3.2. Rainwater Harvesting

Definition. Rainwater harvesting systems store and release rainfall for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground storage tank (also referred to as a cistern or rain tank), where it can be used for non-potable water uses and on-site stormwater disposal/infiltration. Non-potable uses may include landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks), flushing of toilets and urinals, fire suppression (sprinkler systems), supply for cooling towers, evaporative coolers, fluid coolers and chillers, supplemental water for closed loop systems, steam boilers, replenishment of water features and water fountains, distribution to a green wall or living wall system, laundry, and delayed discharge to the combined sewer system.

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

- Disconnection to a pervious or conservation area (see Section 3.3)
- Overflow to bioretention practices (see Section 3.5)
- Overflow to infiltration practices (see Section 3.7)
- Overflow to grass channels or dry swales (see Section 3.11)

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).

Seven primary components of a rainwater harvesting system include:

- Drainage area
- Collection and conveyance system (i.e. gutter and downspouts)
- Pre-screening and first flush diverter
- Storage tank
- Water quality treatment (as required by TRAM)
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are shown in Figure 3.2.1 and discussed in detail in Section 3.2.4.

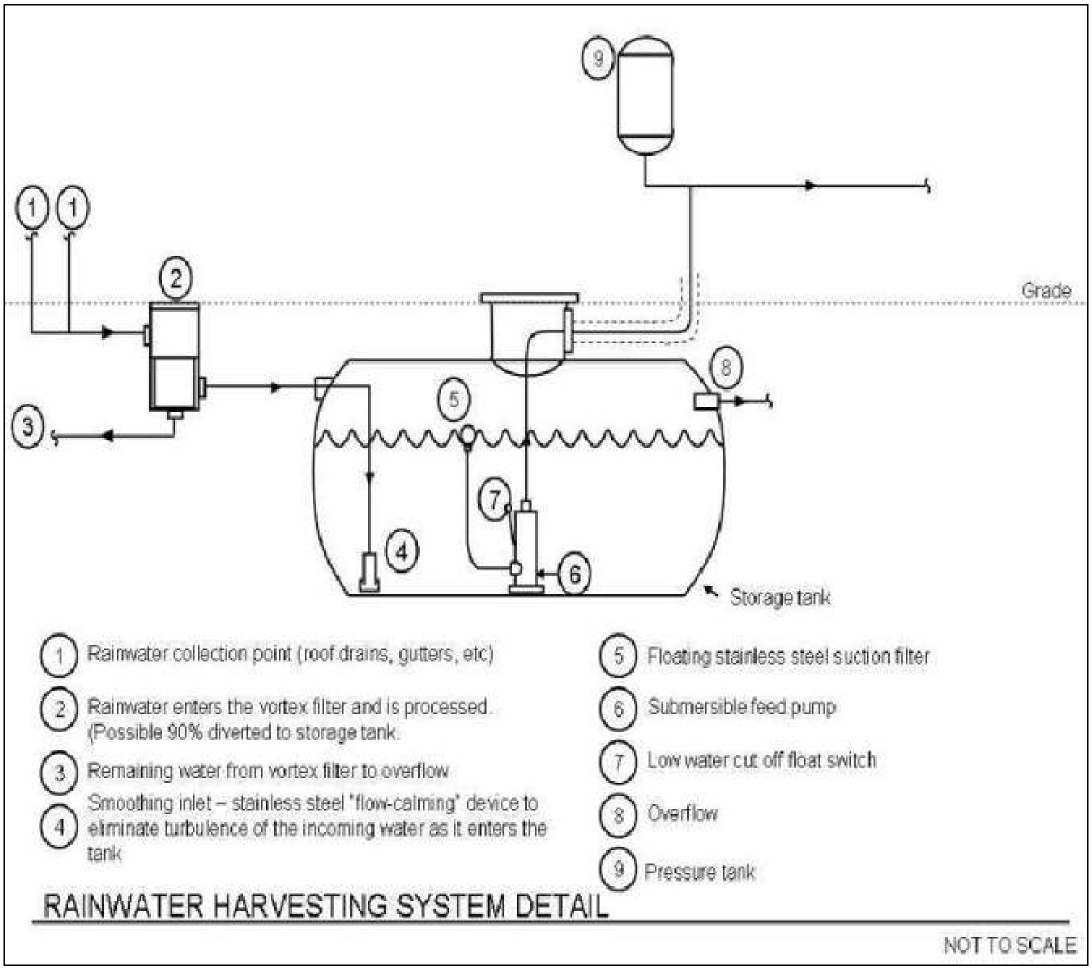

Figure 3.2.1. Sample Rainwater Harvesting System Detail.

3.2.1. Rainwater Harvesting Feasibility Criteria

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

Plumbing Code. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the District Construction Codes (DCMR, Title 12) to determine the allowable indoor uses and required treatment for harvested rainwater. In cases where a municipal backup supply is used, rainwater harvesting systems must have backflow preventers or air gaps to keep harvested water separate from the main water supply. Distribution and waste pipes, internal to the building, must be stamped non-potable and colored purple consistent with District building codes. Pipes and spigots using rainwater must be clearly labeled as non-potable with an accompanying pictograph sign.

Mechanical, Electrical, Plumbing (MEP). For systems that call for indoor use of harvested rainwater, the seal of an MEP engineer is required.

