VIRGINIA RAINWATER HARVESTING MANUAL

Second Edition 2009

Compiled by The Cabell Brand Center

A comprehensive guide to examining, designing and maintaining rainwater harvesting systems to abate stormwater runoff

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This manual would not be possible without the financial assistance of the Virginia Environmental Endowment and Gerald McCarthy. Rainwater Management Solutions in Salem, Virginia and the German-based WISY AG Company served as technical consultants on this project. Their help was pivotal in supplying this manual with modern rainwater harvesting technologies.

Letter from the President of The Cabell Brand Center

The second edition of the Virginia Rainwater Harvesting Manual comes at an exciting time for supporters of rainwater harvesting. Across the country, people are becoming increasingly aware of the need to conserve water and increasingly enthusiastic about green, sustainable living. We are also encouraged by a greater awareness that stormwater runoff from homes and businesses is threatening the health of our rivers, streams, lakes and estuaries. Rainwater harvesting can make a positive impact in all of these areas.

When the Cabell Brand Center was founded in 1987, it began by granting stipends to college students for academic research on poverty and the environment. Instead of funding outreach and restoration programs, research was encouraged because research leads to knowledge, and knowledge leads to solutions. After twenty years, the Center decided to focus its attention on water conservation, particularly rainwater harvesting. In September 2007, the Cabell Brand Center released the first edition of the Virginia Rainwater Harvesting Manual in the midst of a drought. By the end of October of that year, ninety-three (out of 95) counties in Virginia were federally designated as disaster areas due to drought. Delaware, Maryland and Tennessee all received federal disaster designation during this time and the Governor of Georgia declared a state of emergency because of drought conditions. The need to re-examine water use and consider alternative water supplies like rainwater harvesting was apparent.

While the water shortage in Virginia is less drastic today, the need for guidance on rainwater harvesting is no less apparent. Spurred by drought, concerns about stormwater runoff, and a growth in green building practices, rainwater harvesting has seen a dramatic increase in popularity. Unfortunately, this increase in popularity has on occasion led to poorly designed systems and products. While rainwater is a naturally clean water source, improper filtration and storage can lead to human health risks and building design problems. These problematic systems also damage the overall reputation of rainwater harvesting and discourage people from pursuing this important environmental solution. The Manual was created as an introduction to the science of rainwater harvesting and guidance for system design of high quality, safe, and sustainable systems.

The Virginia Rainwater Harvesting Manual is a continuation of the Center's belief that knowledge and science lead to sound decision-making and progress. We hope that it will both encourage readers' interest in rainwater harvesting and guide those who are interested in designing rainwater harvesting systems.

David Crawford, President
The Cabell Brand Center

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Introduction

As the nation is becoming increasingly aware, rainwater harvesting is a building system that collects and conveys rainwater from roofs, filters debris from the water and stores the rainwater for use. Systems can be non-potable or potable, the latter requiring additional filtering after the water is pumped from the tank. Across the United States, people realize the need to conserve water. Rainwater harvesting enjoys widespread use in areas around the world such as Europe and the Caribbean islands, and these systems are a logical solution for our country's water resource challenges.

There is growing enthusiasm about green, sustainable living systems and practices that save water, energy and money, while preserving and improving our natural environment. Rainwater harvesting supplies alternative water for such non-potable uses as irrigation, toilet flushing, laundry, vehicle and facility cleaning, fire suppression systems, HVAC cooling towers and agriculture. Potable rainwater harvesting systems can be used for drinking water, as well as showers/baths, dishwashing, swimming pools and food processing. Rainwater harvesting is a powerful solution to a range of water problems.

"We never know the worth of water, till the well is dry." Thomas Fuller, Gnomologia

Freshwater problems

Though the well is not dry, freshwater supply problems in Virginia, the United States and the world are increasing our awareness of the value of water. With a growing population, declining quality of surface water and groundwater and an aging water infrastructure, the need to explore alternatives to our current water supply system is clear. By collecting rainfall that would normally become runoff and instead using it to meet water needs, rainwater harvesting provides an alternative that both lessens the strain on our current water supply system and helps protect the quality of surface waters.

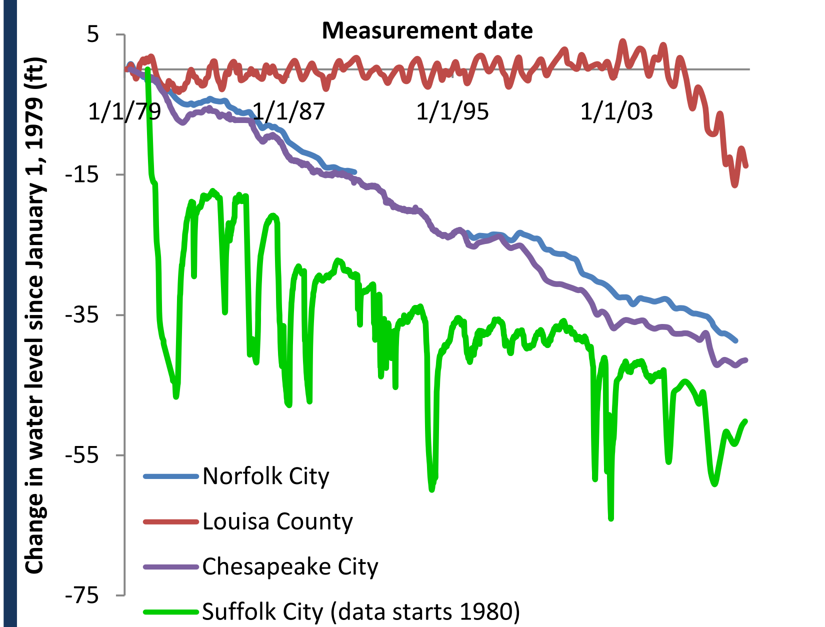


Figure 1. Changes in groundwater levels at monitoring wells at four sites in Virginia. These well all show declining water levels. Data are courtesy of the USGS and available through (http://www.epa.gov/WaterSense/pubs/supply.htm).

Water quantity

The amount of water available today is the same amount of water that was available 100 years ago. Only 2.5% of the world's water is freshwater. The strain on our water supply is evident:

- In less than 20 years, 1.8 billion people will be living in areas with water scarcity (1).
- Worldwide, water consumption is rising at double the rate of population growth (2).
- Even without drought, areas in at least 36 states in the U.S. are expected to have water shortages by 2013 (3).
- Groundwater levels in many areas of Virginia, particularly the coastal areas, have shown steady decline (Fig. 1).

Water quality

An adequate water supply does not just depend on the total quantity of water available, but also depends on the quality of this available water. In Virginia, water is supplied from surface water and groundwater, both of which are susceptible to contamination from pollution.

- Eighty-six percent of the water used in Virginia comes from surface sources (4). Almost eighty percent of lakes and reservoirs in Virginia are identified by the Department of Environmental Quality as impaired or threatened, though none are currently designated as unable to support public water supply (5).
- Groundwater from the deep aquifer below Virginia Beach and Norfolk is too salty for use without further treatment (5).
- Leaking fuel storage tanks, one of the biggest threats to groundwater quality, have been identified at over 24,000 sites in Virginia (5).

Decreasing the load placed upon public and private sources of potable water by utilizing rainwater harvesting can lessen the chance of water quality deterioration due to over-pumping of groundwater resources and reduce the need to explore water sources of questionable quality.

Water infrastructure

Not only is the water supply stressed, but the infrastructure to deliver the water supply is stressed also.

- The EPA estimates that $334 billion will be needed to from 2007 to 2027 for repairs and maintenance on public water systems (6).
- In general, up to 20 percent of the water in a municipal water supply system can be declared "unaccounted for," typically because of leaking conveyance equipment, before corrective action will be taken (7).
- Losses from leaks in municipal water supplies cost an estimated $2.6 billion per year because of an estimated loss of 1.7 trillion gallons of water (8).
- Seventy-five billion kilowatt hours (kWh) of electricity are used for water and wastewater industries in the U.S. each year and water and wastewater services can account for up to 1/3 of a municipality's energy bill (9).

As a decentralized water supply, rainwater harvesting does not depend on this aging infrastructure and is therefore more energy-efficient (10). By reducing the overall demand on the system, an increase in rainwater harvesting could help areas delay development of new water treatment plants and distribution systems.

Stormwater

Virginia is considered a "wet" state, receiving on average 42.8 inches of rainfall a year (4). This rainfall coupled with expanding impervious surface areas, the result of development, creates the potential for increased overland flow of stormwater. Increased impervious areas allow for less infiltration of water during rain events, leading to higher velocity and volume of runoff. This increased runoff carries pollutants and can lead to increased erosion.

- According to the Virginia Department of Conservation and Recreation, "If Virginia continues to grow with the same development patterns as it has in the past, more land will be developed in the next forty years than has been since the Jamestown settlement in 1607" (11).
- The amount of impervious area in the Chesapeake Bay watershed increased by 41% in the 1990s (12).
- According to the Chesapeake Bay Foundation, runoff from these impervious areas, carrying nitrogen, phosphorus, sediment and other contaminants, is considered one of the greatest threats to the health of the Chesapeake Bay and its tributaries (13).

Impact of rainwater harvesting

Rainwater harvesting could have a dramatic, positive impact on all of these problems. According to the US Census, Virginia had an estimated 358,000 more housing units in July 2007 than in July 2000. Assuming that each housing unit has a footprint of 1,500 ft^2, these additional units represent 537 million ft^2 of additional impervious roof area. If each house had a rainwater harvesting system that collected all of the water that fell on the roof, these systems could supply 14.3 billion gallons of water per year. For comparison, the City of Virginia Beach public water supply used 13.5 billion gallons of water in 2007 (4). If these rainwater harvesting systems were put in place, not only would they reduce the demand on surface and groundwater sources, they would also reduce strain on the water supply and delivery infrastructure. One kWh of energy is needed to treat and transport 667 gallons of municipal drinking water (9). Based on a case study in southwest Virginia, a rainwater harvesting system can produce 1,650 gallons of non-potable water per kWh (10). Using rainwater harvesting systems instead of municipal systems to supply 14.3 billion gallons of water could save 12.7 million kWh of energy. Based on the EPA's greenhouse gas equivalencies calculator, this energy savings could mean a reduction in carbon dioxide emissions of 20 million pounds, the equivalent of 1,675 passenger cars. The addition of these rainwater harvesting systems would also reduce stormwater runoff. Using average concentrations of nitrogen and phosphorus in residential runoff (14), these rainwater harvesting systems could reduce nutrient loading to surface waters by over 30,000 pounds of total phosphorus and over 230,000 pounds of total nitrogen per year. While these nutrients are necessary for plant growth, an over-abundance of nutrients can lead to algae blooms and even fish kills, greatly impairing the water quality.

Uses of Harvested Rainwater

Rainwater harvesting is suitable for all building types ranging from residential to commercial and industrial and can be retro-fitted to existing buildings or integrated into new building designs. Collected rooftop water is typically used for non-potable (non-drinking water) demands, but can be treated to drinking water standards and used for potable (drinking water) demands.

While many common water uses are non-potable (see list below), water supplied from the municipal system and wells is generally potable water. Utilizing potable water for non-potable needs wastes resources and can place unneeded strain on local water treatment plants.

Non-potable demands include:

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

*According to Virginia code (12-VAC 5-460-40), the water supply for a public swimming pool must be approved by the State Health Commissioner.

Potable demands include:

- Drinking water
- Cooking
- Bathing
- Dish washing

Types of systems

Rainwater harvesting is an appropriate water supply and stormwater solution for residential, commercial, industrial, and agricultural applications. All systems consist of the same basic components: a collection surface (only roof surfaces are addressed in this document), a conveyance system, pre-tank treatment, water storage and distribution. Harvested rainwater used for indoor use will also often include additional treatment.

Residential

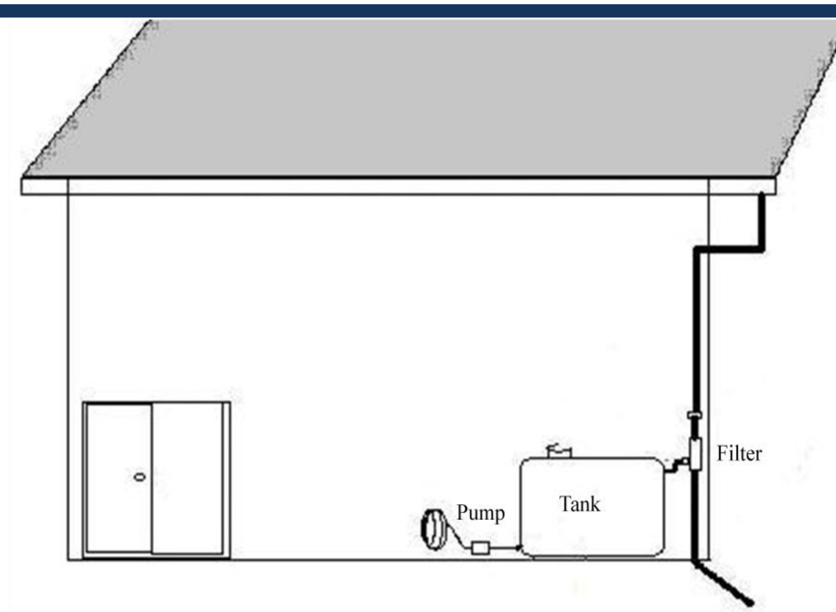


Figure 2. Residential non-potable rainwater harvesting system
Graphic courtesy of Rainwater Management Solutions

Residential systems can be designed for non-potable and potable needs. If a potable water source is available, it is recommended that the rainwater harvesting system be used only for non-potable needs like toilet flushing, laundry washing, and landscape irrigation. These non-potable uses account for 78% of total household water use, with outdoor use alone accounting for 59% of household use (15). Because outdoor use is such a dominant residential water use, bringing harvested rainwater indoors for non-potable use is often not cost-effective, particularly in retro-fit situations. The cost of a rainwater harvesting system is increased when the water is used indoors because plumbing for potable and non-potable rainwater sources must be separate systems. Municipal or well water can serve as a backup source of water if the rainwater runs dry. An air gap or backflow preventer is necessary between rainwater and municipal water supplies leading to the storage tank to prevent cross contamination (see **Backup Water Supply and Plumbing**). Figure 2 shows a small residential non-potable system, suitable for irrigation purposes.

