5.4.10 Rainwater Harvesting

Description: Rainwater can be used as a resource when it is captured from impervious surfaces, stored in cisterns or rain barrels, and reused as non-potable water. Captured rainwater can be used for landscape irrigation, firefighting needs, toilet flushing, or other grey water uses. Toilet flushing in high-use buildings (i.e., schools, visitor centers) is one of the most effective reuse methods. Roof runoff is generally cleaner and more suitable than runoff from parking lots and roads, which require additional treatment and maintenance to address suspended solids. Runoff capture and reuse reduce the volume and peak flow associated with stormwater runoff).

Figure 1: Cistern in a community garden, Chattanooga (Source: Smart Center).

Site Constraints:
- Contributing area
- Tank location
- Proximity to hotspots
- Roof material

Key Design Criteria:
- Tank size
- Pump or gravity distribution
- Drawdown practice
- Overflow

Maintenance:
- Inspect gutters, downspouts, screens , and filters for debris and remove if necessary
- Inspect tank for leaks and accumulated sediment and address if necessary
- Check flow control components and repair or replace as necessary
- Check all piping and repair or replace as necessary

Advantages:
- Provides volume reduction
- Reduces potable water needed for grey water activities
- Contributes to peak rate reduction

Relative Factors:
- Estimated costs: Moderate
- Runoff reduction: High

Disadvantages:
- Water must be emptied from the cistern to provide volume reduction for the next storm which sometimes requires pump(s)
- Water treatment may be necessary depending on the contaminants in the contributing area and the reuse application.
- Reusing runoff for potable uses is not recommended in the U.S., unless water is treated to all required water quality standards.

Design Checklist:
- ❏ Identify management goal(s)
- ❏ Review site constraints
- ❏ Review design criteria
- ❏ Protect site resources
- ❏ Size channel for site conditions
- ❏ Submit plans for review

1. Design

Cisterns may be above- or below-ground tanks made from a variety of materials including wood, concrete, plastic, or stone. A cistern intercepts, diverts, stores, and releases rainfall for future use. The term cistern is used in this SCM and includes smaller rainwater harvesting systems such as rain barrels (Figures 2 and 3). Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and onsite stormwater disposal/infiltration. Non-potable uses may include toilet flushing, irrigation, exterior washing (e.g. car washes, buildings, sidewalks, street sweepers, etc.), cooling tower water, and laundry operations if allowed and approved by local governments.

Figure 2: Set of rain barrels (Source: VADCR, 2011).

Rainwater capture and reuse can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, rainwater harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge, etc). To enhance their runoff reduction and nutrient removal capability, cisterns can be combined with other rooftop disconnection practices, such as infiltration channels, bioretention cells, or street planter boxes. In this SCM, these down-gradient practices are referred to as "secondary runoff reduction practices." While the most common uses of captured rainwater are for non-potable purposes, such as those noted above, in some limited cases rainwater can be treated to potable standards.

Figure 3: Residential Nonpotable System – Roanoke VA (Source: VADCR, 2011).

In many instances, rainwater harvesting can be combined with a secondary, down-gradient runoff reduction practice to enhance runoff volume reduction rates and/or provide treatment of overflow from the rainwater harvesting system. Some candidate secondary practices include:

- Filter Strips
- Infiltration Channels
- Bioretention Cells

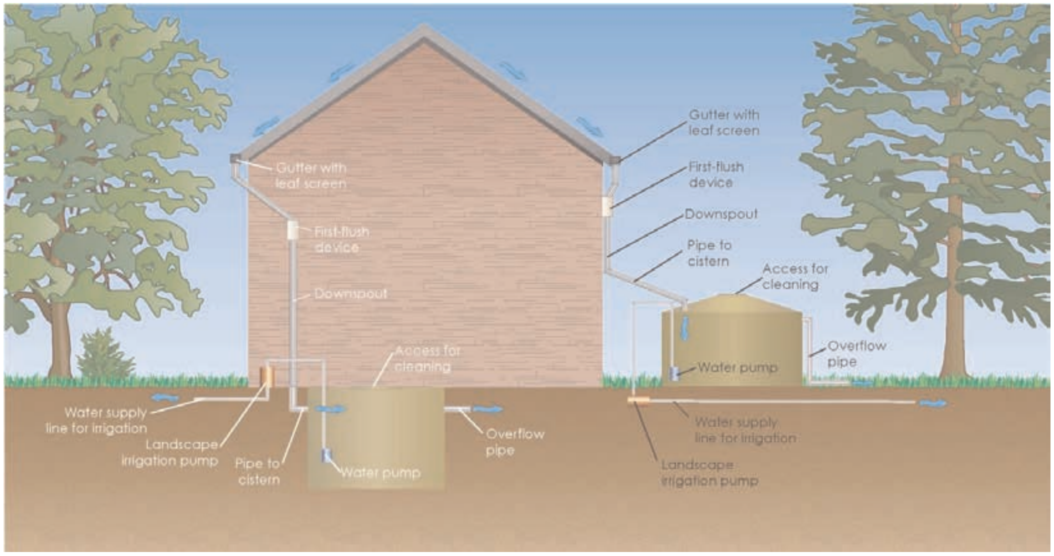


Figure 4: Roof runoff can be captured in cisterns above or below grade and used for irrigation or non-potable water needs (Source: CHCRPC, 2012).

1.1 Suggested Applications

Runoff capture and reuse may be implemented on a variety of sites in urban and suburban environments, on residential, institutional, and commercial properties. Potential applications include office buildings, schools, libraries, multi-family residential buildings, and mixed-use areas for irrigation, fire suppression systems, toilet flushing, or other grey water uses. They can also be used on brownfield sites where the water collected from rooftops is captured and stored before becoming contaminated.

Rainwater harvesting systems can be useful in areas of steep terrain where other stormwater treatments are inappropriate, provided the systems are designed in a way that protects slope stability. Cisterns should be located in level areas where soils have been sufficiently compacted to bear the load of a full storage tank. Harvested rainwater should not be discharged over steep slopes; rather, the rainwater should be used for indoor non-potable applications or outdoor irrigation.

1.2 Site Constraints

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following should not be considered comprehensive and conclusive considerations, but rather some recommendations that should be considered during the process of planning to incorporate rainwater harvesting systems into the site design.

> **NOTE**
>
> Air conditioning condensate (although not a form of stormwater runoff) can also be captured for reuse instead of being discharged to the storm sewer.

1.2.1 Tank Location

Adequate space is needed to house the tank and any overflow structures. Space limitations are rarely a concern with rainwater harvesting systems if they are considered during the initial building design and site layout of a residential or commercial development. Storage tanks can be placed underground, indoors, on rooftops, within buildings that are structurally designed to support the added weight, and adjacent to buildings.

The bearing capacity of the soil upon which the cistern will be placed should be considered because full cisterns can be very heavy. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines, or in consultation with a geotechnical engineer. This is particularly important for above-ground cisterns since significant settling could cause the cistern to lean or topple. A sufficient aggregate or concrete base may be appropriate depending on the soils.

