3.3 Rainwater Harvesting

Definition. Rainwater harvesting systems store rainfall and release it for future use. Rainwater that falls on a rooftop or other impervious surface is collected and conveyed into an above- or below-ground tank (also referred to as a cistern), where it is stored for non-potable uses or for on-site disposal or infiltration as stormwater. Cisterns can be sized for commercial as well as residential purposes. Residential cisterns are commonly called rain barrels.

Non-potable uses of harvested rainwater may include the following:

- Landscape irrigation,
- Exterior washing (e.g., car washes, building facades, sidewalks, street sweepers, and fire trucks),
- Flushing of toilets and urinals,
- Fire suppression (i.e., sprinkler systems),
- Supply for cooling towers, evaporative coolers, fluid coolers, and chillers,
- Supplemental water for closed loop systems and 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 the following:

- Disconnection to a pervious area (compacted cover) or conservation area (natural cover) or soil amended filter path (see Section 3.4 Impervious Surface Disconnection)
- Overflow to bioretention practices (see Section 3.6 Bioretention)
- Overflow to infiltration practices (see Section 3.8 Stormwater Infiltration)
- Overflow to grass channels or dry swales (see Section 3.12 Storage Practices)

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 water supply, decreased water costs for the end user, and potential for increased groundwater recharge).

The seven primary components of a rainwater harvesting system are discussed in detail in Section 3.3.4. Some are depicted in Figure 3.2. The components include the following:

- Contributing drainage area (CDA) surface,
- Collection and conveyance system (e.g., gutter and downspouts) (number 1 in Figure 3.2)
- Pretreatment, including prescreening and first flush diverters (number 2 in Figure 3.2)
- Cistern (no number, but depicted in Figure 3.2)
- Water quality treatment (as required by Tiered Risk Assessment Management (TRAM))
- Distribution system
- Overflow, filter path or secondary stormwater retention practice (number 8 in Figure 3.2)

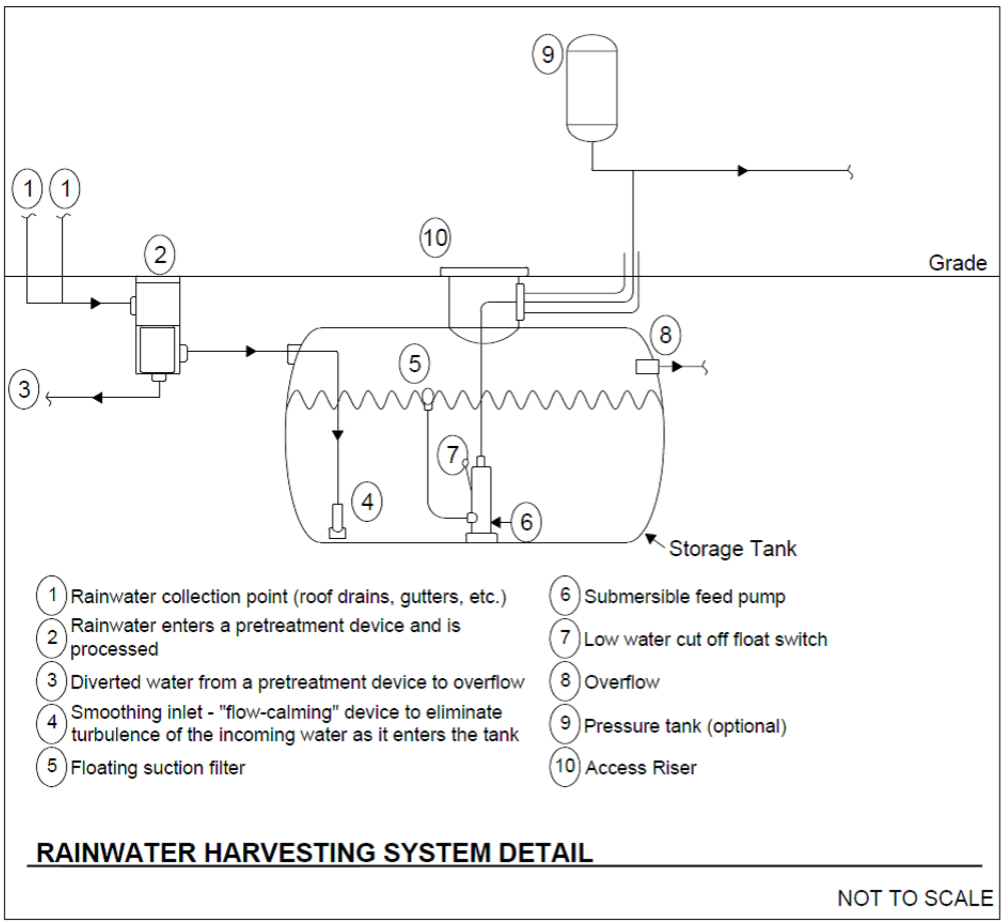

Figure 3.2 Example of a rainwater harvesting system detail.

3.3.1 Rainwater Harvesting Feasibility Criteria

A number of site-specific features influence how rainwater harvesting systems are designed and/or utilized. The following are key considerations for rainwater harvesting feasibility. They are not comprehensive or conclusive; rather, they are recommendations to consider during the planning process to incorporate rainwater harvesting systems into the site design.

Plumbing Code. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the District's 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 the District's 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 TRAM (see Appendix M) 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 cistern 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. Cisterns can be placed underground, indoors, adjacent to buildings, and on rooftops that are structurally designed to support the added weight. Designers can work with architects and landscape architects to creatively site the cisterns. Underground utilities or other obstructions should always be identified prior to final determination of the cistern location.

