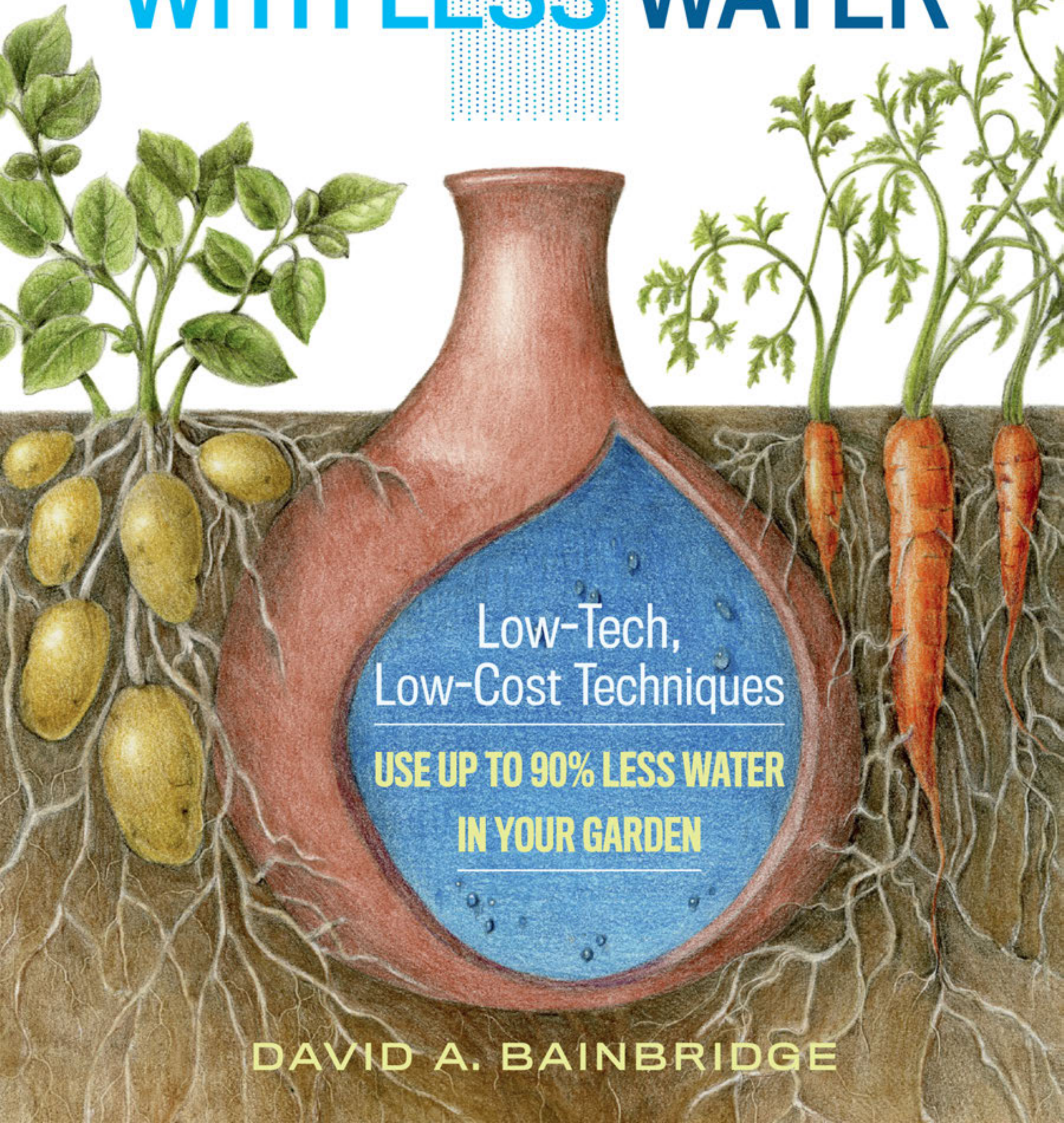
# GARDENING WITH LESS WATER



Low-Tech, Low-Cost Techniques

USE UP TO 90% LESS WATER IN YOUR GARDEN

DAVID A. BAINBRIDGE

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This book is dedicated to
Dr. M. H. Marigowda,
considered by many to be the
father of horticulture for India.
Among his many great
achievements are his techniques
for dryland orchards that gave
good yields but also served as
"progeny orchards," containing
many varieties of a single fruit or
crop to protect the gene pool.
To conserve water and irrigate
crops, he explored many
traditional systems and promoted
both wick and buried clay pot
irrigation. He found that fruit tree
saplings would grow healthily
for nearly a fortnight
on just one buried clay pot
full of water!

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# INTRODUCTION: RUNNING OUT OF WATER

We are running short on water in many parts of the world. Droughts are becoming more common and severe, and the costs of water and food are going up. Farmers and gardeners urgently need to produce more with less water while minimizing the time required to irrigate and weed their gardens or fields. Despite the need for low-cost, simple, improved irrigation systems, scientific research and international development programs largely neglected this challenge until almost the turn of the twenty-first century.



My own research in super-efficient irrigation began in the 1980s. I was working at the Dry Lands Research Institute at the University of California, Riverside, when I first read about buried clay pot irrigation in a book written 2,000 years ago by Fan Shengzhi. Shengzhi had been hired by the emperor of China to help increase the yields of farmers who had too little land and too little water. I was intrigued, and soon, after giving it a try myself, I was hooked.

The super-efficient irrigation systems described in this book address the three most critical problems that gardeners, homeowners, and small land-holders face: water, weeds, and time. Learning from the past is critical to improving irrigation performance, reducing water use, and improving land management. These simple, proven techniques have been adapted from the best traditional practices and augmented and improved with modern materials and research. With them, you can double, quadruple, or even further increase your water-use efficiency.

Many people worldwide and throughout history have faced the same problems and developed systems that enabled them to establish stable, healthful, and enjoyable livelihoods in areas with as little as three inches of rain. No one has done it better than the Nabateans, an ancient Semitic people of the Middle East. Rainwater harvesting and floodwater farming enabled the Nabateans to support flourishing cities and a strong economy in the dry Negev Desert. By learning from them and other people of the past and present, we can do the same with well-planned rainwater collection and management, super-efficient irrigation, careful selection and care of crops, and thoughtful design and construction of buildings and facilities.

My goal from the beginning has been to develop super-efficient, low-cost irrigation systems that will work with low-quality or slightly salty water and can be made and installed by unskilled or non-technical workers using local resources. These practices can provide a sustainable living almost anywhere in the world, whether the climate is exceptionally dry or more temperate. Most of my work has been done in the western part of the Sonoran desert where annual rainfall is only 3 inches and temperatures can soar above 100°F in any month. Because we were working in remote areas, we usually had to bring water in by truck, and some sites required four-wheel drive. Every drop had to count.



Improving water use is important in the United States but critical for the one billion resource-limited farmers around the world who struggle to grow sufficient crops with inadequate water supplies. These growers face difficulties in locations where the climate is moderate but rainfall is seasonal, and they face almost impossible challenges in arid and semi-arid regions.

**Super-efficient irrigation practices can provide a sustainable living almost anywhere in the world, whether the climate is exceptionally dry or more temperate.**

Climate change, including increased climate variability and more severe droughts, is expected to worsen the problems these farmers and gardeners face. The recent drought in the western United States and the severe 2011–12 drought in Mexico suggest what's likely to come. Lake Mead, a reservoir that provides water for 25 million people, reached its lowest point ever in 2015, and some projections for its future are very grim. The global predictions for future droughts are even more sobering.

Continuing research in super-efficient irrigation will help us better prepare for this future. These systems can also reduce the cost and improve the success of environmental restoration, landscaping, and revegetation projects, bringing critically needed trees and shrubs back to degraded watersheds and denuded landscapes. The word is getting out, and enterprising people are bringing these systems to market. Many opportunities exist for start-up companies in super-efficient irrigation and rainwater harvesting.

Teachers, students, gardeners, farmers, and extension agents can

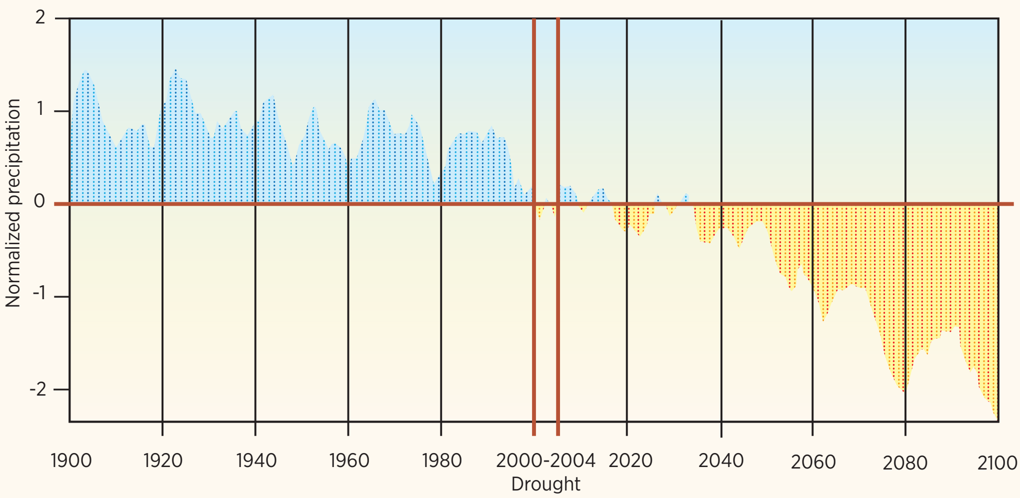
**Lake Mead's "bathtub ring"** clearly shows the effects of drought on the reservoir.

help improve our understanding of super-efficient systems and encourage others to use them through classes, instructional videos, articles, and books. Foundations, universities, cities, states, and federal programs can also help by funding and supporting research and demonstrations. Adding rainwater harvesting and super-efficient irrigation to school and university gardens and landscaping should be a priority.

With this book, you will learn about super-efficient irrigation systems and how you can use them as part of a water-wise garden, landscape, or farm. Once you try these techniques and see them in action, you can adapt them to your situation, even if you have only a sunlit balcony or porch. Try several and see what works for you. Experiment. There is still much to be learned, and you can help: post your pictures, data, and videos online so others can learn from your successes (and problems). We will all need to play a part in reducing our water use, making our food system more sustainable, and restoring degraded landscapes. This book is a step toward that brighter future.

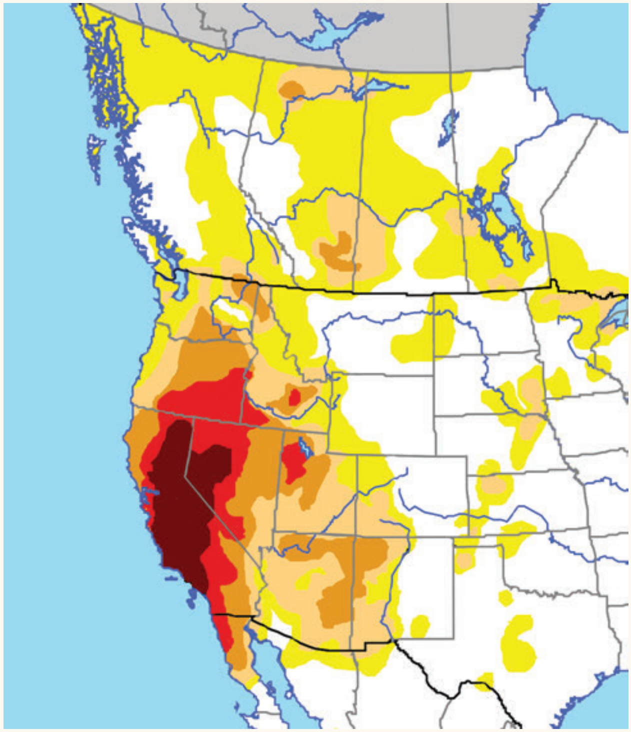


## Western North America Precipitation, 1900–2100




From the 2013 IPCC (Intergovernmental Panel on Climate Change) Models

## U.S. Drought Monitor, West



### Intensity

- D0 Abnormally Dry
- D1 Moderate Drought
- D2 Severe Drought
- D3 Extreme Drought
- D4 Exceptional Drought

Source: www.droughtmonitor.unl.edu

**Global climate change models suggest severe drought may become the norm.**

# SUPER-EFFICIENT IRRIGATION SYSTEMS

PART ONE

**Though they have not been well studied or publicized, super-efficient irrigation techniques have been used for thousands of years in some cases and tested in many soil types and with many different plant species, from flowers to trees.**



As I began researching low-tech, high-efficiency irrigation techniques suitable for remote sites, I asked every visitor to the Dry Lands Research Institute about traditional irrigation systems they had seen. Many had interesting stories to tell but little information about these "primitive" systems. Most were aware of these systems but would not risk their careers by studying them; they had to study modern systems for high-input agriculture. Fortunately, the tides have turned now, and scientists are more willing to study traditional practices that often prove to be very sophisticated and efficient.

Drip irrigation has helped increase water-use efficiency in gardens and farms, but drip systems are for the well-off. To work reliably, the drip emitters require regulated water pressure, pumps, electricity, automated controls, careful filtration, and regular maintenance. They also demand special materials and sophisticated manufacturing methods. I started off using drip systems in the desert but found that drip emitters were easily blocked with sediment and salt and that several insect species specialize in plugging the emitters. Worse yet, coyotes, rabbits, and other animals chewed on and destroyed my drip tubing even when it was dry and open water was available nearby. In a study of repellants to discourage animals from eating my plants in the California desert, all the drip tubing was snipped off before the plants were touched. I better understood why this is often called "spaghetti tubing." These vulnerabilities frustrated me and often led to complete failure of drip systems in remote or less developed areas.

**It is possible to cut water use 90 percent compared to surface irrigation.**

International agricultural research has focused on high-input, high-yield agriculture, and drip can work well for many of these applications. However, the super-efficient systems described in this book make it possible to save even more water with systems that are more reliable and robust and can be made with locally available materials. The lower cost and improved production efficiency of these systems can be critical

**Porous hose** works very well in raised beds. The hose is shown exposed but should be covered with mulch or soil for improved efficiency.



for gardeners and farmers with little water, limited land, and limited resources. Water use can often be cut 90 percent below surface irrigation and 50 percent below drip. Drip systems may deliver one gallon per hour for each emitter, while some of the systems described in this book may use less than a gallon a week or even a gallon a month.

The key to minimizing water use is to get water to the plant just as it is needed, with little or no loss to evaporation and runoff. Getting water into the deep root zone helps. Irrigation systems that automatically self-regulate, such as buried clay pots, porous capsules, porous clay pipes, and capillary wicks, are particularly efficient because the water flow rate varies with plant water demand. More accurately targeted irrigation systems allow water, soil amendments, and fertilizer to be placed where they will benefit crops rather than weeds. Farmers and gardeners also appreciate the fact that these systems reduce the time required for watering and provide water reliably even if left unattended for several days.

These simple, sturdy systems work well and add value. They can dramatically increase plant survival, improve plant growth, and increase crop yield under the most severe



**Demand-responsive irrigation** is the most efficient. In the photo below, the front row is being irrigated by buried clay pots and the next row by porous capsules.

conditions. They reduce water demand and help develop more robust plants that better tolerate drought. The following chapters provide the information you need to get started using these systems. You may eventually use several types to meet the differing needs around your house, garden, or farm. Deep pipes can be best for trees and shrubs, buried clay pots may be best for spreading crops such as melons, and porous hoses may be best for row crops such as carrots. Don't be afraid to try out different combinations, such as wicks with deep pipes, wicks with clay pots, vertical porous hose and clay pots — or whatever works.

**The key to minimizing water use is to get water to the plant just as it is needed, with little or no loss to evaporation and runoff.**

CHAPTER 1

# Buried Clay Pots

**Buried clay pot (also called pitcher or *olla*) irrigation is one of the most efficient systems known, thought to have originated in China thousands of years ago. Filled with water, a buried, unglazed, porous clay pot provides controlled irrigation by capillary flow to plants planted near it.**



They come in various shapes and forms: round pots with narrow necks, cylinders, or standard terra-cotta nursery pots. Because the rate at which water seeps through the pot wall is determined partly by how much water the plant is drawing from the soil, this system is up to ten times more efficient than conventional surface irrigation. Clay pots can be used without pressurized or filtered water and can be made with locally available materials and skills almost anywhere in the world. They are much less likely to be damaged by animals or clogged than drip systems.

I was introduced to clay pot irrigation through a 2,000-year-old Chinese agricultural extension book by Fan Shengzhi, a skilled agronomist

**Ollas have provided** efficient irrigation for more than 2,000 years.

and scientist who prepared his book at the behest of the Emperor to help farmers with limited resources. After reading excerpts from his book, I headed out to the garden at the University of California, Riverside, to install some clay pots. Sure enough, they worked — and worked well — with very little water. In a subsequent test in the California desert, I found that all the trees on buried clay pots were alive and healthy after eight months, while all of the trees receiving the same amount of water with conventional basin irrigation had died.

The following spring I started exploring the use of buried clay pots for growing vegetables. I found that melons and squash grew very well and had minimal weeds, despite an appalling level of weed seeds in the university community garden beds. I also grew some Hopi corn (*Zea mays*) in my shaded back yard with only one-tenth the conventional water use for corn in California.

Meanwhile, I learned that buried clay pot irrigation was still being used on a limited basis in the drylands of India, Pakistan, Iran, the Middle East, and Latin America. The yield of melons grown this way in India, for example, was almost 20 times higher per gallon of water than flood irrigation in California. (I also met a Mexican farmer who put his son through college with clay-pot irrigated melons!) In Ethiopia's semiarid northeast, tomato production was 50 percent higher than with furrow irrigation. In another study, buried clay pots allowed farmers to grow two crops of corn a year, enabling a family to meet their corn needs with only one-tenth of an acre.

Buried clay pot irrigation has been used successfully for a wide range of perennial plants, including citrus, fruit, and nut trees, from pistachio groves in Iran to dry orchards in India to forests in Pakistan. Many of my desert restoration projects in California have been successful with this technique too.

**Getting water directly** to crops can minimize weed growth. *Top:* Traditional surface irrigation. *Bottom:* Wicks and buried clay pots.

The consistent water supply of buried clay pots improves germination, increases crop growth, speeds maturity, reduces diseases, and increases yields, even in places with very high temperatures, low humidity, and desiccating winds. They can also be effective in sandy or gravelly soils that drain very quickly and with salty or alkaline water or soil. Finally, both water and soil amendments can be placed more specifically to benefit crops rather than spread over an entire plot, resulting in fewer weeds and less fertilizer use. In one trial, the weed weight was only 200 pounds per acre with buried clay pots, as opposed to a gigantic 8.5 tons per acre with flood irrigation.

The size of the buried clay pot, the porosity of the clay (a factor of clay mix and firing temperature), pot wall thickness, water quality, and the water demand of the plants all influence how often you will have to refill the pot, but larger ones can afford you a week or more between watering. This makes this technique a good choice for the suburban or urban gardener who may be able to work in the garden only on weekends.

You can choose to keep your pots filled or to fill them periodically.

For our desert work, they would often be completely dry when we returned after two or three weeks — but the trees and shrubs were still alive. In the garden or container, some plants seem to like the added oxygen they get when the pot is nearly empty. This can be especially helpful in fully glazed or plastic containers that don't breathe. Other plants prefer the pots to provide more consistent water, perhaps with a continuous feed line or refilling when they fall to half full. Watch your plants and see what they like best.

Specially manufactured irrigation ollas are now being made and sold in the United States and Australia. Many unglazed pots made in Mexico will work well, and similar pots can be found or made around the world.

**The olla** should be buried up to the neck. A small lid or a rock can be placed over the opening.

## Environmental Restoration

Buried clay pots have great potential to aid tree establishment and environmental restoration projects. During tests in the very hot and dry low desert of California, plant survival with buried clay pots often ranged from 78 to 100 percent when all the plants on traditional basin or surface irrigation systems (including drip) died.

Install the pot as in the garden and refill as possible. If you use a rubber stopper, you can pull it out after a year and water deeper into the soil. Pots can usually be pulled after two to three years.

**Roots of older plants** may grow thick around the pot, but in desert studies, this did not hurt long-term survival.

## Preparing Clay Pots

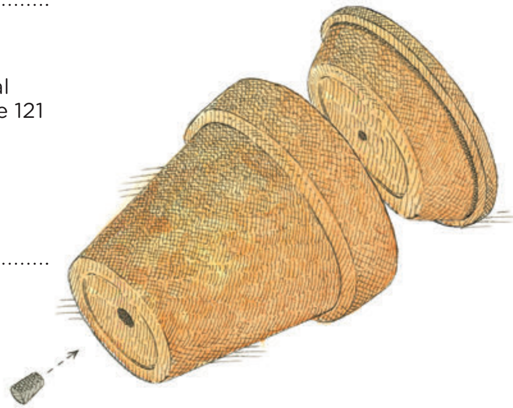
Clay pots must be porous, not glazed, and free of wax, paint, or other impervious coatings. They can be tested by spraying them with water and making sure that the surface becomes damp immediately, or by placing them in a bucket of water and making sure the water wets them fully. I use standard red terra-cotta clay pots because they are available in a wide range of sizes and can be found anywhere. Half-gallon to one-gallon pots are convenient, but smaller and larger pots can be used as well. I have found that the 8-inch diameter, 10-inch-tall pots are a convenient size. The bases that are sold with these pots make excellent lids as well.

**MATERIALS**

- terra-cotta pot and base
- rubber stopper, size 5 for a typical 8-inch pot (see Appendix on page 121 for a chart of stopper sizes)

**TOOLS**

- sandpaper
- (optional) drill with ceramic bit



**1.** Seal the hole in the bottom of the pot with a rubber stopper. For a shrub or fast-growing plant, put the stopper in from the top so you can pull it out later to encourage deeper root growth. For annual plants, put the stopper in from the bottom so you don't have to worry about it being dislodged.

**2.** Once the pots are sealed, you can compare porosity by filling them and either measuring the drop in water level or weighing them repeatedly for a couple of days with a good scale — my kitchen scale is accurate enough. Most terra-cotta pots are very consistent, but occasionally you will find some that are over-fired and impervious in some areas. These areas often appear as an irregular lighter blotch on the clay. After a while, you can recognize this and leave those pots on the nursery shelf.

**3.** Rest the pot base on top of the pot to create a lid. You can simply lift the lids to fill your pots by hand, but if you want them to collect rainwater, you can drill a small drain hole with a ceramic or glass cutting bit.

**4.** If you'd like, paint the rims and lids of clay pots with non-toxic paint to reduce evaporation and make them easier to see in the field.

**Alternative Methods.** To seal the hole, you can also use silicone caulk, epoxy, hot melt glue, or polyurethane glue. Put masking tape on one side of the hole and fill the hole from the other side with the glue or other material.

Pie tins or ceramic plates from thrift stores make good lids if you don't have pot bases. The lid should fit snugly over the top of the pot. For narrow-necked pots, a stone, tile, or small cup will work as a lid.

## Handmade Clay Pots

Clay pots are handmade for irrigation in many parts of the world. The clay mix and firing temperature can be adjusted for ideal porosity. Potters are likely to know how to manage grog (broken and crushed pieces of pottery), clay, sand, and other additives to adjust porosity. Increasing the amount of grog in the terra-cotta will increase porosity. Wall thickness, type of clay, and many other factors may affect porosity as well, so test-fire some samples before starting major production.

Firing temperatures can be adjusted to provide suitable porosity and good durability. Do not fire the clay above 1832°F (1000°C), or the porosity may be reduced. On the other hand, if the pots are too low-fired the clay may break up in very saline or alkaline soil as a result of chemical reactions. Permeable pots can also be made of other materials, including concrete, by adjusting the percentage of fine aggregate and sand.

