Rainwater Harvesting

GUIDANCE TOWARD A SUSTAINABLE WATER FUTURE

V1 | 3.6.2012

CITY OF BELLINGHAM WASHINGTON

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Table of Contents

Letter from the Director

Dear Neighbor,

On behalf of the City of Bellingham, I am pleased and excited to present *Rainwater Harvesting: Guidance toward a sustainable water future.* This guide was developed by the City's Water Conservation Program to assist residents and businesses to conserve and protect our limited drinking water resources by harvesting and using rainwater. Rainwater harvesting accomplishes both water conservation and stormwater management. It is not a new concept—it has been practiced for thousands of years—and it continues to be used today around the world to provide water for many uses, including irrigation, toilet flushing, and clothes washing. Rainwater collection systems range from 55-gallon rain barrels to tanks that store 10,000 gallons or more. Rainwater can also be collected directly in the soil to support plant growth and manage stormwater.

City of Bellingham residents are well-known for their sustainability ethic and are to be commended for their daily efforts to reduce waste and pollution, lower energy use, and conserve water. Integrating rainwater harvesting into daily life will further enhance these actions by helping ensure a sustainable water future. When we use harvested rainwater rather than municipal drinking water for irrigation and toilet flushing, we reduce the demand placed on our drinking water supply, the Lake Whatcom Reservoir. Rainwater harvesting not only conserves water, it also helps reduce energy consumption and protect water quality. It takes energy to produce and distribute drinking water, and it takes water to produce energy.

This guide provides an overview of what rainwater harvesting is, how it can help protect and conserve drinking water supplies, and what the City of Bellingham requires if you want to install your own system.

We hope this guide inspires you to integrate rainwater harvesting into your life to help ensure a sustainable water future for the City of Bellingham.

Sincerely,

Ted Carlson, Public Works Director

City of Bellingham

SECTION A

City of Bellingham's approach to sustainable water management

What is sustainable water management?

Peter Gleick, an international water expert and president of the Pacific Institute, describes sustainable water use as "the use of water that supports the ability of human society to endure and flourish into the indefinite future without undermining the integrity of the hydrological cycle or the ecological systems that depend on it" (Gleick et al. 1995). The City of Bellingham's sustainable water management approach incorporates rainwater harvesting as one strategy to help ensure a safe, cost-effective, and reliable drinking water supply now and in the future. Preparation of *Rainwater Harvesting: Guidance toward a sustainable water future* (Guide) is intended to help city residents and businesses use this strategy. Incorporating rainwater harvesting fosters a shift in how we think about and use our existing finite water resources by pairing an appropriate renewable water source with a range of appropriate end uses.

What is rainwater harvesting?

Rainwater harvesting is the process of collecting water from an impervious surface, such as a roof, or from a pervious surface, such as soil, and routing it to a location where it is beneficially used. This can be conducted passively through storage of water directly in the ground (passive water harvesting) or actively through storage of water in tanks for later use (active water harvesting). For the purposes of this guide, the terms "rainwater harvesting" and "water harvesting" are used interchangeably, and may include harvesting rain falling from the sky and/or harvesting stormwater flowing across permeable or impermeable surfaces. Uses of harvested water can include watering landscapes, toilet flushing, clothes washing, and even using water for drinking and cooking if the water is treated to meet drinking water standards (termed "treated water" or "potable water").

Passive rainwater harvesting

Passive rainwater harvesting systems use land shaping and other techniques to direct, collect, and infiltrate rainwater directly into the soil for beneficial use. Passive rainwater harvesting systems manage stormwater and support vegetation growth. In our area these systems retain rainwater on-site, reducing off-site runoff that can contribute to pollution and flooding. Passive rainwater harvesting systems also collect leaves, twigs, and fruits that drop off plants to the soil below. The plant material decomposes to create mulch that reduces evaporation and recycles nutrients back to the plant.

A typical passive system consists of the following components:

- Catchment surface: Impermeable or permeable area that water flows off of, such as a rooftop, driveway, or a sloped part of the yard.
- Infiltration area: Depressed, mulched, and vegetated areas where water is captured and infiltrated into the soil using earth shaped into microbasins, rain gardens, bioretention swales, or other depressions.
- Overflow structure: An overflow structure, such as a rock-lined spillway, allows excess rainwater to safely flow out of an infiltration area to a desired location where the excess rainwater is beneficially used.

Harvesting rainwater close to where it falls or the surface it flows off of maximizes design efficiency and water harvesting benefits. Passive rainwater harvesting systems can range in size from microbasins a few square feet in size to regional detention basins covering many acres of land. Examples of passive rainwater harvesting techniques include rain gardens, which are large vegetated depressions—sometimes known as bioretention swales, small localized microbasins and associated berms that contain water to support one or several plants; porous pavement that allows water to infiltrate into the soil underlying the porous pavement, and a variety of other strategies (Figure 1). The Washington State University (WSU) Whatcom County Extension's Residential Rain Garden Handbook provides information on designing and constructing a rain garden. This and other passive rainwater harvesting resources are listed in Appendix B.

Preparing for the installation of passive systems typically requires consultation with staff at the City of Bellingham Planning and Community Development Department and/or Public Works Stormwater Division to determine appropriate types of applications. Special considerations apply to sites located in the Lake Whatcom Watershed or other areas that have been designated as having impaired water bodies. Consult with City of Bellingham staff for more information at (360) 778-8300.

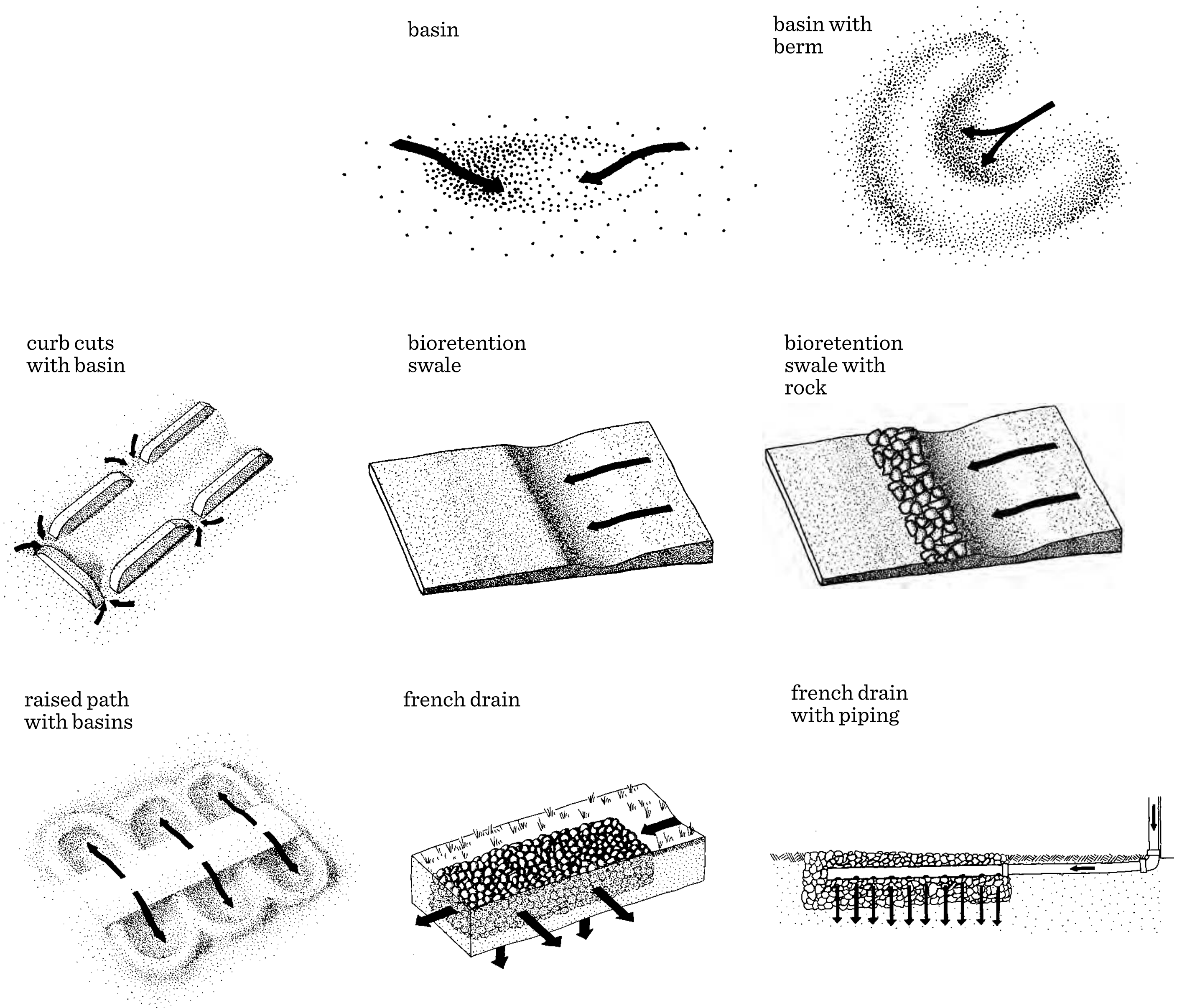


Figure 1. Examples of passive rainwater harvesting systems

Active rainwater harvesting

Active rainwater harvesting systems use equipment to collect, filter, store, and deliver harvested water. Active system storage extends the time when this water can be put to beneficial use both outdoors and indoors. Collection systems can range from 55-gallon rain barrels to meet outdoor watering needs to 10,000-gallon or larger tanks to meet domestic and landscape water needs. Figure 2 shows both aboveground and belowground installations. Unless water is delivered via gravity flow from an aboveground tank, active systems require energy to pump and deliver water. Active systems must be well-maintained to function properly.

The following components are part of a typical active system:

- Collection surface: Impermeable surface, such as a roof, off of which water flows.
- Conveyance system: Components of a conveyance system include gutters and downspouts that move the rainwater from the collection surface to a storage container.
- Pre-tank diverters and filters: Structures that deflect leaves and particles before water enters the tank. The resulting non-potable water (non-drinking water) is suitable for delivery through a hose but will need additional filtration to be suitable for delivery through a drip irrigation system.
- Storage container: A watertight tank (called a cistern in some areas) that stores water. Size, composition, and shape vary greatly. Tanks hold rainwater until the water is put to beneficial use. Tanks can be installed aboveground or belowground and should be light-proof, animal-proof, and insect-proof.
- Water treatment: In addition to pre-tank diverters and filters, advanced water treatment might be needed as water leaves a tank, depending on the intended uses of

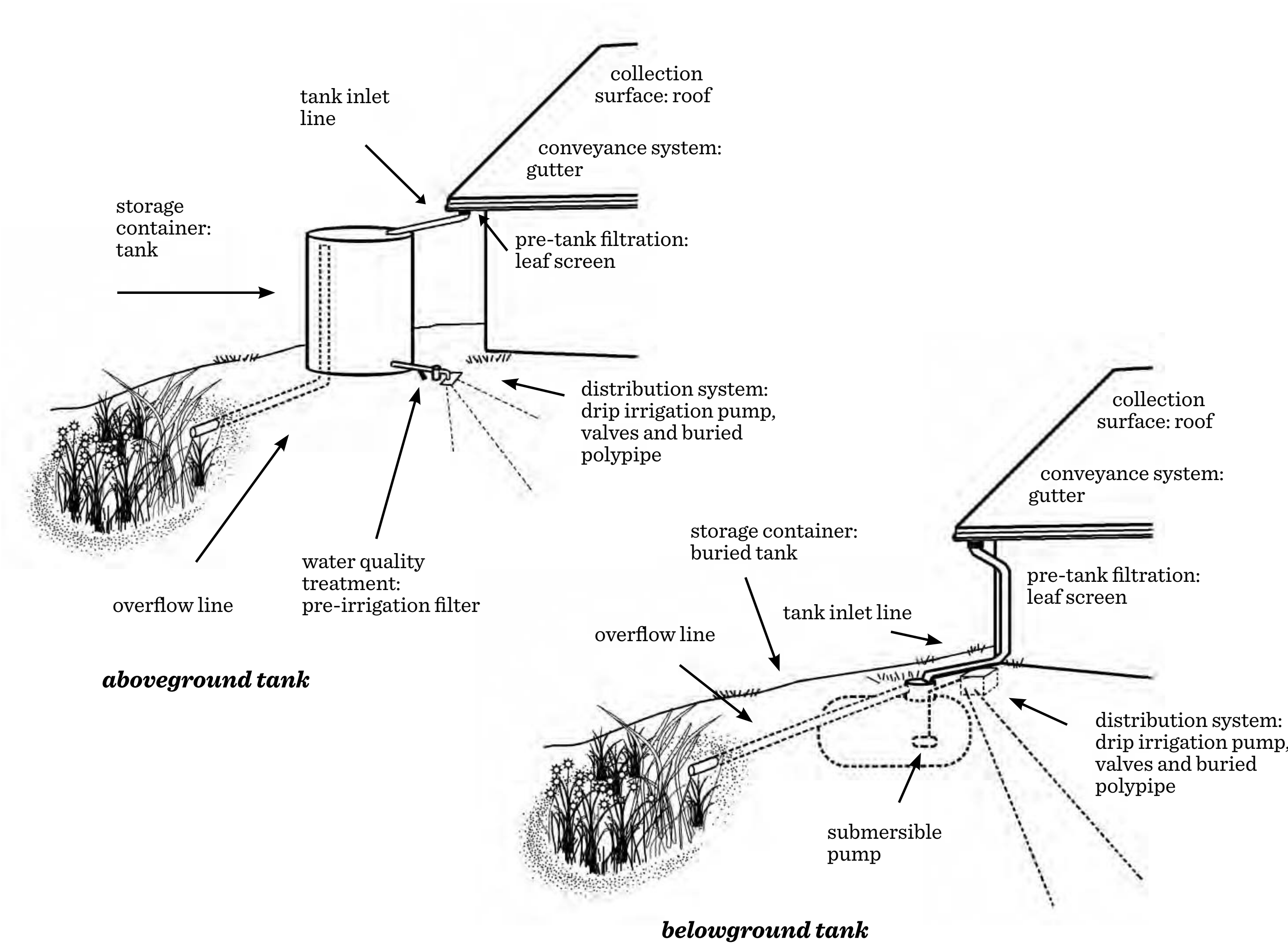


Figure 2. Examples of active rainwater harvesting systems

the water. These uses, and associated treatments, might include:

- Drip irrigation: Large and small particles must be filtered from harvested rainwater to prevent particles from plugging drip irrigation system components.
- Drinking water: If people will consume rainwater, it must meet drinking water standards established by state and local health departments. Depending on its initial quality, a range of water treatment might be needed to bring rainwater to drinking water standards, including carbon filtration, disinfection by ultraviolet light or ozone, and/or other treatment techniques. Treatment of the water should occur after storage in the tank and before delivery to the house.
- Distribution system: The distribution system is made up of components that transport water from the storage container to its intended use. Distribution systems can include gravity-fed water delivered through a hand-held hose or pumped water delivered through a drip irrigation system.

Why is the City encouraging this approach?

The City of Bellingham supports and encourages rainwater harvesting as an important component in its overall efforts to conserve drinking water, reduce peak-day water demand, manage stormwater, and conserve energy. Rainwater harvesting addresses management of both water supply and water demand. Management of the City's water supply, treatment, and distribution systems encompasses issues ranging from water diversion from the Middle Fork Nooksack River into Lake Whatcom to final delivery of treated wastewater to Bellingham Bay.

In meeting current demand and preparing for future population growth, it is important to note that our water supply is affected by climate factors, legal issues, and the cost of treatment and distribution. Of particular concern to the City as a water utility is the increasing cost of meeting peak demands for water during the warm, dry summer. High summer demand stresses available treated water supplies and water delivery infrastructure. As population increases, meeting water delivery expectations during peak demand periods will require a significant financial investment to expand the capacity of the current distribution system.

The City also faces a stormwater management challenge. The presence of phosphorus in the stormwater runoff that flows to Lake Whatcom contributes to the overgrowth of algae. Excessive algae growth not only reduces water quality in a variety of ways, but can also affect the City's ability to maintain adequate treated water supplies. For example, during summer 2009, due to the combination of high algae levels and high water demand, filters at the water treatment plant frequently plugged. Filters had to be taken off line when plugging occurred to backflush algae and maintain water quality. Repeatedly taking the filters off line interfered with the ability of the City's water treatment plant to produce enough water to meet the continued high water demand and reservoir recharge needs. This led to a period of mandatory outdoor watering restrictions.