Rainwater harvesting can serve as an alternative water source for rural homes where municipal water is not available and well drilling has not been successful. Rainwater can also supplement well or municipal water supplies to reduce demand on these supplies to serve non-potable demands in and around the home.

Commercial

Commercial rainwater harvesting systems can supply non-potable water needs. As in residential settings, the majority of commercial use is for non-potable needs. For example, eighty-seven percent of water use in an office building is for restrooms, cooling and landscape use (16). In hotels, fifty-one percent of water use is for restrooms alone (16). Because many commercial facilities want a year-round use for stormwater management needs, rainwater use for toilet flushing is common, especially in buildings with high occupancy loads. The soft rainwater is also beneficial for cleaning purposes as less detergent is needed. Water demand, roof size, and

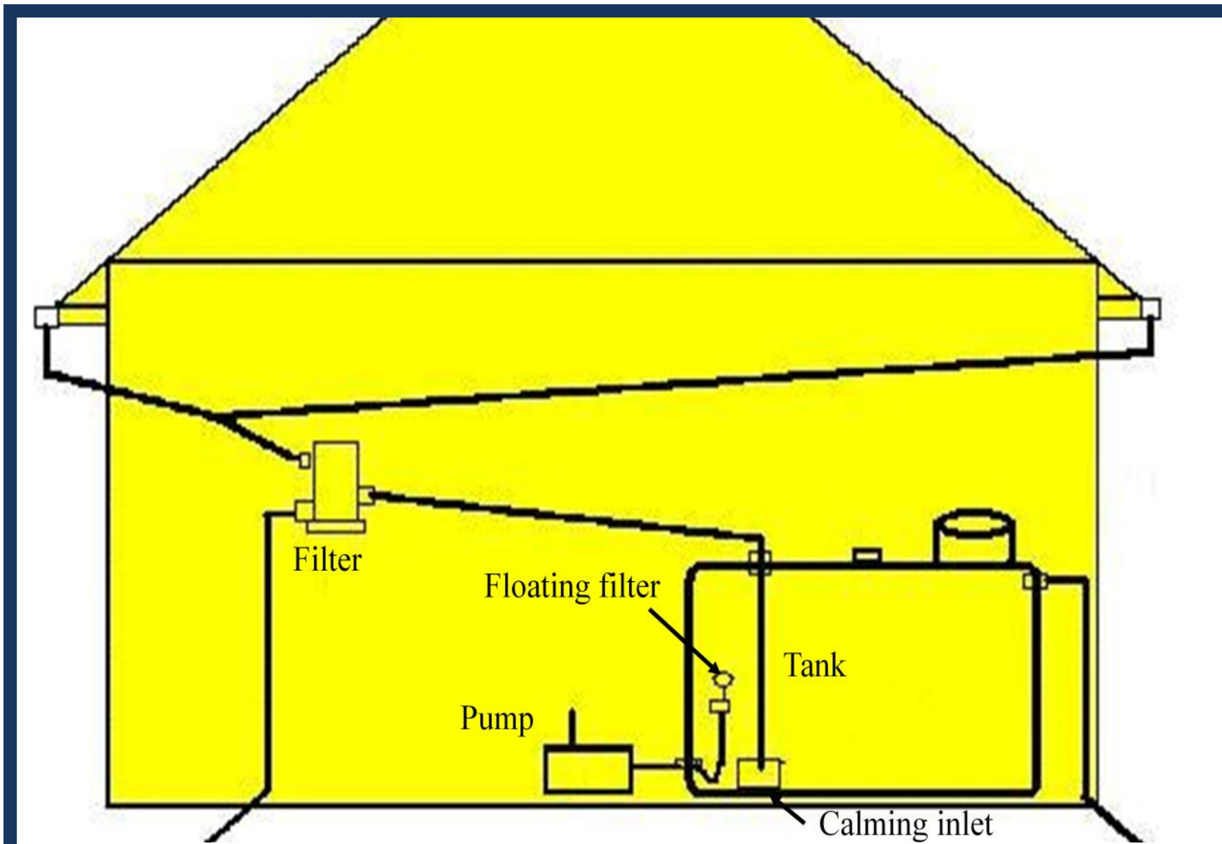


Figure 3: Commercial or large residential above ground non-potable rainwater harvesting system
Graphic courtesy of Rainwater Management Solutions

available onsite storage should be considered when sizing a collection tank. Figure 3 shows a commercial or large residential above ground rainwater harvesting system and Fig. 4 shows a commercial or large residential below ground system. A larger filter is needed to filter water from a larger roof area. In nearly all cases, a submersible or jet pump is necessary to pump water for indoor use. The addition of a calming inlet allows water to enter the tank without disturbing the important sediment layer on the bottom of the tank (See **Rainwater Inlet to the Tank**). A floating filter serves as the elevated uptake point for the pump system. If rainwater is used for potable needs in a commercial setting, the system will typically qualify as a public water system. Any system that supplies drinking water to 15 or more service connections or 25 or more people on 60 or more days per year is subject to the requirements of the federal Safe Drinking Water Act.

Industrial

Industrial buildings with flat roofs can frequently benefit from incorporating a siphonic roof drainage system with a rainwater harvesting system. A siphonic roof drainage system does not require pitched pipes which can reduce or eliminate underground piping. Siphonic roof

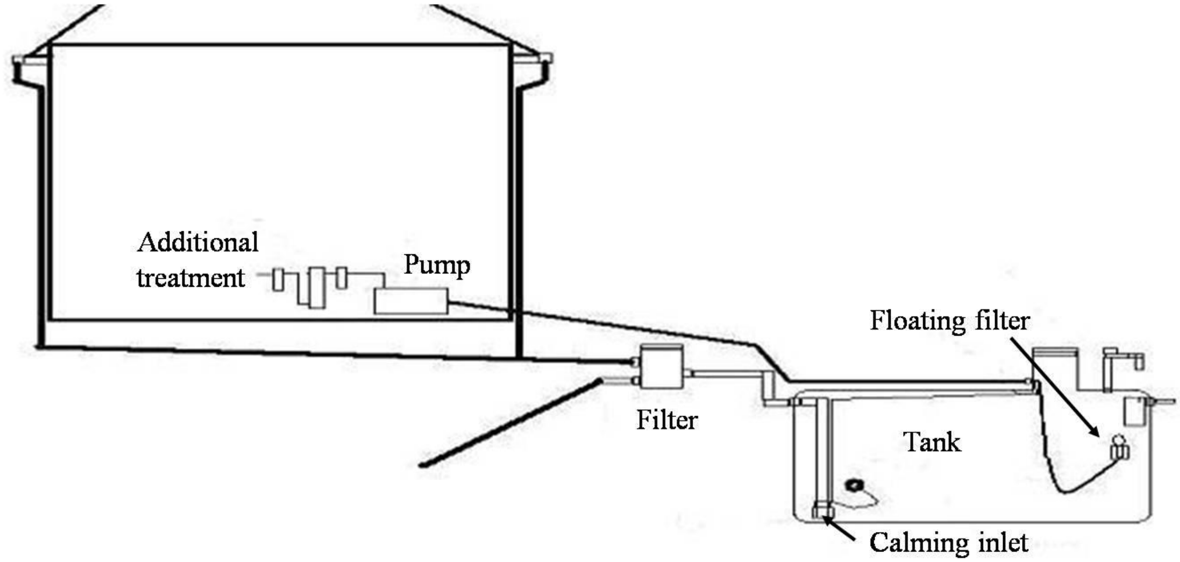


Figure 4. Large residential/commercial rainwater harvesting system with belowground tank for indoor use
Graphic courtesy of Rainwater Management Solutions

drainage systems also use smaller diameter pipes. The pipes have to be full to create a siphon while pipes in conventional roof drainage systems are often only half full. This difference allows siphonic roof drainage systems to carry the same volume of water in smaller pipes which reduces the cost of materials. Installation costs can be reduced by 30 to 40% due to the lower excavation, backfill and trenching costs.

Harvested rooftop rainwater can be used indoors to flush toilets, clean floors, and wash linens or as irrigation. As in the commercial setting, the soft rainwater is beneficial for cleaning purposes as less detergent is needed, which not only saves money but also reduces the amount of detergent released into the environment. In addition, cooling and process water often account for 80-90% of industrial water use (16). Harvested rainwater can be used for cooling in all industries and for process water in many industries.

Some companies opt to store water in a pond due to cost, location and aesthetics. If rainwater is diverted to a pond, it should be equipped with an aerator in the form of a fountain to continually add oxygen (Fig. 5). Water that is not used could also be directed for groundwater recharge.

Figure 5. Collection pond with aeration fountain
Photo courtesy of Rainwater Management Solutions

Rainwater harvesting not only allows a company the potential to reduce water costs, but it also reduces stormwater runoff on the site. The stormwater reduction aspect of rainwater harvesting holds this alternative water source above others because rather than contributing to stormwater runoff or energy consumption, it is reducing pollution and protecting local waterways. The ability of this system to reduce stormwater runoff can also be leverage for obtaining building permits.

Agricultural

Rainwater harvesting is ideal for farm animal drinking water and agricultural and landscape irrigation, as it is salt free, easily attained, and reduces groundwater depletion and pumping from local streams. Rainwater can be collected from rooftop surfaces like barns, clubhouses, greenhouses and equipment storage buildings.

During summer months, Virginia often experiences quick, hard rainfalls. Such rain events produce too much water in too short a time period for the ground to absorb, which results in most of the rainwater being lost to runoff. Rainwater harvesting systems are capable of collecting rainwater from nearby roof surfaces during such rainfalls. Therefore, the heavy storm's rainwater can be reapplied to the field at a suitable rate to promote water infiltration.

Frequently, livestock buildings allow rainwater from the roofs to flow into areas occupied by animals. This situation allows rainwater from these facilities to become contaminated by fecal matter resulting in a greater volume of manure slurry that must be managed. If rainwater from these facilities is harvested, it can be used for watering livestock and washing down facilities and animals. Harvesting rainwater from these facilities can reduce the amount of waste water created as well as decreasing the demand on wells and other water supplies.

Automatic watering troughs are an efficient way to provide clean drinking water to livestock. Most of these units operate using pressure valves and can be fed by an above ground, gravity fed rainwater harvesting system. The roofs of loafing sheds or other agricultural structures can be the source of this water. By decreasing pipe diameter of the pipe feeding the trough, water pressure is increased to a level which can successfully operate the trough's valves. This type of rainwater harvesting system allows for a quality water supply at remote locations.

Fire Suppression

Rainwater harvesting offers alternatives to municipally supplied water for fire suppression. Harvested rainwater can be directed to interior sprinkler systems and used in the advent of a building fire.

Fire suppression can go beyond indoor sprinkler systems and protect buildings from forest fires. Stored water flows backwards into the gutter system and overflows the gutters to form a shield of water. While forest fires are not as common in Virginia as they are in the arid west, rainwater could serve as protection for some homes located in heavily forested areas in the advent of a forest fire.

Another alternative is to collect rainwater for fire hydrants. Rooftop and street runoff can be directed to an underground tank connected to a fire hydrant. This prevents the reliance on potable water to fight fires and can reduce connection costs, especially in areas outside the main water distribution grid. Rainwater harvesting systems can also be used to meet fire suppression water supply requirements in remote areas.

Irrigation

Because irrigation is such a large water use across all building types, reducing the quantity of water needed for irrigation is an important step. Approximately 34% of all water use in the United States is for irrigation (16). Fifty percent of that water can be lost to evaporation and runoff (17).

Therefore, when coupling rainwater harvesting systems with irrigation, home/business owners should take extra steps to ensure the harvested rainwater is applied as efficiently as possible across the landscape. Applying more water than needed can cause runoff and nonpoint source pollution, thus canceling out the conservation and reduction in nonpoint source pollution benefits of rainwater harvesting.

Scheduling

Table 1. Landscape plant crop coefficients (17)

	High	Normal	Low
Trees	0.9	0.5	0.2
Shrubs	0.7	0.5	0.2
Ground cover	0.9	0.5	0.2
Mix: trees, shrubs, Groundcover	0.9	0.5	0.2
Cool season turf		0.8	
Warm season turf		0.6	

Ideally, irrigation should be scheduled based on evapotranspiration (soil evaporation and plant transpiration) data, which is based on recent climatic conditions. Virginia Tech recently developed a website that calculates evapotranspiration based on real-time climate data and can be accessed at http://www.turf.cses.vt.edu/Ervin/et_display.html. The website adjusts evapotranspiration based on turfgrass species, but it can be utilized for all landscape plants. Table 1 from the Irrigation Association Best Management Practice publication details the crop coefficients suitable for all landscape plants. This number adjusts the evapotranspiration based on the water requirements for the type of landscape plant being irrigated.

Historical evapotranspiration data for select Virginia cities is available at the website: http://climate.virginia.edu/va_pet_prec_diff.htm. This website details potential evapotranspiration, which is calculated through historical climate data. This website can be used when determining how much water is needed for irrigation purposes.

Equation to determine water needed for irrigation in inches:

((Monthly ET x Crop Coefficient) – Avg. monthly rainfall) x **acres** x **27,154 gallons/acre**

Example: *Charlottesville, Virginia.*

5.55 inches/month average summer ET

4.31 inches/month average summer rainfall

2,000 ft^2 turfgrass area

(5.55– 4.31 inches/acre) x 0.05 acres x 27,154 gallons/acre = **1,684 gallons/month**

This equation is only an estimation of plant water needs. A rainwater harvesting or irrigation consultant company can determine more accurately the irrigation needs, based on plant type and water needs.

Water Conservation Tips

All landscape irrigators should follow irrigation best management practices, whether for residential application or large-scale park application. The Virginia Rainwater Harvesting Manual stresses the importance of following these best management practices to ensure that the rainwater harvested is utilized efficiently and effectively when irrigating.

The Irrigation Association has a detailed Best Management Practice publication available online at www.irrigation.org/gov/pdf/IA_BMP_APRIL_2005.pdf (17). The following will summarize these findings in coordination with utilizing harvesting rainwater for irrigation purposes.