**Ollas dry** on the shelves at Kersey Ceramics.

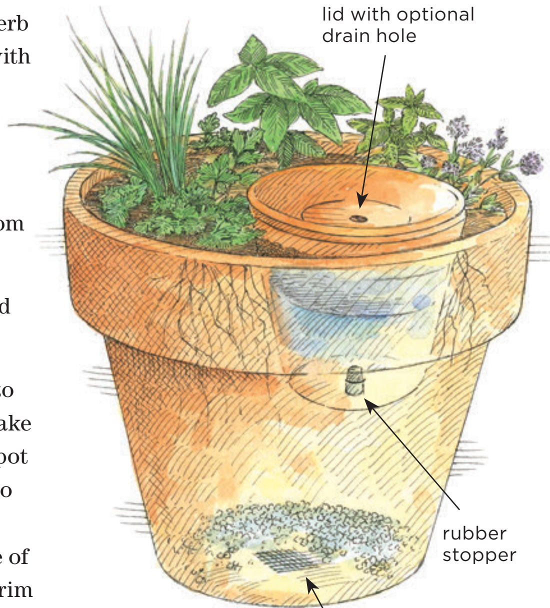
**Potter Diana Kersey** makes ollas by hand at Kersey Ceramics in San Antonio, Texas.

The best shape for a pot depends on its use. A 1- or 2-gallon pot is a convenient size, but pots of 4 or 5 gallons can be used for trees. An olla with a narrow neck and a small hole is easier to cover and plant around, but a pot with a wider top is easier to fill and can catch more rain. A handle makes it easier to lift the lid. For watering plants grown in containers, a slender pot with a taller neck is easier to fit in the container. You can glaze or paint the rim of a pot to increase durability, improve visibility (reducing damage), and just to add some color or character.

## Using Double Clay Pots for Container Plants

Double clay pots work well for landscaping and kitchen gardens and are excellent for propagating cuttings in the nursery or field. I have used double clay pots for a wide range of herbs, flowers, and shrubs. They are helpful for plants such as roses that demand considerable moisture but are sensitive to mold and fungus if the leaves are wetted. Indoors, clay pots in containers can reduce problems of water-logging and rapid drying and make damage to floors and carpets less likely.

Try it yourself with a double-clay-pot herb garden. Use an 18- to 24-inch clay pot with an 8-inch watering pot in the center.




**1.** Seal the hole of the smaller pot and place a screen over the hole in the bottom of the larger outer pot.

**2.** Place pea-sized gravel or coarse sand in the bottom of the outer pot.

**3.** Fill the outer pot with planting mix to within about 6 inches of the surface. Make a hole in the soil and place the smaller pot inside the larger one (you can offset it to one side of the container to allow easy access for refilling) so that the top edge of the small pot will be slightly above the rim of the larger pot. Put the lid on to keep soil out, and fill in around the pot.

**4.** Water the mix and fill the inner pot with water. Let sit overnight.

**5.** Using a trowel, make planting holes near the outer pot rim, and place the plants, cuttings, or seeds in the moist soil. Leave a space between plants on one side to make it easier to lift the lid and refill the pot with water.

**6.** Sprinkle the plants or seeds with a watering can to reduce shock and add a bit more moisture to the surface soil. Keep the inner pot filled with water.

## Aeration

Clay pots can also be used to improve soil aeration in glazed, impermeable containers. These containers can cause problems for many species because of lack of oxygen for the roots. An inverted unglazed clay pot can be set in the center of the container to provide oxygen to the soil mix.

## Garden with Clay Pots

Most plants are very compatible with clay pot irrigation. Fast-growing water hogs such as squash vines will need big pots or more frequent refills. With some sensitive species, the constant moisture can lead to disease problems in damper climates when rain adds extra moisture to the garden. Usually, however, diseases are much reduced because leaves and stems are not wetted and plants are not stressed.

In his book, Fan Shengzhi describes intercropping with buried clay pots. Garlic or onions, with their small plant heads, go well with slower-growing, "spreadier" plants such as tomatoes or cilantro. Buried clay pots also make it easier to grow vegetables under trees such as eucalyptus that have aggressive and active root systems near the soil surface.

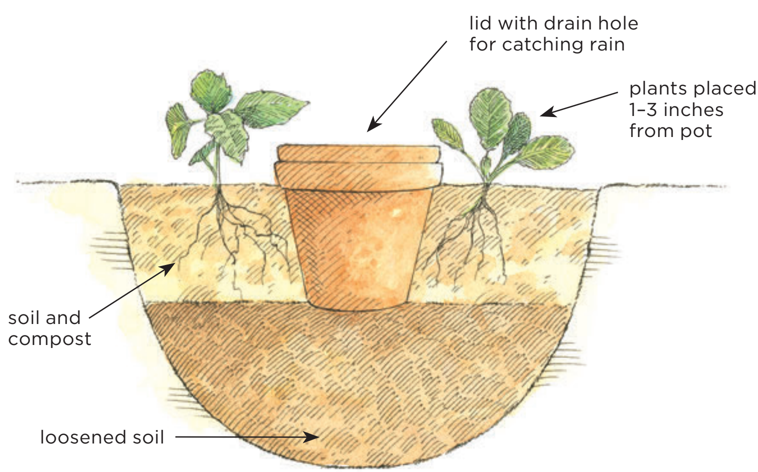
Placing buried clay pots in the garden is simple:

**1.** Dig a planting hole about three times as wide and two times as deep as the pot. Use a garden fork to break up soil at the bottom of the hole, and break up any clods in the soil you have removed. Mix in one-third compost or aged manure, plus amendments and fertilizers as needed. In very heavy soil, mix in some sand and organic matter; in saline or alkaline soil, add gypsum or calcium as needed.

**2.** Partially refill the hole with soil mix so that, when placed, the top of the buried clay pot will be about an inch above the surface of the surrounding soil. The rim on standard red clay pots makes a good soil-line marker. Then set the buried clay pot in place with the lid on.

**3.** Fill the space around the pot and firm it by tamping or pressing on the soil with your hands. Scoop any dirt out of the pot.

**4.** Fill the buried clay pot with water, add a little to the soil outside the pot, and let the soil moisten overnight. This will help you see how close to the pot the seedling or seeds should be placed. In coarse, fast-draining soils they may need to be very close to the pot. With ollas, the wider profile and narrow neck of the pot means the plants will be set further from the neck.



**5.** Place additional pots as needed. Pots may be placed 24 to 36 inches apart in most soils, depending on the size of the pot. Place them closer in sand and farther apart in clay-rich soil, again using the wetted area from your first pot as a guide.

**6.** Now you can place your seeds or plants in the wetted soil. In many soils, the seeds or plants should be placed within 1 to 3 inches of the edge of the buried clay pot. Leave a space between plants on one side of the pot to make it easier to reach the lid for refilling when the plants are fully grown.

**7.** Refill the buried clay pot as needed. Small pots may need to be refilled every two to five days, but larger ones only once every two to three weeks. The time will vary over the growing season. For many plants, you can let the water level drop to the bottom of the pot before refilling, but the terra cotta should remain moist.

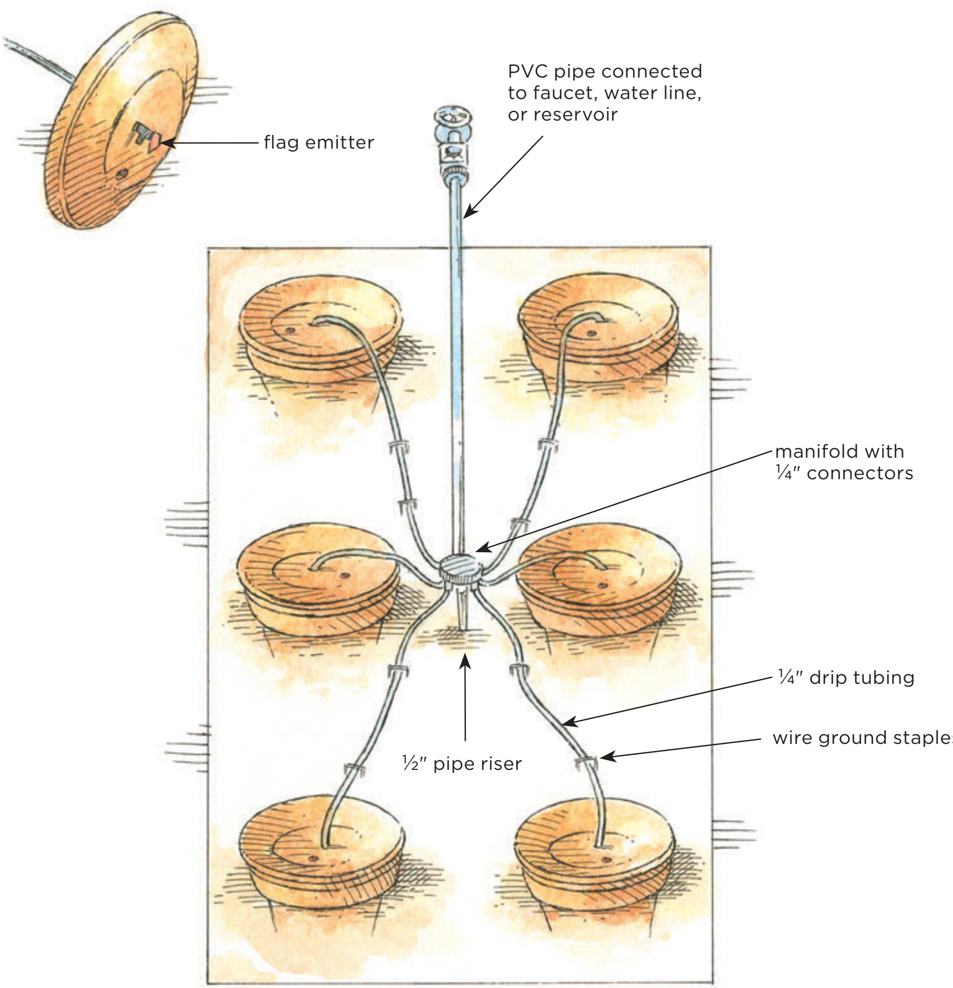
## Maintenance and Storage

Snails and slugs are easy to manage with clay pot irrigation. They tend to collect at the pot/soil seam or crawl into the pot as it dries out and can easily be removed and fed to the ducks. Fertilizer should not be included in the pot water as it may clog pores and lead to algae growth. Apply liquid fertilizer or manure tea outside the pot.

After the season is over, scrub the pots clean and stack them upside down for the winter so they do not trap water and become insect breeders. If calcium starts to build up, they can be soaked in vinegar.

## Self-Filling Pot Systems

Buried clay pots are usually filled individually, but if you will be away often or don't want to bother filling them by hand, they can be connected to a reservoir or water system.



**MATERIALS**

- half-inch PVC pipe and fittings to connect to water line, faucet, or reservoir
- half-inch pipe riser
- manifold with quarter-inch connectors
- quarter-inch drip tubing
- flag emitters (or tubing connectors)
- wire ground staples to hold tubing in place (can be made from coat hanger wire)

**TOOLS**

- drill with quarter-inch ceramic bit
- utility knife

**1.** Install a ½-inch PVC pipe feed line from a manual or automatic control valve on a reservoir, pipe, or faucet to the center of the bed.

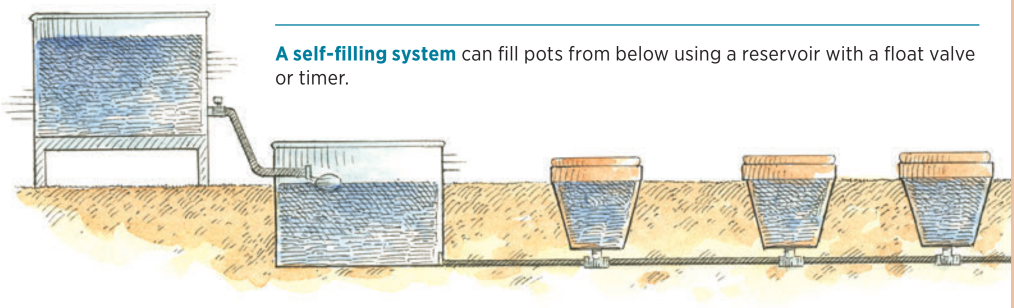
**2.** In the center of the bed, install a ½-inch pipe riser and a manifold with ¼-inch tubing connectors. These are commonly available at your garden or home supply stores.

**3.** Measure the tubing required to reach from the manifold to each pot and cut to length. Connect the ¼-inch tubing to the manifold (dip tubing in a thermos of hot water for 10 to 20 seconds to make it easier to work with), and run it to the pots. Pin the tubing down with wire staples so that it will not get snagged on things.

**4.** Drill a ¼-inch hole in the lid of each buried clay pot, and push the tubing through. Put a flag emitter or a tubing connector on the inside of the lid to keep the tubing from being pulled out.

**5.** Check periodically to make sure your pots are filling properly.

**Alternative Methods.** You can also make a self-filling system by installing plastic fittings in the holes in the bottoms of the pots and linking the pots to a reservoir with a float valve or timer.



**A self-filling system** can fill pots from below using a reservoir with a float valve or timer.

CHAPTER 2

# Porous Capsules

**Porous capsule irrigation is a modern adaptation of buried clay pot irrigation. Water is distributed automatically and continuously by gravity in direct proportion to water use by the plant, leading to very high efficiency. Typically set up to run off a storage tank, bucket, bottle, or pressurized water line, porous capsules can be networked more easily than pots and completely buried. Though you cannot see the water level inside the capsules, burying them reduces the risk of damage, helps keep dirt and bugs out, and minimizes evaporation. Porous capsules improve soil and allow for agricultural development in areas where climate and soil quality have prevented the use of conventional irrigation methods.**

I was inspired to explore the use of porous capsules for desert restoration by the research of Aderaldo de Souza Silva and Dinarte Aéda da Silva and their colleagues in Brazil. They performed a wide range of experiments and demonstrated how water-use efficiency with porous capsules could be four times better than with closed furrow systems, three times better than sprinklers, and two times better than drip systems. Years later, I found the much earlier American studies of Burton E. Livingston (1908, 1918) and Lon Hawkins (1910). Hawkins found that, with porous capsules, a coleus plant could survive on just 1.6 gallons of water over the course of half a year. With container plants, root growth was much better and the plants stayed healthy even when the container was impermeable.

After asking all of our international visitors at the Dry Lands Research Institute about porous capsule irrigation, I was convinced it was worth a try. I started out by gluing clay pots together and installed my first large batch of porous capsules on a commercial landscaping project with a storage tank and valve on a battery timer. The tank was refilled periodically by a water truck, and the system worked well.

Most porous capsules have a volume between a quart and a gallon, and they can come in many shapes and forms: pots, ollas, pipelike sections, vertical cylinders, bottles, and flasks. Each porous capsule may have one to four connectors. The pipes and connectors tend to be relatively large in diameter so that they require little or no filtration. If capsules are used in a series, the water readily moves down the line as water is introduced.

Porous capsules can be set up with a very low head (the reservoir close to the height of the capsules). Indoors or in a greenhouse, these systems will even run on negative pressure, with the reservoir below the height of the capsules, because water is drawn up to the capsule as the plants use it. Outdoors, you'll often need more water, so a low-pressure system may work better. A study in Maryland found that fava beans grew better with porous capsules than with conventional surface irrigation, with each plant using

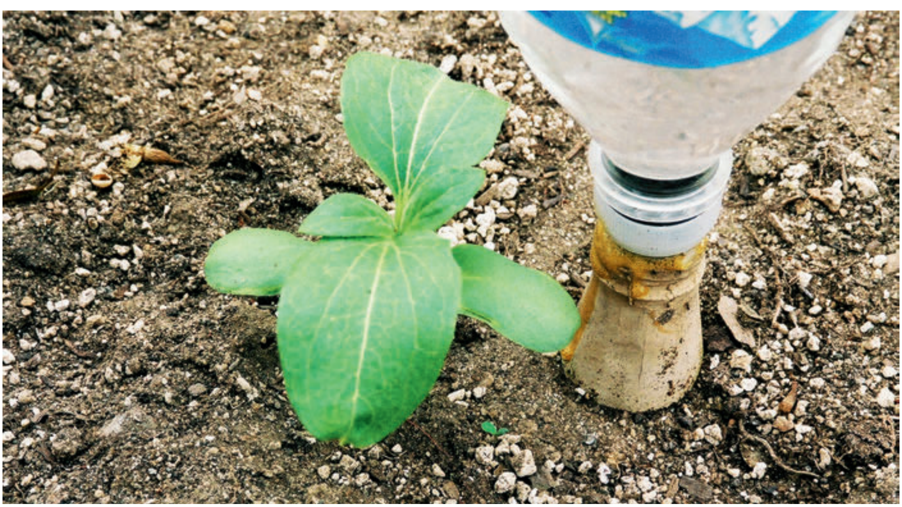
**Above-ground tubing** makes it easier to check water flow in networks of porous capsules.

only one-third of a gallon of water over 49 days. This must be close to the minimum water use possible. In Brazilian crop trials, water consumption was just 3 to 4 inches per acre, one-fifth the water used for conventional irrigation. In Bolivia, potato yield more than doubled with porous capsules, and in Panama fruit tree yield tripled. Porous capsules for the garden are now being made commercially in Australia (see Suppliers, page 123).

Not only are porous capsules useful in greenhouses or in the field, they can be excellent for plant-scaping interiors as well. A large reservoir can offer a very long refill interval for a plant. A wide range of capsule systems for small plants have been developed and sold over the years, manufactured in China, Vietnam, Thailand, and the United States. These are often called plant sitters, plant tenders, water spikes, or ceramic waterers. Some attach to a wine or water bottle and some use a glass sphere as a reservoir, making it easy to monitor water use. Others include tubing that connects to an exterior tank. You can ask for these at local garden shops or find them online. Even Chia Pets, in their many varieties, are a form of porous capsule or clay pot irrigation.

Porous capsules are more costly to make and install than buried clay pots or deep pipes, but in arid environments they will pay for themselves in yield increases, water savings, and reduced weeding time.

**A plastic sports bottle** makes a handy reservoir for a porous capsule.



# Making Porous Capsules

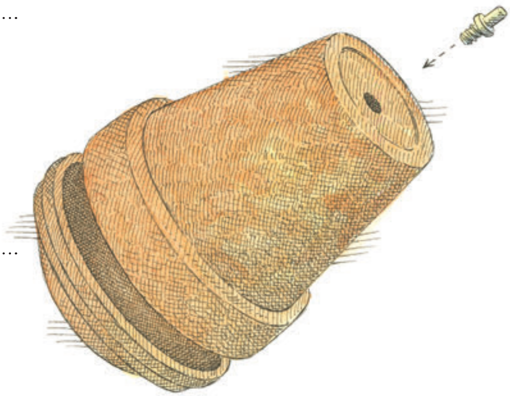
Standard red clay garden terra-cotta pots and pot bases make good porous capsules when glued together. Test the porosity and durability of pots and pot bases before ordering or making a large number of capsules.

**MATERIALS**

- terra-cotta pot and base
- ½-inch threaded-to-barbed plastic fitting

**TOOLS**

- sandpaper
- polyurethane glue or epoxy



**1.** Lightly sand the rim of the pot and pot base on a full sheet of sandpaper (100 to 200 grit) to create a flat surface that will make a watertight joint.

**2.** Glue the plastic fitting into the hole in the pot (follow directions and precautions on glue label). The threads should fit the hole. If the hole in the pot needs to be increased, you can enlarge it with a masonry bit or sandpaper wrapped around a dowel. If the hole is too large, use glue to fill small gaps, or use the rubber stopper method described in Alternative Methods.

**3.** Spread a layer of glue on the rim of the pot and glue the pot and pot base together.

**Alternative Methods.** You can also use two pots of the same size, glued together, with rubber stoppers to seal the holes. A drip-tubing connector will fit snuggly into a ³⁄₁₆-inch hole drilled through a rubber stopper.

## Handmade Capsules

**These porous capsules,** made using a bottle mold, fit into cartons for easy carrying.

You can have porous capsules custom made by a local potter. Fred Edwards, an ecologist and potter on my staff, made two-part molds from both small and large bottles to form porous capsules for my field studies. Once air-dried and fired, these capsules were fairly strong. The bottle-shaped molds Fred made worked well, and the standard sizes made it easy to find cartons for carrying multiple capsules safely. The holes for fittings are best made slightly under size and then drilled or sanded to fit connectors.

## Using Porous Capsules for Container Plants

Water use is much lower and root growth is often much better for container plants with porous capsule irrigation. Even when the outer container is impermeable (a glazed pot, for instance), the plants are less prone to problems of overwatering and disease. Porous capsules can be made small enough to fit pots as small as 6 inches in diameter. Be sure to determine the capsule size needed for a given pot/plant combination before trying it on a larger scale. Tall, thin-necked capsules are easier to fit in containers, but regular capsules can be offset to one side.

**MATERIALS**
- assembled porous capsule with threaded-to-barbed fitting
- plastic reservoir such as a mayonnaise or peanut butter jar

**TOOLS**
- polyurethane glue
- drill with spade bit

**1.** Install a threaded-to-barbed fitting in the capsule as described on page 35, and drill a hole of the same size in the plastic reservoir (a spade bit with spurs makes clean cuts).

**2.** Glue the reservoir to the other end of the fitting on the capsule. Polyurethane glue helps make a tough, leakproof joint.

**3.** Put a couple inches of soil mix into a pot and set your porous capsule in place. Fill the pot with planting mix, covering the capsule so that only the reservoir is visible above the soil.

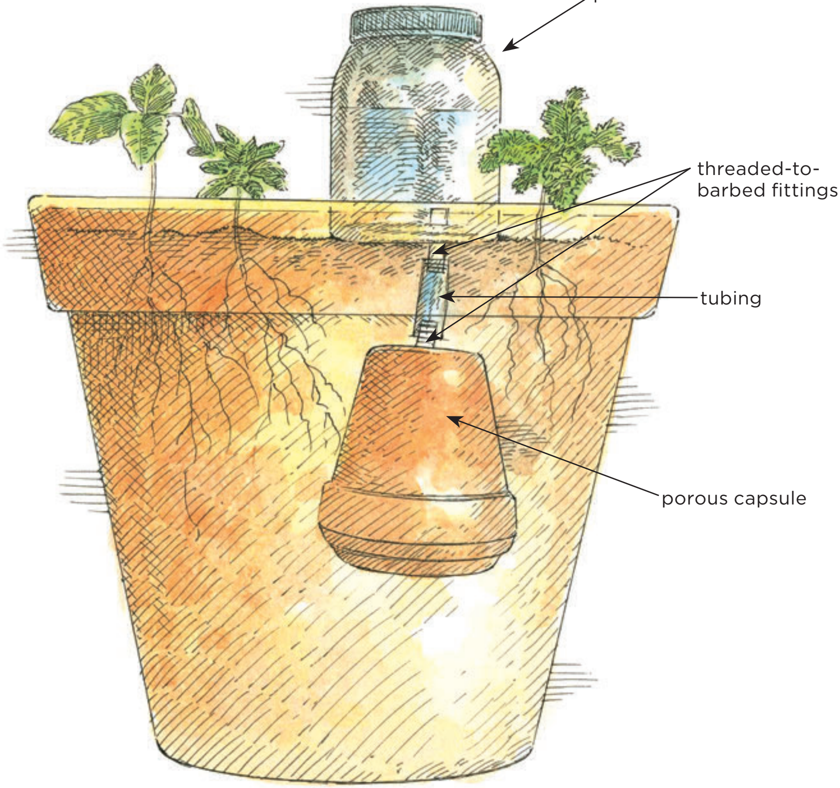
**4.** Water the mix and fill the capsule and reservoir with water. Let it sit overnight.

