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A Guide to Rainwater Harvesting

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Chapter 1

Introduction

Rainwater harvesting is an ancient technique enjoying a revival in popularity due to the inherent quality of rainwater and interest in reducing consumption of treated water.

Rainwater is valued for its purity and softness. It has a nearly neutral pH, and is free from disinfection by-products, salts, minerals, and other natural and man-made contaminants. Plants thrive under irrigation with stored rainwater. Appliances last longer when free from the corrosive or scale effects of hard water. Users with potable systems prefer the superior taste and cleansing properties of rainwater.

Archeological evidence attests to the capture of rainwater as far back as 4,000 years ago, and the concept of rainwater harvesting in China may date back 6,000 years. Ruins of cisterns built as early as 2000 B.C. for storing runoff from hillsides for agricultural and domestic purposes are still standing in Israel (Gould and Nissen-Petersen, 1999).

Advantages and benefits of rainwater harvesting are numerous (Krishna, 2003).

- ◆ The water is free; the only cost is for collection and use.
- ◆ The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems.
- ◆ Rainwater provides a water source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.
- ◆ The zero hardness of rainwater helps prevent scale on appliances,

extending their use; rainwater eliminates the need for a water softener and the salts added during the softening process.

- ◆ Rainwater is sodium-free, important for persons on low-sodium diets.
- ◆ Rainwater is superior for landscape irrigation.
- ◆ Rainwater harvesting reduces flow to stormwater drains and also reduces non-point source pollution.
- ◆ Rainwater harvesting helps utilities reduce the summer demand peak and delay expansion of existing water treatment plants.
- ◆ Rainwater harvesting reduces consumers' utility bills.

Perhaps one of the most interesting aspects of rainwater harvesting is learning about the methods of capture, storage, and use of this natural resource at the place it occurs. This natural synergy excludes at least a portion of water use from the water distribution infrastructure: the centralized treatment facility, storage structures, pumps, mains, and laterals.

Rainwater harvesting also includes land-based systems with man-made landscape features to channel and concentrate rainwater in either storage basins or planted areas.

When assessing the health risks of drinking rainwater, consider the path taken by the raindrop through a watershed into a reservoir, through public drinking water treatment and distribution systems to the end user. Being the universal solvent, water absorbs contaminants and minerals on its

travels to the reservoir. While in residence in the reservoir, the water can come in contact with all kinds of foreign materials: oil, animal wastes, chemical and pharmaceutical wastes, organic compounds, industrial outflows, and trash. It is the job of the water treatment plant to remove harmful contaminants and to kill pathogens. Unfortunately, when chlorine is used for disinfection, it also degrades into disinfection by-products, notably trihalomethanes, which may pose health risks. In contrast, the raindrop harvested on site will travel down a roof via a gutter to a storage tank. Before it can be used for drinking, it will be treated by a relatively simple process with equipment that occupies about 9 cubic feet of space.

Rainwater harvesting can reduce the volume of storm water, thereby lessening the impact on erosion and decreasing the load on storm sewers. Decreasing storm water volume also helps keep potential storm water pollutants, such as pesticides, fertilizers, and petroleum products, out of rivers and groundwater.

But along with the independence of rainwater harvesting systems comes the inherent responsibility of operation and maintenance. For all systems, this responsibility includes purging the first-flush system, regularly cleaning roof washers and tanks, maintaining pumps, and filtering water. For potable systems, responsibilities include all of the above, and the owner must replace cartridge filters and maintain disinfection equipment on schedule, arrange to have water tested, and monitor tank levels. Rainwater used for drinking should be tested, at a minimum, for pathogens.

Rainwater harvesting, in its essence, is the collection, conveyance, and storage

of rainwater. The scope, method, technologies, system complexity, purpose, and end uses vary from rain barrels for garden irrigation in urban areas, to large-scale collection of rainwater for all domestic uses. Some examples are summarized below:

- ◆ For supplemental irrigation water, the Wells Branch Municipal Utility District in North Austin captures rainwater, along with air conditioning condensate, from a new 10,000-square-foot recreation center into a 37,000-gallon tank to serve as irrigation water for a 12-acre municipal park with soccer fields and offices.
- ◆ The Lady Bird Johnson Wildflower Research Center in Austin, Texas, harvests 300,000 gallons of rainwater annually from almost 19,000 square feet of roof collection area for irrigation of its native plant landscapes. A 6,000-gallon stone cistern and its arching stone aqueduct form the distinctive entry to the research center.
- ◆ The Advanced Micro Devices semiconductor fabrication plant in Austin, Texas, does not use utility-supplied water for irrigation, saving \$1.5 million per year by relying on captured rainwater and collected groundwater.
- ◆ Reynolds Metals in Ingleside, Texas, uses stormwater captured in containment basins as process water in its metal-processing plant, greatly offsetting the volume of purchased water.
- ◆ The city of Columbia, Nuevo León, Mexico, is in the planning stages of developing rainwater as the basis for the city's water supply for new

growth areas, with large industrial developments being plumbed for storage and catchment.

- ◆ On small volcanic or coral islands, rainwater harvesting is often the only option for public water supply, as watersheds are too small to create a major river, and groundwater is either nonexistent or contaminated with salt water. Bermuda, the U.S. Virgin Islands, and other Caribbean islands require cisterns to be included with all new construction.

In Central Texas, more than 400 full-scale rainwater harvesting systems have been installed by professional companies, and more than 6,000 rain barrels have been installed through the City of Austin's incentive program in the past decade. Countless "do-it-yourselfers" have installed systems over the same time period.

An estimated 100,000 residential rainwater harvesting systems are in use in the United States and its territories (Lye, 2002). More are being installed by the urban home gardener seeking healthier plants, the weekend cabin owner, and the homeowner intent upon the "green" building practices – all seeking a sustainable, high-quality water source. Rainwater harvesting is also recognized as an important water-conserving measure, and is best implemented in conjunction with other efficiency measures in and outside of the home.

Harvested rainwater may also help some Texas communities close the gap between supply and demand projected by the Texas Water Development Board (TWDB), as the state's population nearly doubles between 2000 and 2050 (Texas Water Development Board, 2002).

In fact, rainwater harvesting is encouraged by Austin and San Antonio water utilities as a means of conserving water. The State of Texas also offers financial incentives for rainwater harvesting systems. Senate Bill 2 of the 77th Legislature exempts rainwater harvesting equipment from sales tax, and allows local governments to exempt rainwater harvesting systems from ad valorem (property) taxes.

Rainwater harvesting systems can be as simple as a rain barrel for garden irrigation at the end of a downspout, or as complex as a domestic potable system or a multiple end-use system at a large corporate campus.

Rainwater harvesting is practical only when the volume and frequency of rainfall and size of the catchment surface can generate sufficient water for the intended purpose.

From a financial perspective, the installation and maintenance costs of a rainwater harvesting system for potable water cannot compete with water supplied by a central utility, but is often cost-competitive with installation of a well in rural settings.

With a very large catchment surface, such as that of big commercial building, the volume of rainwater, when captured and stored, can cost-effectively serve several end uses, such as landscape irrigation and toilet flushing.

Some commercial and industrial buildings augment rainwater with condensate from air conditioning systems. During hot, humid months, warm, moisture-laden air passing over the cooling coils of a residential air conditioner can produce 10 or more gallons per day of water. Industrial facilities produce thousands of gallons

per day of condensate. An advantage of condensate capture is that its maximum production occurs during the hottest month of the year, when irrigation need is greatest. Most systems pipe condensate into the rainwater cistern for storage.

The depletion of groundwater sources, the poor quality of some groundwater, high tap fees for isolated properties, the flexibility of rainwater harvesting systems, and modern methods of treatment provide excellent reasons to harvest rainwater for domestic use.

The scope of this manual is to serve as a primer in the basics of residential and small-scale commercial rainwater harvesting systems design. It is intended to serve as a first step in thinking about options for implementing rainwater harvesting systems, as well as advantages and constraints.

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Chapter 2

Rainwater Harvesting System Components

Rainwater harvesting is the capture, diversion, and storage of rainwater for a number of different purposes including landscape irrigation, drinking and domestic use, aquifer recharge, and stormwater abatement.

In a residential or small-scale application, rainwater harvesting can be as simple as channeling rain running off an unuttered roof to a planted landscape area via contoured landscape. To prevent erosion on sloped surfaces, a bermed concave holding area down slope can store water for direct use by turfgrass or plants (Waterfall, 1998). More complex systems include gutters, pipes, storage tanks or cisterns, filtering, pump(s), and water treatment for potable use.

This chapter focuses on residential or small-scale commercial systems, for both irrigation and potable use.

The local health department and city

building code officer should be consulted concerning safe, sanitary operations and construction of these systems.

Basic Components

Regardless of the complexity of the system, the domestic rainwater harvesting system (Figure 2-1) comprises six basic components:

- ◆ Catchment surface: the collection surface from which rainfall runs off
- ◆ Gutters and downspouts: channel water from the roof to the tank
- ◆ Leaf screens, first-flush diverters, and roof washers: components which remove debris and dust from the captured rainwater before it goes to the tank
- ◆ One or more storage tanks, also called cisterns
- ◆ Delivery system: gravity-fed or pumped to the end use
- ◆ Treatment/purification: for potable systems, filters and other methods to make the water safe to drink

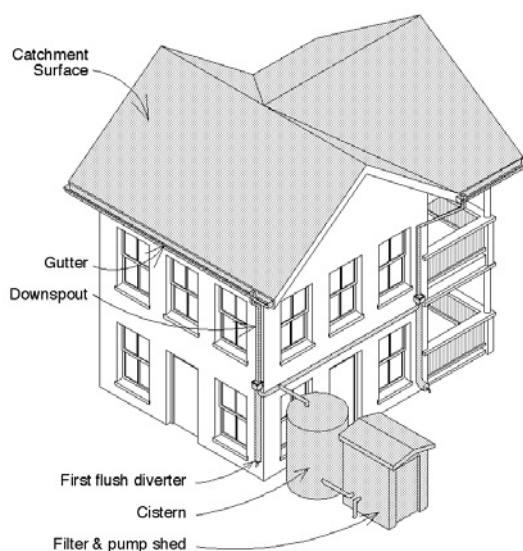


Figure 2-1. Typical rainwater harvesting installation

The Catchment Surface

The roof of a building or house is the obvious first choice for catchment. For additional capacity, an open-sided barn – called a rain barn or pole barn – can be built. Water tanks and other rainwater system equipment, such as pumps and filters, as well as vehicles, bicycles, and gardening tools, can be stored under the barn.

Water quality from different roof catchments is a function of the type of roof material, climatic conditions, and

the surrounding environment (Vasudevan, 2002).

Metal

The quantity of rainwater that can be collected from a roof is in part a function of the roof texture: the smoother the better. A commonly used roofing material for rainwater harvesting is sold under the trade name Galvalume®, a 55 percent aluminum/45 percent zinc alloy-coated sheet steel. Galvalume® is also available with a baked enamel coating, or it can be painted with epoxy paint.

Some caution should be exercised regarding roof components. Roofs with copper flashings can cause discoloration of porcelain fixtures.

Clay/concrete tile

Clay and concrete tiles are both porous. Easily available materials are suitable for potable or nonpotable systems, but may contribute to as much as a 10-percent loss due to texture, inefficient flow, or evaporation. To reduce water loss, tiles can be painted or coated with a sealant. There is some chance of toxins leaching from the tile sealant or paint, but this roof surface is safer when painted with a special sealant or paint to prevent bacterial growth on porous materials.

Composite or asphalt shingle

Due to leaching of toxins, composite shingles are not appropriate for potable systems, but can be used to collect water for irrigation. Composite roofs have an approximated 10-percent loss due to inefficient flow or evaporation (Radlet and Radlet, 2004).

Others

Wood shingle, tar, and gravel. These roofing materials are rare, and the water

harvested is usually suitable only for irrigation due to leaching of compounds.

Slate. Slate's smoothness makes it ideal for a catchment surface for potable use, assuming no toxic sealant is used; however, cost considerations may preclude its use.

Gutters and Downspouts

Gutters are installed to capture rainwater running off the eaves of a building. Some gutter installers can provide continuous or seamless gutters.

For potable water systems, lead cannot be used as gutter solder, as is sometimes the case in older metal gutters. The slightly acidic quality of rain could dissolve lead and thus contaminate the water supply.

The most common materials for gutters and downspouts are half-round PVC, vinyl, pipe, seamless aluminum, and galvanized steel.

Seamless aluminum gutters are usually installed by professionals, and, therefore, are more expensive than other options.

Regardless of material, other necessary components in addition to the horizontal gutters are the drop outlet, which routes water from the gutters downward and at least two 45-degree elbows which allow the downspout pipe to snug to the side of the house. Additional components include the hardware, brackets, and straps to fasten the gutters and downspout to the fascia and the wall.

Gutter Sizing and Installation

When using the roof of a house as a catchment surface, it is important to consider that many roofs consist of one or more roof "valleys." A roof valley occurs where two roof planes meet. This is most common and easy to visualize

when considering a house plan with an “L” or “T” configuration. A roof valley concentrates rainfall runoff from two roof planes before the collected rain reaches a gutter. Depending on the size of roof areas terminating in a roof valley, the slope of the roofs, and the intensity of rainfall, the portion of gutter located where the valley water leaves the eave of the roof may not be able to capture all the water at that point, resulting in spillage or overrunning.

Besides the presence of one or more roof valleys, other factors that may result in overrunning of gutters include an inadequate number of downspouts, excessively long roof distances from ridge to eave, steep roof slopes, and inadequate gutter maintenance. Variables such as these make any gutter sizing rules of thumb difficult to apply. Consult your gutter supplier about your situation with special attention to determine where gutter overrunning areas may occur. At these points along an eave, apply strategies to minimize possible overrunning to improve catchment efficiency. Preventative strategies may include modifications to the size and configuration of gutters and addition of gutter boxes with downspouts and roof diverters near the eave edge.

Gutters should be installed with slope towards the downspout; also the outside face of the gutter should be lower than the inside face to encourage drainage away from the building wall.

Leaf Screens

To remove debris that gathers on the catchment surface, and ensure high quality water for either potable use or to work well without clogging irrigation emitters, a series of filters are necessary. Essentially, mesh screens remove debris

both before and after the storage tank. The defense in keeping debris out of a rainwater harvesting system is some type of leaf screen along the gutter or in the downspout.

Depending upon the amount and type of tree litter and dust accumulation, the homeowner may have to experiment to find the method that works best. Leaf screens must be regularly cleaned to be effective. If not maintained, leaf screens can become clogged and prevent rainwater from flowing into a tank. Built-up debris can also harbor bacteria and the products of leaf decay.

Leaf guards are usually ¼-inch mesh screens in wire frames that fit along the length of the gutter. Leaf guards/screens are usually necessary only in locations with tree overhang. Guards with profiles conducive to allowing leaf litter to slide off are also available.

The **funnel-type downspout filter** is made of PVC or galvanized steel fitted with a stainless steel or brass screen. This type of filter offers the advantage of easy accessibility for cleaning. The funnel is cut into the downspout pipe at the same height or slightly higher than the highest water level in the storage tank.

Strainer baskets are spherical cage-like strainers that slip into the drop outlet of the downspout.

A **cylinder of rolled screen** inserted into the drop outlet serves as another method of filtering debris. The homeowner may need to experiment with various grid sizes, from insect screen to hardware cloth.

Filter socks of nylon mesh can be installed on the PVC pipe at the tank inflow.

First-Flush Diverters

A roof can be a natural collection surface for dust, leaves, blooms, twigs, insect bodies, animal feces, pesticides, and other airborne residues. The first-flush diverter routes the first flow of water from the catchment surface away from the storage tank. The flushed water can be routed to a planted area. While leaf screens remove the larger debris, such as leaves, twigs, and blooms that fall on the roof, the first-flush diverter gives the system a chance to rid itself of the smaller contaminants, such as dust, pollen, and bird and rodent feces.