Installation & Maintenance

- Hire a certified irrigation designer and contractor to design and install your irrigation system. Double your efforts by hiring a WaterSense partner (http://www.epa.gov/watersense/pp/irrprof.htm).
- Design system (type and output) to meet landscape (plant & soil) needs.
- Group plants will similar irrigation needs in the same irrigation zones.
- Large scale irrigation projects should be audited by a certified irrigation auditor to ensure system is applying water uniformly and efficiently.
- Ensure system is routinely maintained to ensure uniform and efficient water application.

Application

- Use drip/micro-irrigation or subsurface irrigation when applicable to reduce water loss through evaporation.
- Base irrigation timing on evapotranspiration rate and climatic conditions, plant needs, slope, soil infiltration, soil moisture, and rainfall.
- Select system components that reduce runoff and maintain sprinkler irrigation below infiltration rate to ensure excess water is not applied. Use soak cycles to ensure appropriate water is applied, while eliminating unnecessary runoff.
- Install water conserving irrigation heads.
- Utilize alternative non-potable water source when available.
- Allow soil moisture to deplete /allow plants to wilt slightly before watering.
- Irrigate in the early morning when evaporation is low. (17)

Table 2. Selected native plants of Virginia (76)

Herbaceous Plants	Trees & Shrubs
Aster	Redbud
Dephinium	Dogwood
Bleeding heart	Sugar maple
Iris	Sweetgum
Phlox	White oak
Black eyed Susan	Water oak
Coneflower	Virginia pine
Lobelia	Witch hazel
Goldenrod	Holly
	Azalea

Native Plants

Including native plants in landscape design reduces irrigation demands, compared to non-native plantings. Native plants are adapted to the local climate and rainfall events. Therefore, supplemental irrigation is minimal. Non-native and invasive plantings may not be adapted to the local climate and often require extra water, fertilizer and pesticides to maintain health. Many commonly known horticultural plants are also Virginia native plants. Table 2 lists commonly known Virginia native plants. For complete listings, visit DCR's website at www.dcr.virginia.gov/natural_hertiage/nativeplants.shtml. To find local nurseries that sell Virginia native plants, visit the Virginia Native Plant society website at www.vnps.org.

The Benefits of Rainwater Harvesting

Environmental

When rain falls, it lands on a rooftop, drains to the gutters and drainpipes, and then is diverted either across land or to storm drain pipes. This rooftop runoff ultimately reaches local waterways. When the rainwater is carried across landscapes, it picks up detrimental pollutants like bacteria from animal excrements or decaying animals, chemicals, metals, nitrogen and phosphorus from fertilizers, oil, pesticides, sediment and trash (18). All of these collected ground surface pollutants contaminate waterways and affect native aquatic plants and animals.

The Virginia Stormwater Management Act states that all localities covered under the Chesapeake Bay Preservation Act or designated as a Municipal Separate Storm Sewer System (MS4) (Fig. 6) are required to adopt a local stormwater management program, while any localities located outside this area may voluntarily adopt a local stormwater management program (Code of Virginia § 10.1-603.3).

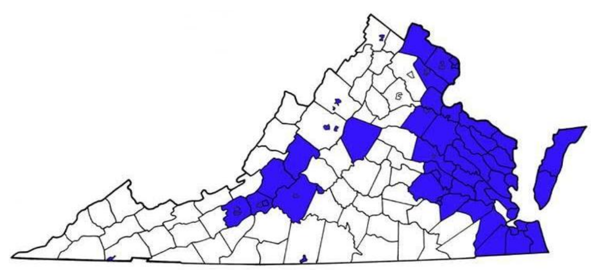


Figure 6. Virginia localities required to establish a local stormwater management program.
Figure created by Virginia Department of Conservation and Recreation.

The Chesapeake Bay and its connecting rivers are plagued by nutrient and sediment pollution, which is a result of stormwater runoff. Effort is placed on protecting the Chesapeake Bay due to the diverse habitats and organisms that live in and around the watershed, which stretches through New York, Pennsylvania, Maryland, Delaware, Virginia, the District of Columbia, and West Virginia. Since Half of Virginia drains into the Chesapeake Bay watershed and two-thirds of Virginia's population lives within the Chesapeake Bay watershed, the health of this area impacts many.

The Virginia Water Resources and Research Center recently developed a tool to assist in determining stormwater Best Management Practices (BMP). Rainwater harvesting was identified as one BMP that would have a "positive impact on the volume, peak rate, and quality of stormwater runoff from a site" (19). Rainwater harvesting was further ranked as the best stormwater BMP for impervious areas greater than 66% and building roofs at a Blacksburg, VA case study site. Rainwater harvesting was ranked higher than other common stormwater BMP's such as vegetated roofs, porous pavement, and bioretention areas for the case study scenarios. (19)

Installing rainwater harvesting systems in areas where nonpoint source pollution from stormwater runoff is a severe threat to stream integrity can significantly reduce pollution loads. Since stormwater runoff can also lead to flooding in areas, harvesting rainwater combats flooding by reducing peak flow from high rain events.

Local cities may wish to investigate the economic and environmental impact of utilizing rainwater when investigating alternative water sources. For example, a student at Portland State University researched the feasibility of installing rainwater harvesting systems in an urban Portland neighborhood. He determined that upon the installation of 4,500 gallon tanks, runoff could be reduced by 68%, while reducing demands on municipal water supplies for non-potable water demands (20). Also, an economic study in Sydney, Melbourne and southeast Queensland investigated the feasibility of utilizing rainwater harvesting over desalination to supply increasing water demands. The report stated that if five percent of households utilized rainwater harvesting, they would collect and supply as much additional water as planned by the desalination plant (21). Desalination is a very expensive process, especially to provide potable water for non-potable needs, and results in toxic concentrated salt by-products. Rainwater harvesting may prove profitable for localities wishing to conserve dollars, water and the environment. The economic benefits of rainwater extend beyond water supply costs, as discussed in the next section.

Economic

The economic feasibility of harvesting rainwater differs based on many factors, i.e. precipitation frequency, water consumption needs, prices of local water and wastewater treatment, cost of installation and maintenance. More importantly is the long-term economic feasibility, which is based on the building's operation lifespan and system design. The combination of a high building lifespan at least 40 years, high-quality and sustainable prefabricated components, and minimum system servicing needs equates to rainwater harvesting being economically feasible and ecologically sensitive.

Utilizing inferior quality, less expensive, prefabricated components translates to higher service costs as these components must be replaced during the life of the building. Installing high-quality prefabricated components that last the life of the building is a sustainable building practice that is both economic and environmentally responsible.

While the most obvious economic benefit of rainwater harvesting is a savings on water bills, rainwater harvesting can also provide significant savings as a stormwater management tool. Integrating rainwater harvesting into the initial stormwater management plan can decrease the size of other stormwater facilities which helps offset the initial cost of a rainwater harvesting system. The costs of stormwater management practices are hard to compare on a "dollars per square feet of impervious area treated" basis, so the economic benefit of rainwater harvesting should be assessed on a case-by-case basis.

The use of rainwater harvesting can also decrease any assessed stormwater fees which are becoming increasingly common in Virginia (Table 3). Some municipalities, such as the city of Chesapeake, which allows for up to a 40% reduction in the stormwater utility fee, have

Table 3. Virginia stormwater utility fees

City	Fee	Unit (sq. ft.)	Source
Portsmouth	$6/month	1,877	http://portsmouthva.gov/publicworks/stormwater/utilityfee.htm
Norfolk *(residential)*	$8.08/month	---	http://www.norfolk.gov/publicworks/stormwater.asp
Norfolk *(non-residential)*	$0.182/month	2,000	
Chesapeake	$6.85/month	2,112	http://cityofchesapeake.net/services/depart/pub-wrks/stormwater-faq.shtml#how_calculate
Newport News	$5.1/month	1,777	http://www.nngov.com/engineering/resources/swmcharge
Prince William County *(single family)*	$26.36/year	---	http://www.pwcgov.org/default.aspx?topic=040076003170000828
Prince William County *(townhome/condo)*	$19.78/year	---	
Prince William County *(non-residential)*	$12.80/year	1,000	

guidelines for how stormwater BMP's, like rainwater harvesting, affect the stormwater utility fee (22). Guidelines from the Virginia Department of Conservation and Recreation on using rainwater harvesting for stormwater management are currently in development.

Taxes

Some states like Texas offer tax incentives for individuals and businesses interested in installing rainwater harvesting systems. In 2001, Virginia passed Senate Bill 1416, which gave income tax credit to individuals and corporations that installed rainwater harvesting systems. Unfortunately, this bill was never funded so it fell to the wayside. However, work is underway to lobby for future tax incentives as rainwater harvesting is an environmentally responsible and economically feasible approach to conserving water and reducing nonpoint source pollution.

Cost of water

From 2003 to 2008, the average cost of water in the United States increased 29.8% (23). Prices will continue to rise due to increasing costs to treat water to adapt to EPA's Safe Drinking Water Act guidelines, upgrade declining infrastructures, and install conservation programs. Most US infrastructure was first installed after World War II and many are at or past the 50 year expected lifespan. Therefore, water costs are sure to rise to help offset the replacement/rehabilitation cost. Reducing potable water demand through rainwater harvesting could eliminate the need for infrastructure expansion.

Installing a rainwater harvesting system can help residents reduce their water supply costs. With rainwater harvesting systems, most of the cost is upfront cost, but systems ultimately pay for themselves within a few years, depending on the system and local water prices. This time could be reduced, depending on how quickly municipal water costs increase. Appropriately designed rainwater harvesting systems will have minimal maintenance costs associated with its upkeep and therefore will show the best long-term relationship between cost and financial benefit.

In some urban areas, rooftop runoff is directed to storm drains and then to water treatment facilities. These large pipes are expensive to install and travel many miles through urban areas. When a heavy rainfall occurs, the water treatment facilities are overwhelmed with stormwater, which causes systems to overflow and even contaminate local waterways with untreated sewage. Classifying rainwater as sewage is unnecessary, wastes resources, and causes unnecessary pollution.

Through a downspout disconnect program, many cities have reduced the number of downspouts connected to sewer systems. In doing so, rooftop runoff is instead land applied. While the disconnect program addresses wastewater treatment overloading, it does not necessarily address nonpoint source pollution from stormwater runoff. In fact, inappropriately directed downspouts (i.e. to impervious surfaces) can increase nonpoint source pollution.

Municipally supplied water is treated to drinking water standards. Potable water is not needed to flush toilets, wash clothes, wash vehicles, fill pools, fight fires, or irrigate lawns. Therefore, additional money and resources are being wasted when potable water is consumed for non-potable demands.

Rainwater harvesting's economic feasibility can also be calculated by its synergistic values. Rainwater is soft, which means less detergent is used and released into the environment. Also, rainwater harvesting systems with a connected vaporization system can raise site humidity and create a healthier microclimate. This is ideal for city areas dealing with air pollution. Likewise, utilizing rainwater as opposed to municipal and well water benefits local streams, lakes, ponds and groundwater sources since less water will be pulled from these sources. Such benefits may not have a direct price tag, but their value is long lasting and considerable.

Installing and utilizing rainwater harvesting systems can have a trickle-down effect and cause other companies/individuals/organizations to be more environmentally conscious for environmental, economic and political reasons. Rainwater harvesting systems typically increase residential property value and offer current and future residents the opportunity to live an environmentally responsible lifestyle.

LEED Certification

With continuing population increases, demand for housing and retail shops will also continue. Thus, development is not likely to stop anytime soon. However, green building design reduces the environmental impact of development. By following green building practices, LEED (Leadership in Energy and Environmental Design) certification can be attained.

In the late 1990's the United States Green Building Council (USGBC) developed a LEED certification process, which certifies buildings based on environmentally conscious design. Rainwater harvesting is one component that can lead to certification, as it is identified as a sustainable water source and reduces environmental impact through reduced stormwater runoff and reliance on municipally supplied water.

To attain basic LEED certification, 26 to 32 points are needed. Rainwater harvesting has received increasing attention in the LEED certification process. Water efficiency, reducing indoor water use by 20% below a baseline case, is now a prerequisite for LEED certification. In addition, with the newly revised guidelines, a rainwater system can be used to gain up to 12 points as follows:

- **SS Credit 6.1: *Stormwater design: Quantity control*** Reduce the total volume of runoff from the site by capturing and re-using the rainwater from the roof
    - **1 point**

- **SS Credit 6.2: *Stormwater design: Quality control*** Capture and re-use or infiltrate rainfall from the 1” storm (storm size will be different in different climate areas)
    - **1 point**
- **WE Credit 1: *Water Efficient Landscaping*** Use rainwater for 50% or 100% of site irrigation
    - **2-4 points**
- **WE Credit 2: *Innovative Water Technology*** Reduce by 50% potable water demand for sewage conveyance by using harvested rainwater
    - **2 points**
- **WE Credit 3: *Maximize Water Efficiency*** Reduce potable water use in the building by 30 -40% by using harvested rainwater
    - **2-4 points**

According the USGBC website, 77 buildings in Virginia have some level of LEED rating, which is up from 20 buildings in 2007, when the first edition of the Virginia Rainwater Harvesting Manual was written (24).

Low Impact Development

Low impact development (LID) aims to mimic a site’s pre-development hydrology through the use of innovative techniques and design. Typical development designs include a variety of impervious surfaces like roofing and paving. Through LID, designs aim to curtail the stormwater runoff from these impervious surfaces or utilize alternative products that infiltrate, filter, store, or detain runoff water

Residents and business owners that wish to retrofit current buildings or build LID dwellings can look to rainwater harvesting as an approach to combating the serious issue of stormwater runoff. Blacksburg, Virginia included rainwater harvesting in their *Design Manual for Low Impact Development*. They identified rainwater harvesting systems promote water conservation, reduce peak flow levels, reduce reliance on ground and surface water, allow for groundwater recharge, and reduce stormwater runoff and nonpoint source pollution (25).

Rainwater harvesting guidelines

During the developmental phase of the modern rainwater harvesting system, some countries investigated water quality and technology improvements. Germany was the leader in these studies between 1987 and 1997. These studies and practical experiences assisted in drafting rainwater harvesting technical standards, which focused on improved prefabricated components. The studies also gathered data referring to potable and non-potable rainwater quality, economic efficiency, and system design.

