

Rainwater



Harvesting

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Why Harvest Rainwater

Can rain save you money? Yes. Even if you live where annual rainfall averages only 12 inches, you can save money by collecting and storing rainwater and using it to irrigate your trees, shrubs and lawn.

Efficient water use is increasingly important to Texas. With the state's growing population and limited supply of both groundwater and surface water, Texans must use water wisely. Rainwater harvesting is an innovative approach anyone can use.

Rainwater harvesting captures, diverts and stores rainwater for later use. Rainwater can even be used for drinking, with proper treatment. But the easiest way to use stored rainwater is for landscaping. In many communities, 30 to 50 percent of the total water is used for landscape irrigation. If that demand for a limited natural resource can be reduced, everyone benefits.

Harvesting rainwater for use in the home landscape:

- Saves you money by reducing your water bills.
- Reduces demand on the municipal water supply.
- Makes efficient use of a valuable resource.
- Reduces flooding, erosion and the contamination of surface water with sediments, fertilizers and pesticides in rainfall runoff.

Rainwater is good for plants because it is free of salts and other minerals that harm root growth. As rainwater percolates into the soil, it forces salts down and away from root zones, allowing roots to grow better and making plants more drought tolerant.

Rainwater harvesting can be used both in large-scale landscapes, such as parks, schools, commercial sites, parking lots and apartment complexes, and in small residential landscapes. Whether your landscape is large or small, developed or new, the principles described here can help you install a rainwater harvesting system.

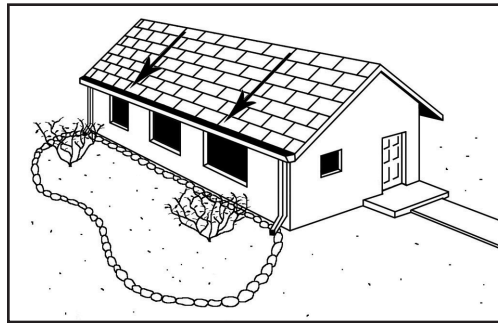
How Rainwater Harvesting Works

A rainwater harvesting system consists of the supply (rainfall), the demand (water needed by plants), and a system for collecting water and moving it to the plants. Simple systems distribute rainwater immediately. Complex systems store some or all of the rainwater for later use.

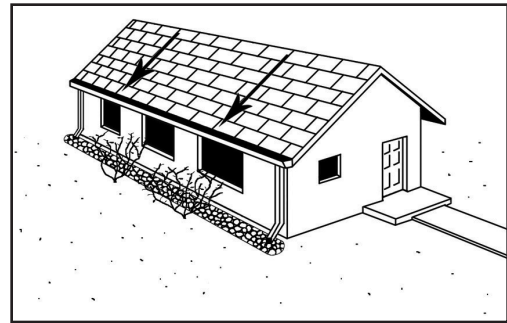
Rainfall. "Runoff" is the rainwater that flows off a surface. If the surface is impermeable (for example, pavement, concrete, roofs), runoff occurs immediately. If the surface is permeable, runoff will not occur until the surface is saturated. Runoff can be harvested (captured) and used immediately to water plants or stored for later use.

Plant Water Requirements. The types and numbers of plants in your landscape, along with their growth stages and sizes, determine the amount of water your plants need to be healthy. Because rainfall varies throughout Texas, different plants have become adapted to conditions in different regions of the state. Plants native to your region are the best choices for your landscape because their water requirements are usually met by normal rainfall amounts.

Water Collection and Distribution System. Rainwater collection and distribution systems can be incorporated into almost any existing site, although it is easier to incorporate them into new construction. Always contact your local water supplier prior to installing any system to ensure compliance with local requirements.



Simple system: Roof catchment, gutters and bermed landscape holding area.



Simple system: Roof catchment, gutters, downspouts and French drain.

Simple Rainwater Harvesting Systems

A simple water harvesting system usually consists of a catchment, a distribution system and a landscape holding area, which can be a concave or planted area with a border or earthen berm to retain water for immediate use. Gravity moves the water from the catchment (for example, the roof) to a different location. Sometimes water is caught in small containers and stored for later use. Water dripping from the edge of a roof to a planted area or a diversion channel located directly below the drip edge is an example of a simple water harvesting system.

Catchments. A catchment is any area from which water can be collected, including roofs, paved areas and the soil surface. The best catchments have hard, smooth surfaces, such as concrete or metal roofing material. The amount of water harvested from a catchment depends on its size, surface texture, slope and rainfall received.

Distribution Systems. Distribution systems channel water from catchments to landscape holding areas. Examples of distribution systems include gutters and downspouts, sloped sidewalks, hillsides, street and parking lot curb cutouts and channels, ditches and swales. If gravity does not cause water to flow through your distribution system, you may need to install a small pump, gates or diverters. You may need to line earthen distribution systems with an impermeable material such as plastic to keep water from soaking into non-target areas. Complex distribution systems, discussed later, also may include pipelines.

Landscape Holding Areas. Concave depressions covered by grass or plants can store water for direct landscape use and reduction of flooding and erosion. Several such holding areas can be chained together through spillways. You can create holding areas by digging out depressions and keeping the resulting soil as a berm or by using berms, moats or soil terracing to make flat areas hold water. You should, however, be aware that digging may expose poorer quality subsoils unsuitable for landscape plants.

Designing and Building a Simple Rainwater Harvesting System

Step #1. Design the Collection and Distribution Systems.

