IRRIGATION BMPS FOR GOLF COURSES IN LOUISIANA AND MISSISSIPPI



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PREFACE

This publication is the third in a series addressing best management practices for Louisiana and Mississippi golf courses. The first publication, Nutrient BMPs for Golf Courses in Louisiana and Mississippi (LSU AgCenter Pub. 3619), and second publication, Water Resource Management BMPs for Golf Courses in Louisiana and Mississippi (Mississippi State Extension Pub. P3365), address many issues that are equally important to protecting water resources on golf courses.

INTRODUCTION

Proper irrigation design, application and scheduling are important to the sustainable operation of golf courses. Unfortunately, rainfall does not consistently occur at the correct time, place or amount despite high annual averages in Louisiana and Mississippi. The imposed stress from improperly applied irrigation can invite other stressors such as weeds, pests and diseases that negatively impact turfgrass health. These stressors may become difficult to control if unfavorable growing conditions persist, especially if the irrigation procedures are not corrected. Irrigating too much or too often can also negatively impact a healthy turfgrass due to leaching nutrients and other mobile chemicals such as pesticides. Standing water can lead to oxygen deprivation that can cause stress to the turfgrass sward and affect the playability of the course. Also, lack of proper irrigation can cause erosion and surface runoff that carries nutrients, sediment or other pollutants to local water bodies. Properly irrigating a golf course has the potential to reduce or alleviate concerns over diminishing water resources, increasing environmental regulation and rising costs.

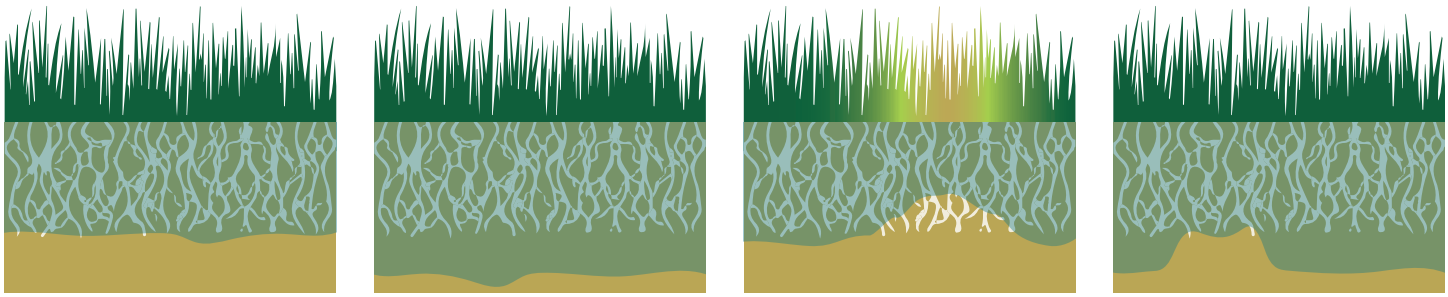
GOALS FOR IRRIGATION BEST MANAGEMENT PRACTICES

The overall goal of irrigation is to supplement rainfall using the least amount of water while maintaining turfgrass. There are two specific concepts that help to define best management practices for irrigation.

Irrigation Efficiency – The ratio of water that was beneficially used to total irrigation applied over a certain amount of time. Beneficial uses of water generally translate to the direct contribution of water to plant growth and overall health but can also refer to leaching of salts, frost protection, germination, establishment and soil preparation.

Inherent in the irrigation efficiency factor are the efficiency of the conveyance system (i.e., irrigation system design), field application efficiency (i.e., ability to achieve a target depth) and distribution uniformity (i.e., how the water is distributed across the field). These many factors affecting irrigation efficiency make it difficult to measure or calculate directly. Instead, following established principles for irrigation system design and targeting plant water requirements for irrigation scheduling can maximize their contributions to achieving high irrigation efficiency. Distribution uniformity, however, is calculable and can be used to approximate the irrigation efficiency of the system.

Distribution Uniformity – A measurement of the evenness of water application across the irrigated area. Lack of uniformity can occur for a variety of reasons; examples include spacing sprinklers too far apart, allowing irrigation to occur during high wind or operating at pressures outside of the design pressure. An irrigation system can be uniform without being efficient, but it cannot be efficient without being uniform (Figure 1).



A) Efficient and Uniform | B) Uniform, Not Efficient | C) Not Uniform, Underwatered | D) Not Uniform, Overwatered

Figure 1. Examples of A) good distribution uniformity and good efficiency, B) good distribution uniformity but poor irrigation efficiency, C) non-uniform and inefficient irrigation resulting in a hot spot, and D) over-watering to address a hot spot that is non-uniform and inefficient.

SYSTEM DESIGN

The only way to receive the full benefits from an investment in irrigation is to start with a properly engineered design. Even the investment of updating an existing system is beneficial over the long term. The smartest available technology cannot fix a poorly designed system. The irrigation contractor will work through the following considerations to design an efficient and effective irrigation system.

WATER SOURCES

All system designs begin with a ***flow rate*** and ***pressure*** from the water source. Thus, the water source is a very important decision that will affect the design of the distribution system as well as the design of the golf course itself.

The easiest water source to utilize for irrigation is a potable supply from a local water utility. Utilities generally know their supply pressure and can provide that information to help with the design. The water quality is also a known factor; the utility is required to report its testing results annually. However, utilities charge their customers for water consumption and those charges will continue throughout the life of the system. The rate structures are unlikely to ever decrease due to decreasing water resources and increasing water treatment costs. For billing purposes, utilities traditionally supply a water meter to measure consumption for billing. This meter can help to easily determine the flow rate at the source.

A more cost-effective option for a utility-supplied water source is to work with the local wastewater treatment facility to obtain access to reclaimed water. Reclaimed water is defined as wastewater that was treated to drinking water standards and considered safe for nonconsumption purposes (e.g., landscape irrigation, toilet flushing, street cleaning, fire protection, cooling towers, etc.). Typically, the consumption fees are much lower than for potable water. Many utilities offer a flat fee for access and do not meter consumption at all. However, each utility is different. They may not be able to

support the infrastructure costs necessary to transport reclaimed water from the treatment facility to the golf course, placing the financial responsibility for infrastructure on the customer. Reclaimed water can be easily identified by purple infrastructure.

Groundwater wells are popular options when the golf course is located far from natural waterways, within a utility service area with unusually high water rates or rural areas without access to water utilities. Typically, groundwater has acceptable water quality and does not require extensive filtration for irrigation. However, water quality of every source should be tested prior to designing the system. An example of a common groundwater quality issue is the presence of iron that can negatively impact system performance if not incorporated into the component selection process. Once a well is installed, pumping costs to lift water from the aquifer are the only costs associated with groundwater due to riparian water rights in both states. However, many groundwater aquifers are depleting faster than their natural recharge rate. Flow rates decline as depletion occurs, which can negatively impact the environment as well as the way water is distributed by the irrigation system. The result is similar to using a hose with a partially open faucet; the lowered rate of flow means that the water does not distribute as far and as evenly as expected throughout the entire landscape within the same amount of time.

Surface water sources can be very effective in humid climates like Louisiana and Mississippi due to normally plentiful rainfall. Examples of surface water sources include adjacent rivers, lakes, retention ponds and oxbows. If there is the possibility of using a public waterway such as a local river or lake, prior permission is required from the state, at minimum, to ensure that the volume being removed for irrigation does not impact the public waterway. If not located near a public waterway, onsite storage can be used to collect rainfall in the form of retention basins. Retention basins can be implemented into water features throughout the course. Fountains or other water features within the basin may be necessary to maintain good water quality by preventing stagnation that leads to algae and aquatic weeds. The size of each retention basin should include enough storage for a few weeks of critical irrigation during summer dry spells while not completely draining the water feature.
More information on retention basins and water quality can be found in the second publication of this series, which is titled "Water Resource Management BMPs for Golf Courses in Louisiana and Mississippi."

COMPONENTS

All golf course irrigation systems require four components at a minimum: a control device, distribution system, water application device and wiring.

Control devices range from time clocks programmed by the irrigator with the simplest irrigation schedule to full-scale computer systems that use programmed logic to make irrigation decisions (Figure 2). These devices are considered the "brain" of the irrigation system.

It is important to select technologies that can be utilized by the person in charge of scheduling irrigation (i.e., the irrigation manager). For example, a sophisticated computer program may not be appropriate if the features of the technology will not be implemented. However, technological upgrades to irrigation systems can maintain or improve efficiency by reducing the need for the irrigation manager to fully understand the various calculations and considerations necessary to operate an efficient irrigation system. For example, software and sensor upgrades can operate the irrigation system by automatically adjusting irrigation based on changing weather conditions.

A)



B)



*Figure 2. Examples of A) a single controller that must be programmed with runtimes and managed for changes in weather if used as a standalone device, **(Photo courtesy of Hunter Industries Incorporated)** and B) a PC-based system that utilizes internet-based resources and/or controllers in series to schedule irrigation based on weather conditions or sensor feedback.**(Photo courtesy of Hydropoint).***

The distribution network primarily consists of a network of pipes or tubing that distributes water from the source to the irrigated area. This portion of the design can be considered the "skeleton" of the system.

Pipes used for standard irrigation systems are typically made from polyvinyl chloride (PVC). Pipe is sold in 20-foot sections but can be cut to fit the application. All PVC pipe is either rated as a ***schedule*** under the Iron Pipe Sizes (IPS) rating system based on pipe wall thickness or as a ***class*** based on the sustained pressure rating.

When rated using the schedule system, the wall thickness of the pipe, which increases with an increase in schedule, correlates to the strength of the pipe (Figure 3). For example, Schedule 80 PVC has a larger difference between the inner (ID) and outer diameters (OD) than Schedule 40 PVC, making it a thicker and stronger pipe. The manufacturer-supplied diameter of the pipe (e.g., 1-inch Schedule 40 PVC) is measured from the OD, thus a Schedule 80 PVC will have a smaller ID and a smaller opening for water flow than Schedule 40 PVC at the same specified diameter, a factor that is important when designing the distribution network. Since schedule rating systems relate directly to wall thickness, pipe strength decreases as pipe diameter increases. For example, a 1-inch Schedule 40 pipe is much stronger than a 12-inch Schedule 40 because the same wall thickness must handle the increased pressure inherent in the increased water volume moving through the pipe.

