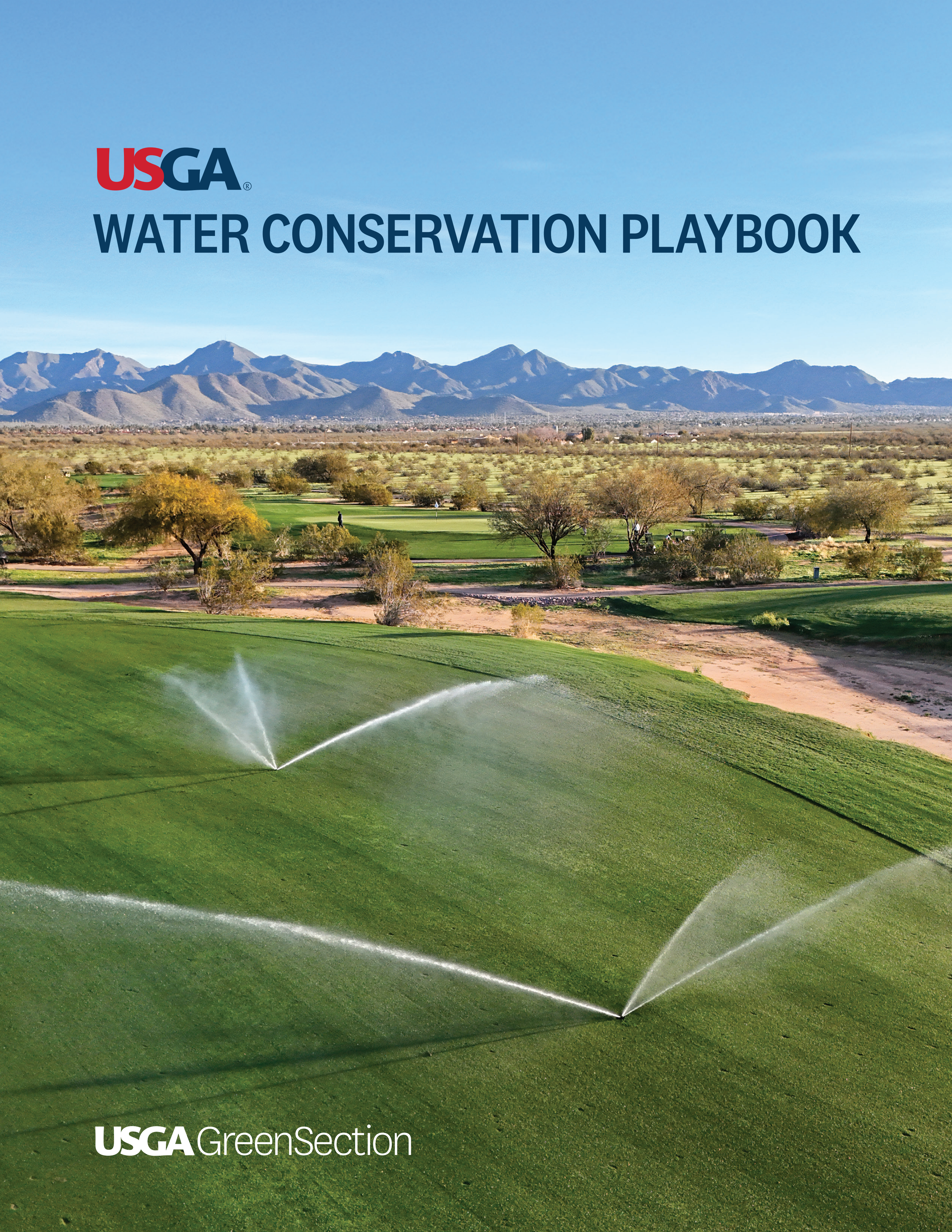
USGA

WATER CONSERVATION PLAYBOOK



USGA GreenSection

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Every Drop Matters

Golf courses cannot exist without water. Ideally, rainfall would provide what golf courses need but, even in wetter climates, rain rarely falls in the amount and frequency necessary to maintain healthy turfgrass or acceptable golf course playability. That is why almost every golf course relies on some form of supplemental irrigation. Applying irrigation in the right amounts, in the right locations, and at the right times is a critical part of successful golf course maintenance – but accomplishing these goals is not easy. There are many challenges in determining turfgrass water needs across potentially hundreds of acres, irrigation systems have limitations and staff time is always in short supply. Golfer expectations can complicate matters further. No matter how committed the superintendent is to using water efficiently, the reality is that balancing all these variables to provide a desirable product and minimize water use is difficult.

With that said, it is important to put golf course water use in context. Contrary to what many believe, golf courses are very efficient water users that represent a very small part of total U.S. water use. The U.S. withdraws nearly 365 million acre-feet of water per year, 37% of which is used for irrigation (USGS, 2015). Golf courses account for about 1.3% of irrigation water use in the U.S. annually, and total golf course water use has declined by almost 30% since 2005, mostly due to improved irrigation practices (Shaddox et al., 2022). However, there is no question that many opportunities exist for golf courses to use less water and there are many potential benefits in doing so.

WATER CONSERVATION IS IMPORTANT

Water is becoming more expensive and increasingly regulated, even in areas where it is relatively plentiful. In dry areas of the western U.S., the cost and availability of water for golf course irrigation poses an existential threat to many courses. Water budgets routinely exceed $1 million per year in places like California and Arizona, and even if courses have the money they may not have any say in their water allocation. Regardless of resources, the water supply for many courses in the West is vulnerable to factors like drought, population growth and politics that are totally outside a course's control.

Courses in wetter parts of the U.S. also face rising water costs and are vulnerable to the politics of water use in their area. Even if there is plenty of water available, that does not mean a golf course will necessarily be able to use it, or that their current access to water will remain the same going forward. Golf courses that normally get adequate rainfall are still vulnerable to drought, and increasingly extreme weather patterns may make longer and more-severe droughts more likely in many parts of the country. Population growth is another factor that affects water availability across the U.S. Fresh water resources are rightly prioritized for human consumption and food production, and recycled and low-quality water sources are being increasingly strained by growing towns and cities – even in places that get plenty of rain. Finding ways to use less water and be more-resilient to drought will be valuable for golf courses everywhere in the years ahead.

Even if water conservation is not a primary concern for a golf facility, more-precise irrigation translates to better playing conditions and healthier turf. Water use is also connected to many other inputs that are scarce and expensive across the golf industry. Irrigated turf must be mown, which requires fuel and staff time. Irrigated turf requires more pesticide applications than non-irrigated areas, which again translates into fuel, staff time and other costs. Using more water requires more pumping, which means higher electrical bills – and the list goes on. Something as simple as irrigating less turfgrass area within a golf course can reduce maintenance costs, increase environmental value and allow the maintenance team to focus scarce resources where they matter most.

THE PLAYBOOK

Since our founding in 1920, the USGA Green Section has advanced water conservation in golf with millions of dollars of research, a wide range of education offerings, and countless consulting engagements with golf courses. This playbook is simply the next step in our efforts to help golf courses optimize their watering and use less when it is possible or necessary. The playbook focuses on nine important water conservation strategies in three broad categories, and provides detailed information about the costs, benefits, limitations and steps for implementing each strategy. These focal areas were developed through a collaboration between university researchers, golf course superintendents and architects, and USGA agronomists and scientists with decades of experience in irrigation management and research. The categories and strategies are as follows:

Fundamental Irrigation Stewardship

Irrigation System Maintenance: Regular maintenance of sprinkler heads and system components to minimize leaks and imprecise watering.

The Effects of Chemical Applications on Water Use and Drought Resistance: Applying products with demonstrated ability to help golf courses improve water use and manage reduced irrigation.

Managing Golfer Expectations to Help Conserve Water: Informing the expectations of golfers, owners and members to balance playing conditions, aesthetics and water use.

Advanced Irrigation Techniques and Conservation Strategies

Site-Specific Irrigation Scheduling: Informing irrigation with data from soil-moisture sensors, weather stations and remote-sensing platforms to make improved irrigation decisions.

Grassing Strategies for Golf Course Water Conservation: Using drought-tolerant turfgrasses, reducing winter overseeding and exploring novel grassing schemes.

Reducing Irrigated Acreage: Decreasing the amount of irrigation by thoughtfully replacing unnecessary turf with low-water-use plants and landscaping.

Subsurface Drip Irrigation: Delivering water directly to the rootzone to improve uniformity and limit evaporation and wind drift.

Water Sourcing and Storage Stewardship

Surface Water Optimization: Reducing unnecessary surface water area and limiting evaporative or seepage losses from golf course lakes and ponds.

Using Recycled Water: Connecting to recycled water sources to reduce a course's reliance on potable and fresh water supplies.

A CHALLENGE

The strategies for water conservation laid out in this playbook range from fundamental to highly advanced. Some can be implemented immediately at low cost, whereas others require significant investment and years of planning. Which ones offer the most benefit for a particular golf course depends on water saving goals, resources available, location and many other factors. Most courses have probably implemented some of these strategies already, but there are always opportunities to do more. Improved turfgrasses, new technology and better irrigation management practices are constantly creating new ways for golf courses to use less water.

The golf industry faces many challenges when it comes to water use, but challenges create opportunities for meaningful change. Over the past several decades, many courses have completely transformed how they use water and realized significant benefits in playing conditions and their overall business. Continuing to advance water conservation in golf will require collaboration between superintendents, researchers, regulators, golfers and communities. It is a constant but necessary pursuit, and we hope this playbook will help.

REFERENCES

Shaddox, T. W., Unruh, J. B., Johnson, M. E., Brown, C. D., & Stacey, G. (2022). Water use and management practices on US golf courses. Crop, Forage & Turfgrass Management, 8(2), e20182.

SECTION 1

Fundamental Irrigation Stewardship

FUNDAMENTAL IRRIGATION STEWARDSHIP

Irrigation System Maintenance

Keeping up with routine irrigation system maintenance isn't easy, but it's a great way to save water and improve playing conditions. Basic tasks like leveling heads and checking arcs can have a big impact. (USGA/Steve Boyle)

SNAPSHOT

This strategy deals with properly adjusting and maintaining irrigation systems. It is a low-impact, low-cost strategy applicable to all golf courses.

Expected cost	< $25K per acre
Ease of implementation	Daily maintenance
Potential water savings for affected area	< 10%
Highest potential impact areas	Nationwide

OVERVIEW

A properly functioning and well-maintained irrigation system will use less water and last longer than a poorly maintained, inefficient system. In most parts of the U.S., it's virtually impossible to maintain golf course turfgrass in a playable condition throughout the year without an irrigation system. In fact, there are very few locations in the world where acceptable golf course turfgrass, particularly putting greens, can be maintained year round without supplemental irrigation. That makes irrigation system maintenance critical. Just like there are equipment technicians on staff to work on specialized golf course mowers, there must be staff time dedicated to caring for the vast and complex irrigation system and its components.

In most cases, the irrigation system is one of the biggest capital investments at a golf facility. A new system can cost $3 million to sometimes more than $5 million, depending on geographic location and system complexity. All irrigation systems – even the best – require constant maintenance and will become more prone to problems with age. Eventually they need to be replaced, but the cost of a new system often means that older systems are used far longer than superintendents would prefer.

Developing a preventive maintenance program is the best way to minimize the severity and frequency of problems and extend the life of a system, regardless of its age. It's also an important strategy to conserve water, reduce energy use and produce better playing conditions.

SCENARIOS FOR USE

The primary goal of irrigation system maintenance is to ensure water is applied to the playing surfaces as uniformly and efficiently as possible. The level and frequency of maintenance required depends on each component of the irrigation system, as well as the age and type of system. The golf course superintendent will typically determine a maintenance schedule for various system components such as pumps, controllers, sprinklers and nozzles, and they are ultimately responsible for the system's upkeep. Most 18-hole golf courses have at least one staff member who spends all or part of their time as an irrigation technician to diagnose and repair leaks, check sprinkler performance and perform myriad other irrigation-related duties.

In addition to routine maintenance and minor repairs, the superintendent, irrigation technician and others will scout for leaks around the course, watch the system run to check for proper operation and ensure sprinklers have correct nozzles, spray arcs and pressure. Occasionally, outside vendors may be needed for audits, major repairs, pump service, complex electrical issues, or emergency repairs during hot and dry weather.

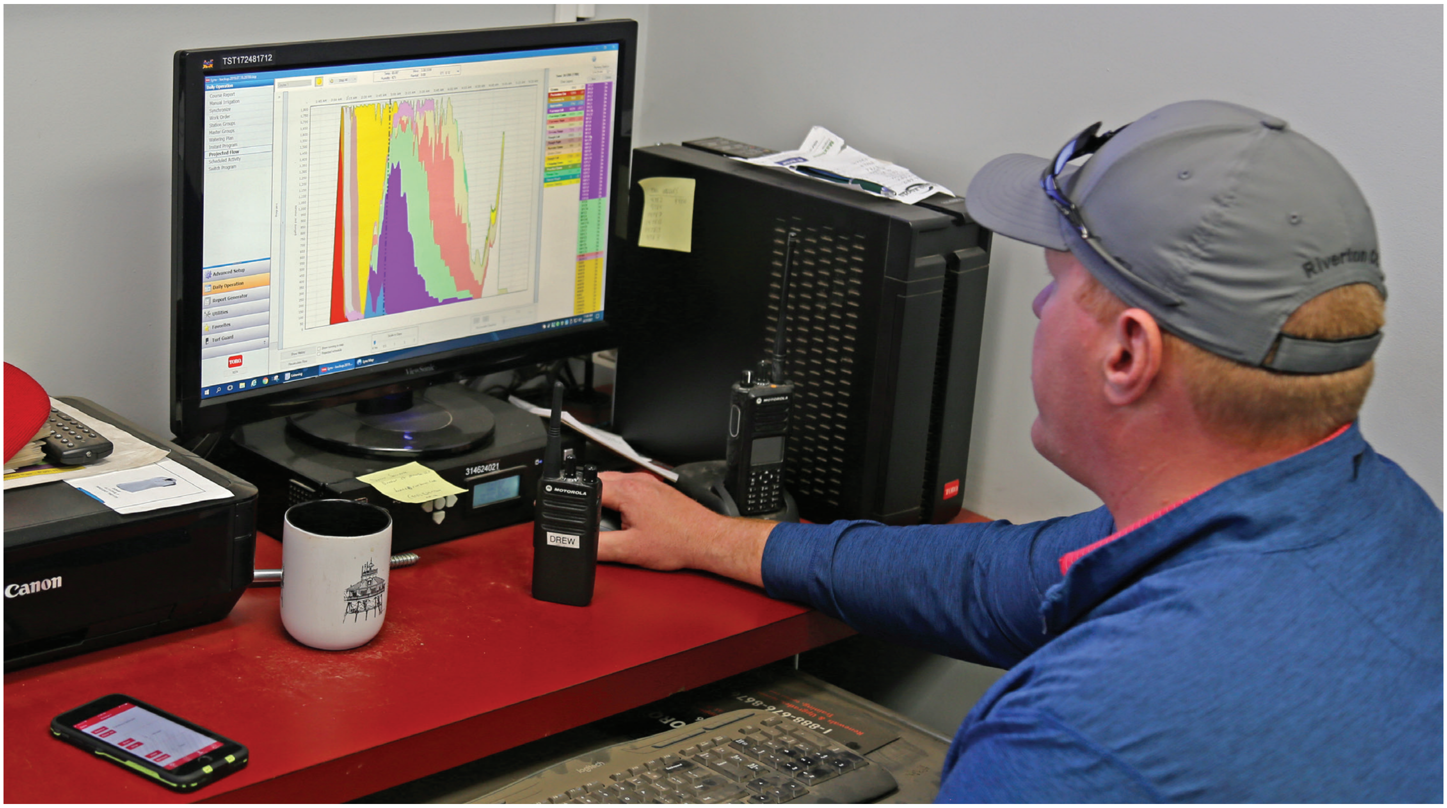
Basic tasks include regular inspection and adjustment of sprinkler heads, cleaning and replacing nozzles, and repairing minor leaks. Tasks that are more complex and require more time include irrigation audits, performing major repairs, and making system upgrades. Making significant changes to the design or configuration of the system goes beyond the subject matter covered in this chapter and typically requires the services of a professional design consultant and an irrigation contractor.

Ideally, a course will have a dedicated irrigation technician that spends most or all of their time making repairs and monitoring system operation. (USGA/JD Cuban)

Focus Areas

Every golf course with an irrigation system must perform regular maintenance. The irrigation system typically "begins" at the water source – e.g., at a well, potable or effluent water connections, an irrigation pond or other water sources. Maintenance of these components is important but usually less frequent than other parts of the system and typically requires the expertise of an outside company. Mainlines and lateral lines move a large volume of water around the course and maintenance is typically focused on repairing pipe breaks and malfunctioning or leaking valves. Wiring is a critical component of the system but typically doesn't require routine maintenance. If pumps and connections to water sources are where the system begins then sprinklers, couplers for hand watering and subsurface drip irrigation emitters are where the system ends. These all-important components are ultimately responsible for distributing water to the turfgrass and typically need the most maintenance – especially sprinkler heads.

Irrigation field controllers may be located around the course, while central control computers, if present, are usually in the golf course maintenance office to simplify irrigation scheduling. They can require occasional electronic troubleshooting and physical or structural maintenance. For example, field controllers can be damaged by lightning or falling branches. Central computer systems may require regular software updates and will also require proper programming of the distribution pipeline system. This is to avoid hydraulic issues that can lead to “pipe fatigue” from water hammer and dynamic (operating) pressure losses due to excessive flow rates (velocity of flow) as well as significant elevation changes on a property.



Along with maintaining irrigation system components on the course, it’s important to keep the information and software in the central irrigation controller up to date.

Site Specifics

Irrigation system maintenance is important for all golf courses, but there is some regionality and site specificity in the emphasis and focus areas. In arid areas like the southwestern U.S., water resources are limited and/or expensive. Incremental savings through maximizing the efficiency of the irrigation system can lead to especially meaningful water and cost savings in areas like this. Another example of regional variation is in colder climates where irrigation systems are winterized – a process where compressed air is forced through the system to remove all water and protect critical components from freeze damage. The process of shutting down and then restarting the system in these areas often requires considerable time and attention. In warmer climates, irrigation systems are used all year, which imposes greater wear and tear. Additionally, areas with recycled water or other water sources with significant suspended particulates may require more frequent maintenance to manage worn or clogged components such as nozzles and sprinklers, and internal components such as drive motors.

Opportunities To Expand Preventive Maintenance

Unfortunately, irrigation system maintenance is often lacking, which leads to inefficient water use. All too often, irrigation maintenance is limited to repairing obvious malfunctions like major leaks and broken components. This is understandable, considering current labor challenges and material costs, but deferred maintenance leads to water waste, worse playing conditions and bigger future problems. Opportunities for most courses to improve their preventive maintenance program include:

Perform audits: Golf courses should audit their irrigation system every couple of years. Audits help to identify inefficient water use, weaknesses in the system, a wide range of functional issues, and they help superintendents maintain a detailed record of maintenance and system performance over time. An audit does not have to cover the entire golf course to provide valuable information. At minimum we recommend auditing the putting green sprinklers and a representative sample of fairways. Covering more will provide more information, but also requires more investment.

Monitor moisture uniformity: Monitoring soil-moisture uniformity in key areas and tracking changes over time will identify opportunities to improve system function and use water more efficiently, especially where unusual topography and/or poor sprinkler performance might influence watering.

Proper training: Staff training and education will improve the team's overall knowledge and awareness of irrigation issues, which means that problems get identified and solved faster. At minimum, all staff should be able to identify unusually wet or dry areas and know to report these issues to someone who can take the next steps toward solving the problem. If certain staff members can be trained to perform basic repairs and maintenance, that reduces the burden on whomever is typically responsible for maintaining the system, freeing them to focus on larger problems.

System upgrades: Using new technologies and making system upgrades increases irrigation precision, reduces water use and improves playability. Even if a new irrigation system is not in the budget, there are many upgrades that can be made to improve the performance of an existing system. Incorporating soil moisture sensors, portable moisture meters and on-site weather stations can improve the quality of irrigation scheduling and save water. Improving coverage by adding/upgrading heads to increase control or address coverage issues is another type of upgrade that can be performed in-house when time allows and deliver meaningful improvement. Adding subsurface drip irrigation for bunker surrounds or tees can improve chronically dry areas.

Conducting irrigation audits on a regular basis is a good way to evaluate the system, identify issues and track changes in performance over time.

BENEFITS

Water Conservation

The amount of water that can be saved through regular irrigation system maintenance is variable and difficult to estimate. What is clear is that leaks, breaks or applying water where it is not intended to go wastes water. Some specific examples of the potential savings include:

Replacing nozzles and sprinkler heads: There is limited information on the benefits of replacing nozzles and sprinkler heads. In a study conducted several years ago, new nozzles reduced water use by 6.5% compared to old nozzles when averaged across six different golf courses in California (Zoldoske, 2003). Similar savings may exist when upgrading to new sprinkler heads depending on the current heads being used.

Adjusting sprinkler arcs: Observing sprinkler arcs to make sure each head is watering only the intended area can save a significant amount of water and will improve playing conditions. Part-circle heads often come out of adjustment. When they do, a significant percentage of their runtime may be spent watering the wrong area. Converting full-circle arcs to part circles to avoid overwatering an area is another example of how routine sprinkler adjustments can save water and improve playing conditions.

Leveling heads and removing obstructions: Raising and leveling heads, trimming turf around them and removing any obstructions that interfere with water thrown from the sprinkler are simple tasks that can save water and improve playing conditions. For example, heads around greens or near bunkers often become low as sand from topdressing or bunker shots accumulates in the turf around them. If they become low enough, water from the sprinkler will be blocked by the surrounding turf and won't reach its intended target area. When a sprinkler head is obstructed consider several options: if the obstruction is permanent (like a wall or tree) then relocating the head is advisable, if the obstruction can be easily removed or relocated (like a sign or low-hanging branch) leave the head in place and address the obstruction. Routine observation and maintenance can prevent or minimize these issues.

Scheduling: Water savings can also be achieved by using ET estimates or moisture sensor data to guide irrigation scheduling, rather than irrigating purely by "feel" or experience. In one study on bermudagrass, water savings of 29% was reported for ET-based scheduling and 39% for soil moisture sensor guided scheduling compared to scheduling purely in increments of time (Serena et al., 2020). Turning off or reducing the runtime of sprinklers in wet areas is another example of how scheduling adjustments can save water.

Turf growth, topdressing and sand splash from bunkers can elevate the surface around sprinkler heads. Low heads eventually need to be raised to ensure proper water distribution.

Improved Playing Conditions

Delivering the right amount of water to the right locations is essential for maintaining quality turf and the desired playability. Wet and dry areas around a golf course are frequently caused by a lack of irrigation system maintenance and they can lead to poor conditions and unhappy golfers. Beyond the playability and turf health impact of obvious issues like leaks, minor adjustments like trimming the turf around sprinklers and checking sprinkler arcs can make the difference between good and excellent conditions, especially on high-profile surfaces like putting greens and approaches. Achieving uniform moisture content and water distribution will lead to better and more-consistent playing conditions, improving the golfer experience.

Maintenance Efficiency

Irrigation system maintenance improves the efficiency and quality of the entire maintenance operation. For example, if sprinklers are not functioning properly, dry areas may require time-consuming hand watering. Wet spots may limit mowing with larger equipment and force the maintenance team to use smaller machinery that is slower and less efficient. Wet areas can also lead to fungal disease and turfgrass death. If dry and wet areas lead to turf decline, valuable staff time may be spent on regrassing projects that could have been avoided. Sprinklers that are out of adjustment can throw water into naturalized areas, causing excessive growth that must then be managed. Leaks cause pumps to cycle on and off more frequently and are wasteful of both water and electricity. Unexpected repairs due to poor maintenance can upend a superintendent's course maintenance plans for the day and negatively impact golfers. A well-maintained irrigation system minimizes these and other similar issues – allowing the staff to operate more efficiently and effectively.

If sprinklers throw water where they shouldn't, that usually means more work for the maintenance team.

CONSIDERATIONS

Lack of Awareness

Unfortunately, the simplicity of regular irrigation system maintenance can lead to a perceived lack of importance. There is a general lack of awareness and understanding about the potential risks of deferred irrigation system maintenance. There also is a general resistance to change in favor of sticking with traditional methods and old components that at least appear to be still functioning. Often the mindset is: "If it is not broken, don't fix it."

Technical Unknowns

There is uncertainty around how the aging of an irrigation system affects the performance of components. It is also difficult to estimate the amount of water that could be saved with improved maintenance. A typical golf course maintenance operation is continually addressing problems with the irrigation system. However, when routine upkeep is abandoned for several years, the decline in system performance can be significant. The useful life of individual components is affected by environmental conditions, amount of use, water quality, level of preventive maintenance, and quality of the original construction and materials. A system's useful life has traditionally been considered approximately 25 years. However, there are examples of courses with functioning systems that are more than 40 years old.

There is also no clear-cut line for when simple components like nozzles need to be replaced. Historical data from irrigation audits can help superintendents identify declining performance. Performing catchment tests on parts of the system where new components have been installed compared to old ones can help quantify the difference in performance and potential water savings.

Practical Challenges

There are some practical issues that make it challenging for golf courses to perform regular maintenance on the irrigation system.

Out of sight, out of mind: Most irrigation system components are located underground. It can be difficult to identify signs of a problem until a major failure occurs.

Available staff: It is challenging to find, train and retain qualified staff that are proficient in repairing and maintaining large irrigation systems.

Nuance: It takes time to learn the nuances of a system in order to successfully maintain it. This also means that the relative value of adjustments will vary from system to system.

Opportunity cost: With so many tasks to complete on a golf course, it's difficult to allocate enough time for irrigation system maintenance. The staff who are skilled in irrigation repair are often in demand for other tasks and if the irrigation system is not broken their time may be prioritized elsewhere.

Budget: If all seems to be going well with the irrigation system, it can be hard to budget for new materials and preventive maintenance when there are other pressing maintenance needs as well.

IMPLEMENTATION

Expected Cost and Time Requirements

Routine irrigation maintenance is traditionally built into general labor costs. The cost for replacement parts varies from a few dollars per nozzle, to a few hundred dollars to replace a sprinkler, to thousands of dollars to service or replace pumps or add in-ground soil moisture sensors to help schedule irrigation. Additional costs also can include specialty tools, electrical components, lubricants, gaskets and seals. Costs vary for professional service repairs or audits (based on the type of service, time required and potential travel) but are typically in the thousands of dollars.

The expected time for common repairs depends on conditions and resources, but the following are some general estimates.

Adjustments: Generally, just a few minutes per sprinkler are needed for routine adjustments. However, considering that a golf course may have thousands of sprinklers, significant staff time can be needed.

Minor repairs: Repairing or lifting low sprinklers to a proper level, or replacing a sprinkler, can take hours depending on soil conditions. Even a minor leak to a lateral line can take most of a day to repair, or potentially longer depending on the circumstances.

Major repairs: A major repair to components like pumps or a mainline can take days and there may be a long wait time for parts or the availability of repair specialists.

Routine maintenance and adjustments may not take much time for an individual sprinkler, but golf courses can have thousands of heads to keep track of. (USGA/JD Cuban)

Assessment and Prioritization

Irrigation system maintenance begins by assessing the quality of the playing surfaces and current system performance. Simply noting wet and dry areas or standing water from seeping sprinkler heads and small leaks is foundational to thoughtfully maintaining the irrigation system. The system components also should be evaluated for wear and tear due to age. Once a list of maintenance items is established, a plan can be developed for the frequency, timing and types of repairs or major upgrades. Comprehensive assessments should be done at least once annually, ideally in advance of the primary irrigation season. A more-detailed assessment can be done by contracting a professional irrigation auditor.

Following assessment, create a regular schedule of irrigation maintenance and determine the budget and labor needs that will provide an adequate level of irrigation system maintenance. Ideally, at least one person on staff will be responsible for, and have the majority of their time allotted to, maintaining the irrigation system under the direction of the golf course superintendent.

Make sure to distinguish between in-season maintenance operations such as edging sprinkler heads, and offseason maintenance such as replacing major components. As part of the offseason maintenance, manual operation of isolation valves should take place (close and open at least once) to exercise the valve.

Prioritize repairs or upgrades based on complexity, cost and potential benefit, and then determine the timeline for implementation. Some tasks can be easily performed by staff, whereas others may require a long-term plan and capital investment or help from an irrigation contractor.

Budget time and resources to educate your staff on how to best operate and maintain the irrigation system and familiarize everyone with how to identify and report issues.

Abnormally wet or dry areas often point to an irrigation issue.

Considerations for Specific Irrigation System Components

Sprinklers

Sprinklers are the end point of the irrigation system and are ultimately responsible for delivering water to turfgrass. Regular inspections and audits, whether in-house or with a certified auditor, ensure that sprinklers are at a proper level and angle adjustment in relation to the turf surface and are not clogged, stuck or rotating improperly. Inspect the area for leaks or other signs of a poor connection between the sprinkler and the swing joint. Depending on the type of turfgrass and growing environment, periodic cleaning and edging is necessary to prevent sprinklers from being obstructed or buried by grass.

Periodic checks will ensure that sprinkler seals and gaskets are not the cause of leaks resulting in water loss and improper operating pressure. If the water pressure at the nozzle is below what is required for the sprinkler to function properly, cleaning the filter screen or inspecting the sprinkler body is necessary. Also, make sure that the body of the sprinkler is not cracked or otherwise damaged and replace if necessary. Many older sprinklers are no longer manufactured and it's sometimes more economical and practical to simply replace a damaged sprinkler with a new one.

Make sure any replacement sprinklers fit your golf course needs in terms of radius, flow, precipitation rate and operating pressure. Match the original sprinkler's specifications as closely as possible. If there is not a good option for doing so, a strategic plan to replace entire areas of complementing sprinklers may become necessary. Harvested sprinklers from an upgrade area can be saved and used for parts and repairs in other parts of the course that have not yet been converted to the new sprinkler model.

It's important to check the connection of the sprinkler with the pipe and also pilot valves, tubes and solenoids, since these connections are prone to leaks and can lead to pressure losses or wasting water. Any casings or assemblies that are beyond repair need to be replaced – including any sprinklers that mowers or aerifiers have permanently damaged. Older sprinklers, such as impact rotors, are no longer manufactured and replacement parts are usually not available. They should be upgraded with modern technology when the time comes. If a sprinkler requires frequent maintenance intervention, it's often more economical to replace it instead of troubleshooting the problem again and again. This also allows you to select sprinklers that perform better and use water more efficiently. Typically, sprinklers are tested and set by the manufacturer to a predetermined operating pressure. Ensure the pressure settings of new sprinklers match the requirements for the one being replaced.

Trimming turf around sprinkler heads is a routine maintenance task that may have to be performed several times each year.

Nozzles

The configuration and type of nozzles have a major impact on the distribution of irrigation water from a sprinkler and can have a big impact on water conservation. Therefore, it's critical to install the correct nozzles and inspect them periodically to ensure proper operation. They are most often made of plastic, but some are made of brass for durability. The friction caused by the high operating pressure and particulates in irrigation water subject nozzles to wear and tear. The recommended replacement rate for sprinkler nozzles is every five to eight years, depending on the frequency of use, amount of flow, water pressure and water quality. Data from occasional catch-can audits can help verify how much distribution uniformity has been affected by use over time. Regularly inspect nozzles for signs of wear or damage. It can be helpful to compare with new nozzles for reference.

Always ensure the actual precipitation rate of nozzles matches the designated precipitation rate in the central control computer. Precipitation rate is indicated by the color of the nozzle. Whenever a nozzle is changed, record the adjustment in the central control computer.

Finally, consider upgrading nozzles with new models or products that have demonstrated water conservation compared to your existing nozzles.

Replacing worn nozzles and adjusting them to achieve the desired coverage can save water and improve turf quality.

Sprinkler valves

There are many types of valves that control the flow of water through an irrigation system. Isolation valves that restrict water flow to parts of the system are discussed later. The focus of this section is on valves that activate sprinklers.

Modern sprinkler technology employs valve-in-head control, which means the valve that activates the sprinkler is part of the sprinkler body itself. In a traditional or "block" system, an independent valve controls multiple sprinklers. These valves are much larger and require more-frequent maintenance. Any type of sprinkler valve will eventually require replacement – just like sprinkler bodies, nozzles and every other part of an irrigation system. Pressure losses or water leaks can be caused by a stuck or malfunctioning valve. Periodically check that all sprinkler valves activate, both electronically and manually. Make any necessary repairs if valves are not operating properly.

The reason for malfunctioning sprinkler valves often is the valve diaphragm or solenoid. Debris commonly prevents the diaphragm from seating, which manifests as seeping sprinklers. Occasionally a clogged tube or orifice in the pilot valve assembly can cause the valve to operate slowly or not open at all. If a solenoid is to blame, the head will typically be stuck on or will not activate electronically. Another common point of failure is the wiring connection with the valve. A multimeter is very useful for checking for an electric signal between the solenoid and controller. This tool can also check for faulty solenoids and diagnose many other issues.

Mainline and lateral lines

Mainlines and lateral lines transport water from the pump to the sprinklers. They are almost always buried underground, making maintenance more challenging. Typically, these pipes are made of polyvinyl chloride (PVC), but older systems can have pipes made of metal or other materials.

Underground leaks can usually be identified by pressure loss or inspecting the property for unusually wet areas. A certified expert can also conduct pressure checks at several points to evaluate the integrity of the irrigation pipes, but this would fall outside of routine annual maintenance. Leaks need to be repaired promptly to ensure the irrigation system can operate at the correct pressure and to avoid wasting water.

Underground leaks in lateral lines and mainlines are usually identified by wet areas at the surface. Repairs must be performed as soon as possible to ensure proper system function and minimize water waste.

Manual isolation valves (both mainline and lateral isolation valves) should be exercised at least once annually. Exercising valves means completely closing and then reopening them to clean the threads of the operating stem and break away any minor corrosion that has developed over time. This task can be reserved for the offseason or times when watering is not a priority. Mainline and lateral isolation valves that do not fully close should be identified for replacement before they are needed in an emergency situation.

Pumps

Pumps provide the pressure and flow to distribute water through the irrigation system. There are simple ways pumps can be maintained by a golf course superintendent or irrigation technician, but more complex issues will require a professional contractor. Regular inspection of the pump house allows you to check for any abnormal noises, leaks or motor overheating.

Many types of pumps require frequent lubrication, or the refilling of an automatic lubrication system. It's important to check the status of seals and gaskets, as they can wear out easily. Any excessive vibration during operation indicates issues with bearings, alignment or impeller damage. It is essential to perform a pressure test at least once per year and record the results and condition of the pumps. This will identify issues and allow for the planning of replacement parts or equipment before failure.

A dynamic pump efficiency test can be done by a contractor. This test can identify worn impellers and bowls and project energy savings if repairs are performed. Occasionally, energy providers will subsidize these tests and/or the needed pump repairs identified.

If a replacement pump becomes necessary, consider upgrading to a modern variable frequency drive (VFD) pump and configuring pumps to minimize stress on pipes. VFDs help pumps operate more efficiently and produce less water hammer, therefore reducing the frequency of catastrophic failures in older pipes.

Visit the pump station regularly to check for any abnormal noises, operation when sprinklers aren't running, leaks and other issues.

Central control system and satellites

Together with satellites, the central computer allows for control of each valve (or zone in a block system) and sets the runtime and schedule for irrigating the golf course. They can be integrated with weather stations and sensors to better decide when and how much to irrigate. These components are less subject to wear and tear, but they can be vulnerable to power surges, corrosion and other failures. Certain preventive measures will increase performance and longevity.

Central controllers can also manage the distribution of water through the system. The software can match flow and operating pressure of pump systems to meet demand, when correctly programmed. This programming is typically operating in the background without any adjustments needed by golf course staff making daily irrigation schedules. The hydraulics portion of the software should be programed by a qualified individual such as the irrigation designer to avoid water hammer and pressure drops resulting from incorrect flow through the system.

Keep up with software updates and the functionality of the central controller. Modern central control systems and two-wire decoders require frequent software and firmware updates. Typically, there are built-in methods for installing these updates but a monthly check will ensure everything is updated as soon as possible.

Satellite controllers out on the course should be inspected routinely for any physical damage or issues with wires that interfere with communication with valves or the central computer. Make sure outdoor components are waterproof and keep pests away. Communication between the central controller and the field satellites should be checked periodically and after any thunderstorms.

Satellites on the course should be inspected routinely for physical damage, wiring issues and the presence of pests or unwanted animals. (USGA/JD Cuban)

For systems with batteries, make sure they hold a charge and are still performing well. If there are any sensors attached to the central controller, such as a weather station or in-ground soil moisture sensors, routinely check their connectivity and functionality.

Wiring

Wiring connects satellites and the central controller to sprinkler valves. While the wires used in golf course irrigation are designed for longevity and typically don't require maintenance, damage can occur. Burrowing animals may chew on wires, or they can be damaged by cultural practices or renovation projects. It is not unusual for a golf course to have multiple stations that need to be run manually for a period of time because of damaged wires. Manual operation is not efficient from a time or water use perspective and should be kept to a minimum. Therefore, it is important to periodically look for symptoms of damaged or broken wires and to make repairs as soon as possible.

Specialized wire locators and other tools are often needed to diagnose and repair breaks in irrigation wires. When repairing or connecting wire underground, direct burial or other similarly rated splice kits must be used. Carefully map any additions, rerouting or "jumping" of irrigation wires to simplify future work on the system. Use the appropriately colored wire when making modifications to avoid confusion.

Proper grounding won't necessarily stop a lightning strike from damaging irrigation system components, but it can certainly minimize any issues. Two-wire systems and associated decoders are particularly susceptible to lightning damage and it's critical they are grounded properly, usually at a minimum of every 500 feet. Satellite field controllers and traditional 14-gauge wire are usually protected through mandatory grounding, but surge protectors can add an extra level of protection.

Isolation and drainage valves

There are various situations when it is necessary to isolate or clear water out of irrigation lines, which requires closing one or more valves. All irrigation and drainage valves need to be easy to find and readily accessible. The turf around valve boxes should be trimmed to keep them from becoming hidden or difficult to open. All valves should be exercised – i.e., fully opened and fully closed – at least once each year to reduce the risk of them getting stuck or not closing properly. Exercising the valves is also an opportunity to identify problems before a crisis hits and a valve will not close.

Filters

Filters and screens protect irrigation system components from contaminants and particles in the water. They are used in pump intakes, sprinkler bodies and other irrigation system components. Clogging will reduce operating pressure and system functionality so inspection and/or cleaning on an annual or regularly scheduled interval should be part of the normal irrigation system maintenance schedule.

IRRIGATION AUDITS

An irrigation audit is used to gather information about the water distribution uniformity, rate of precipitation and overall functionality of an irrigation system. Methods also exist for testing performance of drip irrigation systems. Formal audits are usually conducted by an independent certified professional, but superintendents can use the same methods to perform system checks. An irrigation audit should be performed at minimum every five years.

