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Residential Irrigation and Water Conservation

Texas A&M School of Irrigation
Irrigation Technology Center
Texas AgriLIFE Extension Service

Residential Irrigation and Water Conservation

A Complete Guide for Homeowners and Professionals on Equipment Selection, and the Operation and Management of Landscape Irrigation Systems

by

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INTRODUCTION

Water Supply and Projections for Texas

Texas has abundant, yet limited water resources. The Texas Water Development Board predicts the population of Texas will nearly double in the next 50 years, and water demand is expected to surpass total water supply in the next 20 to 40 years. Today, many areas of Texas face critical water supply conditions. This increasing demand on existing water resources has depleted groundwater resources in some areas and triggered competition for surface water supplies in others. Without careful planning and management, water supplies will become limited in many parts of Texas.

Landscape Irrigation Issues

Installing an automatic irrigation system is a convenient way to supplement plant water needs when rainfall is deficient. However, the majority of homeowners tend to over-water with automatic irrigation systems which can lead to significant water runoff. Water runoff from residential landscapes displaces vital nutrients and sediment from landscapes into storm drains that feed rivers, lakes and streams. Surface and groundwater resources may become polluted by unfiltered irrigation runoff containing fertilizers, pesticides and other landscape chemicals. Timely and efficient irrigation is key to protecting and extending water supplies while maintaining beautiful, healthy landscapes.

Residential Irrigation

Overall, residential water use increases 30 to 60% in the summer due to irrigation. To prevent water waste, reduce water costs, and protect valuable water resources, homeowners must learn to manage and maintain their irrigation systems more efficiently. Understanding when and how long to run the irrigation system, how to adjust the irrigation controller, how to detect leaks, and how to repair common irrigation hardware problems are important concepts for homeowners to understand.

This document will provide the knowledge necessary to improve irrigation efficiency through appropriate selection of system components and proper irrigation scheduling based upon actual irrigation system performance and site-specific conditions.

SECTION 1: LAWS AND REGULATIONS FOR LANDSCAPE IRRIGATION

The design and installation of landscape irrigation systems are regulated in Texas in order to protect the public drinking water supplies. The regulations were originally developed in order to prevent the back flow of water from the irrigation system into the drinking water supply. In recent years, new irrigation regulations have been enacted that focus on promoting efficient irrigation systems for the purpose of landscape water conservation. The Texas Legislature has declared that all irrigation systems:

> *"will by law be designed, installed, maintained, altered, repaired, serviced, and operated in a manner that will promote water conservation."*

In addition, the Legislature has stated that:

> *"the correct practice of irrigation as a science and profession is essential for the protection and conservation of the water resources of the State and should be conducted by individuals who are held to the highest ethical standards."*

Thus, the State regulates who can design, install and repair irrigation systems and the minimum qualifications to do so.

State Laws and Local Ordinances

State regulation of landscape irrigation is through the Commission on Environmental Quality (TCEQ), MC-178, P.O. Box 130897, Austin, Texas 78711-3087; (512) 239-6133; www.tceq.state.tx.us. These regulations are found in Chapter 30 of the Texas Administrative Code, Section 344 (30 TAC 344). Regulations govern the licensing of persons who are permitted to design, install and repair landscape irrigation systems, and give specific requirements that such systems must meet.

City and water utilities may choose to enact regulations in addition to those set forth by the TCEQ. Local ordinances and rules may mandate the use of certain types of controllers, sensors and backflow devices, and regulate the times and days available to irrigate. A copy of the regulations can be acquired by contacting your city's department of public works or water utility.

City Irrigation Inspectors

Municipalities with populations of 20,000 or more are required to have an irrigation ordinance and to employ *Irrigation Inspectors* to enforce state regulations and local ordinances. Irrigation

Inspectors are licensed by the State which has established minimum training and continuing education requirements that inspectors must meet.

Irrigators License Requirements

By definition, a *Licensed Irrigator* is someone who "sells, designs, consults, installs, maintains, alters, repairs, or services an irrigation system, including the connection of such system to any water supply."

To obtain an Irrigators License, you must:

1) Take an approved course ("the Basic Course"),
2) File an application, and
3) Pass an examination.

To maintain your license, you must take 8 hours of continuing education each year or 24 hours over three years.

An Irrigation License is required by law in order to sell, design, install, maintain, alter, repair or service landscape irrigation systems, however certain persons are exempt from having an Irrigation License. These include registered professional engineers, licensed plumbers, municipal employees (for maintenance of city irrigation systems), and homeowners who perform work on their own properties. For more information about licensing and testing contact:
Texas Commission on Environmental Quality: (512) 239-6133.

<u>Homeowner Exemption Rules</u>

Homeowners are allowed to design, install and maintain their own irrigation systems. However, the irrigation system must meet all State rules and regulations, and local ordinances. Homeowners must obtain all necessary permits and have a backflow prevention device professionally installed and tested.

Minimum Design Standards

According to regulations, irrigation systems must always be designed in a manner that will promote water conservation. When designing irrigation systems, all components must meet manufacturers' published design specifications and performance requirements. This includes following manufacturers' recommendations for irrigation applicator spacing and pressure. Failure to follow these recommendations will result in poor uniformity of coverage.

When designing an irrigation system, divide the landscape into different zones or hydro-zones. The size of the zone will depend on the available flow rate and pressure available to the irrigation system and the type of sprinkler device used. A hydro-zone defines an area of the landscape that has a common plant type, microclimate, topography, soil type and water requirement. It is important to have matched precipitation rates across each zone. This means that each zone contains the same type of sprinkler devices with the same precipitation rate.

Avoid spraying water onto impervious surfaces (such as sidewalks and roadways) in order to reduce the potential for runoff and slipping hazards. Above ground sprinklers cannot be used in areas which are less than 48 inches wide with impervious surfaces on each side.

Most irrigation systems are constructed of polyvinyl chloride (PVC) pipe. When sizing pipe, keep in mind that water velocity through the pipe may not exceed 5 feet per second (also known as critical velocity). Keeping to the 5 feet per second rule will prevent damage to irrigation system components. PVC pipe must also be buried at least 6 inches below the ground and primer must be used with glue to joint PVC pipe and fittings.

The irrigation must contain an isolation valve between water meter and backflow prevention device to allow for servicing, altering and repairing the irrigation system. In addition, a rain shutoff sensor must be installed to prohibit irrigation during a measurable rainfall event.

A detailed plan (or design) must be prepared for each site where a new irrigation system is installed. A copy of this plan must be kept on location during the installation of the irrigation system. After installation is complete, an "as installed" drawing must be given to the irrigation system owner. This plan must be drawn to scale and include the following:

- Irrigator's seal, signature and date of signing
- Major physical features and the boundaries of areas to be watered
- North arrow
- Legend
- Zone flow measurement for each zone
- Location and type of each:
    - Controller
    - Sensors (rain, moisture, wind, flow, freeze, etc.)
- Location, type, and size of each:
    - Water source
    - Backflow prevention device
    - Water emission devices (spray heads, rotary heads, bubblers, drip, microsprays, etc.)

  - Valves (including all zone valves, master valves and isolation valves)
  - Pressure regulation devices
  - Mainline and lateral piping
- Scale
- Design pressure

The Licensed Irrigator is required to keep a copy of the “as-installed” irrigation plan for up to three years. Homeowners who install their own irrigation system are exempt from this requirement.

Final Walk-Through Requirements

Once the irrigation system is complete, the Licensed Irrigator or his/her Irrigation Technician must provide a walk-through with the irrigation system owner. The purpose of the walk-through is to educate the owner on how to operate the system correctly in order to help conserve water. The following documents must be provided to the owner:

- Manufacturer’s manual for the irrigation controller
- Seasonal watering schedule
- List of components that require maintenance and the recommended frequency of service
- Irrigation plans showing the “as-is” installed system
- Maintenance checklist

The maintenance checklist must address the following operation and maintenance topics:

- ✓ Checking and repairing the irrigation system
- ✓ Setting the irrigation controller
- ✓ Checking the rain or moisture sensor
- ✓ Cleaning filters
- ✓ Pruning grass and plants away from irrigation emitters
- ✓ Operating the irrigation system
- ✓ The precipitation rate of each zone within the system
- ✓ Water conservation measures currently in effect from the water provider
- ✓ Name of the water provider
- ✓ Suggested seasonal or monthly watering schedule based on current evapotranspiration data for the geographical region
- ✓ Minimum watering requirements for the plant material in each zone based on the soil type and plant material where the system is installed

The checklist must be signed and dated by both the Licensed Irrigator and the irrigation system owner (or owner's representative). The checklist should contain the Irrigator's seal and the following statement:

"This irrigation system has been installed in accordance with all applicable State and local laws, ordinances, rules, regulations or orders. I have tested the system and determined that it has been installed according to the Irrigation Plan and is properly adjusted for the most efficient application of water at this time."

The Licensed Irrigator must also affix a permanent sticker on each controller containing the following information:

- Irrigator's name
- License number
- Company name
- Telephone number
- Dates of warranty period

If the irrigation system is manual, the sticker must be placed on the original maintenance checklist.

The new irrigation system must also have a warranty. The Licensed Irrigator is responsible for all work performed during the warranty period including maintenance, alteration, repair, and service of the irrigation system. The Licensed Irrigator (or business owner) is not responsible for the professional negligence of any other irrigator who subsequently services the same irrigation system.

SECTION 2: UNDERSTANDING THE IRRIGATION SYSTEM

Typical Irrigation System Components and Layout

The typical irrigation system consists of a series of pipes and valves that transport and control the route of water and emission devices (or sprinkler) to apply the water to the targeted area. The term “point of connection” (POC) is used to describe the location where a landscape irrigation system is connected to the water source. Most landscape irrigation systems are connected to a public water supply; however other possible sources include reclaimed water, private water wells, and ponds.

The pipelines in an irrigation system are referred to as mainlines and laterals. A mainline is the pipeline that extends from the POC to a valve on each lateral. Mainlines are usually under constant water pressure. A lateral pipe network delivers water from a zone control valve to emission devices. Lateral lines are pressurized when zone control valves are turned on.

Meters

For most irrigation systems connected to a public water supply, the first piece of equipment is the water meter. A meter is either a mechanical or electronic device that measures water flow. Many cities and water utilities now require the use of a separate water meter for the irrigation system, while many older systems use the same water meter that monitors indoor water use.

Figure 2.1: Residential irrigation meter registering flow in gallons.

In Texas, most meters will record water use in units of 1000 gallons of water. However a few water utilities use meters that displace use in terms of cubic feet of water. Most meters have a small wheel indicator that rotates when water is flowing.

Pipes

PVC is the predominant material used in landscape irrigation systems. Polyethylene (PE) pipe is frequently used in drip irrigation systems. Metal pipe materials such as steel and copper are rarely used due to their expense.

Polyvinylchloride (PVC)

Polyvinylchloride pipe (or PVC) is a semi-rigid plastic pipe used extensively for irrigation systems due to its ease of construction, durability and availability. PVC pipe ranges in size from ½ inch to greater than 18 inches in diameter. PVC is available in various pressure ratings, commonly referred to as “Class” or “Schedule”. For example, Class 200 pipe has a pressure rating of 200 pounds per square inch. This rating is directly related to the wall thickness of the pipe.

Figure 2.2: Irrigation system construction using PVC pipe.

Schedule 40 pipe has the same outside dimension as metal pipe and is often used at the POC when connecting to existing pipelines. The pressure rating of Schedule 40 pipe varies depending on pipe diameter but is higher than is typically needed for landscape irrigation systems. It is seldom used for landscape irrigation systems due to its added cost over Class rated pipe.

Polyethylene (PE)

Polyethylene pipe (or PE) is a flexible plastic pipe commonly used in irrigation systems. PE pipe is generally weaker than PVC, thus requiring greater wall thickness to achieve the equivalent pressure ratings of PVC pipe. Black PE pipe is made with carbon black to make it more resistant to ultraviolet light. Because of its flexibility and resistance to the sun, PE pipe is used primarily for low-pressure drip irrigation systems. In drip irrigation, water emitter devices are either implanted within the PE pipe during the pipe manufacturing process or inserted into the pipe externally during irrigation system construction. Special insert and compression fittings are used to connect and repair PE pipe networks.

Figure 2.3: Black polyethylene pipe (PE) is a flexible alternative to PVC in low water pressure situations.