The simplest first-flush diverter is a PVC standpipe (Figure 2-2). The standpipe fills with water first during a rainfall event; the balance of water is routed to the tank. The standpipe is drained continuously via a pinhole or by leaving the screw closure slightly loose. In any case, cleaning of the standpipe is accomplished by removing the PVC cover with a wrench and removing collected debris after each rainfall event.

There are several other types of first-flush diverters. The ball valve type consists of a floating ball that seals off the top of the diverter pipe (Figure 2-3) when the pipe fills with water.

Opinions vary on the volume of rainwater to divert. The number of dry days, amount of debris, and roof surface are all variables to consider.

One rule of thumb for first-flush diversion is to divert a minimum of 10 gallons for every 1,000 square feet of collection surface. However, first-flush volumes vary with the amount of dust on the roof surface, which is a function of the number of dry days, the amount and type of debris, tree overhang, and season.

A preliminary study by Rain Water Harvesting and Waste Water Systems Pty Ltd., a rainwater harvesting component vendor in Australia, recommends that between 13 and 49 gallons be diverted per 1,000 square feet.

The primary reason for the wide variation in estimates is that there is no exact calculation to determine how much initial water needs to be diverted because there are many variables that would determine the effectiveness of washing the contaminants off the collection surface, just as there are many variables determining the make up of the contaminants themselves. For example, the slope and smoothness of the collection surface, the intensity of the rain event, the length of time between events (which adds to the amount of accumulated contaminants), and the nature of the contaminants themselves add to the difficulty of determining just how much rain should be diverted during first flush. In order to effectively wash a collection surface, a rain intensity of one-tenth of an inch of rain per hour is needed to wash a sloped roof. A flat or near-flat collection surface requires 0.18 inches of rain per hour for an effective washing of the surface.

The recommended diversion of first flush ranges from one to two gallons of first-flush diversion for each 100 square feet of collection area. If using a roof for a collection area that drains into gutters, calculate the amount of rainfall area that will be drained into every gutter feeding your system. Remember to calculate the horizontal equivalent of the “roof footprint” when calculating your catchment area. (Please refer to the Figure 4-1 in Chapter 4, Water Balance and System Sizing.) If a gutter receives the quantity of runoff that require multiple downspouts, first-flush

First-Flush Diverters

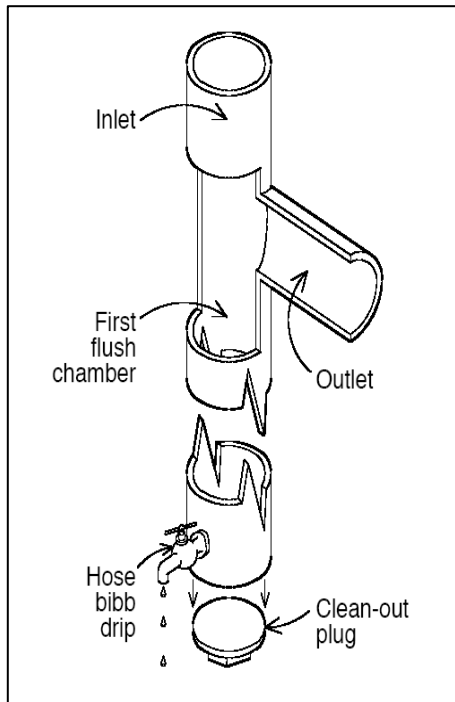


Figure 2-2. Standpipe first-flush diverter

Standpipe

The simplest first-flush diverter is a 6- or 8-inch PVC standpipe (Figure 2-2). The diverter fills with water first, backs up, and then allows water to flow into the main collection piping. These standpipes usually have a cleanout fitting at the bottom, and must be emptied and cleaned out after each rainfall event. The water from the standpipe may be routed to a planted area. A pinhole drilled at the bottom of the pipe or a hose bibb fixture left slightly open (shown) allows water to gradually leak out.

If you are using 3" diameter PVC or similar pipe, allow 33" length of pipe per gallon; 4" diameter pipe needs only 18" of length per gallon; and a little over 8" of 6" diameter pipe is needed to catch a gallon of water.

Standpipe with ball valve

The standpipe with ball valve is a variation of the standpipe filter. The cutaway drawing (Figure 2-3) shows the ball valve. As the chamber fills, the ball floats up and seals on the seat, trapping first-flush water and routing the balance of the water to the tank.

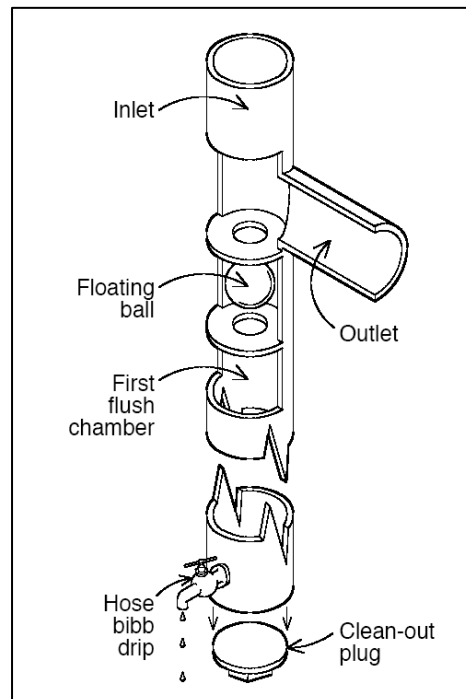


Figure 2-3. Standpipe with ball valve

diversion devices will be required for each downspout.

Roof Washers

The roof washer, placed just ahead of the storage tank, filters small debris for potable systems and also for systems using drip irrigation. Roof washers consist of a tank, usually between 30- and 50-gallon capacity, with leaf strainers and a filter (Figure 2-4). One commercially available roof washer has a 30-micron filter. (A micron, also called a micrometer, is one-millionth of a meter. A 30-micron filter has pores about one-third the diameter of a human hair.)

All roof washers must be cleaned. Without proper maintenance they not only become clogged and restrict the flow of rainwater, but may themselves become breeding grounds for pathogens.

The box roof washer (Figure 2-4) is a commercially available component consisting of a fiberglass box with one or two 30-micron canister filters

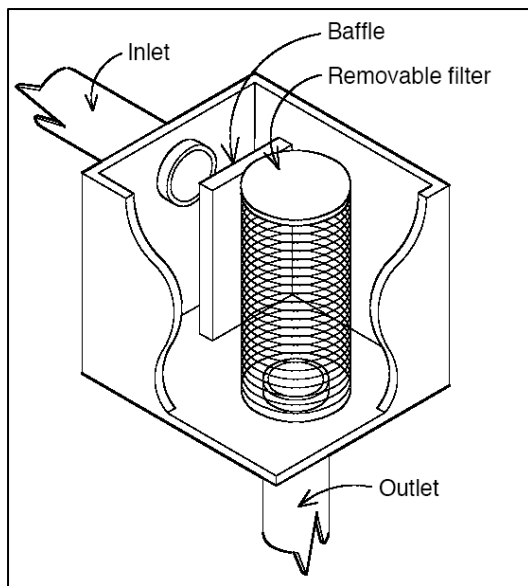


Figure 2-4. Box roof washer

(handling rainwater from 1,500- and 3,500-square-foot catchments, respectively). The box is placed atop a ladder-like stand beside the tank, from which the system owner accesses the box for cleaning via the ladder. In locations with limited drop, a filter with the canisters oriented horizontally is indicated, with the inlet and outlet of the filter being nearly parallel.

Storage Tanks

The storage tank is the most expensive component of the rainwater harvesting system.

The size of storage tank or cistern is dictated by several variables: the rainwater supply (local precipitation), the demand, the projected length of dry spells without rain, the catchment surface area, aesthetics, personal preference, and budget.

A myriad of variations on storage tanks and cisterns have been used over the centuries and in different geographical regions: earthenware cisterns in pre-biblical times, large pottery containers in Africa, above-ground vinyl-lined swimming pools in Hawaii, concrete or brick cisterns in the central United States, and, common to old homesteads in Texas, galvanized steel tanks and attractive site-built stone-and-mortar cisterns.

For purposes of practicality, this manual will focus on the most common, easily installed, and readily available storage options in Texas, some still functional after a century of use.

Storage tank basics

- ◆ Storage tanks must be opaque, either upon purchase or painted later, to inhibit algae growth.

- ◆ For potable systems, storage tanks must never have been used to store toxic materials.
- ◆ Tanks must be covered and vents screened to discourage mosquito breeding.
- ◆ Tanks used for potable systems must be accessible for cleaning.

Storage tank siting

Tanks should be located as close to supply and demand points as possible to reduce the distance water is conveyed. Storage tanks should be protected from direct sunlight, if possible. To ease the load on the pump, tanks should be placed as high as practicable. Of course, the tank inlet must be lower than the lowest downspout from the catchment area. To compensate for friction losses in the trunk line, a difference of a couple of feet is preferable. When converting from well water, or if using a well backup, siting the tanks near the well house facilitates the use of existing plumbing.

Water runoff should not enter septic system drainfields, and any tank overflow and drainage should be routed so that it does not affect the foundation of the tanks or any other structures (Macomber, 2001).

Texas does not have specific rules concerning protection of rainwater systems from possible contamination sources; however, to ensure a safe water supply, underground tanks should be located at least 50 feet away from animal stables or above-ground application of treated wastewater. Also, runoff from tank overflow should not enter septic system drainfields. If supplemental hauled water might be needed, tank placement should also take into consideration accessibility by a water

truck, preferably near a driveway or roadway.

Water weighs just over 8 pounds per gallon, so even a relatively small 1,500-gallon tank will weigh 12,400 pounds. A leaning tank may collapse; therefore, tanks should be placed on a stable, level pad. If the bed consists of a stable substrate, such as caliche, a load of sand or pea gravel covering the bed may be sufficient preparation. In some areas, sand or pea gravel over well-compacted soil may be sufficient for a small tank. Otherwise, a concrete pad should be constructed. When the condition of the soil is unknown, enlisting the services of a structural engineer may be in order to ensure the stability of the soil supporting the full cistern weight.

Another consideration is protecting the pad from being undermined by either normal erosion or from the tank overflow. The tank should be positioned such that runoff from other parts of the property or from the tank overflow will not undermine the pad. The pad or bed should be checked after intense rainfall events.

Fiberglass

Fiberglass tanks (Figure 2-5) are built in standard capacities from 50 gallons to 15,000 gallons and in both vertical



Figure 2-5. Two 10,000-gallon fiberglass tanks

cylinder and low-horizontal cylinder configurations.

Fiberglass tanks under 1,000 gallons are expensive for their capacity, so polypropylene might be preferred. Tanks for potable use should have a USDA-approved food-grade resin lining and the tank should be opaque to inhibit algae growth.

The durability of fiberglass tanks has been tested and proven, weathering the elements for years in Texas oil fields. They are easily repaired.

The fittings on fiberglass tanks are an integral part of the tank, eliminating the potential problem of leaking from an aftermarket fitting.

Polypropylene

Polypropylene tanks (Figure 2-6) are commonly sold at farm and ranch supply retailers for all manner of storage uses. Standard tanks must be installed above ground. For buried installation, specially reinforced tanks are necessary to withstand soil expansion and contraction. They are relatively inexpensive and durable, lightweight, and long lasting. Polypropylene tanks are available in capacities from 50 gallons to 10,000 gallons.



Figure 2-6. Low-profile 5,000-gallon polypropylene tanks

Polypropylene tanks do not retain paint well, so it is necessary to find off-the-shelf tanks manufactured with opaque plastic. The fittings of these tanks are aftermarket modifications. Although easy to plumb, the bulkhead fittings might be subject to leakage.

Wood

For aesthetic appeal, a wood tank (Figure 2-7) is often a highly desirable choice for urban and suburban rainwater harvesters.

Wood tanks, similar to wood water towers at railroad depots, were historically made of redwood. Modern wood tanks are usually of pine, cedar, or cypress wrapped with steel tension cables, and lined with plastic. For potable use, a food-grade liner must be used.



Figure 2-7. Installation of a 25,000-gallon Timbertank in Central Texas showing the aesthetic appeal of these wooden tanks

These tanks are available in capacities from 700 to 37,000 gallons, and are site-built by skilled technicians. They can be dismantled and reassembled at a different location.

Metal

Galvanized sheet metal tanks (Figure 2-8) are also an attractive option for the urban or suburban garden. They are available in sizes from 150 to 2,500 gallons, and are lightweight and easy to relocate. Tanks can be lined for potable use. Most tanks are corrugated galvanized steel dipped in hot zinc for corrosion resistance. They are lined with a food-grade liner, usually polyethylene or PVC, or coated on the inside with epoxy paint. The paint, which also extends the life of the metal, must be FDA- and NSF-approved for potability.



Figure 2-8. Galvanized sheet metal tanks are usually fitted with a food-grade plastic liner.

Concrete

Concrete tanks are either poured in place or prefabricated (Figure 2-9). They can be constructed above ground or below ground. Poured-in-place tanks can be integrated into new construction under a patio, or a basement, and their placement is considered permanent.

A type of concrete tank familiar to residents of the Texas Hill Country is

constructed of stacked rings with sealant around the joints. Other types of prefabricated concrete tanks include new septic tanks, conduit stood on end, and concrete blocks. These tanks are fabricated off-site and dropped into place.

Concrete may be prone to cracking and leaking, especially in underground tanks in clay soil. Leaks can be easily repaired although the tank may need to be drained to make the repair. Involving the expertise of a structural engineer to determine the size and spacing of reinforcing steel to match the structural loads of a poured-in-place concrete cistern is highly recommended. A product that repairs leaks in concrete tanks, Xypex™, is now also available and approved for potable use.



Figure 2-9. Concrete tank fabricated from stacking rings of concrete

One possible advantage of concrete tanks is a desirable taste imparted to the water by calcium in the concrete being dissolved by the slightly acidic

rainwater. For potable systems, it is essential that the interior of the tank be plastered with a high-quality material approved for potable use.

Ferrocement

Ferrocement is a low-cost steel and mortar composite material. For purposes of this manual, Gunitite™ and Shotcrete™ type will be classified as ferrocements. Both involve application of the concrete and mortar under pressure from a gun. Gunitite, the dry-gun spray method in which the dry mortar is mixed with water at the nozzle, is familiar for its use in swimming pool construction. Shotcrete uses a similar application, but the mixture is a prepared slurry. Both methods are cost-effective for larger storage tanks. Tanks made of Gunitite and Shotcrete consist of an armature made from a grid of steel reinforcing rods tied together with wire around which is placed a wire form with closely spaced layers of mesh, such as expanded metal lath. A concrete-sand-water mixture is applied over the form and allowed to cure. It is important to ensure that the ferrocement mix does not contain any toxic constituents. Some sources recommend painting above-ground tanks white to reflect the sun's rays, reduce evaporation, and keep the water cool.



Figure 2-10. Ferrocement tanks, such as this one, are built in place using a metal armature and a sprayed-on cement.

Ferrocement structures (Figure 2-10) have commonly been used for water storage construction in developing countries due to low cost and availability of materials. Small cracks and leaks can easily be repaired with a mixture of cement and water, which is applied where wet spots appear on the tank's exterior. Because walls can be as thin as 1 inch, a ferrocement tank uses less material than concrete tanks, and thus can be less expensive. As with poured-in-place concrete construction, assistance from a structural engineer is encouraged.

In-ground polypropylene

In-ground tanks are more costly to install for two reasons: the cost of excavation and the cost of a more heavily reinforced tank needed if the tank is to be buried more than 2-feet deep in well-drained soils. Burying a tank in clay is not recommended because of the expansion/contraction cycles of clay soil. For deeper installation, the walls of poly tanks must be manufactured thicker and sometimes an interior bracing structure must be added. Tanks are buried for aesthetic or space-saving reasons.

Table 2-1 provides some values to assist in planning an appropriate-sized pad and cistern to meet your water needs and your available space. Many owners of rainwater harvesting systems use multiple smaller tanks in sequence to meet their storage capacity needs. This has the advantage of allowing the owner to empty a tank in order to perform maintenance on one tank at a time without losing all water in storage.

A summary of cistern materials, their features, and some words of caution are provided in Table 2-2 to assist the prospective harvester in choosing the

appropriate cistern type. Prior to making your final selection, consulting with an architect, engineer, or professional

rainwater installer is recommended to ensure the right choice for your situation.