Site Topography. Site topography and cistern 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 cistern outlet pipe at the discharge point must match the invert of the receiving mechanism (e.g., natural channel, storm drain system) and be sufficiently sloped to adequately convey 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 cistern location will also affect pumping requirements. Locating cisterns 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 cisterns 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 may 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 combined weight of the tank and hold-down ballast must meet or exceed the buoyancy force of the cistern. The cistern must also be installed according to the cistern manufacturer’s specifications.

Soils. Cisterns 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 foundation, may be appropriate depending on the soils and cistern characteristics. Where the installation requires a foundation, the foundation must be designed to support the cistern’s weight when the cistern is full consistent with the bearing capacity of the soil and good engineering practice. 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 cisterns and piping associated with the system.

Contributing Drainage Area. The contributing drainage area (CDA) to the cistern is the impervious area draining to the cistern. Rooftop surfaces are what typically make up the CDA, but paved 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 harvesting from a sealed or painted roof surface is desired, it is recommended that the sealant or paint be 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, cistern 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 cistern 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.

Setbacks from Buildings. Cistern overflow devices must be designed to avoid causing ponding or soil saturation within 10 feet of building foundations. While most systems are generally sited underground and more than ten feet laterally from the building foundation wall, some cisterns are incorporated into the basement of a building or underground parking areas. In any case, cisterns 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 other heavy loading, such as deep earth fill. If site constraints dictate otherwise, systems must be designed to support the loads to which they will be subjected.

3.3.2 Rainwater Harvesting Conveyance Criteria

Collection and Conveyance. The collection and conveyance system consists of the gutters, downspouts, and pipes that channel rainfall into cisterns. 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. Typically, gutters should be hung at a minimum of 0.5 percent for 2/3 of the length and at 1 percent for the remaining 1/3 of the length in order to adequately convey the design storm (i.e.., Stormwater Retention Volume (SWRv)). If the system will be used for management of the 2-year and 15-year storms, the gutters must be designed to convey the appropriate 2-year and 15-year storm intensities.

Pipes, which connect downspouts to the cistern, should be at a minimum slope of 1.5 percent 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 must 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 cistern. Overflow pipe(s) must 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) must be screened to prevent access to the cistern by small mammals and birds. All overflow from the system must be directed to an acceptable flow path that will not cause erosion during a 2-year storm event.

3.3.3 Rainwater Harvesting Pretreatment Criteria

Prefiltration is required to keep sediment, leaves, contaminants, and other debris from the system. Leaf screens and gutter guards meet the minimal requirement for prefiltration of small systems, although direct water filtration is preferred. The purpose of prefiltration is to significantly cut down on maintenance by preventing organic buildup in the cistern, thereby decreasing microbial food sources.

Diverted flows (i.e., first flush diversion and/or overflow from the filter, if applicable) must be directed to an appropriate BMP or to a settling tank to remove sediment and pollutants prior to discharge from the site.

Various pretreatment devices 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 cistern. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the cistern at all. A design intensity of 1 inch/hour (for design storm = SWRv) must be used for the purposes of sizing pre-cistern 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-year and 15-year storm intensities must be used for the design of the conveyance and pretreatment portion of the system. The Rainwater Harvesting Retention Calculator, discussed more in Section 3.3.4, allows for input of variable filter efficiency rates for the SWRv design storm. To meet the requirements to manage the 2-year and 15-year storms, a minimum filter efficiency of 90 percent must be met.

- **First Flush Diverters.** First flush diverters (see Figure 3.3) direct the initial pulse of rainfall away from the cistern. 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.
- **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 cisterns. Built-up debris can also harbor bacterial growth within gutters or downspouts (Texas Water Development Board, 2005).
- **Roof Washers.** Roof washers are placed just ahead of cisterns and are used to filter small debris from harvested rainwater (see Figure 3.4). Roof washers consist of a cistern, 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.
- **Hydrodynamic Separator.** For large-scale applications, hydrodynamic separators and other devices can be used to filter rainwater from larger CDAs.

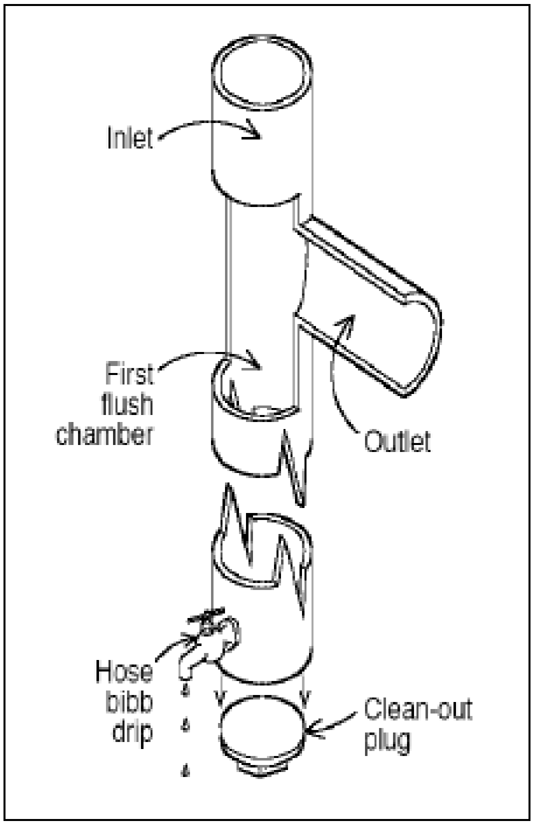

Figure 3.3 Diagram of a first flush diverter. (Texas Water Development Board, 2005)