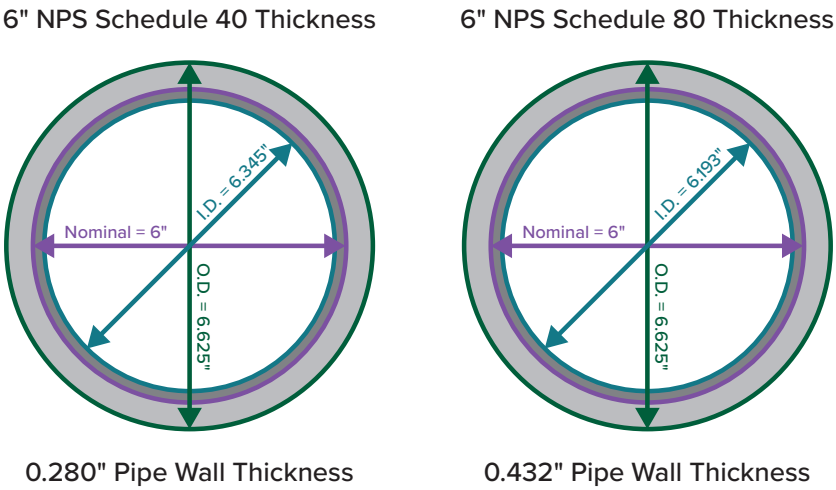


Figure 3. Example of the differences in inner diameter (ID), outer diameter (OD), and wall thickness (WT) of two different PVC schedules.

Typically, the class rating system is most applicable to nonresidential projects, including golf course irrigation systems. Classifications directly relate to the ability of the pipe to handle sustained pressures. For example, Class 200 pipe is rated for up to 200 psi and Class 315 is rated for up to 315 psi. These pipes are designed with a safety factor to account for faults or weaknesses from manufacturing to installation and also allow for surging pressures up to twice the rating for short periods of time. However, frequent or extreme surging can lead to premature failures in water conveyance.

All PVC fittings (i.e., joints) are made from schedule 40 PVC. These fittings can be used to: connect the pipe sections to extend beyond 20 feet, allow changes in direction of the pipe, branch the pipe network into multiple directions and add in-line components. Fittings tend to be a natural weak point for leaks and other potential issues, so it is very important to have a strong connection. Fittings should be connected to pipe using a PVC primer and a PVC cement as glue. The primer should be applied to both items being connected and allowed to dry for about 10 seconds. The cement should then be added to each item and quickly aligned with a quarter turn offset, twisted into the final orientation and held for 15 seconds. Failing to follow all steps in the proper order may result in a weakened joint. The use of these products should occur in a well-ventilated area and utilize appropriate personal protective equipment.

Pipe size selection must be completed from the end of the system back to the water source using the sprinkler specifications for the irrigated area. This methodology allows for estimations of friction losses to ensure that the flow rate at the sprinklers meets the manufacturer-specified requirements while verifying that there is enough available flow at the source. Using basic hydraulics principles, friction loss is estimated as a loss in pressure per 100 feet of pipe and must be converted to the design features. The goal is to ensure that the water velocity does not exceed 5 feet per second and pressure losses within the system are less than 5%. Friction loss charts for various pipe materials, classes and sizes can be found on the Irrigation Association's website or as part of technical resources provided by irrigation manufacturers.

Another commonly used pipe material for irrigation is polyethylene (PE). For golf course applications, this pipe material is dedicated to microirrigation applications in low traffic areas such as landscape beds (Figure 4). There are a number of emitters with different purposes (e.g., drip, bubblers, microsprays) that can connect to the same PE pipe to meet the different water requirements of diverse landscape material. Though microirrigation designs are much more forgiving and adaptable than a traditional sprinkler irrigation system, a balance of pressure and flow rate must still occur at the design phase.



Figure 4. Polyethylene (PE) pipe is traditionally used for microirrigation in low traffic areas such as landscape beds around the clubhouse.

Operational technologies that interface with the control device and distribution network include valves, filtration mechanisms, backflow prevention, pressure regulation, measurement or feedback devices and injection equipment for chemigation or fertigation. There should be significant consideration for locating these technologies together or close proximity when possible for ease of maintenance operations. However, locating these technologies close together can sometimes complicate the design of the distribution system and should be considered in the cost of installation.

Valves are used to control the flow of water throughout the distribution network. The primary valves used for irrigation include a master valve, solenoid valves for each zone or sprinkler, and manual valves (i.e., ball or gate valves) for use during maintenance or special occasions (i.e., wedding held on the 18th hole). They are considered the "heart" of the system.

The **master valve** is used to maintain control of the entire system. Typically located close to the water source, this valve can be a manually controlled device (i.e., gate valve, ball valve) or a large solenoid valve that can connect to the control device. With irrigation systems, solenoid valves are most common because they are wired into the control device to terminate flowing water at the source if a problem is identified. Closing the master valve prevents water flow to the entire irrigation system.

As an example, a lower-than-expected flow rate for zone 5 occurred despite measuring the expected flow rate at the master valve would be an indication of a leak somewhere in the system between the water source and where zone 5 splits from the main line. The control device can deactivate the master valve and stop watering to prevent excessive waste of water resources until the problem is addressed.

Solenoid valves are installed in-line at the start of each zone in the distribution network or can be incorporated into each sprinkler for individual control (Figure 5). These valves receive a signal from the control device that lifts a plunger, allowing an internal diaphragm to move upward and expose the pathway for water to flow through the valve. These valves are designed to be activated electronically by the control device but can be operated manually if necessary. As a product, some solenoid valves include additional functions such as pressure reduction.

In some scenarios, issues may arise that negatively impact electronic control of solenoid valves. A common example is when a sand particle lodges under the solenoid plunger, causing the plunger to remain open and allow water flow despite losing the holding current from the control device. Including **manually controlled valves** such as ball or gate valves throughout key locations within the distribution network can help to maintain control of water flow immediately, allowing time for repairs without wasting water resources. These manual valves also help to isolate irrigation branches during important functions and operations.

Another type of manually controlled valve is called a quick coupling valve or "quick-connect." Installed off the irrigation line, this type of valve allows for quick access to water for running portable sprinklers or using a hose for filling tanks, spraying sidewalks, addressing hot spots or handling temporary or transitional water needs such as irrigating annuals or potted plant materials. These valves can be used as a backup irrigation tool in association with a hose or portable sprinkler when the irrigation system requires maintenance or repair. An L-shaped valve key must be inserted and locked into place or threaded into the valve to access the irrigation water. Similar to an open faucet, water flows freely once the valve key is used. A locking valve key can be dangerous due to tapping into a high-pressure source; failing to fully lock or unlock the lug connection can result in the key spinning off the swing joint and shooting into the air. Threaded connections can improve the safety aspect as well as allow for the utilization of a portion of the available flow rate. These valves are installed in convenient and inconspicuous areas for ease of access and should be used sparingly for irrigation purposes due to their potentially low distribution uniformity and generally high-volume application.

Air release valves should also be considered within the pipe network. Typically called air vents, these devices release trapped air within the pipe network. Air can act as a barrier that restricts water flow, creates water hammer, and causes damage to pipes and fittings. However, the absence of air can also become an issue by creating a vacuum that pulls contaminates into the system. Air vents should be installed at the highest elevation of the system if air release cannot occur in conjunction with other system components.

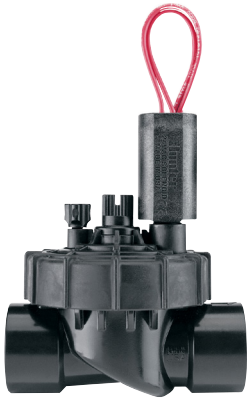


*Figure 5. Example of a solenoid valve. Products may look different based on manufacturer, model, size, and application. (**Photo courtesy of Hunter Industries Incorporated).***

Filtration should be included in an irrigation design for any localized water source such as a groundwater well or surface water sources. Since surface water interacts with environmental debris (i.e., fallen leaves, fish, insects, etc.), it will require significant filtration before entering the distribution network. Both groundwater and surface water may have water quality issues that would be identified through proper testing. There are three types of filtration systems based on the filtration media: screen, disk and sand. The type of filtration system or combination of filtration systems is determined from the expected water quality parameters determined from testing that will negatively impact the operation of the equipment and decrease the projected life of the system.

Backflow prevention should be an included component to all irrigation systems and is mandated by law in most areas of the United States. These devices prevent the flow of water from the irrigation system back into the potable water source. Stopping the backwards flow of water is important to minimizing contamination of drinking water from fertilizers and other common chemicals applied to landscapes. The backwards flow of water can occur from backpressure, when there is a higher pressure in the irrigation system compared to the water source, or backsiphonage, when a high draw of water over a short amount of time creates a vacuum that pulls the water from the irrigation pipes and back into the water source. An example of backsiphonage would be the use of a fire hydrant or a break in a local water main.

The most common backflow prevention devices are: A) atmospheric vacuum breaker [AVB], B) pressure vacuum breaker [PVB], C) double check valve, and D) reduced pressure principle backflow prevention assembly [RP]. An AVB should be installed after every valve in the system, making it less economical for large systems such as golf courses. Placing valves after an AVB will invalidate the effectiveness of backflow prevention. The PVB should be installed between the water source and the valves; only one is required for the system. Some authorities require the PVB to be located within 18 inches of the water source. Both AVB and PVB should be installed at least 12 inches higher than the highest sprinkler head or outlet and should never be submerged in water. A double check valve is basically two check valves in series with two manual shutoffs and access to connections for testing functionality. They can be installed in-line, prior to any valves. The RP is considered to have the highest protection capabilities, applicable for both backpressure and backsiphonage, and is typically required when water is classified as high hazard such as when applying chemicals directly into the irrigation system.

Backflow prevention for irrigation systems is a highly regulated field but is not standardized across the United States. For example, some regulatory authorities automatically classify irrigation systems as high hazard and require RPs for all systems, whereas many other locations specify PVBs as the minimum requirement for small systems that do not have direct chemical injections into the water supply. Thus, selection of a backflow prevention device must meet the local and state regulations for installation and operation. In Louisiana, all backflow prevention devices must be installed by an endorsed backflow prevention specialist. Some irrigation contractors have the endorsement, but it is most common for irrigation contractors to subcontract backflow prevention work to a plumber with the endorsement.

Pressure regulation is an important component to maintaining the correct operating pressure within each zone. All sprinklers have a suggested operating pressure for achieving good distribution uniformity that helps with irrigation efficiency. Having too much pressure will pixelate the water droplets, creating a mist that results in higher water losses to evaporation instead of entering the root zone. Too little pressure will shorten the radius of the water stream from the sprinkler, resulting in uneven distribution across the irrigated area. In all cases, efforts should be made to select sprinkler nozzles with matched precipitation rates and give additional consideration to pressure-compensating nozzles for maximizing efficiency.

