URBAN Waterways

Rainwater Harvesting: Guidance for Homeowners

Although rainwater harvesting has been practiced for thousands of years, recent concerns over water supplies and the environment have prompted many homeowners to consider using rainwater harvesting systems. While advanced systems are available from consultants and vendors, a homeowner can construct a simple system for home use with a basic understanding of its components and function.

A reliable water supply has always been an important part of daily life. Increased development and the 2007 – 2008 drought have focused our attention on water. Most homeowners use potable water (treated drinking water) to satisfy all of their water needs. But in many instances, treated drinking water can be replaced by captured rainwater. For example, harvested rainwater can be used for irrigation, vehicle washing, and flushing toilets. With special treatment and plumbing, it is even possible for harvested rainwater to become the primary water supply for a home or business.

A rainwater harvesting system captures stormwater runoff, often from a rooftop, and stores the water for later use. By using harvested rainwater for purposes that don't require treated drinking water, we reduce the demand on municipal water supplies and increase the sustainability of drinking water supplies. In some cases, a rainwater harvesting system can be used to wash cars or water gardens—even when water restrictions prevent the use of municipal water for those purposes. Also, because a rainwater harvesting system reduces potable water bills, the system can pay for itself over time. Rainwater harvesting systems can improve the environment by capturing nutrients and other pollutants from rooftop runoff, preventing them from contaminating surface waters. Moreover, the nutrients in rooftop runoff, such as nitrogen and phosphorus, can help plants grow when the captured water is used for irrigation.

A rainwater harvesting system consists of four main components (Figure 1):

- The cistern stores runoff for later use.
- The gutter system collects runoff from the rooftop and directs it into the cistern.
- The overflow pipe allows excess runoff to leave the cistern in a controlled manner.
- The outlet pipe, which is sometimes connected to a pump, draws water from the bottom of the cistern for use.

Consider all of these components and how they work together before installing a rainwater harvesting system. The cistern—or water storage tank—is the primary component, so select and locate it based on anticipated water needs. Remember that local plumbing codes might affect the installation and periodic maintenance will be required.

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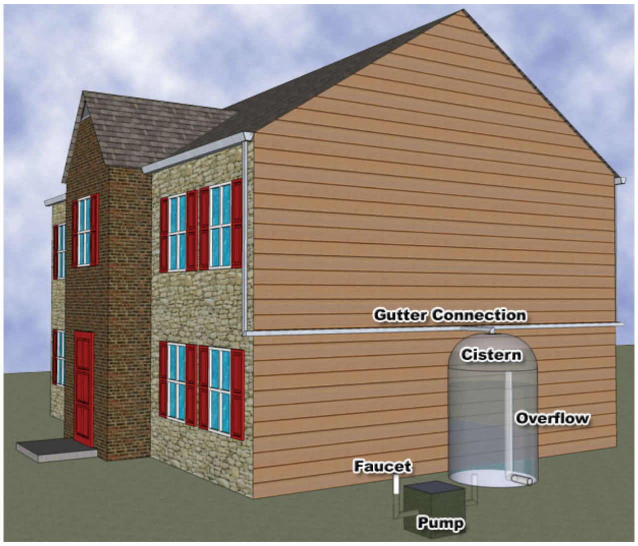

Figure 1. Basic rainwater harvesting system components

CISTERN SELECTION

For most systems, the cistern will have to be ordered and shipped directly to the location where it will be installed. Due to the large size and weight of many cisterns, delivery charges can be substantial. Many online retailers sell tanks that can be used for rainwater harvesting. Some companies focus specifically on rainwater harvesting systems. Homeowners can also find water tanks at local stores that sell agricultural, lawn and garden, or industrial supplies. Select a cistern based on its material, size, whether it will be installed above- or below-ground, and where it will be located.

Cistern Materials

Cisterns can be constructed from a variety of materials. The most commonly available cisterns are made of plastic, fiberglass, or galvanized metal.

Plastic cisterns are generally less expensive than other materials and don't require assembly, but they may not be the best option when aesthetics are a priority. Their appearance can be improved with wraps made of wood or other materials. Plastic cisterns can be moved into place without much difficulty. They are relatively lightweight, and the plastic material can be easily cut or drilled with standard tools to install the necessary valves and fittings.

Metal cisterns are often adapted from grain bins, and their basic appearance is generally preferred to plastic cisterns. Metal cisterns are typically assembled from sections of corrugated galvanized metal, and a plastic liner is installed inside the cistern (Figure 2). Because a liner is needed, it may be difficult for an inexperienced installer to construct a metal cistern.