Creating national and international rainwater harvesting standards can assist in developing low maintenance, safe, and sustainable systems with minimum ecological disturbance. International businesses have made strides in recent years to produce high quality, sustainable rainwater harvesting components, which has influenced the market's expansion. However, the promise for economic gains fueled inferior companies to produce non-sustainable, mediocre products

Today's rainwater harvesting system designs should follow DIN 1989 Part 1: Planning, Installation, Operation and Maintenance (26), to ensure designs are high-quality and safe. German water providers, water quality specialists, local authority districts, professional organizations, and ministries of environment and health all follow these standards.

Adopting DIN 1989 would be another step to establishing international rainwater harvesting standards. All practical experiences confirm that the German standards are sufficient to reach a technically sustainable and safe rainwater harvesting design. Therefore, in countries where such standards and regulations do not exist, i.e. the US, the German standards can be adopted.

Rainwater harvesting design and installation requires a network of professionals. Component prefabrication companies, architects, engineers, craftsmen, water providers and local authority districts all are involved in designing, installing and regulating rainwater harvesting systems. Like every new technology, involving only the most qualified personnel ensures a successful and sustainable product.

Rainwater harvesting systems should be designed to ensure water maintains high-quality while in storage. This is accomplished through the implementation of high-quality products that divert, collect, and store water.

Systems should fulfill the following DIN 1989 guidelines:

- Fortify rooftop runoff with oxygen
- Eliminate fine and coarse particles prior to storage
- Ensure stored water is high in oxygen
- Protect stored water from contamination
- Provide high-quality, sustainable components
- Require minimum maintenance.

In the U.S., rainwater harvesting guidelines and regulations can be divided into two major categories: ones that address the treatment and use of rainwater and ones that address using rainwater harvesting for stormwater management. Unfortunately, the regulations for Virginia are still largely in development, but examples from other states can provide guidance for designing a rainwater harvesting system.

Rainwater harvesting for stormwater management

Interest in using rainwater harvesting for stormwater management has also spurred the growth of regulations. In North Carolina, a properly-sized rainwater harvesting system can be used to downsize other stormwater management BMP's. The water harvested from the roof must be "(1) used on site, or (2) treated and released, or (3) infiltrated" (Division of Water Quality 2008). A computer model from North Carolina State University is used to determine the stormwater benefits of a cistern. A similar model is under development for Virginia which will incorporate recent/pending changes to stormwater regulations and provide an accessible way to design rainwater harvesting systems for stormwater management.

Rainwater as a water supply

As rainwater harvesting has increased in popularity, so have the number of regulations about rainwater harvesting. At this time, the Commonwealth of Virginia does not have regulations specifically addressing the use of harvested rainwater. In the Department of Health regulations in the Virginia Administrative Code (12VAC5-610-1170), guidelines are provided for the use of cisterns but the guidelines are included in the "Sewage handling and disposal regulations" and appear to only apply in situations where harvested rainwater will enter an on-site sewage disposal system. Other states, as well as the federal government, have provided more specific guidelines on the use of harvested rainwater. Faced with a significant drought, the Georgia Department of Community Affairs developed an appendix to the state plumbing code that authorizes the use of harvested rainwater for cooling towers and toilets and urinals (27). This regulation requires filtration of rainwater before distribution for all uses and requires disinfection (UV, ozonation, chlorination, etc) if the harvested rainwater is used for toilets and urinals. Rainwater inside the building must be in purple pipes labeled as non-potable (27). Appendix M of the Oregon plumbing code, adopted in 2008, and the Alternate Method Ruling Number OPSC 08-03 similarly requires that piping for the rainwater system be labeled as non-potable. The Oregon code also mandates gutter screens and first flush diverters and includes guidelines for use as a potable and non-potable water source (28). The Texas Water Development Board has developed extensive guidelines for the use of harvested rainwater in Texas, including use as a public water system (29).

Until Virginia has established guidelines, recommendations from the Low Impact Development Center of the EPA in their publication "Managing Wet Weather through Green Infrastructure: Municipal Handbook: Rainwater Harvesting Policies" may be the best guidance for rainwater harvesting systems in Virginia. This document was designed to help municipalities develop regulations for rainwater harvesting and divides rainwater use into three categories: outdoor use, indoor non-potable use and indoor potable use and gives guidance for water quality and treatment (30).

Design guide

This manual was created primarily to guide readers in designing rainwater harvesting systems. Because statewide standards are not available, guidelines are given based on the best scientific evidence as well as guidelines from the EPA (30), state codes in Oregon (28) and Georgia (27) and the Texas Manual on Rainwater Harvesting (29). The design section works through a rainwater harvesting system from the roof collection surface to the end use. The key considerations for each section are highlighted in blue at the start of the section. For readers who want more information, these considerations are explained further below. Relevant legislation/guidelines specific to that section are highlighted in yellow. All rainwater harvesting systems must be constructed in accordance with the state building code as well as Department of Health regulations. This manual deals only with rainwater harvesting systems collecting from roof surfaces. In rare cases, rainwater can be harvested from parking lots, lawns, etc. However, these surfaces present higher risks of contamination of the stored water and, therefore, generally require more treatment before use. Rainwater collection systems using catchment surfaces other than roofs should only be designed by engineers/designers with experience with rainwater harvesting.

Roof

Key considerations

- Roof materials should be non-porous and smooth.
- For retro-fit installations, the quality of water harvested from the roof (ideally through the gutter and downspout system) should be analyzed to determine appropriate end-uses.
- Copper roofs and roofs with lead components (for example, flashing or solder) should not be used in any application with a potential for human ingestion (for example, drinking water, pool filling, vegetable gardens).
- Aluminum and rubber membrane are recommended roof materials for rainwater harvesting.
- Green roofs should be used with caution in rainwater harvesting and rainwater harvested from green roofs with soil bases should only be used for irrigation.

Relevant legislation/guidance:

- National Standards Foundation, Protocol P151: Health Effects from Rainwater Catchment System Components
- Virginia Administrative Code: Title 12, Agency 5, Chapter 610, Section 1170.Cisterns

Roof materials

When rain falls on a roof, it can pick up contaminants both from the roofing material and material deposited on the roof surface. Material on the roof surface can be controlled some by cleaning the roof and trimming trees back near the roof, but many of the sources of material deposited on the roof, such as nearby industrial facilities, are outside of the rainwater harvesting system designer's hands. Roofing material is, however, a design choice and can have a significant effect on the quality of harvested rainwater. Chemical reactions on the roof are often rapid because of the acidity of rainfall and the high temperatures on many rooftops (31). These reactions make the choice of roofing material an important consideration in designing a rainwater harvesting system, particularly for potable uses. The choice of roofing material will also affect the quantity of rainwater available as some materials absorb water.

Metal roofs

Metal roofs, with the exception of copper and roofs with lead components are recommended for rainwater harvesting. Metal roofs have many advantages for rainwater harvesting, including a smooth surface and a high runoff coefficient. Unfortunately, metals are also leached from many of these roofs (32) (33) (34). Aluminum and zinc are often found in runoff from roofs containing these metals (32). While presence of these metals in a water supply may have aesthetic effects (effects on color from aluminum and effects on odor and taste from zinc), they have not been identified as health risks (35). Ingestion of copper, however, can cause gastrointestinal symptoms and possibly kidney and liver damage with long-term exposure (36). The EPA has identified copper as a primary drinking water contaminant with a Maximum Contaminant Level Goal of 1.3 ppm (36). Copper concentration in runoff from copper roofs can be as high as 12 ppm, even when background rainwater concentrations are low (33). Lead flashing, sometimes used on metal roofs, also presents a significant health risk. Even though lead flashing generally represents only a small percentage of the surface area of a roof, it can still contribute a significant quantity of lead to the run-off causing lead concentrations of up to 0.42 mg/l (37) The EPA identifies a public health goal of zero and an action level of 0.015 mg/l for lead (38). Because of the potential for contamination, copper roofs and roofs with lead components should not be used for potable uses, fruit/vegetable gardening, or pool filling. Other metal roofs, however, are excellent choices for rainwater harvesting systems.

Asphalt shingle

According to the Virginia Administrative Code, asphaltic roofing material cannot be used as a catchment surface for cisterns if the water will eventually be sent to an on-site septic field (12VAC5-610-1170). This section of the code is located in the "Sewage Handling and Disposal" regulations and seems largely to address potable water. Asphalt shingle roofing has been identified as a source of both lead and mercury (39). However, the specific composition of asphalt shingles varies widely. For retro-fit situations with an asphalt roof, preliminary water quality sampling of runoff from the roof is likely the best way to determine appropriate end uses of the water. For new construction, roofing materials other than asphalt shingle are generally preferable.

Wood shingle

Because of a low runoff coefficient and many of the products used to treat wood, wood shingle roofs are not recommended for rainwater harvesting. Chromated copper arsenate (CCA) treated wood and untreated wood have both been shown to contribute arsenic and copper in measurable quantities to runoff (32). Wood shingles can also reduce the pH of runoff, making it more acidic (31).

Cement tile/terra cotta tile

Tile roofs should be used with caution in rainwater harvesting systems. Semi-porous roof surfaces like terra cotta tiles absorb some of the water, thus reducing the system's water collection efficiency. In addition, tiles have been shown to contribute significant quantities of lead, copper and cadmium to runoff (40). Finally, the uneven surfaces and absorbed water in the tiles may create an ideal growing environment for bacteria and algae.

Asbestos

Asbestos/cement shingles and tiles were common roofing materials prior to widespread concern and regulation because of the health effects of asbestos. While the primary health risk of asbestos is inhalation of fibers which can lead to respiratory problems and cancer, some studies have found statistically significant increases in cancer rates, particularly gastrointestinal cancers, in areas with asbestos in the drinking water supply (41). Little research has been done on the asbestos concentration in runoff from roofing material made with asbestos, but the available research does indicate that concentrations may exceed EPA drinking water standards (42). Out of precaution, rainwater harvested from roofs made of asbestos materials is not recommended for any use with significant human contact.

Green roof

Vegetated roof surfaces with a soil base absorb most of the water that falls on the roof and only 10% to 20% of the runoff is collected. The collected runoff is typically a brown color, thus only suitable for landscape irrigation. However, up to 30% of rainfall runoff from vegetated roofs with a gravel base is collected. This water is also a clear color so it is suitable for both indoor and outdoor use.

Membrane roof

Membrane roofs create an ideal surface for rainwater harvesting. These roofs have a high runoff coefficient and have not been shown to add harmful contaminants to the harvested rainwater.

Roofing materials designed for rainwater harvesting

Some international companies have designed roofing material specifically designed for potable rainwater harvesting. The roofing material is typically pre-painted zinc and aluminum coasted steel. Some common brand roofs are Colorbond® and Zincalume®. Although these roofing materials are more common in Australia, the global market allows for availability even in the US. The National Standards Foundation has also established Protocol P151: Health effects from rainwater catchment system components which identifies roof materials and coatings that have been certified to not leach any contaminants at levels identified as harmful to human health in EPA Drinking Water guidelines. A list of certified products is available at http://www.nsf.org/Certified/Protocols/Listings.asp?TradeName=&Standard=P151.

Roof slope

Roofs with a pitch work best for rainwater harvesting, as water is easily moved through gravitational force. Since organic matter can build up between rain events, a steeper roof also allows water to move more efficiently and quickly across the surface, which helps clean the roof surface (43).

Gutters and downspouts or roof drains

Key considerations

- Gutters and roof drains should be designed in accordance to local code.
- Half-round or trapezoidal gutters with 0.5% slope for 2/3 and 1% slope for 1/3 of the length are preferred for rainwater harvesting because of more efficient drainage.
- For large, flat roofs, siphonic roof drainage systems can reduce installation costs and decrease the required burial depth of belowground tanks.

Relevant legislation/guidance

- International Plumbing Code, 2006 Edition, Section 11.4
- American Society of Mechanical Engineers, A112.9.9 "Siphonic Roof Drains"

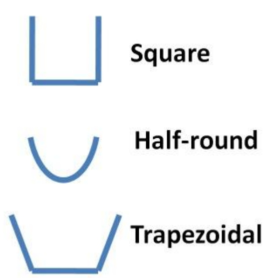


Figure 7. Common gutter shapes

Gutters and downspouts

A rainwater harvesting system is compatible with any gutter and downspout system, but research has shown that some design choices can improve the functioning of the system. Gutters have two main functions: capturing water from the roof (interception) and conveying this water to the downspouts (conveyance). Both of these functions are affected by gutter shape and gutter slope. Research shows that guttering systems should be pitched 0.5% for 2/3 of the length and 1% for the remaining 1/3 of the length and ideally a semi-circular or trapezoidal shape (Fig. 7) for optimal interception and conveyance (44). The change in slope is required because gutters continue to collect rainwater along their entire length (i.e. the part of a gutter near the downspout is carrying water from a bigger roof area and therefore more water than farther from the downspout). Increasing the slope lets the same size gutter carry a greater volume of water. Half-round and trapezoidal gutters are suggested because they are able to drain a greater roof area (i.e. carry more water) with the same amount of material used to make the gutter (the same gutter perimeter). Assuming that the price of gutters is dependent on the amount of material used to make them, the half-round and trapezoidal gutters should be more cost-effective and water velocity should be higher leading to more efficient draining and removal of debris. (44)

Gutter systems should remain free from debris at all times. This ensures water moves freely from roof surfaces to the storage tank. Installing covered gutters or adding guards to existing gutters is ideal to prevent debris buildup and clogging.

Roof drains

While rainwater harvesting systems can be integrated with any roof drain system, siphonic roof drains (Fig. 8) present a number of advantages. Siphonic roof drain systems generally require fewer, and smaller, downpipes and less underground piping. The system designer can frequently locate all downpipes on one side of the building. When siphonic roof drains are used in conjunction with rainwater harvesting, this means that the downpipes can be located near the cistern. When conventional roof drains are used instead of siphonic, pipes often have to be brought longer distances (often either around or under the building). This not only requires additional pipe and site work, but because of the required slope on the pipe, can result in deeper, and therefore more expensive, burial of the cistern (Fig. 9).