Copper

Copper tubing may be used at the point of connection of a residential water source and the public water supply. Copper tubing comes in three types (“K”, “L”, and “M”) which vary in wall thickness and pressure rating. Type K is rated for high pressure while type M is rated for low pressure. Solder or threading is required to connect other pipe and fittings to copper tubing.

Backflow Prevention Devices

Backflow prevention devices are mandated in order to protect public water supplies. These devices prevent water in the irrigation system from flowing back into the public water supply. Backflow, if it occurs, usually is due to “*back pressure*” and/or “*back siphonage*”. Back pressure may occur if the municipal water supply system looses pressure due to a break, for example. In such situations, the water pressure in the irrigation system may be higher than the municipal system which could cause water to flow backwards in the pipe. Backflow prevention devices are also required if the irrigation system is connected to a water well or other water supply.

There are five major types of backflow prevention devices (Table 2.1). State regulations require that, at a minimum an air gap or atmospheric vacuum breaker device be used. If chemicals are injected into the irrigation system, then a reduced pressure device must be used. However, cities and water utilities may require the use of specific types of backflow devices.

Pressure Vacuum Breaker (PVB)

A pressure vacuum breaker (PVB) is designed to prevent back siphonage only. A PVB is similar to an AVB, except for the inclusion of a check valve and spring-loaded air relief valve that opens to break the siphonage when the pressure drops to 1 psi. Downstream cutoff valves allow the PVB to be used under constant pressure. The PVB should always be installed with the supply side at the bottom in a vertical position. A PVB can be installed on the water source side of an irrigation system; however it must be placed at least 12 inches above any downstream piping.

Figure 2.4: Pressure vacuum breakers must be installed at least 12 inches above any downstream piping.

Atmospheric Vacuum Breaker (AVB)

An atmospheric vacuum breaker (AVB) is a device that prevents against back siphonage only. An AVB is a simple and inexpensive device that utilizes a single moving part (a float) that moves up or down to allow either normal flow or air into the piping system. When a backflow situation occurs, the water pressure falls below the atmospheric pressure which causes water to siphon from the irrigation system. When this happens, the float inside the AVB drops and closes the supply side to allow air into the piping system, thereby preventing the backward flow of water.

An AVB must be installed after any control valve and at least 6 inches higher than the highest sprinkler head or drip emitter. Thus a separate AVB is required for each valve installed. Since the float is free moving, the AVB cannot be used under constant pressure for a long period of time (more than 12 hours). It should be installed with the supply side connected at the bottom in a vertical position.

Figure 2.5: Atmospheric vacuum breakers must be positioned at least 6 inches above any downstream sprinkler heads.

Double Check Valve (DC)

The double check valve (DC) is equipped with two spring-loaded check valves connected in series. The double check valve will protect against back siphonage and back pressure under constant pressure. A DC can be installed either above or below grade as long as enough room is allowed for testing. However, some local ordinances do not allow a DC to be installed below grade unless a Y-type strainer is installed on the inlet side of the valve.

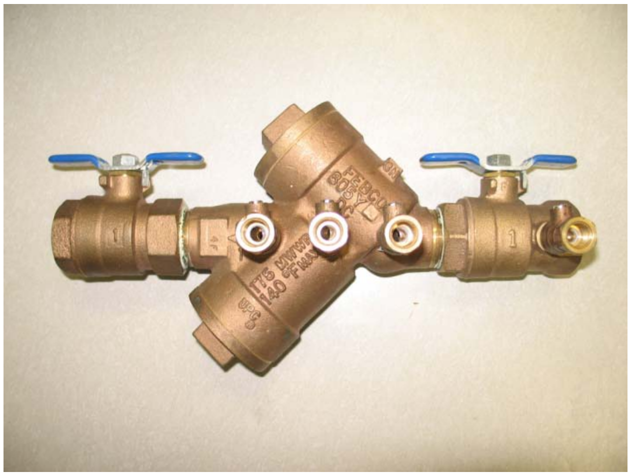

Figure 2.6: Double check valves protect against both back siphonage and back pressure under constant pressure.

Reduced Pressure Device (RP, RPZ)

A reduced pressure backflow prevention device (RP or RPZ) provides more safety than the atmospheric vacuum breaker, pressure vacuum breaker, and the double check valve. The reduced pressure device is constructed of two spring-loaded check valves as well as additional valves and ports that allow water out and air in during a backflow situation. This complex design makes the RP suitable for high-hazard conditions and able to prevent backflow under constant pressure.

Figure 2.7: Reduced pressure principle backflow prevention devices are suitable for high hazard conditions such as irrigation systems utilizing chemical injectors.

Air Gap

An air gap is a physical break which separates the supply and downstream sides of a pipe system. Air gaps protect against both back siphonage and back pressure. When using an air gap, the gap should be greater than two times the diameter of the supply side pipe. An example of an air gap is a kitchen sink. No matter how high the water gets in the sink it cannot travel back into the faucet. A booster pump is commonly used to increase operating pressure in irrigation systems and is typically installed using an air gap for backflow prevention.

Table 2.1. Backflow Devices and their Characteristics

Type	Back Siphonage	Back Pressure	Constant Pressure	Low Hazard	High Hazard	Installation
AVB	✓			✓		Vertical
PVB	✓		✓	✓		Vertical
DC	✓	✓	✓	✓		Vertical or Horizontal
RP, RPZ	✓	✓	✓	✓	✓	Horizontal

Valves

Valves are a vital component of an irrigation system and may be manually, electrically, or hydraulically operated. Electric valves are commonly referred to as solenoid valves. These valves are usually wired to a designated port on the irrigation controller. Electric valves are normally closed and require an electric signal (supplied by the controller) to open the valve and allow water to flow downstream. Once electric current stops, the valve automatically closes thereby preventing water flow downstream.

Figure 2.8: A manual isolation valves must be installed between the water meter and backflow prevention device.

Manual-Isolation Valves

A manual (or isolation) valve is a mechanical device that stops water flow to a downstream piping system. Ball valves, globe valves, gate valves and angle valves are examples of manual or isolation valves. These valves can be opened and closed by turning a handle to the proper position. Isolation valves are required to be installed between the water meter and backflow prevention device on all new irrigation systems, and upstream of any quick-coupler valve connecting a hose bib to an irrigation system.

Master Valves

A master valve is any electric or manual valve installed in the mainline pipe upstream of all station control valves. Master valves are primarily used when there is a threat that the main supply line may be damaged from exposure, freezing or vandalism.

Station Control Valves

A station (or zone) control valve (commonly referred to as a solenoid valve) is an electric valve that, when activated by the controller, allows water to flow from the mainline to the lateral piping.

Figure 2.9: "Normally closed" solenoid valves allow water to pass downstream only after an electric signal is received from the irrigation controller.

Quick-Coupler Valves

Quick-coupler valves (installed on mainlines) are usually found in parks, sports fields, golf courses and remote areas. These valves are kept closed by the combination of an internal spring and water pressure. A special "key" is required to compress a spring which allows water to flow. Quick coupler valves are commonly used when irrigating with reclaimed water as an added layer of safety to prevent unauthorized access and contact with the water. Texas regulations require that a quick-coupler valve is also required if a hose bib is connected to an irrigation system.

Air Relief Valves

Air can sometimes enter the piping system after it the irrigation system is turned off and water drains out of the system. Air relief valves will all the air to be expelled when the irrigation system turns back on.

Figure 2.10: Air relief valves expel trapped air inside a pipe system as it becomes pressurized.

Pressure and Flow Regulation Devices

Pressure is crucial to the operation of any irrigation system. Water applicators require a minimum operating pressure. However, for many residences, too much pressure is a problem. In order to achieve the manufacturer's recommended operating pressure, pressure regulation is required. Two types of pressure regulators are *fixed-pressure* and *adjustable-pressure*. Fixed-pressure regulators are pre-calibrated to discharge water at a known pressure, whereas adjustable-pressure regulators require calibration in the field to achieve the desired pressure.

Figure 2.11: 10 psi pressure regulator ensures constant downstream pressure regardless of upstream fluctuations.

In cases such as gravity-fed systems, water pressure is too low to operate an irrigation system, and a booster pump is required. A booster pump is a mechanical device that converts mechanical forms of energy (usually electricity) into hydraulic energy (flow and pressure). A booster pump may be connected to its own special port on an automatic controller that will turn it on or off at the same time as a station control valve is opened or closed.

Fittings

In addition to the major components used in irrigation systems, multiple types of fittings are used to connect different pipes, valves, and other devices. Fittings are typically constructed from PVC material. Elbows, tees, couplings and bushings secure the irrigation system network together. Fittings may be either slip-on or threaded and are available in a range of sizes.

Figure 2.12: A variety of PVC fittings are available to connect various pipe combinations and sizes.

Water Applicators

Spray Heads

Spray heads apply water in a preset pattern depending on nozzle design. Spray heads are available in different configurations ranging from 20 degrees (part circle) to 360 degrees (full circle) spray patterns. Most spray heads have interchangeable nozzles. The larger the nozzle size (or diameter), the more water may flow through the device.

Figure 2.13: Full-circle spray heads irrigate a mulched planting bed.

Spray heads are generally used to irrigate small and irregular-shaped areas in a landscape because of their spray pattern versatility. Spray heads achieve uniformity by applying larger droplets further away from the head and smaller droplets closer to the head. The correct spacing of spray heads is critical for good water distribution uniformity, and may require that the spray patterns of adjacent heads overlap precisely.

Spray heads may be classified into one of three types:

> Pop-up spray heads are the most common type of spray head used to irrigate small turf areas and low-growing flower and groundcover beds. As water pressure increases, these spring-loaded heads "pop-up" from a housing body located in the ground. Pop-up heads can extend 2 - 12 inches above the body.
>
> Shrub heads are used for tall-growing flower and groundcover beds. Shrub heads have nozzles mounted on rigid plastic, brass or galvanized risers to distribute water above plant material.
>
> Microspray heads are low-volume; low-pressure spray heads used to water small flower beds, flower pots, and individual plant specimens.

Figure 2.14: Shrub head mounted on rigid plastic pipe extends above groundcover for proper spray coverage.

Rotary Heads

Rotary heads are primarily used to irrigate large turf areas such as sports fields, parks and golf courses. The two most common types of rotary heads are *gear driven* (rotors) and *impact-driven* (impact sprinklers).

Figure 2.15: Gear-driven heads (or rotors) are typically used to irrigate large turf areas.

Gear-driven heads are the most widely-used head to irrigate large turf areas. Pressurized water enters the head and turns a water wheel. A series of gears connected to the water wheel regulate the rotation of the head.

Impact-driven heads are rotary sprinklers that operate by using a weighted or spring-loaded arm which is propelled by the water stream as it hits the sprinkler body, causing rotation.

Figure 2.16: Impact-driven head irrigates large area of roses and turf.

Figure 2.17: Multi-stream rotors generally operate at lower pressures compared to conventional rotors and impact sprinklers.

Multi-stream heads apply water in multiple streams over a specified pattern. Generally associated with low application rates, multi-stream heads are less susceptible to wind distortion than other heads and are used on sloped areas and medium sized turf areas.

Bubblers

Bubblers are designed to “flood” a small area (or basin) for a short period of time and should only be used in situations where runoff is not likely. Applications include tree basins, large flower pots and contained planting areas with good drainage. Bubblers are also used to temporarily irrigate large potted plants at wholesale and resale nurseries.

Figure 2.18: Bubblers are commonly used to irrigate newly-planted trees until their root system is sufficiently established to survive on natural rainfall.

Controllers

In automated irrigation systems, the timing and duration of irrigation events is set in the controller. When it’s time to irrigate, the irrigation controller sends electrical signals through buried wire to a control valve which opens allowing water to flow. A wide range of controllers are available to accommodate a small to large number of station control valves. Proper setup (or programming) of the controller is critical to achieve water conservation and ensure efficient irrigation.

The two main types of controllers include electro-mechanical and digital.

Electro-Mechanical

Electro-mechanical controllers are most commonly found in commercial landscapes. These controllers utilize small motors, mechanical switches, gears and other mechanical parts to rotate dials on the controller. Small plastic pins or toggle switches are positioned on the dials to set watering days, irrigation start times and irrigation duration. Irrigation occurs when internal gears rotate the dials to the appropriate positions. Since electro-mechanical controllers contain no internal memory, controller settings remain constant until it is physically changed. Its settings are not altered by power outages.