Water Use. When rainwater harvesting will be used, a Tiered Risk Assessment Management (TRAM) (see Appendix N) must be completed and the appropriate form submitted to DDOE. This will outline the design assumptions, outline water quality risks and provide water quality end use standards.

Available Space. Adequate space is needed to house the storage tank and any overflow. 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 that are structurally designed to support the added weight, and adjacent to buildings. Designers can work with architects and landscape architects to creatively site the tanks. Underground utilities or other obstructions should always be identified prior to final determination of the tank location.

Site Topography. Site topography and storage tank location should be considered as they relate to all of the inlet and outlet invert elevations in the rainwater harvesting system.

The final invert of the outlet pipe from the storage tank must match the invert of the receiving mechanism (e.g. natural channel, storm drain system) that receives this overflow. The elevation drops associated with the various components of a rainwater harvesting system and the resulting invert elevations should be considered early in the design, in order to ensure that the rainwater harvesting system is feasible for the particular site.

Site topography and storage tank location will also affect pumping requirements. Locating storage tanks in low areas will make it easier to get water into the cisterns; however, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter pipes with smaller slopes but will generally reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building or drainage area, to limit the amount of pipe needed.

Available Hydraulic Head. 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, which then serves the internal water demands. Cisterns can also use gravity to accomplish indoor residential uses (e.g. laundry) that do not require high water pressure.

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 is 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), and conducting buoyancy calculations when the tank is empty. 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.

Soils. Storage tanks should only be placed on native soils or on fill in accordance with the manufacturer's guidelines. The bearing capacity of the soil upon which the cistern will be placed must be considered, as full cisterns can be very heavy. This is particularly important for above-ground cisterns, as significant settling could cause the cistern to lean or in some cases to potentially topple. A sufficient aggregate, or concrete base, may be appropriate depending on the soils. The pH of the soil should also be considered in relation to its interaction with the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of underground rainwater harvesting systems, treating all of the rainwater harvesting system components and storm drains as typical stormwater facilities and pipes. The underground utilities must be marked and avoided during the installation of underground tanks and piping associated with the system.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the tank. Rooftop surfaces are what typically make up the CDA, but paved areas and landscaped areas can be used with appropriate treatment (oil/water separators and/or debris excluders). Areas of any size, including portions of roofs, can be used based on the sizing guidelines in this design specification. Runoff should be routed directly from the drainage area 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.

Contributing Drainage Area Material. The quality of the harvested rainwater will vary according to the roof material or drainage area over which it flows. Water harvested from certain types of rooftops and CDAs, 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 surfaces should be avoided. 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).

Water Quality of Rainwater. Designers should also note that the pH of rainfall in the District tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from roof surfaces, 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. Limestone or other materials may be added in the tank to buffer acidity, if desired.

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.

Setbacks from Buildings. Storage tank overflow devices should be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. Tanks must be designed to be watertight to prevent water damage when placed near building foundations.

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.

Discharge to Combined Sewer System. Discharge of harvested rainwater to the combined sewer system is considered an acceptable drawdown method to achieve retention value. However, the drawdown must be limited to a rate which releases the SWRv over at least 72 hours.

3.2.2. Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall 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. Typically, 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 in order to adequately convey the design storm (e.g. Stormwater Retention Volume (SWRv)). If the system will be used for management of the 2-yr and 15-yr storms, the gutters should be designed to convey the appropriate 2-yr and 15-yr storm intensities.

Pipes, which connect 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.

Overflow. 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 pipe(s) 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(s) should be screened to prevent access to the tank by rodents and birds.

3.2.3. Rainwater Harvesting Pretreatment Criteria

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.

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 specification, 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 and typically applies to rooftop runoff.

The diverted flows (i.e. first flush diversion and overflow from the filter) must be directed to an acceptable flow path that will not cause erosion during a 2-yr storm or to an appropriate BMP on the property.

Various first flush diverters are described below. 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 (for design storm = SWRv) 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-yr and 15-yr storm intensities should be used for the design of the conveyance and pre-treatment portion of the system. For the SWRv, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. The Cistern Design Spreadsheet, discussed more in Section 3.2.4, assumes a filter efficiency rate of 95% for the SWRv design storm. To meet the requirements to manage the 2-year and 15-year storms, a minimum filter efficiency of 90% should be met.

- **First Flush Diverters.** First flush diverters direct the initial pulse of rainfall 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 pre-treatment method if the water is to be used for indoor purposes. A vortex filter (see Figures 3.2.2) may serve as an effective pre-tank filtration device and first flush diverter.
- **Leaf Screens.** 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).
- **Roof Washers.** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater (see Figure 3.2.3). 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. The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

- **Vortex Filters.** For large scale applications, vortex filters can provide filtering of CDA rainwater from larger CDAs.