Figure 8. Siphonic roof drain. *Photo courtesy of Jay R Smith Manufacturing Co.*

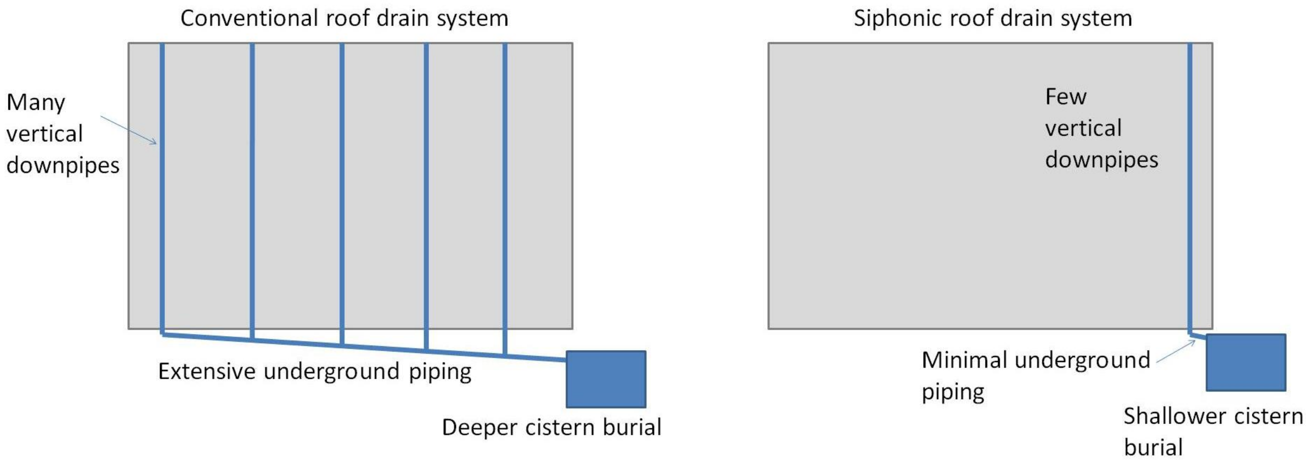


Figure 9. Schematic representations of a conventional roof drain system and a siphonic roof drain system.

First flush diversion and pre-tank filtration

Key considerations

- The first 0.04" of a rain event (25 gallons per 1000 ft^2) should be diverted to a pervious area (preferably a stormwater BMP) and not stored in the tank.
- The first flush diverter or filter should not require maintenance between each rainfall event.
- If necessary, this "first flush" can be stored in a tank used for irrigation only. This tank may require periodic cleaning due to sediment build-up.
- Particles larger than 0.4 mm (1/64") should be filtered out before entering the tank. If this filtration is not possible, the tank system should include a settling area which will require yearly cleaning.

Relevant legislation/guidance

- Virginia Administrative Code: Title 12, Agency 5, Chapter 610, Section 1170.Cisterns

First flush diversion

The initial runoff from a roof surface, called the "first flush" generally rinses the roof, leading to cleaner water as the rainfall continues. For example, both iron and zinc concentrations in runoff from a polyester roof were four times higher during the first 0.08" of rainfall than the steady state concentration later during the same rain event (45). This trend of cleaner water later in a rain event is true for sediment (39), metals (45), bacteria (46), and even pesticides (47). Because most of the possible contaminants are rinsed from the roof during the start of a rain event, diverting the first flush from the tank should greatly improve the stored water quality.

While estimates of the depth of rain required to rinse the roof varies, diverting the first 1 mm (25 gallons per 1,000 ft^2) of rainfall should protect water quality. The depth of rainfall needed to rinse the roof and bring contaminant levels down to steady state depends on the intensity of the rainfall and the type and condition of the roof (48). First flush diversion can be accomplished by fixed volume diverters or first flush filters (Fig. 10). Fixed volume typically filled a holding chamber with rainwater at the start of an event and once the chamber is full, rainwater is then diverted into the tank. The chamber periodically must be cleaned to rid the unit of clogging debris, which decreases the unit's efficiency and impedes the collected rainwater quality. First flush filters, however, divert rainwater until the stainless steel mesh is wet. In this way, the quantity of water diverted is proportional to the intensity of rainfall and may more accurately match the true first flush volume.

Pre-tank filters

Pre-tank filters protect the quality of rainwater stored in the tank by preventing the introduction of debris. A study of rainwater harvesting tanks in Ontario showed generally improved cistern water quality in a system with a vortex pre-tank filter compared to systems with only first flush diverters or no pre-tank treatment (49). The logic behind pre-tank filtration is simple. A build-up of organic debris in the tank would lead to greater decomposition resulting in low oxygen levels and a build up nutrients in the tank. Low oxygen conditions can lead to the development of odors as well as favor the growth of harmful bacteria in the tank.

Filters collect rainwater through a straining action, which occurs through some form of screen or mesh between the rainwater from the roof and the clean rainwater outlet to the tank. Depending on the design of the filter, rainwater quality can be impeded if leaves are allowed collect on the screen or mesh. Not only is the filter's efficiency is reduced, decaying leaves leach contaminants into the stored rainwater. Filters equipped with made screens or mesh that is self-drying and prevent microbial growth are the best at protecting rainwater quality and filter efficiency. Filter fabric should dry between rainfall events to prevent algae and biofilm growth, which could block the fabric pores. Also, fabrics should be made of stable materials that do not change shape and can withstand temperature changes, ice formation, and frost. Stainless steel is considered the best filter fabric because it can withstand all weather conditions, even ice formation and frost, is self cleaning and self drying, maintains shape, and does not rust, thus reducing contamination likelihood.

Figure 10. Filter with first flush and straining capabilities
Image courtesy Wisy AG

There are few filters on the market that utilize both the first flush and straining mechanisms to harvest rainwater. Figure 13 shows a cross section of a filter with a stainless steel bottomless strainer that prevents debris from entering the tank, but also works with a first flush action through the capillary action of the strainer. The stainless steel strainer is allowed to dry in between rain events, thus preventing microbial growth.

The goal of a high-quality filter is to not only eliminate contaminants but also supply oxygen to water during the filtration process. An advanced filter does not restrict the diameter of the gutter and is positioned either vertically connected to the gutter system or horizontally connected to the downspouts.

Modern filters require low maintenance and cleaning and can efficiently collect more than 90% of filtrated rainwater. To ensure the effectiveness of the filter, the appropriate filter should be paired with the appropriate roof area. Also, utilizing high quality filters ensures water is sufficiently filtered, oxygenated and directed to storage tanks.

High quality filters need inspection only a few times a year and should last the lifespan of the building. Purchasing sustainable products for rainwater harvesting further emphasizes the environmental impact by conserving water, energy, and production resources. Research should be conducted to ensure high quality products are integrated into a building's rainwater harvesting design.

Storage tanks

Key considerations

- Aboveground tanks should be opaque to prevent algae growth, UV resistant to prevent tank failure, and piping should be protected against freezing or drained in the winter.
- Belowground tanks must be appropriately load-rated for the site (i.e. under a pedestrian area or a parking lot).
- Tanks should be installed according to manufacturers' instructions.
- Only watertight tanks designed for storage, not stormwater tanks designed for infiltration, should be used in rainwater harvesting systems for indoor use.
- Tanks should be sized according to the roof area and the anticipated demand. For stormwater use, the tank should be sized according to guidelines from the Department of Conservation and Recreation.
- All tanks must include an adequate, screened vent pipe.
- All tanks must have at least a 22" manway for access. For belowground tanks, this manway must be designed to prevent overland flow into the tank.

Relevant legislation/guidance

- NSF Standard 61

Tank selection is based on three main criteria: size, location and material. Tank size is always dependent on the roof area and the anticipated use of the water. However, size decisions may also be based on availability of space on the site, stormwater or LEED® requirements, and the availability of a back-up water supply. Tank size selection will affect possible tank locations and location and size will then help in the selection of tank materials.

Tank sizing

While rainwater harvesting has a number of environmental benefits, it must also be economically viable to enter the mainstream of building practices. Because the tank is often the most expensive component of a rainwater harvesting system (29), decision-making on tank size can have a strong impact on the payback period and economic feasibility of rainwater harvesting (50). The first step in selecting a tank size is choosing a tank selection criterion:

- If the back-up water supply is of poor quality or low quantity, does the rainwater harvesting system need to meet the demand as close to 100% of the time as possible?

- Does the tank need to be the most cost-effective size possible?
- Does the tank need to meet stormwater demands?

In all cases, the tank should overflow occasionally so that floating debris can be skimmed from the water surface. Once the tank sizing criterion has been selected, the most accurate way to select the appropriate tank size is to model the system. The volume of rainwater collected from a surface can be calculated as

Volume of rainwater(gal)=Area of roof(ft^2) x Collection efficiency x Depth of rainfall(in) x 0.62

The collection efficiency is based on both the roof type and the efficiency of the filters and 0.62 is a conversion factor from ft^2-in to gallons. With this equation and estimates of how much water will be used, the system can be modeled to determine the best tank size. Larger tanks are able to supply a greater percentage of demand because they can capture more rain from large events. However, there is often a point of diminishing returns beyond which increasing the tank size provides only a marginal benefit (Fig. 11).

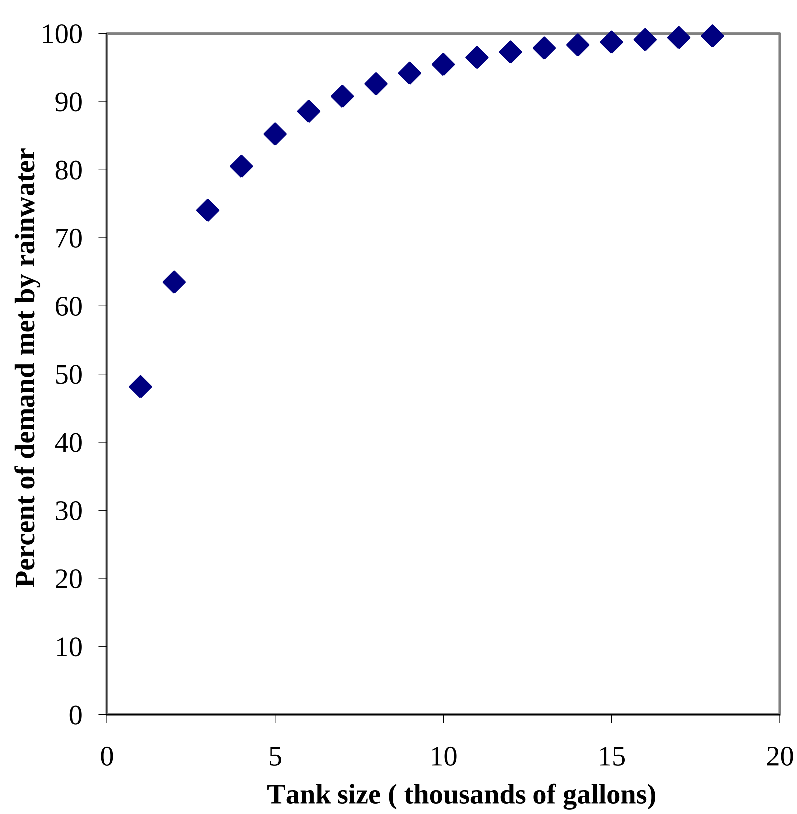


Figure 11. Sample graph showing how storage tank size affects the amount of water supplied by a rainwater harvesting system. As tank size increases, so does the percent of demand met, though the increase is very small at large tank sizes. This hypothetical case of an office building with a 20,000 ft^2 roof collection area and a 600 gallon per day use in Charlottesville, VA is provided courtesy of Rainwater Management Solutions.

Using monthly averages of rainfall can lead to significant errors in tank sizing. Imagine two cities; each receives 4 inches of rain per month. If City A has only one storm a month and all 4 inches of rain fall in one day, a large storage tank will be needed. If City B receives a little rain each day, only a small storage tank will be needed. For example, for a 10,000 ft^2 footprint office building, in City A, the rainwater harvesting storage tank would need to hold over 20,000 gallons, while in City B it could be less than 900 gallons to capture all of the rainfall if water was used every day. Researchers have modeled rainwater systems with time intervals as small as 15 minutes but have found that daily modeling is generally sufficient (51). For many locations in the US, daily rainfall data can be obtained from the National Climatic Data Center or a professional rainwater harvesting company can be consulted for tank sizing assistance. For stormwater management, tank sizing support will soon be available from the Department of Conservation and Recreation.

Tank location

Tanks can be placed either above or below ground. For both options, water should be able to gravity-feed to the tank except in rare circumstances. Locating the tank near the building and the water use reduces the amount of pipe and site work necessary as well as pump demands. Though no hard and fast rules govern the decision of aboveground or belowground tanks, in general, once the storage volume exceeds 10,000 gallons or multiple roof drains or downspouts are being used, belowground storage is often the most viable option. Beyond this, tank location is dependent on aesthetics, climate and soil conditions. Some prefer not to see the storage tank and opt to bury it. However, placing tanks underground adds to the installation costs and may be limited in areas where soil is especially rocky or areas with a high water table. When tanks are installed below ground, water is maintained at a cool temperature and light is blocked, which reduces the chances of bacterial growth.

Tank materials

In general, any water storage tank can be used in a rainwater harvesting system, though a few features of common tank materials must be taken into account. Similar to metal roofs, unlined metal tanks may leach some metals into the stored water which may make water unsuitable for drinking. Concrete tanks provide an advantage over other tanks systems because they neutralize the acidity of harvested rainwater. Some tanks are not suitable for certain climatic areas; wooden tanks are not recommended for hot, dry locations. Since Virginia is a fairly humid state, wood tanks can be used throughout. The tables below reference pictures and descriptions of available tank materials and their corresponding advantages and disadvantages. Storage tanks used in systems that will supply potable water should meet ANSI/NSF Standard 61 and FDA standards.