Digital

Digital controllers (also known as solid state controllers) are the most common type used in landscape irrigation. These controllers have a wide range of programming options and are usually equipped with designated wiring ports for rain sensors, soil moisture sensors and other devices to improve water efficiency.

Smart Controllers

A *smart controller* automatically manages irrigation with limited human intervention and shows promise for improving landscape water management and water conservation. Smart controller technology is still evolving, and there are many different types on the market that vary in complexity, performance and cost. The more sophisticated controllers require numerous site parameters be entered or programmed into the controller including precipitation rate, soil and plant type, root zone depth, slope and microclimate factors. Proper programming of these controllers is critical to performance and may require close study of the operating manual and professional assistance.

Many smart controllers require a communication system and a subscription to a weather database. Pagers are commonly used to transmit evapotranspiration (ET) data to the controller. Another option for data transmission includes direct internet connection. Less sophisticated smart controllers require no communication system.

Little comparative performance testing has been done on smart controllers. However, preliminary testing by the Irrigation Technology Center (ITC) has shown that some simple, inexpensive smart controllers perform just as well as the more complex models.

Smart controllers are separated into four different classifications or technologies. Each class attempts to apply only enough irrigation to meet actual daily or weekly plant water needs (or ET).

> <u>Historic ET controllers</u> irrigate based upon historic ET data stored in the controller. These controllers do not require a subscription or external communication system.
>
> <u>On site sensor controllers</u> utilize sensors, such as a temperature and solar radiation sensor, to calculate ET, or use soil moisture sensors to dictate irrigation schedules. Various types are available with some requiring a subscription and external communication system.
>
> <u>ET controllers</u> receive ET information from an external site which transmits information to the controller using pagers, phone lines, or the internet. The ET data used by these controllers generally is the most accurate and scientifically-based.

Central controllers (on site weather station controllers) are often used on golf courses and other large landscapes and have a complete *ET station* installed on site to calculate and transmit actual daily ET data to the irrigation controller.

Sensors

Soil Moisture Sensors

Soil moisture sensors measure the amount of water in the soil and show promise in improving irrigation water management and reducing water waste. There are various types of soil moisture sensors on the market. The most common technologies used in the landscape include resistance blocks, thermal capacitors and time domain reflectometers (TDR) sensors. With each product, an optimum level of soil moisture is chosen as an indicator of when to irrigate.

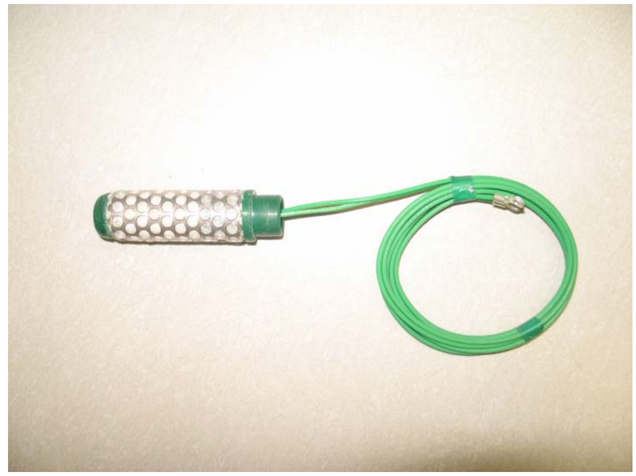

Figure 2.19: Gypsum block used to measure soil moisture deficit.

Soil moisture sensors coupled with irrigation controllers can provide a totally automatic system. Some sensors can be wired directly to the valve circuitry of an automated irrigation system, acting as a soil moisture “thermostat”. The switching mechanism is set to an optimum moisture level threshold which will allow irrigation only when needed, thus preventing over-watering. These sensors can successfully be integrated with irrigation schedules as a further check against over watering.

Figure 2.20: Capacitance moisture sensors detect changes soil moisture by measuring electrical properties in the soil.

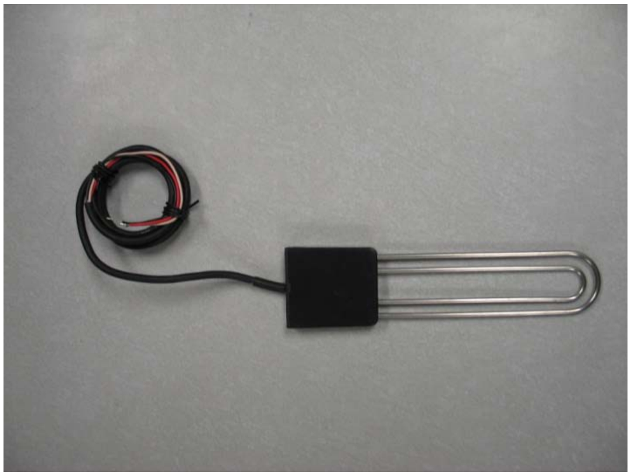

Figure 2.21: Some moisture sensors (like the one shown here) determine soil moisture by measuring the rate at which an electric signal travels through a soil-water solution.

Rain Sensors

Rain sensors are designed to halt irrigation during a rain storm or delay irrigation after a preselected amount of rainfall occurs. Most contemporary controllers have a built in port for easy installation, however any automatic irrigation system can be retrofitted with a rain sensor. Wireless rain sensors are also available which makes retrofitting existing systems easy. Some rain sensors are coupled with freeze sensors and or wind sensors (anemometers) to prohibit irrigation during inclement weather. Most rain sensors only detect rainfall to either cancel or prevent a scheduled irrigation event. However, some more expensive sensors actually measure the amount of rainfall that occurs. These types of rain gages are sometimes coupled with smart controllers to eliminate unnecessary irrigation events.

Figure 2.22: Various types of rain sensors are available to stop an irrigation event after a preset level of rainfall occurs.

Drip Irrigation Systems

Drip irrigation, also referred to as micro irrigation, uses small emitters to deliver water at a low pressure and flow rate. Water lost to runoff, wind drift, and evaporation is greatly reduced by applying water slowly on or just below the soil surface. When managed correctly, drip irrigation is notably the most efficient form of irrigation.

Drip irrigation is becoming popular in landscape irrigation and promoted as a water conservation alternative for small, irregular-shaped planting beds and narrow turf areas. However, caution should be exercised when considering drip irrigation because some products may be easily damaged and rodents in particular enjoy chewing on exposed and buried drip lines.

Drip irrigation is subject to clogging by minerals, trash or other debris in the water. A water analysis is recommended before choosing drip irrigation, particularly for permanently buried systems. All drip systems should have a filter that is properly matched to the product being used. The filter should be checked and cleaned on a regular basis. A flushing manifold is recommended so that trash, soil particles and other debris that may potentially plug emitters are flushed out.

Drip products have different pressure and flow rate limitations. In most cases, drip operates at a much lower pressure than sprinklers; therefore a pressure regulation device is needed. If a drip product operates outside the manufacturer’s recommended pressure, the water distribution pattern and product integrity could be jeopardized.

Advantages

- Low evaporation loss
- No wind drift loss
- Low potential for runoff
- Precise soil moisture control
- Less water pressured required
- Smaller pipe size required
- Reduced weed growth when used with mulch
- Adaptable to steep slopes and small, irregular shaped areas

Disadvantages

- High maintenance; requires regular monitoring
- Cost may be prohibitive for large landscape areas
- Applies water at a slow rate compared to overhead sprinklers

- Requires filtration and pressure regulation
- Drip tape and tubing installed above ground are susceptible to pests and vandalism
- Moderate to high emitter clogging potential
- Subsurface installation may reduce customer confidence (cannot see drip system working)

<u>Hose-end Kits</u>

Most home improvement and garden centers sell simple drip irrigation kits that homeowners can install themselves. These kits typically attach to an outdoor water faucet and are usually less expensive than a commercial grade drip irrigation system. Thus, the overall performance and longevity of the product may be limited.

<u>Turf Irrigation</u>

There have been many successful applications of subsurface drip irrigation systems on turfgrass areas. Most commonly you can find drip irrigation installed in narrow turf areas that is difficult to irrigate with above ground sprinklers, such as a strip of grass between a street and sidewalk.

For turf applications, drip lines should be buried as shallow as practical. The spacing between drip lines will vary depending on the depth and type of soil and emitter spacing, but will generally range from one to two feet.

<u>Planting Beds</u>

Planting beds containing flowers, shrubs and ornamental grasses are commonly irrigated with drip irrigation. These areas are usually small and irregular in shape, thus it can be more difficult to efficiently irrigate with overhead sprinklers. Use of drip irrigation in these areas allows for precise applications of water to individual plants and reduces the potential for runoff.

<u>Design Guidelines</u>

1. *Gather Site Data*

   Determine the surface area, soil type, and types of plants that will be irrigated.

2. *Calculate Peak Plant Water Requirement*

   If multiple plant types exist (such as trees, shrubs, flowers and groundcover) within the irrigated area, determine the peak water requirement based upon the highest water use plant. Ideally you would create separate zones for each plant type for more precise control of water to accommodate various water requirements.

3. *Choose a Drip Product*

Once you know the size of the area and what plant type you are irrigating, choose an appropriate drip product. The first decision will be whether to use an inline emitter (the emitter is already installed within the drip line at equal distances) or an online emitter (the emitter is inserted into drip hose to water individual plants). Next, choose a manufacturer and model of drip product. It is important to choose a product that will be able to meet the plant's daily peak water requirement.

4. *Calculate the Number of Emitters (or length of tubing) Required*

After choosing the drip product, calculate the amount of product needed by either counting the number of plants served by one emitter or by dividing the surface area by the emitter spacing and row spacing.

5. *Size Drip Components*

Select filters, pressure regulators, flow regulators, air relief valves and flush valves sized according to the drip product and design of your system. Drip product manufacturers literature will typically list all components recommended for use with a product, such as the minimum filter size and recommended operating pressure. Flush valves and air relief valves can be purchased based on the size of the drip hose.

Flow requirement is another design factor that must be considered when utilizing drip irrigation. When choosing a drip product, the manufacturer will list the rated flow rate (usually in gallons per hour) per emitter or length of drip line. This is important for determining how many feet of drip product you will be able to install in your landscape. If your water source cannot provide the required minimum flow, then you will need to add additional stations (or valves) or choose a different drip product.

When designing drip irrigation systems, the following guidelines should be followed to determine maximum acceptable flow rates through piping.

- 1/2 inch pipe used for flow rates up to 5 GPM (gallons per minute)
- 3/4 inch pipe used for flow rates from 5 to 9 GPM
- 1 inch pipe used for flow rates from 9 to 15 GPM

Most drip manufacturers have design manuals to help you select the right components and layout your drip system. There are many types of products that will meet the requirements of just about any situation, including drip tape, drip tubing with embedded emitters and drip tubing with “pop-in” emitters. These systems may be permanent, semi-permanent or temporary systems.

Figure 2.23: Drip irrigation emitters may be imbedded during the manufacturing process or may be inserted into flexible tubing.

Drip System Maintenance

The greatest challenges in drip irrigation are product damage and emitter clogging. Most drip lines are constructed of thin-walled material and are often exposed to rodents and vandalism. Because the water passages in most emitters are very small, they easily become clogged by minerals and organic matter. Clogging will lower emission rates and reduce wetting pattern uniformity. Without proper clogging treatment, widespread plant loss can occur due to lack of water.

Contaminants are often present in irrigation water. Soil particles, living and dead organic matter, scale from rusty pipes, insects, thread tape, and PVC shavings are some examples of contaminants that commonly enter the system during construction and installation. Regular cleaning of the filter and periodic line flushing is recommended.

Contaminants may also grow, aggregate, or precipitate in water inside drip lines. Iron oxide, manganese dioxide, calcium carbonate, algae, and bacterial slimes can form in drip systems under certain circumstances. Buildup can also occur on the emitter between irrigation events.

The appropriate treatment for mineral clogging depends on the cause of the problem. Sulfuric and hypochloric acids can be injected to lower the pH of the supply water and to reduce the amount of chemical precipitates. Regular acid treatments are usually necessary to clean emitter passages when concentrations of calcium or magnesium exceed 50 parts per million or when water supply pH exceeds 8.0.