Observe your landscape during a rain to identify its drainage pattern, and then use that pattern to decide how to move water from catchments to plants. Ideas for collection/distribution systems include:

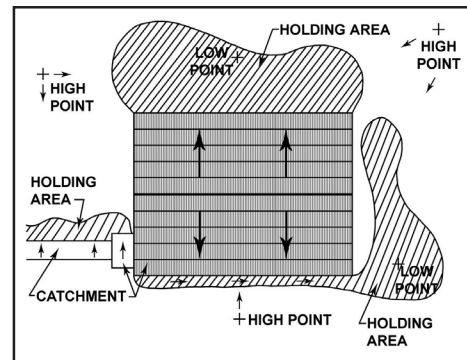
- Use your roof to collect rainwater, then extend downspouts, provide paths or use hoses to move the water to plants.
- Use existing sloped paving to reach plants.
- Design new sidewalks, terraces or driveways with a two percent ($\frac{1}{4}$ inch per foot) slope toward plants.
- Grade unpaved, bare soil to increase and direct runoff.
- Design landscape soil and plantings around foundations to slope away from buildings.

Step #2. Design Landscape Holding Areas.

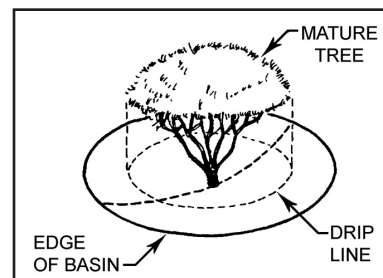
Next, identify landscape depressions with potential for holding water or create new ones near plants.

Tips for designing landscape holding areas include:

- Locate holding areas at least 10 feet away from buildings to avoid structural or pest problems.
- Build level berms or moats around plants to avoid damaging roots, but do not mound soil at plant bases.
- To encourage large root systems, extend holding areas beyond the “drip line,” the outer perimeter of possible runoff from the catchment. (Plants with well-developed root systems are more drought tolerant.)
- Locate new plants at upper edges of concave holding areas to encourage large root systems and to protect them from flooding.
- Connect several holding areas with spillways or channels to distribute water throughout your site.



Site plan showing drainage patterns and landscape holding areas (aerial view).



Tree dripline and basin edge.

Step #3. Select Plants.

To help your water harvesting project succeed, choose native or regionally adapted plants that can withstand both prolonged drought and prolonged inundation. For example, excess water may collect at the bottom of a holding area due to soil saturation, so low-water-use, native riparian trees may be the best choice for large, deep basins. To determine the best plants for your region, consult a guide such as *Xeriscape–Landscape Water Conservation*, publication B-1584 from the Texas A&M AgriLife Extension Service, a part of the Texas A&M University System (see <http://agriflifebookstore.org>). Other plant lists and resources are available at the Texas Master Gardeners' Web site: <http://aggie-horticulture.tamu.edu/mastergd.mg.html> or <http://aggie.horticulture.tamu.edu/extension/publications.html>.

To seed holding basins, select seed mixes containing native or adapted wildflowers, grasses and herbaceous plants. Perennial grasses will hold the soil and prevent erosion.

Compacting soil in landscape holding areas inhibits the movement of water through the soil. Loosen compacted soil by tilling. Add organic matter such as compost to soil that is too sandy to hold water. To reduce evaporation, apply a 1.5- to 2-inch layer of mulch after planting. Organic mulches may increase permeability of tight clay soils but may float if inundated.

Tips on how best to use water free-falling from roof downspouts include:

- Plant large, rigid plants where the water falls.
- Hang a large chain from the downspout to the ground to disperse and slow the water.
- Provide a storage basin to slow the falling water.
- Place rocks or other hard materials under the downspout to prevent erosion by breaking the fall of the water.

Harvesting Water to Reduce Flooding and Erosion

Rain falling on impermeable surfaces runs off immediately, potentially scouring bare soil and creating pockmarked roads. Because the roofs, roads and parking lots that cluster in urban areas are impermeable, even moderate rainfall there may produce large runoff. Water harvesting can prevent flooding and erosion and turn storm water problems into water supply assets by slowing runoff and allowing it to soak into the ground.

Methods to harvest urban rainwater include:

- Crescent-shaped berms around plants on slopes.
- Gabions (piles of large rocks encased in wire mesh).
- French drains (holes or trenches filled with gravel).
- Permeable paving materials, such as gravel, crushed stone and open or permeable paving blocks, on steep slopes.
- Terrace grading (stair-step-like shelves) of slopes.

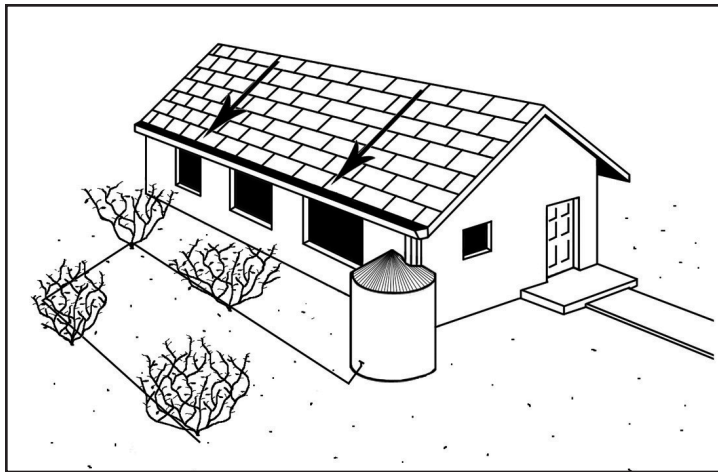
What Makes Up Complex Rainwater Harvesting Systems

To maximize the benefits of rainwater harvesting, complex systems build in storage to provide water between rainfall events. But can such systems collect and store enough rainwater in an average year to irrigate an entire landscape? Yes, if the amount of water harvested (the supply) equals the amount of water needed for irrigation (the demand). Complex water harvesting systems use stored water to balance the supply-demand equation during limited rainfall periods.

