RH-1. Introduction

Source: Rainwater Management Solutions, Inc.

Rainwater Harvesting systems intercept, divert, store and release rainfall for future use. Their runoff and pollutant reduction rates are based on the system's size, configuration, water demand, and use of secondary practices to manage overflow from Rainwater Harvesting systems.

Rainwater Harvesting can be used to:

- Manage the first one inch of rainfall on-site, in part or in whole, depending on the tank size, year-round demand for the water, and use of a secondary, downstream practice to manage tank drawdowns and overflows (See **Table RH-1**).
- Reduce pollutant loads to meet water quality targets (total maximum daily loads or TMDLs) (See **Table RH-2**).
- Retrofit existing developed areas

The capture and reuse of rainwater can significantly reduce stormwater runoff volumes and pollutant loads. By providing a reliable and renewable source of water to end users, Rainwater Harvesting systems can also have environmental and economic benefits beyond stormwater management (e.g., increased water conservation, water supply during drought and mandatory municipal water supply restrictions, decreased demand on municipal or groundwater supply, decreased water costs for the end-user, potential for increased groundwater recharge).

Rainwater that falls on a rooftop is collected and conveyed into an above- or below-ground storage tank where it can be used for non-potable water uses and on-site stormwater infiltration or treatment. Non-potable uses may include flushing of toilets and urinals inside buildings, landscape irrigation, exterior washing (e.g. car washes, building facades, sidewalks, street sweepers, fire trucks, etc.), fire suppression (sprinkler) systems, supply for chilled water cooling towers, replenishing and operation of water features and water fountains, and laundry, if approved by the local authority.

Figure RH-1 further illustrates typical Rainwater Harvesting applications, and **Figure RH-2** illustrates a typical schematic. **Table RH-1** describes the runoff reduction performance and **Table RH-2** describes the pollutant removal performance of Rainwater Harvesting systems. **Table RH-3** is a design checklist to help guide the design process for Rainwater Harvesting systems.

A Cistern Design Spreadsheet is provided as a companion to this specification, and is discussed in more detail in **Supplements 4.2.8.A (Description of Spreadsheet), 4.2.8.B (Step-By-Step Instructions), and 4.2.8.C (Notes on Methodology**) at the end of this specification..

In this specification, the terms cistern and tank are used interchangeably to refer to the storage component of a Rainwater Harvesting system.

RH-1.1. Planning the Practice – Example Applications

Figure RH-1. Example Applications of Rainwater Harvesting

Underground Tank to Irrigate Turf Fields Source: City of Charlottesville, VA

Vehicle Wash Water Source: City of Charlottesville

Indoor Uses: Laundry, Toilet Flushing, Etc.

Figure RH-2. Schematic of Typical Rainwater Harvesting System

1. **Rooftop surface** – Sections RH-3 & RH-4.1
2. **Collection & conveyance system** – Section RH-4.6
3. **Pretreatment** – Section RH-4.7
4. **Storage tank configuration** – Sections RH-4.3 & RH-4.8
5. **Distribution system** – Section RH-4.1
6. **Overflow and/or treatment in secondary runoff reduction practice** – Sections RH-4.3 & RH-4.9

RH-1.2. Rainwater Harvesting Design Options & Performance

Table RH-1 describes the runoff reduction performance functions for Rainwater Harvesting systems. Rainwater Harvesting system design does not have a Level 1 and Level 2 design. Runoff reduction credits are based on the total amount of annual internal water reuse, outdoor water reuse, and tank dewatering discharge calculated to be achieved by the tank system using the Cistern Design Spreadsheet. As noted in **Table RH-2**, pollutant removal rates for the purposes of TMDLs and watershed plans are equal to the runoff reduction rates derived from the Cistern Design Spreadsheet.

Table RH-1. Rainwater Harvesting Runoff Reduction Performance

Description	Applications	Performance Achieved Toward Reducing 1" of Rainfall
Standard Design -- • Year-round use of stored water and/or downstream secondary runoff reduction practice to manage drawdown and overflow from the tank • System components as per the specification	Usually sites with substantial rooftop areas and defined beneficial uses for the stored water. Small-scale (e.g., residential, small-scale commercial) applications are also possible if there are defined outdoor and/or indoor uses of the water.	Credit is variable and determined using the Cistern Design Spreadsheet. Design Volume credit up to 100% is possible if all water from storms with rainfall of 1 inch or less is used through demand, and the tank is sized such that no overflow from this size storm event occurs.

Table RH-2. Pollutant Removal Performance Values for Rainwater Harvesting

Design Level	Total Suspended Solids (TSS)[1]	Nutrients: Total Phosphorus (TP) & Total Nitrogen (TN) [1]
One Design Level	TSS = runoff reduction rate from Cistern Design Spreadsheet[1]	TP & TN = runoff reduction rate from Cistern Design Spreadsheet[1]

[1] TSS and nutrient pollutant load reduction is equal to the runoff reduction rate. No additional pollutant removal rate is applied to the Rainwater Harvesting system. If secondary or downstream practices are used in conjunction with Rainwater Harvesting, TSS and nutrient removal rates are in accordance with the applicable rates for those practices, as noted in **Chapter 3** *of this Manual and the individual specifications in* **Chapter 4**.

RH-1.3. Rainwater Harvesting Design Checklist

Table RH-3. Rainwater Harvesting Design Checklist

CHECKLIST

- ☐ Evaluate site to determine if rainwater can be harvested from rooftops, if there is year-round demand for the collected water, and if local regulatory authorities will allow the practice.
- ☐ Determine the Treatment Volume (Tv) for the target drainage area using the Design Compliance Spreadsheet. Determine if other downstream best management practices (BMPs) will be used in conjunction with Rainwater Harvesting to meet the site Tv goal.
- ☐ Complete the Cistern Design Spreadsheet (see Section RH-4.5 and Supplement 4.2.8.B and C) to evaluate various tank sizes and configurations (see Sections RH-4.2 and RH-4.3) to meet projected demand. The Cistern Design Spreadsheet will generate a runoff reduction rate to "plug into" the Design Compliance Spreadsheet (see below). This rate will be based on tank size, water demand, and possible use of a downstream runoff reduction practice.
- ☐ Using the runoff reduction % generated in the Cistern Design Spreadsheet, return to the Design Compliance Spreadsheet and check overall compliance with the 1-inch reduction standard. Downstream practices may be needed if: (1) there is not a year-round use for the collected water, and/or (2) additional practices are needed on the site to capture the Tv.
- ☐ Check Rainwater Harvesting sizing guidance and ensure adequate storage volume in the cistern and conveyance system – Section RH-4
- ☐ Check design adaptations appropriate to the site – Section RH-6
- ☐ Design Rainwater Harvesting system in accordance with design criteria and typical details – Sections RH-2 & RH-4
- ☐ If downstream runoff reduction practices will be installed to treat outflow and overflow from the cistern and/or to provide additional runoff reduction credit, go to the applicable specification in this Manual for design guidance on that practice.
- ☐ Provide all necessary plan view, profile, and cross-section details along with elevations, materials specifications, grading, and construction sequence notes.