Key Elements of an Audit

Visual inspection: Observe each sprinkler (or zone in a block system) to identify issues causing inefficient water use such as damaged or leaking sprinklers, incorrectly positioned sprinklers, improperly adjusted arcs, low or crooked sprinklers, improper sprinkler spacing, unusual patterns that may indicate low or high water pressure, malfunctioning rain sensors and poor system design features.

Evaluate uniformity: Many of the issues discovered during the inspection will impact the distribution uniformity of irrigation water. Catch-can tests are a common way to measure the uniformity of application and are performed by positioning collection containers in a grid pattern, running the sprinklers, and recording the amount of water in each container. The data from this analysis will identify areas that were overwatered or underwatered relative to the targeted application rate. Often, results of a catch-can test reflect observations of turf quality and playing conditions.

Determine precipitation rate: With simple math, catch-can test results also give the rate of water being applied by the irrigation system. Water pressure, nozzles, sprinkler spacing and many other variables can impact how much water is actually being applied to a given area. Confirming precipitation rates is vital for scheduling irrigation appropriately.

Assess turfgrass water needs: Even two nearby putting greens on the same golf course can have much different water needs. Turfgrass species, soil types, drainage, shade, wind, angle to the sun, time of year and countless other things are all factors to consider in reviewing an irrigation schedule during an audit.

Review irrigation scheduling and methodology: During the audit, the current irrigation schedule will be assessed, and recommendations made based on the above information and other factors. Recommendations may include adopting new methods for scheduling irrigation like using ET measurements or soil moisture sensors as a guide.

Irrigation Audit Considerations

An irrigation audit can be a daunting task – especially with limited resources. It may be more sensible to contract a professional service to conduct a formal audit. You do not necessarily need to audit the entire golf course to gain a good picture of irrigation functionality. Auditing all greens and a representative sample of fairways is a reasonable option. Occasionally, municipalities offer rebates or other programs to assist with irrigation audits, especially when documenting improvement in performance.

Irrigation audits should be performed on key areas of the course at least every five years. Auditing all greens and a representative sample of fairways is a good place to start.

TIPS FOR SUCCESS

Keep up with repairs, don't let the list grow.

There is a lot that goes into golf course maintenance and it can be easy to put off a small irrigation repair or adjustment in favor of completing another task that seems more important. Unfortunately, irrigation issues will just keep coming and the punch list can grow quickly. While you're waiting for a good time to make repairs and adjustments, irrigation issues are having a negative impact on course conditions and likely wasting water. Train staff to perform routine maintenance, assign responsibilities, and budget time for staff to perform maintenance tasks on a consistent basis. This keeps the list of issues from growing too long, optimizes playing conditions, saves water, and reduces the risk of minor problems escalating into emergency repairs.

Watch the system run and listen to the pumps.

Golf course superintendents are busy, and it can be difficult finding time to watch sprinklers run. Yet this is one of the best ways to discover issues with the irrigation system. Whether it's watering-in a wetting agent application or running heads on a hot afternoon, watching sprinklers operate during the day offers a great chance to identify problems. All staff should be trained to identify malfunctioning sprinklers and report them for repair. Listening to your pump station operating is another good way to catch problems before a decline in performance or total failure occurs. Hearing an unusual sound emanating from the pump station, or hearing it cycle on and off when you are not irrigating, is almost always indicative of a problem.

Watching sprinklers run during the daytime is a great way to catch issues.

An irrigation audit is only worthwhile if action follows.

An irrigation audit is a valuable tool that is often cited as a way for golf courses to conserve water. However, it is only information. It is ultimately up to the golf course maintenance staff to ensure the recommendations from an audit are put into practice for water conservation and improved playing conditions to be realized.

Look for “WaterSense” labeling.

The U.S. Environmental Protection Agency (EPA) has released their WaterSense specifications for sprinkler nozzles. Recent studies have found that several models of nozzles reduce water use for irrigation (Li et al., 2019). Installing WaterSense-labeled nozzles or replacing existing ones throughout an irrigation system can save more than 2,400 gallons of water annually on the average-sized residential landscape and can result in significant savings if deployed on golf course acreage. Visit the EPA WaterSense website to learn more.

It takes a team.

The maintenance staff, golfers, golf shop staff and even residents that live around a course can all act as an alert network for irrigation issues. Scouting for leaks and abnormalities is a regular part of irrigation maintenance, but golf courses typically occupy more than 100 acres so it can be challenging to inspect the entire property. Taking some time to educate people who may be out on the course on how to identify issues and get in touch with the superintendent can be a great strategy for catching problems early and engaging staff and stakeholders.

Keep supplies for routine maintenance and major repairs on hand.

It’s hard for golf courses to keep up with routine irrigation maintenance, so you want to make it as convenient and efficient as possible. A key element of that is keeping the supplies and parts necessary on hand and organized for quick access. Every hour can count when it comes to making repairs that shut down large sections of the irrigation system. Larger repair couplers and other parts can also be difficult to find on short notice, particularly on weekends or holidays, so it is important to keep an up-to-date inventory of all irrigation parts. Certain parts that require routine replacement like solenoids and nozzles should be kept in abundance.

Keep irrigation supplies well stocked and organized so that the staff has what they need to make repairs quickly. (USGA/JD Cuban)

Eventually, every golf course needs a new irrigation system.

Keeping up with routine maintenance optimizes the system you have, but declining performance and/or an increasing number of repairs will eventually indicate that it's time for a new irrigation system. New systems can cost up to $6 million and they are seldom a popular investment, but they greatly improve the efficiency and effectiveness of irrigation and the overall maintenance program. New systems feature improved components that break less often and perform better than what is commonly found in systems that are decades old.

BMP CASE STUDIES

"Leveling Sprinkler Heads Conserves Water and Improves Playing Conditions"

USGA Green Section Record, 2017

The Country Club of Detroit had numerous sprinkler heads that were low or tilted and the superintendent recognized that irrigation system performance was being negatively affected. He developed a plan to assess and correct underperforming sprinkler heads that were wasting water and compromising playing conditions. On average, about 30 to 40 sprinkler heads at the Country Club of Detroit required adjustment each year.

The golf course benefitted tremendously from the sprinkler head maintenance program. Playing surfaces were much more evenly watered and golfers were extremely pleased with the improved consistency. The superintendent reported a significant drop in the need for hand watering on fairways, which allows those resources to be reallocated to other maintenance tasks. The unsightly "donuts" of lush, overwatered turf that once surrounded underperforming heads have been eliminated, improving both playing conditions and aesthetics.

"Leveling Irrigation Heads Improves Playing Conditions"

USGA Green Section Record, 2017

Pelham Country Club hired a contractor to raise and level 165 sprinkler heads in just two days, significantly more than the maintenance staff could have completed on their own during the busy summer months. Irrigation efficiency and mowing quality improved immediately after the project was complete. The improved irrigation efficiency helped to conserve water, improve playing conditions and enhance turfgrass quality. Over the course of the season, labor dedicated to hand watering fairways was reduced significantly.

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FUNDAMENTAL IRRIGATION STEWARDSHIP

The Effects of Chemical Applications on Water Use and Drought Resistance

Certain chemical applications can improve the drought tolerance of turfgrass and potentially help courses save water. However, practitioners should verify that any product claims are backed by scientific research and supported by field experience.

SNAPSHOT

This strategy deals with following best general turfgrass management practices that leverage applications of proven chemical products to reduce water use. It is a low-impact, low- to medium-cost strategy applicable for most golf courses.

Expected cost	< $25K per acre
Ease of implementation	Daily maintenance
Potential water savings for affected area	< 10%
Highest potential impact areas	Nationwide

OVERVIEW

Turfgrass management and maintenance practices can enhance drought resistance – and potentially help courses save water – by affecting plant physiology, controlling pests or affecting soil properties. Healthy turfgrass will have a better chance of maintaining its vitality, function and visual appeal, even when water is limited. This chapter will briefly discuss the key components of maintaining healthy turfgrass. We know that various maintenance practices, such as mowing and fertilization, can impact how much water the turfgrass will need and utilize. However, we understand that some of these practices may be difficult to change or modify in golf course settings. Therefore, we will focus on practices and strategies that can be adopted to maintain turfgrass quality with less water.

Applying certain chemicals and products to aid turfgrass during drought is a practice grounded in decades of scientific research and years of practical field experience (Schiavon & Serena, 2023). However, many chemicals or products are less proven (or even completely unproven) when it comes to their potential impact on water use and drought resilience, so turfgrass managers should do their homework. Golf course superintendents continually manage complex mechanisms that govern turfgrass responses to water stress and have developed targeted cultural and application programs to alleviate this abiotic stress. By leveraging these practices, superintendents and turfgrass practitioners can reduce the impact of water scarcity or decreased water use and promote healthier, more resilient turfgrass.

It is important to note that while various product applications can be a valuable tool, they are not a stand-alone solution to drought management or water conservation goals. They should be considered part of a comprehensive approach that includes proper irrigation practices, soil management and other cultural practices. Integrated turfgrass management strategies that incorporate chemicals as one element among many can yield the best outcomes in terms of drought resistance and long-term turfgrass health.

It is important to note that while various product applications can be a valuable tool, they are not a stand-alone solution to drought management or water conservation goals.

SCENARIOS FOR USE

General Turfgrass Culture

Detailing best turfgrass management practices is beyond the scope of this chapter. However, it is important to at least acknowledge that turfgrass selection and basic culture affect water use. Golf courses should establish the most drought-tolerant turfgrass variety or cultivar that suits other site-specific needs (see Chapter 5 for more information). Although mowing heights can affect turfgrass water use, golf courses typically select heights of cut based on playability goals. Additionally, soil biological, chemical and physical properties can affect water use. Many soil chemistry considerations are discussed below, but biological and physical properties are not. Briefly, proper soil management should evaluate and include aeration and soil amendments to alleviate compaction that impairs water infiltration. It is also important to adequately manage the accumulation of thatch and organic matter near the soil surface, which can increase surface wetness at the expense of deeper water percolation and rooting that promotes drought resistance.

Cultural practices play an important role in promoting drought resistance and optimizing water use.

Leveraging Chemicals to Conserve Irrigation Water

Chemical use in turfgrass management should follow local regulations, product label instructions and research-based best practices to ensure user safety, environmental sustainability and efficacy. Using these foundations, golf course superintendents often develop customized maintenance programs based on their knowledge of turfgrass species, site conditions, and expectations.

Fertilizers

Turfgrass fertilizers provide essential mineral nutrition that promotes growth and resilient playing surfaces able to recover from traffic, drought, and other abiotic and biotic stresses. Proper fertilizer programs are especially important for drought resistance because deficiency, excess, or poor application timing of any nutrient can impair the growth and development of leaves, stems and roots, thus limiting turfgrass performance under stress. For example, sufficient phosphorous is essential for root growth, while excessive nitrogen can favor foliar growth to the detriment of rooting. Too much fertilizer, overall, can cause salinity stress, making it more difficult for roots to absorb water. Proper nitrogen applications, in particular, can improve turfgrass performance and visual color during drought.

Nitrogen

As a principal driver of plant growth, moderate nitrogen fertility is important before and during drought stress. Insufficient nitrogen will lead to a quicker decline in turfgrass quality during drought, and excessive nitrogen may impair root proliferation and drought resistance (Kopp & Jian, 2013). While the benefit of sufficient nitrogen during drought stress has been shown in several turfgrass species, evapotranspiration (ET) rates generally increase with nitrogen fertilizer use, which further highlights the importance of moderation. Generally, nitrogen should be applied at infrequent, low rates from a slow- or controlled-release source during drought (Harivandi & Gibeault, 1990).

Moderate nitrogen fertility helps turfgrass withstand drought stress, but applying too much nitrogen can be problematic during a drought.

Phosphorus, potassium and other nutrients

Phosphorous and potassium have been associated with the alleviation of, or hastened recovery from, drought stress. However, their relative benefit often depends on the supply of other nutrients. The beneficial effects of iron fertilizer on creeping bentgrass are not associated with increased drought tolerance (Glinski et al., 1992). Silicon is an alleged "beneficial" (i.e., technically nonessential) micronutrient that has received a lot of attention. Some research has demonstrated that silicon can improve drought tolerance. However, high application rates and the relative lack of field experiments make the value of silicon in drought management questionable. The direct effects of other nutrients on turfgrass drought resistance or tolerance are relatively unstudied.

The best approach for advancing drought resistance with fertilizer is to soil test at least annually with a goal of maintaining soil nutrients slightly above research-based recommendations. Locally calibrated recommendations based on Sufficiency Level of Available Nutrients (SLAN) or Minimum Levels for Sustainable Nutrition (MLSN) are appropriate (Thompson et al., 2023). Of course, traditional soil testing cannot guide the scheduling of some nutrients, such as nitrogen or sulfur, and so plant responses must inform decision making.

Pesticides

Pests can affect turfgrass performance during drought in two ways. First, a prior infection or infestation can reduce turfgrass vigor, reduce drought resistance and inhibit recovery. Second, pests may take advantage of drought-stressed turfgrass and further reduce quality and performance. Therefore, it becomes even more important to manage pests during such conditions. For example:

Herbicides control weeds in turfgrass areas. Weeds compete with turfgrass for water, and drought conditions can exacerbate the proliferation of certain weeds. Preemergence herbicides can be especially useful to prevent weed emergence and maintain playing surface quality when turfgrass is drought stressed or even dormant.

Insecticides help manage turfgrass insect pests such as white grubs, chinch bugs and armyworms. The first sign of damage from root-feeding pests often is wilt, so it is especially important to control these pests to ensure a healthy root system that can access available soil water.

Nematicides help manage nematode infestations, most often in putting greens. Like root-feeding insects, wilt often is a symptom of nematode feeding and improved drought-performance of nematicide-treated turfgrass is associated with increased root biomass (Trenholm et al., 2005).

Fungicides help manage foliar diseases such as dollar spot or brown patch, or root diseases such as take-all patch or Pythium root rot. Turfgrass health benefits from fungicides are similar to those already discussed for insecticides and nematicides. Claims of improved drought tolerance in the absence of disease pressure have become more common with certain groups of fungicides, even though research often does not support the claims (Schiavon et al., 2022). An exception is acibenzolar-S-methyl (ASM), which has been shown in research settings to enhance drought performance in creeping bentgrass by reducing transpirational water loss (Jespersen & Huang, 2017; Shekoofa et al., 2016).

Claims of improved drought tolerance in the absence of disease pressure have become more common with certain groups of fungicides, even though research often does not support the claims.

However, manufacturing companies typically include ASM in fungicide mixes, rather than selling it individually, and more importantly, the frequency and cost of using ASM as a drought-management tool is not economical for most golf courses.

Plant Growth Regulators

Plant growth regulators (PGRs) have many uses including reducing mowing requirements, inhibiting seedheads, promoting the growth of some grasses over others, and enhancing weed control. Because they partially arrest plant growth, PGRs commonly reduce ET rates and some have been shown to improve drought tolerance in turfgrasses and other plants. PGRs are distinguished by class, from A to F. For water conservation purposes on golf course turfgrass, typically only class A and B materials are utilized. Class A PGRs are late-step gibberellic acid inhibitors, while Class B PGRs are early-step gibberellic acid inhibitors.

Trinexapac-ethyl (TE; PrimoMaxx) and prohexadione calcium (Anuew) are the only Class A PGRs and are primarily foliar absorbed. TE, in particular, has been repeatedly shown to improve turfgrass appearance and metabolic function during drought stress (Schiavon & Serena, 2023). In warm-season turfgrass, TE has been shown to reduce water use by 15% to 30% in research settings (Schiavon et al., 2019). Paclobutrazol (Trimmit) and flurprimidol (Cutless) are Class B PGRs and are primarily root absorbed. Paclobutrazol has been shown to reduce visible stress during drought, primarily in cool-season turfgrass (Shahrokhi et al., 2011).

While exact water savings can vary based on specific conditions and PGR type, reductions ranging from 15% to 20% are plausible.

While exact water savings can vary based on specific conditions and PGR type, reductions ranging from 15% to 20% are plausible (Schiavon & Serena, 2023). These water savings are challenging to quantify because several studies have evaluated various ET levels, and only estimated these savings. Golf course case studies are needed.

Soil and Water Conditioners

Soil and water chemistry can affect how water enters and moves within soil and whether it is accessible by plant roots. The main challenges are typically salinity, sodicity and/or water-repellent soils.

Salinity and sodicity

Soil and water salinity are defined as a higher-than-usual concentration of dissolved salts. For most turfgrasses, when the soil has an electrical conductivity of the saturated paste extract higher than 4 decisiemens per meter (dS/m), it is considered saline. Sodicity is when the soil has a concentration of exchangeable sodium higher than 6% compared to other cations (Harivandi et al., 1992).

Entire textbooks have been written on managing salts and sodium, which is beyond the scope of this chapter (see

Duncan et al., 2009). Briefly, high soil salinity can cause drought stress that can only be mitigated by leaching salts through the soil or rootzone. Irrigation water that is high in salts can be treated with reverse osmosis and/or blended with higher quality water to reduce salinity levels. High soil sodicity deflocculates (disperses) soil particles and can only be remedied by displacing excess sodium with calcium or magnesium products followed by leaching. Water high in sodium can be treated with gypsum or acid injection. Golf courses using recycled wastewater for irrigation will experience these issues and should refer to the chapter in this guide dedicated to that subject for more information.

Water-repellent soils

Soils become water-repellent (hydrophobic) when organic compounds and substances coat soil particles. Sandy soils are most likely to experience water repellency conditions, which leads to “localized dry spots” that can persist and are difficult to rewet.

Hydrophobic conditions lead to poor turf quality and inefficient water use.

Soil surfactants

Soil surfactants, also known as wetting agents, reduce the surface tension of water, which improves the polar attraction between water molecules and soil particles. This improves water infiltration and soil moisture uniformity, especially in hydrophobic soils prone to excessive localized drying (USGA, 2018). Some products are marketed as "penetrants" while others are labeled as "retainers" to indicate distinct performance mechanisms related to water movement. However, the properties and practical effects among surfactants on both rootzone volumetric water content (VWC) and turfgrass quality are often similar; differences that do occur are inconsistent and do not necessarily correspond to the marketing terminology (O'Brien et al., 2023). At the same time, surfactant products have demonstrated considerable variability in performance across locations and over time, indicating that both weather and maintenance practices influence wetting agent performance (Throssell, 2005). Considering these external factors and collecting data – such as percent VWC and firmness – before and after soil surfactant applications will help superintendents better understand and optimize the benefits these products can provide to their specific course.

Soil surfactants improve water infiltration and soil moisture uniformity. The plots in this image are from a study of various surfactant programs, with the top-left plot being nontreated.

Soil surfactants are widely used in golf course management, especially on putting greens, and extensive research supports their general benefit (Fidanza et al., 2020; Schiavon & Serena, 2023). Soil surfactants have been studied for their potential to improve turfgrass quality under reduced irrigation regimes. In some studies (Schiavon et al., 2014), surfactant-treated bermudagrass maintained acceptable quality when irrigated at 50% of reference ET. Similar studies further support that soil surfactants can lead to water savings of 20% or more, depending on turf species, climate, traffic and duration of drought (Nolan & Fidanza, 2024). It is important to deliver the soil surfactant to the rootzone through post-application irrigation to realize the water-savings potential.

A cautionary note about "physical water conditioners"

Physical water treatment devices, such as magnetic conditioners, are commonly used in the golf industry. These devices are placed in the irrigation system main water supply line and are primarily marketed as an easy and effective method to treat water. Manufacturers claim that the devices improve water quality, save water and offer other benefits. However, most of the case studies and testimonials presented by manufacturers lack scientific rigor, are not properly replicated in space or time, and lack nontreated controls for comparison. Therefore, this information should always be taken with skepticism. Despite marketing claims, scientific studies have reported no benefit from the use of physical water conditioners (Leinauer et al., 2012). Studies have been conducted under different water salinity levels, drought levels and with different grasses, all without positive results from physical conditioners.

Colorants

Turfgrass colorants include paints, pigments and dyes. The relative amount of binder differentiates these products, mostly in terms of longevity. For example, pigments have less binder, are typically applied at lower rates to growing turfgrass, and do not last as long as paints, which have more binder and are applied at higher rates, often to provide green color to dormant turfgrass. Presently, the primary benefit of colorants is to improve aesthetics and definition during winter dormancy without overseeding. Estimates from Arizona indicate that an acre of non-overseeded bermudagrass requires around 4.5 acre-feet (1.47 million gallons) of water per year, whereas overseeding an acre of bermudagrass increases annual water use to 6.2 acre-feet (2.02 million gallons). Colorants can also be used to temporarily improve turfgrass color during drought stress.

In a study conducted at Clemson University on creeping bentgrass, four commonly used pigments were tested under drought conditions. Although these products did not enhance physiological processes associated with turf performance, they did increase turfgrass quality under drought stress conditions. One product containing titanium dioxide (TiO_2), which is often used in sunscreen, reduced ET rates (McCarty et al., 2014). A recent field study at the University of California, Riverside (UCR), demonstrated that pigment products maintained higher bermudagrass quality under drought conditions (2023 UCR Turfgrass and Landscape Research Field Day Booklet).

Product selection is ultimately predicated on whether leaf surface transparency is needed to support photosynthesis. Further, because pigments affect light transmission, repeated use on actively growing turf may contribute to reduced health over time. Colorants have also been shown to increase heat stress in creeping bentgrass, so care should be taken, especially with paints designed to provide color during winter dormancy (McCarty et al., 2017). Oftentimes, colorants are premixed or tank-mixed with other products, such as fungicides. There is a lack of research specifically investigating the benefit of colorants alone on turfgrass drought resistance.

Using turf colorants to enhance the aesthetics and definition of dormant playing surfaces has helped some courses discontinue winter overseeding, which can lead to significant water savings. (USGA/Chris Keane)

Other Compounds

The products listed below have shown potential to reduce turfgrass water use, but there has been limited research into their effectiveness for drought management and water conservation and their potential benefits for these purposes have yet to be tested on a large scale. However, there is potential for forthcoming experimentation, evaluation and use.

Biostimulants

Many compounds can be used to activate plant defense mechanisms and increase abiotic stress resistance or tolerance, even for drought. However, the effects of these products often are incremental and most pronounced in controlled environments, such as research greenhouses or growth chambers. It can be difficult to reproduce significant or observable results in field research or "real-world" settings. For example, abscisic acid (ABA) is considered a phytohormone and is often categorized as a biostimulant. Exogenous applications of ABA have been shown to improve drought tolerance in several turfgrass species. Research has mostly been limited to growth chambers, but field testing may further support potential benefits of ABA in turfgrass water conservation. Biostimulants should not be considered as a replacement for thoughtful water management and any use should be critically evaluated, including searching for supporting nonbiased research and monitoring field experiences with use areas compared to a nontreated control plot.

Soil amendments

The primary benefit of soil amendments in turfgrass management is to improve the physical properties of soil, including water retention and availability. Organic amendments increase nutrient and water retention, particularly in sandy soil. For example, using biochar as a replacement for peat moss in putting greens has shown potential benefits for bentgrass growth, with the possibility of also improving drought tolerance (Vaughn et al., 2018). Additionally, in a research trial in Riverside, California, biochar was incorporated into the soil and demonstrated benefits in maintaining tall fescue quality under drought conditions (Montgomery, 2018).

It is important to note that with an established turfgrass system, the soil will be higher in organic matter compared to new turfgrass stands or many agricultural soils. It is also difficult to apply and incorporate these compounds into established rootzones. Therefore, most of these soil amendments are added during construction or renovation. Inorganic amendments like sand topdressing can be easily incorporated, but their benefits are not associated with increasing drought tolerance.

There have been some instances of organic compounds that have been incorporated into established turfgrass systems, with benefits lasting up to five years. However, limited information and research are available on the benefits of these compounds in water conservation. Amendments like zeolite and clay can bolster the ability of turf and other plants to withstand drought, potentially reducing water requirements (Miller, 2000). Other research investigated incorporating compost as a topdressing after hollow-tine aeration on Kentucky bluegrass and showed improved water retention and more-efficient water use (Johnson et al., 2009).

Nanocarbon is an emerging soil amendment derived from activated charcoal. In preliminary research reports from UCR, nanocarbon reduced bermudagrass water use by 35% (2021 UCR Turfgrass and Landscape Research Field Day Booklet). Nanocarbon enhances water and nutrient adsorption by increasing both the surface area of soil particles and contact with plant roots (Younas et al., 2021). Moreover, nano-biochar has been shown to improve photosystem function and increase protective enzymes in pear orchards subjected to drought conditions (Lyu et al., 2016).

Though the potential benefits of many soil amendments are intuitive, it's important to remember they may not be cost-effective over large areas.

BENEFITS

Water Conservation

A list of product categories with the most potential for water conservation – as supported by research and practical application – is available in Table 1 along with cost estimates and potential water savings. Many of the products discussed above are not included and users should be thoughtful about any exceptional marketing claims not accompanied by independent, replicated and authenticated research. Also, be aware of product label maximums and the ill-advised repeated use of certain products, such as a single type of fungicide, when considering a product.

Many chemical interventions for drought management are cost-effective and can be easily integrated into existing turfgrass management programs, resulting in a seamless adoption of water-saving measures. However, the trade-off for ease of implementation means a smaller potential impact on water conservation relative to other improvements. Do not expect miracles.

Table 1. The estimated cost and potential water savings of chemicals that can reduce irrigation requirements.

Chemical Category	Application Cost ($/Acre)	Estimated Midpoint* Annual Cost for 25 Acres ($)	Estimated Water Savings in Treated Areas (%)	Typical Application Schedule
Fertilizers	50 to 90	21,000	5%	Monthly
Plant growth regulators	100 to 200	97,500	20%	Based on GDD or Biweekly
Soil surfactants	50 to 200	37,500	20%	Monthly
Colorants	50 to 90	21,000	5%	Monthly
Fungicides	200 to 500	227,500	10%	Biweekly

*Midpoint is the average of the highest and lowest cost per acre. Costs were estimated by talking to superintendents and sales represent atives in the turf industry.

Cost and water savings in the table above are estimates and will vary at individual courses on account of many factors. The potential water savings for each product category noted in this table are not cumulative – applying two products will not necessarily increase the water savings from applying one. Costs assume yearlong use at the schedule in the far-right column, which may not be practical and might exceed product label specifications or logical best use considering issues like preventing the selection of fungicide-resistant pest populations.

While applying the products in this table may help courses save water, we are always faced with the question of return on investment. When making these applications, consider the cost versus likely benefits. For example, applying a soil surfactant or PGR will be a more cost-effective and proven method to conserve water than applying fungicides. The cost-benefit analysis should also include other strategies for water conservation. A course may be able to save more water at less cost using an entirely different approach than making chemical applications.

Improved Turfgrass Quality

Practices such as the application of growth regulators, nitrogen fertilizer and soil surfactants help to improve turf quality. These strategies help superintendents maintain healthier, more-resilient turfgrass that can withstand stress and recover quickly from adverse conditions. The integration of such practices into maintenance routines, along with proper irrigation and soil management, forms a comprehensive approach that maximizes the long-term benefits of improved turfgrass quality.

CONSIDERATIONS

Application Timing

To ensure the best results for any product, it is recommended to begin applications at least one to two months before environmental conditions occur that promote drought stress. It is important to note that recurring applications are necessary for the products in the table above. Additionally, recent research has explored PGR reapplication based on air temperature using growing degree-day models (Kreuser at al., 2017). Research suggests that similar models can be used for other products, as their degradation is also temperature dependent, but more validation is needed (Carlson & Kreuser, 2023).

Record-Keeping and Observations

Maintain a detailed record of all applications – including dates, product amounts, delivery parameters and observations, along with environmental conditions obtained from a weather station. Periodically review the results of the treatment applied. This will help track the effectiveness of the applications and any potential side effects from use. If necessary, adjust the application rates or timing, or switch products based on observations.

An excellent practice is to include a nontreated plot for comparison. This can be accomplished by leaving a nontreated, adjacent strip of turfgrass or by blocking the application in one to two spots with a small sheet of plywood or similar covering.

Nontreated check plots are a good way to evaluate the impact of any application.

Education

New products are continually being developed and existing products are often the subject of ongoing research, especially when there are claims of potential water savings. Continuously educate yourself about the latest research and developments in chemical mitigation for drought stress and water conservation in turfgrass. Attend workshops, regional field days, seminars and webinars to learn about new products, the latest findings and best practices.

Health and Environmental Impacts

All of the products described in this chapter have health and environmental risks if used improperly. To reduce risk, products must be used according to label instructions as well as local, state and federal regulations. Adhere to all requirements for pesticide applicator licenses and additional best practices for use, storage and handling of any products.

Unresolved Technical and Cost Factors

While many chemical products can temporarily relieve drought stress when used preventatively, they should not be a permanent solution. Further, many products have not undergone rigorous testing or evaluation, casting doubt on the veracity of claims. It’s crucial for golf course superintendents to approach these products with caution, ensuring they are well informed about the potential risks and benefits.

TIPS FOR SUCCESS

Sound turfgrass management is the foundation for drought resistance.

Maintaining healthy turfgrass and providing the best possible soil conditions and growing environments is essential for promoting drought resistance. Chemical applications are part of turfgrass management and water conservation, but they are not an alternative to a well-rounded and holistic agronomic program.

Only consider products with claims based on unbiased research.

Plant growth regulators and soil surfactants offer the most potential for water savings among the chemicals used in turfgrass management. Colorants may make it easier to reduce overseeding and therefore water use. Review guides based on scientific literature and consult with technical experts and colleagues to choose suitable products with verified claims.

Using products on larger areas means more potential water savings and higher costs.

Many golf courses currently use some or all of the products described in this chapter, but the applications are typically focused on greens. While decreasing water use on greens may deliver better playing conditions, it will not substantially reduce total water use at the facility because of the relatively small area involved. Applications in fairways and rough have the potential to save more water, but also involve more expense. Keep in mind that as the cost of applications increases, money intended for water-saving efforts may be better spent in other ways.

Timing and application method matters.

An effective product may not yield the desired impact on water use if it is not applied properly or at the right time. Begin applications at least one to two months before drought stress is likely to develop, following label specifications. Pay special attention to post-application irrigation requirements. Products that are designed to improve water movement in the soil typically need to be watered-in thoroughly to achieve maximum effect.

Using a GPS-guided sprayer makes applications more accurate and efficient, which saves time and product.

Consider using a GPS sprayer to make applications more efficient and reduce application costs.

Chemical applications designed to reduce water use or improve drought resistance can be very expensive, especially over larger areas like fairways and roughs. GPS-guided sprayers are more accurate and efficient than traditional sprayers and can help save significant amounts of time and product, especially in large or complex application areas.

For soil surfactants, map and track volumetric water content with soil moisture sensors.

Tracking VWC before and after applying soil surfactants will help you understand how to optimize their use and help you determine when a reapplication might be necessary. Ideally, place sensors in areas that represent typical moisture zones at your course, including areas that tend to be dry or water repellent.

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FUNDAMENTAL IRRIGATION STEWARDSHIP

Managing Golfer Expectations To Help Conserve Water

Raising awareness and building support among golfers is a critical part of any successful water conservation strategy.

SNAPSHOT

This strategy deals with the general relationship between golfer expectations and water use, with emphasis on building understanding and acceptance of the strategies needed to save water. It is a low-cost, potentially high-impact strategy that can be employed at any golf course.

Expected cost	< $25K per acre
Ease of implementation	Additional resources needed
Highest potential impact areas	Nationwide

OVERVIEW

Golfer expectations often dictate how turfgrass is irrigated or otherwise managed. Many golf courses irrigate more than agronomically necessary to meet golfer expectations for aesthetics and presentation. Simply put, the approach to irrigation at many golf courses errs on the side of caution to minimize turf stress and keep playing surfaces dense and green – especially during warm or dry weather. This approach helps ensure aesthetics that engender high levels of golfer satisfaction at the expense of efficient water use. Conversely, deficit irrigation can deliver healthy turf and an enjoyable golf experience at the expense of certain aesthetics.

Golfer expectations also come into play as courses try to manage drought or water restrictions, or implement water conservation strategies like the ones detailed in this playbook. Acute issues like drought can significantly impair aesthetics, and strategies for managing water shortages need to account for golfer expectations and preferences to be successful. Implementing water saving measures like turf reduction or turf conversion can also affect how a course looks and plays. Accounting for expectations and taking steps to encourage "buy-in" from golfers is critical to successfully conserve water.

Golfer expectations are built around established norms, but expectations can be changed.

The USGA has invested considerable time and resources into learning more about what drives golfer satisfaction and has developed a set of metrics to measure it. Through this research, we have unsurprisingly concluded that turfgrass visual quality plays a fundamental role in golfers' experiences. The relationship between turfgrass aesthetics and golfer satisfaction makes periods of drought and significant changes in course maintenance and presentation to conserve water particularly challenging. Yet, there are ways to mitigate these challenges. Understanding what really matters to golfers and what the acceptable thresholds are for playing conditions and aesthetics is an important place to start. Communication is essential. Golfer expectations are built around established norms, but expectations can be changed. There are many examples of golf courses that have dramatically changed water use and course presentation in ways that established a new set of expectations among their customers. This chapter will detail the key drivers of golfer satisfaction, along with strategies for successfully managing expectations to build support for reduced water use.

SCENARIOS FOR USE

Managing Drought and Water Restrictions

Managing golfer expectations is part of any successful effort to conserve water. In cases of drought or short-term water restrictions, a simple and important message might be that changes are necessary temporarily. Golfer experience may not even be affected in the early stages, but proactive communication will be imperative if drought or restrictions endure, and choices need to be made about where limited water resources should be applied. Often, the need for water conservation is not debatable in these situations and the discussion will have to focus on how to achieve goals or mandates. There usually will be a light at the end of the tunnel, regardless of the severity of the short-term disruption, so it can be easier for golfers to adjust their expectations temporarily.

Longer-lasting periods of water shortage will force courses to make increasingly difficult choices. This is where a good understanding of expectations and how golfers view various tradeoffs is critical. For example, most golfers would agree that putting greens should be the top priority for irrigation, with tees and fairways next on the list. Conversely, there's likely not a consensus among golfers about where irrigation should first be reduced. Do you start with clubhouse grounds, the practice range or areas of rough that are out of play? What happens once the "low-hanging fruit" doesn't yield the needed savings?

Along with making choices in where to reduce irrigation, it is also important to explain the overall water conservation plan and its short- and long-term implications. Golfers will want to know how playability and aesthetics will change at various stages in the process. They will want to know how long the changes will last, as well as the plan for recovery after drought or restrictions pass. Depending on the severity of the impact to course conditions, it may be important to emphasize the need for patience in recovery. The course will not return to normal immediately after normal irrigation or rainfall resumes, and it may take months if large areas need to be repaired or reestablished.

Sometimes, the impact of drought or water restrictions varies widely among golf courses in a relatively small area depending on unique site conditions and different local regulations. These differences should be clearly explained.

Mandated water restrictions can have a profound effect on course presentation and playability. It's important to explain to golfers the likely impacts, how long they will last and what will be required for recovery.

Making Fundamental Changes To Reduce Water Use

A separate issue from dealing with transient water scarcity is making fundamental changes to use less irrigation water. These long-term changes will also affect playing conditions and course presentation and golfers may need to be convinced that the changes are necessary. It will be helpful to explain costs and benefits, including with objective demonstrations. Sometimes, these changes involve what golfers would view as a decline in quality. In other cases, there are improvements. However, a golf course may simply be “different” than it was before, without clear positive or negative effects from changes to conserve water.

Regardless of where that balance falls, an effective program of communication to understand and manage expectations is critical to successful water conservation. For example, moving away from a lush, green aesthetic to firmer and drier conditions can save a significant amount of water, and may actually improve playing conditions, but will likely alter aesthetics. Golfers need to understand what to expect to support proposed changes. Many courses have tried maintaining firmer and drier conditions only to have their efforts fail in the face of golfer complaints that could have potentially been reduced with more effective communication. The same applies to bigger changes like large-scale turf reduction or converting playing surfaces to grasses that use less water. These changes can lead to many improvements in the golfer experience, but they can also struggle or fail if golfers are not supportive. In many cases, golfers must approve the spending for something like a new irrigation system or a turf conversion project, so without their support water conservation simply cannot happen.

Converting to drought-tolerant grasses can help courses improve playing conditions and save water, but making fundamental changes to water use can only be successful with golfer support.

CONSIDERATIONS

Understanding What Golfers Want

Through survey research, the USGA has identified five stages of a round of golf that affect golfers' experiences at any facility (Brey & Schoonover, 2020). These stages extend from engagement before golfers arrive, through arrival, during their round specifically, as they prepare to leave and after leaving the facility. Engaging and communicating with golfers before they arrive affords the opportunity to set expectations – especially if drought, recently implemented water conservation strategies or capital improvement projects designed to conserve water may affect their experience. The two stages after the round can be used to further explain important issues that may have affected their round.

Across the five stages, there are over 1,000 touch points that represent a category of golfer experience, including everything from the friendliness of the ranger to the condition of the putting greens. When limiting the focus to the golf stage, the number of touch points is reduced significantly. Turfgrass quality, both aesthetically and functionally, is important to the golfer experience and may be impaired during drought or during construction projects to implement water conservation measures. Water conservation measures may also change what golfers have come to expect from turf conditions, even if the adjustment is not necessarily negative.

The presentation of the golf course is one of the biggest differentiators of golfer satisfaction, exceeded only by pace of play and ranger behavior. Given this, facilities should work to understand how their course conditioning is perceived by golfers, establish a detailed plan to synchronize desired course conditions with water resources and look for opportunities to offset any potential reductions in golfer satisfaction that may come with changes in water use (Pierce 2021, 2022).

Expected Changes In Playing Conditions

The target reduction and duration of a water conservation effort can affect a golf course and the associated golfer experience in myriad ways. Sudden mandates for significant reductions are very likely to impair playing conditions, turf health and course aesthetics. However, even a seemingly small mandated reduction can have the same effects when protracted over a long period of time. It may be more difficult for golfers to conceptualize the slower, but equally detrimental decline in playing conditions and aesthetics that can come from a small but extended water deficit. Well-planned conversions to drought-tolerant grasses can lead to better playing conditions in the long term when courses are faced with extended water shortages, but the new conditions might be quite different than what players have been accustomed to. Reducing the acreage of irrigated turf to make more water available might not change course conditions in the primary playing areas, but it will change how the course looks and plays along the margins of the golf holes.

Because turf conditions and aesthetics are such an important part of golfer satisfaction, it's important to honestly evaluate the expected impact of any water saving program and effectively explain the tradeoffs to the golfers who play the course. Even if improvements in playability are expected eventually, it may take time for changes to mature or for golfers to grow accustomed to the change. This is a common challenge when replacing turf with slow-growing native plants. Some courses may have to reduce water in ways that will unavoidably change or even impair playing conditions and presentation, but there are likely good reasons why that is happening and it is important to tell that story and explain how the facility is working to achieve the best experience possible under the new reality.

It's important for golfers to understand the tradeoffs and potential impacts of various water conservation strategies. (USGA/Logan Smith)

IMPLEMENTATION

Create and Share a Water Use Master Plan

Maintain accurate maps of the golf course and irrigation system that detail your irrigated footprint and expected water use. Confirm expected water use regularly and compare actual use to benchmarks such as the annual evaporative demand and effective precipitation for the property. Don't be afraid to identify areas of the golf course where expected water use could be less, and what would be required to make this a reality. For example, if full-circle irrigation heads or irrigation blocks span areas with disparate water requirements, estimate how much less water could be used with more control over the irrigation system.