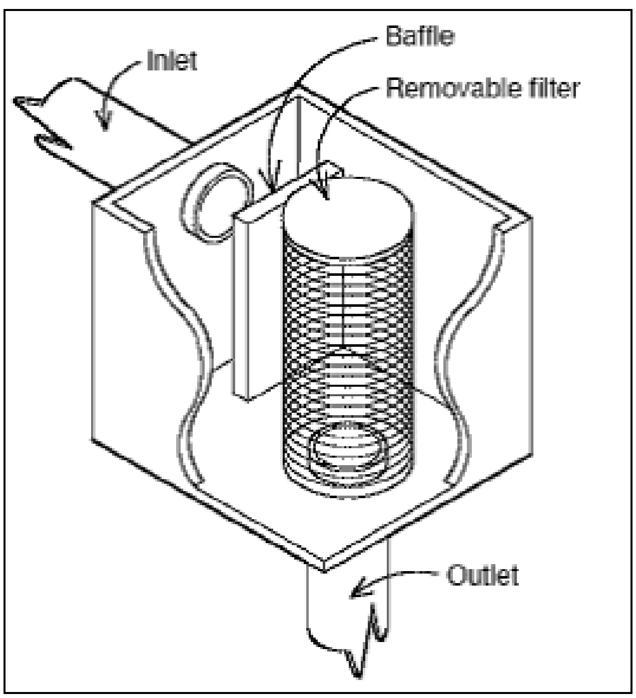

Figure 3.4 Diagram of a roof washer. (Texas Water Development Board, 2005)

3.3.4 Rainwater Harvesting Design Criteria

System Components: Seven primary components of a rainwater harvesting system require special considerations (some of these are depicted in Figure 3.2):

- CDA or CDA surface
- Collection and conveyance system (i.e., gutter and downspouts)
- Cisterns
- Pretreatment, including prescreening and first flush diverters
- Water quality treatment (as required by TRAM)
- Distribution systems
- 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 M.

  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 3.3.2 Rainwater Harvesting Conveyance Criteria.
- **Pretreatment.** See Section 3.3.3 Rainwater Harvesting Pretreatment Criteria.
- **Cisterns.** The cistern is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities generally range from 250 to 30,000 gallons, but they can be as large as 100,000 gallons or more for larger projects. Multiple cisterns can be placed adjacent to each other and connected with pipes to balance water levels and to tailor the storage volume needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Cistern volumes are calculated to meet the water demand and stormwater storage volume retention objectives, as described further below in this specification.

  While many of the graphics and photos in this specification depict cisterns with a cylindrical shape, the cisterns can be made of many materials and configured in various shapes, depending on the type used and the site conditions where the cisterns 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 cistern:

- Aboveground cisterns should be ultraviolet and impact resistant.
- Underground cisterns must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic).
- Underground rainwater harvesting systems must have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. The access opening must be installed in such a way as to prevent surface- or groundwater from entering through the top of any fittings, and it must be secured/locked to prevent unwanted entry. Confined space safety precautions/requirements should be observed during cleaning, inspection, and maintenance.
- All rainwater harvesting systems must 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 3.5 below compares the advantages and disadvantages of different cistern materials.
- Cisterns must be opaque or otherwise protected from direct sunlight to inhibit growth of algae, and they must be screened to discourage mosquito breeding.
- Dead storage below the outlet to the distribution system and an air gap at the top of the cistern must be included in the total cistern volume. For gravity-fed systems, a minimum of 6 inches of dead storage must 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; this may include incorporating an air gap to separate the two supplies.

Table 3.5 Advantages and Disadvantages of Typical Cistern Materials (Source: Cabell Brand Center, 2007; Cabell Brand Center, 2009)

Cistern 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

Cistern Material	Advantages	Disadvantages
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, and 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 (see Appendix M).
- **Distribution Systems.** Most distribution systems require a pump to convey harvested rainwater from the cistern 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 cistern 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 and gravel systems). 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 must be installed to allow the system to be completely emptied, if needed. Above-ground outdoor pipes must be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter if winter use is planned.
- **Overflow.** See Section 3.3.2 Rainwater Harvesting Conveyance Criteria.

Rainwater Harvesting Material Specifications. The basic material specifications for rainwater harvesting systems are presented in Table 3.6. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated cisterns and other system components.

Table 3.6 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 must 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 cisterns. ▪ Be sure to include needed bends and tees.
Pretreatment	At least one of the following (all rainwater to pass through pretreatment): ▪ First flush diverter ▪ Hydrodynamic separator ▪ Roof washer ▪ Leaf and mosquito screen (1 mm mesh size)
Cisterns	▪ Materials used to construct cisterns must be structurally sound. ▪ Cisterns should be constructed in areas of the site where soils can support the load associated with stored water. ▪ Cisterns must be watertight and sealed using a water-safe, non-toxic substance. ▪ Cisterns must be opaque or otherwise shielded to prevent the growth of algae. ▪ 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. Rainwater harvesting systems can have many design variations that meet user demand and stormwater objectives. This specification provides a design framework to achieve the SWRv objectives that are required to comply with the regulations, and it adheres to the following concepts:

- Give preference to use of rainwater as a resource to meet on-site demand or in conjunction with other stormwater retention practices.
- Reduce peak flow by achieving volume reduction and temporary storage of runoff.