**5.** Use a trowel to make planting holes for seedlings. Sprinkle the plants with a watering can to reduce shock.

**6.** Refill the reservoir and capsule as needed.

**Alternative Methods.** If you are using a large container and need the capsule to sit deeper in the soil, you can connect the capsule and reservoir with a short piece of ½-inch tubing and a second fitting.

You can also use a funnel or cut-off sport bottle as a refill port that can be glued directly into the capsule. With this method, in order to speed up filling, create a vent tube made from a straw. Insert the straw through the mouth of the bottle or stem of the funnel down into the capsule, and use a twist tie or wire to hold it to the side.



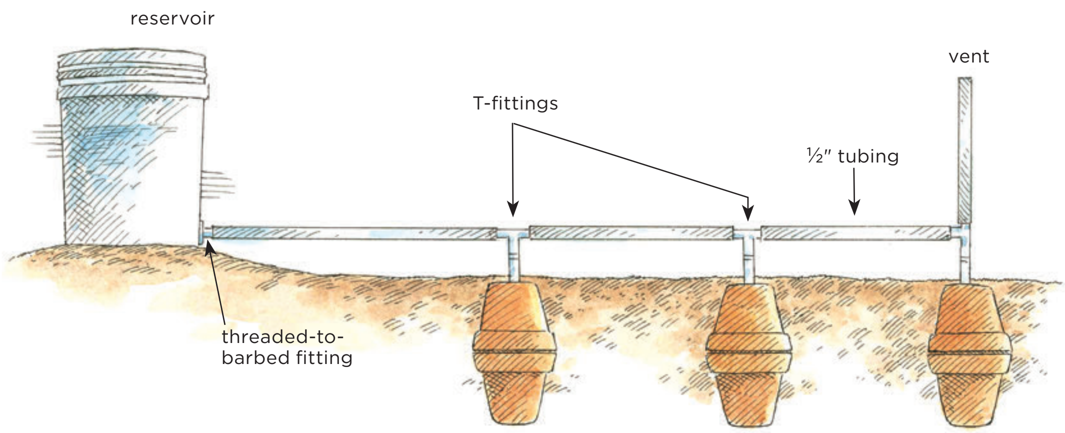

**The reservoir can be connected** directly to the capsule with a single fitting, or, to let the capsule sit deeper inside a larger pot, use a second fitting and a short piece of tubing to lengthen the connection.

## Garden with Porous Capsules

Porous capsules work very well in the garden. Dig a hole for each capsule much like for a buried clay pot. The top of a capsule may be buried 2-4 inches, but with a taller capsule made of two pots, I may leave the top near the surface.

The capsules can be attached to bottles or outfitted with refill funnels, just as for container plants. However, creating a network of capsules will reduce management time for rows of plants. To do this, simply attach a T-fitting to each pot so that it can be connected by tubing to other capsules in a continuous line. The crop will determine spacing, perhaps 2 feet with non-spreading plants and up to 6 feet for melons and squash. If you place the capsules on a slope, water delivery will be greater at the low end, so set them along the contour line to keep them as level as possible.

With another barbed plastic fitting, connect the capsules to a reservoir (such as a 5-gallon bucket) with, perhaps, zero head at the start of the season. The reservoir can then be lifted up to about 18 inches during the maximum growth period to increase water flow. The reservoir can be refilled using a hose or set up with a float valve or timer valve



**Networked porous capsules** reduce the time required for watering.

to fill automatically. At the end of the line of pots, an open vent should be made with tubing or hose. This should extend above the soil to the height of the reservoir to vent air from the system.

Although porous capsules are not as sensitive to clogging as drip emitters, they may eventually clog from sediment or bacterial, fungal, or algal growth. If possible, use a simple 500-mesh filter on the reservoir line or water line to prevent debris from getting into the capsules.

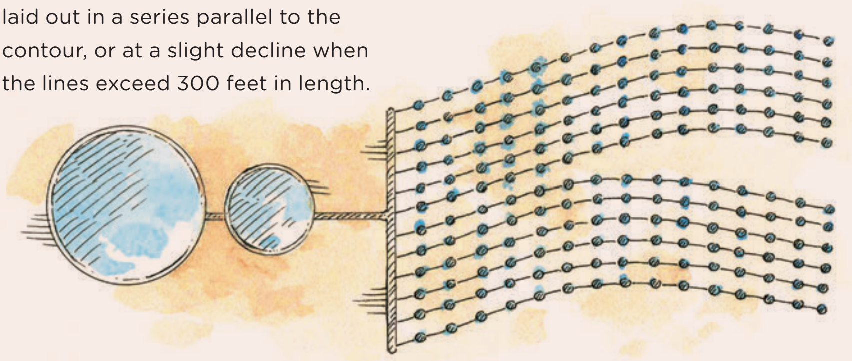
## Low Pressure or No Pressure?

Rainwater from a roof catchment system is ideal for use with porous capsules, because capsules work well at low pressure and the rainwater is salt free. A nice gravity-fed system can be created by connecting a line of porous capsules to a rain barrel.

Capsules used on greenhouse benches or in raised beds can be run at negative pressure, with the reservoir sitting below the capsule. These systems have to be sealed, and the pots are filled the first time by lifting the reservoir (such as a five-gallon bucket) above the capsules until they are filled.

## Commercial Crops

Porous capsules have been used on the farm scale in Brazil, Cuba, Bolivia, and other countries. For commercial production in Brazil, the capsules are buried in a line 6 feet apart, at least 4 inches deep, with up to 320 pots per acre. A typical system will include a reservoir — perhaps a rainwater cistern or tank — feeding a smaller reservoir. A float keeps the water level inside the smaller tank constant, creating a consistent pressure head. A main supply line of ½-inch to ¾-inch PVC pipe is linked to lines of ¼-inch or ½-inch polyethylene or vinyl tubing that connect the porous capsules, which are laid out in a series parallel to the contour, or at a slight decline when the lines exceed 300 feet in length.



## Landscaping Desert

This landscaping project by Highway 86 in the Sonoran Desert used large porous capsules with small feeder lines from a plastic tank filled by a water truck. Survival and growth were excellent after one year and still good at year nine, after many years without irrigation.

installation


year 1

year 9

CHAPTER 3

# Deep Pipes

**Deep pipe irrigation uses a vertical pipe to move water into deeper soil where it is safe from evaporation. I have found this technique very economical and effective for my work planting trees and shrubs in the desert, and it has also worked well for orchards and gardens. Its value was reinforced for me when farmer Tom Trapp of Trapple Orchard in Iowa wrote me the following message:**

"We've had a challenging year here in the Midwest, 90+ degree weather and no rain for 5 weeks now! We installed 3″ x 15″ PVC deep irrigation standpipes, per your concept, when the trees were planted April 20th. While our neighbor's cornfields are burnt and are a complete loss, the bare-root apple trees we planted this spring are holding on. I am certain our new trees would have been goners without your deep pipe irrigation idea!"

In a comparison of irrigation systems for growing grapes in Africa, deep pipe drip irrigation was much more efficient than surface drip or conventional surface irrigation: Root spread reached only 2 feet with surface drip, 3 feet with conventional surface irrigation, but 6 feet with deep pipe drip irrigation. Vine weight was more than double what it was with surface drip, and six times what it was with conventional surface irrigation.

I first became interested in deep placement of irrigation water after conducting tests of root growth and development in desert trees as part of a restoration research project. Desert tree species can grow impressively long tap roots. Anticipating that vigorous roots would improve survival and growth, I needed a method of getting water deep into the soil. Fortunately, an agronomist from India visiting the Dry Lands Research Institute mentioned a tribal practice in which seedlings were placed next to the hollow stem root of a weed after it died. Water was poured into these hollowed-out roots to irrigate the crop.

To get an effect similar to the hollow root, I used sections of PVC pipe with holes drilled down one side to wet the deep soil column. Many other materials can be used as well. My wife has used tall plant containers as deep pipes on two projects. A plastic bottle with small holes punched in one side can be placed upside-down in the soil with a flap cut in the bottom for refilling. Or you can simply bury a plastic bottle upright with a few holes punched in the bottom and take the cap off to fill it. Bamboo with the nodes drilled or punched makes very environmentally friendly deep pipes. The bamboo should be tied or taped to prevent splitting, and a cross pin can be placed near the top to keep lizards out. Commercial deep pipe irrigation systems can now be found at Home Depot and other home and garden stores.

**Deep pipe irrigation** and tree shelters were used for desert restoration in Anza Borrego Desert State Park.

Deep pipes can use low-quality water without extensive support systems and can be set up by unskilled labor using simple materials.

With deep pipe irrigation you can apply water quickly and efficiently with no runoff waste, even on steep slopes, and plants develop much larger root systems, making them better adapted to survive on their own. Deep pipes can use low-quality water without extensive support systems (pressurized, filtered water is not needed) and they can be set up by unskilled labor using simple materials.

For long-term survival and growth, plants will benefit additionally from careful placement in low areas where runoff is concentrated. Tree shelters (see chapter 7) used in conjunction with deep pipes can further reduce water demand and improve survival, even in the desert.

# Make Your Own Deep Pipes

You can make your own low-cost deep pipes with recycled or new pipe, conduit, bamboo with the webs drilled or punched out, or plastic bottles. Deepots and other plant containers can also work. I prefer 2-inch diameter PVC pipe or conduit because it's easy to fill from a water jug. With a drip system, a ½-inch pipe will do. The length of the pipe depends on how deep you would like the roots to grow. Pipes 16 to 24 inches long work well for most situations.

**MATERIALS**

- 2-inch-diameter PVC pipe, 16 to 24 inches
- 4 x 4–inch piece of screen or shadecloth
- polyurethane glue or zip tie

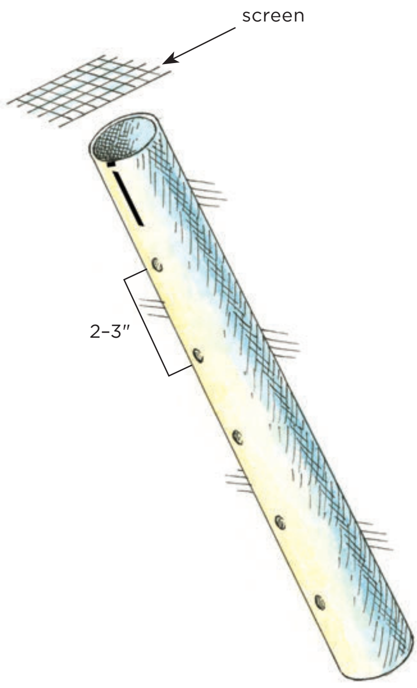
**TOOLS**

- drill with ⅛-inch bit
- marker

**1.** Starting 3 to 6 inches from the top of the pipe (or more, depending on how much pipe you wish to stick up aboveground), drill a row of ⅛-inch holes 2 to 3 inches apart down the side of the pipe. Water seeping through these holes will facilitate root growth in the early stages of development. If shallow-rooted plants from containers are planted next to a deep pipe without these weep holes, the roots may not make contact with the wetted soil even when the pipes are filled with water.

**2.** Mark the top and side of the pipe with a pen or marker so you know what side the holes are on when you bury it and can orient the pipe correctly to water seedlings.

**3.** Cut a piece of screen or shade cloth and glue or zip-tie it over the top of the pipe to keep lizards and other critters from climbing in and getting trapped.




**Alternative Methods.** You can also keep lizards out by setting crossed pins near the top of the pipe. With a larger pipe, place an escape stick inside to allow them to climb out.

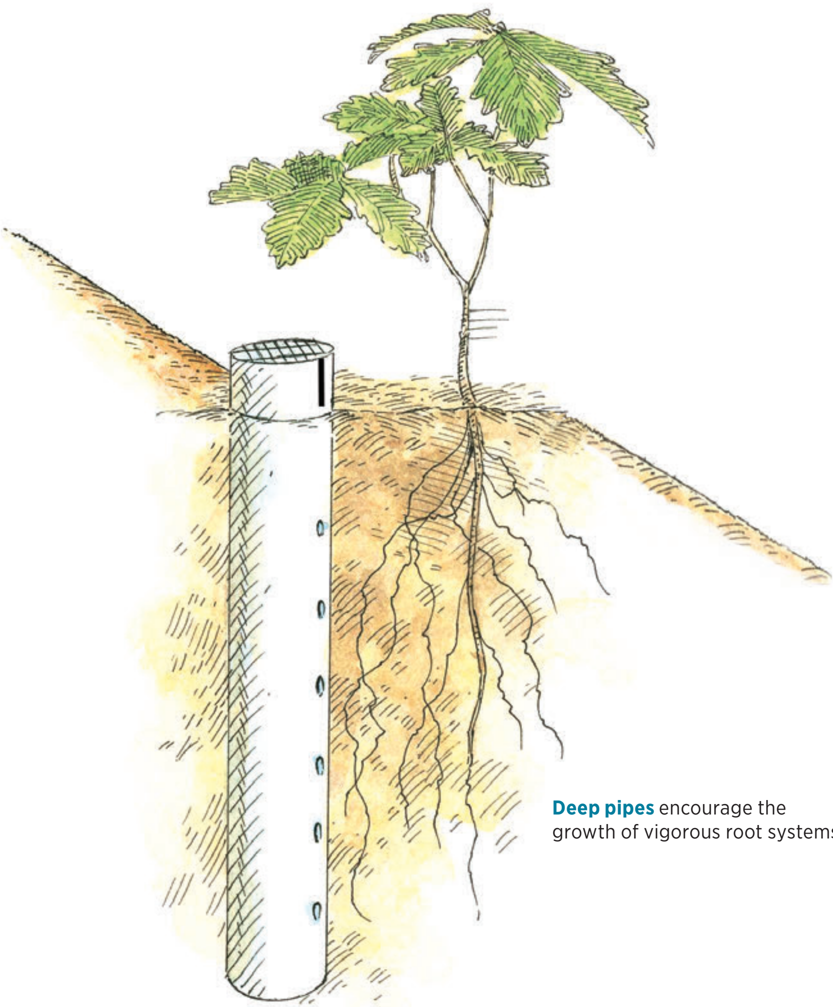
## Using Deep Pipes in the Garden, Orchard, and Landscape

Deep pipes work well for starting orchards and for planting cottonwood poles in riparian areas where very deep watering is needed. (For pole planting in riparian restoration work, deep pipes may be as long as 8 to 10 feet, with a series of holes drilled down one side and a cap on the bottom.) They have also worked well in the garden, but the soil must be well-prepared to allow deep roots to take advantage of the deep water.

*Left:* Deepdrip makes commercial deep pipes. *Bottom left:* Bamboo deep pipes are fully recyclable. *Bottom right:* PVC deep pipes can be used for many years.

For open-ended homemade deep pipes, it is best to dig a hole to place the pipe. If plant roots are short, it may help to seal the bottom of the pipe by taping on a plastic bag. This allows all the water to enter the soil through the small side holes. Once the plant is stronger and roots are deeper, just punch a hole in the plastic film and it will be a deep-watering system.

Set the pipe 10 to 20 inches into the ground near the seedling. When planting on a slope, place the deep pipes on the uphill side of the plant to protect the seedlings from erosion



**Deep pipes** encourage the growth of vigorous root systems.

**This garden bed** shows a networked demonstration of different types of deep pipes.

and sliding debris. They can also be used to help support tree shelters or cages. The pipes can stick up above ground as high as you want. Higher pipes allow you to add more water and are easier to fill, while shorter ones are less noticeable in the landscape. You can also paint them to blend in or stand out.

Deep pipes are typically filled from a water jug or a watering can with the sprinkler rose removed. They can also be filled from a hose or fitted with drip tubing. If you will link the pipes to tubing, it helps to drill a hole in the above-ground part of the pipe to feed the tube in, or cut a slot down from the top. A flag-type adjustable emitter or connector can be placed on the end of the tubing to keep it from getting pulled out, and you can cover the top of the pipe with a cap. Check periodically to make sure water is flowing. Pipes can often be removed 1 or 2 years after the trees or shrubs are well established.

Converting an established shrub or tree from surface to deep pipe irrigation should be done gradually to enable a shift in root development. For a larger tree, several deep pipes should be installed and run for several months or longer to allow a deep rooting system to develop. Then you can gradually taper off the surface irrigation.

CHAPTER 4

# Wicks



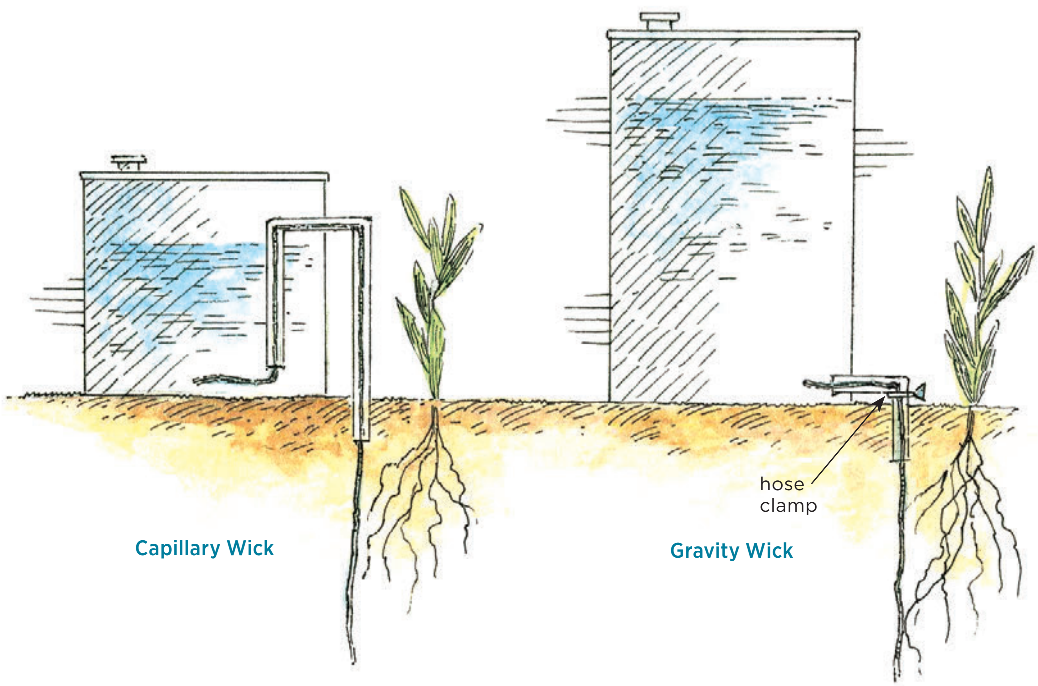
**One of the lesser-known super-efficient irrigation systems uses a fiber wick to conduct water to plants. I was first introduced to this kind of system as it is used in India, where wicks work in conjunction with buried clay pots to irrigate orchard trees. A hole or series of holes were drilled in the buried clay pot, and cotton wicks were inserted to carry the water from the clay pot further into the soil. In the United States, wick systems using capillary mats have become increasingly popular in greenhouses, container production, and interior plantscaping to conserve water and minimize runoff. Wicks can also be used for gardening, farming, nurseries, agroforestry, and environmental restoration.**

**These potted plants** draw water up from the capillary mat they sit on.

The wick material can range from solid braid nylon or polyester (very good durability and capillary transfer), to solid polyester felts, acrylic, cotton, and many other fibers and weaves. Inorganic fibers hold up better and are less likely to mold (water-repellent fibers such as polypropylene will not work). New rope works better if first washed with soap or detergent. You can test your wick material before you start by putting a little food coloring in a cup of water and placing the end of the wick in the cup. The colored water should move quickly up the wick.

The flow rate of water through the wick depends on the wick material and size, as well as the type of system. Wick systems can work a variety of ways: If the flow direction is horizontal, or even upward, water will move slowly and steadily along the wick (often inside a tube to reduce evaporation) by capillary action. You'll get a faster flow if water is traveling with gravity, down a wick from an open or vented container. A sealed container will create negative pressure and a slower flow. An elevated reservoir will increase the flow rate. A range of hybrid systems can be effective too, combining gravity (with full container) and capillary flow (as liquid levels drop below the wick entry point). You can also place a screw hose clamp near the end of the tubing and tighten or loosen it to control flow.





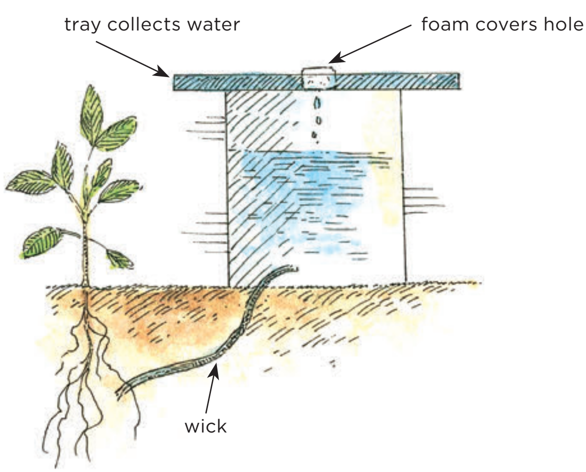

Capillary Wick

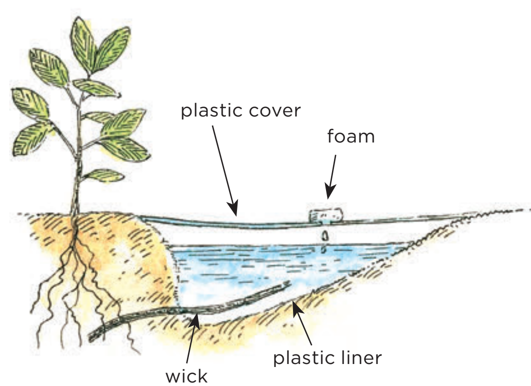
Gravity Wick

Wicks can be very effective for deep watering with minimal water use, and they can be arranged to improve root growth patterns and make trees more robust in high winds. To develop a better understanding of the water-use requirements of seedlings, I set up a capillary wick system in a greenhouse using a palo verde tree seedling in a container filled with coarse sand. After one month, the plant had used less than a quart of water and was still growing with no sign of water stress.

Wicks are being used to some extent in Cuba on farms and orchards. In Australia, Dr. Preslav Trenchev has used wicks to irrigate his nut tree orchards. Each young seedling gets a 5-quart plastic bucket with a gravity wick. Rain is collected by an aluminum tray glued to the cover of the bucket. The tray and cover have a drain hole covered with a piece of permeable plastic foam that allows rain water to seep in and acts as a filter for leaves and other materials while minimizing evaporation. The reservoir fills up when it rains and can provide water to the wick and plant for one to three months. Rainfall in this location is scattered throughout the year, so refill is fairly predictable. For larger trees, Dr. Trenchev digs a small individual reservoir near each young tree, lines it with black plastic, and inserts a wick from the bottom of the reservoir to the tree roots. If it does not rain, the reservoirs can be filled by hand.

**In this system created by Dr. Preslav Trenchev,** rain collects in a large aluminum tray, filters through a small piece of sponge or foam, and runs through a drain hole to the bucket and wick below. For larger trees, water is collected in a dug reservoir lined with plastic.



## Make a Bottle Wick

These simple capillary wicks are easy to make and great for container plants. Threading the wick through plastic tubing reduces evaporation.