Nearly all outdoor watering needs can be met using harvested rainwater. An astounding 50 to 75 percent of a home's indoor water needs can be met as well. With additional conservation, rainwater harvesting can meet even higher percentages of water needs.

How much water is used by City of Bellingham water customers?

City of Bellingham water customers collectively use an average of 10 million gallons of water per day over the course of a year. Daily water use can rise to 20 million gallons for Bellingham water customers in the drier months due to increased outdoor watering. This increase in demand stresses the City's ability to provide adequate drinking water during these times. Average water consumption per person per day in North America is approximately 101 gallons. A well-designed passive water harvesting system can capture almost all the rainwater falling on a site if the system is designed correctly. For a typical 11,000-square-foot residential lot in Bellingham, around 240,000 gallons per year falls on the site. This could meet landscape demand for a typical landscape if it were distributed evenly throughout the year. Passive rainwater harvesting can extend the period of increased soil moisture into the beginning of the dry season, but may not be able to fully support plants as the dry season progresses, especially plants with high water demands.

Active rainwater harvesting can extend the time plants can be supported solely by rainwater. The average collection area of a roof in Bellingham is 2,000 square feet. Thirty-five inches of rain falling on that roof in a year's time can yield up to 43,750 gallons of water runoff—enough to meet the average water demand for one person in a year. Collecting a portion of this rainfall in a tank and using it during dry periods to water plants will help reduce Bellingham's peak treated water demand, save money on your metered water bill, and provide water that is high in nitrogen and low in salts to benefit plant growth.

Why should I harvest rainwater?

The 35 inches of rain annually falling directly on your site are free! Rather than spending money getting rid of water runoff, it makes sense to put this important resource to use. Suburban and urban sites typically have a high ratio of impervious areas—rooftops, parking areas, driveways, sidewalks, and more—to pervious areas covered with vegetation or bare soil. As a result, a surplus of water runoff is available to harvest and put to good use. Both your site and your community benefit from rainwater harvesting (Table 1).

How much does a rainwater catchment system cost?

The cost of rainwater catchment depends on the type, size, and complexity of the system you choose. Passive rainwater harvesting systems are typically inexpensive, especially when homeowners shape the earth themselves. Hiring a landscape contractor to shape the earth for passive rainwater harvesting would be similar in cost to a standard landscape installation. Active rainwater harvesting systems are typically more expensive. Storage tanks vary in price based on size and construction material (e.g., fiberglass, steel, concrete, metal, etc.), but typically range from as low as 50¢ per gallon for fiberglass tanks to as high as $4 per gallon for welded steel tanks. As tank size increases, the unit cost per gallon of storage decreases (Texas Manual on Rainwater Harvesting, Third Edition, 2005). Additional costs include roof improvements, pre-tank filtration, post-tank water treatment, and the water distribution system.

Which type of rainwater harvesting system is best for me?

Both passive and active rainwater harvesting systems save treated water for more important uses, help manage stormwater, and can reduce your metered water bill. Integrating both types of rainwater harvesting strategies into a site will maximize the savings of treated water. The water storage capability of an active system allows use of harvested rainwater for irrigation during the dry season, toilet flushing, clothes washing, and, if properly treated, drinking and cooking. A passive system inexpensively harvests large volumes of water, but has limits regarding timing and how water can be used. Assessing where and

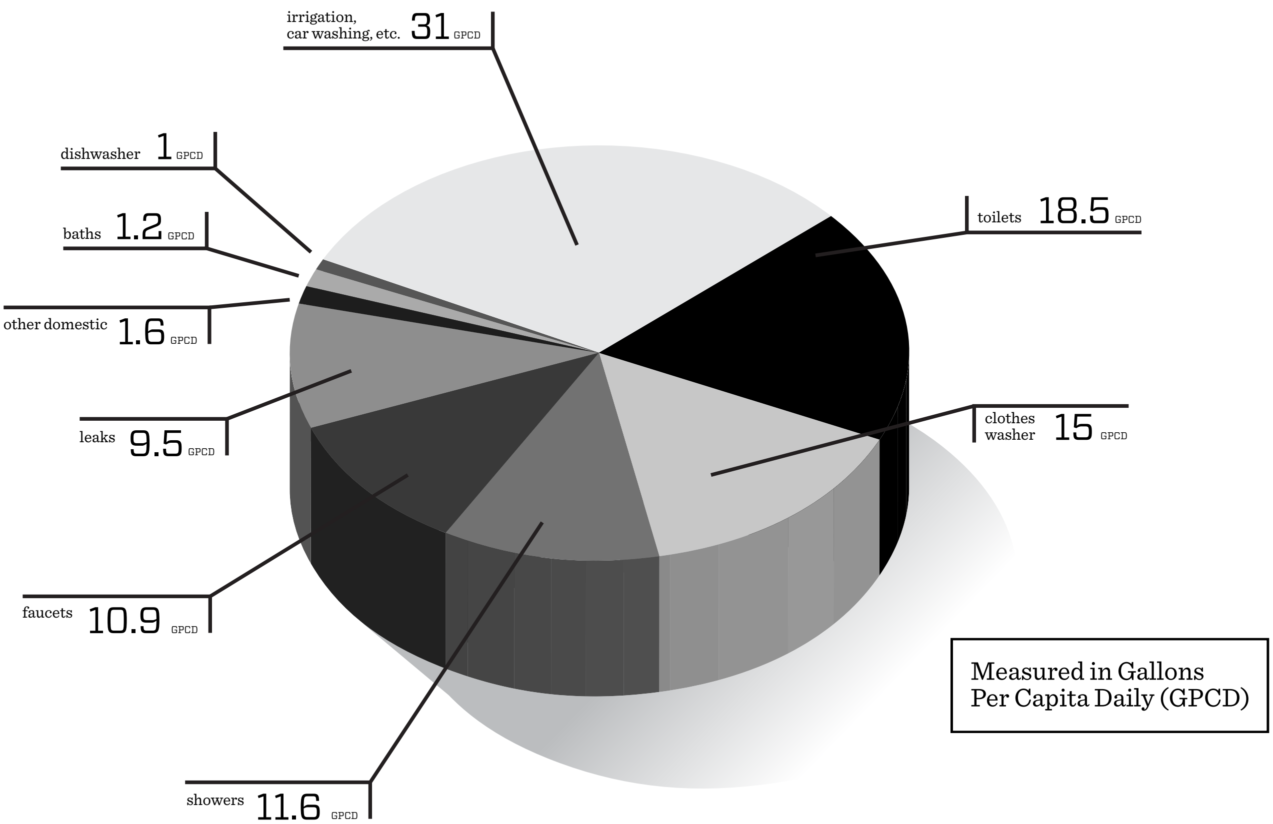


Figure 3. Distribution of average indoor water use of 69.3 gallons per person per day in a North American home (Heaney et.al 1998)

when you need water at your site can help determine whether to use passive rainwater harvesting, active rainwater harvesting, or both. Section D of this Guide will help you determine the best rainwater harvesting strategy for your site.

What is the goal and focus of this rainwater harvesting guide?

A major goal of this Guide is to reduce peak demand for treated water during dry months. Additional and complimentary goals include reducing overall treated water demand, managing stormwater effectively, and promoting water conservation through site design.

To reduce peak demand for treated water, active rainwater harvesting strategies are essential. The focus of this Guide is to help water customers retrofit their homes with active rainwater harvesting systems so they can collect and store rainwater during high rainfall months to use during low rainfall months. The Guide includes the following sections about rainwater harvesting systems. Information is provided about both passive and active rainwater harvesting for outdoor use, with the majority of detail addressing active systems.

- Section A. City of Bellingham's sustainable water management approach
- Section B. Integrating rainwater harvesting with overall site design
- Section C. Design principles for active rainwater harvesting systems
- Section D. Steps in designing and implementing active rainwater harvesting
- The Guide should be used in conjunction with information provided in Appendix B. Rainwater harvesting resources.

Appendix B provides information on a range of books and guides that give greater detail to water harvesting than the scope of this publication allows. Resources for irrigation technology and plant species appropriate for use in water harvesting landscapes are also listed. Guidance and requirements for using harvested rainwater for indoor use are beyond the scope of this publication. Because every site is unique, information provided in the Guide and appendices should be adapted to site-specific conditions. City of Bellingham staff members are available to provide assistance at (360) 778-8300.

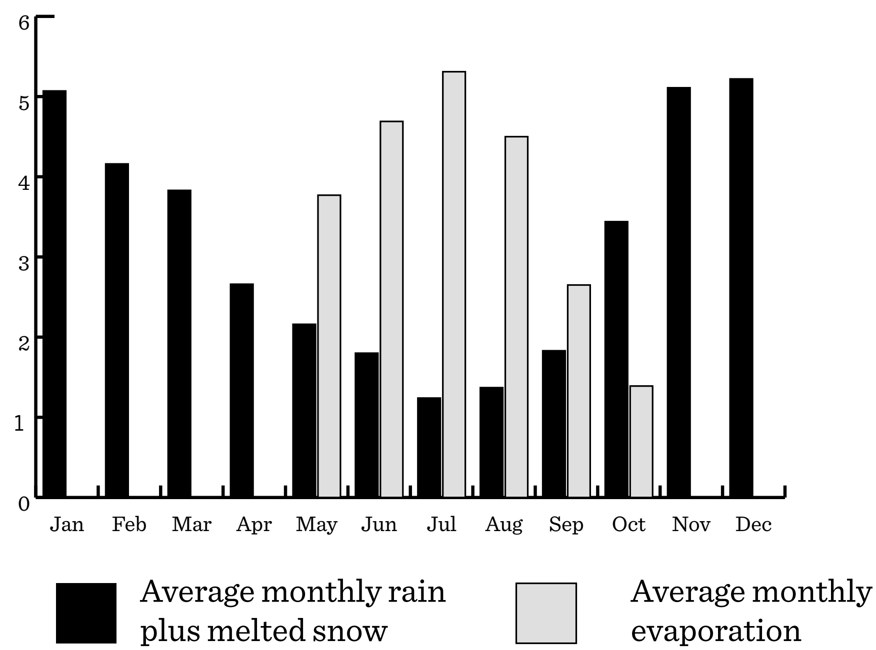


Figure 4. Comparison of average monthly precipitation and evaporation - Bellingham, Washington (1949 - 2004)

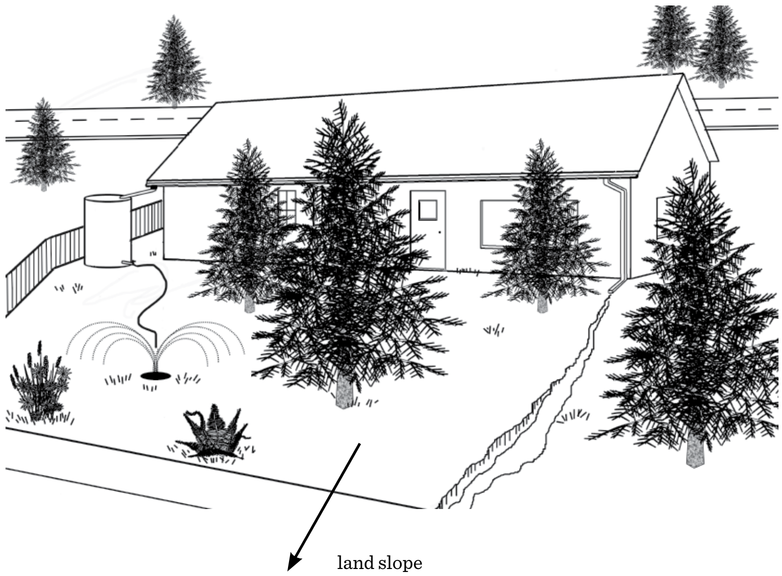


Figure 5a. Non-integrated water harvesting landscape:

- Water, soil and detritus run off the sloped site.
- Downspout water goes unused and causes erosion.
- Evergreen trees block southern sun in winter.
- Isolated, high water-use shrubs are located far from tank.
- Sprinkler loses water to evaporation and runoff.

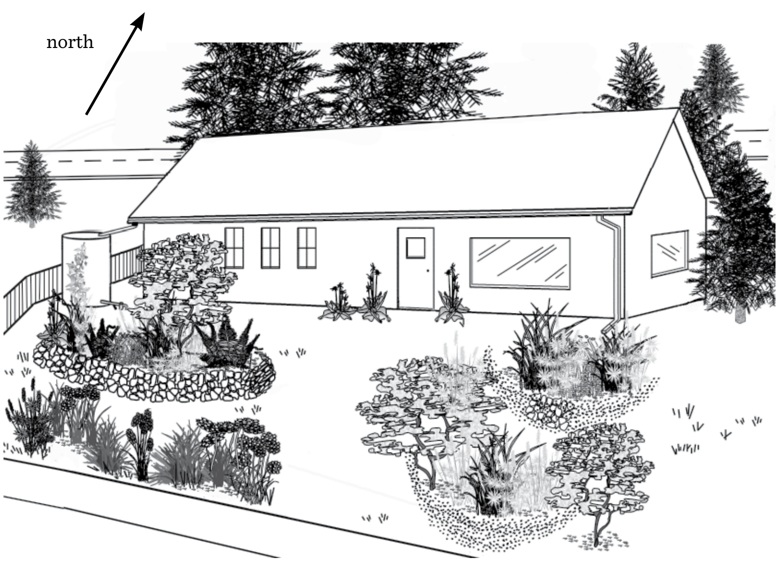


Figure 5b: Integrated water harvesting landscape:

- Water, soil and detritus are captured throughout the site.
- Downspout water is intercepted by first basin with high water-use plants, then overflows into a second basin with moderate water-use plants. The erosion scar is repaired by these basins.
- Evergreen trees are arranged on the north side of the house where they block the house from cold northerly winds in winter.
- Only shrubs, grasses and deciduous trees are planted on the south side of the house so southern light can enter windows in winter.
- High water use shrubs are located near the tank, which feeds drip irrigation to these basins. Moderate water use plants are located next to the house where they can be intermittently hand-watered.
- Drought tolerant plants are placed at the bottom of the slope far from the house since regular watering is not needed, and they get runoff water from the slope.

SECTION B

Integrating rainwater harvesting with other parts of site design

Rainwater harvesting is an important element of a well-designed residential site. Rainwater harvesting strategies are most effective when fully integrated with the site's other elements including vegetation, soils, water flow, solar orientation, and structures (house, driveways, sidewalks, etc.), such that the elements works synergistically to create a productive, self-sustaining site. Generally, the less integration that exists between site elements, the lower the site's productivity and the higher the water use (Figure 5a). In contrast, a higher degree of integration of site elements results in lower water use and a more efficient, productive, and self-sustaining site (Figure 5b).

By adhering to the principles described below, you can integrate rainwater harvesting into your site and realize the benefits that result. These principles are useful when designing new sites and when retrofitting existing sites.

Please note that for the Lake Whatcom Watershed and other areas with impaired water bodies, there are special considerations requiring that some of the principles below be modified for these areas. Consult the City's Permit Center or Stormwater staff at (360) 778-8300 for more information. A map of the areas needing special considerations can be found at: http://www.cob.org/services/environment/lake-whatcom/rules-regs.aspx.

Evaluate your site

Create a map of your site to illustrate what currently exists, where water flows and drains, and where resources and problems exist. (See Section D for detailed guidance on site mapping.) After taking the time to observe, assess, and understand your site, decide what you want to change and how you want to integrate rainwater harvesting strategies with existing or planned site elements.

Select and place site elements so they perform multiple functions

Elements of a site, such as trees, structures, tanks, runoff water, and rainwater harvesting basins, can be selected and placed so that they serve the site in multiple ways to increase productivity and sustainability. For example, select a tree species that provides native fruits. The tree can be placed to shade the house, trimmed to provide firewood, and watered using runoff from the roof.

Integrate rainwater harvesting with the environment

Solar orientation

- Use passive and active rainwater harvesting to support appropriate solar orientation of plantings around the house. Proper landscape design can shade a house from hot summer sun while allowing winter sun to shine into south-facing windows to light and help warm the house, reducing energy costs to cool and heat the house. In general, plant only deciduous trees on the south side of a house to allow the low angle winter sun to shine into windows from the south. Place evergreen trees on the west, north and east sides of a house to block cold winter winds and provide summer shade if needed.