Based on these concepts, this specification focuses on system design configurations that harvest rainwater for internal building uses, seasonal irrigation, and other activities, such as cooling tower use and vehicle washing. While harvested rainwater will be in year-round demand for many internal building uses, some other uses will have varied demand depending on the time of year (e.g., cooling towers and seasonal irrigation). Thus, a lower retention value is assigned to a type of use that has reduced demand.

Design Objectives and Cistern Design Set-Ups. Prefabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. Three basic cistern designs meet the various rainwater harvesting system configurations in this section.

- **Cistern Design 1.** The first cistern set-up (Figure 3.5) 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 cistern 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-year and 15-year storm volumes with this cistern configuration, but the primary purpose is to address the smaller SWRv design storm.

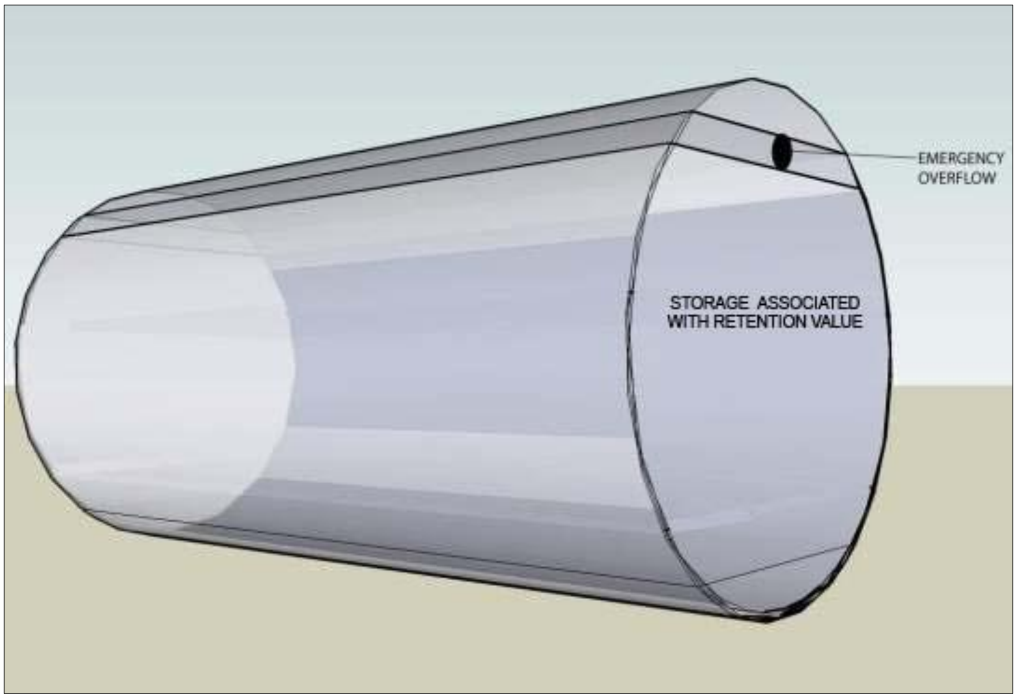

Figure 3.5 Cistern Design 1: Storage associated with the design storm volume only.

- **Cistern Design 2.** The second cistern set-up (Figure 3.6) uses cistern storage to meet the SWRv storage objectives and also uses additional detention volume to meet some or all of the 2-year 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.

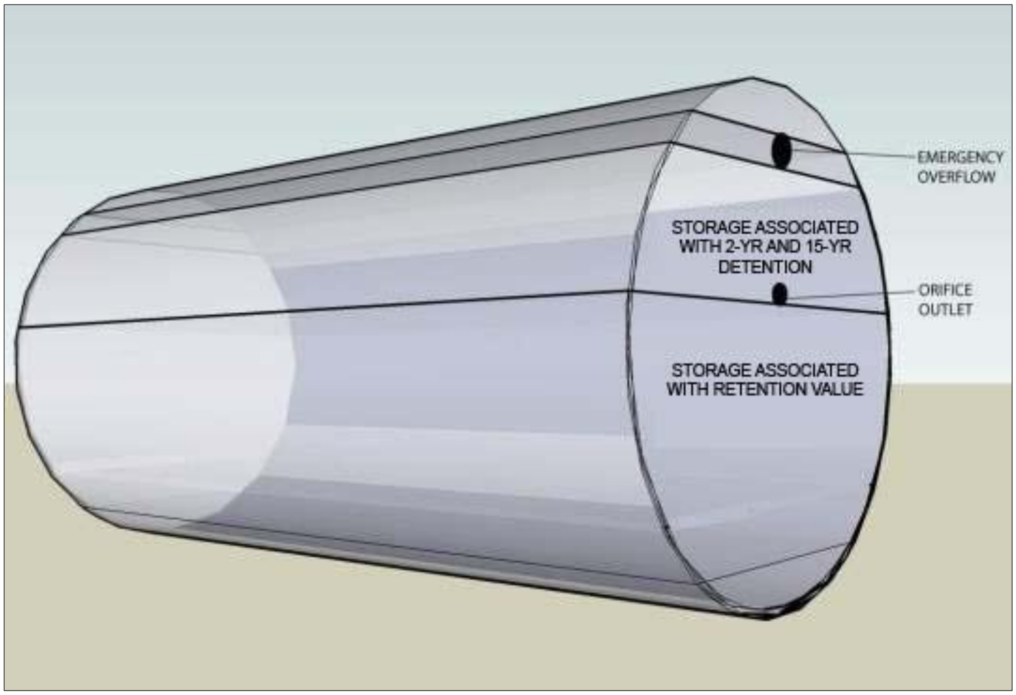

Figure 3.6 Cistern Design 2: Storage associated with design storm, channel protection, and flood volume.