Pressure regulators are in-line devices used to regulate changes in pressure from the water source and can sometimes reduce pressure when needed. Pressure reductions are typically limited to 10% of the supply pressure. For example, placing a 10-psi pressure regulator on an irrigation line with a supply pressure of 50 psi will not be effective for pressure reduction. Also, pressure regulators cannot increase the supply pressure. A booster pump would be an appropriate consideration if consistently low pressures were being supplied. Pressure regulation using these in-line devices is most important for zones with drip irrigation.

Some sprinklers are designed to have pressure regulation built into the device. These sprinklers are labeled as pressure compensating.

Measurement or feedback devices are not necessary for operation of the irrigation system but supply information about the performance of the system. These devices are important to identifying issues before it affects the landscape.

The most common example of a measurement device is a flow meter (Figure 6A) used to estimate water volume that has flowed through a pipe. Typically used for billing of consumptive use by utilities, these meters can aid in determining sprinkler application rates and identify deviations in water use that can help diagnose system issues. For example, a flow meter reading of 1.2 million gallons when a normal irrigation event averages one million gallons could indicate a leak or recent change in flow rate from the water source. Conversely, consumption that is significantly less than the average can indicate that a zone did not run as expected and the system should be evaluated.

Another option to obtain feedback from the system is a flow sensor (Figure 6B). In general, flow sensors provide an estimate of the amount of water passing through it. These devices connect to the irrigation control device and can adjust settings if issues are detected. Some flow sensors report average flow rates but are not always as accurate in estimating volume as a flow meter. However, flow meters usually require manual data collection and addressing issues after analysis, whereas flow sensors can take action immediately if the sensed flow falls outside of expected parameters.

A)



B)



Figure 6. Example of A) a flow meter and B) flow sensors. ***(Photos courtesy of Hunter Industries Incorporated).***

Chemigation and fertigation are defined as the process of applying chemicals or fertilizers directly through the irrigation water. Though generally considered as a component to drip irrigation systems, this process can be accomplished with any well-designed system. It allows for each application to be immediately watered into the root zone without the labor and time required for broadcasting material that requires activation from irrigation or rainfall. Fertilizers can be applied in small quantities over time to reduce the potential of nutrients leaving the landscape from surface runoff and causing water quality issues.

The infrastructure needed to set up fertigation or chemigation include the injection pump system, holding tanks, chemical storage, control equipment for automated injection, and an RP for backflow prevention. This infrastructure requires significant space as well as a containment area in case of spillage. Easy access to the containment area is also required to accommodate liquid chemical deliveries. Product labels associated with chemicals should be consulted for additional requirements beyond normal protocol such as additional backflow prevention or special applicators. All other components of the irrigation system should be selected to accommodate the chemigation process to ensure a long system life.

Water application devices are used to distribute the water across the landscape. There are many options available from both the agricultural and landscape irrigation markets depending on the management needs of the irrigated area. Every sprinkler layout should be designed for head-to-head coverage in a rectangular or triangular design. Thus, a properly designed irrigation zone will have even distribution with either three or four overlapping sprinkler patterns. An individual sprinkler will not provide an even distribution of water alone. Pop-up sprinklers such as rotors and sprays are the most common components on the market.

A **rotor** emits a stream of water with a fixed rotation across the landscape (Figure 7). These sprinklers are commonly used for large turfgrass areas with radii ranging from 20 feet to 60 feet. Due to the large area covered by a single stream, application rates are generally low, making runtimes long.



*Figure 7. Example of rotors irrigating a turfgrass area with head-to-head coverage. (****Photo courtesy of University of Florida).***

A **spray** emits a fixed arc of water without rotation across a smaller area than appropriate for a rotor, usually less than a 25-foot radius. Though sometimes used for mixed ornamental beds, these sprinklers are most appropriate for small turfgrass areas such as greens and areas near the clubhouse or other structures. Application rates for sprays tend to at least double from rotors, resulting in much shorter runtimes compared to rotors.

The **multistream, multitrajectory [MSMT]** nozzle is a newer product that combined the uniformity benefits of a rotor with the sprinkler body and radius of a spray (Figure 8). The nozzle spins while emitting various streams of water at different distances to create an even application. Because these emitters have a higher distribution uniformity, matched precipitation rate and low flow characteristics, MSMT emitters result in water conservation over time when correctly scheduled.



*Figure 8. Example of a MSMT being used to irrigate an area of turfgrass. (**Photo courtesy of Irrigation, Sixth Edition, Vinchesi).***

An ***impact*** sprinkler was a historically popular option, but it typically has a lower efficiency than rotors and sprays. These nozzles sit on a bearing that provides rotation from the force of the water stream but springs back against an arm to create distribution of water along the distance of throw. Impacts are not designed to pop-up, so they are less ideal on an aesthetic level because the sprinklers are always visible within the landscape. However, impacts can be used on traveling or temporary irrigation systems for specific purposes (Figure 9). An example of when impact sprinklers may be useful is during the addition of native shrubs in far rough areas that would not require irrigation post-establishment but would be beneficial during the establishment period. They can also be used in emergency situations when the irrigation system is under maintenance. These temporary systems are sometimes referred to as traveling guns.



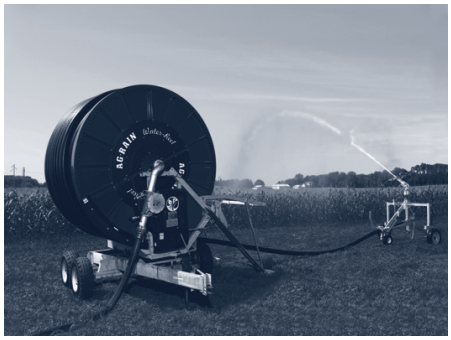


*Figure 9. Example of a traveling gun that utilizes an impact sprinkler head. (**Photo courtesy of Irrigation, Sixth Edition, Kifco Inc.)***

Microirrigation emitters include various options of drip, bubblers and microsprays (Figure 10). The emitters are chosen based on the root ball size, plant water needs and available pressure compared to pressure limits to the emitters. Some emitters are adjustable in their application rate. It is important to note that the term "microirrigation" refers to the small area covered by the emitter and does not imply low application rates. Microsprays, for example, can apply irrigation at rates up to 2 inches per hour within a radius of 6 feet. It is important to determine the irrigation requirement of the area prior to selecting a microirrigation emitter. Soaker hoses are an alternative option to emitters within the microirrigation family of products; the water wicks through the hose lining into the soil.

A)



B)

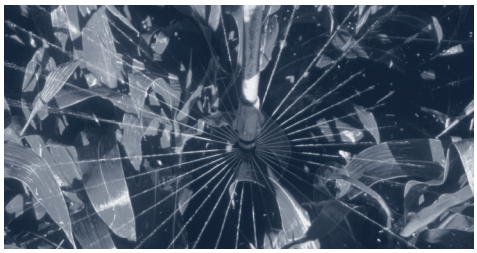


*Figure 10. Examples of microirrigation emitters include A) drip **(Photo courtesy of Irrigation, Sixth Edition, Toro Ag)** and B) microspray **(Photo Credit: Irrigation, Sixth Edition, Nelson Irrigation Corp).***

In most cases, products designed for golf course applications combine multiple aspects of these components into one product to maximize serviceability and control of water application. Specifically, sprinkler products can include pressure regulation, valve control and surge protection built into the design. By incorporating a valve into each sprinkler, an irrigator can choose the portions of the landscape that receives irrigation based on multiple factors including microclimate considerations and playability of the course. Despite the convenience of individualized control and the possibility of targeted water applications, distribution uniformity should be considered when activating individual sprinklers. Also, the control device or water source may have limitations in the number of valves that can be activated simultaneously and should be considered in the system design.

WIRING

Communication between the control device and controllable components of the system occurs through a wired connection. There are two wires required to activate any component: a "hot" wire that supplies electricity and the "common" wire that closes the electrical circuit. Although the irrigation industry continues to explore wireless technology, large-scale systems such as those for golf courses have yet to be successful in consistent and reliable communication. There are currently two types of wiring systems available, which will affect component selection.

Multiwire systems are considered the traditional method for wiring irrigation systems. In this type of system, each valve or other controllable component receives its own hot wire that connects to the control device in a specific individual location. Depending on the locations of each component, the common wire can be shared across multiple components connected to the same power source to minimize the amount of wire needed.

When the control device activates a specific zone of a multiwire system, it sends a 24-volt electrical signal along the wire in a one-way direction to the valve. Once activated, the control device continues to supply a 9-volt signal as a holding current to maintain the open valve until the cycle completes and the control device deactivates the valve. Removing the holding current will allow the valve to close, thus stopping the flow of water and ceasing irrigation of the area.

Because each component has an individual connection to the control device, limitations to the number of zones per control device can occur quickly for large systems. Also, limitations to the wire length can occur based on distance from the control device to the component due to signal loss. Sometimes the best designs shorten wire length by rerouting irrigation lines to a common location close to the control device. This design option results in additional PVC pipe, but operational issues with buried pipes are easier to identify and fix compared to issues with buried wiring.

An alternative to the multiwire system is the ***two-wire*** system. Instead of each component having a dedicated hot wire, all components are connected in series with the same two wires in a shielded cable or jacket rated for ground burial. With this setup, the wires transmit an activation signal paired with a communication signal that identifies the zone by its address or name. Each component must have a decoder as an additional component that provides the address and interprets the signal. Only the components with the correct address will respond to the communication message. Many two-wire systems have two-way communication to obtain feedback about operationality as a maintenance and troubleshooting feature. Sprinklers with built-in valves require two-way communication, resulting in the need for a two-wire system.

Though applicable to both wiring options, two-wire systems primarily fail to operate for the following reasons:

Insufficient grounding – In the humid regions such as the Midsouth, lightning is an expected occurrence and irrigation equipment is a natural outlet for such events. Because all components are connected in a two-wire design, it is very important to provide grounding locations throughout the system to prevent damage to all components if lightning strikes. Grounding can be accomplished by installing copper grounding rods and copper grounding plates using manufacturer specifications.

Improper wire connections – Most valves and other components are located below ground level and have the potential for interacting with water. If water interacts with the wiring connection, the signal for that component is lost through conductivity. Additionally, the loss of signal impacts communication to the rest of the components along the two-wire system. This issue is critical with two-wire systems, which require clear communication with the decoder beyond activation and holding currents. Only manufacturer-approved waterproof wire connectors should be used for these systems.