Table 4. Rainwater tanks

	15,000 gallon fiberglass tank *Image courtesy Containment Solutions*
	1,700 gallon polyethylene below ground tanks *Image courtesy Rainwater Management Solutions*
	1,000 gallon polyethylene above ground tank *Image courtesy of Rainwater Management Solutions*
	100 gallon recycled plastic rain barrel *Image courtesy Rainwater Harvest Specialists, LLC*
	35,000 gallon modular plastic rain tank *Image courtesy Rainwater Management Solutions*
	3,000 gallon steel tank *Image courtesy Aqua Irrigation*

Table 5. Rainwater tank material comparison

Tank Material	Advantages	Disadvantages
Plastic		
Fiberglass	commercially available integral fittings (no leaks) durable with little maintenance light weight	must be sited on smooth, solid, level footing (for aboveground) expensive in smaller sizes
Polyethylene	commercially available affordable, available in variety of sizes easy to install above or below ground little maintenance	can be UV-degradable must be painted or tinted for aboveground installations
Trash cans (20-50 gallon)	commercially available inexpensive	must use only new cans small storage capabilities
Metal		
Galvanized steel tanks	commercially available available in variety of sizes	possible corrosion and rust must be lined for potable use only above ground use
Steel drums (55-gallon)	commercially available	verify prior to use for toxics corrosion and rust can lead to leaching of metals, small storage capabilities
Concrete		
Ferroconcrete	durable suitable for above or belowground installations neutralizes acid rain	potential to crack and leak
Monolithic/Poured-in-place	durable, versatile install above or below ground neutralizes acid rain	potential to crack and leak permanent in clay soil, will need sufficient drainage around tank
Stone, concrete block	durable, keeps water cool in hot climates	difficult to maintain expensive to build
Wood		
Pine, redwood, cedar, cypress	attractive, durable can be disassembled to move available in variety of sizes	expensive site built by skilled technician not for use in hot, dry locations only above ground use

(29), (52), (53)

Tank installation

Tanks must be properly installed to prevent damage. In aboveground systems, piping and small storage tanks must be either drained or protected against freezing during the winter. Aboveground tanks should also be opaque to discourage bacterial growth and UV protected to prevent deterioration of the tank. Commercially available aboveground and belowground tanks should always be installed in compliance with manufacturers' recommendations. Aboveground tanks must on stable soil or a concrete pad and belowground tanks must be designed to support the weight of the soil above and any anticipated traffic loads. All tanks (aboveground and belowground) must have a vent to expel air as rainwater enters the tank and draw air in as rainwater is pumped out of the tank. If the tank overflow does not have a water trap, air can be displaced through the overflow as rainwater enters the tank. In these cases, the vent only needs to be as big in diameter as the water supply line leaving the tank. If air cannot leave the tank through the overflow, the vent diameter should be 1 ½ times the diameter of the inlet pipe. Tank overflows are described in greater detail below.

Rainwater inlet to the tank

Key considerations

- Rainwater should be brought to the bottom of the tank then angled upwards to protect settled sediment and the biofilm.
- Penetrations to the tank should be designed to avoid any pipe constrictions and to provide appropriate oxygenation to the tank.

Relevant legislation/guidance

- Virginia Administrative Code: Title 12, Agency 5, Chapter 610, Section 1170.Cisterns

In a healthy rainwater storage tank, sediments settle to the bottom and often incorporated into the biofilm. Many contaminants in roof runoff are associated with particles (54) and higher contaminant concentrations are often found in this sediment layer (55). Calming inlets, located at the bottom of storage tanks, direct the entering water upwards to prevent disturbing the fine particulate matter and biofilm on the bottom of the tank (Fig. 12). The calming inlet also introduces oxygen into the bottom of the tank. Inlets should be spaced to provide oxygenation throughout the tank.

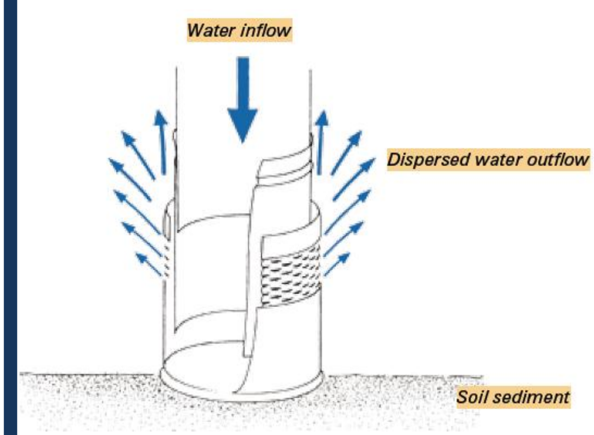


Figure 12. Calming inlet
Image courtesy of Wisy AG.

Biofilm

Biofilms, layers of bacteria attached to a solid surface with a protective binding often made of a chain of carbohydrates, occur throughout nature, on riverbeds and even on human teeth (plaque is a type of biofilm). While few people like to think about a bacteria layer in their water storage tank, biofilms are an important part of a healthy rainwater harvesting system. Research has shown that biofilms in rainwater systems typically develop from bacteria that are common in soil and the environment, accumulate metals and may remove bacteria from the stored rainwater (56). In another study, rainwater was pumped through a "reactor" that contained bacteria. This "reactor" led to a decrease in concentrations of iron, sulfate and nutrients (57). Looking at the function of biofilms in water treatment and distribution can help in understanding biofilms in rainwater harvesting systems.

Biofilms (Fig. 13) have been used in water and wastewater treatment systems to remove organic matter (58). However, biofilms in plumbing distribution systems, the pipes that carry water to homes and businesses, increase corrosion in the pipes and can even shelter disease-causing bacteria (59) (60). These biofilms can be particularly troublesome because they are resistant to most traditional treatment techniques (i.e. chlorination). Using a biofilm in the treatment system, instead of just traditional treatment practices, can decrease the chances of the development of biofilm in the distribution system (58). The bacteria in biofilm use organic matter in the water as a food source. If the biofilm in the rainwater tank digests the available organic matter, the biofilm in the distribution system and any bacteria that may live in the water have a reduced food source which will minimize growth. Even with a stable and healthy biofilm, further treatment of the harvested rainwater is recommended if the water will have high contact with humans. This water should also be tested for harmful bacteria.

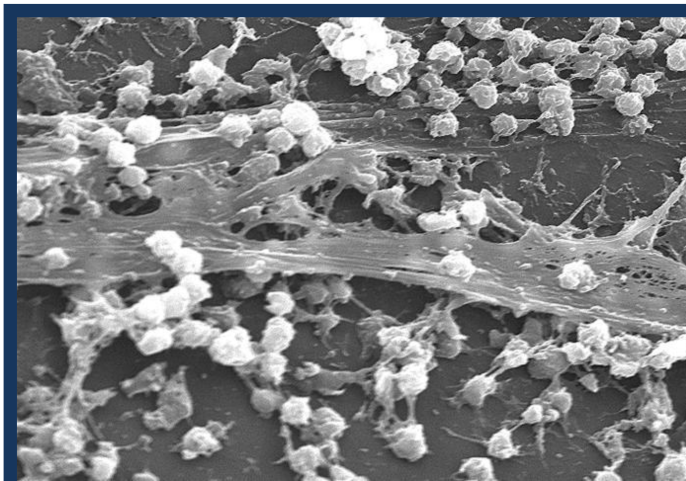


Figure 13. Electron micrograph of a biofilm. The round structures are bacteria, the stringy material between them is a polysaccharide that binds them together, making this a biofilm.
Image is from the Center for Disease Control Public Health Image Library. Photo credit: Janice Carr

The biofilm in a rainwater harvesting storage tank should be protected to ensure high water quality. The tank should never be emptied or cleaned as long as the rainwater passes through a pre-filtering first-flush filter system. Cleaning the tank will kill the biofilm layer. Likewise, no cleaning solutions should be introduced into the rainwater tank. If a system has a backup municipal water source, it is recommended that this water is not deposited into the tank as the treatment chemicals could kill the biofilm layer. The backup water should instead bypass the tank through solenoid valves and appropriate backflow prevention.

Pump system

Key considerations

- Pump systems should be designed to meet the expected peak demand of the end use of rainwater.
- All pumps should have automatically resetting dry-run protection.
- Submersible or jet/booster pumps can be used.
- Harvested rainwater should enter the pumping system through an elevated uptake point, such as a floating filter.

Relevant legislation/guidance

- None

Pumps

Figure 14. Submersible cistern pump with custom-made bottom intake attached to a floating filter.
Photo courtesy of Rainwater Management Solutions

Pumping can be accomplished in a couple of ways. Using a submersible cistern pump is one application and a booster/suction pump is the other. Some applications will require a combination of pumps to meet the required pressures and gallons per minute necessary to meet the demands for the project.

Submersible pumps

Well pumps can be used in rainwater systems, but if a well pump is used, it will need a constant flow of water passing by the motor to keep it cool. To accomplish this, the well pump can be placed in a cooling jacket which is attached to an intake device. Figure 14 shows a submersible pump draws water from the bottom of the pump. To prevent disturbing the biofilm, it is fitted with a floating suction intake.

Booster/Jet Pumps

External booster or suction pumps are popular in rainwater harvesting applications. These pumps rely on lifting the water out of the tank and pushing it to the desired location. External pumps are louder than submersible pumps and must be protected from the weather.

Pump combinations

Some applications may require a submersible pump as well as a jet or booster pump. Normally this application is necessary when the distance from the cistern to the source is significant. The suction feature of the jet or booster pumps may not allow for the pump to keep its prime or supply enough water to meet the pumping requirements. Large applications may require two or more submersible pumps to meet the demand of the booster pump. When using this type of configuration, a controller for the pumps is necessary. Sizing these large pump systems should be accomplished by an experienced pump professional.

Pressure tanks and switches

Very few pumps have the ability to start on their own. It will be important to include a pressure switch and a pressure tank to a rainwater system requiring a pump. If the application uses more than one pump, the pressure switch will activate the control panel and the panel will determine which pump will run to meet the demand. It is also important to consider the size of the pressure tank to ensure that your system operates efficiently and effectively. The rule of thumb for sizing a pressure tank is three times the gallons per minute of the pump equals the gallon size of the pressure tank.

Pump protection

Should your rainwater cistern become low on water, it will be essential that the pump is protected from running while there is not sufficient water for the pump to function. If the pump continues to run without sufficient water, the pump will be damaged. A simple float switch in the rainwater cistern will protect the pump from running when the water level declines. Some pumps include dry run protection; however, many of these pumps require manual resetting. A float switch automatically resets when the tank refills.

Floating filters

To aspirate the water from the tank, a floating filter is located at the end of the pump's suction hose (Fig. 14). As mentioned in the section on calming inlets, sediment, bacteria and other pollutants generally settle to the bottom of the tank, with concentrations of pollutants higher in the bottom sediments than at the surface of the water (55) (61). Studies have also shown that bacteria levels can be higher at the surface of the cistern water than elsewhere in the tank (61). To avoid these two areas of concern, the floating filter takes water from the tank a few inches below the water surface. Floating filters should be designed to never clog, often by using a larger pore size than was used in the pre-tank filtration. Filter fabric should also be high-quality stainless steel, like the first flush filter.

Overflow

Key considerations

- All storage tanks should have an overflow at least equal in size to the inlet.
- This overflow should be directed to a pervious area (or the municipal storm sewer if no other option exists).
- The overflow should provide backflow prevention and use an angle-cut pipe to skim the water surface.

Relevant legislation/guidance

- None

All storage tanks must have an overflow of at least the same diameter as the inlet pipe to prevent backup in the gutters and downspouts or roof drains, but a properly designed overflow can also help protect the water quality in the tank. Overflows should be directed to a pervious area, ideally a stormwater management BMP. This practice will help reduce the chance that overflow from the rainwater harvesting system will generate a runoff problem. In these situations, backflow prevention is needed to prevent the introduction of small animals and prevent against the unlikely backup of water in the system. If discharge to a municipal storm system is the only option, backflow prevention should be increased because of the increased likelihood of a backup in the system. A properly designed overflow should also provide skimming of the water surface. Even with proper pre-tank filtration, some small buoyant debris, such as pollen, will likely enter the tank. A vertical pipe with a slight angled opening provides skimming of the water surface and removes this debris (Fig. 15).

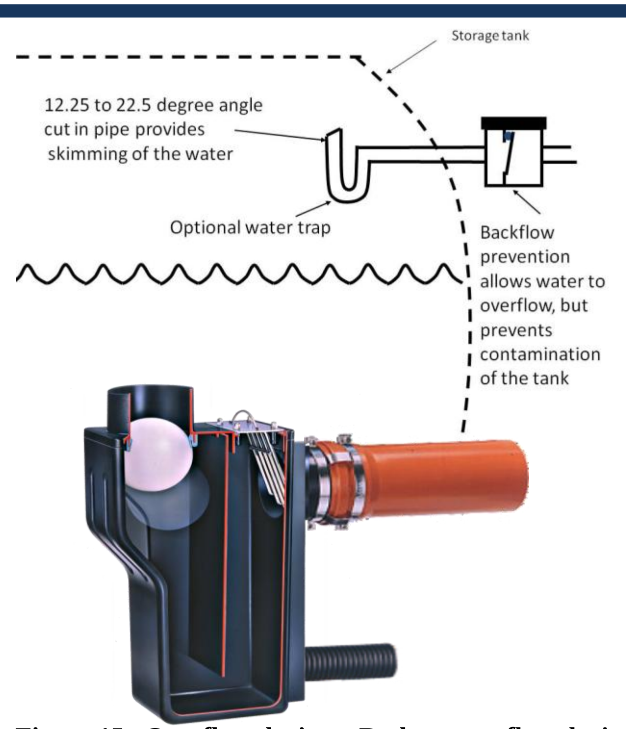


Figure 15. Overflow devices. Both an overflow device made from common plumbing components (top) and a commercially available device (bottom) should provide skimming of the water and prevent entrance of contaminants to the tank.
Images courtesy of Rainwater Management Solutions

Additional treatment

Key considerations

- Harvested rainwater used for outdoor use does not need additional treatment.
- Both potable and non-potable indoor uses require additional sediment filtration and disinfection. Potable uses should also include carbon filtration.
- Harvested rainwater should be tested for pH if the system will involve metal pipes or if desired by the end user. This testing should be done at the point of end-use.

Relevant legislation/guidance

- EPA Safe Drinking Water Act
- NSF/ANSI Standard 42: Drinking Water Treatment Units: Aesthetic Effects
- NSF/ANSI Standard 53: Drinking Water Treatment Units: Health Effects
- NSF/ANSI Standard 55: Ultraviolet Microbiological Water Treatment Systems
- NSF/ANSI Standard 58: Reverse Osmosis Drinking Water Treatment Systems

The general public is often leery about consuming and utilizing rainwater for potable and/or non-potable use, but proper system design makes harvested rainwater a safe water source. The EPA municipal rainwater harvesting handbook outlines recommended minimum water quality levels and required treatment for harvested rainwater used for outdoor uses, non-potable indoor uses and potable indoor uses (Table 6). Additional treatment can be divided into three main categories: sediment filtration, disinfection and aesthetic treatment (Fig. 16). These three categories, as well as treatment for pH, are explored below.