4.2.8. Rainwater Harvesting (RH)

RH- 2. Typical Details

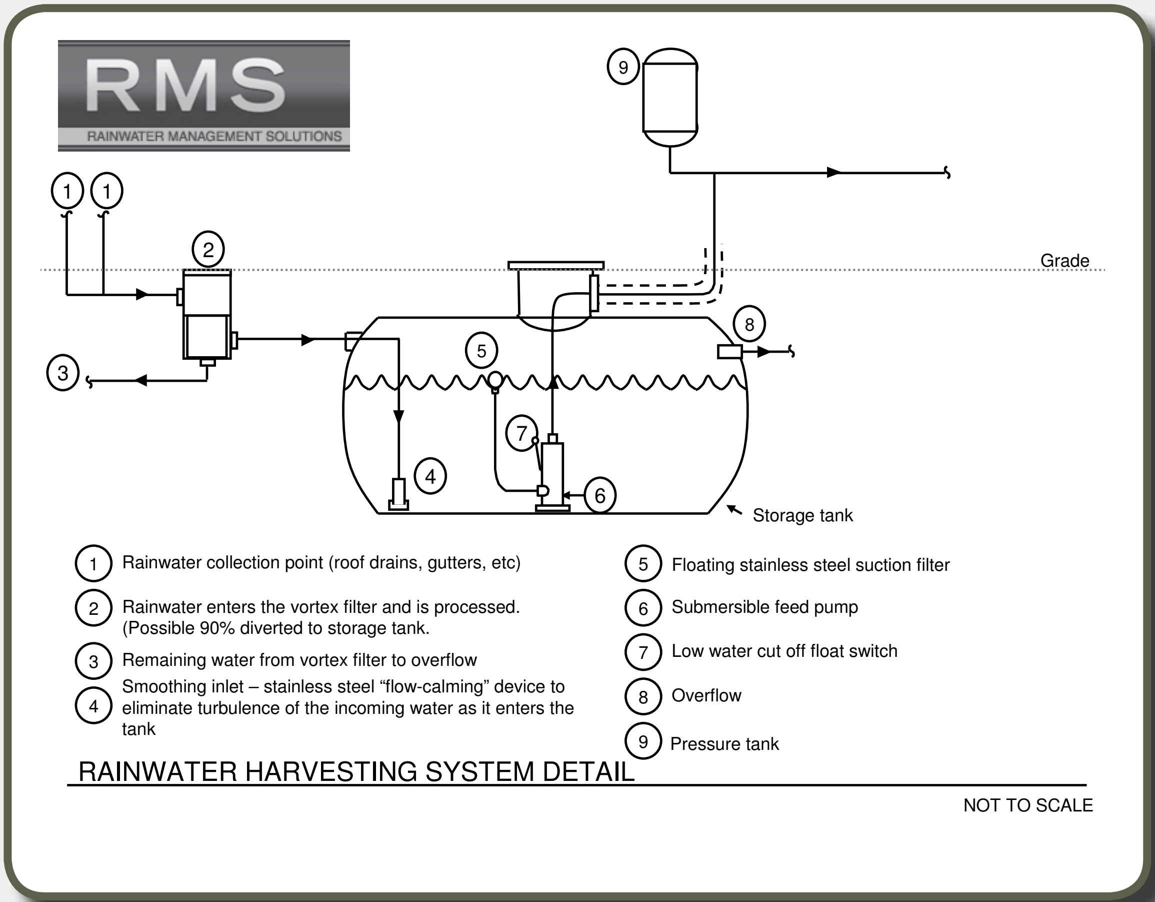

Figure RH-3. Typical Components of Rainwater Harvesting Systems (Source: Rainwater Management Solutions)

Additional details and schematics are provided in **Section RH-4.** **Figures RH-4 through RH-6** provide typical schematics of cistern and piping system configurations, based on the design objectives (year-round internal use, external seasonal irrigation, etc.). **Figures RH-7 through RH-9** provide typical schematics of cistern tank configurations, based on the desired Design Volume (Dv) and stormwater management objectives (Dv only, detention storage, etc.).

RH-3. Feasibility Criteria and Design Considerations

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 some 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 Codes. This specification does not address indoor plumbing or disinfection issues. Designers and plan reviewers should consult the local and state building and health codes 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. Pipes and spigots using rainwater must be clearly labeled as non-potable.

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 (natural channel, storm drain system, etc.) 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 route roof drains from buildings to cisterns. However, it will increase the amount of pumping needed to distribute the harvested rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations may require larger diameter roof drains with smaller slopes. However, this will also reduce the amount of pumping needed for distribution. It is often best to locate a cistern close to the building, ensuring that minimal roof drain slopes and limited enclosure of roof drain pipes are needed.

Consider Elevations Early in Design Process

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.

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 will not subject it to flooding. In areas where the tank is to be buried partially below the water table, special design features must be employed, such as sufficiently securing the tank (to keep it from "floating"), 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. Only rooftop surfaces should be included in the CDA. Parking lots and other paved areas can only be used with appropriate treatment (oil/water separators) and approval by the local review authority. 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 rooftops to Rainwater Harvesting systems in closed roof drain systems or storm drain pipes, avoiding surface drainage, which could allow for increased contamination of the water.

Rooftop Material. The quality of the harvested rainwater will vary according to the roof material over which it flows. Water harvested from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted roofs, galvanized metal roofs, sheet metal or any material that may contain asbestos may leach trace metals and other toxic compounds. In general, harvesting rainwater from such roofs should be avoided. If a sealant or painted 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 West Virginia tends to be acidic (ranging from 4.0 to 5.5), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. 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. Cistern 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. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

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.

RH-4. Design Criteria

RH-4.1. System Components

System Components: There are six primary components of a Rainwater Harvesting system (see **Figure RH-2**):

- Rooftop surface
- Collection and conveyance system (e.g., gutter and downspouts)
- Pretreatment
- Storage tank
- Distribution system
- Overflow, filter path or secondary stormwater retention practice

The system components are discussed below:

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

Collection and Conveyance System: 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. See also **Section RH-4.6, Collection and Conveyance Design Criteria.**

Pretreatment: 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. See also **Section RH-4.7, Pretreatment Design Criteria.**

Storage Tank: The storage tank is the most important and typically the most expensive component of a Rainwater Harvesting system. 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 stepped vertically to match the topography of a site.

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 increase overall storage on-site as needed. Typical Rainwater Harvesting system capacities for residential use range from 1,500 to 5,000 gallons. Storage tank volumes are calculated to meet the water demand and stormwater Design Volume objectives, as described in Section RH-4.8, Storage Tank Design Criteria of this specification.

Distribution System: Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether inside the building, an automated irrigation system, or gradually discharged to a secondary runoff reduction practice. The Rainwater Harvesting system should be equipped with an appropriately-sized pump that produces sufficient pressure for all end-uses. The municipality may require the separate plumbing to be labeled as non-potable.

The typical pump and pressure tank arrangement consists of a multi-stage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump activates to supply additional water to the distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

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, Filter Path and Secondary Runoff Reduction Practice: An overflow mechanism should be included in the Rainwater Harvesting system design in order to handle an individual storm event or multiple storms in succession that exceed the capacity of the tank. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s) and have a diameter and slope sufficient to drain the cistern while maintaining an adequate freeboard height. The overflow pipe should be screened to prevent access to the tank by rodents and birds. See also Section RH-4.6, Collection and Conveyance Design Criteria.

The filter path is a pervious or grass corridor that extends from the overflow to the next runoff reduction practice, the street, an adequate existing or proposed channel, or the storm drain system. The filter path must be graded with a slope that results in sheet flow conditions. If compacted or impermeable soils are present along the filter path, Soil Amendments may be needed (see Appendix D). It is also recommended that the filter path be used for first flush diversions.

In many cases, Rainwater Harvesting system overflows are directed to a secondary runoff reduction practice to boost overall runoff reduction rates. These options are addressed in Section RH-4.9, On-Site Treatment in a Secondary Practice.

RH-4.2. Design Objectives and System Configurations

A Note on Terminology Describing Volume

There are two types of volumes that the designer should consider when designing a best management practice (BMP) plan:

Target Treatment Volume (Tv) = Volume associated with managing 1" of rainfall based on the size and land cover of the contributing drainage area (CDA), as determined by the Design Compliance Spreadsheet. Any given BMP may treat the full Tv or only part of it if used in conjunction with other practices as part of a treatment train.

Design Volume (Dv) = The volume designed into a particular practice based on storage in the practice, as prescribed in the BMP specification. For Rainwater Harvesting, Dv will equal Tv if the CDA is only the rooftop area directed to the Rainwater Harvesting practice. However, if Rainwater Harvesting is used in conjunction with downstream runoff reduction practices, the Dv of the Rainwater Harvesting practice can be a subset of the overall Tv. In such cases, the sum of the Dvs in the Rainwater Harvesting practice plus those of the other practices in the treatment train should equal the total drainage area Tv.

See **Chapter 3** for more information on the runoff reduction design methodology.

For the purposes of this sizing section, the sizing relates to the Dv of the Rainwater Harvesting practice being designed.

Many Rainwater Harvesting system variations can be designed to meet user demand and stormwater objectives. This specification focuses on providing a framework for addressing the Design Volume (Dv) objectives and achieving compliance with the regulations. From a Rainwater Harvesting standpoint, there are numerous potential configurations that could be implemented. However, this specification adheres to the following concepts in order to properly meet the stormwater on-site retention goals:

- System design is encouraged to use rainwater as a resource to meet on-site demand or in conjunction with other runoff reduction practices (especially those that promote groundwater recharge).
- Peak flow reduction (if needed to meet local detention requirements) is realized through reduced volume and temporary storage of runoff.