**MATERIALS**

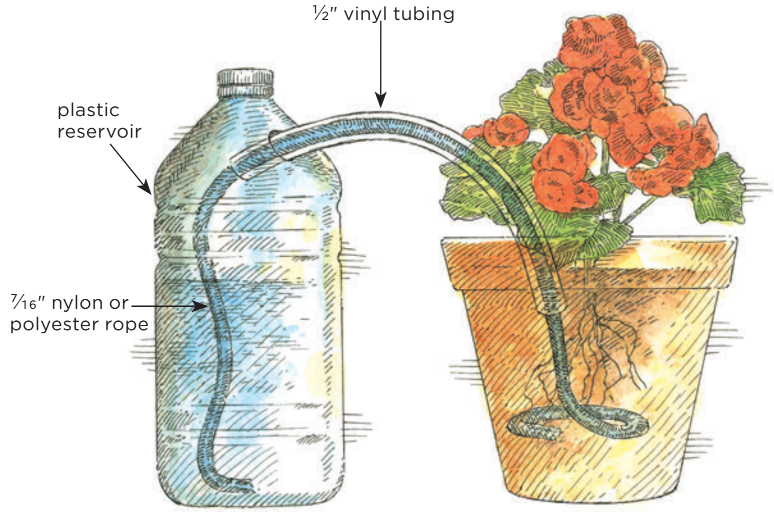
- large plastic water bottle (or other PETE plastic container)
- washed 7⁄16-inch diameter solid braid nylon or polyester rope
- ½-inch (inside diameter) vinyl tubing

**TOOLS**

- utility knife
- coat hanger

**1.** Wash new rope with detergent or soap, rinse, and let dry. (Wash by hand or use a mesh bag to avoid getting the rope tangled around the washing machine impeller.)

**2.** Using a piece of coat hanger wire as hook, thread the wick through a piece of tubing long enough to reach from the bottle to the plant container and two inches into the soil. If you are going to make




several wicks, you can make the material easier to thread through tubing and holes by trimming the fuzz from one end of the nylon rope and melting the nylon with a match or lighter. Use a thick glove or stick to shape the end of the rope into a point (hot melted nylon can cause serious burns on unprotected fingers!).

**3.** Use a knife to make a number of small crosscuts near the top of the plastic bottle so that the tubing can be pushed through. If you need the tubing to bend more than it's willing, you can heat it (with the wick inside) and hold it in a bent position until it cools. Make sure the wick reaches the bottom of the bottle.

**4.** Gently push the other end of the wick down into the soil next to the plant with your finger or a screwdriver. I made a special pusher by cutting a notch in a screwdriver tip with a file. For a new or transplanted container plant, use a wick long enough to circle the pot about half way down so it will surround the seedling. Then plant the seedling and fill in with potting mix.

**5.** Fill the bottle, check periodically, and refill as needed.

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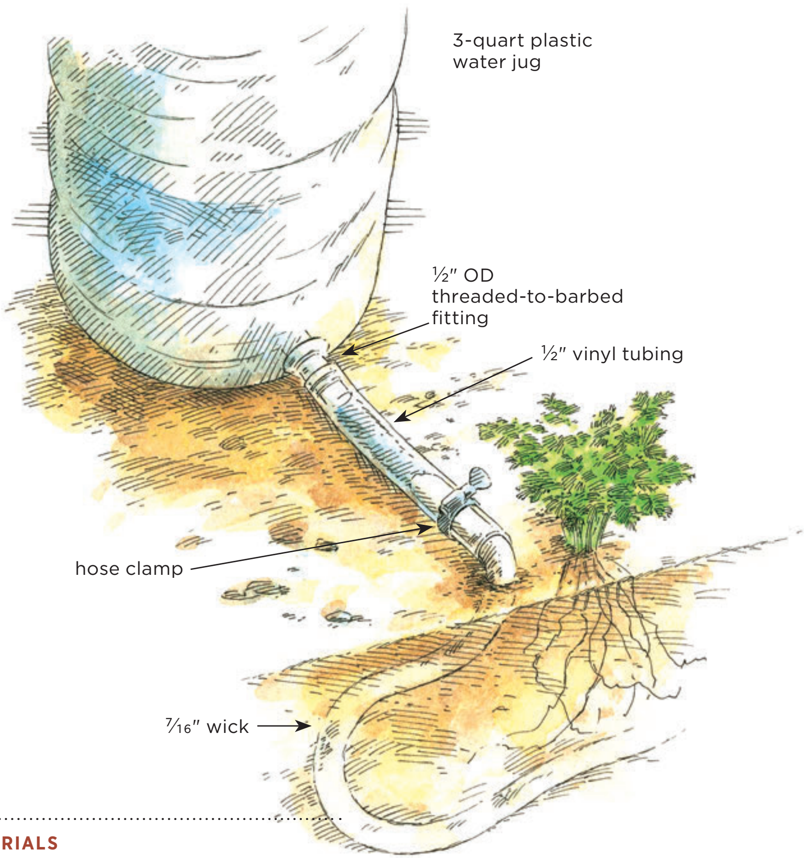
**Alternative Methods.** A one-liter sport water bottle with a valve makes a great simple gravity wick. Instead of cutting a hole in it, cut out the cross web in the valve tip and push a short length of half-inch vinyl tubing onto the top. Then push the wick through the cap and tubing and cut to length. Cut around the base of the bottle, making a flap with a hinge for refilling. Pull the wick out through the flap and tie a loose knot at the end. Then pull the wick back into the bottle and screw on the cap. If the tubing connection is loose, you can tape the joint or use a short piece of heat-shrink plastic tubing to tighten it up. The bottle will need to be tied to a stake to stay vertical.

# Gravity Wick with Fitting and Clamp

With gravity wicks, you'll get the best water control if you use plastic fittings and hose clamps. This slightly more sophisticated system is still simple to make.




**MATERIALS**

- plastic PETE container such as a 3-quart drinking water jug
- threaded-to-barbed fitting with ½-inch OD (outside diameter) thread and ½-inch OD barb
- ½-inch (inside diameter) clear vinyl tubing
- ⁷⁄₁₆-inch diameter wick
- hose clamp with handle (available at auto supply stores)

**TOOLS**

- ⅜-inch spade drill bit
- polyurethane glue

**1.** Drill a hole in the bottom edge of the plastic container with a drill bit slightly smaller than the outside threads so the fitting can be screwed into the container. A spade drill bit with a sharp spur will cut clean holes in plastic if you go slowly. You can leave the bottle clear to watch the water level, or, to reduce risk of algae, paint it or wrap it with foil or tape.

**2.** Lay a bead of polyurethane glue around the hole and screw in the fitting. Let dry.

**3.** Drill or punch a small vent in the cap or top of the reservoir.

**4.** Cut a length of tubing long enough to go from the reservoir to the ground and 2 to 4 inches into the soil; push one end of the tubing onto the barbed fitting. Slip a hose clamp over the other end.

**5.** Push the wick up into the tubing several inches past the clamp. The nut or handle of the clamp should be on top to make it easy to adjust.

**6.** Tighten the hose clamp until the wick is securely fastened. You can count the turns to measure tightness and test flow rates to find a consistent and appropriate flow.

## Garden with Wicks

The simple bottle wicks described in this chapter will all work in the garden. If you find you need to deliver more water to your plants for longer periods of time, try larger wicks and reservoirs, such as a 5-gallon bucket with a threaded-to-barbed fitting near the bottom.

If you will be direct seeding, install the wick and let it run overnight to make sure you put the seeds in wetted soil. For a seedling or young shrub or tree, you can put the wick directly in the planting hole with the plant. You can also drill a deep hole for the wick or push the wick into the soil with a stick or screwdriver. The wick should be near the roots of the vegetable or shrub.

For a wick system that combines the advantages of capillary and gravity wicking, insert the wick about halfway up the bottle. It will act as a





## Wicks in Combination with Other Systems

Wicks can be easily combined with other watering systems. I have used both buried clay pots with wicks and wicks combined with deep pipes. Try your own combinations. The innovative Groasis Waterboxx (below) developed by Pieter Hoff includes rainwater harvesting, wicks, and a reservoir, and provides some plant protection as well.

gravity wick at first; then as the water level drops it will transition into a capillary wick.

The reservoir can be set several inches into the soil to make it more wind resistant. You can also set up multiple wicks from one reservoir to encourage root systems that spread out to make the plant or tree sturdier in the wind. After planting a sapling, you may wish to add a tree shelter (see chapter 7) to protect the plant from wind, sun, blowing sand, and animals.

## Remote Sites

The low water demand of wick systems makes them ideal for remote sites, forestry, and environmental restoration work. A good system for these challenging sites is a 5-gallon jug with 7⁄16-inch wicks. I have also used well-washed 5-gallon recycled fire foam containers. Remember to drill a vent hole in the jug cap. Wicks can also be run off a larger tank with rainwater catchment.

CHAPTER 5

# Porous Hose

**Porous hose (aliases: leaky pipe, leaky tubing, porous pipe, sweating or sweaty hose, weeping hose, soaker hose) lets water seep out through pores in a buried hose. This kind of irrigation has been used successfully in many areas of the world for a wide range of commercial farming and nursery operations but is most popular for small-scale garden and farm use. Unlike porous clay pots, capsules, and pipes, porous hose does not release water according to plant needs and is therefore not as efficient as these other systems. Another drawback of porous hose is that the water is delivered along the entire length of hose, even between plants. However, porous hose has been available, tested, used, and improved for more than 80 years and is the most commercially available of the efficient irrigation techniques.**

Porous hoses are typically made of recycled rubber, with the water release rate depending on pore size and water pressure. They deliver water most uniformly on level ground, where pressure is equal, and don't work as well on sloping or vertical runs (in these situations, hoses should be run on the contour of the slope). If you have level beds at different heights, you'll want to run hoses on the contour with solid hose connections between beds. Low-pressure porous hose can also be set vertically and used like a deep pipe for watering container seedlings or planting trees and shrubs with tap roots.

Porous hose systems are generally intended for intermittent use; you can turn them on and off by hand as needed or use a timer. The goal is to adjust water pressure and flow so the water seeps out slowly, not as little jets of water, and wets the soil thoroughly and deeply without runoff. This might mean watering one or two times a week for 20 to

30 minutes or longer, depending on crop, soil type, hose type, and pressure. A smart controller with moisture sensors, weather sensors, or Internet connections to weather data can improve efficiency.

Variation within and between porous hose manufacturers is substantial, so you'll want to design your layout only after testing the hose you will be using. Discharge can vary as much as 25 to 35 percent for successive pieces of hose cut from the same roll. Porous hoses are typically 0.5, 0.58, or 0.625 inches in diameter in the United States, but quarter-inch porous tubing is also sold. Manufacturers often make hose and fittings with slightly different sizes to frustrate users who would like to mix and match, so stick with the same manufacturer or check sizes carefully.

For some of the suggested uses in this chapter, you will need porous hose that will work with very low pressure. Some types of hose operate at low pressure, but most don't. The recommendation for many porous hoses is for a working

**Porous hose** works well in raised beds.

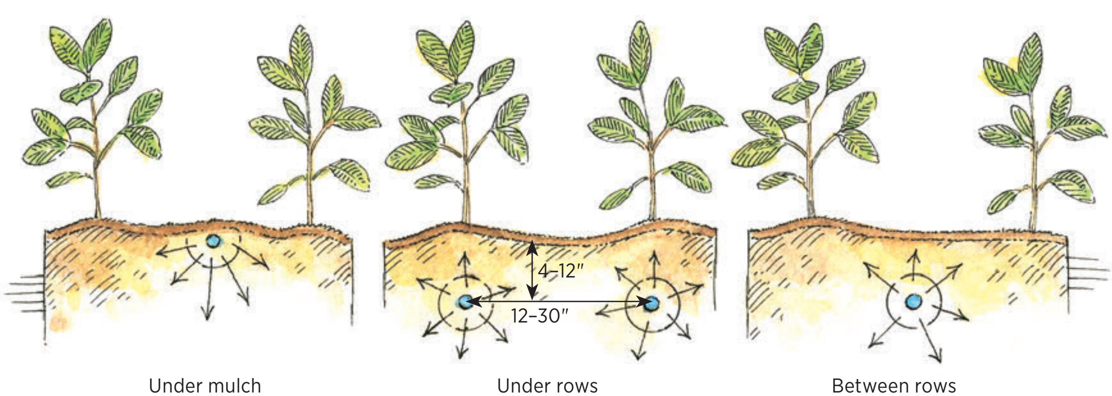
pressure of 5 to 15 psi. (Most systems will require a pressure reducer if attached to city water.) To work with gravity pressure, these hoses will need a reservoir 10 to 30 feet above watering level. Fortunately, you can find porous hose that will operate with 3 feet of head or less. If a low-head water supply such as a rain barrel will be used, make sure you get low-pressure hose. Review the manufacturer's statements on pressure and do a rough check yourself: Lay the hose on the soil surface, connect it to a water supply from a hose or a water tank, and check the width of the wetted area at 30 minutes, one hour, and two hours.

Porous hoses can become clogged with dirty water, algae, bacteria, or buildup of minerals from hard water. A 200 mesh filter on the feed line is often suggested, but 500 mesh is better. Salts may also build up on the outside of the hose over time. These can sometimes be blown off by increasing the water pressure, which will swell the hose and shuck off the salty shell. Small amounts of nitric acid or vinegar can also be used to clear pores. In general, you can expect a decline in discharge rates over time. These problems can be reduced by opening the end and flushing the hose once or twice a year. Porous hose in continuous use may also clog with roots, but with intermittent garden use, this is rarely a problem. In typical subsurface use (or buried with mulch) the hose may last 5 to 10 years or more.

Water conservation is best with the hose set 3 to 6 inches or even deeper. Specific guidelines for installations can be obtained from manufacturers and garden advisors.



**Porous hose can be laid** between rows, directly under rows, or just under mulch.



## Garden with Porous Hose

Setting up a pressurized porous hose irrigation system is easy. The porous hose is usually buried in a trench under or between the rows where vegetables will be planted. If left on the surface, the hose should be held in place with hose pegs or staples and covered with mulch. Common water system pressure from a faucet may be able to get water through 300 feet or more of porous hose, but the water will come out faster near the pressurized end. It is better to set up several shorter lines from a header to equalize pressure.

Row spacing should fit soil, vegetable, flower, or shrub type — perhaps 12 inches for carrots and other narrow plant tops and 24 inches for plants with a larger crown. The area moistened may be 8 inches from the hose in sandy soil and perhaps 12 inches on loamy or clay-rich soil. The hose works best with constant pressure so should be laid as flat as possible. To get the kinks out of a hose that has been tightly coiled, unroll the hose and let it warm up in the sun.

**Installing a faucet** at the corner of a raised bed is easy and convenient. This one was installed with a commercial corner kit.

**Dip the ends** of porous hose in hot water to soften them.

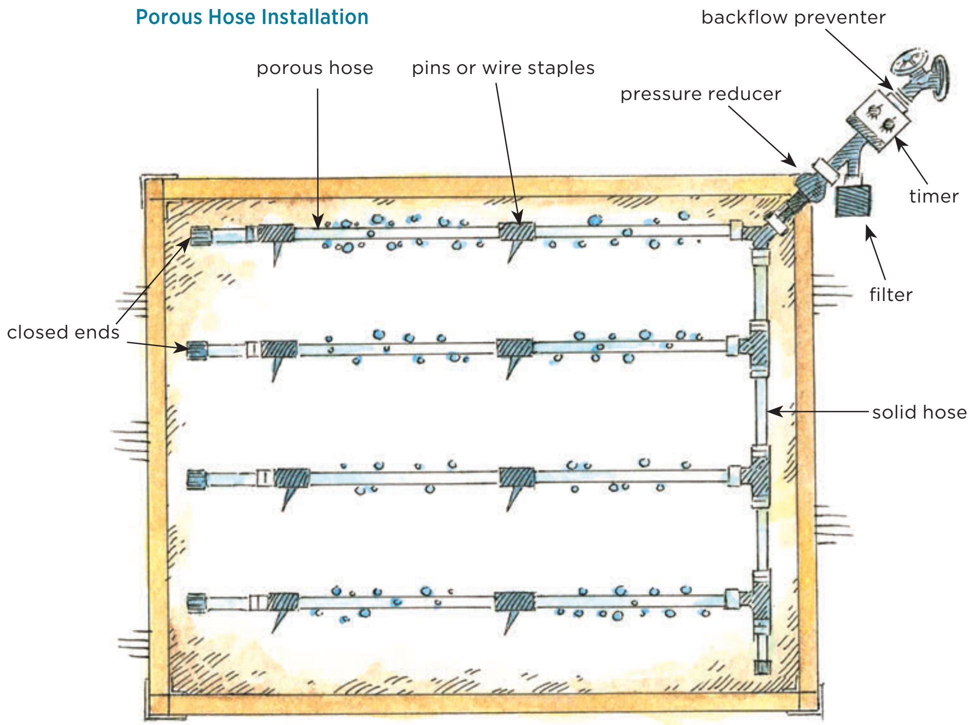
In addition to the porous hose, you will also probably need some regular half-inch hose or pipe to get the water to the garden beds or orchard. Connections are made with barbed connectors, Ts, Ls, and other types of fittings. Buy tubing and fittings from the same manufacturer or carefully check compatibility to make sure they will fit together. Dipping the ends of the pipe and porous hose in hot water (in a thermos bottle) makes it easier to get them over the fittings.

A typical hook-up is shown here, including a backflow preventer, filter, timer, and pressure reducer. A calcium inhibitor filter (as used to protect misting systems) can help in areas with hard water. It is a good idea to flush the system before starting each season. Cycling the hose a few times, from zero to moderate pressure, can help reopen pores.

Short runs tend to work better than long runs and deliver water more uniformly, so a garden might be watered with a number of 10- to 20-foot lines off a header instead of looping a 50- or 100-foot hose back and forth. Some manufacturers suggest having a closed loop while others like closed ends. These ends can be tied over, capped, or plugged.



**Porous Hose Installation**



## Low-Head Reservoir

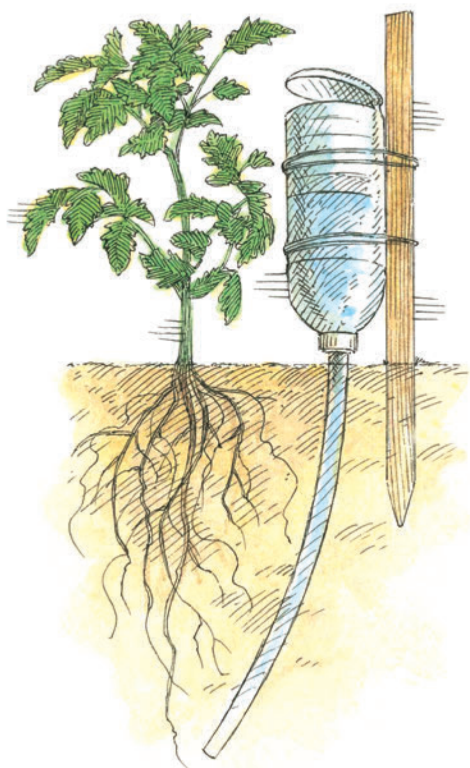
Porous hose irrigation can also be run off a rain barrel or tank. The challenge is finding hose that will work with the low pressure. Low pressure porous hose from Leaky Pipe (LP12UH, ID 9mm, OD 14mm) will work at pressures as low as 1.5 psi. For every foot the tank is raised above the hose, head pressure increases 0.43 psi, so a tank raised 3 to 4 feet would provide sufficient pressure for these hoses. Other low-pressure porous hose can work at even lower pressures. Automatic control can be difficult for low-pressure systems because some timer valves do not work at low pressure — ask before purchasing.

## Vertical Porous Hose

For more precise water delivery and deeper wetting, a vertically placed section of low-pressure, high-flow porous hose can be used to wet a vertical soil column much like a deep pipe does, providing excellent conditions for deep and extensive root growth. The porous hose can be installed before the plant is planted by drilling or digging to desired depth. The bottom end of the hose should be folded over and wired, zip-tied, or plugged. If you use a low-pressure, high-flow porous hose, it can be attached to a recycled bottle or container or fed by a drip emitter.

The necks of plastic sport water bottles often fit inside porous hose perfectly. Make a flap in the bottom of the bottle so that you can refill it. Then secure the porous hose to the top of the bottle with glue or duct tape and set the assembly in the soil vertically, next to the plant to be watered.

**A vertical porous hose system** can be made with a recycled sport water bottle with a flap cut in the bottom.



**Use quarter-inch porous hose** for container plants. As with outdoor plants, a layer of soil or mulch should be added over the tubing to reduce evaporation.

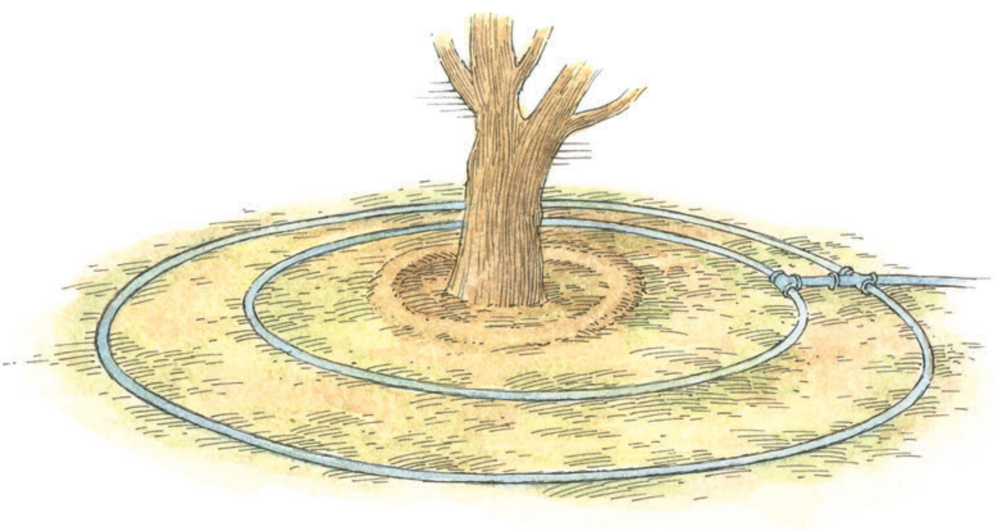
## Micro–Porous Hose for Container Plants

Quarter-inch-diameter porous hose can work well for watering container plants on a patio, for instance. A ½-inch solid line can be used to bring water near the container. Then with a T-fitting or hose punch and connector, run solid ¼-inch tubing to the pot surface. With another connector, add a length of porous tubing and coil it in a circle around the inside of the container before adding potting mix. Add a timer, and containers can be watered properly even while you are on vacation.

## Tree Establishment

By changing the hose characteristics and length, water pressure, and timing, you can choose a suitable moisture pattern for almost any plant type, age, and root system. For trees and shrubs, make a loop of porous hose around the plant. You can also set the hose in a spiral starting 1 to 2 feet out from the trunk and ending just outside the tree canopy. In some cases, a loop or two near the edge of the canopy and another about halfway in will suffice. The goal is to water infrequently but deep, at least 24 to 36 inches in dryland situations. The only way you will know that it is working is to check the depth of the wetting pattern by digging a hole or setting up a moisture meter. You may be able to wean a tree off shallow surface irrigation if you take your time and allow new roots to grow. To start a seedling or cutting, use a vertical section of porous hose.

**Porous hose** can be looped around trees to improve water distribution and root growth.



CHAPTER 6

# Buried Clay Pipe

**Buried porous clay or concrete pipe works like buried clay pots or porous capsules, letting water seep slowly into the soil. Experiments with these systems first began around 1860 and led to a number of patents and tests, often with promising results. Although it is very efficient and has been successful in some applications, porous clay pipe irrigation has been hampered by the manufacturing cost in developed countries, technical problems such as fragility of the pipe, and limited availability. However, handmade clay pipe can be inexpensive when it is made of locally available materials and can be easily replaced if broken.**

Pipes can be made from terra-cotta, specially formulated clay, concrete, or composite. They should have joints that fit together well and can be sealed to prevent root entry and uneven water distribution. Because they have a much larger surface area than porous capsules, porous clay pipes are less likely to clog — but water delivery is less precise and installation is more involved. The water is spread along a continuous horizontal band in the soil, making this system well suited to closely spaced row crops such as carrots and other vegetables.

