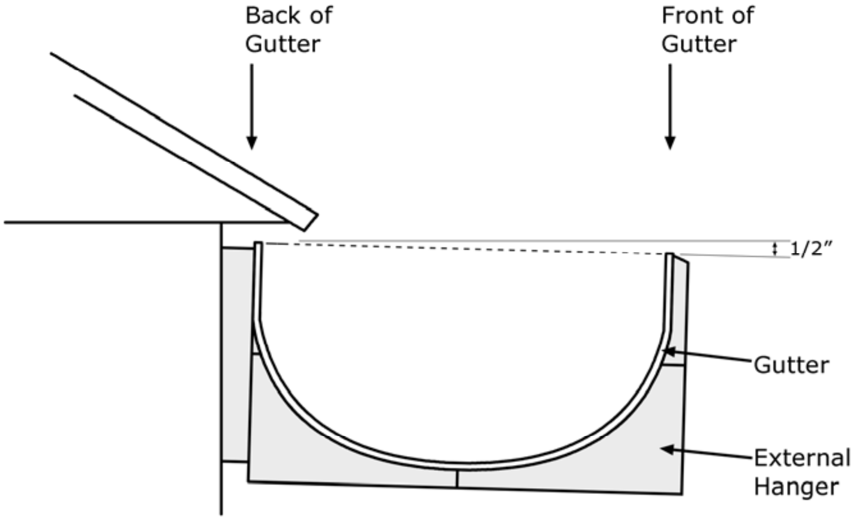


Figure 10.2. General gutter design and details.

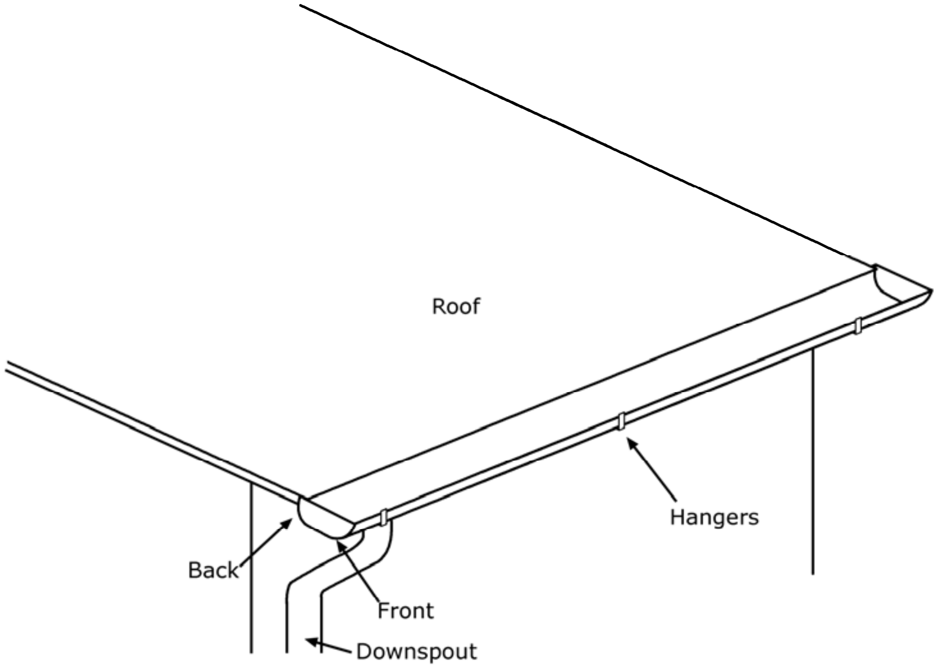


Figure 10.3. External gutter hanger configuration.

Steps to Sizing a Gutter

For gutters, refer to Table 10.1 to compare rainfall intensity (iph), slope of the gutter (inches per foot), and maximum allowable roof area (square feet) to determine gutter size in inches.

Notice that increasing the slope of a gutter increases the area that it serves. In fact, gutters with a slope of 1/2-inch per foot can serve an area almost 3 times as large as a gutter with a slope of 1/16-inch per foot.

Gutters with a slope of 1/2-inch per foot can serve an area almost 3 times as large as a gutter with a slope of 1/16-inch per foot.

The following steps describe the process of sizing a gutter.

1. Determine rainfall intensity number for 60 minutes, 100 year return period for location of catchment area from Table C.6.
2. Calculate catchment footprint (area in square feet).
3. Determine gutter size by using slope, rainfall intensity, and maximum area (Refer to Table 10.1).
4. Compare slopes of gutters and areas to adjust size of gutter if desired.
5. Check size against previously discussed general guidelines for gutters.

Table 10.1. Sizing of gutters (IAPMO, 2000)

Slope of Gutter	Diameter of Gutter	Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates				
	inches	2"/Hr	3"/Hr	4"/Hr	5"/Hr	6"/Hr
1/8"/ft. Slope	3	480	320	240	192	160
	4	1020	681	510	408	340
	5	1760	1172	880	704	587
	6	2720	1815	1360	1085	905
	7	3900	2600	1950	1560	1300
	8	5600	3740	2800	2240	1870
	10	10200	6800	5100	4080	3400
1/4"/ft. Slope	3	680	454	340	272	226
	4	1440	960	720	576	480
	5	2500	1668	1250	1000	834
	6	3840	2560	1920	1536	1280
	7	5520	3680	2760	2205	1840
	8	7960	5310	3980	3180	2655
	10	14400	9600	7200	5750	4800
1/2"/ft. Slope	3	960	640	480	384	320
	4	2040	1360	1020	816	680
	5	3540	2360	1770	1415	1180
	6	5540	3695	2770	2220	1850
	7	7800	5200	3900	3120	2600
	8	11200	7460	5600	4480	3730
	10	20000	13330	10000	8000	6660

Steps to Sizing a Downspout

For downspouts, refer to vertical piping in Table 10.2 to compare rainfall intensity and maximum roof area to determine the sizing. In most instances, the maximum roof area served by a downspout is much less than the total area of a large catchment.

This requires the planner to conceptually divide the roof into smaller areas and utilize more than one downspout. This can be done by dividing the total catchment area by the given maximum roof area for each downspout.

If the use of small downspouts is preferred, the number of downspouts required can be found by choosing the desired size and dividing the related maximum area into the total catchment area. The following steps describe the process of sizing a downspout:

1. Determine rainfall intensity for 60 minutes, 100 year return period for location of catchment area from Table C.6.
2. Calculate catchment footprint (area in square feet).

3. Determine downspout size by using rainfall intensity and maximum area (Refer to Table 10.2). If maximum area is smaller than catchment area, then multiple downspouts will be necessary.
4. Check size against previously discussed general guidelines for downspouts.
5.

Table 10.2. Sizing Roof Drain, Leaders, and Vertical Rainwater Piping (IAPMO, 2000)

Drain, Leader, or Pipe Size	Flow	Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates					
Inches	gpm	1"/Hr	2"/Hr	3"/Hr	4"/Hr	5"/Hr	6"/Hr
2	23	2176	1088	725	544	435	363
3	67	6440	3220	2147	1610	1288	1073
4	144	13840	6920	4613	3460	2768	2307
5	261	25120	12560	8373	6280	5024	4187
6	424	40800	20400	13600	10200	8160	6800
8	913	88000	44000	29333	22000	17600	14667
Millimeters	L/S	25mm/Hr	50mm/Hr	75mm/Hr	100mm/Hr	125mm/Hr	150mm/Hr
50	1.5	202	101	67	51	40	34
80	4.2	600	300	200	150	120	100
100	9.1	1286	643	429	321	257	214
125	16.5	2334	1117	778	583	467	389
150	26.8	3790	1895	1263	948	758	632
200	57.6	8175	4088	2725	2044	1635	1363

Notes: 1. The sizing data for vertical conductors, leaders, and drains is based on the pipes flowing 7/24 full. 2.For rainfall rates not listed, determine the allowable roof area by dividing the area given in the 1 inch/hour (25 mm/hour) column by the desired rainfall rate. 3. Vertical piping may be round, square, or rectangular. Square pipe shall be sized to enclose its equivalent round pipe. Rectangular pipe shall have at least the same cross-sectional area as its equivalent round pipe, except that the ratio of its side dimensions shall not exceed 3 to 1.

Case Study: Monosloped Roof

Frank has a 60-foot-long and 20-foot-wide rectangular barn with a metal roof that he would like to utilize as a catchment for his RWH system. His preference is to minimize the number of downspouts to save money and utilize a single storage container. The barn is located near Memphis, Tennessee, has a catchment footprint of 1,200 square feet, and a monosloped roof. Because of the monosloped roof, all of the runoff water drains toward one of the long sides and allows Frank to utilize one gutter. The following picture is an example of a monosloped roof (Figure 10.4).

Figure 10.4. A monosloped catchment roof acts as the catchment area for the storage tank.

Sizing Gutter

1. Rainfall Intensity Table C.6 = 3.5 iph, rounded to 4 iph.
2. Catchment Footprint = 1,200 ft^2.
3. Gutter Size (Table 10.1) = 7-in. gutter at 1/8-in. per foot of slope.
4. Checked OK against guidelines.

Sizing Downspout

1. Rainfall Intensity Table C.6 = 3.5 iph, rounded to 4 iph.
2. Catchment Footprint = 1,200 ft^2.
3. Downspout Size (Table 10.2) = 3-in. downspout (only one).
4. Checked against guidelines: 3-in. diameter round or a 3x3-in. square downspout does not agree with guideline (Provide 1 square inch of downspout area for every 100 square feet of roof area). Therefore, increase downspout to a 4-in. pipe or use rectangular downspout with dimensions 3 x 4 in.

Aesthetics and Gutter to Downspout Transitions

Many efforts have been made by RWH entrepreneurs and installers to hide unsightly pipes and downspouts as seen in Figure 10.5. Similarly, installers should consider the client's desires to keep a tidy look to their home or business.

Transitions that reduce flow rates may cause debris hang-ups and clogging (Figure 10.6). Connect to a buried conveyance system above the soil with a water tight transition, eliminating the possibility of intrusion of vermin, insects, and foreign material. Figure 10.7 shows a transition that allows puddle-surface water or insects to easily enter the RWH system.

Figure 10.5. A downspout transition is covered by an aesthetically appealing design made to look like a fish.

Figure 10.6. The transition in the downspout to conveyance piping is causing a reduction in flow.

Figure 10.7 A ground-level transition facilitates contamination from surface runoff.

General guidelines for selecting and installing downspouts include:

- PVC pipe can be utilized for downspouts and painted with a primer and latex paint.
- Space downspouts from 20 to 50 feet apart.
- Provide 1-square-inch of downspout area for every 100-square-feet of roof area. (A 2-inch-by-3-inch downspout accommodates 600 to 700 square feet; a 3-inch-by-4-inch downspout accommodates up to 1,200 square feet.)
- When possible use 45-degree angle bends.
- Select downspout configuration (square, round, or corrugated round) depending on your needs.
- Size pipe diameter to convey water to storage containers or filters based on square foot of catchment area.

Summary

Proper sizing and installation of gutters and downspouts is crucial for the efficient conveyance of water from the catchment area to the storage container. The UPC provides tables (Appendix C) with gutter and downspout specifications when considering catchment footprint area and rainfall intensity. Gutter material, shape, and slope directly impact performance and affect water quality. Flow restricting transitions should be avoided along with ground-level pipe connections that may allow entry of contaminants. The aesthetic impact of gutters and downspouts should always be considered.

In many cases, gutters are not sloped at all. In the event that this type of system is being renovated to supply a rainwater harvesting system, gutters should be inspected for standing water and debris. More downspouts may need to be added to manage the desired water flows. This type of set-up will also require more maintenance and cleaning.

References

IAPMO. 2000. Uniform Plumbing Code 2000. The International Association of Plumbing and Mechanical Codes (IAPMO). Los Angeles, CA.

Porter, D.O., R.A.Persyn, V.A. Silvy. 2008. Rainwater Harvesting. Texas AgriLife Extension Service, Fact Sheet number B-6153. May 2008.

Exercises

Directions: Use Table 10.1 and Table C.6 to answer the following questions. The UPC or other reliable data sources may be used.

1. What is the rainfall intensity (iph) and gallons per square foot of catchment footprint for the following locations with the occurrence of a 60-minute storm with a return period of 100 years for the following locations?

    a. Flagstaff, AZ ______ iph ________ gpm/square foot
    b. Omaha, NE ______ iph ________ gpm/square foot
    c. Palm Beach, FL ______ iph ________ gpm/square foot

2. Gary, a homeowner in Omaha, NE, has a 2,400 square foot catchment footprint. What size gutter and downspout(s) should he plan? How many downspouts will be necessary?

    a. Gutter size _________ inches
    b. Downspout size _________ inches
    c. No. of downspouts ________

Rainwater Harvesting:
System Planning

11. Debris Filtering and Removal

The goal of this chapter is to engage the RWH system planner in the process of choosing efficient debris removal devises. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Choose appropriate debris removal device.
2. Discuss downspout screen issues such as accessibility and maintenance.
3. Differentiate between functions of roof washers and first flush diverters.
4. Determine first flush capacity.
5. Determine first flush diverter configuration.
6. Provide client with realistic expectations for debris removal and first flush devices.

Contents

11. Debris Filtering and Removal

Introduction

Animal remains, rodent feces, dust, leaves, sticks, and other debris have a history of finding their way from the catchment area into rain storage devices. During a rainfall event, especially the initial downpour, most debris can be prevented from entering the RWH system by the use of screens, pre-filters, coarse filters, settling devices, roof washers, and first-flush diverters.

Preventing contamination is a high priority and is less costly than removing debris from storage tanks or the distribution system with manual labor or expensive filters. The best strategy consists of multiple levels of prevention and should include first removing large items like leaves and sticks, then addressing dust and sediment and other contaminants later in the treatment train.

Preventing contamination is a high priority and is less costly than removing debris from storage tanks or the distribution system with manual labor or expensive filters.

The type and quantity of debris is site-specific and directly related to environmental factors encompassing the catchment area. No available retail device appears to be fool-proof in all applications, but the following devices or more primitive versions have been used in the past and demonstrated positive results in helping to provide clean, safe water.

Each device and method has both its strengths and weaknesses. As the RWH planner, it is your responsibility to know how the techniques work and where they are most effective.

Gutter Debris Screens

Gutters are great at catching leaves, twigs, water, and other contaminants (Figure 11.1). Gutter leaf screens, leaf guards, and mesh gutter covers are the initial protection device for the RWH system when a roof catchment system is utilized. Many products exist that attach to gutters that shed leaves and twigs during rainfall. Regular maintenance is required, especially when overhanging branches are present.

Figure 11.1. Gutters catch leaves, twigs, and other contaminants that will restrict and decrease flow of water.

Screens should be easily removable for cleaning as part of regular maintenance. Some RWH planners/ trim or remove trees to minimize contamination. Self-cleaning gutter guards and screens that require less frequent maintenance are helpful in minimizing the opportunity for injury to individuals who remove debris and foreign matter from gutters.

Some RWH planners/installers trim or remove trees to minimize foreign material. Due to the threat of falling from a ladder and electrocution from low hanging wires, self cleaning gutter guards or screens are useful.

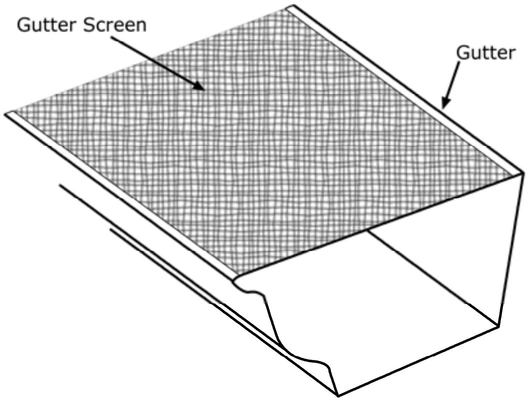


Figure 11.2. Gutter screen installed on a gutter.

Downspout Debris Screens and Filters

There are several devices available on the market that block large debris just prior to entering or exiting the downspout (Figure 11.3). All of these devices require periodic maintenance and cleaning.

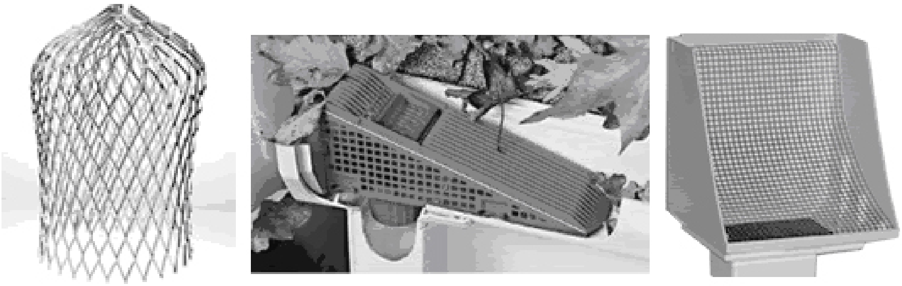


Figure 11.3. Several common downspout screens.

A downside to this style of screen is that they are located at roof level, requiring system owners and operators to climb a ladder. Strainers can be positioned near the outlet of a downspout to facilitate easier observation and frequent clearing.

Other devices filter the water as it passes through the downspout (Figure 11.4).

Figure 11.4. Cutaway view of a downspout filter. (Source: WISY AG, Germany)

Diverters, First Flush Mechanisms, and Roof Washers

Knowing that constituents have the possibility of being present in the collected rainwater leads to the task of addressing the concern. Kim et al. (2005) and Coombes et al. (2000) stated that the initial periods of runoff from a rainwater catchment contain the highest levels of contamination due to constituents being washed off of the roof surfaces. Due to the fact that the initial periods contain the highest levels of contamination, diverting this water can reduce the concentration of contaminants in the storage component of rainwater harvesting systems. Massey University, home to the Rooftop Water Research Center, has found that there is an increased quality of water in water tanks that utilize first flush diverters (Abbot et al., 2006). Abbot et al. (2006) utilized a first flush diverter that employed a floating ball as a barrier to prevent the diverted water from continuing to flow through the collection system.

First Flush Diversion Volume

Recommendations for optimal volumes of first flush water to be diverted vary greatly. The goal for many of the diversion volumes is to divert enough water to effectively reduce contaminant loading without substantially decreasing stored water volumes. Based on current literature there are many suggestions and recommendations to properly size the volume of first flush diverters (Table 11.1).

Table 11.1. Various recommended first flush diversion volumes for rainwater harvesting systems.

First flush volume (in gal on inches of rainfall)	Target criteria	Source
0.01 in	"typical household"	Jenkins and Pearson, 1978
0.016-0.031 in	1076 ft^2	Krishna, 2005
6.6 gal	"average size roof"	Cunliffe, 2004
5.3-6.6 gal	-	WHO, 2004
0.08 in	1076 ft^2	Wade, 2003
1.3 gal	-	Yaziz et al., 1989
0.02-0.04 in	-	Gardner et al., 2004
0.14-0.33 in	based on target turbidities	Martinson and Thomas, 2004
0.002-0.03 in	per 1000 ft^2 based on contamination level	ARCSA, 2009

Many of the recommended diversion volumes are based on rules of thumb due to the fact that contaminant loading to a rainwater harvesting system varies based on rainfall characteristics, debris characteristics, catchment location, number of dry days, catchment area, slope, and material, as well as other site specific variables (Krishna, 2005). Evans et al. (2006) concluded that local weather and environmental conditions highly influence microbial loading and profiles to rooftop collection systems. Abbot et al. (2006) also found that bacterial loading was influenced by the orientation of catchment surfaces to prevailing winds. Evans et al. (2006) and Abbot et al. (2006) are in agreement that bacterial loading on catchment surfaces facing prevailing winds were increased. Each location is site-specific and preventing contamination by diverting rainwater should be discussed with the client so expectations can be realized.

Factors that influence the amount to divert include:

- More diversion is needed with composition roofing; less is needed with metal roofing.
- More diversion is needed if there are trees, overhanging wires, or potential sources of debris on the roof.
- More diversion is needed when there is smog and pollution from the prevailing wind.
- Less diversion is needed with steeper roofs that wash debris more quickly.

While contaminant concentrations have been found to be reduced by first flush diverters, it is known that microbial contaminants still pass through to the storage component in concentrations that are not considered safe for potable use (Ruskin, 1990 and Lye, 1991).

Downspout First Flush Diverter Configurations

The types of first flush diverters utilized throughout the world vary greatly. First flush diverters are commercially available, but first flush diverters are commonly constructed from polyvinylchloride (PVC) pipe and fittings. While there is recommendation and guidance on the volume of water to be diverted, there is not guidance on the construction or design. Further complicating the issue is the fact that first flush diverters vary in where they are positioned in the collection system. First flush diverters can be located at the downspout or somewhere else along the collection piping before the water is stored. Figure 11.5 below illustrates a common downspout first flush diverter and its components.

Research performed by the Texas AgriLife Extension Service has shown that the type of transition fitting utilized is not significant. It was found that diverters that utilize a floating ball as a barrier limit mixing of diverted water with the subsequent flow of harvested rainwater (Figure 11.6).

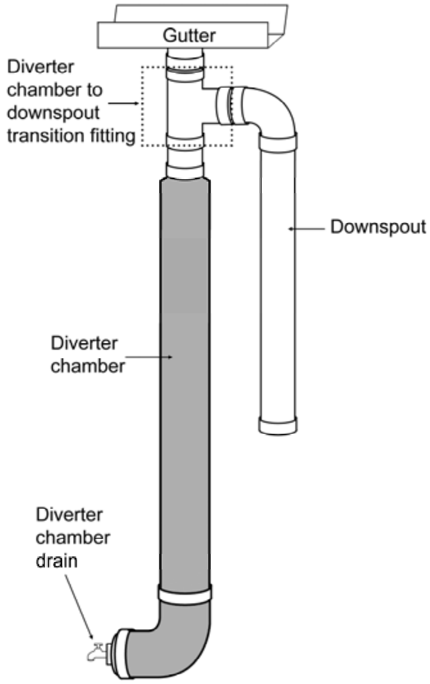


Figure 11.5. Diagram and basic components of a downspout first flush diverter.

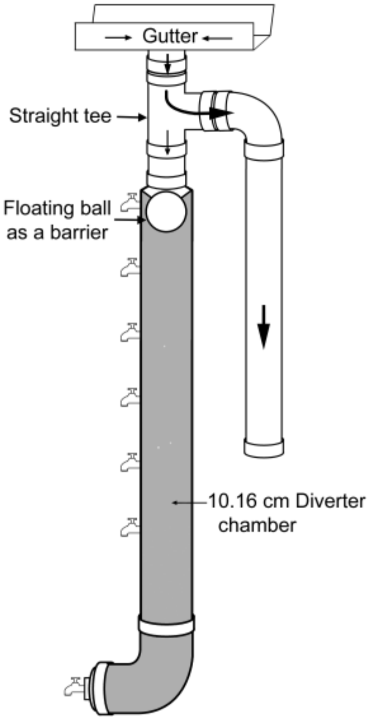


Figure 11.6. Stand-pipe diverter with a floating ball.

Catchment Size and Rainfall Characteristics

As previously stated, the size of a catchment and rainfall characteristics play a role in determining the volume of water that the first flush diverters should divert. These variables ultimately control the flow rate of collected water interacting with first flush diverters. The catchment area contributing to the flow of water to the first flush diverter is typically known or can be altered by changing the collection and diversion system configuration. The rainfall characteristics such as frequency, volume, and intensity are highly variable based on geographic location. The Soil Conservation Service, which is now the Natural Resource Conservation Service, has developed a map of the United States that is divided into regional categories of common storm intensity patterns (Figure 11.7).

Figure 11.7. Applicable region for various SCS Type curves (Soil Conservation Service, 1986).

According to Figure 11.7, the northwestern portion of the United States has Type I rainfall distribution. This designation represents the area with the least intense storm patterns. According to rainfall data collected from storm events over 25 years from 1973 to 1998 from the National Climate Data Center (NCDC) (2009) in Seattle Portage Bay, Washington, the average storm size was 0.4 in. with a mean storm intensity of 0.035 in. per hour (iph). This varies greatly from other locations such as New Orleans, Louisiana, which falls in the Type III rainfall distribution category, where the 36 year average (1963-1999) for mean storm depth was 0.8 in. with a mean intensity of 0.17 iph (NCDC, 2009).

While the rainfall characteristics have been shown to affect the volume of diverted water in relation to removal of contaminants, the flow rate may also affect the ability of the diverter to function properly and keep diverted water from interacting with the subsequent flow of harvested rainwater and being transported to storage. Research conducted by the Texas AgriLife Extension Service showed that as flow rate increases, water in the top portion of the diverter chamber mixes with the flow of water through the transition fitting.

Diverter Chamber Drain

In order for a first flush diverter to function, the diverter chamber must be empty at the onset of a rainfall event. The first water that flows off a catchment area during a rainfall event is diverted from storage and collected in the first flush diverter chamber. Once the diverter chamber is filled, the remaining runoff from the catchment surface is directed through the diverter chamber to downspout transition fitting to the next step in the collection process, which is typically storage. At the end of the rainfall event, the diverter chamber must be emptied to prepare for the next rainfall event. The use of a continuous drain on a downspout first flush diverter is a maintenance technique that allows the diverted water to drain between rainfall events without human attention. This maintenance technique is recommended for first flush diverters (ARCSA, 2009). The technique is pertinent for systems that will not receive routine maintenance after each rainfall event.

Remember when planning or installing diverters, first flush mechanisms, and roof washers to take in to account the type of rainfalls that occur where the system is located.

Downspout first flush diverters like the ones pictured are simple and easily incorporated into existing piping (Figure 11.8). This style is manually operated when it is desirable to channel rainwater to or away from the storage system. Figure 11.9 shows a RWH system in Texas where standpipes are used at each downspout to serve as the first flush diverter.

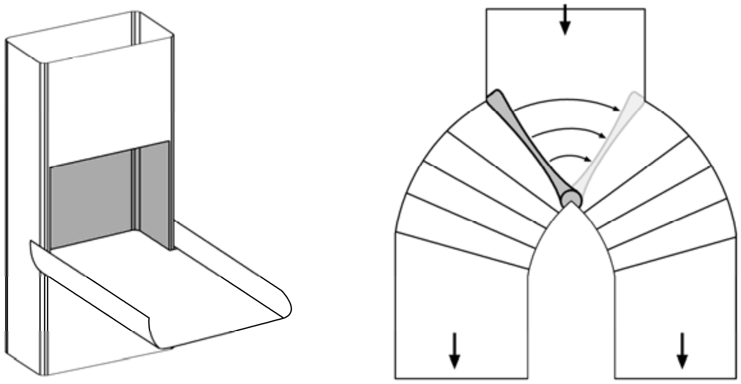


Figure 11.8. Simple first-flush diverters.

The length of the downspout determines the volume (gallons) that can be diverted. Data in Table 11.2 reveal that a 10-foot long 4-inch SCH 40 standpipe diverts about 6.7 gallons of water. In regions where low intensity rainfall (less than 0.25 iph) makes up a significant portion of rainfall events, stand pipe diverters may not be a best choice device because too much rain may be diverted.

Table 11.1. Capacity of various SCH 40 PVC standpipe diverters.

Length Pipe (ft)	4”- Capacity (gal)	6”- Capacity (gal)	8”- Capacity (gal)
1	0.7	1.5	2.6
3	2.0	4.5	7.8
5	3.3	7.5	13
10	6.7	15.0	26.0
15	10.0	22.5	39.0

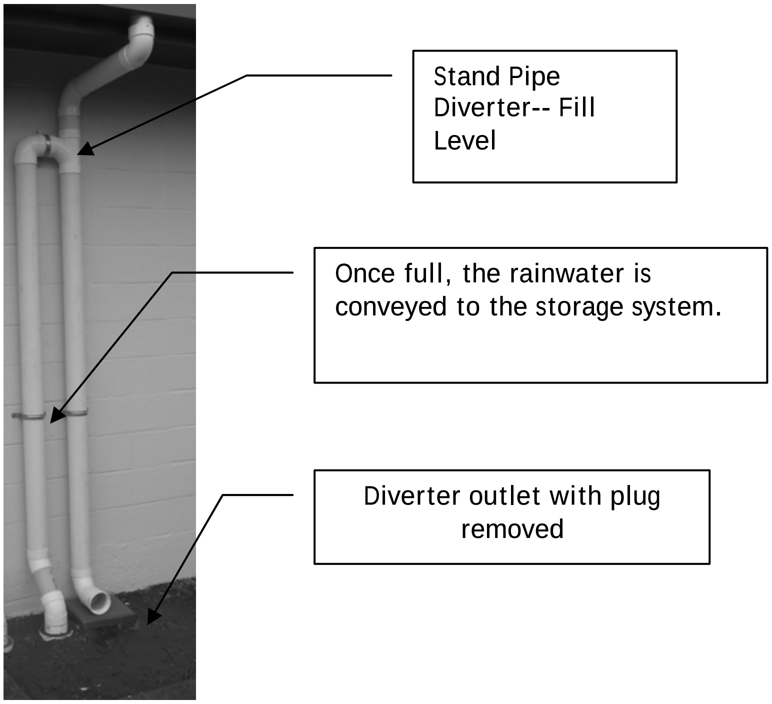


Figure 11.9. Standpipes are used at each downspout to serve as the first flush diverter.

Roof Washers

During a storm, a roof washer allows water to continually pass through a segregated tank. The tank is sometimes segregated with a baffle into two compartments to promote settling of contaminants. In one example of a roof washer is a 30- to 50- gallon tank with an external leaf strainer and an internal screen or filter (Figure 11.10 and 11.11).

The internal screen provides course or fine filtration. Roof washers can weigh in excess of 250 pounds when full and should be located to allow easy access for cleaning. Roof washers that hold water and that are not self-draining require mosquito control.

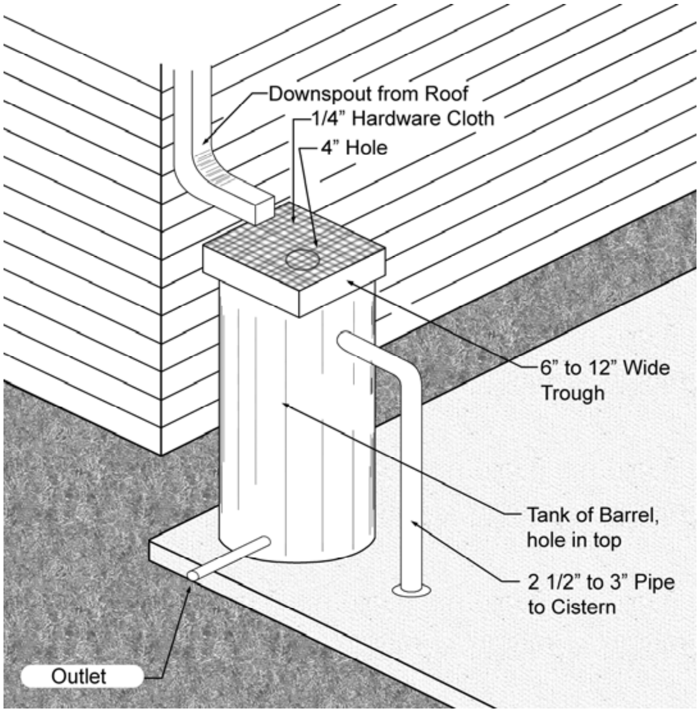


Figure 11.10. Roof washer located at ground level above buried tank.

Figure 11.11. Roof washer on stand located adjacent to an above ground tank.

A box washer (Figure 11.12) is another version of a pre-filter. A baffle divides the chamber, stops large debris, and calms the water. Water must exit by passing through the filter that stops additional debris. A typical box washer has less throughput capacity than a roofwasher and does not divert water. This can be used in combination with a diverter. As with any filtering device, maintenance is critical. As debris builds up, it will hinder the flow of water and could cause water to stand in the washer between rainfall events. This device should be readily accessible and easy to clean regularly.

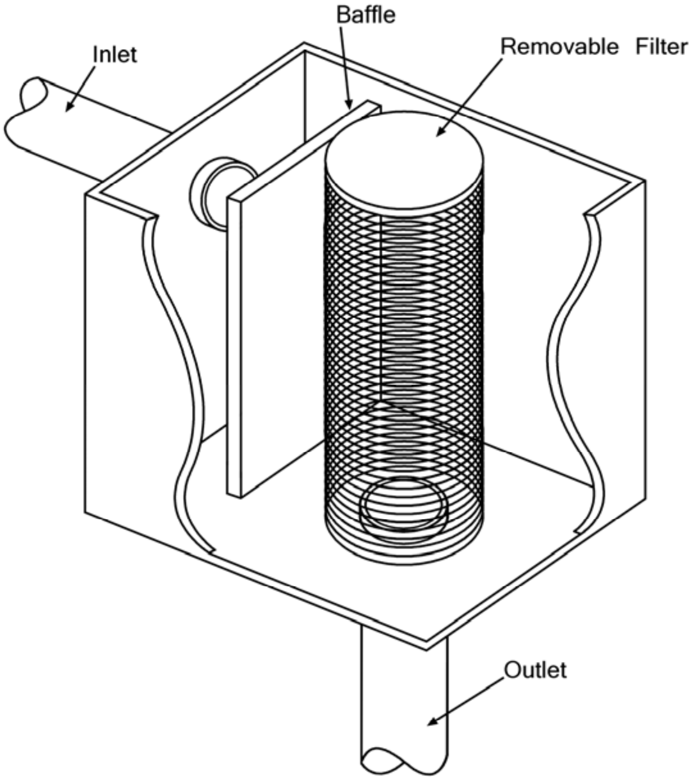


Figure 11.12. Diagram of a box washer.

Another type of roof washer is represented by a vortex filter (Figure 11.13). It relies on centrifugal force of flowing water to allow it to pass through its screen. Water that does not pass through the screen washes debris from the screen to a discharge pipe.

This type of filter must be properly sized for each site. Its efficiency is directly related to flow rates and that is determined by catchment area and rainfall intensity. Graphs of efficiency at differing flow rates are available from the manufacturer.

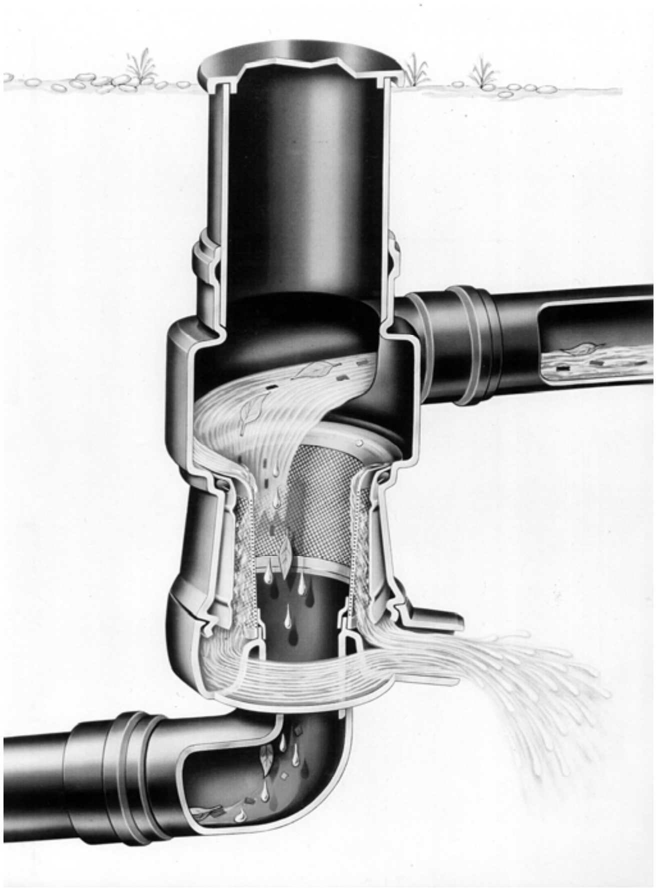


Figure 11.13. Cutaway view of a vortex filter. (Source: WISY AG, Germany)

Basket Filter

Basket filters are commonly placed at the top of a storage tank, covering the inlet of the tank (Figure 11.14). Water is directed from the catchment area to the basket. Basket filters are used to prevent foreign material and insects, such as mosquitoes, from entering the storage tank. It is important that the filter basket be easy to remove and empty as needed. The basket also serves as a calming inlet (discussed in a later chapter) by helping to dissipate some of the incoming water's energy.

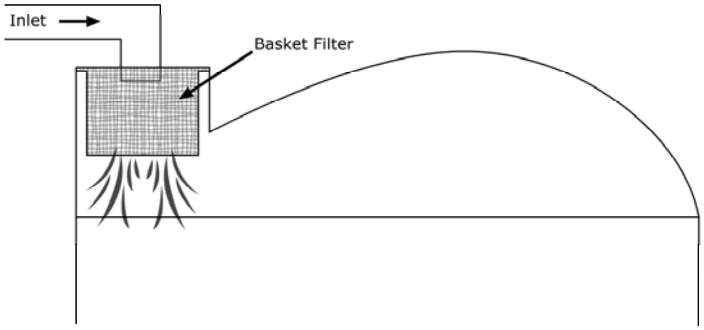


Figure 11.14. Basket Filter

Summary

Leaves, dust, particulate from asphalt shingles, fecal matter, and airborne residues are dislodged and relocated during a rain event. The catchment area, rainfall pattern, presence of birds, and other factors should influence the design and capacity of the filters, washers, and first flush/diverter components. Debris-removing devices should be reasonably accessible to minimize safety concerns and so that routine maintenance will not be avoided.

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Rainwater Harvesting:
System Planning

12. Storage Containers

The goal of this chapter is to engage the RWH system planner in the process of choosing storage tanks. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. List the different types of tanks available for storing rainwater.
2. Discuss advantages and disadvantages of each tank material.
3. Differentiate between aboveground, buried, and partially buried installation issues.
4. Choose best tank considering use, size, cost, and siting issues.
5. Explain how to minimize bacteria growth in a tank.
6. Choose tank materials and installation methods for potable and non-potable uses.
7. Determine inlet and outlet configurations for a tank.
8. Install inlets and outlets on a tank.
9. Discuss techniques to minimize and maximize turbulence in a tank.
10. Prepare an earthen foundation for a tank.
11. Plumb multiple tanks for series or isolation configurations.
12. Discuss tank level indicators.

CONTENTS

12. Storage Containers

Introduction

Since the inception of RWH systems, the most important component has been the storage container used to keep the water safe and secure (Figure 12.1). Clay pots, animal skins, metal and wooden vessels, and earthen dugouts have been used successfully to store water for human consumption.

Figure 12.1. Old cement cistern utilized for decades to store water.

Storage Container Safety and Children

All vessels that are large enough for a small child or infant to enter need to be fitted with safety devices and/or locked lids to prevent unintended entry. Besides drowning, hazards associated with storage containers include lack of oxygen from poor ventilation, fumes from sanitation products like chlorine, electrocution, slipping, and falling.

When children are present, install a ladder guard on external ladders (or remove ladder). Large containers, especially those that are not outfitted with an internal ladder, should only be entered by trained personnel familiar with OSHA confined-space entry procedures. All containers should be emptied of water prior to entry.

Corrugated Steel Tanks and Enclosed Metal Tanks

The use of corrugated steel tanks, those resembling a farm grain bin, is very common due to their availability, price, and aesthetic value (Figure 12.2). The tanks can be assembled on site or can be delivered fully assembled. The capacity of the tank primarily determines if the tank is preassembled or not. Steel corrugated tanks typically come with a steel, conical-shaped top. The top is not always water tight, although simple modifications can be made to seal the top from any rodents or pests. The surface of the roof is not designed for live loadings (i.e., walking on the roof).

All vessels that are large enough for a small child or infant to enter need to be fitted with safety devices and/or locked lids to prevent unintended entry.

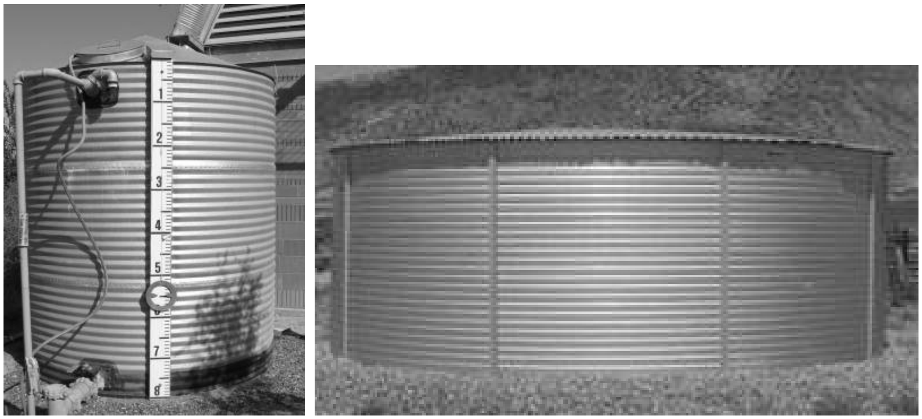

Figure 12.2. Various corrugated steel tanks used to store water.

Enclosed metal tanks are typically prefabricated and assembled off site (Figure 12.3). The tanks are often covered by either a shallow conical top or a very shallow dome top. Most tops are water tight, although each tank's construction ultimately determines this. Modifications can always be made to ensure rodents or other pests do not have access to the water.

When children are present or visit, install a ladder guard on external ladders (or remove ladder).

Figure 12.3. Prefabricated galvanized metal storage tanks.

Inlets and outlets can be installed to accommodate the RWH system (Figure 12.4). Most are lined with a vinyl material to ensure water tightness and reduce rust. Smaller galvanized tanks are manufactured in the range of 300 to 3,000 gallons. Most tanks of this size are sealed on the inside with a NSF approved marine epoxy, Teflon, or vinyl lining.

Figure 12.4. Inlet and outlet.

