6. RAINWATER HARVESTING

Contents

6.1. ACKNOWLEDGEMENTS

While this Chapter was prepared by Staff of the City of Flagstaff, this document was primarily adapted from two publications:

Low Impact Development Stormwater Management Planning and Design Guide. Version 1.0. Toronto, Ontario, Canada. Developed by the Credit Valley Conservation and Toronto and Region Conservation (CVC & TRCA). 2010.

Georgia Rainwater Harvesting Guidelines by The Georgia Department of Community Affairs.

6.2. OVERVIEW

6.2.1. Description

Rainwater harvesting is the process of intercepting, conveying and storing rainfall for future use. Interest in adapting this practice to urban areas is increasing as it provides the combined benefits of conserving potable water and reducing stormwater runoff. When harvested rainwater is used to irrigate landscaped areas, the water is either evapotranspired by vegetation or infiltrated into the soil, thereby helping to maintain the predevelopment water balance.

The rain that falls upon a catchment surface, such as a roof, is collected and conveyed into a storage tank. Storage tanks range in size from rain barrels for residential land uses (typically 50 gallons to 100 gallons in size), to large cisterns for industrial or commercial land uses (see Figure 6.1 for some examples). A typical pre-fabricated cistern can range from 200 gallons to 30,000 gallons in size.

With minimal pretreatment (*e.g.*, gravity filtration or first-flush diversion), the captured rainwater can be used for outdoor non-potable water uses such as irrigation and washing, or in the building to flush toilets or urinals. The capture and use of rainwater can, in turn reduce stormwater runoff volume and pollutant load. Rainwater harvesting systems can also help reduce demand on water resources (such as groundwater aquifers and surface water reservoirs) from which Flagstaff's potable water is drawn.

There are two options for the design and operation of rainwater harvesting systems:

1) Some systems are designed for both outdoor and indoor uses (*i.e.*, dual use systems) with usage continuing throughout the year. In cold climate regions, such as Flagstaff, cisterns for year-round should be installed in such a way that the cistern has contact with the subgrade, which will act as a heat source and insulator. Typically this is done by completely burying the cistern, partially burying it, or constructing a short retaining wall around the cistern and backfilling with soil. In addition, the cistern can be located on a southern side of the site or indoors in a temperature controlled environment to prevent freezing.

2) Other systems are designed for outdoor water usage only, where water demand varies seasonally. Rain barrels or cisterns for seasonal, outdoor water uses can be located above-ground or underground, acknowledging that smaller cisterns (less than 500 gallons) need to be decommissioned annually, prior to the onset of freezing temperatures.

Figure 6.1- Various types of rainwater storage tanks. Clockwise from top left: Rainwater storage in a crawlspace, underground fiberglass cisterns, Bushman® tank, modular and stackable underground cistern, and aboveground cistern with knee wall (center).

6.2.2. Common Concerns

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, partially buried, or indoors to prevent problems associated with freezing, ice formation and subsequent system damage. Alternatively, an outdoor system can be used seasonally.

- *Plumbing Codes:* The International Plumbing Code (IPC) does not directly address rainwater harvesting systems in either the potable water or storm water section of the code. During the dry months it may be necessary to utilize domestic water as a backup to rainwater usage. An air gap and/or a reduced pressure backflow preventer will be required in order to prevent cross-contamination between the rainwater and the domestic water.

- *Standing Water and Mosquitoes:* Rainwater harvesting systems, if improperly managed, can create habitat suitable for mosquito breeding and reproduction. Designers should provide screens on inlets and overflow outlets to prevent mosquitoes and other insects from entering the system. If screening is not sufficient to deter mosquitoes, dunks containing larvicide can be added to storage tanks when harvested water is intended for irrigation only.

- *Child Safety:* Above grade home cisterns with openings large enough for children to enter the tank must have lockable covers. For underground cisterns, manholes should be secured to prevent unwanted access.

- *Drawdown Between Storms:* The extent to which cisterns reduce runoff and peak flows depends on use of the captured rainwater between storms, so that capacity exists to capture a portion of the next storm. Water demand estimations should be submitted for review with the Drainage Report.