Complex rainwater harvesting systems cost more to build but yield greater water savings than do systems without storage. Consider the following factors when deciding whether to invest in a complex water harvesting system:

- Availability of other water supplies for irrigation.
- Need for professional assistance to design and construct a complex system.
- Cost of storage, including the storage container, excavation, pumps, wiring and ongoing maintenance.
- Long investment payback period (sometimes several years).
- Personal commitment to “water conservation ethic.”

To reduce the cost of a complex system, you can (1) build a smaller storage container, harvesting less than the total irrigation water your landscape needs; (2) limit landscape area or reduce plant densities, lessening water demand; or (3) replace high-water-use plants with medium- or low-water-use ones, also reducing the amount of irrigation water needed.



Complex water harvesting system with roof catchment, gutter, downspout, storage and drip distribution system.

How a Complex Rainwater Harvesting System Works

Complex rainwater harvesting systems include catchments, conveyance systems (connecting catchments to storage containers), storage, and distribution systems (directing water where it is needed).

Catchments. The amount of water or “yield” that a catchment provides depends on its size and surface texture. Examples of various surface textures include:

- High yield: Concrete, asphalt or brick paving and smooth-surfaced roofing materials such as metal.
- Medium yield: Bare soil (compacted clay soils yield the most).
- Low yield: Areas with plants, such as grass or groundcover (plants hold water longer, allowing it to infiltrate into the soil rather than run off).

Table 1. Annual approximate supply from roof catchment.

Rainfall (Inches)	Gallons/Square Foot	Rainfall (Inches)	Gallons/Square Foot
0	0	8	5.0
1	0.6	9	5.6
2	1.3	10	6.2
3	1.9	11	6.8
4	2.5	12	7.5
5	3.1	13	8.1
6	3.7	14	8.7
7	4.4	15	9.3

Conveyance Systems. Conveyance systems direct water from catchments to storage containers. Roof catchment systems use canals, from which water flows by gravity into storage containers, or gutters and downspouts, which should be sized to collect as much rainfall as possible. (See Appendix VI for guidelines on gutters and downspouts.)

Storage. Storage makes rainwater available when needed.

Filtration. Before water is stored, it should be filtered to remove particles and debris. Filtration considerations include:

- Degree of filtration: Depends on the size of the distribution tubing and on the emission devices used. For example, microirrigation drip systems require more and finer filtering, with an additional filter at the system inlet, than do hose distribution systems.
- Type of filter: (1) in-line; (2) leaf screens, placed over gutters at the top of the downspout; (3) diversion by roofwashing with a 4-to-6-inch PVC standpipe (with a valve and bottom cleanout) connected to a gutter downspout. The first rainfall that falls, at a rate of 10 gallons for every 1,000 square feet, fills the standpipe, and the rest flows to the downspout connected to the cistern. When the rain stops, the standpipe is drained in preparation for the next rain.

Containers. Storage containers may be made of polyethylene, fiberglass, wood, concrete or metal. Underground containers cost more to excavate, to maintain or to remove, and the need to pump water out of them adds to their cost. Swimming pools, stock tanks, septic tanks, ferro-cement culverts or containers built from concrete blocks, poured-in-place concrete or building rocks can be used for underground storage.

Costs for aboveground storage containers depend on the type of catchment and conveyance system, the degree of filtration and the distance between the container and the area irrigated. Examples of containers that can be used for aboveground storage include 55-gallon plastic or steel drums, barrels, tanks, cisterns, stock tanks, fiberglass fish ponds and swimming pools, as well as buildings or tanks made from concrete blocks, stone, plastic bags filled with sand, or rammed earth. Look under “Tanks,” “Feed Dealers,” “Septic Tanks” or “Swimming Pools” in a telephone directory to find sources of storage containers. You may be able to salvage 55-gallon drums from local businesses, but use only drums free of toxic residues.

Tips for storage container placement and use include:

- Elevate aboveground storage containers to take advantage of gravity flow; for example, place them at the high end of a sloped lot.
- Put storage containers near plants and near or at the end of downspouts.
- Build concave planted areas to allow rainwater to percolate slowly into the soil.
- Hide unsightly containers in an unobtrusive place or behind a structure, screen and/or plants.
- Because smaller cisterns are easy to handle and camouflage, place several of them near the irrigated site.
- For large landscaped areas, connect several tanks to increase storage capacity.
- If rainfall exceeds storage capacity, provide alternative storage for the excess or allow it to spill out. Make sure storage container inlets and overflow outlets are the same size.

Distribution. The distribution system channels water to plants from storage containers, using garden hoses, constructed channels, solid or perforated pipes or manual drip systems, plus (for some systems) gates and diverters to control flow rate and direction. If your system is gravity-fed, you may need to put a manual or an electric valve near the bottom of your storage container. If your system is not gravity-fed, connect an electric pump to a garden hose to transport water to the irrigation site. Drip and other types of integrated distribution systems need pumps to provide necessary pressure for system operation.

If there is not enough rainfall to meet your irrigation demands, add water to your container from an auxiliary source to avoid building an alternative system. If

you connect your system to a municipal or private water supply, you must use an “air gap” or other approved backflow prevention device. If you decide not to use a supplemental water source, make sure any pumps turn off automatically when your tank is empty. (*Integrated distribution systems are complex; make sure to comply with local plumbing and building codes.*)

Designing and Building Complex Rainwater Harvesting Systems

Steps involved in designing a complex water harvesting system include site analysis, calculations, system design, construction and field testing. For large projects or those with several catchments and planting areas, divide the project site into subdrainage areas and repeat these steps for each.

Step #1. Site Analysis

Follow these steps in analyzing your site:

- Draw the site to scale, using arrows to plot existing drainage patterns observed during a rain and showing high and low areas on your sketch.
- Identify possible catchments, such as pavements, roof surfaces and bare earth.
- Identify areas requiring irrigation and sites near them where storage could be located (either above ground or underground).
- Think about ways to move water from catchments to holding areas or storage containers. (Use gravity wherever possible.)
- Think about ways to move water through the site from one landscaped area to another.