Soils

- Reduce soil erosion. Identify eroded areas and the source of runoff water causing the problem. Establish passive and active rainwater harvesting structures to reduce erosive runoff and direct runoff water to locations where it can beneficially support vegetation.
- Retain organic material. Design passive rainwater harvesting basins to retain organic material that drops, blows or flows into the basins. The organic material decomposes to improve soil conditions.
- Mulch soil. Cover exposed soil with mulch to slow evaporation losses of harvested rainwater. Mulch

moderates the temperature of soils, releases nutrients that build healthy soil, and improves the poor drainage characteristics of clayey soils.

Water flow patterns

- Passively and actively harvest rainwater. Using both strategies maximizes water use efficiency and minimizes tank costs because smaller tank capacity will be needed to meet summer demand if plants are receiving rainwater from both sources. Water harvesting basins that capture and retain rainfall also retain irrigation water from tanks and hold mulch around the base of plants.
- Work with existing site topography to harvest water in earthworks. Create multiple small catchment areas throughout the site to hydrate the landscape and maximize retention of rain falling on the site. Address areas of too much flowing or pooling water by reshaping the land surface to redirect water flow and infiltration to more beneficial locations.

Stormwater management

- Maximize passive and active water harvesting. The more rainfall retained at the site, the less potential for high-phosphorus and other pollutant-carrying water to migrate off the site and impact water quality in downstream waterways.
- Use well-composted mulch and reapply it as necessary. Mulch will suppress weed growth within basins and decompose to add nutrients to the soil so you can minimize or completely avoid the use of phosphate-based fertilizers, herbicides, and other soil additives that could impact downstream waterways.

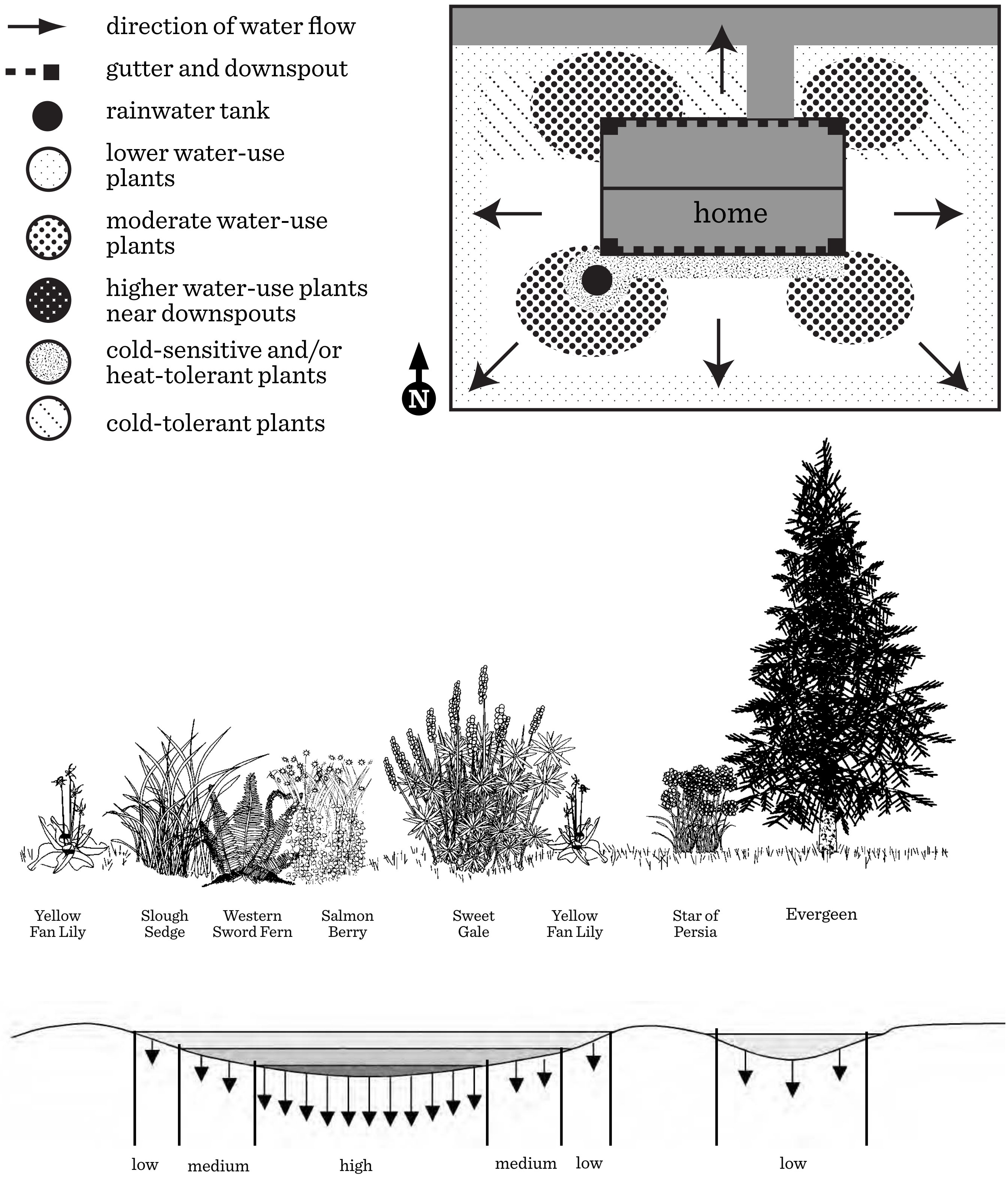
Vegetation

- Minimize water demand and maximize landscape cover by selecting well-adapted plants. Select native plants adapted to wet winters and dry summers and drought-tolerant non-native plants. Appendix B provides resource lists for landscape plants and their adaptive characteristics. High water use landscapes can be transitioned to lower water use landscapes by replacing older plants with appropriate low-water use plants.
- Use harvested rainwater to benefit the health of plants. Rainwater is low in salt and high in nitrogen, a combination that is healthy for plants.
- Place plants in appropriate microclimates. Knowing the characteristic water needs of specific plant species is key to planting them in the right microclimates (Figure 6). Select the best plants for the differing conditions in your yard. Plants that tolerate inundation can be placed within low spots and water harvesting depressions. Drought-tolerant plants that do not like inundation can be placed outside basins in parts of the yard that receive full sun.
- Group plants according to their water needs. By grouping plants this way, one plant species will not dominate the others in taking up water, and the amount of water delivered by irrigation will be appropriate for all plants in the group. Passive water harvesting basins and associated catchment areas should be sized appropriately to meet the water needs of the grouped plants. Consult the Irrigation Water Management Society's website to calculate how much to irrigate your landscape based on the type of plantings and irrigation system you have <http://iwms.org/seattle_area.asp> (Appendix B).
- Provide supplemental watering during plant establishment. Install new plants in the fall and early spring so they develop healthy roots before the stress of the dry season. Once established, reduce supplemental irrigation. Irrigate to the greatest extent possible with passively and actively harvested rainwater.

Site structures

- Start harvesting rainwater at the highest elevation of a site. At most residential sites, the highest elevation is the rooftop. Harvest rooftop runoff water in above-ground tanks to get the maximum use of gravity-fed water delivery.
- Use tanks to serve multiple functions. Tanks—when properly designed and constructed—can be used as structural support for porch roofs, can serve as privacy screens for houses, can serve as trellises for vines, and can serve as fire breaks to protect houses if constructed of steel or concrete.
- Enhance or mitigate microclimates using water harvesting structures. Harsh or beneficial microclimates created by reflected sun and deep shadows can be mitigated, or enhanced, by strategically placing tanks to increase reflected light, mitigate extreme air temperatures, shade building walls, etc.

Figure 6. Plant placement in rainwater harvesting landscapes and microclimates



SECTION C

Design principles for active water harvesting systems

Following simple design principles for designing and installing active water harvesting systems will improve their safety, reliability, water use efficiency, and effectiveness, while reducing costs and maintenance time. The principles below were derived from the work of Brad Lancaster (Lancaster, 2006a, 2006b) (Appendix B), and expanded on by him for purposes of this guidance manual (Lancaster, personal communication, 2011). Review these principles prior to undertaking site design and keep them in mind as you proceed with design and installation.

Ensure adequate inflow

Don't lose water because your system components are too small to handle large storm events. Size gutters, downspouts, and inflow pipes to tanks to handle the maximum rainfall intensity likely to occur in your area. The Rainwater Harvesting: System Planning for gutter and downspout sizing provides sizing guidelines (Mechell, Kniffen, Lesikar, 2010) (Appendix B).

Ensure adequate overflow capacity

Using gravity flow, always utilize overflow water as a resource. The diameter of the tank overflow pipe must be equal to or larger than the diameter of the inflow pipe so excess inflow water does not back up in the tank. Direct overflow water to another tank or to mulched and vegetated infiltration basins. Belowground tanks must be designed so surplus water overflows using the force of gravity alone.

Design your system to collect high quality water

The higher the quality of harvested water, the more options for its potential use. Do not contaminate water by using toxic materials in constructing your gutter, downspout, tank, and piping. Roofing materials also affect the quality of harvested water. Materials rated high enough to allow contact with potable water yield the highest quality harvested rainwater. Many of the technical-focused publications listed in Appendix B provide additional information on non-toxic roofing and construction materials. Dirt, leaves, bird droppings, and other organic and inorganic material that accumulate on the roof and in gutters can contaminate tank water, making it acceptable only for outdoor non-potable uses. Deflecting and filtering materials from the water before it enters the tank, and/or diverting the first flush of water before it flows into the tank, will reduce contamination in the tank.

Design and install a "closed" tank system

Closed tanks are designed to keep out insects, animals, sunlight, and unauthorized people. Tank inlets and outlets are screened to prevent entry of insects and animals, which prevents mosquitoes from breeding and animals from drowning. To prevent the growth of sunlight-dependent algae and bacteria from contaminating harvested rainwater, tanks can be made of opaque materials, painted to make them opaque, or buried. Opaque tank covers keep out insects, animals, and sunlight, and can be locked to keep out children. Covers also reduce water loss to evaporation.

Keep outflow water clean

The tank outflow pipe should be installed a minimum of 4 inches above the bottom of the tank. This will prevent the sludge (sediments, leaf litter, dust, etc.) that accumulates in the bottom of the tank from being pulled into the outflow pipe and potentially clogging downstream irrigation systems.

Maintain access to the inside and outside of your tank

You need access to the inside and outside of your tank to check water levels, inspect for leaks, maintain equipment, clean out the tank, and make repairs. Position aboveground tanks so there is enough space to walk completely around them, especially if the tanks are close to a building.

Vent your tank

All covered tanks that have tight-fitting lids or tops must be vented to prevent a vacuum from forming in the tank when large quantities of water are quickly withdrawn. This vent can take the form of a small diameter pipe perforating the lid and screened to keep out mosquitoes.

Use gravity to your advantage

Place your tank at a location where you can utilize the elevation of the collection surface, the location of the tank, and the free power of gravity to collect rainwater and distribute it around your site. To fully use gravity power, place your tank at a high point in the yard and use full port valves that do not constrict flow. For aboveground tanks, you can always add pumps to increase distribution pressure, but avoid becoming completely dependent on them.

Make using rainwater convenient

Where feasible, place the tank so it is near both the water source (roof) and the water's destination (landscape plants). This will minimize the length of the downspout, pipes, and hoses, which will save money and materials and help maintain water pressure. At the very least, place the tank's hose bibb conveniently close to your point of use rather than placing it on a distant tank.

Select and place your tank so it does more than store water

The more functions your tank fulfills, the more cost-effective it is. By designing a tank to also assist as a privacy screen, fence, retaining wall, property wall, or support pillar for a covered porch you eliminate the cost of buying other materials to accomplish these tasks. Tanks can also support trellises for plants and moderate extreme hot and cold temperatures for plants near the tanks.

Inspect and repair tanks and components

All tanks and components must be regularly inspected to ensure there are no leaks in the system. Any problems should be fixed immediately. It is especially important to inspect system components that are under pressure and to immediately repair them because large volumes of water can quickly escape. Leaks that result in saturation of soils around wall and building foundations can damage these foundations under certain soil conditions.

SECTION D

Steps in designing and implementing active rainwater harvesting

This publication focuses on active rainwater harvesting systems in the City of Bellingham. A frequently asked question is whether an active rainwater harvesting system can collect, store, and deliver enough water to support an entire landscape during an average year. The answer is yes, as long as the total volume of water that your landscape plants receive directly from rainfall and from water storage tanks (the supply) meets or exceeds the water needed to support the landscape (the demand). If landscape demand is reduced by planting low-water-use native plants, drought-tolerant non-native plants, and/or placing plants within or beside passive water-harvesting earthworks, the tank size needed to fully meet water demand can be reduced.

Installation of active rainwater harvesting systems requires detailed planning; careful design of the tank, water treatment, and distribution systems; compliance with all local building codes and applicable regulations; skilled installation; and appropriate landscaping. Design, permitting, and construction should proceed in a logical sequence to ensure the success, efficiency, and cost-effectiveness of the project. It is recommended that an experienced contractor be retained to undertake active system installation, especially placement of heavy tanks and installation of complex plumbing, irrigation, and electrical components. However, homeowners can likely undertake—or assist with—work such as installing gutters and downspouts, trenching, installing irrigation pipes, and landscape planting.

Whether you or a professional installs your active system, you are responsible for ensuring all necessary permits are obtained, installation is done according to permits, and your system is operated safely and effectively. The steps below will help lead you through the process of undertaking active rainwater harvesting in Bellingham, including preparing and submitting a permit application.

Step 1. Create a map of your site

Creating a map of your site will help you visually think through your needs, resources, and water harvesting strategies. Start by obtaining an aerial photo of your site, then use the aerial photo to prepare a map of your site (Figures 7 and 8). Make multiple copies of the map and add items to the map as you develop your water harvesting plan.

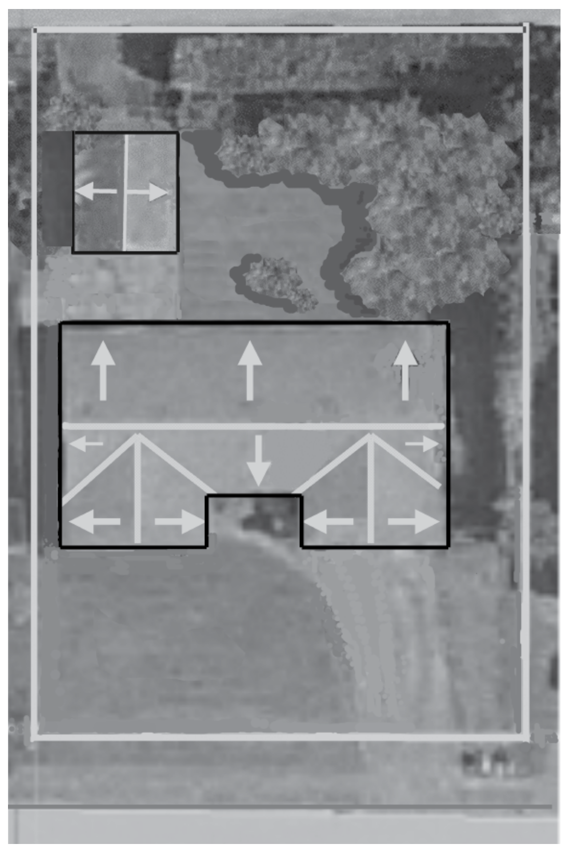


Figure 7. Example aerial photo of residential site in Bellingham obtained from CityIQ Online Map Viewer

Obtain an aerial photo of your site from CityIQ

- Search the City of Bellingham's CityIQ Online Map Viewer located at *http://www.cob.org/cityiq* to obtain an aerial photo of your site along with other useful site information including property boundaries, location of utility services, and more (Figure 7).
- The first time you use this website, you can click on the options under "Getting Started" to learn more about how to use the website, or go straight to "Launch CityIQ Online Map Viewer."
- Once you have launched the online map viewer, you will see a broad map of the City of Bellingham. Now enter your address in the "Search CityIQ for..." box at the top of the page and hit the "search" button. You will see a map of your street with address numbers written on each lot.
- To see an aerial photo with a yellow property line around your site, select the "2008 spring photo" box on the left side of the screen and wait for the aerial photo image to appear (be patient, this may take some time). Note: the property line locations on CityIQ are estimated and may differ by several feet from their actual location.
- To zoom in closer to your site, use the slider bar that appears on the left side of the aerial photo screen, and slide it up toward the "+" sign. To center the image, go to the blue menu bar above the map and select the first button on the left—the "pan" tool. When you place this tool over the aerial photo and click on it, you can shift the image around until your site is centered on the page.
- To see how utility services enter or cross your property, select the "sewer," "storm," and "water" utility boxes on the left side of the screen. Note: Utility locations on CityIQ are estimated and actual locations may differ by several feet from actual locations.
- To see the land contours in your area, select the "contours" box on the left of the screen. This will indicate the slope of the land at your site, and how it relates to land slope on neighboring sites.
- To measure the area of parts of your site, go to the blue menu bar above the map and select the ruler icon which then gives you an "area measure" tool, which you can use to find out the area of your lot and those portions of roofs you might want to actively harvest water from. To get this measurement, click on the corners of the area you want to measure, and double click when the area perimeter is complete. A screen will appear giving you the measurement. Jot down the results, because the measurement screen will not stay on once you go to the next step.
- The next button to the right on the menu bar is the "line measure" tool. Select this tool to get the lengths of property boundaries, roof lines, and other linear measures you are interested in. Click on the ends of the line you want to measure, and double click on the end of the line. A screen will appear giving you the measurement. Jot down the results, because the measurement screen will not stay on once you go to the next step.
- Keep the notes you jotted down on area and line measurements for later use when you prepare your water harvesting plan and apply for permits.
- To save the aerial image of your site, either print the image, or save it as a "pdf" file.

