OVERVIEW

Alternative Irrigation Systems for Arid Land Restoration

by David A. Bainbridge

Southern California desert restorationists have studied traditional methods and developed innovative ways to efficiently water new plantings.

Establishing plants in deserts can be challenging even with supplemental irrigation. The low relative humidity, extreme temperatures, lack of consistent rainfall, tremendous rate of evaporation, and high wind speeds common in desert environments all play important and interrelated roles in water loss from desert soil and plants. These factors make it critical that restorationists use the most appropriate and cost-effective means to deliver water to the root zone of newly planted plants in order to maximize survival and growth. In this paper, I discuss the pros and cons of standard and alternative means of watering plants. This information is derived from experiences that my colleagues and I have had using these systems in the desert areas of southern California and from the experiences of researchers in other countries.

Manual Watering

Water is heavy, awkward to handle, and quickly becomes expensive to move and use in remote sites. For example, an acre-inch of rain weighs more than 100 tons, which is the equivalent of about 300 pickup truck loads of water.

There are several conventional ways to move water: 1) watering cans or jugs, 2) hoses, and 3) vehicles. If hand-watering is necessary, we have found that most people can carry two three-gallon jugs (about 48 lbs.) more easily than carrying one five-gallon jug. We prefer using the ergonomic and easy-to-use French-style watering cans ($25 each from Gardener's Supply). These have a very comfortable handle and a long spout that makes filling deep pipes or pots easy. When possible, hoses can be used. However, dragging them through restoration sites is hard work and can cause damage.

Water trucks, water trailers, and collapse-a-tanks or saddle tanks designed for use in pickup trucks work well for transporting water to remote locations (Figure 1). Whenever possible, I like to use a 3,000-gallon water truck with hoses because with it I can perform a multitude of tasks including irrigating plants, pressurizing irrigation systems, filling on-site tanks that feed irrigation lines, and spray irrigating with side or rear spray booms. When small tanks or a water trailer are used, a hand transfer pump (Guzzler brand from Bosworth Co.), a 12-volt pump, or a small gas-powered pump (model AP125 from Homelite) can be used to refill water containers or pressurize hoses and irrigation systems. In situations where a truck with a water tank can be positioned at an elevation above the watering site, gravity—rather than a pump—will deliver water through a hose (Figure 2).

Often it is more economical to have a water storage tank on site rather than driving a water truck or hauling a water trailer to the site each time. A water truck can be used to fill the tank periodically. We have used a variety of on-site storage tanks and have found that polyethylene tanks are the

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Figure 1. A water truck with a motorized pump and multiple hoses stands ready to water seedlings. *Photos and illustrations courtesy of David A. Bainbridge*

best. Steel tanks rust and are more expensive. The plastic tanks cost about $1 per gallon of storage capacity. The tanks should be fenced in or wired in place to keep them from being blown away by the wind and to reduce the risk of theft or vandalism. We have also found that painting the tanks with latex paint reduces algal growth in the water and sun damage to the plastic. During those times when rainfall is more likely, it may make sense to attach a water-harvesting apron to on-site storage tanks. For example, at our test installation in Anza-Borrego Desert State Park, an EPDM rubber apron was able to capture rainfall even during a 0.12-inch (3-mm) rain event.

Standard Irrigation Systems

Once water is onsite, the choice of an irrigation system becomes critical. The two standard irrigation systems are basin irrigation and drip irrigation, but both are of limited value in remote site irrigation.

Basin irrigation is the old standard. It requires planting in a hand-dug depression approximately 4 inches (10 cm) deep and 20-30 inches (50-75 cm) square. Planting in these depressions improves the microclimate for the plant and makes it less likely that irrigation water and rain will run off and be wasted. We have used basin irrigation as the control treatment for most of our irrigation-system tests. Plants in basins that received the same amount of water as the other treatments (about 0.25 gallon {1 liter} per plant every two weeks) generally have very poor survival (often 2 percent) at these low application rates.