- **Cistern Design 3.** The third cistern set-up (Figure 3.7) creates a constant drawdown within the system. The small orifice at the bottom of the cistern needs to be routed to an appropriately designed secondary practice (i.e., bioretention, stormwater infiltration) that will allow the rainwater to be treated and allow for groundwater recharge over time. The release must 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.

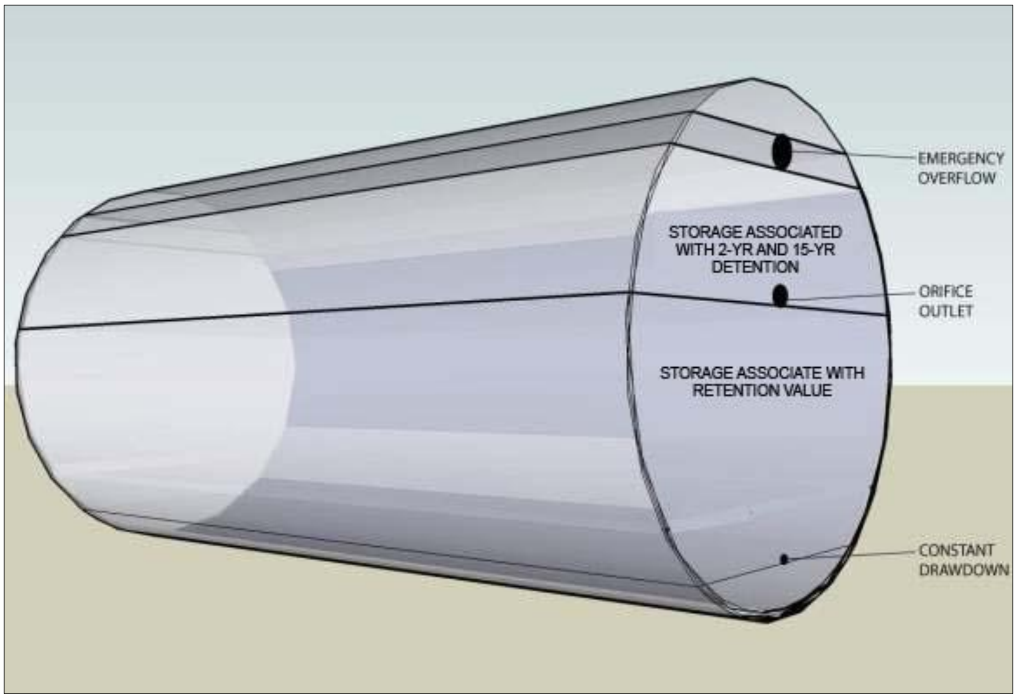

Figure 3.7 Cistern Design 3: Constant drawdown version where storage is associated with design storm, channel protection, and flood volume.

Design Storm, Channel Protection, and Flood Volume. For the purposes of the third cistern design, the secondary practice must be considered a component of the rainwater harvesting system with regard to the storage volume percentage calculated in the General Retention Compliance Calculator (discussed in Chapter 5 and Appendix A). In other words, the storage volume associated with the secondary practice must not be added (or double-counted) to the rainwater harvesting percentage because the secondary practice is an integral part of a rainwater harvesting system with a constant drawdown. The exception to this requirement 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 (for example from the adjacent yard or a driveway). In this case, only these additional areas should be added into the General Retention Compliance Calculator to receive retention volume achieved for the secondary practice.

While a small orifice is shown at the bottom of the cistern in Figure 3.7, 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 were developed using a spreadsheet model that used best estimates of indoor and outdoor water demand, long-term rainfall data, and CDA capture area data (Forasté2011). The Rainwater Harvesting Retention Calculator is for cistern sizing guidance and to quantify the retention value for storage volume achieved. This retention value is required for input into the General Retention Compliance Calculator and is part of the submission of a Stormwater Management Plan (SWMP) using rainwater harvesting systems for compliance. 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 Rainwater Harvesting Retention Calculator can be found later in this section. The spreadsheet can be found on DDOE's website at http://ddoe.dc.gov/swregs.

Rainwater Harvesting Retention Calculator. The design specification provided in this section (Rainwater Harvesting) is linked with the Rainwater Harvesting Retention Calculator. 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 cistern size.

The runoff that reaches the cistern each day is 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 cistern runs dry (reaches the cut-off volume level), then the volume in the cistern 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.

Incremental Design Volumes within Cistern. Rainwater cistern 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 3.8 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., Qp_2, Qp_{15}, and Q_f), but rather provides guidance on sizing for the SWRv design storms.

