

VIRGINIA ~~DCR-DEQ~~ STORMWATER
DESIGN SPECIFICATION No. 6**RAINWATER HARVESTING**

VERSION 2.2

June 2013

**SECTION 1: DESCRIPTION**

Rainwater harvesting systems intercept, divert, store and release rainfall for future use. 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 disposal/infiltration. 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 fountains, and laundry, if approved by the local authority. Replenishing of pools may be acceptable if special measures are taken, as approved by the appropriate regulatory authority.

The design and implementation of a rainwater harvesting system must be coordinated with the end user of the building or structure. The designer must quantify the water supply (system contributions or inputs based on the design rainfall capture and roof area) and demand (indoor year-round or seasonal uses, and outdoor uses) for the subject project. Using this design specification and the accompanying Virginia Cistern Design (VCD) spreadsheet, the designer should estimate the

system size and preferred location, and identify the associated plumbing and pumping system requirements to meet the water demand (e.g., hydraulic lift or pump size, pressure tank, water distribution system, etc.), and ensure that the system meets the intended use and configuration of the proposed development and end user.

This specification provides guidance for the design of a cistern that collects roof runoff. The collection and reuse of surface runoff from parking lots or other surfaces is not addressed in this specification (since a much more robust system to ensure the cleanliness of the runoff would be required so as to not interfere with the mechanical components of the system, as well as to ensure the relative cleanliness of the water for the intended use).

SECTION 2: PERFORMANCE

The overall stormwater functions of the rainwater harvesting systems are described in **Table 6.1**.

Table 6.1: Summary of Stormwater Functions Provided by Rainwater Harvesting

Stormwater Function	Performance
Annual Runoff Volume Reduction (RR)	Variable up to 90% ²
Total Phosphorus (TN) EMC Reduction¹ by BMP Treatment Process	0%
Total Phosphorus (TN) Mass Load Removal	Variable up to 90% ²
Total Nitrogen (TN) EMC Reduction¹ by BMP Treatment Process	0%
Total Nitrogen (TN) Mass Load Removal	Variable up to 90% ²
Channel Protection	Partial: reduced curve numbers and increased Time of Concentration
Flood Mitigation	Partial: reduced curve numbers and increased Time of Concentration
¹ Nutrient mass load removal is equal to the runoff volume reduction rate. Zero pollutant removal rate is applied to the rainwater harvesting system only. Nutrient removal rates for secondary practices will be in accordance with the design criteria for those practices. ² Credit is variable and determined using the Cistern Design Spreadsheet. Credit up to 90% 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 event occurs. The total credit may not exceed 90%.	

The annual runoff volume reduction and pollutant removal performance credits of rainwater harvesting systems are a function of the cistern tank size, configuration, and water demand or use. The annual volume reduction credit is therefore user defined and is a “user input” cell in the Virginia Runoff Reduction Method (VRRM) compliance spreadsheet. The designer can calculate the annual water demand based on single or multiple uses that may be constant on a monthly basis, such as toilet/urinal flushing and laundry, or that vary seasonally, such as landscape irrigation, cooling towers, vehicle washing, etc. A use that is seasonal can be supplemented with a secondary runoff reduction drawdown in order to establish an annual demand. The internal and external

constant and variable monthly water uses are itemized and tabulated within the VCD Spreadsheet to generate the “user input” volume reduction credit.

Note: The secondary runoff reduction drawdown used to compute an annual water demand in the VCD spreadsheet is a component of the rainwater harvesting system design that establishes the “user input” volume reduction credit, and is not entered as a “Downstream Treatment to be Employed” when computing overall BMP strategy compliance using the VRRM compliance spreadsheet.

The VCD spreadsheet is available from ~~DCR~~ DEQ, and the User’s Guide is provided as a companion document. either in **Appendix 6-B** of this design specification or **Chapter 12** of the *Virginia Stormwater Management Handbook* (2nd Edition, 2013).

Section 5 (Physical Feasibility & Design Applications) provides more detail on system configurations and performance credit, including the use of secondary practices.

Leadership in Energy and Environmental Design (LEED®). The LEED® point credit system designed by the U.S. Green Building Council (USGBC) and implemented by the Green Building Certification Institute (GBCI) awards points related to site design and stormwater management. Several categories of points are potentially available for new development and redevelopment projects. **Chapter 6** ~~and the introduction to this chapter of the~~ *Virginia Stormwater Management Handbook* (2nd Edition, 2013) provides a more thorough discussion of the site planning process and design considerations as related to the environmental site design and potential LEED credits. However, ~~VDCR~~ the Virginia Department of Environmental Quality (DEQ) is not affiliated with the USGBC or GBCI and any information on applicable points provided here is based only on basic compatibility. **Designers should research and verify scoring criteria and applicability of points as related to the specific project being considered through USGBC LEED resources**

Table 2.2. Potential LEED® Credits for Rainwater Harvesting¹

Credit Category	Credit No.	Credit Description
Sustainable Sites	SS6.1	Stormwater Design: Quantity Control
Sustainable Sites	SS6.2	Stormwater Design: Quality Control
Water Efficiency	WE1.1	Water Efficient Landscaping: Reduce by 50% ²
Water Efficiency	WE1.2	Water Efficient Landscaping: No Potable Water Use or No Irrigation ²
Water Efficiency	WE2	Innovative Wastewater Technologies ³
Water Efficiency	WE3.1	Water Use Reduction ⁴
Water Efficiency	WE3.2	Water Use Reduction ⁴
¹ Actual system design and/or water demand may not qualify for all the credits listed. Alternatively, the project may actually qualify for credits not listed here. Designers should consult with a qualified individual (LEED AP) to verify credit applicability. ² Applicable if water is used for landscape irrigation. ³ Includes credit for reduction in potable water demand for wastewater conveyance if water is used for flushing. ⁴ Credit 3.1 applied for 20% reduction and Credit 3.2 applied for 30% reduction in potable demand (awarded for flushing, mechanical systems, custodial uses, or potable uses.		

SECTION 3: DESIGN TABLE

Rainwater harvesting system design does not have a Level 1 and Level 2 design table. Runoff reduction credits are based on the total amount of annual water demand calculated using the VCD spreadsheet.

SECTION 4: TYPICAL DETAILS

Figures 6.1 through 6.3 of **Section 5** provide typical schematics of cistern and piping system configurations based on the design objectives (year-round or seasonal demand, etc.).

Figures 6.4 through and 6.66.5 of **Section 5** provide typical schematics of tank configurations, based on the design runoff Treatment Volume (T_v) and stormwater management objectives (T_v only, channel protection, etc.).

SECTION 5: PHYSICAL FEASIBILITY & DESIGN APPLICATIONS

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.

5.1 Site Conditions

Available Space. Adequate space is needed to house the storage tank or 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, on rooftops or within buildings (that are structurally designed to support the added weight), and adjacent to buildings. Designers can work with Architects and Landscape Architects to creatively locate a cistern within the building or site infrastructure. Underground utilities or other obstructions should always be identified prior to final determination of the tank location.

Site Topography and Hydraulic Head. 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 available hydraulic head or total elevation drop is measured from the downspout leaders to the final mechanism receiving gravity-fed discharge and/or overflow from the cistern.

These elevation drops will occur along the sloping lengths of the roof drain piping from the downspout leader at the building to the cistern. A vertical drop also occurs within the filter before the cistern, and finally through the cistern itself. An overflow outlet will typically be located near the top of the storage volume, and when the cistern is designed to include additional detention volume for channel and/or flood protection, an outlet may be included at a midlevel invert specified by the designer. Both the overflow and detention outlet orifices (if specified) will drain the tank

during large storms, routing this water through an outlet pipe, the length and slope of which will vary from one site to another.

All these components of the system have an elevation drop associated with them. The final invert of the outlet pipe must match the invert of the receiving mechanism (natural channel, storm drain system, etc.) that receives the overflow. These elevation drops and associated inverts should be considered early in the design, in order to assess the feasibility of a gravity-feed cistern for the particular site.

Site topography and tank location will also affect the amount hydraulic lift required to pump the water to the distribution system. Locating storage tanks in low areas will make it easier to route roof drains from the buildings to the cistern. However, it will increase the hydraulic lift needed to distribute the rainwater back into the building or to irrigated areas situated on higher ground. Conversely, placing storage tanks at higher elevations will reduce the amount of lift needed for distribution; however it may require larger diameter roof drains with flatter slopes (or the use of a pump) to fill the cistern. In general, it is often best to locate the cistern close to the building, ensuring that the roof surface and downspouts will drain efficiently with gravity flow.

When the water is being routed from the cistern to the inside of a building a pump is typically used to feed a smaller tank inside the building which then serves the internal demands through a gravity feed.

Water Table. Underground cisterns 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, buoyancy calculations should be performed to determine any special design features necessary to keep it from “floating” when the tank is empty. In all cases, the tank must also be installed according to the tank 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 should be considered, as full cisterns can be very heavy and may require an aggregate or concrete base. This is particularly important for above-ground cisterns, since settling could cause the cistern to lean or impact plumbing connections. The pH of the soil should also be considered in relation to the cistern material.

Proximity of Underground Utilities. All underground utilities must be taken into consideration during the design of cisterns and associated piping, treating all of the system components and storm drains as typical stormwater facilities and pipes. Appropriate minimum setbacks from septic drainfields should be observed, as specified by Virginia law and regulations.

Contributing Drainage Area. The cistern's contributing drainage area (CDA) ~~to the cistern~~ is the impervious roof area draining to the tank. Only rooftop surfaces should be considered as CDAs for cisterns. Parking lots and other paved surfaces typically include too many particulates (sediment, organic debris, trash, etc.) and/or pollutants from automobiles, spills, etc. for storage and distribution in a cistern system. Areas of any size, including only portions of a rooftop area,

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 rooftop runoff will vary according to the roof material over which it flows. Runoff from certain types of rooftops, such as asphalt sealcoats, tar and gravel, painted or galvanized metal, sheet metal, or any material that may contain asbestos, may leach trace metals and other toxic compounds. In general, collecting rainwater from such roofs should be avoided, unless sufficient information indicates that these materials will not negatively affect the proposed water use and are allowed by Virginia laws and regulations. If a sealant or paint coating on the 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). The 2009 Virginia Rainwater Harvesting Manual and other references listed at the end of this specification describe the advantages and disadvantages of different roofing materials.

Water Quality of Rainwater. Designers should also note that the *pH* of rainfall in Virginia tends to be acidic (ranging from 4.5 to 5.0), which may result in leaching of metals from the roof surface, tank lining or water laterals to interior connections. Once rainfall leaves rooftop surfaces, pH levels tend to be slightly higher, ranging from 5.5 to 6.0. Limestone or other materials may be added in the tank to buffer acidity, if desired.

Hotspot Land Uses. Collecting rooftop runoff can be an effective method to prevent mixing and possible contamination of rooftop runoff 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 ponding or soil saturation within 10 feet of building foundations. Cisterns should be designed to be watertight to prevent water damage when placed near building foundations. In general, it is recommended that underground tanks be set at least 10 feet from any building foundation.

Vehicle Loading. Whenever possible, underground cisterns 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.

5.2 Stormwater Uses

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

While the most common uses of captured rainwater are for non-potable purposes, such as those noted above, in some limited cases rainwater can be treated to potable standards. This assumes that (1) the treatment methods and end use quality meet drinking water standards and regulations,

and (2) the harvesting system is approved by the Health Department and the local governing authority. Treating harvested water to potable standards will increase installation, operation, and maintenance costs significantly.

5.3 Design Objectives and System Configurations

Many cistern system variations can be designed to meet water user demand and stormwater objectives. This specification focuses on providing a design framework for addressing the T_v reduction objectives and achieving compliance with the Virginia stormwater regulations. From a cistern design and water use standpoint, there are numerous potential water uses and system configurations that could be implemented. However, in terms of the goal of addressing the design T_v , this specification adheres to the following concepts in order to properly meet the stormwater volume reduction goals:

- **Annual runoff reduction volume credit is only awarded for dedicated year-round drawdown/demand for the water.** Seasonal practices (such as irrigation) may be incorporated into the site design, but the cistern design must be supplemented by a secondary runoff reduction drawdown practice with an equal or greater drawdown rate during the non-seasonal months in order to be credited with an annual runoff reduction volume credit (for stormwater purposes).
- 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).
- Pollutant load reduction is realized through reduction of the volume of runoff leaving the site and, when applicable, a downstream treatment practice.
- Peak flow reduction is realized through reduced volume and temporary storage of runoff.

Therefore, the basic cistern design configurations include the following:

1. Year-round indoor use with seasonal indoor and/or outdoor uses;
2. Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice; and
3. Seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice.

There are numerous different variations among these three basic ~~systems~~ configurations. However, the design logic and sizing parameters presented here can be readily applied to any design that is intended to achieve a stormwater management credit.

Configuration 1: Year-round indoor use with seasonal indoor and/or outdoor uses (Figure 6.1).

The first configuration is for year-round indoor use. Typical year-round uses captured in the VCD spreadsheet include toilet and urinal flushing and laundry. Additional uses that are captured in the VCD spreadsheet include irrigation, cooling towers, and a catch-all category of other uses that may include vehicle washing, street sweepers, and other not yet defined year-round or seasonal uses.

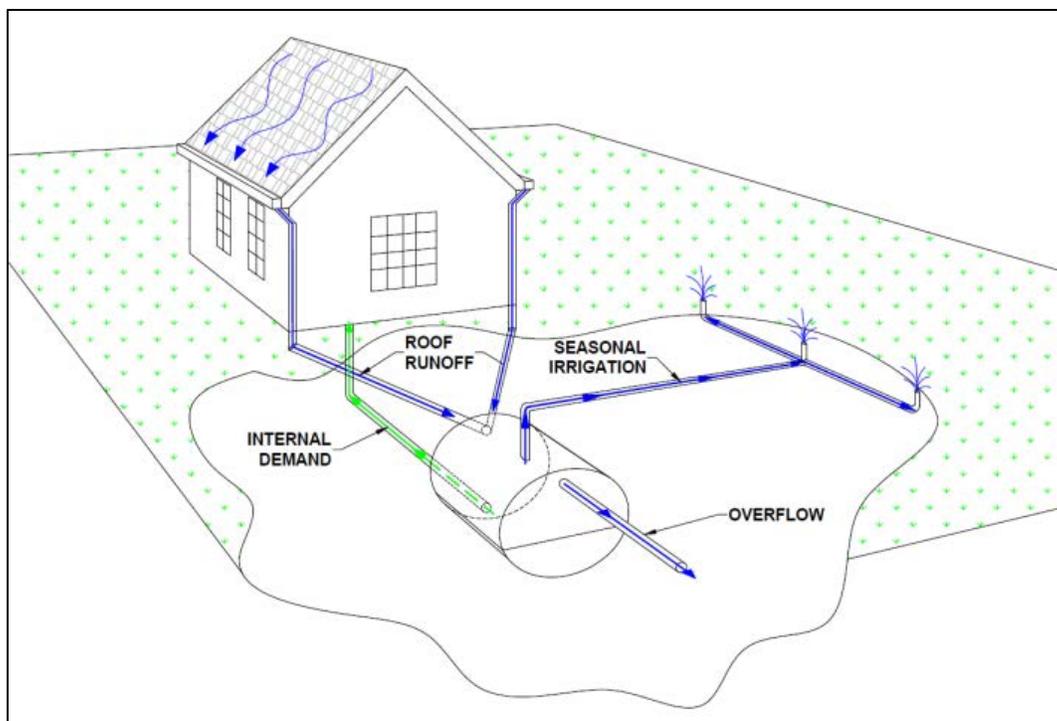


Figure 6.1. Configuration 1: Year-round indoor use with optional seasonal outdoor use

The only runoff reduction volume credit derived from this configuration is the year-round indoor use. While the seasonal uses do not provide an annual credit, they generally use a lot of water (i.e., irrigation) such that the owner may elect to increase the system size to provide for the seasonal demand in order to reduce potable water usage. Further discussion of optimizing the tank size for specific goals is provided in **Section 6** and **Appendix 6-B**.

Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 6.2). The second configuration builds upon the first with the addition of a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish an annual runoff reduction volume credit (in addition to the credit based on the year-round indoor uses). Therefore, the system must account for three uses: year-round internal non-potable water demand, a seasonal outdoor use such as automated irrigation system or cooling towers, and an engineered drawdown to a secondary runoff reduction drawdown practice for volume reduction during non-irrigation (or non-seasonal) months.