Credit Only Applies to Systems with Year-Round Water Use

Credit is only available for year-round drawdown/demand for the water. While seasonal practices (such as irrigation) may be incorporated into the site design, they are not, in and of themselves, considered adequate to derive a year-round runoff reduction credit. If only seasonal use of the water in envisioned, a secondary downstream runoff reduction practice can be incorporated in order to qualify for a runoff reduction credit. In this way, during the non-seasonal months, water can be drained from the tank slowly to be treated by the downstream practice.

The Rainwater Harvesting system design configurations presented in this specification are targeted for continuous (year-round) use of rainwater through (1) internal use, and (2) irrigation and/or treatment in a secondary runoff reduction practice. Three basic system configurations are described below.

Configuration 1: Year-round indoor use with optional seasonal outdoor use (Figure RH-4). The first configuration is for year round indoor use along with optional seasonal outdoor use, such as irrigation. Because there is no on-site secondary runoff reduction practice incorporated into the design for non-seasonal (or non-irrigation) months, the system must be designed and treatment credit awarded for the interior use only. (However, it should be noted that the seasonal irrigation will provide an economic benefit in terms of water usage). Stormwater credit can be enhanced by adding a secondary runoff reduction practice (see Configuration 3 below).

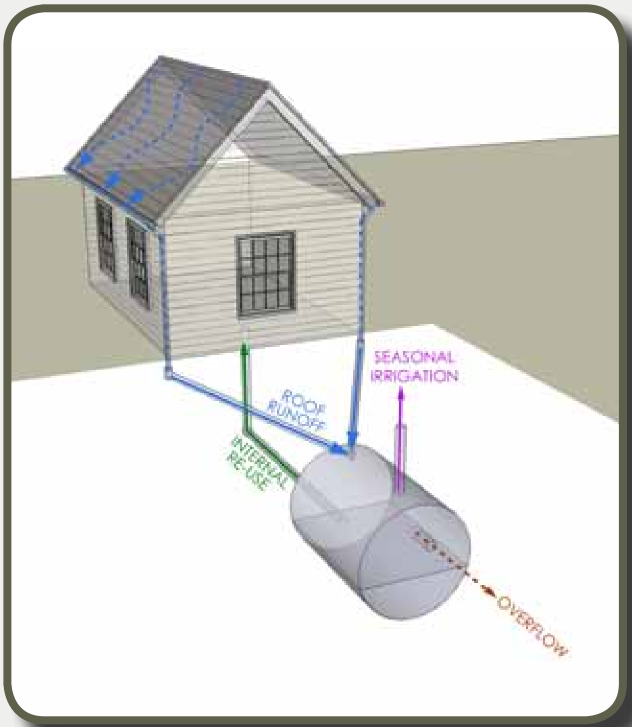

Figure RH-4. Configuration 1: Year-round indoor use with optional seasonal outdoor use. (Source: Alex Forasté)

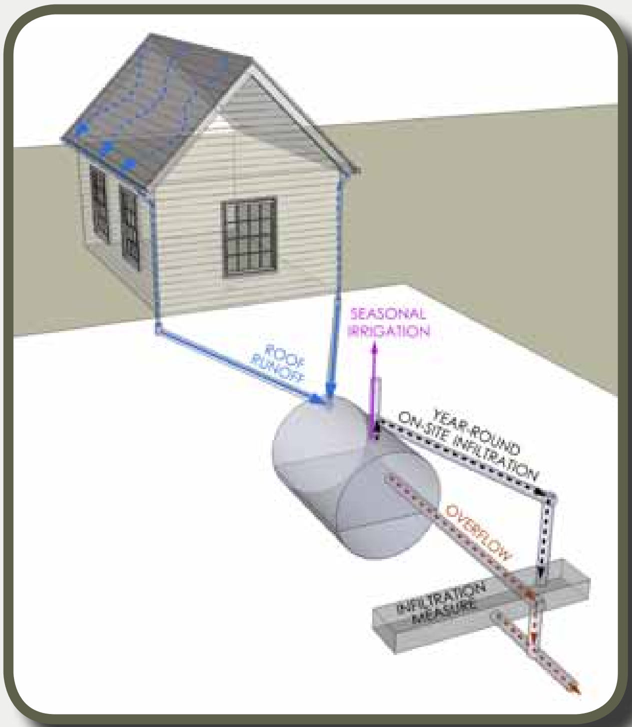

Figure RH-5. Configuration 2: Seasonal outdoor use and approved year-round secondary practice. (Source: Alex Forasté)

Configuration 2: Seasonal outdoor use and approved year-round secondary runoff reduction practice (Figure RH-5). The second configuration uses stored rainwater to meet a seasonal or intermittent water use, such as irrigation. However, because these uses are only intermittent or seasonal, this configuration also relies on an approved secondary practice for stormwater credit. Compared to a stand-alone BMP (without the up-gradient tank), the size and/or storage volume of the secondary practice can be reduced based on the storage in the tank (unless the secondary practice also receives runoff from other areas on the site). The tank's drawdown and release rate should be designed based on the infiltration properties, surface area, and capacity of the receiving secondary runoff reduction practice. The release rate therefore is typically much less than the flow rate that would result from routing a detention facility. The secondary practice should serve as a "backup" facility, especially during non-irrigation months. In this regard, the tank should provide some meaningful level of storage and reuse, accompanied by a small flow to the secondary practice. See Tank Design Set-Ups: Tank Design 3 for more information.

Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal treatment in a secondary stormwater practice (Figure RH-6). The third configuration provides for a year-round internal non-potable water demand, and a seasonal outdoor, automated irrigation system demand. In addition, this configuration incorporates a secondary practice during non-irrigation (or non-seasonal) months in order to yield a greater stormwater credit. In this case, the drawdown due to seasonal irrigation must be compared to the drawdown due to water released to the secondary practice. The minimum of these two values is used for system modeling and stormwater credit purposes.

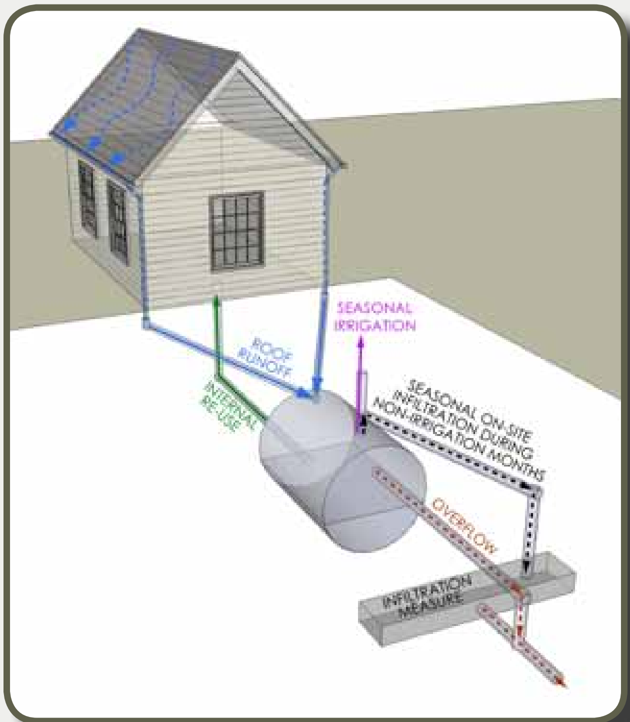

Figure RH-6. Configuration 3: Year-round indoor use, seasonal outdoor irrigation, and non-seasonal on-site treatment in secondary practice. (Source: Alex Forasté)

RH-4.3. 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 RH-7**) maximizes the available storage volume associated with the Dv to meet the desired level of stormwater credit. 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 channel and flood protection volumes (if required by local detention ordinances) with this tank configuration, but the primary purpose is to address the smaller Dv design storms.