Drip systems are popular in arid areas, but our experiences with them led us to conclude that they are rarely suitable for remote sites. The reasons are many. First, they require too much precious water (typical flow rates are 1-2 gallons {2-4 liters} per emitter per hour). Second, they need regulated water pressure and careful filtration to operate properly. Third, many animals, including coyotes, rabbits and dogs, will chew the tubing and pipes even when open water is nearby, and repellents to keep the animals away have not worked for us. Fourth, emitters are easily blocked with sediment, salt, and insects. Finally, drip systems are easily vandalized and expensive to repair. I recommend using drip systems only in situations where routine inspection and maintenance is readily available.

Alternative Irrigation Systems

My colleagues and I have worked with and tested many irrigation systems used by traditional cultures. We have also developed several methods of our own that work well and use much less water. Most of the irrigation systems we have tested are capable of keeping plants alive on 0.25-0.5 gallons (1-2 liters) of water per month, although higher watering rates are desirable and needed to improve plant survival and growth. The most desirable amount is very species and site specific, but increasing the rate to two gallons per month per plant is desirable in most cases. The more promising alternatives we have tested include irrigation by porous hose, deep pipe, watering into a tree shelter, perforated pipe, buried clay pot, wick, porous capsule, and microcatchments. Below is a summary of our findings with each.

Porous Hose Irrigation

This method uses a vertically placed section of porous hose to wet the soil column. The hose can be installed before or at the planting time by drilling a hole in the soil to the desired depth and inserting the hose. The hose can be connected to a water bottle, a water tank, or an irrigation system. However, only the more porous hoses will work at low pressure (we use a fast-rate hose sold by Lee Valley). The pores on these leaky hoses will let water out even when they are simply connected to a bottle. The tighter hoses work only at 7 psi or higher pressure. Our early trials of vertically placed, 12-inch (30-cm) by 0.375-inch (1-cm) diameter porous hose have been very encouraging. Jennifer

Cogswell is presently conducting an experiment comparing deep pipe, porous hose and basin irrigation of coastal sage scrub plants. It appears that when water delivery through a porous hose is fairly consistent throughout the soil column there are excellent conditions for deep root growth

In very windy arid areas, trees may be susceptible to blowing over unless a good root pattern develops. I think that a wind-resistant root architecture could be created by placing three porous hoses in a triangular pattern around the planting hole. These hoses could be left in place until the plants are established because the porous pipe breaks down fairly quickly, usually within two to three years.

Figure 2. A typical arid land water setup using 30-gallon drums and hoses. No pump is required, all water delivery is gravity-fed. Drums must be securely fastened to the bed of the pickup.

Deep Pipe Irrigation

Deep pipe irrigation is a little-known but very effective method for irrigating arid areas (Figure 3). This method uses an open, vertical or near-vertical pipe to concentrate irrigation water in the deep root zone (Mathew 1987, Bainbridge and Virginia 1990). Experiments in Africa have demonstrated that a deep pipe drip irrigation system is much more efficient than surface drip or conventional surface irrigation (Sawaf 1980). Deep pipe irrigation helps the plant develop a much larger root volume than other forms of irrigation, which means that the plant is better able to survive after watering is stopped. Plants started with deep pipe irrigation also respond better to rare summer rains, perhaps because the deep tap roots and extensive root system help maintain the near surface roots by hydraulic lift.

Deep pipe irrigation is commonly done by inserting a 2-inch (5-cm) diameter pipe vertically from 12-20 inches (30-50 cm) deep into the soil near the seedling or tree. The size of the pipe is often determined by the volume of water we hope to deliver at each visit. The pipe is left open at both ends, but the top should be covered with 1 mm hardware cloth to keep out lizards and other animals. (Screen fabricators can make these covers at low cost and they can be attached with silicone caulk.) A cap can also be used but this takes more labor. A series of 1/8-inch (3.2-mm) diameter holes should be drilled about 2-3 inches (5.0-7.5 cm) apart down the side of the pipe nearest the plant to facilitate root growth in the early stages of development. If shallow-rooted, container-grown plants are planted next to a deep pipe, the roots may not make contact with the wetted soil unless the holes are drilled and the pipes filled with water. If a drip emitter wets only the soil in the bottom of the pipe, the young seedling can be left high and dry.