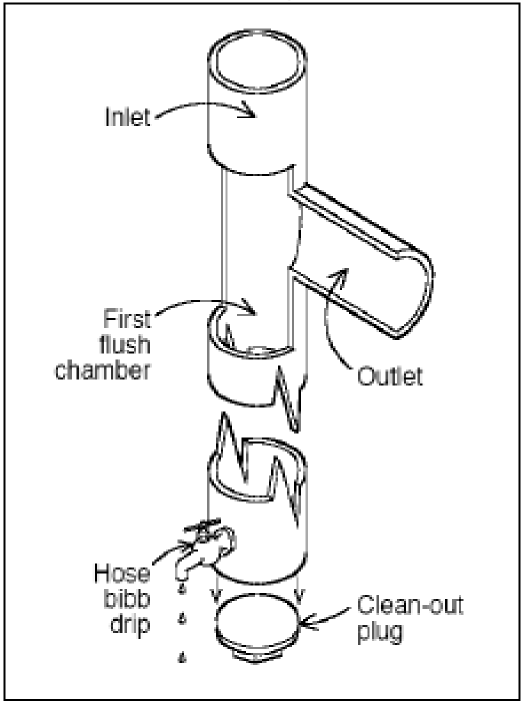

Figure 3.2.2. First Flush Diverter. (TWRB, 2005)

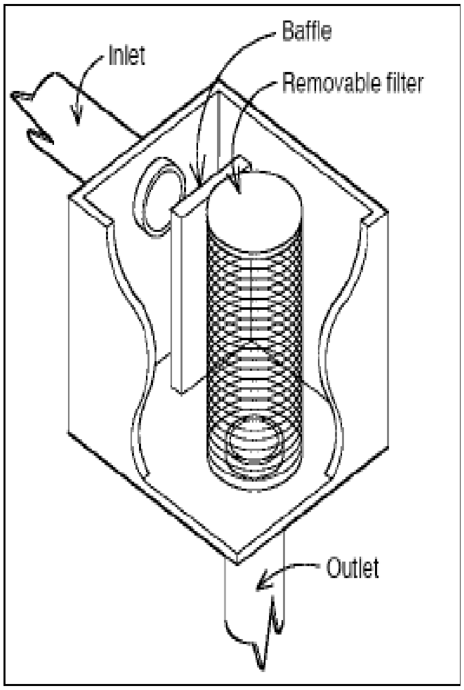

Figure 3.2.3. Roof Washer. (TWRB, 2005)

3.2.4. Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system (Figure 3.2.1) include:

- Drainage area
- Collection and conveyance system (i.e. gutter and downspouts)
- Pre-screening and first flush diverter
- Storage tank
- Water quality treatment (as required by TRAM)
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

- **CDA Surface.** When considering CDA surfaces, note smooth, non-porous materials will drain more efficiently. Slow drainage of the CDA leads to poor rinsing and a prolonged first flush, which can decrease water quality. If the harvested rainwater will be directed towards uses with significant human exposure (e.g. pool filling, public sprinkler fountain), care should be taken in the choice of CDA materials. Some materials may leach toxic chemicals making the water unsafe for humans. In all cases, follow the advice of the TRAM found in

Appendix N.

Rainwater can also be harvested from other impervious surfaces, such as parking lots and driveways; however, this practice requires more extensive pretreatment and treatment prior to reuse.

- **Collection and Conveyance System.** See Section 3.2.2.

- **Pre-Treatment.** See Section 3.2.3.

- **Storage Tanks.** The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities 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 to tailor the volume storage 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 storage volume retention objectives, as described in further below in this specification.

  While many of the graphics and photos in this specification 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 are factors that 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).
  - 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/locked 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. Table 3.2.1 below compares the advantages and disadvantages of different storage tank 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 should have a backflow prevention device to keep municipal water separate from stored rainwater; this may include incorporating an air gap to separate the 2 supplies.

Table 3.2.1. Advantages and disadvantages of various cistern materials (Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009).

Tank Material	Advantages	Disadvantages
Fiberglass	Commercially available, alterable and moveable; durable with little maintenance; light weight; integral fittings (no leaks); broad application	Must be installed on smooth, solid, level footing; pressure proof for below-ground installation; expensive in smaller sizes
Polyethylene	Commercially available, alterable, moveable, affordable; available in wide range of sizes; can install above or below ground; little maintenance; broad application	Can be UV-degradable; must be painted or tinted for above-ground installations; pressure-proof for below- ground installation
Modular Storage	Can modify to topography; can alter footprint and create various shapes to fit site; relatively inexpensive	Longevity may be less than other materials; higher risk of puncturing of watertight membrane during construction
Plastic Barrels	Commercially available; inexpensive	Low storage capacity (20 to 50 gallons); limited application
Galvanized Steel	Commercially available, alterable, and moveable; available in a range of sizes; film develops inside to prevent corrosion	Possible external corrosion and rust; must be lined for potable use; can only install above ground; soil pH may limit underground applications
Steel Drums	Commercially available, alterable, and moveable	Small storage capacity; prone to corrosion, and rust can lead to leaching of metals; verify prior to reuse for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immoveable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immoveable, versatile; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; permanent; will need to provide adequate platform and design for placement in clay soils
Stone or concrete Block	Durable and immoveable; keeps water cool in summer months	Difficult to maintain; expensive to build

- **Water quality treatment.** Depending upon the collection surface, method of dispersal, and proposed use for the harvested rainwater, a water quality treatment device may be required by the TRAM.

- **Distribution Systems.** 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 stormwater treatment practice. The rainwater harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses.

  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. Some systems will not require this two tank arrangement (e.g. low pressure, gravel). 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.

Distribution lines from the rainwater harvesting system should be buried beneath the frost line. 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.

- **Overflow.** See Section 3.2.2.

Rainwater Harvesting Material Specifications. The basic material specifications for rainwater harvesting systems are presented in Table 3.2.2 below. 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 3.2.2. Design specifications for rainwater harvesting systems.