Improper wire stripping – Along the same lines as improper wire connections, good wire stripping techniques are critical to maintaining strong communication between the control device and components. A small nick in the wire, which can be undetectable under the jacket, can leak the signal resulting in poor communication. The amount of time and labor necessary to identify a wiring problem can become very costly due to the difficulty in locating the problem.

Despite the additional cost of adding decoders and grounding, two-wire systems become cost effective when there are more than about 15 irrigation zones within the design plan. Maximum wire lengths vary depending on manufacturer of the components, but two-wire systems can span to as much as 6 miles from the control device, whereas multiwire systems are limited to less than 1,000 feet. Also, two-wire systems are much more adaptable to future changes to the system design, including expansion beyond current zone capacity or adding optional components such as various sensors or other modern technologies.

When mixing water and electricity, electrical considerations to irrigation become important to health and safety of all. If choosing a two-wire irrigation system, selecting an irrigation contractor with two-wire experience and excellent references is highly recommended due to the sophistication of the equipment and expense of fixing future issues.

SELECTIONS AND PLACEMENT

In this part of the design process, the irrigation contractor will provide a design with selected components for review. The considerations listed below should be considered while reviewing any design.

Head-to-head coverage – Sprinklers are designed to be placed so that the outer edge of the water stream of one sprinkler touches the body of the next sprinkler (Figure 11). Sometimes sprinklers are placed farther apart as a cost-saving measure, but this will ultimately hurt distribution uniformity which leads to less efficient irrigation. A common problem from lack of head-to-head coverage is hot spots in the turfgrass.

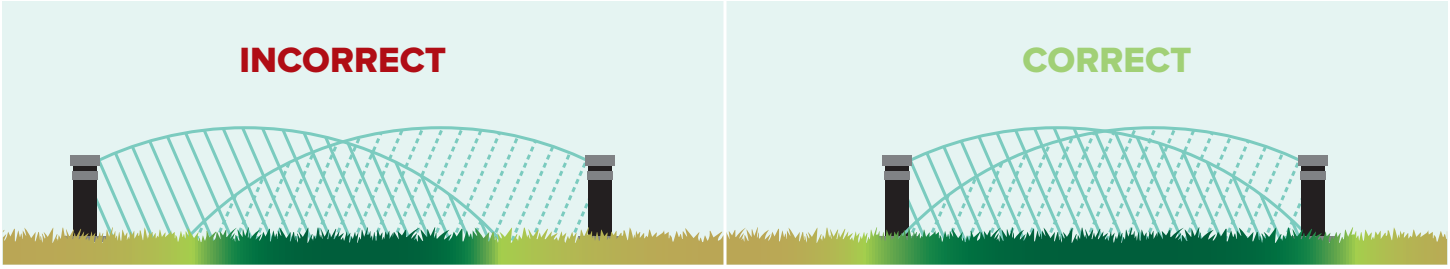
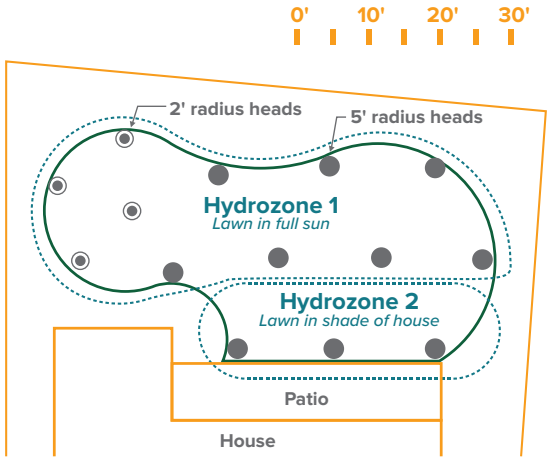


Figure 11. An example of head-to-head coverage between two sprinklers.

Varying sprinkler emitters – Except for microirrigation, sprinkler emitters should be the same style and series throughout a single zone. Rotors, sprays and impacts each have their own application rates and were not designed to be used at the same time in the same zone. Mixing these emitters will result in uneven distribution of water across the landscape and lowered irrigation efficiency.

Hydrozoning – Zones for irrigation should be designed so that plants with similar water needs are irrigated at the same time (Figure 12). Changes in soil type, plant type or hours of sunshine can create the need for different zones. Though a common design flaw, turfgrass and ornamentals should never be irrigated together within the same zone.



Shrubs, if shown, would be in a separate hydrozone.

Figure 12. Example of hydrozoning during the design process.

Branded components – Not all products are interchangeable across manufacturers. Efforts should be made to select components from the same manufacturer, if possible, for ensured compatibility.

Long-term maintenance needs – Each component that may need to be serviced regularly should be in a convenient location that is generally inconspicuous by the public. Colocating equipment, such as in a pump house or other structure, may increase installation costs but reduce labor and maintenance requirements over time. It can also help to secure and protect expensive critical equipment from potential theft or vandalization.

Before any design is approved and construction begins, existing utilities (i.e., phone, gas, cable, oil, etc.) and other potentially buried infrastructure extending through any part of the property must be identified. In some cases, the irrigation design may need to be adjusted to account for existing infrastructure. The contractor should include enough leeway in the timeline to use One Call 811 service to request utility markings. Any damage to unowned utilities on the golf course property will fall under the liability of the owner unless the owner can prove that an 811 call was made, and the contractor followed all legal digging guidelines.

Since most of the equipment will exist below the ground surface, it's important to develop as-built maps as part of the design process. Accurate maps can help to minimize digging and associated landscape damage when attempting to address a leak or make changes to the system, such as adding a zone to a newly planted area. They can also help when hiring a new irrigation contractor to work with the system or training new employees on operation and maintenance. All other infrastructure identified by calling 811 should be clearly marked on the as-built for

future consideration as well. However, anytime irrigation is to be extended a call to 811 prior to installation is advised.

SYSTEM MAINTENANCE

It is in the best interest of the landscape and the irrigation manager to keep the irrigation system operating at the designed capacity. Regular maintenance activities should be conducted on all irrigation systems to alleviate any unfavorable interactions with the environment. Some examples of issues include plant material covering the sprinkler heads and restricts pop-up and water flow, damage to sprinkler heads by mower blades, sunken sprinkler heads from compaction or settling and numerous other minor but costly issues. Also, regular maintenance can minimize impact of the damage from larger unnoticed problems. For example, the separation of PVC pipe along a remote portion of the system due to a poorly glued fitting can result in significant water loss when irrigation is activated. However, long-term damage could include loss of all plant material normally irrigated by that zone or all zones hydraulically connected to that pipe segment and soil erosion from the water pressure released within the soil. Because irrigation normally occurs at night to allow daytime play on the course, a routine maintenance program should be developed.

Maintenance activities should include:

- Following each scheduled irrigation event, check for signs that watering did occur as programmed and that there are no excessively wet areas to the landscape.
- At a minimum of once per month, a wet check should be performed. A wet check is the process of running each zone for a few minutes to verify that all sprinklers are in good repair and operating at the correct pressure. This is generally a visual inspection but can be more detailed if needed.
- At a minimum of once per year, usually at the start of the irrigation season, a full audit should be conducted. In addition to the benefits of the wet check, the audit is used to calculate the distribution uniformity using a catch-can test. It can also be used to calculate the zone application rate that can help to adjust irrigation runtimes if there was a change to the supply pressure from the water source.

Catch-can testing is defined as the process of estimating the distribution of water across the zone during a representative irrigation event. The test begins by placing catch-cans or buckets in a gridlike pattern across a representative area of the zone (Figure 13A). After applying approximately one-half inch of irrigation, water volumes are measured from each catch-can in order to estimate distribution across the landscape (Figure 13B).

A)



B)

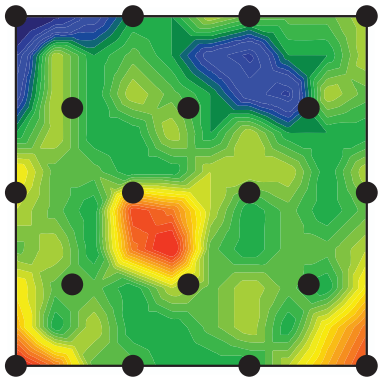


Figure 13. Example of A) a catch can test, ***(Photo courtesy of University of Florida)*** *and B) a spatial image of catch can results that indicates areas that received more (blue) or less (red) water than the average application.*

Catch-can testing can be a lot of work but provides a quantifiable value that can be used to estimate irrigation efficiency. This value is calculated as the lower quarter distribution uniformity [DUlq] using the following equation:

$$DU_{lq} = Vavg_{lq} / Vavg \quad (1)$$

In this equation, Vavg is the average of all catch-can values, and $Vavg_{lq}$ is the average of one-quarter of the buckets that had the lowest measured volumes. For example, if 24 catch-cans are used in a test, the average volume from six cans with the lowest measured volumes would be used for $Vavg_{lq}$ and the average volume from all cans will be used for Vavg.

There can be error inherent in catch-can testing that can lead to a low DU_{lq} value that does not directly reflect the efficiency of the system. Some common examples include incompatibility between the arc of the water and height or angle of the catch-can, higher windspeeds during daytime testing compared to normal irrigation times and the lack of consideration for redistribution in the soil profile. To account for these errors, it is recommended that a DU_{lh} be used as estimated irrigation efficiency instead. The DU_{lh} is calculated as:

$$DU_{lh} = 38.6 + (0.614 \times DU_{lq}) \quad (2)$$

In normal circumstances, DU_{lq} is presented as a decimal value instead of a percentage to distinguish its status from irrigation efficiency. However, Equation 2 requires DU_{lq} to be a percentage for calculation.

For more information on irrigation auditing, please consult the resources on the Irrigation Association website or contact a Certified Golf Irrigation Auditor for help.

SCHEDULING

Irrigation scheduling is the process of determining where, when, and how much water is needed for a landscape or area. Scheduling irrigation is straightforward for a well-designed

system. The factors described below should be considered when scheduling irrigation.

SPRINKLER TYPE

In consideration of scheduling, the type of sprinklers should be selected based on the available flow rate and pressure from the water source while matching the flow rate and pressure requirements for proper operation. Combined with the area of coverage, the flow rate directly relates to the application rate used to calculate the irrigation runtime. Every sprinkler or emitter has an associated application rate, sometimes called a precipitation rate, that can vary based on pressure. The radius can also be affected by differences in pressure. Application rates and pressure information can be found in the technical specifications provided by the manufacturer (Table 1). Operating sprinklers outside of the manufacturer-provided guidelines will result in poor distribution uniformity that lowers irrigation efficiency.