Deep pipes may be filled with water from a water truck, hose, or watering can, or they can be fitted with a drip emitter (Sawaf 1980, Bainbridge and Virginia 1990). Where materials and technology for drip systems are available, deep pipes with drip emitters can be monitored and repaired much more readily than a buried drip system. If a drip system is used, the pipes can be only 0.5 inches (1.3 cm) in diameter instead of the larger pipes needed for hand watering (Figure 4).

Deep pipe irrigation can be used in situations where water quality is low—it does not require pressurized, filtered water. It also has the advantage of using simple materials that can be installed and maintained by unskilled labor. Moreover, deep pipe irrigation provides better water use efficiency due to reduced evaporation, better weed control, and less runoff even on steep slopes. The efficiency of the system multiplies the value of expensive water when compared with conventional,

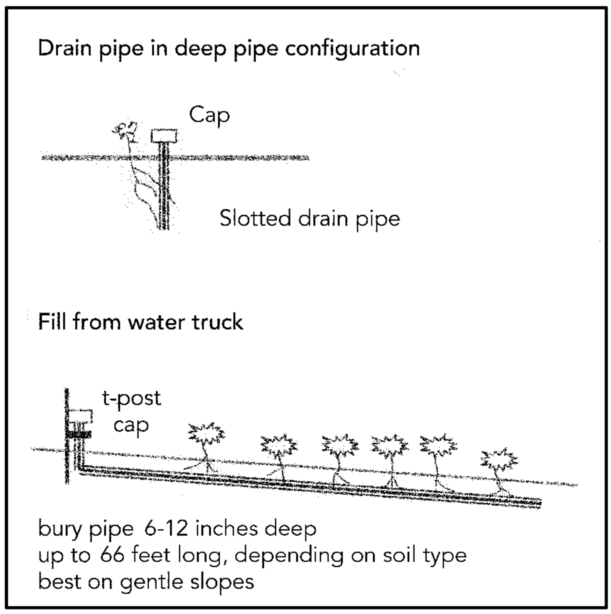

Figure 3. Deep pipes can be used to water single or multiple plants. Two-inch diameter pipe is typically used, which allows filling from a hose or watering can. Deep pipes are cheap and easy to use and maintain.

less-efficient surface irrigation systems. Several pipes may be used for older trees. The pipes can be collected, cleaned, and reused for many years.

Treeshelters

Plant shelters and plant protection can help reduce plant water demand and improve survivorship (Bainbridge 1994, Bainbridge and MacAller 1996). Plants with roots in moist soil can often maintain a higher level of humidity inside the shelter than plants grown in the open. This may help reduce water demand in desert environments where very low humidity and high winds are common. Shelters also protect plants from sandblast and herbivory. These factors enhance survival and growth of plants in treeshelters (Bainbridge 1991, Bainbridge and others 1995).

Watering plants inside a treeshelter is another alternative means of irrigation. Treeshelters can be inserted into the ground around a seedling and used for watering by simply pouring water into them. The amount of water can be calibrated by marking a filling line on the shelter. In our experience, irrigating into treeshelters has worked very well. The shelter eliminates runoff and focuses the watering on the seedling (Bainbridge 1991, 1994). Generally speaking, the increased air temperatures in the shelters have not been a problem, although plants must be hardened off before transplanting into a desert setting because simply transplanting seedlings grown in a cool coastal site into the extreme conditions of the desert could be fatal.

The simplicity of this system and the low water requirements make it worth considering when budgets are limited. I think that combining treeshelters with microcatchment basins would be a good, minimal-cost irrigation system.

Perforated Pipe Irrigation

Buried perforated, horizontal drainage pipe was fairly successful at an initial experiment we conducted along Highway 86 in the Sonoran Desert. This led to a very successful installation of more than a half mile of buried, slotted drainage pipe that was used to water a windbreak at Fort Irwin in the Mojave Desert.

Figure 4. A deep pipe with a drip emitter. This set-up works well in situations where the emitters can be routinely inspected and maintained.