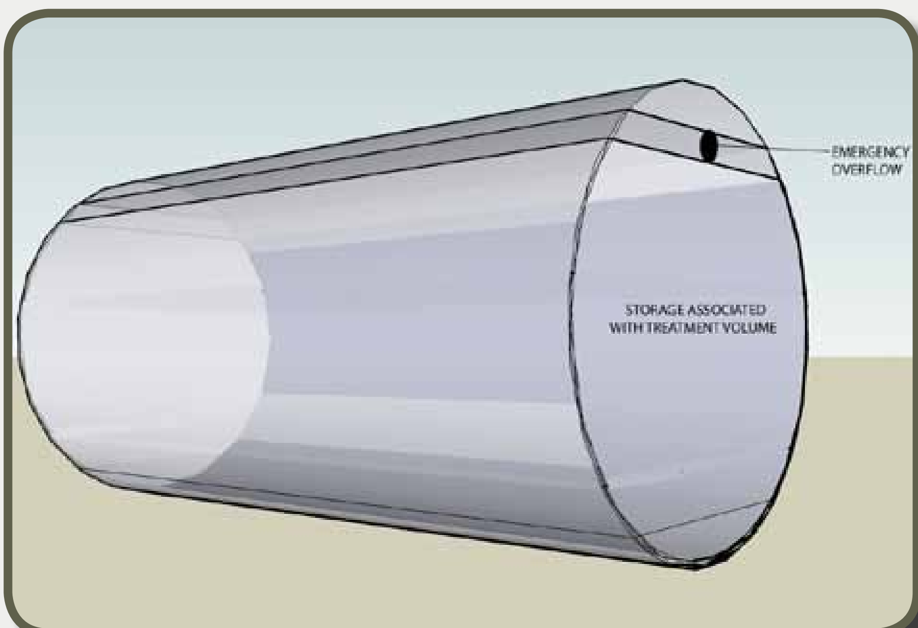

Figure RH-7. Tank Design 1: Storage Associated with Design Volume (Dv) only (Source: Alex Forasté)

Tank Design 2. The second tank set-up (**Figure RH-8**) uses tank storage to meet the Dv storage objectives as well as using an additional detention volume to also meet some or all of any required channel protection and/or flood protection detention volume requirements. An orifice outlet is provided at the top of the design storage for the Dv level, and an emergency overflow is located at the top of the detention volume level.

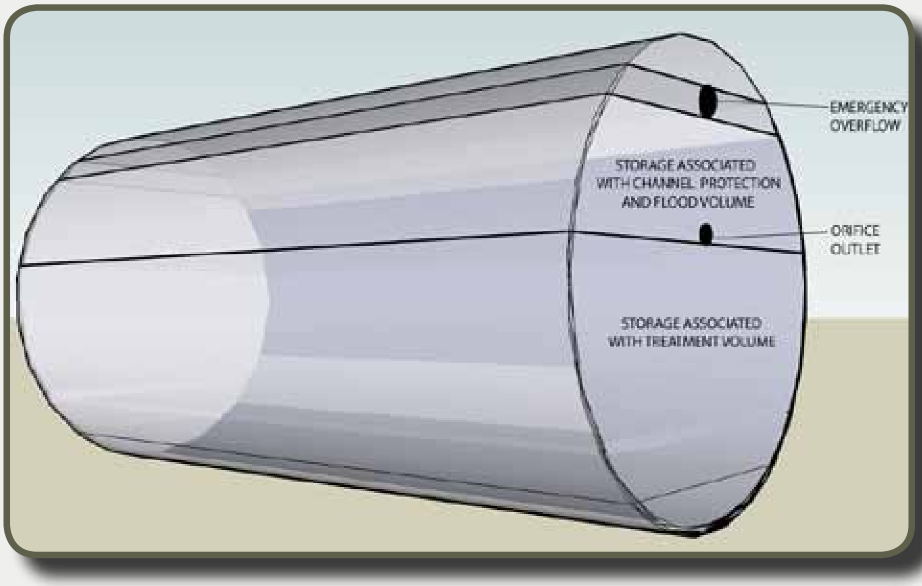

Figure RH-8. Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume (Source: Alex Forasté)

Tank Design 3. The third tank set-up (**Figure RH-9**) 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, micro-scale Infiltration, 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.

While a small orifice is shown at the bottom of the tank in **Figure RH-9**, 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.

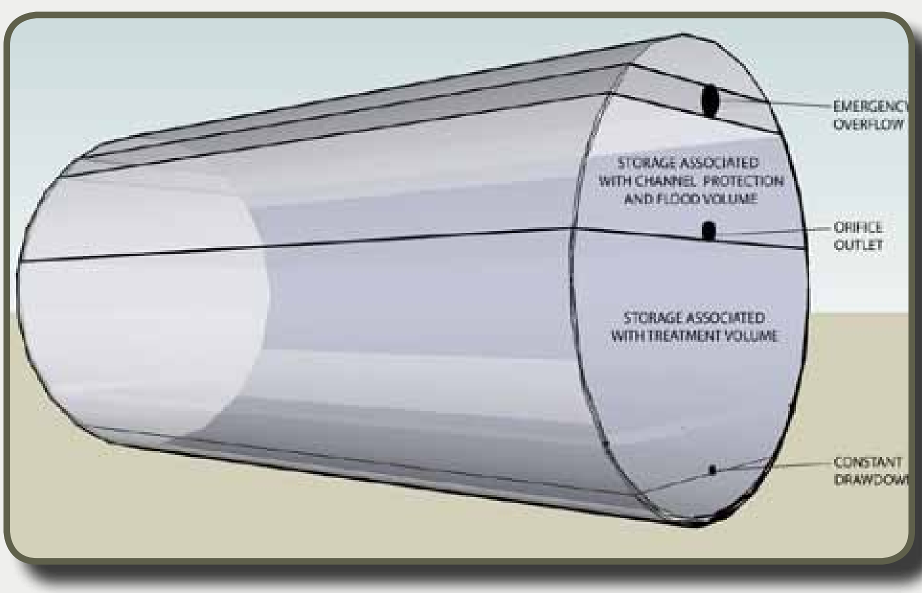

Figure RH-9. Tank Design 3: Constant drawdown, Storage Associated with Treatment, Channel Protection and Flood Volume (Source: Alex Forasté)

RH-4.4. Sizing of Rainwater Harvesting Systems

The Rainwater Harvesting cistern sizing criteria presented in this section was developed using best estimates of indoor and outdoor water demand, long-term rainfall data, and rooftop capture area data, using a spreadsheet model (Forasté and Lawson, 2009). The Cistern Design Spreadsheet is primarily intended to provide guidance in sizing cisterns and to quantify the runoff reduction volume credit for input into the Design 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.

Rainwater tank sizing is determined by accounting for varying precipitation levels, captured rooftop runoff, first flush diversion (through filters) and filter efficiency, low water cut-off volume, dynamic water levels at the beginning of various storms, storage needed for Design Volume (permanent storage), storage needed for temporary detention storage (if required by the local program), seasonal and year-round demand use and objectives, overflow volume, and freeboard volumes above high water levels during very large storms. See **Figure RH-10** for a graphical representation of these various incremental design volumes.

For the purposes of this sizing method, the Dv is assumed to be associated only with the rooftop area draining to the Rainwater Harvesting practice.

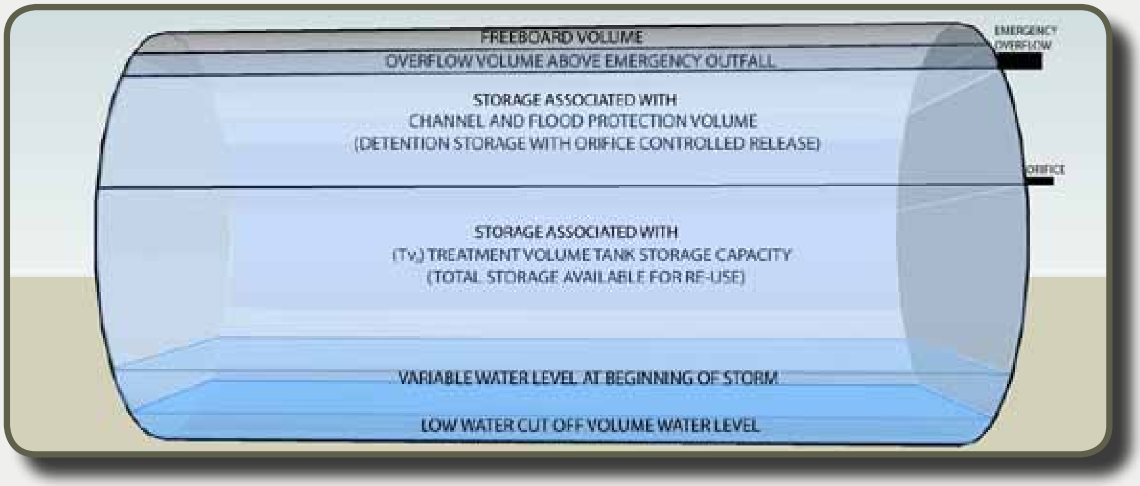

Figure RH-10. Incremental volumes associated with tank sizing. (Source: Alex Forasté)

RH-4.5. Cistern Design Spreadsheet

This specification is linked with the Cistern Design Spreadsheet. The spreadsheet uses daily rainfall data from four localities in West Virginia (Beckley, Morgantown, Moorefield, Huntington) to model performance parameters of the cistern under varying rooftop capture areas, demands on the system and tank size.