Table 1. Example of a technical specifications chart for a spray nozzle with matched precipitation rate (MPR) and 14 ft maximum radius.

Nozzle	Arc	Pressure (psi)	Radius (ft)	Flow (gpm)	Square Precipitation Rate (in/h)	Triangular Precipitation Rate (in/h)
Quarter	90	15	11	0.5	1.59	1.84
		20	12	0.62	1.66	1.91
		25	13	0.76	1.73	2.00
		30	14	0.94	1.85	2.13
Half	180	15	11	1	1.59	1.84
		20	12	1.24	1.66	1.91
		25	13	1.52	1.73	2.00
		30	14	1.88	1.85	2.13
Three Quarter	270	15	11	1.5	1.59	1.84
		20	12	1.86	1.66	1.91
		25	13	2.28	1.73	2.00
		30	14	2.82	1.85	2.13
Full	360	15	11	2	1.59	1.84
		20	12	2.48	1.66	1.91
		25	13	3.04	1.73	2.00
		30	14	3.76	1.85	2.13

The flow rate of a full zone, as opposed to a single emitter, is the summation of the flow rates for all sprinklers within the zone. For example, a turfgrass area measuring 15 feet by 30 feet is irrigated by six 15 Series MPR nozzles in a square spacing at a pressure of 30 psi (Figure 14). The four nozzles at the corners of the area provide 90-degree coverage, or a quarter circle, and the two remaining nozzles provide 180-degree coverage, or half circle. All sprinklers are spaced under head-to-head coverage.

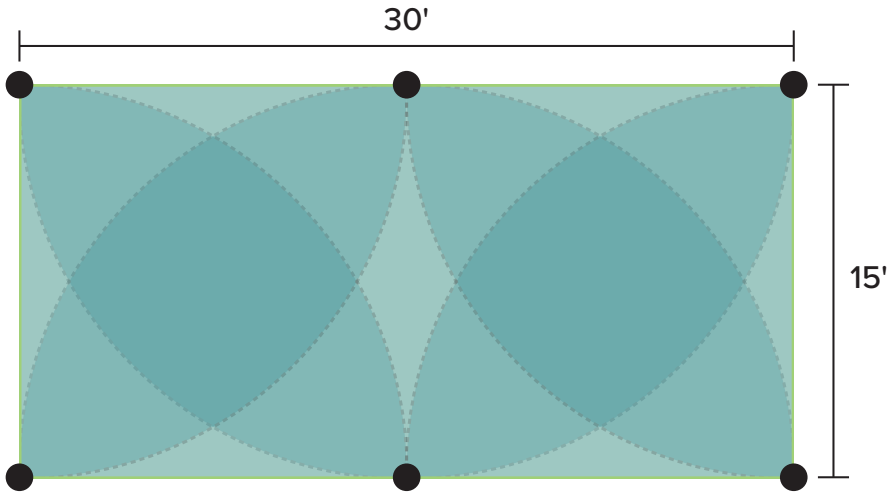


Figure 14. Example turfgrass area with four quarter circle and two half circle sprinklers with head-to-head coverage.

Using the chart in Table 1, the total flow rate required to operate the zone is:

Zone Flow Rate = 0.92 gpm * 4 quarter circle sprinklers + 1.85 gpm * 2 half circle sprinklers = 7.38 gpm

The available flow rate from the water source, measured by a flow meter or flow sensor, should be higher than the flow rate required to operate the zone. Though there are no specific limitations to the difference between the available flow rate and the flow rate required by the irrigation system, pressure restrictions exist for each irrigation system component and should be considered. If the supply pressure differs from the pressure ratings of the equipment, pressure regulation must be added to the design for proper operation.

The application rate is defined as the volume of water applied to a unit area and is calculated as the zone flow rate divided by the area of the zone. Additional conversions to account for measurement units may also be necessary. In this example, the application rate is:

Zone Application Rate = (Zone Flow Rate) / (Zone Area) (3)

Zone Application Rate = (7.38 gal/min) / (30 ft*15 ft) × (1 ft^3) / (7.48 gal) × (60 min) / (1 h) × (12 in) / (1 ft)

Zone Application Rate=1.58 in / h

The application rate for products with matched precipitation rates can be calculated using the expected flow rate of a single sprinkler divided by the area of the circle made by the sprinkler. Because this example utilized nozzles with matched precipitation rates, the application rate can be found in Table 1 without the need for calculation.

PLANT TYPE

A majority of the plant material used on a golf course is turfgrass, but other plants such as flowers, shrubs and trees may be placed in strategic areas of the course for aesthetic reasons. Plant selection is an important aspect in considering the irrigation requirements of a diverse landscape for long-term success. The plant type contributes to estimations of water losses and the root depth that defines the soil profile.

For irrigation purposes, plant selection affects the estimated amount of water exiting the soil profile through evapotranspiration. Evapotranspiration is defined as the transfer of water from the soil profile to the atmosphere through the combined processes of evaporation from the soil surface and transpiration through the plant (Figure 15). Therefore, differences in rooting depth of plant species affects accessible water within the soil profile. The typical process for estimating evapotranspiration for a specific plant includes calculating reference evapotranspiration [ET_O] from local weather data and applying a crop coefficient [K_C] to adjust the reference value to a plant-specific value, termed crop evapotranspiration [ET_C].

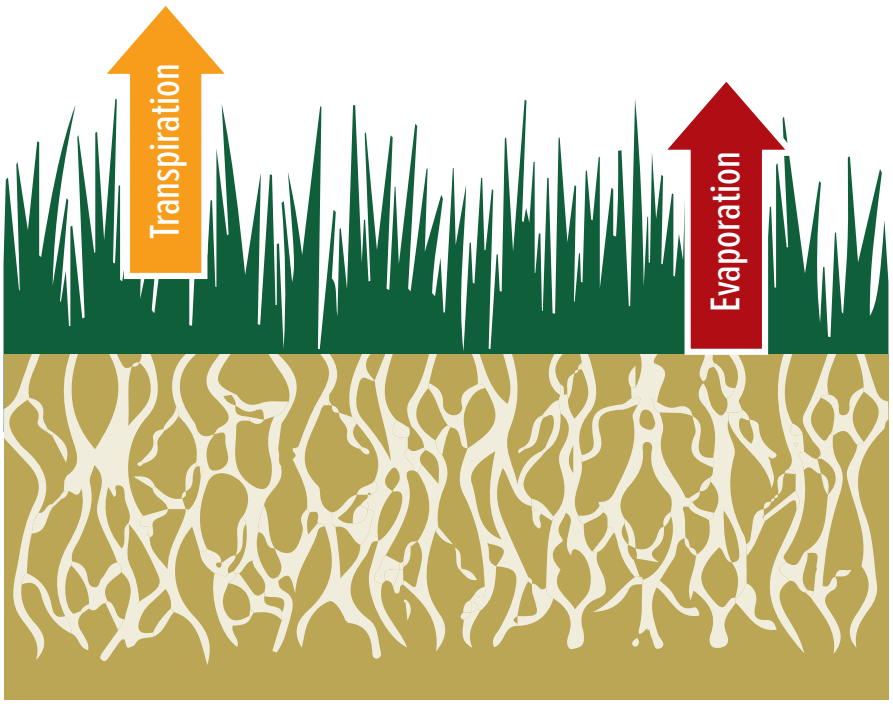


Figure 15. Landscape evapotranspiration represents the combined evaporation from the soil surface and transpiration from the plant material in a landscape system. Transpiration is the dominant term in dense plant materials such as turfgrasses but becomes much more important in mixed-ornamental landscapes.

There are many different equations for estimating ET_O. The preferred method is The ASCE Standardized Reference Evapotranspiration Equation that was published by the American Society of Civil Engineers (ASCE, 2005). This standardized equation is the most accepted form, but accurate estimation requires a regularly maintained and properly installed local weather station that collects air temperature, relative humidity, solar radiation and wind speed at either 6.5 feet or 10 feet above the ground surface. The plant material grown around the weather station, typically a turfgrass, should be cut to maintain a 4.7-inch height and extend for a minimum of 328 feet in all directions around the station without obstruction. The turfgrass should be well-watered on well-drained soil. In some cases, meeting all the requirements for siting a weather station in urban landscapes or naturally difficult terrain may be impossible. Efforts should be made to select a site that best approximates the requirements instead. Alternative equations for estimating ET_O may be more appropriate when there is limited weather data of good quality (e.g., Hargreaves Equation requires temperature only), but long-term deviations without appropriate corrections to the crop coefficient may result in inaccurate estimations of irrigation demand. Many weather networks automatically calculate ET_O from weather data and provide the value directly.

The K_C is defined as the long-term average ratio of ET_C to ET_O of a well-watered plant. Based on this definition, the K_C is used as an adjustment from a generalized ET_O value to the estimated plant water needs of the specific plant species. Thus, each plant material has its own K_C that fluctuates with seasonal variation and growth stage. Once the K_C values are known, they can be used to calculate ET_C using the following equation:

$$ET_C = K_C \cdot ET_O \quad (4)$$

The K_C values are normally provided as monthly averages for perennial crops such as turfgrasses (Table 2). Also sometimes called a plant factor, an annual average K_C can be utilized when monthly values are not available. The recommended annual average K_C is 0.6 for warm-season turfgrasses and 0.8 for cool-season turfgrasses according to ANSI/ASABE S623.1 (ASABE, 2017). The K_C values for annuals follow the normal growth curve with limited transpiration immediately after planting, rapid growth during the development period, and reduced productivity at maturity until senescence but can be approximated by an annual average of 0.8. Woody and herbaceous perennials grown in a wet climate such as Louisiana and Mississippi should begin with a K_C of 0.7.

Table 2. Examples of monthly K_C values for warm-season turfgrasses estimated from various methodologies and locations.