The cistern acts as a detention system during the non-seasonal months that must be designed to slowly draw down at a rate comparable to the seasonal use in order to provide storage for the next storm event. In this way, the system achieves a year-round use and a corresponding annual runoff reduction volume credit. The design and sizing of the secondary runoff reduction drawdown practice is based on a specific drawdown rate, as opposed to the standard BMP sizing criteria of the design T_{VBMP} (or the corresponding peak discharge) required to manage the 1-inch T_v design storm [q_{pTv} – **Chapter 11**, *Virginia Stormwater Management Handbook* (2nd Edition, 2013)]. The secondary drawdown practice sizing will also be influenced by the hydraulic properties of the

practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity. The resulting size and/or storage volume of the secondary runoff reduction drawdown practice will generally be smaller than the stand-alone BMP (e.g., without the up-gradient storage tank).

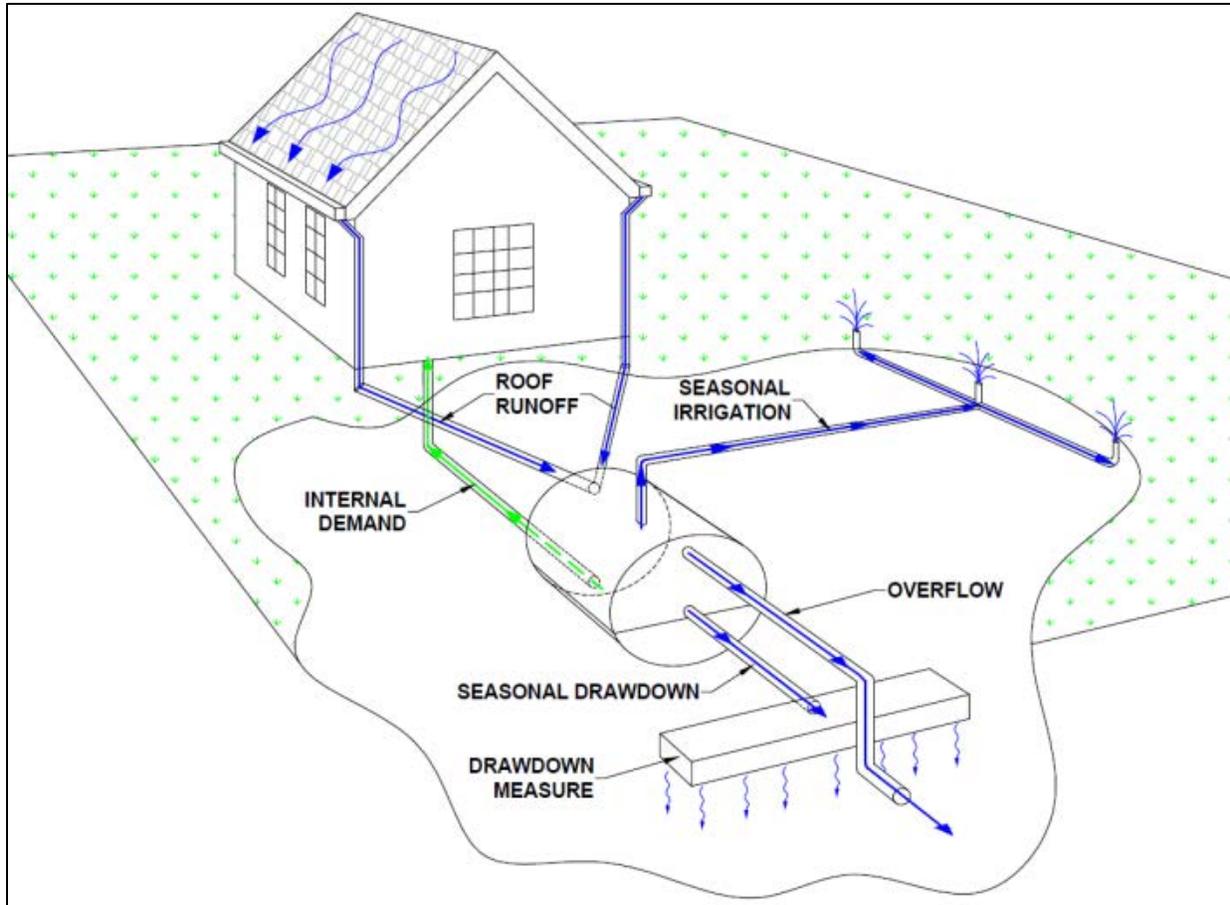


Figure 6.2. Configuration 2: Year-round indoor use with seasonal indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice

Several system design elements are discussed in **Section 6**, including considerations related to secondary drawdown in conjunction with large storm controls (for channel or flood protection).

Configuration 3: Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice (Figure 6.3). The third configuration does not have any year-round uses and therefore uses stored rainwater to meet seasonal or intermittent water uses, while using a secondary runoff reduction drawdown practice in order to supplement the seasonal uses and establish an annual runoff reduction volume credit. In this configuration, the system designer needs to account for only two uses: the seasonal outdoor use (automated irrigation system, cooling towers, etc.) and the engineered drawdown to a secondary runoff reduction practice. Similar to the previous configuration, the tank drawdown rate should be designed to be, at a minimum, comparable to the periodic seasonal use. The drawdown rate and practice sizing

may also be influenced by the hydraulic properties of the practice and the site conditions, such as soil infiltration rates, surface area, and/or retention capacity.

In the case of both Configuration 2 and Configuration 3, the design of the tank size and its drawdown rate and the exfiltration rate and surface area of the drawdown practice may be used to establish a hydraulic routing of the system for sizing purposes. **Appendix 6-C** provides guidance on the sizing of the secondary runoff reduction drawdown practice.

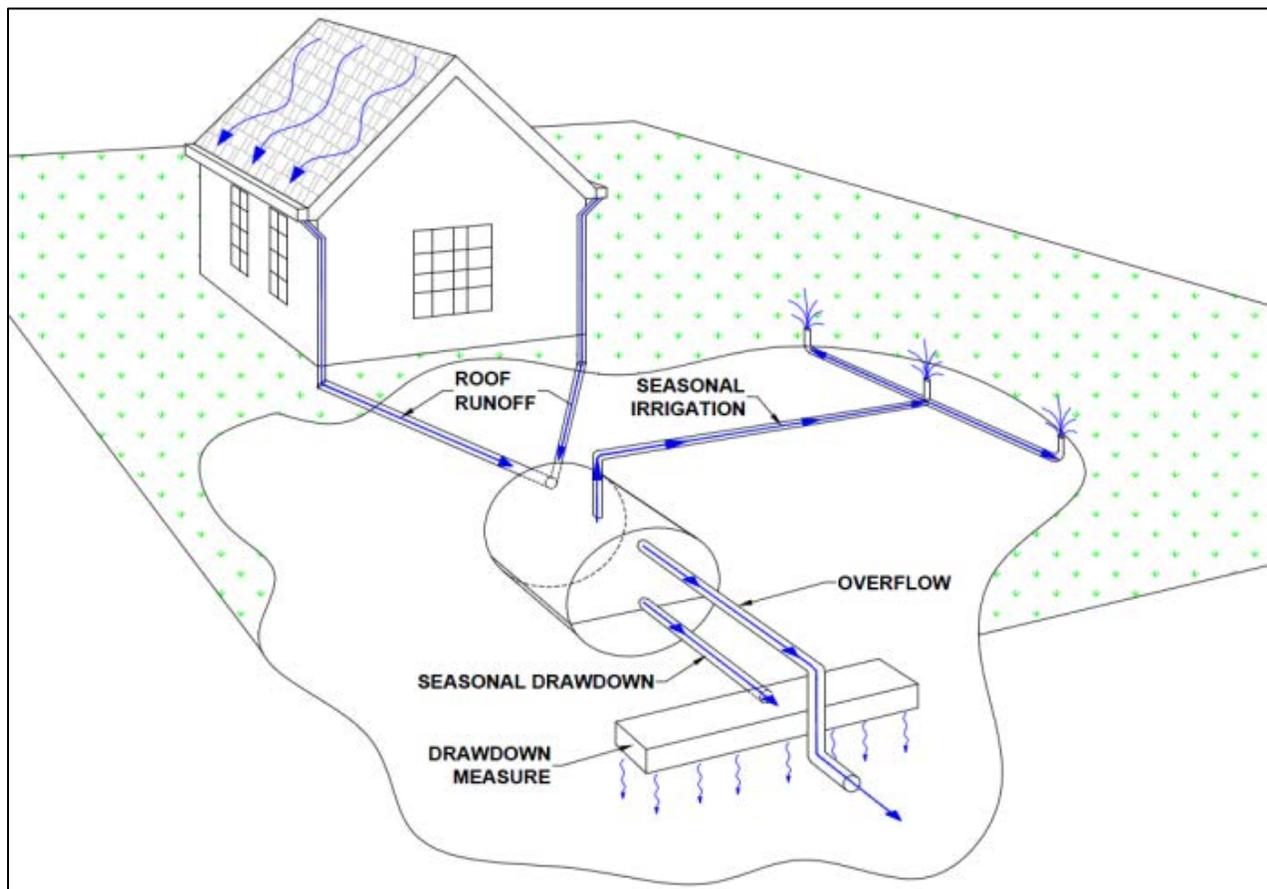


Figure 6.3. Configuration 3: Seasonal only indoor and/or outdoor uses that are supplemented with a secondary runoff reduction drawdown practice

5.4 Design Objectives and Tank Design Set-Ups

Pre-fabricated rainwater harvesting cisterns typically range in size from 250 to over 30,000 gallons. There are two basic tank design configurations used to meet the various rainwater harvesting system configurations that are described in **Section 5.3**.

Tank Design 1. The first tank set-up (**Figure 6.4**) maximizes the available tank storage volume to accommodate the Treatment Volume (T_v) to meet the water demand and achieve the desired runoff reduction volume credit. An emergency overflow exists near the top of the tank. The overflow

outlet may be a gravity flow outlet or a pumped outlet. Alternatively, the overflow may be an external control that backs up the flow before the tank, thereby diverting any additional inflow.

Note: Figures 6.4 and 6.5 are schematic representations of the relative configuration of the storage volume and outlets. If these tanks are configured below grade, there would be a mechanical system to pump the required flow to meet the water demand or drawdown, requiring a float switch or other water level sensor to trigger the pump for meeting a variable demand. An above grade system may include a combination of gravity overflow orifices and a pump system to generate adequate pressure for the intended uses. Figure 6.6 provides a schematic representation of a cistern with a mechanical system included.

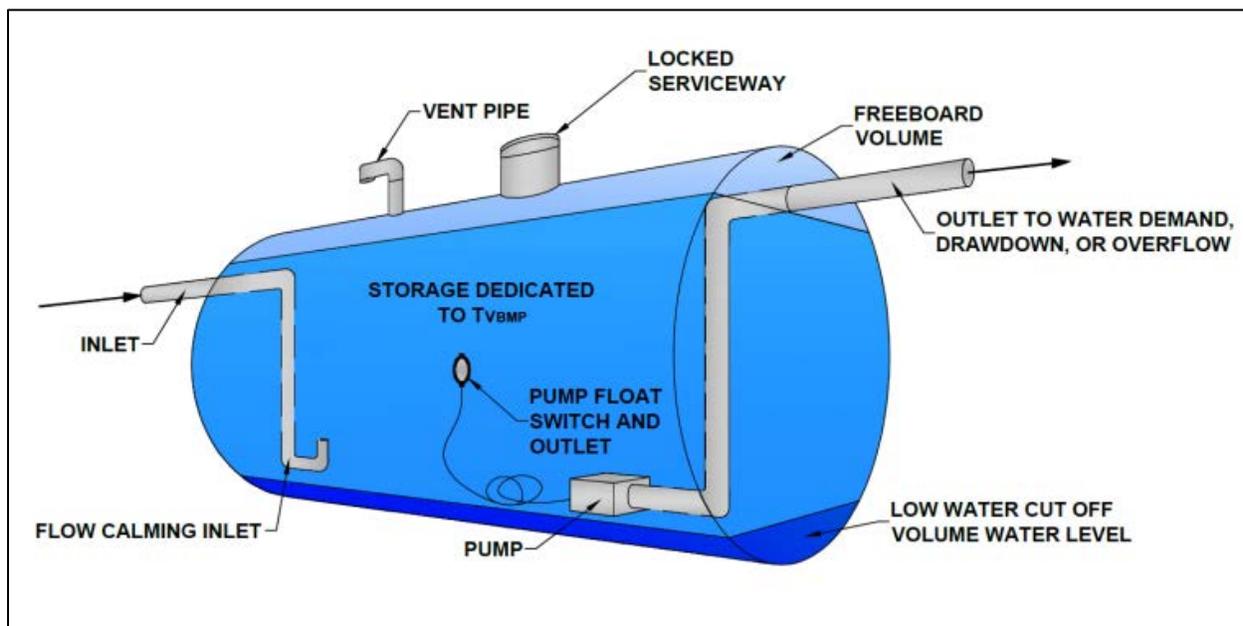


Figure 6.4. Tank Design 1: Storage Associated with Treatment Volume (T_v) only

Tank Design 2. The second tank set-up (Figure 6.5) uses tank storage to manage the T_v and runoff reduction volume credit objectives, as well as using an additional detention volume above the T_v to also meet some or all of the channel and/or flood protection ~~volume-quantity control~~ requirements. For an above ground system, the channel and/or flood protection storage outlet orifice is located at the top of the T_v design storage and sized according to the channel and/or flood protection peak flow requirements. Alternatively, a below grade system would rely on a float switch and pump to achieve the same objectives. An emergency overflow is located at the top of the detention volume level. The VRRM compliance spreadsheet can be used in combination with other approved hydrologic routing programs to model and size the Channel Protection and Flood Protection (detention) volumes.

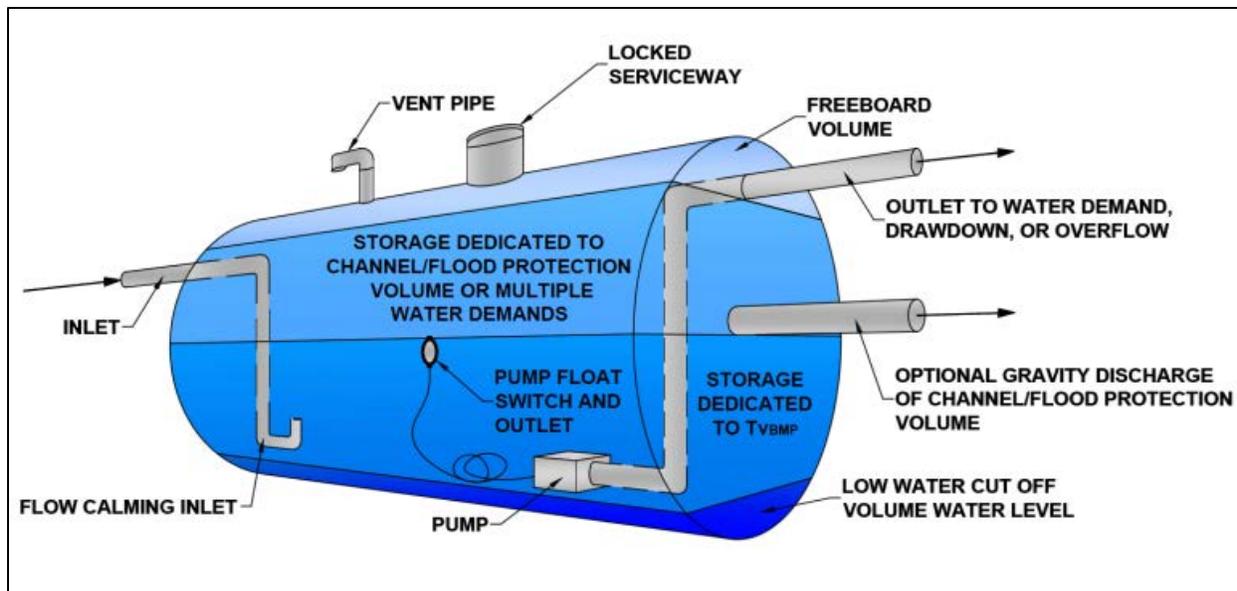


Figure 6.5. Tank Design 2: Storage Associated with Treatment, Channel Protection and Flood Volume

In both cases, the T_v storage is managed with either a gravity discharge or a pump, based on the demand. When a secondary stormwater management BMP is used to enhance the effectiveness of rainwater harvesting as a stormwater management practice, there are two basic applications that can be considered:

- A *secondary runoff reduction drawdown practice* that is part of the cistern system and is used to supplement a seasonal demand by providing a runoff reduction drawdown during the non-seasonal months (thereby establishing an annual runoff reduction volume credit); or
- A downstream runoff reduction or pollutant removal BMP that is selected as a downstream treatment practice in order to manage the remaining portion of the year-round demand. In this case, the year-round demand and runoff reduction volume credit computed in the VCD spreadsheet is less than 100% of the annual T_v , and the *downstream practice to be employed* is selected in the VRRM compliance spreadsheet to provide additional volume reduction, pollutant removal, or both.