Step #2. Calculations

To design a complex water harvesting system, you must first calculate monthly “Supply” (rainfall harvest potential) and monthly “Demand” (plant water requirements), then calculate monthly “Storage/Supplemental Municipal Water Requirement.”

Calculate Supply. The following equation calculates the amount of water (in gallons) that can be harvested from a catchment.

$$\text{SUPPLY (in gallons)} = \frac{\text{Inches of Rainfall}}{1} \times 0.623 \times \frac{\text{Catchment Area (square feet)}}{1} \times \text{Runoff Coefficient}$$

Follow these steps to use the equation:

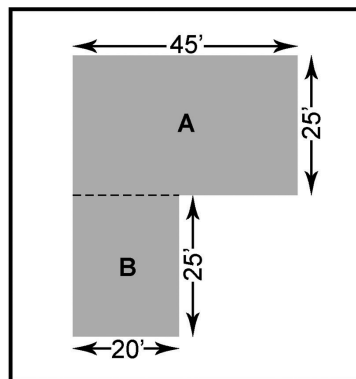
- Multiply rainfall in inches (see Appendix I) by 0.623 to convert inches to gallons per square foot.
- Multiply the result by the area of catchment in square feet (ft²). (For example, a 10 foot x 20 foot roof is 200 ft². For a sloped roof, measure the area covered by the entire roof, usually the length times the width of the building.)
- Multiply this result by the “Runoff Coefficient” (see Appendix II) to obtain the available supply. (The runoff coefficient is the percentage of total rainfall that can be harvested from a particular surface. The higher the runoff coefficient, the less absorbent the surface.)

Example 1: Calculating Supply

Susana wants to build a rainwater harvesting system for her home in San Antonio, Texas. From Appendix I, she enters the rainfall for each month on the Supply Worksheet (see sample on next page). Then she multiplies the inches of rainfall by 0.623 to convert inches to gallons per square foot.

Susana has an “L”-shaped house with asphalt shingle roofing that she plans to use as her primary catchment area. To simplify measurements, she divides the house into two rectangular sections, A and B. The eave-to-eave measurements for section A are 45 ft. x 25 ft., and for section B are 20 ft. x 25 ft.:

$$\begin{array}{lcl} \text{Section A} & 45' \times 25' & = 1,125 \text{ ft}^2 \\ \text{Section B} & 20' \times 25' & = \underline{500 \text{ ft}^2} \\ \text{Total} & & = 1,625 \text{ ft}^2 \end{array}$$



Susana has 1,625 square feet of catchment area. She enters this value in Column C of the Supply Worksheet. She then multiplies the gallons per square foot in Column B by the square footage in Column C to determine the total gallons of rainfall received each month by her catchment. Since the asphalt shingle roof won't shed all of this rainfall, Susana finds the appropriate runoff coefficient (0.9) in Appendix II and enters it in Column E.

Finally, Susana multiplies Column D by Column E to obtain the net harvestable rainfall for the month.

Sample Supply Worksheet

	A	B	C	D	E	F
Follow the lettered instructions for each month.	From Appendix I, enter the rainfall amount in inches for each month.	Multiply "A" by 0.623 to convert inches to gallons per square foot.	Enter the square footage of the catchment surface.	Multiply "B" by "C" to yield the gross gallons of rainfall per month.	From Appendix II, enter the runoff coefficient for your catchment surface.	Multiply "D" by "E" to obtain the total monthly yield of harvested water in gallons.
January	1.66	1.03	1,625	1,681	0.9	1,512
February	1.75	1.09	1,625	1,772	0.9	1,594
March	1.89	1.18	1,625	1,913	0.9	1,722
April	2.60	1.62	1,625	2,632	0.9	2,369
May	4.72	2.94	1,625	4,778	0.9	4,301
June	4.30	2.68	1,625	4,353	0.9	3,918
July	2.03	1.26	1,625	2,055	0.9	1,850
August	2.57	1.60	1,625	2,602	0.9	2,342
September	3.00	1.87	1,625	3,037	0.9	2,733
October	3.86	2.40	1,625	3,908	0.9	3,517
November	2.58	1.61	1,625	2,612	0.9	2,351
December	1.96	1.22	1,625	1,984	0.9	1,786
Annual	32.92			33,327		29,995

Calculate Demand. The demand equation calculates the amount of water a particular landscaped area needs. (*HELPFUL HINT: To make water demand calculations easier, group together new landscape plants with similar water requirements. Such grouping also makes it easier to manage irrigation zones.*)

$$\text{DEMAND (in gallons)} = \frac{\text{Inches of Demand ET}}{\text{Plant Coefficient}} \times 0.623 \times \text{Irrigated Area (square feet)}$$

Follow these steps to use the equation:

- Determine the monthly reference evapotranspiration (ET) in inches for your area. (Appendix III lists ET information for several Texas cities.)
- Multiply ET by the “Plant Water Use Coefficient,” representing the percentage of reference ET a particular plant needs. (See Appendix III for plant coefficients.)
- Multiply the result by 0.623 to convert inches to gallons per square foot.
- Multiply this result by the size of the irrigated area in square feet. (Irrigated area refers to how much area is planted. Do not include unplanted portions of the landscape in your calculations.)

What is Evapotranspiration?