Concrete Tanks

There are two common types of concrete storage containers: ferro-concrete and monolithic-pour concrete. Concrete tanks are durable, very strong, heavy, and installed either aboveground, partially belowground, or belowground. Due to their size and weight, concrete tanks are stationary and should not be moved. Concrete tanks affect the pH level of water. Rainwater tends to be slightly acidic; the concrete contains calcium that aids in raising the pH level of the rainwater closer to neutral.

Rainwater tends to be slightly acidic; the concrete contains calcium that aids in raising the pH level of the rainwater closer to neutral.

Ferro-concrete tanks are a newer approach to tank construction. Ferro-concrete tanks are constructed first by building a frame. A special concrete mixture is then sprayed on the frame, forming the tank. The tank is sturdy and most are installed aboveground. Monolithic-pour concrete tanks are typically expensive but can be molded into the landscape due to their strength.

The term cistern has traditionally been applied to concrete tanks and in some localities special ordinances apply specifically to cisterns that may not apply to plastic tanks. As RWH increases in popularity, one can expect changes in liner specifications, volume, inlet/outlet locations, onsite position relative to proximity to wastewater components and structural integrity. In some locations, all concrete tanks must meet ASTM C913-08 Standard Specification for Precast Concrete Water and Wastewater Structures.

Older tanks that have not been used for a long time should be checked for structural integrity by a professional before use. If approved for use, older tanks may need to be relined or fitted with a vinyl liner.

Wooden Tanks

Tanks made from redwood were popular in the past but now redwood is expensive and less available.

Redwood tanks are best installed in humid climates and should not be painted. If located in a dry climate, the wood will shrink as a result of loosing significant amounts of moisture, allowing water to leak out. In order to keep the tank from leaking, it must be kept full.

Attention: DO NOT MOVE or RELOCATE any tanks that contain water. Rupture will occur. Injury to bystanders is possible.

Fiberglass Tanks

Fiberglass tanks are versatile. They can be installed either aboveground or belowground, depending on their design. Fiberglass tanks are fairly light weight for easy movement, and they are rigid. The tanks can be painted to assist in keeping sunlight out of the tank. If the tank has a leak, in most cases, it can be repaired easily with a fiberglass patch and some epoxy resin. Fiberglass tanks do allow for some drilling and cutting, but caution should be used when cutting into fiberglass. The individual strands of fiberglass are very fine and sharp; they can easily irritate any unprotected skin or eyes.

Polyethylene and Polypropylene Tanks

Large and small storage containers made of polyethylene, polypropylene, or a combination of plastics have become widely used in the past years. These tanks are considered lightweight and portable, especially when empty. Polyethylene is flexible, while polypropylene is more rigid and has a greater strength-to-weight ratio. Both materials can be made to be translucent or colored with pigment to minimize algae growth by blocking sunlight. Plastic tanks can be drilled and cut.

Polyethylene is flexible, but polypropylene is more rigid and has a greater strength-to-weight ratio.

Inlets, Outlets, and Other Openings

Each RWH system is unique, but it is necessary to outfit the storage container with an inlet, outlet, overflow outlet, vent, and an inspection or service port (Figure 12.5). Some tanks must be modified to accommodate multiple outlets and inlets. Wherever possible, inlets and outlets should be configured to minimize stirring in the tank to prevent unnecessary disturbance of settled contaminants. Easy inspection and accessibility for maintenance are essential and directly related to the operational life of the system and consistent water quality.

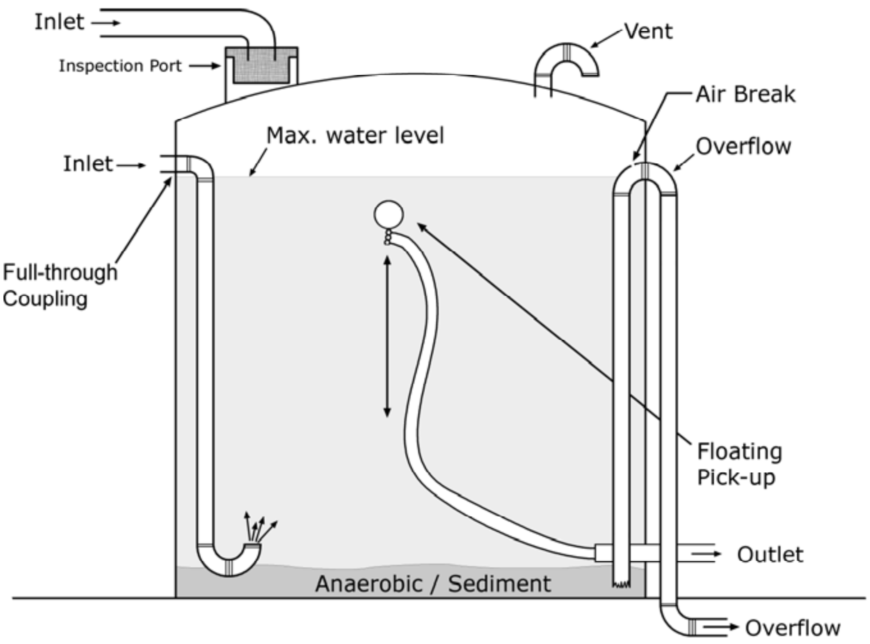

Figure 12.5. A storage container showing major components and features.

If possible, water should not cascade or waterfall from the top of the tank. Regardless of the location of the inlet, water should be released near the bottom of the tank and directed upward. If a basket filter is being utilized as a filtering method, the basket will help dissipate some of the water's energy as it flows through the screen, helping reduce turbulence in the tank.

Inlet piping, whether from the top, side, or bottom, should minimize turbulence of existing stored water and be plumbed in order to allow water tight connections. Full through couplings should be used when piping enters or exits the tank. Figure 12.6 shows different configurations of calming inlets.

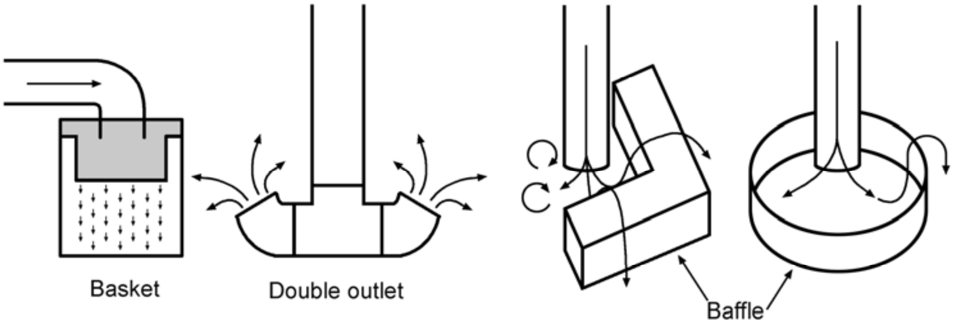

Figure 12.6. Calming inlets

To minimize debris, the pickup for the tank outlet should not take water from the surface or directly off the bottom. Water should enter rigid outlet piping at least 4 inches from the bottom of the tank. If the water is being used for drinking purposes, a floating pick-up outfitted with a fine mesh screen or filter is recommended, but not required (Figure 12.7).

A floating pick up outfitted with a fine mesh screen or filter is recommended, but not required, if the water is being utilized for drinking purposes.

Generally speaking, the best quality water is found just below the water surface, where floating or settled material is not present. In warm climates, the water directly at the surface may also be warmer and less desirable. Installers should ensure the flexible inlet hose is long enough to be serviced and inspected from the inspection port on the tank or cistern.

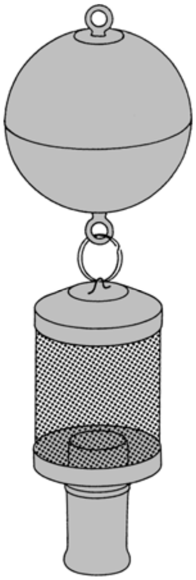

Figure 12.7. Floating tank pick-up. (Source: WISY AG, Germany)

All tank overflow outlets should be at least the same size as the inlet. In the event that a tank fills to capacity during a rain, water needs to be released at an equivalent flow rate as the water entering the tank. This will aid in preventing head pressure build up in the tank and conveyance piping.

Installers should ensure that the flexible inlet hose is long enough to be serviced and inspected from the inspection port on the tank or cistern.

Some RWH installers have used a surface pickup with a 45-degree angle to facilitate entry of larger debris, also referred to as skimming (Figure 12.8). If an outlet draws water from the bottom of a tank, the piping should be vented to prevent siphoning action that allows the tank to inadvertently empty. An outlet that draws water from the bottom of the tank may facilitate removal of settled materials, thus aiding in maintenance of the system.

Overflow outlets and vents should be equipped with a device to prevent entry of rodents or insects. A fine mesh screen with openings no greater than ¼-inch made of non-corrosive material deters larger pests, but a screen with 1/16-inch mesh is necessary to prevent mosquito entry. Covering the overflow outlet with mesh reduces flow capacity and may trap debris, further reducing outflow.

Care should be taken to manage the overflow discharge and direct it to an appropriate runoff conveyance system or location; overflows should be piped so that exiting water does not cause erosion around the tank base, which could lead to movement or failure of the tank.

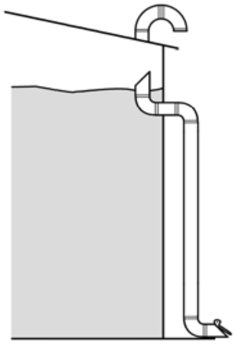

Figure 12.8 Forty-five-degree storage tank overflow outlet to enhance skimming.

In Hawaii, tanks are typically outfitted with wet-conveyance type overflows to prevent entry of uninvited guests and dust. A flooded section of pipe is installed outside of the tank as shown in Figure 12.9. Remember that all tanks should be vented and vents should be pointed downward.

While PVC pipe manufactured in the US should have a UV inhibitor in the plastic, all aboveground PVC fittings and piping (whether an inlet, outlet, overflow device, or other piping) should be coated with a good layer of paint or another covering to block UV light.

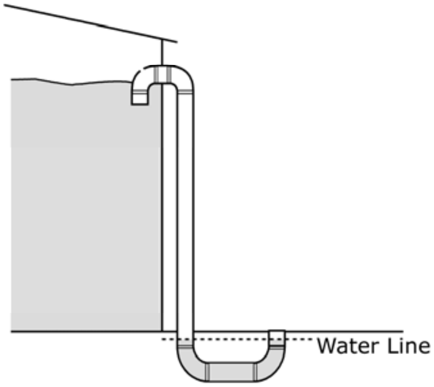

Figure 12.9. Storage tank outfitted with a wet overflow.

Connecting Multiple Tanks

Using multiple tanks, instead of a single tank, affords some advantages. Multiple tanks allow better control of contaminants and the ability to isolate a tank without interrupting supply. Tanks placed in series (Figure 12.10) may increase the biological quality of stored water for drinking.

As water moves from one tank to the next, settling action reduces the settleable solids. Inlet and outlet configurations should minimize turbulence and maximize the length of travel for water entering and then exiting the tank. Tank connections should be located above the sediment.

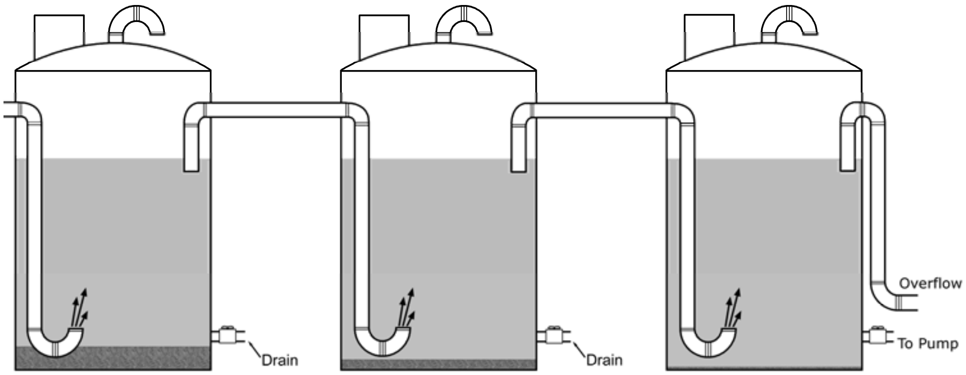

Figure 12.10. Multiple tanks arranged in series to minimize turbulence and maximize settle ability.

Siting Issues

As previously mentioned, once a tank is put into place and plumbed with piping, moving it is difficult. Past experience provides some guidelines for siting tanks to best maximize the performance of the RWH system and minimize negative aesthetic impacts.

The guidelines include:

- Elevate aboveground storage containers to take advantage of gravity flow; for example, place them at the high end of a sloped lot.
- Place storage containers for irrigation purposes near plants.
- Minimize horizontal distance between downspout and tank.
- Hide unsightly containers.
- Provide adequate conveyance for tank overflow water that does not cause erosion of the foundation for the tank or adjacent structures.
- Place tank in a location where additional tanks can be connected.
- Understand slope characteristics of the surrounding landscape to determine where the surface water will flow.

Slope Considerations

Knowing how to read the surrounding topography will keep storage containers from being placed in the path of surface water runoff. Surface runoff can disrupt the foundation of storage containers and could even move containers that are not properly anchored. Slopes are broken into multiple classifications that can help determine where the surface water will flow (Figure 12.11). Figure 12.12 demonstrates how the slope classifications can be applied to a site for analysis. As a general rule of thumb, do not place storage containers in concave areas, which will prevent water from moving around the tank base.

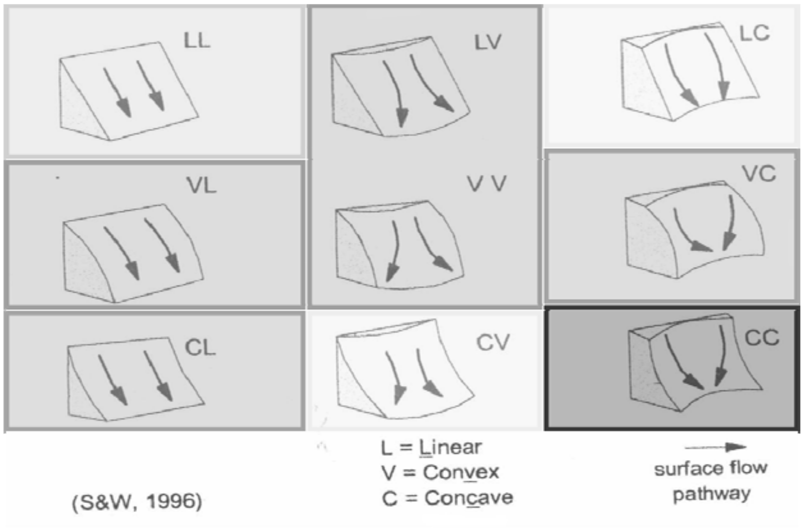

Figure 12.11. Slope classifications.

Foundations, Supports, and Tie Downs

All tanks require a sufficient foundation and need to be secured to prevent movement. The foundation must be level and evenly distribute the load on the tank to prevent cracking or puncture of the tank. Tank levels may change quickly along with changes in temperature that will result in some shrinking/swelling and slight deformation of the tank.

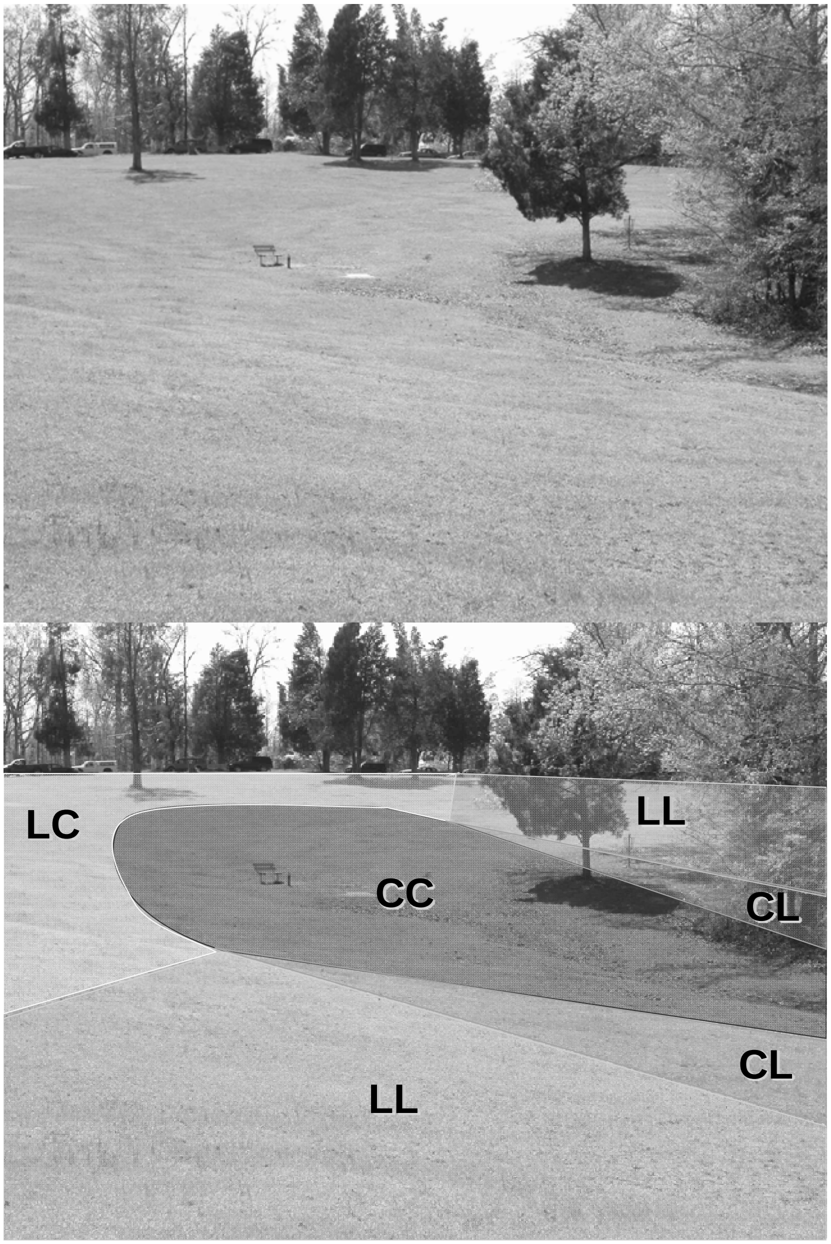

Figure 12.12. Slope classifications applied to a specific site.

A foundation, whether earthen gravel or concrete, is susceptible to erosion. Runoff or water leakage from RWH system components or piping can erode soil adjacent to tanks, resulting in failure of the foundation and even tank rupture. Runoff and tank overflow water should be controlled and conveyed safely away from the foundation.

An earthen foundation for a tank may not be suitable for tanks in excess capacity of 500 gallons in certain soils and environmental. Figure 12.13 shows several 3,000 gallon tanks that have been placed on an imported soil foundation approximately 12 inches in depth. Fortunately, interlocking landscape blocks have been installed to help stabilize the soil and minimize shifting. Individuals who construct earthen foundations should be familiar with safe loading of the soil and effective techniques to prevent soil movement.

Figure 12.13. Imported soil footing for large tanks.

Slight soil movement under and around tanks and tank foundations occurs in all instances, particularly with clay and sand. Clay soils have the capability to shrink and swell, and sand can easily be eroded by wind. The effects of soil movement from settling, shrinking, swelling and erosion can be reduced by adding a layer of loose material like pea-gravel or sand that will absorb shear forces during small movements of the tank or soil. This material should be level, flat, and smooth with no sharp objects able to puncture the tank. In cases where the loose foundation material is not applicable, a concrete foundation will be necessary.

Water weighs 8.34 pounds per gallon and therefore a foundation for a 1,500 gallon tank would need to support a 12,510-pound load from the water plus the tank weight. Even 55-gallon barrels full of water weigh in excess of 400 pounds (Table 12.1).

Table 12.1. Weight of water by gallon

Weight of Water	
Gallons	Weight (lbs)
55	459
150	1,251
250	2,085
500	4,170
1,000	8,340
1,500	12,510

Elevated barrels require ample support to prevent tip over and collapse onto a bystander or child (Figure 12.14). Besides a foundation supporting the tank, anchors must be utilized to prevent the tank from moving. Whether elevated or at ground level, proper anchoring of a tank is necessary in case of high wind, saturated soil or shifting soil.

Figure 12.14. Supports for storage tanks.

Concrete foundations are the best for most large tank installations. Concrete can withstand moisture from soil and resist deterioration. Tanks that are allowed to shift or settle will crack or break plumbing connections. Large tanks should be bolted to appropriate footings while strapping may be adequate for smaller, plastic tanks.

Empty aboveground tanks can be blown over by strong winds; even empty belowground tanks that are improperly selected and installed have been known to become buoyant in wet soils and pop right out of the ground or collapse under the weight of surrounding soil.

A buoyancy equation is suggested to determine the required anchoring forces. For every empty cubic foot capacity of a cistern, the upward buoyant force produced is 62.4 pounds. Concrete tanks (cisterns) offset the buoyancy force because a cubic yard of concrete weighs about 3,300 pounds.

Buoyant Force (pounds) = Volume underground tank (ft^3) X 62.4 lbs/ft^3

Aboveground versus Belowground Containers

Containers placed underground have a higher cost because they are more expensive to install, maintain, and remove than aboveground tanks. RWH systems with underground tanks require pumping to access the water. Shifting and settling soil can cause an underground tank to crack and subsequent leaks are difficult to detect.

Cracking can also allow inflow, by way of seepage, and contamination of stored water. A disadvantage of an aboveground tank is that it is subject to direct sunlight and therefore elevated water temperatures.

Belowground tanks are cooler and even protect storage water from freezing in the winter months, if placed below the frost depth. Aboveground tanks and system components must be opaque to prevent algae growth.

Tanks installed belowground are subject to different risks of contamination. Pooling runoff water, dislodged soil, point source pollution, and other unexpected accumulations of debris may enter through the lid or openings of a belowground tank (Figure 12.16A). Installers should position the elevation of the access to a buried tank at least 8 inches above the final grade of the soil (Figure 12. 17)

Figure 12.16. A buried storage tank is susceptible to contamination from surface runoff.

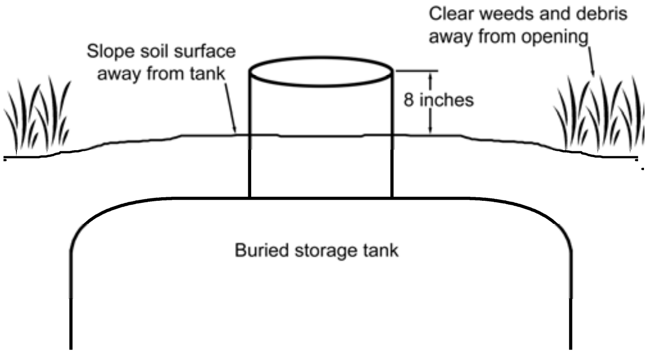

Figure 12.17. The tank opening should rise at least 8 inches above grade.

The following guidelines should be followed when installing underground tanks:

- All tank openings should rise at least 8 inches above the surrounding grade.
- Grade surrounding soil away from tank.

- Move weeds, piles of soil, and burrowing animals away from openings.
- Vehicles and livestock should be prevented from crossing/parking above the tank.
- Do not share trenches or excavations with wastewater treatment system components.
- Maximize the distance between RWH and wastewater treatment system components.
- Bury septic piping and tanks deeper than RWH piping.
- Do not bury RWH tanks near soil treated for termites.
- Discharge from a septic system moves downward and downhill; do not place RWH system components in the discharge path.

Colors and Aesthetic Considerations

Plastic tanks are slightly transparent even though they are colored white, green, or black. White plastic tanks should be avoided, unless painted. Some RWH system operators have reported that algae growth is slowed in black plastic tanks. Fiberglass and concrete tanks can be painted to match adjacent structures or increase aesthetic quality. In some instances, tanks are decorated to promote RWH or covered with attractive wooden planks (Figure 12.18).

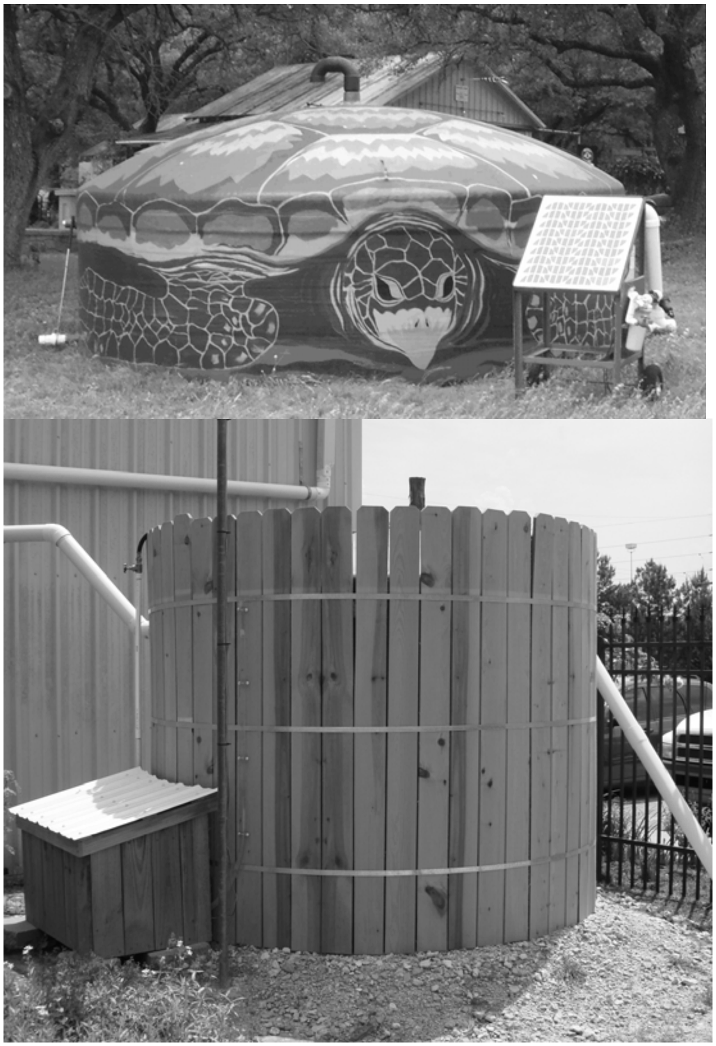

Figure 12.18. Storage tanks can be painted or wrapped in wooden planks to make them more aesthetically pleasing.

Repairing Tanks

Contact the manufacturer for advice on leak repair. All repairs to potable water systems must be made with materials that meet ANSI/NSF standards. When possible, devices used for potable water storage should be replaced if leakage occurs.

Tank Level Indicators

Tanks can be fitted with level indicators that are available from tank manufacturers and other outlets. Although they are simple and easy to install, site glass or clear vinyl vertical site tube level indicators are not recommended because they allow water to be exposed to sunlight if not drained. Site tubes should be drained between readings to prevent algae growth and freezing. A device with a float or a counterpoise, remote radio signal, or other level indicators can be installed on a tank and should not jeopardize water quality.

Containers Storing Treated Water for Drinking

It is not recommended for RWH planners to utilize systems that treat and then store water in a large tank to be used later for drinking (unless chlorine is used for sanitation (TCEQ, 2007)). If chlorine is not used, there will not be any residual protection from contaminants. In some instances, it may be necessary to chlorinate water, place it in storage, and then further treat it prior to immediate consumption. Tanks used to store treated water for drinking should not be installed belowground.

Materials that come into contact with the treated water for drinking, such as inside tank surfaces, coatings, or liners, should meet ANSI/NSF Standard 14 or Standard 61. Do not use porous materials, such as brick, stone, or concrete for internal surfaces that will contact treated water. Plastic tanks left outside and uncovered are more susceptible to degradation from the sun. It is recommended to cover or paint these tanks to extend their life and cool the water. Tank outlets that serve as vents or overflows should face downward and need a screen covering the opening that is made of 1200 micron (16-mesh), corrosion-resistant material to minimize insect (mosquito), and rodent intrusion. Lids, inspections ports, and entryway doors should be fitted with a gasket to prevent contamination.

Dangers of Moving a Full Tank

Recently, a RWH planner discovered the pitfall of attempting to move a completely full 3,000-gallon polyethylene tank. The tank was strapped to a tractor while the operator attempted to drag the tank a few feet. The forces exerted on the tank by the 4-inch strap caused the tank to tear, resulting in a large hole and immediate loss of the contents. Any tank should be completely emptied of its contents prior to any movement or adjustment.

Tank costs

As mentioned, the cost of a storage container is the highest portion of the total cost of a RWH system. Like all prices, tank costs can change rapidly and are directly related to availability and location. In most installations, the storage tank can cost between 50 and 75 percent of the total cost of the installed RWH system. It is also generally accepted that a single storage container is cheaper than multiple, smaller containers totaling the same volume.

Summary

The storage tank is the most important and expensive component of the RWH system. Large tanks are dangerous and entry should be limited to personnel familiar with safe entry procedures and hazards associated with confined spaces. The choice of materials from which tanks are made from is diverse. Choosing the correct tank material composition, siting the tank, preparing a sufficient foundation, and securing the tank are critical for long-term functionality.

Piping between tanks for efficient conveyance of water along with configuring inlets and outlets to minimize turbulence is required to maximize water quality. Special attention should be paid to belowground and partially buried tanks to prevent contamination. Extra consideration is also needed when tanks are used to store treated water. Take into account a client's desire to highlight or hide RWH tanks in their landscape.

Reference

TCEQ. 2007. Harvesting, Storing, and Treating Rainwater for Domestic Indoor Use. Texas Commission on Environmental Quality (TCEQ). GI-366. Jan 2007.

Rainwater Harvesting: System Planning

13. Dry versus Wet Conveyance and Basic Hydraulic Principles

The goal of this chapter is to engage the RWH system planner in the process of differentiating between dry/wet conveyance piping and using basic hydraulic principles to determine the best piping configuration for connecting RWH system components. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Discuss the impact of a wet conveyance system on water quality.
2. List advantages of a dry conveyance configuration.
3. Define head pressure.
4. Determine best piping configuration for connecting multiple tanks.
5. Describe influence of head pressure and pipe size when transferring water from one tank to another.
6. Choose appropriate size of pipe for connecting tanks.
7. Determine placement of valves in order to isolate a RWH component.

Contents

13. Dry versus Wet Conveyance and Basic Hydraulic Principles

Introduction

Each RWH system consists of some means of conveying rainwater from the catchment area to the storage container. Depending on the configuration of the piping of some systems, they will either remain dry or trap water between rains. These instances are respectively referred to as dry and wet conveyance systems.

The efficient conveyance of water by gravity between system components requires a RWH planner to comprehend basic hydraulic principles. Understanding gains and losses of pressure as water flows through a pipe affords the proper sizing of conveyance piping. Properly sized pipes result in maximizing a RWH system's functionality and minimizing costs.

Dry versus Wet Conveyance Systems

Dry conveyance systems are normally empty, as they are filled only during a rain event or transfer of water from one device to another (Figure 13.1). While a RWH planner should make every reasonable effort to configure piping schemes so that water is not trapped or able to puddle, dry conveyance systems sometimes result in inconvenient pipe runs or an attractive nuisance for children (Figure 13.2).

Figure 13.1. A dry conveyance system drains all water from the conveyance piping.

Figure 13.2. Dry conveyance can result in an overhead obstruction or an attractive nuisance for children.

Wet conveyance systems are flooded or partially filled with water on a continuous basis. This condition results when piping orientation and inlet/outlet elevation differences trap water between components. The most common cause of a wet conveyance system is when the inlet to a water storage device is higher in elevation than the lowest point of a conveyance system (Figure 13.3). Some RWH planners include a drain at the lowest point of the conveyance system so that it can be emptied between rains or in preparation for freezing temperatures.

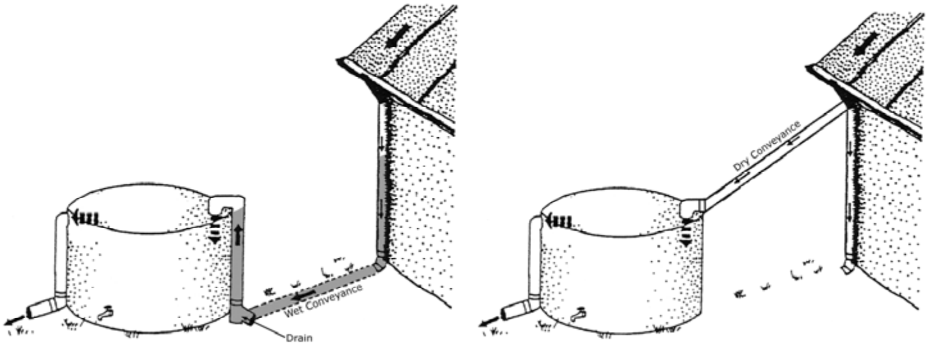

Figure 13.3. Example of wet (left) and dry (right) conveyance systems.

Due to standing water, complications may arise and result in mosquito infestation, algae growth, existence of pathogens, and pipe breakage resulting from freezing. Debris may also build up in this portion of the system. A cleanout should be installed to allow access in order to clear debris. Wet conveyance systems are not preferred for RWH systems that collect water for drinking although they do allow for flexibility in tank placement. In the event a wet conveyance system is utilized for a drinking water system, ensure that the line is frequently drained to prevent freezing and contamination.

Conveyance and Head Pressure

Another issue of a wet conveyance system is related to head pressure build-up during a storm. In Figure 13.4, it is apparent that the downspout will be flooded to the same level as the tank fill level. Curiosity and concern has been raised by RWH planners and installers over the possibility of the downspout filling, causing the gutter to fill and then overflow during an intense storm. The potential to overflow the gutter is examined in the following scenario that applies basic hydraulic principles within a question and answer format.

The example below directly demonstrates the effect of friction in pipe flow. If friction was not present, water would flow at the same rate as gravity. In determining flow in pipe networks we must consider the length of pipe, types of fittings, and type of pipe. Friction loss in SCH 40 PVC pipe and equivalent lengths of several common fittings are listed in Tables 13.1 and 13.2. Equivalent lengths of common fittings have been predetermined to minimize calculations (Table 13.2).

With these lengths, one can add the length of pipe utilized to all the equivalent lengths from each fitting and determine total pipe friction loss. In the event that you wish to determine friction loss in other pipe sizes, lengths, or materials, utilize the following Hazen-Williams Equation.

$$Friction \quad Loss = 10.46L\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.871}}$$

Where;

L = length of pipe (ft)
Q = flow rate (gpm)
D = Actual pipe inner diameter (in)
C= friction coefficient (140-150 for PVC pipe)

When calculating the friction loss in pipe, you can either use the Hazen-Williams friction equation or table 13.1. The following examples will show the two different ways of calculating friction loss.

Table 13.1. Pressure loss due to friction for Sch 40 PVC pipe (feet-hd per 100 ft) (CIDWT, 2008)

	Pipe Size (in.)					
Flow (GPM)	1 (1.049)	1-1/4 (1.38)	1-1/2 (1.61)	2 (2.067)	3 (3.068)	4 (4.026)
1	0.09					
2	0.32	0.08				
3	0.67	0.18	0.08			
4	1.14	0.30	0.14			
5	1.73	0.46	0.21	0.06		
6	2.43	0.64	0.30	0.09		
7	3.23	0.85	0.40	0.12		
8	4.13	1.09	0.51	0.15		
9	5.14	1.35	0.64	0.19		
10	6.25	1.64	0.78	0.23		
11	7.45	1.96	0.92	0.27		
12	8.76	2.30	1.09	0.32		
13	10.16	2.67	1.26	0.37		
14	11.65	3.06	1.45	0.43	0.06	
15	13.24	3.48	1.64	0.49	0.07	
16		3.92	1.85	0.55	0.08	
17		4.39	2.07	0.61	0.09	
18		4.88	2.30	0.68	0.10	
19		5.39	2.55	0.75	0.11	
20		5.93	2.80	0.83	0.12	
25		8.96	4.23	1.25	0.18	
20		5.93	2.80	0.83	0.12	
25		8.96	4.23	1.25	0.18	
30			5.93	1.76	0.26	0.07
35			7.89	2.34	0.34	0.09
40				2.99	0.44	0.12
45				3.72	0.54	0.14
50				4.52	0.66	0.18
60				6.34	0.93	0.25
70				8.43	1.23	0.33
80				10.80	1.58	0.42
90				13.43	1.96	0.52
100				16.33	2.38	0.63
150					5.05	1.34
200					8.61	2.29
250						3.46
300						4.86
350						6.46
400						8.27

Table 13.2. Pressure loss equivalent as pipe length (ft) (CIDWT, 2008)

Diameter of Fitting (in.)	90. Degree Standard Ell	45 Degree Standard Ell	90 Degree Standard Tee	coupling or Straight Run Of Tee	Gate Valve	Globe Valve	Check Valve
	Friction Loss Equivalent as Pipe Length (ft)						
3/8	1	0.6	1.5	0.3	0.2	8	3
1/2	2	1.2	3	0.6	0.4	15	5
3/4	2.5	1.5	4	0.8	0.5	20	7
1	3	1.8	5	0.9	0.6	25	8
1 1/4	4	2.4	6	1.2	0.8	35	11
1 1/2	5	3	7	1.5	1	45	14
2	7	4	10	2	1.3	55	19
2 1/2	8	5	12	2.5	1.6	65	22
3	10	6	15	3	2	80	27
3 1/2	12	7	18	3.6	2.4	100	32
4	14	8	21	4	2.7	125	38
5	17	10	25	5	3.3	140	46
6	20	12	30	6	4	165	54

Case Study: Overflow of Gutter

The RWH storage tank contains water to a depth of 2 feet (Figure 13.4) while the 4 inch PVC downspout has 8 feet of standing water. It is supplied by a roof catchment via a gutter and wet conveyance system. The bottom of the gutter is 3 feet above the inlet level of the tank. The entire conveyance system is plumbed with 4-inch-diameter SCH40 PVC. The total length of pipe used is 20 feet and 2- 90^0 ells and 1- tee is utilized. (Some RWH components such as a roof washer have been omitted to simplify the scenario.)

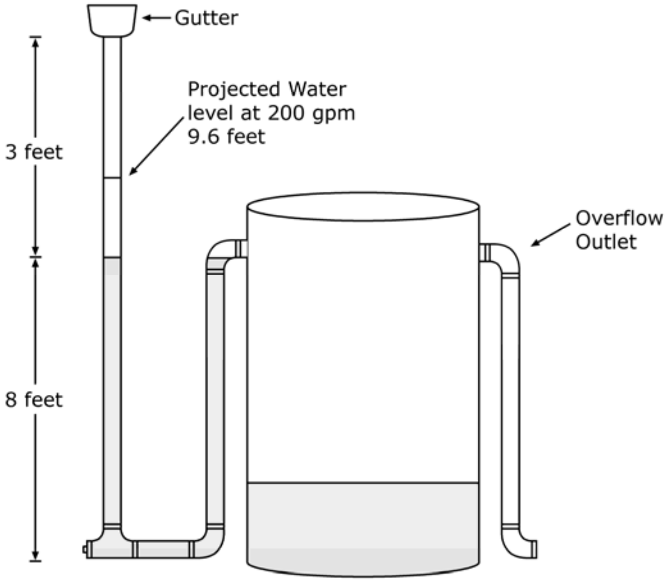

Figure 13.4 Example conveyance system with a determined head pressure of 1.6 feet with an inflow of 200 gpm.

The owner of a RWH system is concerned that his gutter will overflow during a heavy, high intensity rain.

Question: How high will the water get in the downspout during a significant rain with an inflow rate of 200 gpm?

Answer: Using pressure losses during dynamic flow, it was found that the water level in the downspout would rise 1.6 feet.

This was determined by plugging the known quantities into the friction loss equation. The length of pipe in feet was determined to be 20 feet plus the 14 feet of equivalent length that each 4-inch ells and 21 feet of equivalent length that the tee adds (Table 13.2) for a total of 69 feet. The flow rate is 200 gpm, as stated in the question and the C factor of 140 was used for new piping. The inside diameter of the 4-inch SCH 40 was determined to be 4.026 inches (Table A.2) and was plugged into the friction loss equation.

$$Friction \quad Loss = 10.46L\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.871}}$$

Where;
L = length of pipe (ft)
Q = flow rate (gpm)
D = Actual pipe inner diameter (in)
C= friction coefficient (140-150 for PVC pipe)

Plugging the values into the equation gives us the answer in feet of friction loss.

$$1.6\,ft \quad = 10.46(14 \times 2 + 21 + 20)\frac{\left(\frac{200}{140}\right)^{1.852}}{4.026^{4.871}}$$

This flow rate of 200 gpm far exceeds the maximum design flow rate of 144 gpm recommended in this manual by the Uniform Plumbing Code Tables (Table C.1). Obviously, the system is not likely to overflow with a 4 inch downspout and inlet into this system.

Question: What if the system downspout was only 2-inch-diameter SCH 40 PVC and the flow rate is cut in half, 100 gpm? Would it overflow?

Answer: For this problem we will use Table 13.1 to calculate the friction loss in the pipe. The length of pipe for this scenario is the three equivalent lengths from the one tee and two ells plus the 20 feet of pipe for a total of 44 feet (Table 13.2). The flow rate is 100 gpm and friction coefficient is 140. To calculate the friction loss from Table 13.1, you find the friction loss for 2 inch pipe at 100 gpm, which is 16.33 ft.

The value given in the table is for 100ft of pipe, so this value must be scaled down. To scale the number down based on the length of pipe in our scenario, multiply the value by the length and divide by 100 as shown below.

$$7.2\,ft(hd) \quad = {}^{16.33\,ft(hd)}\!\big/_{100\,ft} \times 44\,ft$$

Given a flow rate of 100 gpm, the rise in depth of water in the downspout would be 7.2 feet. The flow rate will make the gutter overflow. The friction loss was calculated using the equivalent lengths of pipe and Table 13.1. The UPC and recommendations from this manual regarding sizing gutters and downspouts limit a 2-inch downspout to a flow of only 23 gpm (Table C.1).