If the rainwater harvesting system will be used to supply drinking water, special cistern materials are required. If cistern-stored water is to be used for drinking purposes, please consult a water-harvesting vendor and local drinking water ordinances. Only certain resins are approved by the FDA for storing potable water. Use of other materials may leach harmful chemicals into the stored water supply that cannot be easily removed by subsequent water treatment.

Cistern color is also important for plastic tanks. Translucent or light-colored materials may permit algae growth within the cistern. Plastic tanks are relatively easy to paint or decorate, and paint, or other coatings can be used to prevent algae growth. Check with your local paint store to make sure you are purchasing paint that will adhere long term to the type of plastic you will be coating.

Cistern Size

The size of the rainwater cistern can have the greatest impact on system cost and performance. Several factors must be considered, including contributing rooftop area, rainfall patterns, and anticipated usage. Researchers at N.C. State University have developed a simulation tool that can help homeowners determine the ideal cistern volume to meet the goals of a rainwater harvesting system. The free rainwater harvester model is available for download: www.bae.ncsu.edu/topic/waterharvesting

Determining contributing rooftop area. Examine the location of downspouts that will drain to the cistern to estimate the rooftop area. Note the slope of the gutter, and visualize what area of rooftop will drain to each downspout. When measuring the rooftop area, it is important to measure the roof's horizontal projection (as if you were looking straight down on the roof from above), ignoring the pitch of the rooftop (Figure 3). Because the roof's slope is not a factor in the area measurements, the contributing area can usually be estimated by measuring the area of the roof at the ground or foundation level.

Anticipating water usage. Estimating how much water will be used from the rainwater harvesting system is *crucial* to selecting an appropriate cistern size. One of the best ways to estimate water usage is to use a simple garden

Figure 2. Metal rainwater cistern being assembled

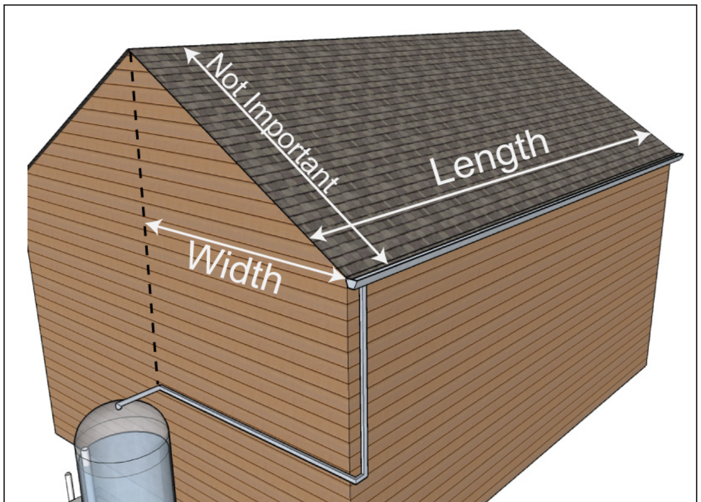

Figure 3. Contributing rooftop area measurements

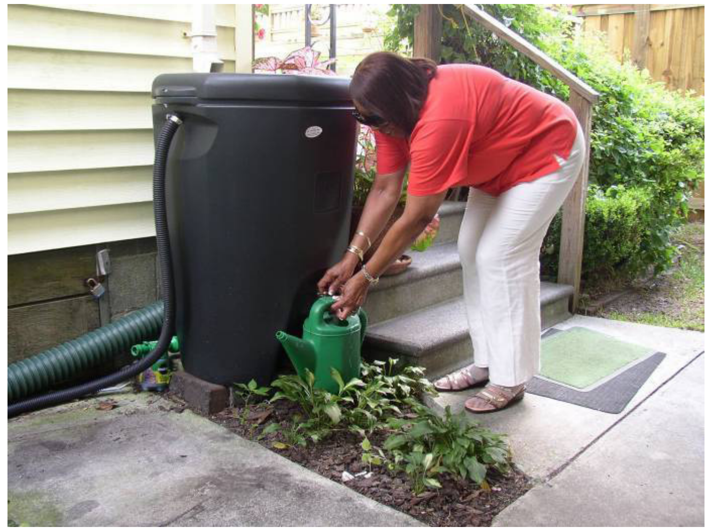

Figure 4. A manufactured rain barrel installed for watering flowerbeds

water meter and record how much water is being used for tasks that will be replaced with harvested rainwater. Garden water meters that measure the number of gallons flowing through a hose or other device are available from a variety of online retailers for about $10. Additional methods for estimating water usage are discussed online in the user manual for the rainwater harvesting model (www.bae.ncsu.edu/topic/waterharvesting).