1.2.2 Contributing Drainage Area

The size of the contributing drainage area(s) must be considered to determine if sufficient runoff will enter cisterns to provide the necessary volume for usage demands. Contributing areas must be evaluated for potential pollutants including metals, fungicides, and herbicides. Often, contributing drainage areas are rooftops. Roofs made of copper or that are treated with fungicides or herbicides should not be used for rainwater capture and reuse. Consideration of roof pitch, roofing materials, and large overhanging trees must be made when evaluating capture and reuse. Pavement areas, such as parking lots, sidewalks, or roadways, may also be captured for irrigation reuse but may require more treatment.

The contributing drainage area to the cistern is the impervious area draining to the tank. In general, only rooftop surfaces should be included in the contributing drainage area. Runoff should be routed directly from rooftops to rainwater harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water. The quality of the harvested rainwater will vary according to the roof material over which it flows. Water harvested from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such roofs should be avoided, unless new information determines that these materials are sufficient for the intended use and are allowed by your local government. If a sealant or paint roof surface is desired, it is recommended to use one that has been certified for such purposes by the National Sanitation Foundation (ANSI/NSF standard).

1.2.3 Elevation Requirement

Site topography and tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system. The total elevation drop will be realized beginning from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern. These elevation drops will occur along the sloping lengths of the underground roof drains from roof drain leader downspouts at the building all the way to the cistern. A vertical drop occurs within the filter before the cistern. The cistern itself must be located sufficiently below grade and below the frost line, resulting in an additional elevation drop. When the cistern is used for additional volume detention for channel and/or flood protection, a peak-rate-attenuating orifice may be included with a low invert specified by the designer. An overflow having an invert elevation will always be present within the system. Both the orifice (if specified) and the overflow will drain the tank during large storms, routing this water through an outlet pipe, the length and slope of which will vary from one site to another. All these components of the rainwater harvesting system have an elevation drop associated with them. The final invert of the outlet pipe must match the invert of the receiving mechanism (natural channel, storm drain system, conveyance to secondary practice, etc.) that receives this overflow. These elevation drops and associated inverts should be considered early in the design in order to ensure that the rainwater harvesting system is feasible for the particular site.

The required hydraulic head depends on the intended use of the water. For residential landscaping uses, the cistern should be sited up-gradient of the landscaping areas or on a raised stand. Pumps are commonly used to convey stored rainwater to the end use in order to provide the required head. When the water is being routed from the cistern to the inside of a building for non-potable use, often a pump is used to feed a much smaller pressure tank inside the building, at a sufficiently high elevation, which then serves the internal demands through gravity-fed head. Cisterns can also use gravity to accomplish indoor residential uses (e.g., laundry) that do not require high water pressure. In cases where cisterns are located on building roofs in order to operate under gravity-fed conditions, the roof structure must be designed to provide for the added weight of the rainwater harvesting system and stored water.

Site topography and tank location will also affect the amount of pumping needed. Locating storage tanks in low areas will make it easier to route roof drains from buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigate areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter roof drains with smaller slopes. However, this will also reduce the amount of pumping needed for distribution. In general, it is often best to locate the cistern close to the building, ensuring that minimum roof drain slopes and enclosure of roof drain pipes are sufficient.

1.2.4 Water Table

Underground storage tanks are most appropriate in areas where the tank can be buried above the water table. The tank should be located in a manner that will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from "floating"), conducting buoyancy calculations when the tank is empty, etc. The tank may need to be secured appropriately with fasteners or weighted to avoid uplift buoyancy. The tank must also be installed according to the tank manufacturer's specifications.

1.2.5 Water Quality

Designers should note that the pH of rainfall in the eastern United States tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Cistern supplies may also need a pH adjustment, since rainwater may be corrosive towards metals in the system if the pH is less than 6.5. Limestone or other materials may be added in the tank to buffer acidity, if desired.

Often, contributing drainage areas are rooftops. Consideration of roof pitch, roofing materials, and large overhanging trees must be made when evaluating capture and reuse. Roofs made of copper or that are treated with fungicides or herbicides should not be used for rainwater capture and reuse. Pavement areas, such as parking lots, sidewalks, or roadways, may also be captured for irrigation reuse but may require more treatment due to the presence of suspended solids.

If runoff contains sediment or other contaminants, additional treatment such as solids settling or UV disinfection may be required prior to using water, depending on usage goal(s) (Metro, 2013). Treatment of water for reuse may be necessary depending on the contaminants in the contributing drainage area. Reusing runoff for potable uses is not recommended, unless the water is treated to meet all required water quality standards. All collection and redistribution of stormwater runoff have the potential to cause human pathogenic issues. All capture and reuse SCMs that involve human contact must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. Both ultraviolet (UV) and ozone disinfection systems are available for this purpose .

1.2.6 Setbacks and Utilities

Cistern overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Storage tanks should be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Underground utilities or other obstructions should always be identified prior to final determination of the tank location. Before digging, call Tennessee One-Call (811) to get underground utility lines marked. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems. Underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system. Appropriate minimum setbacks from septic drain fields should be observed.

1.2.7 Hotspot Land Uses

Harvesting rainwater can be an effective method to prevent contamination of rooftop runoff that would result from mixing it with ground-level runoff from a stormwater hotspot operation. In some cases, however, industrial roof surfaces may also be designated as stormwater hotspots and should not be fitted with cisterns.

1.2.8 Vehicle Loading

Whenever possible, underground rainwater harvesting systems should be placed in areas without vehicle traffic or be designed to support live loads from heavy trucks, a requirement that may significantly increase construction costs.

1.3 Design Criteria

1.3.1 Runoff Volume

Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. This SCM focuses on providing a design framework for addressing the design treatment volume. The actual runoff reduction rates for rainwater harvesting systems are based on tank size, configuration, demand drawdown, and use of secondary practices.

The number of rain barrels or the size of the cistern required will be determined by the drainage area, the intended capture goal, and the usage needs of the reuse application. The designer must select a pump of adequate capacity to meet the flow requirements for the reuse system. A rain barrel or cistern provides volume management within the storage device only. The size of the storage device is dependent on the contributing drainage area.

Underground storage tanks must be above groundwater level. Certain roof materials may leach metals or hydrocarbons, limiting potential uses for harvested rainwater. Underground tanks should be set at least 10 feet from building foundations. Cistern overflows should be designed to avoid soil saturation within 10 feet of building foundations. Systems must be designed for consistent drawdown year round. Aboveground storage tanks should be UV resistant and opaque to inhibit algae growth. Underground storage tanks must be designed to support anticipated loads. Hookups to municipal backup water supplies must be equipped with backflow prevention devices.

1.3.2 Primary Components

Cisterns may be above- or below-ground tanks made from a variety of materials such as wood, concrete, plastic, or metal. Storage devices should be sized to store the appropriate runoff volume from the contributing capture area and reuse needs should be adequate to drain the cistern within 72 hours to ensure that sufficient storage is available for subsequent rainfall events. A rain barrel or cistern provides volume management within the storage device only. The size of the storage device is dependent on the contributing drainage area.