Sizing Conveyance Piping

In a roof catchment RWH system, gutters convey water from the catchment surface to downspouts. Large roofs are outfitted with multiple downspouts. It is a common practice for a RWH planner to route the water from the downspouts into a single line that goes to the storage tank. Obviously, the flow capacity of the piping must meet or exceed the downspout capacity or major problems might occur. It is not recommended to downsize conveyance piping below the gutter flow capacity. Besides causing a backup, debris may get caught in the small piping.

It is not recommended to downsize conveyance piping below the gutter flow capacity. Besides causing a backup, debris may get caught in the small piping.

Table 13.3. Sizing of Horizontal Rainwater Piping (IAPMO, 2000)

Size of Pipe	**Flow, gpm**	**Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates**					
Inches	**1/8"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	34	3288	1644	1096	822	657	548
4	78	7520	3760	2506	1880	1504	1253
5	139	13360	6680	4453	3340	2672	2227
6	222	21400	10700	7133	5350	4280	3566
8	478	46000	23000	15330	11500	9200	7670
10	860	82800	41400	27600	20700	16580	13800
12	1384	133200	66600	44400	33300	26650	22200
15	2473	238000	119000	79333	59500	47600	39650
Inches	**1/4"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	48	4640	2320	1546	1160	928	773
4	110	10600	5300	3533	2650	2120	1766
5	196	18880	9440	6293	4720	3776	3146
6	314	30200	15100	10066	7550	6040	5033
8	677	65200	32600	21733	16300	13040	10866
10	1214	116800	58600	38950	29200	23350	19450
12	1953	188000	94000	62600	47000	37600	31350
15	3491	336000	168000	112000	84000	67250	56000
Inches	**1/2"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	68	6576	3288	2192	1644	1310	1096
4	156	15040	7520	5010	3760	3010	2500
5	278	26720	13360	8900	6680	5320	4450
6	445	42800	21400	14267	10700	8580	7140
8	956	92000	46000	30650	23000	18400	15320
10	1721	165600	82800	55200	41400	33150	27600
12	2768	266400	133200	88800	66600	53200	44400
15	4946	467000	238000	158700	119000	95200	79300

Notes:

1. The sizing data for horizontal piping is based on the pipes flowing full.

2. For rainfall rates other than those listed, determine the allowable roof area by dividing the area given in the 1 inch/hour(25 mm/hour) column by the desired rainfall rate.

A review of the UPC regarding the sizing of horizontal rainwater piping provides some guidelines. It is recommended that all pipes have a slope of at least 1 percent (1/8-inch drop per foot of horizontal distance). Table 13.3 shows the maximum surface area that can be drained given rainfall intensity.

It is recommended that all pipes have a slope of at least 1 percent (1/8-inch drop per foot of horizontal distance).

Using a 6 iph rainfall rate, a 4-inch-diameter pipe provides adequate drainage for a catchment footprint area of up to 1,253 square feet at a flow rate of 78 gpm. A 6-inch pipe drains up to 3,566 square feet during a 6 iph storm at a flow rate of 222 gpm.

In order to determine if a larger pipe size is needed when consolidating piping from downspouts, one should look at the entire catchment area or it may be helpful to consider flow rate capacity of the pipe.
A 6-inch pipe with a 1 percent slope has a maximum flow rate of 222 gpm. A 6-inch pipe will adequately carry two 4-inch pipes at the same slope with a capacity of 78 gpm each.

Sizing Pipes Between Tanks

Larger RWH systems with high storage capacity may be designed using more than one tank. Piping connections between tanks should be arranged to facilitate efficient movement of water with minimum stirring action.

Water entering and exiting tanks at too high of velocity causes turbulence in the tank. Oversized pipes reduce velocity but may add undesired costs for oversized fittings that include isolation valves.

Pipe sizing between tanks must consider inflow rate and pipe sizing. Consider the following example.

Case Study: Pipe Sizing

A site in Birmingham, Alabama, wants to size conveyance piping between two tanks. The tanks are 5 feet apart from one another. The client wants to know if a 2- inch pipe will work.

We will assume that the maximum expected inflow rate of tank one will be 144 gpm based on the design of the system. The length of pipe is 5 feet, the friction coefficient is 140, and the inside diameter of 2-inch SCH 40 pipe is 2.067 inches (Table A.2). Use the friction equation to determine the maximum difference in water level between tanks one and two by plugging the variables into the friction loss equation.

$$Friction \quad Loss = 10.46L\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.871}}$$

Where;

L = length of pipe (ft)
Q = flow rate (gpm)
D = Actual pipe inner diameter (in)
C= friction coefficient (140-150 for PVC pipe)

$$Friction \quad Loss = 1.6\,ft = 10.46 \times 5 \times \frac{\left(\frac{144}{140}\right)^{1.852}}{2.067^{4.871}}$$

This tells us that at 1.6 feet of head the 2- inch pipe will convey the maximum expected inflow. This means that at the maximum expected inflow rate, the water level in tank one will be 1.6 feet higher than that of tank two.

This could warrant each tank to have an overflow. Tank one could fill and need to overflow before tank two fills. If tank one does not have an overflow, water will possibly back up into the gutter and downspout components.

If storage tanks are designed to overflow in to one another, the connecting pipes should be the same size as the inflow piping to minimize water loss.

RWH planners/installers have also connected tanks at the bottom and top to facilitate additional water flow (Figure 13.5). In all situations where tanks are tied together through piping, they must be on stable foundations and anchored to prevent movement. Any lateral or vertical movement can cause failure of rigid piping or the tank itself. Some installers have chosen to connect tanks using flexible PVC or tubing to minimize the risk of pipe failure due to tank movement.

Figure 13.5. Storage tanks tied in at the top.

Desired Features of Multiple Tank Systems

When connecting multiple tanks, isolation valves are recommended so that individual tanks can be taken offline while not interrupting flow from the tanks that remain online (Figure 13.6 and 13.7).

Isolation and piping of multiple tanks are complicated and need to be well thought out. When connected to the bottom of tanks, it is important to have valves located on each side of every tank to facilitate maintenance operations. If a component needs to be changed or a pipe is broken, the entire content of the tank does not need to be drained.

Figure 13.6. Isolation valves between tanks.

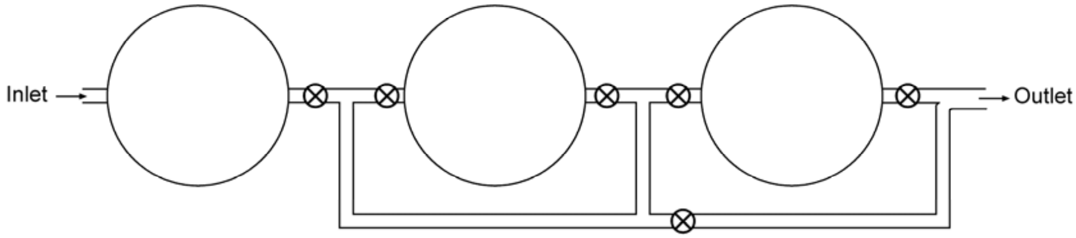

Figure 13.7. Isolation and by-pass piping of multiple tanks connected in series.

In the event that multiple tanks are connected together, there are methods for minimizing turbulence and maximizing the potential for settling of contaminants (Figure 13.8).

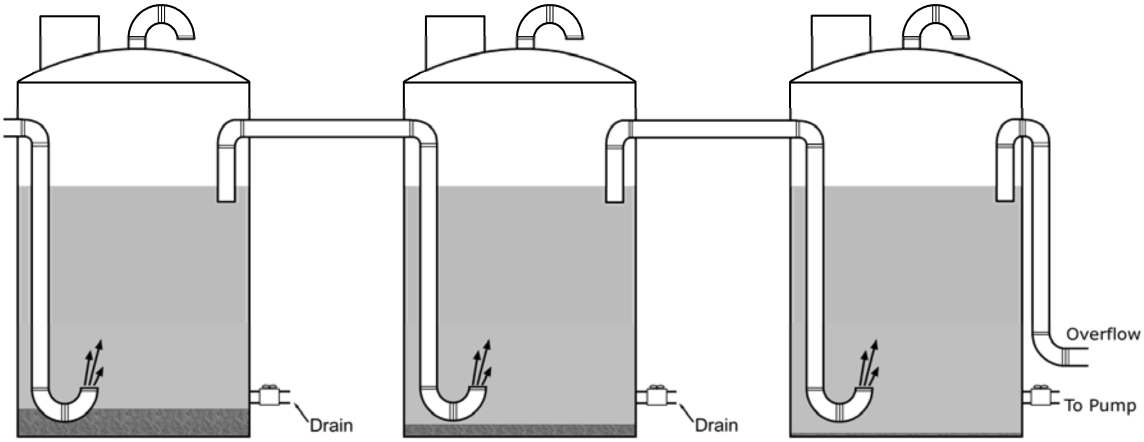

Figure 13.8. Multiple tanks connected in series to minimize turbulence.

Protecting Connections from Traffic

Many tanks, especially when multiple tanks are connected, have fittings, piping, and ancillary equipment at foot level on the ground. This poses tripping hazards for livestock and humans, and it can also be a detriment to system components if damaged. Place piping and fittings to minimize damage and restrict access to plastic piping that can be broken or protect exposed components (Figure 13.9).

When connecting multiple tanks, isolation valves are recommended so that individual tanks can be taken offline while not interrupting flow from the tanks that remain online.

Figure 13.9. Valves and piping are protected.

Summary

The RWH planner should be familiar with the benefits of dry conveyance systems as well as the impact that wet conveyance systems can have on water quality. Pipe sizing between tanks is important and a basic understanding of hydraulics is essential to planning an efficient system that depends on gravity. Proper sizing of pipes connecting multiple tanks and location of overflows will ensure that water does not back up in the system and cause problems.

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Exercise

Directions: Use the information and techniques provided in this chapter and the appendix to answer the following question.

1. A rainwater harvesting system is designed to convey water utilizing a wet conveyance system. The maximum flow expected is 150 gpm. If a total of 160 feet of SCH 40- 4 inch conveyance piping with 3 ells and a tee cleanout are utilized, what will be the water rise in the downspout? (hint: water flows through the straight run of the tee)

Rainwater Harvesting:
System Planning

14. Piping, Fittings, and PVC

The goal of this chapter is to engage the RWH system planner in the process of choosing the most suitable pipe material and connection methods. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Identify pipe materials.
2. Describe piping colors and intended use.
3. Identify high- versus low-pressure pipe and fittings.
4. Describe pipe specifications such as schedule, class and SDR.
5. Discuss IPS standard.
6. Interpret markings and labels on pipes.
7. Connect threaded pipe connections.
8. Measure, cut, and apply primer and glue to PVC pipe and fittings.
9. Determine appropriate trench width and bedding protocol.

Contents

14. Piping, Fittings, and PVC

Introduction

The plan of a RWH planner must include a means to convey water from the catchment area to all system components and eventually to the distribution system. Most conveyance systems consist primarily of plastic pipe and utilize gravity to move the water from one location to the next. Choosing the correct pipe is not simple; there are several choices of plastic pipe available and each has specific characteristics and functions.

Some plastic pipe is not designed to be pressurized while other pipe can withstand high pressures. Unfortunately, these differences are not easily recognizable. This problem is exacerbated by the fact that most of this pipe is white in color and can have the same outside diameter, making it seem to be interchangeable.

Polyvinyl Chloride

Polyvinyl Chloride (PVC) is the most common material used to make plastic pipe and fittings for the pressurized and non-pressurized conveyance of water. PVC piping and fittings have advantages over materials such as steel, aluminum, copper, and polyethylene. PVC pipes are easily installed due to their light weight and have smooth, seamless interior walls. Joints of PVC pipe are ordered in 10- and 20-foot lengths that can be cut with common hand tools that are outfitted with fine-toothed blades or solid wheels. Pipes and fittings are connected together using cement, threaded fittings, flanges, and gasketed ends. Installation costs of PVC systems are lower than copper or steel piping systems.

Polyvinyl Chloride (PVC) is the most common material used to make plastic pipe and fittings for the pressurized and non-pressurized conveyance of water.

PVC is approved by ANSI/NSF organizations for use with potable water partly because it has a smooth interior wall and is inert to attack by strong acids, alkalis, salt solutions, alcohols, and other chemicals. PVC is relatively corrosion free both internally and externally. Most white PVC pipe is not UV resistant and must be painted or otherwise protected from the sun to prevent damage from solar radiation. As a result of having smooth walls and resistance to corrosion and buildup, the pipe has relatively low friction loss. Thick-walled PVC has a high tensile strength, is resistant to impact, and can withstand high pressures for a long period of time. Regarding fire safety, PVC is self extinguishing and does not support combustion.

Acrylonitrile Butadiene Styrene (ABS)

Acrylonitrile Butadiene Styrene (ABS) is a plastic material used to make light, rigid, molded products such as children's interlocking building blocks, golf club heads, and clarinets. Pipes and fittings made from ABS are primarily used for drainage purposes. ABS pipe is made to conform to the ASTM D2661 standard that specifies ABS plastic pipe for drain, waste, and vent (DWV). ABS pipe and fittings can be made to interchange with PVC schedule 40 iron pipe sizes and fittings but is not pressure rated. In pressure applications, misuse can lead to injuries caused by a pipe bursting. ABS fittings are stamped with an ABS label and are recognizable because of their shallow sockets.

ABS pipe and fittings can be made to interchange with PVC schedule 40 iron pipe sizes and fittings but is not pressure rated.

Copper Pipe

Copper pipe has historically been used for potable plumbing inside homes. Copper pipe is susceptible to erosion due to the low pH of rainwater. If a rainwater harvesting system is being installed on a home with copper piping, it is recommended to retrofit the piping or raise the pH before the water reaches the copper piping. The pH can be raised in the storage tank or inline.

Markings for Pipes and Fittings

All PVC pipes have printed external markings along their length (Figure 14.1). Fittings are also marked by letters/ numbers integral to the mold. Pipe markings include the manufacturer's name or trademark, the standard to which it conforms (for example ASTM), the nominal pipe size, and the material designation code.

Figure 14.1. Example marking of ¾-inch SCH 40 PVC pipe. (CIDWT, 2008)

Pressure pipe is marked with the pressure rating; pipes used for drainage only are be marked with DWV for drain, waste, and vent. Schedule number or standard dimension ration (SDR) indicates type of pipe; some pipes are marked for potable water or drain, waist, and vent.

Nominal Size

The nominal size of a pipe is that which most people refer to when they identify a pipe by its size. The nominal diameter differs from the actual diameter of a pipe (Table 14.1). For instance, when one refers to a pipe as 2-inch PVC Schedule 40, the actual outside diameter is 2.375 inches and the inside diameter is 2.067 inches.

Table 14.1. Pipe inner diameter of various pipe specifications (Uni-Bell, 2001)

Nominal Diameter (in.)	Inner diameter in inches					
	Sch 40	Sch 80	SDR 26	SDR 21	SDR 13.5	(API) Flexible PVC
½	0.622	0.546			0.716	0.546
3/4	0.824	0.742			0.894	0.740
1	1.049	0.957	1.195		1.121	0.960
1 ¼	1.380	1.278	1.532	1.502	1.414	
1 ½	1.610	1.500	1.754	1.720	1.618	
2	2.067	1.939	2.193	2.149	2.023	
2 1/2	2.469	2.323	2.655	2.601	2.449	
3	3.068	2.900	3.230	3.166	2.982	
3 ½	3.548	3.364	-----	3.620	3.408	
4	4.026	3.826	4.154	4.072	3.834	

Iron Pipe Size Standard

The Iron Pipe Size (IPS) standard is used by the pipe manufacturing industry to produce pipes with compatible outside diameters. IPS pipes and fittings of the same nominal size are interchangeable even if made from different materials.

Schedule

The term schedule refers to the outside diameter of a pipe and is applied to pipes made from different materials such as PVC or steel. The outside diameters of pipes marked with the schedule designation are the same, but the wall thickness may vary greatly.

The outside diameter of a 2-inch Schedule 40 PVC pipe has the same outside diameter of a 2-inch Schedule 80 PVC pipe. Schedule 80 PVC pipe has a thicker wall and the inside diameter is less. Because of the smaller inside diameter, Schedule 80 pipe has less water carrying capacity.

Schedule 80 PVC pipe has a relatively thick wall, and therefore external threads can be cut into the pipe to allow connection to threaded fittings. Schedule 80 PVC is commonly used in

Schedule 80 PVC is commonly used in aboveground applications where damage from personnel, livestock, or equipment may occur. It is recommended that Schedule 80 be used when connecting centrifugal pumps and pressure tanks.

aboveground applications where damage from personnel, livestock, or equipment may occur. Schedule 80 should be used when piping is subjected to frequent vibrations or jolts. It is recommended that Schedule 80 be used when connecting centrifugal pumps and pressure tanks.

Standard Dimension Ratio

Another designation of pipe that refers to wall thickness and pressure rating is Standard Dimension Ratio (SDR). The SDR is the ratio of pipe diameter to wall thickness.

A pipe with an SDR of 26 has an outside diameter 26 times the thickness of the wall. The chart below compares SDR to pressure rating (Table 14.2). As the pressure rating increases, the SDR number decreases. It is recommended that SDR piping only be used in gravity flow conditions and with low-head pressures.

Table 14.2. SDR and pressure rating (CIDWT, 2008).

SDR	Pressure (psi)
41	100
32.5	125
26	160
21	200
13.5	315

Both SDR and schedule designated pipe have compatible outer diameters that are based on IPS specifications. An SDR pipe of the same outer diameter as a Schedule 40 pipe has a larger inner diameter and smaller wall thickness than the Schedule 40 pipe. Additional pipe specifications can be found in Appendix C.

Class Designations

Because schedule designated pipe changes pressure ratings as diameters and wall thicknesses change, the irrigation industry has required PVC pipe designated by a class system. A class designation is marked on the pipe and indicates the pressure rating of the pipe, regardless of nominal size. Popular class designations include 125, 160, and 200 psi ratings.

Reclaimed water and graywater should not be used as supplemental water for a RWH system that provides drinking water for human consumption.

Pipe Colors

Pipe coloring may indicate the contents, function, or intended use of a plastic pipe. In some cases, manufacturers market a specific pipe color to promote brand loyalty. Imported pipe is available in many colors. In the near future, federal, state, and local authorities will enact more specific requirements on pipe colors and uses for pipes that carry water.

Presently, purple and grey are the only two colors that indicate very specific uses typically found in the RWH industry. Other industry standards do associate colors to piping systems and purpose (Table

14.3). Unfortunately, not all installations are inspected nor do inspectors require installers to follow correct protocol.

Table 14.3. Common Industry Piping Colors System (CIDWT, 2008)

Color	Purpose
Purple	Reclaimed and non-potable water
White	Sewer and potable water
Green	Sewer and non-potable
Yellow	Natural gas
Gray	Electrical wiring
Red	Fire protection water
Orange	Communication

In some states, purple pipe is designated as a carrier for graywater or more specifically reclaimed water. Reclaimed water is municipal wastewater that has been sanitized at a sewage treatment plant but to a lesser degree than public drinking water standards. Water from purple piping systems should be managed as non-potable water but safe to handle and use for irrigation. Reclaimed water and graywater should not be used as supplemental water for a RWH system that provides drinking water for human consumption. Reclaimed water may contain some pathogens that typically are not found in a RWH system.

Safety of Grey Electrical Conduit versus White Plastic Pipe

Never install gray-colored pipe to carry water. Never use white or painted pipe to house electrical conductors. Exchanging gray and white colored pipe endangers utility workers, repair technicians, future system owners/operators, and others who may interact with your RWH or electrical system components.

Do not exchange gray for white or visa-versa even if the pipe is buried. If a RWH planner/installer suspects that pipes have been interchanged or intermingled into a system, then all electrical power should be disconnected and locked-out until pipe contents can be safely determined.

PVC Pipe and Fittings for PW or DWV

The National Sanitation Foundation (NSF) determines standards for marking PVC pipe to indicate whether it is for potable water or drain, waste, and vent. The NSF-pw (potable water) mark identifies the pipe for use with potable systems and the NSF-dwv mark identifies it for use as drain, waste, and vent. The pw/dwv demarcation is also relevant to fittings.

DWV fittings have shallow sockets compared to Schedule 40 fittings of same nominal size.

DWV pipe and fittings are designed for low-pressure applications. DWV fittings have shallow sockets compared to Schedule 40 fittings of same nominal size (Figure 14.2). The shallow socket provides less of a surface area for gluing and will leak or burst if subjected to pressure that is too high. DWV fittings are commonly made of ABS and can be glued to PVC pipe.

Connecting Lengths of Pipe

Lengths of plastic pipe, referred to as joints or sticks, are connected by threading or gluing overlapping ends or fittings together (Figure 14.3). The enlarged end of a pipe, known as a bell-end or socket, receives the smooth end of the pipe. Pipe can be ordered with or without bell ends. Smooth pipe (without bell ends) requires a fitting known as a coupling in order to glue two joints together.

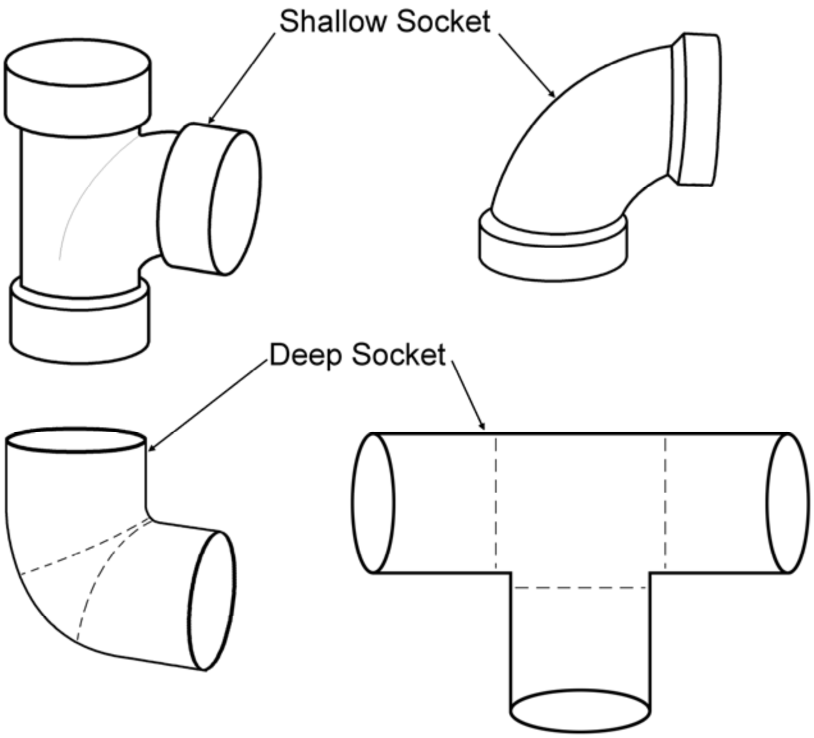


Figure 14.2. Shallow socket and deep socket fittings.

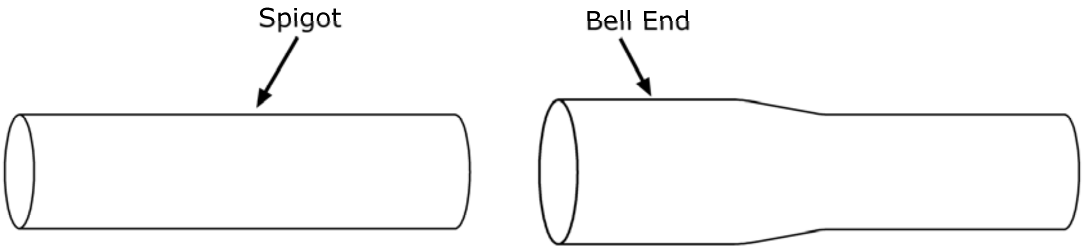


Figure 14.3. Bell end and smooth end of pipe.

Fittings

Pipe fittings are used to connect pipes together, change direction of flow, and provide a means to transition from one size to another or from glued to threaded connections. Fittings are stamped or marked to indicate material, intended purpose, and compatibility sizing such as IPS. Glued fittings have smooth sockets and are often referred to as slip fittings.

Machined bolts do not use NPT style tapered threads.

Threaded Fittings

Threaded fittings are marked with NPT (National Pipe Thread) to indicate compatibility with standard U.S. tapered pipe threads. Machined bolts do not use NPT style tapered threads. Fittings such as male/female adapters provide a means to transition from smooth pipe to threaded pipe or from plastic to steel.

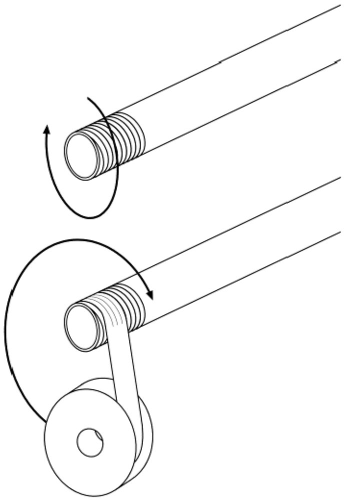
When transitioning from plastic to steel piping, the plastic fitting should have external threads, and the metal fitting should have internal threads. Threaded connections should be hand tightened to avoid damage to the plastic piping.

Sealing Threaded Joints

Leaks are common when plastic threads are used with metal fittings. To ensure a proper seal, Teflon tape or other PVC compatible pipe sealer should be utilized.

Tape or sealant is placed on the external threads, not on internal threads, prior to making the connection. Tape should be wrapped direction as the external threads so it does not unravel as the fittings are tightened (Figure 14.4).

When transitioning from plastic to steel piping, the plastic fitting should have external threads, and the metal fitting should have internal threads.



Tape should be wrapped in the direction on the external threads so that it does not unravel as the fittings are tightened.

Figure 14.4. Proper method of applying Teflon tape to external threads.

If you loosen or disconnect a threaded fitting, the tape and sealer must be removed and the threads cleaned before reapplying tape or sealer. Pipe joint compounds, pastes, or other thread lubricants are not recommended for use with PVC. Use of improper paste-type pipe sealant may result in the failure of the pipe or the fittings. Never use joint compound containing ammonia or chlorine on brass threaded fittings.

Storage and Handling

During storage, PVC pipe should be protected from direct sunlight, excessive heat, and potentially harmful chemicals. Solar radiation (ultraviolet light) damages exposed surfaces of white PVC pipe. Prevent long-term exposure by storing indoors or covering with an opaque tarp. UV-damaged pipe can be recognized by discoloration (yellowing) and loss of flexibility.

If stacked, thin-wall pipes should be placed on top of thick-wall pipes. Long joints should be supported throughout the length of pipe to prevent sagging and deformation. PVC piping is relatively resistant to damage during normal handling, but care should still be taken to prevent denting, scraping, or cracking during the loading, unloading, and storing. Damage can occur if the tie-down straps are over-tightened and if pipes are thrown or dragged. Contact with sharp objects should be avoided. Cracked pipes are not always apparent; individuals should inspect each joint of pipe before installation. If any section of pipe becomes damaged from mishandling or exposure to the sun, that section should be discarded.

Cutting PVC Pipe

Care should be taken when cutting PVC pipe, especially with power tools. Approved safety glasses (Z-87 OSHA) should be worn to protect eyes from flying pieces of PVC pipe when high speed tools or cutters are utilized. Never use a power saw that has a coarse blade (such as a blade for wood) installed to cut PVC pipe. Hand tools such as a ratcheting cutter prevent damage to the pipe and provide a clean surface for gluing (Figure 14.5).

Approved safety glasses (Z-87 OSHA) should be worn to protect eyes from flying pieces of PVC pipe when high speed tools/cutters are utilized.

Figure 14.5. Ratcheting PVC pipe cutter.

Steps for Gluing PVC Joints and Fittings

Solvent welding, commonly known as gluing, is the most common technique for adjoining PVC pipe and fittings that have slip joints. Primer and glue are carefully applied to each piece and when forced together, a chemical reaction occurs that fuses the pieces to form a very strong bond. Use solvents and primers in well ventilated areas because they release strong organic vapors that may cause dizziness. The process of preparing and gluing PVC pipe to a fitting is briefly described below.

1. Preparation: Look over the pipe to make sure it is not damaged. The pipe and fitting should be at the same temperature for at least an hour.

2. Cutting: The pipe must be cut square at the end. Measure the pipe and then cut it safely with a ratcheting cutter or saw with a fine-toothed blade.

3. Deburring: Make sure that all burrs/ridges resulting from cutting are removed with a deburring tool (Figure 14.6 and 14.7) or file (Figure 14.8). A ridge left on the end of the pipe will scrape cement from the inside of the fitting. Pipes in excess of 2-inch nominal diameter should be beveled 10 to 15 degrees on the end (Figure 14.8).

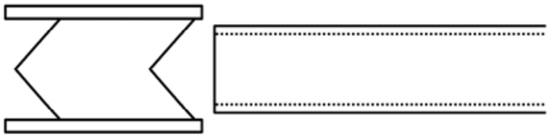


Figure 14.6. Removal of external burrs from PVC pipe (right) with deburring tool (left).

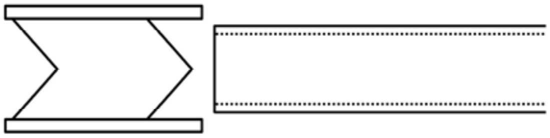


Figure 14.7. Removal of internal burrs from PVC pipe (right) with deburring tool (left).

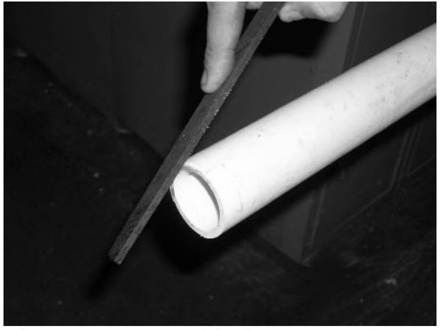


Figure 14.8. A file being used as a technique for beveling large diameter pipe.

4. Cleaning: The exterior and the interior of the pipe should be free of dirt, grease, and moisture. Water should not be flowing through the pipe, or the fusion process will be compromised.

5. Test the fit: Prior to applying primer or cement, assemble the fittings and pipes to ensure all measurements are correct. If the fittings and pipe fit together too tightly, it can be hard to pull them apart. The pipe should slide into the fitting at least one-third of the depth of the socket.

6. Applying primer: Apply primer neatly to all surface areas of the connections (Figure 14.9).

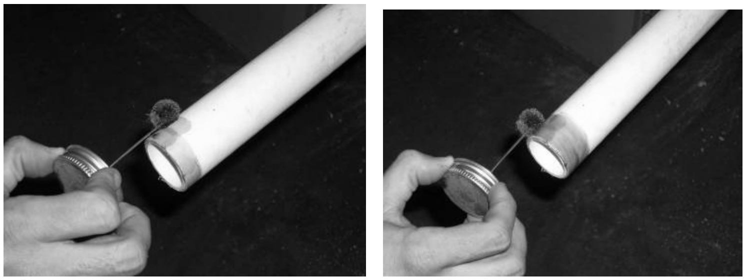


Figure 14.9. Applying primer to the end of a PVC pipe in preparation for gluing.

7. Applying glue: Apply 1 to 2 coats of cement to all surfaces (Figure 14.10). Apply more glue to the spigot end than the fitting or bell end to decrease the running of excess glue into the pipe or fitting.

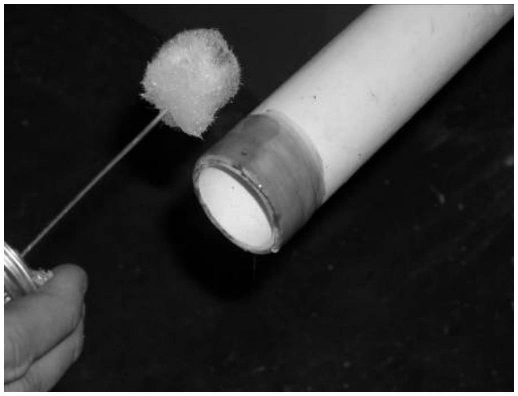


Figure 14.10. Application of glue to primed area of PVC pipe.

8. Connecting: Slip the pipe into the fitting while rotating the pipe one-fourth turn to distribute the glue evenly. Applied force is necessary to keep the pipe from backing out of the socket (up to two minutes in colder conditions) (Figure 14.11).

Slip the pipe into the fitting while rotating the pipe one-fourth turn to distribute glue evenly.

Figure 14.11. Sliding a fitting onto pipe, applying force, and rotating to distribute glue evenly.

Primer and Solvent for PVC

The use of primer for PVC pipe and fittings increases the likelihood of high quality connections. A suitable primer penetrates and softens PVC surfaces more quickly than cement alone. When the temperature is cold, the amount of primer should be increased, along with the time required for the surfaces to fully react, before the glue is applied. Make sure the primer does not puddle inside the socket. Read and follow manufacturer's label instructions. Installers should never substitute other chemicals or substances for use as a primer such as water, acetone, gasoline, diesel, or alcohol.

There are many different solvents on the market. They differ mostly by viscosity and color. It is important to make sure that the solvent used is appropriate for the pipe type, size, and air temperature. If the solvent is old, has a jelly-like appearance, or the viscosity has changed, discard it. Solvents should not be thinned by adding chemicals or substances.

Read the warning labels and take necessary safety precautions such as using eye and skin protective equipment and keeping the solvent and primer away from children.

Read the warning labels and take necessary safety precautions such as using eye and skin protective equipment and keeping the solvent and primer away from children.

In order to have an effective joint, enough cement must be applied to the inside of the fitting as well as the outside of the pipe to fill the gap between the pipe and fitting. The solvent will dissolve the surfaces of the pipe and fitting where it is applied. Do not allow the cement to puddle or run down the inside of the fitting or pipe. Excess cement increases friction loss in the pipe.

The pieces must be assembled quickly while the cement is still wet. If it dries before the pieces are connected, then more cement can be applied to reinitiate the process. Forcefully push the pipe into the fitting, turning a quarter turn to distribute the cement evenly. The connection needs to be held firmly for up to 2 minutes to prevent the joint from pushing apart. The excess bead of cement that forms on the outside of the connection has to be wiped off to prevent the cement from continuing to dissolve the pipe.

When the pipe is inserted into the fitting, the two surfaces fuse as the solvent evaporates. The joint will strengthen as the cement dries so the joint must be given the time required for curing before water pressure is applied. The joint should not be disturbed until it has initially set. The amount of time the joint needs to initially set depends on the air temperature. Table 14.4 shows the recommended initial set times. The joint should not be pressure tested until it has cured. The exact curing time varies with temperature, humidity, and pipe size. Table 14.5 shows suggested curing times. For humidity above 60 percent, allow 50 percent more cure time. Pipe should be pressure tested with water and not with air or other gasses.

Table 14.4 Initial set time for a cemented PVC joint. (Charlotte, 2007)

Temp Range	Pipe Size ½ in. to 1¼ in.	Pipe Size 1½-in to 3 in.
60° -100° F	15 min	30 min
40° – 60° F	1 hr	2 hr
0° – 40° F	3 hr	6 hr

Table 14.5. Minimum curing times for PVC cemented joints with relative humidity of 60% or less* (Charlotte, 2007)

Relative Humidity 60% or Less*	Pipe Size ½ in. to 1¼ in.		Pipe Size 1½ in. to 3 in.	
Temperature Range	≤ 180 psi	180-370 psi	≤ 180 psi	180-315 psi
60°-100° F	1 hr	6 hr	2 hr	12 hr
40°- 60° F	2 hr	12 hr	4 hr	24 hr
0°- 40° F	8 hr	48 hr	16 hr	96 hr

*For humidity above 60%, allow 50% more cure time.

Applicators for Glue and Primer

There are a variety of different types of applicators for the cement and primers. Daubers are usually used on smaller pipe sizes (Figure 14.12). Brushes can be used on any diameter pipe but should have natural bristles. Lastly, rollers are used for the larger pipes with a 4-inch or greater diameter. The width of the applicator's swath should be at least half the diameter of the pipe.

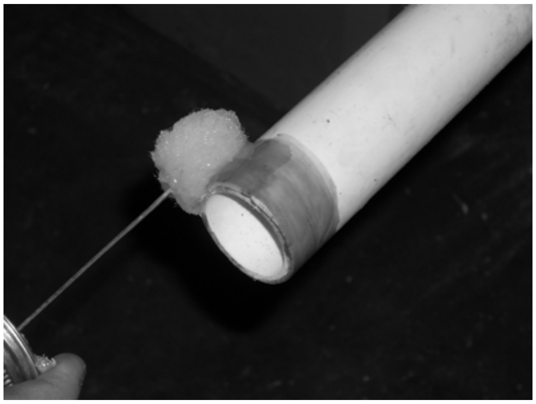


Figure 14.12 Using a dauber to apply glue to a primed PVC pipe.

Storage of Glue and Primer

The primer and cement should be stored away from heat or open flames with the lid closed. As a rule of thumb, the primer and cement should be used within one year of the date stamped on the container. Most importantly, all manufacturer recommendations must be followed.

The primer and cement need to be stored away from heat or open flames with the lid closed.

Trenching and Bedding PVC Pipe

Dig the trenches and prepare them in a way that the pipe will be protected from damage. Trench bottoms should be free of rocks and debris and provide uniform support. If there is ledge rock, hardpan, or large rocks on the trench bottom, the trench should be backfilled with 3 inches of sand prior to installing the pipe (Figure 14.13). The trench width should be cut twice the diameter of the pipe. In cold climates, the piping should be at a depth of 36 inches. The trench backfill should also be free of rocks and debris.

PVC has a low thermal conductivity, but is influenced by the temperature. PVC expands or contracts 3.36 inches for every 100 feet of pipe per every 100 degree Fahrenheit change in temperature. To compensate, the pipe can be snaked from side to side in the trench. Also, install the pipe and backfill the trench during the cool part of the day.

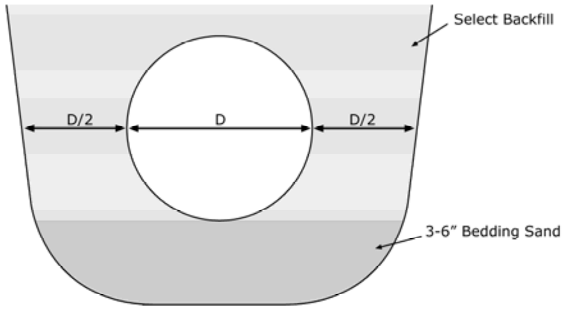


Figure 14.13. Backfill and bedding on PVC pipe.

Summary

Plastic piping is an essential element of the RWH system. Almost every device from the downspout to the sanitation system is connected to PVC pipe or fittings. RWH systems require high- and low-pressure piping, and the consequences of using low-pressure fittings or piping with high-pressure can result in severe injury to a bystander. RWH planners need to be familiar with connection techniques and able to identify the performance specifications of specific pipe and fittings.

Reference

CIDWT. 2008. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Pilot Test Version 2. March 2008.

Charlotte. 2007. Industrial Technical Manual. Charlotte, N.C.: Charlotte Piping and Foundry Company. Available at http://www.charlottepipt.com/Documents/Industrial_Tech_Manual/Industrial_Tech_Manual.pdf. Date Accessed: June 16, 2008.

Rainwater Harvesting: System Planning

15. Pumps and Controls

The goal of this chapter is to engage the RWH system designer in the process of choosing a pump based on performance, type, and application. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Understand advantages of different types of pumps.
2. Convert between psi and feet of head.
3. Use pump curve to identify performance characteristics.
4. Describe pump operating characteristics.
5. Identify pump type.
6. Describe pressure loss and gain as result in differences in elevation.
7. Properly size a pump based on system characteristics.

Contents

15. Pumps and Controls

Introduction

Just as the storage tank is the heart of the RWH system, the pump is the most crucial component of a pressurized distribution system. A pump provides the pressure required to overcome all system losses and satisfy the end user. Inadequate pressure results in poor performance and a disappointed client. Pumps are sized by performance specifications of a certain flow rate at a given pressure.

Pumps are usually either good at producing a high flow rate at a low pressure or a low flow rate at a high pressure. Overall system pressure is affected by changes in elevation and friction losses as water flows through piping, filters, and other components. Understanding a few simple pump operating characteristics can help a RWH planner determine the correct pump for a given set of circumstances.

Pressure and Feet of Head

Most people talk about water pressure in terms of pounds per square inch (psi). This is the same unit that is used to describe the pressure in the tires of a car. Pump manufacturers, however, generally speak in terms of feet of head (Head-ft) when describing the pressure provided by a pump.

Feet of head or head is simply a different unit for pressure. One can easily convert from pressure in psi to pressure in feet of head. 1 psi is equivalent to 2.31 feet of head (HD-ft) and 1 HD-ft is equivalent to 0.43 psi. Table 15.1 illustrates pressure equivalents in psi and HD-ft. Referencing the table can determine that a pump that provides 92.4 HD-ft is supplying a pressure of 40 psi.

Table 15.1. Conversion for pounds per square inch (PSI) and head (HD) in feet.

PSI	Head (ft)
0.433	1.0
1	2.31
5	11.5
10	23.1
15	34.6
20	46.2
25	57.7
30	69.3
35	80.8
40	92.4
45	104
50	115
55	127
60	138
65	150
70	162

Elevation and Pressure

The term “feet of head” originated from the study of the pressure that is exerted at the bottom of a column of water. A water column that is 150 feet tall, regardless of its width or surface area, provides 65 psi of pressure at the base. In other words, a pump would need to provide 65 psi of pressure to pump water over a 150-foot-tall hill.

Most cities provide their residents with 50 to 70 psi of water pressure. This is why water towers are usually about 150 feet tall and built on the tallest hill above the city.

Another application of pressure from elevation is to look at a full rain barrel and determine how much water pressure it can provide to a drip irrigation system.