Disinfection of harvested rainwater for non-potable uses is sometimes seen as overly cautious. Because animals are the primary sources of bacteria to rainwater harvesting systems, bacteria found in rainwater systems may not be infectious to humans (62). The risk from non-potable uses is also low because rainwater should not be ingested in any non-potable use. However, *Legionella*, a bacterium that causes a type of pneumonia through inhalation, has been identified as a disease-causing agent in some rainwater harvesting systems (63) (64). *Legionella* can be easily destroyed by disinfection techniques such as ultraviolet light, making disinfection of harvested rainwater for indoor non-potable uses advisable even though the disease risk is low.

Sediment filtration

Sediment filtration removes fine particles which can carry contaminants and decrease

Table 6. Water quality guidelines and treatment options for harvested rainwater (30)

Use	Minimum water quality guidelines	Suggested treatment options
Potable indoor uses	*Total coliforms* - 0 *Fecal coliforms* - 0 *Protozoan cysts* - 0 *Viruses* - 0 *Turbidity* < 1 NTU	*Pre-filtration* - first flush diverter *Cartridge filtration* - 3 micron sediment filter followed by 3 micron activated carbon filter *Disinfection* - chlorine residual of 0.2 ppm or UV disinfection
Non-potable indoor uses	*Total coliforms* < 500 cfu per 100 mL *Fecal coliforms* < 100 cfu per 100 mL	*Pre-filtration* - first flush diverter *Cartridge filtration* - 5 micron sediment filter *Disinfection* - chlorination with household bleach or UV disinfection
Outdoor uses	N/A	*Pre-filtration* - first flush diverter

Table reproduced from Kloss 2008

the effectiveness of disinfection. While many of the potential contaminants found in rainwater harvesting systems can occur in both dissolved and solid forms, a high percentage is found bound to small particles (54). While many of these particles should have settled in the storage tank, the sediment filter should remove remaining small particles and associated contaminants. Small particles will also affect the clarity of the water and therefore the ability of ultraviolet light to kill bacteria and viruses. According to the EPA guidelines for rainwater harvesting, for non-potable indoor uses, sediment filters should be 5 micron or finer. For potable indoor uses, sediment filters should be 3 micron or smaller (30).

Carbon filtration

Activated carbon is particularly effective at removal of organic compounds, such as pesticides and some hydrocarbons. In addition to mechanical straining, activated carbon removes these contaminants because they adsorb, or stick, to the activated carbon. Activated carbon also frequently improves the aesthetic quality of water (i.e. odor and taste). An activated carbon filter of 3 micron or smaller should be included on all systems for potable use (30). This filter should be placed after the sediment filter.

Disinfection options

Chlorination

Chlorine reacts with water to form HOCl, which inactivates bacteria and viruses. The effectiveness of chlorine is dependent on the clarity of the water as well as the contact time with shorter contact times requiring higher doses of chlorine to achieve appropriate disinfection.

Because the addition of chlorine to the storage tank would disrupt the biofilm, chlorine should not be added to the storage tank. Chlorine should instead be added using an injection system which may require higher concentrations of chlorine because of short contact times. One advantage of chlorine disinfection is the maintenance of a disinfectant residual in the system which should provide protection against the re-growth of bacteria. A chlorine residual of 0.2 ppm should be maintained in potable systems that use chlorine for disinfection (30). Chlorination also requires regular maintenance to replenish the chlorine supply with associated dangers of working with chlorine in an enclosed area.

Ozonation

The process by which ozone destroys bacteria and viruses is not well-understood, but ozone effectively destroys many proteins, which is likely part of the mechanism for ozone disinfection (65). While ozone is a highly effective disinfectant, it is generally less effective at destruction of viruses than destruction of bacteria or protozoa (such as *Giardia*). Unlike chlorine, ozone does not leave a disinfectant residual in the finished water.

Ultraviolet light

Ultraviolet light is a low-cost and effective method for treating bacteria and viruses. Ultraviolet light should only be used following a 5 micron sediment filter because ultraviolet light disinfection is only effective on very clear water. The appropriate dose of ultraviolet light for disinfection of harvested rainwater is 40,000 uw- sec/cm^2 (66).

Figure 16. Water treatment system using a sediment filter, an ultraviolet light and a carbon filter.
Photo courtesy of Rainwater Management Solutions

Reverse osmosis

Reverse osmosis does not destroy or deactivate bacteria or viruses, but instead mechanically filters them out through a membrane. Reverse osmosis uses pressure to force water through a membrane from an area of high concentration of contaminants to an area of very low contaminants (hence the name, reverse osmosis). The membranes typically exclude particles larger than about 0.0001 micron (one micron is 1/1000th of one mm). Reverse osmosis is generally not a recommended disinfection method for rainwater harvesting because most reverse osmosis units waste large quantities of water.

Table 7: Disinfection Options

Treatment	Advantages	Disadvantages
Chlorine	inexpensive, maintains disinfectant residual	odor, taste, carcinogen, does not kill all pathogens
Ozonation	no odor or taste, shorter contact time needed than chlorine disinfection, removes organic matter, color, taste and odor	expensive, no disinfectant residual, requires electricity, potentially toxic, expensive
Reverse osmosis	removes most contaminants	likely to clog, wastes water, no disinfectant residual, requires electricity
Ultraviolet (UV) light	easy to operate, no chemicals needed	no disinfectant residual, requires electricity, not suitable for turbid water

(67), (68), (69)

Treatment for pH

The pH of rain and snow is typically acidic. This low pH level is sometimes cited as a concern in the use of rainwater harvesting systems. However, the pH of harvested rainwater is likely different from the pH of precipitation and most problems with pH can be easily corrected with low-cost, low-maintenance, but highly effective solutions.

Multiple factors affect the pH of precipitation. Rain and snow are naturally slightly acidic because carbon dioxide in the atmosphere leads to development of a weak carbonic acid. However, fossil fuel use has led to emissions of sulfur dioxides and nitrogen oxides which further reduce the pH of rainfall. Acid rain is a widespread problem because atmospheric pollution is carried by the wind and spreads out far from the original source. In Virginia and across the United States, acid rain has damaged high elevation forests, lake ecosystems and other important natural resources as well as man-made structures. Recent years have seen decreasing acidity in surface waters in many areas and decreased concentrations of acid rain pre-cursors, with much of the improvement attributed to the Clean Air Act (70).

While the pH of rainfall in Virginia has generally increased since 1990, progress has been gradual and precipitation is still acidic often in the range of 4.4 to 4.9 pH units (Fig. 17). Acidity can impact plumbing fixtures, plants and human health. However, the acidity of rainfall and the acidity of collected rainwater are not the same. When rain falls on a rooftop, the rain may have chemical reactions with material on the roof or the roof itself (see the **Roof** section for information on the safest roofs for rainwater harvesting). Because of these reactions, the pH of rainwater collected as runoff from a roof surface is usually about one pH unit higher than the pH of rainwater collected at the same time, except for wood shingle which can decrease pH (31) (45). This difference in pH, making the water less acidic, is roughly the same as the difference between tomato juice and black coffee. Based on recommendations from both the EPA and the National Standards Foundation, the pH of water should be above 6.5, particularly with metal plumbing systems. Because acid rain is different in each area, the best solution is to test the pH of water from your rainwater harvesting system. Samples can be taken to a state-certified lab or home testing kits are available for less than $10. If the pH is below 6.5, consider treating the water. A neutralizing agent can be added to the tank to combat pH problems. Pieces of limestone rock can be placed in the tank to assist in neutralizing the water. Other common neutralizing agents and their dose per 1,000 gallons of water are as follows:

- Limestone: 2 oz.
- Quicklime: 1 oz.
- Hydrated lime: 1 oz.
- Soda ash: 1 oz.
- Caustic soda: 1.5 oz. (71)

Another easy solution to problems of pH is to use a concrete storage tank. Limestone in the concrete will help neutralize the acid with no maintenance required. In water quality testing done in cisterns in southwest Virginia, the average pH of water in the cisterns was 7.0, with water in 84% of the cisterns meeting the EPA drinking water standard (pH 6.5 – 8.5) (71). Ninety-three percent of the cisterns studied were made from concrete or concrete block (71) showing the ability of concrete to raise the pH of the stored rainwater.

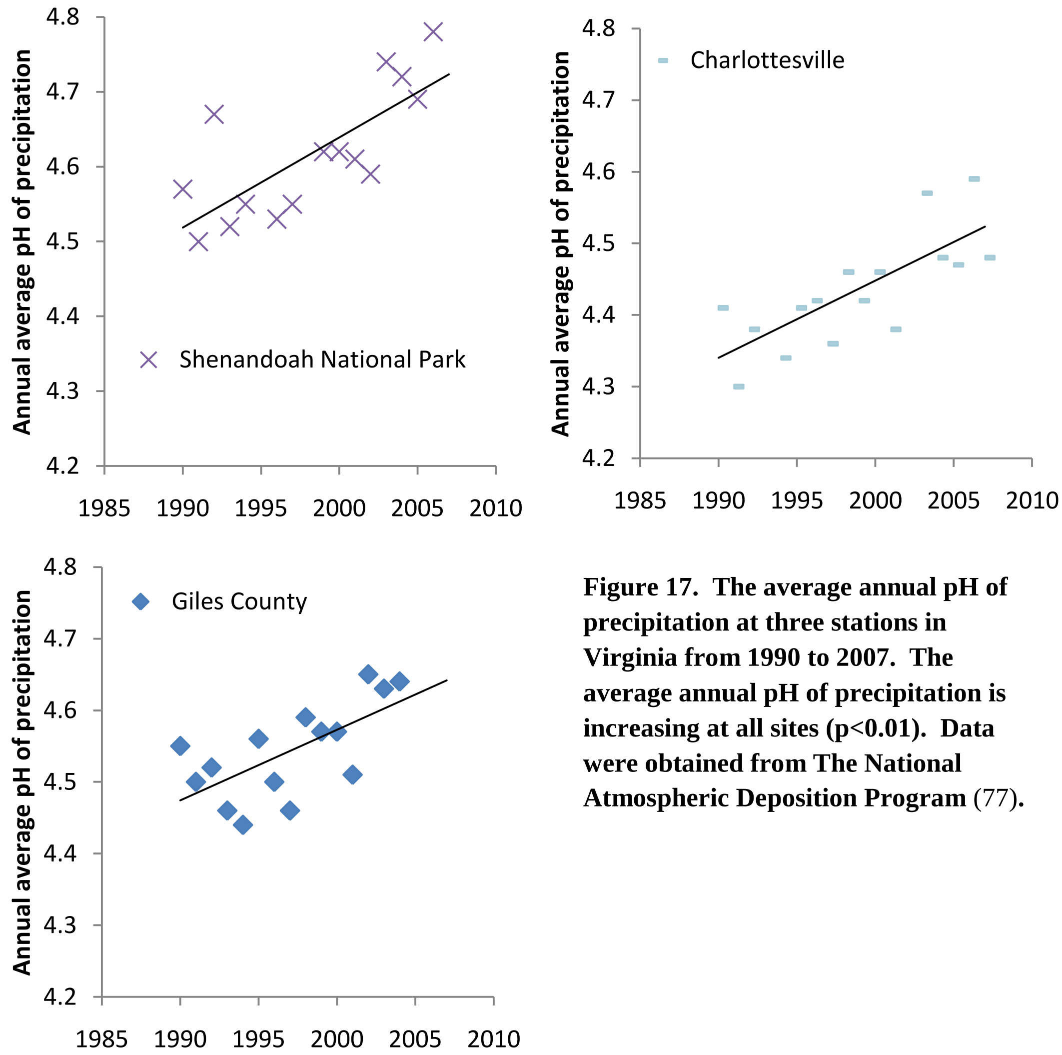


Figure 17. The average annual pH of precipitation at three stations in Virginia from 1990 to 2007. The average annual pH of precipitation is increasing at all sites ($p<0.01$). Data were obtained from The National Atmospheric Deposition Program (77)**.**

Back-up water supply and plumbing

Key considerations

- Rainwater harvesting systems should be properly sized based off of demand and collection area, a backup water supply should be considered if the water need has daily, consistent requirements.
- The primary concern with backup water supplies and rainwater harvesting systems is that harvested rainwater could enter the potable water supply.
- Local building code officials and the health department should be contacted for guidance on approved backflow prevention systems that are used for protection of the potable water supply.

Relevant legislation/guidance

- International Plumbing Code, sections 602 and 603 subject to local building code interpretation

When utilizing both rainwater and potable municipal water supplies, there may be times when rainwater supplies are exhausted, therefore municipal potable water or well water can be considered as a backup for non-potable water needs. To ensure cross contamination does not occur, separate plumbing/piping systems must be installed for both potable and non-potable rainwater. Signs should be displayed at all faucets and spigots supplying non-potable water that state "not drinking water." Also, rainwater spigots must be protected, especially in public buildings, against unauthorized usage. Removing knobs from outside spigots is one approach to prevent unauthorized use. Potable and non-potable plumbing can be distinguished through different color pipes. Purple is often used to designate non-potable water piping. All non-potable water plumbing/piping should be labeled as such.

In the event of a rainwater shortage, tanks can be partially filled with potable municipal supplies or well water. However, filling the tank from a potable source is less desirable than simply having the end use of the rainwater be supplied by the alternate source during periods of low rainfall.

The introduction of treated, municipal water, which may contain chlorine, could have negative effects on the tank's biofilm. Further, it decreases the available volume of the tank for harvesting the next rain event. Rainwater harvesting systems should be designed to incorporate either a backflow prevention device or an air gap to ensure contamination does not occur between the rainwater and potable water supplies. The air gap should allow the space equivalent of 3 times the municipal water supply pipe diameter. See Figure Below. The municipal water inlet must be installed above the highest possible rainwater level and overflow outlet to ensure cross contamination does not occur. Local building officials should be consulted to determine what type of backflow protection is desired in a jurisdiction.