- *On Private Property*: If a rainwater harvesting system is installed on private lots, property owners or managers will need to be educated on their routine operation and maintenance needs, understand the long-term maintenance plan, and possibly could be subject to a legally binding maintenance agreement.

6.2.3. Physical Suitability and Constraints

A number of site-specific features influence how rainwater harvesting systems are designed. Some of the key considerations include:

- *Available Space:* Space limitations are rarely a concern with rainwater harvesting if considered during building design and site layout. Storage tanks can be placed underground, indoors, on roofs, or adjacent to buildings depending on intended uses of the rainwater. Designers must work with architects to site the tanks.

- *Site Topography:* Site topography influences the placement of storage tanks and the design of the rainwater conveyance and overflow systems. Locating storage tanks in low areas of the site will likely increase the volume of rainwater that can be stored for later use, but will increase the amount of pumping needed to distribute the harvested rainwater. Conversely, placing storage tanks at higher elevations will likely reduce the volume of rainwater that can be stored due to structural limitations on the weight of captured rainwater that can be stored, but will also reduce the amount of pumping needed for distribution or eliminate it altogether.

- *Available Head:* The needed head depends on intended use of the water. For residential landscaping uses, the rain barrel or cistern should be sited up-gradient of the landscaping areas or on a raised stand. Gravity-fed operations may also be used for indoor residential uses, such as laundry, that do not require high water pressure. For larger-scale landscaping operations, locating a cistern on the roof or uppermost floor may be the most cost efficient way to provide water pressure.

- *Soils:* Cisterns should be placed on or in native, rather than fill, soils. If placement on fill slopes is necessary, a geotechnical analysis is needed. Underground tanks and the pipes conveying rainwater to and from them, including overflow systems, should either be located below the frost penetration depth, or insulated to prevent freezing during winter.

- *Pollution Hot Spot Runoff:* Rainwater harvesting systems can be an effective stormwater BMP for roof runoff at sites where land uses or activities at ground-level have the potential to generate highly contaminated runoff (*e.g.*, vehicle fueling, servicing and demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites).

- *Setbacks from Buildings:* Rainwater harvesting system overflow devices should be designed to avoid causing ponding or soil saturation within ten feet of building foundations. Storage tanks must be watertight to prevent water damage when placed near building foundations.

- *Proximity to Underground Utilities:* The presence of underground utilities (*e.g.*, water supply pipes, sanitary sewers, natural gas pipes, cable conduits, etc.), may constrain the location of underground rainwater storage tanks.

- *Vehicle Loading:* Underground cisterns should be placed in areas without vehicular traffic. Tanks under roadways, parking lots, or driveways must be designed for the live loads from heavy trucks, a requirement that could significantly increase construction costs.

6.2.4. Benefits to the Watershed

Rainwater harvesting can reduce individual consumers' utility bills, but also represents a larger cost savings. Increased population drives the need for additional water supply infrastructure, including expansion of existing water treatment plants or construction of new ones. Rainwater harvesting, similar to water conservation efforts, reduces the demand for potable water. In particular, peak demand, driven by summertime outdoor watering, is reduced. It also reduces municipal costs associated with treating and pumping potable water to end users.

6.3. DESIGN OF RAINWATER HARVESTING SYSTEMS

6.3.1. Applications

Rainwater harvesting systems can be applied on most residential, commercial, industrial or institutional roofs where rainwater can be captured, stored, and used. They are particularly useful on infill and redevelopment sites that have little room for other stormwater BMPs. Rainwater harvesting systems can be installed underground, indoors, on the ground next to a building or on the roof.

Rainwater that is captured and stored can be used to meet both outdoor and indoor non-potable water uses. Outdoors, harvested rainwater can be used for residential lawn and garden watering, commercial and institutional landscaping irrigation, decorative fountains, or other non-potable uses such as vehicle washing, building washing and fire fighting.

Typically, indoor uses of harvested rainwater are for non-potable purposes only. Toilet flushing is the most common large-scale indoor use of harvested rainwater. Laundry washing is another common residential water use with potential to utilize harvested rainwater, as it does not require potable water nor high water pressure. Separate plumbing, pumps, pressure tanks, and backflow preventers are necessary for indoor use of harvested water. Back-up water supply system arrangements, that can be drawn upon when the cistern runs dry, are also necessary for indoor uses.