Rainwater harvesting design specifications have not routinely included guidance for on-site stormwater infiltration or “disposal” systems. The basic approach is to provide a dedicated secondary runoff reduction or drawdown practice on-site that will allow water within the tank to be discharged at a specified design rate between storm events during the demand “off-season.” The design and sizing of this drawdown feature is based on the rate of cistern drawdown and/or the physical features of the drawdown practice, as discussed in **Section 5.5** below.

The second approach noted above requires that a secondary BMP is designed in accordance with the BMP Design Specifications for the selected runoff reduction or treatment BMP in order to manage the remaining annual volume or T_{VBMP} [see **Chapter 11**, *Virginia Stormwater Management Handbook* (2nd Edition, 2013)]. This BMP is selected in ~~the Column P (Downstream Practice to be Employed)~~ column on the Drainage Area tabs of the VRRM compliance spreadsheet.

5.5. Secondary Runoff Reduction Drawdown Practice

The secondary runoff reduction drawdown practice can be considered a soak-away pit. The concept is to mimic, at a minimum, the same rate of pumping or drawdown during the non-seasonal months in order to establish the annual credit. The use of the drawdown practice is entered into the VCD spreadsheet and is considered an integral part of the rainwater harvesting system and the resulting Runoff Reduction Volume Credit computed by the VCD spreadsheet. This drawdown must not be added (or double-counted) on the VRRM compliance spreadsheet. An exception would occur if the secondary drawdown practice were also located to capture and manage developed area beyond the rooftop area captured by the cistern (such as the adjacent yard, driveway, etc.). In those cases, the drawdown practice is sized for the cistern drawdown volume and rate of flow *and* for the T_{VBMP} from the additional areas (using the sizing criteria from the corresponding BMP Design Specification). This “combined” drawdown and downstream BMP will include complex sizing parameters and must include sufficient documentation to ensure that (1) the contributing drainage areas are accounted for in the VRRM compliance spreadsheet, and ~~that it~~(2) the downstream drawdown BMP is sized properly.

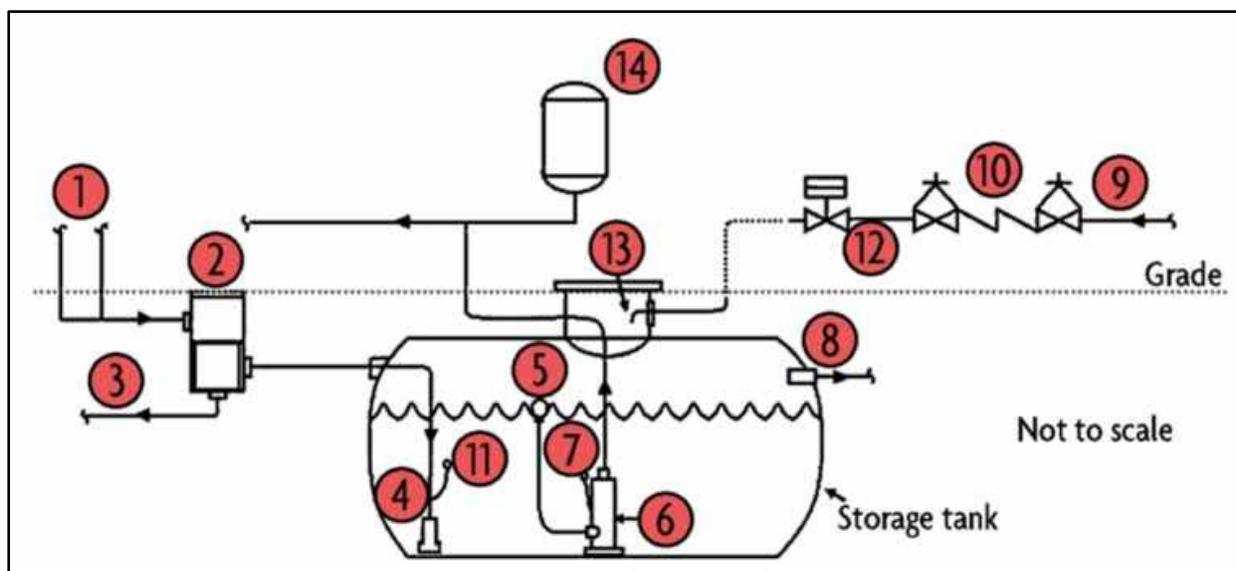
Secondary runoff reduction drawdown practices are generally those practices that have a volume reduction credit, and they may include variations of the following:

- Sheet Flow to a Vegetated Filter or Conserved Open Space: Design Specification No. 2
- Infiltration and Micro-Infiltration: Design Specification No. 8.
- Bioretention and Micro-Bioretention (rain garden): Design Specification No. 9.
- Dry Swale: Design Specification No. 10.

The sizing of the drawdown practice is ultimately based on the rate of the cistern drawdown and the infiltration of the underlying soils. Where an underdrain is used, the design is based on a conservative estimate of the permeability of the engineered soil media. **Appendix 6-C** provides guidance on sizing of secondary runoff reduction drawdown practices.

5.6 System Components

The components of a rainwater harvesting system may include those illustrated in **Figure 6.6** below.



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

Figure 6.6 Sample Rainwater Harvesting System Detail

Source: Rainwater Resources (www.rainwaterresources.com)

Rainwater harvesting systems can be designed and delivered to the site as a fully integrated and designed system that incorporates all the mechanical elements listed above. Descriptions of these system components are provided below:

1. Rooftop Surface and Collection System. 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 other 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.

The collection and conveyance system consists of the gutters, downspouts and pipes that channel stormwater runoff into storage tanks. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system. Aluminum, round-bottom gutters and round downspouts are generally recommended for rainwater harvesting. Minimum slopes of gutters should be specified. At a minimum, gutters should be sized with slopes specified to contain the 1-inch storm at a rate of 1-inch/hour, for treatment volume credit. If volume-quantity control credit will also be sought for stream channel and flood protection, the

gutters should be designed to convey the 2- and 10-year storm, using the appropriate 2- and 10-year storm intensities, specifying size and minimum slope. In all cases, gutters should be hung at a minimum of 0.5% for the first 2/3 of the length and at 1% for the remaining last 1/3 of the length leading to the downspout.

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 size 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.

- 2. *Pre-Treatment: Screening, First Flush Diverters and Filter Efficiencies.*** Pre-filtration is required to keep sediment, leaves, contaminants and other debris from the system. Such debris can create clogging and collect in the cistern, displacing some of the design storage volume. 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 decrease microbial food sources in order to minimize organic buildup in the tank and decrease potential system maintenance.

Each filter has an associated efficiency curve that estimates the percentage of rooftop runoff that will be conveyed through the filter to the storage tank. If filters are not sized properly, a large portion of the rooftop runoff may be diverted and not conveyed to the tank at all. A design intensity of 1-inch/hour should be used for the purposes of sizing pre-tank conveyance and filter components. This design intensity captures a significant portion of the total rainfall during a large majority of rainfall events (NOAA 2004). If the system will be used for channel and flood protection as well, the 2- and 10-year storm intensities should be used for the design of the conveyance and pre-treatment portion of the system. For the 1-inch storm treatment volume, a minimum of 95% filter efficiency is required. This efficiency includes the first flush diversion. The ~~Cistern Design~~VCD Spreadsheet, discussed more in **Appendix 6-B**, assumes a filter efficiency rate of 95% for the 1-inch storm. For the 2- and 10-year storms, a minimum filter efficiency of should be at least 90% - should be met.

- ***First Flush Diverters*** (**Figure 6.7** below). First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove larger debris such as leaves, twigs and blooms from harvested rainwater, first flush diverters can be used to remove smaller contaminants such as dust, pollen and bird and rodent feces. Simple first flush diverters require active management, by draining the first flush water volume to a pervious area following each rainstorm. First flush diverters may be the preferred 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 (Figure 6.8).** Roof washers are placed just ahead of storage tanks and are used to filter small debris from harvested rainwater. Roof washers consist of a tank, usually between 25 and 50 gallons in size, with leaf strainers and a filter with openings as small as 30-microns (TWDB, 2005). The filter functions to remove very small particulate matter from harvested rainwater. All roof washers must be cleaned on a regular basis.

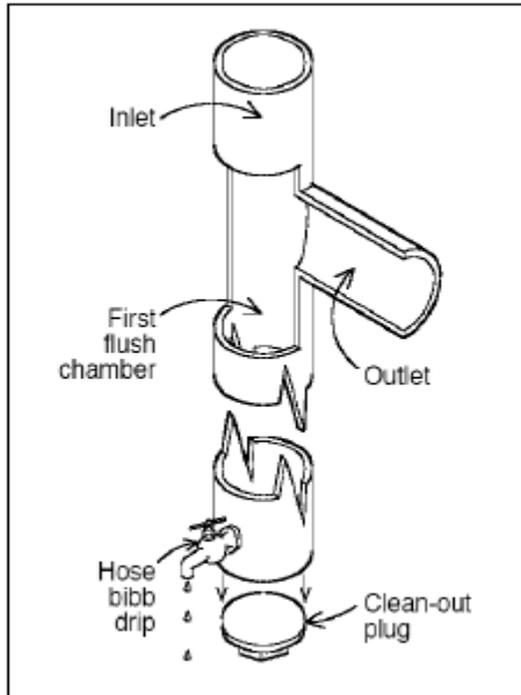


Figure 6.7. First Flush Diverter

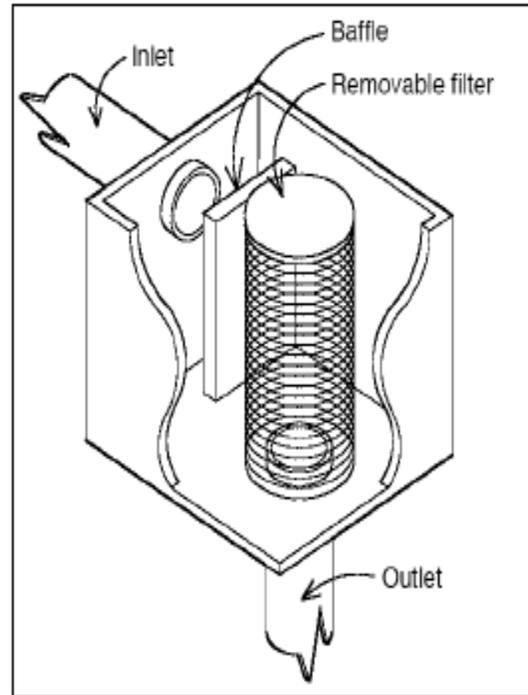


Figure 6.8. Roof Washer

- **Vortex Filters.** For large scale applications, vortex filters can provide filtering of rooftop rainwater from larger rooftop areas. Two images of the vortex filter are displayed below. The first image (**Figure 6.9**) provides a plan view photograph showing the interior of the filter with the top off. The second image (**Figure 6.10**) displays the filter just installed in the field prior to the backfill.



Figure 6.9. Interior of Vortex Filter



Figure 6.10. Installation of Vortex Filter prior to backfill

- 3. First Flush Diversion and Discharge.** The initial first flush from the rooftop must be diverted from the system before rainwater enters the storage tank. Designers should note that the goal for rainwater harvesting systems is to divert the first flush away from the system, as opposed to the traditional stormwater treatment strategy of capturing and treating the first flush. The amount diverted can range from the first 0.02 to the first 0.06 inches of rooftop runoff.

The diverted flows (first flush diversion and overflow from the filter) must be directed to an acceptable pervious flow path that will not cause erosion during a 2-year storm or to an appropriate BMP on the property. Preferably the diversion will be conveyed to the same secondary runoff reduction practice that is used to receive storage tank overflows.

4. ***Storage Tank.*** The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. Cistern capacities range from 250 to over 30,000 gallons. Multiple tanks can be placed adjacent to each other and connected with pipes to balance water levels and increase overall storage on-site as needed. Typical rainwater harvesting system capacities for residential use range from 1,500 to 5,000 gallons. The performance of different sized storage tanks can be evaluated using the VCD spreadsheet to meet the water demand and stormwater treatment volume credit objectives, as described in **Appendix 6-B** of this design specification.

While many of the graphics and photos in this design 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 vertically stepped to match the topography of a site. The following are factors that should be considered when designing a rainwater harvesting system and selecting a storage tank:

- Aboveground storage tanks should be both UV- and impact-resistant.
 - Underground storage tanks must be designed to support the overlying sediment and any other anticipated loads (e.g., vehicles, pedestrian traffic, etc.).
 - Underground rainwater harvesting systems should have a standard-size manhole or equivalent opening to allow access for cleaning, inspection, and maintenance purposes. This access point should be locked or otherwise secured to prevent unwanted access.
 - All rainwater harvesting systems should be sealed using a water-safe, non-toxic substance.
 - Rainwater harvesting systems (including the mechanical systems and internal plumbing) may be ordered from a manufacturer or can be constructed on site from a variety of materials. **Table 6.2** below compares the advantages and disadvantages of different storage tank materials, and **Figures 6.11** thru **6.13** show example system configurations.
 - 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.
 - The inflow pipe should consist of an upturned elbow or other form of a flow-calming configuration to minimize the suspension of solids settled on the tank bottom.
5. ***Floating (outlet) Filter.*** A floating filter is an intake equipped with a stainless steel mesh filter that is suspended just below the tank water surface by a float. The goal is to draw water from just below the surface, above the accumulated particulates that settle to the bottom, and below the suspended material that manages to get through the first flush diverter. The floating filter is connected to the pump and outlet plumbing. (see **Figures 6.4** and **6.5**)

6. **Submersible Pump** (item 14 in *Figure 6.6* above). A shallow well submersible pump that is designed to push water is placed in the lower portion of the cistern to deliver water to a pressure tank. As water is drawn from the pressure tank, the pump is triggered and delivers more water to the pressure tank. A check valve prevents the pressurized water from returning to the cistern.
7. **Low Water Level Sensors.** Several different forms of water level switches are available to shut off the submersible pump when the water level is below the optimal operating depth. A submersible pump is very susceptible to failure from over-heating if operating in dry conditions. (The mechanical systems, including the pump, pressure tank, and back-up supply must all be coordinated to ensure the proper function and longevity of the system.)
8. **Overflow.** The overflow drain or discharge pump should discharge to an appropriately sized conveyance to the downstream BMP, if applicable, or the ~~designated-receiving~~ drainage system.
9. **Back-Up Water Supply.** The back-up water supply is accounted for in the VCD spreadsheet and is intended for a connection that feeds water directly into the cistern.

Note: It is recommended that if municipal water serves as the back-up supply, it should not discharge directly into the cistern since the chemicals of the municipal water supply may kill the biofilm in the tank. Rather, the municipal back-up should bypass the tank through the solenoid valve and backflow preventer.) (Cabell Brand, 2009). However, the spreadsheet does not account for this back-up configuration (which connects to the supply line between the cistern and the building). In either case, the back-up is triggered by low and high water levels, when used, and is calibrated as a percentage of total cistern volume (cistern tank invert to overflow invert). This percent format allows the application of the VCD spreadsheet to all cistern sizes.

10. **Backflow Preventer** (item 13 in *Figure 6.6* above). A backflow preventer in the form of an air gap or check valve is used to prevent the flow from the pressure tank back into the cistern, and from the cistern into the municipal supply line.
11. **Float Switch** (item 12 in *Figure 6.6* above). The float switch controls the pump and the distribution of water based on the demand (internal, seasonal, drawdown, pressure tank, etc., and water levels in the tank). The float switch will open and close the back-up supply solenoid valve.

Table 6.2. Advantages and Disadvantages of Various Cistern Materials

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 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 use for toxics; water pH and soil pH may also limit applications
FerroConcrete	Durable and immovable; suitable for above or below ground installations; neutralizes acid rain	Potential to crack and leak; expensive
Cast in Place Concrete	Durable, immovable, 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 immovable; keeps water cool in summer months	Difficult to maintain; expensive to build

Source: Cabell Brand, 2007, 2009

The images below in **Figures 6.11 to 6.13** display examples of various materials and shapes of cisterns discussed in **Table 6.2** above.