A 4-foot-tall barrel full of water has a hose bib at the bottom and is connected to a drip emitter at the same elevation (Figure 15.1). Referring to the previous table that compares psi and head, we can determine that the emitter would be supplied with approximately 1.7 psi. Once the barrel is half full, the psi drops to 0.87 psi.

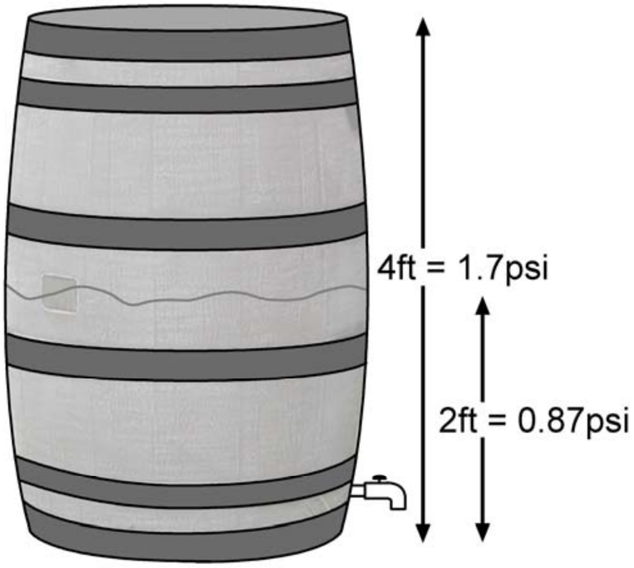


Figure 15.1. Rain barrel water pressure at varying water levels.

Total Dynamic Head

The Total Dynamic Head (TDH) of a pump is the maximum pressure that a pump provides considering static head, pressure head, and friction loss. The static head is the overall vertical distance (upward change in elevation) that a pump must overcome to deliver water to a certain location.

The pressure head is the amount of pressure that the pump must provide at the discharge location. The friction loss is the pressure required to overcome friction in the piping and fittings. The following scenario illustrates these characteristics.

The Total Dynamic Head (TDH) of a pump is the maximum pressure that a pump provides considering static head, pressure head, and friction loss.

Case Study: Pump for Irrigation System

A RWH planner wants to pump water from a storage tank to a drip irrigation system. The pump is located at the base of the tank, and the irrigation system is approximately 40 feet above the pump (Figure 15.2). The drip emitters require a pressure of 25 psi in order to work properly and the entire drip system demands 10 gpm. Piping consists of 60 feet of 1-inch SCH 40 PVC pipe. How much TDH must the pump provide?

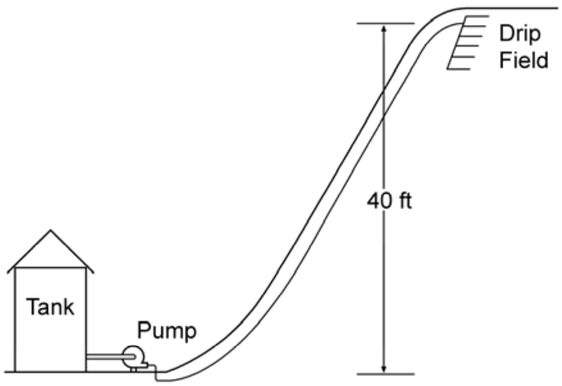


Figure 15.2. Pump supplying water to a higher elevation drip field.

Solution and Answer:

Total dynamic head (TDH) = static head + pressure head+ friction loss

Static head is determined simply by converting the vertical distance in feet to psi.

Static head = 40 HD-ft or 17.3 psi

Pressure head is given by the required emitter pressure of 25 psi.

Pressure head = 57.7 HD-ft (25 psi)

Friction loss is determined by looking at Table A.3. The friction loss in 100 feet of 1-inch SCH 40 pipe at a flow rate of 10 gpm is 6.35 feet of head. This needs to be adjusted for our length of 60 feet. In order to do this, simply multiply 6.35 feet by 60 and divide by 100. This value can be converted to psi by multiplying by 0.43.

Friction loss=6.35 HD-ft x 60/100 x 0.43= 3.8 HD-ft

3.8 HD-ft x 0.43 psi/HD-ft= 1.6 psi

The total dynamic head is then determined by adding static head, pressure head, and friction loss.

TDH = 17.3 psi + 25 psi + 1.6 psi = 43.6 psi

Suction Head

Water pumps are designed to push water, rather than to pull water. When a pump is located above a water source, the pump must pull the water up to the impeller. This is a difficult task for a pump and can reduce the overall operating characteristics (i.e. reduce output pressure or volume).

The term “suction head” is used to describe the pressure required to pull the water into the pump housing. Thirty-three feet is the theoretical maximum height that a pump can lift water, but basic centrifugal pumps should not be required to pull water vertically over a distance of 7 feet. Wherever possible, pumps should be located with respect to the water source such that gravity forces water into the pump housing.

When the suction head is excessive, a condition known as cavitation takes place in the pump impeller housing. Cavitation occurs when bubbles of air and water vapor implode at or near the impeller surface, causing noise, vibration, and the pitting of the impeller surface.

Flow Rate

Besides overcoming potential pressure losses (TDH and suction head), the pump must also provide an adequate amount of water. The flow rate of a pump is another pump operating characteristic and is usually reported in gallons per minute (gpm).

The flow rate provided by a pump is influenced by the size of the impeller and the amount of pressure that is needed. As the pressure requirement goes up, the flow rate drops on a given pump. Pump flow rate in relation to pressure loss is shown graphically by most manufacturers on a pump curve (Figure 15.3).

Every pump has a different pump curve and should be evaluated to ensure that it will perform adequately. As long as the operating point is below the pump curve, the pump has the capability to supply the needed flow rate at the appropriate pressure.

Every pump has a different pump curve and should be evaluated to ensure that it will perform adequately.

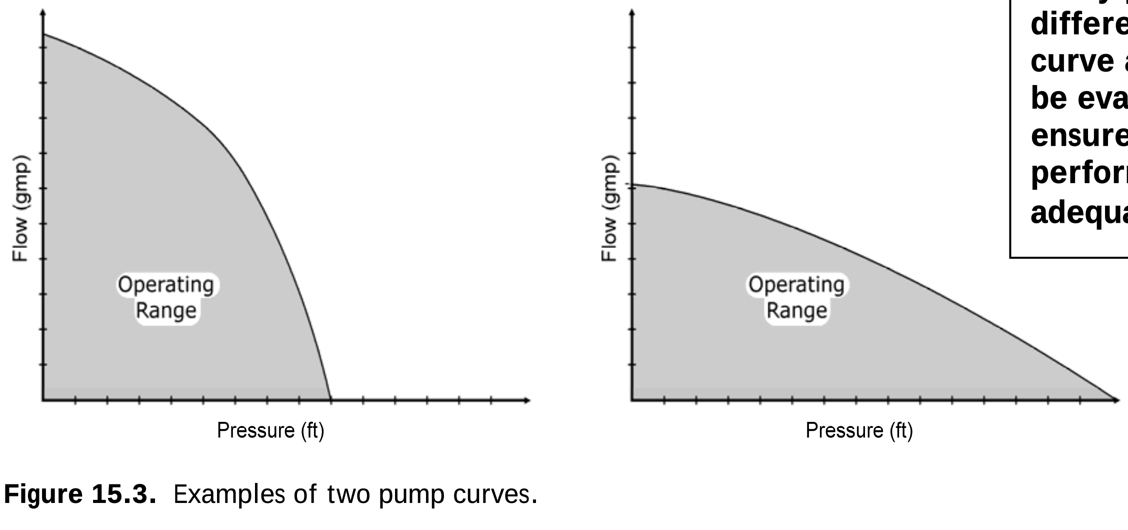


Figure 15.3. Examples of two pump curves.

Basic Pump Parts

There are several basic parts common to most pumps (Figure 15.4). Permanently installed pumps are usually driven by an electric motor and portable pumps are powered by an internal combustion engine (gasoline or diesel engine). A case or pump housing surrounds the impeller which is turned by a shaft from the power source. The pump housing has an inlet (suction) and an outlet (discharge) that is usually fitted with external pipe threads.

If the inlet/outlet is a nominal 2 inches in diameter, then the pump may be referred to as a 2-inch pump. If the pump is powered by a 3-horsepower motor, then it may be referred to as a 3-horsepower pump. Although these are common references, they do not describe the pump operating characteristics that are critical to performance.

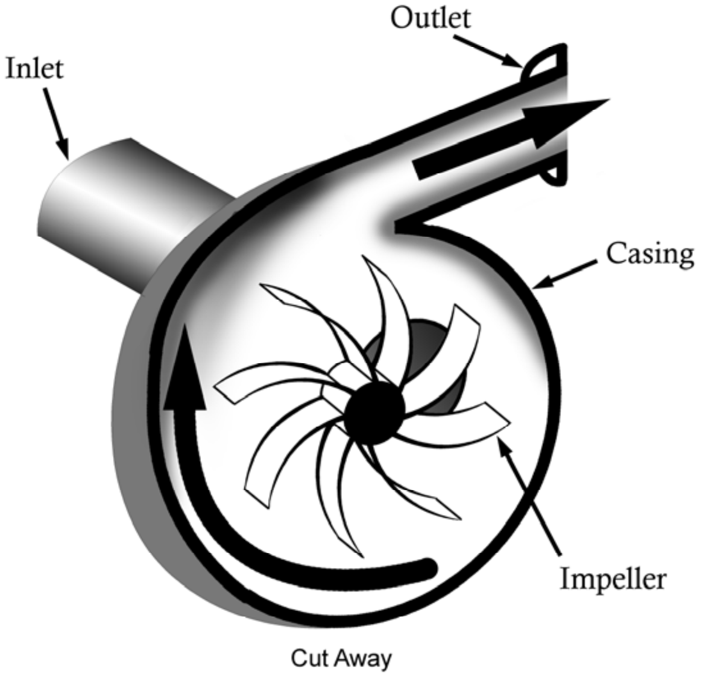


Figure 15.4. Cut away diagram of a centrifugal pump.

Self-Priming Pump

A self-priming pump does not have to be primed by flooding the pump housing with water prior to starting the motor. The convenience of a self-priming pump means it is designed to pull water into the housing, even if the pump is located above the water source. Self-priming pumps are more costly but do not require a foot valve that keeps the intake flooded.

Pressure Tanks

A pressure tank’s purpose is to keep extra water available so that small demands on the system do not trigger the pump to switch on and off for every demand (Figure 15.5). The pressure tank prolongs the life of a pump by decreasing the number of required pump cycles, thereby avoiding the rapid cycling of the pump. This allows the stored water to meet the total demands of the system without over-working the pump. The air pressure in a pressure tank can be checked at the pre-charge valve. Follow manufacturer's recommendations when pressurizing the tank. An over pressurized bladder can burst.

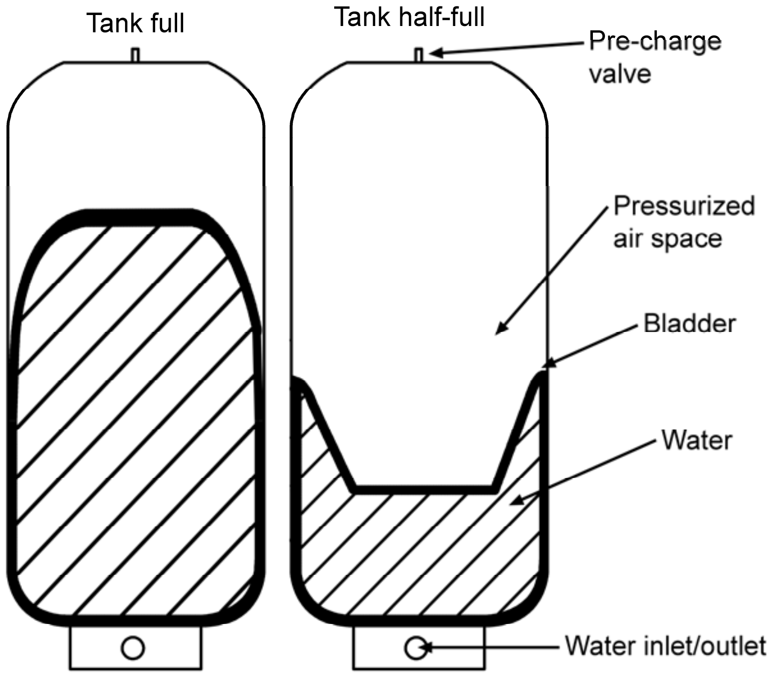


Figure 15.5. Diagram of a pressure tank.

On-Demand/Constant Pressure Pump

On-demand or constant pressure pumps are specifically designed to cycle on and off as demand requires. On-demand pumps do not need a pressure tank.

Pump DOs and DON'Ts

- When plumbing a centrifugal pump, enlarge both the inlet and the outlet one to two sizes in order to minimize the effects of friction loss. This is especially critical on the suction side when pulling water vertically up to the pump housing.
- Never install a direction-changing elbow within a distance from the suction or discharge opening less than the equivalent of 3 to 4 diameters of the openings.
- Keep velocity on suction side to a minimal. Do not exceed 3 fps.
- Pumps should be secured to a slab using rubber mounting bushings. Piping that is connected to a pump should accommodate potential movement or vibration that occurs during operation.

- Except for a coarse screen on a suction pickup, place all filtering devices on the discharge side of the pump.

- Oversize all suction pickup screens to minimize suction side losses.

- For pumps that are **not** designed for on-demand or constant pressure, it is better for the electric motor to run for several minutes rather than starting and stopping it several times in a 10-minute period.

- Use metal/brass fittings when entering or exiting pumps.

- Follow manufacturer recommendations and guidelines when installing and using pumps.

Summary

Choosing the best pump for a client's needs requires matching a pump's operating characteristics to the pressure and flow demands of a system. A RWH planner should become familiar with the total dynamic head and suction head in addition to the effects that elevation changes can have on a system. In addition to choosing the correct pump, the planner must follow the simple installation rules to maximize pump performance without hampering flow or decreasing pressure.

Rainwater Harvesting: System Planning

16. Sanitation

The goal of this chapter is to engage the RWH system planner in the process of developing a comprehensive strategy for sanitizing rainwater. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Discuss Environmental Protection Agency guidelines for potable water.
2. Identify public and non-public drinking water supplies.
3. Identify EPA regulated and non-regulated contaminates for PDWSs.
4. Define SOCs, VOCs, and other common terms used in sanitation.
5. Choose sanitation devices to suit client expatiations.
6. Describe sanitation performance specifications and related ANSI/NSF and other applicable standards.
7. Know proper installation methods for sanitation devices.
8. Plan a treatment train for sanitizing an in-home potable water system.
9. Discuss and test cross connections.
10. Discuss types of treatment.

Contents

16. Sanitation

Introduction

Sanitation is the most important, complicated, and controversial topic related to rainwater. The main concern of the client is “When is my water safe to drink?” Although rainwater is generally thought to be very safe, water is a great medium for harmful pathogens to survive and prosper.

History shows us that many of the past disease outbreaks have involved water. Presently, thousands of people die or become very ill each year due to a lack of clean water. However, water is relatively easy to sanitize and, in fact, clean rainwater may be a significant factor in improving drinking water for peoples around the world. The RWH planner, regardless of applicable or non-applicable regulation for private drinking water systems, is responsible for providing technical performance specifications for sanitation equipment to the client. A client should be informed of the level of protection (or risk) that a treatment strategy affords for a given RWH system.

A client should be informed of the level of protection (or risk) that a treatment strategy affords for a given RWH system.

Regulatory Authority and Planner/Installer Responsibility

The Environmental Protection Agency (EPA) along with other governmental agencies have the authority to regulate the quality of water for public drinking water systems. However, these governmental agencies do not regulate non-public, potable water systems. It is the joint responsibility of the planner and installer to ensure that an adequate system is in place and correctly installed to protect individuals that may drink or come into contact with potable water. After the installation, inspections, and the testing of the system, it is the responsibility of the system owner and/or operator to service and maintain system components in order to best protect users from contaminants, including microorganisms.

Besides the EPA and state agencies, other entities offer recommendations for safe drinking water. The following are website links to organizations that provide information and certification of home treatment systems and devices:

- NSF International: http://www.nsf.org/
- Water Quality Association: http://www.wqa.org/
- The Underwriters Laboratories, Inc.: http://www.ul.com/water/

Safe Drinking Water Act

In 1974, Congress passed the Safe Drinking Water Act (SDWA) to protect public health by regulating the nation's public drinking water supply. Subsequent amendments, as recently as 1996, have enhanced protection of drinking water and required states to protect drinking water sources such as rivers, lakes, reservoirs, springs, and ground water wells. The EPA is authorized by the SDWA to set national health-based standards for drinking water and protect users from naturally occurring and man-made drinking water contaminants.

Ninety chemical, microbiological, radiological, and physical contaminants are presently regulated by the EPA (US EPA, 2009) (Table A.9). In addition, the EPA supports research efforts to identify unregulated contaminants that potentially pose a health risk and may be regulated in the future.

Some contaminants do not pose a health risk to humans, but instead cause skin and tooth discoloration (cosmetic effects) or affect the taste and odor of the water (aesthetic effects). The EPA oversees and sets Secondary Drinking Water Regulations (SDWRs) (Table 16.1), which are non-enforceable guidelines for these types of contaminants. Public water system operators are not required to adhere to the EPA secondary standards, but states may choose to adopt and enforce them. Planners should review state regulations regarding contaminants that are referred to in the EPA SDWRs.

Runoff Water Quality

Understanding the quality of runoff from rooftop surfaces and their potential for public health concerns reinforces the need for proper treatment and sanitation of collected rainwater. Microbial contamination and other water quality problems associated with rainwater harvesting systems are most often derived from the catchment area, conveyance system, or storage components (Lye, 1996).

Microbial and Viral Contamination

Bacterial and viral contaminants found in collected rainwater can lead to gastrointestinal, respiratory, blood infections, and stomach ulcers (Koplan, 1978; Schlech, 1985; Moore, 1995; Klein, 1991). These contaminants are most likely transferred to the catchment surface as a result of contact with animals such as birds, rodents, and insects. Typical, healthy adults tend to tolerate the low levels of bacteria that are present in properly maintained rainwater harvesting systems (Lye, 1996) although the effect of these contaminants, just like others, are amplified in the very young, elderly, and those with weakened immune systems. One-hundred and twenty-five individual residential rainwater collection systems were sampled by Simmons et al. (2001) and microbial pathogens such as aeromanas, cryptosporidium, and salmonella were found in samples.

Massey University in New Zealand conducted a 5 year study of microbial roof water quality from individual homes (Abbott et al., 2008). The study collected samples from 560 homes and determined that at least half of the samples exceeded the local acceptable standards. It was also found that more than 40% of the samples were found to have heavy fecal contamination (Abbot et al., 2008). In these systems, Abbot et al. (2008) found evidence that they were poorly maintained, collected water was not properly disinfected, the conveyance and storage components were poorly designed, and in most cases, even simple measures were not taken to ensure the quality of the water. The likely sources of the problems were determined to be deposition of fecal material and dead animals and insects on the roof, in gutters, and in storage containers.

A study conducted by Abbott, et al. (2006) testing 6 different devices designed to reduce microbial contamination on 6 different tanks, concluded that a tank linked to a first flush diverter yielded very low counts of total coli-forms and Escherichia coli during the study. Abbott, et al. (2006) stated that high levels of these constituents were found in the diverter. This result suggests that first flush diverters are effective in reducing microbial contamination in stored rainwater.

Chemical Contamination

Many volatile chemical and organic compounds have also been found to be present in rainwater harvesting systems across the world. Water samples from roof tops along major transportation routes inside Gdansk, Poland were taken and analyzed for petroleum hydrocarbons, volatile organohalogen compounds, and various pesticides and ions (Polkowska et al., 2002). This study revealed that more than half of the samples taken tested positive for elevated levels of the contaminants in question.

Chemical characteristics of rainwater and rainwater runoff samples in Xanthi, Greece were collected by Melidis et al. (2007). In order to get a representative sample of data, ten sites within the city were selected and sampled that represented various land uses, densities, and traffic volumes. Two years of data and 130 samples were collected. Although rooftop runoff was found to have higher chemical pollutant levels than that of the rainwater alone, Melidis et al. (2007) reported that both were below levels set forth by the Grecian drinking water guidelines.

A study performed by Simmons et al. (2001) found that 14% of 125 rural homes tested had high levels of lead in their collected rainwater that exceeded New Zealand standards for drinking water. In the same study, 1% of the sites were found to exceed zinc guidelines and 2% were found to exceed copper guidelines.

Testing Water

The EPA specifies the analytical methods used to analyze drinking water samples. The laboratories that carry out the analyses are certified by an appointed governmental regulatory agency or the EPA. Testing protocols vary depending on the number of people served, contaminant group, and source of raw water. Water systems are also tested for non-regulated contaminants to help determine which contaminants may be regulated in the future. Because of the diversity of contaminants and contaminant levels throughout the United States and the autonomy that each state has to regulate testing, system operators may find that they are required to test for items not mentioned in this manual.

The EPA does not currently require non-public water supplies to be tested, but installers and planners should check state regulations.

Frequency of Testing

The EPA does not currently require non-public water supplies to be tested, but installers and planners should check state regulations. The frequency in which public water supplies are tested and monitored depends on the system, the source of the water, and contaminants; this ensures all federal and state standards are met.

The EPA recommends testing private well water annually to determine if it meets minimum federal and state standards. In contrast, public water systems that utilize surface water, including rainwater, must adhere to monitoring protocols that may require daily sampling and testing of both source and supply.

Harvested rainwater used for non-public drinking water should be tested at least once each year. Certified testing laboratories may be found by calling the Safe Drinking Water Hotline at 1-800-426-4791 or reviewing the Safewater website: http://www.epa.gov/safewater/labs/index.html.

Harvested rainwater used for non-public drinking water should be tested at least once each year.

Table 16.1. EPA National Secondary Water Standards (US EPA, 2009)

Contaminant	Secondary Standard
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 (color units)
Copper	1.0 mg/L
Corrosivity	noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number
pH	6.5-8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

Health Effects and Higher Risk Populations

Adverse health effects from contaminated drinking water are differentiated by acute and chronic impact. Some contaminants cause acute disorders such as diarrhea or an upset stomach, while chronic effects may occur as a result of long-term ingestion of certain contaminants.

Infants, young children, and individuals who are not in good health because of illness, age, or a weakened immune system may be at a higher risk as a result of the presence of contaminants and/or increased contaminant levels.

A health care provider should be contacted when persons who are in a higher risk population are drinking harvested rainwater, regardless of the techniques and processes used in the sanitation system. For some individuals, the benefits of utilizing potable water that originated from rainwater may be offset by an increased health risk.

Infants, young children, and individuals who are not in good health because of illness, age, or a weakened immune system may be at a higher risk as a result of the presence of contaminants and/or increased contaminant levels.

EPA Definition: Public Water Systems

Public Water System (PWS): *A public water system is a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly services at least twenty-five individuals.*(US EPA, 2009)

Community water system (there are approximately 54,000 in the United States): *A public water system that serves the same people year-round. Most residences including homes, apartments, and condominiums in cities, small towns, and mobile home parks are served by community water systems.* (US EPA, 2009)

Non-community water system: *A public water system that serves the public but does not serve the same people year-round.* (US EPA, 2009)

Non-transient, non-community water system (there are approximately 20,000): *A non-community water system that serves the same people more than six months per year but not year-round (for example, a school with its own water supply is considered a non-transient system).* (US EPA, 2009)

Transient non-community water system (there are approximately 89,000): *A non-community water system that serves the public but not the same individuals for more than six months (for example, a rest area or campground may be considered a transient water system).* (US EPA, 2009)

Treating Raw Water

Harvested rainwater should be similar in quality to surface water, which the EPA considers more likely to be contaminated than ground or well water. Federal and state regulations require that all surface water be treated that is to be used in a public water system (PWS). It is imperative that all harvested rainwater that is intended for potable water (drinking water) be treated effectively to minimize the risk of causing adverse health effects to individuals. Treatment schemes vary from system to system and are only effective if designed, installed, and maintained properly.

It is imperative that all rainwater that is harvested and intended to be used as potable water (drinking water) be treated effectively to minimize the risk of causing adverse health effects to individuals.

Contaminants, including those that pose dangerous health effects and negative cosmetic or aesthetic outcomes, can be removed by filtration, sorption, or inactivated by exposing them to a disinfectant. The devices used in the treatment process are arranged in a particular sequence and referred to as a treatment train.

An example of a treatment train for a personal drinking water system that derives its water from rain might be composed of the following devices: screening, sedimentation, filtration, ultraviolet light exposure, chlorination, and anti-corrosion additives (Figure 16.1). Each device in a treatment train should have a specific purpose to reduce levels of, or eliminate contaminants.

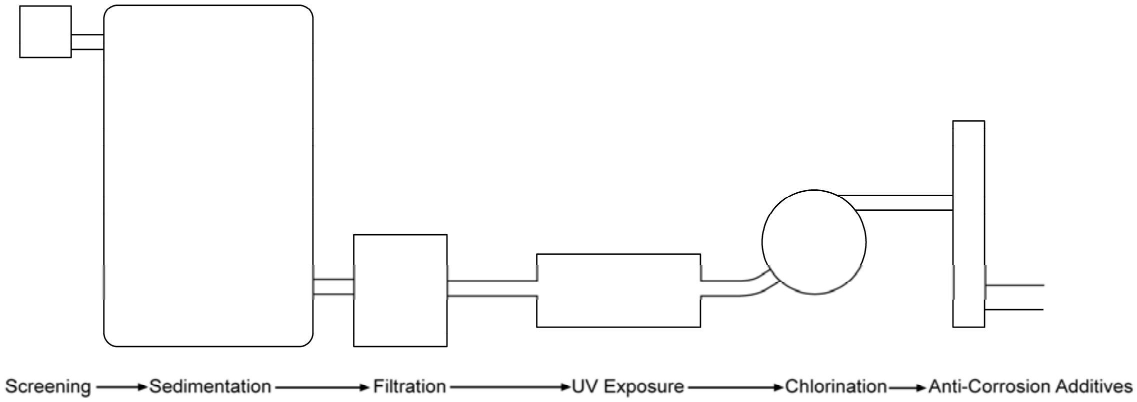


Figure 16.1. Treatment train schematic.

System planners, installers, and individuals responsible for maintenance should obtain at least a basic understanding of pathogenic microbes and whether filtration (direct removal), sorption, or inactivation by disinfectant is the best treatment method. Of course, overlapping treatment techniques provide a measure of comfort in knowing that risk from a contaminant has been minimized.

Although devices that are not certified by an EPA-recognized organization, such as the NSF, are successfully used throughout the United States to protect individual rainwater systems used for drinking, it is recommended that only certified devices be used.

Suppliers and manufactures of certified devices provide installers and users with performance specifications that include the amount and type of contaminant removal or disinfection of microorganisms.

Although devices that are not certified by an EPA-recognized organization, such as NSF, are successfully used throughout the United States to protect individuals drinking rainwater, it is recommend that only certified devices be used.

Types of treatment

Flocculation/Sedimentation

Although not normally used on a small water treatment system, flocculation is a process where alum and iron salts or synthetic organic polymers are introduced to the water. These additives promote coagulation of the small particles into larger particles, causing them to settle or sediment, thereby making the flocculated particles easier to remove from the water.

Table 16.2. Filtration technologies and microorganism removed.(Check with manufacturer to determine contaminants removed.) (Adapted from: TCEQ, 2007)

Filtration Technique	Microorganism Removed
Reverse Osmosis	Protozoa, protozoal cysts, bacteria, and viruses
Nanofiltration	Protozoa, protozoal cysts, bacteria, and viruses
Ultrafiltration	Protozoa, Giardia, >5-6 log
Microfiltration	Protozoa, Giardia, >5-6 log
Cartridge filter	Protozoa
Bag filter	Protozoa

Filtration

Large-scale treatment facilities often times use filtration to remove all particles from the water (Table 16.2). Besides microorganisms, particles that are removed include clays, silts, natural organic matter, precipitates from other treatment processes in the facility, iron, and manganese. Filtration clarifies water and enhances the effectiveness of UV disinfection. Filtration systems that utilize back flushing as a means to self-rinse the filter membrane or element utilize and discard a substantial amount of water.

Ion Exchange

Ion exchange processes are sometimes used in large PWSs to remove inorganic contaminants and to treat hard water. Arsenic, chromium, excess fluoride, nitrates, radium, and uranium can also be removed with an ion exchange process.

Adsorption: Activated Carbon

Adsorption is a process where a substance, such as an organic contaminant (Figure 16.2), is attracted to the surface of a material like activated carbon. This process is efficient in supplementing a water purification system because volatile organic chemicals (VOCs) and synthetic organic chemicals (SOCs) are easily attracted to activated carbon. Filters provide varying degrees of surface area, and as this increases, the more contaminants can be captured. It is recommended that an ANSI/NSF certified activated carbon filter be utilized.

Carbon filters are not a primary sanitation device and should be employed in addition to devices in an effective sanitation train. Maintenance or replacement of a carbon filter is necessary. Because activated carbon filters trap VOCs and SOCs, the carbon filter should be placed upstream of the chlorinator and UV systems, unless it is desirable to remove chlorine from the water.

If a carbon filter is used to remove chlorine from the water, care must be taken to properly size the carbon filter. If the filter is not properly sized, it will not effectively remove chlorine. Sufficient contact time between the water and filter must be achieved, meaning the filter will not work properly if the water flows through it too fast.

Figure 16.2. Animals are one source of organic contaminants on the surface of catchments.

Chlorination

Chlorine has been used to effectively treat drinking water in the U.S. Chlorine can be added to water in a dry, liquid, or gas (not recommended) form and kills most microorganisms and is especially effective against viruses. A notable benefit from the use of chlorine is its ability to continue to protect the water supply system even after long storage intervals or while treated water moves through the distribution system.

It is recommended that chlorine devices used in home drinking water systems be certified and meet ANSI/NSF Standard 60. If activated charcoal filters are employed in the treatment train, chlorinators should be placed downstream. Chorine, unless removed, provides a disinfectant residual and protects the distribution system against bacterial regrowth.

Although chlorination is relatively simple, three variables have an impact on the effectiveness: water pH, temperature, and concentration level. The contact time varies with pH and water temperature (Table 16.3).

Only chlorine compounds that are certified in accordance with ANSI/NSF Standard 60 requirements should be used. Calcium hypochlorite, the solid form, can be purchased in pellets, tablets, and granules. Sodium hypochlorite bleach is a liquid.

Only chlorine compounds that are certified in accordance with ANSI/NSF Standard 60 requirements should be used.

Presently, NSF only certifies some liquid bleaches and most can only be purchased in large volumes. Review the NSF website (http://www.nsf.org/certified/consumer/listings_main.asp) for an updated list of manufacturers. Bleaches that contain fragrances or UV stabilizers are not likely to be certified and should be avoided. Most bleach products intended to be used in swimming pools likely contain cyanide-based UV stabilizers and should be avoided.

Table 16.3. Chlorine concentration and sanitation level. (Adapted from: TCEQ, 2007)

Percent Inactivation	Contact Time (minutes) and Pathogen		
	Virus	Giardia	Cryptosporidium
67.00	0.25	9.00	Not effective
90.00	0.50	19.00	Not effective
99.00	1.00	37.00	Not effective
99.99	3.00	75.00	Not effective

Note: Chlorine is ineffective against treating Cryptosporidium

The EPA has recognized several by-products that result from the use of chorine and individuals may choose to de-chlorinate their water after treatment or at the faucet. Of course, once chlorine is removed from the system, the water supply is no longer protected if pathogens are introduced downstream of the sanitation train.

The water in some tanks may produce a biofilm, which is a structured community of microorganisms. At this time there is not enough scientific data available to determine its value. Studies are currently being conducted in Australia to learn more about the possible benefits of biofilms in rainwater. The addition of chlorine interrupts the lifecycle of the microorganisms and destroys the biofilm.

Ozonation

Ozonation disinfects by introducing ozone gas to the water supply. This is commonly done at the point where the water is used in the distribution system or in the storage tanks. Ozone (O_3) is a triatomic allotrope of oxygen (O_2) formed as O_2 molecules are exposed to electrical voltages. During ozonation, three O_2 molecules are combined to form two O_3 molecules. Ozone quickly reverts back to O_2 and, like ultraviolet light treatment, does not continue to control biological contaminants in the distribution system.

Ozone is a colorless gas that disinfects, oxidizes, deodorizes, and decolorizes. Ozonation is every effective for inactivating Cryptosporidium, bacteria, and other microorganisms.

Ozone is a toxic gas and can cause illness if inhaled in sufficient quantity. Service providers who operate and maintain systems that include ozone generators require specific safety training from equipment manufacturers to ensure that their risk is minimized.

Ultraviolet Light: ANSI/NSF Standards 55, 60

ANSI/NSF Standard 55 Ultraviolet Microbiological Water Treatment Systems provides outcome-based testing requirements for UV devices. An ANSI/NSF 55 certified UV device provides a UV dose of 40 megajoules per square centimeter (mJ/cm^2)and is fitted with a UV detection system that activates an alarm if the unit fails. Failure to provide the adequate dose may be a result of the dirty reactor section or an aged bulb (NSF/ANSI, 2007). Class A certified devices are designed to control pathogens and have been frequently used as the sole treatment device in some in-home drinking water systems**.**

Class B certified devices are not designed to provide protection from pathogens in water that is from non-potable sources. Class B UV devices do not emit a strong enough dose (16 mJ/cm^2) to protect users and are not required to be outfitted with an alarm system (NSF/ANSI, 2007). These devices are solely intended as additional protection and are to be used with drinking water that already meets EPA standards for a PWS.

Class B certified devices are not designed to provide protection from pathogens in water that is from non-potable sources.

Class A certified devices are designed to control pathogens and have been frequently used as the sole treatment device in some in-home drinking water systems.


Figure 16.3. Water filtered prior to exposure to ultraviolet light.

Water should be filtered prior to exposure to ultraviolet light (Figure 16.3). Turbidity decreases the effectiveness of a UV system. A sensor connected to a turbidity monitor can be installed up stream of the UV treatment device that will indicate with a warning when high levels of particulates are in the water.

Turbidity

Turbidity is a term to describe the cloudy appearance of water caused by the presence of tiny suspended particles. High levels of turbidity may interfere with proper water treatment and monitoring by blocking UV light (Figure 16.4). Appropriate filtering can reduce turbidity which can be measured prior to treatment.

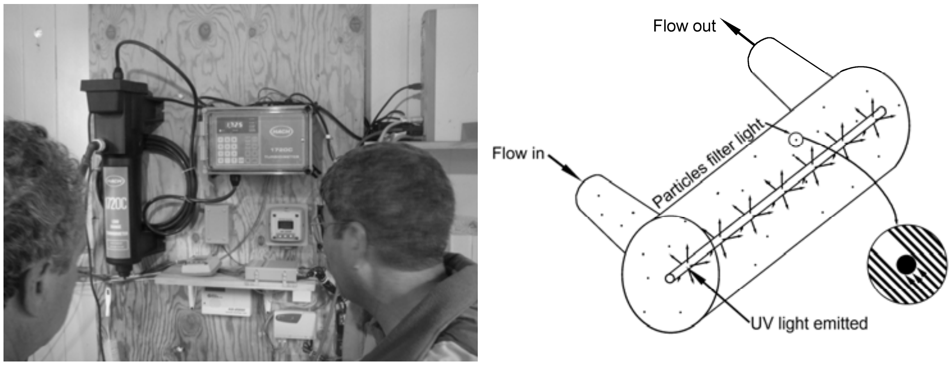


Figure 16.4. A turbidity monitor (left) ensures that water quality is sufficient to not interfere with downstream treatment measures, such as an UV light (right).

By Products of Treatment

As the quality of municipal water and effectiveness of treatment systems continue to be studied, especially in regard to long-term health effects, several mainstream issues have become focal points of discussion and uncertainty in the RWH community. Research has shown that disinfectants themselves can react with naturally occurring materials in the water to form unintended byproducts which may pose health risks (Table 16.4).

A major challenge for water suppliers is balancing the acute risks from microbial pathogens and long-term health effects of disinfection byproducts. The EPA addresses these risks with the Stage 1 Disinfectants and Disinfection Byproducts Rule and the Interim Enhanced Surface Water Treatment Rule.

A major challenge for water suppliers is balancing the acute risks from microbial pathogens and long-term health effects of disinfection byproducts.

Corrosion Control

Collected rainwater generally has a pH of 5.0 to 6.5 and is acidic, whereas water with a pH of 7.0 is neutral. (TWDB, 2005) Unfortunately, acidic water corrodes water pipes, storage tanks, and other plumbing devices that are made of metal. This includes copper piping and fittings held together with solder, some of which contains lead. In older houses or installations with a substantial use of metal in the distribution system, it is possible that measureable amounts of lead and copper will be leached from the piping system. This may result in pin holes forming in copper piping or ingestion of lead by the user. Fortunately, the plastic piping used on newer homes is not conducive to corrosion.

Table 16.4. List of disinfection byproducts from the EPA (US EPA, 2009).

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG1 (mg/L)2	MCL or TT1 (mg/L)2
Bromate	Increased risk of cancer	Byproduct of drinking water disinfection	zero	0.01
Chlorite	Anemia; infants & young children: nervous system effects	Byproduct of drinking water disinfection	0.8	1
Haloacetic acids (HAA5)	Increased risk of cancer	Byproduct of drinking water disinfection	n/a	0.06
Total Trihalomethanes	Liver, kidney, or central nervous system problems; increased risk of cancer	Byproduct of drinking water disinfection	n/a	0.08

Corrosion due to acidity can be minimized by treating stored rainwater with readily available sodium bicarbonate or baking soda. Baking soda, certified by ANSI/NSF Standard 60, can be added to the storage tank after testing the pH reveals a level below 7.4. If the pH measures above 7.0, add 1 pound of baking soda per 10,000 gallons to raise the pH reading 0.1 units. If the pH is less than 7.0, add 2 pounds per 10,000 gallons to raise the pH. It is recommended to wait several days for the pH to stabilize before continuing to treat the water (TCEQ, 2007). The Texas Water Development Board stated that a slight buffering could be achieved by using 1 tablespoon of baking soda to 100 gallons of water (2005).

Another treatment to reduce the corrosive potential of the water includes exposing the water to calcium carbonate (limestone), calcium oxide (lime), or sodium carbonate (soda ash) pellets. Dissolved limestone from the filter increases the hardness of the water and raises the pH. Because of the increased mineral content of the water and potential for scale build-up, a UV disinfectant device should be placed upstream of the calcium carbonate filter. (TCEQ, 2007)

Zinc Orthophosphate has been used by large PWSs and homeowners to control corrosion, especially when high levels of lead have been detected. In the home, a metering pump is used to regulate the addition of zinc orthophosphate to the water supply.

Volatile Organic Chemicals (VOCs) and Synthetic Organic Chemicals (SOCs)

VOCs have a high vapor pressure and low water solubility. Several VOCs are refined organic products such as paints, pharmaceuticals, refrigerants, solvents, fuel oxygenates (MTBE), and by-products produced by chlorination in water treatment, such as chloroform. VOCs have been found in groundwater throughout the United States. RWH system planners and installers who utilize materials not intended for use with potable water sources may inadvertently introduce VOCs into the water supply.

In rural areas, deposition on a catchment as a result of off-target application from aerial spraying may increase the likelihood of SOCs in water.

The presence of SOCs in a RWH system would probably have resulted from the catchment device being exposed to herbicides or pesticides. In rural areas, deposition on a catchment as a result of off-target application from aerial spraying may increase the likelihood of SOCs in water (Figure 16.5). Activated carbon filters can be used to remove VOCs and SOCs. (TCEQ, 2007)

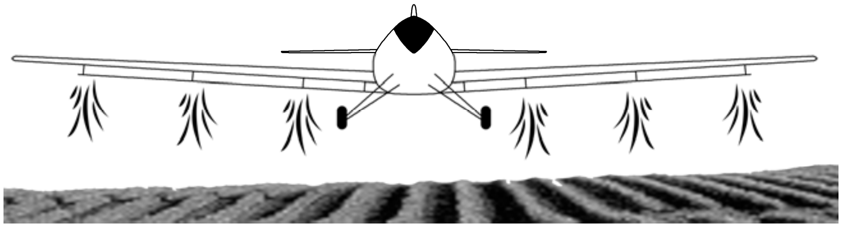


Figure 16.5. Drift or off-target application of chemicals can contaminate catchment areas.

Point of Entry and Point of Use Treatment

RWH planners of potable water systems determine which location of treatment is best for the customer. A sanitation system that treats all of the water that enters an in-home distribution system is referred to as a point-of-entry (POE) system.

Sanitation that occurs at the end of the distribution system, such as a lavatory or spigot, is referred to as a point-of-use (POU) system (Figure 16.6). Each system has advantages and limitations. POE systems protect users at all points of the distribution system, simplifies the treatment and maintenance process, and may reduce installation costs. POU systems require ANSI/NSF devices to be located at each end point of the distribution system.

PWS Supply Protection

Water from rain and water supplied from a PWS can coexist in the same structure or dwelling. Local codes and state agencies generally mandate a specific device or technique to separate each supply. In some states, when a water source from a PWS is present in a dwelling, then all water from other sources, including sanitized rainwater, should be considered as non-potable water and used for non-potable needs. This typically requires the building to be dual plumbed. Check local codes and regulations that may apply.