6.3.2. Typical Details

A typical aboveground rainwater harvesting cistern system is illustrated in Figure 6.2 and an underground system in Figure 6.3.

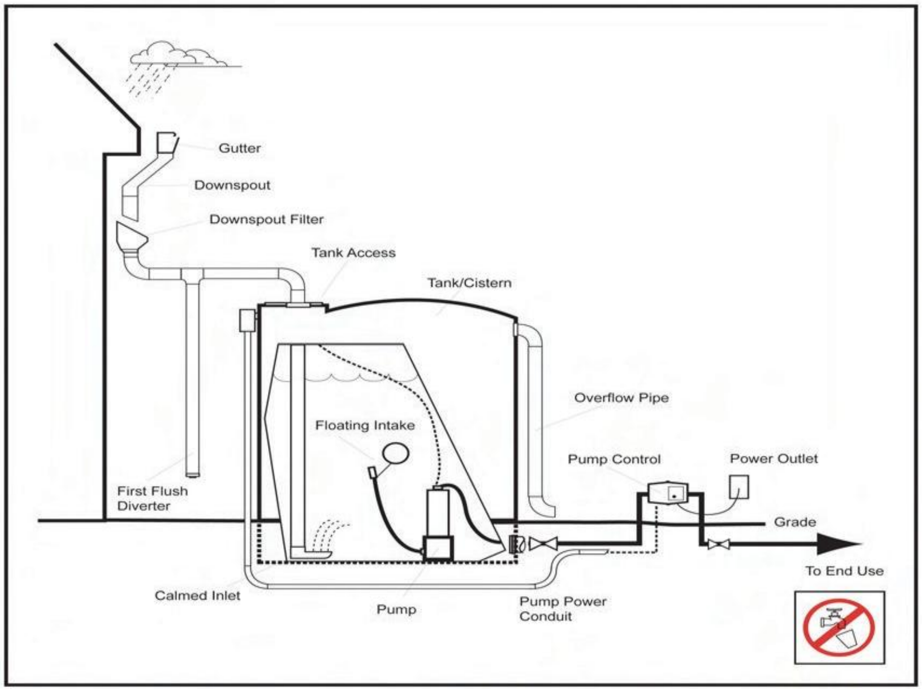

Figure.2 - Aboveground RWH System. If the cistern is on a higher grade, a pump may not be needed. Source: Georgia Rainwater Harvesting Guidelines

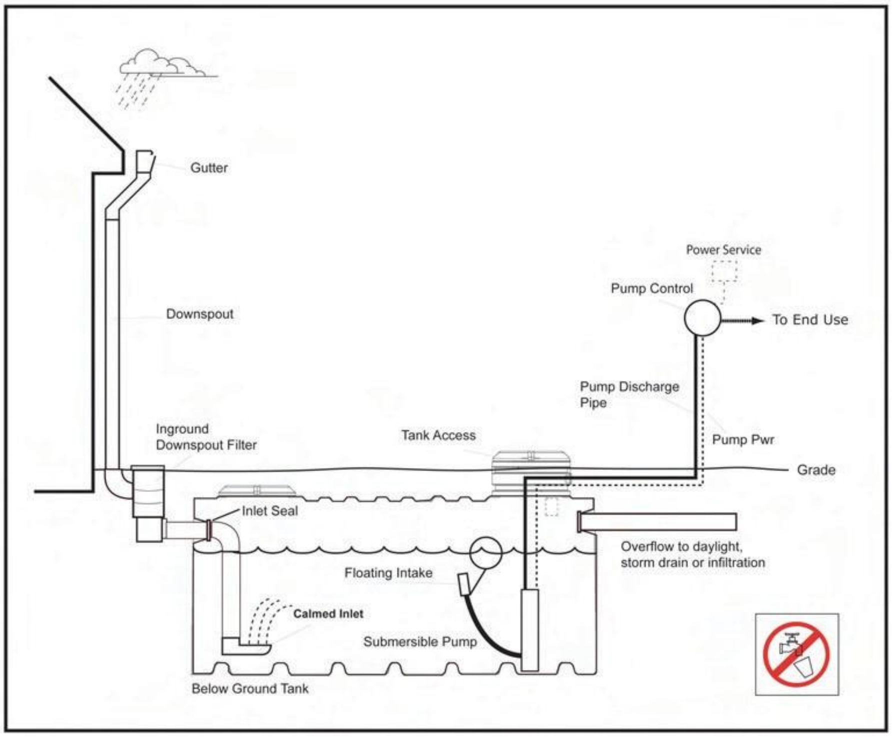

Figure.3 - Schematic of a typical underground RWH system. Source: Georgia Rainwater Harvesting Guidelines