Prepare a map using the aerial photo

- Using the aerial photo as a guide, trace or draw a "birds-eye-view"' sketch of your site to-scale showing lot dimensions and key roof dimensions (Figure 8). Using graph paper can make drawing to scale easier.
- Include the following information on your map:
  - Buildings, porches and pavement;
  - Property boundaries, set back lines, sewer lines or septic tanks and drainfields, electric lines, gas lines, water lines, irrigation lines, and/or any other buried lines and structures to the extent you know where these are;
  - Proposed new utility lines, irrigation lines, and/or any other buried lines;
  - Locations of existing gutters and downspouts, portion of roof draining to them, locations where new gutters and downspouts could be installed;
  - Outlines of trees and areas of shrubs, since these indicate your watering areas.

Step 2. Evaluate your site's watering needs

Determine your overall needs for rainwater harvesting and note them on the map, as appropriate. Indoor, outdoor, maybe both eventually? Passive or active, or not sure?

- What plants do you currently water?
- Do you water with hose or drip? Where is your hose bibb or irrigation controller?
- How long and how frequently do you water?
- Do you want to add more plants? Where would you put them?
- What will the water needs of the new plants be?
- Do you want to change your watering regime? How?

Step 3. Evaluate your site's resources and challenges

After evaluation, show them on the map, as needed, using arrows, shading, and outlining.

- How does water flow between your site and surrounding sites?
- What direction does the land slope in different parts of your yard?
- In your yard, where does water pool or flood? Where does ice buildup in winter? Where does erosion occur?
- Where does water run off your roof?
- Where are the existing gutters and downspouts?
- Once rooftop water hits the ground, where does it flow?
- Where are your existing plants and planned new vegetation?
- Where are areas impacted by wind or shielded from wind? Where are areas getting beneficial winter sun?

Step 4. Determine whether to use passive water harvesting, active water harvesting, or both

All sites benefit from the use of passive rainwater harvesting. Sites that particularly benefit are those that have large areas of landscaping, have high-water-use plants, experience erosion or flooding problems, and/or receive runoff from neighboring properties. Sites where landscapes are being installed or reconfigured are ideal for incorporating passive rainwater harvesting.

All sites benefit from active water harvesting. Sites that particularly benefit are those with high-water-use plants and/or non-native plants that need summer irrigation, sites where rooftop runoff creates problems by pooling or saturating soil around foundations, and sites where indoor use of harvested water is feasible, among others. To determine which strategies to use, and where and when to use them, answer the following questions:

- Do you have any of the conditions listed above that make passive and/or active water harvesting especially beneficial?
- In addition to the addressing the conditions above, what are your goals for water use? Do you want to reduce potable water use, increase water security, improve plant conditions by providing high-nitrogen/ low-salt rainwater, or meet other water-related goals?
- How can you use site resources and reduce site problems using passive or active rainwater harvesting strategies? Which strategies will work best? Erosion problems are best solved with passive systems. Localized flooding from downspouts could be solved with either passive or active systems.
- Are there especially good locations at your site to put in passive water harvesting earthworks or tanks?
- Do you need to add new gutters and downspouts in order to serve a tank or a basin?
- For passive or active systems, do you want to do the work yourself or hire a contractor to assist you?
- Where do you want to focus your financial resources now? In the future?
- Where do you want to focus your physical energy now? In the future?
- For additional information on passive water harvesting systems, see Appendix B. For active systems, follow steps 5-11 below.

Step 5. Determine who will be installing the rainwater harvesting system

A professional tank installer might be needed depending on the active rainwater harvesting system desired. Some active systems may require an engineered design based on the selected tank. For example, if the height to width ratio of your tank is greater than 2:1, a structural engineer's calculations and stamp will be required as part of the building permit application. Step 10 provides complete permitting guidelines. If you are hiring a professional installer, they must have a contractor's license. Your installer should be able to provide information on active system components, prices, and technical needs. If you are designing and installing your own system, think through the design, list the needed components, and systematically assemble these. Not all stores will have all required parts in stock, so plan ahead if ordering is needed.

Step 6. Determine irrigation contractor

Obtain professional assistance if you are adding a drip irrigation system to your site or linking tank water to the irrigation system. If using a tank contractor installation, ensure there is coordination between the two contractors to get the most effective system.

Step 7. Determine if you want an aboveground tank or belowground tank

Tanks are available for installation aboveground or belowground. Tanks need to meet standards for potable water storage regardless of their location relative to land surface and regardless of whether you are collecting rainwater for irrigation or indoor uses. Aboveground and belowground tanks need to be placed in areas not vulnerable to settling, erosion, or slope failure. In addition, aboveground tanks need to be placed on level pads. The City of Bellingham may require the seal and signature of a licensed engineer on the tank plan to ensure safe placement. When choosing between aboveground or belowground tanks, there are a number of factors to consider, as summarized in Table 2.

Step 8. Determine possible tank location and tank overflow location

What size tank do you need to match the size of the catchment surface and the size of the water need?

- What is the best location for your tank considering available space, convenience for watering, locations of downspouts, ability to add new gutters and downspouts, potential to get multiple functions from the tank, and aesthetics?
- Match water needs with water sources. For each part of your yard needing supplemental water, where is the closest downspout location where a tank could potentially be located?
- Are there any safety issues like soil settling, proximity to the basement, blocking access, or others issues that would preclude a tank location?
- What beneficial functions can the tank serve in different locations?
- Would there be objections from a homeowners association or neighbors to a particular tank location? If so, visual screening of tanks can be accomplished by placing trees, shrubs, trellised vines, fencing or masonry in front of the tank.

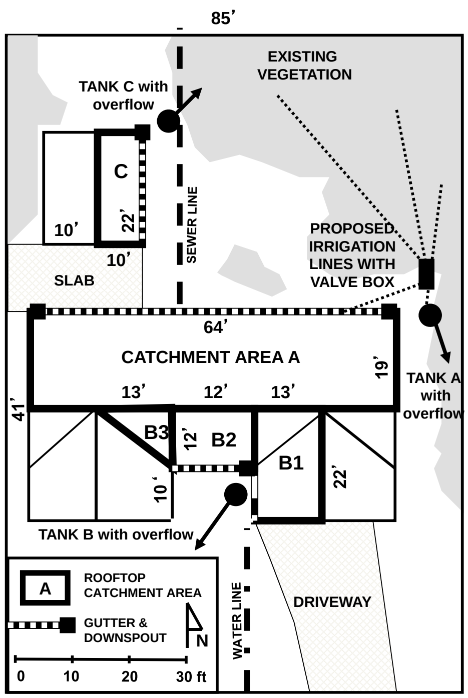


Figure 8. Example water harvesting plan for a residential site in Bellingham

Water harvesting plan illustrates existing and potential locations for tanks, gutters, downspouts and tank overflow water. Tank A would be the best site to serve a drip irrigation system. Tanks B and C would be appropriate sites for hand watering with the tanks, or using passive sprinkler irrigation.

To calculate runoff to potential tank locations at the site shown in Figure 8, first you need the square footage of various roof measurements. These can be obtained from the City IQ Online Map Viewer, where aerial photos of your site are available, and where line and area calculations can be made. See www.cob.org/cityiq/website/index.html Using these measurements you will first calculate catchment areas A, B and C as follows:

Roof Catchment Area A to Tank A:

64 ft X 19 ft = 1,216 square feet

Roof Catchment Area B to Tank B:

Divide the roof shape into rectangles and triangles to calculate area.

Area B1: 22 feet X 13 feet = 286 square feet

Area B2: 12 feet X 12 feet = 144 square feet

Area B3: (13 feet X 12 feet)/2 [formula for a triangle is (base X height)/2]= 78 square feet

Add all B areas together = 508 square feet

Roof Catchment Area C to Tank C:

22 feet X 10 feet = 220 square feet

Now, using the same calculations as for other roofs (see Table 3 in Appendix A), multiply each area above by the annual average rainfall, convert to gallons, and reduce runoff estimates based on the runoff coefficient.

E.g. (35 inches x 1,216 square feet x .6 gallons/square foot x .9 asphalt shingle roof runoff co-efficient = 22,982 gallons per year)

Potential annual roof runoff volume calculation:

[Annual inches of rainfall x roof square footage x .6 gallons/square foot x roof runoff co-efficient (Table 3)]

Runoff from Roof Catchment Area A to Tank A = 22,982 gallons

Runoff from Roof Catchment Area B to Tank B = 9,601 gallons

Runoff from Roof Catchment Area C to Tank C = 4,158 gallons

- For siting tanks, a basic rule of thumb is to draw a line downward from the outside edge of a building footing. That line should be at a 45 degree angle. As long as the tank does not require excavation on the footing side of the line, there should be no problem in case the tank leaks.
- Will there be sufficient access around the perimeter of a tank to install, inspect and maintain a tank? Can you get the tank and installation equipment through or over a gate?
- Is the tank or its hose bibb in close proximity to the plants that need the water? Can you make tank water more convenient and more rewarding to use than municipal water?
- All tanks need an overflow. Where would tank overflow water be directed?
- Can you place the tank to avoid blocking windows that receive winter sun from the south?
- Will you be using gravity flow to deliver water? How high in your site's watershed can a tank be located? The higher the elevation of the tank, the more pressure available for gravity to distribute water from the tank to points downslope without using a pump.
- Can you size and place a tank so another could be installed later to receive overflow from the first tank once finances allow?

Step 9. Determine the type, size, and composition of components

It is important to understand all the components of an active water harvesting system so you can determine the proper sizes and types for your site to ensure they are compatible with one another. The components of an active rainwater harvesting system are: a) Collection surface, b) Conveyance system, c) Pre-tank diverters and filters, d) Storage container – the tank, e) Advanced water quality treatment, and f) Distribution system.

a) Collection surface

At the residential scale, rooftops are the most common surface from which to collect rainwater runoff and convey it to a tank. Roof type can affect the amount and quality

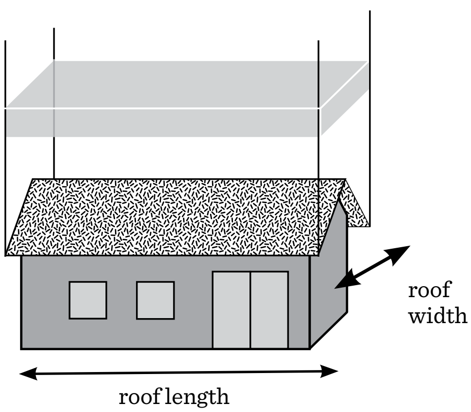


Figure 9. Example water harvesting calculations of potential rooftop runoff from a residential site in Bellingham

Projection of an average 35 inches of rainfall per year over a Bellingham residence. Any roof shape that has the same width and length will receive the same amount of rainfall regardless of roof slope.

tank sizing rule of thumb

10% = **your ideal tank volume**

of your total annual roof catchment volume

If you do extensive outdoor watering, optimally, size your tank to collect one-tenth (10%) of the volume that would come off your roof catchment area you are collecting from in one year. This assumes you will fill and empty the tank 10 times in a year to make full use of all the water that can be harvested annually.

For example: say you used the runoff estimation process outlined in figure 8 to determine that your roof would around about 23,000 gallons of runoff water per year. Harvesting one-tenth of that at a time would require installing a 2,300-gallon tank receiving water from one downspout. Even during the drier months (May-September) when average rainfall is limited to a total of about 5 inches, over 3,200 gallons of rainfall would run off the roof and fill the tank.

If using the ten percent rule would result in too large or too expensive a tank, then at minimum, size the tank to receive all the runoff from a 2-inch rainstorm falling on your designated roof collection area (see Appendix B for resources). Ultimately, the lot size, setbacks on the property, and/or constraints on where the tank can be placed might determine the tank size that works for you.

of water harvested (Appendix A, Table 3). Copper, zinc, or lead roofing materials should not be used for rainwater collection (Uniform Plumbing Code, 2009; Section 1628.1 Roof Surface). Detailed information on different roof types for rainwater collection can be found in the resources listed in Appendix B.

Annual rooftop runoff depends on roof size, surface texture, and average annual rainfall. To calculate this for a roof area from which you want to collect water, follow these steps:

1. Use the aerial photo of your site, or a tape measure, to measure the length and width of the roof areas from which you may want to collect water. The example site shown in Figure 8 has a house and separate shed whose roofs could serve as rainwater harvesting catchment surfaces. Calculations of catchment sizes and potential harvested rainwater are shown in Figure 8.
2. Multiply roof length in feet by roof width in feet to get square feet of rooftop collection area (roof height does not affect water catchment volume).
3. Multiply the square feet of roof area by annual average rainfall of 35 inches. Then multiply this by .6 to convert cubic feet of rooftop water to gallons of rooftop water.
4. Some water will be trapped within the crevices of the roof structure so multiply the gallons of water falling on your roof by the runoff coefficient for your roof type to get actual runoff from the roof (Appendix A, Table 3).

b) Conveyance system from roof to tank

Rainwater typically drains from the roof through gutters and downspouts, which make up the active water harvesting conveyance system. When designing your conveyance system, ensure existing gutters and downspouts are in good condition or repair them as needed. If new gutters and downspouts are to be installed, they should be sized according to the potential rainfall intensity the site will be exposed to, which can be found in Appendix B.

Typically, gutters are made of aluminum or galvanized steel. A common size for residential applications is a 5-inch-wide gutter that drops a minimum of 1-inch for every 16 feet of roof line (1/16 inch per foot of slope). A gutter with more slope can handle a greater volume of water. Wider gutters are also available and are recommended for use in many steep-roof and commercial applications.

As part of the conveyance system, determine how you will fill the tank. Tanks can be filled via overhead downspouts that run from the gutter outlet to the tank inlet at the top or upper wall of the tank (known as a "dry" system). They can also be filled using a U-tube configuration (called a "wet" system) that takes a waterproof downspout underground then enters the tank from the subsurface through a carefully sealed inlet. In this case, water remains in the U-tube at all times but is flushed out and replaced with new water with each rainfall.

When choosing the fill design, take into account the distance between the top of the tank and the point on the roof where the gutter meets the downspout. A wet system design might be preferable to a long overhead fill line if the pipe has to be extended a great distance. Also consider the height of the tank versus the height of the juncture point on the roof and whether an overhead fill line will obstruct people walking between the tank and house. The structure of the tank also affects fill line options. Where a hole cannot safely be made and sealed in the bottom of a tank, filling from the top is required. A wet system configuration can still be used by running the fill line up the outside of the tank to an inlet at the top. Consult Appendix B for additional resources that discuss the two options in more detail.

c) Pre-tank diverters and filters

This first flush of water running off a roof contains particulates composed of dust, detritus, and animals droppings that have accumulated on the roof since the last rainfall. These materials can dissolve in water, encourage algae growth, degrade water quality, accumulate in the bottom of the tank, and clog up irrigation emitters and pumps. Particulates that accumulate on roofs should be diverted from—or filtered out of—roof top runoff before it enters a storage tank. It is highly recommended that some type of pre-tank treatment be used. If particulates make their way through the tank and into the distribution system, replacing particulate-clogged drip irrigation or pump components can be costly.