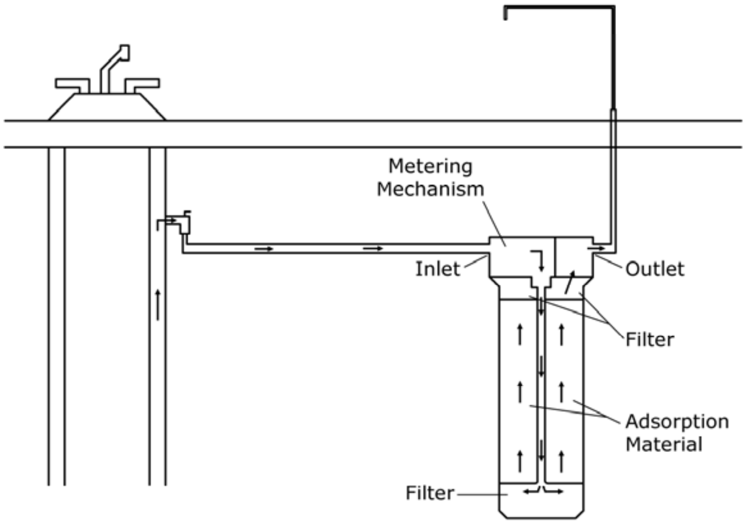


Figure 16.6. Point of use filter

Cross Contamination

Cross contamination occurs when rainwater mixes with water from a municipal supply or PWS (Figure 16.7). Regardless of the level of disinfection and decontamination of the rainwater, PWS owners always consider this condition as contamination.

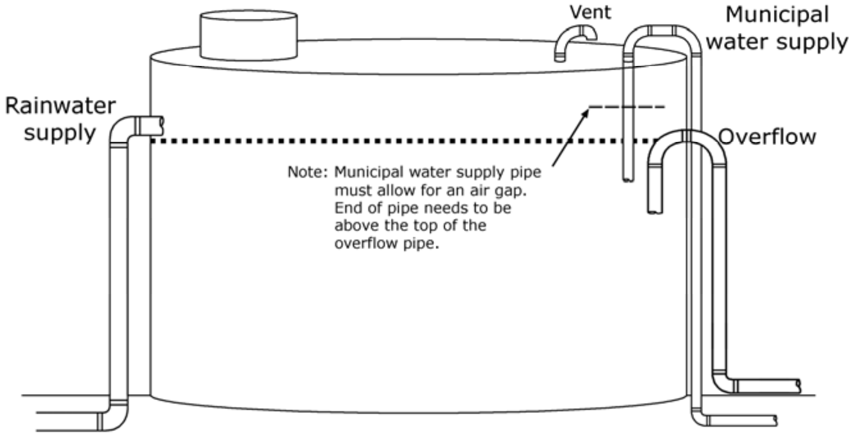


Figure 16.7. Cross contamination from a rainwater tank to a municipal water supply can be caused by a refill pipe being lower than the water level.

Homeowners who collect rainwater and use it in their house are responsible for preventing cross contamination. The water supplies should be separated by mechanical devices or an air gap. A reduced-pressure back flow assembly is one such device. Another common technique to prohibit cross contamination is the use of an air gap.

Individuals may be more familiar with air gap technology than they realize. Currently, PWS supplies are protected from water that has entered a toilet reservoir with an air gap device like the one illustrated below. The reservoir water is prevented from re-entering the water supply because of the air gap (Figure 16.9). A modified arrangement of this style can serve the RWH industry or a simpler device may be used (Figure 16.10).

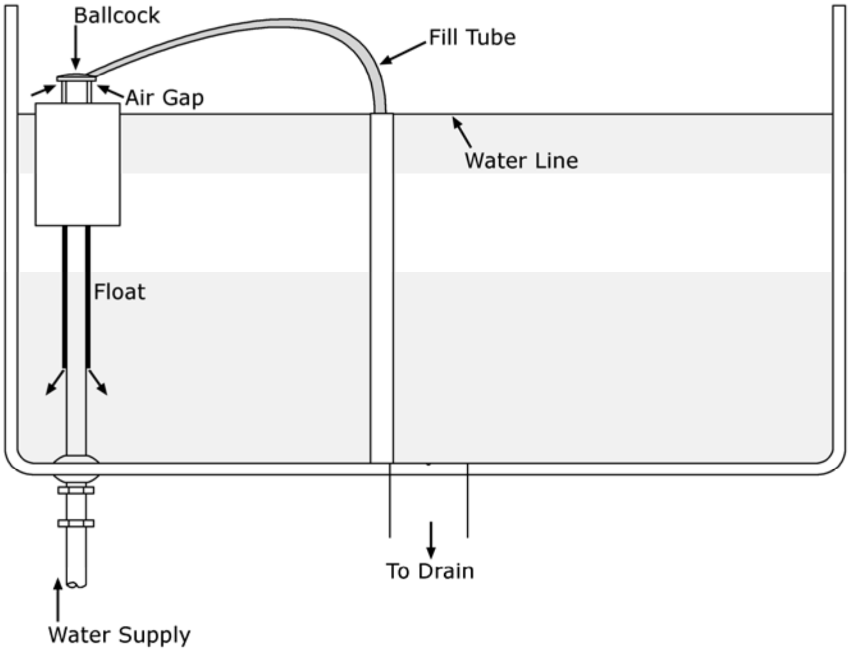


Figure 16.9. Air gap in toilet reservoir.

Figure 16.10. Air gap device used to prevent cross contamination utilizing a solenoid valve.(Courtesy of WISY AG, Germany (left) and Rain Filters of Texas, LLC (right))

Cross Connections

A cross connection occurs when a pipe carrying water from rainfall is inadvertently connected to a pipe carrying water from a local public water supply, such as a city provider (Figure 16.11). Checking for cross connections is necessary to determine if the PWS is at risk.

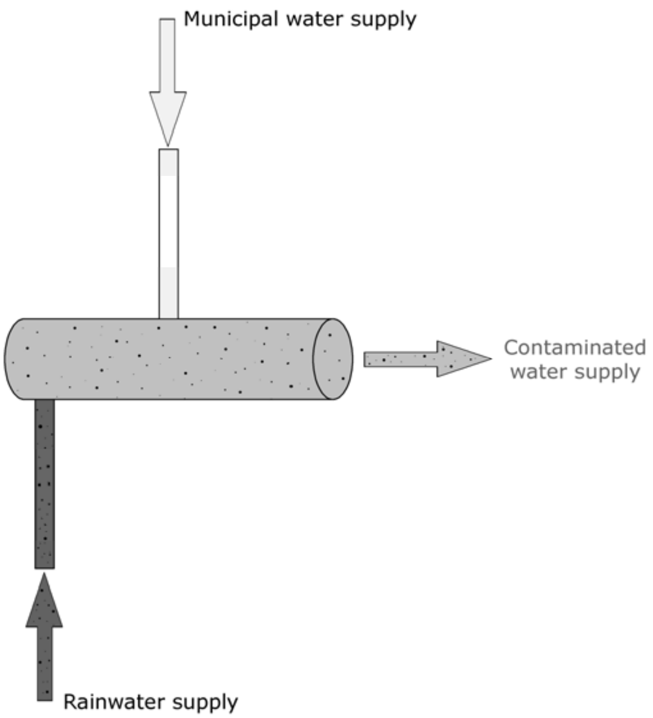


Figure 16.11. An example of how a rainwater pipe cross connection with municipal pipe can contaminate municipal water.

Cross connections can be checked by following these steps:

1. Shut off the municipal water supply.
2. Check all fixtures. If water is seen coming from any fixtures other than those plumbed with rainwater, then a cross connection is likely.
3. Shut off rainwater supply.
4. Open main valve from municipal supply.
5. Check all rainwater fixtures. If water is seen coming from any fixtures that are solely plumbed from the municipal water, then a cross connection is likely.

Common Sanitation Components and Installation

A bulk or course filter/screen is usually installed prior to any components (Figure 16.12). External pipe threads are wrapped in Teflon tape. The screen filter is located after the pump and is accessible to facilitate regular cleaning (Figure 16.13). Finer filters are installed next, prior to UV light exposure (Figure 16.14). Isolation valves should be used on most components to facilitate replacement, cleaning, and removal. Figure 16.15 is a good example of how isolation valves and component set up can be used to reroute water if one component fails and is removed.

Figure 16.12. Course screen filters remove large particulate contaminants from the system.

A filter with fine mesh, ranging from 0.5 to 5 micron, follows the coarse screen filter. When two filters are used, the first filter has a larger micron rating. The second inline filter can range in mesh size from as low as 0.5 to 1.0 absolute micron. Pressure gauges on either side of the filter housing will show a pressure drop when the filters are plugged. A clear filter cover can be used to allow visual inspection, but opaque covers are recommended to reduce algae growth.

Figure 16.13. An accessible filter is easy to maintain and replace.

Figure 16.14. Finer filters remove particles prior to UV light exposure.

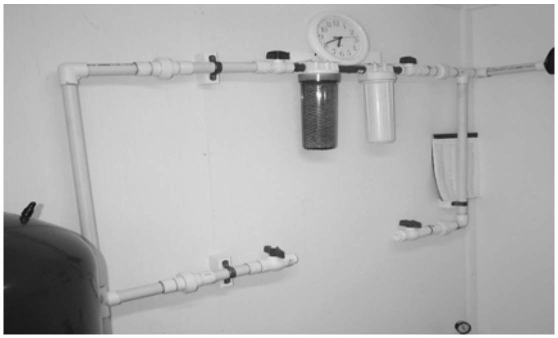


Figure 16.15. Isolation valves allow re-routing of water, as well as removal and replacement of component.

Unions, pressure gauges, isolation valves, and a hose bib are important elements to a filter set up (Figure 16.16). The unions are used to make taking a system apart easier, allowing the removal and replacement of each component. Unions are used to make taking a system apart easier. Here, the pump, pressure tank, and the line to the filters appear to be hard-plumbed (Figure 16.17).

This will make maintenance and repairs difficult. Pressure gauges on either side of the filters allow the system operator to know when the filters become plugged. The filters will have a certain pressure drop across them with clean filters and the pressure drop will increase as the filters become plugged. Having a hose bib in the filter set up allows the operator to drain pressure or can be used for demands that do not require filtered or sanitized water.

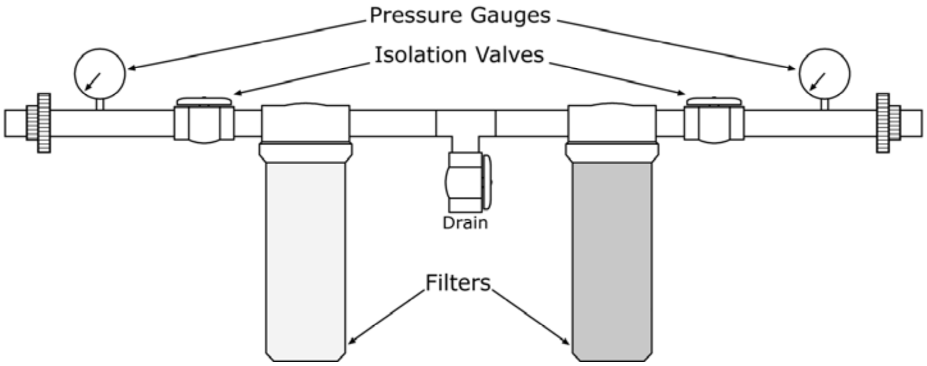


Figure 16.16. Isolation valves, dual pressure gauges, and drain for filter housing

Figure 16.17 The pump, pressure tank, filters, and UV device are all hard-plumbed making maintenance and replacement of components difficult.

Flexible connections allow ease of installation of this UV light device (Figure 16.18). When using this flexible hose, use stainless steel and not copper hot water heater lines. As previously stated, copper can be eroded by rainwater with low pH.

Figure 16.18. Flexible connections on a UV device make installation easy and quick.

Selecting a Treatment Unit

Selecting a water treatment device takes much consideration. Prior to purchasing any system components, the water should be tested by a certified third-party lab. Homeowners may encounter water purification industry representatives that will offer free testing. Be aware, these analyses often test for superficial things only in the water such as salt and hardness and do not include many potential contaminants that pose health effects.

An unbiased lab should be sought out from the list of labs certified nationally or by the state. Nationally certified testing laboratories may be found by calling the Safe Drinking Water Hotline at 1-800-426-4791 or reviewing the Safewater website: http://www.epa.gov/safewater/labs/index.html. Contact the Texas Commission on Environmental Quality (TCEQ) for the testing of Texas public drinking water supplies. This contact information can be found at http://www.tceq.state.tx.us/.

Once the contaminants are identified, a treatment unit or combination of units that addresses those contaminants can be chosen. Besides the level of sanitation provided, other issues that should be considered when choosing system devices are:

- Initial cost
- Operation and maintenance costs and requirements
- Contaminant removal efficiency
- Contaminant disinfection efficacy
- Warranties
- Life expectancy
- Manufacturer’s reputation
- ANSI/NSF standard*
- EPA Registration**

*The National Sanitation Foundation (NSF) provides certification of a product's ability to remove contaminants that affect health. A list of drinking water treatment units with NSF certification can be found online at: http://www.nsf.org/Certified/DWTU/.
**If a product has an EPA registration number, this merely indicates that the unit is registered with the EPA but does not imply EPA approval or certification.

Typical Treatment Train for Homeowner RWH Potable Water System

The following example treatment train is commonly used in RWH systems for homes (Figure 16.19). Large debris is removed, and the tank is plumbed to maximize settling. The water removed from storage is strained with a course filter. Next, a pre-filters strains the water at a 3 to 5 micron level. The pre-filter is followed by an ANSI/NSF standard 53 filter with a 0.5 or 1.0 absolute micron filter.
After filtration, an ultraviolet light that meets ANSI/NSF standard 55, Class A requirements disinfects the remaining contaminants. A water meter should be installed to provide usage data for operation and maintenance logging along with a pressure gauge to identify filter plugging.

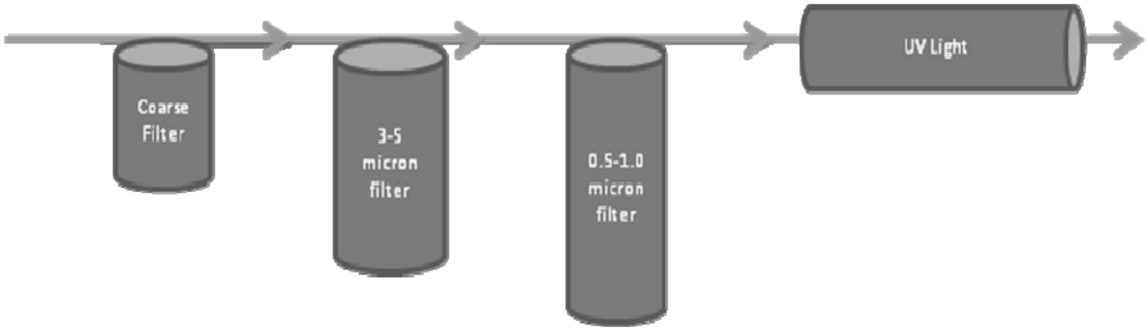
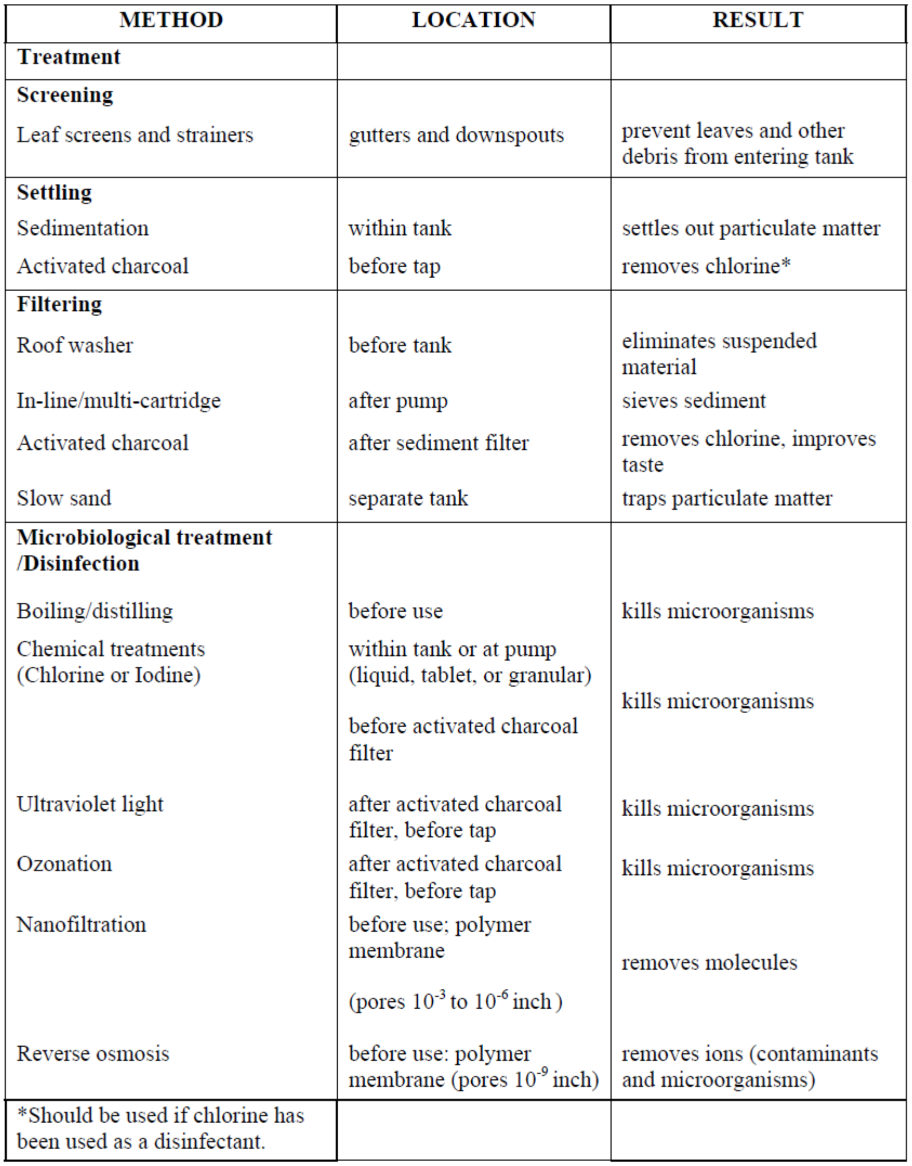


Figure 16.19. Example treatment train utilizing filtration and an UV light.

Although Class A devices only require filtration down to 3 to 5 microns, always remember that multiple levels of protection are recommended. Remember that manufacturer recommendations should always be observed and most manufacturers will provide technical assistance and information to customers. A charcoal filter, prior to the Class A ultraviolet light device, would improve taste and odor.

The following table (Table 16.5) is from the Texas Water Development Board and shows the different treatment technique for rainwater harvesting systems.

Table 16.5. Treatment Techniques (TWDB, 2005)



METHOD	LOCATION	RESULT
Treatment		
Screening		
Leaf screens and strainers	gutters and downspouts	prevent leaves and other debris from entering tank
Settling		
Sedimentation	within tank	settles out particulate matter
Activated charcoal	before tap	removes chlorine*
Filtering		
Roof washer	before tank	eliminates suspended material
In-line/multi-cartridge	after pump	sieves sediment
Activated charcoal	after sediment filter	removes chlorine, improves taste
Slow sand	separate tank	traps particulate matter
Microbiological treatment /Disinfection		
Boiling/distilling	before use	kills microorganisms
Chemical treatments (Chlorine or Iodine)	within tank or at pump (liquid, tablet, or granular) before activated charcoal filter	kills microorganisms
Ultraviolet light	after activated charcoal filter, before tap	kills microorganisms
Ozonation	after activated charcoal filter, before tap	kills microorganisms
Nanofiltration	before use; polymer membrane (pores 10^{-3} to 10^{-6} inch)	removes molecules
Reverse osmosis	before use: polymer membrane (pores 10^{-9} inch)	removes ions (contaminants and microorganisms)
*Should be used if chlorine has been used as a disinfectant.		

Seasonal and Foliage Effects on Water Quality

There are seasonal contaminants that can have a negative impact on water quality, especially if the system is providing potable water. One instance is when a large number of landscape plants in the vicinity of the catchment surface are blooming. Wind can relocate pollen onto the catchment surface where it is washed from the roof and enters the storage container. For example, American oak trees usually release large amounts of pollen, in addition to thick leaves, which are high in tannins. These can result in staining the water, clogging filters, and plugging coarse screens, gutters, and first flush devices.

The impact of blooming plants or defoliation of trees can be minimized by frequent monitoring of screens and filters and the use of multiple tanks. During such times, rainfall can be diverted into non-potable storage and away from storage that is used for drinking water. The pH levels may also temporarily decrease (increase in acidity). Besides pruning trees away from the catchment area, washing the catchment surface removes pollen. When washing the catchment surface, divert all water away from storage to prevent contaminations.

Proper and apparent labeling of untreated rainwater is important to protect public health.

Chlorine can be utilized to oxidize organic material in storage tanks. It must be noted that chlorine reacts with organic material and forms VOCs, so an activated carbon filter may counteract changes in taste or smell. If chlorine is used for this purpose, follow recommended guidelines for shock chlorination of storage tanks.

For safety, place the following label every 2 feet on all piping between the untreated-water storage tank and prior to treatment units (Figure 16.20). All faucets and other outlets of untreated rainwater should be appropriately labeled as well. Proper and apparent labeling of untreated rainwater is important to protect public health.

Figure 16.20. Label to be placed on piping and faucets to notify users of water quality.

Summary

The treatment of water for potable purposes is complicated but important. Knowledgeable individuals should be consulted and only quality products should be chosen. Rainwater is generally thought of as being clean, but adequate precautions and treatment systems should be planned and installed. The client should understand the risks, performance, and maintenance of each device.

Reference

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Rainwater Harvesting: System Planning

17. Operation and Maintenance

The goal of this chapter is to engage the RWH system planner in the process of operating and maintaining major components of a RWH system. Upon completion of this chapter, the participant should be able to accomplish the following objectives:

1. Derive an appropriate start-up procedure for a specific RWH system.
2. Explain system operator responsibilities.
3. Operate and maintain a RWH system.
4. Inspect and clean filters and other components.
5. Determine inspection and maintenance intervals for RWH system components.
6. Record appropriate maintenance data.
7. Keep and maintain records.

Contents

17. Operation and Maintenance

Introduction

The initial start of a system involves testing whether or not the system works and if each component is performing to the manufacturer's specifications. The operation and maintenance of a system is the continuous process of checking to see if individual system components are functioning properly, observing storage volume, and monitoring water usage. Routine maintenance and proper upkeep are directly related to water quality for potable water systems.

Incorrect or deficient maintenance of equipment results in lower water quality and increased health risks. Regular testing for contaminants is a key determinant of system function. Each system is unique and has its own subtle variations in performance and functionality. A system operator learns these nuances and keeps the system operating at an acceptable level.

Incorrect or deficient maintenance of equipment results in lower water quality and increased health risks.

Start-Up Procedures

1. Become familiar with all the maintenance procedures, and double check all devices and components prior to retaining any water.
2. Inspect and clean gutters, downspouts, conveyance piping, screens, and all devices upstream of the tank.
3. Determine through flushing that all components upstream of the tank are working properly.
4. In some cases, divert 100 percent of the rainwater away from the tank until the conveyance piping is no longer flushing construction residue or the chlorine solution used to clean the system.
5. If possible, fill the tank with potable water from a reputable source.
6. All faucets, outlets, and piping with non-potable water should be labeled.
7. Check for leaks.
8. Pressure lines slowly, opening downstream valves to allow air to escape.
9. Open potable water faucets to purge non-treated water.
10. Test water:
    a. Chlorine residual
    b. Bacteria – TC/FC

c. Giardia
d. Cryptosporidium
e. Turbidity
f. pH

System Operator Responsibilities

One person, the system operator, must be responsible for the upkeep of a RWH system.

One person, the system operator, must be responsible for the upkeep of a RWH system. In a case where multiple individuals share in the responsibility of maintaining a system, eventually a breakdown will occur as a result of unattended maintenance. This lack of communication or miscommunication is often referred to as the "he said, she said" scenario. The burden of maintaining a system should rest with a sole individual who takes a keen interest in sustaining the highest quality of water and is capable of recognizing a declining level of performance.

The system operator has the following duties and responsibilities:

- Read each device's owner manual.
- Develop a maintenance plan.
- Replace broken equipment.
- Become familiar with characteristics of contaminants.
- Become familiar with techniques used by system devices to disinfect water.
- Update and store records.
- Check pressure gauges.
- Test water on a regular basis.
- Record data related to usage and water quality.
- Become familiar with each device's performance specifications.
- Document repairs.
- Inspect and decontaminate storage tanks.
- Recognize a decrease in system performance.
- Monitor storage levels.

Gutters

Gutters are designed to catch all the runoff water from a roof. This clever but simple design also results in trapping debris and eventually blocking the flow of water. Monthly inspections of the gutter and removal of all materials, especially organic matter, is necessary to maximize water quality. Additionally, the gutters should be inspected after high intensity storms that include powerful wind gusts. At least once a year, gutters should be flushed to remove sediment and debris lodged in corners, transitions, and internal hangers. New gutters may need to be washed with soap and water to remove oil residue deposited as a result of the manufacturing process; be sure to divert this water. When inspecting and cleaning gutters on ladders be cautious and have someone ensure that the bottom of the ladder is stable. Injuries as a result of falling off ladders are common and dangerous. Use the following list as a reminder when inspecting a gutter.

- Leaves
- Organic matter
- Twigs
- Feces
- Dead animals
- Sagging gutter sections
- Puddled water
- Loose hardware, connections
- Peeling paint
- Corrosion
- Leaks
- Sealer on transitions
- Ants
- Sediment
- Asphalt particles
- Children's toys
- Algae, mold

Debris Screens

Devices used to prevent leaves, twigs, carcasses, and other large debris from entering the storage tank are the first line of defense against contamination (Figure 17.1).

Figure 17.1. An unattended leaf diverter on a downspout.

Figure 17.2. Debris lodged in a gutter can block the downspout screen and result in a flooded gutter.

Leaf screens and gutter filters should be inspected on a monthly basis and after each major rainfall event, especially those that include high winds.

The devices are designed to trap or stop debris; infrequent inspections and cleaning result in blockage, wasted water, and increased chances that decomposing debris will eventually enter the storage tank.

For example, a gutter clogged with leaves creates pooled water (Figure 17.2). The pressure from this pooled water is exerted on the decomposing debris and may force smaller debris particles into the downspout.

Debris screens should be inspected for the following items:

- Leaves
- Carcasses
- Decomposed organic matter
- Loose hardware
- Evidence of blockage
- Proper fitting components

Downspouts

Downspouts should be regularly inspected for debris, loose hardware, and obstruction to flow. Unpainted PVC downspouts should be inspected for algae growth, leaks, and cracks. Over time, exposed PVC can become brittle and yellowish in color. Dented or crushed sections of downspouts hamper flow or may cause leakage.

Roof Washers and First Flush Diverters

Roof washers, some box filters, and first flush diverters are considered a second line of defense against contamination after debris screens. Like a gutter, blockage in this device has negative consequences that result in less than optimal system performance and water quality.

These devices are natural traps for sediment and organic matter; weekly inspection is necessary. Monthly cleaning is suggested, depending on volume of debris encountered. The drains should be kept clear to prevent puddling of water (Figure 17.3).

Roof washers and first flush diverters should be inspected for the following:

- Clogged drain outlet
- Plugged screen
- Corrosion, leaks
- Animals
- Debris
- Mosquitoes
- Sediment
- Algae

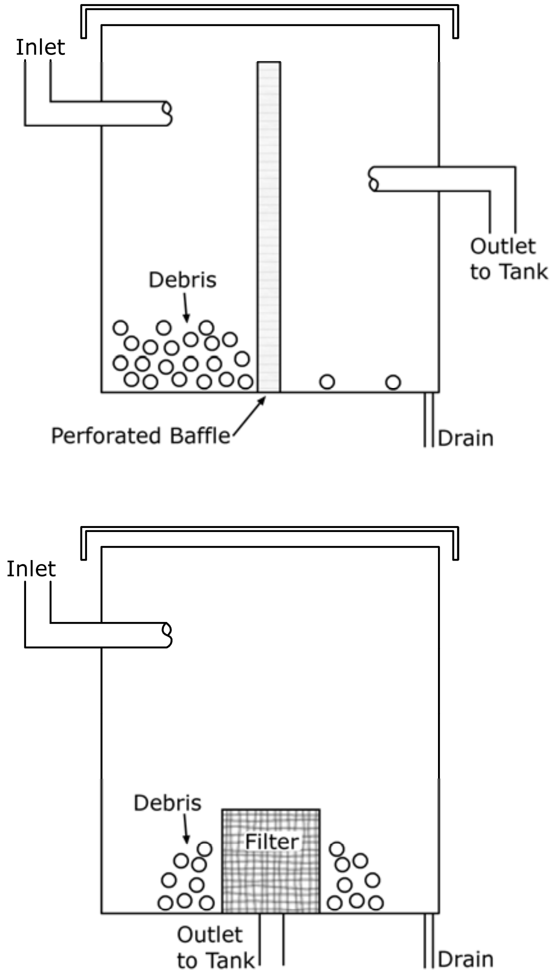

Figure 17.3. Roof washers can become plugged with debris and its removal is necessary to maximize water quality.

Tanks/Storage Containers

The condition of the water in the tank affects water quality throughout the distribution system. Smaller components are relatively easy to clean or replace, but the tank is the least accessible and most difficult to clean. Water quality and conditions in the tank vary greatly from one RWH system to the next.

Most people feel more comfortable with some level of monthly or annual maintenance of a storage tank. Tanks should be inspected monthly or more often if a debris screen or first flush device has been repaired, broken, or clogged.

The tank foundation should be inspected for cracking, erosion, and settling. Concrete slabs should be inspected annually while earthen or loose material foundations should be looked at each month. Changes in landscape elevations and slopes that influence water flow around the base of the tank should be monitored on a monthly basis.

Although experts disagree on whether or not to clean a tank, inspection is not controversial. As recommended, when potable water is desired and stored, a dedicated tank should be used to store this water. When warranted due to inspection or conditions, the tank should be sanitized by thoroughly washing it and applying a water/chlorine mixture to all surfaces.

It is extremely dangerous to enter confined spaces such as tanks or cisterns without proper training and equipment. When necessary to enter a confined space follow OSHA regulations.

The following is a typical tank cleansing procedure:

- Drain tank.
- Follow OSHA confined space entry procedures.
- Never enter a tank without an outside observer.
- Disconnect/lockout all electrical devices.
- Wear proper protective equipment: goggles, rubber boots, and chemical suit.
- Ventilation is key when using chlorine.
- Spray down walls and tank with water/chlorine mixture.
- Allow sprayed surface to dry.
- Rinse thoroughly until debris and chlorine are gone.
- Document cleaning process, date, chemicals used, and ratio of water/bleach.

There are several features of tanks and items that should be checked. All tanks may crack, so they should be checked yearly for water leaking out or in. Vent screens should be checked for nesting animals and blockage. Internal tank features, such as a floating intake, should be checked to make sure that the float is working and that associated flexible tubing is not cracked or broken.

Buried tanks should be inspected more often than aboveground tanks. Changes to underground tanks can occur without being easily noticed. Tank connections should be checked for breakage. Standing water and debris piles should be moved away from tank connections and the main opening.

Piping and Connections

Piping and connections should be checked on a monthly basis. Plastic pipes should be checked for cracks and deformation. PVC plastic that is exposed to sunlight can degrade, turn yellowish in color, and become brittle. A visual inspection of outdoor components and piping should be conducted in the event of an abrupt change of temperature. Repairs that involve replacement and reconnecting of system components should be inspected more often until it is determined that there are no leaks.

Filters

Filters are designed to stop particles of a specific size, preventing them from continuing on in the water stream. As the surface of the filter becomes clogged with particles, the flow is hampered and a drop in pressure results. A water pressure gauge installed on both the upstream and downstream sides of a filter or bank of filters can indicate a drop in pressure. This indicates required maintenance. Some filters can be cleaned while others, especially charcoal, must be replaced. Charcoal filters are replaced after a certain quantity of water has passed through them.

Pumps

Most pumps are maintenance free, until they malfunction. Electric motors provide little warning prior to failure, and under most circumstances they last for years without need for replacement. Multiple starts within a short time period and lack of water in the pump housing contribute to premature failure. Contrary to popular belief, pumps are not damaged when flow is restricted or prevented, unless the water in the case becomes hot to the touch.

The pressure switch that indirectly turns the pump on and off is the first to fail, because it contains moving parts and electrical contacts that become worn or dirty.

Pressure Tanks

Pressure tanks allow pumps to cycle on and off less frequently. On a monthly basis the pressure tank and connection should be checked for leaks and the pressure in the pressure tank should be checked. Follow manufacturer recommendations and initial system design criteria to determine proper pressure.

Ultraviolet Light System

A UV light bulb operates continuously, regardless of flow rate, and has an expected lifespan. Continuous operation produces heat, and UV components may become hot to the touch during prolonged periods of no flow. Change the bulb each year or follow manufacturer recommendations. Ultraviolet bulb intensity diminishes over time and is not recognizable by visual inspection.

After replacing the bulb according to the manufacturer specifications, replace all covers and flood the UV device prior to turning on the light. Be sure that all air bubbles are removed so that the bulb will not overheat. The clear tubing that houses the UV light needs to be wiped down with a lint free cloth on occasion, at least annually depending on the rate of build-up. The NSF Standard Class A UV has an alarm that goes off if the tube is not perfectly clear. The cleaning of the tube or bulb replacement should be documented. Water that passes through the UV system when the bulb is not operating, whether it is burned out or is off due to a power failure should be considered as contaminated and unsafe to drink. A thorough flushing may need to be conducted to rid the potable water system of contaminants after a power failure.

Water Testing

Prior to consuming the water, an initial water quality assessment should be completed. The evaluation should be made by an individual with adequate knowledge and experience. Baseline test results provide a benchmark to compare subsequent results. At a minimum the water should be tested for bacteria, cryptosporidium, and giardia. The original analysis should be kept on file. The system should be retested after major repairs or replacement of sanitation equipment. If an unexpected or unexplained change in water quality occurs, testing for contamination may be appropriate. Yearly testing for total coliform (TC) and fecal coliform (FC) should be completed to serve as an indicator that the system is continuing to work properly. Testing may be viewed by a client as expensive and unnecessary, but it ensures that the water that is being delivered remains at an acceptable quality.

Logging Water Usage

Logging water usage is critical to long-term sustainability of the water supply. Doing this weekly will aid the operator in detecting leaks or other problems with the system. An in line meter is useful in detecting leaks as well as logging normal water usage. The log can also aid in planning the level of water usage in times of drought or low storage volumes. A sample water usage log is provided on page 17-12.

Maintenance Worksheet

A good maintenance worksheet aids in collecting all the relevant information in one place for ease of evaluation. The worksheet ensures that every component of the systems is adequately evaluated. An example work sheet is provided on page 17-13. All worksheets should be saved in a secure location with all other system information.

Inspection Accessibility

Regular inspection and cleaning of RWH components is a key maintenance activity. Impediments that reduce the accessibility to serviceable components of a RWH system result in fewer inspections and cleanings. Devices such as filters, UV lights, leaf screens, and roof washers should be located to facilitate safe and easy inspection and cleaning. The downspout screen in Figure 17.4 is located approximately 14 feet above the ground. Without changing system performance, this device could have been located at a more accessible location only 8 feet above the ground.

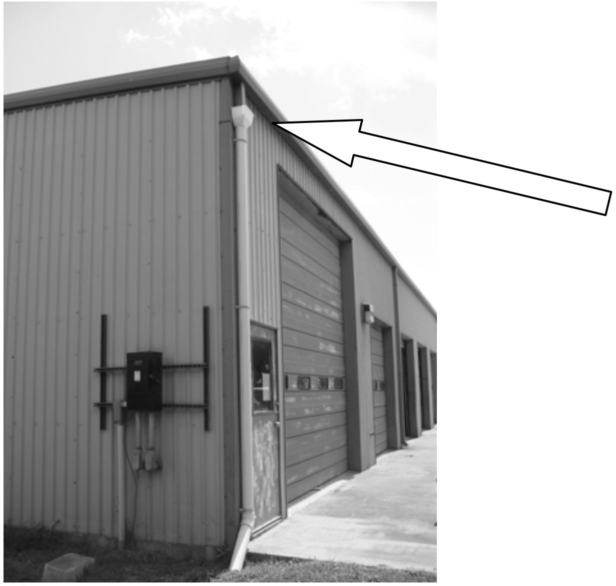

Figure 17.4. Downspouts with leaf guards located 14 feet above the ground can prove to be difficult to clean on a regular basis.

Billy’s Seven Item Checklist

Seven things to look at:

1. In constructing a system, have the roof and tanks set up as early in the process as possible to begin collecting water before you need it. Otherwise, plan on having water delivered if there is not a make-up or back-up supply. Early estimates help determine how much water you will need the first one to two months based on daily needs per person. Roofs, gutters, lines, and pipes also need to be flushed before placing water in the tanks. This may include washing some of the parts with soap and water to remove oils and contaminants. Tanks should be handled as little as possible on the inside to prevent contamination. The initial amount of water coming out of the tank and into the supply lines needs to be cleared out, possibly adding chlorine; there needs to be a supply of water that fills the UV (if used) without air bubbles to prevent the chamber and bulb from overheating. **Never run the UV without water inside it.** Also make sure all lines and all faucets furnishing non-potable water are labeled "non-potable - do not drink" prior to treatment.

2. Checking for leaks is an unending job. Make sure gutters carry the water easily, drain completely, leave no standing water, and direct water as designed. Be sure that dry lines are dry and wet lines are draining if a drain is attached. Check that screens, first flush diverters, gutter guards, filters, over flows, and pumps are all in place and working as planned. This should be on a check list of maintenance items to check regularly or as needed.

3. Run sanitation lines and faucets for a sufficient time to ensure that the water that has been exposed to UV or other treatments is reaching every faucet. Refer to the chlorine recommendations for dose, contact time, and residual.

4. Test water to make sure treatment is working correctly. For bacteria, test both TC and FC as a minimum. EPA recommends conducting tests for giardia and cryptosporidium to prove the system is free of these contaminants. For private systems these are the primary steps. For a municipal system, follow Environmental Protection Agency requirements.

5. Follow up with maintenance on filters, sanitation devices, and all parts to be sure they are functioning as planned.

6. For planners/installers seeking to follow up with a maintenance plan for homeowners, develop a maintenance schedule of actions. Record whether they are to be conducted monthly, quarterly, or annually. Also include the cost of each service, including emergency calls. The following information should also be provided in the form of a manual or binder: installer's name and contact information, company parts, how to

order replacement parts, and how to conduct a personal maintenance step/procedure.

7. If electricity goes out, water flows past the sanitation devices untreated. After the electricity is restored, parts of the initial treatment process should be repeated to prevent contaminant problems.

Information should also be provided in the form of a manual or binder to clients: installer's name and contact information, company parts, how to order replacement parts, and how to conduct a personal maintenance step/procedure.

Summary

A RWH system that is properly operated and maintained will provide a higher quality of water with lower levels of risk than a comparable system that is neglected. Regular inspection and maintenance will aid the operator in fixing minor problems before they escalate. Operators should keep all records of operation and maintenance in case someone becomes ill after consuming the water. These records will aid in conveying the message that the system is performing at its designed level.

Reference

CIDWT. 2008. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Pilot Test Version 2. March 2008.

Water Usage Log
System Location: ______________________________ Installer: ______________________________
Operator: ______________________ Location of Records: ____________________________________

Date	Meter Reading	Water in Storage	Date	Meter Reading	Water in Storage

Maintenance Worksheet (CIDWT, 2008)

System Location: ______________________________ Installer: ______________________________

Operator: ______________________ Location of Records: ___________________________________

Filters: __________________________________ Pump: ____________________________________

Pressure Tank: ____________________________ UV System: ________________________________

Chlinorine Application System: _______________ Date:

____

1) Catchment Surface: Free of Debris? ☐ Yes ☐ No
2) Gutters:
   a) Clean?: ☐ Yes ☐ No
      i) Leaf Screens: ☐ Yes ☐ No
      ii) Gutter Filters: ☐ Yes ☐ No
      iii) Inspection: ☐ Yes ☐ No
      iv) Confined space (O_2 testing): ☐ Yes ☐ No
   b) Downspouts
      i) Intact: ☐ Yes ☐ No
      ii) First flush diverters- drained and clean: ☐ Yes ☐ No
3) Tanks
   a) Piping intact: ☐ Yes ☐ No
      i) Covers/lids/lock outs in place: ☐ Yes ☐ No
      ii) Overflow/vents properly screened: ☐ Yes ☐ No
      iii) Basket screens cleaned: ☐ Yes ☐ No
4) Pressure Tank
      i) Leaks: ☐ Yes ☐ No
      ii) Pump (cycle on)
         (1) Leaks: ☐ Yes ☐ No
5) Filters: ☐ Yes ☐ No
         (1) Rinse filters: ☐ Yes ☐ No
         (2) Change filters: ☐ Yes ☐ No
   b) UV Light
      i) Check operation: ☐ Yes ☐ No
      ii) Change bulb: ☐ Yes ☐ No
      iii) Cleaned quart sleeve: Yes _____ No_____
   c) Chlorine Applicator
      i) Chlorine dose: ______________________
      ii) Filled: ☐ Yes ☐ No
6) Water Quality Testing
   a) Sample taken: ☐ Yes ☐ No
   b) Location from which sample was taken: _________________________
   c) Testing Location: ____
   d) Test to be run: ____

Comments:

Rainwater Harvesting:
System Planning

Appendix A: Tables and Figures

Upon completion of this unit, the participant should be able to accomplish the following objectives:

1. Identify the wall thickness associated with various types of pipes.
2. Identify the ASTM standard specified for pipe and pipe construction.
3. Determine friction loss in pipe flow.
4. Determine the average monthly and yearly rainfall for various US cities.
5. Identify the EPA contaminants and their max limits.

Contents

Pipe Specifications

All piping has specific specifications regarding sizing and usage. The following tables are provided to assist in evaluating piping used in construction of wastewater treatment systems.