Document your water source(s) and any established or expected drought provisions and detail the times of year when playing conditions or aesthetics are likely to be affected by water supply challenges. If you find yourself in a situation of recurring droughts and associated irrigation restrictions, consider implementing permanent water conservation strategies. Make this information available to decision-makers and interested golfers. Whether responding to a mandated reduction or initiating a planning process to fundamentally change irrigation requirements, communicating with key stakeholders is more effective when you are not starting from scratch.

Create and Share a Drought-Emergency Plan

Responding to mandated water conservation is much different than planning to use less water over the long term. A detailed drought-emergency plan for a phased and clear approach to meeting different restrictions – e.g., 10%, 20% or 40% reductions – will ensure that golfers aren't surprised by the impacts. The plan should be flexible and easy to quickly execute when restrictions are imposed to ensure that the course can continue to operate efficiently without compromising critical areas. There are many tradeoffs and choices to be made when it comes to meeting set targets for water reduction. Giving golfers and facility leadership an opportunity to weigh-in on those choices before a drought emergency hits can help to build support for the drought-emergency plan if it ever needs to be implemented.

A drought-emergency plan helps golfers understand which areas of the course will be targeted for water conservation in the event of a drought or varying levels of water restrictions.

Identify and Explain Target Water Savings

Notify golfers of water conservation goals. Define clear, achievable targets and distinguish between short- and long-term needs. Be specific about how much water the course intends to save and why reducing water consumption is important. For some courses it is a matter of cost savings. For others, changes are designed to prepare for future droughts and restrictions. Some courses want to reduce water use purely for playability reasons and not because of any particular shortage. Explaining the rationale for water reduction will help guide decisions on how to achieve it and will build support for the steps taken. Clearly explain the options available for achieving the reductions, as well as how potential strategies will affect aesthetics and playing conditions. For long-term changes, outline how programs like turf reduction or turf conversion will contribute to savings over time.

Take Steps to Minimize Effects on Golfer Experience

Similar to a drought-emergency plan, categorize opportunities to save water and prioritize the strategies and areas that will least affect golfer experience. Initially, the best opportunities will be away from primary playing surfaces and corridors. When identifying "out-of-play" areas for reducing irrigation, use objective tools like the USGA GPS service to map golfer utilization of the course. When water conservation goals dictate that irrigation must be reduced in areas like fairways, using turf colorants can be a good strategy to temporarily maintain the expected aesthetic. When considering permanent changes like turf reduction or conversion, ensure that changes are viewed from a playing experience standpoint and look for opportunities to simultaneously save water and enhance playing conditions.

Demonstrate Water Saving Strategies

Select some test areas to demonstrate potential water conservation strategies and allow golfers to evaluate their performance. This can help adjust expectations and engage people in the process before large-scale changes are made. These demonstrations will also help the superintendent learn about the best way to approach different strategies to ensure a smooth process if it is applied to larger areas. Host workshops or informational sessions to discuss the strategies or technologies being tested and explain what worked and what did not. Provide ongoing updates to ensure that stakeholders feel informed. You can also visit nearby courses that have implemented similar changes to see how they perform on a larger scale and learn from their experience.

This course set up a test area to show how warm-season and cool-season grasses performed under reduced irrigation. Demonstration projects like this one can be a compelling education tool for golfers.

TIPS FOR SUCCESS

Communicate early, often and in different ways.

Keep golfers informed about water use, water conservation efforts, water restrictions and any related changes in course conditions and presentation. Proactively setting expectations and minimizing surprises is essential. Strategically place signs that can educate golfers on measures being implemented and why certain areas of the course may look different. Regular emails, social media posts and newsletters can provide updates, offer insights into any challenges, and outline how changes in water use are achieving the necessary goals.

Be proactive.

Anticipating potential water restrictions and taking early actions to mitigate them is crucial. Many water saving strategies require time and resources to be fully implemented. By implementing measures before they become a necessity, educating golfers about the reasons behind any changes in course conditions, and setting realistic expectations, golf courses can reduce the potential for drastic changes in golfer satisfaction. By communicating transparently and involving golfers in the conservation effort, courses can maintain a positive experience even when conditions are different than what golfers might be used to.

Show golfers the impact of different strategies.

Golfers are more likely to accept changes when they can see and test first-hand how different approaches affect course conditions, playability, and aesthetics. To implement this, a golf course should consider designating specific areas where various water saving strategies can be tested. For example, one hole (or a portion of a hole) might feature a new drought-tolerant turf species, while another could showcase turf reduction or a non-overseeded area. Demonstration areas allow golfers to compare the strategies and gain a better understanding of tradeoffs. It is also an opportunity to showcase improvements in turf health or playability that might not be immediately apparent. Additionally, hosting field days or tours where golfers can walk the course with the superintendent and learn about water saving strategies provides a platform for explaining the reasoning and answering any concerns.

The restoration of Pinehurst No. 2 included a large reduction in irrigated footprint and significant changes in playability and presentation. These changes saved water and also led to positive results from a golfer satisfaction and business standpoint.

Don't be afraid to change expectations.

One of the most important aspects of water conservation on a golf course is recognizing that golfer expectations can evolve, and courses should not be afraid to drive that change. Historically, golfers have been accustomed to lush, green turf, but with water scarcity becoming a more pressing issue, expectations around course aesthetics and playability may need to shift. Successful courses around the country have already redefined their presentation and playability with positive results from a business and water conservation standpoint. When courses communicate effectively, golfers are more likely to accept and even embrace changes. Saving water doesn't have to be negative and could even improve golfer satisfaction and a course's bottom line.

Establish a water use benchmark and goals for improvement.

By first assessing current water usage, turf conditions and golfer satisfaction levels, courses can create a baseline from which to measure the impact of water conservation efforts. Once this benchmark is established, set specific goals related to water consumption and golfer experience. Monitor progress toward these goals to ensure that the chosen strategies are working.

Highlight long-term sustainability benefits.

By framing water saving initiatives as part of a broader, long-term strategy, golf courses can gradually shift the focus from short-term solutions to fundamental changes. Courses should explain how present and future water saving measures help ensure that the course remains viable and enjoyable for years to come, even in the face of future droughts and potential water restrictions. This narrative should include not just environmental impacts, but also financial benefits like lower water bills and reduced maintenance costs that can be reinvested into improving other aspects of the course. Additionally, highlighting how sustainable practices align with industry trends and golfer expectations for environmentally responsible management can elevate the course's reputation. Many golfers, particularly those in younger demographics, increasingly value sustainability. Framing water conservation efforts as part of a forward-thinking, environmentally friendly golf experience may improve golfer satisfaction and loyalty.

BMP CASE STUDIES

"Blogs Provide Effective Communication"

USGA Green Section Record, 2017.

The superintendent at a golf course in Florida uses a blog to keep golfers informed about course conditions and course improvement projects. This has created a direct channel to provide golfers with accurate and timely information so they are not surprised by what they encounter during their round. Some posts are short and focused on timely matters, while others go into greater detail on more complex topics.

"The Benefits of Wetting Agents and Effective Communication"

USGA Green Section Record, 2017.

A golf course in Canada was struggling with wet and dry areas on fairways during the dry summer months. The course had accumulated a deep layer of fairway topdressing that was creating challenges with localized dry spots. The superintendent began a wetting agent program and created an untreated check plot to demonstrate the effectiveness of wetting agents and other applications to golfers. The poor condition of the check plot in comparison to treated areas of the course was a clear demonstration of the effectiveness of wetting agents, fungicides and other treatments. The wetting agent program decreased total water use by 10% during its first year and improved playing conditions and aesthetics.

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SECTION 2

Advanced Irrigation Techniques and Conservation Strategies

Site-Specific Irrigation Scheduling

Using technology like soil-moisture sensors can give superintendents a better understanding of turfgrass water needs throughout a golf course. (USGA/Kyle LaFerriere)

SNAPSHOT

This strategy deals with using weather data and sensors to better estimate turfgrass water needs for irrigation scheduling. It is a high-impact, medium-cost strategy applicable for many golf courses.

Expected cost	< $25K per acre
Ease of implementation	Additional resources needed
Potential water savings for affected area	10% to 30%
Highest potential impact areas	Nationwide

OVERVIEW

One of the most challenging aspects of golf course irrigation is estimating the water requirements of different grasses, under different management regimes and stresses, throughout many different growing environments across hundreds of acres. Varying soil types, sun exposure, traffic patterns and countless other variables affect turfgrass water use in a particular area, and superintendents are inevitably forced to make assumptions about irrigation scheduling. Visually inspecting the course and relying on experience with how turf reacts during different weather conditions is the most basic approach, but leaves lots of room for error and often results in overwatering as superintendents sensibly err on the side of caution. Using a soil probe in representatively wet or dry areas before scheduling irrigation adds information, but the touch and feel aspect of soil sampling is inaccurate and imprecise.

In the past several decades, sensor technology has played an increasing role in golf course maintenance – especially when it comes to irrigation decisions. Many golf courses now have an on-site weather station or at least follow readily available local weather data. Recent USGA and Golf Course Superintendents Association of America (GCSAA) surveys indicate that about half of golf courses use hand-held moisture sensors to guide irrigation decisions (Shaddox et al., 2022; Thompson et al., 2021). However, fewer respondents reported using evapotranspiration (ET) data to schedule irrigation and only 6% of GCSAA survey respondents reported having in-ground soil-moisture sensors, so these technologies are still emerging in terms of their adoption on golf courses. Using sensor technology to enhance a superintendent's understanding of soil moisture and plant water needs has clear potential to improve irrigation decisions over a visual survey of the course, but there are obstacles to adoption. Cost of equipment and data services, and how well certain sensors estimate soil moisture are still challenges. However, research has shown that there is potential to use sensor-based approaches to significantly reduce water use and improve overall turf health and playing conditions. Learning more about these technologies in a turfgrass context and taking results from research settings and applying them to the larger and highly variable environment of a golf course are ongoing efforts. This chapter will review the most common tools currently used to guide site-specific irrigation and will explain the benefits, limitations and ways to implement these tools to advance water conservation goals.

TOOLS FOR SITE-SPECIFIC IRRIGATION

ET-Based Irrigation

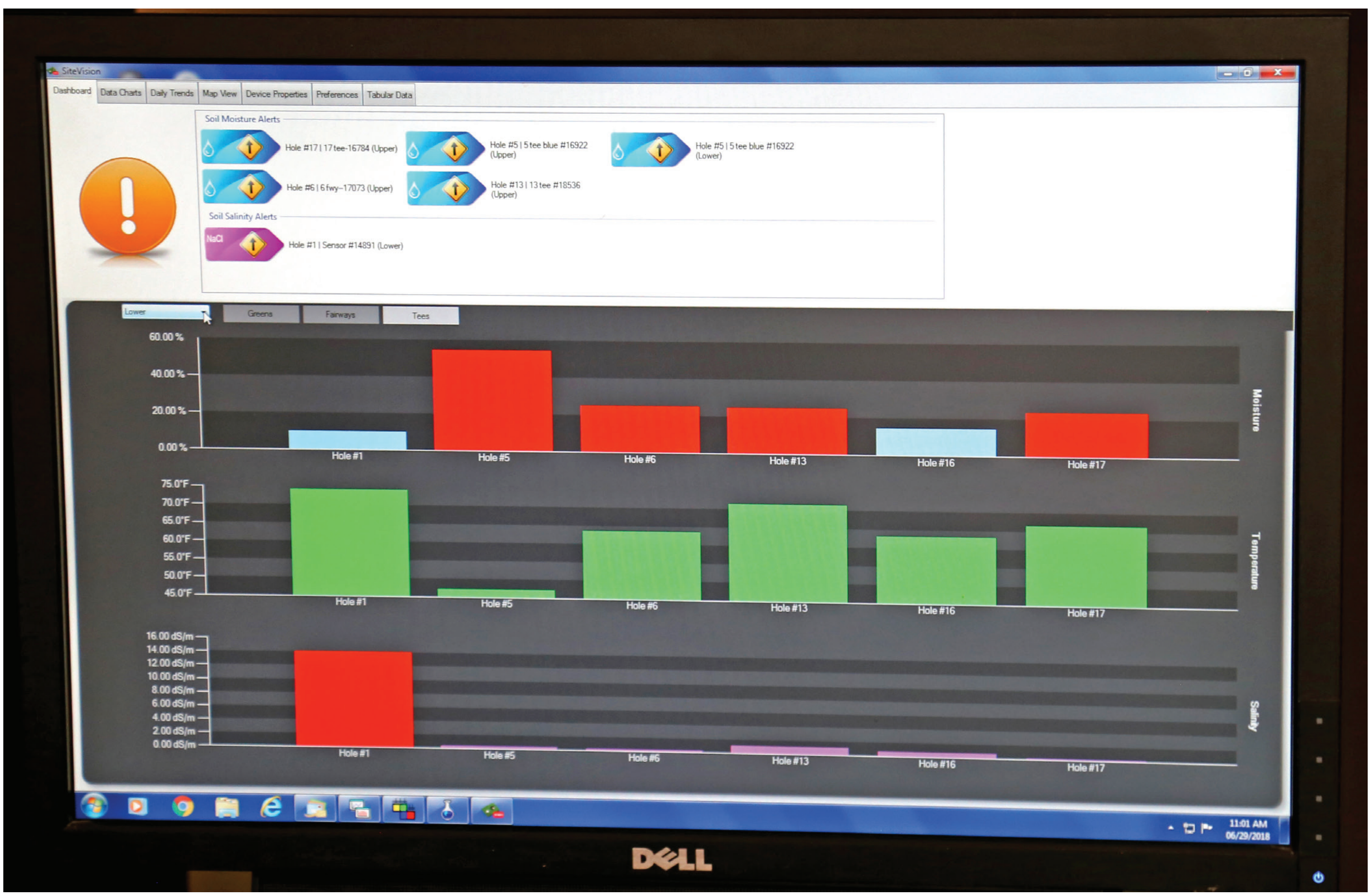
The overarching goal of site-specific irrigation is to precisely deliver only the amount of water necessary for turfgrass growth. Fundamental to this goal is understanding how weather affects turfgrass water requirements. One established method is to schedule irrigation based on ET, which combines estimates of water loss through evaporation from soil and leaves with plant transpiration. By quantifying ET, irrigation inputs can be refined.

To get the most out of ET, it is necessary to appreciate both what it is and what its limitations are. The objectives for this section are to first define and describe ET in simple, everyday language and address common misconceptions and barriers to adoption. We will then discuss key considerations used to refine ET values and maximize their effectiveness as part of site-specific irrigation practices. A key theme to this section is that ET-based irrigation should be seen as a complement to other water-conservation strategies, and that ET data can be used in conjunction with the other site-specific irrigation techniques.

First and foremost, ET-based irrigation is an improvement over runtime- or calendar-based irrigation scheduling as it more precisely incorporates environmental conditions into the amount of water being applied. Furthermore, the inherent flexibility of ET-based irrigation offers the opportunity to adapt a single ET value to different turfgrass species, maintenance practices and microclimates on a golf course. Yet, the adoption of ET-based irrigation on golf courses remains surprisingly low. Less than 20% of respondents from a recent GCSAA survey report scheduling irrigation using ET data from either a weather service or on-site weather station (Shaddox et al., 2022). USGA research indicates that many golf courses still plan to adopt ET-based irrigation scheduling (Thompson et al., 2021), and promoting a practical understanding of ET and associated terminology may enhance adoption.

Soil-Moisture Sensors

Soil-moisture sensors (SMS) have been around for about 40 years, but their use in turfgrass has been primarily in the last 20 years, mostly for scientific research (Bremer & Ham, 2003; Schiavon & Serena, 2023). More recently, SMS have gained traction for use on golf courses, although there is much room for expansion of their use.



In-ground soil-moisture sensors provide data that helps superintendents make more-objective decisions about when and how much to irrigate.

“Controlling an irrigation system without soil-moisture data is like driving a car without a gas gauge,” said Dana Lonn, former managing director for technology at The Toro Company. Using this analogy, when driving without a gas gauge you would tend to fill up your tank earlier than necessary because you don’t want to run out of gas. Similarly, without SMS in turfgrass, most turf managers will irrigate earlier than necessary because they don’t want their turfgrass to run out of water and become drought stressed. The result is often excessive irrigation.

Soil-moisture sensors estimate the amount of water in soil, thus providing the superintendent with data regarding water available to turfgrass plants. This is an advantage over other irrigation scheduling methods such as calendar-based, ET-based, or “look-and-feel” approaches. Because none of these methods use soil-moisture measurements, they often result in improper irrigation amounts and/or timing that wastes water and money. For example, although ET-based irrigation is generally an improvement over calendar-based irrigation, ET values rely on equations that model ET from weather data, and those models are not always accurate. Similarly, factors other than soil moisture may affect the appearance of turfgrass, including pest infestations or abiotic stresses like traffic, soil compaction or nutrient deficiencies. Even obvious wilt may not be for lack of soil moisture. Therefore, turf appearance alone is not always a good guide for irrigation scheduling.

Remote Sensing

Remote sensing is the process of measuring plant characteristics without coming into physical contact with the plants. In turfgrass, remote sensing is typically used to detect stress-related issues, such as the effects of drought, and can be useful for irrigation management. Technically, remote sensing could include standard digital images or videos of turfgrass, such as those taken with a smartphone and evaluated with an app (e.g., to measure green cover), or aerial views from cameras mounted on drones. However, more-complex spectral cameras that measure light reflectance at multiple wavelengths and thermal cameras that measure turfgrass surface temperatures provide additional information about drought and other turfgrass stresses. For example, spectral and thermal cameras may be used to create colorful, detailed maps of stress patterns in turfgrass. Research has shown that these maps can be used to detect some forms of plant stress in controlled settings, including early drought stress in turfgrass before it becomes visible to the naked eye (Hong et al., 2019a & 2019b; Bremer et al., 2023). However, these technologies still have limitations for a large-scale application, including high cost and the potential need for site-specific calibration to improve accuracy.

These technologies should be viewed as an enhancement to the superintendent’s knowledge and experience, not a replacement for it.

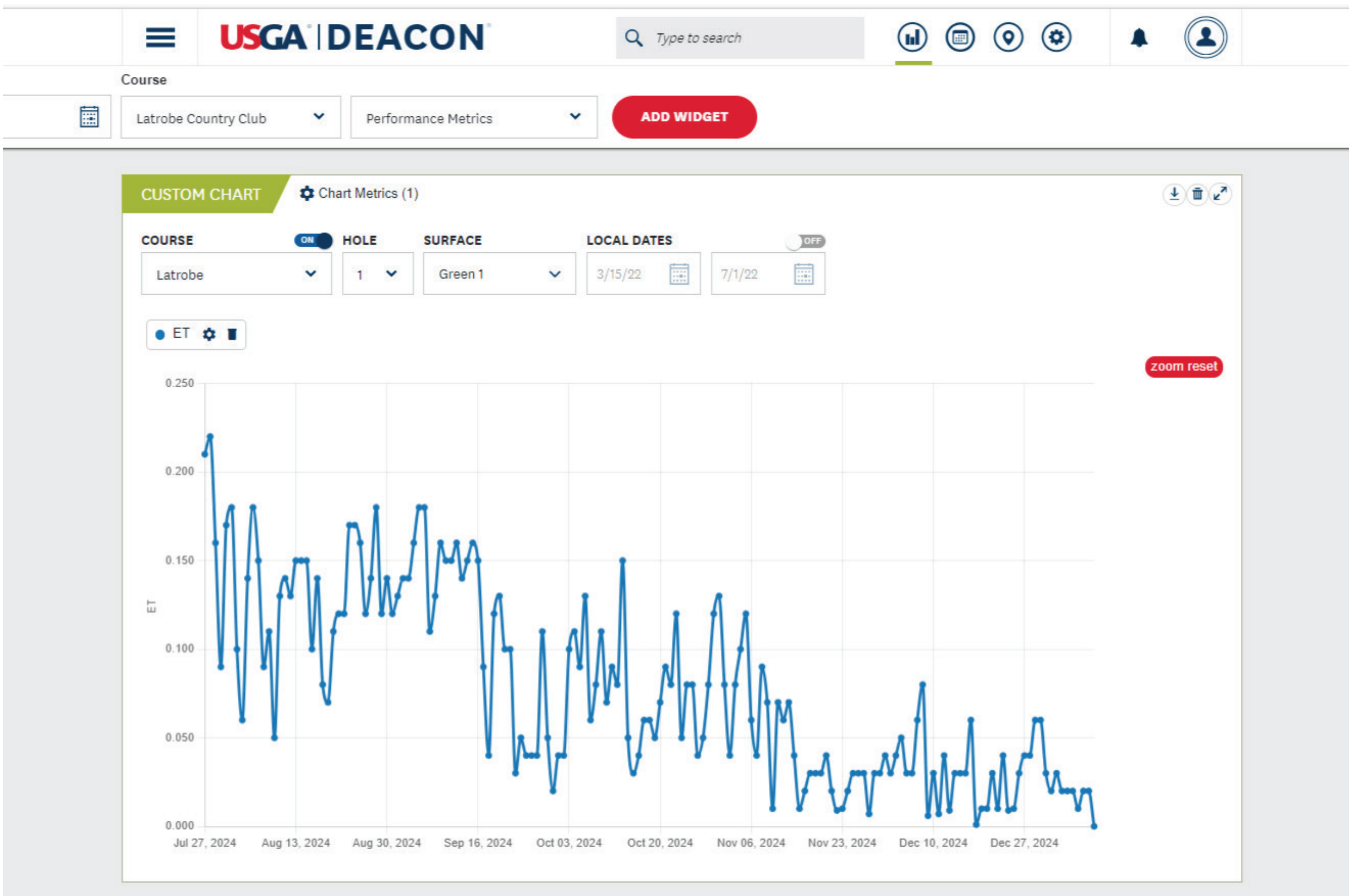
Although remote sensing has been around for about 50 years, it is still considered an emerging technology in golf course and turfgrass settings as it has been used primarily in research. In turfgrass research, remote sensing has typically been utilized with hand-held or vehicle-mounted sensors. However, with the increasing availability and affordability of remote sensing platforms comes a greater ability to evaluate large areas of turfgrass on golf courses (Bremer et al., 2023). Using aerial platforms such as small drones or even data acquired from satellites, turfgrass vegetation and stress maps can be developed relatively rapidly and frequently, providing more timely information for scouting and management decisions. Consultation between the superintendent and a remote sensing specialist may be needed, at least initially, for accurate interpretation of these maps. Nevertheless, there is significant opportunity for more widespread use of remote sensing by the turfgrass industry, including for improved irrigation management.

Summary

Given the increasing water costs and potential limitations in water availability faced by many golf courses, the need for reducing water consumption in the golf industry will continue. Therefore, as ET-based, SMS, and remote sensing technologies are continually improved, their use for irrigation management on golf courses is predicted to increase. These site-specific irrigation tools may be used alone, in tandem, or with other data streams such as weather forecasts. While the ultimate goal is for highly precise and potentially automated irrigation management, the superintendent's input and ability to control the system will remain critical. These technologies should be viewed as an enhancement to the superintendent's knowledge and experience, not a replacement for it.

USING ET-BASED IRRIGATION

ET-based irrigation technology is useful for any type of golf course in any environment, without any particular limitations. It can also be adapted to golf course areas with various irrigation requirements, such as greens, fairways or shaded areas.



Using ET data to guide irrigation scheduling is a proven way to improve water-use efficiency.

In practice, ET data is obtained either from weather services or on-site weather stations. This data is adjusted for cool- or warm-season grasses to better approximate actual turfgrass water requirements. While ET is proven to improve water-use efficiency, adoption on golf courses is still relatively low, likely due to unfamiliarity with the process or misconceptions about its complexity. There can also be challenges adjusting the irrigation control system to properly implement ET-based scheduling, even though nearly all modern systems have the capability. Increasing understanding of ET and its benefits for irrigation scheduling, and integrating it with existing irrigation practices, could lead to broader use and significant water savings on golf courses.

ET Terminology

Evapotranspiration can be measured and calculated with several methods, each offering different ways to represent the water loss from turfgrass systems. Common terminologies used to report and discuss ET are: ET_p, ET_o, ET_{os} and Et_a.

Potential ET (ET_p)

Definition: ET_p refers to the amount of water loss that would occur under ideal conditions with an unlimited water supply, such as from a body of water or a well-irrigated landscape.

Use: ET_p is a theoretical value that assumes no limitations on water availability. It is mainly used as a reference point to understand how much water plants would lose if they had unrestricted access to water.

Measurement: ET_p can be estimated using empirical models that consider weather factors like solar radiation, temperature, wind speed and humidity. Direct measurements and use are less common for ET_p since it assumes unlimited water availability.

Reference ET (ET_o)

Definition: ET_o refers to the amount of ET from a well-watered “reference crop,” which is often a forage crop such as alfalfa or a cool-season grass maintained at a certain height (Allen et al., 1998). It represents the theoretical maximum water loss under current or recent field conditions.

Use: ET_o serves as the baseline for calculating irrigation needs. It is typically reduced by specific percentages to estimate how much water certain turfgrass species would need.

Measurement: ET_o is typically calculated using the same weather data as ET_p. It is often presented in daily or weekly values and is reported in units of depth (inches or millimeters).

Reference ET for short grass (ET_{os})

Definition: ET_{os} is used when ET_o is calculated using a "short crop" reference. It typically refers to the amount of ET from a well-watered cool-season grass (often tall fescue) maintained at or below 4.75 inches. It is a more precise evolution of ET_o that is adapted for turfgrass systems. In practice, ET_{os} and ET_o are often used interchangeably.

Use: ET_{os} serves as the baseline for calculating irrigation needs in turfgrass.

Measurement: Same as ET_o calculation.

Actual ET (ET_a), ET crop (ET_c) or ET turf (ET_t)

Definition: ET_a and ET_c, or less-commonly ET_t, refer to the amount of water lost from a specific turfgrass system, potentially under specific conditions. This value is generally an adjustment from ET_o that better represents water use estimates for cool- or warm-season grasses broadly. It can be more accurate when species- or cultivar-level information is available, or when estimates have been made for specific turfgrasses regionally, seasonally or under different levels of irrigation. Another way to improve ET_a is to more accurately estimate ET_o based on site-specific weather data from several microclimates within a golf course.

Use: ET_a is most useful for site-specific irrigation scheduling when determined in a way that accounts for specific grasses grown in specific microclimates throughout a golf course. It provides a more accurate estimate of water loss based on current or recent conditions, and it is the best ET value for scheduling irrigation.

Calculation: ET_a is calculated by multiplying ET_o by a crop coefficient (K_c), which accounts for the specific characteristics of the turfgrass being grown (e.g., cool-season vs. warm-season grasses). Typically, K_c values are determined through research under controlled conditions.

$$ET_a = ET_o * K_c$$

K_c Values: Generally, warm-season turfgrasses have a K_c value of 0.6, while the K_c value for cool-season grasses is 0.8. These values are only a starting point and can be further refined based on species, cultivars, microclimate and soil conditions. Recently, some studies have looked at seasonal adjustment for K_c values in turf.

ET Measurement

On-site weather stations

On-site weather stations are tools installed directly on a golf course or property to provide hyperlocal weather data that can be used to calculate

An on-site weather station is the best way to obtain ET data that is site-specific to a particular golf course.

ET. These stations allow for real-time, site-specific ET estimation, which can be used to adjust irrigation schedules more precisely.

ET gauges

ET gauges are instruments that mimic water loss from turfgrass systems to estimate ET directly. These gauges are often used for more-direct measurements and can be set up on-site at relatively low cost (around $500). They are helpful for capturing the combined effects of evaporation and transpiration in specific areas. Although popular in the scientific community and for smaller areas, these are typically impractical for golf courses.

Weather networks and ET prediction

State and local networks like AZMET (Arizona), CIMIS (California) or Mesonet (Kansas) provide historical ET_o data. These are typically accurate and reliable values and can be automatically synchronized to the irrigation control system. The National Weather Service (NWS) and National Oceanic and Atmospheric Administration (NOAA) also provide forecasted ET_o (FRET), which predicts ET_o for the next day or week based on forecasted weather data. Research has shown that FRET is a very accurate predictor of ET_o calculated with data from an on-site weather station (Hejl et al., 2022). Although currently limited in use, FRET has great potential to further improve ET-based scheduling.

Where Is the Strategy Typically Used?

On a golf course

On a golf course, ET-based irrigation is typically used to estimate how much water is needed to replace what has been lost through ET to prevent drought stress. In can be used to manage water more precisely across different areas such as greens, fairways and roughs. This is achieved by using data from on-site weather stations or local weather networks to monitor real-time ET rates. Adjustments are made based on specific turfgrass species, microclimates and other localized environmental factors.

Regionally

ET-based irrigation is most commonly used in areas where water conservation is crucial, such as in drought-prone or arid regions like the southwestern United States. In places like Arizona and California, regional weather networks like AZMET and CIMIS provide ET_o data to support large-scale irrigation management. Municipalities, agricultural producers, golf courses and others utilize this data to manage water resources more efficiently.

Opportunities to expand use

There are significant opportunities to expand the use of ET-based irrigation nationwide. While especially crucial in areas where water is increasingly scarce and expensive, ET data is less used in areas that typically don't worry about water scarcity and this should change. As the management of golf courses and other large landscapes becomes more data-driven, integrating ET data with advanced technologies like soil-moisture sensors and remote sensing can provide even more precise irrigation control. Beyond golf courses, expanding this technology into residential and commercial landscaping, parks and sports fields presents a substantial opportunity to improve water conservation on a broader scale.

BENEFITS OF ET-BASED IRRIGATION

Water Efficiency and Savings

ET data is used to adjust irrigation schedules to optimize irrigation for turf health and playing conditions and reduce the risk of overwatering. This approach can lead to significant water savings. Recent research has demonstrated water savings in the 20% to 50% range compared to turfgrass plots irrigated based on a constant runtime, depending on turfgrass species and the environment (Serena et al., 2020).

Site-Specific Adjustments

Using a single ET_a estimate to inform irrigation for a golf course is a mistake. One of the major advantages of ET-based irrigation is the ability to adapt it to the specific conditions of a given site. It accounts for factors like turfgrass species, microclimates, soil conditions and type of playing surface. This allows for more-precise irrigation tailored to the unique needs of different areas on a golf course, which promotes turf health while minimizing water waste.

Data-Driven Decision Making

ET-based irrigation guides decision-making with measurable factors such as temperature, wind speed, solar radiation and humidity to determine how much water is needed. This removes some of the guesswork involved in traditional irrigation scheduling methods, making irrigation decisions more consistent and reliable.

Enhanced Turf Health

By providing a better approximation of water needs, ET-based irrigation helps maintain healthy, high-performing turfgrass. This can prevent common problems associated with overwatering, such as turf disease, waterlogged soils and inefficient nutrient uptake, while helping grass stay as healthy as possible during periods of drought stress.

Flexibility Across Turf Types

ET-based irrigation can be customized for different types of cool-season or warm-season turfgrass by adjusting K_c. This flexibility allows superintendents to fine-tune irrigation amounts based on specific grass species or cultivars, helping optimize water use without sacrificing turf quality.

Integration With Other Technologies

ET-based irrigation can be easily integrated with other water-saving technologies such as soil moisture sensors, remote sensing and smart irrigation controllers. This creates opportunities for even more refined water management, leading to automated systems that dynamically adjust irrigation based on multiple data inputs.

Better Playing Conditions

ET-based irrigation helps superintendents to better estimate the amount of water necessary to sustain turfgrass health on their golf course. Reducing the number of instances where water is overapplied will result in better playing conditions.

LIMITATIONS OF ET-BASED IRRIGATION

Generalization of ET_o and K_c Values

While ET-based irrigation adjusts the ET_o using K_c values, these coefficients are often generalized for broad categories like cool-season or warm-season turfgrass. They do not account for specific species or cultivars. Further, ET_o is commonly calculated and used as a single value, without accounting for variations within a golf course. Superintendents need to refine these estimates based on local conditions to achieve true site-specific irrigation, which can be challenging and requires expertise.

A single daily ET estimate cannot account for the many different microclimates and growing environments on a typical golf course. Scouting is still necessary to assess actual turfgrass water requirements.

Initial Setup Costs

Implementing ET-based irrigation can involve significant up-front costs, especially if on-site weather stations or ET gauges are needed. While national and state weather networks can provide free ET_o data, the most accurate, site-specific ET values come from on-site equipment, which can range in cost from around $500 for basic ET gauges to upward of $12,000 for high-end weather stations.

Complexity and Learning Curve

Despite its benefits, ET-based irrigation can seem complex to those unfamiliar with the technology. Superintendents and staff may need training to understand ET data and how to adjust irrigation schedules accordingly. Misconceptions, such as the belief that ET-based irrigation conflicts with a superintendent's feel for their course, can also act as barriers to adoption.

Weather Variability

ET-based irrigation relies heavily on weather data, which can vary significantly within a region or even across a single golf course. If the ET data used does not accurately reflect the specific conditions of a course, the irrigation schedule may not be optimal. On-site weather stations help address this issue, but they also add complexity and cost to the system.

Adjustment Needs for Seasonal Changes

ET values and crop coefficients need to be adjusted not only for different areas of a course but also for seasonal changes in weather patterns and turfgrass growth rates. For example, warm-season grasses go dormant in some areas during winter, while temperature and moisture fluctuations in the spring and fall can create unique ET challenges. Superintendents must continually monitor and adjust ET data to ensure proper water application all year round.

Weather stations should be placed in representative areas on the golf course rather than hidden near the maintenance facility.

Integration Challenges

While ET-based irrigation systems can integrate with other irrigation management technologies, ensuring smooth integration with existing irrigation hardware, software and weather data systems can be a challenge. Each system must be properly calibrated and maintained to realize the full benefits of ET-based irrigation.

IMPLEMENTATION OF ET-BASED IRRIGATION

One of the most effective ways to implement ET-based irrigation involves installing on-site weather stations that directly monitor weather on the golf course property. These stations provide hyper-localized ET data, which can then be used to fine-tune irrigation scheduling. It may be advisable to install more than one weather station if there are distinct microclimates around the property. Otherwise, estimates of ET will not be as accurate as possible. Weather stations should be placed in representative areas on the golf course rather than hidden near the maintenance facility.

Many modern irrigation control systems can use ET data to control water application automatically. These systems allow superintendents to input ET values and adjust irrigation schedules based on real-time data. This integration reduces manual intervention and makes it easier to optimize water use across different areas of a golf course. It is important to recognize that irrigation scheduling will still need continual refinement based on conditions in the field, regardless of ET integration into scheduling.

TIPS FOR SUCCESS: ET-BASED IRRIGATION

Determine precipitation rates for irrigation zones.

Using ET begins with having accurate precipitation rate information for irrigation zones. Perform regular audits, adjust irrigation system components as needed, and enter any changes into the irrigation control system. Without this information, adjusting runtimes based on changes in ET only perpetuates the guesswork of irrigation scheduling.

Start small and then scale up.

Begin by following ET data and observing how the course changes with consistent irrigation and varying ET. Next, implement ET-based scheduling on a limited part of your course, such as a few fairways, before expanding to other areas. Begin with simpler fairways and then compare the process to fairways with unique or challenging microclimates. Remember that many variables will affect moisture uniformity and the superintendent’s intuition and soil-moisture sensors can further inform scheduling. Refine your process before scaling up to the entire course.

Invest in on-site weather stations.

While regional weather data is useful, on-site weather stations provide more accurate, localized ET values, helping you make better irrigation decisions. Though the up-front cost is higher, the long-term savings in water and improved turf health justify the investment.

Regular calibration of sensors is necessary.

Successful data-driven decision making depends on collecting accurate and consistent data. To optimize ET readings, regularly check, clean and calibrate your weather stations and sensors. This will help avoid data drift, which can lead to over or under watering.

Refine the K_c values used for your course.

Don’t rely on generalized crop coefficients for cool- and warm-season grasses. Customize K_c values based on the specific species, cultivars and microclimates of your course to better reflect the actual water needs.

Use a combination of data sources.

Integrate ET data with other available technologies such as soil-moisture sensors and remote sensing tools. This multisource approach will provide a more complete picture of your turf's water requirements, helping you refine your irrigation scheduling.

Train your staff.

Ensure your team understands ET-based irrigation concepts and how to use the system effectively. Training on topics like ET terminology, weather data interpretation, and irrigation controller adjustments will empower them to manage the process confidently.

Monitor weather patterns regularly and carefully.

Weather conditions fluctuate throughout the year, affecting ET rates. Regularly review weather data to adjust irrigation schedules, and be particularly mindful of transitions during spring and fall when ET rates can change quickly.

Incorporate your expertise, knowledge and feel as a superintendent.

Balance ET data with your experience and knowledge of the course. Use ET-based scheduling as a complement to your feel for the turf's needs, adjusting for localized factors like shade, airflow and soil conditions that data alone may not fully capture.

USING SOIL-MOISTURE SENSORS

When observing data from soil-moisture sensors (SMS) frequently and over time, superintendents will become familiar with how their turfgrass looks and performs at various levels of soil moisture. They learn that at or below a certain level of soil moisture, turfgrass will begin to experience wilt or other undesirable symptoms from drought stress. The soil moisture level at which this occurs becomes a threshold for initiating irrigation. This threshold may vary from one location to another – even within a single green, fairway or rough area – and may change slightly over a growing season and from year to year. Nevertheless, the real-time information provided by SMS becomes invaluable to the water management program.

Managers often build in a buffer, which means irrigating at a slightly higher soil moisture level than the threshold

In-ground soil-moisture sensors help superintendents track moisture trends and identify thresholds for irrigation.

where turfgrass begins to show early signs of drought stress. The amount of buffer will vary based on the superintendent's experience and comfort with visible signs of drought stress on their course. Without a buffer, turfgrass quality may decline over time due to the slight drought stress experienced every time the soil dries to the threshold between irrigation events. Other factors such as soil type, slope, traffic and salinity may affect the desired buffer. For example, sandy soils or south-facing slopes may require slightly greater buffers. A more precise strategy for the development of thresholds is called a "field calibration" and is described in the Tips for Success section later.

Although there are many different types of SMS, dielectric sensors, such as time-domain reflectometers (TDRs) or capacitance sensors, are most common and estimate soil moisture by measuring the dielectric constant of soil, which is highly dependent on soil moisture. The most common type of SMS used on golf courses are portable hand-held units often used to help manage water on putting greens (Whitlark et al., 2023). There are also fixed, in-ground sensors that can be placed throughout a golf course. In-ground sensors have the advantage of providing continuous readings from a consistent location, so changes over time can be easily observed. However, there are practical limits to where and how many in-ground sensors can be placed around a golf course.

Where Is the Strategy Typically Used?

On a golf course

Portable SMS are most commonly used to manage water on putting greens. They are well-suited for this application because of the relatively small area involved and the elevated desire for precision and consistency in putting green playing conditions. Some courses have expanded the use of portable SMS units to tees, approaches and even fairways. While collecting the data across large areas such as fairways is time consuming, golf course superintendents report improved soil moisture consistency and playability resulting from scheduling changes made to individual sprinklers.