Finding a source of porous clay can be a challenge in the United States, so this technique is best suited for the more adventurous gardener or gardener/potter. Although porous clay pipe made specifically for irrigation is available in Japan and Pakistan, it is not on sale here — yet. Recycled older porous sewer pipe or drainpipe can be found in some areas, and in Africa some potters have begun to make it.

Porous concrete pipe may be more readily available but may take some searching to find. A variety of patented systems have also been developed with permeable concrete only at the top or in parts of the pipe. Recent demand for permeable pavement has led to renewed

**These carrots** on buried clay pipe in Pakistan have relatively few weeds growing between rows.

experiments with concrete mixes and materials that should make it easier to manufacture pipes suitable for irrigation.

If porous pipe is so hard to come by, then why bother? The results were clear with one of the first and best experimental tests of buried porous clay pipe subirrigation

**Here, sections of porous clay pipe** are produced and laid out in Pakistan. They can be set at different depths to suit a crop's root development.

conducted in Avignon, France. The 2¾-inch diameter porous clay pipe cylinders were 24 inches long and connected with rubber tubing. They were laid in trenches 16 inches deep and 79 to 98 inches apart. The crops on buried clay pipes gave higher yields, matured earlier, and were less susceptible to disease. Water use was cut 80 percent, and chemical fertilizer use was reduced 50 percent, while the corn yield increased 83 percent, melons 48 percent, and potatoes 34 percent. During the summer, the plots with buried clay pipe only had to be weeded after rains and grew practically no weeds. The researchers summarized the benefits as follows: a significant reduction of labor costs, a reduction in overhead costs (water and fertilizer), higher profits with better and earlier yield, and increased yield per unit area due to the advantage of the irrigation system (constant moisture and optimum aeration of the soil). They noted that the early harvest would make it possible to grow two crops in one season.

Porous clay pipes are usually 3 to 4 inches in diameter, but both much larger and smaller ones have been used. Long pipe sections are easier to seal but harder to make and more awkward to transport. The pipes are typically placed in a level trench 4 to 16 inches beneath the soil surface, laid end to end, and joined with watertight slip joints, cemented joints, or plastic or rubber connectors. As with porous hose, there are two common methods for pipe placement in row crops: either directly under each row or under the midpoint between alternate rows. Pipe grids also work.

Subsurface porous clay pipe irrigation can benefit a range of crops grown under different climatic conditions, even with slightly saline or alkaline irrigation water. In Zimbabwe, a local women's garden group visited a government agricultural research station where they saw a trial using porous clay pipes to irrigate small vegetable beds. Each pipe section was about a foot long. They were laid end to end, loosely butting against each other, at rooting depth along the length of a bed. The women saw that this addressed two of the pressing problems they face — lack of water and lack of time. Because they were already skilled at making clay pots for cooking and storage, they were easily able to make their own pipes. Then, by using buried clay pipe irrigation, they were able to save time and labor by watering just once a week instead of three or four times a week. They also increased vegetable yields and reduced weed problems. The technique caught on, and soon 450 women in the area were using this system.

**A potter** makes porous clay pipe in Africa.

## Gardening with Buried Clay Pipe

The greatest challenge to using porous clay pipe in the United States is obtaining it in the first place. You may be able to find it at an architectural supply house dealing with historic materials, a farm drainage supplier, or a ceramic factory. Some types of drain pipe were porous at one time, but most today are high fired and glazed for durability.

Most potters could make porous clay pipe with some guidance on size, clay mix, strength, and porosity. A pipe 10 to 20 inches long with an outer diameter of 3 to 4 inches and 0.3-inch walls would be a good size to start with. Sections can be made with slip joints that are easily sealed in the field, or they can be made with necks suitable for rubber connectors.

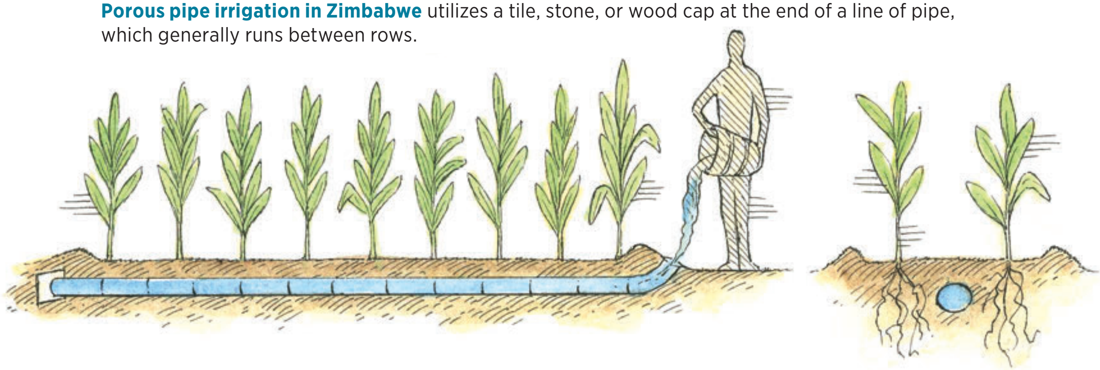
The depth of the pipe and line spacing will depend on soil type, pressure or gravity flow, pipe type, and crops. Pipes can be flat for a short run or slightly sloped for a longer run, perhaps a 1-inch drop over 10 feet. Place larger pipes in a level trench 4 to 16 inches beneath the soil surface, checking for level and slope, and fasten the pipes together. Then partially backfill around the pipes and check levels again. Soil amendments, compost, and fertilizer can be added to the fill near the pipe. Then fill to the surface and plant seeds or seedlings.

To make the pipes easier to fill (whether by hand, hose, or pipes from a tank or reservoir), you can add an elbow with a standing vertical section at the higher end of the pipe run. This system will operate at low pressure or even zero head. An operable gate or valve at the bottom end of the run allows for periodic flushing. Irrigation frequency can be determined by carefully monitoring crops, but it may be as little as once a week.

If plants are started from seed, the goal is to wet just the seed line. In finer soils wetting may extend 24 inches from the pipe, in medium soils 20 inches, and perhaps only 12 inches or less in sandy, fast-draining soils. It is always a good idea to start and run the system for a day or two to see how far the soil is wetted.

Smaller tubes, such as those made by the Japanese company Kubota Minoru Ceramics (the New Karez porous ceramic tube; see page 124), would work well for interior landscaping, containers, or a small garden.

**Porous pipe irrigation in Zimbabwe** utilizes a tile, stone, or wood cap at the end of a line of pipe, which generally runs between rows.



## Related Techniques

### *Perforated or Slotted Pipe*

After being unable to find porous clay pipe in the US, I explored the use of slotted polyethylene drainage pipe. It worked well and led to installation of almost a half-mile of pipe in the Mojave Desert. After the ditch was dug, the pipe was pinned in place with U-shaped rebar staples and then covered, leaving a shallow swale for water collection from rainfall events. Every hundred feet or so, a vertical standpipe allows for watering. The plants are planted on the edge of the ditch above the pipe, not at the bottom of the swale where they may drown or wash out in a large rain event. This system has worked well and has now been replicated on a number of other projects in the area. A fabric or filter fabric sock (sold with slotted pipe in most areas) can keep dirt and roots out of pipes and wick moisture up to the top of the pipe even when the water level drops.

**For the Mojave Desert project**, screens were placed on the ends of standpipes to keep out animals and debris.

**Slotted pipes** can also be used in the garden.

### *Leaky Joints*

Some of the earliest buried pipe irrigation systems leaked water only at the joints between the buried pipes. Nehemiah Clark patented this approach in 1874. Though not as efficient as buried porous clay pipes, it may be the only option if porous pipe is not available. Roots will eventually enter the joints and reduce water flow — just as they do to many homeowners' sewer pipes. A filter fabric wrap may reduce root clogging.

CHAPTER 7

# Tree Shelters

**Tree shelters (sometimes called grow tubes or plant protectors) can be used for irrigation in many soil types and for a range of plant species. The tree shelter, which is simply a plastic tube, is positioned around the seedling and set into the soil; then water is poured into the tree shelter by hand or fed into it by a drip system.**

Water is not as well protected from evaporation as it would be with a deep pipe, but the water is concentrated near the plant and will quickly soak more deeply into the soil. In more humid environments, some species may not tolerate repeated wetting of their leaves and stems (causing mold or rot), but I have rarely encountered problems with my desert plantings. Occasionally, insect outbreaks can develop in shelters, but this is also more likely with garden plants than desert shrubs.

I first explored the value of tree protection in the desert to reduce the impacts of sand blast and hungry herbivores. My first tests used rocks piled around the planting spot. This helped, but in sandy sites I needed an alternative. I tried peat pots with the bottoms cut out, but it was clear more protection was needed. I then tried plastic bottles cut out at the top and bottom and discovered I could water into the shelter. These were better but not easy to stabilize in high winds.

When I first saw Tubex tree shelters at a reforestation conference, I immediately thought they would work even better, and so they have. These double-wall shelters are sturdy and stand up well to high winds and animals if set into the soil and well pinned or staked. In desert situations, we often use ¼-inch rebar pins to stabilize them rather than wooden stakes.

While the most important function of tree shelters is usually protection from browsing by wild or domesticated animals, they also protect shoots from drying winds and reduce moisture stress by creating a more favorable micro-environment with higher humidity. Translucent tree shelters allow sufficient sunlight to get through, and temperatures inside them (with seedlings) are often cooler than outside air temperatures as a result of

**Tree shelters** reduce water use and improve growth and survival. They are often used in vineyard establishment.

evapotranspiration. In the low desert in summer, when soil temperatures may reach 160°F, the tree shelter temperatures usually stay below 120°F. On a day when the air temperature was in the mid to high 90s and the mean ground surface reached 109°F, tree shelters with no trees in them were 96°, and tree shelters with trees were only 89°, slightly below air temperature.

Tree shelters have been especially helpful in desert restoration, but I have also used them in the garden with corn and other tall-growing plants. They can be reused for many years. They provide some protection from cold temperatures and can help you get a good jump on the season by allowing plants to be set out in the garden much earlier in the spring.

Watering plants with a tree shelter is a good compromise between cost and performance for plants that can tolerate wetting. It may be more suitable for fast-draining sandy soils than clay soils where water can sit in the tube too long and damage plants. Water can be poured into the tree shelter from a watering can with the sprinkler rose removed or, for larger projects, filled from hoses from a water tank in a truck. They can also be watered via a drip line from a water tank or pressurized water line. Deeper watering with deep pipes is preferable but adds to cost.

**Drip tubing** can be connected directly to a tree shelter.

## Homemade Tree Shelters in Your Home Landscape

Tree shelters can be made from plastic bottles and containers with the tops and bottoms cut out; green plastic may be slightly better than clear because it provides some shade. Twin wall shelters work even better and can be made with two water bottles of different sizes, one inside the other. Tree protection can also be created with rocks. If the rocks are placed to form a collar they can improve water delivery and reduce evaporative loss, but they are not as good as twin wall shelters.

### Restoration

Tree shelter irrigation was used for the restoration of the *Jurassic Park* movie site in Red Rock Canyon State Park.

**Tree shelters** can be made from recycled plastic bottles.

Plastic tree shelters have occasionally trapped lizards. Place a stick in the shelter so they can climb out. Netting or cross-threaded fish line near the top may be needed in some areas to keep birds out.

Tree shelters can be useful in establishing a home landscape if you are starting with small plants or seedlings. They can reduce plant stress from heat, cold, and wind. The taller tree shelters are excellent for young trees, shrubs that grow up rather than out, and vines. They can be very helpful where elk, deer, or rabbits are damaging plants. I have also used short tree shelters in the garden to protect young seedlings.

# TAKING IT TO THE NEXT LEVEL

PART TWO

Now that you know about the different super-efficient irrigation systems you can make and use in your own home and garden, let's look at the bigger picture. How can you plan to get the most out of the super-efficient systems you choose?

CHAPTER 8

# Water-Wise Gardening Tips

**Water-wise gardening can reduce water demand and improve growth and yield of crops, the beauty of flowers and shrubs, and the health of the soil and landscape. Most of us are using much more water than we need, and we can all make dramatic changes in our gardens, yards, or farms that will make a difference. Cutting water use 50 percent can be relatively easy, but it's possible to go much further. You may find your savings increase each year as you develop your skills and understanding of super-efficient irrigation and water-wise gardening. Many agriculture extension groups, garden associations, water agencies, and sustainable farming groups offer classes or online materials. Some cities and states are now offering financial incentives as well.**

Keep in mind that gardening is also about climate and microclimate. What works in the low desert around Yuma, Arizona, may not work as well in Las Vegas, Santa Fe, or Atlanta. Read with a careful eye, and look for specific information for where you live. Learn from your neighbors, and take classes offered by local experts. Even if they are not familiar with super-efficient irrigation systems, they should be able to help with advice on soils, composting, crop varieties, planting, pest control, and crop timing.

Here are some water-wise gardening tips to get you started.

**1. Give priority to the native plants from your region** that are drought resistant, drought tolerant, or drought avoiding. The growing interest in *xeriscape*, a water-efficient landscaping method developed for arid climates, has made it much easier to find plants that will do well with very little water. Succulents often offer the best flowers for the least water. Your local garden center or nursery can help with advice and will usually sell varieties that do well

**Native plants** are the key to attractive, water-wise landscaping.

in your area, but don't restrict yourself to the handful of choices they offer. Search out the native plant nurseries and specialty growers who work with heirloom and exotic varieties. Look through the catalogs and websites of other companies that offer special heirloom and international varieties. Ask about locally developed and adapted species and cultivars. Where no locally adapted varieties are available, try heirloom cultivars from comparable climates. Ask your neighbors, your cooperative extension agent, and garden clubs what works for them and tastes best. Visit the local farmers' markets and see what is being grown and sold.

**2. Choose varieties that are dryland adapted.** Many of these heirloom varieties have been selected over generations to do well with less water. Some, such as Hopi corn, have adapted with very deep, fast-growing roots. Also, crops and flowers that can be started indoors early in the season and then planted in the garden in very early spring will complete their life cycle by the time it gets really hot and dry. Trees that are very drought resistant include olives, pomegranates, loquat, macadamias, carob, and mesquite. Dwarf-type trees can also reduce water use and will do well in pots or containers. These can be surprisingly productive. Our Meyer lemon churns out delicious lemons all year long in San Diego!

**Dwarf trees** can be very productive in containers, and water use can be minimized with ollas, porous capsules, or microporous hose.

**3. Replace your lawn** with water-conserving native plants, xeriscape, or gardens. With super-efficient irrigation, the replacement plants will use less water than a lawn. Rainwater harvesting (chapter 9) can also provide much, if not all, of the water for the new landscape. In many areas, homeowner associations will resist or not permit lawn removal, but they may allow artificial grass to be installed. The more expensive types of artificial turf are surprisingly lifelike, but these fake lawns do heat up in the summer. Some states have realized the importance of removing lawns and have passed laws limiting the power of homeowner associations. In the West, the reality of ongoing drought has many agencies offering financial incentives to remove lawns.

**Xeriscaping** with efficient irrigation can be attractive while using very little water.

**4. Plant in blocks instead of rows** to reduce evaporation losses and weed growth. Plants can also benefit from zoning so that plants with similar water demand are in the same area. This way, water application can be timed to meet plant needs without overwatering some plants and underwatering others. In rainwater-based systems, the zoning is often done with the most water-needy plants nearest to the water source. This helps ensure that when water runs short the plants that need water most are going to get it.

**5. Keep your soil healthy and uncompacted** so that irrigation water can move through more easily. Roots will grow denser and deeper and develop better partnerships with beneficial mycorrhizal fungi and nitrogen-fixing bacteria. Double digging to provide deep friable soil can dramatically improve crop growth and plant health on degraded compacted soils; it is best done in spring with moist soil and cooler temperatures.

**6. Check your soil's drainage.** You can check drainage by digging a hole 18 to 24 inches deep and filling it with water. Fill it again the next day. If it doesn't fully drain after one or two days, the drainage may be impaired. This may indicate that the topsoil was all removed during grading for the housing development or that one or more layers of caliche exist. In arid areas, caliche is found as a light-colored layer in the soil where the soil particles have been cemented together by calcium carbonate. A raised bed may be the best answer. In some cases you can improve drainage by deep ripping and adding lots of organic matter, sand, or, for clay-rich soils, calcium (as gypsum). Good drainage in potting mixes is also important.

**7. Use mulch** to reduce the evaporation of water from the soil, keep soil temperatures down, and help control weeds. Gravel mixed with coarse sand has been used as mulch for hundreds if not thousands of years in China to conserve moisture. (In a recent study, this kind of mulch reduced water loss 82 percent over 14 days; runoff decreased 95 percent during summer rains.) On a small plot, gravel can be raked up at season's end, sieved to remove the dirt, and reapplied. Many seeds require warmer soil temperatures to germinate, so bare soil may be best when seeds are first planted in spring. Early summer is prime time to maximize mulch. For landscaping, shrubs, and trees, you can add mulch earlier.

**8. Consider irrigating with greywater.** Where water supplies are very short, some people use greywater from sinks, laundry, and showers to sub-irrigate crops where the water will not contact the parts we eat. (Berries, fruit and nut trees, tomatoes, and peppers are fine, but not lettuce, cabbage, or melons.) If you choose soaps and shampoos carefully, this water will not harm your plants. Cities, counties, and states may have rules governing greywater reuse. Ask first before installing a greywater recycling system to see if there are any financial incentives or restrictions.

## Cities Get on Board

Some cities now make recycled wastewater available, often in magenta-colored pipes to prevent cross connections. This water is usually suitable only for landscaping but when treated to a higher standard can be used for agricultural crops.

CHAPTER 9

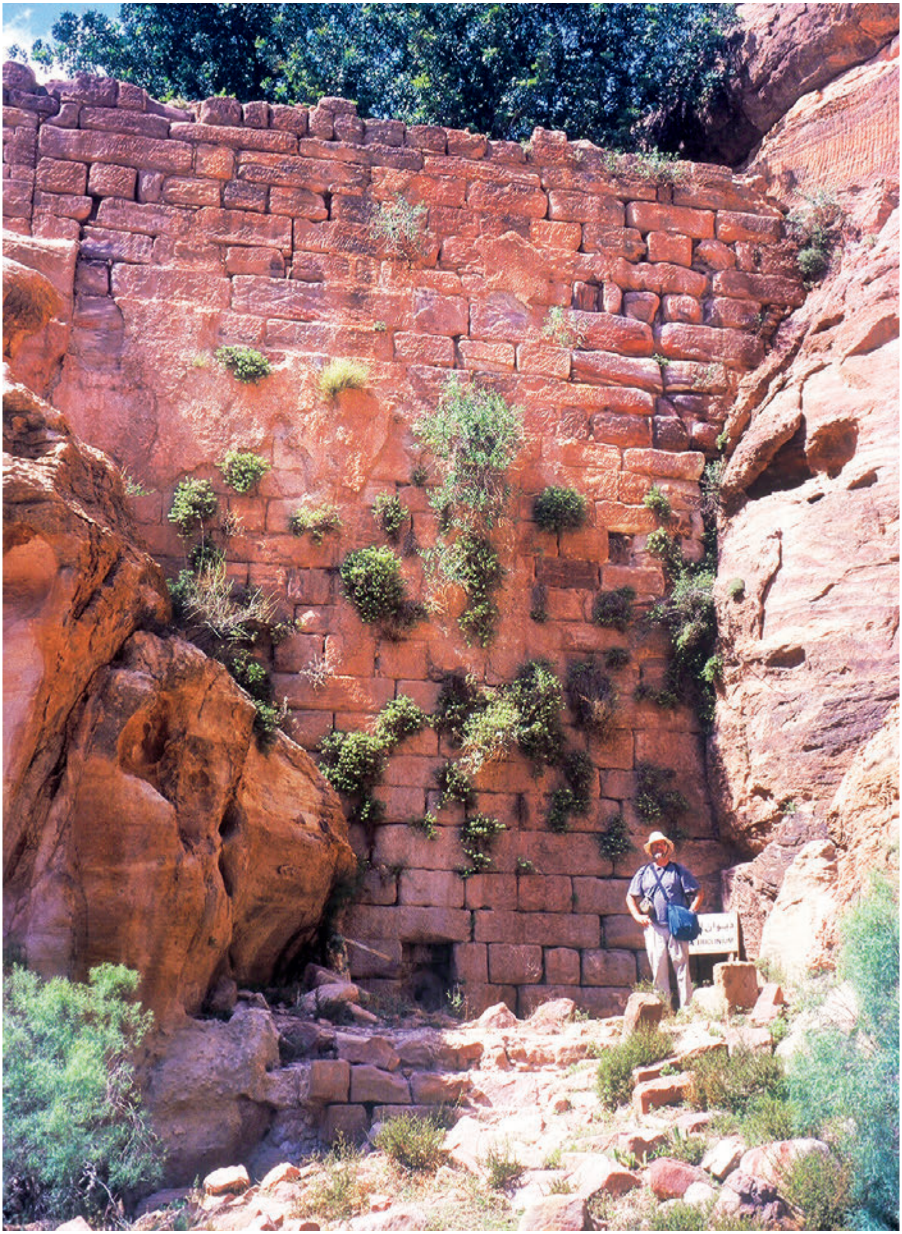
# Rainwater Harvesting

**Rainwater harvesting is a great complement to the super-efficient irrigation systems described in this book and can help provide critically needed water for growing crops, landscaping, and other uses around the home, farm, school, or office. Even in very arid areas, gardens and orchards can benefit from captured rainwater used in the most efficient, demand-responsive ways possible.**

Ancient civilizations developed very sophisticated rainwater harvesting systems. The Nabatean people of the Negev Desert were the masters of this practice. They developed finely tuned, site-adapted catchment, runoff, dam, and channel systems that harnessed rains and flash floods to irrigate crops and fill the cisterns needed to support farms and a city in the harsh desert. Long ignored, these practices have been rediscovered as rainwater harvesting becomes a key component of more sustainable living, gardening, and farming.

Rainwater harvesting requires a catchment area, a collection system, and storage. The most common catchments are roofs, patios, and walkways, but other impermeable surfaces such as roads and even compacted soil can also work. Keep in mind, however, that road runoff is often contaminated with antifreeze, oil, and other materials. This can be fine for landscape plants but not so good for the garden. Water is usually harvested from relatively clean impervious surfaces where an inch of rain will deliver more than a half gallon per square foot of surface. Ten inches of rain on a 1,000-square-foot roof will provide about 6,000 gallons of water. An intense thunderstorm can deliver 1,000 gallons in less than an hour.

Many cities and states now encourage rainwater harvesting in development regulations or offer incentives for people or firms installing rainwater harvesting systems. Texas was the first state in the US to embrace rainwater harvesting, but Hawaii, North Carolina, and other states are now catching up. North



**The ancient Nabateans** built this dam in Petra, Jordan, to collect rainwater.

Carolina and the Florida Keys have rainwater harvesting rebate programs. The city of Tucson, Arizona, has been a leader in rainwater regulations and now requires some commercial facilities to meet 50 percent of their landscape demand using harvested rainwater, prepare a site water harvesting plan and water budget, meter outdoor water use, and use irrigation controls that respond to soil moisture conditions at the site. Parts of Australia have relied on rainwater harvesting for decades and many building codes now require catchment and storage systems, with tanks up to 800 gallons required along the Gold Coast.

## Capturing Rainwater at Your Home

Roof catchment systems are the simplest and most common forms of rainwater harvesting systems. A basic example is shown on the following page.