Item	Specification
Gutters and Downspouts	Materials commonly used for gutters and downspouts include polyvinylchloride (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 tees.
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 watertight and sealed using a water-safe, non-toxic substance. ▪ Tanks should be opaque to prevent the growth of algae. ▪ Reused tanks should be fit for potable water or food-grade products. ▪ Underground rainwater harvesting systems should have a minimum of 18 inches of soil cover and be located below the frost line. ▪ The size of the rainwater harvesting system(s) is determined through design calculations.
Note: This table does not address indoor systems or pumps.	

Design Objectives and System Configuration. Many rainwater harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a design framework for achieving the SWRv objectives for compliance with the regulations. From a rainwater harvesting standpoint, there are numerous potential configurations that could be implemented. However, in terms of addressing the design storm, this specification adheres to the following concepts in order to properly meet the stormwater retention goals:

- System design is encouraged to use rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the rainwater harvesting system design configurations presented in this specification are targeted for use of rainwater through (1) internal use and (2) seasonal irrigation. While internal use results in a steady year-round demand for the harvested rainwater, seasonal irrigation will vary with the time of year, and the retention value is reduced accordingly.

Design Objectives and Tank Design Set-Ups. 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 that are described below.

- **Tank Design 1.** The first tank set-up (Figure 3.2.4) maximizes the available storage volume associated with the SWRv to meet the desired level of stormwater retention. This layout also maximizes the storage that can be used to meet a demand. An emergency overflow exists near the top of the tank as the only gravity release outlet device (not including the pump, manway or inlets). It should be noted that it is possible to address 2-yr and 15-year storm volumes with this tank configuration, but the primary purpose is to address the smaller SWRv design storm.

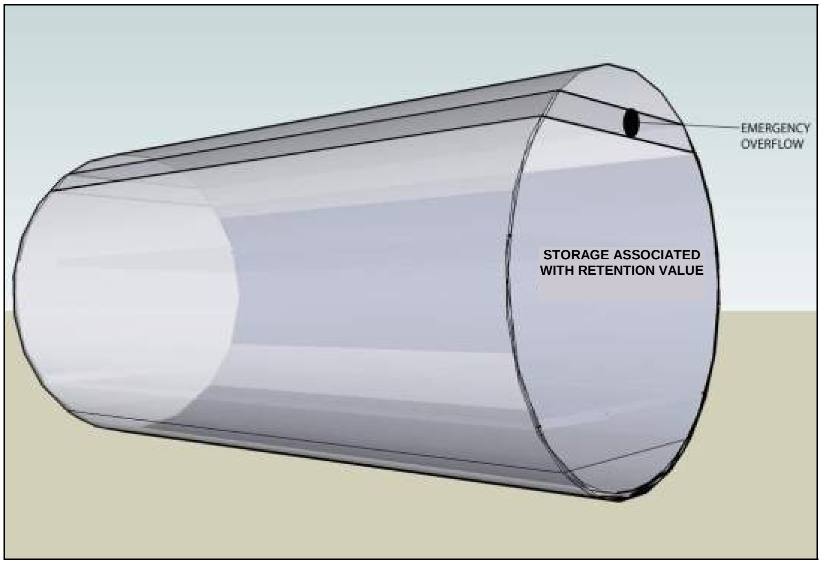

Figure 3.2.4. Tank Design 1: Storage Associated with the Design Storm Volume Only.

- **Tank Design 2.** The second tank set-up (Figure 3.2.5) uses tank storage to meet the SWRv storage objectives as well as using an additional detention volume to also meet some or all of the 2-yr and 15-year storm volume requirements. An orifice outlet is provided at the top of the design storage for the SWRv level, and an emergency overflow is located at the top of the detention volume level.

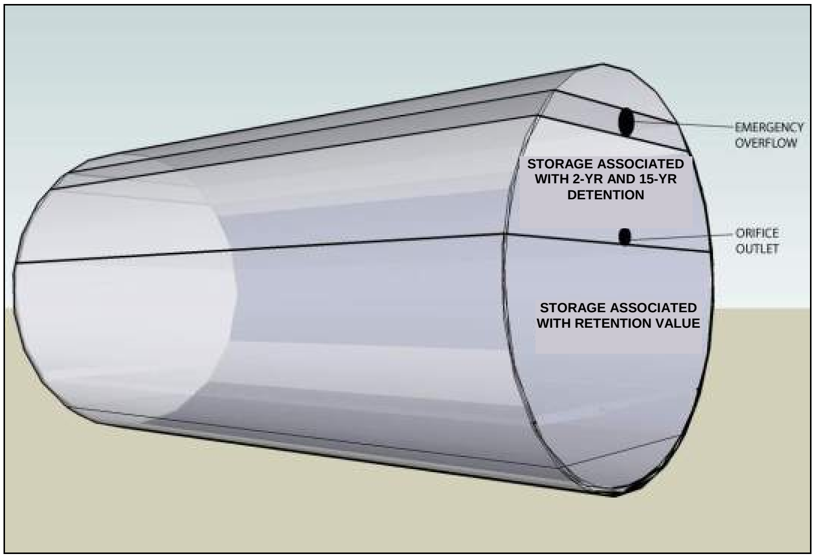

Figure 3.2.5. Tank Design 2: Storage Associated with Design Storm, Channel Protection, and Flood Volume.