RAIN BARRELS

Rain barrels are less expensive alternatives to large rainwater harvesting systems and can be used to meet small outdoor water demands. A rain barrel is typically constructed from a 55-gallon container and has the same main components as a large rainwater harvesting system, including a gutter connection, overflow, and outlet valve or faucet (Figure 4). Because 55-gallon barrels are used to store and transport a variety of materials, used barrels are inexpensive to obtain. But they may require special cleaning, depending on their previous use. The relatively small size of a rain barrel usually does not merit the cost of installing a pump because gravity flow is generally adequate to fill a hand watering can. Although a rain barrel does not provide enough water to irrigate a lawn, it can be used to store water for hand-watering plants in a small garden area.

Above Ground or Below?

Several factors should be considered when deciding whether a rainwater cistern will be installed above or below ground. Above-ground cisterns are typically easier to install than below-ground because excavation for the cistern and plumbing network are not necessary. And below-ground cisterns have limited accessibility after installation, making it difficult to repair leaks or other problems. Due to their increased structural requirements and potential floatation concerns, below-ground cisterns are generally more expensive than their above-ground counterparts. (Do not place a plastic cistern manufactured for above-ground use in the ground; it will collapse.)

Unlike an above-ground cistern where some low pressure needs and casual uses can be satisfied without a pump, the use of a pump is required to obtain water from an underground cistern. Additionally, some pumps may not be appropriate for an underground cistern because the pump must be installed below the water level or be capable of providing adequate suction lift. A submersible pump or jet pump designed for shallow wells is a suitable option for pulling water from an underground cistern. Pump selection is discussed in detail in *Choosing a Pump for Rainwater Harvesting* (AG-588-08).

The main advantage of below-ground cisterns is that they do not occupy valuable space in a yard. Below-ground cisterns also offer flexibility as to cistern location because rooftop runoff can be routed through buried pipes.

CISTERN LOCATION

The primary constraint in selecting a cistern location is the position of the gutter downspouts. Although there is some flexibility in routing gutter pipes to various locations, it is generally easiest and most cost effective to place the cistern near an existing downspout (Figure 5). When possible, locate the cistern near the site where water will be used. Transporting water over long distances will increase pump requirements.

Before deciding where to locate a cistern, contact your local utilities companies to locate any underground pipes or cables that might be affected by a cistern or its structural support. Because cisterns can be incredibly heavy when filled with water, avoid placing the cistern over any buried pipes, septic tanks, or drain fields that may not support the load exerted by it. (Your local health department can provide assistance if you have a septic system and have difficulty locating it.) Do not locate an underground cistern immediately adjacent to a building, because excavation and installation could damage or compromise the foundation.

CISTERN STRUCTURAL SUPPORT

In some cases, the weight exerted by the cistern and the water it holds may require more structural support than the in-situ soil can provide. North Carolina soils are generally presumed to support at least 2,000 pounds per square foot. Based on the cistern's volume, footprint (the square footage it occupies), and the density of water, you can determine whether additional structural support for a cistern is necessary. The load exerted by the cistern can be calculated using Equation 1 (below). If the calculated load is greater than the load bearing capacity of the soil (2,000 pounds per square foot), some type of structural support will be required. Structural support for an above-ground cistern could consist of a concrete or gravel pad installed using standard building design practices. Alternatively, a cistern with a larger footprint or smaller volume could be selected to reduce the cistern load.

Sand, stone, or gravel backfill and anchoring—or even the use of a poured concrete pad—may be required to support an underground cistern. Be sure to follow the manufacturer's instructions and any local regulations when installing an underground cistern.

OVERFLOW SIZING AND INSTALLATION

Some type of overflow or bypass is required to release water when the cistern has reached its capacity. The cistern overflow must handle the same flow as the gutter system,

Figure 5. Above-ground cistern located at the corner of a house near existing downspouts *(image courtesy of LSU Ag Center)*

which is runoff from a 100-year, 1-hour storm event. The required overflow size can be determined by using Table 1 for cities throughout North Carolina. Using the row for the city closest to the proposed cistern installation, select an overflow diameter such that the maximum roof area in Table 1 is greater than the rooftop area contributing water to the cistern.