This drainage pipe can be installed easily if the proper heavy equipment is available (typically in areas where farm drains are commonly installed). Using a specialized plow and pipe roll installer, pipe can be installed very economically in soils that are deep, have few rocks or caliche layers, and are not severely compacted. For long rows of plants, a tractor operator will dig a sloping ditch 12-16 inches (30-40 cm) deep into which the horizontal pipe is laid with vertical standpipes tied to posts at intervals based on the slope and flow direction. The pipe is then covered with soil. The vertical standpipes, which are covered with 1-mm hardware cloth or standard metal caps, are used to put water in the buried pipe. These linear system are most appropriate for areas with: 1) gentle slopes of 10 degrees or less; 2) few rocks to interfere with grading and planting; 3) firm, compatible soils (sites with highly erosive sandy soils should be avoided); and 4) sites with easy access for water trucks. Drain pipes may also be included at the low point of a microcatchment basin to move water more quickly into the deep soil.

Buried Clay Pot Irrigation

Buried clay pot irrigation is an efficient, traditional system for dryland irrigation (Bainbridge 2001) that utilizes buried, unglazed clay pots filled with water to provide a steady supply of moisture to plants growing nearby. The water seeps out through the walls of the unglazed pot at a rate that is in part determined by the plant's water needs.

Most standard red clay pots are suitable for irrigation once the bottom hole is plugged. (Silicone caulk works better than rubber stoppers or corks for this purpose. Simply place masking tape across the hole inside the pot, turn the pot over, and then, using a caulking gun, fill the hole with silicone caulk.) Buried clay pots can be filled by hand or connected to a pipe network or water tank. A tight-fitting clay or metal lid (aluminum pie tin) with drain holes to allow rain into the pot should be used. Rocks should be glued to lightweight lids to keep lids from blowing away (Figure 5).

There are numerous advantages to using buried clay pot irrigation. First, pots are not as sensitive to clogging as drip emitters, although they may clog over time (after 3-4 seasons) and require renewal by reheating the pots. Second, the system does not require a pressurized water system, which is difficult to establish and maintain at remote sites. Third, animals are less likely to damage or clog buried pots than aboveground drip systems. Fourth, by selecting lids that collect rainfall, any precipitation that does fall can be conserved and used. Finally, buried pots are more robust than drip systems because they do not rely on continuous supplies of power or water to operate.

The controlled water delivery from buried clay pots provides both young seedlings and planted seeds with a steady supply of water under typical desert conditions, and in soils that drain quickly. Researchers in Pakistan used buried clay pot irrigation to establish acacia (*Acacia* spp.) and eucalyptus (*Eucalyptus* spp.) trees in an area with 8 inches (200 mm) of annual precipitation (Shiek'h and Shah 1983). The trees irrigated with clay pots grew 20 percent taller than trees that were hand-watered at the same rate. The clay pot irrigation increased survival from 65 percent to 96.5 percent. Kurian and his colleagues (1983) also used buried clay pot irrigation to grow mesquite (*Prosopis* spp.) seedlings. In that case, trees irrigated with clay pots were more than three times taller than rainwater-fed trees and 70 percent taller than surface-irrigated trees.

By providing stable soil moisture around the pot, the clay pot system may also allow seeds in the soil bank to germinate and grow. We have found that unplanted annuals have germinated and set seed on clay pot sites while the surrounding area remained barren. Buried clay pots have also worked well to increase the germination of native seeds we planted at our Travertine site in the Sonoran Desert. This leads me to think that seeding in combination with buried clay pots may be a reasonable alternative to planting container-grown plants—and may prove to be much cheaper.

Buried clay pots also allow restorationists to place both water and soil amendments where they will benefit seedlings rather than weeds. For example, researchers in India found the dry weight of weeds in crops irrigated by buried clay pots was only 13 percent of the weight of weeds in control plots irrigated by basin irrigation (Reddy and Rao 1980). Buried clay pots are also invaluable in areas affected by salinity or where saline water is the only water available (Mondal 1983, 1984).

Buried clay pots are worth considering in areas where water is expensive, water supplies are limited, drainage is rapid, or where salinity and alkalinity are a problem. They should also be used to solve problems at landscaping and revegetation sites.