- **Tank Design 3.** The third tank set-up (Figure 3.2.6) creates a constant drawdown within the system. The small orifice at the bottom of the tank needs to be routed to an appropriately designed secondary practice (e.g. rain garden, urban bioretention) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release should not be discharged to a receiving channel or storm drain without treatment, and maximum specified drawdown rates from this constant drawdown should be adhered to, since the primary function of the system is not intended to be detention.

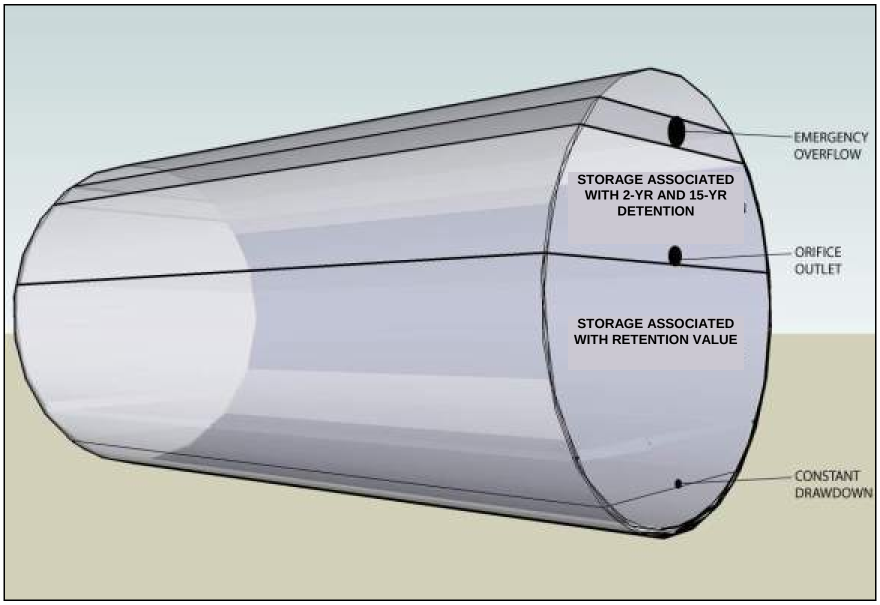

Figure 3.2.6. Tank Design 3: Constant drawdown, Storage Associated with Design Storm, Channel Protection and Flood Volume.

> For the purposes of this tank design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume percentage calculated in the Compliance Spreadsheet. In other words, the storage volume associated with the secondary practice must not be added (or double-counted) to the rainwater harvesting percentage. The reason for this is that the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown. The exception to this would be if the secondary practice were also sized to capture and treat impervious and/or turf area beyond the area treated by rainwater harvesting (i.e. the adjacent yard or a driveway). In this case, only these additional areas should be added into the Compliance Spreadsheet (details found in Chapter 5 and Appendix A) to receive retention volume achieved for the secondary practice.
>
> While a small orifice is shown at the bottom of the tank in Figure 3.2.6, the orifice could be replaced with a pump that would serve the same purpose, conveying a limited amount of water to a secondary practice on a routine basis.

Sizing of Rainwater Harvesting Systems. The rainwater harvesting cistern sizing criteria presented in this section was developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté and Lawson, 2009). The Cistern Design Spreadsheet (CDS) is primarily intended to provide guidance in sizing cisterns and to quantify the storage volume achieved for input into the Compliance Spreadsheet for stormwater management compliance purposes. A secondary objective of the spreadsheet is to increase the beneficial uses of the stored stormwater, treating it as a valuable natural resource. More information on the CDS can be found later in this Section. The spreadsheet can be found on DDOE’s website.

Incremental Design Volumes within Cistern. Rainwater tank sizing is determined by accounting for varying precipitation levels, captured CDA 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 the design storm (permanent storage), storage needed for 2-year or 15-year 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 3.2.7 for a graphical representation of these various incremental design volumes.

The design specification described in this Section (Rainwater Harvesting) does not provide guidance for sizing larger storms (e.g., 15-yr, Qf) but rather provides guidance on sizing for the SWRv design storms.