The Cistern Design Spreadsheet is a design tool for Rainwater Harvesting, but it is also used to derive the runoff reduction credit for a particular design (Forasté and Hirschman, 2010). This credit is then plugged into the Design Compliance Spreadsheet to gage site compliance. Often, Rainwater Harvesting will have to be used in conjunction with other downstream practices in order to meet the 1" performance standard.

The supplements to this specification provide detailed guidance on using the Cistern Design Spreadsheet. The supplements are as follows:

- Supplement 4.2.8.A is a description of the spreadsheet parameters, inputs needed to use the spreadsheet, and spreadsheet outputs that can be used for system design and deriving the runoff reduction credit.
- Supplement 4.2.8.B provides step-by-step guidance for using the various tabs in the spreadsheet.
- Supplement 4.2.8.C contains some additional notes on the spreadsheet methodology and assumptions.
- Supplement 4.2.8.D includes recommendations for Rainwater Harvesting plan submittals and a checklist that can be used by designers and plan reviewers.

RH-4.6. Collection and Conveyance Design Criteria

The following additional design criteria apply to collection and conveyance components of the Rainwater Harvesting system:

At a minimum, gutters should be sized with slopes specified to convey at least 1-inch/hour If the system will also be used for detention of larger storms, the gutters should be designed to convey the 2-yr and 15-yr storms, using the appropriate 2-yr and 15-yr storm intensities. In all cases, gutters should be hung at a minimum of 0.5% for 2/3 of the length and at 1% for the remaining 1/3 of the length.

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

RH-4.7. Pretreatment Design Criteria

The following additional design criteria apply to pretreatment components of the Rainwater Harvesting system:

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 of rooftop runoff.

The diverted flows (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 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 detention of larger storms, 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 1-inch Dv, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion.

- **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 (**Figure RH-11**). 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 below) 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 (**Figure RH-12**). Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

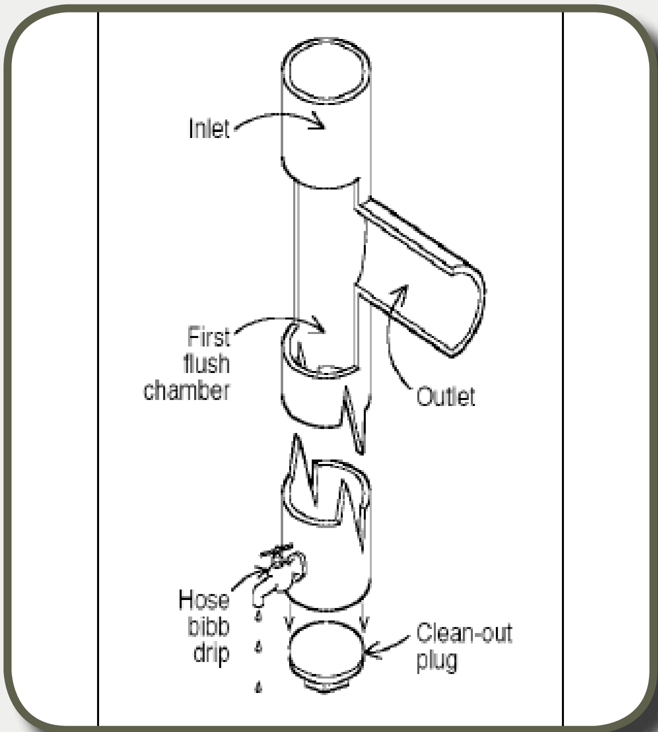

Figure RH-11. First Flush Diverter

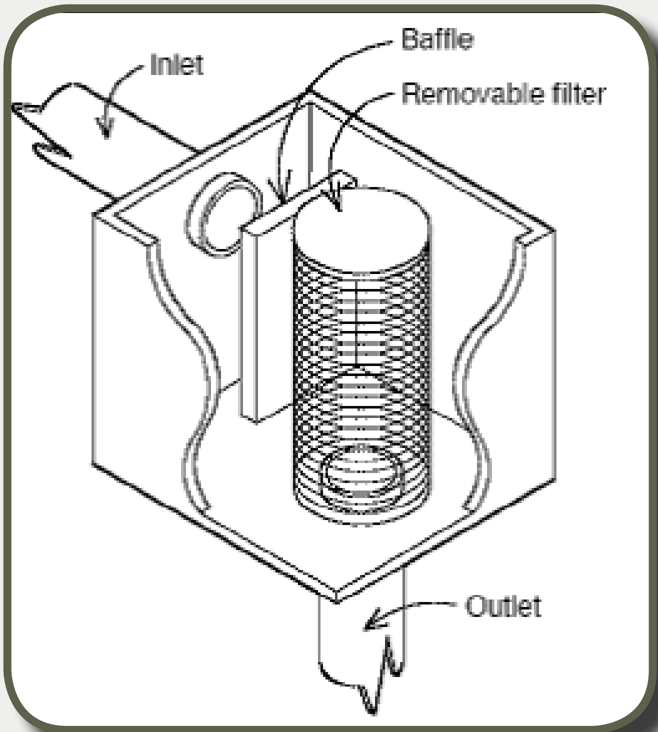

Figure RH-12. Roof Washer

Source: Texas Water Development Board (2005)

- **Vortex Filters:** For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas. Figure RH-13 shows a plan view photograph showing the interior of a vortex filter with the top off. Figure RH-14 displays the filter just installed in the field prior to backfill.

Figure RH-13. Interior of Vortex Filter. (Source: Rainwater Management Solutions)

Figure RH-14. Installation of Vortex Filter prior to backfill. (Source: Rainwater Management Solutions)

RH-4.8. Storage Tank Design Criteria

The following 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, etc.).
- Storage tanks should have a standard size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be secured to prevent unwanted access.
- The design of the tank should allow for removal of problematic sediment/debris that may accumulate in the tank, by vacuum or other methods.
- 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. See **Section 5, Materials Specifications**.
- 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 two supplies.

RH-4.9. On-Site Treatment in a Secondary Practice

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

- Impervious Surface Disconnection (**Specification 4.2.2**); This may include release to a soil amended filter path
- Vegetated Filter Strip (**Specification 4.2.1**)
- Grass Swale (**Specification 4.2.**5)
- Infiltration and micro-Infiltration (**Specification 4.2.6**)
- Water Quality Swale, Rain Garden, or Urban Bioretention (**Supplements 4.2.3.A, B & C**)

The secondary practice approach is useful to help achieve the desired treatment credit when demand is not enough to sufficiently draw water levels in the tank down between storm events. Of course, if demand for the harvested rainwater is relatively high, then a secondary practice may not be needed or desired.

A secondary practice may be particularly useful to employ in sites that use captured rainwater for irrigation during part of the year, but have no other use for the water during non-irrigation months. During non-irrigation months, credit cannot be realized unless on-site infiltration/treatment or another drawdown mechanism creates a year-round drawdown, since no stormwater benefit would be realized during non-seasonal periods.

The design of the secondary practice should account for soil types, ground surface areas, release rates, methods of conveyance (gravity fed or pumped), time periods of operation, and invert elevations to determine the disposal rate and sizing of the practice (both storage volume and surface area).