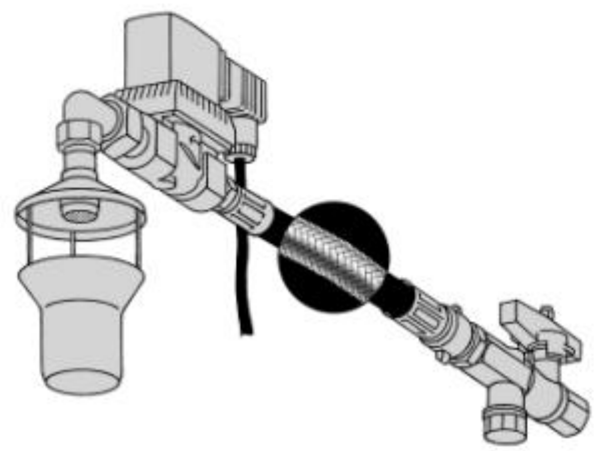


Figure 18. An air gap assembly
Photo courtesy of WISY AG

Backup water supplies can be activated by a variety of means. Commonly, if the water level in the rainwater harvesting tank becomes low, a float switch or switches will be activated shutting off the rainwater harvesting pump and activating a valve allowing water to flow from the backup source. An alternative is to use a pressure differential system. In this system the rainwater harvesting system operates at a higher pressure than the backup source. When the rainwater harvesting system pump cuts off due to a low water situation, the lower pressure water from the backup source is no longer held back by the higher pressure water and begins to flow to the fixtures being served by the rainwater harvesting system. Figure 19 illustrates how a pressure differential backup water supply system could be constructed.

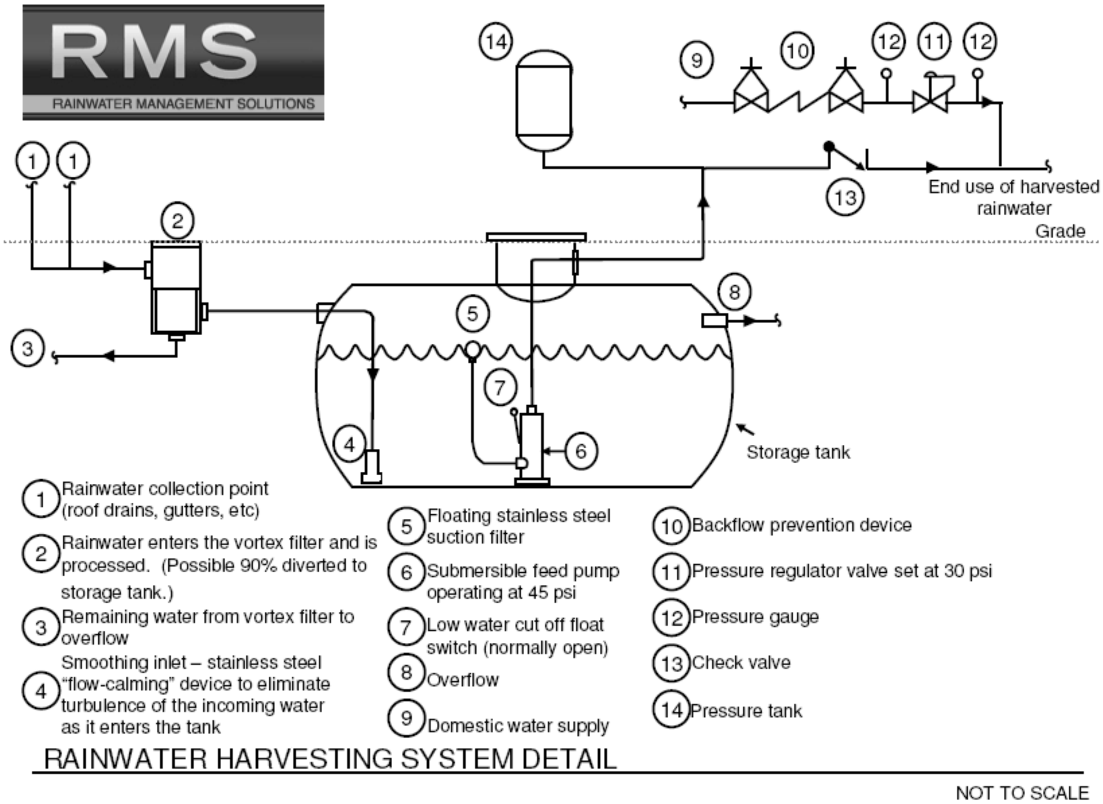


Figure 19. Belowground tank with municipal water back-up.
Schematic courtesy of Rainwater Management Solutions

Future directions

While rainwater harvesting is an ancient technology, modern rainwater harvesting has only recently gained a foothold in the United States. Modern rainwater harvesting is based on scientifically sound principles and research. As the popularity of rainwater harvesting grows, so will our understanding of the components necessary for a safe and sustainable water supply from rainwater. This document represents the best practices to date; design practices that have consistently been shown to produce high-quality harvested rainwater.

Case Studies

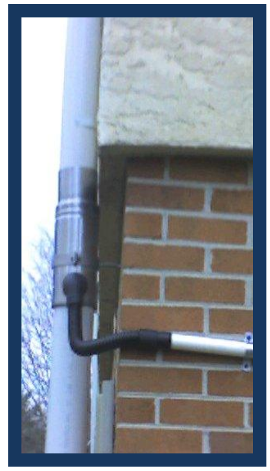
Many individuals and companies within Virginia have adopted rainwater harvesting practices for a variety of reasons. The following will cover examples of actual rainwater harvesting systems located throughout Virginia, including why rainwater harvesting was chosen, design challenges and the benefits of utilizing rainwater harvesting on the site.

Residential: Charlottesville

A multi-family housing complex was establishing a community urban farm and needed a water supply to irrigate it. Instead of having one family pay for the water, the community decided to use a community rainwater harvesting system.

Design challenges:

- Because the property is leased, the clients wanted to be able to remove all of the components if necessary.
- The tanks needed to be located so that they would be unobtrusive and not block the windows from any unit.



Design solution:

Five 1,000 gallon tanks were placed behind bushes with one downspout, with an in-line downspout filter, supplying water to each tank. The tanks were selected because they are tall and narrow and would not block any of the windows. The bottoms 6" of the tanks were buried and outlets from the tanks were all connected by underground piping. The burial of the pipe prevented a trip hazard and discourages vandalism since the tanks are next to a busy street. A single booster pump was placed in a concrete vault to supply a frost-free yard hydrant.

Commercial: Roanoke

When the Claude Moore Educational Complex in downtown Roanoke was being renovated the designer faced many of the common challenges of renovations: a confined budget and a confined site. The designers needed a solution to fulfill the city's stormwater requirements without using a lot of space and also wanted to achieve LEED certification.

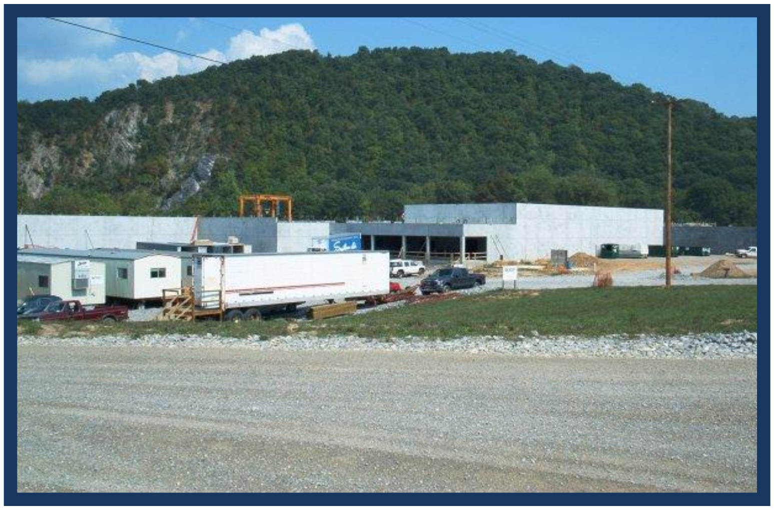
Design challenges:

- Only part of the building could be retrofitted with new roof drains and piping because of budget constraints.
- The city required on-site stormwater management, but many traditional stormwater management solutions (for example, a detention pond) would not fit on the site.

Design solution:

Siphonic roof drains were used to direct rainwater from a portion of the roof to one corner of the lot. The use of siphonic roof drains instead of conventional roof drains made it possible to direct all of this water to one location without extensive underground piping. The rainwater is then filtered through two vortex filters and into two 2,500 gallon polyethylene belowground tanks. The harvested rainwater is used for flushing toilets and urinals greatly reducing indoor water use. This reduction in indoor water use as well as the reduction in stormwater runoff helped the building become the first LEED® certified building in downtown Roanoke. The area over the storage tanks is used as an outdoor seating area, making this a great stormwater solution for a confined site.

Institutional: Roanoke County



The Western Virginia Regional Jail is located next to the Roanoke River, so development of this site required highly effective stormwater management. The Regional Jail also wanted to become the first LEED® certified jail.

Design challenges:

- The flat topography of the site required shallow burial of any belowground tanks.
- The large area of the building (264,000 ft^2 footprint) provided a large collection area for rainwater but would require an extensive piping next to bring dedicated non-potable piping to the entire facility.

Design solution:

Instead of using harvested rainwater for toilet flushing throughout the building, as originally planned, harvested rainwater is instead used for laundry. This design decision reduced the amount of piping needed because non-potable pipe only needed to be run to one location, not throughout the facility. This decision will also save the facility money because less detergent is needed for laundry washed with soft rainwater than laundry washed with harder municipal or well water. Siphonic roof drains were used because of the large roof area and the need to keep the tank burial depth as shallow as possible. The pitched belowground pipes on a conventional roof drain system would have both increased the amount of required site work and forced the cistern depth deeper. Even with the siphonic roof drains, the elevation was too constrained to allow space for first flush diversion and pre-tank filtration. Instead, the first of the four 30,000 gallon storage tanks acts as a settling chamber. Because the system does not have pre-tank filtration, fine floating filters are used in the tank farthest from the rainwater input. While these filters will have to be cleaned periodically, the use of fine floating filters instead of coarse floating filters helps protect the pumps and reduce clogging in the additional sediment filters inside the facility. The first storage tank will also require yearly cleaning. While a design with first flush diversion and pre-tank filtration is preferred, this project showcases a possible alternative strategy when these steps are not possible.

Government: Charlottesville

The managers of the City of Charlottesville's Fourth Street Yard and Warehouse Facility had a problem: The gutters were failing on the warehouse and they drained directly onto the parking lot. Further, it seemed to make sense to capture the water instead of just trying to manage it as street cleaning equipment sat in the parking lot through which the water from the roof flowed.

Design Challenges:

- The existing gutter was formed into the steel roof.
- The street cleaning equipment needed to be filled rapidly.
- Street cleaning personnel will not have access to the building when they are filling their equipment.

Design Solution:
The existing gutter was left in place but breached so that water could flow into a new gutter system that was placed just below it. Water from approximately 4,000 square feet of roof is directed to a single collection point which takes it to a vortex filter, mounted on the side of the warehouse, and then to a 3,000 gallon above ground tank. The water is pumped from the tank using a 50 gallon per minute pump which sits inside the warehouse, just behind the tank. Street cleaning equipment is filled from a 2.5 inch connection on the side of the building. Water flow is controlled by a quarter turn ball valve. The pump is actuated by a pressure switch and tank system meaning that the street cleaning crews do not have to access the pump system in order to fill their equipment. All external piping and valves are insulated and protected against freezing.

Institutional: Manassas Park

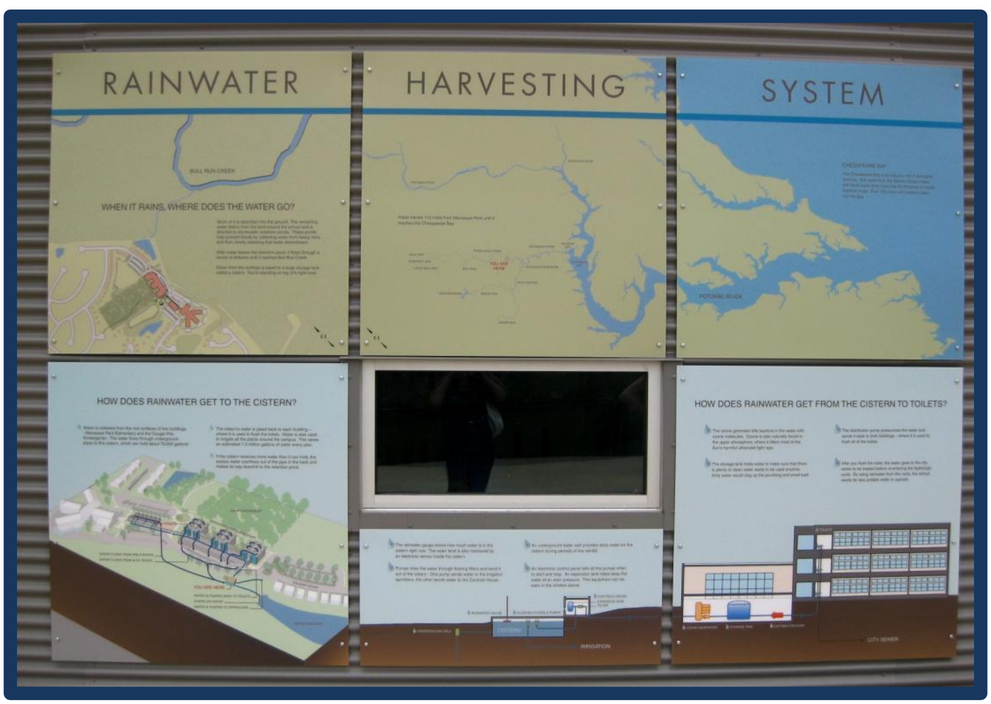
When the Manassas Park City School system was renovating Cougar Elementary School, they wanted a state of the art school with an effective stormwater management plan and opportunities to educate students on the need for environmental protection.

Design Challenges:

- As a government entity, the school system wanted to be sure to keep a responsible school construction budget.
- The school system wanted to be sure that the rainwater harvesting system included an educational component.

Design Solution:

A grant from the Virginia Department of Conservation and Recreation helped provided funding for a 69,800 gallon cistern collecting from 61,500 ft^2 of roof area. The harvested rainwater filtered with two vortex filters before entering the cistern and is treated by ozonation before entering the school and used indoors for toilets and urinals. The system also features signs educating students on the water cycle and water conservation. The system is estimated to save 1.3 million gallons of water per year.



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