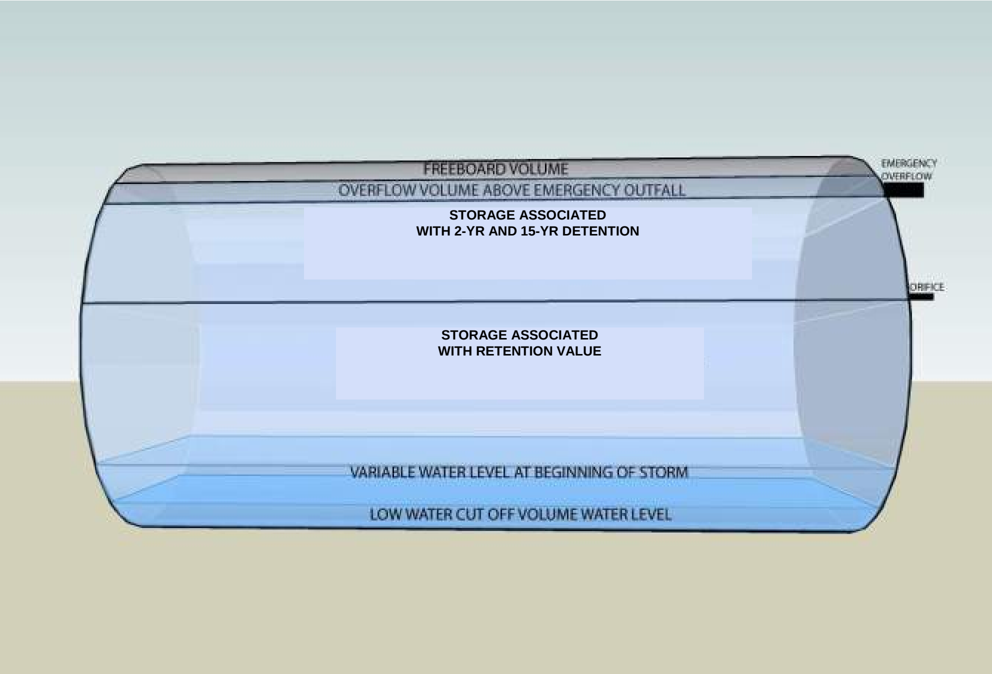

Figure 3.2.7. Incremental Design Volumes Associated with Tank Sizing.

The “Storage Associated with the Design Storm” is the storage within the tank that is modeled and available for reuse. While the SWRv will remain the same for a specific CDA, the “Storage Associated with the Design Storm” may vary depending on demand and storage volume retention 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.

Cistern Design Spreadsheet (CDS). The design specification provided in this Section (Rainwater Harvesting) is linked with the CDS. The spreadsheet uses daily rainfall data from September 1, 1977 to September 30, 2007 to model performance parameters of the cistern under varying CDAs, demands on the system, and tank size.

A runoff coefficient of 0.95 for CDA surfaces and a filter efficiency rate of 95% for the SWRv is assumed. It is also assumed that filters are to be installed on all systems and that the first flush diversion is incorporated into the filter efficiency. The remaining precipitation is then added to the water level that existed in the cistern the previous day, with all of the total demands subtracted on a daily basis. If any overflow is realized, the volume is quantified and recorded. If the tank runs dry (reaches the cut-off volume level), then the volume in the tank is fixed at the low level, and a dry-frequency day is recorded. The full or partial demand met in both cases is quantified and recorded. A summary of the water balance for the system is provided below.

- **Water Contribution**
  - **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and drainage area captured, as defined by the designer.

  - **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement tank levels. Note that municipal backups may also be connected post-tank (i.e. a connection is made to the non-potable water line that is used for pumping water from the tank for reuse), thereby not contributing any additional volume to the tank.

- **Water Losses**

  - **Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95% of the rainfall that lands on its surface (i.e. $R_v = 0.95$).
  - **First Flush Diversion.** The first 0.02 to 0.06 inches of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is assumed to be contained within the filter efficiency rate.
  - **Filter Efficiency.** Each filter has a filter efficiency curve associated with the rate of runoff and the size of the storm it will receive from the CDA. It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the SWRv storm will be successfully captured. This means that a minimum of 95% of the runoff should be conveyed into the tank. The filter efficiency value is not adjustable at this time and cannot be modified as an input value in the CDS, but it should not be less than 95%. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch/hour should be used for the SWRv. The appropriate rainfall intensity values for the 2-year and 15-year storms should be used when designing for larger storm events.
  - **Drawdown (Storage Volume).** This is the stored water within the cistern that is reused or directed to a secondary stormwater practice. It is the volume of runoff that is reduced from the CDA. This is the water loss that translates into the achievable storage volume retention.
  - **Overflow.** For the purposes of addressing the SWRv (not addressing larger storm volumes), orifice outlets for both detention and emergency overflows are treated the same. This is the volume of water that may be lost during large storm events or successive precipitation events.

Results for all Precipitation Events. The performance results of the rainwater harvesting system for all days during the entire period modeled, including the full spectrum of precipitation events, is included in the “Results” tab. This tab is not associated with determining the storage volume achieved, but rather it may be a useful tool in assisting the user to realize the performance of the various rainwater harvesting system sizes with the design parameters and demands specified.

- **Demand Met.** This is where the demand met for various size cisterns and CDA/demand scenarios is reported. A graph displaying the percentage of demand met for various cistern sizes is provided in this tab. Normally, this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided below in Figure 3.2.8.

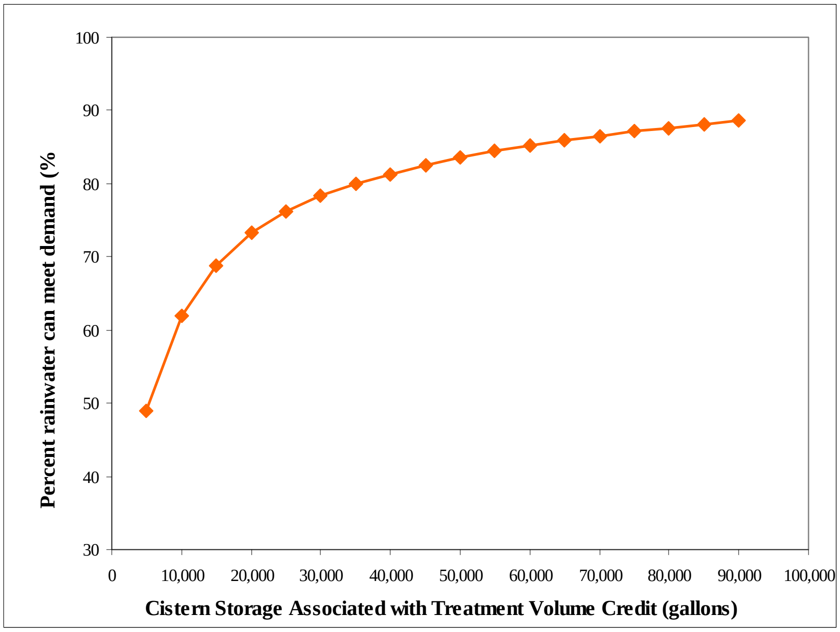

Figure 3.2.8. Percent Demand Met Vs. Storage for Reuse (Example).