Figure 5. A tin pie plate rests on top of a buried clay pot full of water. The clay pot slowly releases its water into the soil, irrigating the plant placed next to it or seeds sown in the soil. A small rock is glued to the tin pie plate to keep the plate from blowing away.

Wick Irrigation

Wick irrigation systems have been used in India in conjunction with buried clay pot irrigation (Mari Gowda 1974). A hole or series of holes is punched in the buried clay pot and a porous wick is inserted in the hole(s). The material wicks the water from the container into the soil and provides a slow, steady source of moisture to encourage root development and plant growth (Figure 6).

We tried a small field test of wick irrigation on a very dry, east-facing slope at the Travertine site where we compared mesquite (*Prosopis glandulosa*) transplants irrigated with wicks and others irrigated by hand watering. We found that wick-irrigated mesquite survived longer and grew faster than the hand-watered transplants. We did not calculate the water consumption precisely, but it appeared to be about 4 teaspoons (20 ml) per day. On the downside, animals chewed up several of the wick irrigation systems.

In 1990 I installed nylon wicks fed by a buried pipe reservoir along Highway 86 in the Sonoran Desert. Plant survival has been modest—in line with earlier studies—but water use is extremely low and installation costs were also low.

In a hot, dry greenhouse at the University of California, Riverside, I set up an experiment to test whether a wick irrigation system could provide enough water for a single palo verde (*Cercidium floridum*) seedling that I had planted in a bucket of 16-grit silica sand. I hypothesized that if wick irrigation would work in this coarse, readily drained sand it would work almost anywhere. After one month the plant was still growing and exhibited no signs of water stress, despite using only 0.2-0.4 teaspoons (1-2 ml) per day. I made subsequent field trials with mesquite and a wick system that consisted of 0.4-gallon (1.6-liter) plastic reservoirs, plastic tubing, and 0.2-inch (5-mm) cotton wicks. The cotton wicks became moldy and biological activity developed in the reservoirs, which probably limited water transfer. Nonetheless, plant survival still improved. Woven or braided (not twisted) nylon wicks that have been washed with detergent will also work as will old, weathered nylon rope.

Porous Capsule Irrigation

Porous capsule irrigation is an efficient modern adaptation of the buried clay pot irrigation method (Silva and others 1981a, Silva and others 1981b, Silva and others 1985a, Silva and others 1985b). Porous capsules are made with porous, low-fired clay in a way that makes them easier to tie into a piped network than traditional clay pots. They can also be made by gluing two clay pots together. In either

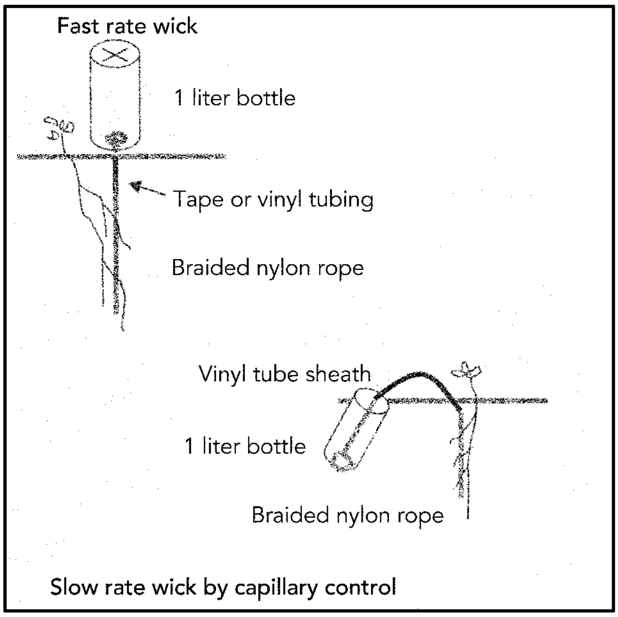

Figure 6. Wick irrigation is an ancient technology for watering plants in arid environments. Nylon wicks work best, cotton wicks become moldy.