Figure 6.11. Example of Multiple Fiberglass Cisterns in Series



Figure 6.12. Example of two Polyethylene Cisterns



Figure 6.13.a Metal Tanks

Source: Practical Environmentalist (www.practicalenvironmentalist.com)



Figure 6.13.b Residential Applications:

Left: brick and stucco Source: Village Craftsmen (www.villagecraftsmen.com)
Right: Residential Polyethylene Source: EcoUrban LLC (www.ecourbanllc.com)

Distribution Systems. Most distribution systems require a pump to convey harvested rainwater from the storage tank to its final destination, whether that is a pressure tank inside a building, an automated irrigation system, or a gradual discharge to a secondary runoff reduction drawdown practice. The typical pump and pressure tank arrangement consists of a submersible pump with a float switch and water level sensors that sends water on demand out of the storage tank and 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 pressure tank or distribution system. The backflow preventer is required to separate harvested rainwater from the main potable water distribution lines.

The following should be considered in the layout and design of the distribution system:

- Distribution lines to and from the cistern tank should be buried beneath the frost line.
- Distribution lines from the rainwater harvesting system to the building should have shut-off valves that are accessible when snow cover is present.
- The distribution lines should include a drain plug, cleanout sump or other access point so the lines can be completely drained, if needed.

- Above-ground outdoor pipes should be insulated or heat-wrapped to prevent freezing and ensure uninterrupted operation during winter. For new construction, consider interior roof drains to prevent drain lines from freezing.

Overflow. An overflow mechanism should be included in the rainwater harvesting system design in order to manage individual or combined storm events that exceed the design capacity of the cistern. An *external* overflow system would simply back up the inflow pipe and force any additional flow to be diverted to the overflow conveyance. An internal overflow system (i.e., pump discharge) should have a flow capacity equal to or greater than that of the inflow pipe(s) in order to prevent water from backing up into the collector system, or be combined with an external overflow. The overflow system must be designed with an adequate pipe diameter and slope sufficient to convey the discharge to the designated outlet.

SECTION 6: DESIGN CRITERIA

6.1. Sizing of Rainwater Harvesting Systems

The rainwater harvesting cistern sizing criteria presented in this specification and the VCD spreadsheet was developed using best estimates of indoor and outdoor year-round and seasonal water demand, long-term rainfall data, and rooftop capture area data (Forasté and Lawson, 2009; Forasté 2013). The VCD spreadsheet is primarily intended to provide guidance in sizing cisterns for purposes of achieving a runoff reduction volume credit for storms less than or equal to a depth of 1-inch. This credit is then entered into the VRRM compliance spreadsheet for compliance with the water quality requirements

The VCD spreadsheet performs continuous simulation, using 30 years of daily rainfall data paired with the user input for predicting the water fluctuations within the system, in order to help the designer select the optimal cistern size. The continuous simulation considers the historical frequency of the design (1-inch) rainfall depth, the volume of captured runoff based on the roof area, the losses associated with the first flush diversion and filter efficiency, and the water levels at the beginning and end of storms according to the tank drawdown, based on the user-entered water demand and the selected tank size. The spreadsheet then predicts the dynamic water levels over the one-year period and estimates the number of overflow and dry days per year and the cumulative daily and equivalent year round water use and determines the corresponding runoff reduction volume credit. These outputs allow the designer to optimize the system sizing and configuration and the corresponding runoff reduction volume credit. **Appendix 6B** provides a full description of the VCD spreadsheet.

6.2. Incremental Design Volumes within the Cistern

In addition to sizing the cistern for the 1-inch design rainfall, the designer may size the cistern for the management of larger storms (channel and flood protection requirements). In general, the cistern size is increased as needed to accommodate the additional storage above the 1-inch $T_{V_{BMP}}$ volume level. The additional storage is that which is needed to accommodate the attenuation of the 1-year or 10-year design storm runoff for channel protection (energy balance) or flood

protection, respectively. A gravity discharge orifice is located above the T_{VBMP} volume and sized for the allowable discharge or a regulated pump discharge is installed that is activated by a float switch when the water surface in the cistern exceeds the T_{VBMP} level. **Figure 6.14** provides a schematic representation of the potential incremental design volumes when managing the additional storm events.

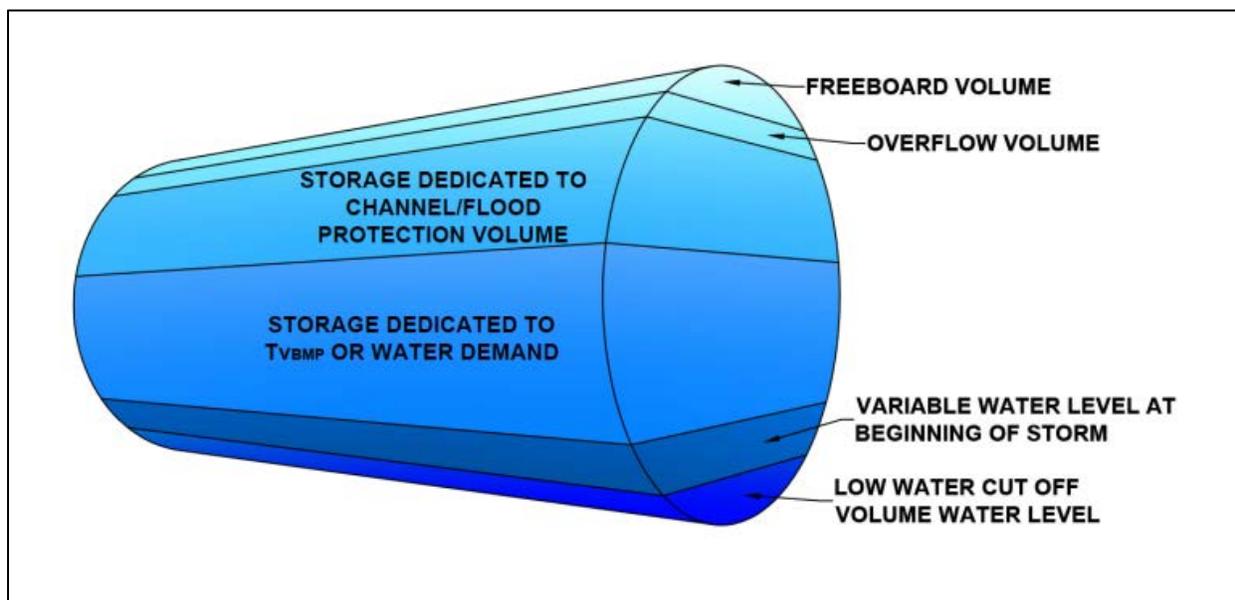


Figure 6.14. Incremental Design Volumes associated with tank sizing

The “Storage Dedicated to T_{VBMP} ” labeled in **Figure 6.14** is the storage modeled and available for use to meet the annual water demand. While the design T_{VBMP} is a function of the roof area and is constant, the actual storage volume dedicated to meeting the demand may vary depending on the size of the tank selected and corresponding runoff reduction volume credit. The cistern design will also include volume dedicated to a low water cutoff at the bottom (meaning the tank should never run completely dry), as well as an overflow volume and freeboard at the top.

This specification is primarily focused on guidance for managing the 1-inch target T_{VBMP} and does not address the design or sizing for channel and flood protection volume within a cistern. See **Chapter 10** (“Uniform Stormwater BMP Sizing Criteria”) and **Chapter 11** (“Engineering Computations”) of the *Virginia Stormwater Management Handbook* (2nd Edition, 2013) for more information on design volumes and outlet sizing criteria associated with other target design storms.

6.3 Sizing Using the Virginia Cistern Design (VCD) Spreadsheet

This specification is directly linked to the VCD spreadsheet which can be downloaded from the Virginia Stormwater BMP Clearinghouse web site at:

<http://www.vwrrc.vt.edu/swc/NonProprietaryBMPs.html>

The spreadsheet uses 30 years of daily rainfall data from four localities in Virginia (Richmond, Alexandria, Lynchburg, and Harrisonburg) to model the performance parameters of the cistern under varying rooftop capture areas, water demands, and tank sizes. As such, the VCD spreadsheet is a design tool for estimating the optimal size of a cistern based on the design rainfall, rooftop area, and water demand, and computing a corresponding runoff reduction volume credit (Forasté and Hirschman, 2010). This credit is then plugged into the VRRM compliance spreadsheet to evaluate the overall compliance of the BMP strategy.

New development and redevelopment projects in ultra-urban settings may be able to meet the entire project's stormwater management requirements with a rainwater harvesting system managing the rooftop runoff. Larger developments with other site improvements in addition to the rooftop, such as parking lots, driveways, pedestrian plazas, etc., will likely require additional BMPs to manage these other areas of the site (or pursue offsite compliance options) in order to meet the overall site requirements. In these cases, the rainwater harvesting runoff reduction volume credit will be one of several BMPs entered into the VRRM compliance spreadsheet. See **Appendix 6-B** for a detailed description of how to use the Cistern Design Spreadsheet

6.4. Design for Potable Water Calculations

In situations with insufficient potable water supply, rainwater can be treated and used for potable water supply subject to state and local health requirements (the Virginia Department of Health maintains regulations pertaining to use of rainwater to meet potable water demand). **Rainwater for potable water supply is not addressed in this design specification.** If this use is permitted by the appropriate public health authority, and the rainwater harvesting system is equipped with proper filtering equipment, the increased annual water demand would increase the runoff reduction volume credit while reducing the demand on the municipal water supply, resulting in commensurate cost savings. It would also enable the use of a more standard plumbing system, since potable and non-potable water would no longer need to be separated.

6.5. Rainwater Harvesting Material Specifications

The basic material specifications for rainwater harvesting systems are presented in **Table 6.3** below. Designers should consult with experienced rainwater harvesting system and irrigation installers on the choice of recommended manufacturers of prefabricated tanks and other system components.

Table 6.3. Design Specifications for Rainwater harvesting systems

Item	Specification
Gutters and Downspout	<p>Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead should not be used as gutter and downspout solder, since rainwater can dissolve the lead and contaminate the water supply.</p> <ul style="list-style-type: none"> ▪ 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	<p>At least one of the following (all rainwater to pass through pre-treatment):</p> <ul style="list-style-type: none"> ▪ First flush diverter ▪ Vortex filter ▪ Roof washer ▪ Leaf and mosquito screen (1 mm mesh size)
Storage Tanks	<ul style="list-style-type: none"> ▪ 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-suitable 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.
<p>Note: This table does not address indoor systems or pumps.</p>	

SECTION 7: REGIONAL & SPECIAL CASE DESIGN ADAPTATIONS

7.1. 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. However, substrate should be examined beneath the cistern location to ensure the weight of the structure can be supported.

7.2. Coastal Plain

Above-ground rainwater harvesting systems are a preferred practice in the coastal plain, since they avoid the flat terrain, low head and high water table conditions that constrain other stormwater practices.

7.3. Steep Terrain

Rainwater harvesting systems are ideal in areas of steep terrain.

7.4. Cold Climate & Winter Performance

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.

Winter-time operation of above-ground systems may be challenging, depending on tank size and whether heat tape is used on piping. If not protected from freezing, rainwater harvesting systems should be disconnected, drained and taken off-line for the winter, resulting in a seasonal use (and *thereby eliminating the runoff reduction volume credit*).

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

7.5. Linear Highway Sites

Rainwater harvesting systems are generally not applicable for linear highway sites.

SECTION 8: CONSTRUCTION

8.1. Construction Sequence

It is advisable to have a single contractor install the rainwater harvesting system, outdoor irrigation system and secondary runoff reduction practices. The contractor should be familiar with the sizing, installation, and placement of rainwater harvesting systems. The rainwater harvesting system must be connected to components to the plumbing system by a licensed plumber.

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.

- Identify the tank location on the site
- Route all downspouts or roof drains to pre-screening devices and first flush diverters
- Install the tank in accordance with the approved plans or the manufacturer's recommendations
- Install the pump (if required, and if not pre-engineered into the tank) 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 path has been stabilized with vegetation.

8.2. 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 installed and discharges as shown on plans
- Rainwater harvesting system foundation is constructed as shown on plans
- Catchment area and overflow area are stabilized
- Secondary runoff reduction practice(s) is installed as shown on plans
- Inflow and outflow pipes and distribution system are constructed in accordance with the approved plans and have been tested for water-tightness.

SECTION 9: MAINTENANCE

9.1. Maintenance Agreements

The Virginia Stormwater Management regulations (4 VAC 50-112) specify the circumstances under which a maintenance agreement must be executed between the owner and the VSMP authority, and 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.

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

- A rainwater harvesting systems must include a long term maintenance agreement consistent with the provisions of the VSMP regulations, and must include a list of the recommended maintenance tasks and a copy of an annual inspection checklist.
- When a rainwater harvesting system is installed on a private residential lot, the homeowner should be educated by being provided a simple document that explains the purpose of the system and its routine maintenance needs. .
- A deed restriction, drainage easement or other legal mechanism enforceable by the VSMP authority must be in place to help ensure that the rainwater harvesting system is maintained and operational, as well as to pass the knowledge along to any subsequent owners.
- Ideally, this legal mechanism should grant authority for the VSMP authority to access the property for inspection of the tank (if external), the overflow conveyance, and any secondary runoff reduction drawdown BMP(s).
- As an alternative, a property owner may document that the system has been inspected and maintained by a qualified third party inspector.

9.2. Maintenance Inspections

All rainwater harvesting system components should be inspected by the property owner in the Spring and the Fall each year. A comprehensive inspection by a qualified third party inspector is recommended at least once a year but, at a minimum, should occur and be documented once every three years. An example maintenance inspection checklist for Rainwater Harvesting can be accessed in **Appendix 9-C** of **Chapter 9** of the *Virginia Stormwater Management Handbook* (2nd Edition, 2013).

9.3. 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 6.4** describes routine maintenance tasks to keep rainwater harvesting systems in working condition.

Table 6.4. 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	

SECTION 10: COMMUNITY & ENVIRONMENTAL CONCERNS

Although rainwater harvesting is an ancient practice, it is enjoying a revival due to the inherent quality of rainwater and the many beneficial uses that it can provide (TWDB, 2005). Some common concerns associated with rainwater harvesting that must be addressed during design include:

Winter Operation. Rainwater harvesting systems can be used throughout the year if they are located underground or indoors to prevent problems associated with freezing, ice formation and associated system damage. Alternately, an outdoor system can be used seasonally or year-round if special measures and design considerations are incorporated. See **Section 7.4** for further guidance on winter operation of rainwater harvesting systems.

Local Plumbing Codes. Designers and plan reviewers should consult local building codes to determine if they explicitly allow the use of harvested rainwater for toilet and urinal flushing. In

the cases where a municipal backup supply is used, rainwater harvesting systems are typically required to have backflow preventers or air gaps to keep harvested water separate from the main water supply. Pipes and spigots using rainwater must be clearly labeled as non-potable.

Mosquitoes. In some situations, poorly designed rainwater harvesting systems can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on above- and below-ground tanks to prevent mosquitoes and other insects from entering the tanks. If screening is not sufficient in deterring mosquitoes, dunks or pellets containing larvicide can be added to cisterns when water is intended for landscaping use only.

Child Safety. Above-grade residential rainwater harvesting systems must not have unsecured openings large enough for children to enter the tank. For underground cisterns, manhole access should be locked or otherwise secured to prevent unwanted access.

SECTION 11: REFERENCES

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

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

Center for Watershed Protection (CWP). 2007. *Urban Stormwater Retrofit Practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Ellicott City, MD.

City of Portland, Environmental Services. 2004. *Portland Stormwater Management Manual*. Portland, OR. <http://www.portlandonline.com/bes/index.cfm?c=dfbcc>

City of Tucson, AZ. 2005. *Water Harvesting Guidance Manual*. City of Tucson, AZ. Tucson, AZ.

Coombes, P. 2004. *Water Sensitive Design in the Sydney Region. Practice Note 4: Rainwater Tanks*. Published by the Water Sensitive Design in the Sydney Region Project. <http://www.wsud.org/planning.htm>

Credit Valley Conservation. 2008. *Credit River Stormwater Management Manual*. Mississauga, Ontario.

Forasté, J. Alex and Hirschman David. 2010. *A Methodology for using Rainwater Harvesting as a Stormwater Management BMP*. ASCE International Low Impact Development Conference, Redefining Water in the City. San Francisco, CA.

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

Forasté, J. Alex. 2013 Virginia Cistern Design Spreadsheet v2.1.