The first instinct of new users of in-ground SMS often is to place them in putting greens. While a few in-ground SMS can help generally compare specific greens over time, the flexibility and spatial resolution offered by portable SMS makes them a better fit for the nuances of putting green irrigation. In-ground SMS are better suited for larger areas such as fairways, which are also better targets for water conservation. Because in-ground SMS can't be placed everywhere on a golf course, superintendents must identify locations that are representative of the various growing conditions and playing surfaces on the course. For example, you may want to place in-ground sensors in several fairway locations that tend to get dry, tend to stay wet, or tend to have moderate soil moisture. In that way, the information from a handful of sensors can be extrapolated throughout the course. If the representative dry areas all have inadequate soil moisture, but moderate areas have adequate soil moisture, chances are good that only drier areas of the course require irrigation at that time.

Portable soil-moisture sensors are well suited for use on putting greens because you can take many readings in a relatively small area to optimize watering. (USGA/Kyle LaFerriere)

Regionally

Nationally, about half of all respondents to a recent Golf Course Superintendents Association of America (GCSAA) survey reported using hand-held SMS units, regardless of region (Shaddox et al., 2022). Only 6% of respondents reported using in-ground SMS. Early adopters of SMS in fairways and roughs have been primarily in the southwestern U.S., where water scarcity and costs are a constant factor in golf course management.

Opportunities to expand use

Few golf courses have utilized SMS in fairways and roughs. However, in-ground SMS on fairways and roughs offer an excellent opportunity for the golf industry to reduce water use because these areas make up the majority of irrigated golf course acreage (Gelernter et al., 2015; Whitlark et al., 2023), and there is inherent difficulty in estimating irrigation needs over large areas. Using in-ground SMS in representative locations can be a valuable tool to conserve water and improve playing conditions.

Interestingly, water savings from SMS are often larger in wetter regions and years than they are in arid regions and dry years, indicating that golf courses in all climates can benefit from using SMS. In wetter locations or years, SMS-based irrigation scheduling often increases the duration between irrigation events relative to traditional calendar-based irrigation. The result is more bypassed irrigation events and greater water savings.

In arid regions, reports of water savings among golf courses using SMS are mixed, ranging from 20% less water applied to no significant change. Within an individual golf course, experience has shown that SMS reduce irrigation frequencies or run times primarily in wetter areas, while irrigation scheduling does not change as much in dry areas. Therefore, it is recommended that superintendents in arid regions carefully evaluate the potential for water savings with SMS placement across their course, perhaps in consultation with SMS experts, before implementing an SMS program.

BENEFITS OF SOIL-MOISTURE SENSORS

Expected Water Savings

Turfgrass studies have revealed significant water savings when using in-ground SMS to guide irrigation decisions compared with calendar-based and ET-based irrigation (Cardenas-Lailhacar & Dukes, 2012; Chabon et al., 2017; Dyer et al., 2021). Water savings have typically ranged from 20% to more than 80%, with greater savings typically seen in wetter regions, as discussed above. Most research has been conducted on small plots and residential lawns, but early reports from ongoing studies also indicate significant water savings (24%-46%) on golf course fairways when using in-ground SMS compared to traditional and ET-based irrigation (Straw et al., 2022b).

Water savings should begin immediately after incorporating SMS data into irrigation decision-making. However, establishing thresholds for triggering irrigation and their associated buffers may take a few days or weeks after SMS installation – depending on climate, soils, turfgrass species, superintendent experience and other factors. Furthermore, thresholds will change throughout the year based on day length, sun angle, and other plant- or soil-related factors.

Better Playing Conditions

Using SMS will improve the precision of water management, which will translate to improved playing conditions. Recent research has shown the inevitable soil-moisture variability within and over different fairways from nine traditionally irrigated golf courses (Straw et al., 2022a). Leveraging SMS data is a good way to reduce that variability and improve playing conditions.

The technology associated with SMS is also evolving in ways that will make them even more valuable for optimizing water use on areas like greens, even if the water savings is limited. For example, real-time digital mapping of locations where moisture readings are taken is a valuable feature that helps superintendents understand what areas need water and allows the staff responsible for irrigation to communicate more effectively.

Data from soil-moisture sensors allows for more-precise watering, which leads to better playing conditions and healthier, more-consistent turf.

LIMITATIONS OF SOIL-MOISTURE SENSORS

Sampling Challenges

Soil-moisture sensors can only be used to sample very limited areas on a golf course and there can be a high degree of variability in soil moisture even within a small space. Measurements from portable moisture meters on greens can vary widely within a few inches, and these are taken in areas with relatively consistent soil media and generally more precise irrigation. When you consider the soil and microclimatic variability across large fairway and rough areas, the challenges of sampling are evident. While more data is always better, there are cost and practical limitations to how much coverage SMS can provide across a course. Research has shown that a minimum of three to four samplings per 1,000 square feet would be necessary to sufficiently account for the spatial variability in soil moisture (Magro et al., 2022). Therefore, developing an effective, representative sampling method to establish hydrozones prior to installing SMS is an important challenge to overcome.

Calibration

The data coming from SMS is only useful if it is accurate. Portable and in-ground SMS may require calibration initially and potentially on an ongoing basis, depending on manufacturer specifications. Deterioration of the rods of portable units commonly reduces accuracy and these components must be monitored and replaced as needed. These sensors are exposed to the environment and are also vulnerable to other types of damage that can affect their measurements. Soil salinity is another factor that can affect the quality of soil-moisture estimates. Research has demonstrated that common SMS options accurately track soil moisture up to salinity levels of 4 or 5 deciSiemens per meter (Dukes, 2020; Serena et al., 2020). Higher salinity levels may reduce accuracy of some SMS, so selecting ones that are accurate at higher salinities, or at least can also measure salinity, is crucial in such areas.

Improper Installation and Damage

In-ground SMS must be installed properly to deliver accurate data, but it can be easy to make small errors like failing to fully insert the sensor rods into the soil or not installing sensors at a consistent depth in each location. The risk of minor installation mistakes reducing data quality is something superintendents need to be aware of. Improper installation can also lead to signal loss or poor reception, which ultimately leads to data loss.

Depending on where in-ground SMS are installed, they may also be at risk for damage during aeration. This is especially true on greens, which are aerated on a regular basis. The maintenance team must be aware of sensor locations and will have to either remove them from the ground prior to aeration or use shallower aeration techniques that can pass over the sensors without damaging them. Skipping aeration and other cultural practices in the area around the sensor is not recommended because that can potentially lead to long-term agronomic issues.

IMPLEMENTATION OF IN-GROUND SOIL MOISTURE SENSORS

Using portable SMS is a well-understood process in the golf course maintenance industry. They are most often used on putting greens to optimize soil-moisture uniformity and putting green playability. Portable SMS can also be used to map other areas of a golf course to identify soil-moisture hydrozones and determine where to place in-ground SMS.

Successfully using in-ground SMS involves several decisions and steps, including deciding on the number of sensors to use, selecting a type or brand, deciding whether to use wireless SMS or SMS connected to the irrigation system with underground cables, the depth and location within and among irrigation zones, and field calibrations to develop irrigation thresholds. The assistance of a consultant who is experienced with in-ground SMS is recommended for most circumstances. A good place to start is to install sensors in areas field staff have identified as “wet,” “moderate” and “dry” on several fairways, preferably based on actual soil moisture measurements taken with a hand-held SMS unit. Another consideration is the platforms and software associated with SMS. The ability to view SMS data across locations and time may impact how readily data can be implemented into irrigation decision making.

Within each irrigation zone where SMS are installed, placement must be at a representative location for the data to be broadly applicable.

Placement of Soil-Moisture Sensors Within an Irrigation Zone

In most situations, proper installation of in-ground SMS will require consultation with experts experienced in using SMS in turfgrass. Improper installation of the SMS may result in significant errors in function and accuracy, leading to poor results from the SMS system.

Within each irrigation zone where SMS are installed, placement must be at a representative location for the data to be broadly applicable. The recommended method for deciding on representative locations is to measure soil moisture in a series or grid pattern across each irrigation zone with a portable, GPS-enabled SMS or specialty sensing systems (Straw et al., 2022b). For example, several courses in Arizona used portable SMS to measure soil moisture every 12 paces along lines (traverses) spaced 12 paces apart, yielding 30 to 80 measurements a grid pattern across sampled fairways. Alternately, a protocol developed by researchers at the University of Minnesota recommends collecting data every eight to 10 steps, while following a serpentine pattern through the fairway, for up to 150 measurements per fairway.

Data from this sampling effort can then be used to generate a soil moisture map for each fairway. Specialized software can expedite this process. The range of observed soil moisture across fairways can then logically be divided into three or more sub-ranges for soil moisture classes, and maps should be used to classify each irrigation zone into one of the defined classes. Typically, at least one in-ground SMS should be placed to represent each soil-moisture class.

If this approach is not feasible, then in-ground SMS placement may be determined with teamwork between the SMS consultant and irrigation manager, who should have a good sense about general soil-moisture classifications and representative locations for each irrigation zone. Placement may be more straightforward in zones that are level and have relatively consistent soils. If a zone has undulating slopes or variations in soil type, compaction or microclimate, then SMS placement will be more complicated. At the very least, some type of soil-moisture measurement across these locations would be extremely helpful for guiding irrigation decisions.

If irrigation heads can be controlled individually across a golf course, superintendents can create “hydrozones” in their irrigation programming by grouping the irrigation heads into categories based on the relative wetness or dryness of soils surrounding each head (Straw et al., 2022b). For example, Hydrozone 1 could be fairway heads surrounded by relatively wet soils (high soil moisture), Hydrozone 2 could be those surrounded by relatively dry soils (low soil moisture), and Hydrozone 3 could be those surrounded by relatively average soil moisture (medium soil moisture). More than three irrigation hydrozones may be required to improve precision. An advantage to this approach is that only one SMS per hydrozone might be required, assuming irrigation heads get classified correctly and the soil moisture is similar around the heads in each zone.

If the irrigation heads are controlled in blocks rather than individually, it is recommended that each block of heads be evaluated and grouped with other blocked zones that have similar soil moisture values. Using this method, a single SMS could be used to represent all irrigation blocks with similar soil moisture. While there will likely be some variation in soil moisture within each sprinkler block, the limitations in irrigation control make it difficult to find a better solution. It is not practical to put a SMS in each block of sprinklers and using some SMS is better than using none. A typical number of SMS used across a course is 10 to 30, but the number of SMS required for any given course could fall outside that range. An SMS consultant can help courses find the best solution for their unique site characteristics.

After in-ground SMS are installed, there could be air pockets or lose soil around the SMS rods. The first heavy irrigation or rainfall will help to “seat” soil around the SMS, allowing for proper soil-to-sensor contact. Shortly after installation, it may be worth comparing moisture readings from a portable SMS and in-ground SMS to make sure there are no large discrepancies. Note that moisture values would not be expected to be identical between the two sensors because they are measuring slightly different soil depths and locations. In some instances, it may be necessary to relocate SMS if the superintendent determines they are not representative of soil moisture in their immediate vicinity based on portable SMS measurements and other indicators like visual observations of turfgrass quality. Regardless of location, we recommend that all in-ground SMS on the course measure at the same soil depth.

In-ground soil-moisture sensors should be installed at a consistent depth throughout the course to make measurements directly comparable.

Field Calibration of Sensors

All SMS are calibrated by the manufacturer for accuracy of soil moisture measurements, most likely in a laboratory, before being distributed to customers. However, a number of factors in the field affect the measurements and desired irrigation thresholds compared to what might be found in a laboratory setting. These include soil type, soil compaction, slight variations in SMS installation, and the amount of organic material or plant roots adjacent to the sensors. Furthermore, irrigation thresholds will be impacted by turfgrass species, different microclimates, and cultural practices such as mowing height and aerification. Therefore, it is recommended to conduct a calibration in the field after the SMS are installed to account for these factors. After the field calibration, low value warnings and irrigation thresholds can be adjusted accordingly. This field calibration may be required at least at the beginning of each year and perhaps more frequently if conditions change during the growing season.

Field calibrations are conducted over one or two soil dry-down periods to help determine the soil moisture level at which irrigation should be applied for each irrigation zone. The best approach for field calibration is to begin immediately after a rainfall that fills the soil profile to field capacity. If in an arid region where little or no rainfall has occurred or is expected, then the turfgrass should be irrigated until soils are wet at the depth of the SMS. Using this method, the soil moisture will likely be less uniform than after rainfall, which could affect the precision of irrigation threshold values compared to field calibrations developed after rainfall. Regardless, the irrigation threshold for each SMS should be developed based on the general turfgrass quality desired by the superintendent across the zone.

After the dry down begins, the superintendent should monitor soil moisture values for each SMS and the associated turfgrass quality and appearance across the irrigation zone over the next few days. The soil moisture value at which the turfgrass begins to show signs of wilt or drought stress will become the initial irrigation threshold, although adjustments like added buffers can be made according to the superintendent's comfort level. Turfgrass quality should be carefully monitored during the next few irrigation cycles to determine if the soil moisture threshold needs adjustment. Remember that the absolute value of the threshold will likely differ among hydrozones and may change over time.

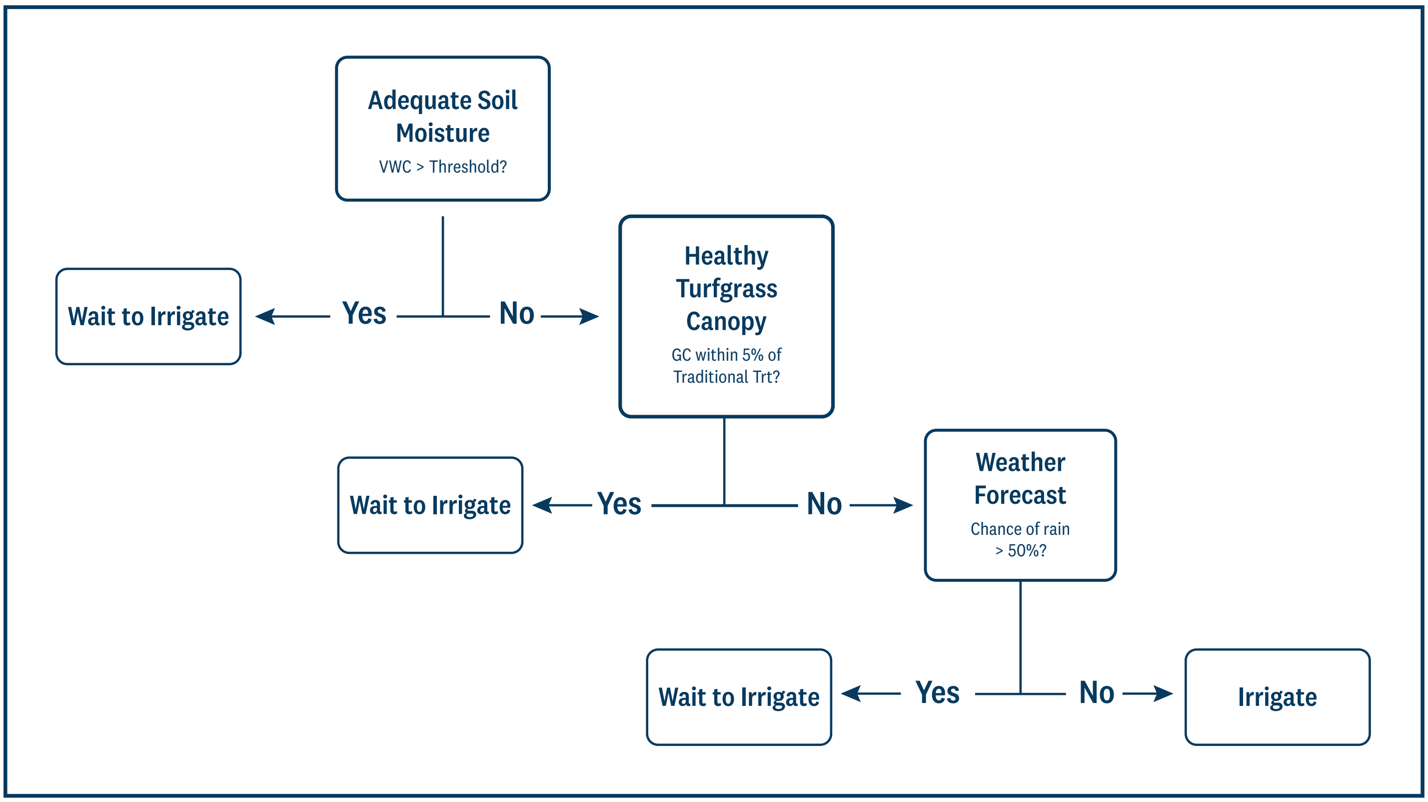
If a slight decrease in turfgrass quality is unacceptable, then a slightly higher threshold or buffer may be necessary. This can be accomplished by adding a few percentage points to the initial soil moisture threshold and continuing to monitor turfgrass quality when using this level as a trigger for irrigation. Incremental adjustments can be made if the first buffer is insufficient to maintain the desired turfgrass quality. Golf courses have found that the threshold will change from season to season and oftentimes a larger buffer is necessary during summer months or in chronically dry areas such as crests of south-facing slopes.

Maximizing Sensor Efficiency

Use a decision tree

If more water savings are desired, the relatively simple irrigation decision tree shown in Figure 1 may be used (Dyer et al., 2021). More research is needed to evaluate this method, but initial results indicate an additional 15% water savings compared with using SMS thresholds alone.

Figure 1: A decision tree for making irrigation decisions based on SMS data and additional criteria.



VWC = volumetric water content; GC = turfgrass green cover; Traditional Trt = traditional well-watered turfgrass. Source: Dyer et al., 2021.

The decision tree requires three criteria to be evaluated before irrigation is applied:

1. Soil moisture declines to the irrigation threshold as described above. Irrigation is then delayed further until a second criterion is met.

2. Turfgrass quality is allowed to decrease to a lower threshold that can be determined in a couple of ways. The most practical way is to set this lower threshold based on the turfgrass appearance at the point of maximum allowable decline. A second way is to set the lower threshold based on a certain percentage of decline in green cover below that of well-watered turfgrass. In Figure 1, a threshold of 5% decline in green cover is used as an example. To utilize this approach, a method for measuring turfgrass green cover is required. There are various apps that can be used. Also, an

area of well-watered turfgrass of the same species and mowing height may be useful as a reference point. Either way, after this second threshold is reached, irrigation is delayed again until a third criterion is evaluated.

3. If the forecasted probability of rainfall is greater than 50% within the next 24 hours, irrigation can be delayed to allow for the possibility of benefitting from rainfall, which could save additional water. The exact forecasted rain probability can be adjusted according to the superintendent's preference.

When using the decision tree, thresholds for the first criteria (soil moisture level) and second criteria (maximum allowable decline in turfgrass appearance or green cover) should be developed cautiously, especially where highly manicured green turfgrass is the expectation. If the turfgrass experiences too much drought stress when these thresholds are reached, the result could be a decline in turfgrass quality over time. Conversely, if greater water savings are necessary and some reduction in turfgrass quality is acceptable, then there may be more incentive to adjust the thresholds to lower levels of soil moisture, turfgrass appearance or green cover, and possibly forecast rainfall probability.

Common Mistakes

Installation issues

Proper installation of SMS should avoid air gaps between the sensor and the surrounding soil. The sensors should also be oriented according to the manufacturer's specifications – e.g., horizontal or vertical placement. Sensors should be installed at the proper depth within the rootzone and at a consistent depth. It is also important to ensure a successful connection with a base station or the internet, depending on whether you are using wireless or buried electrical cable connections.

Improper SMS data is often used for scheduling

A common misconception is to manage irrigation scheduling according to the average soil moisture across all SMS. However, managing irrigation according to average soil moisture is almost always a mistake. It is critical to manage irrigation scheduling according to the SMS that represents each hydrozone, blocked zone or group of blocked zones – not an average of all SMS across the property.

It is recommended that the hydrozones or grouped blocked zones represented by a single SMS be reevaluated several times per year – e.g., seasonally due to changes in sun angle and day length. It is not unusual for the high, medium and low soil-moisture areas to change, especially on courses with tall trees or slopes. While this may not require SMS to be moved, it may require installing additional SMS to capture the changes in soil moisture status.

Damage to SMS during aeration

SMS and any associated buried cables can be damaged by aeration. Marking the locations of SMS and any buried cables with GPS during installation will help to locate and avoid them when aerating turfgrass. Keep in mind that continuously skipping aeration above or near SMS may eventually result in thatch or compaction issues that could significantly alter soil moisture and turf health in those areas. In some instances, less-disruptive aeration immediately surrounding or even above the SMS may be necessary periodically, but at a shallower depth to avoid damage.

It is important to know the precise location of all in-ground soil-moisture sensors to make sure they are not damaged by aeration, drainage projects or other maintenance practices.

TIPS FOR SUCCESS: IN-GROUND SOIL-MOISTURE SENSORS

Using in-ground SMS in large areas like fairways and roughs results in the most water savings.

Large areas such as fairways and roughs account for the most water use on a golf course. It is also difficult to estimate water requirements on these surfaces because there is so much variability in soil type, sun exposure and many other factors. Installing in-ground SMS in these areas, rather than focusing solely on greens, can significantly reduce water consumption across the course and improve playing conditions.

Classify irrigation zones by water needs to create categories of “hydrozones.”

Not every part of a golf course needs the same amount of water. By classifying areas into hydrozones – e.g., wet, moderate and dry – you can strategically place in-ground SMS in representative areas of each zone to monitor soil moisture accurately. The key is to reduce the number of sensors required by using one SMS to represent the average conditions in each zone. However, it's crucial to regularly monitor these zones and recalibrate the zones if needed, especially as turfgrass demands change seasonally.

Field calibration is required for developing accurate irrigation thresholds.

While manufacturers calibrate SMS for general accuracy in a lab setting, the unique conditions on your course can impact soil moisture estimates. Conducting a field calibration immediately after installation is vital for tailoring SMS to your specific site conditions.

Consult with experts to ensure proper selection, installation and setup.

Consulting with an experienced professional during the setup of your in-ground SMS network can help avoid common pitfalls such as improper sensor placement, depth errors or misalignment with irrigation zones. Experts can also guide you in selecting the right SMS model. For courses using recycled or high-salinity water, selecting SMS models that can accurately measure salinity is crucial to ensure the system remains reliable and delivers actionable data under those conditions.

Seasonal adjustments to thresholds will be needed in certain areas.

Turfgrass water needs change with the seasons, especially during transitions from cool to warm months or during periods of high heat or humidity. Regularly reevaluate your SMS settings, including moisture thresholds, to ensure they reflect current turf conditions. For example, during the summer turf may need more frequent irrigation and a larger buffer may be necessary to prevent stress during extended dry periods. Conversely, turfgrass water needs decrease during cooler months, allowing a lower buffer or extended intervals between irrigation events. Additionally, factors like changing shade patterns or seasonal wind shifts can influence how much water is required in different areas. Parts of the course that are dry in one season may become wet in another, so continual evaluation is needed, and sensors may have to be added or moved over time to account for these variables.

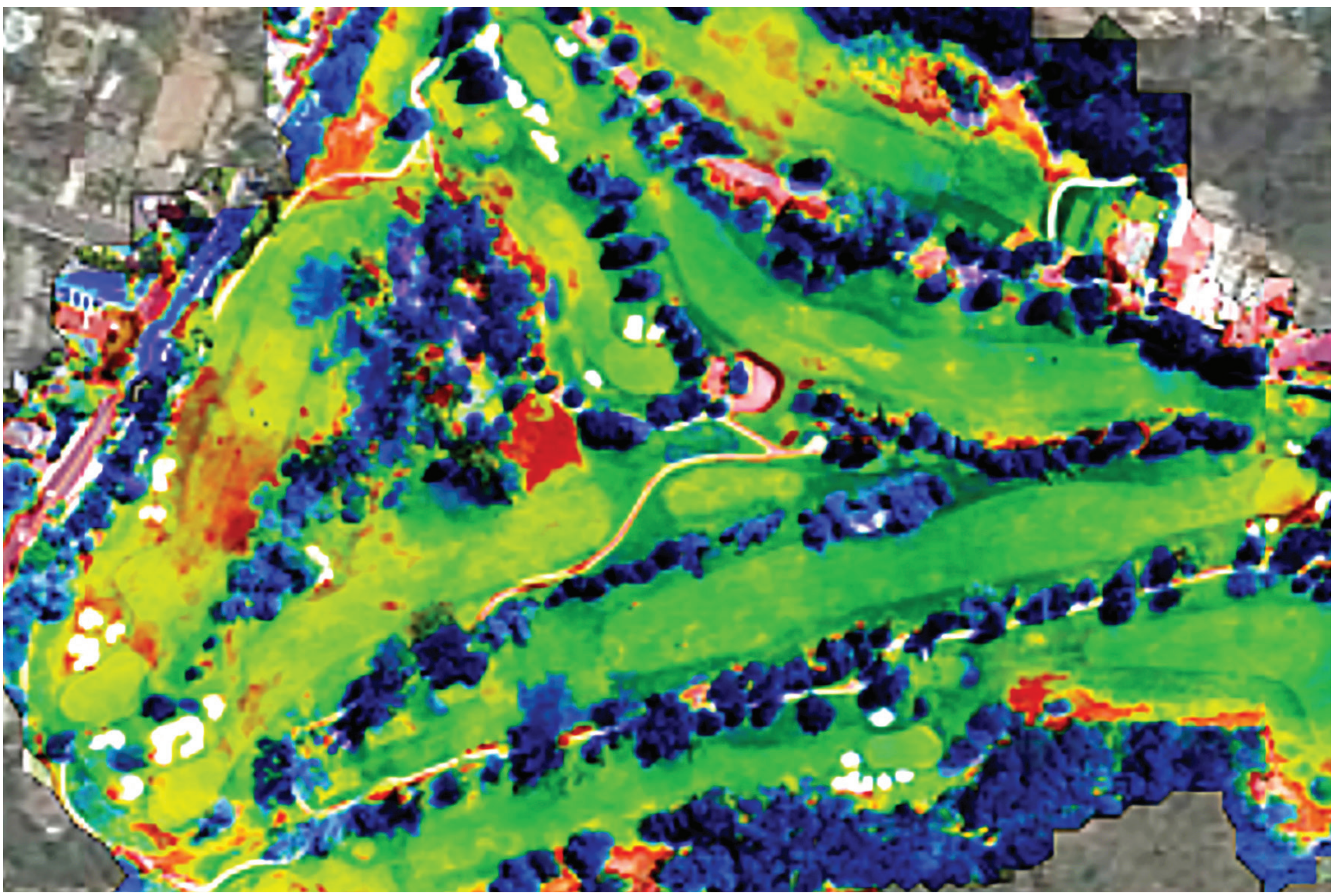
Implement a decision tree for additional water savings.

For superintendents looking to maximize water savings, employing a decision-tree method can save additional water over using soil-moisture thresholds alone by adding criteria like visual turf quality and probability of rainfall. This approach can lead to an additional 15% water savings (Dyer et al., 2021). This is especially useful for courses located in regions where water restrictions or high water costs necessitate extra conservation efforts.

USING REMOTE-SENSING TECHNOLOGY

The use of remote-sensing technology for irrigation management in the turfgrass industry is emerging, with various methods that differ in complexity and expense. The challenge with many remote-sensing tools is that, without continual calibration and "ground truthing," it's difficult to relate data directly to soil moisture, which is essential for making accurate and improved irrigation decisions. Images taken with mobile apps are a type of remote sensing that is relatively simple and inexpensive. For example, smartphone apps are available that estimate green cover of a turfgrass surface. This technology is typically used for fertility management but could also be used to evaluate the effects of drought or other stresses on the reduction in green cover (Patrignani & Ochsner, 2015). This technology could potentially be used in the decision-tree technique described in the SMS section above, where a decline in green cover is required before irrigation is triggered.

It is critical to note that nearly any issue that causes turfgrass stress – e.g., high traffic, soil compaction or pest infestations – may also result in elevated turfgrass canopy temperatures. On pocketed greens with poor air circulation, higher turfgrass temperatures may indicate heat stress rather than drought stress, especially if soil moisture is high. In



Remote-sensing technology can be used to map various indications of turf stress and soil moisture content, but this information must be verified in the field to make the best possible decisions about watering.

this scenario, steps to improve airflow are more beneficial than additional irrigation, but you would not recognize that from the remote sensing output alone. For the foreseeable future, where high turfgrass temperatures are observed using remote-sensing technology, ground truthing is necessary to confirm the cause, whether it is drought related or otherwise.

Hand-held infrared meters or thermal cameras mounted on poles near greens can be used to monitor drought or heat stress and enhance irrigation management. As turfgrass begins to undergo drought or heat stress, transpiration slows and leaf temperature begins to rise, which is detected by the technology. Dry spots on a green that require hand watering can be identified by the colored temperature maps created by these tools – often before stress is visible to the human eye.

Ground-based, vehicle-mounted spectral cameras that measure reflectance indices, such as the normalized difference vegetation index (NDVI), give a scale of relative turf health that can also be used to develop colored vegetation or "heat" maps of a golf course. This can help identify stressed areas of turfgrass prior to traditional methods of scouting. Hand-held NDVI meters are also available for comparative spot measurements between healthy turfgrass and areas of suspected or obviously stressed turfgrass.

Commercial drones with standard, infrared or hyperspectral cameras are increasingly being used in golf course management, including for irrigation scouting. Some superintendents utilize drones themselves, whereas others take a more comprehensive and expensive approach and hire companies to fly drones and create color-coded vegetation or heat maps from acquired data. Spectral images from drones may be useful in detecting drought-stress patterns in turfgrass across a golf course that may not be evident at ground level, such as when irrigation heads are defective or need adjustment.

Hyperspectral and thermal cameras may identify areas of turf stress that are not evident from images taken with a standard camera. This is because spectral cameras measure reflectance, and thermal cameras measure longwave emissions (temperature) from the turfgrass in wavebands outside the visible spectrum. From a practical perspective, these cameras detect important plant properties not necessarily visible to the naked eye (Bremer et al., 2023).

Another important aspect of remote sensing is the frequency of measurements. To identify or monitor early or progressing drought stress – or other issues such as pest infestations – frequent flights are necessary. Daily flights are likely required to collect actionable information and identify trends, but it can be extremely difficult to collect and process data at this frequency. Data from these flights may also be useful for delaying irrigation events, possibly in tandem with soil-moisture sensors. Potential benefits include water savings, directing hand watering staff toward stressed areas of turfgrass, identifying malfunctioning irrigation heads, and detecting other issues such as soil compaction or turfgrass damaged from high traffic.

Maps from frequent drone flights also provide valuable historical records that can be referenced in the future. Some superintendents have benefitted from knowledge gained about problematic areas of their course by using drone-mapping services for one or two years and then discontinuing the service. The decision to discontinue may be based on budgetary or other constraints. However, such a strategy would not likely be useful for identifying or managing any new issues that may appear in future years, whether related to irrigation or other causes of turfgrass stress.

A note about vegetation or heat maps provided by some drone services

Developing these maps requires significant postprocessing, which typically involves uploading images from the drone for the company to create maps and return them, usually within a few hours. Superintendents will likely require some initial training to properly interpret the maps, which contain much useful information but also a significant amount of "noise" that must be filtered out. Also, at present, ground truthing is usually required to understand the specific cause of the stress identified on colored vegetation maps. Colored vegetation or heat maps are useful for identifying stressed areas of turfgrass, but the cause is not necessarily evident from the map. This is true of both spectral and thermal images.

Colored vegetation or heat maps are useful for identifying stressed areas of turfgrass, but the cause is not necessarily evident from the map.

Where Is the Strategy Typically Used?

On a golf course

Remote sensing may be focused on known problem areas that require intensive evaluation or diagnosis – e.g., temperature maps of greens on hot days. Remote sensing can also include mapping the whole golf course on a routine basis, which can help guide broader irrigation management decisions and identify trouble areas that require further investigation.

Regionally

The use of off-the-shelf commercial drones for golf course management is increasing across the U.S. Hiring companies that provide drone-based services for frequent flights and vegetation maps is more common at golf courses with higher budgets.

Opportunities to expand use

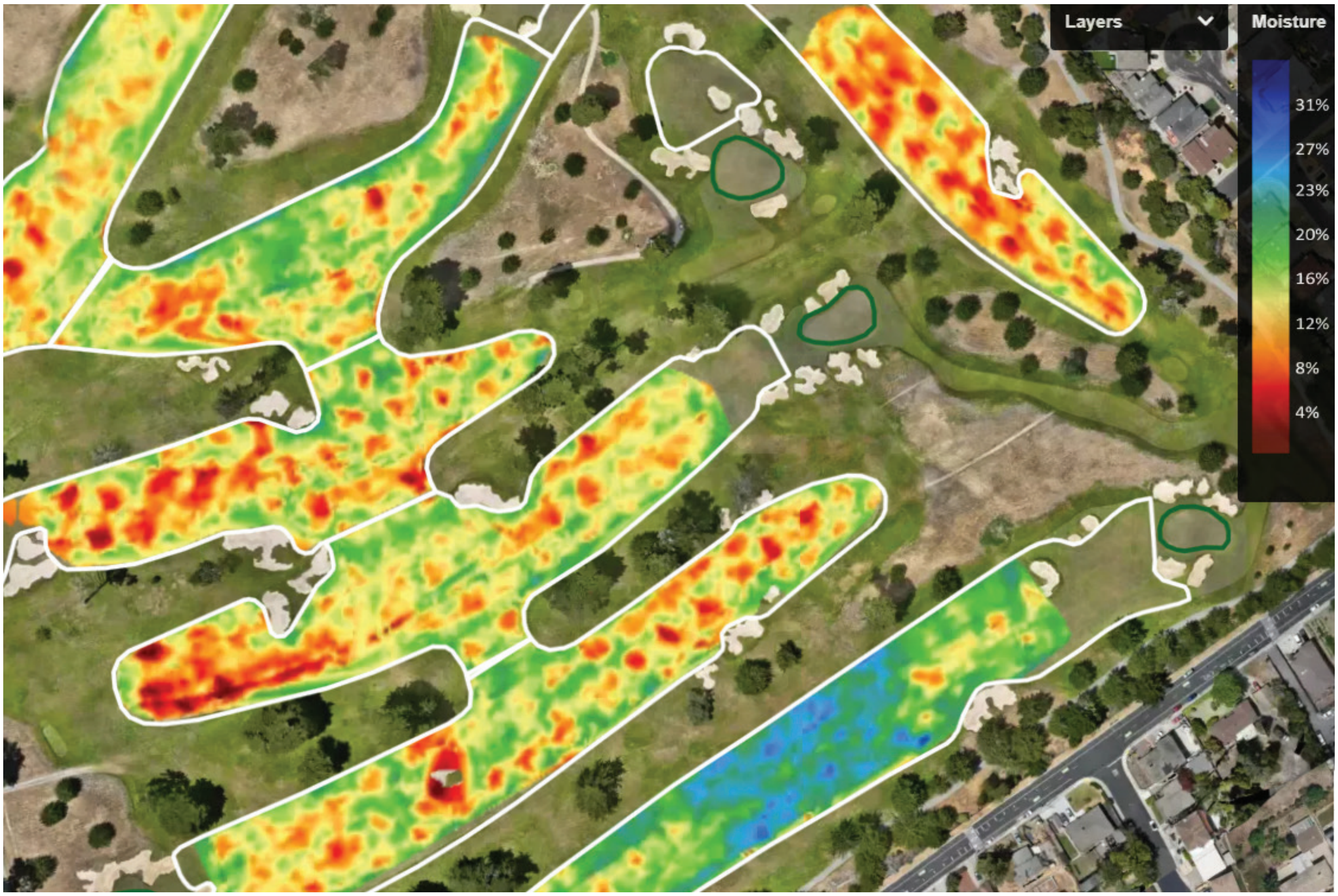
The use of autonomous drone flights with no on-site pilot is an emerging industry. Autonomous drones are available on the market, but federal regulations are still being developed and must be adhered to. Presumably, daily or otherwise frequent autonomous flights over a golf course may become more practicable and affordable in the near future. This approach has the advantage of allowing for increased frequency of flights with minimal staff time required.

The availability and affordability of satellite data is increasing. Satellite data can be obtained periodically during the season, from which turfgrass vegetation and stress or heat maps can be developed. The current frequency and sensitivity of publicly available satellite imagery is a hurdle for the type of precision required in making golf course irrigation decisions.

L-band radiometers, which can be mounted on mowers or other golf course vehicles to map soil moisture, have received much attention recently (Houtz et al., 2023). While the L-band radiometer may hold promise for improving turfgrass irrigation management, more research is necessary before it can be recommended for widespread use.

Ongoing research indicates that, as with other remote-sensing technologies, on-site calibration is required for data to be accurate and useful for irrigation scheduling (Leinauer et al., 2023).

The use of thermal imaging from drones, possibly combined with spectral imaging from drones, may enhance the establishment of irrigation hydrozones. Such images may also aid in optimizing SMS placement within irrigation zones.



Radiometers can be mounted on mowers or other vehicles to efficiently gather and present information about soil moisture. Calibrating and assessing this information with soil-moisture sensor data is important.

BENEFITS OF REMOTE SENSING

Expected Water Savings

Anecdotal reports of 10% water savings have been reported on golf courses that use various remote-sensing technologies, and some companies claim 15% to 20% water savings, but little scientific research has been conducted to validate such claims. Presumably, water savings could begin shortly after implementation of remote sensing applications and last as long as measurements continue. There will be a period of learning in terms of becoming familiar with map interpretation, ground truthing areas identified as potentially drought-stricken on maps, and developing irrigation management practices based on data from the maps. This process may require consultation between the superintendent and a remote sensing specialist.

Improved Scouting

One of the primary potential advantages of remote-sensing technologies as they currently stand is improved scouting. It is possible to gather information about large areas of the course in a relatively short amount of time, and to potentially see problems and patterns that may not be visible to staff on the ground. However, routine scouting by the staff will still be necessary for the many issues these technologies cannot detect, and any potential problem spots identified through remote sensing will have to be visited by staff to diagnose the issue. There will also be an ongoing process of calibration and ground truthing the imagery that comes from remote-sensing technologies, which is an added step.

Ease of Use and Implementation

Ease of use will depend upon the form of remote sensing being implemented. Smartphone apps to identify reductions in green cover are relatively simple and could be used by anyone with a smartphone. Using drones with standard video cameras requires a drone and an experienced pilot with an Unmanned Aircraft Systems (UAS) license. Such a license from the Federal Aviation Administration (FAA) is required when flying drones for any commercial purpose, including evaluating the condition of turfgrass by a golf course superintendent using their own drone. Using drones equipped with spectral and thermal cameras have the same legal requirements, but in most cases will also require some postprocessing of data. Typically, this would be accomplished by hiring a company to make flights with the appropriate drones and return the colored vegetation or temperature maps (and their interpretation) to the superintendent. In general, using remote sensing technology is fairly simple if the budget is available. Interpreting and acting on the information is often the bigger challenge.