RH-5. Materials Specifications

The basic material specifications for Rainwater Harvesting systems are presented in **Table RH-4**. 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 RH-4. Design specifications for Rainwater Harvesting systems

Item	Specification
Gutters and Downspout	Materials commonly used for gutters and downspouts include polyvinylchloride 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 water tight and sealed using a water-safe, non-toxic substance. ▪ Tanks should be opaque to prevent the growth of algae. ▪ Re-used tanks should be fit for potable water or food-grade products. ▪ Underground Rainwater Harvesting systems should have a minimum of 18 to 24 inches of soil cover and be located below the frost line. ▪ The size of the Rainwater Harvesting system(s) is determined during the design calculations.

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

Table RH-5 compares the advantages and disadvantages of different storage tank materials.

4.2.8. RAINWATER HARVESTING (RH)

Table RH-5. 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 water tight 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

The images in Figures **RH-15** to **RH-17** display three examples of various materials and shapes of cisterns discussed in **Table RH-5** above.

Figure RH-15. Example of Multiple Fiberglass Cisterns in Series (Source: Rainwater Management Solutions)

Figure RH-16. Example of two Polyethylene Cisterns (Source: Rainwater Management Solutions)

Figure RH-17. Example of Modular Units (Source: Rainwater Management Solutions)

4.2.8. Rainwater Harvesting (RH)

RH-6. Design Adaptations

RH-6.1. Karst Terrain

Above-ground Rainwater Harvesting systems are a preferred practice in karst, as long as the rooftop surface is not designated as a stormwater hotspot.

RH-6.2. Steep Terrain

Rainwater Harvesting systems are ideal in areas of steep terrain as long as the tank or cistern itself is installed in a stable configuration (e.g., on a flat pad).

RH-6.3. Cold Climate & Winter Performance

Rainwater Harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternately, an outdoor system can be used seasonally, or year round if special measures and design considerations are incorporated. Outdoor 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 credit may not be granted for the practice during that off-line period.

RH-6.4. Stormwater Retrofitting

Rainwater Harvesting is an excellent candidate for retrofitting, especially on sites where space is limited and/or where rooftops constitute a fairly high percentage of the site impervious cover. Retrofit considerations include design of the plumbing system where indoor use of harvested rainwater is envisioned, the type of existing roof material, conflicts with utilities for underground tanks, and space available for a downstream runoff reduction practice if needed to get a runoff reduction credit.

For more information on retrofitting, see the Center for Watershed Protection's manual, ***Urban Stormwater Retrofit Practices*** (Schueler et al., 2007).

4.2.8. Rainwater Harvesting (RH)

RH-7. Construction & Installation

RH-7.1. Construction Sequence

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 roof drains to pre-screening devices and first flush diverters

- Properly install the tank
- Install the pump (if needed) and piping to end-uses (indoor, outdoor irrigation, or tank dewatering release)
- Route all pipes to the tank
- Stormwater should not be diverted to the Rainwater Harvesting system until the overflow filter path has been stabilized with vegetation.

RH-7.2. 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 runoff reduction practice(s) installed as shown on plans

4.2.8. Rainwater Harvesting (RH)

RH-8. Maintenance Criteria

RH-8.1. Maintenance Agreements

Section C.b.5.ii(C) of the MS4 General Permit requires a maintenance agreement and plan between the property owner or operator and the local program authority (for municipal separate storm sewer systems). This section sets forth inspection requirements, compliance procedures if maintenance is neglected, notification of the local program upon transfer of ownership, and right-of-entry for local program personnel.

All Rainwater Harvesting systems must be covered by a drainage easement to allow inspection and maintenance. The easement should include the tank, the filter path and any secondary runoff reduction practice. If the tank is located in a residential private lot, its existence and purpose must be noted on the deed of record. Homeowners will need to be provided with a simple document that explains the purpose of the Rainwater Harvesting system and routine maintenance needs. Where legally binding maintenance agreements apply, they should specify the property owner's primary maintenance responsibility, require homeowners to pay to have their system inspected by a qualified third party inspector, and authorize the qualifying local program staff to access the property for inspection or corrective action in the event this is not done.

RH-8.2. Maintenance Inspections

All Rainwater Harvesting systems components should be inspected by the property owner in the spring and fall each year. A comprehensive inspection by a qualified third party inspector should occur every third year. Example maintenance checklists for Rainwater Harvesting systems can be found in Appendix A of this Manual.

RH-8.3. Rainwater Harvesting System Maintenance Schedule

Maintenance requirements for Rainwater Harvesting systems vary according to use. Systems that are used to provide supplemental irrigation water have relatively low maintenance requirements, while systems designed for indoor uses have much higher maintenance requirements. **Table RH-6** describes routine maintenance tasks to keep Rainwater Harvesting systems in working condition.

Table RH-6. Suggested maintenance tasks for Rainwater Harvesting systems

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

Key: O = Owner I = qualified third party inspector

RH-8.4. 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.

RH-8.5. Cold Climate Considerations

At the start of the winter season, vulnerable above-ground systems that have not been designed to incorporate special precautions from freezing should be disconnected and drained. It may be possible to reconnect the 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.

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Supplement 4.2.8.A

Description of the Cistern Design Spreadsheet & Inputs

The Cistern Design Spreadsheet uses daily rainfall records and an accounting of inputs and outflow in a continuous model to calculate the runoff reduction volume associated with 1 inch of rainfall. The spreadsheet is a design tool for Rainwater Harvesting, but is also used to derive the runoff reduction credit used in the Design Compliance Spreadsheet for compliance with the 1-inch on-site retention standard.

Water Contributions & Losses to the System

A runoff coefficient of 0.95 for rooftop surfaces and a filter efficiency rate of 95% for the 1-inch storm are assumed. It is 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 to rooftop.** The volume of water contributing to the Rainwater Harvesting system is a function of the rainfall and rooftop 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:

- **Rooftop Runoff Coefficient (Rv).** The rooftop is estimated to convey 95% 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 directed to filters is diverted from the system in order to prevent clogging with debris. This value is assumed to be contained within the filter efficiency rate.
- **Filter Efficiency.** Each filter has an efficiency curve associated with the rate of runoff and the size of the storm it will receive from a rooftop. It is assumed that, after the first flush diversion and loss of water due to filter inefficiencies, the remainder of the 1-inch storm will be successfully captured. A minimum of 95% of the runoff from a 1-inch storm must be able to pass through the filter and be conveyed into the tank. Some localities may also require a minimum filter efficiency for a larger storm event (e.g. minimum 90% filter efficiency for 2 or 10-year storm), depending on design objectives and local review agency policy. For the purposes of selecting an appropriately sized filter, a rainfall intensity of 1-inch/hour should be used for the 24 hour, 1-inch storm. The local rainfall intensity values for the 2 and 10 year storms should be used when designing for flood control/detention volumes, if required by the local program.
- **Drawdown (Design Volume, Dv).** This is the stored water within the cistern that is reused or directed to a secondary runoff reduction practice. It is the volume of runoff that is reduced from the rooftop drainage area. This is the water loss that translates into the Runoff Reduction Volume credit in the Site Compliance Spreadsheet. The Runoff Reduction Volume credit is the volume reduction that is achieved toward reducing the 1" reduction performance standard in the MS4 General Permit (see **Chapter 3** of the Manual).
- **Overflow.** For the purposes of addressing the Dv, 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.

Spreadsheet Inputs

The spreadsheet model requires the following user inputs, as applicable:

Regional location. Indicate the region that is closest to where the practice is being installed. Rainfall data associated with that region will automatically provide the relevant precipitation data for the design storm for that area.

Roof area. The user must estimate the total rooftop area that will be captured for contribution to the system; this, combined with the target storm (1 inch of rainfall), yields the volume of rooftop runoff to be managed.

Irrigation use. The user must supply the total pervious area (in square feet) that will be irrigated; the spreadsheet will automatically calculate the demand based on a 1-inch per week watering during the appropriate season, unless the user specifies a different watering rate. The user can enter a start date and an end date in the year to specify the irrigation season (e.g., March 30 to September 1). If an on-site infiltration system is designed, the lesser drawdown rate (irrigation or on-site infiltration during the off-season) must be used to quantify the Runoff Reduction volume credit.