Gowland, D. and T. Younos. 2008. *Feasibility of Rainwater Harvesting BMP for Stormwater Management*. Virginia Water Resources Research Center. Special Report SR38-2008. Blacksburg, VA.

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.

North Carolina Division of Water Quality. 2008. *Technical Guidance: Stormwater Treatment Credit for Rainwater Harvesting Systems*. Revised September 22, 2008. Raleigh, NC.

Northern Virginia Regional Commission. 2007. *Low Impact Development Supplement to the Northern Virginia BMP Handbook*. Fairfax, Virginia.

Schueler, T., D. Hirschman, M. Novotney and J. Zielinski. 2007. *Urban stormwater retrofit practices*. Manual 3 in the Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. 2008. Technical Support for the Baywide Runoff Reduction Method. Chesapeake Stormwater Network. Baltimore, MD. www.chesapeakestormwater.net

U.S. Green Building Council. *LEED Reference Guide for Green Building Design and Construction*, Latest Edition.

APPENDIX 6-A

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 meeting a water demand and as a tool for addressing stormwater management requirements, is also highly dependent on the efficiency of capturing and conveying rainwater from the building rooftop (or other impervious cover) to the storage tank.

The following lists are recommended items that designers may want to consider, and plan reviewers may want to require for the submittal of rainwater harvesting systems being used as a stormwater management tool.

A. Incorporation of the Rainwater Harvesting System into the Site Plan Grading and Storm Sewer Plan construction documents, as follows:

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

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

1. The Cistern or Storage Unit material and dimensions in a scalable detail (use a cut sheet detail from Manufacturer, if appropriate).
2. Include the specific filter performance specification and filter efficiency curves. Runoff capture from the rooftop area for a 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 the filter efficiency curves. A minimum of 95% filter efficiency should be met for the Treatment 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. Show the specified materials and diameters of inflow and outflow pipes.

4. Show the inverts of the orifice outlet, the emergency overflow(s), and, if applicable, the receiving secondary runoff reduction practice or on-site infiltration facility.
5. 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.
6. Include a cross section of the storage unit displaying the inverts associated with the various incremental volumes denoted in #B-5 above (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 peak discharge values for the 1-inch storm, 1-year storm and 10-year storm 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 the regulatory authority.
3. Provide calculations showing that the roof drains, at their specified size, slope and material, will convey the design storm specified by the regulatory authority.
4. Provide a print-out of the “Input” tab of the Cistern Design Spreadsheet, as modeled.
5. Provide a print-out of the “Results – Runoff Reduction Volume Credit” tab of the Cistern Design Spreadsheet, as modeled.
6. Provide a print-out of the “Results” tab of the Cistern Design Spreadsheet, 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.
1. An Agreement Form or a Note on the plans should be included to ensure that the minimum demand that was specified in the stormwater management plan submittal 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 secondary runoff reduction practice is not achieving the year-round drawdown as specified, an alternative stormwater management plan may need to be required.

APPENDIX 6-B

CISTERN DESIGN SPREADSHEET DESCRIPTION AND INPUTS

The following provides a detailed description of the Virginia Cistern Design (VCD) spreadsheet, the user inputs, and an interpretation of the spreadsheet outputs.

6-B.1 User Input

Regional Location and Target Storm

Precipitation data for four different regions of Virginia can be selected for use within the model. The user should select the region closest to the project location:

- Richmond International Airport
- Reagan International Airport (Alexandria)
- Lynchburg Regional Airport
- Millgap 2NNW (near Harrisonburg)

The VCD spreadsheet uses daily rainfall data from September 1, 1977 to September 30, 2007 to model performance parameters of the cistern under varying rooftop capture areas and demands on the system and tank size. The precipitation data is the same that was utilized by the Virginia Stormwater Management Program (VSMP) regulations to establish the 90th percentile 1-inch water quality Treatment Volume target storm event.

Roof Area Captured

The *Roof Area Captured* represents the water input to the system. Opportunities for additional (optional) inputs (e.g. air conditioning condensate) are also provided. However, the roof area is the primary source of water. The rooftop is estimated to convey 95% of the rainfall that lands on its surface (i.e., $R_v = 0.95$). Additional water losses associated with the first flush diversion and filter efficiency, as well as other water inputs, are also entered into the design and discussed later in this section.

*Note: The spreadsheet automatically selects a range of cistern tank sizes based on the roof area since this will be the primary driver of system sizing and efficiency. The designer may override the automatic sizing by entering a sizing multiplier, discussed further in **Section 6-B.3**.*

Indoor Demand – Flushing Toilets & Urinals

The designer estimates the water demand associated with flushing of toilets and urinals by entering the number of people using the building and the flush volume for each type of fixture or, alternatively, by entering the estimated computed usage in gallons per day.

***NOTE:** The VCD spreadsheet can be used to size both commercial buildings and residential applications with regard to indoor water demand for water closet and urinal flushing. However, commercial buildings generally have greater stormwater management requirements associated with the large areas of impervious cover, and correspondingly limited areas to manage the stormwater. This makes rainwater harvesting a very practical solution for managing the rooftop area of the developed site. Calculations of water demand are based on the expected number of people using the building and industry standards for frequency of flushing published by the U.S. Green Building Council (USGBC), as described in this section.*

Alternatively, residential applications generally have a relatively small rooftop area and indoor water demand associated with water closet flushing. As such, the accuracy of the predicted demand is critical to the effectiveness and value of the system as an alternative water supply. Therefore, if the designer is evaluating the application of a rainwater harvesting system for a residential structure, ranging from single family detached to high density (i.e., multi-story condominiums or apartments with centralized cistern plumbing), the indoor flushing water demand should be calculated and entered into cell L37 of the spreadsheet using flush frequencies based on the number of fixtures, number of bedrooms, or other accepted standard rather than using the VCD spreadsheet calculation based on the number of people using the building, as described below.

The spreadsheet computational procedure for estimating the demand for flushing is derived for use in building design, where the typical fixture count consists of both urinals and water closets. The user enters the following information:

- Number of people using the building;
- Number of gallons per each urinal flush (if no urinals are proposed, set this to zero);
- Number of gallons per each toilet flush;
- The days of the week the building is in use; and
- The hours per day the building is in use.

The computation is based on assumptions regarding an even split between male and female occupants, the number of urinal and water closet flushes per 8-hour period per male and female occupant, the volume of each flush, etc., as outlined in the USGBC LEED Reference Guide for Green Building and Construction. If no urinals are proposed and the number of gallons per flush is set to zero, the corresponding urinal flushes attributed to males are automatically carried over to the toilet/water closet flushes.

The designer is encouraged to consult with the USGBC documents or other references listed in order to calculate water demands for specific building uses or, more importantly, for residential

indoor demands. The assumptions for residential units (24-hour occupants) are different than for buildings

Indoor Demand – Laundry

The user may elect to include laundry washing as an indoor demand. While residential uses may have limited estimated water demand for laundry, this can be a significant water use for institutional facilities. The spreadsheet performs a simple water demand calculation based on the following user data entry:

- Number of loads per day;
- Gallons of water per load; and
- The number of days of the week in which laundry use is expected (e.g. Monday through Friday).

Alternatively, the user may enter a previously calculated laundry demand (gallons/day) and the corresponding days of expected use. If no laundry demand is proposed, setting the number of loads (or gallons per load) to zero will eliminate this demand.

Outdoor Use – Irrigation

Irrigation demand represents a significant water use. However, using a stormwater irrigation strategy from which to derive a runoff reduction credit requires a more sophisticated cistern/irrigation system than would typically be applied. First, the concept of irrigating a landscaped area during a rain event is counter-intuitive to the concept of reducing runoff. Second, most areas of Virginia do not typically irrigate year-round; the vegetation goes dormant and does not need water and, more important, the irrigation system must be winterized to protect it from freezing. For these reasons, the rainwater harvesting system should include a “*smart control*” to read the soil moisture and automatically stop any irrigation until the soil dries out. (As an example, it is becoming less and less common to see sprinkler systems operating on an automated schedule and watering the landscape during or immediately after rain events.) The system should also include a “*secondary runoff reduction drawdown*” practice to draw down the cistern during the winter months, comparable to the daily or weekly design drawdown of the irrigation months.

- ***Smart Control:*** A smart control is not required. However, it will allow for more economical use of the rainwater, preserving it for use during dry periods. When the smart control is selected, the spreadsheet sums the rainfall depth of the previous 7 days on a daily basis and, when the accumulation is equal to or greater than the user-specified irrigation rate, the irrigation is switched on. If the accumulation was less than the user-specified irrigation rate, then a supplemental irrigation volume is applied, but only up to the specified irrigation rate. If no precipitation occurred, then the full irrigation rate is applied.
- ***Secondary Runoff Reduction Drawdown Practice:*** The secondary runoff reduction drawdown practice is intended to mimic the seasonal irrigation rate during the non-seasonal period, while also limiting the system’s exposure to freezing. The secondary drawdown practice and drain line would typically be shorter and designed specifically to alleviate freezing potential. The

drawdown practice is a runoff reduction BMP that is sized according to the drawdown rate (as opposed to the T_{VBMP} sizing formula).

The designer should check the *Secondary Runoff Reduction Drawdown Practice* box on the spreadsheet if a drawdown practice will be used to achieve the annual runoff reduction volume credit. The design drawdown (gal/day) and the off-season months are automatically computed to supplement the seasonal irrigation. The following illustrates the use of seasonal irrigation with and without the smart control and secondary runoff reduction drawdown practice. Consider a commercial building with the following user information entered:

- Region: Millgap near Harrisonburg (Region 3);
- Roof area captured: 10,000 ft²
- No indoor demand (flushing toilets/urinals or laundry);
- Seasonal irrigation:
 - No smart control;
 - Area to irrigate: 10,000 ft²
 - Average weekly irrigation: default value of 1-inch/week, or a user defined application rate (a note describing the standard irrigation rate values for different types of systems appears when the user selects the turquoise irrigation application rate data entry cell);
 - Seasonal period: the user enters the irrigation application rate for the months that irrigation will be applied. In this example, select May through October.

Figure 6-B.1 below illustrates the seasonal irrigation water use for a typical year (without the secondary drawdown practice). The use is only during the irrigation months and therefore the Runoff Reduction Volume Credit is zero. **Figure 6-B.2** below illustrates the same project site with the seasonal irrigation supplemented with a secondary runoff reduction drawdown practice entered as follows:

- The Secondary Runoff Reduction Drawdown practice box is checked (and the spreadsheet automatically applies the same discharge of 891 gal/day during the months of November through March).

The secondary runoff reduction drawdown practice is designed to manage a daily discharge of 891 gal/day, and the spreadsheet now provides an annual runoff reduction volume credit. Refer to **Appendix 6-C** for a secondary runoff reduction drawdown practice sizing example.

Note: The daily discharge of the irrigation water can be managed as a continuous discharge over 24 hours or a larger discharge over a shorter interval. In either case, the designer will be required to establish the minimum and maximum flow rates and ensure the pump and float switch are calibrated and the drawdown practice is sized accordingly.

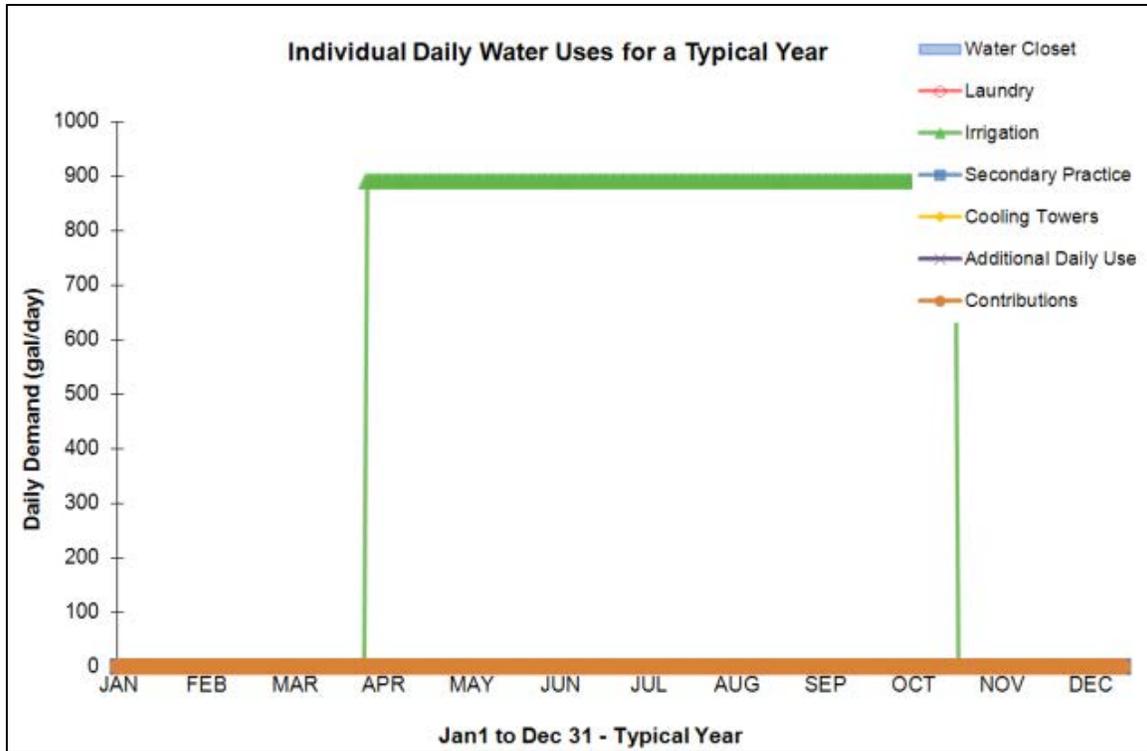


Figure 6-B.1. Seasonal Irrigation with no Smart Control and No Secondary Drawdown Practice

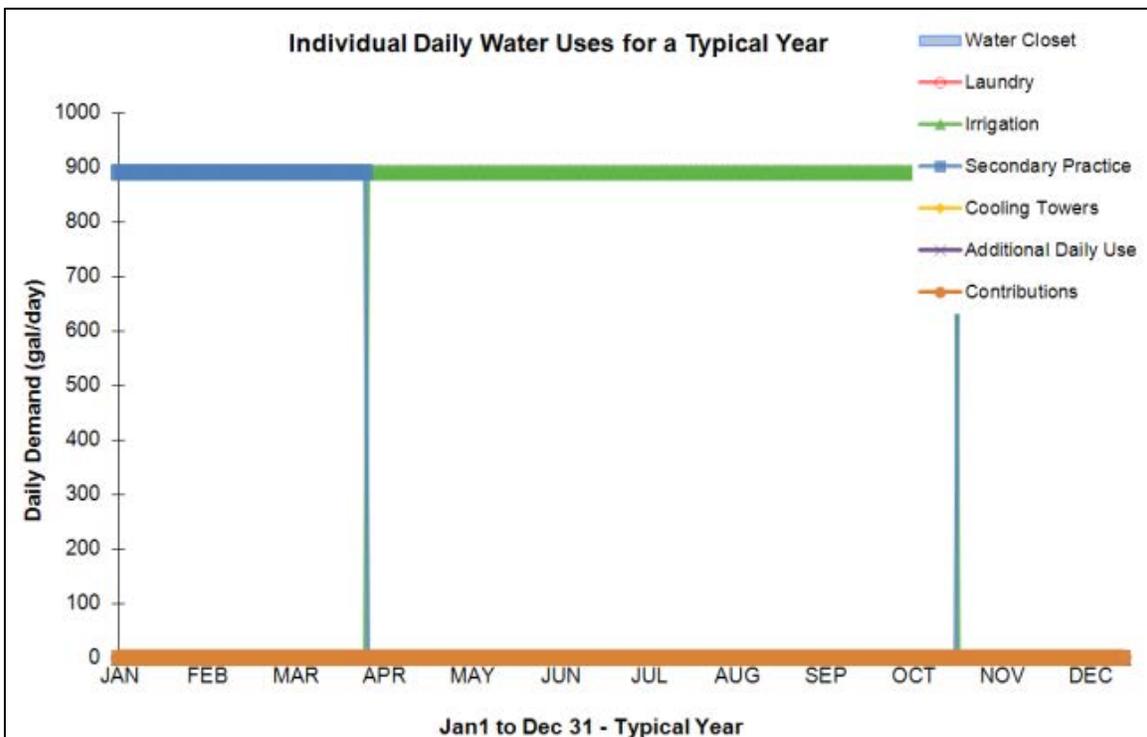


Figure 6-B.2. Seasonal Irrigation (green) with a Secondary Drawdown Practice (blue)

This same project site is illustrated in **Figure 6-B.3** with a smart control. Note that the use of the smart control predicts a more erratic daily water use (based on the historical rainfall records, although it is expected that a similar pattern would be observed in actual use). It should also be noted that the smart control will reduce the overall modeled water use based on the periodic interruption in irrigation due to rainfall.