Simple strategies for pre-tank treatment include mechanical filtration systems and "first flush" systems. Neither will prevent all particulates from entering the tank, but each should yield a significant improvement in water quality. Debris excluders are mechanical filtration devices that are the first line of defense to keep particulates out of cisterns. These devices prevent larger pieces of debris from entering the tank, while water passes freely through them into the tanks. It is important to have easy and convenient access to filters for inspection and maintenance. On peaked roofs where leaf screens are appropriate, filters should be placed higher than the tank, but low enough to allow easy inspection and maintenance. Additional filtration of smaller particles is also wise, especially if water will be distributed through a drip irrigation system.

Table 4 in Appendix A summarizes pre-tank diverters and filtration options. The pre-tank strategies listed in Table 4 do not remove toxins, viruses, or bacteria. It is possible to eliminate these and other contaminants using advanced water quality treatment prior to the water entering the distribution system, but this level of treatment is not necessary for landscape irrigation purposes.

d) Storage container – tank composition, fittings and size

Harvested water is collected and stored in tanks of various shapes, materials, and sizes. Tanks can be made of polyethylene, fiberglass, reinforced concrete, or metal, and are typically the most important component of an active rainwater catchment system. Only those tanks that are approved for potable water use are permitted in Bellingham, even though the intent may not be to provide drinking water from the tank. Using tanks that are approved for potable water storage prevents the introduction of toxic elements into your rainwater harvesting system, giving you the potential to use the system for potable water in the future. Characteristics of different types of are shown in Table 5.

Other considerations in selecting tanks include the need for air vents, overflow piping, and clean-out ports. All tanks must have an air vent so air can enter the tank when water is pumped out and air can leave the tank during high rainfall events when tanks are rapidly filling. Underground tanks typically have a vent pipe that protrudes from the ground. Make sure all vent pipes deflect insects, animals, and direct sunlight. One way to deflect animals and mosquitoes is to have a screen covering that is small enough to keep mosquitoes from entering.

Overflow piping is essential to safely convey excess water out of a tank when the tank is full and more rainwater is coming in. The overflow piping must carry the excess water to a point where it can be safely discharged to the land surface using gravity alone. Design your system so overflow water is beneficially harvested in the soil, or, if that's not possible, discharged as surface runoff. Cost factors for overflow piping include the type of pipe, the length of the pipe run to a safe discharge point, and the design for controlling erosion when large flows of water periodically pass through the pipes. Overflow piping should also deflect insects, animals, and direct sunlight. If debris is allowed to enter the tank, however, putting screens on overflow pipes can cause debris to back up and prevent the tank from overflowing. A one-way flap valve or screen installed on the overflow pipe, which automatically opens when water flows and snaps shut when it does not, will not clog.

Clean-out ports allow entry into the bottom of tanks to inspect for leaks, seal leaks, and remove debris and sludge, if needed. Prebuilt tanks may have entry ports built into them. Note that large tanks should only be entered by trained personnel familiar with Occupational Safety Health Administration (OSHA) procedures.

It is not essential that a tank be so large that it meets all the outdoor water needs of a site. It is more realistic to design a system where tank water is used when it is available and treated water is used when the tank is empty. Tank size may be limited by cost, feasibility of placement, the size of roof area that's being harvested from, and many other factors. There is no perfect one-size-fits-all tank, so a backup water supply should always be accessible to supplement stored rainwater, if necessary. Ideally a tank system should be large enough so there is little or no overflow loss during peak rainfall months, and enough storage capacity exists to meet any additional future demands (Downey & Schultz, 2009).

To select an appropriate tank size for your site, take into account the roof area you want to collect from, annual rainfall, downspout location, available space, planned water uses, and site conditions. There are several rules of thumb you can use to help determine an appropriate tank size, as described in the Tank Sizing sidebar in this section.

e) Water quality treatment for drip irrigation

In addition to diversion and filtration of particulates before water enters a tank, supplemental filtration will be needed after water leaves the tank and prior to water entering a drip irrigation system. Filtration of small particulates prior to water entering drip systems is accomplished using inline filters installed within the distribution piping. Additional information about this is provided in Section f along with the discussion of the distribution system.

f) Distribution system

The distribution of harvested rainwater consists of two basic processes: providing sufficient pressure to move water out of the tank and providing a means to deliver water to its intended use. Harvested rainwater can be moved out of the tank using gravity flow or using more complex electric- or solar-powered systems. Piping, hoses, and in many cases irrigation technology are used to deliver water to its intended use. Note that hose threads and pipe threads are not the same size although there are parts that allow connections between hose and pipe threads. Different types of pipes have different inside diameters, just as different brands of drip lines have different diameters. For example, Schedule 40 and Schedule 80 PVC have different inside diameters. Consult resources listed in the Appendix B for more detailed information on conveyance systems. This section provides an overview of the functions and components of typical rainwater harvesting distribution systems.

It is important to note that distribution systems can be responsible for more water waste than tank collection, conveyance, and storage systems combined. If you forget to turn off a hose that taps a tank, tank water can quickly drain away. When a pressurized pipe leaks 24 inches below ground, it will often go unnoticed until a large volume of water has been wasted. When a pump or irrigation system gets stuck in the "ON" position, it does not take long for a tank to drain. Paying close attention to good design, maintenance, and operation of the distribution system is key to efficient tank water use.

Moving water out of the tank

Water can be moved out of a tank with or without external energy inputs. Gravity-fed systems passively deliver water from the tank to the end use. Human energy is needed to operate hand pumps. External energy is needed to power sump pumps (positioned inside the tank) and in-line pumps (positioned outside the tank), which typically provide more pressure per square inch (psi) than gravity-fed or hand-pump systems. All rainwater hose bibb outlets or valves should always be marked as "NON-POTABLE WATER. DO NOT DRINK."

Gravity-fed systems

Passive distribution through the use of gravity is possible when the water level in a tank is higher than the elevation of the water's intended point-of-use. For every foot of water elevation above the point-of-use, you gain 0.433 psi of pressure. Pipe friction can reduce gravity pressure, so minimize pipe loss by using large diameter hoses and/or 1-inch interior-diameter distribution pipes. Smaller diameter drip irrigation lines can branch off from these larger lines. Using full-port valves (ball valves in which the hole the water passes through in the valve is the same diameter as the pipe) will allow unrestricted water flow.

Per manufacturer's recommendations, the minimum pressure needed to operate drip irrigation systems is between 10 psi and 15 psi. Therefore, the bottom elevation of tanks in gravity-fed systems needs to be 25- to 35-feet higher than the elevation of drip irrigated plants. This elevation difference would typically only be possible on a site where there is substantial slope and the rooftop collection area and tank were located high on the slope. Raising a tank artificially to gain more elevation difference is typically not feasible. Each gallon of water weighs 8.35 pounds so adequate structural support of an elevated tank is of paramount importance and difficult to achieve for the average homeowner without professional expertise; in addition the rooftop would need to be higher than the intake point on the tank. Do not be discouraged however, as people do successfully operate gravity-fed drip irrigation on sites with less elevation difference. These systems may not work fully to manufacturer's recommendations but they can support plants. Gravity-fed drip systems require good landscape design with appropriate plants placed in appropriate locations, the diligence to operate the system by hand, and the ability to be present to operate the system as needed to support the plants.

Electric and solar pumps

Many systems use electric or solar powered pumps to move water out of tanks. Electric pumps provide sufficient pressure to deliver water to plants using a garden hose or a drip irrigation system. Pumping systems can be operated manually or can be automated at an additional cost. Typical systems utilize sump pumps or inline pumps. A variety of solar pumps are also available, which rely solely on the sun—or on a combination of sun and electricity—to operate.

Sump pumps

Sump pumps are the least expensive electric pumps available. Sump pumps are placed inside the tank and must be submerged in water to work. The pump intake point must be at least 6 inches above the bottom of the tank to prevent the intake of material that has settled to the bottom. This placement will reduce the frequency of pump cleanup, repair, or replacement. Inside the tank, the sump pump should be attached to a cable, wire, rope, or chain for ease of removal and to position the intake point at the correct distance above the bottom of the tank. It is important that the pump automatically shuts off when the water supply drops below the pump intake point, otherwise the pump will burn out. All systems should be designed to allow easy access to the pump for monitoring, maintenance, repair, or replacement, as needed.

A simple sump pump can be purchased for under $100 and can be easily connected. The greatest expense associated with a sump pump is hiring a licensed electrician to connect the pump, the ON/OFF switch, and the automatic shut off mechanism for when the water level gets below the pump intake point.

Inline pumps

An inline pump is installed along—or "inline" with—the distribution pipe that emerges from the tank. Inline pumps are contained in a pump housing that protects the pump from weather, animals, and tampering. Pump housings are typically located underground, but they can also be constructed aboveground in a separate structure. Inline pumps can distribute water via a garden hose or drip irrigation system.

Many inline pumps have a drain to let water out in the fall before freezing occurs, and a priming hole for adding water to start up the pump in the spring. The depth and slope of pressurized lines served by the pump will dictate whether the pump needs to be drained or primed. Follow manufacturer's directions for draining and priming the pump. Inline pumps have the advantage of being easily accessible if they malfunction. However, they have the disadvantage that any leaks can flood a pump housing quickly if an overflow pipe has not been installed.

Irrigation methods

Typically, gravity-fed systems or sump pumps are sufficient to supply the water pressure needed for hose watering. Sump or inline pumps are usually used to provide the needed water pressure for drip irrigation and/or higher pressure hose watering and sprinkler systems. The differences in cost, complexity, ease of operation, and other characteristics between hose watering and drip irrigation systems are summarized in Table 6 and discussed below. Table 8 summarizes multiple options for distribution of water from a rainwater tank. Schematic diagrams of these options are illustrated in Figures 10a-10e.

Hose watering

Hose watering requires nothing more than a manually operated hose bibb or valve and someone to move the hose (Table 8, Figure 10a and 10b). A hose nozzle can be added to control the flow rate of water and conserve water. Thoughtful landscape design can make hose watering easier and more efficient. With grading that effectively uses gravity, a hose watering system leaves much of the work to nature. On sloped sites, group plants in basins so

gravity-fed hose delivery

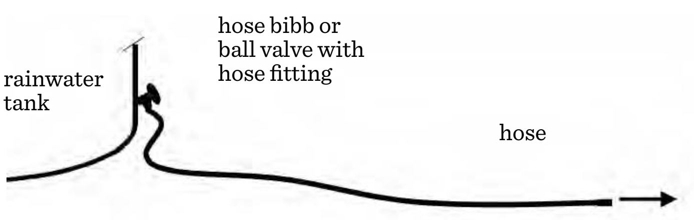


Figure 10a. Gravity-fed hose delivery: Watering plants with a garden hose using gravity pressure alone is the simplest and least expensive way to distribute tank water. The elevation of the bottom of tank must be above the elevation of plants. It is useful at sites with a small to medium number of plants, where the owner is willing to hand water.

pump-fed hose delivery

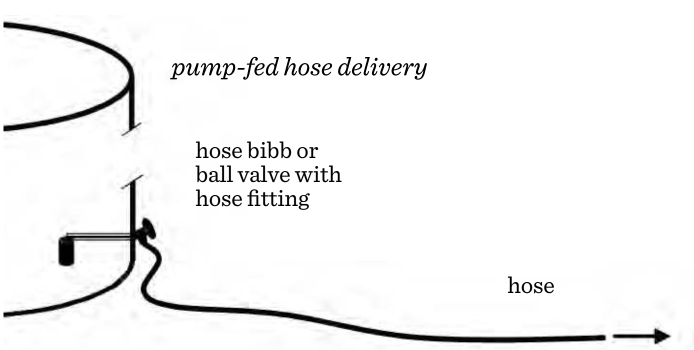


Figure 10b. Pump-fed hose delivery: Adding a pump to the tank delivery system increases water pressure, which is helpful when gravity pressure is weak and is essential when the tank is located downhill from the watering point. The pump needs an electrical source and can be located inside or outside the tank. The tank also needs an automatic switch to shut off the pump when the tank water level is low.

several can be watered with each hose placement and design overflow depressions so water works its way down the slope from one plant group to the next. If the tank hose bibb is located next to the treated water hose bibb, there is a higher likelihood the tank water will be used. Other efficiencies can be gained by placing the water-thirsty plants close to rainwater tank valve or hose bibb. Even if you use drip irrigation, it is beneficial to install a valve or hose bibb to allow for spot watering with a hose.

Drip irrigation
Drip irrigation (commonly known as "drip") directs water to the root zones of plants using a network of tubing that releases a slow trickle of water into the soil for a set watering time through properly sized and placed emitters (Table 8, Figure 10c-10e). Drip is a highly efficient water-delivery method when properly installed, monitored, and maintained. For more information about drip irrigation, see resources in Appendix B. It is critical to design and install drip irrigation systems with sufficient "elbow room" to access, inspect, change, and clean system components.

Other distribution options are available for use under the low pressure conditions that exist in gravity-fed systems (Table 8, Figure 10c). These are designed to distribute water to plants that are lower in elevation than the tank elevation, and range from the use of T-tape and soaker hose to drilling periodic small holes in black poly pipe to allow gravity-fed water to flow out toward plants. Drip irrigation can also be used with gravity-fed systems, but requires the use of large volume emitters designed for this purpose (Appendix B).

Consult a landscape consultant to find out the average water needs for existing or proposed plants at your site based on the number and size of drip emitters and the frequency of watering typically needed for such plants. Keep in mind that unless you adjust the system appropriately to reduce or stop irrigation, drip irrigation will continue indefinitely even after plants become well enough established to make it on their own. Not all drip equipment will work with a water supply that is gravity-fed or low-pressure so consult manufacturers of drip equipment on the required pressure to operate the system effectively. Drip irrigation systems can be

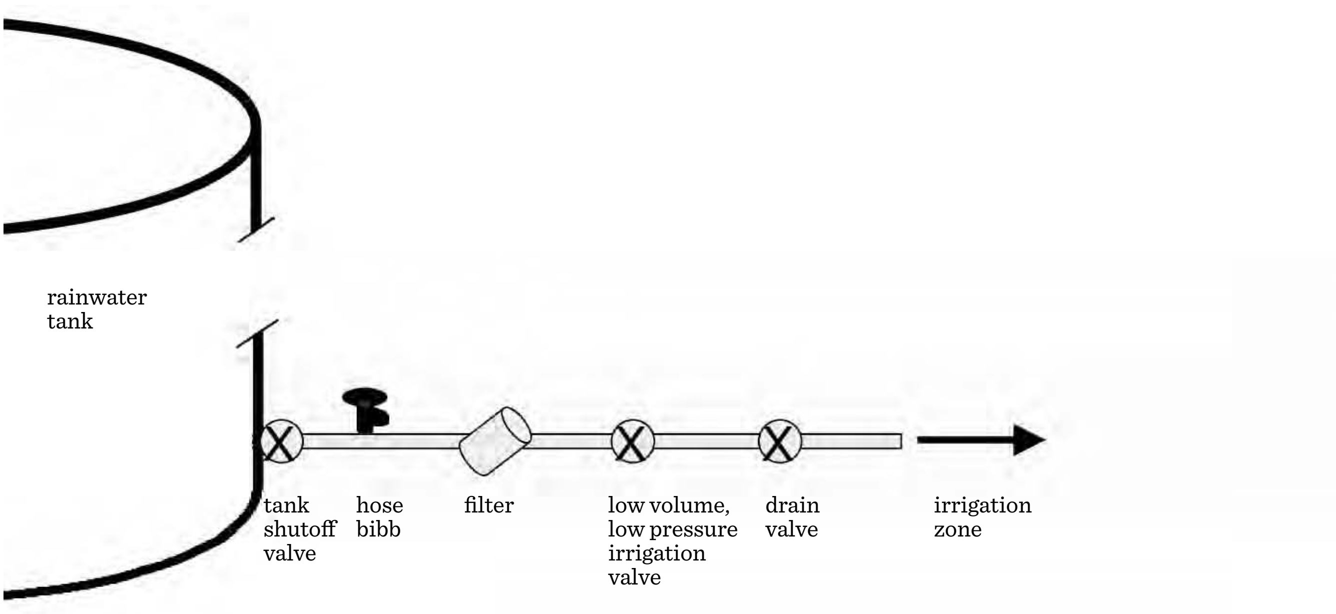


Figure 10c. Gravity-fed Drip and Other Irrigation Strategies: A variety of irrigation strategies can be used to deliver gravity-fed water to plants without hand watering, as long as the elevation of the bottom of tank is above the elevation of plants. These strategies can include distribution of water to drip irrigation lines with gravity-friendly emitters or distribution of water to bubblers, T-tape, soaker hose, perforated polypipe, branched polypipe and other strategies. The higher the tank elevation relative to the elevation of plants, the greater the gravity pressure. Water distribution may be uneven due to the lack of consistent water pressure throughout water lines.

installed to use either gravity-fed or pump-fed water from a water harvesting tank (Table 8, Figure 10c and 10d).