LIMITATIONS OF REMOTE SENSING

The Technology is Relatively New in Golf

The use of remote sensing for irrigation management in turfgrass is emerging. Spectral and thermal cameras, both ground and aerial, have been used widely in turfgrass research and have been very effective at identifying drought stress in controlled settings (Bremer et al., 2023). Ongoing research is being conducted to develop specific guidelines for irrigation management on golf courses using remote sensing, but much work remains to be done (McCall & Roberson, 2022). Early results in some of these studies have not shown a strong relationship between known soil moisture and estimates from certain technologies, so golf course superintendents must be cautious about product claims at this point in the development and application of remote-sensing technology in golf course maintenance (Isom, 2024).

Physical and Legal Restrictions

Drones have performance and legal limitations that may affect the ability to utilize remote sensing at a desired time and location. For example, drones cannot be flown during windy or rainy weather. Flights may also not be allowed over residential areas or within 5 miles of airports or controlled airspace without authorization from the FAA and possibly local authorities as well.

Drones with spectral or thermal cameras have additional limitations (Bremer et al., 2023; McCall et al., 2022). These flights should not occur during periods of intermittent clouds, which can diminish data quality. Flights should also be limited to midday, when the solar angle is highest. Flights during low sun angles or periods with wet turfgrass surfaces may result in diminished data quality. Maps may contain significant "noise," such as tree (and even turfgrass canopy) shadows, mowing patterns that affect light reflectance and mowing height variations that can make interpretation difficult. The assistance of a remote-sensing specialist will be helpful in differentiating the signal from the noise. Data from satellites may also be unavailable during periods with cloud cover or when the satellite does not pass over a given golf course at the desired time.

Ongoing research is being conducted to develop specific guidelines for irrigation management on golf courses using remote sensing, but much work remains to be done.

Image Resolution

Image resolution increases from satellites to small drones to ground-based vehicles and higher resolution results in finer detail and more-actionable information. For example, resolution from satellites may be as low as 100 square feet per pixel, but newer low-Earth-orbit satellites may have resolutions closer to 11 square feet per pixel. The image resolution of maps derived from drone data can be in the range of 1 to 3 square inches, while ground-based vehicles may offer sub-inch resolution. High-resolution images from drones and ground-based vehicles generate large files that are good for turfgrass research, but data processing time could be a bottleneck for field applications, especially if data must be uploaded for analysis and limited bandwidth is available (Bremer et al., 2023). Consulting with a remote sensing specialist is recommended to determine appropriate image resolution for the purposes of irrigation management.

IMPLEMENTATION OF REMOTE SENSING

For most golf courses, using remote sensing will require the assistance of an experienced consultant, at least initially. The consultant provides expertise in remote sensing applications and interpretation of data, but the superintendent's knowledge of the golf course and ability to ground truth potential issues identified on maps is also critical.

The use of remote sensing for golf course water management is in its infancy, so few specific protocols have been developed for successful application. However, the following are a few strategies a superintendent could consider. In each of these strategies, consultation with a remote sensing specialist is advised to guide selection of sensor type, spatial resolution requirements and whether to use aerial, ground or hand-held devices to collect measurements. A consultant can also help the superintendent accurately interpret the data, determine the optimal frequency of measurements, develop thresholds for irrigation and help calibrate the sensors.

Initially, scouting the entire golf course using remote sensing may be useful to identify areas of turf that may be under or over watered, or that are suffering from some other type of stress. A rudimentary survey could be conducted using a drone equipped with a standard video camera to view the golf course from an aerial perspective. A more detailed evaluation could be conducted with spectral or thermal cameras mounted on a drone or a ground vehicle. If only one survey is possible and water management is the focus, ideal timing would be during a period of high drought stress when limitations in the irrigation system and water management program would be most visible. If additional surveys with a drone or ground vehicle are conducted, which is recommended, the series of maps will help evaluate the mitigation or progression of drought stress or other turf stressors. Such maps can also be used to modify irrigation scheduling, improve soil moisture consistency, conserve water and improve playing conditions.

Imagery from aerial drones can identify areas of turf stress and potential irrigation issues, making scouting more efficient.

If surveying the entire golf course with remote sensing technology is not feasible due to budgetary or other factors, then remote sensing could be used to target areas of concern or areas that may have known or suspected drought-related issues. For example, using hand-held or pole-mounted infrared cameras on greens can identify specific hot spots for hand watering, which could conserve water.

Using remote sensing data in combination with other sensors, such as SMS, can help confirm whether drought stress is truly affecting turfgrass (Bremer et al., 2023). For example, when remote sensing indicates the turfgrass is under some type of stress and a SMS in the same vicinity indicates the soil is relatively dry, then most likely the turfgrass is experiencing drought stress. Weather data could also be used to confirm if drought stress is the likely problem, such as during windy and hot conditions with high rates of ET or when rainfall has been insufficient.

Golfer Impacts

The effects of implementing remote sensing should be minimal on a golf course. If drones are used, it may be desirable to avoid flights during times of heavy play and to avoid flying over people for safety purposes. Drones can illicit varying responses from individuals and may evoke privacy concerns, so communication with golfers about what information is being collected is important to alleviate any concerns. Golfers may also be interested in how new technology is being used on the course and the imagery is often visually appealing, so remote sensing can be a good chance to educate golfers about various golf course maintenance efforts, including water conservation.

TIPS FOR SUCCESS: REMOTE SENSING

Set clear goals for water conservation.

Begin by identifying the specific outcomes you want to achieve with remote sensing technology. Whether your aim is to detect drought stress, monitor overall turf health or optimize irrigation scheduling, understanding these goals will guide your approach. For example, if you are primarily concerned with spotting early signs of drought stress, you may want to choose specific tools like thermal cameras or NDVI sensors that offer real-time insights into turf stress levels.

Know and adhere to all drone regulations.

Drones offer immense potential for collecting aerial data, but it’s crucial to understand the legal and technical limitations. Ensure that your drone operations comply with local and federal regulations, such as obtaining an FAA UAS license for commercial flights and following registration requirements. Be aware that drones cannot fly in certain conditions, like high winds or rain, and they may require special permissions when operating near airports or populated areas. They also have strict altitude limitations and require special lights for operation around dawn and dusk.

Validate remote sensing data with ground truthing.

Remote sensing technology can provide valuable information about large areas in an efficient manner, but it's important to "ground truth" the data to ensure its accuracy. For example, if remote sensing detects areas of potential drought stress, cross-check that data with soil moisture sensors or a standard soil probe to confirm whether the issue is related to water stress or other factors like compaction or disease. Inconsistency in the environment and in the technology can lead to discrepancies between remote sensing data and actual soil moisture, so it is important to verify conditions on the ground before making irrigation decisions.

Choose the right tools.

Different remote sensing tools serve different purposes, from smartphone apps that assess green cover to more advanced drones equipped with thermal or spectral cameras. Select the tool that best aligns with your course's needs and budget. For example, if you need high-resolution data across large areas, a drone equipped with an NDVI sensor may be ideal. For spot checks of specific turf areas, hand-held infrared temperature meters or thermal cameras may suffice.

Measure as frequently as possible for better data.

Remote sensing is most effective when used regularly. Frequent measurements, whether daily or weekly, help detect the onset of stress or other issues like disease before they become visible to the naked eye. This proactive approach allows you to address problems early, reducing the need for drastic corrective measures. If using drone flights or satellite imagery, plan for regular data collection to create a historical record, making it easier to track trends and respond quickly to emerging issues.

Work with experts to ensure accuracy.

Remote sensing generates large amounts of data, which can be difficult to interpret without expertise. Work with a remote sensing consultant or specialist to ensure your data is correctly calibrated and that maps or imagery are processed accurately. Specialists can help filter out "noise" and make the data more actionable. They can also assist in identifying key trends that can lead to improved irrigation strategies or turf health management. University researchers or other independent scientists will be an important resource. Relatively little research has been conducted on using remote-sensing technologies in turfgrass management or has shown the direct efficacy of most remote-sensing technologies for irrigation scheduling improvements outside of controlled research settings.

Build a record of historical data.

Over time, the data you gather through remote sensing creates valuable historical records that can be used for future planning. By analyzing trends, such as recurring stress patterns in specific areas, you can anticipate problems before they arise and adjust your management practices accordingly. Historical data can also be used to justify resource allocation, adjust irrigation infrastructure or optimize playability across the course.

University researchers and other independent experts are studying remote-sensing technology for use in turfgrass management. Their insight is valuable if your course is thinking about using this technology. (USGA/Bill Hornstein)

BMP CASE STUDIES

"Five Proven Methods to Improve Moisture Uniformity"

USGA Green Section Record, 2021.

A golf course in Palm Desert, California, has been using in-ground soil moisture sensors for more than five years. The superintendent installed four sensors across 40 acres of fairways on one golf course. The sensors were placed into representative "dry," "moderately dry," "moderately wet," and "wet" areas determined by mapping the fairways using the Toro PrecisionSense 6000 system. The turf care team reviewed sensor data daily, in addition to scouting and monitoring ET data, to schedule irrigation. This strategy has yielded more-consistent moisture conditions across fairways and roughs, and has resulted in 10%-14% water savings, which translates into an additional savings in electrical costs associated with pumping.

"Moisture and Salinity Monitoring Through In-Ground Sensors"

USGA Green Section Record, 2015.

In-ground sensors that measure soil moisture, soil temperature and soil salinity were installed strategically throughout Prestwick Country Club in Myrtle Beach, South Carolina, in areas designated as wet, dry, or average moisture. Upgraded irrigation control software displays real-time soil moisture readings from the sensors in an easy-to-read format and allowed each sprinkler head to be correspondingly designated as wet, dry or average. Prestwick's golf course superintendent reported that overall turf conditions improved with the addition of this technology and that the course is seeing about a 25% savings in both water usage and electricity consumption to run the irrigation pumps.

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Grassing Strategies for Golf Course Water Conservation

Turfgrass conversion has helped many golf courses save water, but there are a lot of variables to consider and patience is necessary to achieve the desired results.

SNAPSHOT

This strategy deals with establishing turfgrasses that use less water and reducing winter overseeding. It is a high-impact, high-cost strategy applicable to many golf courses, especially where warm-season grasses are well-adapted but not in use.

Expected cost	$25K to $80K per acre
Ease of implementation	Large capital project
Potential water savings for affected area	10% to 30%
Highest potential impact areas	Western and southern U.S., and throughout the transition zone

OVERVIEW

Grass selection is a fundamental part of successful golf course management. Different grass species – and even different cultivars of the same species – can have a significant impact on the maintenance requirements, aesthetics and playability of a golf course. The availability of improved turfgrass cultivars, changing weather patterns, and shifting priorities in playing conditions have led many courses to make grassing changes in recent years. Increased use of warm-season grasses in dry and transitional climates is a great example. Water conservation is a primary driver of this trend, but better playing conditions for more of the year is also a key factor.

When it comes to saving water through grassing changes, rough and fairway areas offer the greatest opportunity simply because of how large they are. Renovation costs can be high and there will be downtime when play is not possible, but converting from cool-season to warm-season grasses routinely yields at least a 25% reduction in water use in converted areas. Where water is expensive, the investment in turf conversion typically pays off in seven to eight years. There also may be an opportunity to reduce water use where warm-season grasses not specifically developed for low-water-use characteristics are already in use, and the relative benefit will vary regionally and based on irrigation strategies.

Winter overseeding of warm-season grasses should be avoided whenever possible, as it dramatically increases annual water use and impairs playing conditions outside of the overseeded period.

The potential water savings that comes with converting from one cool-season turfgrass to another is lower than converting from cool-season to warm-season grasses, but there is still significant value in considering the water-conservation benefits of newer and improved cool-season cultivars (Braun et al., 2022b). Even without substantial water savings, establishing drought-resistant cool-season cultivars in areas such as bunker faces can improve irrigation and maintenance efficiency by reducing the need for time-consuming hand watering and deliver better turf conditions. Other benefits include better heat, drought and disease resistance, which all mean better turf conditions throughout the primary playing season, and potentially significant savings through reduced pesticide applications that can pay for the cost of the project within several years.

SCENARIOS FOR USE

Where Is the Strategy Typically Used?

Converting to improved or better-adapted turfgrass cultivars is an effective strategy for golf courses seeking to reduce water use, improve playing quality, or both. Turfgrass cultivars are available to enhance the drought resistance of any playing surface. However, fairways are a common target for conversion because they have a larger footprint than putting greens or tees and a relatively higher expectation for management than rough.

Warm-season grasses are more drought-resistant, have lower water requirements than cool-season grasses and are well suited for warmer climates, making them a viable option for regions with hot summers or prolonged dry periods if winters aren’t too cold. Newer cool-season grasses with improved disease and drought resistance can reduce pesticide and water use, while also improving playability. Growth habits impact how a specific turfgrass deals with drought and is an important consideration. When irrigation is unavailable, turfgrasses like bermudagrass or Kentucky bluegrass that spread via rhizomes and/or stolons recover better from dormancy after prolonged drought. Turfgrasses also respond differently to deficit irrigation, a common strategy to reduce water use.

Golf courses in warm and dry climates have saved considerable amounts of water by converting large areas like fairways and roughs from cool-season to warm-season grasses.

Opportunities to Expand Use

While some golf courses have adopted newer drought-resistant grasses, there are many more courses that can still benefit. Opportunities exist to expand the use of improved warm-season grasses to more regions, especially as breeding efforts continue to improve the cold-tolerance of these grasses. There are also many areas in the southern U.S. where bermudagrass cultivars from the 1950s and 1960s continue to prevail. Newer bermudagrasses have lower water-use rates than these older industry standards. Where warm-season grasses are not plausible, but water conservation is required or desired, thoughtful selection of drought-resistant cool-season grasses is critical.

The biggest impediment to courses saving water through turf conversion is not a lack of grassing options, it is the understandable reluctance to incur the cost and extended disruption associated with making the conversion. Optimizing regrassing processes and educating courses about the potential return on investment are both important aspects of helping more courses save water through turf conversion.

BENEFITS

Expected Water and Cost Savings

Converting from a cool-season to warm-season turfgrass will achieve the most-significant water savings. At least a 25% or more reduction in water use can be expected in converted areas (Whitlark, 2022; Whitlark et al., 2023). Comparatively, savings of 10% to 20% can be expected from establishing a drought-resistant cool-season grass, or similarly, replacing an older warm-season grass with an improved, drought-resistant cultivar (Amgain et al., 2018; Ketchum et al., 2023; Minor et al., 2020; Serena et al., 2023). Actual savings will vary depending on differential water use between existing and new cultivars and various site conditions.

For courses with high water costs, such as in the southwestern U.S., the savings associated with using a cultivar that requires less irrigation can help the project pay for itself in a relatively short period of time. Many conversions can pay for themselves in just a few years (Minor et al., 2020), and even multimillion-dollar projects can break even in less than eight years, especially when considering other cost savings from improved cultivars such as reduced fertilizer and pesticide use (Whitlark, 2022). Turfgrass conversion projects have a range of costs and the ultimate payback period for any project will mostly vary depending on grassing method, management costs of the old and newly established grass and lost revenue during the project. In unique situations, some golf courses have creatively limited course closure during regrassing, reducing their payback period to less than two years (Jacobs & Gross, 2019).

Converting from a cool-season to warm-season turfgrass will achieve the most-significant water savings.

Better Playing Conditions

One of the biggest motivations for converting to grasses that use less water is the prospect of better playing conditions. Using cool-season grasses in areas with hot summers often means there will be higher water use and softer conditions through some of the primary playing season. Converting to grasses that use less water and are more drought-resistant means playing surfaces can be kept firmer and healthier during these times. The risk of disease and turf loss is also higher with frequent irrigation and when grasses are otherwise stressed, so converting to improved cultivars usually means better consistency.

Courses that have an evolved mix of various grasses on a particular playing surface will also realize improved playing conditions with a uniform stand in converted areas. Aside from potential differences in growth rate or habit, each of the different grasses in mixed stands tend to struggle the most during different seasons, leading to ongoing inconsistency throughout the year. Mixes of cool-season and warm-season grasses are especially challenging and can also complicate general turfgrass management considerations.

Addressing Salinity Problems

One of the most difficult challenges in turfgrass management is dealing with soil and water that are high in salts. Water quality problems are common in the arid and semiarid regions of the U.S., but also appear in humid areas like Florida. Further, coastal areas and anywhere recycled wastewater or an impaired well is used for irrigation will likely deal with water quality issues at some level. Competition for potable, non-potable and recycled water resources has changed turfgrass management and irrigation practices in many areas.

Using grasses like seashore paspalum (pictured here) has allowed courses in some areas to utilize lower-quality water sources that may be less expensive or more available than other options.

As a result, salt tolerance has become a more important consideration for turfgrass selection. Warm-season turfgrasses are generally more tolerant of lower-quality irrigation water sources. Therefore, in addition to simply requiring less water, converting from cool-season to warm-season grasses can help a course reduce total water use and improve maintenance efficiency by making better use of lower-quality water sources. This could mean using recycled irrigation water when it would have previously been difficult, or it could mean less need for leaching irrigation events to mitigate salt accumulation. Within warm-season grasses, there are species such as seashore paspalum, that better tolerate higher salt content in irrigation water. Similarly, salt tolerance can differ greatly among cultivars within species and care should be taken to review relevant research if salinity is a consideration during a regrassing project.

CONSIDERATIONS

Selecting the Right Turfgrass

When selecting a turfgrass, the intended playing surface, local climate and soil conditions as well as irrigation needs and resources are most important to consider. Several resources are available to help identify the turfgrass species and cultivars best suited for a situation. The USGA Green Section, university extension programs, the National Turfgrass Evaluation Program (NTEP), the Turfgrass Water Conservation Alliance (TWCA), or the Alliance for Low Input Sustainable Turf (A-LIST) provide extensive research results for all major turfgrass species.

Identifying which grass options will perform best and establishing an in-house trial on the course with several cultivars is an excellent way to make a final decision. This also allows golfers, decision-makers and others at the facility to inspect the quality of each grass so there are no surprises after the renovation. Again, focusing on larger areas such as fairways and roughs achieves the most-significant reduction in irrigation.

Establish the test plots in the turfgrass nursery area, on the driving range, or in the fairway or rough areas of the course. Some superintendents locate trials in problem areas where existing turfgrass fails annually or in areas that will receive limited irrigation in the future. Most land-grant universities have replicated turfgrass trials that can be observed by appointment or during field days.

The National Turfgrass Evaluation Program (NTEP) is a valuable resource for research-based information about which grasses can potentially save the most water at your course.

Understanding Drought Resistance

The overall ability for plants to survive drought is termed "drought resistance." Turfgrasses increase their drought resistance with different inherent morphological and physiological mechanisms that are essential to understand when selecting the turfgrass best suited to a particular environment. Drought-resistance mechanisms include drought avoidance, tolerance and escape. In simple terms, drought avoidance means that a turfgrass will maintain growth and quality longer during drought stress by conserving or accessing more water, whereas turfgrasses exhibiting tolerance or escape mechanisms will not.

Drought avoidance specifically refers to the ability of a turfgrass to maintain a higher plant water status by reducing water lost through transpiration or by increasing water uptake to meet transpirational demands. Turfgrasses primarily achieve this through deeper rooting but can also directly reduce transpiration through various mechanisms. Tall fescue is unique among cool-season grasses for its excellent drought avoidance characteristics. All warm-season grasses generally exhibit strong drought avoidance, but bermudagrass, buffalograss and seashore paspalum are species of interest to golf that are exceptional at avoiding drought stress (Fry & Huang, 2004).

Drought tolerance is the ability of a turfgrass to endure drought and survive. Dormancy is commonly associated with drought tolerance, but a turf must successfully recover from dormancy to exhibit strong drought tolerance. Drought-tolerant turfgrasses typically have low transpiration rates and are able to avoid dehydration of cells during severe drought, especially in meristem tissues, by accumulating solutes that attract water – a phenomenon called osmotic adjustment. When irrigation or precipitation occurs following drought, the ability to spread via stolons and/or rhizomes is an important characteristic of drought-tolerant grasses. The fine fescues and Kentucky bluegrass are unique to cool-season grasses because of their exceptional drought tolerance traits. Buffalograss, zoysiagrass, and bermudagrass are most noted for drought tolerance among warm-season grasses (Fry & Huang, 2004).

Drought escape means a plant completes its life cycle (from germination to seed setting) before succumbing to drought stress. Escape is exhibited by annual plants and weeds.

Determining Water Requirements for Turfgrasses Using Evapotranspiration

Since the 1980s, scientists have documented the water used by turfgrass species in terms of evapotranspiration (ET). Evapotranspiration estimates the amount of water a turfgrass species uses over a given period of time and combines evaporation from soil and leaves with plant transpiration. Reference ET (ET_o) is typically the starting point for understanding the irrigation requirements for a particular location and is commonly estimated using environmental data for a hypothetical grass field that is well-watered and mowed at approximately 5 inches (Allen et al., 1998). This hypothetical grass field obviously differs from most turfgrass areas, especially golf course turfgrass areas, and years of controlled research have helped estimate actual turfgrass ET (ET_a) by developing multipliers, referred to as crop coefficients (K_c), that appropriately reduce ET_o.

Generally, warm-season turfgrasses have a K_c value of 0.6, while the K_c value for cool-season grasses is 0.8. This difference translates to an expected 20% to 30% reduction in water use by warm-season grasses compared to cool-season grasses. A range of more specific K_c values exist for major turfgrass species and cultivars, which have been used to classify turfgrass species by relative ET efficiency (Table 1). High-density, low-growing turfgrasses like bermudagrass, zoysiagrass and buffalograss have the lowest water-use rates. The fine-leafed fescues rank medium for cool-season species, while Kentucky bluegrass, annual bluegrass and creeping bentgrass typically exhibit very high water-use rates. Researchers continually refine K_c values with new methods, in new locations, and as new grasses are released. There have been incremental changes in how we understand the range of ET rates for specific species, and newer estimates typically fall within or very near the ranges presented in Table 1 and the general warm-season and cool-season K_c values above remain valid starting points for grass selection (Braun et al., 2022a; Colmer & Barton, 2017).

Table 1. Summary of mean rates of turfgrass evapotranspiration.

Cool-Season Grasses	Warm-Season Grasses	Mean Summer ET Rate (Inches Per Week)	Relative Ranking (ET Rate)
	Buffalograss	1.4-1.9	
	Bermudagrass hybrids	0.9-1.9	
	Centipedegrass	1.0-2.5	Low
	Common bermudagrass	0.8-2.5	
	Zoysiagrass	1.0-2.2	
Hard fescue		1.9-2.3	
Chewings fescue		1.9-2.3	
Red fescue		1.9-2.3	Medium
	Bahiagrass	1.7-2.3	
	Seashore paspalum	1.7-2.3	
	St. Augustinegrass	0.9-1.9	
Perennial ryegrass		1.8-3.1	
	Carpetgrass	2.4-2.8	
	Kikuyugrass	2.3-2.8	
Tall fescue		1.0-3.5	High
Creeping bentgrass		1.4-2.8	
Annual bluegrass		>2.8	
Kentucky bluegrass		1.1- >2.8	
Italian ryegrass		>2.8	

This table is based on summaries and reviews of numerous published articles. Sources: Balogh & Walker, 1992; Beard & Kenna, 2008.

It's important to remember that these generalizations do not fully reflect the drought-resistance potential of various turfgrass species or especially cultivars. Relative ET rates should be considered along with a grass' ability to avoid or tolerate drought, the nature of expected drought periods and golfer expectations during and following drought.

A common way to approach this challenge has been to determine turfgrass performance and ET rates under different levels of deficit irrigation, and the NTEP has coordinated several nationwide trials with various deficit-irrigation strategies. Turfgrass ET rates obviously decline under deficit irrigation and warm-season grasses consistently perform best. Bermudagrass stands out among warm-season grasses under limited irrigation in these trials, and tall fescue tends to require less water than other cool-season grasses. For example, the best bermudagrass cultivars in a recent NTEP trial required 0.14 inches of irrigation per week to maintain acceptable quality, whereas the best zoysiagrass and buffalograss cultivars required 0.28 inches of irrigation per week (NTEP, 2022; Serena et al., 2023). When comparing Kentucky bluegrass and tall fescue cultivars in a different trial, the average water requirement to maintain acceptable turf quality among 15 Kentucky bluegrass cultivars ranged from 0.56 to 0.77 inches of irrigation per week. In contrast, the irrigation required by 18 tall fescue cultivars ranged from 0.49 to 0.56 inches (NTEP, 2020).

Developing better estimates for ET_a can be done in two ways. First, ET_o estimates are readily available at a daily scale and should be at least seasonally adjusted for irrigation programming. Estimates can be further improved by making site-specific adjustments to account for the microclimates of individual irrigation zones. Second, K_c values can be improved by considering specific cultivar(s) and how a cultivar performs in a specific location and season. Ultimately, ET_o and K_c values are a valuable starting point for understanding irrigation requirements during grass selection, and superintendents can adjust as needed for estimating actual water requirements for irrigation. Research is ongoing to refine K_c estimates for different grass species and cultivars under different irrigation regimes and in different regions of the U.S.

Climate Zones and Turfgrass Adaptation

Climate is the prevailing combination of weather conditions over time – including light, temperature, precipitation and wind. All of these factors influence the growth and development of turfgrasses. Temperature extremes and precipitation patterns are key environmental factors that affect the range of turfgrass adaptation. Cool-season turfgrasses grow best at air temperatures between 60 and 75 F. In contrast, warm-season turfgrasses grow best at air temperatures between 75 and 95 F. Apart from temperature extremes or water supply challenges that may fundamentally limit the use of a grass in a particular climate zone, these optimal ranges help define the expected growing season for grasses that will allow recovery from damage or provide expected aesthetics.

Managing Adjacent Surfaces

A challenging aspect of converting some playing areas to drought-resistant grasses is how to manage adjacent areas with different water requirements. This is a common issue when converting cool-season fairways to warm-season turf, but not the adjacent rough. Unless the irrigation system already can (or is redesigned to) irrigate fairways and rough separately, the rough will likely experience regular drought stress and other associated issues under an irrigation regime designed for the warm-season fairways. If this is not acceptable, the rough may also have to be converted to fully realize potential water savings and optimize conditions in both areas.

Another issue with having different turfgrasses adjacent to one another is the potential for encroachment and contamination. This can happen with warm-season fairways creeping into cool-season greens or roughs, or it can happen with older warm-season grasses contaminating a new stand of an improved warm-season cultivar. There are various ways to create buffers and manage regrowth and encroachment, but there will likely be a constant struggle any time different grasses are located next to each other. Converting more area to improved cultivars will limit this potential challenge.

BRIEF DESCRIPTIONS AND CONSIDERATIONS FOR DIFFERENT GRASSES

The following is an overview of cool-season and warm-season grasses commonly used on golf courses in the U.S. Together with the information presented above, this material can help golf courses select grasses to optimize water use at their facility.

Cool-Season Turfgrasses

Kentucky bluegrass

A multipurpose turfgrass commonly used for golf course roughs and fairways, Kentucky bluegrass is a long-lived perennial widely adapted throughout cool-season growing areas. It also can be used in cool, semiarid and arid regions if irrigated. Kentucky bluegrass has exceptional drought tolerance and can survive drought, initiate new shoot growth, and spread via rhizomes when moisture conditions improve. The ability to spread by rhizomes also allows the species to recuperate from traffic and divots. Summer dormancy may occur from drought or heat stress, with the aboveground foliage becoming brown. Although comparable to most cool-season grasses for drought avoidance, attempting to maintain Kentucky bluegrass quality during severe drought will require more water than tall fescue. Conversely, Kentucky bluegrass or a fine fescue would better survive and recover from an extended period without precipitation or irrigation.

Perennial ryegrass

Perennial ryegrass is generally short-lived, but it can persist indefinitely if not subjected to extremes in temperature or high disease pressure. Typically, perennial ryegrass survives under cold winter conditions when protected by consistent snow cover. Ryegrass is generally considered a high water user, with ET requirements of 1.8 to 3.1 inches per week, and has no distinguishing drought-resistance characteristics.

Perennial ryegrass has two primary uses. In cooler climates, it is frequently used alone or in combination with Kentucky bluegrass in sunny locations for tees, fairways and roughs. Perennial ryegrass monostands are commonly overseeded annually to maintain coverage and density. When mixed with Kentucky bluegrass, perennial ryegrass is intended to provide quick establishment and is largely replaced by Kentucky bluegrass as the stand matures. In parts of the southern and western U.S., perennial ryegrass is the main overseeding grass for tees, fairways and roughs. Seeded in late August and early September, it remains green until late spring, when temperatures warm and it dies as the underlying bermudagrass breaks dormancy. Golf courses with water conservation goals should generally avoid winter overseeding since it can increase irrigation requirements by 20% or more due to the establishment and maintenance irrigation of the ryegrass (B. Whitlark, personal communication, August 27, 2024). Alternatives to overseeding are discussed later.

Overseeded ryegrass can provide high-quality aesthetics and playing conditions in areas where bermudagrass goes dormant during winter, but at the cost of increased annual irrigation and damage to the understory bermudagrass.

Fine fescue

Fine fescues are long-lived perennials widely distributed throughout the cooler climates of the U.S. that are used primarily for golf course roughs and naturalized or native areas, with limited use on fairways and putting greens in the U.S. Poor heat tolerance limits the geographic distribution of fine fescue compared to Kentucky bluegrass. Creeping red fescue is distinguished from other fine fescues because it spreads through a creeping growth habit, although somewhat less vigorously than Kentucky bluegrass. Chewings and hard fescue have bunch-type growth habits.

All the fine fescues have narrow, upright leaves. They are superior to other cool-season grasses for shade adaptation, and their water-use rate is lower than Kentucky bluegrass and perennial ryegrass. Fine fescues exhibit exceptional drought tolerance and can be a persistent and low-maintenance stand in suitable climates and enhance water conservation. The species also has better salt tolerance than other cool-season grasses.

Turf-type tall fescue

Turf-type tall fescue is a long-lived perennial grown in the transition zone between cool, humid and warm regions. It persists as far north as the Great Lakes and as far south as Atlanta and Dallas. Tall fescue is fairly heat tolerant compared to other cool-season species because of its deep rooting characteristics that also confer exceptional drought avoidance relative to other cool-season species. The drought tolerance of tall fescue is inferior to that of Kentucky bluegrass and the fine fescues as it does not as readily recuperate from extended periods without water. Tall fescue also can suffer winter injury in the coldest areas of the northern United States.

Tall fescue is exceptionally drought- and wear-tolerant among cool-season species and is underutilized on golf courses in the transition zone that cannot utilize warm-season grasses to acquire these traits. It is superior to Kentucky bluegrass and perennial ryegrass in shade tolerance but inferior to fine fescues in the shade. Tall fescue use on golf courses is typically restricted to rough. Newer cultivars have finer texture and tolerate lower mowing and make reasonably good low-maintenance fairways or tees, but this is not a common use. Tall fescue has limited recuperative capacity and is commonly mixed with Kentucky bluegrass for this reason.

Bentgrasses

Generally not known for drought resistance, creeping bentgrass is primarily grown as a turfgrass for golf course putting greens, tees and fairways. It has vigorous creeping stolons that develop at the ground surface, forming a fine-textured turf with superior shoot density, uniformity and turfgrass quality when closely mowed. Several creeping bentgrass cultivars have improved heat tolerance for high soil and air temperatures and have improved dollar spot resistance. Developing improved varieties of creeping bentgrass has long been the focus of many university-based turfgrass breeding programs. Creeping bentgrass is more tolerant of heat and drought than annual bluegrass but typically is not a species sought out to advance water conservation goals.

Colonial bentgrass differs from creeping bentgrass because it has less spreading capability through rhizomes or stolons. Colonial bentgrass exhibits dormancy and rapid recovery with drought stress. Velvet bentgrass has an extremely fine texture, forming a very dense turf. Its rate of spread by stolons is greater than colonial bentgrass but less than creeping bentgrass. Velvet bentgrass also exhibits better drought tolerance than creeping bentgrass.

Annual bluegrass (*Poa annua*)

Although a desirable and high-quality turf on many golf courses, annual bluegrass is often considered a weed that is usually managed rather than controlled. More-perennial biotypes may become a significant or dominant component of intensively managed golf course fairways, tees and greens. Its fundamental

Poa annua is less tolerant of drought and heat than other cool-season grasses used on golf courses. If water conservation is a priority, converting *Poa annua* playing surfaces to grasses that require less water should be considered.

limitation is that it is more susceptible to cold, heat, disease, insect, ice and drought stresses than most cool-season species. Although annual bluegrass is less tolerant of heat and drought than other cool-season golf course grasses, it remains a popular choice for putting greens due to its density and overall putting quality. However, if water conservation is a priority, consider replacing annual bluegrass playing surfaces with other species like creeping bentgrass.

Warm-Season Turfgrasses

Bermudagrass

Bermudagrass is a fast-growing turfgrass species that spreads by stolons and rhizomes. It has excellent drought avoidance and tolerance. Extremely heat tolerant but intolerant of shade, bermudagrass is the dominant golf course grass in the South, as well as the hot-summer climates of the western U.S. Bermudagrass is versatile and can be used on all golf course playing surfaces. Where growing conditions are suitable, improved bermudagrass cultivars have the best potential to help golf courses conserve water, whether they are converting from cool-season turf or older warm-season cultivars.

Changing weather patterns and the development of bermudagrass cultivars with improved cold tolerance is expanding the useful range of this grass, especially on fairways and tees. Golf courses as far north as Pennsylvania and New Jersey are using bermudagrass on various surfaces, as are golf courses north of the San Francisco Bay Area along the west coast. This allows these courses to provide better playing conditions during the hot summer months and to use less water throughout the year when compared to cool-season species. One trade-off with this expanded range is a shorter growing season and the increased risk of winter injury. Courses that are thinking about converting from cool-season grasses to bermudagrass (or any warm-season grass) have to evaluate whether a shorter growing season is acceptable and consider the benefits of saving water and having better summer playing conditions in most years against the risk of potential freeze damage in an unlucky year.

While seeded cultivars are becoming more available, the best-performing bermudagrasses used on golf courses today are exclusively established by using sprigs or sod. This means the establishment period will be longer or more expensive than what is possible with seeded cool-season grasses. The time required to establish from sprigs, or the expense involved in grassing with sod, is an obstacle that limits conversion to improved bermudagrasses.

Where growing conditions are suitable, converting cool-season fairways and rough to bermudagrass can decrease water use in those areas by 25% or more. The development of bermudagrasses with improved cold-tolerance is making this conversion an option for a growing number of golf courses.

Zoysiagrass

This perennial, slow-growing grass is widely adapted across the warm-season growing area of the U.S. It forms a uniform, dense, low-growing and high-quality turf that spreads by stolons and rhizomes. Although zoysiagrass does best in full sun, it can tolerate shade conditions better than many other warm-season species. Winter color retention and the playing surface quality of dormant zoysiagrass are other potential benefits. Even though it typically uses more water than bermudagrass, better dormant quality may eliminate the need for overseeding, which could lead to less water consumption throughout the year in some environments.

Traditionally, zoysiagrasses have been planted vegetatively by sprigs, plugs or sod and are slow to establish compared to bermudagrass, which has been a significant limitation in their use for larger areas on golf courses. However, a few seeded cultivars are available, and more will be available in the future. Plant breeders have also developed several zoysiagrass cultivars with faster sod production characteristics and better adaptation to a broader range of environmental conditions. If the winter qualities of zoysiagrass allow golf courses to avoid overseeding or using cool-season grasses in warm climates, the water saving opportunities are significant.

Seashore paspalum

Seashore paspalum is known for its ability to survive high levels of salt in irrigation water and soil, making it a popular option in areas with poor water quality and locations where inundation with seawater is a risk. This turfgrass is found on golf courses in coastal regions of the U.S. from Texas to the Carolinas, and on the islands of Hawaii. It is a popular grass in Puerto Rico and throughout the Caribbean. Seashore paspalum spreads by rhizomes and stolons, and breeding efforts continue to improve cold tolerance, density, resistance to pests and other characteristics. Most improved cultivars for golf courses are established vegetatively by sod or sprigs. Seeded cultivars like ‘Pure Dynasty’ provide options for less-expensive establishment or in situations where importing vegetation is prohibited. As a water-conservation strategy, seashore paspalum provides the most value for its tolerance of poor-quality or recycled water high in salts.

Native Grasses

Native grasses have the greatest potential in regions where water availability, water quality, poor soils or a challenging climate are limiting factors in providing quality turfgrass. However, the domestication of native species into viable golf course turfgrasses is not a simple task. Alkaligrass, blue grama, wheatgrasses, buffalograss and inland saltgrass are a few species that have potential as turfgrasses for the arid west or when irrigating with saline water. Of these, buffalograss and inland saltgrass have been the subject of considerable research in terms of their golf course feasibility and plant breeders have worked on developing improved cultivars that could be suitable for low-maintenance fairway and rough applications.

Buffalograss

This cold-tolerant, stoloniferous, native prairie grass can be used for low-maintenance fairways, tees and rough. Seeded cultivars of relatively high quality are available, but because of its reputation as a low-maintenance grass, buffalograss has not been widely adopted on golf courses. It is fairly common in lawns or other general-use turfgrass areas compared to other native grasses and can make an exceptional low-maintenance rough where adapted. It greens up earlier than bermudagrass in the spring and turns brown after the first fall freeze. Buffalograss does not have the same density as traditional turfgrasses, especially under lower mowing heights, and therefore cannot provide the same aesthetics and playability as other warm-season grasses. It has exceptional overall drought resistance and is best suited to advance water conservation in areas that will receive little to no irrigation after establishment.

Inland saltgrass

This grass is native to western North America and exhibits very high salt tolerance. Its aspect and growth habit are similar to other warm-season grasses with the presence of stolons and rhizomes. Currently, the use of inland saltgrass is limited on golf courses. However, plant selection, breeding efforts and research have been conducted for the past 40 years to bring this grass into the golf industry. It can make an exceptional, well-adapted grass for naturalized and low-maintenance areas where water and resources are limited. Saltgrass use is limited by lack of awareness, the commercial availability of improved cultivars and the availability of management information. Research is promising and ongoing.

IMPLEMENTATION

Converting to Warm-Season Grasses

Transitioning from established cool-season or warm-season grasses to a new warm-season grass that uses less water involves completely renovating the turf area. Consult fellow turfgrass professionals familiar with your region to develop a plan for a successful transition and with help choosing the most-suitable warm-season grass cultivars based on your particular needs and site conditions. For more information, please see the USGA Green Section Record article "Converting to Bermudagrass Fairways."

Step 1: Control existing grasses

Effective control of existing grasses takes time and patience. Begin treating existing turf with multiple applications of glyphosate in early spring when temperatures are above 50 F. Allow regrowth in between applications, which will require 14-21 days. For cool-season grasses, at least two applications should be made, but three or more may be required. For bermudagrass and other warm-season grasses, make three to five applications of glyphosate, also allowing time for regrowth in between applications. Tank-mixing fluazifop will improve control of bermudagrass over glyphosate alone. Do not mow for seven days before or after applications. Maintaining soil moisture to allow existing turf to recover between applications is critical to achieve the necessary control of existing grasses. For bermudagrass, apply one pound of nitrogen per 1,000 square feet one week after the first herbicide application to promote regrowth. Disturbing the soil between herbicide applications is also beneficial. Manage surface organic matter by fraise mowing, core aerating, vertical mowing or dragging with a metal-tine rake. Do not plant within seven days of the final herbicide application unless you remove the fluazifop from the last application. If seeding, up to a 30-day delay may be needed following the last herbicide application.