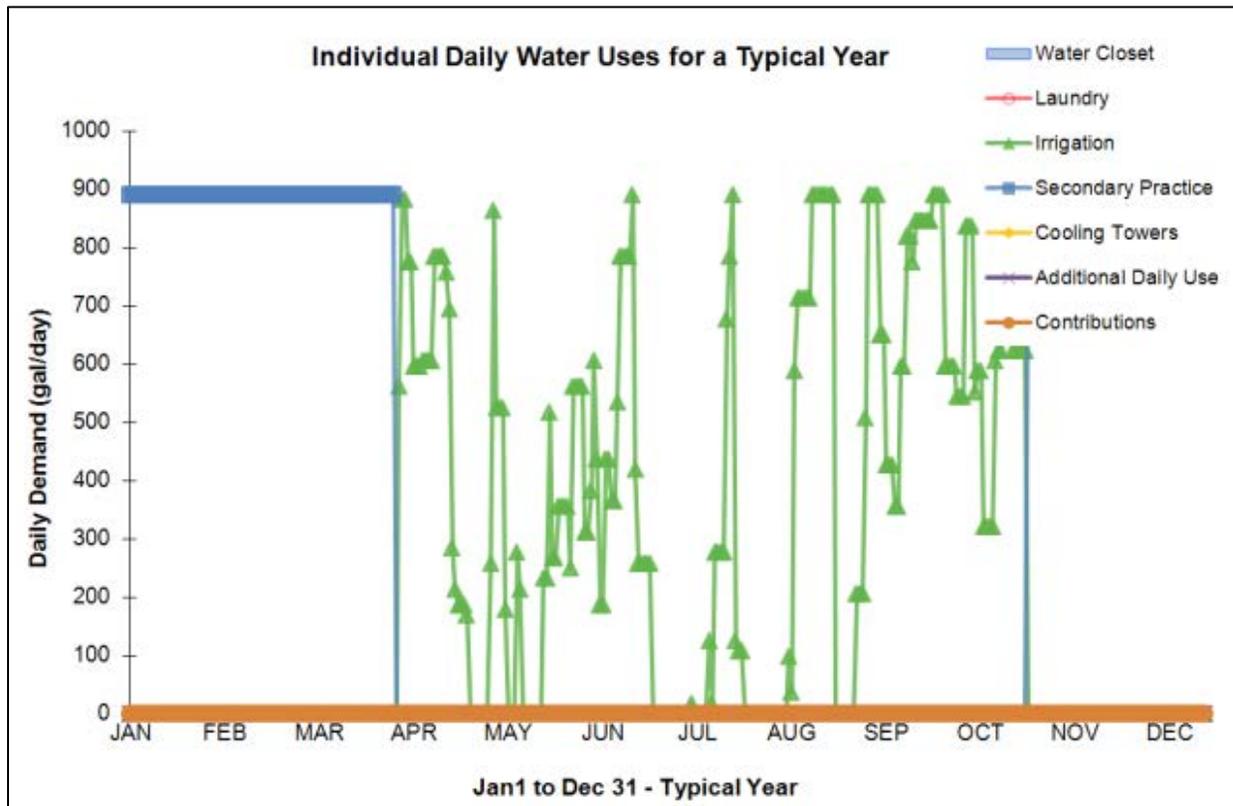
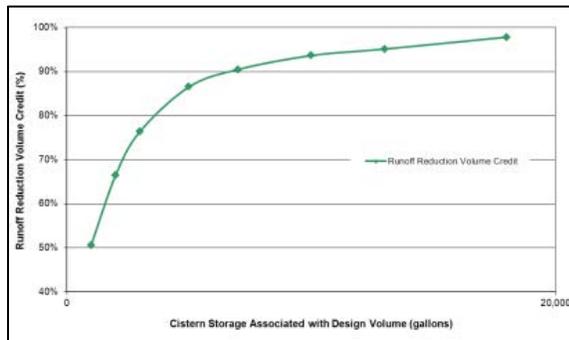


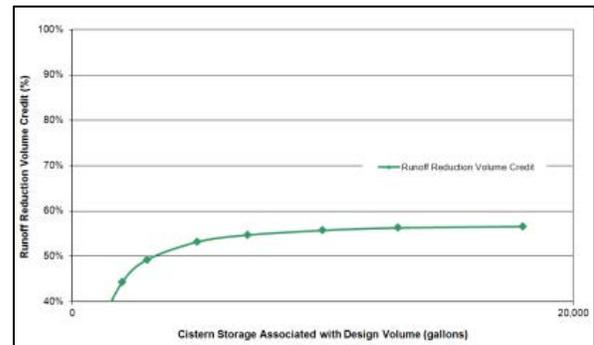
Figure 6-B.3. Seasonal Irrigation (green) with a Smart Control and a Secondary Drawdown Practice (blue)

Figure 6-B.4 illustrates the difference in the annual runoff reduction volume credit *without* (a) and *with* (b) the smart control. So while the smart control provides for a more practical and beneficial use of the rainwater, it will result in a lower overall annual credit.

Note: Irrigation systems that are designed to achieve a runoff reduction volume credit should be equipped with a smart control.



6-B.4a. Without a Smart Control



6-B.4b. With a Smart Control

Figure 6-B.4. Runoff Reduction Volume Credit Chart (Seasonal Irrigation and Secondary Drawdown Practice)

Cooling Towers

Cooling towers are an integral component of many refrigeration systems, providing comfort or process cooling across a broad range of applications. They are the point in the system where heat is dissipated to the atmosphere through the evaporative process, and are common in numerous manufacturing processes. Cooling towers are also commonly used to provide comfort cooling for large commercial buildings including airports, office buildings, conference centers, hospitals, hotels, and high-rise apartment buildings. The water demand for cooling towers is dependent on several factors, including the type of system (there are several variations). The designer must consult with the mechanical system designer to determine the estimated monthly demand for the cooling system (gal/day).

Additional Daily Use

This user input is for any additional seasonal or year-round water demand. Many jurisdictions have implemented street sweeping programs. New street sweeping technology has evolved to the use of regenerative air machines that don't leave the familiar trail of wet pavement. However, these machines use just as much water, if not more; it's just not sprayed onto the pavement.

Another common use is truck and equipment washing. Many different public works vehicle and equipment fleet operators, fire stations, school and municipal bus facilities, etc., conduct routine vehicle washing in order to maintain the operational status and cleanliness of the vehicles. Ideally this operation is housed in a contained facility where the wash water is captured and treated. Rainwater harvesting is ideally suited for this type of operation.

Dog kennels are also well suited for rainwater use to conduct daily facility wash downs. Similar to truck washing, these operations must be drained to an approved treatment facility.

The user determines the daily demand (gal/day) for each month and enters the value into the spreadsheet.

Contribution from Other Sources

This represents any additional water inputs that may contribute to the supply vs. demand water balance. For example, air conditioning condensate during summer months is one such source. Large commercial air conditioning systems can generate a continuous flow over the course of the summer months. Similarly, any routine line flushing or other water discharge can be directed into the cistern for use. The designer estimates the daily supply (gal/day) and enters it into the spreadsheet for each month that flow is expected.

Municipal Backup Supply

The designer may choose to install a municipal backup water supply to supplement tank levels during periods of high demand, or more likely, during periods of dry weather. It is preferable to connect the municipal backup supply line to the post-tank supply line (i.e. a connection is made to the non-potable water line that carries water from the tank for use elsewhere), thereby not contributing any additional volume to the tank. Adding treated municipal water, which may contain chlorine, to the tank could have negative effects on the tank's biofilm (Cabell Brand Center, 2009.) Furthermore, it decreases the available volume of the tank for harvesting the next rain event.

If the municipal backup is designed to augment the water levels in the tank (i.e., connected to the tank rather than the post-tank supply as described above), then the designer should check the *Municipal Backup Supply* box on the spreadsheet, and enter the *low water* level trigger for when to add water, and a *high water* trigger for when to stop. This is entered as a percentage of the total tank volume (e.g., entering 10% means to add water to the tank when the water level goes down to 10% of the tank volume; entering 70% means to stop filling when the water level reaches 70% of the tank volume). This way, the low and high water values can be applied to any size tank selection. The designer must then ensure that the municipal backup supply solenoid valve float switch is calibrated for these elevations.

Whether the backup supply is connected to the tank or, alternatively, to the post-tank supply line, the system should be designed to incorporate either a backflow preventer or an air gap to ensure contamination does not occur between the rainwater and potable water supplies. Local building officials should be consulted to determine the desired type and location of the backflow protection device.

Initial Abstraction

Initial abstraction (I_a) is defined as all water losses before runoff begins, and includes water retained in surface depressions, water taken up by vegetation, evaporation, and infiltration of water into the soil. The spreadsheet allows the user to account for rooftop configurations that may reduce the direct discharge of runoff to the cistern to some amount less than 100% of the rainfall that hits the roof. The general runoff equations already account for some minor losses associated with initial wetting and minor evaporation early in the rain events by establishing a CN of 98, and a Rational Method and VRRM runoff coefficient of 0.95 for impervious cover. This is generally applied to pavement and other surfaces that tend to be irregular with shallow depressions and cracks, etc.

Alternatively, a sloped roof will have minimal losses, while a flat roof may have some retention with the build-up of debris around scupper drains. In either case, designers should leave this value set to 0 unless an alternative value can be adequately documented and justified. Any value other than zero will result in the spreadsheet calculating less runoff volume entering the cistern.

First Flush Filter Diversion and Efficiency

- ***First Flush Diversion:*** The first 0.02-inch to 0.05-inch of rainfall that is directed to filters is diverted from the system in order to prevent clogging it with debris. This value is typically 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. This means that a minimum of 95% of the runoff from a 1-inch storm should be conveyed into the storage tank. The filter efficiency value in the VCD spreadsheet is adjustable between 90 and 100%. This value should not be less than 95% without documentation of the filter efficiency. Some localities may require that a minimum filter efficiency for a larger storm event be met (e.g. minimum 90% filter efficiency for 2-year or 10-year storm), depending on design objectives and local review agency policy. For the purpose 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-year and 10-year storms should be used when designing for channel and flood protection volumes.

6-B.2 Results: Runoff Reduction Volume Credit

The Runoff Reduction Volume Credit tab on the VCD spreadsheet provides the designer with information on the performance of the system when considering only those storms that are less than 1-inch in depth. The runoff reduction volume credit results on this tab exclude the application of any water demand that is not year-round. So while the graphs that represent the *Individual Daily Water Uses for a Typical Year*, the *Cumulative Daily Water Use and Equivalent Year-Round Use*, and the *Average Annual Overflow Volume* will all show representative volume being consumed on a seasonal basis, the *Runoff Reduction Volume Credit Table and Graph* will not show any credit (and the *Cumulative Daily Water Use and Equivalent Year-Round Use* graph will not show an equivalent year-round use).

The following provides a summary of the various output graphs that are provided on this tab that are intended to help the designer select the most appropriate or effective tank size, once the designer establishes the contributing rooftop area and water demand.

Runoff Reduction Volume Credit: Once a year-round use is established, even with a highly variable seasonal demand, this tab will generate a range of Runoff Reduction Volume Credit corresponding to a range of tank sizes. Revisiting **Figure 6-B.4a**, the Runoff Reduction Volume Credit gradually increases with an increase in the tank size selection. Therefore, if the designer selects a 1,000 gallon tank, the runoff reduction volume credit is only 51% (which is then

transferred by the designer to the VRRM compliance spreadsheet), while a 5,000 gallon tank yields an 87% annual credit.

Examination of the plot of the Runoff Reduction Volume Credit as a function of tank size (**Figure 6-B.4a**) reveals an inflection point where the system is optimized in terms of size versus credit. The slope of the curve flattens above the 5,000 gallon tank size indicating a reduced rate of return. This implies that the most optimal cistern design is with a 5,000 gallon tank. The same information is displayed in tabular form above the plot.

Note: The analysis of additional system sizing is available if the designer elects to increase the size of the cistern tank above the default values that are automatically selected as a function of the roof size. Refer to Section 6-B.3: Cistern Water Levels and Precipitation during the Year.

Average Annual Overflow Volume & Number of Overflow Days per Year: The effect of the tank size selection on the runoff reduction credit is illustrated in the plot shown in **Figure 6-B.5**. A 1,000 gallon tank is expected to average an annual overflow volume of 71,000 gallons/year (of a total of 145,000 gallons of runoff contributed to the system during storms of ≤ 1 inch) during 46 days of the year (approximated from the historical rainfall data). Conversely, the 5,000 gallon tank performance can be reviewed on the same plot as overflowing significantly less volume, thus achieving a greater runoff reduction volume credit.

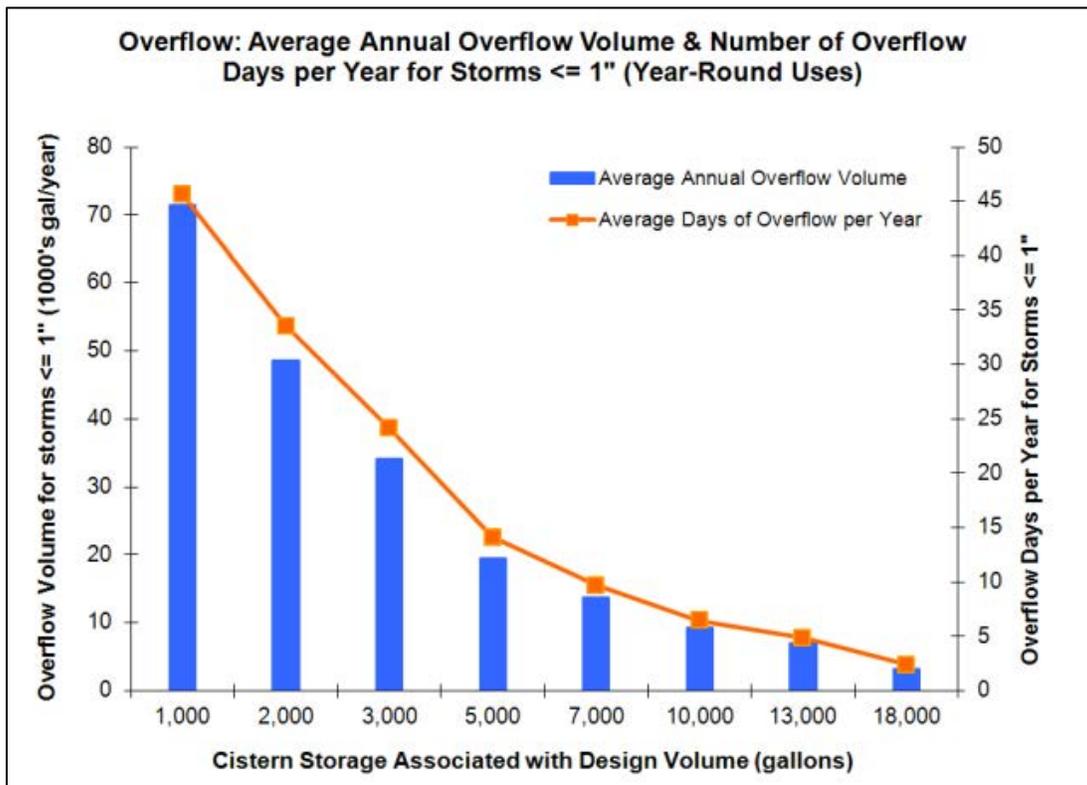
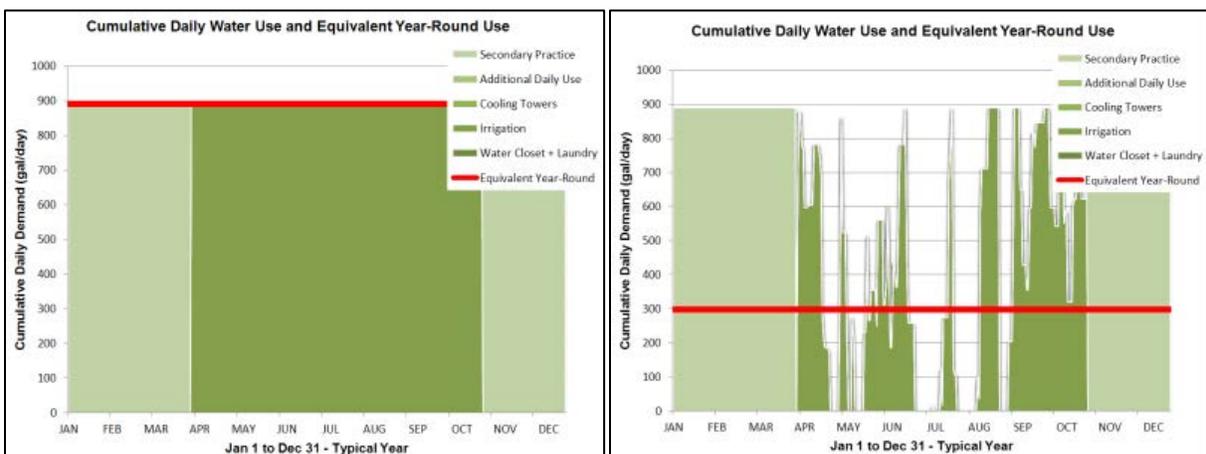


Figure 6-B.5. Average Annual Overflow Volume & Number of Overflow Days per Year

Individual Daily Water Uses for a Typical Year: An example of this plot is displayed in **Figure 6-B.1** and **Figure 6-B.2** above. These represent the individual seasonal demand for irrigation supplemented with a secondary runoff reduction drawdown practice. **Figure 6-B.3** displays the *Individual Daily Water Uses* when a smart control is used to manage irrigation during periods of rain.