At some point, larger cisterns no longer provide significant increases in percentages of demand met. Conversely, the curve informs the user when a small increase in cistern size can yield a significant increase in the percentage of time demand that is met.

- **Dry Frequency.** Another useful measure is the dry frequency. If the cistern is dry a substantial portion of the time, this measure can inform the user that he/she may want to decrease the size of the cistern, decrease the demand on the system or explore capturing more CDA to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.
- **Overflow Frequency.** This is a metric of both overflow frequency and average volume per year for the full spectrum of rainfall events. This will inform the user regarding the design parameters and magnitude of demand and associated performance of the system. If the system overflows at a high frequency, then the designer may want to increase the size of the cistern, decrease the CDA captured, or consider other mechanisms that could increase drawdown (e.g. increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not evident otherwise. One such inter-relationship is the percentage of demand met versus tank size compared to the percentage of overflow frequency versus tank size, depicted on the same graph. A range of cistern sizes that tends to emerge, informing the designer where a small increase or decrease in tank size can have a significant impact on dry frequency and overflow frequency. Conversely, outside this range, changes in cistern sizes would yield small changes to dry frequency and overflow frequency, yet yield a large trade-off compared to the cost of the rainwater harvesting system.

Results for SWRv. The amount of CDA runoff volume that the tank can capture and use or draw down for all precipitation events of 1.2 inches or 3.2 inches or less is also quantified and recorded. These results are presented on the "Results-Storage Volume Achieved" tab. This information is used to calculate the storage volume achieved, which is used as an input to the Compliance Spreadsheet.

- **Storage Volume Achieved.** A series of storage volumes achieved are calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the retention achieved versus cistern size. While larger tanks yield more retention, they are more costly. The curve assists the user to choose the appropriate tank size, based on the design objectives and site needs, as well as to understand the rate of diminishing returns.
- **Overflow Volume.** The frequency of cistern overflows and the average annual volume of the overflows resulting from precipitation events of 1.2 inches or less, or 3.2 inches or less are also reported in this tab. A chart of the Storage Volume Achieved and Overflow Frequency versus the storage volume is provided. An example is shown below in Figure 3.2.9.

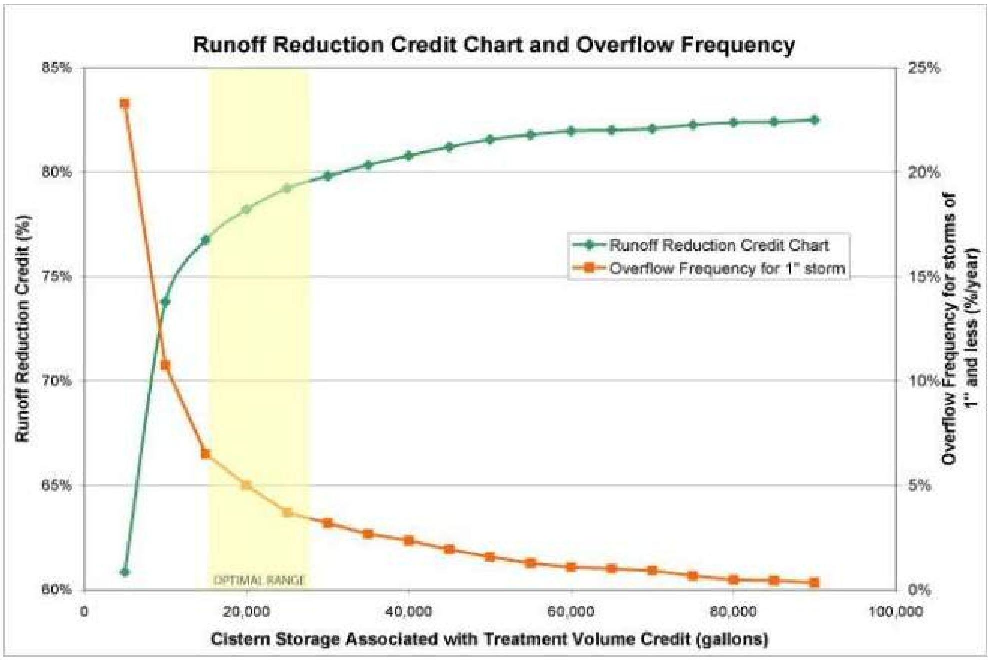

Figure 3.2.9. Percent Storage Volume Achieved vs. Storage for Non-potable Uses (Example).

These plotted results establish a trade-off relationship between these two performance metrics. In the above example, a 20,000 gallon cistern optimizes the storage volume achieved and the overflow frequency (near the inflection point of both curves).

Results from Cistern Design Spreadsheet to be Transferred to Compliance Spreadsheet. There are two results from this Cistern Design Spreadsheet that are to be transferred to the

Compliance Spreadsheet, as follows:

- **Storage Volume Value.** Once the cistern storage volume associated with the storage volume value has been selected, transfer that achieved percentage into the Storage Volume Spreadsheet column called "Percent Retention Achieved (%)" in the "Rainwater Harvesting" row in the blue cell (cell I32).
- **Contributing Drainage Area (CDA).** Enter the CDA that was used in the Cistern Design Spreadsheet in the same row into the Drainage Area columns in the blue cell (cell B26-D31).