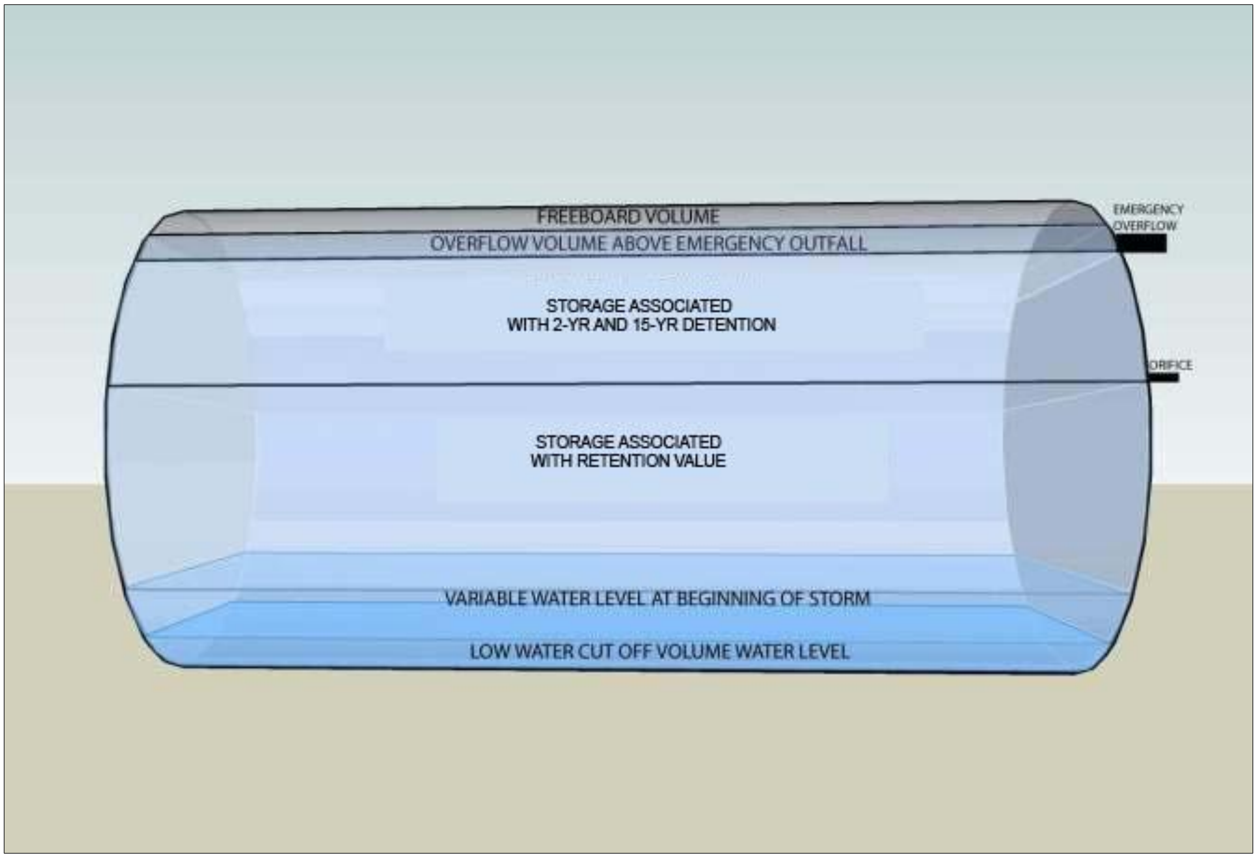

Figure 3.8 Incremental design volumes associated with cistern sizing.

The "Storage Associated with the Retention Value" is the storage within the cistern that is modeled and available for reuse. While the SWRv will remain the same for a specific CDA, the "Storage Associated with the Retention Value" 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.

Water Contribution

- **Precipitation.** The volume of water contributing to the rainwater harvesting system is a function of the rainfall and CDA, as defined by the designer.
- **Municipal Backup (optional).** In some cases, the designer may choose to install a municipal backup water supply to supplement cistern levels. Note that municipal backups may also be connected post-cistern (i.e., a connection is made to the non-potable water line that is used for pumping water from the cistern for reuse), thereby not contributing any additional volume to the cistern. Municipal backup designs that supply water directly to the cistern are not accounted for in the Rainwater Harvesting Retention Calculator.

Water Losses

- **Drainage Area Runoff Coefficient.** The CDA is assumed to convey 95 percent of the rainfall that lands on its surface (i.e., Rv = 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.** 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. For the 1.2-inch storm, a minimum of 95 percent of the runoff should be conveyed into the cistern. For the 3.2-inch storm, a minimum of 90 percent of the runoff should be conveyed. These minimum values are included as the filter efficiencies in the Rainwater Harvesting Retention Calculator, although they can be altered (increased) if appropriate. The Rainwater Harvesting Retention Calculator applies these filter efficiencies, or interpolated values, to the daily rainfall record to determine the volume of runoff that reaches the cistern. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1 inch per hour shall be used for the SWRv. The appropriate rainfall intensity values for the 2-year (3.2-inch) and 15-year storms shall 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 for 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 instead 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.

- **Percentage of Demand Met.** This is where the percentage of demand met for various size cisterns and CDA/demand scenarios is reported. A graph displaying the percentage of demand met versus the percentage of overflow frequency 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 3.9.

  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 that demand is met.