Cumulative Daily Water Use and Equivalent Year Round Use: **Figures 6-B.6a** and **6-B.6b** represent the same information on a cumulative basis for these same year-round demands (**6-B.6a** without the smart control, and **6-B.6b** with the smart control). The solid red line represents the equivalent year-round demand upon which the annual credit is based. (The solid red line is not displayed when the demand is limited to the seasonal irrigation without a secondary drawdown practice).



6-B.6a. Without a Smart Control

6-B.6b. With a Smart Control

Figure 6-B.6. Cumulative Daily Water Use and Equivalent Year Round Use

The following example illustrates these same plots when considering a combination of water demands. Continuing with the same project site, additional water demands are applied as follows:

- Roof area captured: 10,000 ft²
- Indoor demand (flushing toilets/urinals or laundry):
 - People using building: 80
 - Urinal (gal/flush): 0.8
 - Toilet (gal/flush): 1.6
 - Days in use: Monday thru Friday
 - Hours per day: 8
 - Spreadsheet-computed total daily indoor demand: 320 gallons
- Seasonal irrigation:
 - No smart control
 - Area to irrigate: 10,000 ft²
 - Average weekly irrigation: 1-inch/week, April through October
- Secondary Runoff Reduction Drawdown: Yes (891 gal/day November thru March)
- Additional Daily Use:

- Combined daily use for street sweepers and vehicle washing as shown in **Figure 6-B.7**:

ADDITIONAL DAILY USE											
Additional daily use (bus wash, street sweepers, etc)											
This value is user defined and is provided to allow for any other unanticipated, or not yet defined, demand value.											
Enter the average daily demand for each month throughout the year. (gallons/day)											
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
50	50	100	200	200	200	200	200	200	200	100	100
Select the first day of the week this water will typically be used (e.g. Monday).										<input type="text"/>	Monday
Select the last day of the week this water will typically be used (e.g. Friday).											Friday

Figure 6.B.7. Combined Daily Use for Street Sweepers and Vehicle Washing

The *Individual Daily Water Uses for a Typical Year* for the combined seasonal and year-round demands are represented in **Figure 6-B.8**. The corresponding *Cumulative Daily Water Use and Equivalent Year-Round Use* is represented in **Figure 6-B.9**. Note that irrigation still represents the single largest use and that the equivalent annual use is a conservative estimate based on the lowest monthly combined demand: the water closet (320 gal/day) and irrigation (891 gal/day) demand plus the lowest additional use (50 gal/day in January and February) for a calculated annual demand of 1,261 gal/day. The designer can readily model different scenarios of water demand and tank size to advise the client of the range of options in terms of stormwater credit and potable water savings.

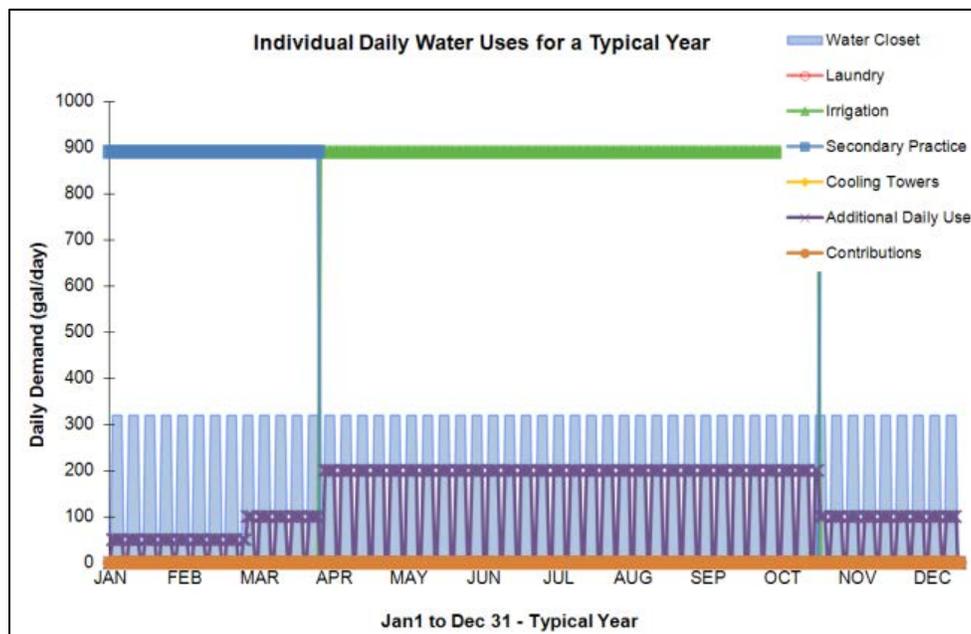


Figure 6-B.8. Individual Daily Water Uses for a Typical Year

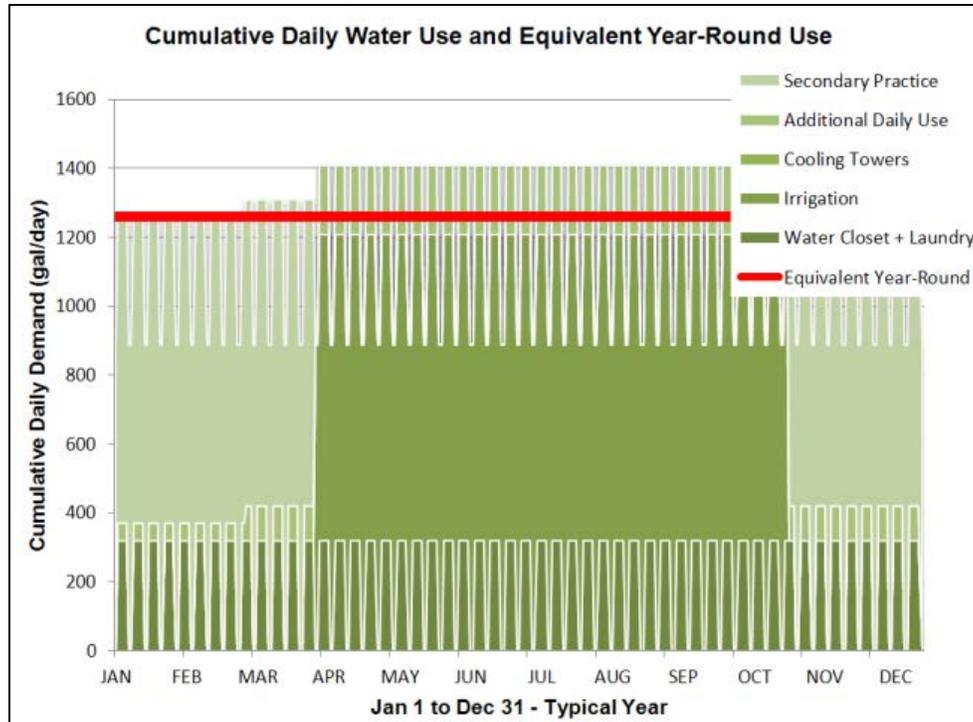


Figure 6-B.9 Cumulative Daily Water Use and Equivalent Year-Round Use

6-B.3 Results: Data from All Storms

The results tab provides the designer with a dashboard of system performance metrics that enables balanced and informed decisions regarding the water demands and system size, considering *all* rainfall events. Most of the information on this tab is represented in tabular form at the top of the sheet: *RESULTS: Using Precip Data from All Storms with Year-Round and Seasonal Uses*. In addition, the following graph plots provide a visual representation of the system performance:

Overflow Volume and Number of Overflow Days for All Storms and All Uses (including year-round and seasonal use – **Figure 6-B.10**): This plot displays both overflow frequency, in terms of number of overflow days per year, and the average annual overflow volume per year for the full spectrum of rainfall events. This will help the designer optimize the tank size, as related to the demand (adjust the tank size or the demand). If the system overflows at a high frequency, the designer may consider:

- Increasing the size of the cistern. Refer to the description of the plot of *Cistern Water Levels and Precipitation during the Year*;
- Increasing the water demand (e.g. increasing the area to be irrigated or other daily use); or
- Decreasing the area of rooftop captured by the cistern.

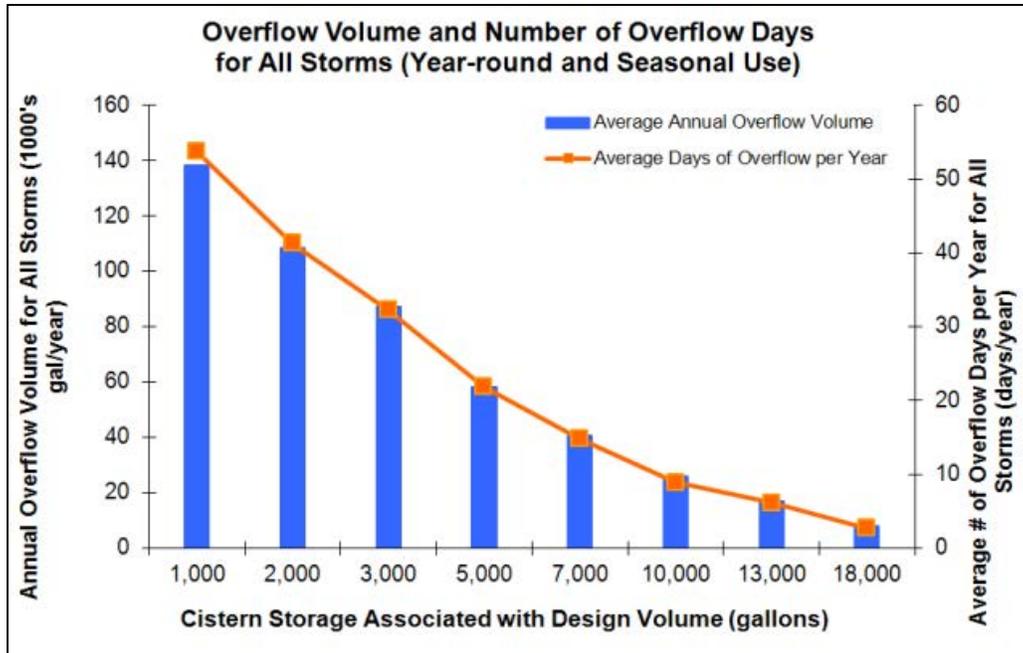


Figure 6-B.10. Overflow Volume and Number of Overflow Days for all Storms and All Uses

Average Water Level in Cistern (Figure 6-B.11): This plot reports the average daily cistern water level over the 30-year modeled period. It provides a general picture of how the system water level is reacting to the water balance between supply and demand. This may be most useful for designs that are targeting retention of specific storm events (as opposed to average annual volume reduction).

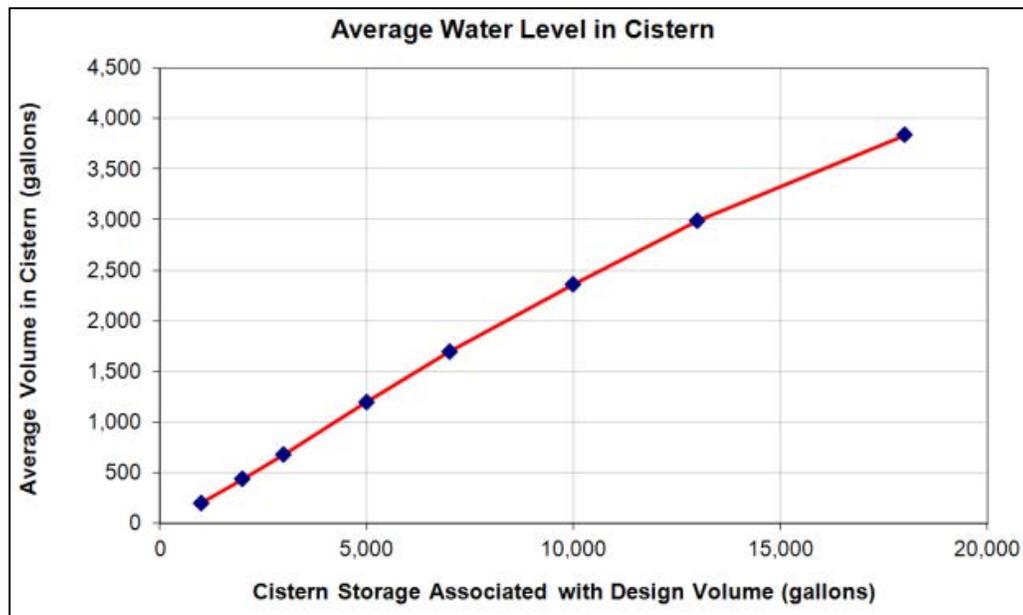


Figure 6-B.11. Average Water Level in Cistern

Average Dry Days per Year (Figure 6-B.12 below): This plot is generally opposite that of the overflow volume. This plot is generally the primary indicator of a lack of supply – i.e., not enough rooftop area to meet the demand. This can be especially evident regarding water demand for such things as cooling towers or process water at large-scale institutional facilities. This may also indicate whether there is a need to incorporate a municipal backup supply to ensure sufficient water supply through the system at all times.

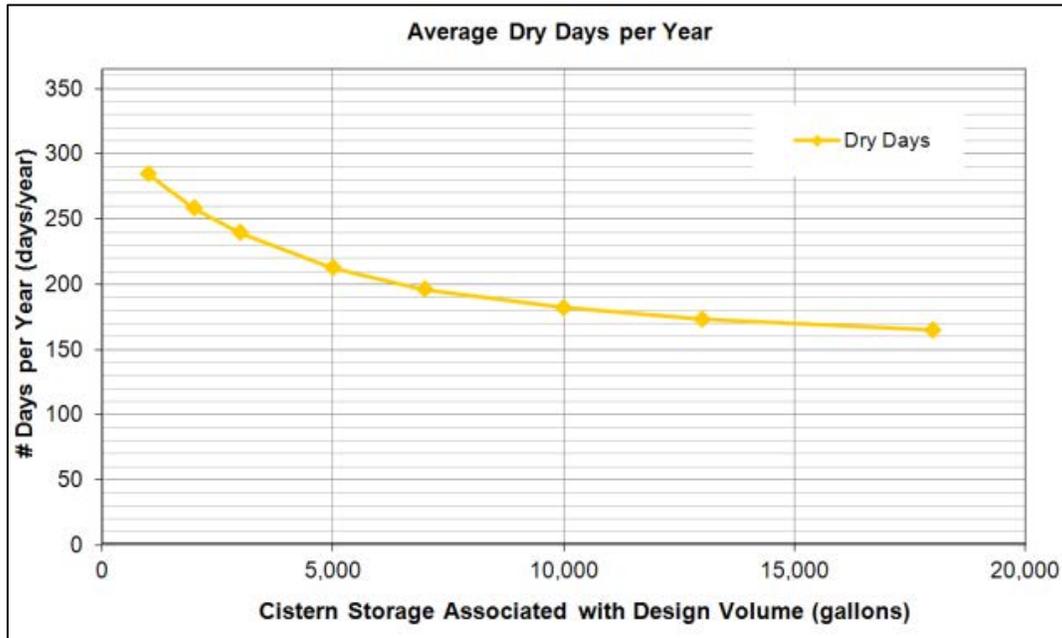


FIGURE 6-B.12. Average Dry Days per Year

If the cistern is frequently dry, the designer may consider:

- Decreasing the size of the cistern;
- Decreasing the demand on the system; or
- Capturing more rooftop area to provide a larger supply, if feasible.