Step 2: Prepare the soil

Use vertical mowing, aeration and mower scalping to remove as much of the material left on the surface as possible. The no-till method works best when establishing the new turfgrass by sod. If you prefer to till the soil prior to planting, three common methods (once herbicide applications are complete) are using an asphalt grinder, a Blecavator or a RotaDairon. These methods will improve soil characteristics, but they require sprinkler removal before tilling and finish grading prior to planting to smooth out the surface.

Tilling the soil before planting may be desirable, especially when planting sprigs. However, steps must be taken to protect irrigation system components and finish grading will be necessary to smooth out the surface.

Step 3: Planting

Choosing to sprig the new grass means the materials and planting process are cheaper than sodding. Still, the cost difference may not be significant when factoring in lost revenue from the additional course closure time required to establish sprigs. After planting sod in an area, it could reopen for play in as little as two or three weeks, whereas sprigging will require a minimum of eight to 10 weeks for establishment. Planting sprigs also has the advantage of not introducing foreign soil like sodding does. If planting into a sand-capped fairway, this consideration is particularly important.

When converting from one bermudagrass to another, it is better to plant sod primarily for improved control of the existing turf and weeds. Sodding increases the success rate of establishing a dominant stand with fewer inputs such as water, fertilizer and pesticides. Sodding also ensures full turfgrass cover and, if laid between spring and the end of July, will allow the new turf to establish healthy rhizomes before winter.

When sprigging, if you have not tilled the soil you should soften it with aggressive aeration and irrigation to effectively cut the sprigs in. Plant 400 to 800 bushels of sprigs per acre in the morning and water immediately. Roll fairways with a 2- to 6-ton asphalt roller to push sprigs into the ground and produce a smoother, firmer playing surface. The sprigged area should be closed during this time. Finally, depending on the species being established, consider whether specialty herbicide applications can help control weeds and improve establishment.

Sodding is more expensive than sprigging or seeding in terms of materials and cost to install, but quicker establishment with sod means less disruption to the golf calendar, better weed control and potentially a better finished product.

What if Warm-Season Grasses Aren't Possible?

Converting from cool-season grass to warm-season grass is the scenario that will save the most water in terms of grassing strategies. However, freezing temperatures and the risk of winter injury limit the use of warm-season grasses in colder climates, even arid ones. While cool-season grasses are not inherently as drought-resistant as warm-season grasses, some species and cultivars exhibit better drought tolerance than others.

Selecting the best cool-season grass cultivar to help your course use less water will depend on several factors including your location, climate, soil type, maintenance practices and preferences. More information on drought-resistant cultivars can be found in TWCA, A-LIST and NTEP reports. As always, it is strongly recommended to select several cultivars that have promising research and field results and test them at your course under your unique site conditions and maintenance program before making a final decision.

The seasonal timing for establishing a cool-season grass will be different than for warm-season grasses. Late summer is generally the preferred time to seed or sod cool-season grasses. Therefore, initiating the control of existing grasses can be delayed into summer to align with the preferred seeding or sodding date and reduce the period of disruption to the golf course.

Eliminate Winter Overseeding to Save Water During Dormancy

Eliminating overseeding of warm-season grasses and playing on dormant turf can significantly reduce water use. Although dormant turfgrass does not provide any recovery from traffic or divots, non-overseeded bermudagrass, if well maintained, can provide an excellent playing surface. Some golf courses are experimenting with zoysiagrass to obtain better winter playing conditions without overseeding. Generally, the quality of dormant zoysiagrass is slightly better than dormant bermudagrass, especially over longer periods of dormancy. Zoysiagrass also offers a firmer and denser surface, which is more resistant to divot and traffic injury. For both species, using pigments or colorants to maintain a green appearance can help enhance aesthetics during dormancy without requiring active growth.

Estimates from Arizona indicate that an acre of non-overseeded bermudagrass requires around 4.5 acre-feet (1.47 million gallons) of water per year. Overseeding an acre of bermudagrass increases annual water use to 6.2 acre-feet (2.02 million gallons). The 2020 median fairway acreage for a golf course in the Southwest was 29.3 acres (Shaddox et al., 2023). Overseeding that area with cool-season grass would require nearly 50 more acre-feet (or more than 16 million gallons) of water per year – for only one golf course.

An increasing number of golf courses – including Pinehurst No. 2 pictured here – that used to overseed in the winter have discontinued the practice to improve year-round playing conditions and conserve resources like water and fuel.

TIPS FOR SUCCESS

Measure your current water use and establish a target.

The first step in successful water conservation on a golf course is to accurately measure current water use to establish a baseline. Once this is done, set a target for water reduction. If turf conversion is part of your water conservation plan, this baseline information will help you choose a species or cultivar that helps meet your goals. It is important to have realistic expectations and to recognize that water savings will not be at their full potential in the early years of establishing new grasses.

Recognize that warm-season grasses have limitations.

Converting from cool-season to warm-season grasses offers enticing water savings, but it is important to recognize that even improved warm-season grasses have limitations. Before transitioning to a warm-season grass, assess the environmental challenges in your region, especially the risk of extremely cold temperatures. Additionally, consider golfer expectations for playability and aesthetics throughout the year, particularly in regions with colder winters where warm-season grasses may go dormant for several months. Balancing these factors will help ensure that the chosen grasses provide a high-quality playing surface while meeting water conservation goals.

While the functional range for using warm-season grasses is shifting into cooler climates, all it takes is a few days of extreme cold to create lasting damage like we see on this golf course in Tennessee. The benefits and limitations of any grassing option must be carefully weighed.

Use unbiased data when selecting grasses.

Selecting the right grass for your course should be based on reliable and unbiased data. Use resources from NTEP, TWCA and A-LIST, as well as university research, to compare the performance of different grass species and cultivars in your climate. These trials provide objective data on drought resistance, water-use efficiency and overall turfgrass quality, helping you make informed decisions that align with both environmental sustainability and golfer needs.

Establish test areas at your course.

Establishing small-scale test areas in challenging parts of the course, such as high-traffic zones or areas prone to drought stress, allows you to test the performance of different turfgrass species. Manage these plots according to best practices and observe their performance over two to three years. During this period, gather feedback from stakeholders, including course staff and golfers, to assess playability and overall satisfaction with the grassing options.

There are pros and cons to every regrassing method.

It can be difficult to decide between sodding for immediate cover or seeding/sprigging, which both require longer times for establishment but cost less in materials and installation. There are agronomic benefits to seeding or sprigging, but those can be outweighed by timing considerations. Whatever grassing method you choose, try to allow more than enough time to eliminate the existing grasses, prepare the soil and establish the new turf. Too many

Visit the production fields that you are considering purchasing seed, sod or sprigs from. This is an opportunity to make sure everything meets your standards before issues like weeds or pests arrive at your course.

courses struggle with turf conversions simply because they did not allow enough time to do the job properly with the many unpredictable variables involved.

Do your homework when sourcing plant material.

Once you've chosen the appropriate turfgrass cultivar based on regional suitability and performance data, work with a reputable sod, seed or sprig producer. Visit the production fields to inspect the quality of the turf and ensure that it meets your specifications before purchase. Quality checks are essential to avoid introducing any pests, diseases or weeds that could affect the health or playing conditions of your new turf. Courses establishing bermudagrass will want to be on the lookout for "off-types" that may be present in the fields and could be introduced onto your course. Dealing with undesirable grasses or weeds can be very challenging after establishment

Soil testing before planting will help you create the best possible growing environment.

Prior to planting, conduct soil tests to identify nutrient deficiencies, pH imbalances or issues with soil texture. These tests guide decisions on soil amendments such as adding sand, fertilizers or organic matter to create an optimal growing environment for the new grass. Regrassing projects are inherently disruptive and require some time where the course is closed. While this has many negative aspects, one benefit of this disruption is that it provides an opportunity to make soil improvements that are difficult or impossible while the course is open.

Be patient and adjust management practices to realize benefits.

After planting, allow sufficient time for the turf to become fully established before subjecting it to regular play. Once the grass is established, management practices – particularly irrigation – must be reviewed and adjusted to reflect the needs of the new turf. This might involve reducing water input, adjusting mowing heights and applying fertilizers appropriately to promote deep rooting and sustained health. Patience during this period is critical for long-term success. The peak playing conditions and full water conservation potential of a new grass will not be realized likely for several years after planting. While this may not be what golfers and decision-makers want to hear, it is the reality of a long-term investment in a better and more-sustainable turfgrass.

BMP CASE STUDIES

Birnam Wood Golf Club, Santa Barbara, California

Birnam Wood Golf Club historically maintained a mixed stand of cool-season turfgrasses, sometimes called the "California turf surprise." This turf composition produces acceptable playing conditions but never delivers a premier golf experience, and the water demand is higher than it would be for warm-season turf. Historically, Birnam Wood budgeted for about 185 acre-feet of water use annually (approximately 60 million gallons), costing nearly $200,000 per year.

The golf course's leadership recognized an opportunity to improve the consistency of playing conditions and reduce resource inputs, most notably irrigation water, by converting the cool-season turf to bermudagrass. In 2015 and 2016, the golf course converted 31 acres of fairway to 'Santa Ana' bermudagrass and the roughs to 'Tifway 419' bermudagrass. In addition, they replaced 7.2 acres of irrigated turf with low-water-use landscaping.

After the renovation, the golf course water budget is about 135 acre-feet annually, a 25% reduction in annual water inputs. The course's water cost per unit has increased by over 500% in the past decade, and water costs today are nearly $11.00 per hundred cubic feet. The 25% water reduction saves the facility over $100,000 annually at current prices. The conversion has also saved approximately $100,000 annually in fertilizer, seed and pesticides. The cost of the project, which included minimal soil preparation and sodded bermudagrass, was about $1.25 million. Within seven years, the project paid for itself.

Menlo Country Club, Redwood City, California

Menlo Country Club in the San Francisco Bay Area converted the fairway on their sixth hole from perennial ryegrass to 'Santa Ana' bermudagrass in 2018 to see whether water savings and improved playability would justify converting all the fairways. Golf course superintendent Chris Eckstrom documented significant water savings on this fairway – noting that 25% savings over cool-season grasses is very realistic. Based on this success, in 2021, the golf course converted the remaining 33 acres of perennial ryegrass fairways to 'Santa Ana' bermudagrass and replaced 2.4 acres of turf with naturalized grasses.

The golf course realized a 20% water savings during the first year alone, while the fairway turf was still immature. Future water savings should be even more significant. With a water budget of nearly $1 million annually and water costs increasing 5% to 8% yearly, the $2.6 million project – including Blecavating the soil in fairways and sodding the bermudagrass – will pay for itself in less than eight years. Menlo Country Club realized additional economic savings by reducing the use of pesticides, and golfers are pleased with the improved quality and consistency of the new bermudagrass fairways.

USGA Green Section Podcast: Chris Eckstrom on Regrassing Cool-Season Fairways With Hybrid Bermudagrass

"Using Turf Colorants Instead of Overseeding"

USGA Green Section Record, 2017.

Maintaining a resort golf course in the transition zone can be challenging. At Brunswick Plantation and Golf Resort in Calabash, North Carolina, one of the major challenges was managing the transitions into and out of winter overseeding. The overseeding process restricted golf carts to paths and impaired playing conditions for a month each fall. In spring, competition between bermudagrass and ryegrass caused further playability issues. The result was very poor fairway playing quality during some of the best golfing weather. By converting from overseeding to using colorants the course was able to reduce water use by 30%, maintain the desired green color, and eliminate the diminished playing conditions during the fall planting and spring transition.

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ADVANCED IRRIGATION TECHNIQUES AND CONSERVATION STRATEGIES

Reducing Irrigated Acreage

Reducing the acreage of irrigated turf is a great way to save significant amounts of water, but managing a low-water-use landscape comes with its own challenges.

SNAPSHOT

This strategy involves reducing the total amount of turfgrass a golf course irrigates. It is a high-impact, medium-cost strategy applicable to many golf courses, especially in arid regions where water is scarce or expensive.

Expected cost	$25K to $50K per acre
Ease of implementation	Large capital project
Potential water savings for affected area	> 50%
Highest potential impact areas	Nationwide

OVERVIEW

Regarding golf course water conservation, no strategy saves more water over a given area than eliminating irrigated turfgrass – so long as the replacement landscape can be maintained with little or no irrigation. Many golf courses irrigate more acreage than is required to deliver a desirable playing experience, even in regions where water conservation is a priority. There are playability, aesthetic and practical reasons why this is the case, along with general resistance to change and the fact that many courses simply do not see a need to reduce their irrigated acreage. However, for golf courses looking to save water, reducing irrigated acreage is one of the most impactful strategies available – but it is not without cost. Establishing a new landscape that can handle reduced irrigation requires investment over multiple seasons, and labor costs can actually increase in non-irrigated areas even if water use is brought down to zero because of high expectations for playability and presentation.

Discontinuing irrigation in an area is easy enough, but figuring out what to replace irrigated turfgrass with and how to manage the new landscape successfully is often quite challenging.

Reducing irrigated acreage requires converting mown, irrigated turfgrass areas to alternative plant and landscape materials that do not require much or any irrigation to survive in a particular environment. These "naturalized areas" can be established in many ways and take many forms. Golfers often envision long grasses in these areas, but shrubs, wood chips and various forms of xeriscaping can all be effective. How these areas are designed, established and managed determines water savings, maintenance costs and the impact on the golfer experience. Discontinuing irrigation in an area is easy enough, but figuring out what to replace irrigated turfgrass with and how to manage the new landscape successfully is often quite challenging.

SCENARIOS FOR USE

The primary reasons for reducing the irrigated acreage of a golf course are conserving water and other resources and/or achieving architectural and aesthetic goals. The relative importance of these motivations will influence the placement, design and maintenance of areas identified for conversion. Out-of-play areas are typically the starting point, but it may be desirable to have non-irrigated areas extending closer to the line of play to optimize resource savings or have a more significant impact on strategy and aesthetics. Remember that the more visible and in-play these areas are, the more maintenance will typically be required to meet golfer expectations.

Where Is the Strategy Typically Used?

Most courses looking to reduce irrigated acreage will first target areas along the property's margins. However, this can create conflict with adjacent property owners, which is a consideration to be aware of. Beyond the margins, areas around tees and between tees and fairways are another common target. These areas do not often see much play, but they are highly visible which can have design and management implications. Areas between holes and behind greens are also common targets for eliminating irrigated turfgrass. The spacing between holes and the property's topography will significantly impact how practical it is to discontinue irrigation in these areas. Landscape areas around the clubhouse and entry drive do not require irrigated turfgrass for playability, but presentation is important when considering non-irrigated alternatives. These scenarios illustrate the fact that establishing non-irrigated areas may require different approaches in different parts of the property and that design and maintenance of these areas will vary from course to course and even within the same course, depending on the overall goals and resources available.

Reducing irrigated turfgrass acreage has been performed on golf courses across the U.S. Courses in the western U.S. often reduce irrigated acreage to decrease their water costs or focus a limited water supply on primary playing areas. Some areas of the West have incentivized courses to eliminate irrigated turfgrass with rebate programs. In areas where rainfall is more plentiful, creating naturalized areas is often part of architectural or aesthetic changes to a course – or part of an effort to focus more resources closer to the line of play.

Areas between holes, around tees and along the property line are popular targets for turf reduction.

Opportunities To Expand Use

While many courses have increased their acreage of non-irrigated landscape in recent years, there are significant opportunities at many courses to employ this strategy with limited impact on play. Some courses do not have enough irrigated turfgrass acreage to make significant reductions, especially in areas of the Southwest where courses were built with irrigated turfgrass limitations in place. However, a high percentage of courses east of the Mississippi have opportunities to reduce their irrigated acreage, and a surprising number in the west also do.

To put the potential for reduction in context, in the Desert Southwest, golf courses typically irrigate less than 90 acres of turfgrass. For instance, the state of Arizona has had a law since the 1990s preventing any new golf course from having more than 90 acres of turf. Many courses in this area were designed with limited water use in mind and only irrigate 60-70 acres. These courses are still playable and enjoyable, especially if some effort is made to facilitate playability around the margins of the turfgrass area. Many golf courses outside this region irrigate far more than 70-90 acres of turfgrass. While the turfgrass-reduction potential will vary from course to course, a good guideline is to irrigate less than 100 acres of maintained turfgrass. Technology tools like the GPS service provided by the USGA Green Section can help courses objectively assess how much irrigated turf they need to maintain and where reductions can be made with minimal impact on playability.

BENEFITS

Significant Water Conservation

Converting irrigated turfgrass to various forms of naturalized grasses or non-irrigated landscapes can eventually translate to 100% water savings in those areas, depending on the plant materials and environments. In areas where rainfall is sufficient, there is not much reason to irrigate these areas beyond watering in pest control products or germinating seeds. In areas that experience periods of extreme drought, it may be necessary to irrigate naturalized or low-water-use landscapes to keep plants alive, but the irrigation requirement would still be approximately 60%-80% less than what is required to maintain irrigated turfgrass.

Other Resource Savings

Converting areas to non-irrigated or low-water-use landscapes will absolutely translate into less mowing time and fuel savings. It would also be reasonable to expect no fertilizer inputs after establishment and few if any plant protectant applications. Depending on the environment, location on the course, and expectations, there can also be significant labor savings. However, labor costs can just as quickly increase in non-irrigated areas if they are expected to be playable and free of weeds and debris.

Architectural and Aesthetic Changes

Reducing irrigated acreage can transform how a course looks and plays. Often, turfgrass reduction results in greater definition and texture across the golf course. Naturalized areas can also be used to accentuate or alter the strategy and challenge of a hole. Adding naturalized grasses or low-water-use plants can also be less disruptive and potentially less expensive than other architectural modifications that would achieve a similar impact on strategy. However, it is important to remember that there is a wide cost range for creating these areas depending on the desired replacement landscape.

Turf reduction can help courses achieve architectural and aesthetic goals while also saving water.

Problem Solving

Establishing non-irrigated or low-water-use areas can be an opportunity to solve a range of problems. Many golf courses have areas that they struggle to maintain because of poor irrigation coverage, poor soils, tree-root competition or drainage issues. Converting them from maintained turfgrass to other options typically solves, or at least hides, those problems. Removing turfgrass adjacent to homesites mitigates problems with overspray onto neighboring properties. Turfgrass removal around teeing grounds allows for more-targeted irrigation with improved distribution. Installing subsurface drip irrigation on tees elevates the water savings to a whole new level.

CONSIDERATIONS

Expectations for Playability and Aesthetics

Creating non-irrigated or low-water-use landscapes on a golf course is always more complicated than turning off the sprinklers and not mowing an area. Arguably, the two biggest challenges are playability and presentation issues. Golfers may hear about plans for water-saving areas and envision wispy expanses of tall grass that blow in the breeze but still make it easy to find balls. In reality, very few environments support this situation naturally. It often takes a lot of labor and weed management to produce anything resembling what golfers may have in mind.

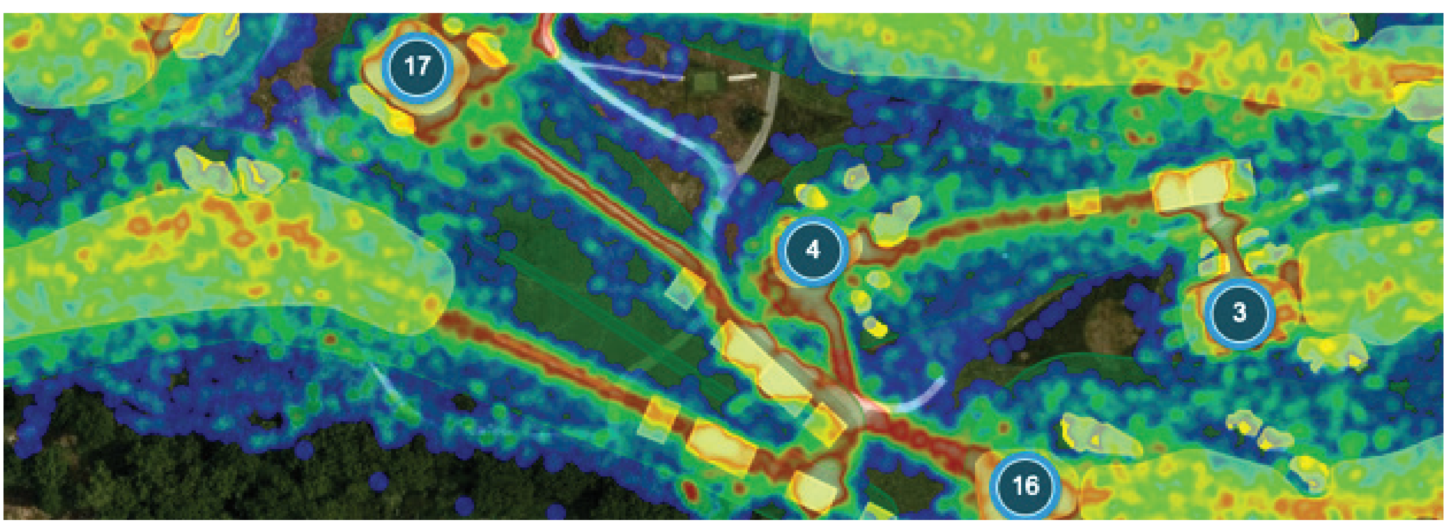
Similar challenges arise with low-water-use areas that feature expanses of bare soil, mulch or rock, which are a more natural fit in many arid and sandy regions. These landscape treatments are vulnerable to erosion and being overrun by weeds. When placed on slopes, mulch and small rocks are prone to erosion. Deep channels can form, affecting playability and potentially depositing soil and debris on adjacent turfgrass areas. Even low-water-use areas with minimal vegetation require continual management, especially if expectations for aesthetics are high.

Regardless of the environment, there needs to be a clear understanding of expectations and reality when creating non-irrigated areas.

Regardless of the environment, there needs to be a clear understanding of expectations and reality when creating non-irrigated areas. Achieving meaningful water savings while delivering acceptable aesthetics and playability at a reasonable maintenance cost is no easy task.

Choosing Areas for Conversion

The success of turfgrass-reduction programs depends heavily on the locations chosen for conversion. Non-irrigated areas fall under less scrutiny when located far from play, but as they come closer to the action they can touch off a steady



GPS technology can show exactly where golfers go during a round and which areas get little use. That information can help courses identify turf reduction areas that will have limited impact on play.

stream of criticism related to lost balls, impact on the pace of play, and overall presentation. It is easy to stand on a tee and think an area is well out of play, but the reality is that golfers end up all over a golf course, and losing a few balls in thick native grasses can wear on anyone's patience. Even if they "shouldn't have hit it there," the reality is that they did, and they are paying customers whose experience matters. This is why it is so important to work with a golf course architect when planning to reduce irrigated turfgrass acreage and to utilize technology that allows us to better understand how golfers of different skill levels typically play a course.

The process of selecting areas for conversion can be guided by using a GPS service. These services provide players with a GPS tracker used during play. The data is then downloaded and used to generate heat maps of where players travel and hit shots on the course. Areas that seldom or never get visited are a good place to start with turfgrass removal.

Dealing With Existing Plant Material

One approach to establishing non-irrigated areas is to let the existing turfgrass grow and stop watering it. This can work well in some regions and for some courses, especially if the expectations for playability and presentation are not high and the focus is on resource conservation – whether that's water, labor or any other input. Unfortunately, the grasses in most rough areas do not readily transform into a desirable low-water-use naturalized area, so the challenge becomes eliminating the existing grasses and preparing the area for something new. Herbicide applications, stripping, tilling and various other approaches are used separately or together to eliminate the existing turfgrass, but it can be stubborn and may continue resurfacing for many years to come. Stripping and/or tilling also gives existing weed seeds in the soil an opportunity to emerge, making weed management a universal challenge among these projects.

Establishing New Vegetation and/or Soil Treatment

Once the existing vegetation has been dealt with, the challenge of establishing the new plant material comes. Almost regardless of the plants selected, there will be a multiyear process of establishment and maturation before a desirable state is reached. Native grasses take a long time to establish, and native shrubs and groundcovers may remain small and unnatural looking for years. In the meantime, weeds, erosion and numerous other issues will complicate establishment. In most cases, the new vegetation will require some form of irrigation during the establishment period. It may be possible to water these areas with existing sprinklers, or a new irrigation design may be required that includes drip irrigation for native plants or sprinklers for overhead watering. Do not expect significant water savings in the early going, and do not remove sprinklers in these areas without a plan for how the new landscape will be irrigated until it is fully established.

Supplemental irrigation must be provided if existing trees are to remain in place. Desirable trees have often declined rapidly when turfgrass is removed around them and overhead irrigation is shut off. Multiple lines of drip irrigation placed in rings around the desirable trees is a good strategy to preserve tree health, although some level of tree loss should be expected with any turfgrass removal project. Another option is adding small pop-up spray heads or bubblers to water trees in turfgrass reduction areas. There has been speculation that trees in previously turfed areas typically have shallower roots and will perform better with overhead irrigation.

Turfgrass reduction areas don't necessarily need to be comprised of long grasses. A mix of plants and various-sized rock and aggregate can be a great solution for extremely dry climates.

Turfgrass-reduction areas may also be designed as bare ground or treated with some form of soil cover, such as mulch or rock. Different forms of mulch have been successfully used to mitigate weeds and erosion while producing an attractive appearance in turfgrass-reduction areas. Depending on the mulch's size, various playability challenges may arise. Mulch often needs to be refreshed annually or biannually, and if color and aesthetics are paramount, then painting may be necessary. Various sizes of rock can also be used as a ground cover in turfgrass-reduction areas. A surface like decomposed granite, with very small rock particles, is better for playability but has greater potential for erosion from wind and water. Furthermore, the small rock particles often get transported onto mown turfgrass by vehicles and golf shoes, which can damage mower reels and blades. Rocks larger than 1 inch in diameter can be used strategically to reduce erosion and weeds but can be problematic when located close to play. Using a combination of smaller rocks on flat areas and closer to play while using larger rocks on slopes and farther from play has worked well.

Developing a Management Program

When establishing any type of non-irrigated or low-water-use area, a successful management program will be a constant voyage of discovery. Some challenges are easily anticipated, but many unexpected ones will arise, and the challenges will evolve over time. Weeds that were problematic in the early phases of establishment may disappear, only to be replaced by an entirely new set of weeds. The areas that prove problematic from a playability standpoint may not align with what was predicted, and targeted mowing and spraying may be required to address concerns. The frequency of mowing and the amount of weed control may change yearly depending on the weather, and erosion issues may start small and worsen. Managing plant density will be challenging in many environments, and superintendents must continually adjust their programs to produce the desired look. Additional seeding is often necessary for naturalized grass areas, and the desired species will likely evolve. It should become obvious which plants and grasses are most successful and favoring what grows best is a good philosophy.

Some challenges are easily anticipated, but many unexpected ones will arise, and the challenges will evolve over time.

IMPLEMENTATION

Establish Water Conservation Goals

If water conservation is the primary reason for a turfgrass-reduction program, the first step in the process is figuring out how much water the course wants or needs to save. The quick answer will probably be "as much as possible," so it may be more productive to think about a minimum amount of water savings that would make the project worthwhile and work up from there. Once a target savings range has been identified, the next step is understanding how much irrigation different playing surfaces receive in a typical year. Some courses have this data readily available, but others may not. Knowing how many gallons per acre are applied to rough, fairway and landscape areas in an average year will help you identify target areas and calculate when turfgrass removal has reached the desired level. It is also important to factor in the irrigation requirements of the new landscape that will replace irrigated turfgrass. Otherwise, actual water savings will be overestimated.

Identify Target Areas

Once a water-saving goal has been identified, it is time to select the target areas for turfgrass reduction. The optimal design for each course will depend on the goals for resource savings, the desired playability and aesthetics, and the budget for conversion and long-term maintenance. If water conservation is the primary goal, converting more irrigated area will mean greater savings. However, remember that many courses have experienced increased labor costs with conversion to low-water-use areas. It is important to understand what the expectations are and where the balance lies between water savings and labor costs.

Regardless of the goals or priorities of a turfgrass-reduction program, it is always wise to work with a qualified golf course architect. They will be able to guide a facility through the many trade-offs among playability, strategic value, aesthetics and potential water savings. These decisions will determine the success or failure of turfgrass reduction in the eyes of golfers, and if they are not happy it can mean higher maintenance costs or even complete reversal of certain areas back to irrigated turfgrass.

The first places to target are the "out-of-play" areas, but what exactly that means is not always easy to define. Anyone's experience as a golfer has shown them that shots end up just about everywhere on a golf course, even places that most would consider completely out of play. This is where objective tools like mapping golfer traffic with GPS trackers can be a tremendous asset. Observing where golfers have and have not gone over an extended period can help identify conversion areas that would truly have a limited impact on play. If going beyond those areas is desired, at least it will be with a clear understanding of what the impact on play is likely to be.

Working with a golf course architect to plan turf reduction areas will help balance water conservation goals with the impact on strategy and aesthetics.

The layout of the irrigation system is also a key consideration. It is important to either lay out turfgrass-reduction zones with respect to the location of existing heads or plan for changes to the irrigation layout. If turfgrass-reduction zones do not correspond to the location of the heads, the result might be areas of maintained turfgrass that are too dry, or naturalized areas that are too wet. If a choice must be made between these two options, dry areas of maintained turfgrass are usually preferable from a playability and aesthetic standpoint as they will act as a transition zone between irrigated turfgrass and non-irrigated areas. Sprinkler overthrow into turfgrass-reduction areas should be avoided as much as possible because this can promote excessively dense vegetation, weed growth and undesirable aesthetics.

When reducing irrigated turf without changing the existing irrigation, the best thing to do is coordinate the new turf-reduction limits with the existing sprinkler head layout. When this is not possible, work with an irrigation designer to add backup heads or try to have a "rooster tail" nozzle spraying out the back of an existing head to irrigate any turfgrass area that does not correspond perfectly with the sprinkler layout. If a new irrigation system is being planned, that is an excellent opportunity to consider turfgrass reduction because the system can be laid out around the new grassing lines.

Another critical factor in locating turfgrass-reduction areas is the treatment that will replace irrigated turfgrass. If the turfgrass-reduction areas will be relatively playable – like sandy hardpan with scattered grasses and groundcovers – there is more leeway to encroach on the line of play. If turfgrass-reduction areas will be unplayable – like high-density plantings or larger rock – they will likely need to be farther from the line of play to minimize conflict with golfers. Even areas that seem out of play will come into play more often than anyone would like to admit, so it is usually better to err on the side of caution. A great example is the area directly in front of the tees. Many golfers would say it is out of play, but we've all seen our fair share of topped tee shots and nobody likes looking for a lost ball 20 feet in front of the tee.

Turfgrass reduction is not typically something that needs to happen all at once, and trying to do too much too fast can lead to many avoidable issues.

When laying out turfgrass-reduction areas, remember that there can be different treatments depending on the proximity to play. Areas on the far periphery of the golf course can potentially receive less maintenance or a different planting scheme than high-visibility or high-traffic areas. Identifying these differences can help optimize overall resource conservation. Converting smaller test areas that are well out of play before working closer to the line of play can help avoid problems and build consensus around different approaches. Turfgrass reduction is not typically something that needs to happen all at once, and trying to do too much too fast can lead to many avoidable issues.

It is often best to allow the golf course architect to identify what they initially believe would be an ideal turfgrass-reduction plan without worrying too much about the irrigation design or other potentially limiting factors. Once that is established, the review process can begin to consider the amount of irrigated acreage removed, the expected water savings, the irrigation design, aesthetics and playability, and maintenance considerations like the location of trees or problematic turfgrass areas.

Decide Who Will Do the Work

Turfgrass removal projects are often completed when the golf course is busy and the turfgrass is actively growing. Therefore, the maintenance team is busy with routine maintenance. This is why it is often best to use a skilled contractor to complete turfgrass-reduction projects. However, many courses have used a hybrid approach where the golf course maintenance team makes the herbicide applications to control existing turfgrass and then assists the contractor with cleanup, irrigation adjustments and plantings. Some complete the work in-house to save money, but the reallocated labor will come at the cost of what can be completed on the golf course. How low-water-use areas are designed will play a significant role in this decision. Large areas of complex landscaping will almost certainly require the assistance of a contractor and/or additional maintenance staff, whereas smaller areas that are established by simply discontinuing maintenance can be quickly done in-house.

Select Alternative Plant Materials, Landscaping or Soil Treatment

There are several key considerations in selecting alternative plant materials and soil treatments when water savings is the highest priority. Species and planting density have a big impact on potential water savings. Mistakes have been made by overplanting or using plants that consume more water than other options. For example, planting inappropriate trees in environments where they require irrigation can lead to more water use than turfgrass over a given area. However, planting appropriate trees could have environmental and playability benefits. Any new trees in turf-reduction areas should be able to tolerate minimal to no irrigation once established.

Before selecting plants for low-water-use areas, it is wise to visit with the local university cooperative extension agents, local and state water authorities and water purveyors who likely have an extensive list of well-adapted, low-water-use plants. The golf course architect, a landscape architect and a regional USGA agronomist will also be good sources of ideas for vegetation selection and placement. Visit nearby courses that have undergone similar turfgrass-reduction projects and discuss the advantages and disadvantages of their chosen treatment. Begin to evaluate ideas years before the project, if possible. Select one or several out-of-play areas on the course, install different treatments, see how they perform and solicit golfer feedback. These trials are invaluable for becoming more comfortable with the conversion process, subsequent management and the impact on playability. Experience demonstrates that there is no easy, cookie-cutter answer for what to plant or how to treat the soil in turfgrass-reduction areas. There are trade-offs involved in every option. The following is an overview of the most common treatments used to replace irrigated turfgrass on a golf course.

Testing various planting options before implementing a turf reduction program will help you evaluate aesthetics, playability and overall performance.

Naturalized grasses and ground covers

"Naturalized" is a loosely defined term to describe tall grasses that may or may not be native to the area, but are expected to use less water than maintained turfgrass – or no water at all, depending on the climate. If this type of planting is the preferred option for replacing irrigated turfgrass, it is best to start small with demonstration areas planted using grasses identified by local experts. Naturalized grasses will establish slowly and often will not achieve the desired look until 3-4 years after planting. It may be advisable to create some form of transitional area between the maintained turfgrass and tall naturalized grasses to help with playability and pace of play. Some courses mow the margins of naturalized grass areas in key locations, whereas others establish buffers with no vegetation at all. The USGA Green Section Record article "Native Grasses and Ground Covers as Turfgrass Alternatives in the Southwest" contains lists of suitable plants for arid climates and results from studies evaluating their use in places like Arizona.

Rock and mulch

A mix of mulch and plantings can be a playable and attractive option for turf reduction areas.

Various sizes of rock and mulch are commonly used in turfgrass-reduction areas, especially in the Desert Southwest. In 2024, costs for this type of landscape rock spread 2 inches deep range from $18,000 to $25,000 per acre. The type of rock used is typically 0.375-inch diameter or less, and most often, courses use 0.125-inch diameter or less because it easily compacts and golfers can hit a recovery shot with relative ease. However, the small rock will erode with wind and water, especially when placed on slopes. Some courses have successfully used larger landscape rock or "rip rap" in these scenarios, but costs are significantly higher for the larger rock. Some courses in dry climates would rather repair erosion after the infrequent rain events rather than spend additional money on large rocks. Where water flows into the course from off-site, such as from homesites or streets, it is often best to use larger rock or leave these areas as turfgrass for erosion mitigation.

Mulch is another commonly used option in turfgrass-reduction areas. Locally sourced mulch is best, and some courses with an abundance of trees may be able to keep pace with mulch replacement by chipping their own material on-site. Mulch is often applied 2-4 inches deep and will likely need annual replenishment to maintain this depth. Mulch helps mitigate soil erosion, is relatively easy to play golf from, and is easy to find golf balls in.

Landscape plantings

Low-water-use plants with slow growth habits are best for turfgrass-reduction areas. Many state water agencies supply a list of low-water-use plants for regions within their state. It is often best to plant small, 1- to 5-gallon pot plants at wide spacing. While this aesthetic often elicits complaints initially because it appears “barren,” in a few short years the mature look will be appreciated.

Bare soil

Maintaining areas of bare soil or very sparse vegetation instead of turfgrass is also an option. In arid environments, this option works relatively well since no irrigation is required, weed pressure is minimal and heavy rains are infrequent. However, in areas that receive more than about 15 inches of annual rain, weed pressure will be significant without any competition. A good preemergence and postemergence weed-control program will be necessary to maintain a clean appearance. A box blade is frequently used in bare soil areas to knock down small weeds, smooth out ruts from erosion, and create a smooth and attractive appearance. While a bare soil treatment is less costly to install, maintenance is necessary depending on the level of expectations. Sites with sandy soil and/or limited rainfall have a better chance of maintaining reasonable playability in these areas. Heavy soils with no plant cover can quickly become a quagmire if rainfall is frequent.

Bare soil can also be an alternative to irrigated turfgrass, especially in areas that receive very little rainfall and don’t have much slope in the terrain. Bare ground in wetter climates will have issues with mud, erosion and weed pressure.

Expected Cost and Timeframe

The cost of creating turfgrass-reduction areas varies widely depending on the treatment chosen. Costs can range from as low as $12,000 per acre to over $180,000 per acre. The least-expensive projects are completed in-house with no soil preparation work and minimal plantings. These projects simply involve killing the existing turfgrass with one or more herbicide applications and installing some form of soil cover, or even leaving bare soil. Higher-end projects include a golf course architect and landscape architect, a contractor to complete the turfgrass removal and replanting process, and significant irrigation modifications.

Eliminating the Existing Turfgrass

Courses use a variety of methods to remove existing turfgrass and, as might be expected, results are highly variable. Replacing a bermudagrass area can be as simple as one herbicide application followed by covering with several inches of rock. Initial costs for this process are minimal compared to others, but courses need to budget for a regimented spray program to control bermudagrass reemergence. If the water is turned off in these areas and plantings are minimal, the results are surprisingly good. The expectation should be to manage turfgrass reemergence for three to four years with a routine herbicide program.

For a more robust turfgrass removal program, especially where warm-season grasses are present, two or three herbicide applications are necessary and may be followed by mechanical removal. A fall herbicide application is suggested to injure the warm-season grass prior to winter dormancy. Resume applications the following spring once there is regrowth. A good guideline is to plan on three herbicide applications spaced approximately three to four weeks apart to allow enough time for warm-season grass regrowth between applications. If replacement plants receive drip irrigation or no irrigation, warm-season turfgrass reemergence is less likely. However, if the area is to be planted with naturalized grasses that require irrigation, a more thorough chemical program is necessary to minimize warm-season grass reemergence. Cool-season turfgrass is easier to control than warm-season turfgrass. One or two nonselective herbicide applications will suffice in most cases.