Install the overflow near the top of the tank, leaving several inches between the overflow and top of the tank for storage during intense storms. A bulkhead fitting installed near the top of the tank will provide a sturdy connection point for the overflow pipe; however, these fittings can be expensive, especially for large diameters. Because an overflow connection at the top of the tank will not be submerged under pressure and a perfect seal with the cistern

EQUATION 1

Calculation of cistern load to determine need for structural support

$$\textbf{Cistern Load} = \frac{\text{Capacity x 8.35 lb/gal + Cistern Weight}}{\text{Footprint Area}}$$

Capacity: Cistern volume in gallons

Cistern Weight: Weight of the empty cistern in pounds. The weight of an empty plastic cistern can be approximated as 0.3 lb/gal if the specific weight is unknown.

Footprint Area: Area of the cistern that will be in contact with the ground in square feet.

EXAMPLE

A 1,000-gallon plastic cistern has a diameter of 7.25 feet. Determine if additional structural support is required.

$$\textbf{Cistern Load} = \frac{(1{,}000 \text{ gal x } 8.35 \text{ lb/gal}) + (1{,}000 \text{ gal x } 0.3 \text{ lb/gal})}{\pi \text{ x } (7.25 \text{ ft} \div 2)^2} = 210 \text{ lb/ft}^2$$

The cistern load of 210 pounds per square foot is well below the soil load-bearing capacity of 2,000 pounds per square foot; therefore, the cistern does not need additional structural support.

Table 1. Maximum roof area (square feet) drained by specified overflow diameters (inches) for select N.C. cities

	Maximum Roof Area (ft²) by Overflow Diameter (in.)					
Overflow Diameter	**½ in.**	**1 in.**	**2 in.**	**2.5 in.**	**3 in.**	**4 in.**
Asheville	38	157	720	1,170	1,740	3,320
Boone	33	144	631	1,020	1,530	2,910
Charlotte	37	155	710	1,150	1,720	3,280
Elizabeth City	32	132	603	981	1,460	2,780
Fayetteville	33	142	624	1,010	1,510	2,880
Franklin	38	165	724	1,170	1,760	3,340
Greenville	31	131	598	973	1,450	2,760
Raleigh	38	160	715	1,160	1,740	3,300
Rocky Mount	36	150	687	1,110	1,670	3,170
Wilmington	26	110	498	810	1,210	2,300
Winston Salem	40	165	756	1,230	1,830	3,490

wall is not necessary, a variety of PVC fittings can be adapted to connect the overflow pipe. If the overflow is routed through the bottom of the tank, as shown in Figure 6A, a bulkhead fitting is required to prevent leaks. For underground cistern installations, the overflow can be installed with a t-fitting on the pipe carrying water from the gutter to the cistern. For both above- and below-ground cisterns, it is important to protect, armor, or reinforce the soil around the overflow outlet to prevent erosion.

FAUCET OR OUTLET INSTALLATION

To draw water from the cistern, some type of faucet or outlet pipe must be installed. Although a valve located near the bottom of the cistern can be used to pull water from the cistern for small uses, such as filling watering cans, a pump is necessary to supply adequate pressure for many demands. Pump selection is discussed in detail in *Choosing a Pump for Rainwater Harvesting (AG-588-08)*.

The outlet should be installed at least 6 inches above the bottom of the cistern to provide room for sediment storage. Because the outlet connection will be subject to substantial water pressure, a bulkhead fitting is necessary to prevent any leaks. Install a bulkhead fitting by drilling a hole into the cistern and threading the fitting through the hole (Figure 7). Because installing a bulkhead fitting requires access from the inside of the tank, it is often worth the extra expense to have the bulkhead fitting installed by the cistern vendor.