Indoor demand. The user then needs to define the parameters relating to indoor use of water, if rainwater is intended for such purposes. If specific daily water demand has been calculated for the indoor uses, those values can be entered directly into the spreadsheet (dark blue cells). Otherwise, the spreadsheet will automatically calculate the demand according to the following criteria and inputs:

- Flushing Toilets/Urinals – The user enters the average number of people that use the building within a day, the days on which the building is regularly used within a week, and the number of hours the building is usually used during a day. The user also enters the gallons of water used per flush by urinals and toilets in the building (default set at 0.8 and 1.6 gallons, respectively). The spreadsheet calculates demand, based on three flushes per person per day.
- Laundry – The user enters the number of loads of laundry done per day, the average water use for each load of laundry, and the days of the week on which laundry is done. If a household only does 2 loads of laundry per week, for example, the user could specify that 1 load is done per day and laundry is done only Monday through Tuesday. The spreadsheet calculates average daily demand for laundry water based on these values.

Additional Daily Use. The user may enter an additional demand, such as bus or fire truck washing, street sweeper filling, etc.

Chilled Water Cooling Towers. The user may enter a quantity of water that will be needed for use in chilled water cooling towers.

Secondary Runoff Reduction Practice Drawdown. A cell is provided to enter an additional drawdown for secondary runoff reduction practices linked to the Rainwater Harvesting system, if applicable. The permissible flow to be directed is dependent upon the storage volume and surface area of the receiving secondary practice, and shall be based on the capacity of the secondary practice to store, infiltrate, and/or filter the flow coming to it. The secondary practice must be considered "part of" the rainwater harvesting system to utilize this slow-release drawdown option and must not be 'double-counted' elsewhere as an additional BMP.

Initial Abstraction. This is an optional input and provided as a mechanism for users that would like to specify an additional abstraction of the amount of rainwater that can be captured from the roof. This may be associated with roof material texture, conveyance, obstructions, etc. For reference: for CN = 98, Ia = 0.041"; for CN = 95, Ia = 0.105"; for CN = 90, Ia = 0.222".

First Flush Filter Diversion and Efficiency. The user enters the efficiency of the rainwater system's pre-treatment filter(s) associated with a 1-inch storm. Although this filter efficiency value can be defined by the user, the value must be 95% or higher to achieve Runoff Reduction Credit.

See Supplement 4.2.8.B for step-by-step guidance on using the spreadsheet.

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 Runoff Reduction Volume Credit, but rather 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.

- **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 rooftop area captured, or consider other mechanisms that could increase drawdown (e.g. increase the area to be irrigated, incorporate or increase on-site infiltration, etc.).
- **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 rooftop area to provide a larger supply, if feasible. It can also provide useful insight for the designer to determine whether he/she should incorporate a backup water supply to ensure sufficient water supply through the system at all times.
- **Demand Met.** This is where the water demand met for various size cisterns and rooftop area/demand scenarios is reported. The Water Supply Chart in this tab displays the percentage of demand met by various cistern storage sizes. Normally, this graph assists the user in understanding the relationship between cistern sizes and optimal/diminishing returns. An example is provided in **Figure RH-18**.

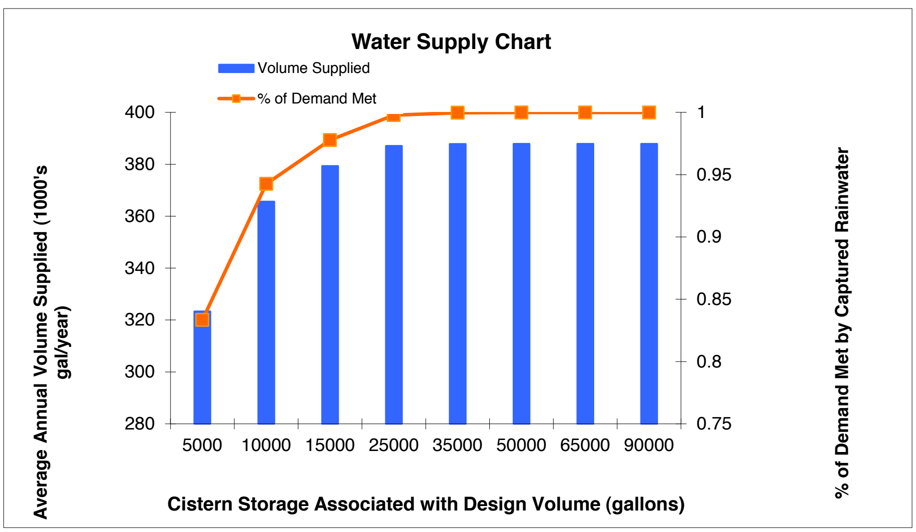

Figure RH-18. Percent Demand Met Vs. Cistern Storage Volume/Size

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 water demand that is met.

- **Inter-relationships and Curves of Diminishing Returns.** Plotting various performance metrics against one another can be very informative and reveal relationships that are not otherwise evident. One such inter-relationship is the number of dry days versus overflow frequency, depicted on the same graph. A range of cistern sizes 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 Precipitation Events of 1 Inch or Less

The amount of rooftop runoff volume that the tank can capture and use or draw down for all precipitation events of 1 inch or less is also quantified and recorded. These results are presented on the "Results-RR Volume Credit" tab. This information is used to calculate the Runoff Reduction Volume Credit, which is used as an input to the **Design Compliance Spreadsheet**.

- **Runoff Reduction Volume Credit.** A series of Runoff Reduction Volume Credit values are calculated for multiple sizes of cisterns. A trade-off curve plots these results, which allows for a comparison of the credit earned versus cistern size. While larger tanks yield more credit, 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 inch or less are also reported in this tab. A chart of the overflow frequency and overflow volume is provided. An example is shown below in **Figure RH-19**.

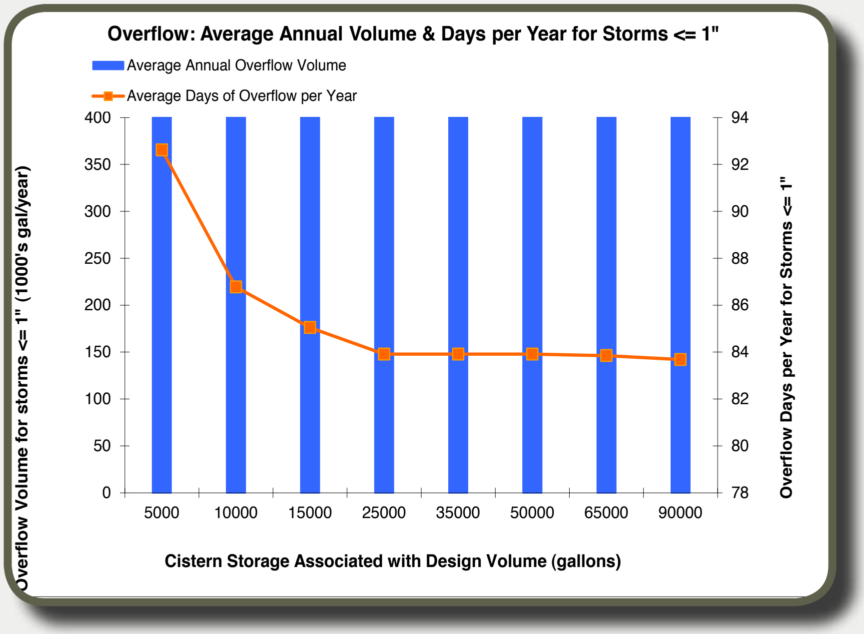

Figure RH-19. Overflow Volume and Frequency (for Storms <= 1")
Vs. Cistern Storage Volume

Results from Cistern Design Spreadsheet to be transferred to Design Compliance Spreadsheet

There are two results from this Cistern Design Spreadsheet that are to be transferred to the Design Compliance Spreadsheet, as follows:

1. **Runoff Reduction Volume Credit:** Once the cistern storage volume has been selected, simply transfer the associated Runoff Reduction credit percentage into the Design Compliance Spreadsheet column called "% Credit" in the "Rainwater Harvesting" row in the blue cell.
2. **Contributing Drainage Area:** Enter the rooftop area that was used in the Cistern Design Spreadsheet in the same row into the "Impervious Cover in Contributing Drainage Area (acres)" column in the blue cell.

Completing the Sizing Design of the Cistern

Consider the following volume requirements when selecting a final cistern size.

1. **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 modeled volume.

2. **Cistern Storage Associated with Design Volume (Included).** This is the volume that was designed for using the Cistern Design Spreadsheet.
3. **Adding Locally-Required Stormwater Detention Volumes (Optional).** Additional detention volume may be added above and beyond the cistern storage associated with the Dv. Typical routing software programs may be used to design for this additional volume.
4. **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.