### Catchment

The catchment area you need can be determined by estimating the water you need for the crops you want to grow. For a home with 1,000 square feet of impervious tile or metal (preferably baked enamel or approved epoxy coated — not aluminum), the rainfall collection over the year may be 70–90 percent of annual rainfall.

### Gutters and Downspouts

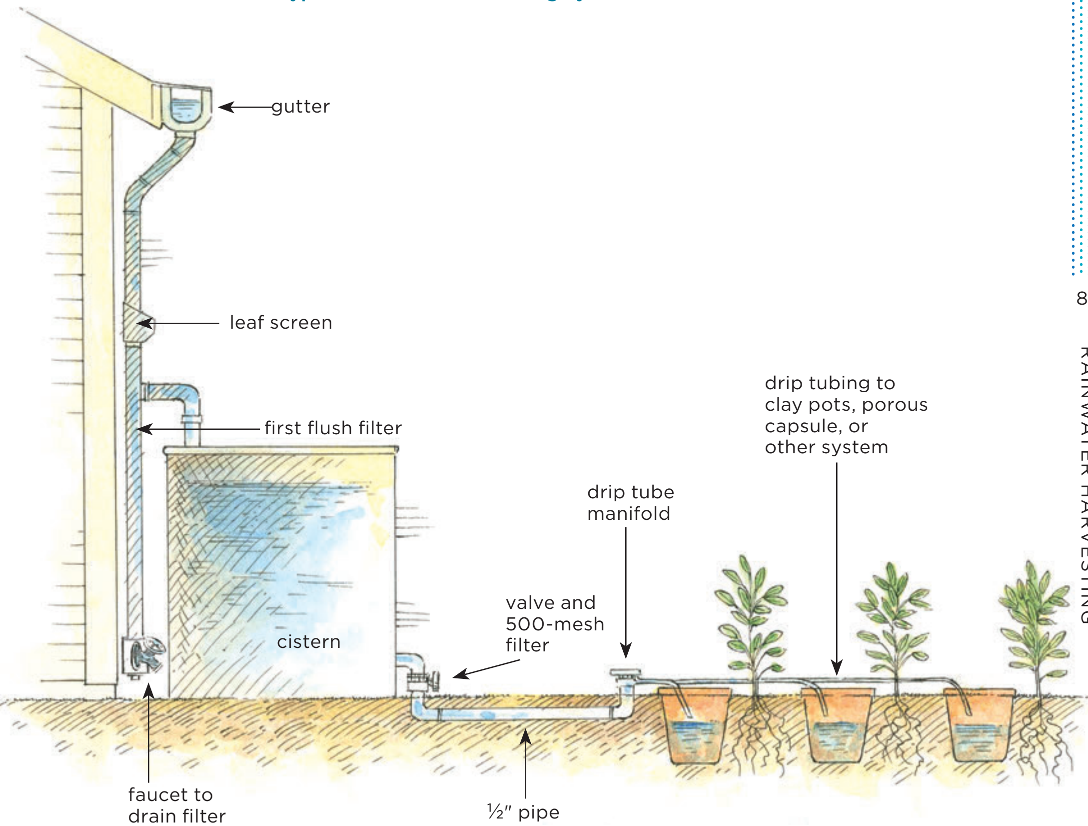
Gutters and downspouts are needed to collect the water. To take advantage of high rainfall rates, roof gutters must be big enough and sloped for good drainage. The rule of thumb for gutter slope is 1⁄16-inch per foot to the downspouts. Downspouts must be large enough to drain the gutters rapidly. A minimum of 1 square inch of downspout opening for every 100 square feet of roof is suggested. Gutter screens can help keep debris out of the water. Additional filtering can be done at the gutter-to-downspout transition with a sloped screen. Rain barrels should have a screen as well to keep debris and insects out. For the simplest system, downspouts can be run through a first flush and roughing filter into an aboveground tank or rain barrel.

### Filtering

First flush filtering lets the rain clear the roof of dirt, bird droppings, and

Note: In Colorado and Utah, which have some of the worst water laws in the nation, rainwater harvesting with a storage tank may be illegal except under specific conditions. Check before installing tanks or cisterns in those states.

## A Typical Rainwater Harvesting System



other debris before actually being collected for use. It is most often used in arid climates where there may be long periods of time between rainfalls. One of the easiest first flush filters runs water into a chamber that must fill up before clean water can flow into the cistern or tank. In some a floating ball rises up and seals the dirty water in the chamber, letting the water from the now clean surface run into the collection tank. The first flush chamber usually has a slow drip or outlet to a planted area so that it will be empty again by the next time it rains.

In places such as San Diego, where it may not rain for nine months, a manual valve can be used to divert all the water from the season's first rainfall to flush away accumulated dust and deposits. More elaborate flush or continuous filtering systems are also available. Water for use in porous irrigation systems should also be cleared by settling and/or with sand or mesh filters on its way into or out of the cistern.

## Storage

To get the water to a storage tank, you can run pipes under sidewalks or decks and then back up to the storage tank. Water will be left in the lower parts of the pipe and can be used for irrigation with a spigot and valve. The water will have to be drained before winter and freeze risk.

How much storage do you need? It depends on the rainfall pattern and anticipated use. If you are using rainwater collection as a supplemental water supply, your storage can be as simple as a rain barrel. But while a barrel of rainwater is nice to have, it won't go very far. For a garden, you might want to harvest a few hundred gallons or even a few thousand or tens of thousands of gallons. If you are using rainwater to fill specific irrigation needs, the storage volume needed can be estimated by setting up a water budget for the year, with monthly or weekly water use and average rainfall plotted in a table or chart. Think of the water supply like your bank account — you make withdrawals and rain makes the deposits. The chart on the following page shows a simple example for the desert where I live.

In an area where all the rain that falls must be collected, then assume

Note: Drinking water systems have their own specifications and requirements. Material selection, filtering, and careful maintenance is particularly important. Approved water quality testing may be required for home drinking water systems, and will almost certainly be required for community drinking water systems.

### Sample Rainwater Harvesting for San Diego

(For a 2,000-square-foot collection surface)

| | Irrigation Demand (gal) | Avg. Rainfall (in) | Collected (gal) | Stored at Month End (gal) |
|---|---|---|---|---|
| **January** | 200 | 2.25 | 2,790 | 2,590 |
| **February** | 200 | 1.69 | 2,096 | 4,486 |
| **March** | 200 | 1.98 | 2,455 | 6,741 |
| **April** | 600 | 0.92 | 1,141 | 7,282 |
| **May** | 800 | 0.29 | 360 | 6,841 |
| **June** | 1,200 | 0.08 | 99 | 5,740 |
| **July** | 1,200 | 0.04 | 50 | 4,590 |
| **August** | 1,200 | 0.06 | 74 | 3,464 |
| **September** | 1,200 | 0.22 | 273 | 2,537 |
| **October** | 500 | 0.40 | 496 | 2,533 |
| **November** | 200 | 1.20 | 1,488 | 3,821 |
| **December** | 200 | 1.52 | 1,885 | 5,506 |
| **Year total** | 7,700 | | 13,207 | |

10,000 gallons of storage collecting an average of 1,200 gallons per month would provide adequate water for a garden of ⅓ to ½ acre using super-efficient irrigation.

tank size based on annual rainfall. Tanks must be fairly big to provide the water needed for a full garden season. Large concrete tanks can be placed under patios or decks. A 20-by-10-foot tank just 3 feet high will hold more than 4,000 gallons.

In an area with rainfall spread out over the season or in a bimodal pattern, the storage capacity size can be reduced. If it rains almost every month, the storage can be much smaller. San Diego has an annual average rainfall of only 10 inches, with high year-to-year variability, and it falls mostly in just a couple of months in the winter; therefore, capacity needs to be large. Some of the early homes here included 30,000 gallons of storage. Tanks or cisterns must be screened or managed to prevent insect problems and to keep out animals, children, and snakes. Access hatches should be locked.

**There are many options** for commercial rainwater collection tanks that are made to be unobtrusive and conserve space.

Water barrels and rainwater tanks can be purchased at your local hardware or garden center and are usually the most expensive element of a rainwater harvesting system. A 1,500-gallon polyethylene tank can cost as much as $1,000 plus transport. The lowest-cost tank is probably homemade with ferrocement, but this takes some practice. The simplest installation is an opaque plastic tank (it can be challenging to get paint to stick to plastic, so opaque is best for limiting algae growth). It is easiest to have it sitting on the ground but it may be placed on an elevated platform to provide more water pressure. If additional pressure is required, water can be pumped up to a tank on a hill (this can be done with a simple photovoltaic system and pump without batteries) or pressurized with a pump, pressure tank, pressure switch, and check valve (familiar to well owners), or an on-demand pump.

Narrow, stacking, and vertical tanks designed for rainwater harvesting are increasingly available at home building centers, and some will fit very nicely in side yards. Recycled food-grade plastic drums will also work. These can be put in a series so they fill up sequentially. (A series of tanks can also be used as insurance against a leak, valve failure, or errant rifle shot.) The tanks will last longer and the water will be cooler if they are kept in a tank barn or shed. A plastered straw-bale shed will keep the tank water at a very uniform temperature and minimizes risk of freezing pipes and valves.

A rainwater harvesting system is a living system, and to keep it operating efficiently it needs to be cared for properly. The gutters and roughing filters will need to be cleaned, and silt may need to be removed from the cistern or tanks periodically. For more information on how to build a rainwater catchment system, see the resources listed on page 124.

## Going Big

Cisterns can be an attractive sign of a commitment to water conservation. The Lady Bird Johnson National Wildflower Research Center in Austin collects rainwater in a series of cisterns. Rainwater from the central rooftop of nearly 17,000 square feet feeds two 20,000-gallon cisterns and the 5,000-gallon tower cistern. Several other cisterns add to the total capacity of 65,000 gallons. With an average rainfall of 30 inches annually, these systems can collect more than 300,000 gallons of rainwater every year.

CHAPTER 10

# Landscaping for Water Catchment

**Rain or flood water can be captured directly in the field through landscaping, mulching, and design. Some systems are difficult to make without equipment, but most require only simple hand tools and willing workers. The best rainwater harvesting choices for a given area will depend on the culture, community, economy, crops, rainfall, soils, and climate. Many are best done as a group activity that can help build or restore a sense of community.**

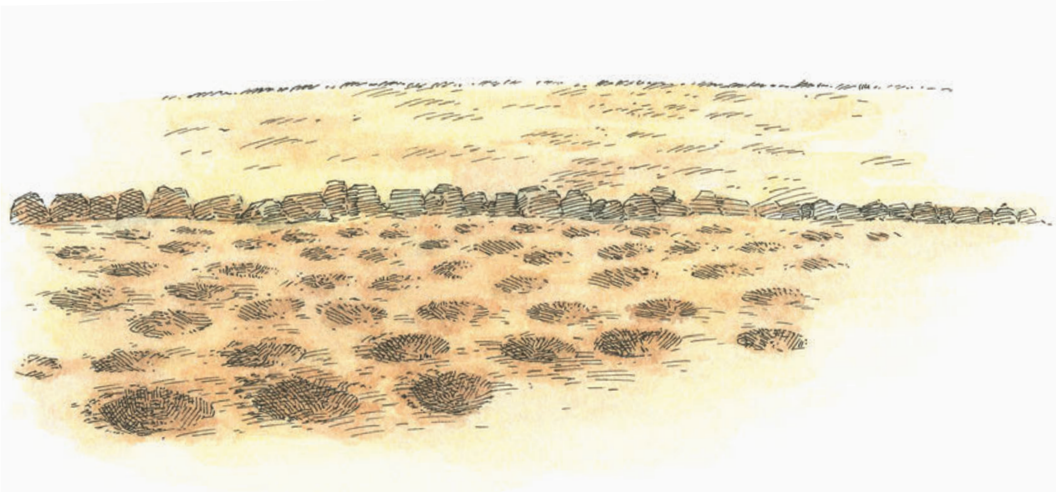
**This rainwater harvesting system** in Anza Borrego Desert State Park would start collecting water with only 1⁄100 inch of rain. The plastic catchment surface provided water for a restoration project at the end of a challenging four-wheel-drive road.

Water flows are powerful and demand respect. One of the best learning experiences is watching and experimenting with various rainwater harvesting systems during rainstorms. You are likely to find that water is smarter and more devious than you are at first. On the following pages are some examples of in-field water harvesting strategies.

**Microcatchments** are small watersheds that harvest runoff water with very shallow and low-velocity water flow. The catchment area may be left unaltered, or it may be defoliated, compacted, covered with plastic, or coated with wax or water-resistant chemicals to enhance runoff. Microcatchments are best used on gentle slopes (typically less than 5 percent). Small, regularly spaced earth ridges are constructed around the edges with the soil excavated from a planting basin at the lowest corner.

**Ridges and basins** can be created by raking or scooping soil along contour lines to act as mini dams. Ridging also modifies the microclimate and can improve early seed germination. Ridges and basins can be made more resistant to damage with a series of tied-back cross ridges so that one cell of a contour basin can fail instead of the whole basin. Cross-slope collection ditches or swales may be interspersed to collect excess water on the slope during severe storms.

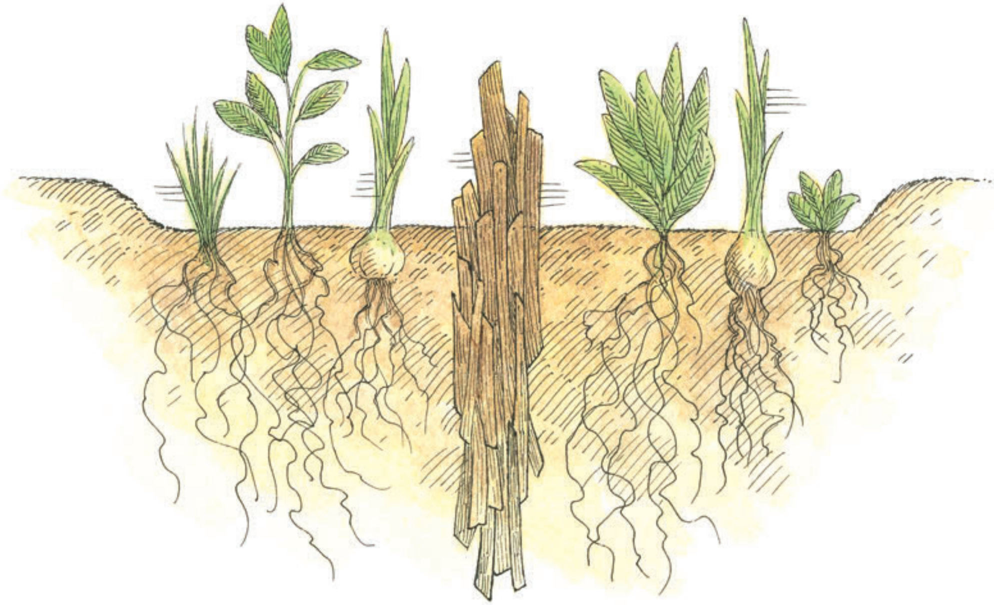
**Swales and collection ditches** are low, wide troughs, usually set on contour or with a very slight slope to collect rainwater to fill ponds or water fields, orchards, or gardens. They can be heavily mulched to prevent erosion. Collection ditches are usually deeper and often have a slightly steeper gradient to collect water and move it to a tank, storage basin, or farm field. In either case, slopes are kept low to reduce the risk of erosion in severe storms. Water routed to a pond or tank can be allowed to settle and later pumped up to a cistern or pond. Rainwater held in swales and basins can also help with groundwater recharge.



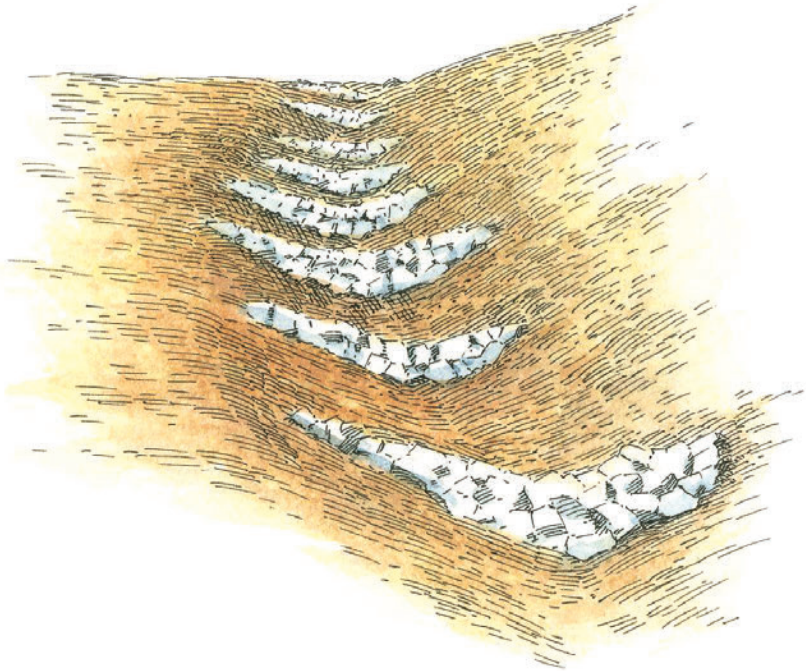


**Soil pits,** or *zai*, collect water and reduce evaporation from the soil surface and plants (by providing some protection from wind). Pits, perhaps a few feet across and 6–12 inches deep, are most effective on slopes of less than 8 percent where natural water infiltration is limited. They can be dug by hand using a large hoe or shovel. A team of people can pit a large area in one day. Combine pits with a buried clay pot and you have a very water-wise planting.

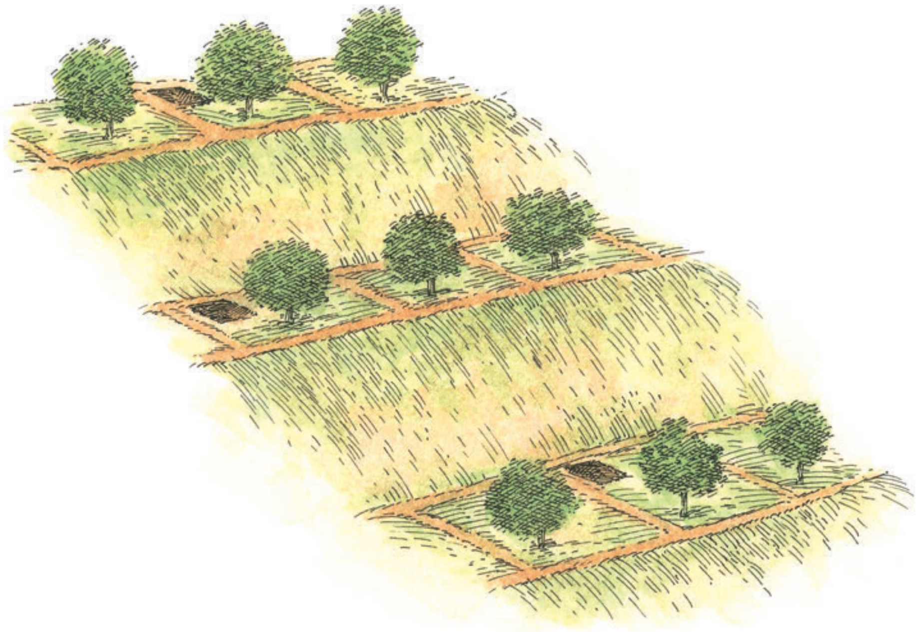
**Effective in dryland farming,** soil pits can be dug by hand to save rainwater and improve crop yields, as shown here in Burkina Faso.



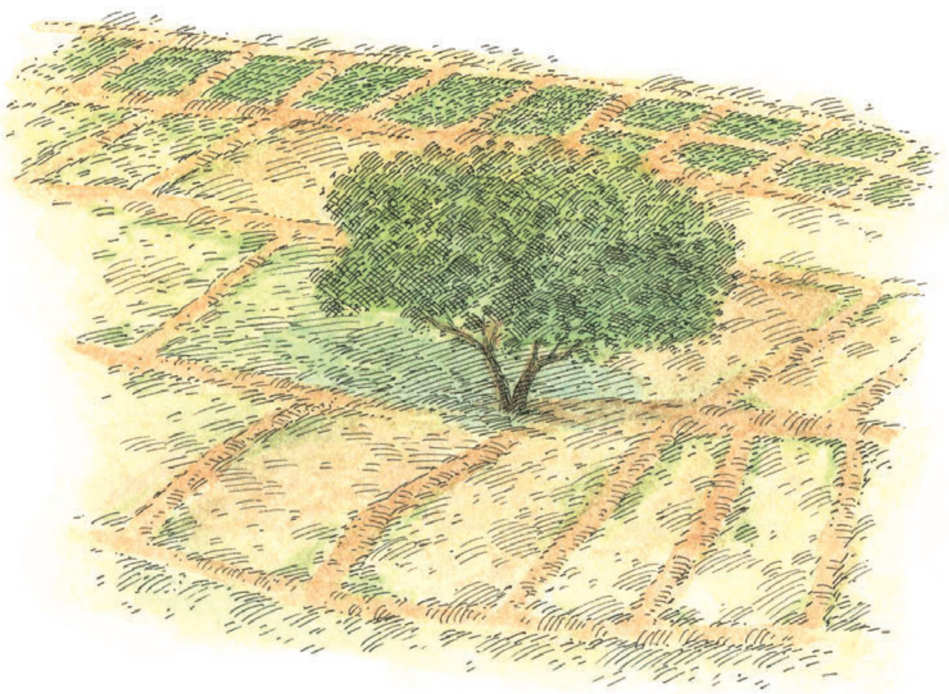
**Vertical mulching** consists of placing straw, sticks, or brush upright in the soil to help move water deeper into the ground. Vertical mulch can slow water movement, provide open channels for water penetration, provide safe sites for seeds to catch and sprout, serve as a wind break to trap seeds and dust, offer shade and cover for seedlings, and provide a source of below-ground organic matter to help return the soil ecosystem to health. Many materials can be used for vertical mulch, including broom corn, straw, native hay, brush, and reeds.



**Check dams** have been used for millennia to protect fields and help capture rainwater. They are small dams built across a swale, ditch, or channel to reduce erosion and allow sediments and pollutants to settle; they also slow water flow during storms. Check dams may be made of rock, brush, bamboo, fabric, wire mesh, wire and stones, wire and brush, wire and gravel, or wood. Virtually all can work well if designed properly, but poorly designed, placed, or built structures can increase erosion. Permeable structures develop lower pressures and are less likely to fail outright. They also allow the sediment to drain, and are more likely to grow vegetation that can further stabilize the gully.



**Terracing** is one of the most common responses to erosion and runoff retention. Although most people are more familiar with the terraced rice paddies of Japan and Indonesia, similar terraces are built for grains and crops in dry lands ranging from Yemen to China. More water can be retained by making the terrace slope inward and by adding small pits or ponds to store water. Trees, shrubs, or grasses may be planted on the outside edge where the soil is deepest and most fertile; this also helps stabilize the edge, captures soil, and builds up the terrace. Many terraces in China have been used continuously for thousands of years.



**Grid gardens** are often used to help capture rainfall in arid regions. Raised beds, developed for wet areas, are more widely known and promoted, but waffle-like sunken beds work better in dry lands. The ridges between basins are compacted, kept weed-free, and often paved with stones. They divert rain into the planted areas, while the depression of the soil in the basin captures water and allows it more time for deeper infiltration. The basin also reduces wind stress and evaporation.

**The Anasazi people** of the Southwest developed sophisticated rainwater harvesting systems with dams, reservoirs, and control gates. Crop yields were good in most years. Here is a farming terrace with a series of check dams at Mesa Verde.