GUTTER SYSTEM

An existing gutter system can be easily modified to direct rainwater into a cistern. In most cases, some type of gutter screen or filter is desirable to prevent debris from entering the system. Although more expensive, screens installed across the length of the gutter are less likely to

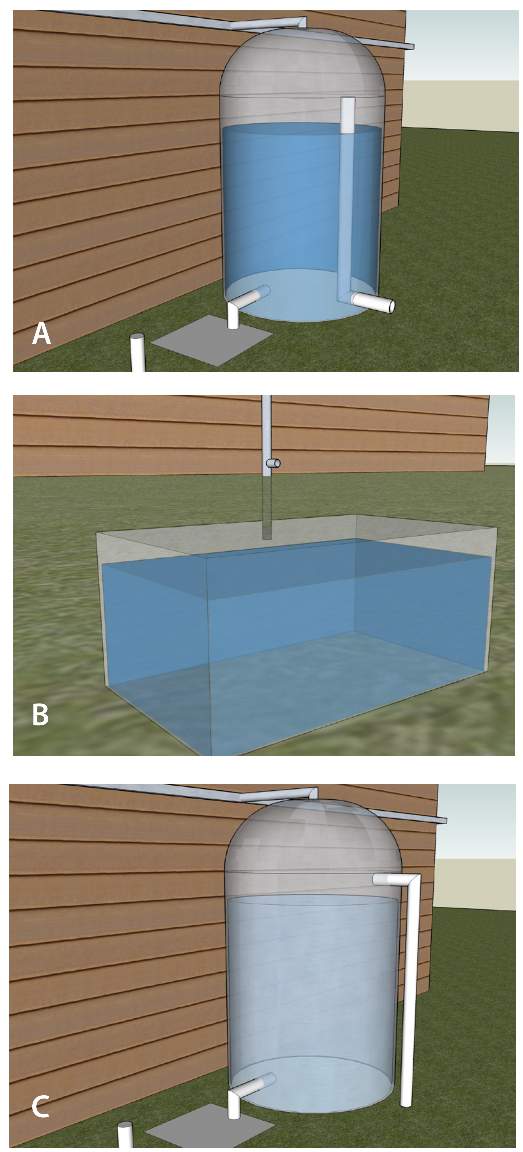

Figure 6 A, B, C. Basic overflow configurations

UNDERGROUND CISTERNS: SPECIAL CONSIDERATIONS

Underground cisterns offer some flexibility as to installation location because runoff can be piped underground to the cistern. In fact, piping runoff away from the house is preferred because installing an underground cistern immediately adjacent to a house may cause damage to the house foundation during excavation. Because of the potential structural and safety concerns, it is important to comply with all underground cistern installation instructions and regulations.

- Before beginning an underground cistern installation, contact your local utilities companies to locate any underground pipes or cables.
- Depending upon the specific underground cistern being installed, sand, pea gravel, or crushed stone backfill material may be required.
- Consult the product literature to determine the required specifications for backfill material, excavation depths, and the depth of soil required over the cistern.
- In areas where the water table can rise above the bottom of the underground cistern, special consideration is required to ensure that the cistern is properly anchored against any potential buoyancy and is structurally suited to handle these additional forces.
- An underground tank must be properly vented to the atmosphere to prevent the buildup of pressure or vacuum within the tank. Vents are often incorporated into a tank or can be attached as a basic fitting.

Figure 7. Bulkhead fitting installed at the base of a cistern

Figure 8. Stickers and decals remind users that untreated cistern water is not safe for drinking.

clog and cause gutter overflows than filters located only at the downspout. Metal gutter downspouts and fittings are available from home improvement stores and can be used to route rainwater into a nearby cistern. Remember that metal downspouts are generally attached to a building and may require additional structural support when spanning any substantial distance to a cistern. Corrugated plastic pipes are an alternative to metal downspouts that may ease installation and require less structural support. To prevent mosquitoes from breeding within the cistern, any open pathways to the captured water should be covered by 1-millimeter or smaller mesh screen.

Several approaches can be used to direct more water to a rainwater harvesting system. The easiest and safest way to contribute more water is to pipe water from multiple existing downspouts into the cistern. Using this approach provides water from a greater rooftop area without risk of exceeding the downspout or gutter capacity. In locations where it is not practical to direct water from multiple downspouts into the cistern, it may be possible to modify the gutter system so that more water is directed to a single downspout.

Standard gutter systems are designed to efficiently remove water from the rooftop and gutter through numerous downspouts. Any modifications to the gutter system without careful consideration can result in overflows or structural failure. In North Carolina, gutters are designed to carry water for the 100-year, 1-hour storm event, the same event used for sizing the cistern overflow. Carefully consider Tables 2 and 3 before modifying gutters to direct water into a cistern. Table 2 lists the maximum rooftop area that can be safely drained by various gutter configurations, while Table 3 lists the maximum roof area that can be drained by a downspout.