For drip systems connected to a public water supply, biological clogging will not be a problem due to the high levels of chlorine. Drip systems connected to non-potable water supplies such as private water wells will need regular injections of chorine to control clogging.

If chemicals are injected into an irrigation system to prevent or control clogging, a high hazard backflow prevention device (typically a RPZ) <u>must</u> be connected to the system.

Contact a Licensed Irrigator or a local irrigation dealer for assistance on specific clogging problems.

Figure 2.24: A screen (or filter) shown here can help prevent clogging of drip emitters, and when cleaned regularly can extend the life of the system.

Screens and Filters

Debris such as plastic and sediment in the irrigation water can affect the performance of an irrigation system. Drip emitters, diaphragm valves, backflow prevention devices and sprinkler heads are highly susceptible to clogging. Therefore it is important to have a screen or filter installed on irrigation systems. Screen size and type will vary based on the irrigation system’s flow rate.

Flushing Valves

Soil and other types of particles that accumulate in drip lines over time must be periodically flushed out of the system. For small systems, a valve or cap can be placed at the end of the system to allow the drip lines to be manually flushed. For large systems, a flushing manifold is required to flush multiple lines at one time.

Irrigation System Maintenance

Routine maintenance of an irrigation system is just as important to irrigation efficiency as proper design and installation. Even an irrigation system designed specifically for high efficiency can waste huge amounts of water if not maintained in sound working condition. Vandalism, traffic, electrical problems, landscape equipment damage, debris in the water system, freezing weather, equipment fatigue, defective materials and poor workmanship all limit irrigation performance and efficiency. Homeowners and landscape managers must inspect irrigation system components at least seasonally and observe its operation frequently to prevent water waste, high water costs, and plant damage.

Maintenance Checks

During regular maintenance checks, each sprinkler head should be inspected for proper pop-up and seating, nozzle obstructions and correct spray patterns. Checking the system one zone at a time will help to identify any malfunctioning valves and controller problems.

Higher than normal water bills may be the first indication of a slow leak. To find the source of a leak, look for areas in the landscape that appear lusher than the surrounding area. Various leak detectors are available that can help pinpoint a leak and save valuable time and money. For large irrigation systems, pressure gauges located at strategic points in the mainline can be useful for detecting leaks.

The irrigation system should be checked for proper water pressure. Too much water pressure causes spray nozzles to fog or mist. Even a light wind can significantly carry the mist, distort the wetting pattern, and cause plant water stress. Too little water pressure shortens the spray distance from the nozzle, leaving a distinct pattern of green circles on the landscape. In hot, dry weather these problems become apparent quickly; whereas in cooler, wetter weather, the effects may not be obvious for some time.

Guidelines for Buying an Irrigation System

Purchasing an irrigation system is a major investment that can add value to your property or become a major liability. When hiring an irrigation contractor be sure to do your homework and seek out professionals with proven track records of success and customer satisfaction. Following are guidelines that can help you get started on the right track.

<u>Contractor/Designer Qualifications</u>

- Does the contractor/designer have the required licenses?
- What is his/her experience?

<u>Design and Installation Features</u>

- What is the life expectancy of the irrigation system and its components?
- Have all safety features been included?
    - Backflow prevention device
    - Isolation valves and/or master valve
- What are the options for future upgrades and expansion?

<u>Specific Operating and Design Parameters</u>

- How evenly is irrigation applied for each zone?
    - Is matched precipitation rate used?
    - Do water applicators operate within the manufacturer's recommendations?
    - Are water applicators spaced for head to head coverage?
- Is the system equipped with a rain or moisture shut off device?
- What is the design precipitation rate of each zone?
- What is the anticipated quantity and cost of irrigation used?
- What is the recommended programming for the irrigation controller?

<u>Plant Needs</u>

- Will the planting beds be separated from turf areas?
- Are microclimate factors considered in separating the irrigating zones?

<u>Estimate</u>

- What does the cost estimate cover?
    - Price of system including labor, material, and local taxes and permits

    - Sprinkler system design, product specifications, parts lists, cut sheets, guarantees
- For how long is the estimate good?

Warranty

- What are the warranties on individual components and system design performance?
- Is the contractor financially capable of standing behind their warranties?
- What is the availability of replacement parts?
- Does the contractor provide operating instructions to the consumer?
- What is the recommended maintenance schedule for the irrigation system?

SECTION 3: HOW TO TEST THE PERFORMANCE OF AN IRRIGATION SYSTEM

Irrigation system tests should be done as part of a regular maintenance schedule. Irrigation testing as discussed in this section covers how to inspect irrigation system hardware and performance, and includes different methods for determining precipitation rate for individual irrigation zones. Systems should be inspected regularly to identify sources of water waste and inefficiency since routine mowing, weed eating, and traffic can easily damage sprinkler heads which may go unnoticed. Any problems should be corrected as soon as possible to avoid excessive water costs and plant damage.

System Inspection

A comprehensive inspection of irrigation system components should be performed periodically to ensure that all equipment is functioning properly and to identify any need for retrofits, redesign or product replacement. Before you begin, pull out the irrigation plan, landscape plan or sketch out the property on a piece of paper. Use this document to mark the location and type of irrigation controller, backflow prevention device, meter, and sprinkler heads. You should also note the location of planting beds, trees, walkways and other important landscape features.

The irrigation system should be operated one zone at a time and observed for any hardware, design or performance problems that may result in water waste or poor irrigation efficiency. Specific problems should be recorded on the irrigation plan or site map to save time later during repair. When possible, flag all problem sprinkler heads that need immediate attention.

Early detection of these common irrigation system problems will save water and money, and help to protect your landscape investment.

- Clogged spray nozzles
- Too much or too little water pressure
- Sprinkler heads not raised to grade and aligned vertically
- Leaking sprinkler heads
- High grass preventing proper spray patterns
- Sprinkler heads not aligned along the perimeter of a site
- Controller and valves not working properly
- Flow meter turning when system is turned off

Broken and leaking sprinkler heads should be replaced or repaired as soon as possible. All sprinkler heads should turn freely and not be sunken below grade, blocked by high grass, or misaligned vertically. Sprinklers located along sidewalks and driveways should be adjusted when possible to avoid spraying water onto impervious surfaces such as sidewalks and driveways.

The irrigation system should also be observed for proper water pressure. Proper operating pressure is essential for good irrigation system performance. All sprinkler heads and emitter devices are designed and manufactured to operate within a specific pressure range. When operating pressure is outside of this range, the spray distance and wetting patterns become distorted. Inadequate water pressure results in large water drops and a short spray radius.

Since most irrigation systems are designed for head to head coverage (meaning the spray from one head extends to the adjacent head and vice versa) distribution uniformity also suffers. Too much water pressure causes severe misting, high wind drift losses, and uneven water application. Correcting pressure problems will require changes in the irrigation system hardware.

Precipitation Rate Test

Precipitation rate is a measure of how fast an irrigation system applies water (in inches per hour). The precipitation rate can vary significantly from zone to zone. Knowing the actual precipitation rate of each zone is critical for setting the controller to apply a specific amount of water. For example, to apply 1 inch of water, a zone with a precipitation rate of 1 inch per hour would need to operate for 1 hour. Whereas a second zone with a precipitation rate of 2 inches per hour would only need to operate for 30 minutes to apply the same amount of water.

Alternatives for determining zone precipitation rate include the **catch can method**, the **meter method**, and the **area/flow method**.

<u>Catch Can Method</u>

Done properly "catch can tests" provide the most accurate measure of precipitation rate and indicates how evenly water is distributed throughout the zone (known as *distribution uniformity*). Catch cans are placed in a grid-like pattern within each zone being tested. The irrigation zone is then operated for a short period of time. Catch can volume (or depth) is then recorded and used to calculate precipitation rate.

Catch Can Options - A catch can "catches" the irrigation water during a test and holds it for measurement. Any device can be used as a catch can as long as you measure the volume of water caught with a graduated cylinder and calculate the throat opening (or top of the catch can through which the water enters). However, the most convenient and time efficient method is to use catch cans specifically designed and manufactured for irrigation system testing. These devices require the lowest test runtimes in order to produce an accurate measurement, and can usually give water volume directly in milliliters or water depth in inches.

A straight sided device (such as a tuna can) can be used as catch cans, however, long test run times are necessary to collect a readable depth of water. In addition, water depth must be measured with a ruler where accuracy is compromised. Rain gages are another option, but their costs may be similar to catch cans specially designed for irrigation testing.

Catch cans, such as the *Aggie Catch Can* shown in Figure 3.1, and stainless steel stands are available for purchase at the Texas AgriLIFE Extension Bookstore: http://agrilifebookstore.org/.

Figure 3.1: The "Aggie Catch Can" is convenient for measuring precipitation rate for overhead sprinkler systems.

Test Conditions - Catch can tests should be performed when winds are calm to prevent spray pattern distortion and erroneous readings. To avoid windy conditions, irrigation system tests should generally be performed early or late in the day. A general rule of thumb is to avoid catch can testing when wind speed exceeds 10 mph or is strong enough to distort water streams and spray patterns.

Can Placement - An effective and efficient pattern for catch can placement is to place the devices "at sprinkler heads" and "halfway between heads". This simple placement pattern requires the least number of catch cans while providing adequate coverage over the test area. Be sure that all cans are roughly equally spaced in a grid-like pattern. Avoid placing catch cans too close to sprinkler heads as the water stream can knock over the can. When placing catch cans on slopes, make sure that the catch can is positioned level to the horizon, not at an angle. An example of proper catch can placements is shown in Figures 3.1.

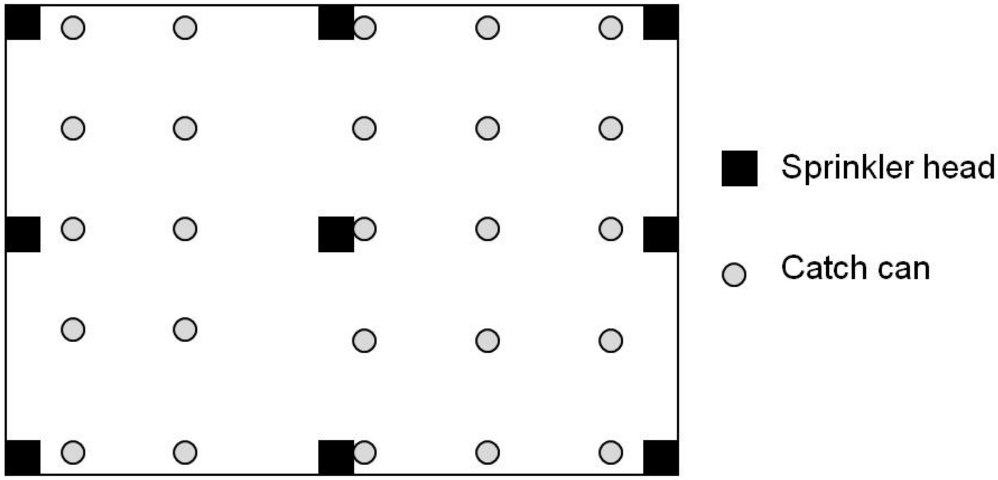

Figure 3.1: Example catch can placement using "at sprinkler heads" and "halfway between heads" spacing pattern.

Test Runtimes - Zones should be operated long enough to fill the catch can to a depth that can be accurately read. It is not necessary to run each zone the same length of time. Generally, rotors or impact sprinkler heads should complete at least three full rotations. Test runtimes for these types of heads usually ranges from 10 to 30 minutes, while zones with spray heads only require 4 to 7 minutes of runtime to provide accurate measurements due to their relative high precipitation rates and non-rotating pattern.

Data Collection - The volume caught in each catch can is usually measured to the nearest milliliter. Some catch cans also allow you to read the depth of water in inches. Catch can test results should be recorded onto data sheets or noted directly on the site map for later analysis.

Calculating Precipitation Rate - After catch can testing is complete, precipitation rate can be calculated for individual zones using the following equations, or by utilizing software specifically designed for this purpose. Table 3.1 gives a sample set of catch can readings for Zone 1. Catch can reading are in milliliters. Example 1 demonstrates how to calculate precipitation rate (in inches per hour) using catch can test data.

Table 3.1. Catch Can Test Results for Zone 1.