6.3.3. Design Guidance

As shown in Figure 6.4 below, there are six components of a rainwater harvesting system:

- Catchment area;
- Collection and conveyance system (*e.g.* gutters, downspouts, pipes);
- Pretreatment system (*e.g.*, filters and first-flush diverters);
- Storage tank (*e.g.*, rain barrels or cisterns);
- Distribution system; and
- Overflow system.

Guidance regarding the design of each of these components is provided below.

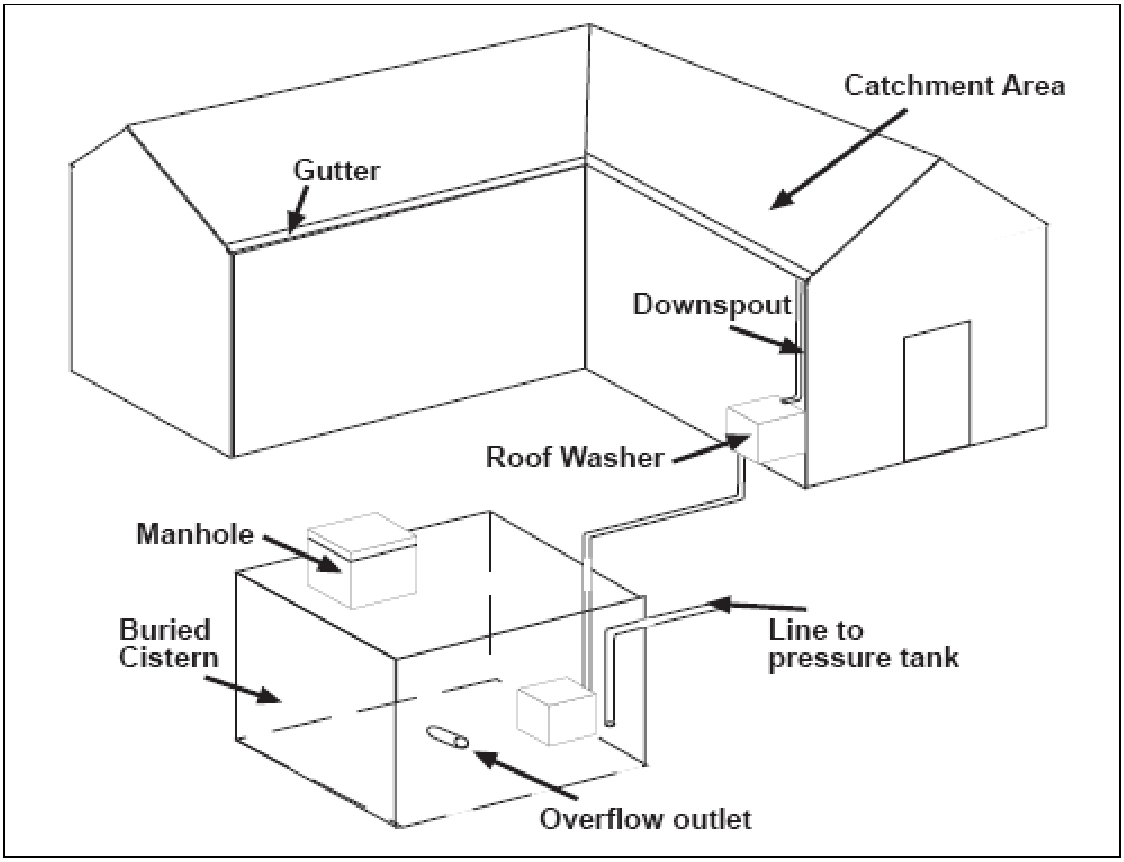

Figure 6.4 - Components of a residential harvesting cistern system. Source: Credit Valley Conservation and Toronto and Region Conservation (CVC & TRCA). 2010. *Low Impact Development Stormwater Management Planning and Design Guide*. Version 1.0. Toronto, Ontario, Canada.