Eliminating the existing turfgrass can be a significant challenge in creating low-water-use areas. One or more herbicide applications will likely be required, depending on the existing turf and the replacement landscape that is planned. (USGA/Kohjiro Kinno)

Mechanical tools such as a box blade can be used to remove turfgrass for disposal. The removal process is usually most efficient if the sod is cut first and then scraped into piles. Alternatively, healthy sod can be harvested and used in strategic areas on the golf course. Especially for warm-season grasses, herbicides will be necessary approximately three weeks after stripping when the grass reemerges. Minimal soil preparation is strongly suggested. Removing more than the top 0.25 to 1 inch of surface material is not necessary nor recommended. More-aggressive removal or rototilling results in greater weed pressure and unnecessarily increases costs. If mulch or aggregate material is going to be placed over the turf reduction area, an edge 1-2 inches deep should be created along the turf margin and tapered into the turf-reduction area to tie-in the landscape material and prevent it from spilling into the maintained turfgrass.

Healthy turf in removal areas can be harvested and used elsewhere on the golf course. Allow some time after stripping for any regrowth and then treat with herbicides. (USGA/Kohjiro Kinno)

Establishing the New Landscape

Irrigation

Independent irrigation of the turfgrass and turfgrass-removal areas is essential for a successful project. While it is ideal to eventually discontinue watering in turfgrass-reduction areas, in most climates it is a good idea to leave sprinklers in place when planting naturalized grasses for the establishment phase and for supplemental water if necessary during the summer months. Where woody vegetation is installed, drip irrigation is often used. Experience has shown that a riser made from schedule 80 PVC pipe and equipped with a pressure-regulated drip emitter is superior to a flexible pipe and “spaghetti” tubing, which are easily dug up and damaged.

Maintenance is often a challenge along the margin between irrigated turfgrass and turfgrass removal areas. Overspray from the turf areas contributes to weeds and undesirable growth in the naturalized areas. Or, if the sprinklers are too far from the edge of the naturalized area, courses end up with dry turf. Having part-circle irrigation heads properly placed along the perimeter of the irrigated area is the first step in managing this issue, and courses can expect to move some heads around to accommodate the new planting scheme. Making sure these heads stay properly adjusted is another important step, but all it takes is some wind to create enough overspray to cause problems. A novel idea is to install subsurface drip irrigation in a band approximately 10 to 12 feet wide into the remaining irrigated turfgrass. The overhead sprinklers can then be offset the same distance toward the line of play, thus significantly reducing overspray and water waste in the turfgrass-reduction areas. Some courses have found success managing a 6- to 10-foot-wide strip of bare ground, rock or mulch with no vegetation adjacent to the turfgrass. This facilitates easy spraying for weed control and allows golfers to find errant shots that just missed the turf. This type of treatment will fit better in some environments than others.

Ideally, turf reduction boundaries will correspond with sprinkler locations so that heads can cover the irrigated turf without throwing water into the turf reduction area.

Soil preparation and planting methods

It is not necessary to rototill the soil to establish naturalized grasses or other vegetation. In fact, the less soil disturbance there is, the better. Soil disturbance increases the risk of erosion, and it can bring unwanted weed seeds to the surface. A good strategy to establish naturalized grasses is hydroseeding with no soil preparation. Otherwise, utilize an aerator with solid tines on a tight spacing to create shallow (0.25 to 1 inch) holes to catch and hold the seed.

Maturation

Newly introduced turfgrass-reduction areas usually receive the greatest amount of discussion and complaints during the first year. Grasses or plantings can look sparse at first, and weed issues are to be expected. Erosion may also be a problem as the new plantings establish. All of these factors can concern golfers. Naturalized grasses will require the greatest amount of grow-in time, typically three to four years before reaching maturity. These species are significantly slower to establish than turfgrass from seed. While turfgrasses may germinate in five to seven days and produce a dense stand in only a few months, naturalized grasses often require five to six months or more. Furthermore, turfgrass-reduction areas are often located on steep terrain with a variety of sun exposure, complicating establishment. It is usually necessary to reseed areas, likely comprising 30% or more of the entire turfgrass-reduction acreage. Some areas will need reseeding more than one time and over multiple years. Weeds will emerge and reemerge and compete with the desirable species. Establishment and management can be frustrating for several years, and patience is key. Eliminating cart use in these areas is essential.

People need to be prepared for a multiyear establishment and maturing process before turfgrass-reduction areas really start to look good.

Establishing shrubs and trees with drip irrigation is often less complicated than establishing naturalized grasses. Probably the best piece of advice is to start with small plants and ample space between them. Allow several years for the plants to grow and mature. Small plants will outgrow larger plants eventually, and they are less expensive to purchase and plant. Small plants on an appropriate spacing will look sparse initially, and golfers may express concern. People need to be prepared for a multiyear establishment and maturing process before turfgrass-reduction areas really start to look good. Set realistic expectations, have patience, make irrigation adjustments, evolve with what works best and replant when necessary.

Long-term maintenance

Maintaining native grasses and other plants like wildflowers to continuously provide a natural appearance will require monitoring and considerable labor resources. The same is true of landscape plantings with woody species. A wide variety of weeds will encroach upon these areas and require timely maintenance if they interfere with play, aesthetics or functionality. Weed control is a complex challenge in most types of turfgrass-reduction areas because it can be difficult to apply effective postemergence products broadly without damaging the desired plants. Backpack spraying and manual weed pulling are common tasks in turfgrass-reduction areas, especially if expectations are high for presentation and playability.

Developing an effective mowing program for naturalized grass areas is an important part of long-term maintenance and can greatly assist in managing weeds and overall density. The timing and frequency of mowing these areas will vary from year to year depending on the weather and weed pressure. In wet years, it may be necessary to mow down naturalized areas earlier and more often than planned to keep them manageable. This may not be the preferred aesthetic, but weather and soil conditions will always determine how best to manage naturalized grass areas. Selective mowing in key locations is another common management strategy to maintain playability and minimize complaints. Oftentimes, courses will mow one or two passes adjacent to playing areas to help speed up the pace of play.

Managing weeds is a challenge in turf reduction areas. If there are high expectations for weed control, backpack spraying and hand pulling will likely be necessary.

Erosion is another challenge that will require ongoing maintenance. It is very common for courses to install remedial drainage features in turfgrass-reduction areas once erosion issues reveal themselves. Depending on the situation, creating ditches and retention basins may be enough to solve the problem; in other situations, water will need to be captured and carried away in drainage pipes. Adjustments to the planting plan may also be necessary in areas where erosion becomes a problem. The desired plants may lack the ability to keep soil in place, so it may become necessary to look for other low-water-use options or to restore turfgrass in areas where low-water-use plantings have proven unsuccessful.

Being flexible with the composition of the plant community in turfgrass-reduction areas is an important part of managing costs and expectations. Some weeds are problematic and must be managed, but others may not really be an issue and can be tolerated. The planting scheme initially imagined will almost certainly evolve. Some plants and grasses will thrive in some areas and fail in others, or weeds may become the dominant plant in some areas without causing much of an issue. In fact, a hardy population of weeds may save certain areas from total failure. Courses should try to be as pragmatic as possible when it comes to managing the plant community in naturalized areas, otherwise maintenance costs can spiral upward.

TIPS FOR SUCCESS

Beware of the impact on the labor budget.

Many courses have found that eliminating irrigated turfgrass areas saves water yet it leads to more staff time spent in those areas for weeding, selective mowing and other tasks. How significant the labor impacts might be goes back to the goals of the project and the expectations – and a recognition that expectations may change over time. Golfers may say they are comfortable with weeds and lost balls in “out-of-play” areas, but once they discover how frequently they hit shots into those areas they often demand more maintenance. Developing a landscape design and maintenance program in some test areas is a good strategy to get everyone on the same page and evaluate the labor impacts of turfgrass reduction.

If there are high expectations for presentation and playability in naturalized areas, labor costs to maintain those areas can be higher than for mown rough.

Do not be afraid to treat different areas differently.

Not all turfgrass-reduction areas need to be designed, planted or maintained in the same way. Certain high-visibility and high-traffic areas will likely require more resources to provide acceptable quality, whether they are planted with native grasses, xeriscape or any other treatment. In areas farther out of sight, there may be opportunities for less-intensive maintenance that leads to water conservation and labor savings when compared to mown, irrigated turfgrass. Identifying the distinction between in-play and truly peripheral areas can help optimize many decisions.

Fine fescue is not always the answer.

Many golfers imagine seas of long grass blowing in the breeze when they think about "naturalized" or non-irrigated areas, but this aesthetic is not native or easy to maintain in most areas. Trees, shrubs, small plants and groundcovers are what would naturally grow in most places, and going in a different direction from the native vegetation can require additional resources. This is not to say that native vegetation is easy to establish or maintain – or that it will necessarily deliver the desired playability and presentation – but it is important to at least consider a broader range of planting options when it comes to turfgrass-reduction areas than grasses which may or may not be native to a particular area. A good way to start planning turfgrass-reduction areas is to look at non-irrigated areas along roadsides or in parks to see what is growing there. Plants that thrive in those environments could be a relatively low-maintenance option for turfgrass-reduction areas on a golf course.

Mowing is part of management.

Turfgrass-reduction areas tend to be more problematic when they are too thick rather than too thin. Golfers may complain about poor coverage or erosion, but if they can find and play their ball the complaints are generally fewer. Unfortunately, the vegetation in turfgrass-reduction areas often gets too thick, leading to a poor aesthetic and lost balls. This is especially true in areas with regular rainfall and soils that retain moisture well. While the goal may be having long grass with seedheads visible throughout much of the year, a rainy stretch of weather can make turfgrass-reduction areas grow out of control, and there's nothing wrong with mowing them down to more manageable heights. The desired contrast from rough areas will still be achieved, just with fewer complaints about weeds and lost balls. This same logic can apply to routine management. If resources can't keep up with weed control and density management in non-irrigated areas, it might be better to just mow them at the highest possible height several times each year to keep things as playable and presentable as possible.

Mowing is an important part of managing naturalized grasses in turf r eduction areas. If a course is having issues with density or weeds in these areas, more-frequent mowing may be the answer.

Be careful with turfgrass reduction in front of the tee.

The area around teeing grounds is often a prime target for turfgrass reduction, but if new plantings are likely to produce lost balls, it may be better to avoid the area immediately in front of most tee decks. While truly expert players are unlikely to top a tee shot, many other players routinely have this issue, especially if there is a lot of tall grass right in front of them. Losing a ball after a poor tee shot is particularly aggravating and golfers are more likely to spend extra time looking for a lost ball close to the tee, even if they have little chance of finding it. A corridor of mown rough in front of the tees, even if it is not irrigated, can be very helpful for keeping things moving and minimizing controversy about non-irrigated areas.

Hardpan is not necessarily low maintenance.

Areas of bare ground within a turfgrass-reduction area can be excellent for playability, but depending on the soil type and climate they can be hard to maintain. In areas that receive consistent rainfall, bare ground will be under continual weed pressure. If those weeds tend to be low-growing and playable, they might be acceptable. If they tend to be tall, dense or aggressive growers, they can become a real problem in areas that were intended to be exposed soil. Erosion can also be an issue in hardpan areas depending on the nature of the soil, topography and climate. Sandy soils make for excellent, playable hardpan but are also vulnerable to erosion from heavy rains. Steep slopes and intense rainfall will exacerbate erosion issues further. If hardpan soil is desired as part of a turfgrass-reduction area, selective weed control and erosion repair should be planned as part of the long-term maintenance program.

Turfgrass-reduction areas may still require irrigation.

Most turfgrass-reduction options require some irrigation during establishment and maturation. In arid climates, irrigation may be required during the summer months, although significantly less than maintained turfgrass would require. Watering-in preemergence weed control applications and other pest control products may also be necessary. Accounting for these irrigation needs is an important part of success. Many courses have mistakenly viewed these areas as “non-irrigated” only to find themselves running hoses and portable sprinklers from fairway quick couplers during establishment and beyond. Having some form of automatic irrigation in turf reduction areas is a valuable and potentially necessary asset.

Build golfer and homeowner support.

For most courses, gathering golfer and homeowner support for turfgrass reduction is crucial to the project’s success. While some golfers living on the course may support turfgrass reduction, when the project lands in their backyard the sentiment may change. Building support for turfgrass-reduction projects will take time, several years in some instances. But perseverance and gathering support from industry professionals inside and outside of the facility will go a long way. The facts that coincide with turfgrass reduction are powerful. Courses facing escalating water costs or water restrictions may not have much choice, and golfers and homeowners will eventually support turfgrass reduction if the alternative is to shut down the course and parcel the land into real estate. Courses have garnered support from being good neighbors. Reach out to each and every homeowner in the community, especially those along the course, and explain the reasoning behind the decision to remove turfgrass.

Keep up to date with trimming, pruning and vegetation removal.

Volunteer plants and trees will establish themselves in almost all turfgrass-reduction areas. In some cases, the vegetation will be welcome and provide additional texture, vertical definition and interest to the golf course. However, dense trees and shrubs may obscure views across the course, block air circulation and shade nearby turfgrass. Deferring trimming, pruning and removals for several years will result in dense vegetation that looks unsightly, slows the pace of play and can attract unwanted pests. The longer you wait to manage volunteer trees and shrubs, the more challenging and expensive it will be to return the area to the desired appearance.

Tell the story of water conservation.

Conserving water while preserving a functional, attractive and playable golf course is a win-win for the facility, the neighborhood, the state, the region and the golf industry. Document the savings and share that story with public leaders. Think beyond sharing with golfers and homeowners and reach out to the water purveyor and local, state and regional government officials. Sharing the success of water conservation strategies can help facilitate financial and political support for these projects from water purveyors and other government authorities.

BMP CASE STUDIES

"Naturalizing Areas Helps Maximize a Limited Water Supply"

USGA Green Section Record, 2017.

A golf course in Massachusetts with a limited groundwater allocation struggled to manage periods of summer drought, causing noticeable turfgrass loss and a decline in playing conditions. A decision was made to convert approximately 15 acres of maintained rough to naturalized fine fescue that would not require irrigation once established, nor affect play. The turfgrass reduction project contributed to a 4-5 million gallon reduction in annual irrigation and made more water available for primary playing areas, which helped address limitations on water use.

"Native Grasses Yield Water Savings"

USGA Green Section Record, 2017.

An Arizona golf course went from 220 acres of irrigated turf to 80 acres as part of a renovation designed to improve sustainability and decrease water use. 140 acres of formerly irrigated turf was converted to naturalized grasses and native desert vegetation, leading to tens of millions of gallons in water savings each year.

Subsurface Drip Irrigation

Subsurface drip irrigation offers significant opportunities for water savings and improved irrigation uniformity when compared to traditional overhead sprinklers.

SNAPSHOT

Subsurface drip irrigation delivers water directly to the rootzone more efficiently than sprinklers. It is a high-impact, high-cost strategy applicable for golf courses with sufficient financial resources and major conservation goals.

Expected cost	> $50K per acre
Ease of implementation	Large capital project
Potential water savings for affected area	> 30%
Highest potential impact areas	Arid and semiarid regions like the southwestern U.S.

OVERVIEW

Subsurface drip irrigation (SDI) is plastic tubing placed below the soil surface that delivers water into the rootzone. SDI has been used in agriculture for several decades but isn't as common in golf course irrigation. When it has been used in golf, it's typically in landscape beds and bunker faces. It has also been widely used for other turfgrass areas that require precise watering and are difficult to reach, such as parking lot islands.

When water is sprayed into the air from a sprinkler, it's subject to wind drift, overspray, runoff, evaporation and possibly missing the target. For these reasons, at best, an efficient sprinkler system can theoretically achieve 75% distribution uniformity of the low quartile (DUlq) under field conditions. This means at minimum 25% of irrigation water is misapplied even when a system is functioning well, and delivering adequate moisture to the entirety of the coverage area will require increased irrigation runtime (which may result in overwatering other areas) or supplemental irrigation, often in the form of labor-intensive hand watering to prevent localized drying. In contrast, SDI systems are highly efficient, achieving 95% DUlq when properly installed and functioning (Camp et al., 1997).

Recent research has demonstrated SDI's ability to sustain turfgrass with 50% to 80% less water than overhead irrigation when used on small island tees (Whitlark et al., 2023). Several golf courses in the Southwest are implementing small-scale SDI along with their sprinkler systems. However, there are limitations to SDI, such as the cost and disruption of installation and its potential vulnerability to damage during aeration.

SCENARIOS FOR USE

Drip irrigation is most commonly used in ornamental planting beds. However, this application involves different tubing and very different management considerations than SDI in turfgrass areas. Perhaps the most common use of SDI in golf course turfgrass areas has been on bunker faces to reduce imprecise irrigation, soil erosion and runoff that often leads to droughty turfgrass. Without SDI, the most common solution to managing dry bunker faces is supplemental hand watering, which is time and labor intensive and may not deliver the desired results.

Irrigating the turf around bunkers is probably the most common current application for SDI on golf courses. It is a more effective and efficient way to water these difficult areas than overhead sprinklers or hand watering.

Several golf courses are also implementing SDI on smaller island tees. SDI allows the direct application of water only to the turfgrass rootzone, avoiding any overspray to nonirrigated areas. In addition to saving water, this reduces weed control and other maintenance of the tee surrounds, especially if they are intended to be nonirrigated. Other golf courses have used SDI on driving range tees, which has the added benefit of eliminating irrigation hitting synthetic mats that may be placed behind the tee. There are also some instances of SDI use for independent irrigation of trees in naturalized areas. There are not many examples of SDI being used in fairway and rough areas, but the few courses that have tried it report water savings of up to 40% compared to overhead irrigation. A few superintendents have also tested SDI on putting green collars. In one known instance, SDI has been installed in a putting green constructed according to USGA recommendations.

SDI systems have proven to be highly effective on island tees where they deliver significant water savings and improved distribution uniformity compared to overhead sprinklers.

BENEFITS

Water Conservation

Studies have shown that SDI can reduce water use by 30% to 80% compared to overhead irrigation (Serena et al., 2019; Whitlark et al., 2023). How much water can be saved will depend on various factors, including the irrigated turfgrass species, the local climate, soil type, existing irrigation system and the watering schedule. In research and demonstration studies, the larger water savings from a percentage standpoint are primarily correlated with eliminating overspray into off-target areas. A good example is the potential water savings on individual island tees surrounded by nonirrigated naturalized area. Using SDI over a larger area like a fairway would offer more modest water savings from a percentage standpoint, but a higher potential savings in terms of total gallons. Increased soil moisture uniformity, reduced evaporative losses, and reduced wind-drift losses associated with SDI may still deliver an estimated 40% water savings compared to a sprinkler system in fairway or rough areas.

Improved Turfgrass Quality

SDI can improve turfgrass health, appearance and playability by providing more precise and uniform irrigation. Reducing surface wetness can reduce disease incidence and weed populations. Less water at the surface also reduces the risk of runoff, compaction and soft playing conditions.

Greater Precision

SDI essentially eliminates off-target irrigation due to overspray or runoff, which greatly improves precision. Not only does this translate to water savings and improved turf quality as noted in the sections above, but this can also help to reduce maintenance and improve the aesthetic presentation of adjacent areas. In situations where off-target irrigation leads to unwanted plant establishment and growth in naturalized areas, there may be considerable labor costs associated with dense growth or weed establishment that requires some combination of mowing, hand labor and/or herbicide applications to manage.

Overspray from these tee sprinklers not only wastes water, it also promotes unwanted plant growth in the native areas surrounding the turf, which then requires additional maintenance. SDI can eliminate these issues.

Less Impact on Play

SDI allows irrigation to occur without interfering with play. Many golfers do not like to see sprinkler heads running in front of them and they certainly don't like being hit with irrigation water. SDI eliminates these issues and allows areas of the course to be watered during play, if necessary.

Ease of Use and Maintenance

Once in place, SDI systems are arguably easier to use and repair than traditional irrigation systems with more complex components. Repairs are straightforward and although regular cleaning of filters is required, it is a minor task.

CONSIDERATIONS

Installation

SDI installation costs and challenges are greater over a given area of turf than overhead sprinklers. Therefore, water cost and water availability likely play an important role in the decision to invest in SDI. More research and demonstration projects are needed to test the suitability of SDI for watering larger areas like fairways, where more meaningful water savings can be achieved but installation complexities also increase. More product and machinery development is needed to improve installation methods, increase speed and lower cost.

Installing SDI is more challenging and expensive over a given area of turf than installing overhead sprinklers. (USGA/Bill Hornstein)

Climate

SDI is most valuable where evapotranspiration rates are high, precipitation is scarce and water must be purchased at a significant cost, making dry climates like the western and southwestern U.S. ideal opportunities to use this technology.

Soil Type

Soil type can affect the design, installation and scheduling of SDI. For instance, water movement in clay soil is slower than in sandy soil; therefore, irrigation timing can be challenging and needs to follow a cycle and soak schedule. Installation spacing, depth and emitter flow rate are other considerations when installing SDI in heavy soils. Most of the research conducted so far has been in sandy soil, but it's expected that the benefits of SDI are similar in clay soils.

Turfgrass Species

SDI has been successfully tested on most turfgrass species used in the golf industry. However, there is limited information about its use on annual bluegrass and perennial ryegrass. SDI might be less suitable for these species because of their shallower root systems. This may be a particularly important factor where perennial ryegrass is used to overseed bermudagrass fairways.

Checking and cleaning filters is part of the routine maintenance that is necessary to ensure SDI systems function properly. (Bernd Leinauer)

Maintenance

Like any other irrigation system, SDI systems require continual maintenance. Insufficient care will lead to diminished performance and ultimately, the failure of an SDI system. System filters need to be checked on a regular schedule and the drip tubing needs to be monitored for leaks and clogging.

With the system buried in the ground, these issues can be difficult to identify. However, when leaks happen, water bubbles will form on the surface or there will be washed-out soil where water gushes to the surface. Dry or dead turf in an area with SDI may indicate some type of clogging malfunction. We recommend checking the area with a portable soil moisture meter and if dry, exposing a few drip emitters in these droughty areas, running the system and visually inspecting the delivery of water.

System filters will require frequent cleaning. However, self-flushing filters or better filtration at the pump station can reduce maintenance requirements for these components.

Water Quality

Turf areas that are irrigated with SDI have been shown to accumulate more salts in the top few inches of soil (i.e., between the surface and the tubing emitters) compared to a sprinkler system. Leaching of these salts is limited to rain events unless sprinklers are also maintained. This means the risk of salinity stress for turfgrass is greater with SDI than overhead irrigation when irrigation water is high in salts and annual precipitation is low and infrequent. Water hardness or the presence of biofilms and algae can promote emitter clogging as well.

Root Intrusion

SDI system manufacturers have developed different strategies to prevent root intrusion, which is particularly important for emitter lifespan. For instance, some emitters are embedded with preemergence herbicide with a slow rate of release. Other companies use copper to prevent roots from entering and clogging emitters. Another way to prevent root intrusion is installing a slow-release herbicide filter. Other root-intrusion preventions consist of injecting chemicals such as herbicides or acids into the irrigation water.

Cultivation and Topdressing

Because SDI is commonly buried only 4 to 6 inches below the surface, deep cultivation may damage tubing. Regular topdressing may eventually reduce the efficacy of an SDI system by raising the rootzone beyond its reach.

SDI tubing can be damaged by aeration and cultivation equipment, which may limit the cultural practices available in areas irrigated by SDI. This section of dripline was punctured by an aerator. (Bernd Leinauer)

Double System

Many turfgrass fertilizers, pesticides and other products are currently formulated for application to the turfgrass surface followed by overhead irrigation to water them in. For these reasons, an SDI system should currently be considered as an add-on to a traditional overhead system. However, installing and maintaining two irrigation systems may not be feasible for some golf courses.

Unresolved Technical and Cost Factors

While SDI has proven effective in agriculture, landscape settings and on small golf course tees, listed below are some of the important challenges that must still be resolved to make expanded use on golf courses a reality.

Design and installation

Few have experience designing or installing large SDI systems for golf course turfgrass because there are not many currently in existence. Cost-benefit analyses are currently difficult to perform due to the lack of firm pricing information on material, design and installation costs. However, installing SDI is currently more expensive than installing a standard overhead sprinkler system.

Depth and spacing

The recommended lateral spacing and depth of driplines is currently generalized, but likely has site dependencies related to soil type, topography and turfgrass species. The standard recommendation for a spacing of 12 inches and depth of 4 to 6 inches should be tested in different scenarios.

Durability

The long-term performance of SDI systems must be evaluated. They are typically assumed to last 20 to 40 years, but there are no examples of large-scale systems that have been in place on a golf course for that long.

IMPLEMENTATION

Installing an SDI system requires several steps which are outlined below. Before getting started, you should consult with a qualified irrigation designer and contractor with experience in SDI to ensure the quality of design and installation. Every site and situation will present unique challenges, so there is not a one-size-fits-all approach to installing an SDI system. However, there are fundamental steps that apply to most projects

Once you have identified a target area for SDI, work with a qualified irrigation designer to develop a plan for the system layout and components. (USGA/Bill Hornstein)

Step 1: Planning

Evaluate the area to be irrigated

First, determine the size and shape of the area to be irrigated (hydrozone) and consider the longest dripline run. Remember that there are manufacturer-dependent limits for the length of each run of drip tubing. Next, evaluate the soil composition to ensure drip tubing can be buried – it's a good idea to test a small area before deciding on tubing installation method (pulling or trenching). If slopes are present, the driplines should run perpendicular to slopes and water should enter the zone at the highest point to minimize resistance from gravity when filling the lines. Independent zoning, flush valves at the lowest point, and pressure-compensating drippers can all help increase the DU on slopes. Finally, determine the irrigation requirements and root depth of the grass species and make sure the SDI can meet those needs.

Recommendations for selecting and laying out SDI components

Drip system components, dripline spacing, tubing depth and emitter flow rate will all be site dependent. At minimum, the system should have emitter filtration, pressure compensation, check valves and root-intrusion prevention. Begin by determining the location of the header, footer and main valve. Consider installing multiple valves and zones for larger areas. Header and footer lines that are 1 inch in diameter allow for a zone of up to 1,200 square feet. Emitter flow rate should typically be between 0.5 and 0.6 gallons per hour (GPH). In clay soils, a lower flow rate should be used, about 0.3 or 0.4 GPH. Do not exceed the maximum allowed slope for pressure-compensating emitters; this is typically 10 ft of difference from the highest to the lowest point in any zone.

For drip tubing, do not exceed the manufacturer-specified maximum length of a single line of drip. Each manufacturer guarantees uniform water distribution up to the maximum length, after which water friction and pressure loss disrupt functionality. Lines should be buried 4 to 6 inches deep. It is not recommended to install SDI shallower than 4 inches because of potential damage to the lines and components from aeration. Installing deeper than 6 inches reduces the capillary rise of water to the surface, which may negatively impact turfgrass quality. Keep in mind that the depth of drip tubing will increase over time with frequent topdressing.

Step 2: Determining Installation Method and Site Preparation

New construction

If there is no turfgrass present, the drip lines can be laid out and covered with soil or capping material, followed by final grading and turfgrass installation. This method avoids the process of trenching or pulling the lines into the soil and can work particularly well on tees if there is no concern about raising the level of the tee with new capping material. This approach is more difficult over large areas where stripping and replacing topsoil or importing and spreading material to cover the drip lines becomes more challenging and time consuming. Trenching or pulling the lines is still an option in new construction settings if it is desired to avoid the material capping process.

Existing playing surface

When turfgrass is present, several different approaches can be utilized. The first is to remove all the existing turfgrass from the target area using a sod cutter, assemble the SDI system at grade, cover it with a new capping material and replace the sod. This works well in situations where the cost of additional capping material and the increase in elevation of adding it are not significant considerations. You can also remove sod and strip the existing rootzone material to the desired depth of the SDI system and then replace that material once the SDI system has been assembled. This approach has the advantage of maintaining the existing grade and using on-site material, but you have to excavate, store and replace the rootzone material, which has costs and challenges associated.

Removing turf and rootzone material prior to installing drip irrigation allows you to lay out, assemble, and test the entire system at the desired grade.

Another method is to trench directly into the turfgrass and place drip tubing, or use a vibratory plow or a mole adapter to pull drip tubing into place. Trenching or pulling dripline into existing turfgrass may generate turf damage requiring longer recovery and there will be disruption to the surface grade that needs to be addressed. It is also more challenging to maintain accurate depth and spacing when trenching or pulling drip tubing. Regardless of the installation approach, some trenching will be necessary to connect drip tubing to header and footer lines or other components.

A hybrid version of the above approaches is to remove the existing turf, trench or pull the SDI pipes into the exposed soil, smooth out the surface to a finished grade and then replace the turf. It is easier to smooth out the disruption caused by pulling or trenching the pipes when the soil is exposed than when it is covered with turf and the overall disruption to the turf would potentially be less.

One method to install drip irrigation is by pulling the pipes. If pulling drip lines into existing turf, there will be surface disruption that needs to be addressed. (USGA/Bill Hornstein)

Once the SDI system is fully assembled and tested, cover the piping, grade the surface smoothly and install the turf.

Step 3: Installation

There are many different ways to install SDI systems depending on the nature of the project and the particular circumstances of the site. An experienced contractor or golf course superintendent will have a method that works best for them, but there are several key factors to be mindful of in any installation regardless of the specifics.

Don’t allow soil or debris to fall into the drip tubing during the layout or installation process. This material can lead to clogging and reduced performance in the future. For oddly shaped or round areas, the last few rows of tubing do not have to be connected to the header. Instead, an extension loop can be made from the last header-connected dripline. Successive extensions are permissible.

Once everything has been connected, run water through the system for several minutes with the flush valve at the end of the line open to remove any soil particles or debris that might have entered the system during installation. Pressure test the system and check for leaks by closing the flush valve and charging the system. Let it run for several minutes and several cycles of pressurization and depressurization. Repair any leaks you observe. If the system has been installed into exposed soil, run it again prior to finished grading and grassing to observe the wetting pattern and make sure nothing has been damaged during the installation.

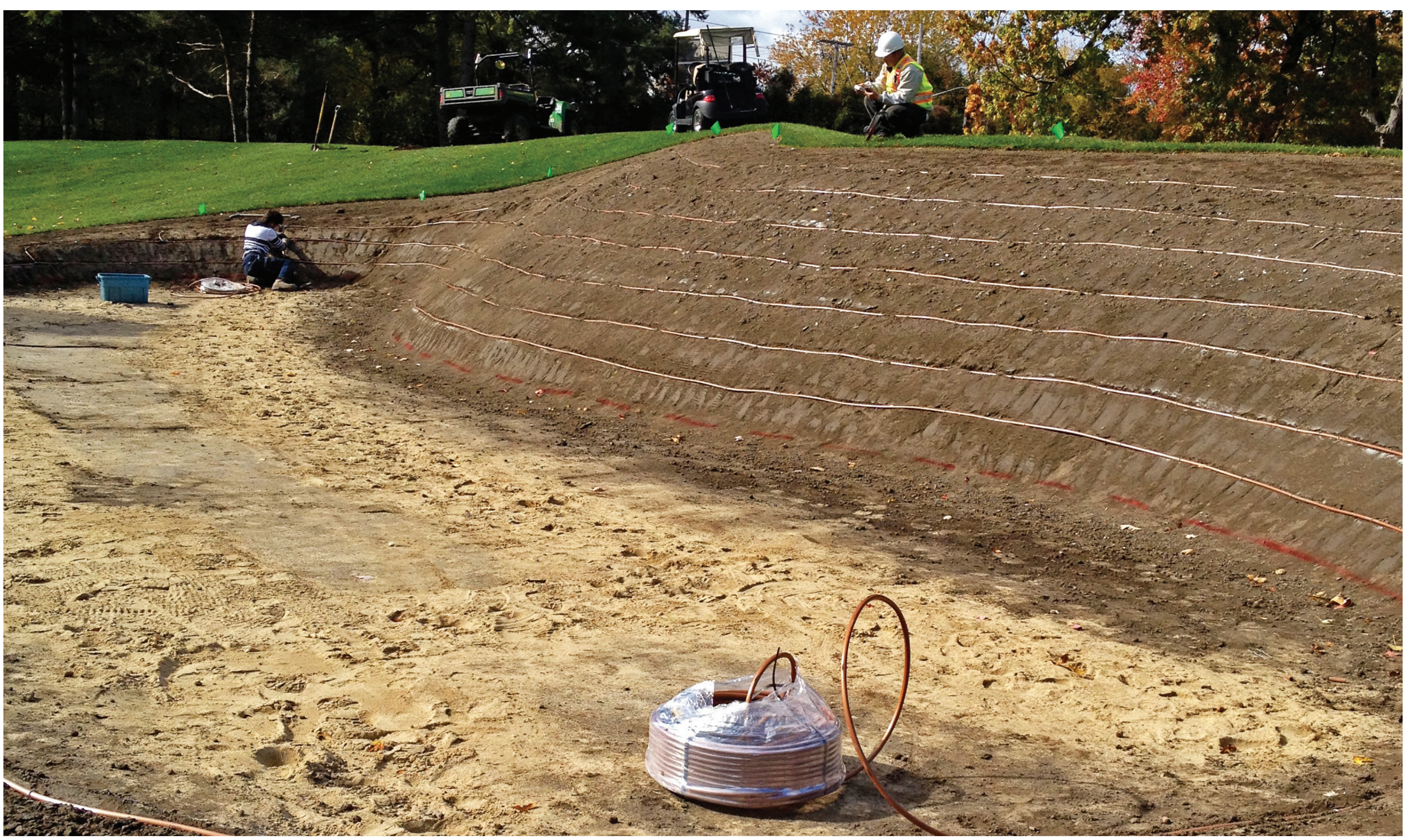
TIPS FOR SUCCESS

Test your planned SDI layout in a small area prior to making a large installation.

Standard spacing is 12 inches between driplines and emitters, however, there are various factors that influence what will be the best layout for a specific application – e.g., topography, soil type and turf species. Golf courses should test different layout options in representative areas before moving forward with a larger project. You may develop one layout or flow rate that works best in certain areas and another for different situations. Testing will help you gain comfort with installing and operating the system, and will help optimize performance.

Evaluate slope impacts in the installation area.

In flat areas, like teeing grounds, the direction and orientation of the dripline are not important, as the flat area ensures excellent water distribution and uniform movement. On slopes, it is recommended to install the dripline across the slope to limit the impact of gravity. Keep in mind that higher ground will require more frequent watering and drip tubing should be appropriately zoned along slopes to accommodate.



On steep slopes, like this bunker face, it is recommended to install driplines across the slope to limit the impact of gravity on flow through the pipes.

Emitter orientation is not critical, spacing is.

Staggering emitters to achieve some form of triangulation comparable to sprinkler layouts is not as important as ensuring the proper spacing between lines. Additionally, the orientation of the emitter hole is not important, it doesn't matter if the holes are pointing up or down in the trenches, water will seep out and moisten the soil in all directions regardless.

Ensure your drip system contains all essential components.

Manufacturers require filtration and a flush valve, and driplines and emitters should be protected against root intrusion. Consider the optimal operating pressure and adjust by installing a pressure regulator. Most manufacturers also require an air-release valve in SDI systems. Occasionally, the installation of an automatic flush valve or an indicator is recommended. Make sure to include recommended components and install them properly to ensure desired performance.

Consider installing a way to check functionality.

It can be difficult to know if an SDI system is operating correctly because all the components are underground. Major leaks are usually evident, but clogged emitters and other issues may not be easy to identify. Installing water meters or moisture sensors can alert you to a malfunction. Some superintendents use a small pop-up sprinkler at the end of the line with no nozzle as an indicator. If the sprinkler pops up when the line is charged, then you know the valve is functioning properly and the line has adequate pressure. There are specifically designed indicators that can be used instead of a pop-up head, however these are more common in landscaping installations.

Installing a closed pop-up sprinkler at the end of a drip line allows you to see if the line is properly charged and coming on when expected.

A filtration system at the main valve is a good investment.

If larger areas or numerous zones will be installed, consider including a large filtration system at the main valve. These will optimize performance and longevity of the other system components. These valves are often self-flushing, which eliminates the need for constant maintenance.

SDI installation involves some disruption.

Installing SDI systems requires a certain amount of disruption to the soil and turf if it is present. In smaller settings, turfgrass removal prior to installation has resulted in faster and better recovery than disk-trenching directly into the turf.

For larger installations, consider using a vibratory plow to minimize damage to the existing stand. Compacting the ground with a heavy roller may be necessary after plowing drip lines.

Leaving the turf in place has the advantage of being less labor-intensive and more cost effective; however, it requires a longer healing time than removing and replacing the sod. Ideally, SDI system installation can be timed to coincide with renovation or regrassing projects when the existing turf has either been removed or is not a concern.

Installing SDI systems involves some disruption. Ideally, drip systems are installed into exposed soil where the surface can be easily smoothed out prior to grassing.

There's no need to use special backfill material.

We have tested SDI and observed no issues in native soils with higher sand or clay content, as well as in a sand profile amended with organic material. You do not need to remove the native soil and install a special backfill material over the drip lines.

SDI systems require routine maintenance.

It's common to develop leaks or clogging in SDI systems. Periodically check the efficiency and proper functionality of the system. A flow meter or pressure gauge can be used to easily determine the appropriate frequency for cleaning filters. When flow and pressure fall below the optimal range, the filter must be cleaned.

TECHNICAL NOTES

Glossary of SDI System Components and Their Basic Function

Drip tubing

The drip tubing is the irrigation line buried in the ground. It can be made of polyethylene (PE), polyvinyl chloride (PVC) or rubber. PE is the most commonly used material because it is flexible, durable and resistant to chemicals, temperature fluctuation, and ultraviolet radiation during storage. In general, drip tubing is approximately 0.5 inch in internal diameter, with different manufacturers differing slightly to allow perfect fittings with their branded components. The thickness of the drip tubing wall varies across manufacturers but is generally greater than agricultural and landscaping products. Drip tubing is equipped with emitters, which are described in the following section. Prior to 2000, commercial drip tubing was made of a porous material with the entire line seeping water. However, tubing of this nature had short longevity and its use is now limited to vegetable gardens.

Drip tubing is commonly made of flexible polyethylene with an internal diameter of 0.5 inches.

Emitters

Emitters, occasionally called drippers, are devices placed inside the drip tubing that control the flow and delivery of water into the soil. In the early implementation of SDI, an emitter was a perforation in the tubing that allowed a small amount of water to escape.

Today, there are several types of emitters. Most manufacturers use “integral emitters.” These emitters are an integral part of the tubing, meaning they are incorporated during the manufacturing process and molded into the tubing. They are spaced at a predetermined distance (e.g., 9, 12, 15, 18, or 24 inches). “In-line emitters” are an evolution of the integral emitter. These are designed and constructed separately from the tubing and inserted into the line. In-line emitters are classified by their flow rate, normally expressed in gallons per hour (GPH).

Emitters are typically pressure-compensating. This means they are designed to provide a constant flow of water and maintain the same delivery under sloping conditions – typically up to 10 feet of slope per zone. Rarely, emitters can be used that are not pressure-compensating, making their flow rate dependent upon water pressure.

Emitters are now built with a microfiltration system. This labyrinth of channels is designed to capture any particulates that might have entered the system. Other modern features include self-cleaning emitters with a built-in check valve, as well as patented technologies to prevent root intrusion. The emitter check valve is an essential component for installation on slopes, as they prevent water from draining out when the system is shut off. Built-in check valves also prevent any debris from entering the system through the emitters. For these reasons, emitters equipped with a check valve are becoming an industry standard.