Table 2-1. Round Cistern Capacity (Gallons)

Height (feet)	6-foot Diameter	12-foot Diameter	18-foot Diameter
6	1,269	5,076	11,421
8	1,692	6,768	15,227
10	2,115	8,460	19,034
12	2,538	10,152	22,841
14	2,961	11,844	26,648
16	3,384	13,535	30,455
18	3,807	15,227	34,262
20	4,230	16,919	38,069

Rain barrel

One of the simplest rainwater installations, and a practical choice for urban dwellers, is the 50- to 75-gallon drum used as a rain barrel for irrigation of plant beds. Some commercially available rain barrels are manufactured with overflow ports linking the primary

barrel to a second barrel. A screen trap at the water entry point discourages mosquito breeding. A food-grade plastic barrel used for bulk liquid storage in restaurants and grocery stores can be fitted with a bulkhead fitting and spigot for garden watering. Other options include a submersible pump or jet pump.

Table 2-2. Cistern Types

MATERIAL	FEATURES	CAUTION
Plastics		
Trash cans (20-50 gallon)	commercially available; inexpensive	use only new cans
Fiberglass	commercially available; alterable and moveable	must be sited on smooth, solid, level footing
Polyethylene/polypropylene	commercially available; alterable and moveable	UV-degradable, must be painted or tinted
Metals		
Steel drums (55-gallon)	commercially available; alterable and moveable	verify prior to use for toxics; prone to corrosion and rust;
Galvanized steel tanks	commercially available; alterable and moveable	possibly corrosion and rust; must be lined for potable use
Concrete and Masonry		
Ferrocement	durable and immovable	potential to crack and fail
Stone, concrete block	durable and immovable	difficult to maintain
Monolithic/Poured-in-place	durable and immovable	potential to crack
Wood		
Redwood, fir, cypress	attractive, durable, can be disassembled and moved	expensive

Adapted from *Texas Guide to Rainwater Harvesting, Second Edition*, Texas Water Development Board, 1997.

Pressure Tanks and Pumps

The laws of physics and the topography of most homesteads usually demand a pump and pressure tank between water storage and treatment, and the house or end use. Standard municipal water pressure is 40 pounds per square inch (psi) to 60 psi. Many home appliances –

clothes washers, dishwashers, hot-water-on-demand water heaters – require 20–30 psi for proper operation. Even some drip irrigation system need 20 psi for proper irrigation. Water gains 1 psi of pressure for every 2.31 feet of vertical rise. So for gravity flow through a 1-inch pipe at 40 psi, the storage tanks would

have to be more than 90 feet above the house.

Since this elevation separation is rarely practical or even desirable, two ways to achieve proper household water pressure are (1) a pump, pressure tank, pressure switch, and check valve (familiar to well owners), or (2) an on-demand pump.

Pumps are designed to push water rather than to pull it. Therefore, the system should be designed with the pumps at the same level and as close to the storage tanks as possible.

Pump systems draw water from the storage tanks, pressurize it, and store it in a pressure tank until needed. The typical pump-and-pressure tank arrangement consists of a $\frac{3}{4}$ - or 1-horsepower pump, usually a shallow well jet pump or a multistage centrifugal pump, the check valve, and pressure switch. A one-way check valve between the storage tank and the pump prevents pressurized water from being returned to the tank. The pressure switch regulates operation of the pressure tank. The pressure tank, with a typical capacity of 40 gallons, maintains pressure throughout the system. When the pressure tank reaches a preset threshold, the pressure switch cuts off power to the pump. When there is demand from the household, the pressure switch detects the drop in pressure in the tank and activates the pump, drawing more water into the pressure tank.

The cistern float filter (Figure 2-11) allows the pump to draw water from the storage tank from between 10 and 16 inches below the surface. Water at this level is cleaner and fresher than water closer to the bottom of the tank. The device has a 60-micron filter. An external suction pump, connected via a

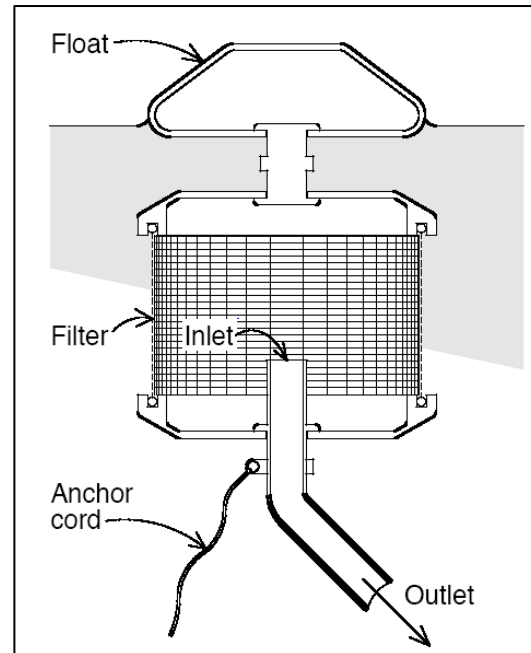


Figure 2-11. Cistern float filter

flexible hose, draws water through the filter.

On-demand pump

The new on-demand pumps eliminate the need for a pressure tank. These pumps combine a pump, motor, controller, check valve, and pressure tank function all in one unit. They are self-priming and are built with a check valve incorporated into the suction port. Figure 2-12 shows a typical installation of an on-demand pump and a 5-micron fiber filter, 3-micron activated charcoal filter, and an ultraviolet lamp. Unlike conventional pumps, on-demand pumps are designed to activate in response to a demand, eliminating the need, cost, and space of a pressure tank. In addition, some on-demand pumps are specifically designed to be used with rainwater.

Treatment and Disinfection Equipment

For a nonpotable system used for hose irrigation, if tree overhang is present, leaf screens on gutters and a roof washer

diverting 10 gallons for every 1,000 square feet of roof is sufficient. If drip irrigation is planned, however, sediment filtration may be necessary to prevent clogging of emitters. As standards differ, the drip irrigation manufacturer or vendor should be contacted regarding filtering of water.

For potable water systems, treatment beyond the leaf screen and roof washer is necessary to remove sediment and disease-causing pathogens from stored water. Treatment generally consists of filtration and disinfection processes in series before distribution to ensure health and safety.

Cartridge Filters and Ultraviolet (UV) Light

The most popular disinfection array in Texas is two in-line sediment filters – the 5-micron fiber cartridge filter followed by the 3-micron activated charcoal cartridge filter – followed by ultraviolet light. This disinfection set-up is placed after the pressure tank or after the on-demand pump.

It is important to note that cartridge filters must be replaced regularly. Otherwise, the filters can actually harbor bacteria and their food supply. The 5-micron filter mechanically removes suspended particles and dust. The 3-micron filter mechanically traps microscopic particles while smaller organic molecules are absorbed by the activated surface. In theory, activated charcoal can absorb objectionable odors and tastes, and even some protozoa and cysts (Macomber, 2001).

Filters can be arrayed in parallel for greater water flow. In other words, two 5-micron fiber filters can be stacked in one large cartridge followed by two 3-micron activated charcoal filters in



Figure 2-12. Typical treatment installation of an on-demand pump, 5-micron fiber filter, 3-micron activated charcoal filter, and an ultraviolet lamp (top).

another cartridge. The ultraviolet (UV) light must be rated to accommodate the increased flow.

NSF International (National Sanitation Foundation) is an independent testing and certification organization. Filter performance can be researched using a simple search feature by model or manufacturer on the NSF website. (See References.) It is best to purchase NSF-certified equipment.

Maintenance of the UV light involves cleaning of the quartz sleeve. Many UV lights are designed with an integral wiper unit. Manual cleaning of the sleeve is not recommended due to the possibility of breakage.

UV lamps are rated in gallons per minute. For single 5-micron and 3-micron in-line filters, a UV light rated at 12 gallons per minute is sufficient. For

filters in parallel installation, a UV light rated for a higher flow is needed. In-line flow restrictors can match flow to the UV light rating.

UV lights must be replaced after a maximum of 10,000 hours of operation. Some lights come with alarms warning of diminished intensity.

Ozone

Chemically, ozone is O₃: essentially a more reactive form of molecular oxygen made up of three atoms of oxygen. Ozone acts as a powerful oxidizing agent to reduce color, to eliminate foul odors, and to reduce total organic carbon in water. For disinfection purposes, an ozone generator forces ozone into storage tanks through rings or a diffuser stone. Ozone is unstable and reacts quickly to revert to O₂ and dissipates through the atmosphere within 15 minutes.

A rainwater harvesting system owner in Fort Worth uses an ozone generator to keep the water in his 25,000 gallons of storage “fresh” by circulating ozone through the five tanks at night. A standard sprinkler controller switches the ozone feed from tank to tank.

Membrane Filtration (Reverse Osmosis and Nanofiltration)

Membrane filtration, such as reverse osmosis and nanofiltration work by forcing water under high pressure through a semipermeable membrane to filter dissolved solids and salts, both of which are in very low concentrations in rainwater. Membrane processes, however, have been known empirically to produce “sweeter” water, perhaps by filtering out dissolved metals from plumbing.

A certain amount of feed water is lost in any membrane filtration process. Reject

water, referred to as “brine,” containing a concentrate of the contaminants filtered from the feed water, is discharged. The amount of reject water, however, is directly proportional to the purity of the feed water. Rainwater, as a purer water source to begin with, would generate less brine. Reverse osmosis membranes must be changed before they are fouled by contaminants.

Reverse osmosis (RO) equipment for household use is commercially available from home improvement stores such as Lowe’s and Home Depot.

Chlorination

For those choosing to disinfect with chlorine, automatic self-dosing systems are available. A chlorine pump injects chlorine into the water as it enters the house. In this system, appropriate contact time is critical to kill bacteria. A practical chlorine contact time is usually from 2 minutes to 5 minutes with a free chlorine residual of 2 parts per million (ppm). The time length is based on water pH, temperature, and amount of bacteria. Contact time increases with pH and decreases with temperature. K values (contact times) are shown in Table 3-3.

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Chapter 3

Water Quality and Treatment

The raindrop as it falls from the cloud is soft, and is among the cleanest of water sources. Use of captured rainwater offers several advantages.

Rainwater is sodium-free, a benefit for persons on restricted sodium diets.

Irrigation with captured rainwater promotes healthy plant growth. Also, being soft water, rainwater extends the life of appliances as it does not form scale or mineral deposits.

The environment, the catchment surface, and the storage tanks affect the quality of harvested rainwater. With minimal treatment and adequate care of the system, however, rainfall can be used as potable water, as well as for irrigation.

The falling raindrop acquires slight acidity as it dissolves carbon dioxide and nitrogen. Contaminants captured by the rain from the catchment surface and storage tanks are of concern for those intending to use rainwater as their potable water source. The catchment area may have dust, dirt, fecal matter from birds and small animals, and plant debris such as leaves and twigs. Rainwater intended for domestic potable use must be treated using appropriate filtration and disinfection equipment, discussed in Chapter 2, Rainwater Harvesting System Components.

Total dissolved solids (TDS) in rainwater, originating from particulate matter suspended in the atmosphere, range from 2 milligrams per liter (mg/l or ppm)¹ to 20 mg/l across Texas, compared with municipal water TDS

ranges of 100 ppm to more than 800 ppm.

The sodium content of some municipal water ranges from 10 parts per million (ppm) to as high as 250 ppm. Rainwater intended solely for outdoor irrigation may need no treatment at all except for a screen between the catchment surface and downspout to keep debris out of the tank, and, if the tank is to supply a drip irrigation system, a small-pore filter at the tank outlet to keep emitters from clogging.

Considerations for the Rainwater Harvesting System Owner

It is worth noting that owners of rainwater harvesting systems who supply all domestic needs essentially become owners of their “water supply systems,” responsible for routine maintenance, including filter and lamp replacement, leak repair, monitoring of water quality, and system upgrades.

The rainwater harvesting system owner is responsible for both water supply and water quality. Maintenance of a rainwater harvesting system is an ongoing periodic duty, to include:

- ◆ monitoring tank levels,
- ◆ cleaning gutters and first-flush devices,
- ◆ repairing leaks,
- ◆ repairing and maintaining the system, and
- ◆ adopting efficient water use practices.

In addition, owners of potable systems must adopt a regimen of:

- ◆ changing out filters regularly,

¹ For dilute aqueous solutions mg/l is approximately equal to ppm because a liter of water weighs one kilogram.

- ◆ maintaining disinfection equipment, such as cleaning and replacing ultraviolet lamps, and
- ◆ regularly testing water quality.

Water Quality Standards

No federal or state standards exist currently for harvested rainwater quality, although state standards may be developed in 2006.

The latest list of drinking water requirements can be found on the United States Environmental Protection Agency's website. (See References.) The next section discusses the potential vectors by which contaminants get into rainwater. For those intending to harvest rainwater for potable use, the microbiological contaminants *E. coli*, *Cryptosporidium*, *Giardia lamblia*, total coliforms, legionella, fecal coliforms, and viruses, are probably of greatest concern, and rainwater should be tested to ensure that none of them are found (Lye, 2002). County health department and city building code staff should also be consulted concerning safe, sanitary operations and construction of rainwater harvesting systems.

Factors Affecting Water Quality

pH (acidity/alkalinity)

As a raindrop falls and comes in contact with the atmosphere, it dissolves naturally occurring carbon dioxide to form a weak acid. The resultant pH is about 5.7, whereas a pH of 7.0 is neutral. (A slight buffering using 1 tablespoon of baking soda to 100 gallons of water in the tank will neutralize the acid, if desired. Also, a concrete storage tank will impart a slight alkalinity to the water.) While Northeast Texas tends to experience an even lower pH (more acidic) rainwater than in other parts of

the state, acid rain is not considered a serious concern in Texas.

Particulate matter

Particulate matter refers to smoke, dust, and soot suspended in the air. Fine particulates can be emitted by industrial and residential combustion, vehicle exhaust, agricultural controlled burns, and sandstorms. As rainwater falls through the atmosphere, it can incorporate these contaminants.

Particulate matter is generally not a concern for rainwater harvesting in Texas. However, if you wish, geographic data on particulate matter can be accessed at the Air Quality Monitoring web page of the Texas Commission on Environmental Quality (TCEQ). (See References.)

Chemical compounds

Information on chemical constituents can also be found on the TCEQ Air Quality website. (See References.)

In agricultural areas, rainwater could have a higher concentration of nitrates due to fertilizer residue in the atmosphere (Thomas and Grenne, 1993). Pesticide residues from crop dusting in agricultural areas may also be present.

Also, dust derived from calcium-rich soils in Central and West Texas can add 1 mg/l to 2 mg/l of hardness to the water. Hard water has a high mineral content, usually consisting of calcium and magnesium in the form of carbonates.

In industrial areas, rainwater samples can have slightly higher values of suspended solids concentration and turbidity due to the greater amount of particulate matter in the air (Thomas and Grenne, 1993).

Catchment surface

When rainwater comes in contact with a catchment surface, it can wash bacteria, molds, algae, fecal matter, other organic matter, and/or dust into storage tanks. The longer the span of continuous number of dry days (days without rainfall), the more catchment debris is washed off the roof by a rainfall event (Thomas and Grenne, 1993; Vasudevan, 2002).

Tanks

The more filtering of rainwater prior to the storage tanks, the less sedimentation and introduction of organic matter will occur within the tanks. Gutter screens, first-flush diverters, roof washers, and other types of pre-tank filters are discussed in Chapter 2. Sedimentation reduces the capacity of tanks, and the breakdown of plant and animal matter may affect the color and taste of water, in addition to providing nutrients for microorganisms.

Most storage tanks are equipped with manholes to allow access for cleaning. Sediment and sludge can be pumped out or siphoned out using hose with an inverted funnel at one end without draining the tank annually.

Multiple linked tanks allow one tank to be taken off line for cleaning by closing

the valve on the linking pipe between tanks.