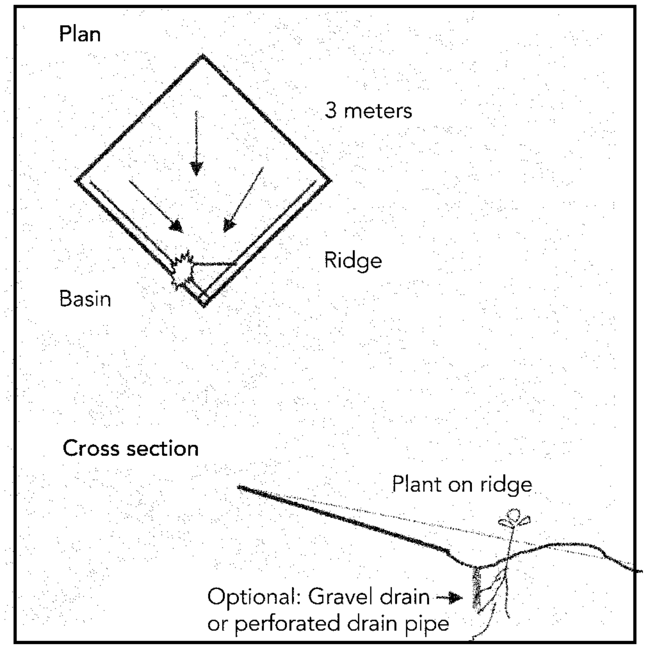

Figure 7. Schematic of a microcatchment—another Old World technology. Microcatchments are simple and inexpensive to construct and have been used to grow many crops in places such as North Africa. Their primary drawback is that they work only when it rains. They do not store water for extended periods of time.

method, two tubes must be run to each capsule to allow air to escape when water is poured in.

We have found porous capsule irrigation effective, but more costly to make and install than buried clay pots or deep pipes. The capsules are not as sensitive to clogging as drip emitters, although they may eventually clog with sediment or bacterial, fungal, or algal growth. Capsules can be set up with relatively large diameter connectors, perhaps 0.372 inch (1 cm) or larger, that would require less filtration and lower pressure than the small tubing used with many drip emitters.

Microcatchments

Capturing and using any rain that falls is always desirable. Several types of systems have been used over the past several decades—microcatchments, pitting, imprinting, and the use of straw bundles (Dixon and Simanton 1980, Bainbridge 1996, 1999, Edwards and others 2000, Bainbridge and others 2001). Here I concentrate on microcatchments—specially contoured areas with slopes and berms designed to increase runoff from rain and concentrate its laminar flow into small dams or depressions (Shanan and Tadmor 1979). Rain falling into microcatchments is effectively concentrated because it runs down the catchment slope and is then "stored" in the soil, where it is available to plants but protected from evaporation. Moreover, microcatchment areas can be tailored to provide optimal runoff volume for specific plants and soil conditions.

Microcatchments are simple and inexpensive to construct and can be built with local materials and labor (cover photo and Figure 7). Because they rely on rainwater, they are relatively inexpensive and the water has a low salt content. Therefore they increase leaching and can be used to reduce soil salinity. The use of microcatchments techniques in Arizona has made saline lands that were retired from groundwater-irrigated agriculture productive again.

Many crops have been grown in microcatchments, including citrus in North Africa. Evenari (1975) observed that smaller microcatchments (about 120 yd^2 {100 m^2}) had higher relative water yield per unit surface area than larger catchments (about 1200 yd^2 {1000 m^2}). Microcatchments have also been used to supplement rainfall for water-stressed native vegetation. For instance, we found that microcatchments improved the survival and growth of native transplants in the Mojave Desert (Edwards and others 2000). Similarly, Ehrler and his colleagues (1978) found that jojoba (*Simmondsia chinensis*) grown with microcatchments were larger in volume and produced more flowers and seeds than jojoba growing outside the catchments.

The primary drawback with microcatchments is that they work only if it rains. For example, in one of our microcatchment test plots only two plants survived because it did not rain for almost 18 months. Ideally we would have watered the plants until the next rainfall. This is very easy with catchments but we did not have the budget for it. Microcatchments may also be combined with other irrigation systems that can keep the plants alive and growing during the critical first months. Once established, plants can usually survive for some time without rain and will respond rapidly following a rain large enough to fill the catchment basin.