There are six primary components of a rainwater harvesting system

- Roof surface
- Collection and conveyance system
- Pre-screening and first flush diverter
- Storage tank(s)
- Distribution system
- Overflow, filter path, or secondary runoff reduction practice

Each of these system components is discussed below.

Roof surface: The rooftop should be made of smooth, non-porous material with efficient drainage either from a sloped roof or an efficient roof drain system. Slow drainage of the roof leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater is selected for uses with significant human exposure (e.g. pool filling, watering vegetable gardens), care should be taken in the choice of roof materials. Some materials may leach toxic chemicals making the water unsafe for humans.

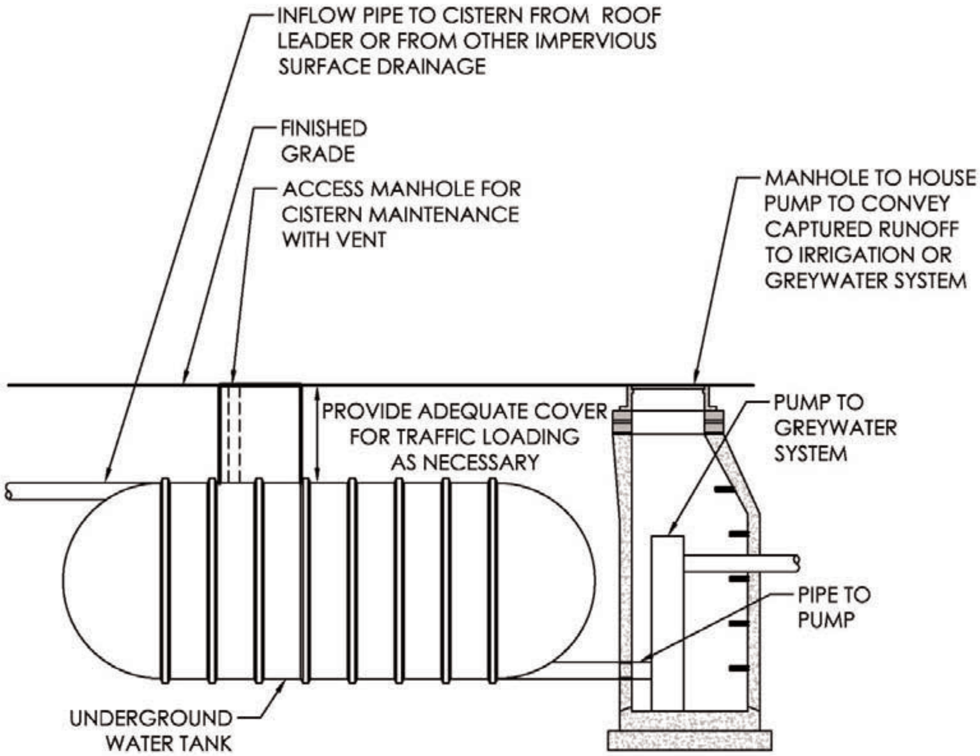


Figure 5: Cross-section of an underground cistern (Source: CHCRPC).

Collection and conveyance system: The collection and conveyance system consists of the gutters, downspouts, and pipes that channel stormwater runoff into storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Minimum slopes of gutters should be specified. At a minimum, gutters should be sized with slopes specified to contain the 1-inch storm at a rate of 1-inch/hour for treatment volume credit. If volume credit will also be sought for channel and flood protection, the gutters should be designed to convey the 2- and 10-year storm, using the appropriate 2- and 10-year storm intensities, specifying size and minimum slope. In all cases, gutters should be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

Pipes connecting downspouts to the cistern tank should be at a minimum slope of 1.5% and sized/designed to convey the intended design storm, as specified above. In some cases, a steeper slope and larger sizes may be recommended and/or necessary to convey the required runoff, depending on the design objective and design storm intensity. Gutters and downspouts should be kept clean and free of debris and rust.

Pre-screening and first flush diverter: Inflow must be pre-screened to remove leaves, sediment, and other debris. For large systems, the first flush (0.02 – 0.06 inches) of rooftop runoff should be diverted to a secondary treatment practice to prevent sediment from entering the system. Rooftop runoff should be filtered to remove sediment before it is stored. Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for pre-filtration of small systems, although direct water filtration is preferred. All pre-filtration devices should be low-maintenance or maintenance-free. The purpose of pre-filtration is to significantly cut down on maintenance by preventing organic buildup in the tank, thereby decreasing microbial food sources.

When runoff enters a rain barrel or cistern through roof leaders, it should pass through a first-flush diverter that is self-draining with a cleanout. Runoff captured from paved surfaces may enter a subsurface cistern through stormwater structures and piping, or after first passing through a water quality, pretreatment SCM. A first-flush diverter with a cleanout should be a part of the piping system conveying runoff to the cistern.

For larger tank systems, the initial first flush must be diverted from the system before rainwater enters the storage tank. Designers should note that the term “first flush” in rainwater harvesting design does not have the same meaning as has been applied historically in the design of stormwater treatment practices. In this SCM, the term “first flush diversion” is used to distinguish it from the traditional stormwater management term “first flush”. The amount can range between the first 0.02 to 0.06 inches of rooftop runoff. The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate SCM on the property for infiltration. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive tank overflows.

Various first flush diverters are described on the following pages. In addition to the initial first flush diversion, filters have an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1-inch/hour should be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA, 2004). If the system will be used for channel and flood protection, the 2- and 10-year storm intensities should be used for the design of the conveyance and pretreatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. For the 2- and 10-year storms, a minimum filter efficiency of 90% should be met.

First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs, and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen, and bird and rodent feces. Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred pretreatment method if the water is to be used for indoor purposes. A vortex filter may serve as an effective pre-tank filtration device and first flush diverter.

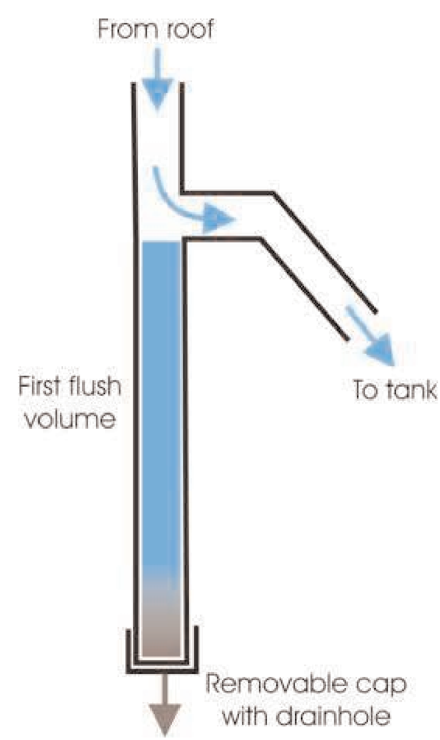


Figure 6: Simple first flush diverters (Source: Boodram and Cox).