## Curb Cuts

Street landscaping in Tucson is increasingly irrigated with rainwater. Curb cuts, which the city now allows with a permit, let water flow out of the street and into landscape plantings. These cuts can be done with hand tools or machines. A concrete cutting contractor would be helpful for multiple cuts. Rainwater harvesting from streets can transform a neighborhood from barren to fruitful.

CHAPTER 11

# Developing a Plan for Your Patio, Garden, Home, or Farm

**A well-developed plan for your garden, patio, home, or farmstead will help you achieve the most efficient water use. The first step is a careful analysis of the microclimate, site, resources, and your goals. How much water is available? What is the average rainfall pattern? What are the extremes? How cold does it get? What are the soils like? What do you wish to eat or grow? Do you wish to attract butterflies, bees, and hummingbirds? Is it for beauty, home use, or sale? Can edible landscaping work for you? Can native, locally adapted species be used? How much time and energy will you be able to invest? What are the historical solutions to the challenge of water and crops in this area? Take your time and improve your knowledge year after year.**

The availability of water will often shape the choices of crop and land management practices. Under very severe water limitations, only a few key plants — such as tomatoes, onions, garlic, and chilies — may be grown using the most water-conserving systems, such as buried clay pots. With additional water, a more complete mix of vegetables, potatoes, grains, nuts, fruits, and berries can be produced. For trees and shrubs, deep pipe or wicks might be used, while porous clay pipe, porous hose, or slotted pipe can work well for row crops. Spreading plants such as melons, cucumbers, and squash are often best planted with well-spaced buried clay pots or porous capsules. How will the garden or farm be zoned to match plants with similar water demands?

Next, think about your options and goals. Will you just have room for a few pots on the patio? Can you convert an area of grass or turf into

### Which Irrigation System Should You Use?

The following chart compares the different irrigation types and their effectiveness in different applications.
(E=excellent, G=good, F=fair, na=not appropriate)

| Irrigation System | Garden | Establishing an Orchard | Maintaining an Orchard | Establishing a Forest | Restoration | Container Plants | Landscape |
|---|---|---|---|---|---|---|---|
| **Deep pipe** | G | E | G | E | E | E | E |
| **Wick** | G | E | na | E | E | E | E |
| **Buried clay pot** | E | G | F | G | G | E | E |
| **Porous clay pipe** | E | F | F | F | F | G | G |
| **Porous capsule** | E | G | F | G | G | E | E |
| **Porous hose** | G | G | F | G | F | G | G |
| **Vertical porous hose** | F | G | F | E | E | E | G |
| **Perforated pipe** | G | F | G | F | F | F | E |
| **Tree shelter** | F | G | na | G | G | F | F |

garden or water-wise landscaping and be reimbursed by the city or water district? Will you be upgrading an existing garden? What do you like and what do you wish to change in the landscape? Do you want lovely low-maintenance flowers? Food production around the seasons? How much time, money, and energy do you wish to put into it?

Will you just have room for a few pots on the patio? Can you convert an area of grass or turf into garden or water-wise landscaping?

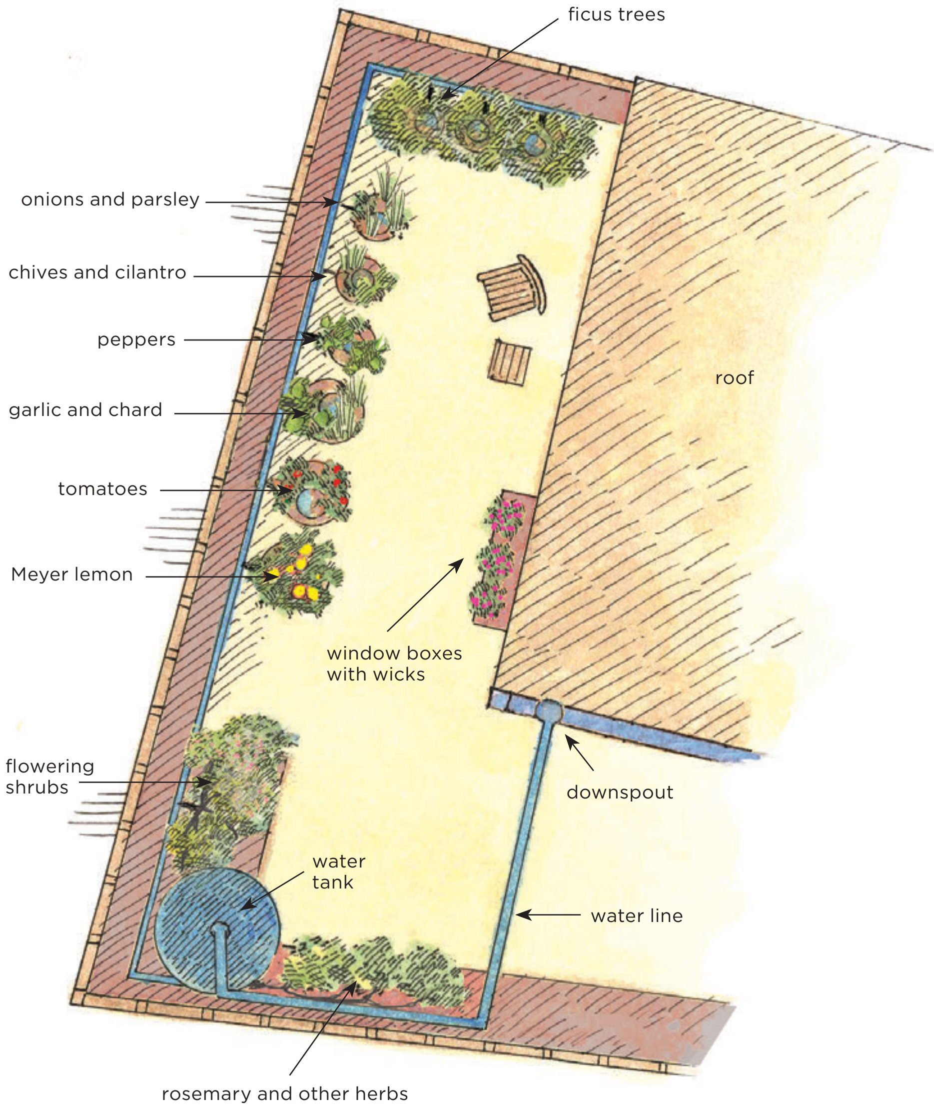
You may find it helpful to create a site map starting with an overhead image from Google Earth, or you can simply measure and plot the area on a sheet of paper. Identify the areas that get good sun, limited sun, or almost no sun. Show the patios, gardens, gutters, faucets, and landscape that you have and hope to improve. What kind of pots or containers do you want to use or already have? Do you like to use raised planting beds? You may want to measure the water pressure in the water lines with a pressure gauge if water flow is weak or very powerful. What surfaces are impermeable to water (roof, patio, driveway) and can be used to capture and store rainwater? Can you install curb cuts and use water from the road to water parts of your landscape? Can you recycle household waste by using greywater irrigation and making compost? Where will the compost pile go? How will winter snow and ice affect your irrigation system, pipes, faucets, water storage, and water harvesting systems?

If you have a larger property, where will different crops be grown? Where, how, and when can you install water catchments, cisterns, reservoirs, check dams, swales, terraces, and ponds? Over time you should be able to increase the water supply and crop yields manyfold. It is likely several types of super-efficient irrigation systems will be needed, alone or in combination. Start small or go big! The following sample plans should help jump-start your imagination.

## Plan for a Townhouse with Patio

Even if you just have a patio, it helps to plan it on paper. What areas get full sun? How will you get water to the plants on the patio? What areas do you wish to keep open for tables and chairs? A barbeque? Once you know what areas are available for planting, you can decide on the containers you will use. Terra-cotta pots are good because they breathe well. Many companies also make very stylish plastic pots that are lightweight, unbreakable, and easier to handle. You can also buy or make planting boxes. If you have a wood deck, make sure to install impervious pot bases and flashing to protect the wood from wet pots, leaks, or drains.

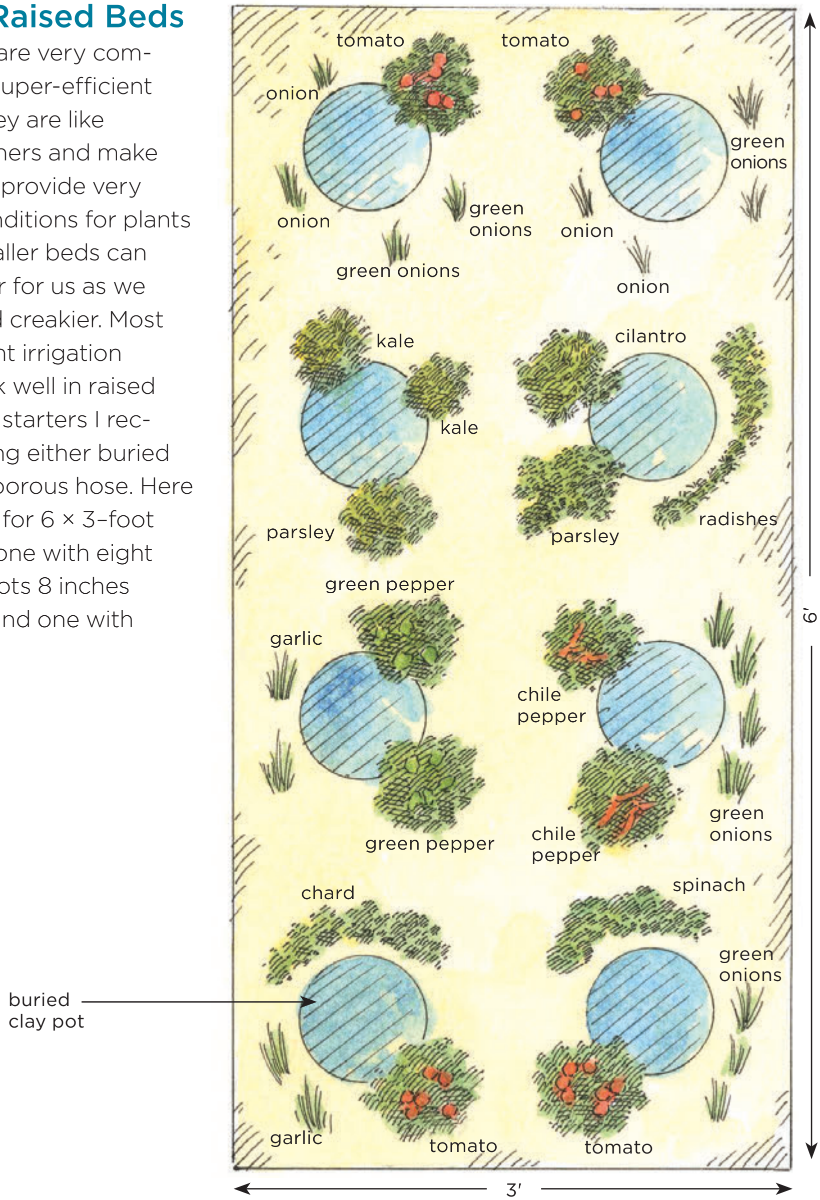
The sketch shows the layout for a small patio and deck. The larger pots are 18 inches across and will be watered using 8-inch buried clay pots. These are well suited for herbs, tomatoes, dwarf fruit trees, and other crop plants. Trees with high water demand may be watered with a porous hose ring. The medium-sized pots are 10 inches in diameter and will be watered with porous capsules made from two 3½-inch clay pots glued together and offset to one side. The capsules work well for shrubs, flowers, and smaller plants. The window boxes are full of flowers and will be watered with either the commercial Wickinator (see Resources, page 124) or a homemade system of bottle wicks.



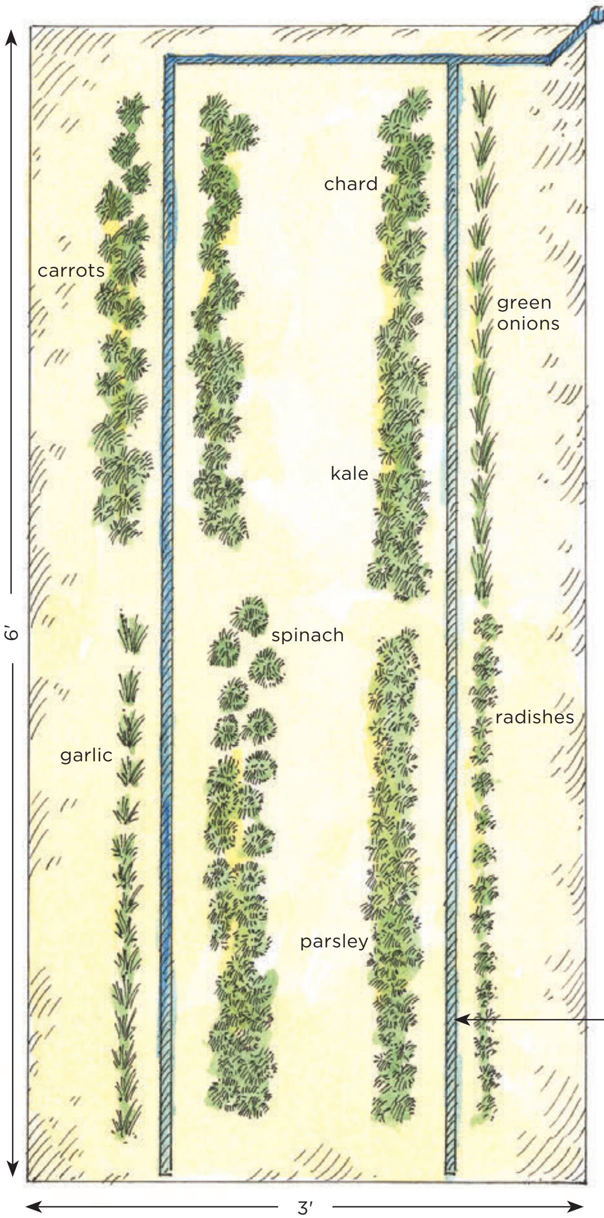

**This patio plan combines a range** of irrigation systems for efficient water use. The rosemary and other herbs are grown in the soil with deep pipes. The ficus trees, which need more water, use porous hose. Vegetables are grown in containers with buried clay pots and porous capsules, and the annual flowers in the window box are on wick irrigation.

## Plan for Raised Beds

Raised beds are very compatible with super-efficient irrigation. They are like super-containers and make it possible to provide very good soil conditions for plants to prosper. Taller beds can make it easier for us as we get older and creakier. Most super-efficient irrigation systems work well in raised beds, but for starters I recommend using either buried clay pots or porous hose. Here are the plans for 6 × 3–foot raised beds, one with eight terra-cotta pots 8 inches in diameter, and one with porous hose.

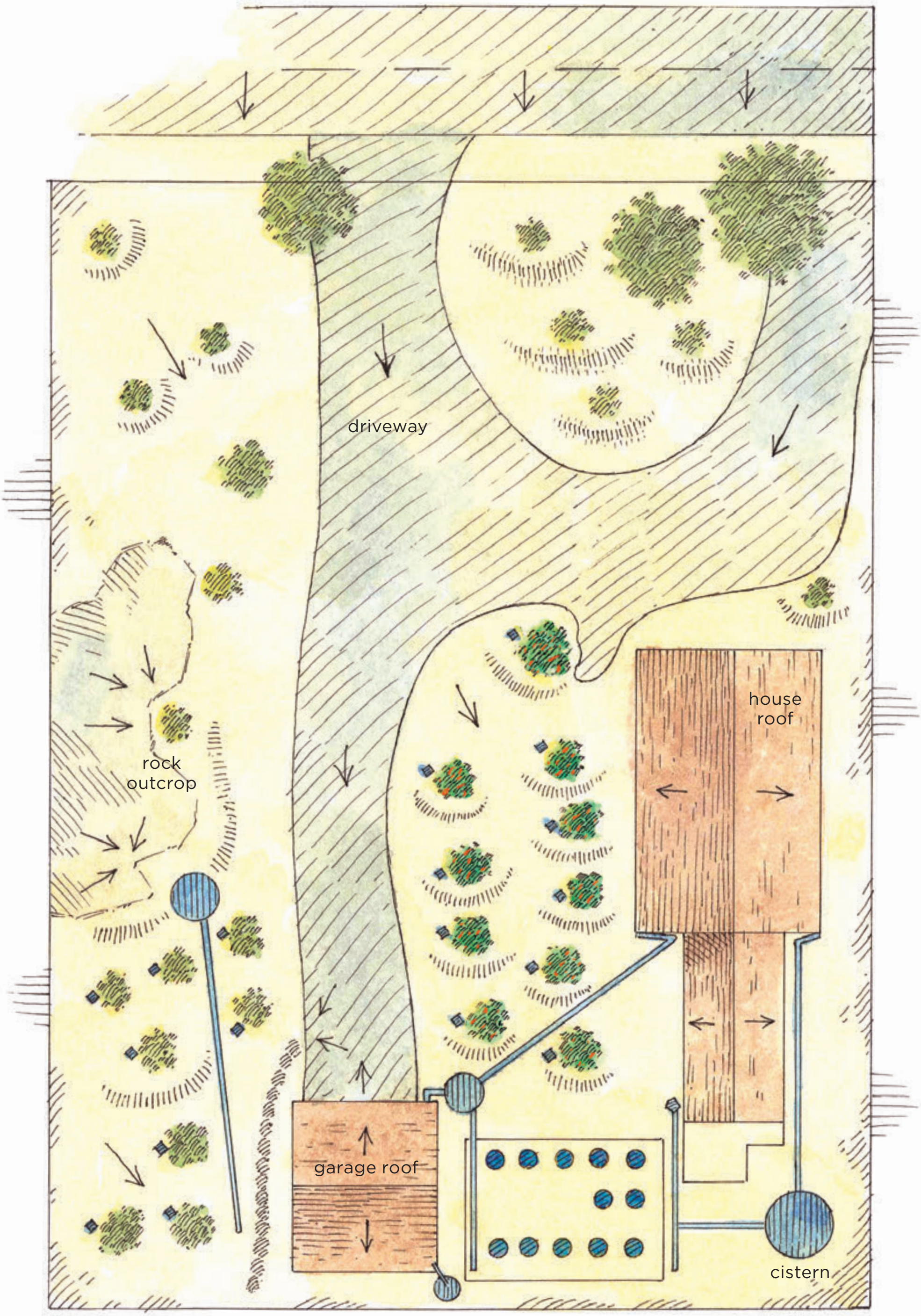



**Plan for a raised bed with clay pot irrigation.** Leave some open spaces between plants so that you can refill the pots. Low plants like garlic and green onions allow easy access.




**Plan for a raised bed with porous hose.** Make sure to plant in the area wetted by the hose. Place smaller plants on the outside and spreadier ones on the inside for easier harvesting.

Buried clay pots are more efficient than porous hose because they are demand responsive. Mixing large and small plants on a pot makes it easier to lift the lid and fill the pot. For example, the plot shows mixes such as a tomato plant with garlic and onions, or chile pepper with radishes. The raised beds could also be set up for automatic watering using a ½-inch feed pipe on a timer leading to the porous hose or to a riser and manifold in the middle of the bed (see page 30).



driveway
rock outcrop
house roof
garage roof
cistern

## Plan for a Home and Yard

Start with a plot map to create a super-efficient irrigation plan. You can develop this off a Google Earth view or a plan made with a tape measure. Note the areas that are impervious to rain. Measure the roof area and plot monthly rainfall to determine how much clean water you can collect and how big your storage tanks should be.

Then decide what you want for your landscape and garden and choose the super-efficient irrigation systems that will work best for each area of the yard. The example shown here is for Cortez, Colorado. This is a very dry place with only 12 inches of rain a year, but the rain is equally likely to come in almost any month. In winter it comes as snow and some will be lost to the wind. Almost 33,000 gallons can be collected during the rainfall months, making it possible for collection to exceed demand during many months of the year. Water use in the home will be slightly more than the roof collection—but if we add a collection system for the exposed rocks, we could meet the full yearly demand most years. Storage for the roof collection could use at least a 1,500-gallon tank for the house and 500-gallon tanks for the garage and rock collection area. The irrigation systems shown are well suited for this very dry climate. Deep pipes and microcatchments supply rainwater for shrubs and trees in the landscape, while buried clay pots are used in the garden.

**Key:**

 water flow direction

 cistern

 deep pipe

 microcatchments, swales & berms

 fruit and nut trees

 native trees and shrubs

 buried clay pot

## Plan for a Farm

Developing a super-efficient irrigation plan for a farm, greenhouse, or ranch is rewarding. It would take a book or two to describe all the work that can to be done for this level of planning, but the short story is as follows.

Start with a good map of the property, preferably an orthophoto that shows the buildings, roads, trails, fences, and vegetation with overlaid topography lines showing elevation. Using the map, identify the watersheds of the property and direction of water flow. Indicate where water is needed to irrigate crops and forage or provide water to the household and farm animals. Note areas where flooding has or may occur. Plot water use for the year and collect and chart rainfall

*continued on page 110*

## Seven Seeds Farm

### Williams, Oregon

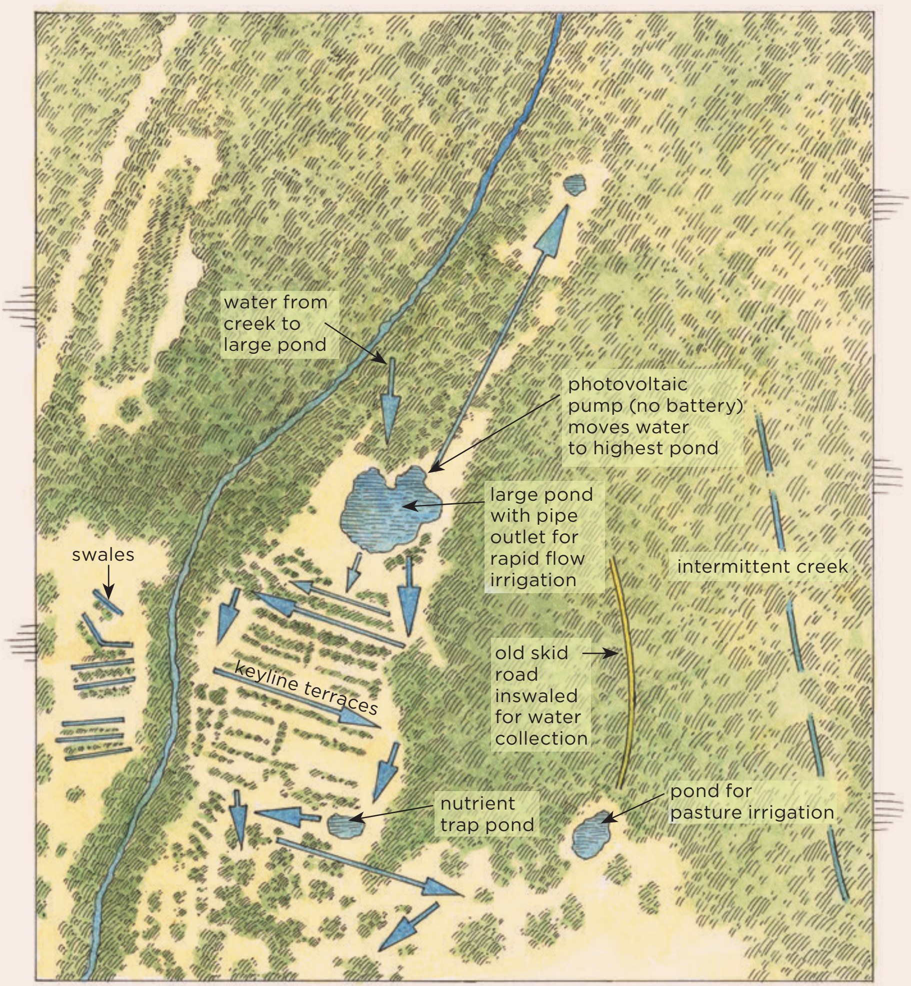
The best way to show a farm plan is with a working example. Seven Seeds Farm has been growing certified organic seed for many national-scale mail order seed companies since 1997. They are fairly unique within the world of seed companies because they produce much of the seed they sell. Most companies buy much (or all) of their seed from multinational corporate seed houses that emphasize genetically engineered vegetable seeds that cannot be saved and replanted. Seven Seeds Farm produces biodynamic fruits and vegetables distributed through a cooperative Community Supported Agriculture (CSA) group called the Siskiyou Sustainable Cooperative. They also raise ducks, chickens, turkeys, and sheep and raise several species of fish in their ponds.