Conclusions

The efficiency of irrigation systems depends on many factors including soil type, plant species, plant container type and preparation, soil structure and soil fertility, weed competition, and site microclimate. The most appropriate system for a given site should be chosen after reviewing survival and growth goals and water availability, plant species' water demand, labor skill and availability, and budget. The cost of all of these systems is modest compared to the total cost of installing a plant at a remote site (Table 1).

Plants generally should receive a treeshelter or cage, so the minimal system in most cases would be the treeshelter irrigation method. These can be even more effective if they are installed within a microcatchment for supplemental water when it rains. Deep irrigation can improve survival and growth and both porous hose and deep pipe systems will typically be the first choice. The deep pipe with treeshelter systems are inexpensive and durable and after plant establishment the pipes or treeshelters can be pulled and reused.

For linear plantings the buried slotted drainage pipe irrigation systems have been very effective. The pipe must be left in the ground, however, and this may not be suitable for many restoration projects. Buried clay pot systems can be very effective, but are costly. They may be appropriate where direct seeding is used or where seeds in the soil seed bank are expected to germinate and grow. Buried clay pots with treeshelters may provide good plant growth from seed at a cost below container planting. The clay pots can also be recycled. The porous capsules and wick systems require more labor for construction than other systems but both could probably be commercially produced at competitive costs. Basin and drip irrigation have limited value in most remote locations.

Even with the best preparation and planting, few seedlings will survive transplanting to the Sonoran or Mojave Desert without supplemental irrigation. In our early trials, survival with only one supplemental watering was about 2 percent. Conventional surface irrigation provides little benefit over no irrigation unless the watering frequency is greater than once every two weeks or involves large amounts of water. In contrast, the deep pipe, perforated pipe, buried clay pot, porous capsule and treeshelter systems have worked well, and the porous tube system looks very promising.

Buried clay pots and porous capsules may also work well for certain applications and species that require more consistent soil moisture. Most of these systems can be tied into pipe networks (with drip emitters if pressurized water is available, with open tubing if not) or refilled periodically with a hose or a 3-gallon (12-liter) jug.

These alternative and little known irrigation systems can dramatically increase survival and improve plant growth even in severe desert conditions. Supplemental irrigation should be provided for as long as possible, perhaps once every two weeks in the first three months and then once a month for two summers. These effective and efficient irrigation systems should also be considered for much wider use in restoration, landscaping and revegetation because they work well and save water.

Table 1. Estimated costs for a remote site, one growing season (800 plants) (varies widely by site, pay rate, not including transportation or water cost).

Irrigation Method	Materials and Labor	Water Demand	Survival
Porous hose	$3	low	high
Deep pipe	$3.25	low	high
Clay pot, lid	$4.50	moderate	high
Porous capsule*	$6	low	high
Perforated drain pipe	$3	moderate	moderate
Microcatchment	$15	moderate	moderate
Drip**	$2.50	moderate	moderate
Wick	$3	very low	moderate
Basin	$3	high	very low

*requires water tank, gravity pressure
**requires water tank, filters, pressure (tower or pump), risky without regular maintenance

Alternative Irrigation Equipment and Supplies

Screen disks for deep pipes
TWP Inc. *www.twpinc.com/index.html*
Porous tubes (soaker hose)
High rate soaker tube from Lee Valley Garden Supply *www.leevalley.com*
(Drip Master, AquaPore, Moisture Master)
French ergonomic watering can
Gardener's Supply *www.gardeners.com*
Saddletanks and collapse-a-tanks
Terra Tech *www.terratech.net*
Ben Meadows Company *www.benmeadsows.com*
Forestry Suppliers *www.forestry-suppliers.com*
General Supply Corporation *www.generalsupplycorp.com*
Transfer pumps
Hand pump: Guzzler, Bosworth Co. *www.bosworth.thomasregister.com/olc/bosworth/*
Gas pump: Homelite, eg. AP125 *www.homelite.com*
Battery powered irrigation timers
A good selection at Lee Valley and Gardener's Supply
www.easycart.net/ecarts/dripsupply/BATTERY_OPERATED_TIMERS.htm

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