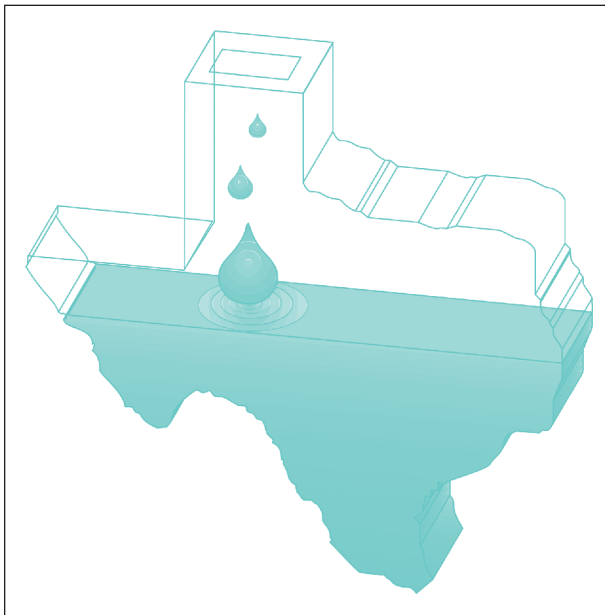
Evapotranspiration (ET) is the combined loss of water from the soil and other wet surfaces due to evaporation and plant transpiration (plant uptake and use of water). ET is an estimate of potential planted-area water demand in inches. Plant type and climate (temperature, wind, amount of sunlight and humidity) primarily determine ET. A baseline ET is calculated for a reference crop, usually a cool-season grass with heavy water demands. Since most plants do not use as much water as the cool-season grass, the reference ET rate then must be multiplied by a plant coefficient to adjust for the types of plants actually grown.

Drought-sensitive plants require approximately the total estimated ET amount of water. Drought-tolerant plants may be able to thrive on a fraction of the potential maximum water demand.

Example 2: Calculating Demand

Susana has a small lawn with a sprinkler system and a 1,200-square-foot densely planted area of high-water-use trees, shrubs and flowers. To avoid the expense of installing an electric pump, Susana wants to operate her rainwater project by gravity flow. But because the sprinkler system cannot be operated by gravity flow, she decides to use her rainwater system to irrigate only her flowers, trees and shrubs.

1. Using the Demand Worksheet (see sample on following page), Susana calculates the potential water needs (demand) for her rainwater-irrigated area. From Appendix IV, she enters the evapotranspiration rate for San Antonio, Texas into Column A.
2. Since Susana's landscape contains primarily high-water-use plants, she uses a plant coefficient of 0.75 (see Appendix III). She enters this value in Column B.
3. She then multiplies A by B to get the estimated number of inches of water her plants will require. She enters the result in Column C.
4. She multiplies Column C by 0.623 to convert inches to gallons per square foot and enters the result in Column D.
5. In Column E, she enters the total square feet of landscaping she hopes to water with her rainwater system.
6. Finally, she multiplies Column D by Column E to determine how much water her landscape will need for each month.



The amount of rainwater available for harvesting and storage varies across Texas due to climate diversity.

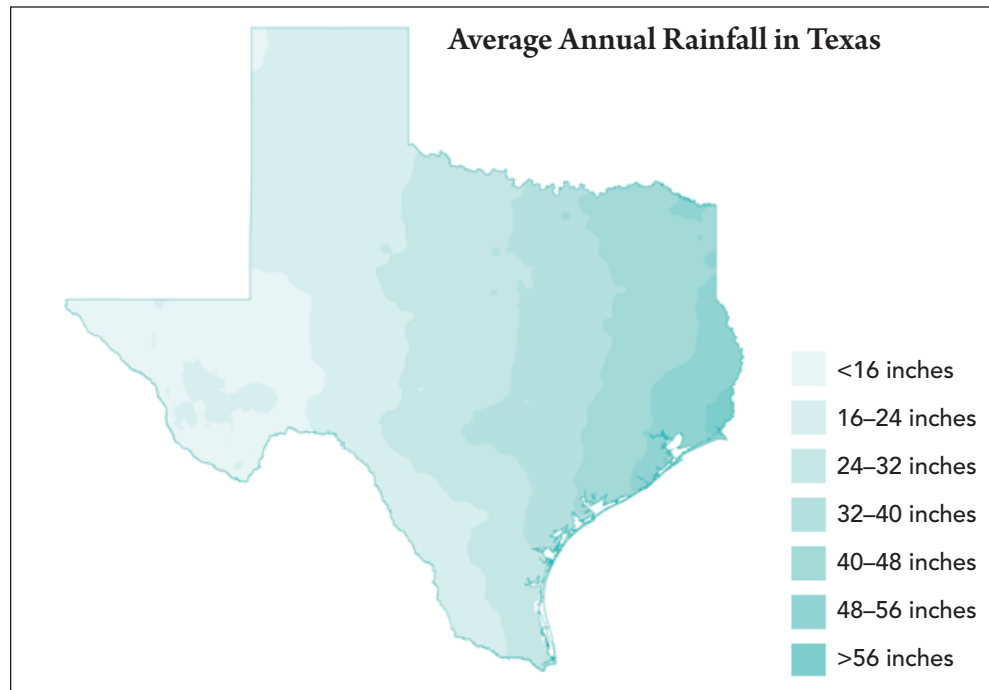
Sample Demand Worksheet

	A	B	C	D	E	F
Follow the lettered instructions for each month.	From Appendix IV, enter the ET amount in inches for each month.	From Appendix III, enter the appropriate plant water use coefficient.	Multiply "A" by "B" to obtain plant water needs in inches.	Multiply "C" by 0.623 to convert inches to gallons per square foot.	Enter the total square footage of landscaping.	Multiply "E" by "D" to obtain your total <u>demand</u> in water gallons.
January	2.07	0.75	1.55	0.97	1,200	1,161
February	2.77	0.75	2.08	1.29	1,200	1,553
March	4.40	0.75	3.30	2.06	1,200	2,467
April	5.33	0.75	4.00	2.49	1,200	2,989
May	7.58	0.75	5.69	3.54	1,200	4,250
June	8.21	0.75	6.16	3.84	1,200	4,603
July	7.96	0.75	5.97	3.72	1,200	4,463
August	8.03	0.75	6.02	3.75	1,200	4,502
September	6.19	0.75	4.64	2.89	1,200	3,471
October	4.95	0.75	3.71	2.31	1,200	2,775
November	3.14	0.75	2.36	1.47	1,200	1,761
December	2.15	0.75	1.61	1.00	1,200	1,206
Annual	62.78		47.09			35,201

Once Susana has calculated supply and demand for each month, she can determine her system's maximum storage needs. Although containers of any size will reduce Susana's dependence on municipal water, to take full advantage of available rainfall she should build enough storage to meet total irrigation water needs (see Sample Demand Worksheet on page 13 and example on page 12).