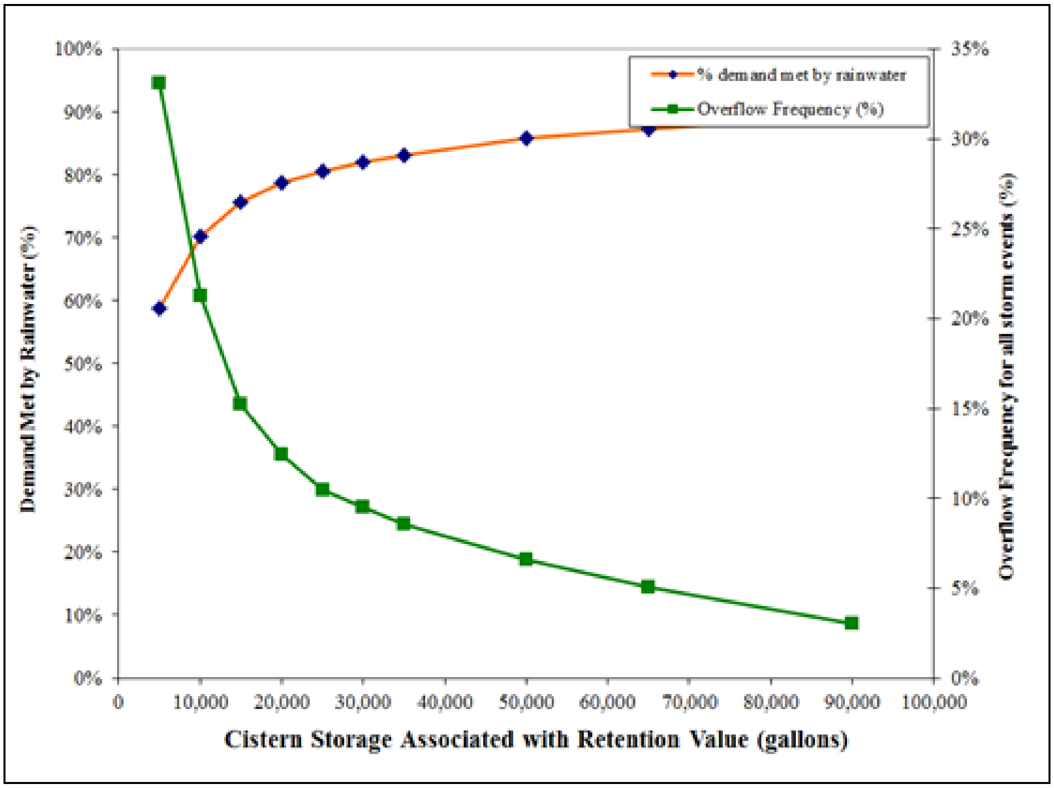

Figure 3.9 Example of percent demand met versus cistern storage.

- **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 metric will inform the user regarding the design parameters, 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. An example of this usefulness is demonstrated when the plot of “percentage-of-demand-met versus cistern size” is compared against the plot of “the percentage-of-overflow-frequency versus cistern size.” By depicting these plots on the same graph, a range of optimum cistern sizes emerges. This informs the designer where a small increase or decrease in cistern size will have a significant impact on dry frequency and overflow frequency. Looking outside this range will indicate where changes in cistern sizes

will not have significant influence over dry frequency and overflow frequency, but may offer a large trade-off compared to the cost of the rainwater harvesting system.

Results for Retention Value. The retention value percentage of CDA runoff volume that the cistern can capture for a 1.7-inch storm on an average daily basis given the water demands by the user is presented on the “Results-Retention Value” tab. This information is used to calculate the retention value percentage, which is used as an input to the General Retention Compliance Calculator.

- **Retention Value Percentage Achieved.** The percentage of retention value achieved is 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 cisterns yield more retention, they are more costly. The curve helps the user to choose the appropriate cistern size, based on the design objectives and site needs, and to understand the rate of diminishing returns.
- **Overflow Volume.** The volume of the overflows resulting from a 1.7-inch precipitation event is also reported in this tab. A chart of the retention value and overflow frequency versus the storage volume is provided. An example is shown in Figure 3.10.

  These plotted results establish a trade-off relationship between these two performance metrics. In the example in Figure 3.10, a 13,000 gallon cistern optimizes the storage volume achieved and the overflow frequency (near the inflection point of both curves).

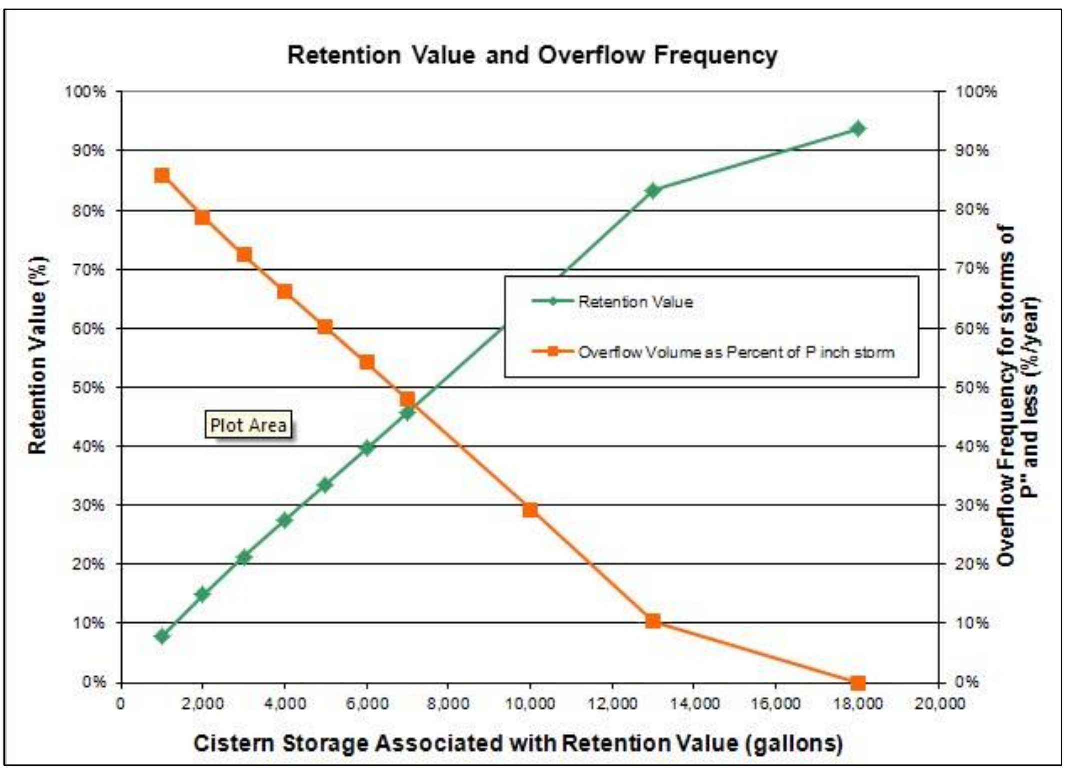

Figure 3.10 Example of retention value percentage achieved versus storage for non-potable uses.