For gravity-fed drip irrigation systems there should be an inline drip irrigation Y-filter installed “upstream” of any irrigation controller and emitters in the distribution line. The inline filter is needed to remove small particles to ensure efficient drip irrigation. A standard drip irrigation filter in the 150-200 mesh range (i.e., 75-100 microns) should be sufficient if monitored and cleaned monthly.

There are many ways to design pump-fed drip irrigation systems. The selection of components, their specification, and the exact order of their use should be determined with the help of an irrigation professional. In general, the following elements should be included:

- A pump can be installed internally or externally to the tank. It must include an automatic shut off valve to prevent it from operating when water level drops below the tank intake level.
- A pressure tank is needed to induce water to flow from the water harvesting tank to the pressure tank when water pressure drops below a predetermined level. Drip irrigation requires a minimum of 10-15 psi and preferably around 15-30 psi to operate effectively. A 6-gallon pressure tank or inline pump system that includes a small built-in pressure tank may be suitable for your drip irrigation system.
- An inline filter removes small particles to ensure efficient drip irrigation. A standard drip irrigation filter in the 150-200 mesh range (i.e., 75-100 microns) should be sufficient if monitored and cleaned monthly.
- An inline pressure regulator moderates water pressure in the irrigation delivery pipes.
- For systems with a frost-proof pump housing or self-draining sump pump, a hose bibb can be installed to allow spot hose watering. Identify the hose bibb as a source of non-potable rainwater and consider locking the handle. (NOTE: Purple is the Universal Plumbing Code’s [UPC] color for non-potable water sources.)
- To allow for winterization, position a drain in the irrigation line at an elevation lower than all the components being drained.
- To split the water flow into different irrigation zones, attach the primary PVC irrigation line to an irrigation valve box that contains one valve for each irrigation zone you want to establish. Separate zones are recommended for trees, shrubs, and perennials, grouped according to similar water needs. For automatic irrigation systems, each valve will be attached to a solenoid that is connected with low voltage wire to an irrigation controller.

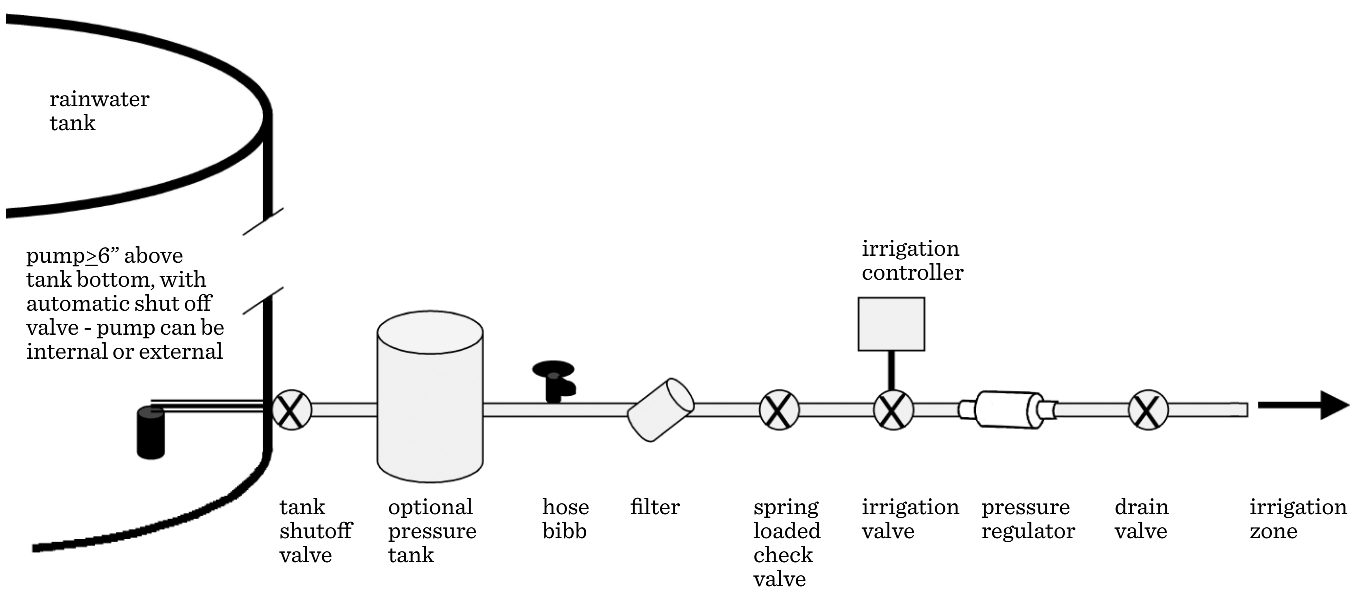


Figure 10d. Pump-fed Drip Irrigation system: A pump-fed pressurized drip irrigation system is useful for sites where added water pressure is needed to serve multiple plants at varying elevations and distances from the tank. An automatic shut-off switch is needed to turn off the pump when the tank water level is low. The system can be manually or automatically operated.

- A manual control or automatic irrigation controller needs to be installed to turn the drip system on and off. The controller can be battery operated or electrically wired. An automatic controller is costly, but is highly recommended because it saves time and is more reliable than a manual system.
- The outlet pipe from the valve box is typically 1/2 to 1-inch flexible polypropylene tubing buried under the soil or tacked to the soil surface and covered with mulch to reduce evaporation.
- A digital water-level meter can be installed to indicate the water level in the water harvesting tank. Simpler water level meters are also available.

If plants demand on-going regular irrigation, consider installing a drip irrigation system in which harvested rainwater is used when it is available and treated City water is automatically used when rainwater is not available (Table 8, Figure 10e). Drip systems that are hooked up to both treated water and harvested rainwater must be carefully designed to prevent any possible contamination of the City's treated water by harvested rainwater. Installing a backflow prevention valve or designing an air gap into the rainwater tank delivery line are two strategies that can address this. To ensure that no potential for cross-contamination exists for a system plumbed with both treated water and rainwater, a professional contractor or engineer must design that portion of the irrigation system. All necessary permits must be obtained before installing this type of system.

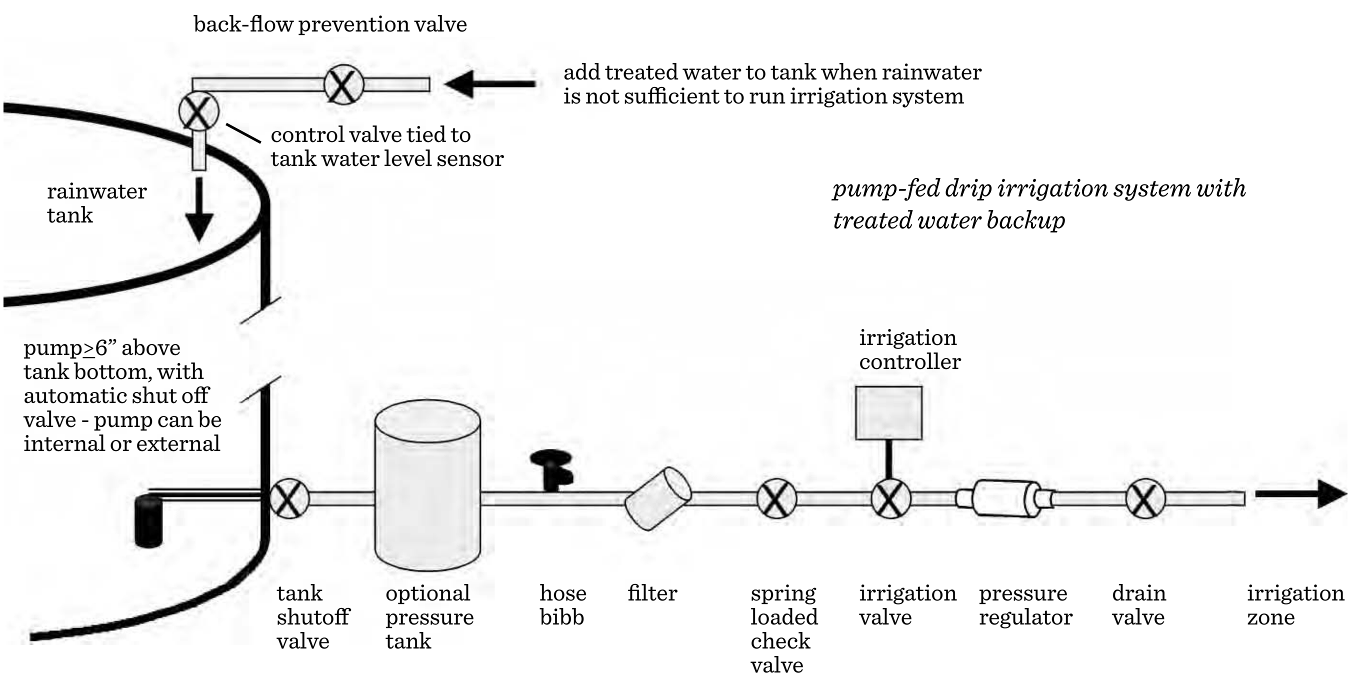


Figure 10e. Pump-fed Drip Irrigation System with Treated Water Backup: The most complex distribution system is drip irrigating plants using pressurized rainwater when it is available, and using treated water as a backup supply when rainwater is low. There are two ways to accomplish this: 1)when rainwater gets low in the tank, add treated water to the top of the tank, then continue to supply the drip irrigation system using water from the tank; or 2) when rainwater gets low in the tank, automatically switch to treated water to directly supply the drip irrigation system. Use this system when the on-going demands of the irrigation system require a back-up water supply to keep the system operating automatically on schedule. Note: When interconnecting treated water and rainwater systems, it is imperative that your system automatically prevents any cross-contamination between rainwater and treated water.

Step 10. Prepare and submit application for tank permit

When the type of water harvesting system has been determined (e.g., active, passive, aboveground or below-ground tanks) and map and site plan have been drafted, review the permitting flowchart on the following pages to determine which permits, if any, are needed for your water harvesting system. In addition to the Bellingham Municipal Code, the following codes have been adopted by the City of Bellingham and pertain to rainwater harvesting. City staff are available at the Permit Center to help with clarification of these codes and rules.

- 2009 Uniform Plumbing Code (UPC) and Amendments – Chapters 51-56, 51-57 WAC
- 2009 International Building Code (IBC) and Amendments – Chapter 51-50 WAC
- 2009 International Residential Code (IRC) and Amendments –Chapter 51-51 WAC
- 2009 Washington Cities Electrical Code
- 2008 National Electrical Code

Step 11. Install your tank and keep it safe and well maintained

- Installation
  - After all permits and approvals have been received, obtain materials.
  - Locate all buried utilities in areas where excavation will occur.
  - Following your water harvesting plan, proceed with installation using a contractor or doing the work yourself.
- Safety once the tank is installed
  - Lock the tank lid to prevent access by children.
  - Screen the inflow pipe to keep out mosquitoes and animals.
  - Do not drink tank water unless it has been properly treated and tested to confirm that it meets drinking water standards.
  - If the tank is co-plumbed with potable water for an irrigation system, make sure backflow protection is installed and functioning.
  - Tank entry may constitute confined space entry. Abide by all safety requirements for confined space entry during installation and when subsequently inspecting, repairing, and cleaning the inside of a tank.
- Maintenance and inspection
  - Make sure pre-tank diverters, first flush devices, and filters are correctly positioned and cleaned, especially after major rainfall events.
  - Inspect the tank monthly for signs of leaking and repair leaks immediately.
  - Check irrigation system periodically for leaks and proper operation.

Ultimately, the type of water harvesting system a person chooses is largely determined by their budget, end-uses, and site conditions. The beauty of water harvesting is that there is a system that can be designed to address nearly all of those variables using the steps listed above.

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Glossary

Note: The following definitions have been developed specifically for use in this manual and are not intended to be generalized to other uses.

Active rainwater harvesting systems: All elements of rainwater harvesting systems that result in the capture and retention of rainwater in containers for beneficial use at a later time.

Bioretention swale: A curvilinear depression in the land surface that collects stormwater. Generally has a mounded berm on the downslope side that assists in retaining stormwater.

Capillary rise: The tendency of water in soil to rise due to the strong attraction of water molecules to each other and to small pore spaces between soil particles.

Closed tank: Storage containers that are screened off from insects and animals and are opaque to sunlight. These prevent mosquito breeding, animal drowning, and buildup of algae and bacteria growth from contaminating harvested water.

Contour line: A line of equal elevation along a land surface.

Detention/retention basin: An on-site structure that alters the volume of stormwater flowing away from a site by temporarily or permanently holding stormwater runoff within the structure.

Graywater: Water drained from bathroom sinks, showers, tubs, and clothes washers that is put to beneficial use at the site where it is generated rather than discharged to sewer or septic systems.

Impervious: A non-permeable (non-porous) solid surface. Used interchangeably with "impermeable" surface.

Infiltration: Movement of water from the surface to below ground through soil pore spaces.

Integrated design: A highly efficient site design that matches site needs with site resources and products, and takes into account water harvesting/drainage, solar orientation and access, winds, and many other factors. An integrated design saves resources while improving the function and sustainability of the site.

Microclimate: Very localized conditions that exist at sites due to sun angles, water availability, proximity to building shade and reflected light, proximity to vegetation, wind conditions, and other factors affecting a site.

Non-potable water: Water that does not meet standards for drinking water.

Overflow device: Component of an active or passive rainwater harvesting structure that allows excess water to flow out of the structure without damaging the structure.

Passive rainwater harvesting systems: Systems that use land shaping and other techniques to direct, collect, and infiltrate rainwater directly into the soil where water is put to beneficial uses such as supporting vegetation and managing stormwater.

Peak day demand: Highest citywide water use in a day during a one-month period.

Pervious: A porous surface that allows liquids such as water to percolate through the surface. Used interchangeably with "permeable."

Potable water: Water that has been treated to meet drinking water standards.

Rainwater: Liquid precipitation falling from the sky before it hits a solid surface.

Rainwater harvesting: The process of collecting water from an impervious surface such as a roof, or from a pervious surface such as soil, and routing it to a location where it is beneficially used. This can be conducted actively through storage of water in tanks for later use (active water harvesting), or passively through storage of water directly in the ground (passive water harvesting). For purposes of this guide, the terms "rainwater harvesting" and "water harvesting" are used interchangeably, and may include harvesting rain falling from the sky and/or harvesting stormwater flowing across permeable or impermeable surfaces.

Storage container: A watertight tank (called a cistern in some areas) that stores water. Size, composition, and shape vary greatly.

Stormwater: Rainwater becomes stormwater once it lands on a surface.

Treated water: For purposes of this guide, treated water is water that has been treated by the City of Bellingham to meet drinking water standards. As used here, "treated water" is synonymous with "potable water."

Uniform Plumbing Code, 2009: A set of specifications for construction adopted by the City of Bellingham and the State of Washington.

Watershed: A term commonly used to describe a catchment area within which all stormwater drains toward a common collection point. Used in this guide to describe those drainage areas affecting a particular site, which might include upslope areas draining toward the site or downslope areas receiving drainage from the site.

Xeriscaping: Landscaping that saves water by using water conserving designs, drought-tolerant plants, rainwater harvesting techniques, reduced turf area, appropriate irrigation methods, soil improvements, mulching, and proper maintenance practices.