Completing the Sizing Design of the Cistern. The total size of the cistern tank is the sum of the following four volume components:

- **Low Water Cutoff Volume (Included).** A dead storage area must be included so that the pump will not run the tank dry. This volume is included within the Cistern Design Spreadsheet volume modeled.
- **Cistern Storage Associated with Design Volume (Included).** This is the volume that was designed for using the Cistern Design Spreadsheet.
- **Adding Channel Protection and Flood Volumes (Optional).** Additional detention volume may be added above and beyond the Cistern Storage associated with the design storm volumes for the 2-year or 15-year events. Typical routing software programs may be used to design for this additional volume.
- **Adding Overflow and Freeboard Volumes (Required).** An additional volume above the emergency overflow must be provided in order for the tank to allow very large storms to pass. Above this, overflow water level will be an associated freeboard volume. This volume must account for a minimum of 5% of the overall tank size; however, sufficient freeboard should be verified for large storms. These volumes need to be added to the overall size of the cistern tank.

3.2.5. Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements should include the proposed delineation of planting areas to be irrigated, the planting plan, and quantification of the expected water demand. The default water demand for irrigation is 1.0 inches per week over the area to be irrigated. Justification must be provided if larger volumes are to be used.

3.2.6. Rainwater Harvesting Construction Sequence

Rainwater Harvesting Installation. It is advisable to have a single contractor to 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 pipes 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.

Construction Inspection. The following items should 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 stormwater treatment practice(s) is installed as shown on plans

An example construction phase inspection checklist for rainwater harvesting practices can be found in Appendix L.

3.2.7. Rainwater Harvesting Maintenance Criteria

Maintenance Inspections. It is highly recommended that periodic inspections and maintenance be conducted for each system. Example maintenance checklists for rainwater harvesting systems can be found in Appendix M.

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 3.2.3 describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 3.2.3. 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

Table 3.2.3 (cont'd). Suggested maintenance tasks for rainwater harvesting systems.

Activity	Frequency
Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices	O: Once a year
Inspect water quality devices	I: According to Manufacturer
Provide water quality analysis to DDOE	I: As indicated in TRAM
Inspect tank for sediment buildup	I: Every third year
Clear overhanging vegetation and trees over roof surface	O: 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	

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.

Cold Climate Considerations. Rainwater harvesting systems have a number of components that can be impacted by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, winter-time operation may be more challenging, depending on tank size and whether heat tape is used on piping. If not protected from freezing, these rainwater harvesting systems must be taken offline for the winter and stormwater treatment values may not be granted for the practice during that off-line period. At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions should be disconnected and drained. It may be possible to reconnect former roof leader systems for the winter.

For underground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

A declaration of covenants that includes all maintenance responsibilities to ensure the continued stormwater performance for the BMP is required. The declaration of covenants specifies the property owner's primary maintenance responsibilities, and authorizes DDOE staff to access the property for inspection or corrective action in the event the proper maintenance is not performed. The declaration of covenants is attached to the deed of the property. An example form is provided at the end of Chapter 5 though variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the District Government. It is submitted through the Office of the Attorney General (OAG). All SWMPs have a maintenance agreement stamp that must be signed for a building permit to proceed. A maintenance schedule must appear on the SWMP. Additionally, a maintenance schedule is required in schedule c of the declaration of covenants.

Covenants are not required on government properties, but maintenance responsibilities must be defined through a partnership agreement or a memorandum of understanding.

Waste material from the repair, maintenance, or removal of a BMP or land cover change shall be removed, and the maintenance contractor shall submit a written report to DDOE within forty-eight (48) hours after disposing of the waste material. The report shall include:

(a) The name, address, phone number, and business license number of the contractor transporting the waste materials;
(b) Date of removal;
(c) The address of the BMP;
(d) Type of BMP serviced;
(e) Amount and type of waste material removed;
(f) The name and location of the facility where the waste material was disposed of; and
(g) A sworn statement that disposal was in compliance with applicable federal and District law.

3.2.8. Rainwater Harvesting: Stormwater Compliance Calculations

Rainwater harvesting practices receive a partial retention value for the SWRv that is equivalent to the percent retention achieved (%) determined by using the CDS, as described in Section 3.2.4.

3.2.9. References

Cabell Brand Center. 2007. *Virginia Rainwater Harvesting Manual*. Salem, VA. http://www.cabellbrandcenter.org

Cabell Brand Center. 2009. *Virginia Rainwater Harvesting Manual, Version 2.0*. Salem, VA. (Draft Form) http://www.cabellbrandcenter.org

Forasté, J. Alex and Lawson, Sarah. 2009. *Cistern Design Spreadsheet*, McKee-Carson, Rainwater Management Systems, Inc., and Center for Watershed Protection, Inc.

National Oceanic and Atmospheric Administration (NOAA). 2004. *NOAA Atlas 14 Precipitation-Frequency Atlas of the United States, Volume 2, Version 3.0*. Revised 2006. Silver Spring, MD.

Texas Regional Water Board (TWDB). 2005. The Texas Manual Rainwater Harvesting. Third Ed. Austin, TX.