Water Treatment

The cleanliness of the roof in a rainwater harvesting system most directly affects the quality of the captured water. The cleaner the roof, the less strain is placed on the treatment equipment. It is advisable that overhanging branches be cut away both to avoid tree litter and to deny access to the roof by rodents and lizards.

For potable systems, a plain galvanized roof or a metal roof with epoxy or latex paint is recommended. Composite or asphalt shingles are not advisable, as toxic components can be leached out by rainwater. See Chapter 2 for more information on roofing material.

To improve water quality, several treatment methods are discussed. It is the responsibility of the individual installer or homeowner to weigh the advantages and disadvantages of each method for appropriateness for the individual situation. A synopsis of treatment techniques is shown in Table 3-1. A discussion of the equipment is included in Chapter 2.

Table 3-1. Treatment Techniques

METHOD	LOCATION	RESULT
Treatment		
Screening Leaf screens and strainers	gutters and downspouts	prevent leaves and other debris from entering tank
Settling Sedimentation Activated charcoal	within tank before tap	settles out particulate matter removes chlorine*
Filtering Roof washer In-line/multi-cartridge Activated charcoal Slow sand	before tank after pump after sediment filter separate tank	eliminates suspended material sieves sediment removes chlorine, improves taste traps particulate matter
Microbiological treatment /Disinfection Boiling/distilling Chemical treatments (Chlorine or Iodine) Ultraviolet light Ozonation Nanofiltration Reverse osmosis	 before use within tank or at pump (liquid, tablet, or granular) before activated charcoal filter after activated charcoal filter, before tap after activated charcoal filter, before tap before use; polymer membrane (pores 10^{-3} to 10^{-6} inch) before use: polymer membrane (pores 10^{-9} inch)	 kills microorganisms kills microorganisms kills microorganisms kills microorganisms removes molecules removes ions (contaminants and microorganisms)
*Should be used if chlorine has been used as a disinfectant.		

Adapted from *Texas Guide to Rainwater Harvesting, Second Edition*, Texas Water Development Board, 1997.

Chlorination

Chlorination is mentioned here more for its historical value than for practical application. Chlorine has been used to disinfect public drinking water since 1908, and it is still used extensively by rainwater harvesters in Hawaii, the U.S. Virgin Islands, and in older rainwater harvesting systems in Kentucky and Ohio. Chlorine must be present in a concentration of 1 ppm to achieve disinfection. Liquid chlorine, in the form of laundry bleach, usually has 6 percent available sodium hypochlorite. For disinfection purposes, 2 fluid ounces (¼ cup) must be added per 1,000 gallons of rainwater. Household bleach products, however, are not labeled for use in water treatment by the Food and Drug Administration. A purer form of chlorine, which comes in solid form for swimming pool disinfection, is calcium hypochlorite, usually with 75 percent available chlorine. At that strength, 0.85 ounces by weight in 1,000 gallons of water would result in a level of 1 ppm.

In either case, it is a good idea to carefully dilute the chlorine source in a bucket of water, and then stir with a clean paddle to hasten mixing (Macomber, 2001). Chlorine contact times are shown in Table 3-2.

The use of chlorine for disinfection presents a few drawbacks. Chlorine combines with decaying organic matter in water to form trihalomethanes. This disinfection by-product has been found to cause cancer in laboratory rats. Also, some users may find the taste and smell of chlorine objectionable. To address this concern, an activated carbon filter may be used to help remove chlorine.

Chlorine does not kill *Giardia* or *Cryptosporidium*, which are cysts protected by their outer shells. Persons with weakened or compromised immune systems are particularly susceptible to these maladies. To filter out *Giardia* and *Cryptosporidium* cysts, an absolute 1-micron filter, certified by the NSF, is needed (Macomber, 2001).

Table 3-2. Contact Time with Chlorine

Water pH	Water temperature		
	50 F or warmer	45 F	40 F or colder
Contact time in minutes			
6.0	3	4	5
6.5	4	5	6
7.0	8	10	12
7.5	12	15	18
8.0	16	20	24

UV Light

UV light has been used in Europe for disinfection of water since the early 1900s, and its use has now become

common practice in U.S. utilities. Bacteria, virus, and cysts are killed by exposure to UV light. The water must go

through sediment filtration before the ultraviolet light treatment because pathogens can be shadowed from the UV light by suspended particles in the water. In water with very high bacterial counts, some bacteria will be shielded by the bodies of other bacteria cells.

UV lights are benign: they disinfect without leaving behind any disinfection by-products. They use minimal power for operation. One should follow manufacturer's recommendations for replacement of bulbs.

Testing

Harvested rainwater should be tested before drinking and periodically thereafter. Harvested rainwater should be tested both before and after treatment to ensure treatment is working. It is advisable to test water quarterly at a minimum, if used for drinking.

Harvested rainwater can be tested by a commercial analytical laboratory, the county health departments of many Texas counties, or the Texas Department of Health.

Before capturing rainwater samples for testing, contact the testing entity first to become informed of requirements for container type and cleanliness, sample volume, number of samples needed, and time constraints for return of the sample.

For instance, for total coliform testing, water must usually be captured in a sterile container issued by the testing entity and returned within a maximum of 30 to 36 hours. Testing for pH, performed by commercial analytical laboratories must be done on site; other tests are less time-critical.

A list of county health departments that will test for total and fecal coliform can be found on the Texas Department of State Health Services (TDSHS) website.

(See References.) The testing fee is usually between \$15 and \$25. Homeowners should contact the health department prior to sample collection to procure a collection kit and to learn the proper methods for a grab sample or a faucet sample.

Texas Department of State Health Services will test for fecal coliforms for a fee of \$20 per sample. (See References.) A collection kit can be ordered from TDSHS at (512) 458-7598.

Commercial laboratories are listed in telephone Yellow Pages under Laboratories—Analytical & Testing. For a fee, the lab will test water for pathogens. For an additional fee, labs will test for other contaminants, such as metals and pesticides.

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Chapter 4

Water Balance and System Sizing

The basic rule for sizing any rainwater harvesting system is that the volume of water that can be captured and stored (the supply) must equal or exceed the volume of water used (the demand).

The variables of rainfall and water demand determine the relationship between required catchment area and storage capacity. In some cases, it may be necessary to increase catchment surface area by addition of a rain barn or outbuilding to capture enough rainwater to meet demand. Cistern capacity must be sufficient to store enough water to see the system and its users through the longest expected interval without rain.

The following sections describe ways to determine the amount of rainfall, the estimated demand, and how much storage capacity is needed to provide an adequate water supply.

Intended End Use

The first decision in rainwater harvesting system design is the intended use of the water. If rainwater is to be used only for irrigation, a rough estimate of demand, supply, and storage capacity may be

sufficient. On the other hand, if rainwater is intended to be the sole source of water for all indoor and outdoor domestic end uses, a more precise reckoning is necessary to ensure adequate supply.

How Much Water Can Be Captured?

In theory, approximately 0.62 gallons per square foot of collection surface per inch of rainfall can be collected. In practice, however, some rainwater is lost to first flush, evaporation, splash-out or overshoot from the gutters in hard rains, and possibly leaks. Rough collection surfaces are less efficient at conveying water, as water captured in pore spaces tends to be lost to evaporation.

Also impacting achievable efficiency is the inability of the system to capture all water during intense rainfall events. For instance, if the flow-through capacity of a filter-type roof washer is exceeded, spillage may occur. Additionally, after storage tanks are full, rainwater can be lost as overflow.

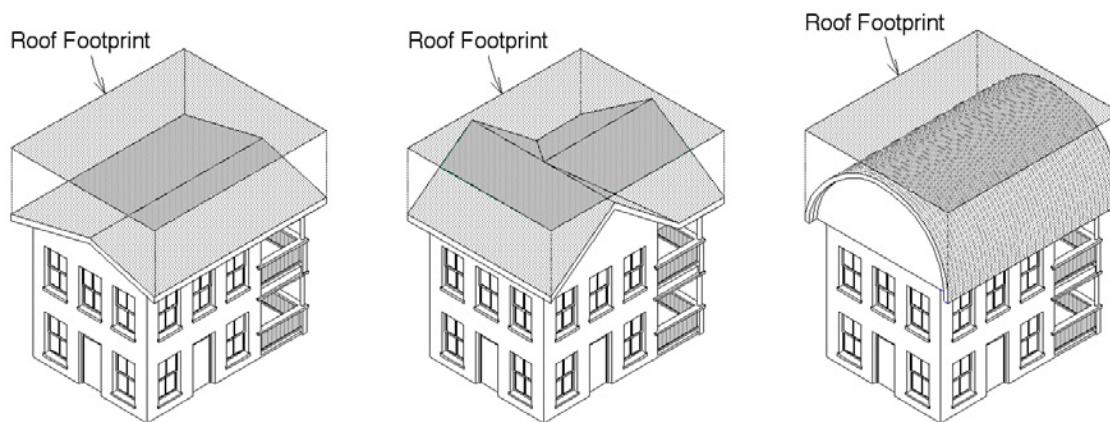


Figure 4-1. Catchment areas of three different roofs

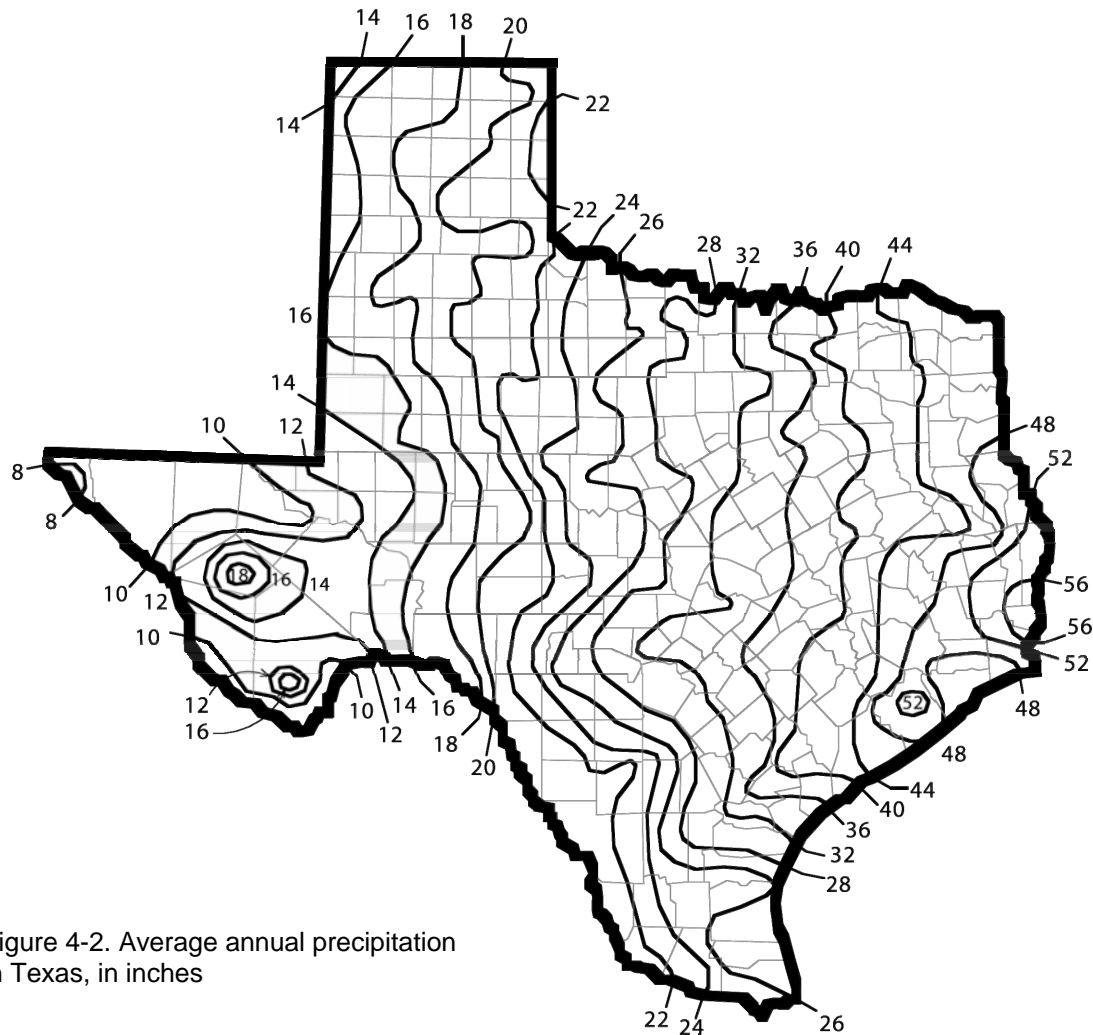


Figure 4-2. Average annual precipitation in Texas, in inches

For planning purposes, therefore, these inherent inefficiencies of the system need to be factored into the water supply calculation. Most installers assume an efficiency of 75 percent to 90 percent.

In most Texas locations, rainfall occurs seasonally, requiring a storage capacity sufficient to store water collected during rainy times to last through the dry spells. In West Texas, total annual rainfall might not be sufficient to allow a residence with a moderate-sized collection surface to capture sufficient water for all domestic use. Some residences might be constrained by the area of the collection surfaces or the

volume of storage capacity that can be installed.

Collection Surface

The collection surface is the “footprint” of the roof (Figure 4-1). In other words, regardless of the pitch of the roof, the effective collection surface is the area covered by collection surface (length times width of the roof from eave to eave and front to rear). Obviously if only one side of the structure is guttered, only the area drained by the gutters is used in the calculation.

Rainfall Distribution

In Texas, average annual rainfall decreases roughly 1 inch every 15 miles,

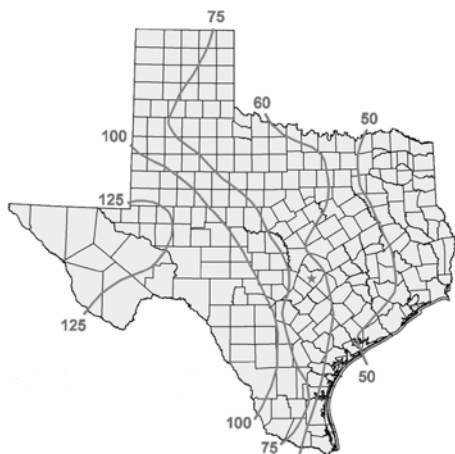


Figure 4-3. Maximum number of dry days (Krishna, 2003)

as you go from east to west (Figure 4-2), from 56 inches per year in Beaumont to less than 8 inches per year in El Paso. As one moves westward across the state, the prevalence and severity of droughts must also be considered.

To ensure a year-round water supply, the catchment area and storage capacity must be sized to meet water demand through the longest expected interval without rain. For instance, in West Texas, the historic longest span of continuous dry days has exceeded three months. For reference purposes, a contour map of historical maximum number of dry days in Texas is shown in Figure 4-3 (Krishna, 2003). If the rainwater harvesting system is intended to be the sole water source for a household, the designer must size the system to accommodate the longest anticipated time without rain, or otherwise plan for another water source, such as a well backup or hauled water.

Also, rainfall from high-intensity, short-duration rainfall events may be lost to overflow from storage tanks or splash-out from the gutters. Although these intense rainfall events are considered part of the cumulative annual rainfall,

the total available volume of such an event is rarely captured.

Another consideration is that most rainfall occurs seasonally; annual rainfall is not evenly distributed throughout the 12 months of the year. The monthly distribution of rainfall is an important factor to consider for sizing a system. Monthly rainfall data for selected Texas cities is given in Appendix B.

Monthly Rainfall

Two different estimators of monthly rainfall are commonly used: average rainfall and median rainfall. Average annual rainfall is calculated by taking the sum of historical rainfall and dividing by the number of years of recorded data. This information is available from numerous public sources, including the National Climate Data Center website. (See References.) Median rainfall is the amount of rainfall that occurs in the midpoint of all historic rainfall totals for any given month. In other words, historically for the month in question, half of the time the rainfall was less than the median and half of the time rainfall was more than the median. Median values and average rainfall values for representative Texas cities are provided in Appendix B.