		Catch Can Volume (milliliters)				
Zone #:	1	40	50	40	50	40
Test run time (minutes):	10	30	50	40	30	30
Throat area of catch device (in^2):	15	50	50	40	30	40
		30	40	50	50	30
		40	20	20	30	40

$$PR = \frac{\sum V \times 3.6612}{n \times a_t \times t_R}$$

Where:

PR - Precipitation rate (inches per hour)
∑V - Summation of all catch can volumes (milliliters)
3.6612- Constant, converts milliliters to cubic inches and minutes to hours
n - Number of catch cans
a_t - Throat area of catch can (square inches)
t_R - Test run time (minutes)

Example 1: Catch can readings in milliliters

∑V = 960 milliliters
n = 25 catch cans
a_t = 15 square inches
t_R = 10 minutes

$$PR = \frac{960 \times 3.6612}{25 \times 15 \times 10}$$

PR = 0.94 inches per hour

Table 3.2 gives a sample data set of catch can readings for Zone 2. Catch can reading are in inches. Example 2 demonstrates how to calculate precipitation rate (in inches per hour) using catch can test data.

Table 3.2. Catch Can Test Results for Zone 2.

					Catch Can Depth (inches)				
Zone #:				2	0.30	0.20	0.40	0.30	0.50
Test run time (minutes):				10	0.50	0.20	0.30	0.20	0.30
Throat area of catch device (in^2):				n/a	0.40	0.20			

$$PR = \frac{\sum D \times 60}{n \times t_R}$$

Where:

PR - Precipitation rate (inches per hour)
$\sum$D - Summation of all catch can depths (inches)
60 - Constant, converts minutes to hours
n - Number of catch cans
t_R - Test run time (minutes)

Example 2: Catch can readings in inches

$\sum$D = 3.8 inches
n = 12 catch cans
t_R = 10 minutes

$$PR = \frac{3.8 \times 60}{12 \times 10}$$

PR = 1.90 inches per hour

Meter Method

In the meter method, the total volume of water delivered to an irrigation zone (usually in gallons) is recorded at the water meter during the test. Coverage area of the zone (in square feet) must also be measured. The meter method tends to be less accurate than the catch can method and does not indicate how evenly water is distributed throughout the irrigation zone. Water lost to leaking pipes, misaligned sprinkler heads, wind drift and evaporation are not accounted for with this method.

When reading water meters, it's important to verify whether the meter records in gallons or cubic feet. For meters that record gallons, it's important to note whether the meter records in units of gallons or 1000 gallons.

Table 3.3 gives a sample data set for zone 3 using the meter method. Water volume is in gallons. Example 3 demonstrates how to calculate gross precipitation rate in inches per hour using meter test data.

Table 3.3. Water Meter Test Results for Zone 3.

Zone #:	3
Test run time (minutes):	10
Initial reading (gallons):	346000
Final reading (gallons):	346400
Zone coverage area (square feet):	2500

$$PR = \frac{G \times 96.25}{A \times t_R}$$

Where:

PR - Precipitation rate (inches per hour)
G - Gallons of water consumed
96.25 - Constant, converts gallons and square feet to inches and minutes to hours
A - Zone coverage area (square feet)
t_R - Test run time (minutes)

Example 3. Meter readings in gallons

G = 400 gallons (346,400 gallons - 346,000 gallons)
A = 2500 square feet
t_R = 10 minutes

$$PR = \frac{400 \times 96.25}{2500 \times 10}$$

PR = 1.54 inches per hour

Area/Flow Method

Sprinkler heads are rated in gallons per minute (or GPM) which varies with sprinkler type (rotor, spray, impact, etc.), nozzle size, and operating pressure. Sprinkler flow rates are listed in manufacturer's catalogs. In the *area/flow method*, the total flow into a zone is determined by adding the rated flow rates of each individual sprinkler head. Precipitation rate is then calculated based upon the total flow into a zone (in gallons per minute) and the zone's coverage area (in square feet). The following equation is used to calculate precipitation rate using the area/flow method. Figure 3.2 illustrates the coverage area and sprinkler flow rates for Zone 4. Example 4 demonstrates how to calculate precipitation rate in inches per hour using the area/flow method.

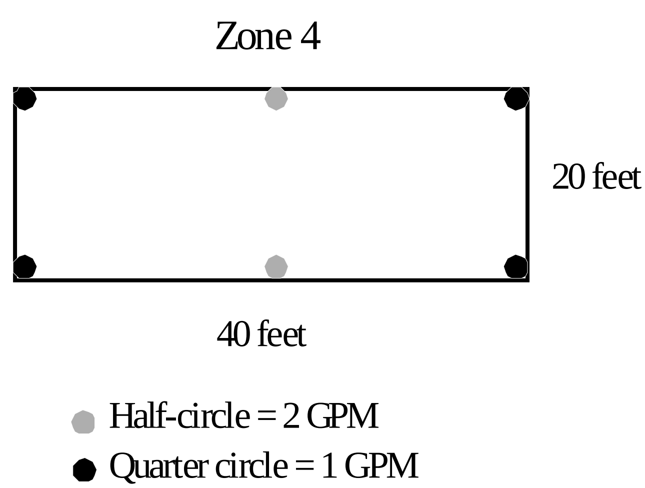

Figure 3.2: Zone 4 sprinkler layout and nozzle flow rates.

$$PR = \frac{GPM \times 96.25}{A}$$

Where:

PR - Precipitation rate (inches per hour)
GPM - Total rated flow rate from all sprinklers (gallons per minute)
96.25 - Constant, converts gallons and square feet to inches and minutes to hours
A - Zone coverage area (square feet)

<u>Example 4</u>. Precipitation rate using the area/flow method (from Figure 3.2)

GPM = 8 GPM {(2 heads x 2 GPM/head) + (4 heads x 1 GPM/head)}
A = 800 square feet (20 feet x 40 feet)

$$PR = \frac{8 \times 96.25}{800}$$

PR = 0.96 inches per hour

Determining Zone Runtimes

In too many cases, irrigation controllers are mistakenly set to operate most (if not all) irrigation zones the same length of time even though the precipitation rate normally varies from zone to zone. A simple method for calculating zone runtime that accounts for precipitation rate is show below.

$$RT = \frac{WR \times 60}{PR}$$

Where:

RT - Zone run time (minutes)
WR - Plant water requirement (inches per week)
60 - Constant, converts hours to minutes
PR - Zone precipitation rate (inches per hour)

<u>Example 5</u>: Zone runtime in <u>minutes</u>

WR = 1 inch per week
PR = 2 inches per hour

$$RT = \frac{1 \times 60}{2}$$

RT = 30 minutes (per week)

SECTION 4: IRRIGATION SCHEDULING AND LANDSCAPE WATER MANAGEMENT

Irrigation scheduling is the process of determining when and how much to irrigate. This involves predicting how much water a plant will need in the coming days or weeks and how much water is currently available in the soil to meet this need. Proper irrigation scheduling is an important aspect of landscape water management.

Plant Water Use

Turfgrass and ornamentals (groundcover, shrubs, and trees) are the two major classifications of plants found in residential landscapes. Although the water requirements of each classification can vary widely, the processes and purposes for water use by plants are similar.

Plants use water for four major purposes:

- To allow photosynthesis, where water is split in the process of manufacturing the plant’s food
- To transport dissolved chemicals and minerals, such as fertilizers from the plant root hairs to the rest of the plant
- To control the physical shape and direction of plant growth, since water pressure in plant cells provides structure
- To control leaf temperature through transpiration – by far the major use in warm climates

Transpiration

Transpiration is the process by which a plant loses water primarily from its leaves and is the primary source of plant water use. Transpiration is the driving force (or suction) for the roots’ absorption of moisture from the soil. Of the water that enters the roots, about 90 percent leaves the plant through transpiration. The other 10 percent of water is used in chemical reactions and in plant tissues. Transpiration is necessary to drive mineral transport from the soil to plant parts, for the cooling of plant parts through evaporation, to move sugars and plant chemicals, and for maintaining pressure in the plant cells.

Transpiration is a complex plant process essential to plant growth and development; however, large amounts of water can be lost each day through transpiration with no visible benefit to the plant. For example, on a hot summer day in Texas, a single pecan tree can transpire 260 gallons of water. The challenge in irrigation is to provide enough water to maintain plant health without applying luxuriant amounts that may simply be lost to transpiration.

A plant's transpiration rate is directly affected by the soil moisture level and the weather. As soil dries, transpiration slows because it becomes increasingly difficult for the plant to pull water from the soil. Transpiration increases as the temperature and total amount and intensity of light (solar radiation) rises. Increases in wind speed also increase transpiration. Likewise as relative humidity decreases, transpiration increases – this is a major factor affecting water use.

The driving force for transpiration and water movement through the plant is the tremendous affinity that dry air has for water. Water moves from an area of high relative humidity to an area of low relative humidity. For example, air at a relative humidity of 50 percent will pull moisture from plant tissue, which is near 100 percent saturation.

The relative humidity in the air space between leaf cells approaches 100 percent; therefore, when the stomata (leaf pores) are open, water vapor rushes out. As water moves out, a bubble of high humidity is formed around the stomata. This bubble of humidity helps slow down transpiration and cool the leaf. If winds blow the humidity bubble away, transpiration increases.

ET (Evapotranspiration) and Plant Coefficients

Plant water use can be described in terms of ET (evapotranspiration). ET is amount of water a plant will use and includes both evaporation from the soil surface and transpiration from the plant surface. ET may be calculated for specific plant types using climate data such as temperature, relative humidity, wind speed and solar radiation. The current theory of ET and how to calculate it is well understood and has been the subject of much scientific research over the past 60 years.

Reference evapotranspiration (ET_o) is used as a "reference" from which the water requirement of specific plant types can be calculated. A table listing average monthly ET_o values for major regions of Texas are listed in the Appendix.

To calculate the water use from ET_o, a *plant coefficient* (K_c) is used. Often, an *adjustment factor* (A_f) is also used. ET of a plant is calculated as follows:

$$ET_{plant} = ET_o \times K_c \times A_f$$

Common K_c values for warm season and cool season turfgrass is 0.6 and 0.8, respectively.

<u>Adjustment Factor</u>

For grasses, the K_c value represents the amount of water needed for maximum growth or production (such as making hay with grass crops). An adjustment factor is almost always used in turfgrasses in order to modify the K_c for "allowable stress". This is done because, while we want a healthy, good quality turf, we are not trying to produce as much lawn clippings as possible. Turfgrass quality can be preserved with much less water. For most sites an allowable stress adjustment factor of 0.6 (or 60 percent) is used. This value has been found to produce good quality turfgrass with no visible stress.

Coefficients for Other Plant Materials

Very little research has been conducted to determine the coefficients for landscape plants other than turfgrass. One way to estimate coefficients is to classify the plants into one of three categories as shown in Table 4.1. For example, turfgrasses and annual flowers will most likely be in the "regular watering" class, perennial flowers and tender shrubs might be in the "occasional watering" class, and tough woody shrubs, vines and trees might be in the "natural rainfall" class. Of course, the most appropriate classification will change from region to region depending on how well plants are adapted to local climate and rainfall conditions.

Table 4.1. Coefficients According to Plant Classifications by Water Requirements

Once plants are established, the plants will thrive on …	Coefficient
Natural rainfall –	0.3
Occasional watering –	0.5
Regular watering –	0.8

Soil and Irrigation Frequency

Soil Moisture

Understanding the basic principles of soil moisture storage and management is necessary to efficiently use water in the landscape and to reduce the potential from runoff and deep percolation (water flow through soil and below the root zone).

Sources and losses of soil moisture are illustrated in Figure 4.1. Water is usually supplied by rainfall or irrigation. Some of this water is lost due to direct evaporation and runoff, while some infiltrates into the soil. When adequate soil moisture levels exist, plants can extract water from the soil through the root system. Much of the water that the plant takes up transpires through the leaves.

If there is more water than the soil can hold, excess water will percolate through the root zone and carry essential nutrients with it. Deep percolation can carry pollutants to underlying groundwater. Locations with high water tables may experience water moving up through the soil due to capillary forces.