APPENDIX A
Tables

Table 1 . Benefits of rainwater harvesting

Individual benefits	Collective benefits for City of Bellingham
Save drinking water at the household scale by watering plants with harvested rainwater instead.	Save drinking water at the community scale that would otherwise be used to water plants, and avoid increased costs to meet peak treated water demand in summer.
Reduce on-site erosion and flooding and the costs to manage runoff.	Reduce off-site erosion, stormwater runoff, and water-borne pollution and associated control costs.
Reduce the metered water portion of your utility bill.	Reduce community financial and energy costs to treat and deliver drinking water.
Use water that is “delivered” to your site for free and has minimal treatment costs when used outdoors.	Reduce community expenditures to expand water supply and treatment infrastructure as population grows.
Extend the life of landscaping, which benefits from the high nitrogen and low salt content of harvested rainwater.	Extend the life of community stormwater infrastructure and reduce impacts to the Lake Whatcom Reservoir from runoff water.

Table 2. Comparison of characteristics of aboveground tanks and belowground tanks

Factors	Aboveground tanks	Belowground tanks
NOTE: Both aboveground and belowground tanks must be approved for potable water storage		
Cost to install	Less expensive to install than belowground tanks since little or no excavation and backfilling are needed.	Excavation is an additional cost for belowground tanks. Installation can be more complex. Depending on depth to groundwater, tanks may need to be strapped or anchored in the ground. Need to backfill dirt following tank placement.
Expertise needed to install	Small and simple storage containers, such as rain barrels, can be installed by homeowner. Large and complex tanks will require professional assistance.	Need professional engineering assistance to design buoyancy mitigation for underground tank installations.
Access	Can be designed for easy access to all sides and top of tank to inspect and repair as needed.	Only the top ports are easily accessible. Sides and bottom are underground so it is harder to detect leaks and inspect tank condition.
Susceptibility to heat and cold	Susceptible to water and pipes freezing. The lower the water level, the more similar tank water temperature will be to outdoor temperatures, whether hot or cold. Insulate pipes against freezing to prevent leaks.	Belowground elements are buffered from both freezing and excessive heat. Know the frost depth for your area and drain and/or insulate pipes within that depth so no leaks occur.
Water conveyance options	Can use gravity flow to convey water through hose or irrigation system if there is sufficient head pressure, or can distribute water using a pump. The higher the elevation of the tank above its intended use, the more gravity pressure is available.	Must use a pump to convey water unless the water use is located lower in elevation than the buried tank.
Aesthetics	Tanks are still unusual in the public's perception. May be objections to placing them in highly visible areas. May need to screen aboveground tanks to improve aesthetics.	Tank is not visible, so no aesthetic issues other than visibility of ports.
Use of space	Tanks take up space in yards that could be used for other purposes so make maximum use of aboveground tanks to serve multiple functions such as shading, privacy screen, visual screens, wind abatement, moderating heat and cold, and as an ornamental element.	Takes up very little surface space. Options for location is affected by the ability to get excavation equipment and installation equipment into the proposed tank site. May be limitations on what you can put over the buried tank.

Table 3. Characteristics of common roof materials found in the Pacific Northwest for harvesting rainwater

Roofing material	Runoff coefficient	Durability	Water quality issues
Metal	0.95	Very durable, most efficient collection surface	Galvalume® roofing produces better quality water for indoor use than other more porous roofing materials (Mendez et al. 2011). Galvanized metal is a common roofing material used for harvesting rainwater, painted or unpainted (Harvest H2O website, 2011) Copper, zinc and lead roofing materials should not be used for rainwater collection (Uniform Plumbing Code, 2009).
Asphalt shingle	0.90	Commonly used, efficient collection	Filtration for outdoor use and treatment for indoor use necessary
Cedar shakes	.80-.85	Long-lasting durability	Susceptible to moss, lichen, and algae growth

CAUTION: With the exception of galvanized steel, which is chemically coated with zinc, do not harvest rainwater if copper, lead, and zinc strips are present in roof materials because they produce very poor quality runoff.

Copper, zinc, or lead roofing materials should not be used for rainwater collection (Uniform Plumbing Code, 2009; Section 1628.1 Roof Surface). Detailed information on different roof types for rainwater collection can be found in the resources listed in Appendix B.

Table 4. Pre-tank diverter and filtration options

Type	Description and functions	Placement	Example devices	Important notes on use
Debris excluders	Coarse screen that prevents large material from entering a tank. Important if trees overhang roof.	On top of the gutter or downspout inlet of a peaked roof or along the downspout between gutter and tank inlet, but not at the bottom of the downspout.	Sloped rainheads (leaf eater, leaf beater), gutter guards, debris traps, leaf catchers, leaf screens.	Do not use on flat roofs with parapets that have small openings to let water out. Clogged outlets could back up water onto the roof causing roof leaks. Select only self-cleaning types of debris excluders.
Small particulate inlet filter	Various types of barrels with internal filters that intercept small particulates before they enter the storage tank. Different types for aboveground and belowground tanks.	Along the tank inlet line, after excluders or diverters, but before water enters the tank.	In-ground filters include basket filters, downspout rainwater filters, vortex filters. In-tank filters include types include fine-mesh floating filters that filter water prior to entering a submersible pump.	Some types can be self-cleaning if positioned at a proper angle and sufficiently sized for the volume of water and size of particulates being filtered. Important to use if water will go through a drip irrigation system.

Table 5. Characteristics of tank materials for harvesting rainwater

Tank material	Cost per gallon	Durability	Available sizes
Polyethylene	50¢-$1.00/gal	High	50-10,000 gallons
Fiberglass	50¢-$2.00/gal	High	500-20,000 gallons
Reinforced concrete	30¢-$1.25/gal	Medium	≥10,000 gallons
Corrugated steel & metal	50¢-$1.50/gal	Medium	150-3,000 gallons

Table 6. Comparison of hose watering and drip irrigation distribution systems

Elements	Hose watering	Drip irrigation systems
Materials	Valve (hose bibb) to tap the tank, hose.	Connection to pump, irrigation pipe, pipe connections, emitters, PVC glue, timer, and/or valve.
Installation	Attach hose to tank valve.	Dig trenches, cut and glue pipe, fit emitters, operate valve or timer.
Operation and maintenance	Manually open and close valve, move hose.	Inspect and repair irrigation lines and emitters, operate valve or irrigation timer.
Compatibility with passive water harvesting	Most effective when combined with passive water harvesting strategies so both direct rainfall and hose water are contained within basins.	Can be combined with passive water harvesting when plants with similar irrigation water needs are placed together within basins.
Impacts on plant selection and placement	Watering can be labor intensive, so works best when plants with similar water needs are placed in close proximity. Use drought-tolerant native plants to avoid need for long-term watering.	Maximum flexibility in plant selection and placement because number and size of emitters controls water application.
Plant watering efficiency	Minimal control over amount of water applied. Tendency to overwater.	Maximum control over amount of water applied.
Annual and seasonal adjustments	Needs special attention during plant establishment. Check soil moisture during different seasons and adjust watering as needed.	Adjust irrigation timers to provide optimal irrigation during establishment and seasonal rainfall changes. Install “smart controller” that adjusts water distribution based on local rainfall and humidity.

APPENDIX B

Rainwater Harvesting Resources

Useful Keyword Searches

Cisterns, collecting rainwater, rainwater catchment systems, rainwater harvesting, rainwater harvesting filtration, rainwater tanks, zero pressure timer

Websites

HarvestH2O.com

This site is dedicated to the advancement of sustainable water management practices for individuals, families, communities, and businesses. The website has LOTS of information: links to news articles (regional, national and international), Frequently Asked Questions (FAQs), resources, vendors, products, projects, etc. *www.harvesth2o.com*

American Rainwater Catchment Systems Association (ARCSA)

ARCSA is a non-profit organization whose mission is to promote sustainable rainwater harvesting practices to help solve potable, non-potable, stormwater, and energy challenges throughout the world. *www.arcsa.org*

Irrigation Water Management Society

The Irrigation Water Management Society is a non-profit organization committed to promoting the wise and efficient use of water in golf, landscape, and agriculture. Visit the website to calculate how much to irrigate your landscape based on the type of plantings and irrigation system you have. *www.iwms.org/seattle_area.asp*

Irrigation Tutorials

Jess Stryker has prepared a series of detailed tutorials to instruct readers on all aspects of irrigation. Some specialized topics include pumps and drip irrigation guidelines. Additional topics include Designing a New Irrigation System, Saving Water & Irrigation System Operation, and Repairs and Fixing Irrigation Problems. *www.irrigation-tutorials.com/*

Publications — technical focus

Rainwater Collection for the Mechanically Challenged by Suzy Banks with Richard Heinichen

Published by Tank Town Publishing, 2006. By all accounts, this book manages to be both educational and entertaining. Subjects covered include determining how much rainwater you'll need and troubleshooting a problem pump, and how to hang gutters, run your trunk line, install check valves, and disinfect your rainwater without using chemicals. www.rainwatercollection.com (also available at Bellingham Public Library, *www.bellinghampubliclibrary.org*)

Rainwater Harvesting for Drylands and Beyond, Volume 1: Guiding Principles by Brad Lancaster

Published by Rainsource Press, 2006, revised 2009. Over 150 illustrations and six appendices including patterns of water flow and erosion, water harvesting traditions, calculations, plant lists, worksheets, and resource lists. www.HarvestingRainwater.com (also available at Bellingham Public Library, *www.bellinghampubliclibrary.org*)

Rainwater Harvesting for Drylands and Beyond, Volume 2: Water-Harvesting Earthworks by Brad Lancaster

Published by Rainsource Press, 2006, revised 2009. Subjects include rainwater harvesting, passive water harvesting, landscape design, ecology, sustainable development, do-it-yourself technology, sustainable stormwater management, and erosion control. www.HarvestingRainwater.com (available at Bellingham Public Library, *www.bellinghampubliclibrary.org*)

Rainwater Harvesting: System Planning by Justin Mechell, Billy Kniffen, and Bruce J. Lesikar

Published by Texas AgriLife Extension Service, 2010. The manual provides information about proper planning, sizing of system and components, installation, and using rainwater for inside and outside use. Topics include gutter and downspout sizing, rainfall intensity, and wet and dry conveyance systems. It offers the technical information needed by the professional, but is also useful for the do-it-yourselfer needing guidance to install a small system. www.rainwaterharvesting.tamu.edu/ (publication number: B-6240) (also available at Bellingham Public Library, *www.bellinghampubliclibrary.org*)

Slow it. Spread it. Sink it! A Homeowner's and Landowner's Guide to Beneficial Stormwater Management

Published by Sonoma Valley Groundwater Management Program, 2010. This publication comprises chapters on understanding and evaluating stormwater runoff around your home, Best Management Practices for stormwater around the home, difficult sites and site constraints, local projects, and a resources guide. Available online at: www.sscrcd.org/rainwater.php

Texas Manual on Rainwater Harvesting, Third Edition, 2005; Texas Water Development Board

Published by the Texas Water Development Board, Third Edition, 2005. Subjects covered include rainwater harvesting system components, water quality and treatment, water balance and system sizing, rainwater harvesting guidelines, cost estimation and financial and other Incentives. *www.twdb.state.tx.us/publications/reports/rainwaterharvestingmanual_3rdedition.pdf*

Rain Garden Handbook for Western Washington Homeowners

Published by Washington State University Pierce County Extension, 2007. Information on designing and building a rain garden to protect our streams, lakes, bays, and wetlands. *county.wsu.edu/mason/nrs/water/Documents/Raingarden_handbook.pdf*

Water Storage: Tanks, Cisterns, Aquifers and Ponds by Art Ludwig

A do-it-yourself guide to designing, building, and maintaining water tanks, cisterns and ponds, and managing groundwater storage. It will help you with your independent water system, fire protection, and disaster preparedness, at low cost, using principles of ecological design. Includes how to make ferrocement water tanks. Published by Oasis Design, 2005 *oasisdesign.net/*

Publications — background info

Managing Wet Weather with Green Infrastructure – Municipal Handbook

The handbook is a series of documents, with the Rainwater Harvesting Policies chapter prepared by Christopher Kloss for the U.S. Environmental Protection Agency in 2008. Available to view online, this chapter contains interesting data and insight into how cities across the U.S. are changing their policies toward water management in response to current and predicted potable water shortages. *www.epa.gov/npdes/pubs/gi_munichandbook_harvesting.pdf*

Publications — other jurisdictions

Rainwater Harvesting

Published by Department of Consumer and Business Services, Building Codes Divisions, Oregon Smart Guide. The guide provides great illustrations of active rainwater harvesting system components. *www.bcd.oregon.gov/pdf/3660.pdf*

Rainwater Harvesting: Supply From the Sky

Published by the City of Albuquerque, 1995. The guide includes overview and consideration of both simple and complex rainwater harvesting system design and construction, calculating and balancing supply and demand, guidelines for gutters and downspouts and how to build a rain barrel. *www.ose.state.nm.us/water-info/conservation/Albq-brochures/rainwater-harvesting.pdf*

Harvesting Rainwater for Landscape Use, by Patricia H. Waterfall and Christina Bickelmann

Published by Cooperative Extension, College of Agriculture and Life Sciences, University of Arizona, 2nd ed., 2004. This is a basic guide with calculations for estimating water needs of landscape vegetation. *www.cals.arizona.edu/pubs/water/az1344.pdf; www.water.az.gov*

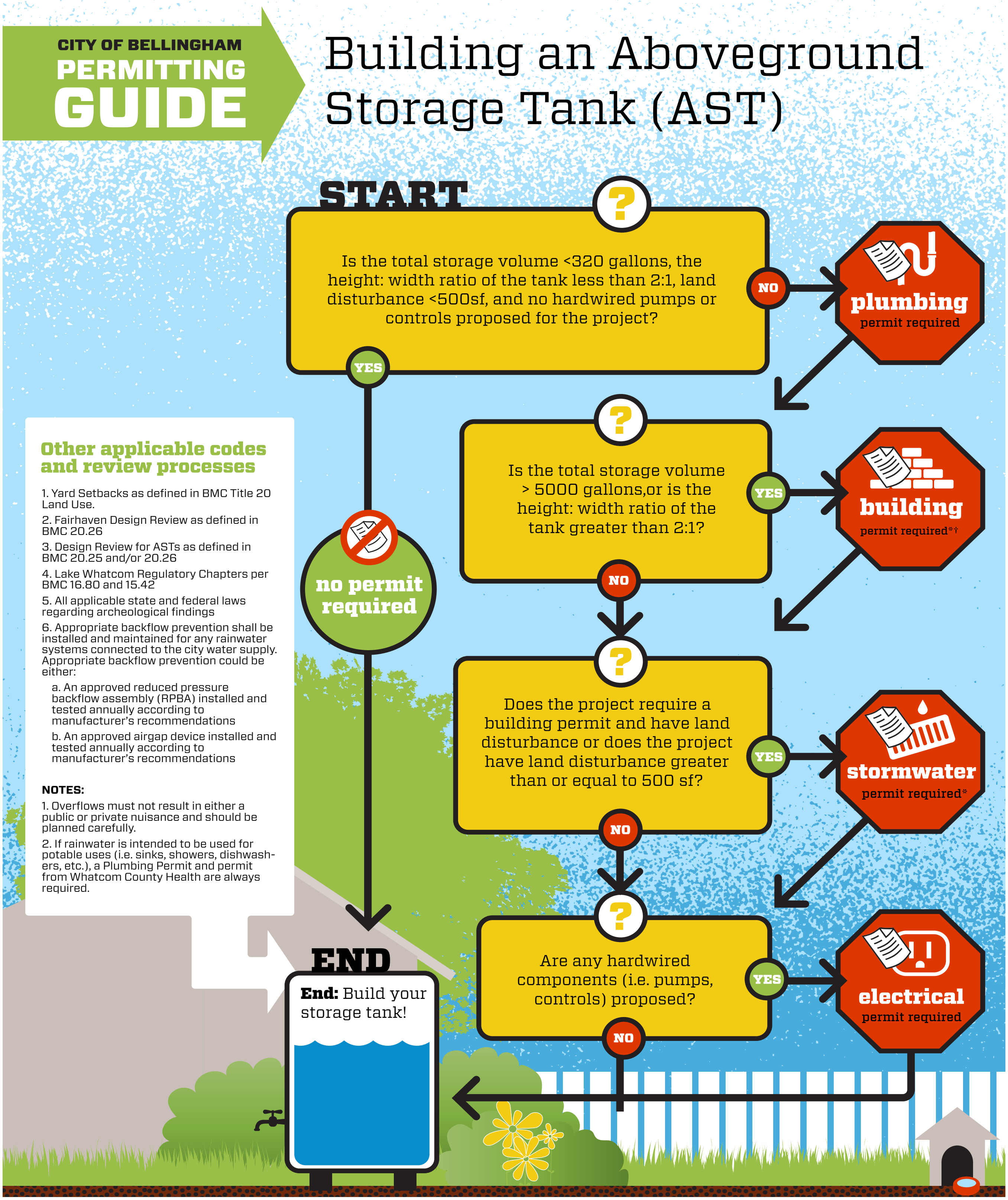
Roof-Reliant Landscaping Rainwater Harvesting with Cistern Systems in New Mexico by Nate Downey and Randall D. Schultz