Table A.1. Pipe diameter and wall specifications (CIDWT, 2008)

Nominal Diameter (in.)	OD (in.)	Minimum Wall Thickness (tolerance) in inches			
		Sch 40	Sch 80	SDR 26	SDR 35
¼	.540	0.088 (.02)	.119 (.02)		
½	.840	0.109 (.02)	.147 (.02)		
3/4	1.050	0.113 (.02)	.154 (.02)		
1	1.315	0.133 (.02)	.179 (.021)		
1 ¼	1.66	0.14 (.02)	.191 (.023)	.064	
1 ½	1.90	0.145 (.02)	.200 (.024)	.073	
2	2.375	.154 (.02)	.218 (.026)	.091	
2 1/2	2.875	.203 (.024)	.276 (.033)	.110	
3	3.5	.216 (.026)	.300 (.036)	.135	.093
3 ½	4.0	.226 (.027)	.318 (.038)	-----	----
4	4.5	.237 (.028)	.337 (.040)	.173	.120

Table A.2. Pipe inner diameter of various pipe specifications (Uni-Bell, 2001)

Nominal Diameter (in.)	Inner diameter in inches					
	Sch 40	Sch 80	SDR 26	SDR 21	SDR 13.5	(API) Flexible PVC
½	0.622	0.546			0.716	0.546
3/4	0.824	0.742			0.894	0.740
1	1.049	0.957	1.195		1.121	0.960
1 ¼	1.380	1.278	1.532	1.502	1.414	
1 ½	1.610	1.500	1.754	1.720	1.618	
2	2.067	1.939	2.193	2.149	2.023	
2 1/2	2.469	2.323	2.655	2.601	2.449	
3	3.068	2.900	3.230	3.166	2.982	
3 ½	3.548	3.364	-----	3.620	3.408	
4	4.026	.3.826	4.154	4.072	3.834	

Table A.3. ASTM Standards Related to PVC pipe (CIDWT, 2008)

	Standard #
Schedule 40,80 & 120 Pipe	D1785
Threaded Fittings, Schedule 80	D2464
Plastic Fittings, Schedule 80	D2467
Plastic Fittings, Schedule 40	D2466
SDR Pipe	D2241
Solvent Cements for PVC Pipe and Fittings	D2564
Recommended Practice For Making Solvent-Cemented joints with PVC Pipe and Fittings	D2855

Friction Loss

Table A.4. Friction losses for Schedule 40 PVC pipe (feet per 100 ft) (CIDWT, 2008)

Pipe Size (in.)						
Flow (GPM)	1 (1.049)	1-1/4 (1.38)	1-1/2 (1.61)	2 (2.067)	3 (3.068)	4 (4.026)
1	0.09					
2	0.32	0.08				
3	0.67	0.18	0.08			
4	1.14	0.30	0.14			
5	1.73	0.46	0.21	0.06		
6	2.43	0.64	0.30	0.09		
7	3.23	0.85	0.40	0.12		
8	4.13	1.09	0.51	0.15		
9	5.14	1.35	0.64	0.19		
10	6.25	1.64	0.78	0.23		
11	7.45	1.96	0.92	0.27		
12	8.76	2.30	1.09	0.32		
13	10.16	2.67	1.26	0.37		
14	11.65	3.06	1.45	0.43	0.06	
15	13.24	3.48	1.64	0.49	0.07	
16		3.92	1.85	0.55	0.08	
17		4.39	2.07	0.61	0.09	
18		4.88	2.30	0.68	0.10	
19		5.39	2.55	0.75	0.11	
20		5.93	2.80	0.83	0.12	
25		8.96	4.23	1.25	0.18	
20		5.93	2.80	0.83	0.12	
25		8.96	4.23	1.25	0.18	
30			5.93	1.76	0.26	0.07
35			7.89	2.34	0.34	0.09
40				2.99	0.44	0.12
45				3.72	0.54	0.14
50				4.52	0.66	0.18
60				6.34	0.93	0.25
70				8.43	1.23	0.33
80				10.80	1.58	0.42
90				13.43	1.96	0.52
100				16.33	2.38	0.63
150					5.05	1.34
200					8.61	2.29
250						3.46
300						4.86
350						6.46
400						8.27

Table A.5. Friction loss equivalent as pipe length (ft) (CIDWT, 2008)

Diameter of Fitting (in.)	90. Degree Standard Ell	45 Degree Standard Ell	90 Degree Standard Tee	coupling or Straight Run Of Tee	Gate Valve	Globe Valve	Check Valve
	Friction Loss Equivalent as Pipe Length (ft)						
3/8	1	0.6	1.5	0.3	0.2	8	3
1/2	2	1.2	3	0.6	0.4	15	5
3/4	2.5	1.5	4	0.8	0.5	20	7
1	3	1.8	5	0.9	0.6	25	8
1 1/4	4	2.4	6	1.2	0.8	35	11
1 1/2	5	3	7	1.5	1	45	14
2	7	4	10	2	1.3	55	19
2 1/2	8	5	12	2.5	1.6	65	22
3	10	6	15	3	2	80	27
3 1/2	12	7	18	3.6	2.4	100	32
4	14	8	21	4	2.7	125	38
5	17	10	25	5	3.3	140	46
6	20	12	30	6	4	165	54

Pipe Volume

Table A.6. Pipe volume (gallons) per foot of pipe (CIDWT, 2008)

	Pipe Size (in.)	Type of Pipe				
		SDR 26 (Class 160)	SDR 21 (Class 200)	Sch 40	Sch 80	Corrugated Tubing
Volume (gal per ft of pipe)	0.75			0.028	0.022	
	1	0.058	0.058	0.045	0.037	
	1.25	0.096	0.092	0.078	0.067	
	1.5	0.126	0.121	0.106	0.092	
	2	0.196	0.188	0.174	0.153	
	3	0.426	0.409	0.384	0.343	
	4	0.704	0.677	0.66	0.597	0.653
	6	1.53	1.47	1.5	1.35	1.47
	8	2.59	2.49	2.6	2.37	

Table A.7. Pipe volume (gallons) per 100 feet of pipe (CIDWT, 2008)

	Pipe Size (in.)	Type of Pipe				
		SDR 26 (Class 160)	SDR 21 (Class 200)	Sch 40	Sch 80	Corrugated Tubing
Volume (gallons per 100 feet of pipe)	0.75			2.8	2.2	
	1	5.8	5.8	4.5	3.7	
	1.25	9.6	9.2	7.8	6.7	
	1.5	12.6	12.1	10.6	9.2	
	2	19.6	18.8	17.4	15.3	
	3	42.6	40.9	38.4	34.3	
	4	70.4	67.7	66	59.7	65.3
	6	153	147	150	135	147
	8	259	249	260	237	

Table A.8. 30-year average monthly rainfall (Source: National Climate Data Center) (NCDC, 2009)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
BIRMINGHAM AP,AL	5.5	4.2	6.1	4.7	4.8	3.8	5.1	3.5	4.1	3.2	4.6	4.5	54.0
HUNTSVILLE, AL	5.5	5.0	6.7	4.5	5.2	4.2	4.4	3.3	4.3	3.5	5.2	5.6	57.5
MOBILE, AL	5.8	5.1	7.2	5.1	6.1	5.0	6.5	6.2	6.0	3.3	5.4	4.7	66.3
MONTGOMERY, AL	5.0	5.5	6.4	4.4	4.1	4.1	5.3	3.6	4.2	2.6	4.5	5.0	54.8
ANCHORAGE, AK	0.7	0.7	0.7	0.5	0.7	1.1	1.7	2.9	2.9	2.1	1.1	1.1	16.1
ANNETTE, AK	9.7	8.1	8.0	7.4	5.7	4.7	4.3	6.1	9.5	13.9	12.2	11.4	100.8
BARROW, AK	0.1	0.1	0.1	0.1	0.1	0.3	0.9	1.0	0.7	0.4	0.2	0.1	4.2
BETHEL, AK	0.6	0.5	0.7	0.7	0.9	1.6	2.0	3.0	2.3	1.4	1.4	1.1	16.2
BETTLES,AK	0.8	0.6	0.6	0.4	0.9	1.4	2.1	2.5	1.8	1.1	0.9	0.9	14.0
BIG DELTA,AK	0.3	0.4	0.2	0.2	0.8	2.4	2.8	2.1	1.0	0.7	0.6	0.4	11.9
COLD BAY,AK	3.1	2.6	2.5	2.3	2.7	2.9	2.5	3.6	4.5	4.5	4.8	4.3	40.3
FAIRBANKS, AK	0.6	0.4	0.3	0.2	0.6	1.4	1.7	1.7	1.1	0.9	0.7	0.7	10.3
GULKANA,AK	0.5	0.5	0.4	0.2	0.6	1.5	1.8	1.8	1.4	1.0	0.7	1.0	11.4
HOMER, AK	2.6	2.0	1.8	1.2	1.1	1.0	1.5	2.3	3.4	2.8	2.9	3.0	25.5
JUNEAU, AK	4.8	4.0	3.5	3.0	3.5	3.4	4.1	5.4	7.5	8.3	5.4	5.4	58.3
KING SALMON, AK	1.0	0.7	0.8	0.9	1.4	1.7	2.2	2.9	2.8	2.1	1.5	1.4	19.4
KODIAK, AK	8.2	5.7	5.2	5.5	6.3	5.4	4.1	4.5	7.8	8.4	6.6	7.6	75.4
KOTZEBUE, AK	0.6	0.4	0.4	0.4	0.3	0.6	1.4	2.0	1.7	1.0	0.7	0.6	10.1
MCGRATH, AK	1.0	0.7	0.8	0.7	1.0	1.5	2.3	2.8	2.4	1.5	1.5	1.4	17.5
NOME, AK	0.9	0.8	0.6	0.7	0.7	1.1	2.2	3.2	2.5	1.6	1.3	1.0	16.6
ST. PAUL ISLAND, AK	1.7	1.3	1.1	1.1	1.2	1.4	1.9	3.0	2.8	2.7	2.9	2.1	23.2
TALKEETNA, AK	1.5	1.3	1.3	1.2	1.6	2.4	3.2	4.5	4.4	3.1	1.8	2.0	28.2
UNALAKLEET, AK	0.4	0.3	0.4	0.4	0.6	1.3	2.2	2.9	2.1	0.9	0.7	0.5	12.4
VALDEZ, AK	6.0	5.5	4.5	3.6	3.1	3.0	3.8	6.6	9.6	8.6	5.5	7.6	67.4
YAKUTAT, AK	13.2	11.0	11.4	10.8	9.8	7.2	7.9	13.3	20.9	24.0	15.2	15.9	160.4
FLAGSTAFF, AZ	2.2	2.6	2.6	1.3	0.8	0.4	2.4	2.9	2.1	1.9	1.9	1.8	22.9
PHOENIX, AZ	0.8	0.8	1.1	0.3	0.2	0.1	1.0	0.9	0.8	0.8	0.7	0.9	8.3
TUCSON, AZ	1.0	0.9	0.8	0.3	0.2	0.2	2.1	2.3	1.5	1.2	0.7	1.0	12.2
WINSLOW, AZ	0.5	0.5	0.6	0.3	0.4	0.3	1.2	1.3	1.0	0.9	0.6	0.5	8.0
YUMA, AZ	0.4	0.3	0.3	0.1	0.1	0.0	0.2	0.6	0.3	0.3	0.1	0.4	3.0
FORT SMITH, AR	2.4	2.6	3.9	3.9	5.3	4.3	3.2	2.6	3.6	3.9	4.8	3.4	43.9
LITTLE ROCK, AR	3.6	3.3	4.9	5.5	5.1	4.0	3.3	2.9	3.7	4.3	5.7	4.7	50.9
NORTH LITTLE ROCK, AR	3.4	3.3	4.9	5.0	5.4	3.5	3.2	3.0	3.5	3.8	5.7	4.5	49.2
BAKERSFIELD, CA	1.2	1.2	1.4	0.5	0.2	0.1	0.0	0.1	0.2	0.3	0.6	0.8	6.5
BISHOP, CA	0.9	1.0	0.6	0.2	0.3	0.2	0.2	0.1	0.3	0.2	0.4	0.6	5.0
EUREKA, CA.	6.0	5.5	5.6	2.9	1.6	0.7	0.2	0.4	0.9	2.4	5.8	6.4	38.1
FRESNO, CA	2.2	2.1	2.2	0.8	0.4	0.2	0.0	0.0	0.3	0.7	1.1	1.3	11.2
LONG BEACH, CA	3.0	3.0	2.4	0.6	0.2	0.1	0.0	0.1	0.2	0.4	1.1	1.8	12.9
LOS ANGELES AP, CA	3.0	3.1	2.4	0.6	0.2	0.1	0.0	0.1	0.3	0.4	1.1	1.8	13.2
LOS ANGELES C.O., CA	3.3	3.7	3.1	0.8	0.3	0.1	0.0	0.1	0.3	0.4	1.1	1.9	15.1
MOUNT SHASTA, CA	7.1	6.5	5.8	2.7	1.9	1.0	0.4	0.4	0.9	2.2	5.1	5.4	39.2
REDDING, CA	6.5	5.5	5.2	2.4	1.7	0.7	0.1	0.2	0.5	2.2	4.0	4.7	33.5
SACRAMENTO, CA	3.8	3.5	2.8	1.0	0.5	0.2	0.1	0.1	0.4	0.9	2.2	2.5	17.9
SAN DIEGO, CA	2.3	2.0	2.3	0.8	0.2	0.1	0.0	0.1	0.2	0.4	1.1	1.3	10.8
SAN FRANCISCO AP, CA	4.5	4.0	3.3	1.2	0.4	0.1	0.0	0.1	0.2	1.0	2.5	2.9	20.1
SAN FRANCISCO C.O., CA	4.7	4.2	3.4	1.3	0.5	0.1	0.0	0.1	0.3	1.2	3.3	3.2	22.3

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
SANTA BARBARA, CA	3.6	4.3	3.5	0.6	0.2	0.1	0.0	0.1	0.4	0.5	1.3	2.3	16.9
SANTA MARIA, CA	2.6	3.2	2.9	0.9	0.3	0.1	0.0	0.1	0.3	0.5	1.2	1.8	14.0
STOCKTON, CA	2.7	2.5	2.3	1.0	0.5	0.1	0.1	0.1	0.3	0.8	1.8	1.8	13.8
ALAMOSA, CO	0.3	0.2	0.5	0.5	0.7	0.6	0.9	1.2	0.9	0.7	0.5	0.3	7.3
COLORADO SPRINGS, CO	0.3	0.4	1.1	1.6	2.4	2.3	2.9	3.5	1.2	0.9	0.5	0.4	17.4
DENVER, CO	0.5	0.5	1.3	1.9	2.3	1.6	2.2	1.8	1.1	1.0	1.0	0.6	15.8
GRAND JUNCTION, CO	0.6	0.5	1.0	0.9	1.0	0.4	0.7	0.8	0.9	1.0	0.7	0.5	9.0
PUEBLO, CO	0.3	0.3	1.0	1.3	1.5	1.3	2.0	2.3	0.8	0.6	0.6	0.4	12.4
BRIDGEPORT, CT	3.7	2.9	4.2	4.0	4.0	3.6	3.8	3.8	3.6	3.5	3.7	3.5	44.2
HARTFORD, CT	3.8	3.0	3.9	3.9	4.4	3.9	3.7	4.0	4.1	3.9	4.1	3.6	46.2
WILMINGTON, DE	3.4	2.8	4.0	3.4	4.2	3.6	4.3	3.5	4.0	3.1	3.2	3.4	42.8
WASHINGTON DULLES AP, D.C.	3.1	2.8	3.6	3.2	4.2	4.1	3.6	3.8	3.8	3.4	3.3	3.1	41.8
WASHINGTON NAT'L AP, D.C.	3.2	2.6	3.6	2.8	3.8	3.1	3.7	3.4	3.8	3.2	3.0	3.1	39.4
APALACHICOLA, FL	4.9	3.8	5.0	3.0	2.6	4.3	7.3	7.3	7.1	4.2	3.6	3.5	56.5
DAYTONA BEACH, FL	3.1	2.7	3.8	2.5	3.3	5.7	5.2	6.1	6.6	4.5	3.0	2.7	49.3
FORT MYERS, FL	2.2	2.1	2.7	1.7	3.4	9.8	9.0	9.5	7.9	2.6	1.7	1.6	54.2
GAINESVILLE, FL	3.5	3.4	4.3	2.9	3.2	6.8	6.1	6.6	4.4	2.5	2.2	2.6	48.4
JACKSONVILLE, FL	3.7	3.2	3.9	3.1	3.5	5.4	6.0	6.9	7.9	3.9	2.3	2.6	52.3
KEY WEST, FL	2.2	1.5	1.9	2.1	3.5	4.6	3.3	5.4	5.5	4.3	2.6	2.1	38.9
MIAMI, FL	1.9	2.1	2.6	3.4	5.5	8.5	5.8	8.6	8.4	6.2	3.4	2.2	58.5
ORLANDO, FL	2.4	2.4	3.5	2.4	3.7	7.4	7.2	6.3	5.8	2.7	2.3	2.3	48.4
PENSACOLA, FL	5.3	4.7	6.4	3.9	4.4	6.4	8.0	6.9	5.8	4.1	4.5	4.0	64.3
TALLAHASSEE, FL	5.4	4.6	6.5	3.6	5.0	6.9	8.0	7.0	5.0	3.3	3.9	4.1	63.2
TAMPA, FL	2.3	2.7	2.8	1.8	2.9	5.5	6.5	7.6	6.5	2.3	1.6	2.3	44.8
VERO BEACH, FL	2.9	2.5	4.2	2.9	3.8	6.0	6.5	6.0	6.8	5.0	3.0	2.2	51.9
WEST PALM BEACH, FL	3.8	2.6	3.7	3.6	5.4	7.6	6.0	6.7	8.1	5.5	5.6	3.1	61.4
ATHENS, GA	4.7	4.4	5.0	3.4	3.9	3.9	4.4	3.8	3.5	3.5	3.7	3.7	47.8
ATLANTA, GA	5.0	4.7	5.4	3.6	4.0	3.6	5.1	3.7	4.1	3.1	4.1	3.8	50.2
AUGUSTA,GA	4.5	4.1	4.6	2.9	3.1	4.2	4.1	4.5	3.6	3.2	2.7	3.1	44.6
COLUMBUS, GA	4.8	4.5	5.8	3.8	3.6	3.5	5.0	3.8	3.1	2.3	4.0	4.4	48.6
MACON, GA	5.0	4.6	4.9	3.1	3.0	3.5	4.3	3.8	3.3	2.4	3.2	3.9	45.0
SAVANNAH, GA	4.0	2.9	3.6	3.3	3.6	5.5	6.0	7.2	5.1	3.1	2.4	2.8	49.6
HILO, HI	9.7	8.9	14.4	12.5	8.1	7.4	10.7	9.8	9.1	9.6	15.6	10.5	126.3
HONOLULU,HI	2.7	2.4	1.9	1.1	0.8	0.4	0.5	0.5	0.7	2.2	2.3	2.9	18.3
KAHULUI, HI	3.7	2.4	2.4	1.8	0.7	0.2	0.5	0.5	0.4	1.1	2.2	3.1	18.8
LIHUE, HI	4.6	3.3	3.6	3.0	2.9	1.8	2.1	1.9	2.7	4.3	4.7	4.8	39.6
BOISE, ID	1.4	1.1	1.4	1.3	1.3	0.7	0.4	0.3	0.8	0.8	1.4	1.4	12.2
LEWISTON, ID	1.1	1.0	1.1	1.3	1.6	1.2	0.7	0.8	0.8	1.0	1.2	1.1	12.7
POCATELLO, ID	1.1	1.0	1.4	1.2	1.5	0.9	0.7	0.7	0.9	1.0	1.1	1.1	12.6
CHICAGO,IL	1.8	1.6	2.7	3.7	3.4	3.6	3.5	4.6	3.3	2.7	3.0	2.4	36.3
MOLINE, IL	1.6	1.5	2.9	3.8	4.3	4.6	4.0	4.4	3.2	2.8	2.7	2.2	38.0
PEORIA, IL	1.5	1.7	2.8	3.6	4.2	3.8	4.0	3.2	3.1	2.8	3.0	2.4	36.0
ROCKFORD, IL	1.4	1.3	2.4	3.6	4.0	4.8	4.1	4.2	3.5	2.6	2.6	2.1	36.6
SPRINGFIELD, IL	1.6	1.8	3.2	3.4	4.1	3.8	3.5	3.4	2.8	2.6	2.9	2.5	35.6
EVANSVILLE, IN	2.9	3.1	4.3	4.5	5.0	4.1	3.8	3.1	3.0	2.8	4.2	3.5	44.3
FORT WAYNE, IN	2.1	1.9	2.9	3.5	3.8	4.0	3.6	3.6	2.8	2.6	3.0	2.8	36.6
INDIANAPOLIS, IN	2.5	2.4	3.4	3.6	4.4	4.1	4.4	3.8	2.9	2.8	3.6	3.0	41.0

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SOUTH BEND, IN	2.3	2.0	2.9	3.6	3.5	4.2	3.7	4.0	3.8	3.3	3.4	3.1	39.7
DES MOINES, IA	1.0	1.2	2.2	3.6	4.3	4.6	4.2	4.5	3.2	2.6	2.1	1.3	34.7
DUBUQUE,IA	1.3	1.4	2.6	3.5	4.1	4.1	3.7	4.6	3.6	2.5	2.5	1.7	35.5
SIOUX CITY, IA	0.6	0.6	2.0	2.8	3.8	3.6	3.3	2.9	2.4	2.0	1.4	0.7	26.0
WATERLOO, IA	0.8	1.1	2.1	3.2	4.2	4.8	4.2	4.1	3.0	2.5	2.1	1.1	33.2
CONCORDIA, KS	0.7	0.7	2.4	2.5	4.2	4.0	4.2	3.2	2.5	1.8	1.5	0.9	28.4
DODGE CITY, KS	0.6	0.7	1.8	2.3	3.0	3.2	3.2	2.7	1.7	1.5	1.0	0.8	22.4
GOODLAND, KS	0.4	0.4	1.2	1.5	3.5	3.3	3.5	2.5	1.1	1.1	0.8	0.4	19.8
TOPEKA, KS	1.0	1.2	2.6	3.1	4.9	4.9	3.8	3.8	3.7	3.0	2.3	1.4	35.6
WICHITA, KS	0.8	1.0	2.7	2.6	4.2	4.3	3.3	2.9	3.0	2.5	1.8	1.4	30.4
GREATER CINCINNATI AP	2.9	2.8	3.9	4.0	4.6	4.4	3.8	3.8	2.8	3.0	3.5	3.3	42.6
JACKSON, KY	3.6	3.7	4.4	3.8	5.2	4.7	4.6	4.1	3.8	3.2	4.2	4.3	49.4
LEXINGTON, KY	3.3	3.3	4.4	3.7	4.8	4.6	4.8	3.8	3.1	2.7	3.4	4.0	45.9
LOUISVILLE, KY	3.3	3.3	4.4	3.9	4.9	3.8	4.3	3.4	3.1	2.8	3.8	3.7	44.5
PADUCAH KY	3.5	3.9	4.3	5.0	4.8	4.5	4.5	3.0	3.6	3.5	4.5	4.4	49.2
BATON ROUGE, LA	6.2	5.1	5.1	5.6	5.3	5.3	6.0	5.9	4.8	3.8	4.8	5.3	63.1
LAKE CHARLES, LA	5.5	3.3	3.5	3.6	6.1	6.1	5.1	4.9	6.0	3.9	4.6	4.6	57.2
NEW ORLEANS, LA	5.9	5.5	5.2	5.0	4.6	6.8	6.2	6.2	5.6	3.1	5.1	5.1	64.2
SHREVEPORT, LA	4.6	4.2	4.2	4.4	5.3	5.1	4.0	2.7	3.2	4.5	4.7	4.6	51.3
CARIBOU, ME	3.0	2.1	2.6	2.6	3.3	3.3	3.9	4.2	3.3	3.0	3.1	3.2	37.4
PORTLAND, ME	4.1	3.1	4.1	4.3	3.8	3.3	3.3	3.1	3.4	4.4	4.7	4.2	45.8
BALTIMORE, MD	3.5	3.0	3.9	3.0	3.9	3.4	3.9	3.7	4.0	3.2	3.1	3.4	41.9
BLUE HILL, MA	4.8	4.1	4.8	4.3	3.8	3.9	3.7	4.1	4.1	4.4	4.6	4.6	51.2
BOSTON, MA	3.9	3.3	3.9	3.6	3.2	3.2	3.1	3.4	3.5	3.8	4.0	3.7	42.5
WORCESTER, MA	4.1	3.1	4.2	3.9	4.4	4.0	4.2	4.1	4.3	4.7	4.3	3.8	49.1
ALPENA, MI	1.8	1.4	2.1	2.3	2.6	2.5	3.2	3.5	2.8	2.3	2.1	1.8	28.4
DETROIT, MI	1.9	1.9	2.5	3.1	3.1	3.6	3.2	3.1	3.3	2.2	2.7	2.5	32.9
FLINT, MI	1.6	1.4	2.2	3.1	2.7	3.1	3.2	3.4	3.8	2.3	2.7	2.2	31.6
GRAND RAPIDS, MI	2.0	1.5	2.6	3.5	3.4	3.7	3.6	3.8	4.3	2.8	3.4	2.7	37.1
HOUGHTON LAKE, MI	1.6	1.3	2.1	2.3	2.6	2.9	2.8	3.7	3.1	2.3	2.1	1.8	28.4
LANSING, MI	1.6	1.5	2.3	3.1	2.7	3.6	2.7	3.5	3.5	2.3	2.7	2.2	31.5
MARQUETTE, MI	2.6	1.9	3.1	2.8	3.1	3.2	3.0	3.6	3.7	3.7	3.3	2.4	36.3
MUSKEGON, MI	2.2	1.6	2.4	2.9	3.0	2.6	2.3	3.8	3.5	2.8	3.2	2.6	32.9
SAULT STE. MARIE, MI	2.6	1.6	2.4	2.6	2.5	3.0	3.1	3.5	3.7	3.3	3.4	2.9	34.7
DULUTH, MN	1.1	0.8	1.7	2.1	3.0	4.3	4.2	4.2	4.1	2.5	2.1	0.9	31.0
INTERNATIONAL FALLS, MN	0.8	0.6	1.0	1.4	2.6	4.0	3.4	3.1	3.0	2.0	1.4	0.7	23.9
MINNEAPOLIS-ST.PAUL, MN	1.0	0.8	1.9	2.3	3.2	4.3	4.0	4.1	2.7	2.1	1.9	1.0	29.4
ROCHESTER, MN	0.9	0.8	1.9	3.0	3.5	4.0	4.6	4.3	3.1	2.2	2.0	1.0	31.4
SAINT CLOUD, MN	0.8	0.6	1.5	2.1	3.0	4.5	3.3	3.9	2.9	2.2	1.5	0.7	27.1
JACKSON, MS	5.7	4.5	5.7	6.0	4.9	3.8	4.7	3.7	3.2	3.4	5.0	5.3	56.0
MERIDIAN, MS	5.9	5.4	6.9	5.6	4.9	4.0	5.5	3.3	3.6	3.3	5.0	5.3	58.7
TUPELO, MS	5.1	4.7	6.3	4.9	5.8	4.8	3.7	2.7	3.4	3.4	5.0	6.1	55.9
COLUMBIA, MO	1.7	2.2	3.2	4.2	4.9	4.0	3.8	3.8	3.4	3.2	3.5	2.5	40.3
KANSAS CITY, MO	1.2	1.3	2.4	3.4	5.4	4.4	4.4	3.5	4.6	3.3	2.3	1.6	38.0
ST. LOUIS, MO	2.1	2.3	3.6	3.7	4.1	3.8	3.9	3.0	3.0	2.8	3.7	2.9	38.8
SPRINGFIELD, MO	2.1	2.3	3.8	4.3	4.6	5.0	3.6	3.4	4.8	3.5	4.5	3.2	45.0
BILLINGS, MT	0.8	0.6	1.1	1.7	2.5	1.9	1.3	0.9	1.3	1.3	0.8	0.7	14.8

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GLASGOW, MT	0.4	0.3	0.5	0.8	1.7	2.2	1.8	1.3	1.0	0.7	0.4	0.4	11.2
GREAT FALLS, MT	0.7	0.5	1.0	1.4	2.5	2.2	1.5	1.7	1.2	0.9	0.6	0.7	14.9
HAVRE, MT	0.5	0.4	0.7	0.9	1.8	1.9	1.5	1.2	1.0	0.6	0.5	0.5	11.5
HELENA, MT	0.5	0.4	0.6	0.9	1.8	1.8	1.3	1.3	1.1	0.7	0.5	0.5	11.3
KALISPELL, MT	1.5	1.2	1.1	1.2	2.0	2.3	1.4	1.3	1.2	1.0	1.5	1.7	17.2
MISSOULA, MT	1.1	0.8	1.0	1.1	2.0	1.7	1.1	1.2	1.1	0.8	1.0	1.2	13.8
GRAND ISLAND, NE	0.5	0.7	2.0	2.6	4.1	3.7	3.1	3.1	2.4	1.5	1.4	0.7	25.9
LINCOLN, NE	0.7	0.7	2.2	2.9	4.2	3.5	3.5	3.4	2.9	1.9	1.6	0.9	28.4
NORFOLK, NE	0.6	0.8	2.0	2.6	3.9	4.3	3.7	2.8	2.3	1.7	1.4	0.7	26.7
NORTH PLATTE, NE	0.4	0.5	1.2	2.0	3.3	3.2	3.2	2.2	1.3	1.2	0.8	0.4	19.7
OMAHA EPPLEY AP, NE	0.8	0.8	2.1	2.9	4.4	4.0	3.9	3.2	3.2	2.2	1.8	0.9	30.2
OMAHA (NORTH), NE	0.8	0.8	2.3	3.1	4.6	3.8	3.8	2.9	3.0	2.5	1.7	1.0	30.1
SCOTTSBLUFF, NE	0.5	0.6	1.2	1.8	2.7	2.7	2.1	1.2	1.2	1.0	0.8	0.6	16.3
VALENTINE, NE	0.3	0.5	1.1	2.0	3.2	3.0	3.4	2.2	1.6	1.2	0.7	0.3	19.5
ELKO, NV	1.1	0.9	1.0	0.8	1.1	0.7	0.3	0.4	0.7	0.7	1.1	0.9	9.6
ELY, NV	0.7	0.8	1.1	0.9	1.3	0.7	0.6	0.9	0.9	1.0	0.6	0.5	10.0
LAS VEGAS, NV	0.6	0.7	0.6	0.2	0.2	0.1	0.4	0.5	0.3	0.2	0.3	0.4	4.5
RENO, NV	1.1	1.1	0.9	0.4	0.6	0.5	0.2	0.3	0.5	0.4	0.8	0.9	7.5
WINNEMUCCA, NV	0.8	0.6	0.9	0.9	1.1	0.7	0.3	0.4	0.5	0.7	0.8	0.8	8.3
CONCORD, NH	3.0	2.4	3.0	3.1	3.3	3.1	3.4	3.2	3.2	3.5	3.6	3.0	37.6
MT. WASHINGTON, NH	8.5	7.3	9.4	8.4	8.2	8.4	8.0	8.1	8.6	7.7	10.5	8.8	101.9
ATLANTIC CITY AP, NJ	3.6	2.9	4.1	3.5	3.4	2.7	3.9	4.3	3.1	2.9	3.3	3.2	40.6
ATLANTIC CITY C.O.,NJ	3.4	2.9	3.8	3.3	3.2	2.5	3.4	4.2	3.0	2.7	3.0	3.2	38.4
NEWARK, NJ	4.0	3.0	4.2	3.9	4.5	3.4	4.7	4.0	4.0	3.2	3.9	3.6	46.3
ALBUQUERQUE, NM	0.5	0.4	0.6	0.5	0.6	0.7	1.3	1.7	1.1	1.0	0.6	0.5	9.5
CLAYTON, NM	0.3	0.3	0.6	1.0	2.1	2.2	2.8	2.7	1.6	0.7	0.5	0.3	15.1
ROSWELL, NM	0.4	0.4	0.4	0.6	1.3	1.6	2.0	2.3	2.0	1.3	0.5	0.6	13.3
ALBANY, NY	2.7	2.3	3.2	3.3	3.7	3.7	3.5	3.7	3.3	3.2	3.3	2.8	38.6
BINGHAMTON, NY	2.6	2.5	3.0	3.5	3.6	3.8	3.5	3.4	3.6	3.0	3.3	3.0	38.7
BUFFALO, NY	3.2	2.4	3.0	3.0	3.4	3.8	3.1	3.9	3.8	3.2	3.9	3.8	40.5
ISLIP, NY	4.3	3.3	4.8	4.1	3.9	3.7	2.9	4.5	3.4	3.6	3.9	4.1	46.5
NEW YORK C.PARK, NY	4.1	3.2	4.4	4.3	4.7	3.8	4.6	4.2	4.2	3.9	4.4	4.0	49.7
NEW YORK (JFK AP), NY	3.6	2.7	3.8	3.8	4.1	3.6	3.9	3.6	3.5	3.0	3.5	3.3	42.5
NEW YORK (LAGUARDIA AP), NY	3.6	2.8	3.9	3.7	4.2	3.6	4.4	4.1	3.8	3.3	3.7	3.5	44.4
ROCHESTER, NY	2.3	2.0	2.6	2.8	2.8	3.4	2.9	3.5	3.5	2.6	2.8	2.7	34.0
SYRACUSE, NY	2.6	2.1	3.0	3.4	3.4	3.7	4.0	3.6	4.2	3.2	3.8	3.1	40.1
ASHEVILLE, NC	4.1	3.8	4.6	3.5	4.4	4.4	3.9	4.3	3.7	3.2	3.8	3.4	47.1
CAPE HATTERAS, NC	5.8	3.9	5.0	3.3	3.9	3.8	5.0	6.6	5.7	5.3	4.9	4.6	57.8
CHARLOTTE, NC	4.0	3.6	4.4	3.0	3.7	3.4	3.8	3.7	3.8	3.7	3.4	3.2	43.5
GREENSBORO-WNSTN-SALM-HGHPT,NC	3.5	3.1	3.9	3.4	4.0	3.5	4.4	3.7	4.3	3.3	3.0	3.1	43.1
RALEIGH, NC	4.0	3.5	4.0	2.8	3.8	3.4	4.3	3.8	4.3	3.2	3.0	3.0	43.1
WILMINGTON, NC	4.5	3.7	4.2	2.9	4.4	5.4	7.6	7.3	6.8	3.2	3.3	3.8	57.1
BISMARCK, ND	0.5	0.5	0.9	1.5	2.2	2.6	2.6	2.2	1.6	1.3	0.7	0.4	16.8
FARGO, ND	0.8	0.6	1.2	1.4	2.6	3.5	2.9	2.5	2.2	2.0	1.1	0.6	21.2
GRAND FORKS, ND	0.7	0.6	0.9	1.2	2.2	3.0	3.1	2.7	2.0	1.7	1.0	0.6	19.6
WILLISTON, ND	0.5	0.4	0.7	1.1	1.9	2.4	2.3	1.5	1.4	0.9	0.7	0.6	14.2

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AKRON, OH	2.5	2.3	3.2	3.4	4.0	3.6	4.0	3.7	3.4	2.5	3.0	3.0	38.5
CLEVELAND, OH	2.5	2.3	2.9	3.4	3.5	3.9	3.5	3.7	3.8	2.7	3.4	3.1	38.7
COLUMBUS, OH	2.5	2.2	2.9	3.3	3.9	4.1	4.6	3.7	2.9	2.3	3.2	2.9	38.5
DAYTON, OH	2.6	2.3	3.3	4.0	4.2	4.2	3.8	3.5	2.7	2.7	3.3	3.1	39.6
MANSFIELD, OH	2.6	2.2	3.4	4.2	4.4	4.5	4.2	4.6	3.4	2.7	3.8	3.3	43.2
TOLEDO, OH	1.9	1.9	2.6	3.2	3.1	3.8	2.8	3.2	2.8	2.4	2.8	2.6	33.2
YOUNGSTOWN, OH	2.3	2.0	3.1	3.3	3.5	3.9	4.1	3.4	3.9	2.5	3.1	3.0	38.0
OKLAHOMA CITY, OK	1.3	1.6	2.9	3.0	5.4	4.6	2.9	2.5	4.0	3.6	2.1	1.9	35.9
TULSA, OK	1.6	2.0	3.6	4.0	6.1	4.7	3.0	2.9	4.8	4.1	3.5	2.4	42.4
ASTORIA, OR	9.6	7.9	7.4	4.9	3.3	2.6	1.2	1.2	2.6	5.6	10.5	10.4	67.1
BURNS,OR	1.2	1.1	1.2	0.9	1.1	0.7	0.4	0.5	0.5	0.7	1.1	1.3	10.6
EUGENE, OR	7.7	6.4	5.8	3.7	2.7	1.5	0.6	1.0	1.5	3.4	8.4	8.3	50.9
MEDFORD, OR	2.5	2.1	1.9	1.3	1.2	0.7	0.3	0.5	0.8	1.3	2.9	2.9	18.4
PENDLETON, OR	1.5	1.2	1.3	1.1	1.2	0.8	0.4	0.6	0.6	1.0	1.6	1.5	12.8
PORTLAND, OR	5.1	4.2	3.7	2.6	2.4	1.6	0.7	0.9	1.7	2.9	5.6	5.7	37.1
SALEM, OR	5.8	5.1	4.2	2.8	2.1	1.5	0.6	0.7	1.4	3.0	6.4	6.5	40.0
SEXTON SUMMIT, OR	4.7	4.3	3.9	2.4	1.4	0.9	0.4	0.6	1.2	2.9	5.3	5.2	33.2
GUAM, PC	5.6	5.1	4.2	4.2	6.4	6.3	11.7	16.2	13.7	11.9	9.3	6.1	100.6
JOHNSTON ISLAND, PC	1.6	1.3	2.0	1.9	1.1	0.9	1.4	2.1	2.5	2.8	4.8	2.7	25.0
KOROR, PC	11.2	9.7	8.8	9.5	11.3	17.5	17.0	14.5	11.7	13.4	11.6	12.3	148.4
KWAJALEIN, MARSHALL IS., PC	5.1	3.7	3.8	7.6	8.6	8.9	10.2	10.4	11.8	11.5	10.7	7.9	100.4
MAJURO, MARSHALL IS, PC	8.1	6.9	8.4	11.3	11.5	11.1	12.4	12.0	12.0	13.7	12.8	11.5	131.7
PAGO PAGO, AMER SAMOA, PC	14.0	12.1	11.2	11.2	10.4	5.9	5.8	6.4	7.4	10.0	11.2	13.4	119.0
POHNPEI, CAROLINE IS., PC	12.5	9.8	14.0	16.9	19.4	17.1	16.7	16.4	14.9	16.3	14.7	15.9	184.6
CHUUK, E. CAROLINE IS., PC	8.6	8.8	8.2	10.9	11.3	12.8	12.5	15.1	13.1	10.7	11.1	11.0	134.0
WAKE ISLAND, PC	1.4	1.9	2.4	2.1	1.7	2.0	3.4	5.6	4.8	4.3	2.8	1.9	34.2
YAP, W CAROLINE IS., PC	7.2	5.5	6.1	5.6	8.2	13.5	13.3	14.4	13.5	12.3	8.8	9.3	117.6
ALLENTOWN, PA	3.5	2.8	3.6	3.5	4.5	4.0	4.3	4.4	4.4	3.3	3.7	3.4	45.2
ERIE, PA.	2.5	2.3	3.1	3.4	3.3	4.3	3.3	4.2	4.7	3.9	4.0	3.7	42.8
HARRISBURG, PA	3.2	2.9	3.6	3.3	4.6	4.0	3.2	3.2	3.7	3.1	3.5	3.2	41.5
MIDDLETOWN/HARRISBURG INTL APT	3.2	2.9	3.6	3.3	4.6	4.0	3.2	3.2	3.7	3.1	3.5	3.2	41.5
PHILADELPHIA, PA	3.5	2.7	3.8	3.5	3.9	3.3	4.4	3.8	3.9	2.8	3.2	3.3	42.1
PITTSBURGH, PA	2.7	2.4	3.2	3.0	3.8	4.1	4.0	3.4	3.2	2.3	3.0	2.9	37.9
AVOCA, PA	2.5	2.1	2.7	3.3	3.7	4.0	3.7	3.1	3.9	3.0	3.1	2.6	37.6
WILLIAMSPORT, PA	2.9	2.6	3.2	3.5	3.8	4.5	4.1	3.4	4.0	3.2	3.6	2.9	41.6
BLOCK IS.,RI	3.7	3.0	4.0	3.7	3.4	2.8	2.6	3.0	3.2	3.0	3.8	3.6	39.8
PROVIDENCE, RI	4.4	3.5	4.4	4.2	3.7	3.4	3.2	3.9	3.7	3.7	4.4	4.1	46.5
CHARLESTON AP,SC	4.1	3.1	4.0	2.8	3.7	5.9	6.1	6.9	6.0	3.1	2.7	3.2	51.5
CHARLESTON C.O.,SC	3.6	2.6	3.8	2.4	2.8	5.0	5.5	6.5	6.1	3.0	2.2	2.8	46.4
COLUMBIA, SC	4.7	3.8	4.6	3.0	3.2	5.0	5.5	5.4	3.9	2.9	2.9	3.4	48.3
GREENVILLE-SPARTANBURG AP, SC	4.4	4.2	5.3	3.5	4.6	3.9	4.7	4.1	4.0	3.9	3.8	3.9	50.2
ABERDEEN, SD	0.5	0.5	1.3	1.8	2.7	3.5	2.9	2.4	1.8	1.6	0.8	0.4	20.2
HURON, SD	0.5	0.6	1.7	2.3	3.0	3.3	2.9	2.1	1.8	1.6	0.9	0.4	20.9
RAPID CITY, SD	0.4	0.5	1.0	1.9	3.0	2.8	2.0	1.6	1.1	1.4	0.6	0.4	16.6