Water Supply Chart (Figure 6-B.13, below): There are two elements to this chart: *Annual Volume of Water Supplied* and *Percent of Demand Met* for a range of cistern storage sizes. The first provides a quantitative estimate of the total volume of harvested water captured and used to meet site demands. This metric may assist designers interested in meeting certain water conservation goals. It may also be used to estimate reductions of municipally supplied and purchased public water. The second result indicates how much of the demand can be met by the harvested rainwater for various size cisterns. Similar to the *Dry Days per Year* plot, this graph assists the designer in understanding the relationship between cistern sizes, rooftop areas (the supply), and the demand placed on the system. If dry frequency is high and the percent of demand met is low, the designer may consider:

- Increasing the captured rooftop area (if available); or
- Eliminating/reducing some of the water demands.

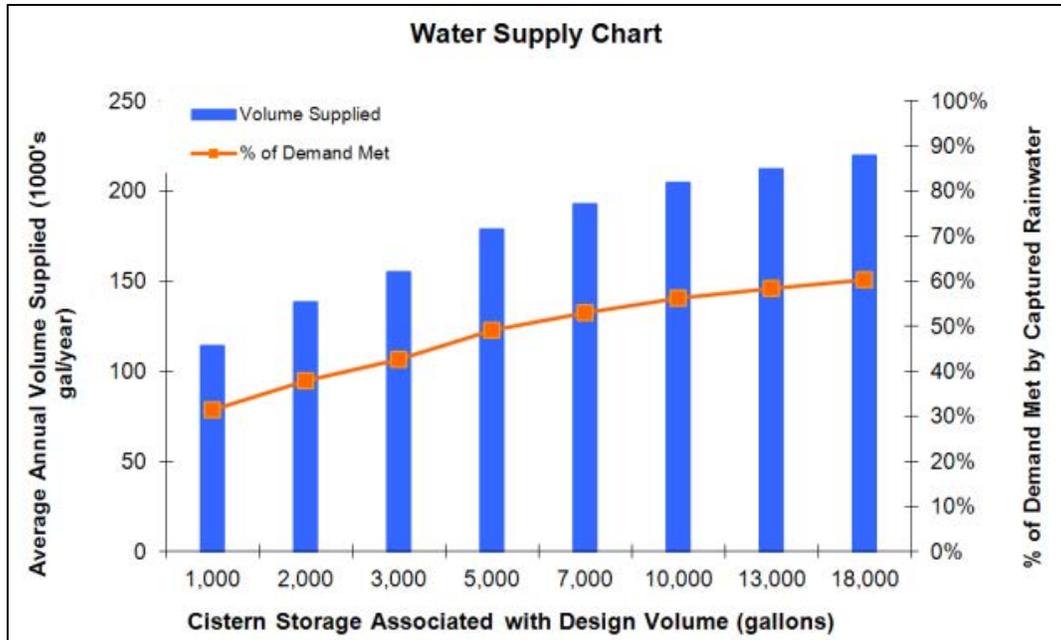


FIGURE 6-B.13. Water Supply Chart

Cistern Water Levels and Precipitation during a Normal Rainfall Year (Figure 6-B.14 below): This plot shows the daily cistern water levels and 24-hour precipitation events over the course of a typical year. The designer must *Select the Cistern Size* from a drop down menu, located on the left immediately above the chart, to activate it.

The choice of sizes available for analysis is predetermined based on the roof area being captured (as entered in the data input tab). For example, a 10,000 ft² roof area will result in a range of cistern tank sizes from 1,000 gallons to 18,000 gallons. If the designer is interested in seeing the relative influence of tank size on system performance by increasing this range, he may expand this range by selecting a *Size Multiplier*, located on the right immediately above the chart. Selecting a multiplier of 2 increases the range of sizes analyzed by both of the spreadsheet results tabs: 1,000 to 35,000 gallons. This increased range of sizes is also now available to select in the *Select the Cistern Size* drop down menu.

The designer may also *Select the Type of Rainfall Year* as *Normal*, *Wet*, or *Dry*.

Note: *The designer must select the Cistern Size from the drop down menu in order to activate the plot of the Cistern Water Levels and Precipitation during the Year. The designer may also increase the range of tank sizes evaluated by the spreadsheet and the tank sizes available to select from the drop down menu. Only one size at a time can be represented on this plot.*

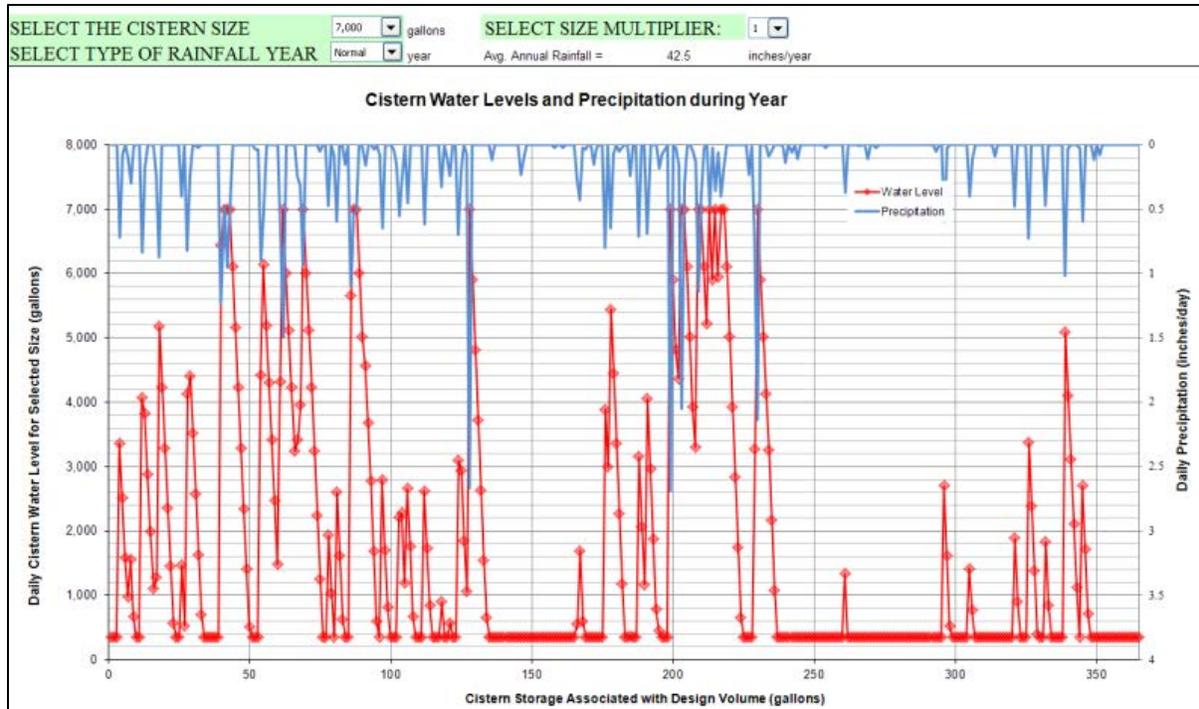


Figure 6-B.14. 7,000 Gallon Cistern Water Levels and Precipitation during a Normal Rainfall Year

This plot is useful in that it gives the designer a general understanding of how the cistern is operating under a variety of conditions and how it reacts to sudden storm events. Possibly more than any of the other plots, this plot will clearly display the water level fluctuations over time. It can be especially helpful in identifying whether the tank is simply too small to meet the demand, prompting either selection of a bigger tank, or provision of a municipal backup.

Similarly, this plot will also clearly reflect when the roof area being captured is too small to meet demand. Consider the plot of **Figure 6-B.14** showing the number of dry days. Increasing the tank size will not overcome the lack of water supply during the relatively dry period of September through October of the typical year. Increasing the tank size would reduce the overflow frequency and volume (**Figure 6-B.10**) and slightly decrease the number of dry days per year (**Figure 6-B.12**), but not to the extent that the size will overcome the lack of roof area to generate enough volume of water to meet the demand (even considering all storms).

The designer can switch the tank size and/or multiplier, as well as the type of rainfall year (*wet*, *normal*, or *dry*) and readily see the changes in the system performance as displayed by these plots.

6-B.4 Completing the Sizing Design of the Cistern

The following volume requirements may be considered when selecting a final cistern tank size:

- **Adding Channel Protection and Flood Volumes (Optional).** Additional detention volume may be provided above the storage volume dedicated to the T_{VBMP} , in order to address stream channel protection and flood protection requirements. Typical routing software programs may

be used to design for this additional volume. The local VSMP plan review authority may require one of the following for channel and flood protection design:

- Accepting an adjusted curve number (methodology as presented in the VRRM compliance spreadsheet);
 - Accounting for the T_{VBMP} volume (and any additional volume) captured in the cistern when modeling the site/drainage area using a hydraulic routing program; or
 - Requiring that the hydraulic routing of the site/drainage area assumes that the cistern T_{VBMP} storage volume is full.
- ***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.

6-B.5 Results to Be Transferred to VRRM Compliance Spreadsheet

The *results* plots display much of the same information in a variety of ways to help the designer optimize the rainwater harvesting system in order to achieve various water conservation and consumption goals, as well as meeting the runoff reduction requirements for the project. There are two results from the VCD spreadsheet that must be transferred to the New Development or Redevelopment Runoff Reduction Spreadsheet:

1. **Runoff Reduction Volume Credit:** Once the cistern tank size has been selected, the Runoff Reduction Volume credit corresponding to the selected tank size is entered into the appropriate VRRM compliance spreadsheet Drainage Area tab (cell F24)
2. **Credit Area:** The rooftop area that was entered into the VCD spreadsheet is entered in the “credit area” column of the appropriate VRRM compliance spreadsheet Drainage Area tab (cell G24)

APPENDIX 6-C

SECONDARY RUNOFF REDUCTION DRAWDOWN PRACTICE SIZING EXAMPLE

The sizing and design of the *Secondary Runoff Reduction Drawdown (drawdown) Practice* is based on the same design principles as the infiltration basin or trench, or any of the volume reduction practices that incorporate a design volume based on a T_{VBMP} . However, the drawdown practice will be subject to a much lower flow of runoff – the flow required to mimic the drawdown of the seasonal demand (i.e., irrigation). Therefore, the sizing of the volume component is not based on the T_{VBMP} or a multiple (or fraction) thereof, but rather the volume of the equivalent daily drawdown.

Design Considerations:

In general, the drawdown practice is not a typical BMP, due to some practical differences:

- As stated above, the runoff is based on a pumped drawdown from the cistern. The rate of the drawdown is based on the design weekly application volume (i.e., 1-inch per week over the designated area to be irrigated) rather than the potential high rate of inflow (q_{pTv}) that is associated with mid-Atlantic rain events. This volume can be discharged to the drawdown practice at the same rate and frequency as the seasonal irrigation, or at a more convenient rate and frequency based on preferred timing of pump on/off cycles.
- The runoff volume has already been through a first flush diversion and a filter, and has also settled any additional material within the cistern and, thus, has been subjected to the equivalent of a very efficient pre-treatment practice. Therefore, the design safety factor of two (one-half the field verified infiltration rate) and other elements associated with infiltration are not necessary.

Note: The designer may consider keeping the infiltration rate safety factor or applying some other sizing factor once the minimum design surface area has been determined and the practice has been located on the site, in order to ensure that a saturated soil condition does not impact any site improvements).

- The discharge to the drawdown infiltration practice need not be a surface discharge. Depending on the physical siting of the cistern (above or below ground) and the piping system, a winter drawdown could be completely buried (with appropriate access points to ensure inspection, maintenance, and rehabilitation when needed). The discharge to the infiltration system can be designed comparable to a septic system.
- The overflow of the portion of the T_{VBMP} that is in excess of the cistern tank capacity is accounted for in the annual runoff reduction volume credit and need not be delivered to the drawdown practice.

- Similarly, the cistern overflow for large storm bypass should likewise bypass the drawdown practice. Designers should also ensure that any surface drainage from other site features adjacent to the building do not drain to the drawdown practice. If they do, then the drawdown practice should be sized accordingly, which makes for a complex design, with some volume being assigned to a T_{VBMP} (along with the required pretreatment mechanisms) and entered into the VRRM compliance spreadsheet, while accommodation of the remaining volume is designed according to the drawdown rate).

Infiltration is the most practical application for a drawdown practice, and can it be applied in several different configurations (refer to BMP Design Specification 8: Infiltration, for additional design information). Designers may also consider bioretention or dry swales.

Design Example:

Use the same project site discussed in **Appendix 6-B**, with the 10,000 ft² roof area and the following additional information:

- Region: Millgap near Harrisonburg (Region 3)
- Roof area captured: 10,000 ft²
- No indoor demand (flushing toilets/urinals or laundry)
- Seasonal irrigation:
 - No smart control
 - Area to irrigate: 10,000 ft²
 - Average weekly irrigation: default value of 1-inch/week
 - Seasonal period: May through October.

In order to achieve a runoff reduction volume credit, the secondary drawdown practice must be designed to mimic the average weekly irrigation volume of 1-inch over the 10,000 ft². This water demand is converted to gallons per day in the spreadsheet and is calculated as follows:

$$(1'')(10,000 \text{ ft}^2) \left(\frac{1 \text{ ft}}{12 \text{ in}} \right) \left(\frac{1 \text{ week}}{7 \text{ days}} \right) = 119 \text{ ft}^3 / \text{day}$$

$$(119 \text{ ft}^3 / \text{day}) \left(\frac{7.48 \text{ gal}}{\text{ft}^3} \right) = 891 \text{ gal} / \text{day}$$

This volume is conservative, since it generally ignores losses associated with the first flush diversion and the filter. Continuing with the drawdown practice sizing, refer to **BMP Design Specification No 8: Infiltration, Equation 8.2** from that design specification (**Equation 6-C.1** below) provides the maximum depth of the underground reservoir (filled with stone) or infiltration trench and is modified to eliminate the safety factor applied to the infiltration rate, and to shorten the drawdown to one day, as follows:

Equation 6-C.1 (Modified Eq. 8.2). Maximum Underground Reservoir Depth

$$d_{max} = (f \times t_d) / (\eta \times 12)$$

Where:

- d_{max} = maximum depth of the infiltration practice (feet)
 f = measured infiltration rate = 0.15 in./hr (typical HSG C)
 t_d = maximum drawn down time = 24 hours
 η = porosity of the stone reservoir (assume 0.4)

$$d_{max} = (0.15 \times 24) / (0.4 \times 12)$$

$$d_{max} = 0.75 \text{ feet}$$

Equation 6.C-2 (Modified Equation 8.4). Underground Reservoir Surface Area

$$SA = Dv / \eta \times d + [(f \times t_f) / 12]$$

Where:

- SA = Surface area (ft².)
 Dv = Design drawdown volume for the seasonal demand = 119 ft³
 η = Porosity of stone reservoir (assume 0.4)
 d = Infiltration depth (maximum based on the results of **Equation 6-C.1** = 0.75 ft.
 f = Measured infiltration rate = 0.15 in./hr (typical HSG C)
 t_f = Time to fill the infiltration facility (24 hours)

$$SA = 119 \text{ ft}^3 / 0.4 \times 0.75 + [(0.15 \times 24) / 12]$$

$$SA = 198 \text{ ft}^2$$

Similar design procedures outlined in **BMP Design Specification No 8: Infiltration** provide for a surface runoff reduction drawdown practice. The designer must be cautious to ensure that the soil conditions, and any adjacent structures, utilities, or other features are adequately protected from possible periodic soil saturation.

APPENDIX 6-D

NOTES REGARDING THE CISTERN DESIGN SPREADSHEET USE AND METHODOLOGY

If a rainwater harvesting use is only seasonal (e.g. summer irrigation), the spreadsheet sets the input for irrigation to zero (0) for the purpose of the Runoff Reduction Volume credit. However, this does not apply if a secondary runoff reduction practice is designated to infiltrate/treat an equivalent volume of rainwater during the “off-season”.

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

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

Where:

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

And

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

Where: $Tv\%$ = Treatment Volume credit (%)

$$\sum_{i=1}^n Vu = \text{Runoff Reduction Volume.}$$

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)

The VCD spreadsheet calculations should always be included with the stormwater management submittal package for local plan review. See **Appendix 6-A** for more information on recommended submittal package checklists and materials.