Calculate Maximum Storage/Supplemental Water Use. Once you have calculated how much rainfall you can potentially harvest and how much irrigation water you need, use a "checkbook" method to determine monthly harvested water balance and amount of supplemental water (municipal or from another source) needed to meet any shortfalls. The calculations in the following sample worksheet use the scenario from Examples 1 and 2. To keep things simple, calculations are performed on a monthly basis, although the amount of available water changes daily.

"Cumulative Storage" refers to available water. To determine the current month's cumulative storage, add the previous month's cumulative storage to the current month's yield, then subtract the current month's demand from that total. If the remainder is positive, place it in the Cumulative Storage column for the current month. If the remainder is negative (that is, if irrigation demand is greater than stored water supply), place it in the Supplemental Water Use column to indicate the amount of supplemental water needed for that month.



Sample Storage/Supplemental Water Use Worksheet

Month	Yield	Demand	Cumulative Storage (Yield minus Demand)	Supplemental Water Use
YEAR 1				
January	1,512	1,161	351	0
February	1,594	1,553	392	0
March	1,722	2,467	0	353
April	2,369	2,989	0	620
May	4,301	4,250	51	0
June	3,918	4,603	0	634
July	1,850	4,463	0	2,613
August	2,342	4,502	0	2,160
September	2,733	3,471	0	738
October	3,517	2,775	742	0
November	2,351	1,761	1,332	0
December	1,786	1,206	1,912	0
YEAR 2				
January	1,512	1,161	2,263	0
February	1,594	1,553	2,304	0
March	1,722	2,467	1,559	0
April	2,369	2,989	939	0
May	4,301	4,250	990	0
June	3,918	4,603	305	0
July	1,850	4,463	0	2,308
August	2,342	4,502	0	2,160
September	2,733	3,471	0	738
October	3,517	2,775	742	0
November	2,351	1,761	1,332	0
December	1,786	1,206	1,912	0

Balancing Supply and Demand. In this scenario, during the summer Susana's landscape demand always requires a supplemental water supply. But during the winter months, rainwater supply exceeds demand due to low evapotranspiration rates, so water can be saved for spring and early summer water deficit periods.

Every site generates unique supplies and demands. For some sites, rainwater harvesting systems always provide enough water to meet irrigation demands, while for others, harvesting can only partially satisfy such demands. Remember that supply fluctuates from year to year, depending on the weather (when and how much it rains). Demand can increase with warmer-than-normal weather, as the landscape ages and plants grow larger, and while new plants get established.

If supplies of harvested water do not meet irrigation demands, balance your water harvesting checkbook either by increasing supply or by reducing demand.

To increase supply:

- Increase your catchment's area or runoff coefficient.
- Use another source of water, such as your municipal supply.

To reduce demand:

- Reduce landscaped area.
- Reduce plant density.
- Replace high-water-use plants with lower-water-use plants.
- Use mulch to reduce surface evaporation.

Step #3. Final design and construction.

Catchments and Landscaping. Use your site analysis and your supply and demand calculations to determine size and location for catchment areas. Use gutters and downspouts to carry water from a roof catchment to your storage areas. (Consult Appendix VI for tips on selecting and installing gutters and downspouts.) Design or retrofit roofs or shade structures to maximize your catchment area. If you cannot provide a catchment large enough to meet maximum landscape water requirements:

- For existing landscapes, reduce plant water demand either by lowering plant density or by selecting lower-water-use plants.
- For new landscapes, select types and numbers of plants that can be supported by the water harvested from your existing catchment.

To use harvested water most efficiently, group together plants with similar water needs. And remember that new plantings, even of native plants, need increased amounts of irrigation during their establishment period, which can range from 1 to 3 years. (Use supply and demand calculations to determine the amount of water needed for new plantings.)

Storage Containers and Distribution. Use storage containers large enough to hold your calculated supply. Place containers close to plants and, to take advantage of gravity flow, higher than planted areas. Use pipes, hoses, channels and drip systems to distribute water. For drip systems and those without gravity flow, use a small pump to move water through the lines. Select drip irrigation filters with 200-mesh screens and clean them regularly.

Step #4. Field testing.

Once you've built your water harvesting system, "field test" it during rains. Determine whether water is moving where you want it to go or whether some of it is being lost. Determine if holding areas adequately contain water. Make changes to your system as required.

Maintaining Your Rainwater Harvesting System

Developing a water harvesting system is actually an ongoing process to be improved and expanded over time. For example, you may discover additional areas where water can be harvested or channeled. Inspect your water harvesting system before each rainy season (and, ideally, after every rainfall) to keep the system operating optimally.

Use this maintenance checklist to keep your system in top condition:

- Keep debris out of holding areas.
- Control and prevent erosion; block erosion trails.
- Clean and repair channels.
- Clean and repair dikes, berms and moats.
- Keep debris out of gutters and downspouts.
- Flush debris from storage container bottoms.
- Clean and maintain filters, especially those on drip irrigation systems.
- Expand watering basins as plants grow.