Month	North Central Florida[1]	North Carolina[2]	California[3]
January	0.35	NI[4]	0.61
February	0.35	NI	0.54
March	0.55	NI	0.76
April	0.80	NI	0.72
May	0.90	0.44	0.79
June	0.75	0.59	0.68
July	0.70	0.57	0.71
August	0.70	0.53	0.71
September	0.75	0.57	0.62
October	0.65	0.51	0.54
November	0.60	NI	0.58
December	0.45	NI	0.55

[1]Values were calculated using the Eddy correlation method and bahiagrass (Jia et al., 2009).
[2]Values were calculated using weighing lysimeters and hybrid bermudagrass (Pinnix and Miller, 2019).
[3]Values were calculated using unknown methods as an average across common bermudagrass, zoysiagrass and St. Augustinegrass (Meyer et al., 1985).
[4]NI=Not Irrigated

In addition to the growth stage, the K_C varies based on weather conditions (i.e., seasonal fluctuations, low moisture holding capacity of the air in humid climates) and soil type (i.e., heavy textures require more energy from the plant to transpire the same amount as light textures). Crop coefficients specific to Louisiana are not readily available for most plants but can be approximated from other sources. When trying to identify crop coefficients for the Midsouth, efforts should be made to select values from humid regions with similar soil types, if possible.

Sometimes, the designation of ET_C is exclusively used for agricultural crops and does not represent horticultural plant material. Instead, the calculation is expressed as landscape evapotranspiration [ET_L]:

$$ET_L = K_L \cdot ET_O \quad (5)$$

Under this expression, the landscape coefficient [K_L] can be affected by plant species as K_C, plant density [K_d], stress [K_s], and microclimate [K_{mc}].

$$K_L = K_C \cdot K_d \cdot K_s \cdot K_{mc} \quad (6)$$

The K_d is equal to 1 in healthy turfgrass systems and estimated as generalized percentages for mixed-ornamental landscapes (i.e., 25%, 50%, 75%, 100%). The K_{mc} is also generalized as percentages based on amount of sunlight with 100% indicating full sun. The K_s is used to decrease long-term averages when soil moisture is limited. If good irrigation scheduling leads to a well-watered plant material, the Ks equals 1 for all species.

SOIL TYPE

The soil type is an important factor in determining the amount of storage available within the root zone. Every soil profile consists of air, water, and the particle itself. The available water holding capacity [AWHC] of a specific soil profile is affected by both texture and structure.

The ***soil texture*** is a classification of the soil type by the size and quantity of the soil particles present within a representative portion of the root zone. A few classification standards exist for various purposes, but the standard used for agricultural applications is the U.S. Department of Agriculture soil textural triangle (Figure 16). Each texture has its own AWHC characteristics that can be used in the beginning of parameterization with adjustments for site-specific situations over time. Most soil testing laboratories provide the percentages of sand, silt and clay within the results provided to the client.

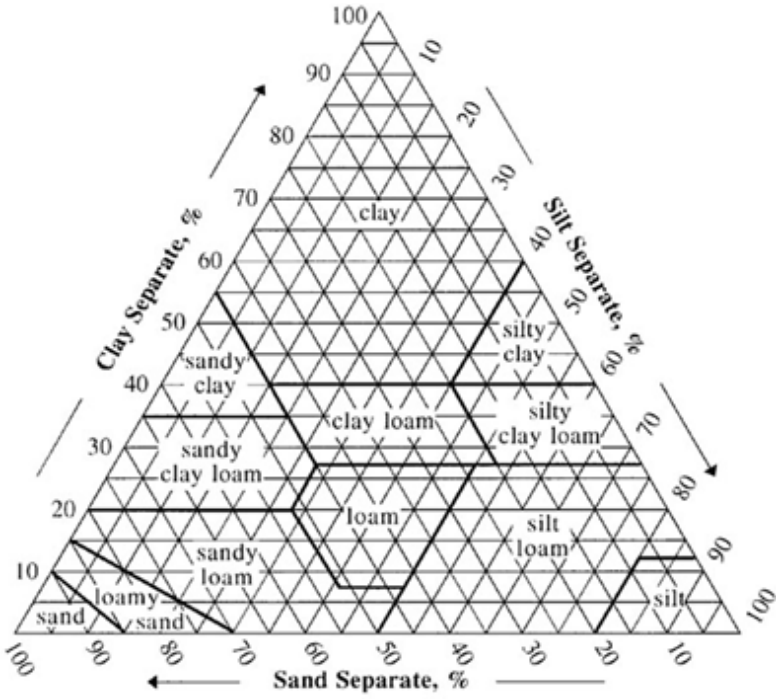


Figure 16. The USDA soil texture triangle can be used to classify soils based on the distribution of particle sizes within a representative soil sample (USDA NRCS, 2020).

The ***soil structure*** refers to the orientation of the soil particles within the profile. Effort should be made to either construct or maintain a well-structured soil for optimum plant health. Situations that result in deviations from the expected soil structure of a specific soil texture can lead to differences in parameterization of AWHC. Common examples of soil structural issues that reduce AWHC include compaction and tillage. However, following best management practices for a healthy landscape can build organic matter [OM], which is the best option for improving soil structure and increasing AWHC.

In the landscape, the soil is three dimensional with a specific volume associated with each component. However, volumes require a known area for interpretation. For example, an irrigation application of 500,000 gallons would result in vastly different amounts of water in the soil profile when applied to 2,000 square feet as opposed to 20,000 square feet. As a result, many terms related to irrigation are described as volume per unit area, which results in a depth, or as a volumetric percentage of the total. Depth and volumetric percentages are comparable and translatable across a variety of landscapes and can be used interchangeably with a known root zone depth.

Each specific soil profile has three thresholds that help to define AWHC: saturation [S], field capacity [FC] and permanent wilting point [PWP] (Figure 17).

Saturation is achieved when the soil profile contains only water and soil particles but no air. This amount of moisture can reduce ET_C and stress the plant material if maintained for too long. Saturation is not a naturally sustainable level of moisture; drainage due to gravity occurs when the downward forces created by water weight exceeds the surface tension forces holding the water within the pore space.

The maximum amount of water held by the soil without drainage due to gravity is called ***field capacity.*** This moisture level is the target for irrigation applications. Irrigating beyond field capacity is a waste of water resources that directly translates to an unfavorable financial burden.

Permanent wilting point is the minimum amount of water that can be stored within the soil profile. The water present at this moisture level adheres to the soil particles through surface tension. Additional energy beyond what can be provided by the environment is needed to remove the remaining moisture at PWP (i.e., oven drying).

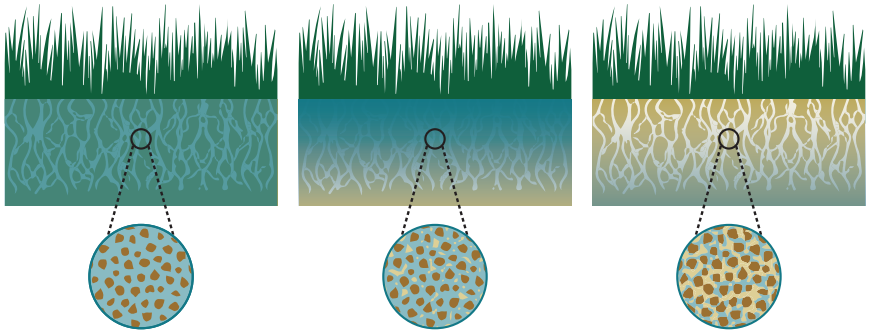


Figure 17. Visualization of (left to right) saturation, field capacity, and permanent wilting point from the root zone of a turfgrass.

The AWHC is the amount of moisture that can be stored within the soil. It is calculated using FC and PWP when both terms are expressed as a volumetric water content using the following relationship:

$$AWHC = FC - PWP \quad (7)$$

The plant available water [PAW] represents the AWHC when expressed as a depth of the soil profile or root depth (RD). The PAW can be calculated as:

$$PAW = AWHC \times RD \quad (8)$$

The PAW depletes as ET_C leaves the soil profile. Reaching PWP is an undesirable outcome as most plant material cannot fully recover from such deficit moisture conditions. As a result, a maximum allowable depletion [MAD] is used as a threshold for triggering an irrigation event. The MAD is selected based on the overall water requirements of the plant material, but usually ranges from 40%-60%. In other words,

$$RAW = PAW \times MAD \quad (9)$$

The depletion occurring from FC to MAD is called readily available water [RAW]. Once RAW is fully depleted, irrigation should be applied to maintain a well-watered landscape. If soil moisture falls below MAD and deficit occurs, the K_s is enacted to represent the difficulty in removing water from the soil by the plant using the following relationship:

$$K_s = (SWL_i - PWP) / (MAD - PWP) \quad (10)$$

Microclimate

Microclimates can be described as the situational considerations to a localized area such as an irrigated zone that affects climatic parameters associated with ET_C and ultimately changes the irrigation requirement. The climatic parameters associated with the calculation of ET_C include solar radiation, relative humidity, temperature and windspeed. For example, a small turfgrass area within a major city, surrounded by buildings and concrete structures, may experience increased temperatures compared to measurements from a local weather station due to the heat island effect. Similarly, elevated greens in open areas will have very different microclimate considerations than surface-level greens located near tree lines.

Though any of these parameters can possibly affect the irrigation requirement, solar radiation is the primary parameter under consideration for microclimate adjustments. The amount and strength of sunlight received throughout the daytime hours can greatly impact the amount of ET_C from the irrigated area. As a result, K_{mc} can also be referred to as the sun/shade factor by some industry professionals.

In general, warm-season turfgrasses prefer six to eight hours of sunlight per day. In situations where this preference is being met, the K_{mc} should equal 1 (or 100%). Conversely, the K_{mc} should be less than 0.25 (or 25%) for areas where plant material receives little to no sunshine, such as in breezeways or directly against the northside of a building. Areas that receive partial shade across the entire zone resulting in less than six to eight hours of sunlight will fall somewhere between 0.25 and 1. Zones that have multiple microclimates should use a K_{mc} that represents either the conditions of the largest representative area or the area affected the most by over or under irrigation. Though this situation frequently exists, proper hydrozoning will alleviate issues with mixing microclimates.

Slope

Adjusting irrigation events for slope considerations affects how irrigation is scheduled and not the amount applied. Irrigating large slopes in one long event can exceed the infiltration rate of the soil and cause surface runoff. Instead, these irrigation events should be broken into short and frequent applications of water with significant time between events to allow for infiltration. This practice is called cycle/soak where cycle time refers to the shorter irrigation event and soak time refers to the wait time between cycles.

There are no scientific standards for determining cycle/soak times. It is recommended that once the total runtime is calculated, this total can be broken into two to three irrigation cycles with 30-60 minutes between each cycle for soaking. Then, these times can be refined by trial and error to minimize surface runoff.