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
SIOUX FALLS, SD	0.5	0.5	1.8	2.7	3.4	3.5	2.9	3.0	2.6	1.9	1.4	0.5	24.7
BRISTOL-JHNSN CTY-KNGSPRT,TN	3.5	3.4	3.9	3.2	4.3	3.9	4.2	3.0	3.1	2.3	3.1	3.4	41.3
CHATTANOOGA, TN	5.4	4.9	6.2	4.2	4.3	4.0	4.7	3.6	4.3	3.3	4.9	4.8	54.5
KNOXVILLE, TN	4.6	4.0	5.2	4.0	4.7	4.0	4.7	2.9	3.0	2.7	4.0	4.5	48.2
MEMPHIS, TN	4.2	4.3	5.6	5.8	5.2	4.3	4.2	3.0	3.3	3.3	5.8	5.7	54.7
NASHVILLE, TN	4.0	3.7	4.9	3.9	5.1	4.1	3.8	3.3	3.6	2.9	4.5	4.5	48.1
OAK RIDGE,TN	5.1	4.5	5.7	4.3	5.1	4.6	5.2	3.4	3.8	3.0	4.9	5.4	55.1
ABILENE, TX	1.0	1.1	1.4	1.7	2.8	3.1	1.7	2.6	2.9	2.9	1.3	1.3	23.8
AMARILLO, TX	0.6	0.6	1.1	1.3	2.5	3.3	2.7	2.9	1.9	1.5	0.7	0.6	19.7
AUSTIN/CITY, TX	1.9	2.0	2.1	2.5	5.0	3.8	2.0	2.3	2.9	4.0	2.7	2.4	33.7
AUSTIN/BERGSTROM, TX	2.2	2.0	2.4	2.6	5.1	3.4	2.0	2.5	2.9	4.0	3.0	2.5	34.7
BROWNSVILLE, TX	1.4	1.2	0.9	2.0	2.5	2.9	1.8	3.0	5.3	3.8	1.8	1.1	27.6
CORPUS CHRISTI, TX	1.6	1.8	1.7	2.1	3.5	3.5	2.0	3.5	5.0	3.9	1.7	1.8	32.3
DALLAS-FORT WORTH, TX	1.9	2.4	3.1	3.2	5.2	3.2	2.1	2.0	2.4	4.1	2.6	2.6	34.7
DALLAS-LOVE FIELD, TX	1.9	2.3	3.1	3.5	5.3	3.9	2.4	2.2	2.7	4.7	2.6	2.5	37.1
DEL RIO, TX	0.6	1.0	1.0	1.7	2.3	2.3	2.0	2.2	2.1	2.0	1.0	0.8	18.8
EL PASO, TX	0.5	0.4	0.3	0.2	0.4	0.9	1.5	1.8	1.6	0.8	0.4	0.8	9.4
GALVESTON, TX	4.1	2.6	2.8	2.6	3.7	4.0	3.5	4.2	5.8	3.5	3.6	3.5	43.8
HOUSTON, TX	3.7	3.0	3.4	3.6	5.2	5.4	3.2	3.8	4.3	4.5	4.2	3.7	47.8
LUBBOCK, TX	0.5	0.7	0.8	1.3	2.3	3.0	2.1	2.4	2.6	1.7	0.7	0.7	18.7
MIDLAND-ODESSA, TX	0.5	0.6	0.4	0.7	1.8	1.7	1.9	1.8	2.3	1.8	0.7	0.7	14.8
PORT ARTHUR, TX	5.7	3.4	3.8	3.8	5.8	6.6	5.2	4.9	6.1	4.7	4.8	5.3	59.9
SAN ANGELO, TX	0.8	1.2	1.0	1.6	3.1	2.5	1.1	2.1	3.0	2.6	1.1	0.9	20.9
SAN ANTONIO, TX	1.7	1.8	1.9	2.6	4.7	4.3	2.0	2.6	3.0	3.9	2.6	2.0	32.9
VICTORIA, TX	2.4	2.0	2.3	3.0	5.1	5.0	2.9	3.1	5.0	4.3	2.6	2.5	40.1
WACO, TX	1.9	2.4	2.5	3.0	4.5	3.1	2.2	1.9	2.9	3.7	2.6	2.8	33.3
WICHITA FALLS, TX	1.1	1.6	2.3	2.6	3.9	3.7	1.6	2.4	3.2	3.1	1.7	1.7	28.8
MILFORD, UT	0.7	0.8	1.2	1.0	0.9	0.4	0.8	1.0	0.9	1.1	0.8	0.6	10.3
SALT LAKE CITY, UT	1.4	1.3	1.9	2.0	2.1	0.8	0.7	0.8	1.3	1.6	1.4	1.2	16.5
BURLINGTON, VT	2.2	1.7	2.3	2.9	3.3	3.4	4.0	4.0	3.8	3.1	3.1	2.2	36.1
LYNCHBURG, VA	3.5	3.1	3.8	3.5	4.1	3.8	4.4	3.4	3.9	3.4	3.2	3.2	43.3
NORFOLK, VA	3.9	3.3	4.1	3.4	3.7	3.8	5.2	4.8	4.1	3.5	3.0	3.0	45.7
RICHMOND, VA	3.6	3.0	4.1	3.2	4.0	3.5	4.7	4.2	4.0	3.6	3.1	3.1	43.9
ROANOKE, VA	3.2	3.1	3.8	3.6	4.2	3.7	4.0	3.7	3.9	3.2	3.2	2.9	42.5
OLYMPIA, WA	7.5	6.2	5.3	3.6	2.3	1.8	0.8	1.1	2.0	4.2	8.1	7.9	50.8
QUILLAYUTE, WA	13.7	12.4	11.0	7.4	5.5	3.5	2.3	2.7	4.2	9.8	14.8	14.5	101.7
SEATTLE C.O., WA	5.2	4.1	3.9	2.8	2.0	1.6	0.9	1.2	1.6	3.2	5.7	6.1	38.3
SEATTLE SEA-TAC AP, WA	5.1	4.2	3.8	2.6	1.8	1.5	0.8	1.0	1.6	3.2	5.9	5.6	37.1
SPOKANE, WA	1.8	1.5	1.5	1.3	1.6	1.2	0.8	0.7	0.8	1.1	2.2	2.3	16.7
WALLA WALLA WASHINGTON	2.3	2.0	2.2	1.8	2.0	1.2	0.7	0.8	0.8	1.8	2.9	2.5	20.9
YAKIMA, WA	1.2	0.8	0.7	0.5	0.5	0.6	0.2	0.4	0.4	0.5	1.1	1.4	8.3
SAN JUAN, PR	3.0	2.3	2.1	3.7	5.3	3.5	4.2	5.2	5.6	5.1	6.2	4.6	50.8
BECKLEY, WV	3.2	3.0	3.6	3.4	4.4	3.9	4.8	3.5	3.2	2.6	2.9	3.1	41.6
CHARLESTON, WV	3.3	3.2	3.9	3.3	4.3	4.1	4.9	4.1	3.5	2.7	3.7	3.3	44.1
ELKINS, WV	3.4	3.2	3.9	3.5	4.8	4.6	4.8	4.3	3.8	2.9	3.4	3.4	46.1
HUNTINGTON, WV	3.2	3.1	3.8	3.3	4.4	3.9	4.5	3.9	2.8	2.7	3.3	3.4	42.3
GREEN BAY, WI	1.2	1.0	2.1	2.6	2.8	3.4	3.4	3.8	3.1	2.2	2.3	1.4	29.2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
LA CROSSE, WI	1.2	1.0	2.0	3.4	3.4	4.0	4.3	4.3	3.4	2.2	2.1	1.2	32.4
MADISON, WI	1.3	1.3	2.3	3.4	3.3	4.1	3.9	4.3	3.1	2.2	2.3	1.7	33.0
MILWAUKEE, WI	1.9	1.7	2.6	3.8	3.1	3.6	3.6	4.0	3.3	2.5	2.7	2.2	34.8
CASPER, WY	0.6	0.6	0.9	1.5	2.4	1.4	1.3	0.7	1.0	1.1	0.8	0.6	13.0
CHEYENNE, WY	0.5	0.4	1.1	1.6	2.5	2.1	2.3	1.8	1.4	0.8	0.6	0.5	15.5
LANDER, WY	0.5	0.5	1.2	2.1	2.4	1.2	0.8	0.6	1.1	1.4	1.0	0.6	13.4
SHERIDAN, WY	0.8	0.6	1.0	1.8	2.4	2.0	1.1	0.8	1.4	1.4	0.8	0.7	14.7

Table A.9. EPA Contaminants and Max Limits/Goals Contaminants Regulations (US EPA, 2009)

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
Disinfectants				
Chloramines (as Cl2)	Eye/nose irritation, stomach discomfort; anemia	Water additive used to control microbes	MRDLG=4[1]	MRDL=4.0[1]
Chlorine (as Cl2)	Eye/nose irritation, stomach discomfort	Water additive used to control microbes	MRDLG=4[1]	MRDL=4.0[1]
Chlorine dioxide (as ClO2)	Anemia; infants & young children: nervous system effects	Water additive used to control microbes	MRDLG= 0.8[1]	MRDL= 0.8[1]
Microorganisms				
Cryptosporidium	Gastrointestinal Illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero	TT
Giardia lamblia	Gastrointestinal Illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero	TT
Heterotrophic plate count	HPC has no health effects; it is an analytic method used to measure the variety of bacteria that are common in water. The lower the concentration of bacteria in drinking water, the better maintained the water system is	HPC measures a range of bacteria that are naturally present in the environment	n/a	TT
Legionella	Legionnaire's Disease, a type of pneumonia	Found naturally in water; multiplies in heating systems	zero	TT
Total Coliforms (including fecal coliform and E. Coli)	Not a health threat in itself; it is used to indicate whether other potentially harmful bacteria may be present	Coliforms are naturally present in the environment; as well as feces; fecal coliforms and *E.Coli* only come from human and animal fecal waste	zero	TT
Turbidity	Turbidity is a measure of the cloudiness of water. It is used to indicate water quality and filtration effectiveness (e.g., whether disease-causing organisms are present). Higher turbidity levels are often associated with higher levels of disease-causing microorganisms such as viruses, parasites and some bacteria. These organisms can cause symptoms such as nausea, cramps, diarrhea, and associated headaches.	Soil Runoff	n/a	5.00%
Viruses	Gastrointestinal Illness (e.g., diarrhea, vomiting, cramps)	Human and animal fecal waste	zero	TT
Inorganic Chemicals				
Antimony	Increased blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder	0.006	0.006

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
Arsenic	Skin damage or problems with circulatory systems, and may have increased risk cancer	Erosion of natural deposits; runoff from orchards, glass & electronics production wastes	0	0.010 as of 01/23/06
Asbestos (fiber >10 micrometers	Increased risk of developing benign intestinal polyps	Decay of asbestos cement in water mains; erosion of natural deposits	7 million fibers/liter	7 MFL
Barium	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits	2	2
Beryllium	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defence industries	0.004	0.004
Cadmium	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints	0.005	0.005
Chromium (total)	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits	0.1	0.1
Copper	Short term exposure: Gastrointestinal distress Long term exposure: Liver or kidney damage People with Wilson's Disease should consult their personal doctor if the amount of copper in their water exceeds the action level	Corrosion of household plumbing systems; natural deposits	1.3	TT[8]; Action Level= 1.3
Cyanide (as free cyanide)	Nerve damage or thyroid problems	Discharge from steel/metal factories and from plastic and fertilizer factories	0.2	0.2
Fluoride	Bone disease (pain and tenderness of the bones); Children may get mottled teeth	Water additive which promotes strong teeth; erosion of natural deposits; discharge from fertilizer and aluminum factories	4	4
Lead	Infants and children: Delays in physical or mental development; children could show slight deficits in attention span and learning abilities Adults: Kidney problems; high blood pressure	Corrosion of household plumbing systems; natural deposits	zero	TT[8]; Action Level= 0.015

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
Mercury (inorganic)	Kidney damage	Erosion of natural deposits; discharge from refineries and factories; runoff from landfills and croplands	0.002	0.002
Nitrate (measured as Nitrogen)	Infants below the age of six months who drink water containing nitrate in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	10	10
Nitrite (measured as Nitrogen)	Infants below the age of 6 months who drink water containing nitrite in excess of the MCL could become seriously ill and, if untreated, may die. Symptoms include shortness of breath and blue-baby syndrome.	Runoff from fertilizer use; leaching from septic tanks, sewage; erosion of natural deposits	1	1
Selenium	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines	0.05	0.05
Thallium	Hair loss; chances in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories	0.0005	0.002
Organic Chemicals				
Acrylamide	Nervous system or blood problems; increased risk of cancer	Added to water during sewage/wastewater treatment	zero	TT[9]
Alachlor	Eye, liver, kidney, or spleen problems; anemia; increased risk of cancer	Runoff from herbicides used on row crops	zero	0.002
Atrazine	Cardiovascular system or reproductive problems	Runoff from herbicides used on row crops	0.003	0.003
Benzene	Anemia; decrease in blood platelets; increased risk of cancer	Discharge from factories; leaching from gas storage tanks and landfills	zero	0.005
Benzo(a)pyrene (PAHs)	Reproductive difficulties; increased risk of cancer	Leaching from linings of water storage tanks and distribution lines	zero	0.002
Carbofuran	Problems with blood, nervous system, or reproductive system	Leaching from soil fumigant used on rice and alfalfa	0.04	0.04
Carbon tetrachloride	Liver problems, increased risk of cancer	Discharge from chemical plants and other industrial activities	zero	0.005
Chlordane	Liver or nervous system problems; increased risk of cancer	Residue of banned termiticide	zero	0.0002

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
Chlorobenzene	Liver or kidney problems	Discharge from chemical and agricultural chemical factories	0.1	0.1
2,4-D	Kidney, liver, or adrenal gland problems	Runoff from herbicides used on row crops	0.07	0.07
Dalapon	Minor kidney changes	Runoff from herbicides used on rights of way	0.2	0.2
1,2-Dibromo-3-chloropropane (DBCP)	Reproductive difficulties; increased risk of cancer	Runoff/leaching from soil fumigant used on soybeans, cotton, pineapples, and orchards	zero	0.0002
o-Dichlorobenzene	Liver, kidney, or circulatory system problems	Discharge from industrial chemical factories	0.6	0.6
p-Dichlorobenzene	Anemia, liver, kidney, or spleen damage, changes in blood	Discharge from industrial chemical factories	0.075	0.075
1,2-Dichloroethane	Increased risk of cancer	Discharge from industrial chemical factories	zero	0.005
1,1-Dichloroethylene	Liver problems	Discharge from industrial chemical factories	0.007	0.007
cis-1,2-Dichloroethylene	Liver problems	Discharge from industrial chemical factories	0.07	0.07
trans-1,2-Dichloroethylene	Liver problems	Discharge from industrial chemical factories	0.1	0.1
Dichloromethane	Liver problems, increased risk of cancer	Discharge from industrial chemical factories	zero	0.005
1,2-Dichloropropane	Increased risk of cancer	Discharge from industrial chemical factories	zero	0.005
Di(2-ethylhexyl) adipate	Weight loss, liver problems, or possible reproductive difficulties	Discharge from industrial chemical factories	0.4	0.4
Di(2-ethylhexyl) phthalate	Reproductive difficulties; liver problems, increased risk of cancer	Discharge from industrial chemical factories	zero	0.006
Dinoseb	Reproductive difficulties	Runoff from herbicides used on soybeans and vegetables	0.007	0.007
Dioxin (2,3,7,8-TCDD)	Reproductive difficulties; increased risk of cancer	Emissions from waste incineration and other combustion; discharge from chemical factories	zero	0.00000003
Diquat	Cataracts	Runoff from herbicides use	0.02	0.02
Endothall	Stomach and intestinal problems	Runoff from herbicides use	0.1	0.1
Endrin	Liver problems	Residue of banned insecticide	0.002	0.002
Epichlorohydrin	Increased risk of cancer, and over a long period of time, stomach problems	Discharge from industrial chemical factories, an impurity of some water treatment chemicals	zero	TT[9]
Ethylbenzene	Liver or kidney problems	Discharge from petroleum refineries	0.7	0.7

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
Ethylene dibromide	Problems with liver, stomach, reproductive system, or kidneys; increased risk of cancer	Discharge from petroleum refineries	zero	0.00005
Glyphosate	Kidney problems; reproductive difficulties	Runoff from herbicides use	0.7	0.7
Heptachlor	Liver problems, increased risk of cancer	Residue of banned termiticide	zero	0.0004
Heptachlor epoxide	Liver problems, increased risk of cancer	Breakdown of heptachlor	zero	0.0002
Hexachlorobenzene	Liver or kidney problems; reproductive difficulties; increased risk of cancer	Discharge from metal refineries and agricultural chemical factories	zero	0.001
Hexachlorocyclopentadiene	Kidney or stomach problems	Discharge from chemical factories	0.05	0.05
Lindane	Liver or kidney problems	Runoff/leaching from insecticide used on cattle, lumber, and gardens	0.0002	0.0002
Methoxychlor	Reproductive difficulties	Runoff/leaching from insecticide used on fruits, vegetables, alfalfa, and livestock	0.04	0.04
Oxamyl (Vydate)	Slight nervous system effects	Runoff/leaching from insecticide used on apples, potatoes, and tomatoes	0.2	0.2
Polychlorinated biphenyls (PCBs)	Skin changes, thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer	Runoff from landfills; discharge of waste chemecals	zero	0.0005
Pentachlorophenol	Liver or kidney problems, increased risk of cancer	Discharge from wood preserving factories	zero	0.001
Picloram	Liver problems	Runoff from herbicides use	0.5	0.5
Simazine	Problems with blood	Runoff from herbicides use	0.004	0.004
Styrene	Liver, kidney, or circulatory system problems	Discharge from rubber and plastic factories; leaching from landfills	0.1	0.1
Tetrachloroethylene	Liver problems; increased risk of cancer	Discharge from factories and dry cleaners	zero	0.005
Toluene	Nervous system, kidney, or liver problems	Discharge from petroleum refineries	1	1
Toxaphene	Kidney, Liver, or thyroid problems; increased risk of cancer	Runoff/leaching from insecticide used on cotton and cattle	zero	0.003
2,4,5-TP (Silvex)	Liver problems	Residue of banned herbicide	0.05	0.05
1,2,4-Trichlorobenzene	Changes in adrenal glands	Discharge from textile finishing factories	0.07	0.07
1,1,1-Trichloroethane	Liver, nervous system, or circulatory problems	Discharge from metal degreasing sites and other factories	0.2	0.2

Contaminant	Potential Health Effects from Ingestion of Water	Sources of Contaminant in Drinking Water	MCLG[1] (mg/L)[2]	MCL or TT[1] (mg/L)[2]
1,1,2-Trichloroethane	Liver, kidney, or immune system problmems	Discharge from industrial chemical factories	0.003	0.005
Trichloroethylene	Liver problems, increased risk of cancer	Discharge from metal degreasing sites and other factories	zero	0.005
Vinyl chloride	Increased risk of cancer	Leaching from PVC pipes; discharge from plastic factories	zero	0.002
Xylenes (total)	Nervous system damage	Discharge from petroleum factories and chemical factories	10	10
Radionuclides				
Alpha particles	Increased risk of cancer	Erosion of natural deposits of certain minerals that are radioactive and may emit a form of radiation known as alpha radiation	zero	15 picocuries per Liter (pCi/L)
Beta particles and photon emitters	Increased risk of cancer	Decay of natural and man-made deposits of certain minerals that are radioactive and may emit forms of radiation known as photons and beta radiation	zero	4 millirems per year
Radium 226 and Radium 228 (combined)	Increased risk of cancer	Erosion of natural deposits	zero	5 pCi/L
Uranium	Increased risk of cancer, kidney toxicity	Erosion of natural deposits	zero	30 ug/L as of 12/08/03

Notes

[1] Definitions:
Maximum Contaminant Level (MCL) - The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.
Maximum Contaminant Level Goal (MCLG) - The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
Maximum Residual Disinfectant Level (MRDL) - The highest level of a disinfectant allowed in drinking water. There is convincing evidence that addition of a disinfectant is necessary for control of microbial contaminants.
Maximum Residual Disinfectant Level Goal (MRDLG) - The level of a drinking water disinfectant below which there is no known or expected risk to health. MRDLGs do not reflect the benefits of the use of disinfectants to control microbial contaminants.
Treatment Technique - A required process intended to reduce the level of a contaminant in drinking water.

[2] Units are in milligrams per liter (mg/L) unless otherwise noted. Milligrams per liter are equivalent to parts per million.

[3] EPA's surface water treatment rules require systems using surface water or ground water under the direct influence of surface water to (1) disinfect their water, and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:

- Cryptosporidium: (as of1/1/02 for systems serving >10,000 and 1/14/05 for systems serving <10,000) 99% removal.
- Giardia lamblia: 99.9% removal/inactivation
- Viruses: 99.99% removal/inactivation
- Legionella: No limit, but EPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
- Turbidity: At no time can turbidity (cloudiness of water) go above 5 nephelolometric turbidity units (NTU); systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month. As of January 1, 2002, turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
- HPC: No more than 500 bacterial colonies per milliliter.
- Long Term 1 Enhanced Surface Water Treatment (Effective Date: January 14, 2005); Surface water systems or (GWUDI) systems serving fewer than 10,000 people must comply with the applicable Long Term 1 Enhanced Surface Water Treatment Rule provisions (e.g. turbidity standards, individual filter monitoring, Cryptosporidium removal requirements, updated watershed control requirements for unfiltered systems).
- Long Term 2 Enhanced Surface Water Treatment Rule (Effective Date: January 4, 2006) - Surface water systems or GWUDI systems must comply with the additional treatment for Cryptosporidium specified in this rule based on their Cryptosporidium bin classification calculated after the completion of source water monitoring.
- Filter Backwash Recycling; The Filter Backwash Recycling Rule requires systems that recycle to return specific recycle flows through all processes of the system's existing conventional or direct filtration system or at an alternate location approved by the state.

[4] more than 5.0% samples total coliform-positive in a month. (For water systems that collect fewer than 40 routine samples per month, no more than one sample can be total coliform-positive per month.) Every sample that has total coliform must be analyzed for either fecal coliforms or E. coli if two consecutive TC-positive samples, and one is also positive for E.coli fecal coliforms, system has an acute MCL violation.

[5] Fecal coliform and E. coli are bacteria whose presence indicates that the water may be contaminated with human or animal wastes. Disease-causing microbes (pathogens) in these wastes can cause diarrhea, cramps, nausea, headaches, or other symptoms. These pathogens may pose a special health risk for infants, young children, and people with severely compromised immune systems.

[6] Although there is no collective MCLG for this contaminant group, there are individual MCLGs for some of the individual contaminants:

- Trihalomethanes: bromodichloromethane (zero); bromoform (zero); dibromochloromethane (0.06 mg/L): chloroform (0.07mg/L).
- Haloacetic acids: dichloroacetic acid (zero); trichloroacetic acid (0.02 mg/L); monochloroacetic acid (0.07 mg/L). Bromoacetic acid and dibromoacetic acid are regulated with this group but have no MCLGs.

[7] The MCL values are the same in the Stage 2 DBPR as they were in the Stage 1 DBPR, but compliance with the MCL is based on different calculations. Under Stage 1, compliance is based on a running annual average (RAA). Under Stage 2, compliance is based on a locational running annual average (LRAA), where the annual average at each sampling location in the distribution system is used to determine compliance with the MCLs. The LRAA requirement will become effective April 1, 2012 for systems on schedule 1, October 1, 2012 for systems on schedule 2, and October 1, 2013 for all remaining systems.

[8] Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

[9] Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used in drinking water systems, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows:

- Acrylamide = 0.05% dosed at 1 mg/L (or equivalent)
- Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent)

Storm Frequency

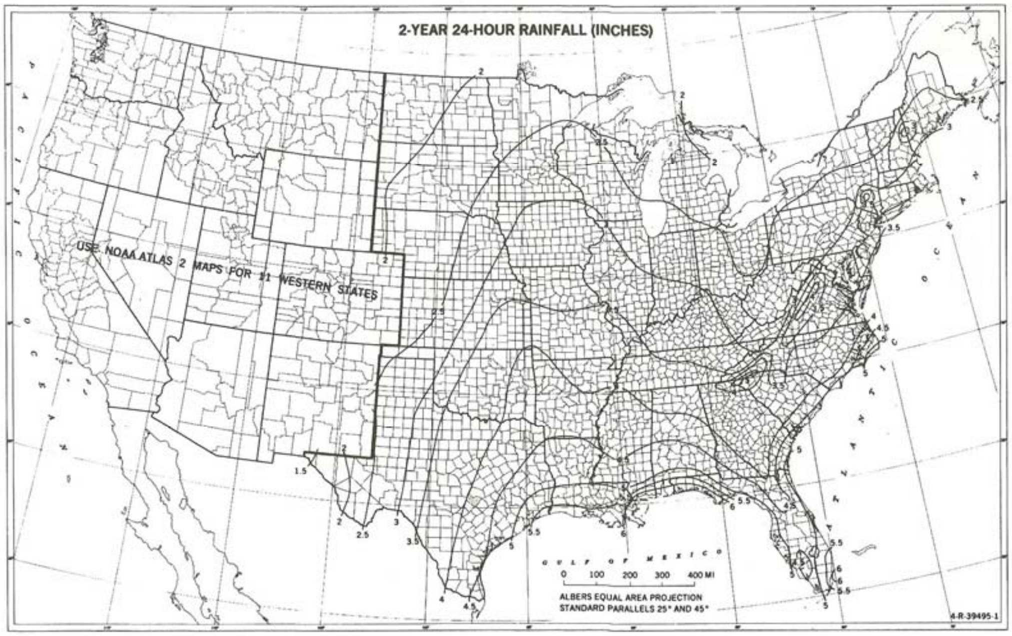

Figure 3A.1 Two-year, 24-hr rainfall. From Soil Conservation Service (1986).

Figure A.1. Two-year, 24 hour rainfall event. (SCS, 1986)

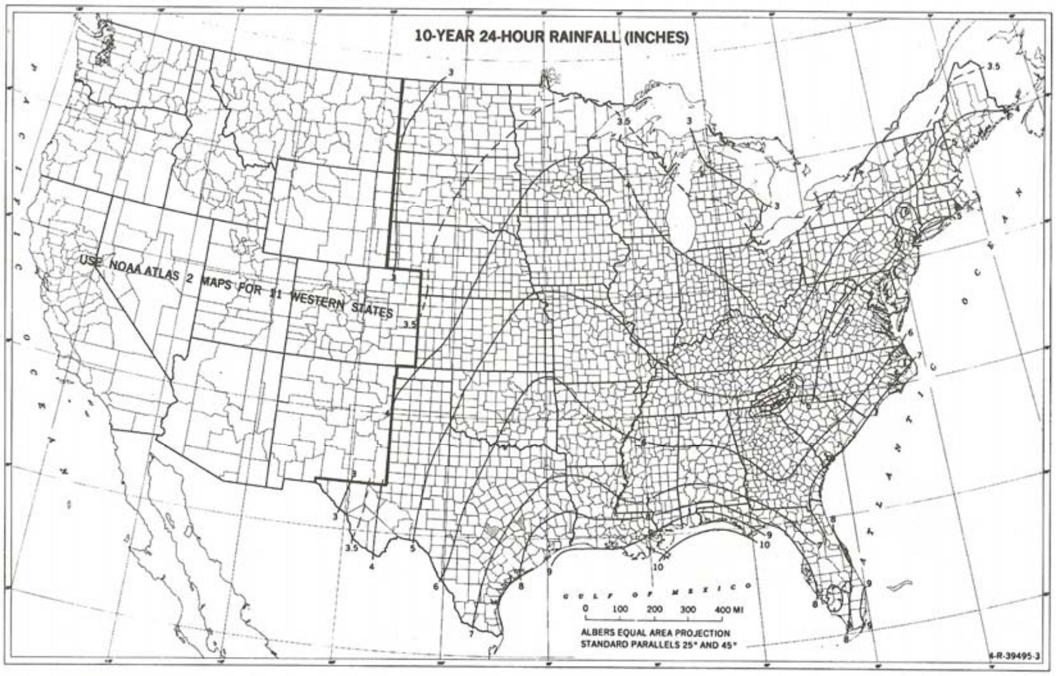

Figure A.2. Ten-year, 24 hour rainfall event. (SCS, 1986)

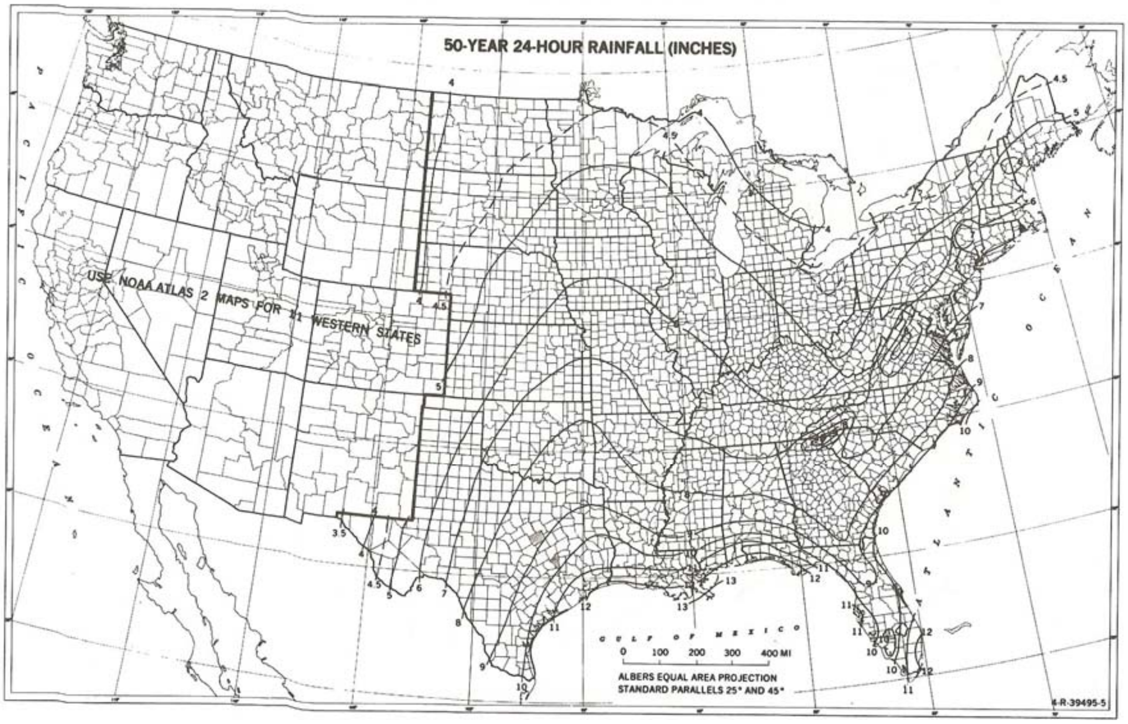

Figure A.3. Fifty-year, 24 hour rainfall event. (SCS, 1986)

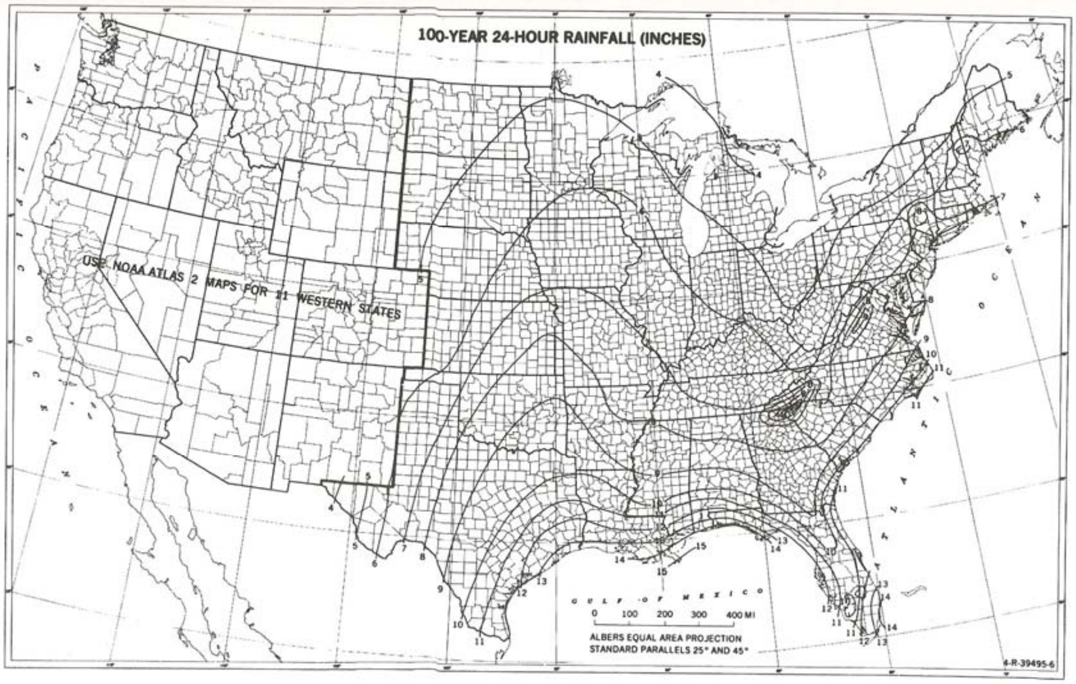

Figure A.4. One hundred-year, 24 hour rainfall event. (SCS, 1986)

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Rainwater Harvesting: System Planning

Appendix B: Math Review

Contents

In order to effectively install rainwater harvesting systems, it is necessary to understand some basic math and be able to work through specific equations. This section begins with a review of some basic mathematical terms and proceeds with the presentation of important equations.

Relevant Terms

Length: *[One Dimension]* Expressed in:

- Inches
- Feet
- Yards
- Miles
- Meters

Area : *[Two Dimensions]*
Measurement of a surface in square units. Expressed in:

- Inches^2 or square inches
- Feet^2 or square feet
- Yards^2 or square yards
- Acres

Volume: *[Three Dimensions]*
Capacity of a container such as a pipe or a tank. Expressed in:

- Inches^3 or cubic inches
- Feet^3 or cubic feet
- Yards^3 or cubic yards
- Gallons, liters

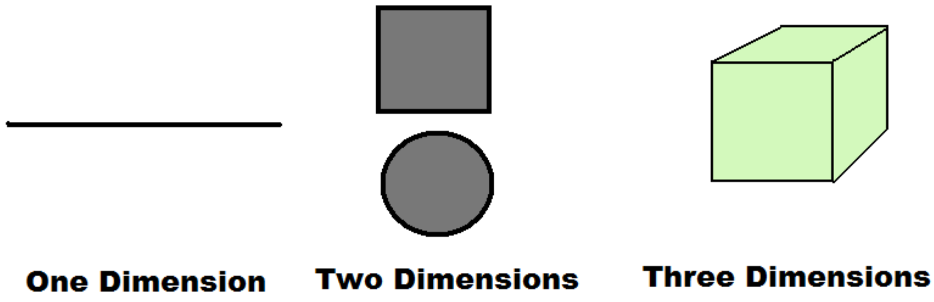


Figure B.1. Special dimensions.

Diameter: Distance from one side of a circle to the other across the center point. Pipe diameter is expressed in outer diameter (OD) or inner diameter (ID). Note the difference between ID and OD of a pipe. The abbreviation for diameter is “d”.

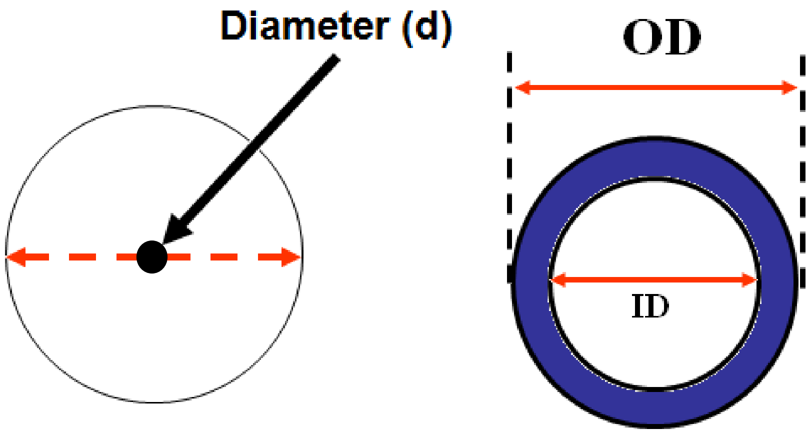


Figure B.2. Diameter.

Radius: Distance from the center point to the side of the circle. It is also one-half the diameter of a circle. The symbol for radius is “r”.

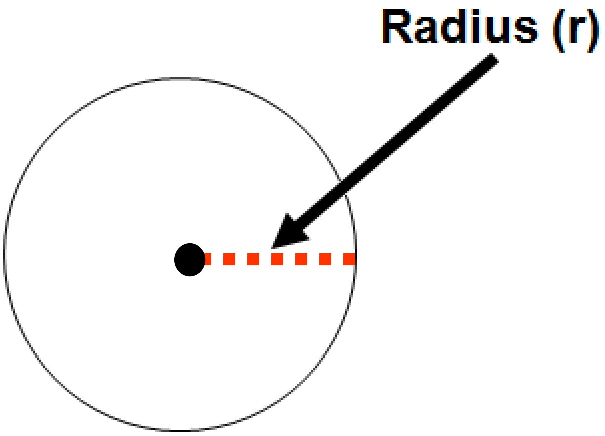


Figure B.3. Radius.

Circumference: Length of the external boundary of a circle.

Pressure: Force applied to a unit area commonly expressed in pounds per square inch (psi) (e.g., pressure of water in a force main that is 60 psi), feet of head (1 psi is equal to 2.31 feet of head), or pounds per square foot (psf) (e.g., a tank lid that is designed to support 150 psf).

Flow rate: Volume per unit time commonly expressed as gallons per minute (gpm), gallons per day (gpd), or cubic feet per second (cfs).

Flow velocity: Distance per unit time commonly expressed as feet per second (fps).

Pump delivery rate (PDR): Flow delivered by a pump at a specified total dynamic head expressed as volume per unit time. It is the rate at which wastewater is pumped to the soil treatment area or treatment unit typically expressed in gallons per minute (gpm).

Units

Always remember to keep track of units when applying formulas. For example, width in inches cannot be multiplied by length in feet. If a tank is 4 feet wide and 102 inches long, first convert length to feet or width to inches. As in:

4 ft x 8.5 ft. = 34 ft^2 or
48 in. x 102 in. = 4896 in.^2

Both answers are right – just in different units.

To convert units, multiply or divide by the appropriate conversion factor. For example, because there are 12 inches in every foot, multiply by 12 inches/foot to convert feet to inches. Or, to convert inches to feet, divide by 12 (same as multiplying by 1 foot/12 inches). Likewise, convert square inches to square feet by dividing by 144 or $(12)^2$. Or, to convert square feet to square inches, multiply by 144. Table B.1 gives conversion factors for units commonly used in the onsite wastewater industry. Some equations have constants factored into them that will convert all units used in the equation to the desired unit. In this case be sure that all values have the units specified by the equation.

Table B.1. Conversion Factors

MULTIPLY	BY	TO OBTAIN
Acres	43560	Square Feet
Atmospheres	33.9	Feet of Water
Centimeters	0.3937	Inches
Cubic Feet	7.48052	Gallons
Cubic Feet	28.32	Liters
Cubic Feet/Second	449	Gallons/Minute
Cubic Meters	35.31	Cubic Feet
Cubic Meters	264.2	Gallons
Cubic Meters	10^3	Liters
Cubic Yards	27	Cubic Feet
Cubic Yards	202	Gallons
Feet	30.48	Centimeters
Feet	0.3048	Meters
Feet of Water	62.43	Pounds/Square Foot
Feet of Water	0.434	Pounds/Square Inch
Gallons	3785	Cubic Centimeters
Gallons	0.1337	Cubic Feet
Gallons	3.785	Liters
Gallons water	8.3453	Pounds of Water
Gallons/Minute	2.228×10^{-3}	Cubic feet/Second
Gallons/Minute	1440	Gallons/Day
Gallons/ Minute	0.06308	Liters/Second
Gallons/Day	6.944×10^{-4}	Gallons/Minute
Gallons/Day/Square Foot	1.604	Inches/Day
Grams	2.205×10^{-3}	Pounds
Grams/Liter	1000	Parts/Million
Hectares	2.471	Acres
Horsepower	33,000	Foot-pounds/Minute
Horsepower	0.7457	Kilowatts
Inches	2.54	Centimeters
Inches/Day	0.6234	Gallons/Day/Square Foot
Kilograms	2.205	Pounds
Kilowatts	1.341	Horsepower
Kilowatt-hours	2.655×10^6	Foot-pounds
Liters	103	Cubic Centimeters
Liters	0.03531	Cubic Feet
Liters	0.2642	Gallons
Meters	3.281	Feet
Milligrams/Liters	1	Parts/Million
Million Gallons/Day	1.54723	Cubic Feet/Second
Parts/Million	8.345	Pounds/Million Gallons
Pounds	453.5024	Grams
Pounds of Water	0.1198	Gallons
Pounds/Square Inch	2.31	Feet of Water
Pounds/Square Inch	2.036	Inches of Mercury
Temperature (˚C) + 17.78	1.8	Temperature (˚F)
Temp. (˚F) - 32	5/9	Temp. (˚C)

Basic Calculations

Circumference

Circumference of a circle is:
$2 \pi r$
Where:
π is a constant equal to 3.14 and
r is the radius of the circle.

For example, the circumference of a pipe with a diameter of 3 in OD is:

2 x 3.14 x 1.5 in. = 9.42 in.