Median rainfall provides for a more conservative calculation of system sizing than average rainfall. The median value for rainfall is usually lower than the average value since large rainfall events tend to drive the average value higher. In other words, the sum of monthly medians is lower than the annual average due to the fact that the arithmetic average is skewed by high-intensity rainfall events. For planning purposes, median monthly rainfall can be used to estimate water availability to a

reasonable degree of certainty (Krishna, 2001).

For example, in the sample calculations at the end of this chapter, the average annual rainfall for Dallas is about 35.0 inches, but the sum of the monthly medians is only 29.3 inches.

Calculating Storage Capacity

Once the median or average potential for rainfall capture is known from rainfall data and catchment area, it will be necessary to calculate storage capacity. The decision of whether rainwater will be used for irrigation, potable and domestic use, or both, will dictate water demand, and therefore, capacity.

A simple method of roughly estimating storage capacity popular among professional installers is to size the storage capacity to meet quarterly demand. The system is sized to meet estimated demand for a three-month period without rain. Annual estimated demand is divided by four to yield necessary storage capacity using this approach. This approach, however, may result in a more expensive system due to higher storage costs.

If a rainwater harvesting system is to be the sole water supply, overbuilding ensures a safety margin. As with many things in life, it helps to hope for the best but plan for the worst. Even when budget constraints may not allow the user to install as much storage capacity as a sizing method may indicate, it is important to provide for an area where additional tanks or cisterns can be installed at a later date when finances permit.

The Water Balance Method Using Monthly Demand and Supply

One method of determining the feasibility of a proposed system is the monthly water balance method. This method of calculation is similar to maintaining a monthly checkbook balance. Starting with an assumed volume of water already in the tanks, the volume captured each month is added to the previous balance and the demand is subtracted. The initial volume of water in the tanks would be provided by hauling or capturing water prior to withdrawing water from the system. An example is presented at the end of this chapter.

Data and calculations can be entered on an electronic spreadsheet to enable the user to compare different variables of catchment area and storage. It is suggested that homeowners experiment with different variables of storage capacity and, if applicable, catchment surface to find individual levels of comfort and affordability for catchment size and storage capacity.

As mentioned above:

- ◆ catchment area and rainfall determine supply, and
- ◆ demand dictates required storage capacity.

A commitment to conserving water with water-saving fixtures, appliances, practices indoors, and low-water-use landscaping outdoors is an essential component of any rainwater harvesting system design. Not only is conservation good stewardship of natural resources, it also reduces the costs for storage capacity and related system components.

If the amount of rainwater that can be captured – calculated from roof area and rainfall – is adequate or more than

adequate to meet estimated demand, and meets the physical constraints of the building design, then storage capacity can be sized to meet estimated demand. If the monthly amount of water that can be captured, accounting for dry spells, is less than monthly estimated demand, then additional catchment area or supplemental supplies of water (such as groundwater from a well) will need to be considered.

In drier areas, no matter how large the storage capacity, catchment area may need to be increased with a rain barn or additional roof area to meet demand.

At the end of this chapter, an example of a water balance calculation is shown for the City of Dallas.

Estimating Demand

A water-conserving household will use between 25 and 50 gallons per person per day. (Note that total gallons per capita per day figures published for municipalities divide all the water distributed by the population, yielding a much larger amount per capita than actual domestic consumption.)

Households served previously by a water utility can read monthly demand from their meter or water bill to find monthly demand for purposes of building a new rainwater harvesting system. Divide the monthly total by the number of people in the house, and the days in the month to get a daily per capita demand number.

Water conservation is covered later in this chapter. Households solely dependent upon rainwater should adopt

efficient water use practices both indoors and outdoors.

Estimating indoor water demand

Indoor water demand is largely unaffected by changes in weather, although changes in household occupancy rates depending upon seasons and ages of household members, more water use during the hot summer months, and very minor changes in consumption of water due to increases in temperature may be worth factoring in some instances. The results of a study of 1,200 single-family homes by the American Water Works Association (AWWA) in 1999 found that the average water conserving households used approximately 49.6 gallons per person per day (American Water Works Association, 1999).

Table 4-1 can be used to calculate indoor water demand. Many households use less than the average of 49.6 gallons per person found in the 1999 report by the AWWA, *Residential End Uses of Water*. The water volumes shown in the table assume a water-conserving household, with water-conserving fixtures and good practices, such as shutting off the water while brushing teeth or shaving. Overall demand in showers, baths, and faucet uses is a function of both time of use and rate of flow. Many people do not open the flow rate as high as it could be finding low or moderate flow rates more comfortable. In estimating demand, measuring flow rates and consumption in the household may be worth the effort to get more accurate estimates.

Table 4-1. Estimating Indoor Daily Domestic Demand

	A. Water consumption using conserving fixtures	B. Assumptions from AWWA Residential End- Use Study	C. Adjustments to assumptions (adjust up or down according to actual use)	D. Number of persons in household	E. Household monthly demand A x (B or C)x D x 30
Toilets (use only appropriate type)					
ULFT	1.6 gal/flush	6 flushes/ person/day			
Dual Flush	1 gal/flush liquids 1.6 gal/flush solids	6 flushes/ person/day			
Baths & showers					
Showerhead	2.2 gal/min	5 minutes/ person/day			
Bath	50 gal/bath	NA			
Faucets (personal hygiene, cooking, and cleaning of surfaces)	2.2 gal/faucet/min	5 minutes/ person/day			
Appliances or uses which are measured on a per-use basis (not a per-person basis):					
Clothes washer Front-loading (horizontal-axis)	18–25 gal/load	2.6 loads/week			
Dishwasher	8 gal/cycle	0.7 cycles/day			
Miscellaneous other					
Total					

One can use Table 4-1 if the designer prefers to incorporate known or expected behavioral habits into the water demand estimates. The values in the first column are to be multiplied by variables reflecting your own household water use

patterns. The average values in the second column are offered for information, but as with all averages, are subject to wide variation based upon actual circumstances. An example is dual flush toilets – multiply three flushes

per day liquid only (1 gpf), and add three flushes per day for solids (1.6 gpf), $(3 \times 1) + (3 \times 1.6) = 7.8$ gallons multiplied by 3 persons = 23.4 gpd household demand \times 30 days = 702 gallons per month. The authors recommend verifying any assumptions against the records of historical use from a municipal water bill if available.

Indoor water conservation

Indoor domestic water conservation can be achieved by a combination of fixtures, appliances, and water-conserving practices. The advantage of water-conserving appliances is that they require no change in household routine. Some water-conserving practices need user action, such as turning off the water while brushing teeth or shaving; washing vegetables in a pan rather than under a stream; washing only full loads of laundry and dishes; and keeping a pitcher of water in the refrigerator, rather than waiting for cold water to arrive from a faucet.

Water conservation appliances include:

- ◆ **Ultralow flush toilets (ULFTs).** Since 1993, only ULFTs with 1.6 gallons per flush may be sold in the United States. Older toilets should be replaced with the more efficient models. Some of the ULFTs require special early closing flappers to maintain their low-flow rates, so care should be taken in purchasing the correct replacement flapper for leaking toilets. If purchasing a new toilet, those that do not use early closure flappers are recommended. Dual-flush toilets (using less volume for liquid wastes) are also a good choice for a water-wise household.
- ◆ **Faucet aerators and efficient showerheads.** These fixtures are

designed to use 2.2 gallons per minute at 60 psi, or 2.5 gpm at 80 psi (Table 4-1). Studies have shown that most people feel comfortable at less than full flow rates, so using the new fixtures (which are the only ones sold in the United States since 1992) should provide you with an efficient and comfortable experience.

- ◆ **Hot water on demand.** These wall-mounted units heat water just prior to use, eliminating the waste of waiting for hot water from the water heater while cold water is allowed to flow down the drain. Hot water loop systems keep hot water continuously circulating to achieve the same goal, but can use more energy. Another on-demand unit heats water quickly only when activated by a pushbutton, rather than circulating water through a loop, saving both water and energy. A rebate from San Antonio Water System (SAWS) is available for installation of this type of on-demand circulation system.
- ◆ **Horizontal-axis (front-loading) clothes washers.** Because clothes are tumbled through a small volume of water in the bottom of the drum (rather than washed in a full tub of water), this appliance can save up to half the water of a traditional clothes washer. It is also as much as 42 percent more energy efficient. A list of front-loading, horizontal-axis clothes washers is maintained by the Consortium for Energy Efficiency online. (See References.) Several municipal utilities in Texas, including City of Austin, SAWS, and Bexar Met, offer rebates for the purchase of these energy- and water-efficient appliances.

Estimating outdoor water demand

Outdoor water demand peaks in hot, dry summer. In fact, as much as 60 percent of municipal water demand in the summer is attributable to irrigation.

The water demands of a large turfgrass area almost always preclude the sole use of harvested rainwater for irrigation.

Many urban dwellers capture rainwater for irrigation of vegetable and ornamental gardens. Because it is free of salts and minerals, rainwater promotes healthy plant growth. In urban areas, rainwater harvesters may reduce their water bill by substituting harvested rainwater for municipal water for garden irrigation.

For both the health of landscape plants and water use-efficiency, the best way to water plants is according to their needs. For most plants adapted to Texas' climate, water stress is visually evident well before plant death. Signs of water stress include a gray blue tint to leaves, leaf rolling, and in the case of turfgrass, a footprint that does not spring back. Watering infrequently and deeply has been shown to promote plant health, waiting until plants need the water helps the water user to be sure that they are growing a healthy landscape.

For planning purposes, historical evapotranspiration can be used to project potential water demands. Evapotranspiration is the term for water use by plants, the combination of evaporation from the soil and transpiration from the plant leaves. An estimated value called potential evapotranspiration is available on the Texas Evapotranspiration website, or can be calculated from weather-related data. (See References.)

A recommended general reference for water-wise landscaping is *Xeriscape: Landscape Water Conservation*, publication B-1584, available online. (See References.) Other plant lists and resources are available at the Texas Master Gardeners' website. (See References.) Many municipal water utilities, including those in the cities of El Paso, Houston, Austin, San Antonio, and the Metroplex area have published water-wise landscaping information tailored to local climate and soil conditions

It is recommended that rainwater harvesting families install landscapes of native and adapted plants, and also ascribe to the seven principles of Xeriscaping. A water-wise landscape can be quite attractive, while conserving water and demanding less care than a garden of non-native or non-adapted plants.

Principles of Water-Wise Landscaping

1. Plan and design for water conservation.
2. Create practical turf areas.
3. Group plants of similar water needs together.
4. Use soil amendments like compost to allow the soil to retain more water.
5. Use mulches, especially in high and moderate watering zones, to lessen soil evaporation.
6. Irrigate efficiently by applying the right amount of water at the right time.
7. Maintain the landscape appropriately by fertilizing, mowing, and pruning.

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Rainwater Harvesting System Sizing Sample Water Balance Calculations for Dallas, Texas

Two methods of determining system sizing are shown below. In the first example, monthly average rainfall data are used, and in the second example, monthly median rainfall data are used for calculations. Monthly rainfall data for several locations in Texas are provided in Appendix B.

Keep in mind that the basic monthly water balance calculation is

Water available (gallons) = Initial volume in storage (gallons) + gallons captured – gallons used. In an especially wet month, gallons in storage + gallons captured may exceed storage capacity; storage capacity could become a limiting factor, or a slightly larger cistern may be considered.

Assumptions

- Demand of 3,000 gallons/month
- Collection efficiency of 85 percent
- 0.62 gallons per square foot of roof area per inch of rain
- 10,000-gallon storage capacity
- 1,000 gallons in storage on January 1 to start out. (The water may have been collected between the time of system completion and new home occupancy, or it may be hauled water; systems designed for irrigation use only should be completed in the fall to collect rainwater during the slow-/non-growth season.)
- Irrigation volume is estimated based upon a small ornamental landscape, and limited supplemental irrigation, since this example is used for potable supply.

Calculations using Monthly Average Rainfall Data

First calculate the number of gallons collected in January. Using the average value of 1.91 inches of rain for January in Dallas (from Appendix B), the number of gallons of rainwater that can be expected to be stored in January from a 2,500-square-foot roof assuming 85% collection efficiency is determined from the equation:

Rainfall (inches) x roof area x 0.62 gal/sq ft /in. rain x collection efficiency

In this example:

$$1.97 \text{ in. rainfall} \times 2,500 \text{ sq. ft. catchment} \times 0.62 \text{ gallons/in. rain/sq. ft.} \times 0.85 \text{ collection efficiency} = 2,595 \text{ gallons}$$

To calculate gallons in storage at the end of each month, add the volume of water already in storage (1,000 gallons in this example) to the gallons collected and subtract the monthly demand.

$$1,000 + 2,595 - 3,000 = 595 \text{ gallons available in storage at the end of January}$$

This calculation is repeated for each month. To help you follow Table 4-2, please read below:

The value in Column E is added to Column F from preceding row and then A is subtracted. If calculated storage amount is zero or less, use zero for the next month. Rainfall exceeding storage capacity is ignored (water lost). The table shows that a collection surface of 2,500 square feet is adequate to meet expected demand (Column F should be more than zero at all times, if not the collection area needs to be increased or the monthly demand should be reduced).

Calculations using Monthly Median Rainfall Data

Table 4-3 shows the results of using monthly median rainfall (Column D), and performing the same calculations as before. Using monthly median rainfall data is a more conservative method, and is likely to provide a higher reliability than using average rainfall data for system sizing.

Homeowners can easily try different values for collection surface and storage capacity using an electronic spreadsheet, downloadable in Excel format from the Texas Water Development Board www.twdb.state.tx.us/assistance/conservation/alternative_technologies/rainwater_harvesting/rain.asp

**Table 4-2. Sample Water Balance Calculations for Dallas, Texas
(Using Average Rainfall and a 2,500-square-foot collection surface)**

Month	A. Water demand	B. Irrigation demand (watering by hose or bucket)	C. Total demand (gallons)	D. Average rainfall (inches)	E. Rainfall collected (gallons)	F. End-of- month storage (1,000 gal. to start)
January	3,000	0	3,000	1.97	2,596	595
February	3,000	0	3,000	2.40	3,162	757
March	3,000	150	3,150	2.91	3,834	1,441
April	3,000	150	3,150	3.81	5,020	3,311
May	3,000	150	3,150	5.01	6,601	6,762
June	3,000	150	3,150	3.12	4,111	7,723
July	3,000	150	3,150	2.04	2,688	7,261
August	3,000	150	3,150	2.07	2,727	6,838
September	3,000	150	3,150	2.67	3,518	7,206
October	3,000	150	3,150	3.76	4,954	9,010
November	3,000	0	3,000	2.70	3,557	9,567
December	3,000	0	3,000	2.64	3,478	10,000*

* Note that there were 44 gallons of overflow in December in this example. A 10,000-gallon cistern appears to be appropriate under the given assumptions.

**Table 4-3. Sample Water Balance Calculations for Dallas, Texas
(Using Median Rainfall and a 2,500-square-foot collection surface)**

Month	A. Water demand	B. Irrigation demand (watering by hose or bucket)	C. Total demand (gallons)	D. Median rainfall	E. Rainfall collected	F. End-of- month storage (1,000 gal. to start)
January	3,000	0	3,000	1.80	2,372	372
February	3,000	0	3,000	2.11	2,780	151
March	3,000	150	3,150	2.36	3,109	111
April	3,000	150	3,150	2.98	3,926	887
May	3,000	150	3,150	4.27	5,626	3,363
June	3,000	150	3,150	2.85	3,755	3,968
July	3,000	150	3,150	1.60	2,108	2,926
August	3,000	150	3,150	1.74	2,292	2,068
September	3,000	150	3,150	2.50	3,294	2,212
October	3,000	150	3,150	2.94	3,873	2,935
November	3,000	0	3,000	2.00	2,635	2,570
December	3,000	0	3,000	2.10	2,767	2,337

This table shows that it is critical to start with an initial storage (1,000 gallons), otherwise the cistern may run out of water in February/March, under the given assumptions.