Leaf screens are mesh screens installed over either the gutter or downspout to separate leaves and other large debris from rooftop runoff. Leaf screens must be regularly cleaned to be effective. If not maintained, they can become clogged and prevent rainwater from flowing into the storage tanks. Built up debris can also harbor bacterial growth within gutters or downspouts (TWDB, 2005).

Screens should be used on gutters, inlets, and outlets to limit debris entering the system. A first-flush diverter may be used to prevent leaf litter and other debris from rooftops from entering cisterns. Captured runoff has the potential to collect sediment, metals, dust, bird waste, and other foreign components that may contribute to pathogenic growth, discolor collected water, or add an odor to reused water. These concerns may be minimized by avoiding collection of water from areas with large overhanging trees and installing gutter guards to prevent leaf litter and other large debris from entering the cistern from roofs. Regular inspection and cleaning of both the distribution system and the cistern tank itself will prevent contamination of reuse systems from sediment, trash, and debris.

Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater. Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas.

When runoff enters a rain barrel or cistern through roof leaders, it should pass through a first-flush diverter that is self-draining with a cleanout (see Figure 6). Runoff captured from paved surfaces may enter a subsurface cistern through stormwater structures and piping, or after first passing through a water quality, pretreatment SCM. A first-flush diverter with a cleanout should be a part of the piping system conveying runoff to the cistern.

Storage tank(s): Storage tanks are sized based on consideration of indoor and outdoor water demand, long-term rainfall and rooftop capture area. (Metro, 2013) The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities can range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage onsite as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater treatment volume objectives, as described in this section.

While many of the graphics and photos in this SCM depict cisterns with a cylindrical shape, the tanks can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the tanks will be installed. For example, configurations can be rectangular, L-shaped or step vertically to match the topography of a site. The following factors should be considered when designing a rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks should be UV and impact resistant.
- Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
- Underground rainwater harvesting systems should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured to prevent unwanted access.
- All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
- Rainwater harvesting systems may be ordered from a manufacturer or can be constructed on site from a variety of materials.
- Storage tanks should be opaque or otherwise protected from direct sunlight to inhibit algae growth and should be screened to discourage mosquito breeding and reproduction.
- Dead storage below the outlet to the distribution system and an air gap at the top of the tank should be added to the total volume. For gravity-fed systems, a minimum of 6 inches of dead storage should be provided. For systems using a pump, the dead storage depth will be based on the pump specifications.
- Any hookup to a municipal backup water supply must have a backflow prevention device to keep municipal water separate from stored rainwater. Check with your local government for any regulations pertaining to this.

Distribution system: The rainwater harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses. Distribution lines should be installed with shutoff valves and cleanouts, and should be buried beneath the frost line or insulated to prevent freezing. Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. Separate plumbing labeled as non-potable may be required. The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

Lines from the rainwater harvesting system to the building should have shut-off valves that are accessible when snow cover is present. A drain plug or cleanout sump, also draining to a pervious area, should be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes should be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter. (Metro, 2013)

Overflow, filter path, or secondary runoff reduction practice: The system must be designed with an overflow mechanism to divert runoff when the storage tanks are full. Overflows should discharge to pervious areas set back from buildings and paved surfaces, or to secondary SCMs. All rain barrels and cisterns must provide a safe way for water to exit the system when it is full, such as when large storms generate more stormwater runoff than the storage device is designed to hold. The cistern can be designed to slowly drain to the landscape between storm events to provide capacity. The overflow should convey runoff to an approved discharge point. The size of the overflow device or orifice should be equal in area to the total of all inlet orifices.

An overflow mechanism should be included in the rainwater harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds.

The filter path is a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system. The filter path must be graded with a slope that results in sheet flow conditions. If compacted or impermeable soils are present along the filter path, compost amendments may be needed. It is also recommended that the filter path be used for first flush diversions. In many cases, rainwater harvesting system overflows are directed to a secondary runoff reduction practice to boost overall runoff reduction rates.

Backup: When used for grey water reuse (such as toilet flushing), a backup water supply is required to supplement the system during dry periods. Backflow preventers must be installed on water service lines from cisterns. Collection and reuse systems must include an emergency overflow for large storm events.

Area and Dimensions: The number of rain barrels or the size of the cistern required will be determined by the drainage area, the intended capture goal, and the usage needs of the reuse application. If water is to be pumped from the cistern, the designer must select a pump of adequate capacity to meet the flow requirements for the reuse system.

Water Quality: All capture and reuse SCMs must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. All cisterns should be shaded to the maximum extent possible to help prevent algal growth. Storage tanks should be placed in cool, shaded areas to help prevent algal growth. Cisterns must be watertight, vented, completely covered or screened, composed of non-reactive materials, and be approved for potable water storage, although runoff cannot be used for potable needs without treatment. This includes irrigation water that has any human contact (i.e., sprinklers). If the storage device is open to the air, a screen or other cover is necessary to prevent mosquito breeding. Cistern seams should be checked regularly for leaks.

Design criteria: The rainwater harvesting cistern sizing criteria presented in this section was developed using best estimates of indoor and outdoor water demand, long-term rainfall data, and rooftop capture area data. Rainwater tank sizing is determined by accounting for varying precipitation levels, captured rooftop runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for treatment volume (permanent storage), storage needed for channel protection and flood volume (temporary detention storage), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See Figure 7 for a graphical representation of these various incremental design volumes.

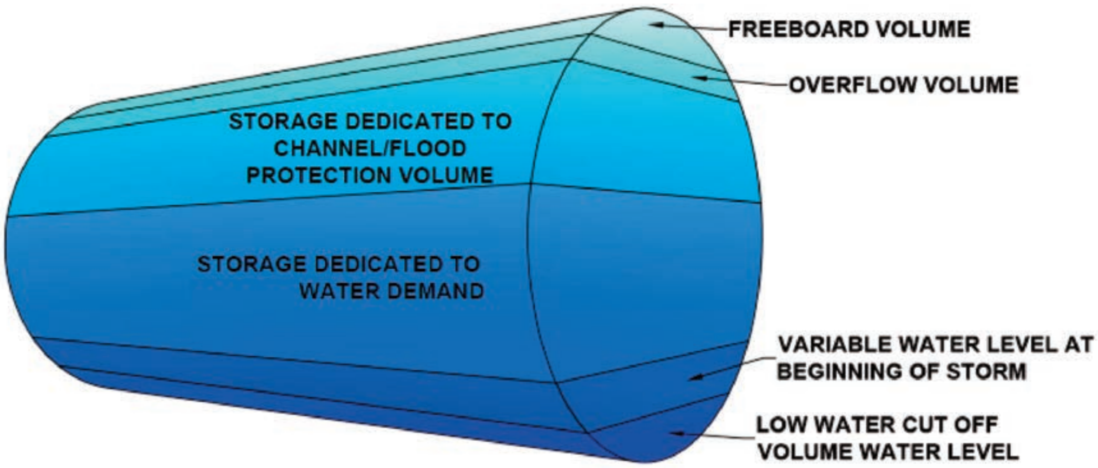


Figure 7: Incremental Design Volumes associated with tank sizing (Adapted from VADCR, 2013, p.24).