Although annual precipitation in this location averages 42 inches (often with some snow), most of the rain falls in winter. The summers and fall can be desert dry with temperatures in the upper 90s or low 100s degrees F. Water harvesting is critically important and includes a comprehensive set of ponds, collection ditches, swales, terraces, vegetation management, and distribution controls. The goal — as it should be on most farms and ranches — is to capture the water and hold it as high as possible, hold it as long as possible, and use it wisely.

Water harvesting includes retention of water from the intermittent stream and almost year-round stream that pass through the property. A large pond above the farm fields is the first point of capture. From here water is pumped with a photovoltaic pump without battery backup to a high pond. This makes it easier to distribute water and adds more pressure head to operate.

Water can be released from a pipe outlet or collected from the overflow. This water is distributed by a sinuous pattern of keyline terraces dropping 1 foot per 100 feet. These terraces are lightly insloped and collect rainwater as well as distribute irrigation water across the slope. The pipe outlet is used for rapid flow flood irrigation, a system that allows for deep watering with less evaporation than sprinkler irrigation and no special irrigation equipment. This is not as efficient as the watering systems described in this book, but it can be useful for farms and ranches. Seven Seeds has done an exemplary job of managing water but still needs to develop super-efficient systems for their gardens.

Soils are carefully prepared and managed to maintain excellent tilth, nutrients, and organic matter. This speeds root development and improves plant health and yields. It also improves infiltration from rainfall and melting snow. Water management on this property has helped maintain base flow in the creek, increased groundwater recharge, and improved well flow for downstream properties.



*continued from page 107*
data. Identify areas with erosion, salt buildup, or other problems.

Once you have this information, you can start to create a plan for developing rainwater harvesting and super-efficient irrigation systems. Keep water as high as possible in the landscape. P. A. Yeomans refined this concept in Australia by identifying what he called *keylines* for each valley. These keylines occur at grade changes where a slightly downsloping swale or ditch can easily move water out of a channel or gully to irrigate slopes or be transferred to a reservoir area. Keylines can be used to help route fences, trails, and road layouts to assist with water capture and control. Getting permanent fences and roads in the right place is very important. Most existing infrastructure was put in without considering water flow and ecosystem health. Decide where you might install ponds, swales, and terraces. Will you need to put in check dams? How much water will roof areas provide? Would a rainwater catchment system be worth adding? Where should you place cisterns? How will you move water around? How much can you afford to do each year? Prioritize. If it seems overwhelming, consider a consulting visit with a keyline practitioner.

Once you know where your water sources will be, you can work out what you will be growing and where you will need super-efficient irrigation systems. For many small farms, deep pipes on drip lines, porous hose, and slotted pipes will work well for fruit trees and berries. For row crops, low-pressure porous hose works well. For small gardens of high-value specialty crops or when water is very limited, porous capsules and buried clay pots may be the best solution. Precise water delivery can minimize weed growth and let more energy be applied to more profitable tasks on the farm.

CHAPTER 12

# Our Water Future

**With super-efficient irrigation systems and rainwater harvesting, people's quality of life can be improved around the world, even during times of drought. Individual decisions make a big difference, and you can help, starting with your home garden and then reaching out to your neighborhood and homeowner's association, local schools and colleges, community gardens, towns, cities, states, and the nation.**

## Begin at Home

First things first: start with what you control, your garden and your yard. America's 40 million home gardeners can save water, time, and money while growing more food. If just 1 million gardeners adopt super-efficient irrigation and cut water use only 30 percent, we will save 1.5 billion gallons of water every year. But we can do much better than that. If all the gardens in America switched to the most efficient systems and rainwater harvesting, then savings would exceed 25 billion gallons a year. The savings from improving landscape irrigation could be even greater.

But it all starts one home at a time. Once you have your super-efficient irrigation systems in place and feel good about how they work, talk to your neighbors; invite them over to see for themselves. Tell the local newspaper and TV station about it. Help ensure that water-wise gardening and rainwater harvesting are encouraged, not outlawed.

To help pay for your installation, you may be able to get funding from your city or state. Many cities now have incentives for replacing water-wasting landscapes with water-efficient gardens and landscaping. Payments often cover at least half the cost. In addition, more cities are starting to offer incentives for rainwater harvesting. In Tucson both active harvesting (collecting rainwater in containers) and passive harvesting (modifying the landscape to direct rainfall toward vegetation and surface basins) are eligible. Rooftop harvesting with storage tanks can be rebated half the cost of the system up to $2,000. Installing passive rainwater-harvesting gardens and landscaping can earn homeowners $500.

Austin, Texas, offers rebates of $25 for every 100 square feet converted from healthy turf grass to water-efficient native plant beds up to $1,250. Austin also has a rainwater harvesting rebate program covering up to 50 percent of the system cost, with a total maximum lifetime rebate amount of $5,000 per site. Similarly, Chandler, Arizona, offers up to $3,000 for converting turf into xeriscape and up to $200 for installing xeriscape in the front or back yards of new homes. This could include a xeriscape food-producing garden. Many other cities offer similar rewards for being more water-wise. Contact your local water district or water supplier and look online for water conservation incentives in your area.

These rebates are an excellent start, but similar rebates or rewards for super-efficient irrigation systems would be even better, particularly in neighborhoods where money and resources are severely limited. I would suggest full-cost coverage for the first system in each neighborhood if the owner agrees to hold a "show and tell" at least twice a year for three years. Seeing is believing!

## You Can

**Get online and research water conservation incentives in your city and state.**

## Neighborhoods and Homeowners Associations

Working at the neighborhood scale can be very rewarding because big changes in infrastructure can help hundreds of people become more water efficient all at once. I helped change the city engineering regulations so that the Village Homes solar subdivision in Davis, California, could adopt aboveground drainage to collect rainwater. This took a great deal of work and debate with the public works department, who wanted to run all the rainwater into storm drains. Now the swales, basins, and drainage areas in Village Homes not only provide water for the trees and shrubs in the landscape but also provide excellent habitat for wildlife. And when the first really heavy rain came after this neighborhood was finished, it was one of the only developments that did not flood. Rainwater harvesting reduces stormwater flows, improves groundwater recharge, and also costs less. One developer I met saved more than a million dollars by switching from storm drains to aboveground drains and retention basins.

If you have a homeowners association (HOA), see if you can work with them to revise rules to make it easier for homeowners to install and use super-efficient irrigation, water-conserving landscaping, and rainwater harvesting systems. In many areas, HOAs may resist or not permit lawn removal, but some states have now passed laws limiting their power. In 2009, for example, the Florida legislature amended the state HOA Act to prevent HOAs from prohibiting the use of "Florida friendly" landscaping that does not require sprinklers and chemicals to survive. Texas followed with a similar law in 2013 signed by Governor Rick Perry. In California, Section 4735 of the Davis-Stirling Act makes void and unenforceable certain provisions of HOA governing documents that ban the use of drought-tolerant plants or water-efficient landscaping.

## You Can

**Work with your homeowners association to revise rules about lawns and native landscaping.**

## Schools

The rapidly growing number of student gardens at schools and universities can play a critical role in educating people about super-efficient irrigation. There are enough school gardens in San Diego now to support a competition for best student garden. Super-efficient irrigation, rainwater harvesting, and water-wise gardening are easy to integrate into a curriculum and can provide essential hands-on learning.

Mike Nicklas, the founder and president of Innovative Design in Raleigh, North Carolina, has shown how well water harvesting can work for schools. With his help, Northern Guilford Middle School alone saves 4.5 million gallons a year. His delightful passive solar designs dramatically cut the cost of heating and cooling and eliminate tons of global warming gas emissions every year. At the Roy Lee Walker elementary school in McKinney, Texas, six large stone cisterns squat near the building, each brimming with nearly 10,000 gallons of rainwater collected from the school's roof. A 30-foot windmill powers a filtering system that removes sediment from the collected water. This water then irrigates the water-conserving buffalo grass and native plant landscaping.

The rainwater harvested at schools can easily support food-producing school gardens, especially if those gardens adopt super-efficient irrigation systems. The harvested water can also help meet the need for water for toilet flushing. Many school districts have embraced the idea as drought tightens its grip.

Write to your state and federal representatives and tell them you would like to see a competitive grants program for the nation's 25,000 high schools and 100,000 elementary schools that would provide full funding for integrated rainwater harvesting, garden development, and support for management and monitoring for 5,000 schools a year. Gardens for these younger students have proved their value. Rainwater harvesting can provide better water for gardens, better food for students, and salt-free water for landscaping. With appropriate filtration and treatment, it can also provide water for use in the school buildings.

Global efforts deserve support as well. The International Rainwater Harvesting Alliance "Blue Schools" program is an excellent example. Their integrated approach can be seen in their work in Tamale, Ghana, which included construction of a rainwater harvesting system for every school (33 water tanks total); the



**The Public Works Department** in Charlottesville, Virginia, has installed a 1,000-gallon rainwater harvesting system at Burnley-Moran Elementary School, providing water for the schoolyard garden.

**Through the Blue Schools** program, an orphanage in Anwia Nkwanta, Ghana, has a rainwater harvesting system that provides water for domestic use as well as the garden.

installation of 161 toilets, 62 urinals, and hand washing facilities at the schools; a rainwater harvesting system for the Sankpagla Clinic; 6,000 trees planted on school grounds; and 12 school vegetable gardens.

The nation's 6,000 colleges and post-secondary institutions are also well suited for rainwater harvesting and super-efficient irrigation for landscaping and gardens. Many colleges now have food-producing gardens run by students, but too few have installed rainwater harvesting systems and super-efficient irrigation systems. One exception is the University of Arizona in Tucson where the visitor center has a two-tank cistern system that collects more than 200,000 gallons a year, enough water to cover all of the water-efficient garden's irrigation needs. In addition, a large area of concrete was removed and planted with native trees such as mesquite, creating a lush, rain-watered oasis in the middle of the Sonoran Desert.

But much more remains to be done to support school design that incorporates rainwater harvesting, super-efficient irrigation, and garden food production, all of which provide essential life lessons for students. As Mike Nicklas says, "If educational buildings are respectful of the environment, the students will consider environmental stewardship an important value. Our schools should make a strong statement that saving energy and protecting the environment are important. The message that we give to future generations, through the schools we build for them, should not be underestimated."

## You Can

**Tell your state and federal representatives that you would like to see a competitive grants program to create and support school gardens with super-efficient irrigation.**

## Community Gardens and Community Farms

The nation's 10,000 community gardens and the ever-growing number of community supported agriculture (CSA) programs have been innovative leaders in improving access to fresh food for people in urban and suburban areas. They are also great test and demonstration sites

**GrowNYC** has installed rainwater systems at many of their community gardens.

for super-efficient irrigation systems and rainwater harvesting. People from all walks of life come to community gardens, making them ideal places for demonstration and education. The farmers who run CSAs provide delicious and sustainable locally grown food to their members and often have the opportunity to educate their members about water efficiency.

Community garden projects are thriving around the country, and the University of California Cooperative Extension Service has developed an excellent startup guide for those who wish to get on board. The nonprofit GrowNYC has built more than 80 rainwater harvesting systems in New York City community gardens, which collect over a million gallons of rainwater a year. These gardens and programs can do even better when they install super-efficient irrigation systems to complement their rainwater harvesting. Encourage your local garden to get started, or try a simple system, such as buried clay pots, in your own community garden plot. People are bound to ask about what you are doing and may decide to try it out themselves.

## You Can

**Set up a super-efficient irrigation system in your community garden plot. Invite others to check out what you are doing.**

## Commercial Development

Tucson, Arizona, became the first city in the United States to mandate rainwater harvesting in commercial buildings. In 2008, the Tucson City Council passed the Commercial Rainwater Harvesting Ordinance requiring that commercial facilities constructed after 2010 must harvest enough rainwater to account for half of the water they use on their landscapes. The law was the first of its kind in the country and set the standard for other cities to follow.

In Texas, Pliny Fisk III at the Center for Maximum Potential Building Systems looked at the rainwater and solar collection potential of big box stores in Austin. He found that the roofs of big box stores could potentially provide 15 percent of the city's water demand and 20 percent of its electricity. Under Austin's Commercial Incentive Program, rebates may reach $40,000 for installing new equipment and processes to save water.

The challenge remains to encourage businesses, cities, and water districts to move beyond the "stop faucet leaks" stage of water conservation to aggressive rainwater harvesting and water-wise gardening and landscaping with super-efficient irrigation systems. Big goals are needed. Businesses should aim to cut water use 50 or 70 percent, not just 5 percent.

## You Can

**Start a conversation at your business or place of employment about how the company can conserve water (and save money).**

## State-Level Action

The best water conservation policies protect health, improve the economy, and promote rainwater use, resource conservation, and sustainability. States should provide guidelines, rules, regulations, and financial incentives that are outcome-based — not overly prescriptive — and include monitoring and evaluation. States can also help by supporting training for building inspectors and other regulators who may have to inspect or approve super-efficient irrigation or rainwater harvesting plans for government projects, review tax or financial rebates, or oversee private development.

Current rules and policies that may inadvertently block installation of water-saving systems or make them prohibitively expensive should be eliminated. This is particularly important for small, simple systems that needn't be regulated at all, including some greywater systems. In a spherically senseless interpretation of water law, Colorado has outlawed rainwater harvesting: the water resources department claims that the state owns all the water that falls from the sky and that water harvesting systems with tanks restrict downstream use. (Under this interpretation it should also be illegal for farmers to plow any new fields, and houses should not be allowed to have lawns, both of which also restrict downstream water use.) You can, however, use — but not collect! — water from downspouts for landscaping. Buried clay pots with holes in the lids would likely be allowed . . . but Trenchev's water-harvesting pans with reservoirs and wicks (page 52) might be found to be illegal.

Utah has similar rules, as a smart, forward-thinking Toyota dealer discovered. Mark Miller constructed a large rainwater collection system at his dealership to use for washing new cars. This clean, salt-free water is ideal for the job. But he soon discovered this was an "unlawful diversion of rainwater." As Miller notes, "Utah's the second driest state in the nation. Our laws probably ought to catch up with that." Fortunately, a compromise was worked out and his system was not ordered removed.

In contrast, Texas offered residents the first state-supported rainwater harvesting manual way back in 1996 and provides state property and sales tax exemptions for commercial installations. Texas House Bill 3391, approved in 2011, is one of the most far-reaching and comprehensive rainwater harvesting laws ever passed and would be a good model for other states and cities.

## The World

Super-efficient irrigation, rainwater collection, and watershed rehabilitation can improve the quality of life, health, and outlook of people around the world. But it will take a concerted effort by individuals, families, communities, nongovernmental organizations, agencies, institutions, and funders to make it happen.

The challenge is immense, especially in places already seeing drought due to climate change. Changes in the jet stream, which many believe are related to climate change, put California in a severe drought affecting the entire state. More than half the state was in exceptional drought and 80 percent in severe drought by Thanksgiving Day, 2014. This led to severe overuse of groundwater and rapidly declining water tables. In some areas of the Central Valley the water table has dropped 200 feet in recent years, as much as 5 feet a month during peak use.

The Global Drought Information System reports that by the last half of 2014, short-term global drought conditions continued or intensified across much of eastern and northern China and in central Russia. Parts of western China have seen a reduction in grasslands, which affects nomadic herders' ability to feed their animals. In Africa, drought continued to intensify in the far north and south. In southeastern South Africa most rivers were not flowing normally, with some completely drying up; more than 80 percent of wells being used as alternative water sources had dried up. In South America, drought remained entrenched across much of southern and western Brazil; reservoirs feeding São Paulo hydroelectric facilities contained less than 10 percent capacity. The British Isles were still reeling from the driest September in the last 104 years. South Australia recorded its driest October on record, with low rainfall totals affecting adjacent parts of Victoria and New South Wales.

Super-efficient irrigation is critical for small farmers such as the 99 million in India struggling with too little land (for many just 0.6 acre) and too little water. It may be able to help stem the tragic epidemic of suicide by farmers in India — more than 300,000 since recordkeeping started in 1995. In China 200 million small farmers have seen their land holdings drop from 1.7 acres in 1980 to 1.3 acres in 2000. These small farms typically include three or four very small plots, with more than half of the plots less than a quarter acre. Such plots are well-suited for demand-responsive irrigation systems such as buried clay pots and porous capsules, and for the very low-cost systems such as wicks and porous hose.

In some areas, we are making strides forward. Many international groups are working toward the Millennium Goals formulated by the United Nations, including reducing the number of schools in the world

**More efficient irrigation** will be critical for dealing with widespread drought and abandoned or degraded drylands.

without access to drinking water or basic sanitation facilities, and improving gardening skills. Super-efficient irrigation should soon be added to these groups' tool kits. Two stalwart groups are Practical Action (based in the UK) and the Centre for Science and Environment in India (CSE). CSE started its work on water issues back in the 1980s when it became clear that the current water management paradigm, based on massive irrigation projects and over-exploitation of surface and groundwater resources, would prove inadequate. Their educational outreach is outstanding, and as might be expected, their office building has a rainwater harvesting system. CSE started by pushing for policy reforms in the water sector that would mainstream the harvesting of rainwater in both urban and rural areas.

Demonstration projects have played a critical role in the amazing story of rainwater harvesting in Gansu, China. More than 3 million rainwater harvesting systems and cisterns have been installed over the last 25 years. These have transformed people's lives by improving drinking water quality and providing critically needed water for food production. In Thailand a program to support cisterns led to 10 million new cisterns in just 10 years. This also created new jobs, and as experience grew the prices dropped to just $20 for a large tank. In 2002, the city of Chennai in India opened a privately funded Rain Centre, the first in the country, for the city's 9 million residents. The center's mission is to provide citizens with information and assistance in harvesting rainwater using displays, models, videos, and a library. The center reaches out to school children, college students, architects, engineers, plumbers, city officials, residents, and anyone else interested in learning. The success of Chennai's rain center has led to the creation of others in additional cities.

The success these initiatives have had with rainwater harvesting can be applied to the challenge of introducing and supporting super-efficient irrigation systems. Online materials, courses, and publications in many languages are needed to encourage research, development, and implementation of water-efficient irrigation practices.

Super-efficient irrigation and rainwater harvesting can, and must, play a major role in a more sustainable water future. This future is ours to make. With care and attention, even the most degraded yard or wasteland can be brought back to health and will produce a sustainable yield of food, forage, and beauty.

# APPENDIX

## Rubber Stopper Sizes for Clay Pot Holes

| Stopper Size | Top Diameter (inches) | Bottom Diameter (inches) | Diameter Hole Fits (inches) |
|---|---|---|---|
| #000 | ½ | 5⁄16 | 7⁄16 |
| #00 | 19⁄32 | 13⁄32 | ½ |
| #0 | 21⁄32 | ½ | 19⁄32 |
| #1 | ¾ | 9⁄16 | 11⁄16 |
| #2 | 25⁄32 | ⅝ | 23⁄32 |
| #3 | 15⁄16 | 23⁄32 | 27⁄32 |
| #4 | 1 | ¾ | 15⁄16 |
| #5 | 1 1⁄16 | 29⁄32 | 1 |
| #6 | 1¼ | 1 1⁄32 | 1⅛ |
| #7 | 1 7⁄16 | 1 3⁄16 | 1 5⁄16 |
| #8 | 1⅝ | 1 5⁄16 | 1½ |

## Metric Conversion Charts

1 HCF (100 cubic feet) = 748 gallons / 2,831.7 liters

Length

| To convert | to | multiply |
|---|---|---|
| inches | millimeters | inches by 25.4 |
| inches | centimeters | inches by 2.54 |
| inches | meters | inches by 0.0254 |
| feet | meters | feet by 0.3048 |

Volume

| Measurement | Is equivalent to |
|---|---|
| 1 gallon | 3.785 liters |
| 1 cubic foot | 28.3 liters |
| 1 acre foot | 1,233 cubic meters |

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Manufacturers and suppliers were very helpful in supplying samples, information, and details about their products. Many thanks also to those who were willing to share their photographs.

# SUPPLIERS

Most materials needed to create the super-efficient watering systems described in this book are easy to find at local garden supply centers and hardware stores. Below are listed some suppliers for the harder-to-find items as well as the producers of commercially made systems.

## Ollas

**Diana Kersey**
San Antonio, Texas
210-573-7418
kerseyceramics.com

**Dripping Springs OLLAS**
512-227-4048
drippingspringsollas.com

**Growing Awareness Urban Farm**
East Central Ministries
Albuquerque, New Mexico
505-266-3590
eastcentralministries.org/growing-awareness-urban-farm.aspx

**GrowOya**
Vancouver, British Columbia
orders@growoya.com
growoya.com

**Urban Homestead Supply & Farmstand**
Pasadena, California
626-765-5704
urbanhomesteadsupply.com

## Porous Capsules

**Texas Hill Country Ceramics and Gifts**
Spicewood, Texas
830-693-6218
texashillcountryceramics.com
*Porous capsule plant tenders*

**Wetpot Industries and Enviro Pots Pty. Ltd**
Queensland, Australia
800-603-828
wateringsystems.net

## Deep Pipes

**Green King**
Chandler, Arizona
866-469-4330
deepdrip.com
*Deep Drip irrigation pipes*

**Stuewe & Sons**
Tangent, Oregon
800-553-5331
stuewe.com
*Plant containers, including Deepots*

## Wicks

**Flower Window Boxes**
Cumming, Georgia
888-505-7715
flowerwindowboxes.com
*Self-watering window boxes, including the Wickinator*

**Groasis B.V.**
Steenbergen, The Netherlands
info@groasis.com
groasis.com
*Groasis Waterboxx*

**LandLife Company**
Amsterdam, The Netherlands
info@landlifecompany.com
landlifecompany.com
*COCOON planting system*

**U.S. Rope & Cable**
National Tool Grinding
800-331-2973
us-rope-cable.com
*½" solid braid nylon (not blended), sold by the foot*

**United States Plastic Corporation**
Lima, Ohio
800-809-4217
usplastic.com
*Nylon tubing and plastic hose fitting ½" HB x ½" NPT*

## Porous Hose

**Leaky Pipe Systems**
Maidstone, England
leakypipe.co.uk
*Low-pressure porous hose (LP12UH, ID 9mm, OD 14mm, good to 0.1bar)*

**Rain Barrel Soaker Hose**
rainbarrelsoakerhose.com
*Low-pressure porous hose (OD 0.58 inch) and low-pressure solar timer*

## Buried Clay Pipe

**Kubota Minoru Ceramics**
Saga, Japan
+81-955-46-3164
kyuemongama.com/en

## Rainwater Harvesting

Many manufacturers are now selling rainwater storage tanks, filters, and screens. These are a couple I particularly recommend:

**Bushman**
866-920-8265
www.bushmanusa.com
*Full range of tanks, including slimline tanks*

**Rainwater Hog**
888-700-1096
rainwaterhog.com
*Modular tanks*

Note: Additional technical information and comprehensive references for scientific studies and experimental data will be available under SEI Resources at works.bepress.com/david_a_bainbridge.

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