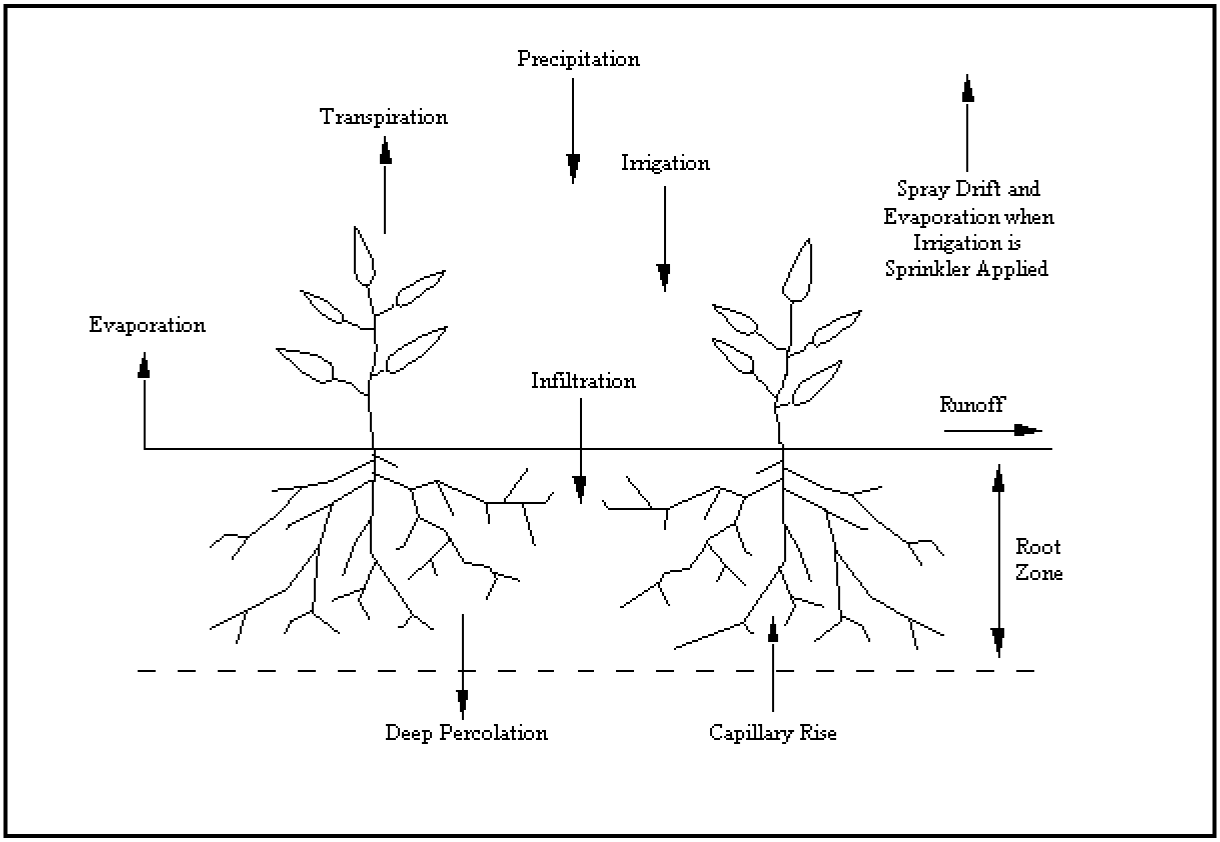

Figure 4.1: Sources and losses of soil moisture.

Soil Moisture Storage

Soil is a mixture of inorganic an organic materials. The size and total volume of pore space are functions of both the soil's texture and structure. Clay soils can hold greater amounts of water because of the relatively large surface areas of individual clay particles and the large number of very small pores. Sand particles, on the other hand, have relatively small surface areas that contain a smaller number of pores which are larger in size. Water drains more easily from these larger pores due to gravity. Figure 4.2 illustrates the relationship between soil texture and the amount of water held in the soil.

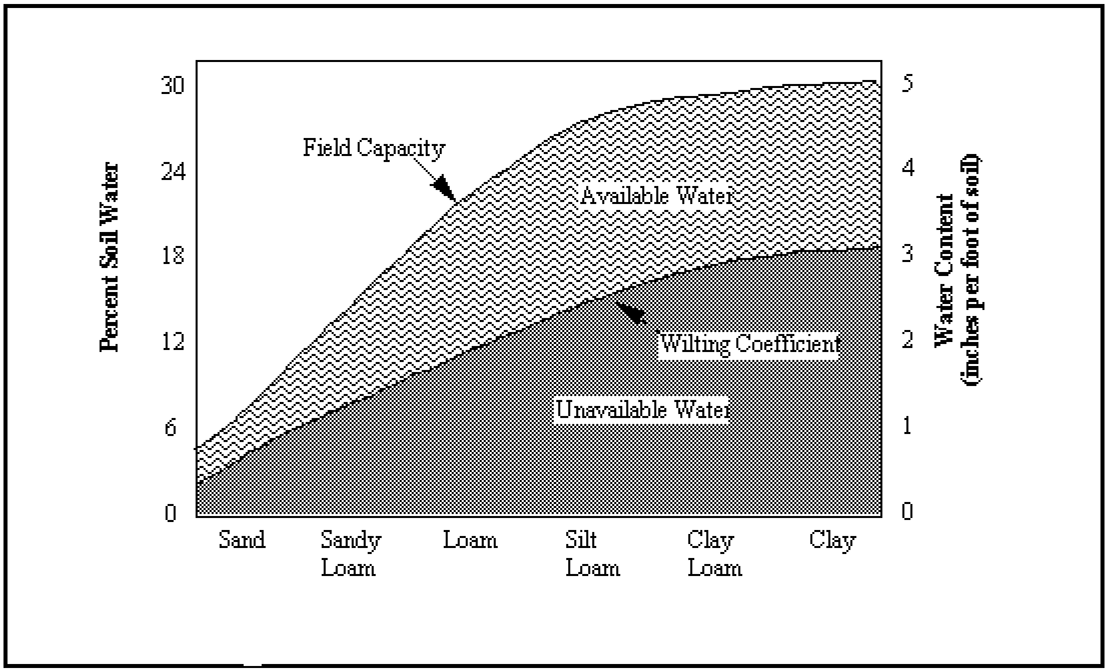

Figure 4.2: Soil water retention curves for major soil types.

Knowing the water holding capacity of soils is important in determining both the amount and frequency of irrigation. Soils with low water holding capacity must be irrigated more frequently and in smaller amounts than soils with high water holding capacity. In Table 4.2, approximate water storage capacities are listed for several soil classifications.

Table 4.2. Approximate water-holding capacity of soils in inches of water per foot of soil (in/ft)

Soil Texture	Moisture held at field capacity	Moisture held at permanent wilting point	Available moisture	Available moisture at MAD = 50%
Sands	1.0 – 1.4	0.2 – 0.4	0.8 – 1.0	0.45
Sandy loams	1.9 – 2.3	0.6 – 0.8	1.3 – 1.5	0.70
Loams	2.5 – 2.9	0.9 – 1.1	1.6 – 1.8	0.75
Silt loams	2.7 – 3.1	1.0 – 1.2	1.7 – 1.9	0.90
Clay loams	3.0 – 3.4	1.1 – 1.3	1.9 – 2.1	1.00
Clays	3.5 – 3.9	1.5 – 1.7	2.0 – 2.2	1.05

Available Soil Moisture

The available moisture (or available water holding capacity) of the soil is measured in terms of the inches of water stored per foot of rootzone depth. It is the difference between the amount of moisture held at field capacity (all soil pores filled with water) and the amount of water remaining in the soil at the permanent wilting point (the plant can no longer pull water from the soil). Heavy textured soils such as clay usually have high water storage capacity per unit depth compared to light textured soil such as sand.

Available water is the total amount of water contained in the rootzone that is useful to the plant. It is calculated by multiplying the available water holding capacity of each soil layer in the rootzone by the depth of that layer. Available water is typically measured in inches. The depth of the rootzone defines the actual soil depth from which the plant can draw water and nutrients. Moisture below this depth cannot be reached by the plant and is therefore not useful. Knowing the depth of the rootzone is necessary to determine how much irrigation water is needed. Many factors may restrict root development such as high water tables, shallow soils, and variations in soil type, soil fertility and salinity.

Soil samples should be taken in several locations in the landscape to obtain an accurate representation of:

- The depth of the “active” or effective rootzone (depth containing about 80% of the total root mass)
- Thickness and composition of the soil to the bottom of the active rootzone

Soil Oxygen

Soil is also a reservoir for oxygen, which is needed by the plant in order to take up water. If oxygen is forced out of the soil by flooding (i.e., water fills all available pore spaces in the soil), then most plants cannot take up water. This phenomenon explains how plants can wilt when they are over-watered.

Managed Allowable Depletion (MAD)

Managed allowable depletion (MAD) refers to the process of letting the soil dry to a pre-selected soil moisture content between irrigation events. Allowable depletion defines the total amount of available water that can be depleted from the soil without adversely affecting plant growth and development. Some plants are more drought tolerant than others and can tolerate dryer soil conditions. Research has shown that most plants can extract about 50 percent of the total available soil moisture without showing signs of stress.

MAD is expressed as the fraction of the total available water that can be removed from the soil before irrigation should occur. For example, if the MAD is 50 percent and the total water holding capacity is 2 inches then the plant can use 1 inch of water (2 inches x 0.50) before irrigation is needed.

One popular method of irrigation scheduling is the "moisture balance" or "checkbook system" where the soil (specifically the depth of soil containing active roots) is considered the "bank account" and the "currency" is water. The goal is to maintain a positive balance of water, yet minimize excess (or wasted water). Deposits include rainfall and irrigation. Withdrawals include the amount of water consumed through plant transpiration and water evaporated from the soil surface. This is called evapotranspiration (or ET).

Figure 4.3 illustrates the concept behind the moisture balance method to determine when and how much to irrigate. The following factors are considered:

- Soil water holding capacity
- Allowable soil moisture depletion between irrigation events
- Plant water use (ET rate)

The objective is to irrigate before the maximum allowable depletion is reached; and then reapply only enough water through irrigation to fill the soil to its water holding capacity.

The moisture balance method, although simplistic, is helpful in determining when and how much to irrigate. The accuracy of this method can be improved by using site-specific ET and rainfall data, and soil moisture sensors. Moreover, observation of plant response to irrigation amount and frequency, and experience in irrigation scheduling are irreplaceable in increasing the accuracy of the moisture balance method.

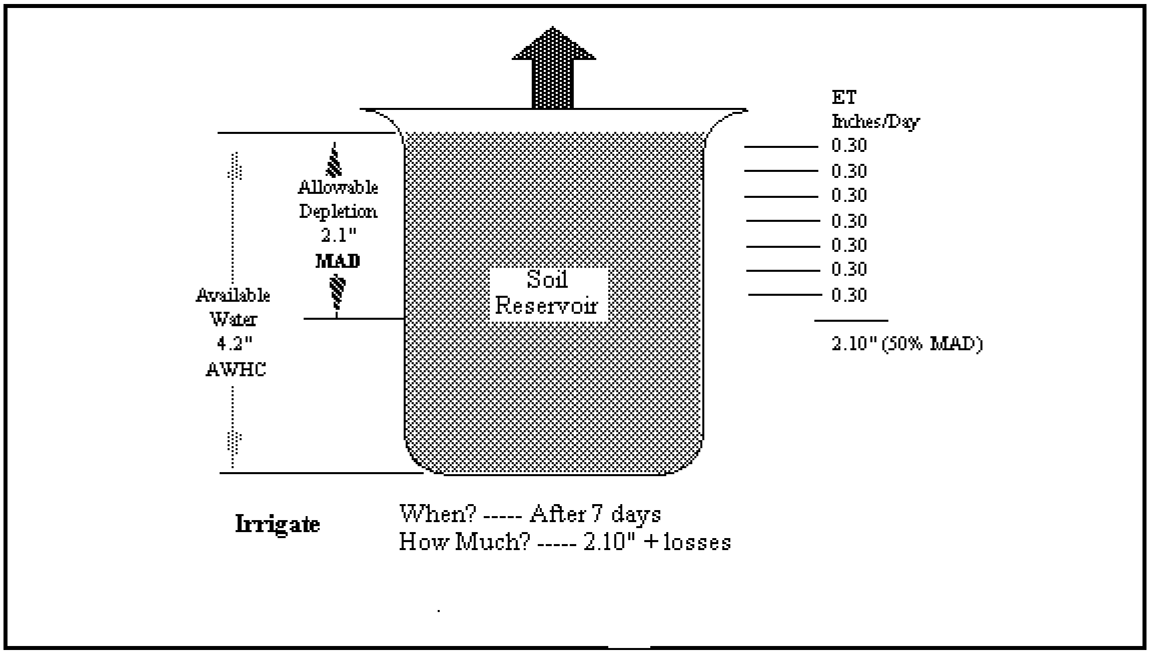

Figure 4.3: The water balance method of irrigation scheduling.