Soil Water Balance

The soil water balance is an irrigation scheduling methodology that accounts for factors that affect water moving in and out of the active root zone (Figure 18). This method is also called the checkbook method due to its resemblance to balancing a checkbook with deposits and withdrawals. This approach can be as simple or complicated as the manager desires and is most appropriate when there is access to reputable daily reference evapotranspiration (ET_O) and rainfall values. The most basic form of this method can typically get managers in the ballpark for needed irrigation events, which is an improvement from making an uninformed decision.

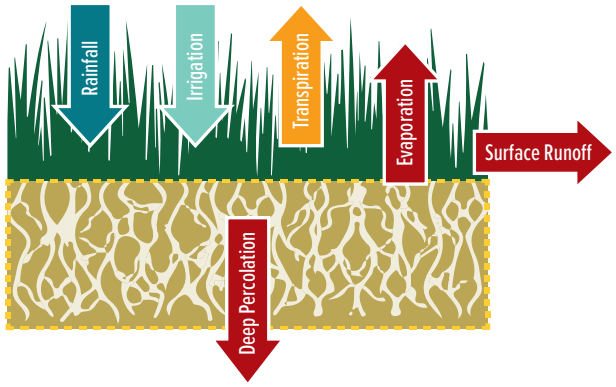


Figure 18. A soil water balance is an accounting method for keeping track of water movement in and out of the root zone, indicated by the dashed yellow line.

The soil water balance is the process of keeping track of the parameters that affect water movement within the root zone using the following equation:

$$SWL_i = SWL_{i-1} - ET_C + R_T + I_N - P_d - RO \quad (11)$$

SWLi = Soil water level on day i

SWL_{i-1} = Soil water level on day i-1

ET_C = Crop evapotranspiration

P_d = Deep percolation

I_N = Net irrigation

R_T = Total rainfall

RO = Surface runoff

The SWL on the first day is chosen based on field conditions at the time of planting. In humid environments such as Louisiana and Mississippi, calculations can begin at FC approximately one to two days after a substantial rainfall or irrigation event. Each subsequent day after the first day, the SWL is calculated using Equation 11. Total rainfall is a measured value that can be obtained directly with an onsite rain gauge or estimated from a local weather source. If irrigation is scheduled to replace soil moisture lost from ET_C only, then deep percolation and surface runoff can be estimated as zero for ease of calculation.

Irrigation is scheduled when the SWL_i reaches MAD and RAW has been depleted. Irrigation can be classified into three different terms: gross irrigation (I_G), net irrigation (I_N), and effective irrigation (I_E). Gross irrigation is the total amount of water applied to meet the irrigation requirement while taking distribution and conveyance inefficiencies into account using distribution uniformity. Net irrigation is the amount of water needed to increase the soil moisture to FC using a perfect irrigation system. In other words,

$$I_N = I_G \times DU_{lh} \quad (12)$$

Effective irrigation is the portion of I_N that enters the root zone. If irrigation is scheduled and applied appropriately, net irrigation and effective irrigation are the same. However, specific circumstances can result in surface runoff or deep percolation despite storage availability within the soil profile, decreasing effective irrigation. In general, these actions are controllable factors that can improve effectiveness with best management practices.

In addition to the factors in Equation 11, a soil water balance requires the following information:

- Soil physical characteristics – Provides suggested values for field capacity, permanent wilting point, maximum allowable depletion and maximum root depth.
- Variety-specific crop information – Aids in determining irrigation needs based on crop growth stages by utilizing crop coefficients and growing season length
- Weather conditions – Adjusts for field condition changes such as rainfall
- Initial moisture conditions – Sets the threshold for triggering irrigation and initial moisture in the soil on day No. 1.

A weakness of the soil water balance is that the components are estimated and not directly measured from the landscape. For example, if 2 inches of total rainfall were measured, it can be difficult to determine how much rainfall infiltrated the root zone and can be considered usable to the plant. These deficiencies can be overcome with experience or by using more sophisticated approaches such as smart irrigation technologies. The best time to verify a soil water balance is after an intense rainfall that results in soil moisture achieving field capacity or higher. The soil water balance should predict maximum soil moisture on that day.

As with any model, it is important to start with accurate inputs to receive informative and usable output. If real-time information is not readily available for your landscape, long-term average values can be substituted. For best results, the soil water balance can be managed using a spreadsheet. Some examples of currently available tools were developed by Michigan State University and Purdue University.

Once the depth of required irrigation is estimated, it can be used in combination with the zone application rate [AR] to calculate the runtime [RT].

$$RT = I_G / AR \times (60 \text{ min}) / (1 \text{ h}) \quad (13)$$

This RT can be programmed into the control device for each zone using the zone application rate.

SMART IRRIGATION TECHNOLOGIES

Smart technologies were designed to help an irrigator make good irrigation scheduling decisions based on plant water needs.

Current smart technologies include weather-based irrigation controllers [WBIC] and soil moisture sensor [SMS] systems. Both technologies vary in functionality and complexity, but no smart technology can fix a poorly designed or nonfunctional irrigation delivery system. In fact, the additional irrigation efficiency achieved by utilizing one of these technologies can exacerbate already existing issues such as hot spots if steps are not taken to correct existing irrigation equipment deficiencies.

SOIL MOISTURE SENSORS

All SMS products include a sensor buried in the root zone of the soil profile that estimates the amount of available moisture. Most SMS provide direct feedback of soil moisture conditions and can bypass unnecessary irrigation events. Some products can be used to turn each zone on or off to maintain a specific moisture range over time. Additionally, some SMS products include a sensor controller as an intermediary communication tool between the sensor and irrigation controller.

There are many different types of sensors on the market with a large range in accuracy and capabilities for consideration. The two basic methods for describing soil moisture are soil water potential and volumetric water content.

Soil water potential represents the energy associated with the forces holding water in the soil that must be overcome by the plant. As the soil begins to dry, soil water potential increases as a negative pressure. As the soil becomes wet from rainfall or irrigation and soil water content increases, the soil water potential approaches zero. The primary benefit to utilizing a soil water potential sensor is that the values for saturation (0 cb), FC (10-30 cb), and PWP (1500 cb) are consistent across all soil types. However, MAD is dependent on soil type and should be selected based on how water moves through the soil profile.

The most popular soil water potential sensor is the Watermark (Irrometer Company, Inc., Riverside, California). This solid-state sensor uses a pair of electrodes embedded in a granular matrix that measures electrical resistance. The measured resistance value correlates to soil water tension. These sensors are most beneficial in soils that create a tight seal with the sensor, such as in soils with high silt content. However, they are not recommended in sandy soils because of the potential for poor contact between the sensor and soil and in shrink-swell soils as the soil can pull away from the sensor throughout the irrigation season. Additionally, accuracy of resistance sensors is highly affected by soil temperature and salinity; they may require frequent calibration. Various products utilize this sensor as part of their own product (Figure 19).

A)



B)



*Figure 19. Example of A) a sensor that measures soil water potential and B) a sensor controller added onto a basic irrigation controller. (**Photos courtesy of Hunter Industries Incorporated).***

Typically, these sensors must be soaked in water and dried prior to installation so that the sensor experiences a large moisture range. Also, installation should include using a soil slurry and the slurry should be allowed to equilibrate to the surrounding soil conditions before controlling irrigation. The instructions for installing a soil water potential sensor should be followed explicitly.

Volumetric water content sensors primarily rely on a measurement of the relative permittivity, or dielectric constant, to estimate soil moisture. Relative permittivity is the factor by which the electric field decreases between two charges relative to a vacuum. While many soil components (minerals, nutrients and air) contribute to relative permittivity of soil, the permittivity of water is substantially higher than any other component; thus, it can be assumed that major shifts in these numbers are due to fluctuations in soil moisture. Changes in soil moisture can be indirectly estimated as the change in relative permittivity when measured from within the soil profile.

Multiple variations exist for sensor methodology in estimating volumetric water content. Below describes some of the most popular options available (Figure 20).

Time domain reflectometry [TDR] – This sensor correlates the travel time of an electrical energy wave along a specific transmission line to the amount of water in the soil. In most cases, the transmission lines are metal rods in duplicate or triplicate. These sensors are the least responsive to salinity because they utilize a range of frequencies in the signal to help reduce error.

Time domain transmissometry [TDT] – This sensor has the same methodology as the TDR, but the transmission lines are metal loops instead of rods.

Frequency domain reflectometry [FDR] – The most frequently used capacitance sensor, they create an electrical circuit between two metallic rings with opposite charges while using the soil as a capacitor between them. The sensor relates resonant frequency to volumetric water content. Because these sensors utilize an electric field that can transcend physical limitations, they are housed inside a plastic tube or barrier for ease of installation.



Figure 20. Examples of TDR sensors. ***(Photos courtesy of Acclima, Inc.)***

These sensors provide a volumetrically based value for estimated soil moisture as a decimal or percentage. Multiplying this value by the root zone depth will provide an estimated depth of water within the root zone that can be directly compared to depths estimated with the soil water balance. For example, a 12-inch root zone depth with a volumetric water content of 25% would equal 3 inches of water within the soil. However, soil moisture readings are only representative of the area immediately around the sensor; this should be taken into account when calculating a depth. A sensor located within the top six inches of the soil profile would not directly represent soil moisture at a 20-30-inch depth. Also, interpretation of volumetric water content is highly dependent on the soil type. Thus, FC, MAD and PWP must be known or estimated prior to using a sensor of this measurement type.

These volumetric water content sensors work consistently across many soil types and textures with less need for calibration compared to resistance methods that estimate soil water potential. Caution should be used on shrink-swell clays as the loss of contact between the sensor and soil can produce inaccurate readings. Installation should occur in an undisturbed soil column, if possible, and all installations should follow the manufacturer instructions. In addition to soil moisture, additional measurements such as soil temperature and electrical conductivity can be incorporated into certain sensor technologies.

Typically, sensors are most effective when permanently installed and directly connected to the irrigation system. If exploring wireless sensor technology, much effort should be placed in ensuring that site-specific considerations do not affect communication. Many times, communication requires line-of-sight between the sensor and the communication hub. Trees, shrubs, sloping landscapes, buildings or other structures can restrict or prevent access to the data. Another alternative with less permanency within the landscape are portable soil moisture sensors. These devices are advantageous for the hands-on irrigation manager who prefers less automation to irrigation decisions, but the difference in accuracy between resistance and capacitance sensors still applies with these portable devices.

Quantifying available soil moisture can be used as an independent irrigation scheduling tool or included in the soil water balance to overcome the challenges associated with estimating effective irrigation and effective rainfall. These technologies will continue to evolve with new technologies and advancements.