Area

The *area of a circle* is πr^2 or 3.14 x radius x radius. The area of a circle with a diameter of 3 in is:

3.14 x (1.5 in. x 1.5 in.) = 7.07 in.^2

The *area of squares and rectangles* is found by multiplying the length by the width. The area of a rectangle 5 foot wide and 7 feet long is:

5 ft x 7 ft = 35 ft^2

The *area of a triangle is* half of the base of the triangle multiplied by its height.

Volumes

Volumes related to cubes or rectangular tank

The *volume of a cube or rectangular tank* is found by multiplying the length by the width by the height depth:

length x width x depth = units^3

There are two possible volumes that you may need to calculate for a tank: the tank volume and the external volume. Tank volume is the total volume of a tank from the inside bottom of the tank to the inside top of the tank and is therefore calculated using the inside dimensions of the tank. The external volume is related to the amount of void space that the tank will fill when installed in the soil and is calculated using the outside dimensions of the tank.

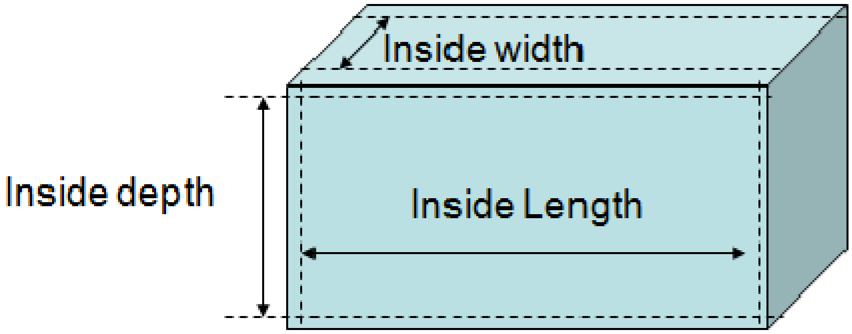
A tank is 4 feet wide, 5 feet deep, and 8 feet long. What is the tank's void space in the soil in cubic feet?

8 ft x 4 ft x 5 ft = 160 ft^3

If the tank has walls that are 2 inches thick and the top and bottom of the tank are 3 inches thick, what is the tank volume?

The internal dimensions would be:

92 in. x 44 in. x 54 in. = 218592 in.^{3} or 126.5 ft^3



A more useful calculation is the *tank capacity*. For a septic tank, the tank capacity is the volume calculated using the depth from the invert of the outlet to the bottom of the tank.

L x W x Liquid depth = Tank Capacity (ft^3)

Note that liquid depth is measured inside the tank. If this is not possible, use outside measurements and estimate a wall thickness of about 2 inches. Another option is to contact the manufacturer for dimensions.

8 ft x 4 ft x 4.25 ft = 136 ft^3

To express tank capacity in gallons, use a conversion factor. One cubic foot (1 ft^3) holds 7.48 gallons of water or effluent. This number is used repeatedly in the onsite wastewater industry and is worth remembering. For residential systems, it is reasonable to round 7.48 to 7.5 gallons per cubic foot. However, rounding 7.48 to 7.5 may affect the accuracy of calculations related to larger capacity systems.

136 ft^3 x 7.48 gal/ft^3 = 1017 gal

If you know the tank's length and width, you can determine how many *gallons per inch* of liquid depth using the equation:

$$\text{L (ft)} \times \text{W (ft)} \times \frac{1\text{ ft}}{12\text{ in.}} \times \frac{7.5\text{ gal}}{\text{ft}^3} = \frac{\text{gal}}{\text{in.}}$$

The units cancel out to leave gallons per inch.
To think about it another way, essentially calculate the volume of 1 foot of tank depth in gallons and then divide by 12 to get gallons per inch.

Example: A tank is 10 ft long and 4.5 ft wide. How many gallons are there per inch of liquid depth?

$$10\text{ ft} \times 4.5\text{ ft} \times 1\text{ ft} \times \frac{7.5\text{ gal}}{\text{ft}^3} = 337.5\text{ gal}$$

$$\frac{337.5 \text{ gal}}{12 \text{ in.}} = 28.12 \frac{\text{gal}}{\text{in.}}$$

To look at it another way, if you know the tank volume in gallons and the total tank depth in inches, just divide to get gallons per inch.

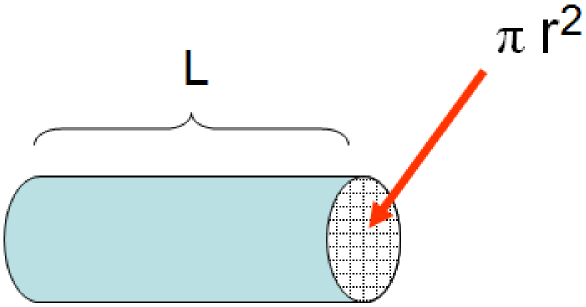
Example: If the tank volume is 1200 gallons and is 60 inches deep, how many gallons per inch are in the tank?

$$\frac{\text{Volume (gal)}}{\text{Depth (in.)}} = \frac{1200 \text{ gal}}{60 \text{ in.}} = \frac{20 \text{ gal}}{\text{in.}}$$

Volume of a Cylinder

To figure *volume in a cylindrical tank or in a pipe* (which is just a long cylinder), this is the formula that applies.

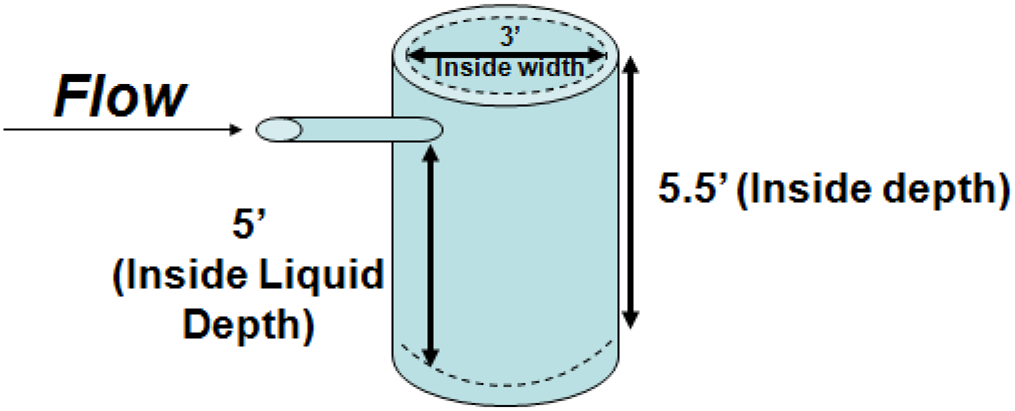
cross-sectional area (πr^2) x length or depth



Example: A pump basin is 3 feet in diameter and 5.5 feet tall. The invert of the inlet to the basin is 5 feet above the bottom. What is the basin capacity? Remember that the radius equals ½ of the diameter.

$$(3.14 \times 1.5 \text{ ft} \times 1.5 \text{ ft}) \times 5 \text{ ft} = 35.3 \text{ ft}^3$$

$$35.3 \text{ ft}^3 \times \frac{7.5 \text{ gal}}{\text{ft}^3} = 264.75 \text{ gal}$$



The *gallons per inch of a cylindrical tank* can be found in a manner similar to a rectangular tank by multiplying the cross-sectional area by 1foot /12 inches and 7.5 gallons per cubic foot.

$$\text{Gal per in.} = \pi r^2 \times \frac{1\ \text{ft}}{12\ \text{in.}} \times \frac{7.5\ \text{gal}}{\text{ft}^3} = \frac{\text{gal}}{\text{in.}}$$

Volume of a pipe can be calculated the same way:

$$\pi r^2 \times \text{length} \times 7.5\ \text{gal/ft}^3$$

Remember that nominal pipes do not measure exactly what they are called. For instance, 2-inch Sch 40 pipe has a diameter of 2.067 inches, and 2-inch Sch. 80 measures 1.939 inches inside. Volumes for various pipe specifications can be found in Appendix A.

Volume of Triangular Shapes

When an excavation (or fill area) has sloped sides, the volume is often divided into shapes that have simple calculations for deriving volumes. For example, in the following figure, the volume of the excavation would be found by breaking the shape into two triangular pieces and a rectangle. The volume of the rectangular section can be calculated in the same manner as described above for rectangular tanks. The triangular section (volume shaded in the figure) can be found by:

$$\tfrac{1}{2} \times \text{base} \times \text{height} \times \text{length}$$

Friction Loss in a Pipe

Friction loss is the reduction in pressure of liquid flowing through pipe and associated devices as a result of contact between the liquid and the pipe walls, valves, and fittings. Friction loss varies with flow rate and pipe diameter. Table A.4 in appendix A shows calculated values for friction loss at various flow rates and pipe diameters of Schedule 40 PVC. The values are given in friction loss per 100 feet so the length of the pipe must first be divided by 100 before being multiplied by the factor given in the table or graph. The values from the table are estimated using the Hazen-Williams equation:

$$Friction \quad Loss = 10.46L\frac{\left(\frac{Q}{C}\right)^{1.852}}{D^{4.871}}$$

where

L = length of pipe (feet) (include addition of equivalent lengths for fittings see Table D.5 in Appendix A)

Q = flow rate (gpm)

D = actual pipe inner diameter (inches)

C= friction coefficient (The friction factor (C) is a unitless value that is dependent of the pipe's inner surface's roughness. The lower the value of C, the greater the friction loss. Values for the friction factor for PVC pipe range from 140 to 150. For new pipe, 150 is often used as the factor. This manual assumes that with time the pipes will become less smooth resulting in a lower friction factor so a value of 140 was used in estimating the friction loss).

Note: The smaller the pipe diameter and the greater the flow rate, the more friction loss in a given length of pipe.

Example:

What is the friction loss generated by liquid flowing at 32 gpm through 100 feet of 1½-inch Schedule 40 PVC assuming C=140?

Friction loss (ft) = $10.46 \times 100 \times [(32/140)^{1.852}]/(1.61^{4.871})$

$= 1046 \times (.23^{1.855})/ 10.17$

$1046 \times .065/10.17 = 6.7$ ft of friction loss

Flow from an Orifice

Flow from an orifice varies with the orifice size and distal pressure. The flow from the orifice can be found using the equation:

$$q = 11.79\, d^2 h_d^{1/2}$$

where:

q = orifice flow rate (gpm),

d = orifice diameter (inches),

h_d= distal in-line pressure (feet).

The equation assumes free flow from the orifice.

Example:

Assuming 3.5-feet pressure head in each lateral and 5/32-inch holes:

Flow rate = 0.54 gal/min (gpm)

Pump Delivery Rate (PDR)

The pump delivery rate can be found by dividing the volume of water the pump delivered by the amount of time it took to deliver the water.

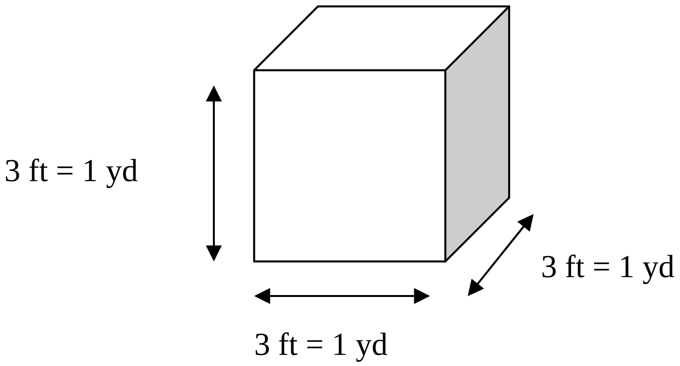
$$\text{PDR} = \frac{\text{gal of water pumped}}{\text{pump run time (min)}}$$

For example, if a pump delivers 40 gallons to a soil treatment area in 5 minutes then the PDR is:

$$\frac{40\text{ gal}}{5\text{ min}} = 8\text{ gal/min}$$

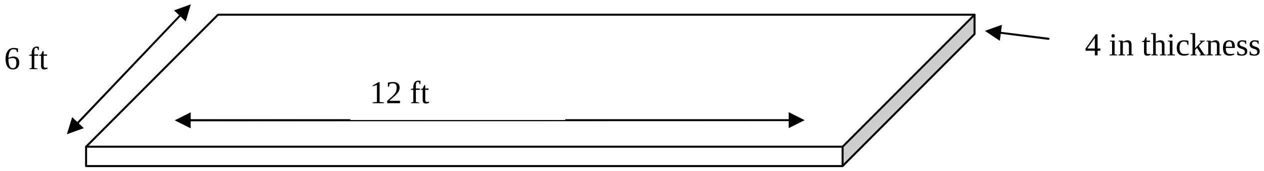
Concrete

Concrete is purchased by the cubic yard (yd^3). Most folks refer to concrete volume as just yards. To figure cubic yards needed, one must find the volume of the forms in cubic feet. Then, convert the volume to cubic yards by diving by 27. A square block with 3-foot long sides is a cubic yard. For example: 3ft x 3ft x 3ft = 27 ft^3. And, 1 yd^3 = 27 ft^3



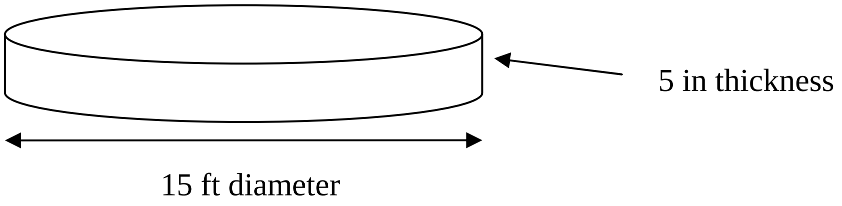
Exercises:

1) Determine the number of cubic yards of concrete required for a foundation for a RWH storage tank. A 4-inch thick rectangular slab with dimensions of 6 feet by 12 feet is to be poured for a small tank foundation. Volume of steel and rebar chairs is not considered.



Volume = width x length x depth
Volume = 12ft x 6ft x 4/12ft
Volume = 24 ft^3
Volume = $25ft^3/27ft^3$ = $\underline{0.88yds^3}$

2) How many cubic yards of concrete are required to pour a 15 foot diameter pad that is 5 inches thick? Volume of steel and rebar chairs is not considered.



Volume = width x length x depth
width x length = area in square feet
Volume = area x depth (quick and neat way to view the volume formula)
Area of a circle = $\pi \times r^2$ or $\pi \times (d/2)^2$

Volume = $\pi \times (15/2)^2\ ft^2 \times 5/12ft$
Volume = $73.63ft^3$
Volume = $73.63t^3/27ft^3$ = $\underline{2.73yds^3}$

Dynamic Pressure Loss in a Pipe

As water flows through a level pipe, the flow rate and velocity remain constant, but pressure drops. For instance, if a water pump is used to push water through a PVC pipeline that is 400 feet long, there will be a measureable loss of pressure from the pump to the end of the pipe. Pressure losses also occur in shorter runs of pipe and when multiple fittings are used to change the direction of flow. Pressure loss also occurs when water travels through system components such as filters, water meters, or UV sanitation devices. As a rule; as flow increases in a pipe, water velocity increases and pressure drop increases.

Pressure loss occurs because of the friction between the inside wall of the pipe and the moving water. The rough surface of the inner wall of the pipe, even of plastic PVC pipe, causes eddies to form. Eddies or vortices develop next to the wall of the pipe similar to the way eddies form adjacent to rocks in a swift moving creek. Just like in a creek, as water velocity increases, the vortices grow in size. As the vortices increase, the ability of water to flow smoothly through a pipe decreases.

This disturbance in the flow path of the water consumes energy and causes pressure to drop. The change in pressure drop increases exponentially as velocity increases. In most cases, once the velocity of the water in a pipe reaches a velocity of 5 feet per second (fps), the pressure losses are so great that an impractical amount of energy is needed to overcome the losses in order to maintain system functionality. Enlarging the pipe size maintains flow rate, decreases water velocity and decreases pressure losses.

Pressure drop through a pipeline, multiple fittings, or system components is predictable. Determining pressure loss in a pipeline is based on flow rate, velocity, and type of pipe. Pressure drop can be calculated using a formula or determined by referring to the appropriate tables. Pressure drop in pipe is found in a friction loss table. Pressure drop in fittings and system components are found in a pipe-length equivalent chart or reference tables provided by the manufacturer.

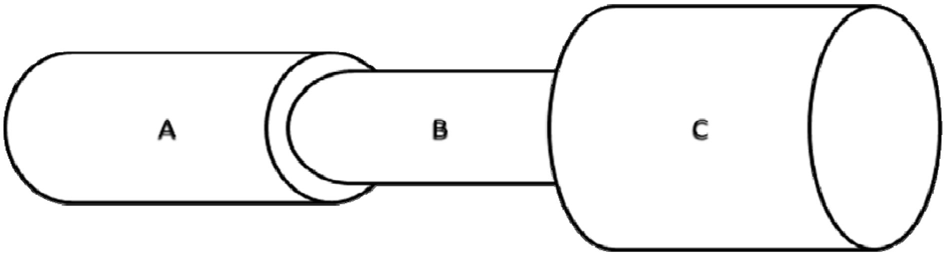
Remember: Flow rate is the volume of water moving through a pipe during a given time frame and is measured in gallons per minute (gpm). Water velocity is the speed that water travels through a pipe and is measured in feet per second (fps). Pressure is the force applied to a given area of the inside wall of a pipe and is measured in pounds per square inch (psi) or feet of head (Hd-ft).

Figure XX represents three sections of pipe that are connected to form a pipeline, but have differing diameters. The nominal size of each lettered section is as follows: A = 8”, B = 4” and C = 12” . the following assumptions can be made about the pipeline when water is flowing. The flow rate (Q) for each section is equal. The velocity of the water is greatest in section B and least in section C.

Section A: 8-inch diameter
Section B: 4-nch diameter
Section C: 12-inch diameter

Q = Flow rate
V = Velocity

$Q_A = Q_B = Q_C$
$V_A < V_B > V_C$
$V_C < V_A < V_B$



Elementary Algebra

Linear Equation – a linear equation may contain one or more variables where each term is a constant or a product of a constant and a single variable. The exponents of the variables are always 1. Examples of linear equations:

$X = 5a$; $a + b + c = 10$; $x = y$; $y = mx + b$

The following are non-examples of linear equations:

$Y = mx^2 + b$; $c^2 = a^2 + b^2$

Manipulating Linear Equations

In some cases, we need to rearrange a formula to assist us in easily solving for an unknown quantity. The following is an example of how easily we can manipulate a formula to help us find catchment surface area.

Variables:

Harvested H2O = H
Depth = D
Catchment Area = A
Conversion = 0.623

Formula:
$H = A \times D \times 0.623$

This formula can be rearranged in order to solve for any one of the variables. For instance, if we knew our rainfall amount and how many gallons of water we needed to harvest, our unknown would be Catchment Area. Rearrange the formula to solve for Catchment Area (A).

$A = H / (D \times 0.623)$

Example:

How many square feet are required to catch 20,000 gallons of water if the rainfall is 30 inches.

$A = 20{,}000 / (30 \times 0.623)$

$A = 1{,}070\text{ft}^2$

References

CIDWT. 2008. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment. Pilot Test Version 2. March 2008.

Rainwater Harvesting:
System Planning

Appendix C: Uniform Plumbing Code

Upon completion of this unit, the participant should be able to accomplish the following objectives:

1. Identify proper sizing of roof drains, leaders, and vertical rainwater piping.
2. Identify proper sizing of horizontal rainwater piping.
3. Identify proper sizing of gutters.
4. Identify maximum rainfall rates for various US cities.

Contents

THESE TABLES ARE FROM THE UNIFORM PLUMBING CODE 2000 EDITION- CHAPTER 11: STORM DRAINAGE

These tables are provided as a reference. For design purposes, please refer to Chapter 11 of the Uniform Plumbing Code 2000 Edition

Table C.1. Sizing Roof Drain, Leaders, and Vertical Rainwater Piping (IAMPO, 2000)

Size of Drain, Leader or Pipe	Flow	Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates					
Inches	**gpm**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
2	23	2176	1088	725	544	435	363
3	67	6440	3220	2147	1610	1288	1073
4	144	13840	6920	4613	3460	2768	2307
5	261	25120	12560	8373	6280	5024	4187
6	424	40800	20400	13600	10200	8160	6800
8	913	88000	44000	29333	22000	17600	14667
Millimeters	**L/S**	**25mm/Hr**	**50mm/Hr**	**75mm/Hr**	**100mm/Hr**	**125mm/Hr**	**150mm/Hr**
50	1.5	202	101	67	51	40	34
80	4.2	600	300	200	150	120	100
100	9.1	1286	643	429	321	257	214
125	16.5	2334	1117	778	583	467	389
150	26.8	3790	1895	1263	948	758	632
200	57.6	8175	4088	2725	2044	1635	1363

Notes:

1. *The sizing data for vertical conductors, leaders, and drains is based on the pipes flowing 7/24 full.*
2. *For rainfall rates other than those listed, determine the allowable roof area by dividing the area given in the 1 inch/hour (25 mm/hour) column by the desired rainfall rate.*
3. *Vertical piping may be round, square, or rectangular. Square pipe shall be sized to enclose its equivalent round pipe. Rectangular pipe shall have at least the same cross-sectional area as its equivalent round pipe, except that the ratio of its side dimensions shall not exceed 3 to 1.*

Table C.2. Sizing of Horizontal Rainwater Piping (IAMPO, 2000)

Size of Pipe	**Flow, gpm**	**Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates**					
Inches	**1/8"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	34	3288	1644	1096	822	657	548
4	78	7520	3760	2506	1880	1504	1253
5	139	13360	6680	4453	3340	2672	2227
6	222	21400	10700	7133	5350	4280	3566
8	478	46000	23000	15330	11500	9200	7670
10	860	82800	41400	27600	20700	16580	13800
12	1384	133200	66600	44400	33300	26650	22200
15	2473	238000	119000	79333	59500	47600	39650
Inches	**1/4"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	48	4640	2320	1546	1160	928	773
4	110	10600	5300	3533	2650	2120	1766
5	196	18880	9440	6293	4720	3776	3146
6	314	30200	15100	10066	7550	6040	5033
8	677	65200	32600	21733	16300	13040	10866
10	1214	116800	58600	38950	29200	23350	19450
12	1953	188000	94000	62600	47000	37600	31350
15	3491	336000	168000	112000	84000	67250	56000
Inches	**1/2"/ft. Slope**	**1"/Hr**	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**
3	68	6576	3288	2192	1644	1310	1096
4	156	15040	7520	5010	3760	3010	2500
5	278	26720	13360	8900	6680	5320	4450
6	445	42800	21400	14267	10700	8580	7140
8	956	92000	46000	30650	23000	18400	15320
10	1721	165600	82800	55200	41400	33150	27600
12	2768	266400	133200	88800	66600	53200	44400
15	4946	467000	238000	158700	119000	95200	79300

Notes:

1. The sizing data for horizontal piping is based on the pipes flowing full.

2. For rainfall rates other than those listed, determine the allowable roof area by dividing the area given in the 1 inch/hour(25 mm/hour) column by the desired rainfall rate.

Table C.3. Sizing of Horizontal Rainwater Piping (Metric) (IAMPO, 2000)

Size of Pipe	**Flow**	**Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates**					
	10mm/m Slope						
Millimeters	**L/S**	**25mm/Hr**	**50mm/Hr**	**75mm/Hr**	**100mm/Hr**	**125mm/Hr**	**150mm/Hr**
80	2.1	305	153	102	76	61	51
100	4.9	700	350	233	175	140	116
125	8.8	1241	621	414	310	248	207
150	14.0	1988	994	663	497	398	331
200	30.2	4273	2137	1424	1068	855	713
250	54.3	7692	3846	2564	1923	1540	1282
300	87.3	12375	6187	4125	3094	2476	2062
375	156.0	22110	11055	7370	5528	4422	3683
	20mm/m Slope						
Millimeters	**L/S**	**25mm/Hr**	**50mm/Hr**	**75mm/Hr**	**100mm/Hr**	**125mm/Hr**	**150mm/Hr**
80	4.3	413	216	144	108	86	72
100	6.9	985	492	328	246	197	164
125	12.4	1754	877	585	438	351	292
150	19.8	2806	1403	935	701	561	468
200	42.7	6057	3029	2019	1514	1211	1009
250	76.6	10851	5425	3618	2713	2169	1807
300	123.2	17465	8733	5816	4366	3493	2912
375	220.2	31214	15607	10405	7804	6248	5205
	40mm/m Slope						
Millimeters	**L/S**	**25mm/Hr**	**50mm/Hr**	**75mm/Hr**	**100mm/Hr**	**125mm/Hr**	**150mm/Hr**
80	4.3	611	305	204	153	122	102
100	9.8	1400	700	465	350	280	232
125	17.5	2482	1241	827	621	494	413
150	28.1	3978	1988	1325	994	797	663
200	60.3	8547	4273	2847	2137	1709	1423
250	108.6	15390	7695	5128	3846	3080	2564
300	174.6	24749	12374	8250	6187	4942	4125
375	312	44220	22110	14753	11055	8853	7367

Notes:

1. The sizing data for horizontal piping is based on the pipes flowing full.

2. For rainfall rates other than those listed, determine the allowable roof area by dividing the area given in the 1 inch/hour(25 mm/hour) column by the desired rainfall rate.

Table C.4. Size of Gutters (IAMPO, 2000)

Slope of Gutter	**Diameter of Gutter**	**Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates**					
	inches	**2"/Hr**	**3"/Hr**	**4"/Hr**	**5"/Hr**	**6"/Hr**	
1/8"/ft. Slope	3	480	320	240	192	160	
	4	1020	681	510	408	340	
	5	1760	1172	880	704	587	
	6	2720	1815	1360	1085	905	
	7	3900	2600	1950	1560	1300	
	8	5600	3740	2800	2240	1870	
	10	10200	6800	5100	4080	3400	
1/4"/ft. Slope	3	680	454	340	272	226	
	4	1440	960	720	576	480	
	5	2500	1668	1250	1000	834	
	6	3840	2560	1920	1536	1280	
	7	5520	3680	2760	2205	1840	
	8	7960	5310	3980	3180	2655	
	10	14400	9600	7200	5750	4800	
1/2"/ft. Slope	3	960	640	480	384	320	
	4	2040	1360	1020	816	680	
	5	3540	2360	1770	1415	1180	
	6	5540	3695	2770	2220	1850	
	7	7800	5200	3900	3120	2600	
	8	11200	7460	5600	4480	3730	
	10	20000	13330	10000	8000	6660	

Table C.5. (Metric) Size of Gutters (IAMPO, 2000)

Slope of Gutter	**Meters**	**Maximum Allowable Horizontal Projected Roof Areas Square Feet at Various Rainfall Rates**					
	Millimeters	**50.8 mm/hr**	**76.2 mm/hr**	**101.6 mm/hr**	**127 mm/hr**	**152.4 mm/hr**	
5.2mm/m Slope	80	31.6	21.0	15.8	12.6	10.5	
	100	66.9	44.6	33.4	26.8	22.3	
	125	116.1	77.5	58.1	46.5	38.7	
	150	178.4	119.1	89.2	71.4	59.5	
	175	256.4	170.9	128.2	102.2	85.3	
	200	369.7	246.7	184.9	147.7	123.1	
	250	338.9	445.9	334.4	267.6	223.0	
	Millimeters	**50.8 mm/hr**	**76.2 mm/hr**	**101.6 mm/hr**	**127 mm/hr**	**152.4 mm/hr**	
10.4mm/m Slope	80	44.6	29.7	22.3	17.8	14.9	
	100	94.8	63.3	47.4	37.9	31.6	
	125	163.5	108.9	81.8	65.4	54.5	
	150	252.7	168.6	126.3	100.8	84.1	
	175	362.3	241.5	181.2	144.9	120.8	
	200	520.2	347.5	260.1	208.1	173.7	
	250	947.6	631.7	473.8	379.0	315.9	
	Millimeters	**50.8 mm/hr**	**76.2 mm/hr**	**101.6 mm/hr**	**127 mm/hr**	**152.4 mm/hr**	
20.9mm/m Slope	80	63.2	42.2	31.6	25.3	29.7	
	100	133.8	89.2	66.9	53.5	63.2	
	125	232.3	155.0	116.1	92.9	109.6	
	150	356.7	237.8	178.4	142.7	171.9	
	175	512.8	341.9	256.4	204.9	241.4	
	200	739.5	493.3	369.7	295.4	346.5	
	250	133.8	891.8	668.9	534.2	618.7	
41.7mm/m Slope	**Millimeters**	**50.8 mm/hr**	**76.2 mm/hr**	**101.6 mm/hr**	**127 mm/hr**	**152.4 mm/hr**	
	80	89.2	59.5	31.6	25.3	29.7	
	100	189.5	126.3	66.9	53.5	63.2	
	125	328.9	219.2	116.1	92.9	109.6	
	150	514.7	343.3	178.4	142.7	171.9	
	175	724.6	483.1	256.4	204.9	241.4	
	200	1040.5	693.0	369.7	295.4	346.5	
	250	1858.0	1238.4	668.9	534.2	618.7	

THIS TABLE IS FROM THE UNIFORM PLUMBING CODE 2000 EDITION- APPENDIX D: SIZING STORMWATER DRAINAGE SYSTEMS

These tables are provided as a reference. For design purposes, please refer to Appendix D of the Uniform Plumbing Code 2000 Edition. The rainfall rates in this table should be used for design unless higher values are established locally.

Table C.6. Maximum Rates of Rainfall for Various Cities (The rainfall rates in this table are based on U.S. Weather Bureau Technical Paper No. 40. Chart 14: 100-Year 60-Minute Rainfall (inches).) (IAMPO, 2000)

Storm Drainage 60-Minute Duration, 100-Year Return		
States and Cities	**Inches/Hour**	**GPM/Square Foot**
ALABAMA		
Birmingham	3.7	0.038
Huntsville	3.3	0.034
Mobile	4.5	0.047
Montgomery	3.8	0.039
ALASKA		
Aleutian Islands	1.0	0.010
Anchorage	0.6	0.006
Bethel	0.8	0.008
Fairbanks	1.0	0.010
Juneau	0.6	0.006
ARIZONA		
Flagstaff	2.3	0.024
Phoenix	2.2	0.023
Tucson	3.0	0.031
ARKANSAS		
Eudora	3.8	0.039
Ft. Smith	3.9	0.041
Jonesboro	3.5	0.036
Little Rock	3.7	0.038
CALIFORNIA		
Eureka	1.5	0.016
Lake Tahoe	1.3	0.014
Los Angeles	2.0	0.021
Lucerne Valley	2.5	0.026
Needles	1.5	0.016

States and Cities	**Inches/Hour**	**GPM/Square Foot**
Palmdale	3.0	0.031
Redding	1.5	0.016
San Diego	1.5	0.016
San Francisco	1.5	0.016
San Luis Obispo	1.5	0.016
COLORADO		
Craig	1.5	0.016
Denver	2.2	0.023
Durango	1.8	0.019
Stratton	3.0	0.031
CONNECTICUT		
Hartford	2.8	0.029
New Haven	3.0	0.031
DELAWARE		
Dover	3.5	0.036
Rehoboth Beach	3.6	0.037
DISTRICT OF COLUMBIA		
Washington	4.0	0.042
FLORIDA		
Daytona Beach	4.0	0.042
Ft. Myers	4.0	0.042
Jacksonville	4.3	0.045
Melbourne	4.0	0.042
Miami	4.5	0.047
Palm Beach	5.0	0.052
Tampa	4.2	0.044
Tallahassee	4.1	0.043
GEORGIA		
Atlanta	3.5	0.036
Brunswick	4.0	0.042
Macon	3.7	0.038
Savannah	4.0	0.042
Thomasville	4.0	0.042

States and Cities	Inches/Hour	GPM/Square Foot
HAWAII		
Rainfall rates in Hawaiian Islands vary from 1-1/2 inches/hour to 8 inches/hour, depending on location and elevation. Consult local data.		
IDAHO		
Boise	1.0	0.010
Idaho Falls	1.2	0.012
Lewiston	1.0	0.010
Twin Falls	1.1	0.011
ILLINOIS		
Chicago	2.7	0.028
Harrisburg	1.2	0.032
Peoria	1.0	0.030
Springfield	3.0	0.031
INDIANA		
Evansville	3.0	0.031
Indianapolis	2.8	0.029
Richmond	2.7	0.028
South Bend	2.7	0.028
IOWA		
Council Bluffs	3.7	0.038
Davenport	3.0	0.031
Des Moines	3.4	0.035
Sioux City	3.6	0.037
KANSAS		
Goodland	3.5	0.036
Salina	3.8	0.039
Topeka	3.8	0.039
Wichita	3.9	0.041
KENTUCKY		
Bowling Green	2.9	0.030
Lexington	2.9	0.030
Louisville	2.8	0.029
Paducah	3.0	0.031

States and Cities	Inches/Hour	GPM/Square Foot
LOUISIANA		
Monroe	3.8	0.039
New Orleans	4.5	0.047
Shreveport	4.0	0.042
MAINE		
Bangor	2.2	0.023
Kittery	2.4	0.025
Millinocket	2.0	0.021
MARYLAND		
Baltimore	3.6	0.037
Frostburg	2.9	0.030
Ocean City	3.7	0.038
MASSACHUSETTS		
Adams	2.6	0.027
Boston	2.7	0.028
Springfield	2.7	0.028
MICHIGAN		
Detroit	2.5	0.026
Grand Rapids	2.6	0.027
Kalamazoo	2.7	0.028
Sheboygan	2.1	0.022
Traverse City	2.2	0.023
MINNESOTA		
Duluth	2.6	0.027
Grand Forks	2.5	0.026
Minneapolis	3.0	0.031
Worthington	3.4	0.035
MISSISSIPPI		
Biloxi	4.5	0.047
Columbus	3.5	0.036
Jackson	3.8	0.039
MISSOURI		
Independence	3.7	0.038

States and Cities	Inches/Hour	GPM/Square Foot
Jefferson City	3.4	0.035
St. Louis	3.2	0.033
Springfield	3.7	0.038
MONTANA		
Billings	1.8	0.019
Glendive	2.5	0.026
Great Falls	1.8	0.019
Missoula	1.3	0.014
NEBRASKA		
Omaha	3.6	0.037
North Platte	3.5	0.036
Scotts Bluff	2.8	0.029
NEVADA		
Las Vegas	1.5	0.016
Reno	1.2	0.012
Winnemucca	1.0	0.010
NEW HAMPSHIRE		
Berlin	2.2	0.023
Manchester	2.5	0.026
NEW JERSEY		
Atlantic City	3.4	0.035
Paterson	3.0	0.031
Trenton	3.2	0.033
NEW MEXICO		
Albuquerque	2.0	0.021
Carlsbad	2.6	0.027
Gallup	2.1	0.022
NEW YORK		
Binghamton	2.4	0.025
Buffalo	2.3	0.024
New York	3.1	0.032
Schenectady	2.5	0.026

States and Cities	Inches/Hour	GPM/Square Foot
Syracuse	2.4	0.025
NORTH CAROLINA		
Ashville	3.2	0.033
Charlotte	3.4	0.035
Raleigh	4.0	0.042
Wilmington	4.4	0.046
NORTH DAKOTA		
Bismark	2.7	0.028
Fargo	2.9	0.030
Minot	2.6	0.027
OHIO		
Cincinati	2.8	0.029
Cleveland	2.4	0.025
Columbus	2.7	0.028
Toledo	2.6	0.027
Youngstown	2.4	0.025
OKLAHOMA		
Boise City	3.4	0.035
Muskogee	4.0	0.042
Oklahoma City	4.1	0.043
OREGON		
Medford	1.3	0.014
Portland	1.3	0.014
Ontario	1.0	0.010
PENNSYLVANIA		
Erie	2.4	0.025
Harrisburg	2.9	0.030
Philadelphia	3.2	0.033
Pittsburg	2.5	0.026
Scranton	2.8	0.029

States and Cities	Inches/Hour	GPM/Square Foot
RHODE ISLAND		
Newport	3.0	0.031
Providence	2.9	0.030
SOUTH CAROLINA		
Charleston	4.1	0.043
Columbia	3.5	0.036
Greenville	3.3	0.034
SOUTH DAKOTA		
Lemmon	2.7	0.028
Rapid City	2.7	0.028
Sioux Falls	3.4	0.035
TENNESSEE		
Knoxville	3.1	0.032
Memphis	3.5	0.036
Nashville	3.0	0.031
TEXAS		
Corpus Christi	4.6	0.048
Dallas	4.2	0.044
El Paso	2.0	0.021
Houston	4.6	0.048
Lubbock	3.3	0.034
San Antonio	4.4	0.046
UTAH		
Bluff	2.0	0.021
Cedar City	1.5	0.016
Salt Lake City	1.3	0.014
VERMONT		
Bennington	2.5	0.026
Burlington	2.3	0.024
Rutland	2.4	0.025
VIRGINIA		
Charlottesville	3.4	0.035

States and Cities	Inches/Hour	GPM/Square Foot
Richmond	4.0	0.042
Roanoke	3.3	0.034
Norfolk	4.0	0.042
WASHINGTON		
Seattle	1.0	0.010
Spokane	1.0	0.010
Walla Walla	1.0	0.010
WEST VIRGINIA		
Charleston	2.9	0.030
Martinsburg	3.0	0.031
Morgantown	2.7	0.028
WISCONSIN		
La Cross	2.9	0.030
Green Bay	2.5	0.026
Milwaukee	2.7	0.028
Wausau	2.5	0.026
WYOMING		
Casper	1.9	0.020
Cheyenne	2.5	0.026
Evanston	1.3	0.014
Rock Springs	1.4	0.015

Reference

IAPMO. 2000. Uniform Plumbing Code 2000. The International Association of Plumbing and Mechanical Codes (IAPMO). Las Angeles, CA.

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Appendix D: Websites and Agencies

Contents

Web sites and Agencies

Environmental Protection Agency
http://www.usepa.gov

Environmental Protection Agency Indoor Water Use
http://www.epa.gov/watersense/pubs/indoor.html

Environmental Protection Agency Safe Drinking Water
http://www.epa.gov/safewater/labs/index.html

Handbook for Developing Watershed Plans to Restore and Protect Our Waters
http://www.epa.gov/nps/watershed_handbook/

Surf Your Watershed
http://www.epa.gov/surf

General Industry Standards of Occupational Safety and Health
http://www.osha.gov

National Climatic Data Center
http://hurricane.ncdc.noaa.gov/cgi-bin/HPD/HPDStats.pl

NSF Certification
http://www.nsf.org/Certified/DWTU/

NSF International
http://www.nsf.org/

NSF Manufacturers’ List
http://www.nsf.org/certified/consumer/listings_main.asp

Office of the State Climatologist
http://climate.tamu.edu

The Red Cross
http://www.redcross.org

Texas Commission on Environmental Quality (TCEQ)
http://www.tceq.state.tx.us/

The Underwriters Laboratories, Inc.
http://www.ul.com/water/

Water Quality Association
http://www.wqa.org/

Western Region Climate Center
http://www.wrcc.dri.edu/pcpnfreq.html

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Appendix E: Answers to Exercises

Contents

Appendix E: Answers to Exercises

Chapter 6 Exercises - Answers

1. What is the depth of the rainfall for month of June for the following locations?

a.	Yakutat, AK	7.2 inches
b.	Savannah, GA	5.2 inches
c.	Baton rouge, LA	5.3 inches
d.	Koror, PC	17.5 inches
e.	Yakima, WA	0.6 inches

2. What are the annual rainfall totals for the following locations?

a.	Phoenix, AZ	8.3 inches
b.	M. Washington, NH	101.9 inches
c.	Pensacola, FL	64.3 inches
d.	Indianapolis, IN	41.0 inches
e.	Corpus Christi, TX	32.3 inches

3. Identify the three months with the highest rainfall for each city.

a.	Lynchburg, VA	May, July, September
b.	Las Vegas, NV	January, February, March
c.	Allentown, PA	May, August, September

Chapter 7 Exercises - Answers

1. Nick, a homeowner, reports to Brett, the RWH planner, that his house receives 15 inches of rainfall in the summer months. Brett estimates that Nick has a catchment footprint area of 1,000 square feet. Approximately how many gallons of rainwater could be captured?

   9,345 gallons

2. Bob has a catchment footprint surface area of 3,000 square feet for his range cattle. Approximately how may gallons can he catch for each inch of rainfall?

   1,869 gallons

3. Ricki wants to catch about 15,000 gallons of water during a time when her house gets 5 inches of rainfall. How large of a catchment footprint area is required?

   5,000 square feet

Chapter 10 Exercises - Answers

1. What is the rainfall intensity (iph) and gallons per square foot of catchment footprint for the following locations with the occurrence of a 60-minute storm with a return period of 100 years for the following locations?

    a. Flagstaff, AZ __2.3____ iph _0.024_______ gpm/square foot
    b. Omaha, NE __3.6____ iph _0.037_______ gpm/square foot
    c. Palm Beach, FL __5.0____ iph _0.052_______ gpm/square foot

2. Gary, a homeowner in Omaha, NE, has a 2,400 square foot catchment footprint. What size gutter and downspout(s) should he plan? How many downspouts will be necessary?

    a. Gutter size _________ inches
        - Table C.6 – 3.6 iph (go with 4.0 iph)
        - Area = 2,400 square feet
        - Table 10.1 – 8 inch gutter
        - Slope: 1/8 inch per foot

    b. Downspout size _________ inches
        - 4 iph
        - Area = 2,400 square feet
        - One 4-inch downspouts or two 3-inch downspouts

    c. No. of downspouts _ One 4-inch downspouts or two 3-inch downspouts _______

Chapter 13 Exercise - Answer

1. A rainwater harvesting system is designed to convey water utilizing a wet conveyance system. The maximum flow expected is 150 gpm. If a total of 160 feet of SCH 40- 4 inch conveyance piping with 3 ells and a tee cleanout are utilized, what will be the water rise in the downspout?
    - 2.999 ft

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