<u>Soil Infiltration Rate</u>

Another soil characteristic which impacts irrigation scheduling is *infiltration rate*. Infiltration rate describes how quickly water enters the soil. If water is applied faster than the infiltration rate, runoff will occur. The infiltration rate of a soil is not constant, but tends to decrease dramatically over time as water is applied (Figure 4.4). For this reason dry soils absorb water faster than wet soils. Slope, compaction, and sodium/salinity levels can also influence soil infiltration rates. Aeration, leaching, and cycle-soak irrigation are commonly-used practices used to address infiltration rate problems.

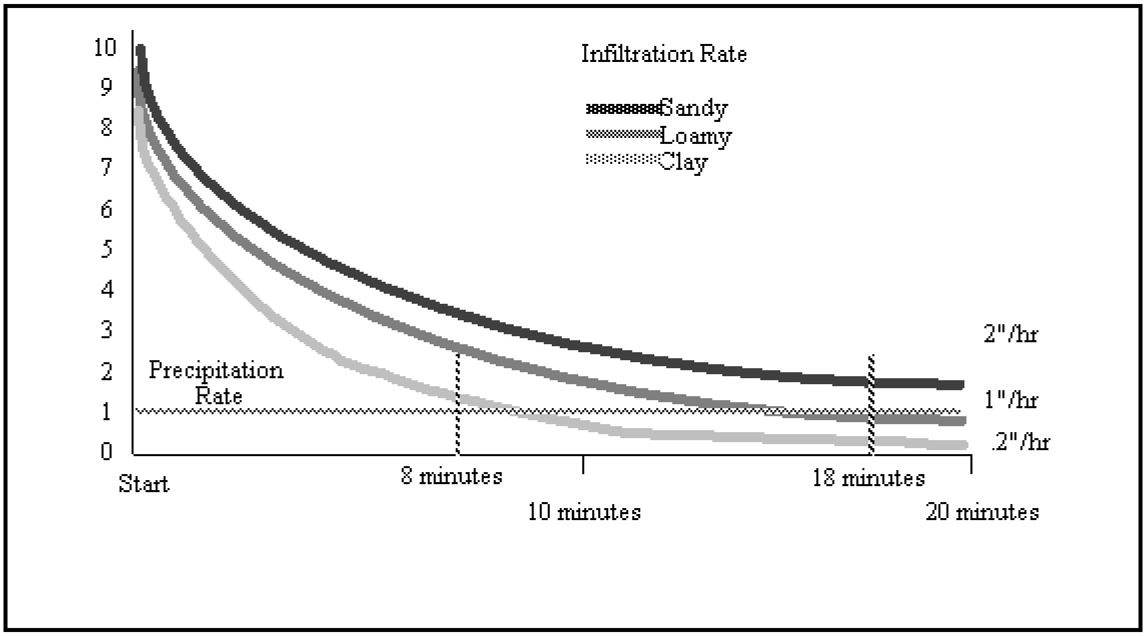

Figure 4.4: Typical infiltration rates in a dry, deep soil and how they change with time.

Irrigation System Efficiency

The efficiency of an irrigation system refers to how much of the water applied actually is used by the landscape. Water may be lost in a number of ways including spray drift losses (if irrigating in windy conditions), runoff (if water is applied faster than the soil can absorb it), and deep percolation (if more water is applied than can be stored in the rootzone). Various terms are used to define irrigation system efficiency, including *application efficiency*, *distribution efficiency* (or distribution uniformity), and *overall efficiency*.

Application Efficiency

The term *application efficiency* usually refers to the amount of water lost in the air between the time it leaves the sprinkler head and hits the ground (i.e., spray drift losses). Irrigating in winds above 10 to 15 mph can result in a loss of 40% or more of the water leaving the sprinkler head. Weather factors often have the greatest effect on application efficiency; particularly wind speed, relative humidity and solar radiation (sunlight intensity). This is a reason to avoid irrigating during the heat of the day and during windy conditions.

Water droplet size is also a factor of irrigation efficiency. Generally, the smaller the droplet size, the more water will be lost to evaporation. Too much water pressure creates a large amount of small droplets, thus greatly reducing the application efficiency. “Poor application efficiency” means that the system must be run longer to put out the targeted amount of water.

Distribution Efficiency or Distribution Uniformity

Distribution uniformity (DU) is a measurement of how uniform water is applied over the intended irrigated area (see Figure 4.5). If an irrigation system had a DU of 100%, then all areas would receive exactly the same amount of water. However, 100% DU is not possible. Design problems such as poor sprinkler spacing, improper spray patterns, incorrect nozzle selection and too much or too little operating pressure often result in the over-application of water in some areas, and under-application of water in others. The goal of a good designer should be to apply water as uniformly as possible within an individual zone.

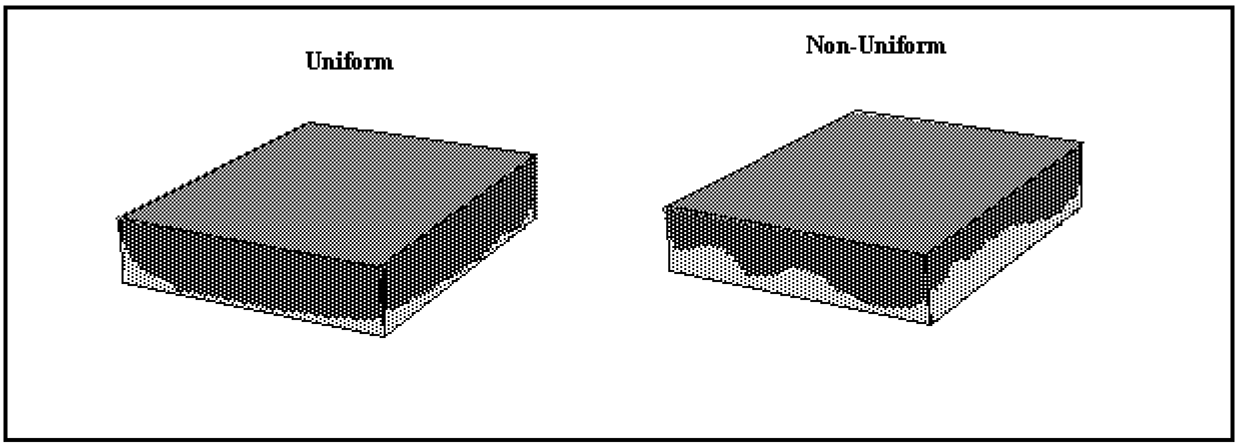

Figure 4.5: Illustration of "uniform" versus "non-uniform" application of water.

Poor distribution uniformity in landscape irrigation is almost always compensated by applying excessive amounts of water to ensure that all areas in a landscape receive enough water. This results in over-saturation in a significant portion of the landscape, unnecessary water runoff, and high water costs. A better solution is to improve the uniformity of water application through proper design and product selection.

Overall Irrigation System Efficiency

Overall irrigation efficiency is defined as the amount of water usable to the plant divided by the total amount of water delivered through the irrigation system. All losses are considered, including leaks in the pipelines, application losses, water waste caused by poor distribution uniformity, deep percolation, runoff, etc. Thus, it is possible for a system to have high uniformity and low overall efficiency. Ideally an irrigation system would be both uniform efficient, thereby ensuring plant health while minimizing water waste.

Figure 4.6 illustrates that efficiency is a measure of the amount of water stored in the root zone divided by the amount of water applied with irrigation. Overall efficiency is a measure of both the equipment and the management at a site, while distribution uniformity is primarily related to the system's mechanical performance.

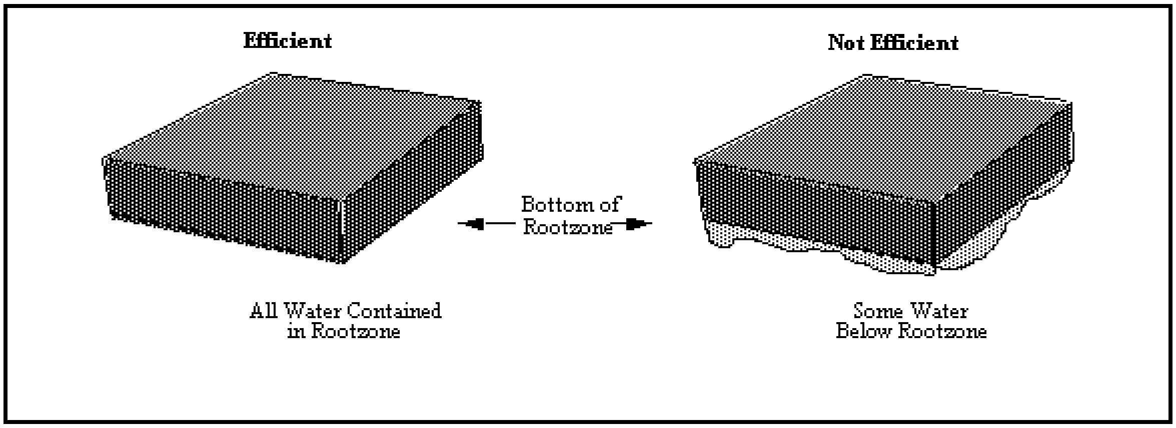

Figure 4.6: Illustration of an "efficient" versus "inefficient" irrigation event.

SECTION 5: LANDSCAPE PRACTICES AND CONCEPTS FOR WATER CONSERVATION

In addition to proper irrigation design and scheduling, understanding how plants react to water stress can help homeowners and irrigation managers identify problem areas and make appropriate landscape design changes as necessary to further conserve water and save money. Some of these principles and practices are discussed in this section.

Plant Response to Lack of Water

When plants experience a lack of water, several responses can occur. The most common sign of drought stress is wilting. However, plants also show other signs, including leaf rolling, color changes, leaf scorching, and defoliation. Most turfgrasses show stress by wilting, as indicated when footprints are seen after a walk across the lawn. Turfgrasses with wider leaves, such as St. Augustine, reduce water loss by rolling their leaves lengthwise in an attempt to reduce the exposed surface area. Stressed turfgrasses often exhibit a dull color versus the shiny green color of a healthy plant.

Many tender flowers and shrubs will also show these signs along with scorching of the leaf edges (or margins). Brown, crispy margins occur when less than adequate supplies of water are flowing through the plant. Some plants in the landscape will defoliate during drought stress in an attempt to lessen the demand for water and increase its ability to survive drought. An example of this response is seen in ocotillo (Fouquieria splendens), a desert plant.

Managing Plant Stress

The goal of the landscape manager is to reduce plant water stress in order to maintain a quality landscape. When adequate moisture is available to the plant, a continuous flow of water exists from the root hairs up to the leaves. If inadequate moisture is present in the soil or if the rate of evaporation from the leaves exceeds the rate at which water can be moved through the plant, then water stress ensues.

During hot and dry summer months, moderate stress is tolerated by most plants on a daily basis, as long as moisture is replenished during the low-stress night period. However, severe or prolonged moisture stress will result in permanent wilting and damage to the plant. Plants differ greatly in their ability to extract water from the soil and in the absolute amount of water required for normal plant growth and development. Some plants, in fact, are classified as “drought tolerant” because they can function with “dry” soil conditions.

The following physical features improve a plant's drought tolerance:

- Deep and well-developed root systems
- Waxy leaf surfaces
- Leaf hairs which reduce air flow past the leaf surface
- Shiny surfaces which reflect light
- Leaves which fold up or drop under stress conditions

Too much water in the root zone can also be damaging to the plant due to a reduction in oxygen in the area around the root hairs. This can occur from over-irrigating or irrigating too often which does not allow the soil to drain or allow oxygen in. Thus, a proper irrigation schedule should supply the right amount of water before harmful stress occurs and in a sufficient quantity to replenish the amount of water used since the last irrigation.

Landscape Water Conservation Principles

The philosophy for irrigating a landscape centers on meeting the water requirements of each plant without wasting water. Actual water requirements vary with the species, as evident by their natural environments (desert plants versus rain forest plants). However, most plants are opportunistic, and will use excess water through wasteful transpiration and lush growth.