6.3.4. Catchment Area

The catchment area is simply the surface from which rainfall is collected. Generally, roofs are used as the catchment surface for a rainwater harvesting system, although rainwater harvested from other source areas, such as low traffic parking lots and walkways, may be suitable for some non-potable uses (*e.g.*, irrigation and outdoor washing). The quality of the harvested water will vary according to the type of source area and material from which the catchment area is constructed. Water harvested from parking lots, walkways and certain types of roofs, such as asphalt shingle, tar and gravel, and wood shingle roofs, should only be used for landscape irrigation or toilet flushing due to potential for contamination with toxic compounds. To minimize contamination of roof catchment areas with natural debris it is recommended that overhanging tree branches be trimmed back.

6.3.5. Collection and Conveyance System

The collection and conveyance system consists of the gutters, downspouts and pipes that channel runoff into the storage tank. Gutters and downspouts should be designed as they would for a building without a rainwater harvesting system with the addition of screens to prevent large debris from entering the storage tank (also see Pretreatment). When sizing gutters and downspouts, designers should design the conveyance system in a way that minimizes the frequency of overflow events. For a residential collection system, less detail may be needed. For dual use rainwater cisterns (used year-round for both outdoor and indoor uses), the conveyance pipe leading to the cistern should be buried at a depth no less than the frost penetration depth and have a minimum 1% slope. If this is not possible, conveyance pipes should either be located in a heated indoor environment (*e.g.*, garage, basement) or be insulated or equipped with heat tracing to prevent freezing. All connections between downspouts, conveyance pipes and the storage tank must prevent entry of small animals or insects into the storage tank.

6.3.6. Pretreatment

Pretreatment is needed to remove debris, dust, leaves, and other debris that accumulates on roofs and prevents clogging within the rainwater harvesting system. Different levels of pretreatment should be provided, depending on what the harvested water will be used for. Pretreatment devices should be easily accessible for inspection and maintenance. For dual use cisterns that supply water for irrigation and toilet flushing only, filtration or first-flush diversion pretreatment is recommended. To prevent ice accumulation and freezing damage during periods of cold weather, first-flush diverter pretreatment devices should be either installed in a temperature controlled indoor environment, buried below the local frost penetration depth or be insulated or equipped with heat tracing. If none of these measures can be taken, it may be necessary to disconnect the device from the conveyance system prior to the onset of freezing temperatures. Additional information about some common pretreatment devices is provided below and examples are shown in **Figure 6.5**.

- *Gutter or Downspout Filters:* Filters designed to remove leaves and other large debris from roof runoff such as leaf screens. Screen-type filters must be regularly cleaned to be effective; if not maintained, they can become clogged and prevent runoff from flowing into the storage tanks. Depending on how much sun falls on the gutter during winter, it may be necessary to install heat tape to prevent ice dams from forming.

- *First Flush Diverters:* First flush diverters direct the initial pulse of stormwater runoff away from the storage tank. While leaf screens effectively remove large 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 animal droppings. Simple first flush diverters require gradual release drains or active management to drain the first flush water volume following each runoff event and regular cleaning to ensure they do not become clogged. First-flush diverters should be sized according to the desired amount of runoff to divert from the storage tank. A general rule of thumb is 3-10 gallons per 1000 sf of catchment area, or follow the manufacturer's recommendations if using a proprietary device.

- *In-ground Filters*: Filters placed between a conveyance pipe and an underground storage tank, designed to remove both large and fine particulate from harvested rainwater. A number of proprietary designs are available (*e.g.*, 3P Technik, GRAF, Rainharvesting Systems, WISY). Like leaf screens, they require regular cleaning to ensure they do not become clogged.

- *In-tank Filters*: Filters installed on the intake pipe within the storage tank (*e.g.*, floating suction filters). They require regular inspection to ensure they do not become clogged.