The "Storage Associated with the Treatment Volume" is the storage within the tank that is modeled and available for reuse. While the Treatment Volume will remain the same for a specific rooftop capture area, the "Storage Associated with the Treatment Volume" may vary depending on demand and runoff reduction credit objectives. It includes the variable water level at the beginning of a storm and the low water cut-off volume that is necessary to satisfy pumping requirements.

Material specifications: Examples of basic material specifications for rainwater harvesting systems are presented in Table 1. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 1: Design Specifications for Rainwater Harvesting Systems.

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include PVC pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply. • The length of gutters and downspouts is determined by the size and layout of the catchment and the location of the storage tanks. • Be sure to include needed bends and trees.
Pre-Treatment	At least one of the following (all rainwater to pass through pre-treatment): • First flush diverter • Vortex filter • Roof washer • Leaf and mosquito screen (1 mm mesh size)
Storage Tanks	• Materials used to construct storage tanks should be structurally sound. • Tanks should be constructed in areas of the site where native soils can support the load associated with stored water. • Storage tanks should be water tight and sealed using a water-safe, non-toxic substance. • Tanks should be opaque to prevent the growth of algae. • Re-used tanks should be fit for potable water or food-grade products. • Underground rainwater harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line. • The size of the rainwater harvesting system(s) is determined during the design calculations.

Note: This table does not address indoor systems or pumps.

1.3.3 System Configurations

From a rainwater harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of the goal of addressing the design treatment volume, this SCM adheres to the following concepts in order to properly meet the stormwater volume reduction goals:

- Runoff reduction volume credit is only available for dedicated year-round drawdown/demand for the water. While seasonal practices (such as irrigation) may be incorporated into the site design, they are not considered to contribute to the treatment volume credit (for stormwater purposes) unless a drawdown at an equal or greater rate is also realized during non-seasonal periods (e.g. treatment in a secondary runoff reduction practice during non-irrigation months).
- System design is encouraged to use rainwater as a resource to meet onsite demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Pollutant load reduction is realized through reduction of the volume of runoff leaving the site.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the rainwater harvesting system design configurations presented in this SCM are targeted for continuous (year-round) use of rainwater through (1) internal use, and (2) irrigation and/or treatment in a secondary practice. Three basic system configurations are described below.

Configuration 1: Year-round indoor use with seasonal indoor and/or outdoor uses (Figure 8). The first configuration is for year-round indoor use. Typical year-round uses include toilet and urinal flushing and laundry. Additional uses include irrigation, cooling towers, and a catch-all category of other uses that may include vehicle washing, street sweepers, and other not yet defined year-round or seasonal uses.

The only runoff reduction volume credit derived from this configuration is the year-round indoor use. While the seasonal uses do not provide an annual credit, they generally use a lot of water (i.e., irrigation) such that the owner may elect to increase the system size to provide for the seasonal demand in order to reduce potable water usage.

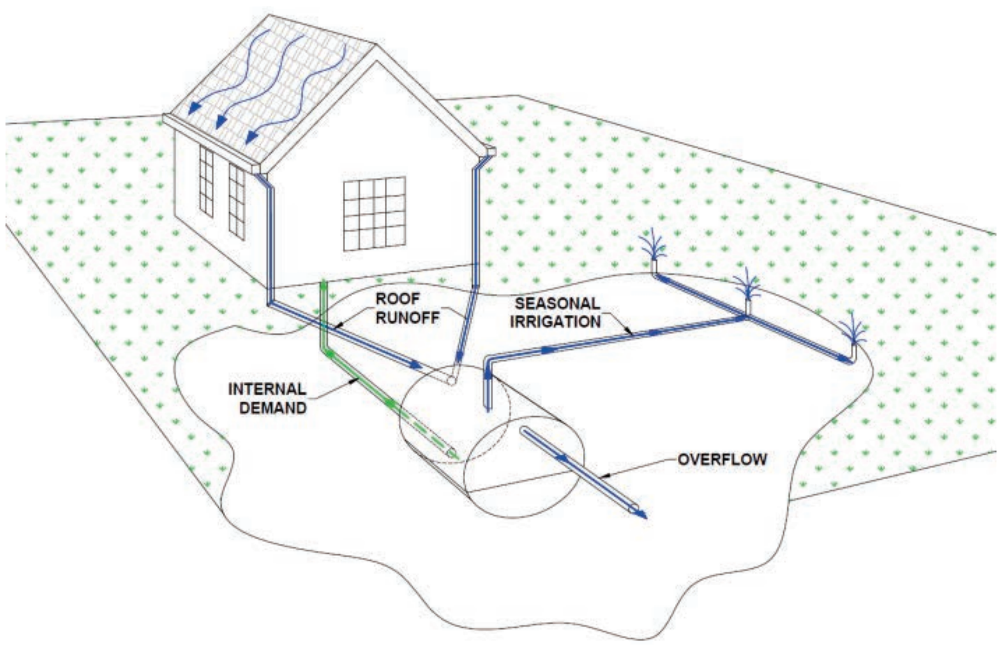


Figure 8. Configuration 1 Year-round indoor use with seasonal indoor and/or outdoor uses (Source: VADCR, 2013).

Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 9). The second configuration builds upon the first with the addition of a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish a runoff reduction volume credit (in addition to the credit based on the year-round indoor uses). Therefore, the system must account for three uses: year-round internal non-potable water demand, a seasonal outdoor use such as automated irrigation system or cooling towers, and an engineered drawdown to a secondary runoff reduction drawdown practice for volume reduction during non-irrigation (or non-seasonal) months.

The cistern acts as a detention system during the non-seasonal months that must be designed to slowly drawdown at a rate comparable to the seasonal use in order to provide storage for the next storm event. In this way, the system achieves a year-round use and a corresponding runoff reduction volume credit. The design and sizing of the secondary runoff reduction drawdown practice is based on a specific drawdown rate, The secondary drawdown practice sizing will also be influenced by the hydraulic properties of the practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity. The resulting size and/or storage volume of the secondary runoff reduction drawdown practice will generally be smaller than the stand-alone SCM (e.g., without the up-gradient storage tank).