The graph below (Figure 4-4) illustrates the information from Tables 4-2 and 4-3, previous page. The area under the curves represents the amount of water in storage at the end of each month. The assumptions from the example on the previous page are: a Dallas family of three using 33 gallons per person per day for indoor use, plus irrigation demand as shown in the examples, a collection efficiency of 85 percent, and a roof area of 2,500 square feet. The upper curve denotes water availability using average monthly rainfall data, and the lower curve is based on the monthly median rainfall. A 10,000-gallon cistern is planned in this example for storage of rainwater.

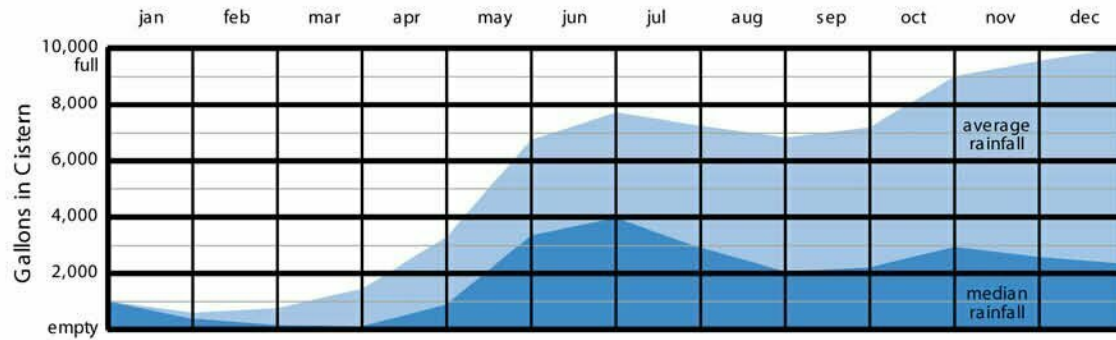


Figure 4-4. Volume of water in storage, using average rainfall data and median rainfall data for Dallas, Texas

Chapter 5

Rainwater Harvesting Guidelines

No national standards exist for rainwater harvesting systems. As a result, efforts abound to give assistance to those considering using rainwater as a water supply at state and local levels. In Texas the voluntary approach has been the hallmark of water conservation efforts, and a Water Conservation Best Management Practices (BMP) Guide produced by the Texas Water Development Board (TWDB) in 2004 included a section on Rainwater Harvesting and Condensate Reuse for use by water providers. (See References.) Guidance in other parts of the country ranges from voluntary guidelines such as BMPs to codes and ordinances stipulating minimum standards for various aspects of rainwater harvesting. The wide variety in approaches is summarized in this chapter by sharing a few key examples of the initiatives that are available to assist the planner of a rainwater harvesting system.

RWH Best Management Practices

Water Conservation Implementation Task Force Guidelines. In 2003 a statewide Water Conservation Implementation Task Force was appointed by the TWDB under a legislative mandate to develop recommendations for water conservation for the state of Texas. Best management practices reached by a consensus of the Task Force address rainwater harvesting and air conditioner condensate in the Task Force Water Conservation Best Management Practices Guide (TWDB, 2004).

American Rainwater Catchment Systems Association. The American Rainwater Catchment Systems

Association (ARCSA) is in the process of publishing guidelines for potable and nonpotable rainwater harvesting systems. The guidelines will be available on the ARCSA website at www.arcsa-usa.org.

Other Voluntary Guidelines

A number of University-level programs have published guidelines that are helpful to rainwater designers and planners. Included among them are Texas Cooperative Extension's guidelines and the University of Arizona's "Harvesting Rainwater for Landscape Use," both of which focus on capturing rainwater for outdoor irrigation. The University of Hawaii College of Tropical Agriculture and Human Resources in Hawaii produced "Guidelines on Rainwater Catchment Systems in Hawaii," which has information for people using rainwater for potable consumption. (See References.)

These guidelines for potable systems recommend that storage tanks be constructed of non-toxic material such as steel, fiberglass, redwood, or concrete. Liners used in storage tanks should be smooth and of food-grade material approved by the U.S. Food and Drug Administration (Macomber, 2001).

Building Codes

In addition to voluntary effort, some states and municipalities are choosing to establish rules. Ohio, Kentucky, Hawaii, Arizona, New Mexico, Washington, West Virginia, Texas, and the U.S. Virgin Islands are considering or have developed rules related to rainwater harvesting.

Rules, ordinances, building codes, and homeowner association covenants nationwide run the gamut from requiring rainwater harvesting systems on new construction to prohibiting tanks as an eyesore.

In Texas, HB 645, passed by the 78th Legislature in 2003, prevents homeowners associations from implementing new covenants banning outdoor water-conserving measures such as composting, water-efficient landscapes, drip irrigation, and rainwater harvesting installations. The legislation allows homeowners associations to require screening or shielding to obscure view of the tanks.

The State of Ohio has the most extensive rules on rainwater harvesting in the United States, with code on cistern size and material, manhole openings, outlet drains, overflow pipes, fittings, couplings, and even roof washers. Ohio's rules also address disinfection of private water systems. (See References.)

Cistern Design, Construction, and Capacity

Cistern design is covered by rules in some states, often embedded in the rules for hauled water storage tanks. In Ohio, cisterns and stored water storage tanks must have a smooth interior surface, and concrete tanks must be constructed in accordance with ASTM C913, *Standard Specification for Precast Concrete Water and Wastewater Structures*. Plastic and fiberglass tank materials and all joints, connections, and sealant must meet NSF/ANSI Standard 61, *Drinking Water System Components*.

In the U.S. Virgin Islands, Bermuda, and other Caribbean islands (islands without large reservoirs or adequate groundwater reserves), all new construction and even

building expansion must have a provision for a self-sustaining water supply system, either a well or a rainwater collection area and cistern.

The rules for private water systems in the U.S. Virgin Islands state that new cisterns must have a minimum capacity of 2,500 gallons per dwelling (Virgin Islands Code, Title 29, Public Planning and Development).

The U.S. Virgin Islands specifies that cisterns for hotels or multi-family dwellings have a minimum capacity of 10 gallons per square foot of roof area for buildings of one story, and 15 gallons per square foot of roof area for multi-story buildings, although the requirement is waived for buildings with access to centralized potable water systems.

The City of Portland, Oregon, requires a minimum cistern capacity of 1,500 gallons capable of being filled with harvested rainwater or municipal water, with a reduced pressure backflow prevention device and an air gap protecting the municipal supply from cross-connection (City of Portland, 2000).

Backflow Prevention and Dual-Use Systems

The option of “dual-supply” systems within a residence – potable harvested rainwater supplemented with water from a public water system with appropriate backflow prevention – is an option that might be explored for residences which cannot collect enough rainwater.

In most Texas locations, rainfall occurs seasonally, requiring a large storage capacity to hold enough water collected during rain events to last through the dry spells.

Allowing for a connection to the public water supply system could serve to promote harvested rainwater as a supplemental water source to customers already connected to the public water supply infrastructure.

This “conjunctive” use would require an appropriate backflow prevention device to keep rainwater from entering the public water supply due to a drop in pressure in the utility’s distribution system.

The City of Portland has approved supplemental use of public utility water at a residence since 1996. The code includes specific guidance for design and installation of the system. It also limits rainwater to nonpotable uses. The Portland Office of Planning and Development publishes a RWH Code Guide which includes FAQ and the relevant code sections (City of Portland, 2000).

The State of Washington Building Codes Council in 2002 developed guidelines for installation of rainwater harvesting systems at commercial facilities. They are similar to the City of Portland guidelines mentioned above, but require a larger cistern size, determined by the size of the catchment area, which is limited to roof areas. In 2003, the Washington State Legislature approved a 10 percent reduction in stormwater fees for any commercial facility that installed a rainwater harvesting system in compliance with the guidelines (Washington State Legislature, 2003).

Required Rainwater Harvesting Systems

Perhaps the most supportive ordinances are those requiring rainwater harvesting in new construction.

For instance, Santa Fe County, New Mexico, passed the precedent-setting regulation requiring rainwater harvesting systems on new residential or commercial structures of 2,500 square feet and larger. A bill requiring rainwater harvesting systems on all new construction narrowly missed passage in the New Mexico legislature (Darilek, 2004; Vitale, 2004)

The City of Tucson, Arizona, has instituted requirements for water harvesting in its land use code as a means of providing supplemental water for on-site irrigation. In fact, “storm water and runoff harvesting to supplement drip irrigation are required elements of the irrigation system for both new plantings and preserved vegetation” (City of Tucson Code, Chapter 23).

Water harvesting in Tucson is also intended to help in meeting code requirements for floodplain and erosion hazard management (City of Tucson Code, Chapter 26).

2005 Rainwater Harvesting Legislation

The Texas Legislature passed House Bill (HB) 2430 in May 2005, establishing a rainwater harvesting evaluation committee to recommend minimum water quality guidelines and standards for potable and nonpotable indoor uses of rainwater. The committee will also recommend treatment methods for indoor uses of rainwater, methods by which rainwater harvesting systems could be used in conjunction with existing municipal water systems, and ways in which that the state can further promote rainwater harvesting. The committee consists of representatives from the Texas Water Development Board Texas Commission on

Environmental Quality, Department of State Health Services, and the Texas Section of the American Water Works Association. The committee will provide its recommendations to the Legislature by December 2006.

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Chapter 6

Cost Estimation

Developing a budget for a rainwater harvesting system may be as simple as adding up the prices for each of the components and deciding what one can afford. For households without access to reliable groundwater or surface water, and too remotely located to hook up to the existing potable supply infrastructure, the information in this chapter will assist in determining how large a system can be installed for a set budget, and the range of costs for an ideal system. For some, the opportunity to provide for all or a portion of their water needs with rainwater is an exercise in comparing the costs with other options to determine which is most cost-effective. This chapter provides some information on cost ranges for standard components of rainwater systems for

both potable use and for irrigation. It also has a brief section on comparing costs with other types of water supply.

The single largest expense is the storage tank, and the cost of the tank is based upon the size and the material. Table 6-1 shows a range of potential tank materials and costs per gallon of storage. The size of storage needed (see Chapter 4, Water Balance and System Sizing) and the intended end use of the water will dictate which of the materials are most appropriate. Costs range from a low of about \$0.50 per gallon for large fiberglass tanks to up to \$4.00 per gallon for welded steel tanks.

As tank sizes increase, unit costs per gallon of storage decreases.

Table 6-1. Storage Tank

	Cost	Size	Comments
Fiberglass	\$0.50–2.00/gallon	500–20,000 gallons	Can last for decades w/out deterioration; easily repaired; can be painted
Concrete	\$0.30–1.25/gallon	Usually 10,000 gallons or more	Risks of cracks and leaks but these are easily repaired; immobile; smell and taste of water sometimes affected but the tank can be retrofitted with a plastic liner
Metal	\$0.50–1.50/gallon	150–2,500 gallons	Lightweight and easily transported; rusting and leaching of zinc can pose a problem but this can be mitigated with a potable-approved liner
Polypropylene	\$0.35–1.00/gallon	300–10,000 gallons	Durable and lightweight; black tanks result in warmer water if tank is exposed to sunlight; clear/translucent tanks foster algae growth
Wood	\$2.00/gallon	700–50,000 gallons	Esthetically pleasing, sometimes preferable in public areas and residential neighborhoods
Polyethylene	\$0.74–1.67/gallon	300–5,000 gallons	
Welded Steel	\$0.80–\$4.00/gallon	30,000–1 million gallons	
Rain Barrel	\$100	55–100 gallons	Avoid barrels that contain toxic materials; add screens for mosquitoes

Gutters and downspouts (Table 6-2) are needed to collect the water and route it to the tank. Two types of gutters are available for the “do-it-yourselfers”: vinyl and plastic, which are available for

approximately the same cost. For those desiring professionally installed materials, costs range from \$3.50 to \$12 per foot of gutter, including materials and installation, in 2004.

Table 6-2. Gutters

	Cost	Comments
Vinyl	\$.30/foot	Easy to install and attach to PVC trunk lines
Plastic	\$.30/foot	Leaking, warping and breaking are common problems
Aluminum	\$3.50-6.25/foot	Must be professionally installed
Galvalume	\$9-12/foot	Mixture of aluminum and galvanized steel; must be professionally installed

Some method of discarding the first flush of rain from the roof is necessary to remove debris. The simplest method is a vertical PVC standpipe, which fills with the first flush of water from the roof, then routes the balance of water to the tank.

The roof washer, placed just ahead of the storage tank, usually consists of a tank with leaf strainers and a filter. A commercially available model has a series of baffles and a 30-micron filter.

Table 6-3. Roof Washers

	Cost	Maintenance	Comments
Box Washer	\$400-800	Clean the filter after every substantial rain	Neglecting to clean the filter will result in restricted or blocked water flow and may become a source of contamination
Post Filtering w/ Sand Filter	\$150-500	Occasionally backwash the filter	Susceptible to freezing; a larger filter is best
Smart-Valve Rainwater Diverter Kit	\$50 for kit	Occasional cleaning	Device installed in a diversion pipe to make it self-flushing and prevent debris contamination; resets automatically

Roof washers consist of a tank, usually between 30- and 50-gallon capacity, with leaf strainers and a filter. A roof washer is a critical component of potable systems and is also needed to filter small particles to avoid clogging drip irrigation emitters. A wide range of equipment is available with different flow capacity and maintenance requirements. In Table 6-3 a list of different equipment used to intercept and pre-filter the water shows a range of costs from \$50 to more than \$800. It is important that the rainwater harvester pick a roof washer that is adequate for the size of collection area.

Table 6-4 shows the ranges for pump costs including pressure tanks. Demand-activated pumps such as Grundfos may not require a pressure tank, and can often provide enough water to meet a home's demand for instantaneous flow. Careful thought should be given to the possibility of multiple simultaneous demands upon the system in determining the appropriate size pump. The range for pump costs runs from \$385 for the low-end tankless pump, to more than \$1,000 for the combined price of a high-end pump and pressure tank.

Table 6-4. Pumps and Pressure Tanks

	Cost	Comments
Grundfos MQ Water Supply System	\$385-600	Does not require a separate pressure tank
Shallow Well Jet Pump or Multi-Stage Centrifugal Pump	\$300-600	These require a separate pressure tank
Pressure Tank	\$200-500	Galvanized tanks are cheaper than bladder tanks but often become waterlogged, and this will wear out the pump more rapidly

For those planning a potable system, or if a drip irrigation system is used, some sort of filtration is necessary. Rainwater harvesting suppliers can assist the end user in purchasing the right equipment for his/her needs and the expected demand.

It is important for the end user intending to use rainwater for potable supply to include disinfection among the water treatment components. The costs vary

widely depending upon intended end-use, the desired water quality, and preferences of the user. As shown in Table 6-5, combined filtration/disinfection costs can cost up to \$1,000 or more. Chapter 2, Rainwater Harvesting System Components, will assist you in choosing the right filtration and/or disinfection equipment for your system.

Table 6-5. Filtering/Disinfection

	Cost	Maintenance	Effectiveness	Comments
Cartridge Filter	\$20-60	Filter must be changed regularly	Removes particles >3 microns	A disinfection treatment is also recommended
Reverse Osmosis Filter	\$400-1500	Change filter when clogged (depends on the turbidity)	Removes particles >0.001 microns	A disinfection treatment is also recommended
UV Light Disinfection	\$350-1000; \$80 to replace UV bulb	Change UV bulb every 10,000 hours or 14 months; the protective cover must be cleaned regularly	Disinfects filtered water provided there are <1,000 coliforms per 100 milliliter	Water must be filtered prior to exposure for maximum effectiveness
Ozone Disinfection	\$700-2600	Effectiveness must be monitored with frequent testing or an in-line monitor (\$1,200 or more)	Less effective in high turbidity, can be improved with pre-filtering	Requires a pump to circulate the ozone molecules
Chlorine Disinfection	\$1/month manual dose or a \$600-\$3000 automatic self-dosing system	Monthly dose applied manually	High turbidity requires a higher concentration or prolonged exposure but this can be mitigated by pre-filtering	Excessive chlorination may be linked to negative health impacts.

Operating Costs

There are also operating costs that should be considered as you prepare your budget. As with any water treatment system, the cleaner the water needs to be, the greater the effort required to maintain the system.