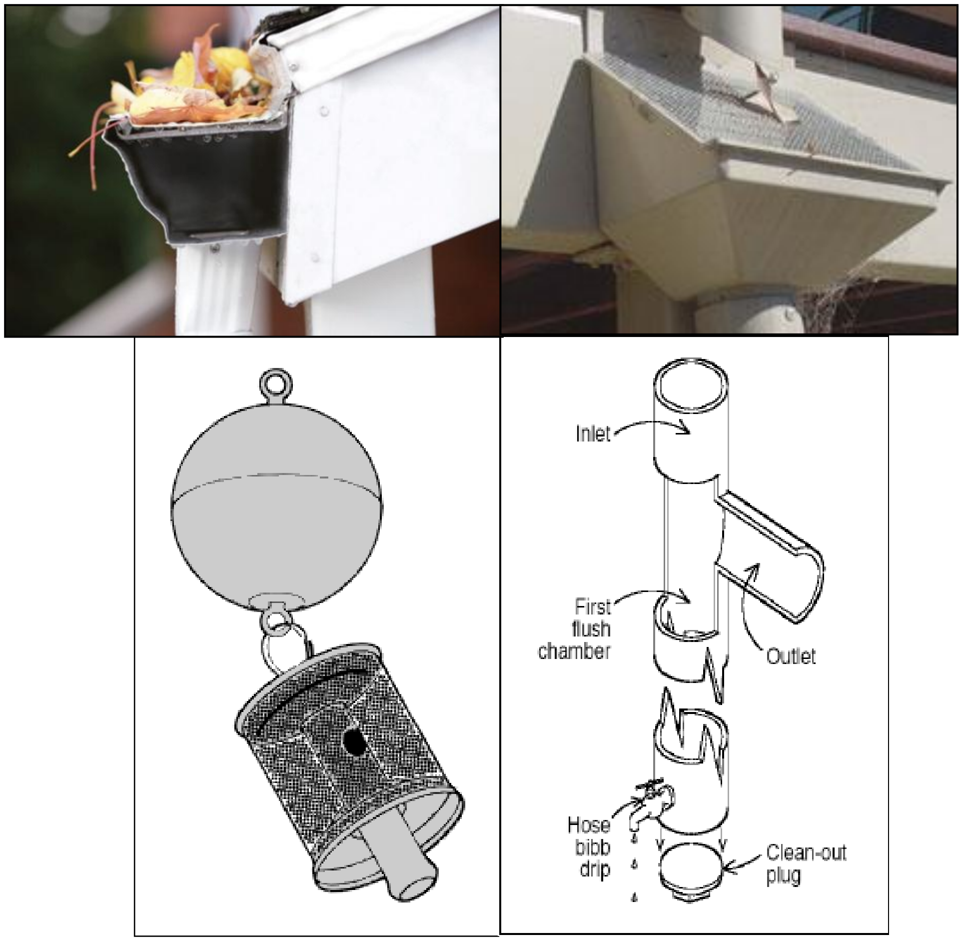

Figure 6.5 – Examples of Pretreatment Devices. Clockwise from top left: Leaf screens on guttrer (Leaf Eater®, © Rainwater Harvesting Ltd.) and downspout (Fixa-Tech®, © Alu-Rex Inc.), First-flush diverter (Source: TWDB); Floating suction filter (© WISY). Source: Credit Valley Conservation and Toronto and Region Conservation (CVC & TRCA). 2010. *Low Impact Development Stormwater Management Planning and Design Guide*. Version 1.0. Toronto, Ontario, Canada.

6.3.7. Storage Tank

The storage tank is the most important and typically the most expensive component of a rainwater harvesting system. The required size of storage tank is dictated by several variables: rainfall and snowfall frequencies and totals, the intended use of the harvested water, the catchment surface area, aesthetics, and budget. However, the most common sizing criteria may be the LID requirement of reusing the volume of water generated from a 1 inch rain event over impervious surfaces or the RWH requirement of harvesting enough water from the roof to meet landscape irrigation demand or the volume from a one inch rain event. In addition to the above criteria, a suggested starting point for sizing the storage tank would be based on the predicted use of the harvested rainwater (*e.g.*, toilet flushing and outdoor uses) over a 30-60 day period, typically the length of the driest period of the year between spring and monsoon rains.

Dual use rainwater harvesting systems (both outdoor and indoor use) can be sized based on the demand principles used for site-specific traditional water and wastewater design. These estimates can be broken down into usage by aspects of the plumbing system such as toilets.