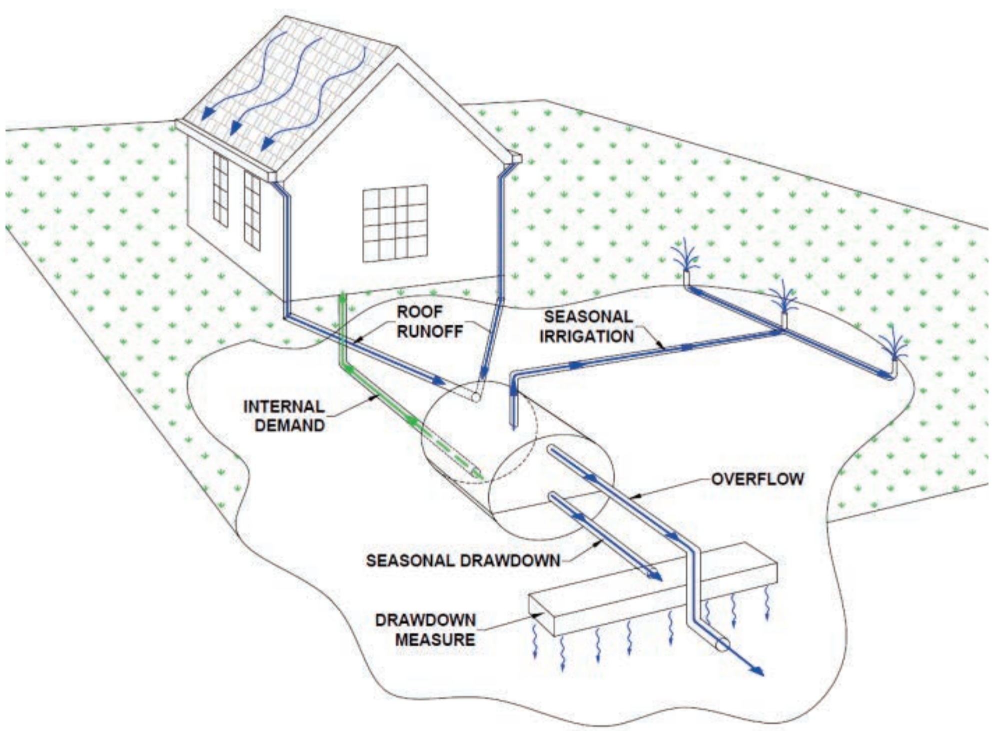


Figure 9: Configuration 2 Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Source: VADCR, 2013).

Configuration 3: Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 10). The third configuration does not have any year-round uses and therefore uses stored rainwater to meet seasonal or intermittent water uses, while utilizing a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish a runoff reduction volume credit. In this configuration, the system need only account for two uses: the seasonal outdoor use (automated irrigation system, cooling towers, etc.) and the engineered drawdown to a secondary runoff reduction drawdown practice. Similar to the previous configuration, the tank drawdown rate should be designed to be, at a minimum, comparable to the periodic seasonal use. The drawdown rate and practice sizing may also be influenced by the hydraulic properties of the practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity.

In the case of both Configuration 2 and 3, the design of the tank size and drawdown rate and the exfiltration rate and surface area of the drawdown practice may be utilized to establish a hydraulic routing of the system for sizing purposes.

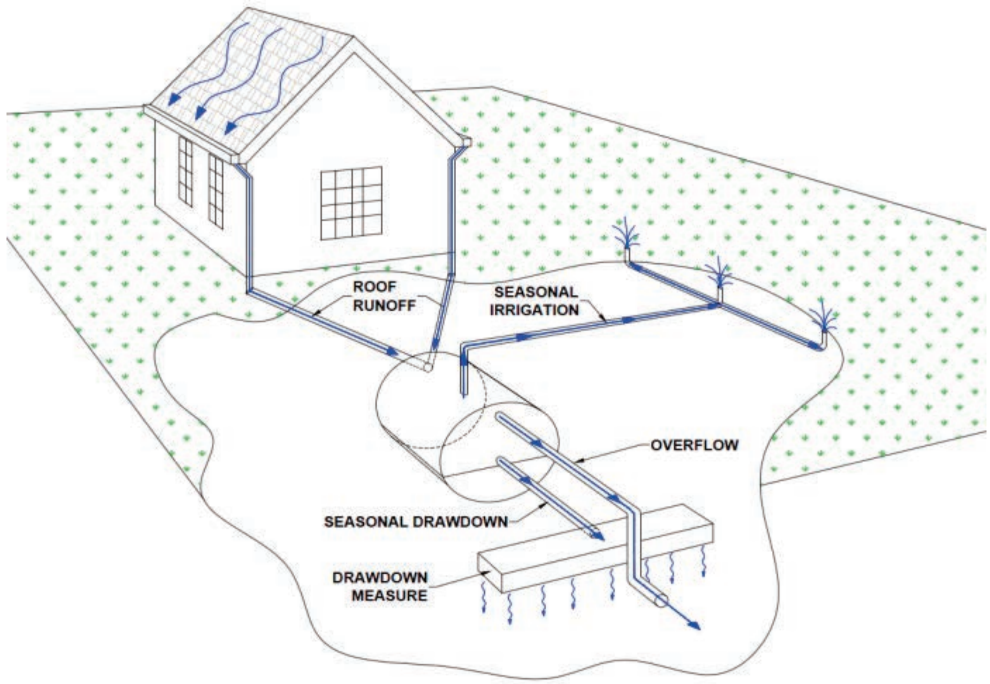


Figure 10: Configuration 3 Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Source: VADCR, 2013).

1.3.4 Tank Configurations

Pre-fabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are three basic tank design configurations used to meet the various rainwater harvesting system configurations. (VADCR, 2011)

Tank Design 1. The first tank set-up (Figure 11) maximizes the available tank storage volume for the treatment volume to meet the water demand and achieve the desired runoff reduction volume credit. An emergency overflow exists near the top of the tank. The overflow outlet may be a gravity flow outlet or a pumped outlet. Alternatively, the overflow may be an external control that backs up the flow before the tank thereby diverting any additional inflow.

> **Note:** Figures 11 and 12 are schematic representations of the relative configuration of the storage volume and outlets. If these tanks are configured below grade there would be a mechanical system to pump the required flow to meet the water demand or drawdown, requiring a float switch or other water level sensor to trigger the pump for meeting a variable demand. An above grade system may include a combination of gravity overflow orifices and a pump system to generate adequate pressure for the intended uses. Figure 13 provides a schematic representation of a cistern with a mechanical system included.

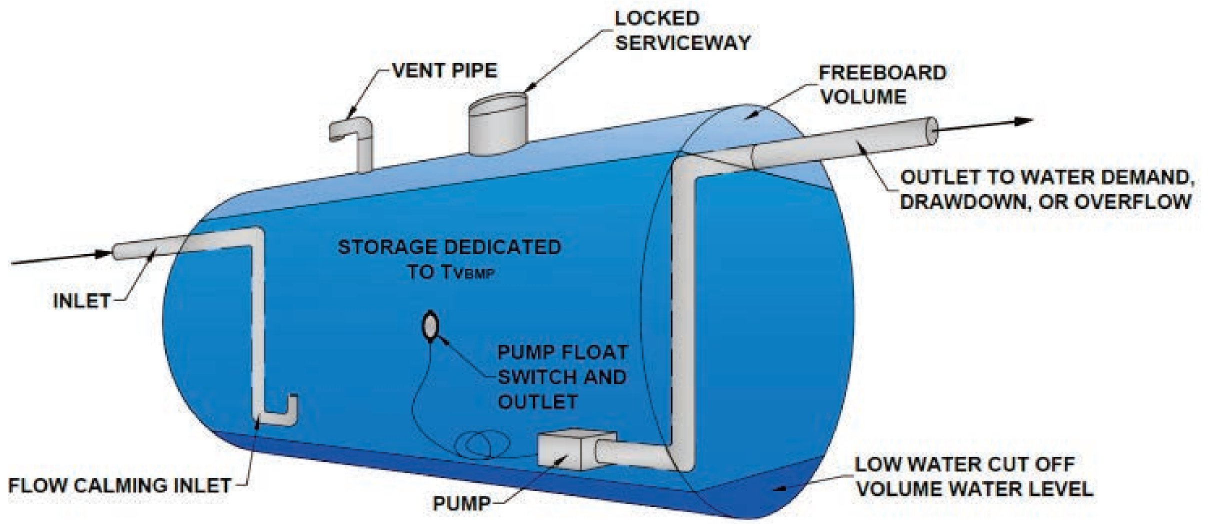


Figure 11: Tank Design 1 Storage Associated with Treatment Volume only (Source: VADCR, 2013).