Once your system is operating, monitor landscape water use to find out the amount of water saved. For new water harvesting basins in existing landscapes, compare previous years' (preharvesting) water bills with postharvesting figures. When new plants are added to a water harvesting area, water savings begin as soon as they are planted and continue for as long as you irrigate with harvested rainwater.

Appendix I

Average Monthly Rainfall (Inches) for Texas Cities*													
City**	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Abilene	0.97	1.13	1.41	1.67	2.83	3.06	1.69	2.63	2.91	2.90	1.30	1.27	23.77
Amarillo	0.63	0.55	1.13	1.33	2.50	3.28	2.68	2.94	1.88	1.50	0.68	0.61	19.71
Austin	2.21	2.02	2.36	2.63	5.12	3.42	2.03	2.51	2.88	3.99	3.02	2.53	34.72
Brownsville	1.36	1.18	0.93	1.96	2.48	2.93	1.77	2.99	5.31	3.78	1.75	1.11	27.55
College Station	3.32	2.38	2.84	3.20	5.05	3.79	1.92	2.63	3.91	4.22	3.18	3.23	39.67
Corpus Christi	1.75	1.62	1.84	1.73	2.05	3.48	3.53	2.00	3.54	5.03	3.94	1.74	32.25
Dallas/Fort Worth	1.90	2.37	3.06	3.20	5.15	3.23	2.12	2.03	2.42	4.11	2.57	2.57	34.73
Del Rio	0.57	0.96	0.96	1.71	2.31	2.34	2.02	2.16	2.06	2.00	0.96	0.75	18.80
El Paso	0.45	0.39	0.26	0.23	0.38	0.87	1.49	1.75	1.61	0.81	0.42	0.77	9.43
Galveston	4.08	2.61	2.76	2.56	3.70	4.04	3.45	4.22	5.76	3.49	3.64	3.53	43.84
Houston	3.68	2.98	3.36	3.60	5.15	5.35	3.18	3.83	4.33	4.50	4.19	3.69	47.84
Lubbock	0.50	0.71	0.76	1.29	2.31	2.98	2.13	2.35	2.57	1.70	0.71	0.67	18.68
Midland	0.53	0.58	0.42	0.73	1.79	1.71	1.89	1.77	2.31	1.77	0.65	0.65	14.80
Port Arthur	5.69	3.35	3.75	3.84	5.83	6.58	5.23	4.85	6.10	4.67	4.75	5.25	59.89
San Angelo	0.81	1.18	0.99	1.60	3.09	2.52	1.10	2.05	2.95	2.57	1.10	0.94	20.90
San Antonio	1.66	1.75	1.89	2.60	4.72	4.30	2.03	2.57	3.00	3.86	2.58	1.96	32.92
Victoria	2.44	2.04	2.25	2.97	5.12	4.96	2.90	3.05	5.00	4.26	2.64	2.47	40.10
Wichita Falls	1.12	1.57	2.27	2.62	3.92	3.69	1.58	2.38	3.19	3.11	1.68	1.68	28.81

* Data obtained from the Office of the State Climatologist (<http://climate.tamu.edu>).

** Average rainfall for locations near those listed or for specific time periods may vary from the averages shown here.

Appendix II

Runoff Coefficients*		
Character of Surface	High	Low
<i>Roof</i>		
Metal, gravel, asphalt shingle	0.95	0.75
<i>Paving</i>		
Concrete, asphalt	0.95	0.70
Brick	0.85	0.70
<i>Gravel</i>	0.70	0.25
<i>Soil</i>		
Flat (2% or less), bare	0.75	0.20
Flat (2% or less), with vegetation	0.60	0.10
<i>Lawns, Sandy Soil</i>		
Flat (2% or less)	0.10	0.05
Average (2% to 7%)	0.15	0.10
<i>Lawns, Heavy Soil</i>		
Flat (2% or less)	0.17	0.13
Average (2% to 7%)	0.22	0.18

*Data obtained from: Haan, C.T., B.J. Barfield and J.C. Hayes, *Design Hydrology and Sedimentology for Small Catchments*, Academic Press; and Waterfall, P.H., 1998, *Harvesting Rainwater for Landscape Use*, Arizona Department of Water Resources.

Appendix III

Plant Water Use Coefficients	
Plant Type	Percentage
Low Water Use (Blue Grama, Desert Willow)	0.20
Medium Water Use (Buffalograss, Bermudagrass)	0.50
High Water Use (St. Augustine, Fescue)	0.75

The plant water use coefficient represents the water needs of a particular plant relative to rates of reference evapotranspiration (ET_r). Thus, a low-water-use plant requires only 20 percent of ET_r, but a high-water-use plant requires 75 percent of ET_r. New plantings of all types require more water. Supplemental water must be supplied when a plant's water use requirement (demand) exceeds the amount of water available from precipitation (supply).