Cisterns may be ordered from a manufacturer or can be constructed on site from a variety of materials including fiberglass, polypropylene, wood, metal and concrete. Above-ground tanks are often plastic while integrated tanks are usually cast-in-place concrete. Underground tanks may be concrete or plastic. All cisterns should be sealed using a water safe, non-toxic substance.

Regardless of the type of storage tank used, they should be opaque or otherwise protected from direct sunlight to inhibit algae growth and screened to discourage mosquito breeding and reproduction. Tanks should be accessible for cleaning, inspection, and maintenance.

Partially bury the cistern, and/or build a short retaining wall around the cistern and backfill with soil, to help insulate the cistern and prevent freezing. Larger cisterns may develop an ice layer up to 8 inches thick on the surface, but will not typically freeze solid and will likely not cause damage to the cistern.

The location, size and configuration of a cistern on a given site depends upon several factors which need to be weighed to arrive at an optimum design:

1. Whether the cistern can be integrated within the building or installed underground;
2. Accessibility for construction and maintenance;
3. Desired storage capacity;
4. Site grading;
5. Proximity constraints (*e.g.*, proximity to catchment area, overflow discharge location, control components of pump and pressure system, building foundations, underground utilities, trees).

Storage tank volume should be designed to achieve an optimal balance between meeting water demand, achieving stormwater management requirements and controlling the overall cost of the system. The volume of dead storage below the intake to the distribution system and an air gap at the top of the tank should be considered in selecting the storage tank capacity. 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.

6.3.8. Distribution System

Most distribution systems are gravity fed or operated using pumps to convey harvested rainwater from the storage tank to its final destination. Typical outdoor uses use gravity to feed hoses via a tap and spigot. For underground cisterns or large sites, a water pump is needed. This can be a typical pump for distributing non-pressurized water for landscaping applications.

Indoor rainwater harvesting systems usually require a pump, pressure tank, back-up water supply line and backflow preventer. The typical pump and pressure tank arrangement consists of a multistage centrifugal pump, which draws water out of the storage tank and sends it into the pressure tank, where it is stored for distribution. When water is drawn out of the pressure tank, the pump kicks on and supplies additional water to the distribution system. Many indoor systems also have a back-up municipal water supply line feeding into them (*i.e.*, "make-up" line) to provide a means of topping up the cistern with potable water when rainwater levels in the cistern fall below a specified level. A backflow preventer is required on "make-up lines" to prevent harvested rainwater from backing up into potable water supply lines.

6.3.9. Overflow System

An overflow system must be included in the design in the event that multiple storms occur in succession and fill the rainwater storage. Overflow pipes should have a capacity equal to or greater than the inflow pipe(s). The overflow system may consist of a conveyance pipe from the top of the cistern to a pervious area downgradient of the storage tank, where suitable grading exists. The overflow discharge location should be designed as simple downspout disconnection to a pervious area, vegetated filter strip, or grass swale. When discharging overflows to a pervious area, the conveyance pipe should be screened to prevent small animals and insects from entering the pipe.

Where site conditions do not permit overflow discharge to a pervious area, the conveyance pipe may need to be indirectly connected to a storm sewer. An indirect connection to a storm sewer can be created by:

1. Overflowing from the inlet line (*e.g.*, roof downspout) to a pervious or impervious area that drains to a storm sewer;

2. Overflowing to a tile drain;

3. Overflowing via overland flow to a sewer grate.

Overflow conveyance pipes can also be directly connected to a storm sewer with incorporation of a backflow preventer (*i.e.*, backwater check valve) to prevent contamination of stored rainwater in the event that the storm sewer backs up during intense storm events.

6.3.10. Design Specifications

Recommended design specifications for rainwater harvesting systems are provided in Table 6.1.

Table 6.1 - Design specifications for rainwater harvesting systems

Component	Specification	Quantity
Gutters and Downspouts	Materials commonly used for gutters and downspouts include polyvinylchloride (PVC) pipe, vinyl, aluminum and galvanized steel. Lead should not be used as solder as rainwater can dissolve the lead and contaminate the water	Determined by the size and layout of the catchment and the location of the storage tanks.