<u>Grouping Plants and Zoning the Irrigation System</u>

Grouping plants together with similar water requirements allows the irrigation system to be designed in such a way to facilitate proper irrigation scheduling. Classifying plants based upon the system offered in Table 4.1 is one option. For example, turfgrasses and annual flowers will most likely be in the "regular watering" zone. Perennial flowers and tender shrubs might be in the "occasional watering" zone, and the tough woody shrubs, vines and trees might fall in the "natural rainfall" zone. The irrigation system is then divided into the appropriate number of zones (or stations) to match the water needs of the landscape, thus making irrigation scheduling easier and more effective.

<u>Deep, Infrequent Irrigation</u>

Irrigation should enhance the plant's natural ability to obtain water. In most cases, watering deep and infrequent will force a plant to develop a deeper root system that will prove beneficial in drought periods. Recall, however, that soil type and soil oxygen depletion can limit root depth. Clay soil restricts root growth more than sand; therefore, any given plant will usually have a deeper root system in sand than in clay soil.

When scheduling irrigations, space out irrigation events as much as possible to encourage the roots to grow deeper. For example, when twice-a-week irrigation is necessary, space out irrigation events three or four days apart.

Time of Day to Irrigate

One of the simplest ways to reduce water waste is to irrigate late evening or early morning when wind speed and evaporation is low. The optimal irrigation window is between 3 am and 6 am. As the sun comes up water dries from plant surfaces, thus minimizing the potential for fungus and disease problems that thrive in wet conditions.

Multi-cycling Irrigation

In trying to achieve deep, infrequent watering, ponding or runoff may occur before the irrigation cycle is complete, especially on a heavy clay soil with a low infiltration rate. When this occurs, multi-cycling (or dividing the irrigation event into multiple start times) is necessary to prevent water waste. Multi-cycling features exist on many brands of automatic controllers. This option can be programmed with a rest (or soak) time to allow water to infiltrate into the soil before irrigating again.

Turfgrass Applications

In general, turfgrass comprises the largest percentage of land area and is the greatest user of water in a typical residential landscape. It also tends to have a shallow root system compared to other landscape plants thus requiring more frequent irrigation. Care should be taken in selecting the most appropriate turfgrass for its intended use, planting location and maintenance requirements.

St. Augustine and Bermuda are the two most popular turfgrasses in Texas, but Zoysia and buffalo grass are growing in popularity. Turfgrass types vary in the amount of water stress they can withstand and in their ability to recover from periods of drought. As landscape irrigation becomes more scrutinized and regulated in an attempt to eliminate waste and extend existing water supplies, many homeowners are looking for more drought-tolerant turfgrasses that exhibit the ability to recover after prolonged periods without rainfall. Homeowners can replace large areas of turfgrass with low-water-use groundcover beds, impervious surfaces such as patios and decks, and native plant species that have a proven ability to survive weather extremes.

When planning turfgrass areas in the landscape, consider the ease or difficulty in watering efficiently. Areas that are long and narrow or small and odd-shaped are difficult to water efficiently with any irrigation equipment. Try to eliminate long, narrow areas and incorporate more rectangular and square shapes in the design.

SECTION 6: PROGRAMMING RESIDENTIAL IRRIGATION CONTROLLERS

Failure to properly program an irrigation controller is a major cause of water waste. Understanding how to use the basic features and set irrigation schedules appropriate for the irrigation system and landscape water requirements is essential. Following is an overview of how to program typical residential irrigation controllers. A typical controller generally requires the following five inputs:

- Current time
- Current date
- Irrigation start time
- Irrigation run time
- Watering days

Figure 6.1: Irrigation controller in "Auto" mode.

Figure 6.2: Irrigation controller in "Run" mode.

Consider the following factors when programming a controller:

- Precipitation rate of the zone or station
- Slope and runoff potential
- Cycle and soak irrigation
- Watering day and time restrictions

Precipitation rate and slope are important because they can lead to runoff if the controller is set to run too long. Ideally, irrigation systems should be designed so that the precipitation rate of the zone does not exceed the infiltration rate of the soil. However, this is not always practical, thus cycle and soak (or multiple cycles) is required to prevent significant runoff.

Figure 6.3: Irrigation controller in "Run" mode.

To find out if your controller falls under watering restrictions, contact your local water purveyor.

Set Controller Date and Time

- Turn the dial to the *Date/Time* setting. (Some controllers will have two settings; one for date and another for time.)

- Use the **Up/Down** arrows on the controller to adjust the date and time.

- To adjust between *Month/Day/Year* and *Hour/Minutes*, most controllers will have **Right/Left** arrows to toggle between settings. Other controllers have either an **Enter** or **Next** button.

Figure 6.4: "Current Date" mode selected.

Figure 6.5: "Current Time/Date" mode selected.

Figure 6.6: "Set Current Date/Time" mode selected.

Set Irrigation Start Times

- Turn the dial to the *Start Time* setting.
- Use the **Up/Down** arrows on the controller to adjust the Start Time. (Some controllers will only utilize one controller start time, whereas others require a start time for each station entered.)
- Use the **Right/Left** buttons or **Enter/Next** button to toggle between stations.

Figure 6.7: "Watering Start Time" mode selected.

Figure 6.8: "Program Start Times" mode selected.

Figure 6.9: "Set Program Start Times" mode selected.

Select Days to Water

- Turn the dial to the *Days to Water* setting.
- Use the **Up/Down** arrows on the controller to select the watering day.
- Use the **Right/Left** buttons or **Enter/Next** button to toggle between days.

Figure 6.10: "Custom Cycle - Set Days to Water" mode selected.

Figure 6.11: "Days to Water" mode selected.

Figure 6.12: "Set Days to Water" mode selected.

Set Individual Zone (or Station) Runtimes

- Turn the dial to the *Runtimes* setting.
- Use the **Up/Down** arrows on the controller to adjust the runtimes.
- Use the **Right/Left** buttons or **Enter/Next** button to toggle between station runtimes. *(Note: The terms station, valve and zone are used interchangeably on controllers.)*

Figure 6.13: "Set Valve Run Time" mode selected.

Figure 6.14: "Zone Run Times" mode selected.

Figure 6.15: "Set Station Run Times" mode selected.

Average Monthly Reference Evapotranspiration (ET_o) for Major Texas Cities (inches per month)

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Abilene	2.08	2.57	4.14	5.48	6.47	7.65	8.36	7.46	5.48	4.21	2.67	2.08	**58.65**
Amarillo	1.84	2.27	3.73	5.06	5.89	7.51	8.08	7.29	5.61	4.05	2.40	1.78	**58.65**
Austin	2.27	2.72	4.34	5.27	6.39	7.15	7.22	7.25	5.57	4.38	2.74	2.21	**57.51**
Brownsville	2.65	3.03	4.48	5.17	6.03	6.32	6.68	6.65	5.21	4.34	3.01	2.59	**56.16**
College Station	2.20	2.71	4.22	5.20	6.25	6.89	7.10	6.85	5.60	4.30	2.80	2.20	**56.32**
Corpus Christi	2.42	2.95	4.28	5.17	5.95	6.43	6.68	6.65	5.21	4.34	3.01	2.59	**55.68**
Dallas/Ft Worth	2.00	2.46	3.96	5.14	6.21	7.06	7.40	7.25	5.49	4.19	2.59	2.10	**55.85**
Del Rio	2.47	3.01	4.76	6.01	6.98	7.41	7.57	7.41	5.77	4.35	2.91	2.36	**61.01**
El Paso	2.74	3.53	6.07	8.19	9.83	11.12	9.19	8.94	7.69	5.89	3.58	2.49	**79.26**
Galveston	2.20	2.60	4.10	5.00	6.11	6.60	6.20	6.00	5.50	4.20	2.80	2.30	**53.61**
Houston	2.36	2.83	4.32	5.01	6.11	6.57	6.52	6.08	5.57	4.28	2.90	2.35	**54.90**
Lubbock	2.35	2.63	4.41	5.53	6.93	7.73	7.63	7.20	5.54	4.19	2.61	2.33	**59.08**
Midland	2.20	2.78	4.46	5.91	7.21	8.20	9.23	8.62	6.95	4.31	2.78	2.16	**64.81**
Port Arthur	2.25	2.63	3.95	5.09	6.12	6.60	5.81	5.61	5.46	4.18	2.76	2.23	**52.69**
San Angelo	2.88	3.13	5.31	7.01	8.48	9.16	9.29	8.49	6.60	5.08	3.37	2.54	**71.34**
San Antonio	2.42	2.90	4.42	5.47	6.47	6.97	7.31	6.99	5.64	4.44	2.85	2.36	**59.93**
Uvalde	2.44	2.95	4.62	5.85	6.70	7.21	7.50	7.31	5.70	4.40	2.89	2.36	**59.93**
Victoria	2.35	2.87	4.29	5.77	6.39	6.70	6.92	6.70	5.36	4.41	2.93	2.33	**57.02**
Waco	2.13	2.62	4.03	5.31	6.45	7.15	7.40	7.50	5.70	4.41	2.70	2.17	**54.05**
Weslaco	2.50	2.57	3.96	4.90	6.12	6.53	7.00	6.58	4.79	3.96	2.85	2.29	**54.05**
Wichita Falls	1.94	2.46	4.07	5.50	6.70	7.54	7.97	7.72	5.79	4.30	2.62	1.95	**58.56**

Average Monthly Rainfall for Major Texas Cities (inches per month)

City	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Abilene	1.01	1.10	1.19	2.09	3.31	2.90	2.09	2.45	2.75	2.48	1.28	1.04	**23.68**
Amarillo	0.59	0.58	0.93	1.24	2.74	3.40	2.88	2.99	1.89	1.41	0.62	0.57	**19.84**
Austin	2.11	2.41	2.05	3.01	4.38	3.46	2.05	2.23	3.38	3.35	2.28	2.46	**33.16**
Brownsville	1.33	1.31	0.90	1.63	2.31	2.85	1.69	2.46	4.95	3.36	1.61	1.18	**25.58**
College Station	2.87	2.88	2.50	3.77	4.73	3.79	2.24	2.43	4.30	3.64	3.07	3.15	**39.37**
Corpus Christi	1.57	1.88	1.33	2.06	3.09	3.19	1.84	3.33	5.30	3.54	1.56	1.60	**30.30**
Dallas/Ft Worth	1.94	2.44	3.12	3.15	5.43	3.18	2.09	2.10	2.42	4.01	2.43	2.50	**34.82**
Del Rio	0.53	0.91	0.86	1.89	2.39	1.90	1.54	1.72	2.59	1.94	0.85	0.65	**17.76**
El Paso	0.42	0.41	0.30	0.21	0.33	0.72	1.56	1.48	1.42	0.72	0.35	0.62	**8.57**
Galveston	3.33	2.58	2.43	2.55	3.46	4.14	3.77	4.23	5.36	3.17	3.32	3.59	**41.93**
Houston	3.70	2.99	3.48	3.49	5.22	5.13	3.25	3.79	4.45	4.65	3.89	3.64	**47.70**
Lubbock	0.52	0.61	0.82	1.26	2.62	2.67	2.12	2.07	2.53	1.99	0.62	0.64	**18.47**
Midland	0.54	0.61	0.47	0.77	2.02	1.59	1.83	1.65	2.04	1.56	0.58	0.53	**14.18**
Port Arthur	4.86	3.96	3.30	3.86	5.02	5.68	5.31	5.04	5.77	4.20	4.22	5.13	**56.34**
San Angelo	0.83	1.05	0.93	1.68	2.86	2.20	1.16	1.77	2.78	2.21	0.96	0.78	**19.20**
San Antonio	1.61	1.90	1.68	2.53	3.99	3.57	1.83	2.58	3.29	3.29	2.11	1.72	**30.09**
Victoria	2.28	2.12	2.08	2.93	4.95	4.77	3.03	3.08	5.37	3.72	2.51	2.33	**39.17**
Waco	2.07	2.39	2.51	3.43	4.59	2.80	1.88	1.66	3.07	2.91	2.48	2.49	**32.28**
Wichita Falls	1.08	1.31	1.91	2.72	4.59	3.36	2.05	2.16	2.94	2.69	1.55	1.56	**27.93**

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