Appendix IV

City**	Average Monthly Evapotranspiration (Inches) for Texas Cities*												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Abilene	1.20	1.60	3.90	4.70	7.90	8.61	8.75	8.15	7.10	4.90	2.80	1.00	60.61
Amarillo	1.20	1.50	3.80	5.00	8.88	9.72	9.61	8.95	6.80	4.70	2.60	1.20	63.96
Austin	2.00	2.66	4.30	5.27	7.55	8.28	8.12	8.20	6.22	4.93	3.08	2.08	62.69
Brownsville	2.57	3.18	4.53	5.31	6.88	7.31	7.59	7.33	5.98	5.16	3.40	2.42	61.66
College Station	2.00	2.65	4.23	5.22	7.57	8.35	8.20	8.41	6.25	4.91	2.83	2.04	62.66
Corpus Christi	2.42	3.06	4.56	5.31	6.97	7.53	7.89	7.45	5.95	5.12	3.28	2.30	61.84
Dallas/Fort Worth	1.80	2.45	4.09	5.15	7.41	8.42	8.76	8.13	6.13	4.49	2.62	1.72	61.17
Del Rio	1.30	1.80	4.30	5.20	8.01	8.71	8.26	8.24	7.70	6.00	3.00	1.10	63.62
El Paso	1.30	1.70	4.20	5.60	8.88	9.91	9.24	8.32	7.60	5.20	3.00	1.10	66.05
Galveston	1.65	2.10	3.14	4.04	4.84	5.18	4.97	5.10	5.05	3.99	2.51	1.71	44.28
Houston	2.02	2.71	4.03	5.23	7.48	8.08	7.79	7.78	6.06	4.90	3.06	2.12	61.26
Lubbock	1.20	2.10	4.60	5.40	8.37	9.23	9.06	8.26	6.60	5.00	2.30	1.00	63.12
Midland	1.30	1.70	4.20	5.60	8.60	9.23	9.10	8.35	7.60	5.20	3.00	1.10	64.98
Port Arthur	1.98	2.71	4.09	4.93	7.09	7.66	7.25	7.27	5.82	4.74	2.95	2.00	58.49
San Angelo	1.30	1.80	4.30	5.20	8.01	8.71	8.26	8.24	7.70	6.00	3.00	1.10	63.62
San Antonio	2.07	2.77	4.40	5.33	7.58	8.21	7.96	8.03	6.19	4.95	3.14	2.15	62.78
Victoria	2.13	2.78	4.34	5.18	7.13	7.65	7.94	7.59	6.09	5.02	3.19	2.23	61.27
Wichita Falls	1.10	1.50	3.70	4.50	7.89	8.86	9.20	8.50	6.70	5.20	2.10	0.90	60.15

* Data obtained from <http://texaset.tamu.edu/pet.php>

** Average evapotranspiration for locations near those listed or for specific time periods may vary from the averages shown here.

Appendix V

Worksheet 1: Sample Supply Worksheet

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	A	B	C	D	E	F
Follow the lettered instructions for each month.	From Appendix I, enter the rainfall amount in inches for each month.	Multiply "A" by 0.623 to convert inches to gallons per square foot.	Enter the square footage of the catchment surface.	Multiply "B" by "C" to yield the gross gallons of rainfall per month.	From Appendix II, enter the runoff coefficient for your catchment surface.	Multiply "D" by "E" to obtain the total monthly yield of harvested water in gallons.
January						
February						
March						
April						
May						
June						
July						
August						
September						
October						
November						
December						
Annual						



Worksheet 2: Sample Demand Worksheet

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	A	B	C	D	E	F
Follow the lettered instructions for each month.	From Appendix IV, enter the ET amount in inches for each month.	From Appendix III, enter the appropriate plant water use coefficient.	Multiply "A" by "B" to obtain plant water needs in inches.	Multiply "C" by 0.623 to convert inches to gallons per square foot.	Enter the total square footage of landscaping.	Multiply "E" by "D" to obtain your total landscaping demand in gallons.
January						
February						
March						
April						
May						
June						
July						
August						
September						
October						
November						
December						
Annual						

Worksheet 3: Storage/Supplemental Water Use Calculations

Month	Yield	Demand	Cumulative Storage (Yield minus Demand)	Supplemental Water Use
YEAR 1				
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				
YEAR 2				
January				
February				
March				
April				
May				
June				
July				
August				
September				
October				
November				
December				

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Appendix VI

Guidelines for Gutters and Downspouts

Gutters and downspouts for distributing rainwater should be the correct size, durable, attractive and well-suited to buildings on which they are used. Because specifications depend on gutter type and special considerations such as snow load or roof construction, you should consult a company specializing in gutter design and installation for product advice.

General guidelines for selecting and installing gutters include:

- Select gutters at least 5 inches wide.
- Select gutters made from galvanized steel (29 gauge minimum) or aluminum (.025 inch minimum).
- To enhance flow, slope sectional gutters $\frac{1}{16}$ inch per 1 foot of gutter; slope seamless gutters $\frac{1}{16}$ inch per 10 feet.
- Use expansion joints at connections for straight runs exceeding 40 feet.
- Keep the front of the gutter $\frac{1}{2}$ inch lower than the back.
- Provide gutter hangers at least every 3 feet (every foot in areas of heavy snow load).
- Select elbows with 45, 60, 75 or 90 degree angles, as needed.

General guidelines for selecting and installing downspouts include:

- Space downspouts from 20 to 50 feet apart.
- Provide 1 square inch of downspout area for every 100 square feet of roof area. (A 2-inch-by-3-inch downspout will accommodate 600 to 700 square feet; a 3-inch-by-4-inch downspout will accommodate up to 1,200 square feet.)
- Do not exceed 45-degree angle bends.
- Select downspout configuration (square, round or corrugated round) depending on your needs.
- Use 4-inch-diameter pipes to convey water to storage containers or filters.



Appendix VII

Other Publications and References

City of Albuquerque, *Rainwater Harvesting: Supply from the Sky*.

Billy Kniffen, *Rainwater Harvesting in Menard County* (Menard County Extension).

Lower Colorado River Authority, *Saving from a Rainy Day* (Austin, Texas).

Wendy Todd Price and Gail Vittori, *Texas Guide to Rainwater Harvesting*, Second Edition (Texas Water Development Board, 1997).

Jerry Turrentine, *Wildlife Watering Facilities* (United States Department of Agriculture – Natural Resource Conservation Service, 1992).

Patricia H. Waterfall, *Harvesting Rainwater for Landscape Use* (Arizona Department of Water Resources, 1998).

Title 30, Texas Administrative Code, Chapter 344.



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