Published by New Mexico Office of the State Engineer, 2009. This manual is designed to introduce the concept of roof-reliant landscaping in a logical manner that begins with a basic introduction to xeriscaping (waterwise landscaping techniques) and continues through a detailed "how-to" discussion of cistern system design, construction and maintenance.
www.ose.state.nm.us/water-info/conservation/pdf-manuals/Roof-Reliant-Landscaping/Roof-Reliant-Landscaping.pdf

Water Harvesting Guidance Manual

Published by The City of Tucson, Department of Transportation, Stormwater Management Section, 2005. The water harvesting manual provides basic information and design ideas for developments that are subject to the water harvesting requirements of the City of Tucson Land Use Code. This includes commercial sites, public buildings, subdivisions and public rights-of-way. The manual is also useful for homeowners. *http://dot.ci.tucson.az.us/stormwater/downloads/2006WaterHarvesting.p*df

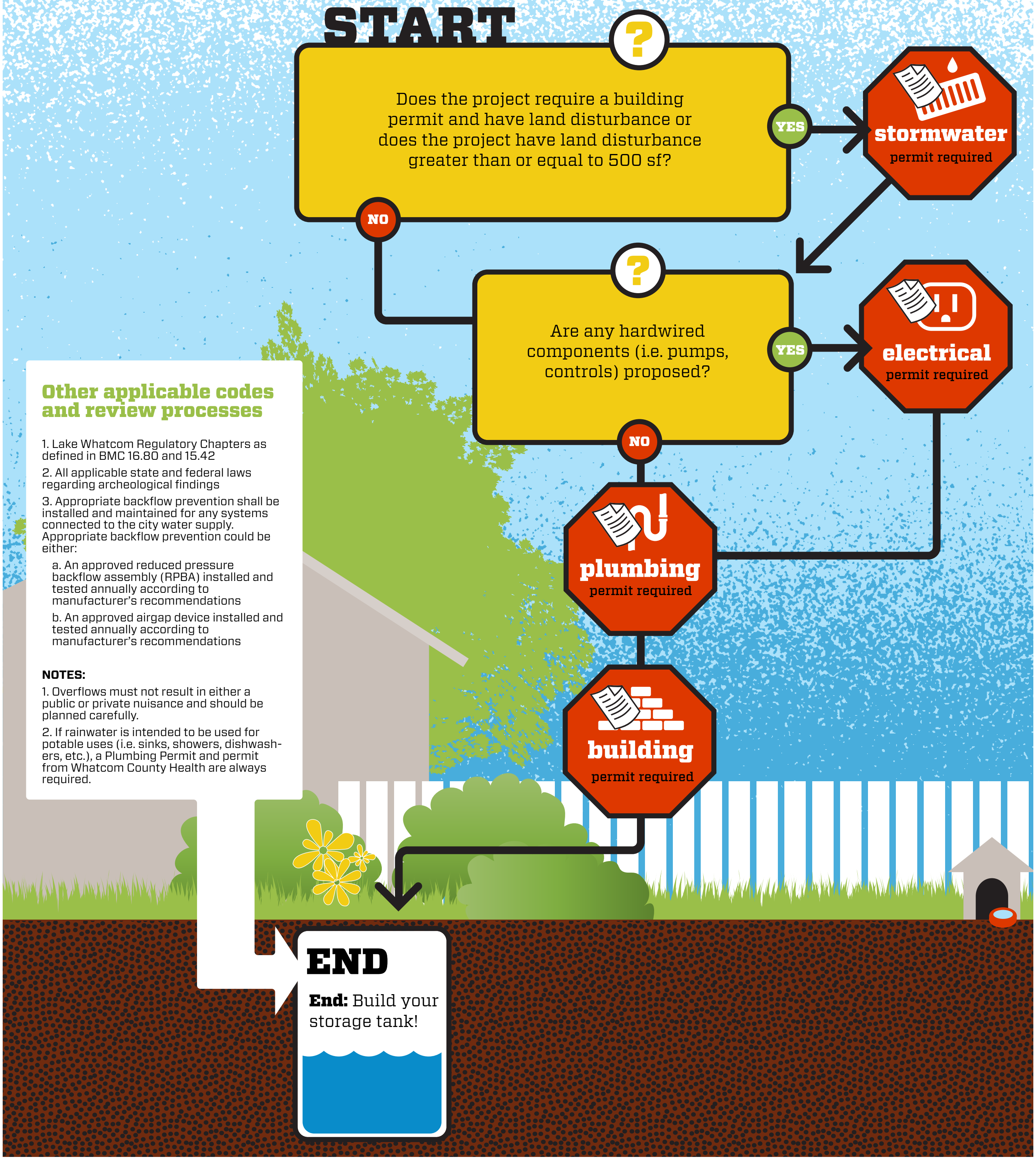
APPENDIX C:



CITY OF BELLINGHAM
PERMITTING
GUIDE
Building an Aboveground Storage Tank (AST)
START
Is the total storage volume <320 gallons, the height: width ratio of the tank less than 2:1, land disturbance <500sf, and no hardwired pumps or controls proposed for the project?
NO
plumbing
permit required
YES
no permit required
Is the total storage volume > 5000 gallons,or is the height: width ratio of the tank greater than 2:1?
YES
building
permit required*†
NO
Does the project require a building permit and have land disturbance or does the project have land disturbance greater than or equal to 500 sf?
YES
stormwater
permit required*
NO
Are any hardwired components (i.e. pumps, controls) proposed?
YES
electrical
permit required
NO
END
End: Build your storage tank!
Other applicable codes and review processes
1. Yard Setbacks as defined in BMC Title 20 Land Use.
2. Fairhaven Design Review as defined in BMC 20.26
3. Design Review for ASTs as defined in BMC 20.25 and/or 20.26
4. Lake Whatcom Regulatory Chapters per BMC 16.80 and 15.42
5. All applicable state and federal laws regarding archeological findings
6. Appropriate backflow prevention shall be installed and maintained for any rainwater systems connected to the city water supply. Appropriate backflow prevention could be either:
a. An approved reduced pressure backflow assembly (RPBA) installed and tested annually according to manufacturer's recommendations
b. An approved airgap device installed and tested annually according to manufacturer's recommendations
NOTES:
1. Overflows must not result in either a public or private nuisance and should be planned carefully.
2. If rainwater is intended to be used for potable uses (i.e. sinks, showers, dishwashers, etc.), a Plumbing Permit and permit from Whatcom County Health are always required.

CITY OF BELLINGHAM PERMITTING GUIDE

Building an Underground Storage Tank (UST)

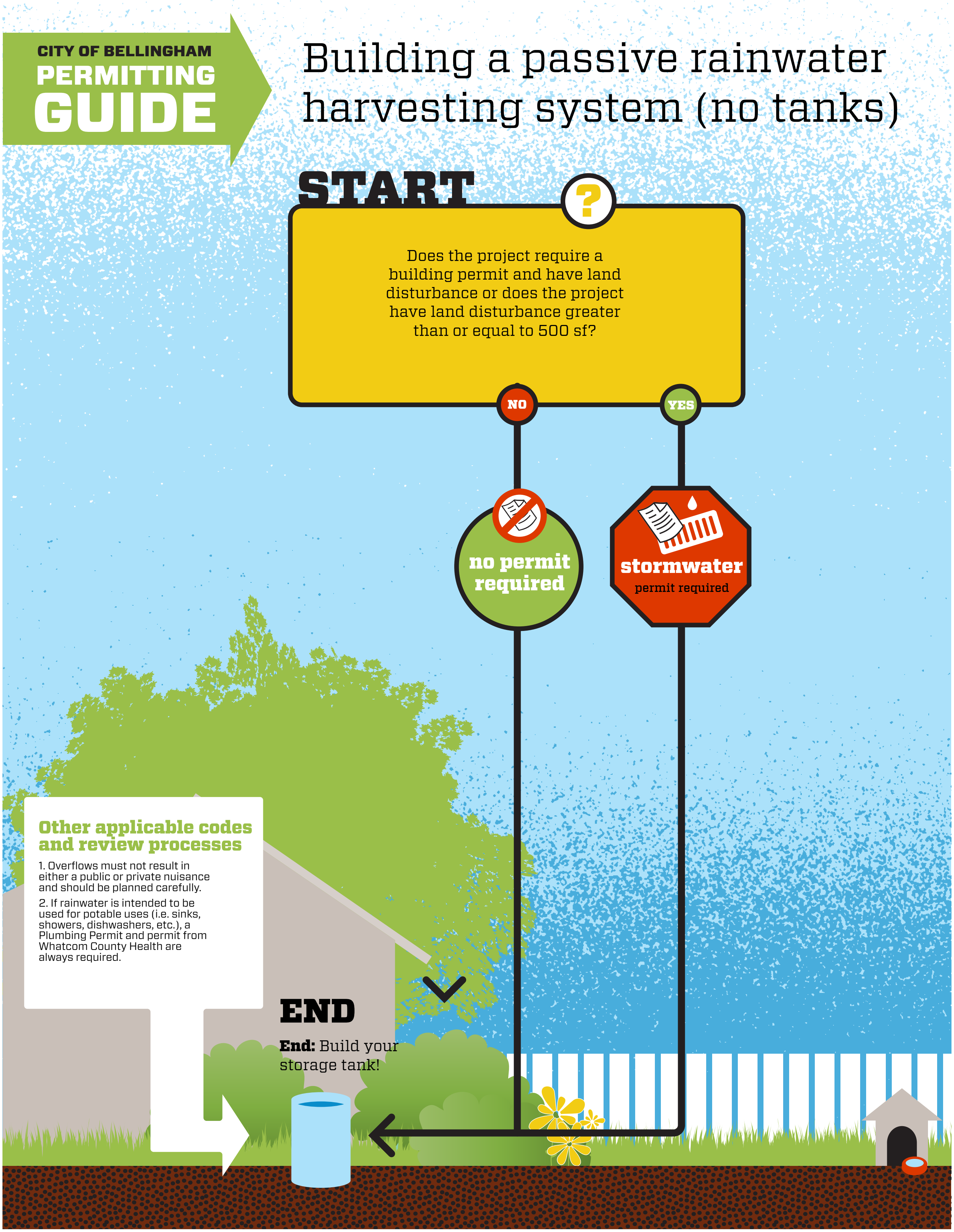


Other applicable codes and review processes

1. Lake Whatcom Regulatory Chapters as defined in BMC 16.80 and 15.42
2. All applicable state and federal laws regarding archeological findings
3. Appropriate backflow prevention shall be installed and maintained for any systems connected to the city water supply. Appropriate backflow prevention could be either:
   a. An approved reduced pressure backflow assembly (RPBA) installed and tested annually according to manufacturer's recommendations
   b. An approved airgap device installed and tested annually according to manufacturer's recommendations

NOTES:

1. Overflows must not result in either a public or private nuisance and should be planned carefully.
2. If rainwater is intended to be used for potable uses (i.e. sinks, showers, dishwashers, etc.), a Plumbing Permit and permit from Whatcom County Health are always required.


CITY OF BELLINGHAM
PERMITTING
GUIDE
Building a passive rainwater harvesting system (no tanks)
START
?
Does the project require a building permit and have land disturbance or does the project have land disturbance greater than or equal to 500 sf?
NO
YES
no permit required
stormwater
permit required
Other applicable codes and review processes
1. Overflows must not result in either a public or private nuisance and should be planned carefully.
2. If rainwater is intended to be used for potable uses (i.e. sinks, showers, dishwashers, etc.), a Plumbing Permit and permit from Whatcom County Health are always required.
END
End: Build your storage tank!

APPENDIX D:

Example water harvesting systems

Jimerson Residence Rainwater System

Owner Joyce Jimerson has been harvesting rainwater for years. As a staff member with Washington State University (WSU) Whatcom County Extension, Joyce was among the first rain barrel instructors in the county. Over time Joyce accumulated six barrels to supplement outdoor irrigation. After her daughter adopted three ducks (which quickly expanded to six), a plastic duck pond became part of the rainwater collection system.

In August 2010 Sue Blake, a WSU Extension colleague, returned from a rainwater harvesting class armed with the knowledge and motivation to help Joyce replace her duct-taped rain barrel system with a large, tidy cistern system incorporating a permanent duck pond. With the help of class participants, the group project became WSU Extension's first demonstration cistern system.

Approximate Cost

~$1,200

Permits

No Whatcom County permits were required at the time of installation.

About the System

- Collection Surface: Collects water from 450-square foot roof section; a one-inch storm will yield about 250 gallons from this roof area. Roof is constructed of asphalt shingles.
- Conveyance System: Unscreened 4-inch aluminum gutters connected to aluminum downspout.
- Pre-tank Diverter & Filters: Screened downspout to remove large debris and a first flush device.
- Storage: Two dark green, high-density polyethylene 305-gallon tanks for a total storage volume of 610 gallons. After tanks were installed, they were primed and painted to reduce the amount of ultra-violet light penetrating the tanks and help discourage algae growth. Tanks are also certified to collect water that could (with proper treatment) be used for drinking water and a duck pond.
- Water Treatment: None.
- Distribution System: Rainwater is gravity fed from tanks to duck pond to underground irrigation system.
- Overflow: Routed to duck pond, and to secondary overflow area when needed.

Lessons Learned

- Glue the plumbing together or eventually leaks will occur.
- It is challenging to get even flow throughout the irrigation system.

RE Patch Community Garden Rainwater System

The City of Bellingham's Water Conservation Program staff designed and built this rainwater collection system to demonstrate how community members can integrate rainwater harvesting into their outdoor watering practices. The system was designed to accommodate the newly planted edible landscape garden and forest garden, which were designed and installed under the leadership of Homestead Habitats, with the help of Bellingham Urban Gardens (BUGS) and Cascadia Mushrooms. Through a series of workshops, community participants created eleven raised vegetable beds built from reclaimed materials donated from The RE Store. Other planting areas included perennials and native plants. The planting areas are maintained by community members and neighbors of the RE Patch garden collective.

Approximate Cost

~$1,000

Permits

None necessary – system meets City of Bellingham permit exemption requirements.

About the System

- Collection: Collects water from one downspout off of a 6,900 square foot roof area composed of metal roofing material. An estimated one-inch storm will yield about 3,900 gallons from this roof area.
- Conveyance System: The existing downspout on the building was cut to accommodate connection to the catchment system tanks via a rubber coupling. Depending on the type of tank and the diameter and shape of the inflow hole, a rubber coupling can be used to connect the downspout to the first tank. Components were "dry fit" before being glued and tanks were connected with 2-inch PVC pipe and bulkhead fittings, sized per the Rainwater Harvesting System Planning manual (Mechell et al. 2010).
- Pre-tank Diverters & Filters: A 1/16-inch screened downspout filter was installed inline on the existing downspout to prevent debris from entering the tanks.
- Storage: In keeping with the mission and theme of the RE Store, three 275-gallon capacity food-grade liquid storage tanks were retrofitted for use as rainwater collection tanks. Linked together, the system holds up to 825 gallons of rainwater. Available space closest to the garden and along the north side of the building allowed for optimal catchment area and ease of use. The translucent plastic tanks were primed with a plastic paint primer and painted a solid color to reduce the amount of ultra-violet light penetrating the tanks and help discourage algae growth. A vent cap was installed to allow for efficient flow and vacuum relief for each tank.
- Water Treatment: None.
- Distribution System: A transitional fitting was necessary in order to allow a standard garden hose bibb to be installed on the tank outlets, since the tanks did not have standard hose bibb threading. Harvested rainwater is used to hand water the raised beds and landscaping.
- Overflow: Routed to existing storm drain system where original downspout was directed.

Lessons Learned

- Determine how tank water is to be used. If hand-watering is going to be the predominant use, construct a concrete block base to site the tanks on. If other method is preferred, a concrete pad or metal ring around a gravel base would also work.