Fortunately, with filter cartridges, this just means regular replacement of the cartridges, and with the disinfection system, following the manufacturers'

recommendations for regular maintenance. But proper operation and maintenance of the system does add to total costs.

Filter cartridges should be replaced per manufacturer's specifications, based upon the rate of water use.

Some of the operating costs and time expenditures necessary for system maintenance are regularly cleaning gutters and roof washers, checking the

system for leaks by monitoring water levels, and paying close attention to water use rates to determine if an invisible leak has sprung. Although the “do-it-yourselfers” can handle all of these tasks with little added financial burden, the time for regular maintenance and operation must be set aside to operate a successful system.

Comparing to Other Sources of Water

In some areas of Texas the cost of drilling a well can be as high as \$20,000

with no guarantee of hitting a reliable source of water. The deeper the well, the more expensive the effort will be. Also, well water can have very high TDS levels in some aquifers, resulting in “hard” water. Rainwater is naturally soft and has become a preferred option in some parts of rural central Texas with costs lower than or equal to those of drilling a well, and reliability high enough to justify reliance on weather patterns, rather than on an aquifer’s water quality and quantity.

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Chapter 7

Financial and Other Incentives

Financial incentives and tax exemptions encourage the installation of rainwater harvesting systems. The Texas Legislature has passed bills, and some local taxing entities have adopted rules that provide tax exemptions for rainwater harvesting systems. A few public utilities have implemented rebate programs and rain barrel distribution events that encourage rainwater harvesting by residential, commercial, and industrial customers. In addition to financial incentives, performance contracting provisions in state code can be used to encourage installation of rainwater harvesting systems. This chapter includes a brief description of methods for determining the appropriate size of an incentive by local governments.

In addition to financial incentives, administrative contracting rules for state and local governments encourage the use of rainwater harvesting as an alternative water source in Texas.

Tax Exemptions

Property tax exemption for commercial installations (State-wide exemption)

A constitutional amendment passed as Proposition 2 by Texas voters in November 1993 exempted pollution control equipment, including water-conserving equipment at nonresidential buildings, from property taxes. Rainwater harvesting equipment at commercial installations is considered water-conserving equipment. The intent of this amendment to Article VIII of the Texas Constitution was to ensure that capital expenditures undertaken to comply with environmental rules and

regulations did not raise a facility's property taxes, by adding Section 11.31 to Chapter 11, and Section 26.045 to Chapter 26 of the Texas Tax Code.

The Texas Commission on Environmental Quality (TCEQ) established procedures and mechanisms for use determination under Texas Administrative Code (TAC) Title 30, Chapter 17.

To qualify for the property tax exemption, (1) a facility must first receive a determination from the TCEQ that the property is used for pollution control purposes, and (2) the applicant then submits this use determination to the local tax appraisal district to obtain the property tax exemption.

The Application and Instructions for Use Determination for Pollution Control Property and Predetermined Equipment List, as well as instructions for applying for Property Tax Exemptions for Pollution Control Property, are downloadable from the TCEQ website. (See References.)

Property tax exemptions extended (State-wide)

Passed in 2001 by the 77th Texas Legislature, Senate Bill 2 amended Section 11.32 of the Texas Tax Code to allow taxing units of government the option to exempt from taxation all or part of the assessed value of the property on which water conservation modifications have been made. The taxing entity designates by ordinance or law the list of eligible water conservation initiatives, which may include rainwater harvesting systems.

County property tax exemptions

Homeowners planning to install rainwater harvesting systems should check with their respective county appraisal districts for guidance on exemption from county property taxes. Links to some county appraisal districts, as well as the Office of the State Comptroller's Application for Water Conservation Initiatives Property Tax Exemption, can be found online. (See References.)

Hays County is one of the fastest-growing counties in Texas, and is also the county with the most rapidly increasing number of new rainwater harvesting installations in the state. Hays County encourages rainwater harvesting with a \$100 rebate on the development application fee.

For rainwater harvesting systems serving as the sole source of water for a residence, Hays County grants a property tax exemption from county taxes for the value of the rainwater harvesting system. Guidelines for rainwater harvesting benefits and qualification can be found at the Hays County website. (See References.)

Homeowners in other parts of the state should consider approaching their local government to see if such a property tax exemption could be passed in their locale.

Sales Tax Exemption (State-wide)

Senate Bill 2 exempts rainwater harvesting equipment and supplies from sales tax. Senate Bill 2 amended Subchapter H of the Tax Code by adding Section 151.355, which states:

“Water-related exemptions. The following are exempted from taxes imposed by this chapter: (1)

rainwater harvesting equipment or supplies, water recycling and reuse equipment or supplies, or other equipment.”

An application for sales tax exemption is included as Appendix D, or can be downloaded from the Office of the State Comptroller. (See References.)

Municipal Incentives

In addition to tax exemptions, two Texas cities offer financial incentives in the form of rebates and discounts to their customers who install rainwater harvesting and condensate recovery systems.

City of Austin Rainwater Harvesting Programs

The City of Austin Water Conservation Department promotes both residential and commercial/industrial rainwater harvesting. (See References.) The City of Austin sells 75-gallon polyethylene rain barrels to its customers below cost, at \$60 each, up to four rain barrels per customer. City of Austin customers who purchase their own rain barrels are eligible for a \$30 rebate.

Customers may also receive a rebate of up to \$500 on the cost of installing a pre-approved rainwater harvesting system. The rebate application includes a formula to calculate optimum tank size and a list of area suppliers and installation contractors. (See References.)

Commercial entities may be eligible for as much as a \$40,000 rebate against the cost of installing new equipment and processes to save water under the Commercial Incentive Program. (See References.)

New commercial or industrial sites that develop capacity to store sufficient water

on-site for landscape irrigation may be able to receive an exemption from installing an irrigation meter.

San Antonio Water System Large-Scale Retrofit

Rainwater harvesting projects are eligible for up to a 50-percent rebate under San Antonio Water System's (SAWS) Large-Scale Retrofit Rebate Program. (See References.) SAWS will rebate up to 50 percent of the installed cost of new water-saving equipment, including rainwater harvesting systems, to its commercial, industrial, and institutional customers. Rebates are calculated by multiplying acre-feet of water conserved by a set value of \$200/acre-foot. Equipment and projects must remain in service for 10 years. The water savings project is sub-metered, and water use data before and after the retrofit are submitted to SAWS to determine if conservation goals are met. To qualify for the rebate, an engineering proposal and the results of a professional water audit showing expected savings are submitted.

The rebate shortens the return on investment period, giving an incentive to industry to undertake water-conserving projects.

Determining How Much of a Financial Incentive a Utility May Wish to Offer

To determine whether a municipal utility should consider offering a rebate or financial incentive to stimulate the use of rainwater harvesting, benefits and costs must be presented on an economic basis. This is most easily accomplished by condensing the factors into terms of dollars per acre-foot (\$/AF) and comparing that to the cost of building a new water supply project. The spreadsheet included in the TWDB's Report No. 362, Water Conservation

Best Management Practices Guide (p. 118 to 130), gives an example and the steps in calculating the net present value of conserved water.

This approach requires the utility to estimate the potential for water savings due to rainwater harvesting systems installed and the likely number of participants in a program.

Rainwater Harvesting at State Facilities

In 2003, the 78th Texas Legislature, second session, passed HB9, which encourages rainwater harvesting and water recycling at state facilities. The bill requires that the Texas Building and Procurement Commission appoint a task force charged with developing design recommendations to encourage rainwater harvesting and water recycling at state facilities built with appropriated money.

The intent of HB9 is to promote the conservation of energy and water at state buildings. The bill requires that before a state agency may use appropriated money to make a capital expenditure for a state building, the state agency must determine whether the expenditure could be financed with money generated by a utility cost-savings contract.

If it is determined to be not practicable to finance construction with utility cost savings, rainwater harvesting and water recycling are encouraged by HB9.

In addition the Texas Education Code (Section 61.0591) provides an incentive to institutes of higher education for achieving goals set by the Texas Higher Education Coordinating Board (THECB) including:

“energy conservation and water conservation, rainwater harvesting, and water reuse.”

The code states that not less than 10 percent of THECB total base funding will be devoted to incentive funding.

Performance Contracting

Another means of encouraging the installation of water- or energy-efficient equipment is to pay for the equipment through the savings in utility bills. This method of financing water conservation has been used by commercial and industrial consumers, and is written into state code for government buildings in several locations.

The Texas Education Code (Chapter 44.901 and Chapter 51.927), the Texas Local Government Code (Chapter 302.004), and the State Government Code (Chapter 2166.406) allow public schools, institutes of higher education, state building facilities, and local governments to enter into performance contracts. Performance contracting allows a facility to finance water- and energy-saving retrofits with money saved by the reduced utility expenditures made possible by the retrofit. In other words, the water- and energy-conserving measures pay for themselves within the contracted period. More information on performance contracting can be found on the State Energy Conservation Office website. (See References.)

Following are descriptions of alternative water sources that are eligible for performance contracts:

“landscaping measures that reduce watering demands and capture and hold applied water and rainfall, including: (a) landscape contouring, including the use of berms, swales, and terraces; and (b) the use of soil

amendments that increase the water-holding capacity of the soil, including compost.”

“rainwater harvesting equipment and equipment to make use of water collected as part of a stormwater system installed for water quality control.”

“equipment needed to capture water from nonconventional, alternate sources, including air-conditioning condensate or graywater, for nonpotable uses, and metering equipment needed to segregate water use in order to identify water conservation opportunities or verify water savings.”

Performance contracts serve as a win-win opportunity for school districts and institutes of higher education to effect improvements on facilities for water- and energy-conservation without incurring net construction costs.

The State Energy Conservation Office, in *Suggested Water Efficiency Guidelines for Buildings and Equipment at Texas State Facilities*, recommends that use of alternative water sources be explored for landscape irrigation use. (See References.) Suggested water sources include captured stormwater or rainwater, air-conditioner condensate, water from basement sump pump discharge, and other sources, in accordance with local plumbing codes.

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Appendix B

Rainfall Data

The following data are provided for representative Texas cities in various geographical areas to assist in assessing the optimal storage size for a particular rainwater harvesting system. Each rainwater harvesting system designer should assess the variables of water demand, rainfall, catchment surface area, storage capacity, and risk tolerance when designing a rainwater harvesting system, especially one intended to be the sole water source.

Abilene

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.35	3.60	5.16	6.80	13.17	9.60	7.52	8.18	11.03	10.68	4.60	6.28
Median	0.81	0.73	0.90	1.88	2.47	2.30	1.69	1.62	2.25	2.09	0.94	0.77
Average	1.00	1.05	1.17	2.05	3.22	2.90	2.03	2.40	2.71	2.56	1.24	1.03
Average annual rainfall												23.36

Amarillo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.00	0.00	0.04	0.01	0.10	0.28	0.03	0.00	0.00	0.00
Maximum	2.33	1.83	4.01	5.84	9.81	10.73	7.59	7.55	5.02	6.34	2.26	4.52
Median	0.33	0.42	0.58	0.86	2.45	3.08	2.59	2.79	1.61	0.97	0.43	0.35
Average	0.52	0.55	0.93	1.18	2.67	3.40	2.80	2.93	1.84	1.44	0.59	0.53
Average annual rainfall												19.39

Austin

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.00	0.00	0.00
Maximum	9.21	6.56	6.03	9.93	9.98	14.96	10.54	8.90	7.44	12.31	7.95	14.16
Median	1.27	2.30	1.73	2.20	3.68	2.89	1.15	1.27	2.98	2.82	1.88	1.42
Average	1.77	2.37	1.90	2.83	4.33	3.54	1.73	2.18	3.17	3.63	2.25	2.26
Average annual rainfall												31.96

Brady

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.10	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	6.40	5.30	4.30	6.02	8.00	7.70	13.55	11.30	9.45	7.04	10.40	7.90
Median	0.60	1.26	0.90	1.78	3.10	1.87	0.85	1.34	2.40	1.70	1.10	0.70
Average	1.03	1.50	1.26	2.07	3.40	2.40	1.80	2.01	2.86	2.34	1.43	1.28
Average annual rainfall												23.38

Brownsville

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.07	0.34	0.01	0.00
Maximum	4.79	10.25	5.72	10.35	9.12	8.52	9.43	9.56	20.18	17.12	7.69	3.98
Median	0.77	0.84	0.41	0.84	1.86	2.22	0.96	2.45	4.69	2.92	0.90	0.78
Average	1.31	1.38	0.80	1.62	2.39	2.55	1.50	2.69	5.19	3.62	1.55	1.10
Average annual rainfall												25.70

College Station

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.22	0.1	0.29	0.08	0.23	0.09	0	0	0.32	0	0.19	0.23
Maximum	15.6	9.82	6.07	12.5	11.38	12.63	7.06	10.63	12.13	12.91	8.33	10.72
Median	2.205	2.72	2.12	3.75	4.515	2.895	1.97	1.84	4.12	3.18	2.92	2.635
Average	2.87	2.88	2.5	3.77	4.73	3.79	2.24	2.43	4.3	3.64	3.07	3.15
Average annual rainfall												38.75

Corpus Christi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.01	0.00	0.00	0.00	0.00	0.03	0.00	0.10	0.49	0.00	0.00	0.01
Maximum	10.78	8.11	4.89	8.04	9.38	13.35	11.92	14.79	20.33	11.88	5.24	9.80
Median	0.99	1.36	0.78	1.39	2.70	2.43	1.04	2.64	4.00	2.60	1.34	0.90
Average	1.54	1.85	1.36	2.03	3.12	3.16	1.80	3.28	5.21	3.50	1.57	1.59
Average annual rainfall												30.00

Dallas

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.18	0.13
Maximum	8.46	7.60	8.70	15.40	13.74	10.30	7.34	5.12	10.67	14.00	7.54	8.90
Median	1.80	2.11	2.36	2.98	4.27	2.85	1.60	1.74	2.50	2.94	2.00	2.10
Average	1.97	2.40	2.91	3.81	5.01	3.12	2.04	2.07	2.67	3.76	2.70	2.64
Average annual rainfall												35.10

El Paso

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
Maximum	2.23	1.69	2.26	1.42	4.22	3.18	5.53	5.57	6.68	3.12	1.63	3.29
Median	0.29	0.34	0.18	0.09	0.10	0.36	1.18	1.06	0.96	0.55	0.24	0.42
Average	0.42	0.40	0.30	0.21	0.32	0.70	1.57	1.45	1.38	0.71	0.36	0.61
Average annual rainfall												8.43

Houston

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.36	0.38	0.11	0.43	0.04	0.26	0.45	0.31	0.80	0.05	0.41	0.64
Maximum	9.78	5.99	8.52	10.92	14.39	16.28	8.10	9.42	11.35	16.05	10.07	9.34
Median	2.82	2.63	3.19	2.59	5.02	3.55	2.69	3.52	3.92	3.79	3.27	3.41
Average	3.68	2.95	3.40	3.54	5.36	5.07	3.05	3.69	4.31	4.63	4.09	3.54
Average annual rainfall	48.45											

Lubbock

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	4.05	2.51	3.34	5.63	13.38	8.43	7.20	8.85	8.55	10.80	2.67	2.24
Median	0.33	0.39	0.63	1.08	2.23	2.37	2.07	1.78	1.87	0.98	0.45	0.42
Average	0.52	0.62	0.90	1.24	2.64	2.95	2.16	2.15	2.49	1.81	0.67	0.56
Average annual rainfall	18.49											

San Angelo

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.01	0.00	0.00	0.26	0.05	0.00	0.00	0.00	0.00	0.00	0.00
Maximum	3.65	4.47	5.00	5.10	11.24	6.01	7.21	8.13	11.00	8.68	3.55	3.98
Median	0.58	0.62	0.65	1.29	2.32	2.09	0.70	1.38	2.38	1.90	0.68	0.33
Average	0.79	1.04	0.92	1.66	2.78	2.20	1.10	1.75	2.83	2.24	0.98	0.76
Average annual rainfall	19.12											

San Antonio

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.00	0.01	0.03	0.02	0.00	0.01	0.00	0.00	0.05	0.00	0.00	0.03
Maximum	8.52	6.43	6.12	9.32	12.85	11.95	8.29	11.14	13.09	17.96	8.51	13.96
Median	1.10	1.85	1.27	1.94	3.04	2.70	1.21	2.00	2.24	2.75	1.93	1.09
Average	1.59	1.92	1.66	2.52	3.97	3.61	1.82	2.45	3.08	3.42	2.24	1.69
Average annual rainfall	29.96											

Waco

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	0.03	0.00	0.04	0.12	0.52	0.27	0.00	0.00	0.00	0.00	0.13	0.04
Maximum	5.92	7.69	5.56	13.37	15.00	12.06	8.58	8.91	7.29	10.51	7.03	9.72
Median	1.55	2.00	2.22	2.76	3.87	2.34	0.82	0.96	2.57	2.37	2.29	1.94
Average	1.83	2.28	2.25	3.30	4.49	2.98	1.82	1.76	3.02	3.12	2.40	2.31
Average annual rainfall	31.68											

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Appendix C Case Studies

Lady Bird Johnson Wildflower Center Austin

4801 La Crosse Avenue
Austin, Texas 78739
(512) 292-4100
<http://www.wildflower.org>

Capacity: 70,000 gallons
Catchment area: 17,000 square feet
Demand: Gardens and landscaping

Harvested rainwater from three separate catchment areas provides 10 to 15 percent of the garden and landscaping irrigation of the Lady Bird Johnson National Wildflower Research Center in Austin. An integral part of its architecture, the Center's rainwater harvesting system serves to not only conserve water, but also as a public education tool. The Center collects water from 17,000 square feet of roof space and can store more than 70,000 gallons in on-site cisterns.