Tank Design 2. The second tank set-up (Figure 12) uses tank storage to manage the runoff reduction volume objectives as well as using an additional detention volume to also meet some or all of the channel and/or flood protection volume requirements. For an above ground system, the channel and/or flood protection storage outlet orifice is located at the top of the design storage and sized according to the channel and/or flood protection peak flow requirements. Alternatively, a below grade system would rely on a float switch and pump to achieve the same objectives. An emergency overflow is located at the top of the detention volume level.

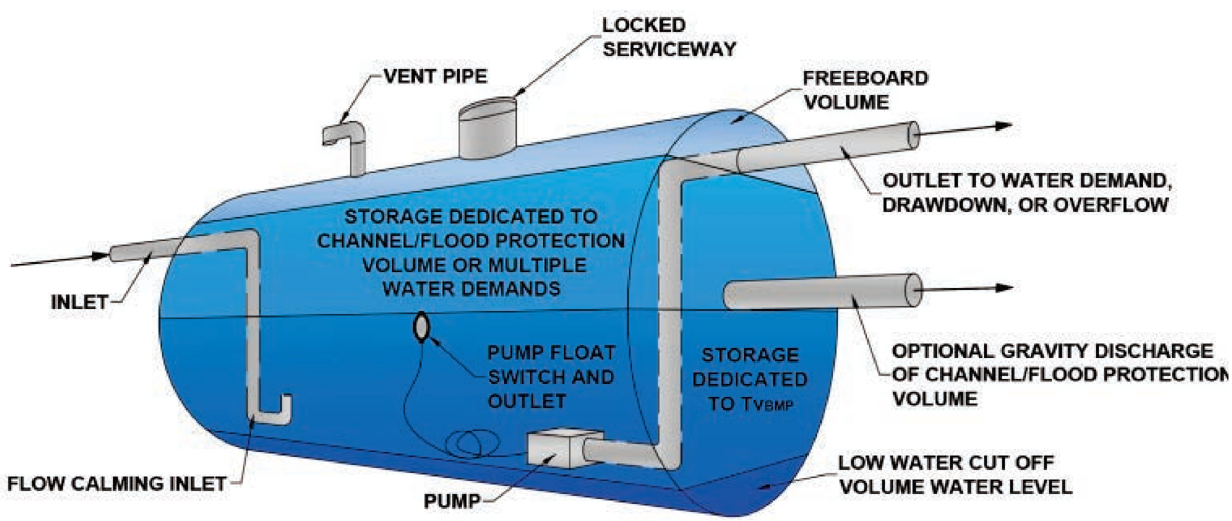


Figure 12: Tank Design 2 Storage Associated with Treatment, Channel Protection and Flood Volume (Source: VADCR, 2013).

1.3.5 Secondary Practices

Recent rainwater harvesting system design materials do not include guidance for onsite stormwater infiltration or "disposal". The basic approach is to provide a dedicated secondary runoff reduction practice onsite that will ensure water within the tank will gradually drawdown at a specified design rate between storm events. Secondary runoff reduction practices may include the following:

- Downspout Disconnection, excluding rain tanks and cisterns. This may include release to a compost-amended filter path.
- Sheet Flow
- Grass Channel
- Infiltration Trench
- Bioretention
- Urban Bioretention. Storage and release in foundation planter.
- Water Quality Swale

The secondary practice approach is useful to help achieve the desired treatment volume when demand is not enough to sufficiently draw down water levels in the tank between storm events. Of course, if demand for the harvested rainwater is relatively high, then a secondary practice may not be needed or desired. Use of a secondary practice may be particularly beneficial for sites that use captured rainwater for irrigation during part of the year, but have no other use for the water during non-irrigation months. During non-irrigation months, credit cannot be realized unless onsite infiltration/treatment or another drawdown mechanism creates a year-round drawdown, since no stormwater benefit would be realized during non-seasonal periods. The design of the secondary practice should account for soil types, ground surface areas, release rates, methods of conveyance (gravity fed or pumped), time periods of operation, and invert elevations to determine the disposal rate and sizing of the practice (both storage volume and surface area).

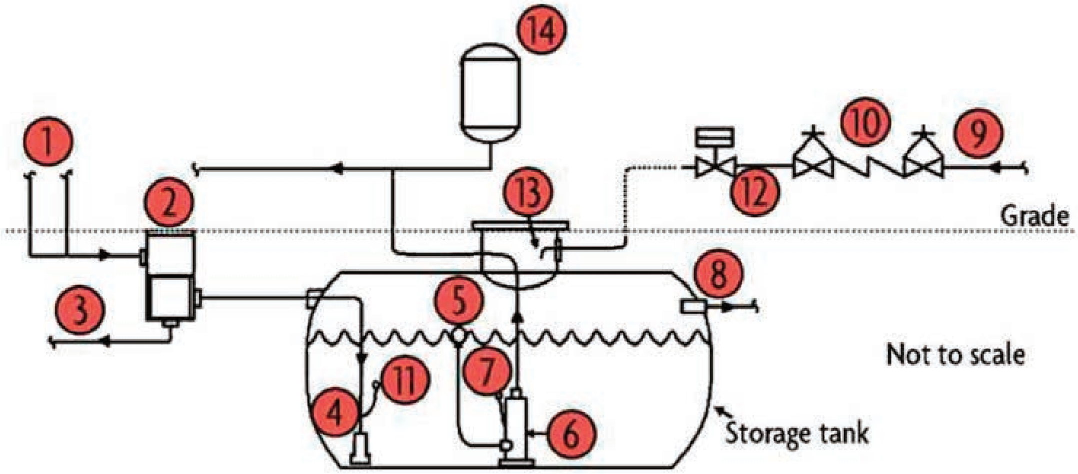
1.3.6 Safety Considerations

All collection and redistribution of stormwater runoff have the potential to cause human pathogenic issues. All capture and reuse SCMs that involve human contact must include disinfection components to prevent human health and safety issues arising from any potential contact with the collected water. Both ultraviolet (UV) and ozone disinfection systems are available for this purpose.

Spigots or hose bibs at above-grade cisterns should be labeled "NON-POTABLE" and be equipped with an atmospheric vacuum breaker. Backflow preventers must be installed on water service lines from cisterns. Safety labels should be placed on cisterns stating "NON-POTABLE" and "DROWNING HAZARD." Distribution lines and other system appurtenances must be clearly labeled as non-potable water.