Results from the Rainwater Harvesting Retention Calculator to be Transferred to the General Retention Compliance Calculator. There are two results from the Rainwater Harvesting Retention Calculator that are to be transferred to the General Retention Compliance Calculator, as follows:

- **Contributing Drainage Area (CDA).** Enter the CDA that was used in the Rainwater Harvesting Retention Calculator in the same row into the Drainage Area columns in the blue cell (cell B26-D31).
- **Retention Value.** Once the cistern storage volume associated with the retention value has been selected, transfer that achieved percentage into the General Retention Compliance Calculator column called "% Retention Value" in the "Rainwater Harvesting" row (cell I33).

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

- **Low Water Cutoff Volume (Included).** A dead storage area must be included so the pump will not run the cistern dry. This volume is included in the Rainwater Harvesting Retention Calculator's modeled volume.
- **Cistern Storage Associated with Design Volume (Included).** This is the design volume from the Rainwater Harvesting Retention Calculator.
- **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 cistern to allow very large storms to pass. Above this overflow water level, there will be an associated freeboard volume that should account for at least 5 percent of the overall cistern size. Sufficient freeboard must be verified for large storms, and these volumes must be included in the overall size of the cistern.

3.3.5 Rainwater Harvesting Landscaping Criteria

If the harvested water is to be used for irrigation, the design plan elements must 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.

3.3.6 Rainwater Harvesting Construction Sequence

Installation. It is advisable to have a single contractor to install the rainwater harvesting system, outdoor irrigation system, and secondary retention 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.

1. Choose the cistern location on the site
2. Route all downspouts or pipes to prescreening devices and first flush diverters
3. Properly install the cistern
4. Install the pump (if needed) and piping to end uses (indoor, outdoor irrigation, or cistern dewatering release)
5. Route all pipes to the cistern
6. Stormwater must not be diverted to the rainwater harvesting system until the overflow filter path has been stabilized with vegetation.

Construction Supervision. The following items should be inspected by a qualified professional 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

DDOE's construction phase inspection checklist for rainwater harvesting practices and the Stormwater Facility Leak Test form can be found in Appendix K.

3.3.7 Rainwater Harvesting Maintenance Criteria

Maintenance Inspections. Periodic inspections and maintenance shall be conducted for each system by a qualified professional.

DDOE's maintenance inspection checklists for rainwater harvesting systems and the Maintenance Service Completion Inspection form can be found in Appendix L.

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 3.7 describes routine maintenance tasks necessary to keep rainwater harvesting systems in working condition. Maintenance tasks must be performed by an "Inspector Specialist," certified by the American Rainwater Catchment Association.

Maintenance tasks must be documented and substantially comply with the maintenance responsibilities outlined in the declaration of covenants.

Table 3.7 Typical Maintenance Tasks for Rainwater Harvesting Systems

<table>
<tr><th>Responsible Person</th><th>Frequency</th><th>Activity</th></tr>
<tr><td rowspan="4">Owner</td><td>Four times a year</td><td>Inspect and clean prescreening devices and first flush diverters</td></tr>
<tr><td>Twice a year</td><td>Keep gutters and downspouts free of leaves and other debris</td></tr>
<tr><td>Once a year</td><td>▪ Inspect and clean storage cistern lids, paying special attention to vents and screens on inflow and outflow spigots. Check mosquito screens and patch holes or gaps immediately
▪ Inspect condition of overflow pipes, overflow filter path, and/or secondary stormwater treatment practices</td></tr>
<tr><td>Every third year</td><td>Clear overhanging vegetation and trees over roof surface</td></tr>
<tr><td rowspan="3">Qualified Third Party Inspector</td><td>According to Manufacturer</td><td>Inspect water quality devices</td></tr>
<tr><td>As indicated in TRAM</td><td>Provide water quality analysis to DDOE</td></tr>
<tr><td>Every third year</td><td>▪ Inspect cistern for sediment buildup
▪ Check integrity of backflow preventer
▪ Inspect structural integrity of cistern, pump, pipe and electrical system
▪ Replace damaged or defective system components</td></tr>
</table>

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding. Designers must provide screens on above- and below-ground cisterns to prevent mosquitoes and other insects from entering the cisterns. 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 temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs.

For above-ground systems, wintertime operation may be more challenging, depending on cistern 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.

Declaration of Covenants. 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. A template form is provided at the end of Chapter 5 (see Figure 5.4), although variations will exist for scenarios where stormwater crosses property lines. The covenant is between the property and the Government of the District of Columbia. It is submitted through the Office of the Attorney General. 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 Exhibit 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. Waste material from the repair, maintenance, or removal of a BMP or land cover shall be removed and disposed of in compliance with applicable federal and District law.

3.3.8 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 Rainwater Harvesting Retention Calculator, as described in Section 3.3.4. Rainwater harvesting is not an accepted total suspended solids treatment practice.

3.3.9 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. http://www.cabellbrandcenter.org/Downloads/RWH_Manual2009.pdf

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