One of the most prominent features of the center is the 43-foot native-stone-façade tower cistern, which is built around a 5,000-gallon storage tank. Metal rooftops totaling an area of 17,000 square feet drain into the tower cistern and two 25,000-gallon tanks collect a total of about 300,000 gallons in an average rainfall year. A pressurized distribution system delivers water from the large tanks to an irrigation system. The municipal water supply is linked to the systems with backflow prevention devices to prevent water contamination.

The 3,000-gallon entry cistern, fed by an elevated stone-faced aqueduct draining just less than 1,200 square feet of roof area, is reminiscent of rainwater cisterns used by original Hill Country settlers. The Little House cistern captures rainwater from a roof area of about 700 square feet in the Children's Area.

In addition, the Wetland Pond, the Commons Well, and the Balcony Spring together collect 2,500 gallons per inch of rain from the roofs, although water from these features is not used for irrigation.



The entry cistern at the Lady Bird Johnson Wildflower Research Center is reminiscent of the stone-and-mortar cisterns used by Hill Country settlers. Water from a 1,200-square-foot roof area is conveyed to the entry cistern via an aqueduct.

H-E-B Austin

6900 Brodie Lane
(corner William Cannon Blvd. and Brodie Lane)
Austin, Texas 78745

Capacity: 28,000 gallons
Catchment area: 50,000 square feet
Demand: Native and adapted plant
landscape

Two 8,000-gallon and two 6,000-gallon painted steel tanks are fed from a 24-inch-diameter collection pipe draining the 50,000-square-foot roof. Using efficient drip irrigation, captured rainwater irrigates an adjacent water-thrifty landscape of native and adapted trees and ornamentals. Walkways and plant labels enhance the attractiveness of the site.

The four tanks are connected with 6-inch PVC pipes and valves, allowing a tank to be taken off-line to be drained and cleaned.

H-E-B, based in San Antonio, prides itself on environmental stewardship in the communities where its supermarkets conduct business. H-E-B saves 6.2 million gallons of water annually by recycling condensation from manufacturing steam equipment.



The H-E-B at the corner of Brodie Lane and William Cannon Blvd. in south central Austin irrigates an adjacent landscape of water-thrifty plants with rainwater stored in four painted steel tanks totaling 28,000 gallons. A 24-inch-diameter pipe conveys water from the roof to the tanks.



Tanks are linked with 6-inch PVC pipe. Valves allow taking one or more tank off-line for draining or cleaning.

Sunset Canyon Pottery Dripping Springs

4002 E. Highway 290
Dripping Springs, Texas 78620
(512) 894-0938

Sunset Canyon Pottery supplies all its potable and pottery works water demand with water stored in a 46,000-gallon ferrocement tank. When visiting this site on private property, please first request permission from Sunset Canyon Pottery staff.

The ferrocement tank at Sunset Canyon Pottery supplies process water for pottery works, as well as potable water for the straw-bale studio and gift shop. The tank was constructed first by forming an armature of steel reinforcement bars, then spraying on a cement-like material similar to that used for in-ground swimming pools.

New Braunfels Municipal Utility District New Braunfels

New Braunfels Utilities Service Center
355 FM 306
New Braunfels, Texas 78130

The New Braunfels Utilities Service Center, completed in 2004, captures rainwater in four 1,000-gallon plastic-lined galvanized steel tanks, one located at each building wing. Water is used to irrigate the landscape of native and adapted plants. The metal tanks form both a practical and aesthetic feature of the architecture of this public building.



Four lined, galvanized steel tanks will capture water for irrigation of native and adapted plants.

Hays County Cooperative Extension Office San Marcos

1253 Civic Center Loop
San Marcos, Texas 78666
(512) 393-2120

Capacity:	750-gallon galvanized metal tank 1,600 polyethylene tank
Catchment area:	2,500 square feet
Demand:	Demonstration garden
Cost:	\$1,125



The Hays County Extension Office captures rainwater from half the roof area of its 5,000-square-foot building in two tanks: a 750-gallon galvanized steel tank and a 1,600-gallon black polypropylene tank using existing guttering and downspouts. Plans are in the works for water to be gravity-fed to an adjacent Master Gardener demonstration garden.

As a demonstration project, a 750-gallon galvanized steel tank captures rainwater from the 5,000-square-foot roof of the Hays County Extension Office.

Edwards Aquifer Authority San Antonio

1615 N. St. Mary's Street
San Antonio, TX 78215
(210) 222-2204

Capacity: 2,500 gallons
Catchment area: 1,135 square feet
Demand: Landscaping

The Edwards Aquifer Authority collects rainwater from a catchment area of 1,135 square feet in two cisterns. Water is delivered through gravity flow into a 500-gallon polypropylene tank in the courtyard area. The second cistern, a 2,000-gallon ranch-style metal cistern, is located on the front lawn, visible from the street. Harvested rainwater is used to irrigate the 266-square-foot courtyard, and 2,700-square-foot lawn.



A 2,000-gallon, ranch-style metal cistern is one of two tanks that capture rainwater for landscaping at the Edwards Aquifer Authority building. (Photo courtesy: Lara Stuart)

J.M. Auld Lifetime Learning Center Kerrville

1121 Second Street
Kerrville, Texas 72028
(830) 257-2218

Capacity: 6,600 gallons
(Two 3,300-gallon stacked concrete ring tanks)
Catchment area: 5,000 square feet
Demand: Adjacent gardens
Pondless waterfall
Total Cost: \$10,500
Breakdown: Two 3,300 concrete tanks, \$4,766
Plumbing supplies, \$520
Pump, pressure tank, switch, \$1,535
Gutter work, \$541
Electrical supplies, \$160
Trencher rental, \$175
In-kind labor, Kerrville ISD, \$2,800



Stacked concrete ring 3,000-gallon tank at the Auld Center, Kerrville, showing first flush diverter and cistern.

The Auld Lifelong Learning Center of Kerrville Independent School District is a community education facility operated by Kerrville Independent School District. Installed in 2003, two 3,300-gallon stacked concrete-ring tanks collect rainwater from a 5,000-square-foot roof. Tanks are located at the back corners of the building, with a transverse 3-inch PVC pipe conveying the rainwater drained from the front half of the roof. Five-gallon first flush diverters at each corner capture the dust and debris of the initial runoff of each rainfall event.

Tanks are fitted with unique water-level sight gages. Vertical rods the same length as the tank height are suspended on floating platforms within the tank. The length of rod protruding from the tops of tanks indicates water level.

Captured rainwater will irrigate several adjacent themed gardens. In addition, a unique water feature, a recirculating waterfall, adds aesthetic interest.

Menard ISD Elementary School Menard

200 Gay St.
Menard, Texas 76859

Container garden and landscape-plant irrigation
Capacity: 1,000-gallon green polyethylene tank
Catchment area: 600 square feet
Demand: 50 emitters: 20 landscape plants, 30 container garden emitters
Total cost: \$475
Breakdown: Tank, \$400
Connections and valves/roofwasher, \$35
Black poly pipe and emitters, \$40

The rainwater harvesting system serves multiple purposes of education, beauty, and habitat improvement at Menard Independent School District Elementary School. The wildscape provides the requirements of food, water, and shelter for native animals. The demonstration site aids in teaching students about healthful wildlife habitats and container and landscape gardening. The water features, gazebo, and rock walkway enhance the outdoor esthetics of the school. A backyard wildscape at Menard Elementary School demonstrates the requirements of food, water, and shelter for rangeland maintenance conducive to supporting wildlife. Using existing gutters and downspouts from the roof of Menard Elementary School, rainwater is diverted into two 1,000-gallon green polypropylene tanks. One tank supplies a birdbath made of rocks with natural cavities and a prefabricated pond. Both water features are supplied with water conveyed by gravity pressure through 3/4-inch PVC pipe and drip emitters. Native plants provide a food source and cover for wildlife.



Using existing gutters and downspouts, rainwater harvesting techniques were used to create a backyard wildscape. The principles of wildscape construction can be transferred to large wildlife management programs.



Menard Elementary School rainwater harvesting installation showing downspout, 1,000-gallon poly tank, and gazebo (left) surrounded by native and adapted landscape plants. In this very attractive installation, harvested rainwater (using existing gutter and downspouts) furnishes water not only to the landscape, but also to a watering pond, birdbath, and wildlife guzzler. (Photo courtesy: Billy Kniffen)

Walker County Cooperative Extension Office Huntsville

102 Tam Road
Huntsville, Texas 77320
(936) 435-2426

Capacity:	550-gallon polyethylene tank
Catchment area:	1,500 square feet
Demand:	Master Gardener demonstration plot
Total cost:	Total: \$230
Breakdown:	Used 550-gallon tank, \$150 Plumbing supplies and fittings, \$70 Glue, thinner, and paint, \$10



Rainwater captured from the 1,500-square-foot roof of the Walker County Extension office is stored in a 550-gallon polypropylene tank, a type readily available at ranch supply retailers. The 10-gallon flush diverter is the vertical standpipe visible to the left of the tank. Captured rainwater irrigates an adjacent Master Gardener demonstration garden, foreground.

The Walker County Master Gardeners and staff of Texas Cooperative Extension, supervised by agricultural county agent Reginald Lepley, installed a rainwater harvesting system at the Walker County Extension office for a cost of less than \$250. A used white 550-gallon polypropylene tank was thoroughly cleaned and pressure-washed, and painted with brown latex paint to discourage algae growth. Raising the tank on concrete blocks allows gravity flow to a 10-foot by 25-foot Master Gardener demonstration garden. A detailed parts list, instructions and tips for rainwater harvesting in general, and more information on this installation can be found at urbantaex.tamu.edu/D9/Walker/AG/HomeHort/WCMG/hortdemo/Waterdemo/index

AMD/Spansion FAB25 Austin

5204 E. Ben White Blvd.
Austin, Texas 78741

Rainwater drained from the facility's roofs and groundwater from the building perimeter drains furnish all the water needed for landscape irrigation on AMD's Spansion site in east Austin. Water is collected and stored in a 10,000-gallon fiberglass tank, and then pressurized through the site irrigation loop using surplus pumps. The water savings has been verified at about 4.75 million gallons per year using online flow meters. In-house engineers designed the system and facilities tradespersons installed the tank, pump, piping, and electricity. The irrigation reclaim system has a three-year return on investment.

The plant also has segregated drains that allow the reuse and recycling of rinse water from the wafer manufacturing process for cooling tower and Ultra-pure treatment plant makeup drastically reducing city-supplied water. The water savings from the rinse water reuse system is approximately 210 million gallons per year and had a return on investment of less than one year.

J.J. Pickle Elementary School/St. John Community Center Austin

Corner of Blessing and Wheatley Avenues
Austin, Texas

A model of sustainable design and building, the J.J. Pickle Elementary and St. John Community Center in northeast Austin is a joint project of Austin Independent School District and the City of Austin. Water from a portion of the 116,200-square-foot facility drains into three tanks, which provide cooling water to the air-conditioning system.

For energy savings, the classrooms, gym, dining area, and City library use sunlight rather than electric lights during the day. The complex opened in January 2002, with operational and maintenance cost savings of \$100,000 expected each year.

The complex includes a public elementary school, shared gymnasium, a health center, public and school libraries, and a community policing office. The cost of construction is \$13.6 million, with the AISD funding about \$8.3 million and the City of Austin funding about \$5.3 million. The money came from a 1996 School District bond election and a City 1998 bond package.



Water collected from the roof of the J.J. Pickle Elementary School and St. John Community Center is stored in three large tanks behind the building and used as cooling water for the complex's air-conditioning system.

Feather & Fur Animal Hospital Austin

9125 Manchaca Road
Austin, Texas 78748

Captured water from the roof, parking lot, and condensate from the air conditioners is the sole source irrigation water for a 1-acre turf landscape at the Feather & Fur Animal Hospital in South Austin. Dr. Howard Blatt first explored ways to make use of an existing hand-dug 18,000-gallon underground cistern. The project has since been expanded to take advantage of other rainwater sources.



The Feather & Fur Animal Hospital in South Austin features a standing-seam metal roof for rainwater harvesting.

Rainwater collected from a standing-seam metal roof gravity flows into the cistern. Then water from the parking lot flows through a water quality pond with gabion for sedimentation and filtration treatment. From the pond, water flows via a 6-inch pipe to catch basin. A small sump pump empties to a 12,500-gallon fiberglass tank. Additionally, the primary condensation line from the air handlers also drains into the gutter and downspout system, which services the roof.

Pomerening/Dunford Residence Bexar County

The Pomerening/Dunford family lives on the western edge of Bexar County and uses rainwater harvesting for all of their potable needs. The four-year-old installation features two 10,000-gallon cisterns that store captured water from a 2,400-square-foot collection area.




Two 10,000-gallon cisterns collect rainwater at the Pomerening/Dunford residence in Bexar County.

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Appendix D

Tax Exemption Application Form

 01-339 (Back)
(Rev. 6-04/5)

TEXAS SALES AND USE TAX EXEMPTION CERTIFICATION

Name of purchaser, firm or agency	
Address (Street & number, P.O. Box or Route number)	Phone (Area code and number)
City, State, ZIP code	

I, the purchaser named above, claim an exemption from payment of sales and use taxes (for the purchase of taxable items described below or on the attached order or invoice) from:

Seller: _____


Street address: _____ City, State, ZIP code: _____

Description of items to be purchased or on the attached order or invoice:

Purchaser claims this exemption for the following reason:

I understand that I will be liable for payment of sales or use taxes which may become due for failure to comply with the provisions of the Tax Code: Limited Sales, Excise, and Use Tax Act; Municipal Sales and Use Tax Act; Sales and Use Taxes for Special Purpose Taxing Authorities; County Sales and Use Tax Act; County Health Services Sales and Use Tax; The Texas Health and Safety Code; Special Provisions Relating to Hospital Districts, Emergency Services Districts, and Emergency Services Districts in counties with a population of 125,000 or less.

I understand that it is a criminal offense to give an exemption certificate to the seller for taxable items that I know, at the time of purchase, will be used in a manner other than that expressed in this certificate and, depending on the amount of tax evaded, the offense may range from a Class C misdemeanor to a felony of the second degree.

 Purchaser	Title	Date
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NOTE: This certificate cannot be issued for the purchase, lease, or rental of a motor vehicle.

THIS CERTIFICATE DOES NOT REQUIRE A NUMBER TO BE VALID.

Sales and Use Tax "Exemption Numbers" or "Tax Exempt" Numbers do not exist.

This certificate should be furnished to the supplier. Do **not** send the completed certificate to the Comptroller of Public Accounts.