Supplement 4.2.8.B

Step-By-Step Instructions for Using the Cistern Design Spreadsheet

Tab 1: INPUT

1. Select a Region in the drop down menu that is located closest to the proposed site.
2. Enter the rooftop area to be captured and routed to the cistern (square feet).
3. Enter the Irrigation data, as described in Supplement 4.2.8.A (Spreadsheet Inputs) of this design specification.
4. Enter the Indoor Demand – Flushing toilets/urinals, as described in Supplement 4.2.8.A.
5. Enter the Indoor Demand – Laundry, as described in Supplement 4.2.8.A.
6. Enter and Additional Daily Uses (gallons per day).
7. Enter the amount that will be used for Chilled Water Cooling Towers (gallons per day).
8. Enter the On-Site infiltration design drawdown rate (gallons per day).
9. Enter an Initial Abstraction value (inches), if desired.
10. Enter the filter efficiency percentage for the 1-inch storm at a 1-inch/hour intensity. A minimum of 95% must be achieved. However, if the filter achieves a higher efficiency rate, this higher value can be entered.

Tab 2: JULIAN DAY CALENDAR

This tab is included for assistance in selecting a start date and end date for various water uses shown in Tab 1. The day of the year should be selected according to the Julian day dates specified in this tab.

Tab 3: RESULTS – RR VOLUME CREDIT

11. Select the Results – Runoff Reduction Volume Credit tab to view modeling results for the 1-inch storm.
12. Observe the results for the Runoff Reduction Volume Credit highlighted in the far right column of the table, as it relates to the cistern storage volume. If this credit is much higher or lower than design objectives for many of the cistern storage sizes, the input values should be assessed to determine if the demand can be increased or decreased.

Tab 4: RESULTS

13. Select the Results tab to view the modeling results for all storm events.
14. Observe the results for overflow frequency, dry frequency and percent of demand met by rainwater.
15. If the demand met for a particular storage size is adequate, observe the dry frequency, overflow frequency and Runoff Reduction Volume Credit. If these parameters meet design objectives and balance trade-offs reasonably

well, move to the next step. If any of the resulting performance values are not acceptable design objectives, then re-visit the input spreadsheet to assess whether lower or higher demands can be achieved (e.g. decrease/increase in irrigation frequency; increase/decrease in the rooftop area captured, if feasible; etc.).

RESULT TO BE TRANSFERRED TO RUNOFF REDUCTION SPREADSHEET

16. **First Value to Transfer:** Once the cistern storage volume and its associated Runoff Reduction Volume Credit has been selected, simply transfer that credit amount into the Design Compliance Spreadsheet. Enter it into the column called "Credit," in the appropriate cell.
17. **Second Value to Transfer:** Then enter the rooftop area that was used in the same row and in the Cistern Design Spreadsheet into the "Credit Area (acres)" column in the blue cell.

Supplement 4.2.8.C

Notes Regarding the Cistern Design Spreadsheet Methodology

If a rainwater use is only seasonal (e.g. summer irrigation), the spreadsheet sets the input for that use to zero for the purpose of calculating the Runoff Reduction Volume (RRv) credit. However, this does not apply if a secondary runoff reduction practice is designated to infiltrate/treat an equivalent volume of rainwater.

With each documented daily use, the runoff volume is reduced. The RRv credit is a percentage equivalent to the sum of all the stored rainwater that is used/infiltrated during a 30 year period, divided by the entire volume that is generated during that same period for all precipitation events of 1-inch or less. That is:

$$Tv\% = \frac{\sum_{i=1}^{n} Vu}{\sum_{i=1}^{n} Tv}$$

Where:

$$\sum_{i=1}^{n} Tv = \sum_{i=1}^{n} \left[Pi \times SA \times Rv \times \left(\frac{1\,ft}{12\,in} \right) \times \left(\frac{7.48\,gallons}{1\,cf} \right) \right]$$

And

$$\sum_{i=1}^{n} Vu = \sum [Tv - ff - Ov]$$

NOTE: This is the total volume of runoff that has been removed from the runoff for storms of 1 inch or less for the entire 30 year period. It is calculated adding the contribution all precipitation of 1 inch or less, times the runoff coefficient, minus the first flush diversion, minus the overflow.

ff = First flush diversion and filter overflow due to filter inefficiency
Ov = Overflow from precipitation events of 1 inch or less
Rv = Runoff Coefficient of the rooftop = 0.95
Pi = Precipitation of 1 inch or less (inches)
SA = Surface area of the rooftop that is captured and conveyed to the cistern (sq. ft.)
i = Start day of modeling (first day modeled in 1977)
n = End day of modeling (Last day modeled in 2007)
Tv = Treatment Volume of the cistern, assuming the Tv applies to a drainage area that is only the rooftop draining to the system.

The spreadsheet calculations should always be included with the stormwater management submittal package for local plan review. See **Supplement 4.2.8.D** for more information on recommended submittal package items.

Supplement 4.2.8.D

Plan Submittal Recommendations

It is highly recommended that designers of Rainwater Harvesting systems coordinate design efforts and communicate intent to both site designers and building architects, since a Rainwater Harvesting system links the building to the site. The effectiveness of such a system, in terms of use for demand and as a stormwater management tool, is also highly dependent on the efficiency of capturing and conveying rainwater from the building rooftop to the storage tank.

The following lists are items that plan reviewers may want to recommend and/or require for submittals of Rainwater Harvesting systems being used as a stormwater management tool:

A. Incorporation of Rainwater Harvesting system into site plan grading and storm sewer plan construction documents, as follows:

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

B. Rainwater Harvesting system construction document sheet, to show the following:

1. The cistern/tank or storage unit material and dimensions in a scalable detail (use a cut sheet detail from manufacturer, if appropriate).
2. Include the specific filter performance specification and filter efficiency curves. Runoff estimates from the rooftop area captured for 1-inch storm should be estimated and compared to filter efficiencies for the 1-inch storm. It is assumed that the first flush diversion is included in filter efficiency curves. A minimum of 95% filter efficiency should

be met for the Runoff Reduction volume credit. If this value is altered (increased) in the Cistern Design Spreadsheet, the value should be reported. Filter curve cut sheets are normally available from the manufacturer.

3. Include elevation of pump intake point and low water cut-off level in tank.
4. Show the specified materials and diameters of inflow and outflow pipes.
5. Show the inverts of the inlets, drawdown orifice (if applicable), outlets, the emergency overflows, and, if applicable, the receiving secondary runoff reduction practice.
6. Show the incremental volumes specified for: (a) the low water cut-off volume level; (b) the storage volume associated with the Runoff Reduction volume credit; (c) the storage volume associated with the Channel Protection Volume (if applicable); (d) the storage volume associated with the Flood Protection Volume (if applicable); and (e) the overflow freeboard volume.
7. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes (if requested by the reviewer).

C. Supporting Calculations and Documentation

1. Provide a drainage area map delineating the rooftop area (square feet) to be captured and indicating the 1-inch storm, 1 year storm and 10 year storm peak discharge values on the plan (11x17 is sufficient).
2. Provide calculations showing that the gutter, at its specified size and slope, will convey the design storm specified by regulatory authority.
3. Provide calculations showing that the roof drains, at their specified size, slope and material, will convey the design storm specified by regulatory authority.
4. Cistern Design Spreadsheet: a print-out of the "Input" tab, as modeled.
5. Cistern Design Spreadsheet: a print-out of the "Results - Runoff Reduction Volume Credit" tab, as modeled.
6. Cistern Design Spreadsheet: a printout of the "Results" tab, as modeled.

D. Stormwater Management Forms

1. The owner should treat a Rainwater Harvesting system as he/she would treat any other stormwater management facility. If a stormwater management maintenance agreement form is required by the jurisdiction, then the same form should be submitted for a Rainwater Harvesting system.
2. An agreement form or note on the plans should be included to ensure that the minimum demand that was specified in the stormwater management plan submittal documents is being met. Likewise, if the property (and Rainwater Harvesting system) is transferred to a different owner, the new owner must be held responsible to ensure the system will continue to archive the specified year-round drawdown. If the year-round drawdown is not being met as specified, an alternative stormwater management plan may be required.

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