Component	Specification	Quantity
	supply.	Include needed bends and tees.
Pretreatment	At least one of the following: ▪ leaf and mosquito screens (1 mm mesh size); ▪ first-flush diverter; ▪ in-ground filter; ▪ in-tank filter. Large tanks (2,500 gallons or larger) should have a settling compartment for sediment removal	1 per inlet to the collection system.
Storage Tanks	▪ Materials used to construct storage tanks should be structurally sound. ▪ Tanks should be installed in locations where native soils or building structures can support the load associated with the volume of 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. ▪ Previously used containers to be converted to rainwater storage tanks should be fit for potable water or food-grade products. ▪ Cisterns above- or below ground must have a lockable opening of at least 18 inch diameter.	The size of the cistern(s) is determined during the design calculations.
Note: This table does not address indoor systems or pumps.		

6.4. CONSTRUCTION CONSIDERATIONS

For installation, it is advisable to have an experienced contractor who is familiar with cistern sizing, installation materials, and proper site placement. A minimum one-year warranty is recommended.

6.4.1. Sequencing

Stormwater should not be diverted to the cistern until the catchment area (if something other than a roof) and overflow area have been stabilized.

6.4.2. Construction Inspection

The following items should be inspected prior to final sign-off on the stormwater management construction:

- Catchment area matches plans;
- Overflow system is properly sized and installed;
- Pretreatment system is installed;
- Screens are installed on all openings;
- Cistern foundation is constructed as shown on plans; and
- Catchment area and overflow area are stabilized.

6.5. MAINTENANCE

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. All rainwater harvesting system components should undergo regular inspections every six months during the spring and fall seasons. The following maintenance tasks should be performed as needed to keep rainwater harvesting systems in working condition:

- keep leaf screens, gutters and downspouts free of leaves and debris;
- check screens and patch holes or gaps immediately;
- clean and maintain first flush diverters and filters, especially those on drip irrigation systems;
- inspect and clean storage tank lids, paying special attention to vents and screens on inflow and outflow spigots; and
- replace damaged system components as needed.

6.5.1. Mosquito Control

If screening is not sufficient to deter mosquitoes, the following techniques can be used for harvested rainwater intended for landscaping use:

- add a few tablespoons of vegetable oil to smother larvae that come to the surface; and
- use mosquito dunks or pellets containing larvicide.

6.5.2. Winter Operation

Rainwater harvesting systems have a number of components that can be affected by freezing winter temperatures. Designers should give careful consideration to these conditions to prevent system damage and costly repairs. For above-ground systems, winter-time operation may not always be possible, depending on type of installation and size of storage tank. See Section 6.2.1 and 6.2.2 for more information. These systems must be taken offline for the winter. Prior to the onset of freezing temperatures, above-ground systems should be disconnected and drained. For below-ground and indoor systems, downspouts and overflow components should be checked for ice blockages during snowmelt events.

6.6. OTHER RESOURCES

Several other manuals that provide useful design guidance for rainwater harvesting are:

Georgia Rainwater Harvesting Guidelines
http://www.dca.state.ga.us/development/ConstructionCodes/programs/documents/GARainWaterGdlns.040209.pdf

Canadian Standards Association publications
http://www.csa-intl.org/onlinestore/

Portland Stormwater Management Manual
http://www.portlandonline.com/bes/index.cfm?c=dfbcc

Rainwater Harvesting Systems for Montana
http://www.montana.edu/wwwpb/pubs/mt9707.html

Texas Rainwater Harvesting Manual
http://www.twdb.state.tx.us/publications/reports/RainwaterHarvestingManual_3rdedition.pdf

Tucson, AZ Water Harvesting Guidance Manual
http://dot.ci.tucson.az.us/stormwater/downloads/2006WaterHarvesting.pdf

University of Guelph. 2010. *Ontario Guidelines for Residential Rainwater Harvesting Systems*. Guelph, ON.

University of Guelph and Toronto and Region Conservation Authority (TRCA). 2010. *Rainwater Harvesting System Design Tool.* www.sustainabletechnologies.ca

Water Sensitive Planning Guide for the Sydney Region: Practice Note 4 - Rainwater Tanks.
http://www.wsud.org/planning.htm