1.4 Typical Details

The components of a rainwater harvesting system may include those illustrated in Figure 13.



1. Rooftop surface and rainwater collection system (roof drains, gutters, etc.)
2. Pre-treatment (screening, first flush diverters, filters, etc.)
3. Discharge of excess or diverted first flush to overflow or downstream practice
4. Flow calming inlet
5. Floating (outlet) filter
6. Submersible pump
7. Low water cut off float switch
8. Overflow to secondary runoff reduction drawdown practice, downstream runoff reduction or pollutant removal SCM, or conveyance system
9. Municipal back-up water supply
10. Back flow preventer
11. Float switch to control water levels
12. Solenoid valve
13. Air gap
14. Pressure tank

Figure 13: Sample rainwater harvesting system detail (Source: VADCR, 2011).

2. Construction

For the purposes of site peak rate control, the designer may adjust the Curve Number value based on the volume managed by the treatment volume during a portion of a 24-hour storm event.

2.1 Pre-Construction

Site Protection: Prior to installing a rain barrel or cistern, clean roofs, gutters, and downspouts and install effective leaf screens.

2.2 Construction

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with rainwater harvesting system sizing, installation, and placement. A licensed plumber is required to install the rainwater harvesting system components to the plumbing system. A standard construction sequence for proper rainwater harvesting system installation is provided below. This can be modified to reflect different rainwater harvesting system applications or expected site conditions:

- Choose the tank location on the site
- Route all downspouts or roof drains to pre-screening devices and first flush diverters
- Properly install the tank
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release)

- Route all pipes to the tank
- Stormwater should not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.
- Install rain barrels and cisterns on level surfaces.
- Consider head required to provide necessary pressure for the designed reuse.

Follow the manufacturer's instructions for rain barrel or cistern installation.

2.3 Inspections

The following items shall be inspected prior to final sign-off and acceptance of a rainwater harvesting system:

- Rooftop area matches plans
- Diversion system is properly sized and installed
- Pretreatment system is installed
- Mosquito screens are installed on all openings
- Overflow device is directed as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary runoff reduction practice(s) is installed as shown on plans

As-Built: After the cistern has been installed, the developer must have an as-built certification of the cistern conducted by a registered professional engineer. The as-built certification verifies that the SCM was installed as designed and approved. The following components are vital components of a properly working cistern and must be addressed in the as-built certification:

Incorporation of Rainwater Harvesting System into the site Grading and Drainage Plan, as follows:

1. Include a roof plan of the building that will be used to capture rainwater, showing slope direction and roof material.
2. Display downspout leaders from the rooftops being used to capture rainwater.
3. Display the storm drain pipe layout (pipes between building downspouts and the tank) in plan view, specifying materials, diameters, slopes and lengths, to be included on typical grading and utilities or storm sewer plan sheets.
4. Include a detail or note specifying the minimum size, shape configuration and slope of the gutter(s) that convey rainwater

Rainwater Harvesting System Construction Document sheet, to show the following:

1. The Cistern or Storage Unit material and dimensions in a scalable detail (use a cut sheet detail from manufacturer, if appropriate).
2. Include the specific Filter Performance specification and filter efficiency curves. Runoff estimates from the rooftop area captured for 1-inch storm should be estimated and compared to filter efficiencies for the 1-inch storm. It is assumed that the first flush diversion is included in filter efficiency curves. A minimum of 95% filter efficiency should be met for the Treatment Volume credit. If this value is altered (increased), the value should be reported. Filter curve cut sheets are normally available from the manufacturer. Show the specified materials and diameters of inflow and outflow pipes.
3. Show the inverts of the orifice outlet, the emergency overflows, and, if applicable, the receiving secondary runoff reduction practice or on-site infiltration facility.
4. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes (if requested by the reviewer).

3. Construction

Plans must indicate that sufficient access is provided to allow for regular maintenance activities.

3.1 Agreements

The Tennessee MS4 permit suggest that a maintenance agreement should be executed between the owner and the local stormwater program or local government responsible for stormwater management. The local stormwater program may set forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

Rainwater harvesting systems can be complex and often will include mechanical components and therefore should be inspected and maintained by qualified personnel. The following are suggested minimum requirements for establishing accountability for the system to remain operational when a runoff reduction volume credit is applied to the system:

- Rainwater harvesting systems must include long term maintenance agreements consistent with the provisions of the local stormwater program's regulations, and must include the recommended maintenance tasks and a copy of an annual inspection checklist.
- When rainwater harvesting systems are applied on private residential lots, homeowners should be educated regarding their routine maintenance needs by being provided a simple document that explains their purpose and routine maintenance needs. .
- A deed restriction, drainage easement or other mechanism enforceable by the local stormwater program must be in place to help ensure that the rainwater harvesting system is maintained and operational, as well as to pass the knowledge along to any subsequent owners.
- The mechanism should, if possible, grant authority for the local stormwater program staff to access the property for inspection of the tank (if external), the overflow conveyance, and any secondary runoff reduction drawdown practice.
- As an alternative, property owners may document that their system has been inspected and maintained by a qualified third party inspector.

3.2 Schedules

All rainwater harvesting systems components should be inspected by the property owner in the Spring and the Fall each year. A comprehensive inspection by a qualified third party inspector is recommended at least once a year, but at a minimum should occur and be documented at a minimum once every five years. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in Appendix F.

3.3 Rainwater harvesting system maintenance schedule

Maintenance requirements for rainwater harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. **Table 2** describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 2: Suggested Maintenance Tasks for Rainwater Harvesting Systems.

Activity	Frequency
Keep gutters and downspouts free of leaves and other debris	O: Twice a year
Inspect and clean pre-screening devices and first flush diverters	O: Four times a year
Inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately	O: Once a year
Inspect condition of overflow pipes, overflow filter path and/or secondary runoff reduction practices	O: Once a year
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	I: Every third year
Check integrity of backflow preventer	I: Every third year
Inspect structural integrity of tank, pump, pipe and electrical system	I: Every third year
Replace damaged or defective system components	I: Every third year
*Key: **O** = Owner **I** = qualified third party inspector*	

4. Community and Environmental Concerns

Although rainwater harvesting is an ancient practice, it is enjoying a revival due to the inherent quality of rainwater and the many beneficial uses that it can provide. Some common concerns associated with rainwater harvesting that must be addressed during design include:

- ***Winter Operation:*** Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternately, an outdoor system can be used seasonally, or year round if special measures and design considerations are incorporated.
- ***Local Plumbing Codes:*** Designer and plan reviewers should consult local building codes to determine if they explicitly allow the use of harvested rainwater for toilet and urinal flushing. In the cases where a municipal backup supply is used, rainwater harvesting systems are typically required to have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.
- ***Mosquitoes:*** In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use.
- ***Child Safety:*** Above-grade residential rainwater harvesting systems cannot have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be secured to prevent unwanted access.

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