WEATHER-BASED IRRIGATION CONTROLLERS

The WBIC category of products is the most diverse on the market. All WBICs utilize estimations of ET_O to aid in irrigation scheduling, but products vary in how ET_O is collected and used. The following generally summarizes many types of products currently available, but given the wide range, these descriptions may not fit all products relatable to the category.

Historical – This type of WBIC uses historical monthly ET_O estimations to seasonally adjust irrigation application throughout the year. These values can be provided by the user or determined using latitude and/or ZIP code.

Standalone – These WBICs utilize on-site weather data to calculate daily ET_O. In addition to the controller, a weather data collection device must be installed in a representative location. Though some utilize full weather stations, many products offer compact weather monitors that provide an abbreviated estimation of ET_O using an alternative equation than the ASCE standard.

Signal-based – The ET_O is estimated from publicly-available weather data and broadcast to the controller. A company collects weather data based on the ZIP code programmed into the controller, calculates ET_O, and pushes it out daily. In most cases, this type of WBIC requires a monthly or annual payment for cellular service.

Wi-Fi – These controllers are the newest type of WBIC. They utilize weather data available from online sources to estimate ET_O while also adjusting irrigation days/times based on weather forecasting. The location is determined through the IP address associated with the Wi-Fi connection.

A majority of products conduct a proprietary version of the soil water balance to determine the irrigation day and runtime for each zone. As such, they must be programmed with information pertaining to plant type, soil type, sprinkler type, microclimate and slope. Just like any model, the success of an irrigation schedule determined by a WBIC is highly dependent on the information programmed into it. Parameterization of these devices should be completed by a knowledgeable irrigation professional or with help from cooperative extension services.

Alternatively, some products designed for regions that restrict irrigation to certain days of the week will maintain a running total of ET_O since the last irrigation event and schedule the entire amount each time. Also, many WBICs that utilize historical ET_O will still need to be programmed with a runtime for each zone that represents the hottest and driest time of year. These controllers use the historical ET_O values to automatically adjust the runtime for seasonal variation. However, they tend to perform poorly when adjusting irrigation in years where the weather patterns fall outside of the historical average.

Rainfall is one of the most important factors in irrigation scheduling. Given the humid nature of the Midsouth, any WBIC should

incorporate rainfall measured on-site independent of how the WBIC estimates ET_O.

MAKING A SELECTION

Selecting between weather-based and soil moisture-based technologies is primarily up to the preferences of the irrigation manager. Both types of technologies have options available at all price points. Thus, the benefits and limitations to each technology should be considered prior to investment.

In situations of terrain restrictions or inconvenient sensor installation, a weather-based technology may be the preferred option because it can be installed away from the irrigated landscape. However, weather-based systems tend to use the soil water balance with estimates of ET_O without real-time feedback from the root zone. Accumulations of error in estimations can become substantial over time but can be corrected with a large rainfall event.

Research by the University of Florida, also located in a rainfall-dominated climate, has shown that water savings by SMS systems ranged from 42% to 72% during normal/wet seasons and -1% to 64% during dry weather conditions (Cárdenas-Lailhacar and Dukes, 2012). Ranges were presented because not all sensor brands had the same accuracy. The WBICs averaged annual water savings of 43% in turfgrass research environments (Davis et al., 2009). However, multiple studies from across the United States have shown that the water conservation potential of WBICs highly depends on the use of a well-watered irrigation strategy (Davis and Dukes, 2014; Mayer and DeOreo, 2010). The WBICs can increase irrigation application when deficit strategies were in place previously. It is important for all smart technologies to be installed and programmed by someone who is knowledgeable about the technology and its features.

LICENSURE AND CERTIFICATION

The standards for golf course irrigation are set and maintained by the irrigation industry through the Irrigation Association (IA). In addition to IA's advocacy work, they strive to provide professional development such as training, certification and workforce development. The Certified Golf Irrigation Auditor (CGIA) certification teaches best management practices for auditing, conducting minor repairs and scheduling irrigation. The Certified Irrigation Technician [CIT] certification is ideal for in-house employees with installation, renovation, repair and troubleshooting responsibilities. At the very least, these certifications should be expected from contractors hired to perform these types of activities to ensure basic proficiency. You can find all six landscape certifications on the IA website.

In addition to IA certifications, the irrigation industry supports the United States Environmental Protection Agency's WaterSense Program. This program was designed to promote water-efficient products, programs and practices to protect future water supplies. Specifically for irrigation, WaterSense conducts product testing of WBICs and pressure-regulating spray bodies using a third-party testing lab. The testing specification for SMS is almost finalized. They also certify WaterSense partners, including irrigation contractors, that comply with their educational requirements on water efficiency. More information can be found on their website.

In Louisiana, irrigation contractors as well as in-house employees that work with commercial irrigation systems must hold an irrigation contractor license administered through the Louisiana Department of Agriculture and Forestry. The license is required for the supervisor of the project as an assumption that they will inspect the work of their technicians, but it is suggested that anyone interacting with an irrigation system receive a basic education. In addition to passing the exam, the contractor must provide proof of certificate of liability insurance with minimums of $25,000 per person for bodily injury and $50,000 per person for property damage. Once the license is obtained, the contractor must participate in six credit hours of continuing education within three years to maintain the license. LDAF has specific expectations for approving continuing education classes such as generalized content and total number of educational hours in addition to meals and breaks. The Louisiana Irrigation Association (LIA) provides the most opportunities throughout the year for continuing education. Those interested in obtaining the license or sending their employees for additional education should consider an LIA course. Local distributors and manufacturers of irrigation products also occasionally hold approved recertification classes around the state.

There are no official regulatory or educational requirements for irrigation contractors that conduct work in Mississippi.

CONCLUSION

Best management practices for irrigation focus on the ability to achieve the highest irrigation efficiency possible while maintaining acceptable plant health. Best management can be achieved from a properly designed irrigation system with regular maintenance and a scientifically determined irrigation schedule.

The irrigation design should be completed by a qualified professional familiar with scientific principles in various areas such as hydraulics, electricity and agronomy. Selecting an irrigation professional certified by IA or partnered with WaterSense can help to ensure that the contractor is up to date on available irrigation methods, products and technologies through their continuing education requirements.

There are many products, instruments, and tools that can aid with proper irrigation scheduling. The variety of available technologies can make it difficult to choose the best and most cost-effective methods. Tools that are flexible and provide more detailed information are often more costly, whereas tools that may be more economical initially, quite often have limited utility and accuracy. When selecting any combination of irrigation scheduling tools, it is essential that the tools and technology are compatible with the intended goals of the production system and the irrigation manager.

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NOMENCLATURE REFERENCE LIST

Abbreviation	Name	Common Units	Description
AR	Application rate	Inches per hour	The volume of water applied to a unit area over a certain amount of time.
AVB	Atmospheric vacuum breaker	---	Type of backflow prevention device.
AWHC	Available water holding capacity	%	Amount of available storage space in the root zone.
DUlq	Lower quarter distribution uniformity	Unitless	Method to estimate the uniformity of the distribution of water for a zone, typically measured using catch-can testing.
DUlh	Lower half distribution uniformity	Unitless	Method to estimate the uniformity of the distribution of water for a zone when the lower quarter calculation is too low.
ET_C	Crop evapotranspiration	Inches	Evapotranspiration from the crop.
ET_L	Landscape evapotranspiration	Inches	Evapotranspiration from the landscape.
ET_O	Reference evapotranspiration	Inches	Evapotranspiration from a reference crop that is used to estimate ETC or ETL.
FC	Field capacity	%, inches	Maximum amount of water by volume that can be stored in the soil profile without drainage due to gravity.
i	Interval	Days	Indicator for timestep in scheduling calculations.
ID	Inner diameter	Inches	Measurement of the inside of the pipe's cross section.
I_G	Gross irrigation	Inches	Depth of irrigation required after taking efficiency into account.
I_N	Net irrigation	Inches	Depth of irrigation needed within the soil profile.
K_C	Crop coefficient	Unitless	Long-term average ratio of ETC to ETO.
Kd	Density coefficient	Unitless	Adjustment factor for low density plantings when calculating ETC or ETL.
KL	Landscape coefficient	Unitless	Long-term average ratio of ETL to ETO.
Kmc	Microclimate coefficient	Unitless	Adjustment factor for amount of sun or shade when calculating ETC or ETL.
Ks	Stress coefficient	Unitless	Adjustment factor for when the plant material is not considered well-watered.
MAD	Maximum Allowable Depletion	%	Portion of soil water that can be depleted before triggering irrigation.
MPR	Matched precipitation rate	---	Designation indicating that sprinklers apply the same depth over the specified area for uniform applications.
MSMT	Multi-stream, multi-trajectory	---	Type of spray nozzle with uniformity benefits of a rotor.
OD	Outer diameter	Inches	Measurement of the outside of the pipe.
OM	Organic matter	---	Carbon-based material that improves AWHC.
PAW	Plant available water	Inches	AWHC expressed as a depth.
Pd	Deep percolation	Inches	Water that transitions to below the root zone.
PE	Polyethylene	---	Common material used for drip tubing.
PVB	Pressure vacuum breaker	---	Type of backflow prevention device.

Abbreviation	Name	Common Units	Description
PVC	Polyvinyl Chloride	---	Common material used for hard irrigation pipe.
PWP	Permanent wilting point	%, inches	Minimum amount of water stored in the soil and inaccessible by the plant.
RAW	Readily available water	Inches	Portion of PAW that can readily deplete before causing stress in the plant material.
RD	Root depth	Inches	Depth of soil profile that roots can access water.
RO	Surface runoff	Inches	Water applied to the landscape that does not enter the soil profile.
RP	Reduced-pressure principle backflow prevention assembly	---	Type of backflow prevention device for high hazard classifications.
RT	Total rainfall	inches	Depth of rainfall that fell to the ground.
RT	Runtime	Minutes	Length of time for applying irrigation.
S	Saturation	%	Maximum amount of water in soil profile by volume resulting in no air in void space and drainage due to gravity.
SMS	Soil moisture sensor	---	Device that estimates soil moisture in the profile.
SWL	Soil water level	Inches	Depth.
v	Volume	mL, inches	Measurement of volume in catch-cans. If area of the opening of each catch-can is identical, depth can be used instead.
WBIC	Weather-based irrigation controller	---	Type of controller that schedules irrigation for the irrigator based on weather conditions.
WT	Wall thickness	Inches	Difference between inner and outer diameter of the cross-sectional area of a pipe.

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