WATER SUPPLY PLUMBING CODES

Because widespread public interest in rainwater harvesting systems is a relatively recent development, many plumbing codes do not address the use of harvested rainwater. Plumbing codes are constantly evolving. Consult someone familiar with local codes to determine which plumbing fixtures (such as tubs, toilets, and sinks) can legally be supplied with harvested rainwater and what specific regulations apply. Many of the restrictions associated with plumbing codes can be avoided by maintaining entirely separate plumbing networks and using harvested rainwater for outdoor purposes only. Regardless of the plumbing network, any faucet or fixture supplied by the rainwater harvesting system must be properly labeled with its source. Harvested rainwater contains pathogens and other pollutants at levels that pose health concerns if consumed. Installing signs or labels that warn of these health concerns is important to prevent any potential hazards (Figure 8).

Table 2. Maximum roof area (square feet) drained by specified gutter diameters (inches) and slopes (%) for select N.C. cities

	Maximum Roof Area (ft^2) by Gutter Slope (%) and Diameter (in.)							
Slope	**½% Gutter Slope**				**1% Gutter Slope**			
Diameter	**3 in.**	**4 in.**	**5 in.**	**6 in.**	**3 in.**	**4 in.**	**5 in.**	**6 in.**
Asheville	216	457	794	1,210	305	648	1,110	1,720
Boone	189	401	697	1,070	267	568	980	1,510
Charlotte	213	451	784	1,200	301	640	1,100	1,700
Elizabeth City	181	383	665	1,020	255	543	936	1,440
Fayetteville	187	397	689	1,050	264	562	969	1,490
Franklin	217	460	799	1,220	307	652	1,120	1,730
Greenville	179	380	660	1,010	253	538	929	1,430
Raleigh	214	454	789	1,210	303	644	1,110	1,710
Rocky Mount	206	436	758	1,160	291	618	1,060	1,640
Wilmington	149	316	550	844	211	449	773	1,190
Winston Salem	227	480	833	1,280	320	680	1,170	1,810

Table 3. Maximum roof area (square feet) drained by specified downspout diameters (inches) for select N.C. cities

	Maximum Roof Area (ft^2) by Gutter Diameter (in.)		
Gutter Diameter	**2 in.**	**3 in.**	**4 in.**
Asheville	914	2,790	5,840
Boone	802	2,450	5,120
Charlotte	902	2,750	5,760
Elizabeth City	765	2,340	4,890
Fayetteville	793	2,420	5,060
Franklin	920	2,810	5,870
Greenville	759	2,320	4,850
Raleigh	908	2,770	5,800
Rocky Mount	872	2,660	5,570
Wilmington	632	1,930	4,040
Winston Salem	960	2,930	6,130

RAINWATER HARVESTING SYSTEM MAINTENANCE

With routine maintenance, rainwater harvesting systems should provide a sustainable nonpotable water supply for many years. Over time, sediment carried by incoming runoff will be deposited within the bottom of the cistern and may require removal. Using a first-flush diverter or sediment trap will reduce sediment inputs into the cistern (Figure 9). In most cases, a 6-inch sediment storage zone at the bottom of the cistern should provide years of sediment storage. If sediment buildup is a concern, install a valve at the bottom of the cistern to regularly drain the sediment-laden water. Due to the risk of drowning and exposure to toxic gases, a homeowner should never enter a cistern for maintenance or any other purpose.

Check gutter connections every three to four months and after intense rainfall to check for any damage. Clean gutters of leaves and debris as needed and at least seasonally. Check mosquito screens periodically to ensure they are in place and not blocked by debris. Maintain any pumps or filters used in the rainwater harvesting system according to the manufacturer's recommendations.

Figure 9. First flush diverter installed for a residential rainwater harvesting system

RESOURCES

RELATED FACT SHEETS

Related Fact Sheets in the Urban Waterways series (AG-588), North Carolina Cooperative Extension Service, N.C. State University:

Hunt, W. F. and L. L. Spizr. 2006. *Permeable Pavements, Green Roofs, and Cisterns: Stormwater Treatment Practices for Low-Impact Development* (AG-588-6). Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/BMPs4LID.pdf

Jones, M. P. and Hunt, W. F. (2006). *Choosing a Pump for Rainwater Harvesting* (AG-588-8). Online: http://www.bae.ncsu.edu/stormwater/PublicationFiles/Pump4Cisterns2006.pdf

RELATED WEB SITES

Rainwater Harvesting at North Carolina State University: http://www.bae.ncsu.edu/topic/waterharvesting

N.C. State University BAE Stormwater Engineering Group: http://www.bae.ncsu.edu/stormwater

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