Filter types

Filtration is essential for an SDI system to operate properly. Filtration prevents clogging of the emitters from debris and sediment in irrigation water. Filtering requirements depend on the quality of the irrigation water source and the particle size of what needs to be removed. Common filtration systems for SDI include screen filters, media filters and disk filters. Each type is described in detail below.

Screen filters

These filters are designed to remove solid particles and debris from the water. They work by physically straining the water as it passes through a screen or mesh. Screen filters are generally rated by the size of the particles that can be captured, usually measured in microns. The smaller the micron rating, the finer the mesh of the filter and the more particles they can remove from the water. To prevent clogging, screen size needs to be chosen based on the water quality and the size of the emitters. In general, screen filters do not remove bacteria, algae or microfilm from the water.

Media filters

Media filters are designed to remove particles such as sand, sediment and debris from the irrigation water. The basic principle behind a media filter is to force the water through a medium that captures and collects impurities. This type of filter mimics the natural filtration that happens during aquifer recharge when water moves through the soil profile. For this reason, the normal medium used is sand. These are typically referred to as “sand filters” and perform like the ones commonly used for swimming pools. However, the medium can be fine gravel or other porous materials like plastic or PVC. They can be operated by pressure using a pump or they can be gravity driven.

Disk filters

These filters are preferred to screen filters for their durability and resistance to corrosion. While regular screen filter mesh and disk filters are both made of metal and/or plastic compounds, disk filters are more durable and resistant to rips and tears of the membrane. They consist of a series of disks, stacked on top of each other, that allow water to pass through and suspended particles to be captured. They are relatively low-maintenance and have good longevity.

Disk filters are durable and require relatively little maintenance. They are typically used for smaller SDI systems and would be installed at the valve to the drip system.

Filter location and maintenance

Correctly locating filters and maintaining them regularly is necessary to ensure the SDI system’s proper functioning. Below are some key considerations.

Position of filters

Where filters are placed will depend on the type. Typically, large screen filters and sand filters are placed after the pump station and provide filtration to large quantities of water. Smaller filters will be placed after the valve and their size will be a function of the flow rate.

Cleaning filters

Regular filter cleaning is required to ensure proper function of the SDI system. Media filters are typically cleaned by backwashing (or backflushing), which consists of running water in the opposite direction and expelling debris from the system. This results in some waste if there isn't a way to reuse the backflushed water. It might also be necessary to occasionally add or replace the filter media as some may be lost during the backwash cycle.

Screen and disk filters are easier to clean. These filters can also be backflushed, and some manufacturers provide an automated system for cleaning. However, the easiest way is to periodically remove the screen or the disk, check their integrity and wash them clean of debris. The frequency of cleaning and maintenance of these filters can be easily estimated by the presence of a flow meter or pressure gauge. When the flow and pressure are reduced below the optimal range, the filter must be cleaned.

Pressure regulator

Drip systems work at a lower pressure than the overhead irrigation system. Therefore, a pressure regulator is essential to ensure that consistent and appropriate water pressure is delivered to the emitters throughout the SDI system. The primary function of a pressure regulator is to reduce and maintain the water pressure within a suitable range for the emitters according to each manufacturer's specifications. High pressure can damage emitters and burst driplines, leading to leaks and inefficiency. Conversely, low pressure reduces irrigation volume, uniformity and ultimately turfgrass performance.

Pressure regulators can be installed in various locations within the SDI system. Typically, the pressure regulator is combined with the valve and installed before the header line.

Air release valve

Because SDI tubing is buried, any air that enters the system during installation or as a result of changes in pressure or temperature can become trapped and cause blockages or uneven water distribution. Air release valves allow air to escape the system and be replaced with water, ensuring that the system operates efficiently and effectively. The valve is typically installed at high points in the SDI system, where the air will most likely accumulate. As water flows through the system, any air present will be pushed toward the valve, which opens to allow the air to escape. Once the air has been released, the valve closes again to prevent water escaping.

Moreover, air release valves serve the critical function of preventing the formation of a vacuum (i.e., negative pressure) in the irrigation pipes and driplines when the system turns off. When water flow in the SDI system stops, a vacuum can occur in the pipes due to the residual water remaining in the driplines. This can cause problems such as soil and debris being sucked into the driplines, leading to clogging and reduced water flow in subsequent irrigation cycles. The air release valve is designed to automatically open when the pressure in the irrigation pipes drops below a certain threshold, allowing air to enter and replace the water in the driplines, preventing the formation of a vacuum. This helps maintain the irrigation system's efficiency and ensures consistent water flow and distribution.

Flush valve

An automatic flush valve is a device used to remove debris and sediment that may accumulate in the SDI system. The valve is typically installed at the low point in the SDI system and is designed to open periodically, allowing water to flow out of the system. The automatic flush valve is triggered by a timer or a pressure-differential switch, which opens the valve and allows water to flow through the system for a predetermined amount of time. During this time, any debris or sediment accumulated in the system is flushed out, preventing clogging and ensuring the water is evenly distributed throughout the SDI system.

When the drip system is turned on, the automatic flush valve opens briefly to allow a surge of water to flow through the system. This allows any debris that might have accumulated at the system's lowest point to be flushed out. The automatic flush valve typically operates for a short period of time at the beginning of every cycle. In smaller installations, a pressure-differential valve is typically preferred. In larger installations, a manual or time-triggered flush valve is preferred.

When the SDI system is turned off, the flush valve functions as an air release valve. Allowing water to exit and empty the dripline is important to prevent root intrusion, mineral buildup and to avoid excessive growth of bacteria, algae and fungi within the drip lines.

Automatic flush valves need to be inspected periodically. Some larger debris can block or limit the functionality of this device. This could lead to automatic valves remaining open during system operation. When the valve is stuck open, the system loses an excessive amount of water and the distribution uniformity is reduced.

Drip systems have various fittings that allow the user to design a layout for any area.

Fittings

Other minor components for SDI systems include typical irrigation fittings such as couplings, tees and elbows of various angles. These fittings allow the user to design a layout to fit irrigated areas of any shape. Couplings or small rubber plugs are used to make repairs when driplines are compromised.

BMP CASE STUDIES

"Subsurface Drip Irrigation Reduces Water Use on Tees"

USGA Green Section Record, 2019

In 2016, 12 tees at the Club at Las Campanas in New Mexico were fitted with differing SDI systems using various installation methods. Each system has performed very well. An average of 50% less water is used compared to overhead irrigation. Using SDI on these island tees has also eliminated overspray into adjacent areas.

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SECTION 3

Water Sourcing and Storage Stewardship

WATER SOURCING AND STORAGE STEWARDSHIP

Surface Water Optimization

Water features are common on golf courses in many environments. While they can have functional, strategic and environmental benefits, they can also be a source of water loss. Optimizing their design and maintaining them carefully will limit unnecessary water use.

SNAPSHOT

This strategy addresses limiting the loss of water from surface water features on golf courses. It is a medium-impact, high-cost strategy applicable for many golf courses.

Expected cost	> $50K per acre
Ease of implementation	Large capital project
Potential water savings for affected area	Up to 50% with water-loss management. Up to 100% if surface water is replaced by non-irrigated landscape.
Highest potential impact areas	Nationwide, especially in arid regions with high annual evaporation

OVERVIEW

Water features offer many benefits to golf courses and their surrounding communities. They provide irrigation water storage, habitat for aquatic plants and wildlife, and stormwater management that can mitigate damage during rain events. Golf course water features can also filter runoff before it continues downstream. USGA-funded research has shown that water can be cleaner when exiting a golf course than when it entered (Kohler et al., 2004). Water features also contribute to the strategy of the golf course and overall aesthetics of the property.

However, water features come with their own unique set of management challenges, and they can create issues for courses looking to conserve water. Evaporation, leakage, debris and sediment accumulation, and lack of maintenance can diminish the benefits of golf course water features and lead to significant water losses or a reduced supply of irrigation water. The presence of constructed golf course water features in areas prone to drought can also create a misperception that golf courses are using water for decoration while communities are trying to conserve.

Two comprehensive surveys recently conducted by the Golf Course Superintendents Association of America (GCSAA) report that surface water features cover an estimated 141,746 acres on U.S. golf courses compared to 1,044,924 acres of irrigated turfgrass. Reducing or eliminating unnecessary constructed surface water features can help golf courses conserve water by reducing the amount of water used to fill water features and by reducing evaporative losses. However, it is important to note that the evaporative loss from water areas is similar to the losses from turf areas, so what replaces the water feature is an important consideration. Replacing a pond with turf that needs to be irrigated may not save much water. Another benefit to having only essential surface water features is that they are costly and sometimes difficult to manage. For example, leaks can lead to wasted water and various playability issues, and can be very expensive to fix.

The good news is that with a measured approach that includes careful analysis, planning and execution, surface water optimization can be achieved. It may involve eliminating, consolidating or redesigning and rebuilding existing water features. It could also mean using better management strategies. When trying to optimize the constructed surface water features on a golf course, it is important to understand the potential trade-offs in water storage, stormwater management capacity and course strategy that may come with altering water features to save water. The goal should be to quantify how much water is being used for surface water features, especially constructed surface water features, and to reduce that amount where possible so that it can be redirected elsewhere or not used at all.

SCENARIOS FOR USE

The optimization of surface water on golf courses applies primarily to constructed bodies of water such as ponds, lakes and creeks. The term “surface water” is defined as the footprint or measured surface area when the feature is full of water. To get the total for a golf course, you simply measure the edges of all bodies of water and express the total in square footage or acreage. Total surface area of water features is important because this represents the quantity exposed to the atmosphere and subject to evaporative loss. Surface water loss due to leaks also must be considered, and there are strategies to help golf facilities locate and mitigate leaks.

Where Is the Strategy Typically Used?

Optimization is especially important for surface water features that require active replenishment to be maintained at a desired level. Replenishment means that water is being drawn from another source, so mitigating that consumption is of value. The concern about how much water is required for surface water features is intensified when water is scarce and/or expensive and could be used elsewhere on the course or conserved entirely. The distinction between surface water features that must be continually filled to a desired level and ones that are naturally fed to maintain their level is an important one to make. In many instances, it is not always an obvious distinction.

Bodies of surface water on golf courses in arid climates are vulnerable to evaporation and their level will not be maintained by rainfall.

Reducing Surface Water Area Where Possible

Most golf courses will benefit from keeping surface water features to a minimum. Even when water is “free” and has no cost to the facility, there is a cost associated with many other aspects of water features and their required maintenance. Certainly, every golfer has encountered a few unkempt water features in their travels. The cost to remedy issues like siltation and aquatic weed growth is directly proportional to the surface area of the water feature – a simple premise that supports reducing surface water features wherever possible.

There are limited exceptions to this, including where surface water storage is mandatory. For example, treated effluent water must be stored in ponds or lakes on some golf courses where there isn't another discharge option. Storage capacity for flood control would be another example. Still, exception is the key word here.

All decisions to reduce the number or area of constructed water features must strike a balance that preserves golf strategy, aesthetics, functional drainage, stormwater management, and making sure that ample water is stored for irrigation needs. Less can be more, provided that we do not compromise the core design hallmarks of a golf course, nor diminish the challenge and appeal to golfers. Whatever is done needs to be handled by a golf course architect in concert with the management team at the facility to balance the many considerations involved.

Evaporation Management Strategies

The best way to reduce evaporation from a surface water feature is reduction or elimination. If water surface area reduction is desired, a solution may be to deepen the reservoir to maintain volume and reduce evaporation. When these strategies aren't possible, physical barriers also can potentially reduce evaporation. Tree shade, windbreaks and pond flotation devices – such as the plastic spheres often seen in industrial ponds – can reduce evaporation. Plastic covers or even floating solar panels have been used to reduce evaporation from surface water in various settings. Obviously, these measures come with an aesthetic impact that may not pass muster. Further, some barriers may reduce dissolved oxygen in water, which can reduce water quality and can be problematic for aquatic plants and animals.

Golf courses should not take for granted that the sources they rely on to sustain surface water features will always be available.

Opportunities To Expand Use

Courses located in the Sun Belt – i.e., states in the South and West from Florida and Georgia through the Gulf states into California – can benefit greatly from this strategy because their water features experience greater losses from evaporation. Even in areas where water resources are not in short supply, continually recharging some bodies of water to keep them aesthetically pleasing can amount to significant unnecessary water use.

An important consideration is the type of water being used to refill water features. Potable water is in short supply in many regions, so conservation is critical. Fresh water from rivers, lakes and underground sources is also of great conservation importance. Even reclaimed and brackish water are becoming more important for potable supply with new technologies and initiatives like direct potable reuse (DPR) in arid regions. Golf courses should not take for granted that the sources they rely on to sustain surface water features will always be available.

SOURCES OF WATER LOSS AND POTENTIAL WATER SAVINGS

Any surface water feature maintained in any region will be subject to evaporative losses. This accounts for most of the water lost from surface water features and is, of course, higher in warm and dry climates like the Desert

Southwest. The other main way surface water features lose water is through leaks in the materials designed to retain water within the footprint of the feature. We cover these and a few other sources of water loss in the sections below.

Evaporation

Evaporation rates depend on region, climate and even microclimatic factors like the amount of shade and air movement that impact a body of water. In the continental U.S., water loss from evaporation varies from less than 20 inches in regions such as the coastal Pacific Northwest to more than 80 inches in parts of the Southwest. Across most of the U.S., evaporation rates are in the range of 40 to 60 inches per year. The higher end of this range includes most of the warmer climates in the U.S., extending from California across the South to Florida. Especially in these regions, it is typical to find golf courses where annual evaporation greatly exceeds the amount of natural rainfall. In these situations, the amount of evaporative water loss from surface water features can be dramatic, and that amount increases when the surface area of ponds and lakes is larger than necessary.

As an example, a 1-acre lake in Southern California can be expected to experience a net loss of roughly 5 feet of water every year through evaporation – accounting for the influence of temperature, humidity, rainfall, drought dispersion, solar radiation and wind. The annual net evaporative loss, not including potential leaks, is 5 feet multiplied by the total surface area of open water. So, the 1-acre golf course lake in our example can be expected to lose about 5 acre-feet of water per year. For perspective, 5 acre-feet of water is equivalent to 1.6 million gallons, or roughly the amount of water required to fill two and a half Olympic-size swimming pools.

According to the land-use survey from the GCSAA referenced earlier, the median 18-hole U.S. golf course had 5.7 acres of surface water in 2021, representing 4% of total facility acreage. In the southwestern U.S., the median 18-hole golf course had 4.1 acres of surface water, and total projected surface water acreage on golf courses in the Southwest was 8,064 acres. Based on the example above, this means that potentially 40,320 acre-feet of water, or 13.1 billion gallons, are evaporated from golf course surface water features annually in the Southwest. By comparison, the water-use survey conducted by the GCSAA indicates that projected water use for golf courses in the southwestern U.S. was 487,332 acre feet in 2020, meaning potential surface water evaporation represents 8.3% of projected water use for golf course in that region.

Substantial amounts of water can be lost to evaporation from golf course water features in hot and dry climates.

Estimates of annual precipitation and evaporation can give a partial picture of net evaporative potential for a given location. However, monthly estimates will be more informative and will highlight the time of year when replenishing certain surface water features may be most needed – i.e., when evaporation exceeds precipitation, especially for consecutive months. For example, even in a rainy climate like Seattle, evaporation often exceeds precipitation in summer months, resulting in the lowering of surface water levels. Of course, the reverse also can be true and sometimes water must be released from lakes and ponds to prevent overtopping.

Ideally, the total area of constructed surface water features on a golf course should be the minimum required to adequately store water for irrigation, provide necessary retention of stormwater, and provide interest to the golf experience. It also is important to remember that where storage is needed, reducing surface area can be offset by making water features deeper to achieve the same volume of water with less evaporation.

Leaks

The most-difficult water loss to measure from surface water features is leakage. Whether water features are lined or unlined, they may have significant leaks. Even small, seemingly insignificant leaks can amount to considerable water loss over time. Leaks are also typically escalating in nature and small leaks become larger over time as water moves through and expands voids. Many superintendents continue to replenish ponds and lakes, not really knowing for certain whether they are losing water from evaporation or because of leakage.

Other Loss Factors

Breaches: This situation is where a pond or lake water overtops and "leaks" behind an artificial liner. Technically, this is not a leak but a correctable condition that will require resetting the water level or raising portions of the lined shoreline. Unlike underwater leaks, such breaches are much easier to pinpoint as it is simply a matter of raising the level of the pond until it is evident that water is overtopping in a particular area.

Waterfalls, fountains and rapids in streams can increase evaporative loss because the water is mixed with air.

Waterfalls, rapids and aeration: Water that gets mixed with air, such as waterfalls, rapids in streams, and fountains, can experience increased water loss. Evaporation is accelerated when water is churned with air by such features. A balance should be struck where water quality can be improved by aeration and movement to prevent stagnation, yet evaporation is minimized. Water loss from waterfalls and fountains may be difficult to measure, but a rule of thumb is that as much as one percent of each gallon pumped or moved for such features can be lost above and beyond typical evaporation. This is commonly referred to as "splash loss."

Vegetation: Finally, surface water can be lost when shorelines are heavily planted or allowed to overgrow with waterborne plants. Cattails, for example, consume water at a significant rate. Other plants that live around or in water can have high water-use rates depending on species, plant size and plant density. While some plants, such as floating lily pads, cover the water surface and can reduce evaporation, they also consume water, and their net water conservation potential can be difficult to discern. Some tree varieties can be invasive to a water feature with aggressive roots that may eventually damage liners and should be avoided. Trees also consume water.

Maintenance Inputs

If surface water features are to look and perform as intended, they will require constant maintenance. Repairing liners, removing trees, aquatic weed control, replacing bulkheads and retaining walls, maintaining aeration devices like fountains or bubblers, and repairing breaches are just some of the tasks golf course superintendents need to perform regularly to ensure proper function. If surface water features are part of stormwater management infrastructure, even more attention needs to be paid to maintaining proper function to minimize the risk of property damage. This can include costly dredging, removing sediment and debris deposits in waterways and repairing pipes. Additional maintenance costs that can be reduced by decreasing the area of surface water features include:

- Managing shoreline erosion and controlling plant growth.
- Mowing turfgrass edges along surface water bodies, which is often hazardous.
- Cost of eventually relining ponds or lakes.
- Electricity and labor costs to pump or transfer water between surface water bodies.
- Capital costs to replace, repair and maintain water infrastructure such as wells and pipes.
- Costs associated with water quality management.
- Insurance premiums associated with open bodies of water, generally based on the number of water features and the likelihood of them being an attractive nuisance.

Finding out whether a water feature is leaking is a tricky task. It can be even more difficult to figure out where it is leaking from.

CONSIDERATIONS

Determining Whether an Existing Water Feature Is Leaking

Finding out whether a water feature is leaking is a tricky task. It can be even more difficult to figure out where it is leaking from. Rarely is there one spot that is leaking. Most of the time, because artificial liners wear out and are subject to the same conditions, leaks will be widespread. A plastic liner that is intended to last for 25 years typically begins to wear out and leak in multiple locations simultaneously. The same holds true for other liner types.

Unfortunately, leaks are not isolated to the actual pond, lake or creek itself. The pipes and conveyances that deliver water to such features, as well as the pipes that extend from water bodies for irrigation intake or transfers between ponds, can be prone to leaks. Leaks are elusive and can be among the most maddening water-loss issues to locate and resolve.

Resources for golf facilities to help determine if and where leaks are occurring include working with a golf irrigation consultant, lake management contractor or golf course builder. These professionals will often have the skills to assist superintendents in locating leaks. Specialized inspection procedures may involve using dyes to trace water flow toward leaks, underwater and pipeline cameras, and qualified scuba divers trained to inspect lake liners and the many pipe and intake penetrations through those liners.

Surface water features should not be arbitrarily eliminated or made smaller without careful consideration and planning.

Preserving the Integrity of the Golf Course Design

Water features can be of great value to the overall golf experience. They can bring charm, intrigue, tranquility and drama to a golf hole or series of golf holes. In his book "Routing the Golf Course," Dr. Ed Sadalla, a noted professor of environmental psychology, wrote: "Water is a dominant visual landscape resource and almost always increases scenic value." Dr. Sadalla went on to point out that many of the greatest golf holes in the world derive their greatness from water. Further, three-time Masters champion and multiple-time winner on the PGA Tour Jimmy Demaret noted "If you moved Pebble Beach 50 miles inland, no one would have heard of it" (Richardson, 2002). According to Dr. Sadalla, the impact of water on golf course architecture has been shown to depend on factors like land-to-water contrast, shoreline complexity, size of the water body and internal contrast, such as vegetative elements within or around a water feature.

Surface water features should not be arbitrarily eliminated or made smaller without careful consideration and planning. The best advice will come from a qualified golf course architect and irrigation consultant who can study the value of a pond, lake or stream while considering the strategic, aesthetic and experiential value the water brings to the golf course.

Golf course water features can provide valuable habitat and other environmental benefits. These must be carefully considered before making alterations.

Environmental Benefits

Whether a golf course water feature is constructed or not, they often provide various environmental benefits including wildlife habitat and stormwater filtration.

These benefits must be carefully understood before alterations are made to golf course water features and, in many cases, regulations may prohibit changes because of the existing or potential environmental benefits or harm. If some environmental benefits are affected by alterations to a surface water body, there may be ways to preserve or even enhance them in the replacement landscape treatment or elsewhere on the course while also achieving the goal of reducing unnecessary water use. Finding the best possible solution among these tradeoffs requires thorough planning and careful consideration.

Impact on Quality of Life

Removing water features can have an emotional effect on people. Humans are naturally drawn to water because of its role in our survival. Early civilizations settled near water because it was an important resource to thrive. Our evolutionary bond with water is why we derive pleasure from its presence. It has been shown to promote feelings of safety, tranquility and positivity (Wilson, 1984).

Studies on the psychological effects of water have been persistent throughout the history of environmental psychology. Human benefits from the presence of water include its restorative properties, recovery from mental fatigue and social benefits when water features become the focal point for community connection or gathering (Kaplan, 1995; Strang, 2004; Maas et al., 2009; Gascon et al., 2017).

Impact on Property Value

Golf courses are often built as an amenity of a larger residential development, and water views or waterfront property significantly increase property values. Reducing the size of water features or removing them altogether can elicit a negative response from homeowners who live adjacent to golf course ponds or lakes and benefit from increased property values.

Making changes to golf course water features may have a real or perceived impact on adjacent property values. Addressing potential concerns requires active community engagement.

IMPLEMENTATION

Step 1: Analyze Existing Features to Identify Goals and Opportunities

Establish goals

Every project should begin with a clear understanding of goals. In this case, the goal is smarter use of surface water as a functional, aesthetic and strategic component of the golfing experience. Engage a golf course architect to determine how changes to water features will affect the overall strategy and experience. Engage other experts to help determine the potential water savings of various approaches to modifying those water features. A comprehensive inventory and analysis of water features, drainage patterns and water requirements are critical for identifying alternatives to the current arrangement of surface water on a golf course.

Optimizing the amount of surface water on a golf course can vary from simple adjustments to more complex, integrative efforts. As noted earlier, modifying existing water features needs careful consideration due to the potential regulatory, environmental, social and economic implications. Altering or removing a water body can impact the golf course's functionality, appearance and compliance with regulations.

Assemble your team

Decisions regarding water features impact not only the golf course but also its surroundings. Assemble a multidisciplinary team that may include a golf course architect, engineers, environmental consultants, landscape architects and irrigation specialists. You may even want to include community leaders if the golf course handles stormwater from residential areas or has homes adjacent to water features. This diverse expertise and perspective ensures that all social, environmental and economic aspects are considered.

Surface water analysis

Evaluate whether the current size and/or location of water features aligns with their purpose and with the golf course's current water use goals. Assess each water feature to determine if alteration or removal is desirable and feasible.

If water conservation is an important goal at a golf course, every water feature should be evaluated for functional purpose, strategic impact, environmental value and the potential water savings from shrinking or removing it.

Rank the importance of surface water features

Consider the importance of each water body at the facility. Listed below are categories of surface water features, organized by their relative importance. This classification can be helpful in identifying which water features may be feasible to eliminate or reduce in surface area.

Essential surface water feature: Any body of water that helps protect people or property through stormwater management, or is used to store treated effluent that cannot otherwise be distributed, normally cannot be changed and therefore options are very limited.

Essential habitat: Protected water areas cannot be altered without mitigation and approval. Whenever a water feature is or has become important habitat, any change to the size may result in environmental harm. Therefore, this category of open water needs careful assessment and will typically not be available for significant change. However, if artificially refilled, many surface water bodies may not be considered protected. This determination varies by jurisdiction and many variables apply.

Essential storage: Primary irrigation reservoirs like storage lakes and ponds must be sized to hold an appropriate volume to efficiently irrigate the facility. The key term here is "essential," and it is important to know that volume and how it works with drawdown – i.e., the lowering of the water level when pumping and irrigation use is at its peak – and refilling back to the desired level. Essential storage is therefore a question to be studied early on.

A golf course may also choose to reduce total irrigated area, which would save water on its own and reduce the amount of water that needs to be stored for irrigation. It is surprising how many golf courses have taken the step to reduce irrigated turfgrass acreage, yet do not reduce the size of their irrigation storage ponds to fit their new water storage requirements. More drastic approaches are to replace all or part of the irrigation reservoir with storage tanks, either below or above ground. This can be costly because required volumes will typically take multiple tanks or extremely large tanks.

Nonessential, but strategically important: If the water feature is important to golf strategy, then it must be given the utmost consideration, even if it does not serve a critical storage or retention function. While water may be the preferred challenge, if water conservation is an overriding factor the feature can be converted into terrain that is landscaped and aesthetically pleasing yet functions as an obstacle in the same way it would if filled with water. The Rules of Golf accommodate such conversions by allowing courses to identify "penalty areas" regardless of whether they are filled with water or not. In many cases, taking an old pond or lake and creating a new feature without water can be a great way to both save water and create interest. Fields of native grasses and ground covers, waste areas, wildflowers, desert landscaping and passive wetlands all require far less water to manage than a surface water feature yet can be an exciting addition to a golf course.

Nonessential: These are the easy, low-hanging fruit when it comes to eliminating surface water. If water conservation is a primary goal and a constructed pond, lake or stream does not add necessary storage or golf strategy, nor is it of real value in terms of aesthetics, then it should be removed. Especially if there is a regular refilling requirement or if its upkeep is expensive. Golfers, homeowners or others may claim that a nonessential surface water feature should not be removed for any number of reasons, but usually there is an alternative that meets their needs and the water conservation goals of the facility.

Identify opportunities and constraints

After conducting an inventory of water features and understanding their purpose and importance, explore what modifications are feasible. The fact that a feature is manufactured doesn't automatically permit alterations or removal. Many artificial water features built decades ago have since gained regulatory protection as wetlands, Waters of the United States, or areas of interest to authorities. These features were often created with specific functional purposes such as irrigation, stormwater management, recreation, water treatment or habitat creation. The challenge is to determine whether these features present constraints or opportunities. Some may be subject to regulatory restrictions, while others may have outlived their original purpose and offer potential for site improvement. Consulting an environmental engineer or consultant is crucial to understanding the possibilities and guiding a golf course through potential changes.

Public outreach

Engaging the community, golfers, homeowners and other stakeholders early in the process can help avoid conflicts and build support for proposed changes to the golf course's surface water features. Public input can provide valuable insights, and hearing concerns fosters goodwill and ensures alignment with community values.

Step 2: Planning and Design

Once the team identifies goals, existing conditions and opportunities for reducing surface water area, it is time to develop design options. With input from other consultants, the golf course architect should formulate alternatives to open water that meet functional needs and follow sound golf course design principles. Ensure that planning adheres to regulatory requirements and considers the long-term impacts on golf strategy, aesthetics and environmental sustainability. The consulting team must account for the course's topography, soil and climate while respecting the course's design and hopefully enhancing playability and pace of play with any changes. Replacing water hazards with alternative features can enhance a course's strategic intent and character. Some other design considerations are discussed below.

Pace of play

Water features can contribute to slow play depending on their size and location. When an area of surface water is altered or replaced, pace of play should be considered and a golf course architect should be engaged to offer advice.

Water rights

Water rights are complex and must always be considered when making modifications to water features. Whether local in nature, such as a homeowners' association maintaining agreements to preserve a particular lake or pond, or more complicated surface or groundwater rights for impounding water on a golf course, the legal implications of water rights are not to be taken lightly. A water rights attorney familiar with the specific jurisdiction of the golf course property should be consulted.

Dredging and silt removal

Often, the deficiencies of ponds and lakes used for irrigation storage are due to long-term silt and organic matter accumulation that makes the water shallower. This reduced storage can also exacerbate drawdown and cause shoreline erosion from an inconsistent water level. Rebuilding a lake with less surface area is a good opportunity to explore dredging to make the water deeper. This will optimize storage capacity within a smaller footprint.

Water features can be made deeper to maintain or increase their capacity even while their surface area is decreased.

Wildlife

Changing or eliminating golf course water features can potentially have impacts on plants and animals that benefit from the water feature or depend on it for survival. A qualified biologist who understands the nuances of golf facilities is the best resource to evaluate and help mitigate any impacts of this nature.

Rating and slope

Removing or altering a water feature can affect the difficulty of the course and the Course Rating and Slope Rating. A golf course architect will be able to help the course balance strategic and challenge considerations with water conservation goals to find the best possible outcomes.

Step 3: Executing the Plan

The execution phase of a surface water optimization project is critical to achieving the desired outcomes. This phase involves more than just implementation, it requires careful attention to details, developing ongoing water management strategies, and maintaining continued communication to achieve long-term goals.

Regulations and permits

Before proceeding with any modifications, golf course managers must review local regulations and permitting requirements related to water bodies. The following factors must be considered:

Environmental regulations: Laws aim to protect ecosystems and wildlife habitats, many of which depend on water bodies like ponds, lakes and wetlands. These areas may be protected or designated as critical habitats, which could restrict any modifications. Golf course managers need to comply with these regulations to ensure sustainability and avoid legal consequences.

Zoning regulations: Zoning laws dictate how land can be used. Water bodies may be subject to specific zoning rules, such as restrictions on their expansion or mandatory buffer zones. Understanding these regulations ensures that any modifications are compliant with local zoning requirements.

Water usage regulations: In areas facing water scarcity, water consumption on golf courses is often closely regulated. Modifying or removing water bodies might be part of a water conservation strategy, but it's essential to comply with usage limits and explore sustainable management practices.

Impact on surrounding areas: Modifying water features can affect local hydrology, drainage and water availability for nearby properties or ecosystems. Careful consideration must be given to the broader environmental impact and balancing your operational needs with community and ecological concerns.

Construction

During construction, the focus is on executing the planned water optimization strategies. The effort can involve significant earthwork, reshaping existing features, or installing new drainage systems. In addition, new irrigation components may be installed to better manage water flow and distribution across the course.

Liner options

Knowing how your surface water features are currently lined – or not lined – is an important first step. Once the functionality of the existing liners is understood, plans for modifications can be made. There are several common approaches to lining water features and there may be specific requirements in your area. If the goal in this project is water conservation, you want to select a liner that is unlikely to leak.

Relying on clay soil or a high water table: Unlined lakes and ponds may rely on clay soils, or in some cases may be situated over a high water table where there is an equilibrium of pressure that keeps the water body full without leakage losses. Other water features may have been lined with a layer of clay soil, which is a common practice in construction of water features where clay soils are available. The clay layer, when properly specified and applied, is intended to form an impermeable barrier that does not allow water to move beyond it. This approach is not always precise, which often is discovered too late. The result is that water eventually breaches the clay layer.

Plastic liners: Today, the most reliable liner materials include high-density polyethylene (HDPE) and other sheet plastics that are seamed together and separate water from the underlying soil. These liners are often plated with soil to conceal the liner and prevent it from floating to the surface. While plastic liners are highly effective, they can still have issues. These barriers can be damaged, incorrectly installed, or may not be set to a consistent surface level, in which case the water can overtop it and leak behind portions of the liner. Settling, soil shifting and shoreline erosion also can cause overtopping. Repairing leaks in HDPE and sheet plastics is problematic. When such liners fail due to age or widespread damage, replacement is the typical remedy and costs are often significant

Most liners for golf course ponds today are made from plastic. While these liners are highly effective, they do require monitoring for damage, leaks or overtopping.

Soil additives: Soil additives such as bentonite (a swelling clay) or liquid polymers can be blended with native or imported soils to form a sealing layer. An advantage to this approach is that additive liners can be reapplied should the layer need repair.

Concrete: Concrete is rarely used to line water features today due to the porous nature of most concrete mixes. Nonetheless, there remain many concrete-lined ponds throughout the world.

Long-Term Maintenance and Monitoring

Once construction is complete, ongoing maintenance and monitoring of surface water features is essential to ensure their continued functionality. Monitoring efforts should include measuring water levels and tracking refilling requirements to provide data that can inform future adjustments.

If the project includes removing a water feature altogether, it will be essential to monitor the success of the replacement landscape treatment. For example, if we fill in a lake or pond, it will be essential to ensure the health and stability of the growing medium for turfgrass, vegetation or other ground cover materials. It is also essential to ensure that the area previously designed to hold water will no longer hold water and that the area performs as designed.

Education and Communication

The success of surface water optimization projects hinges on engaging with those who interact with the golf course. Education and communication are not just tools but the keys to unlocking this engagement. Golf course staff need to be educated about the benefits of changes to surface water features. Players can be informed about how they impact water conservation, helping to foster a culture of environmental stewardship. Engaging nearby communities can further extend the positive environmental impacts, particularly when water management practices also contribute to reducing flooding risks or improving local water quality. Effective communication ensures all stakeholders understand the importance of these initiatives and their role in protecting water resources.

TIPS FOR SUCCESS

Conduct a water feature audit.

If you are looking to save water at your course, don’t overlook the opportunities presented by surface water features. Conduct a comprehensive evaluation of all water features on the course. Understanding the current state of ponds, lakes and other water bodies will help identify areas with excessive evaporation or leaks. Use tools like geographic information systems (GIS) or drones to map the surface areas and pinpoint high-evaporation zones. Assess whether you can meet the functional, aesthetic and strategic needs of the golf course with fewer or smaller man-made water features.

Minimize surface area and maintain water volume.

One of the best ways to reduce water loss from evaporation is by minimizing the surface area of water features. Larger surface areas contribute to more evaporation, which increases water usage. By deepening ponds or lakes, you can maintain the same water volume with a smaller footprint, which cuts down on evaporation and helps conserve water.

Classify water features by importance.

Not all water features serve the same purpose. Prioritize water features based on their importance for irrigation, stormwater management or habitat. Essential features should be preserved, while nonessential or purely decorative ponds can be made smaller or eliminated.

Utilize native vegetation for shoreline protection.

Planting native vegetation along water feature shorelines can help control erosion, reduce evaporation, and lower water usage. These plants require less irrigation and maintenance than turfgrass, making them ideal for conserving water while adding value to the landscape and filtering any runoff entering the water features.

Surrounding golf course water features with native vegetation can limit erosion and filter runoff from the golf course before it enters the water body. Native buffers also provide habitat for plants and wildlife.

Monitor evaporation and leakages.

Install evaporation pans and use water-level loggers to track water loss over time. Utilize dye testing or hire professional services to identify hidden leaks in liners, pipes or drainage systems.

Assemble a multidisciplinary team for major projects.

Water optimization projects require expertise in many areas, from golf course architecture to environmental compliance. Engaging a multidisciplinary team early in the planning process ensures that all social, environmental and strategic aspects of the project are considered.

Address regulatory compliance early.

Modifying or removing water features often requires navigating environmental laws and permits. Engage local regulatory bodies early to ensure that all modifications comply with zoning laws, water rights and environmental protections. By understanding the regulatory landscape beforehand, golf courses can avoid delays and legal complications.

Engage stakeholders in decision-making.

Golf course water features often have sentimental or aesthetic value to players and surrounding communities. Engage golfers, homeowners and environmental groups early in the planning process. Open communication and outreach efforts will help gather feedback, build support and minimize resistance to changes that optimize water use.

Plan for long-term maintenance and monitoring.

Long-term success in water conservation relies on consistent maintenance and monitoring of irrigation systems and water bodies. Develop a maintenance schedule to check for leaks, manage silt accumulation and monitor water levels regularly. Proper staff training ensures that the course can maintain water efficiency over time while keeping operational costs down.

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WATER SOURCING AND STORAGE STEWARDSHIP

Using Recycled Water

Recycled water can be a more reliable and affordable water source that reduces demand for potable and fresh water, but connection costs are high and using lower-quality water requires management to limit impacts on turf health.

SNAPSHOT

This strategy involves irrigating golf courses with recycled water and managing the associated challenges. Converting some portion of a golf course's water use to a recycled source is a high-impact, medium- to high-cost strategy applicable to golf courses that have access to recycled water.

Expected cost	Ongoing mitigation of lower-quality water sources	Connection to water treatment plant
	$25K to $50K per acre	>$1M per mile from source
Ease of implementation	Daily maintenance	Large capital project
Potential water savings for affected area	Depending on availability, recycled water can replace up to 100% of water drawn from other sources.	
Highest potential impact areas	Nationwide, especially in the southwestern and southeastern U.S.	

OVERVIEW

Converting golf course irrigation to recycled water will reduce demand for potable, surface and groundwater supplies. Recycled water costs less than potable sources and may come with less risk of water restrictions. Unlike other water sources, quantities of recycled water will also increase with population growth. However, it is likely that demand for recycled water will also increase as fresh water becomes scarcer and more water users search for alternative options. Another potential benefit of recycled water is that it contains nutrients that can reduce fertilizer requirements.

However, recycled water also comes with challenges. Water quality issues, such as salinity, can be detrimental to turfgrass growth. Environmental conditions play a crucial role in these challenges – e.g., arid conditions could exacerbate the effects of salinity, but rainy conditions could encourage nutrient leaching. Moreover, recycled water quality often fluctuates during the year, so superintendents must frequently test alternative irrigation water sources to understand how the water may affect their turf.

Recycled water can play a valuable role in diversifying a golf course's water portfolio, but accessing recycled water can be challenging and expensive – and for many courses there is no recycled water source available. If a course is able to connect to a recycled water source, careful management will be required to maximize the benefits and minimize potential issues.

SCENARIOS FOR USE

If costs and availability were equal, a golf course superintendent would never choose to irrigate with recycled water over fresh water because the lower quality of recycled water makes it more challenging to use. The cost and availability of water is typically what drives the decision to use recycled irrigation water. For this reason, recycled water for golf course irrigation is typically in highest demand in the western and southwestern U.S. where water costs and the risk of water restrictions are both higher than other parts of the country. It is important to note that the salinity management considerations discussed in this chapter also apply to irrigation with other poor-quality water sources, such as saline aquifers or impaired surface or groundwater.

Where Is the Strategy Typically Used?

On a golf course

Any part of a golf course may be irrigated with recycled water, but certain turfgrass species better tolerate the stresses of recycled water. For example, if a golf course has warm-season fairways and cool-season putting greens, they may be more likely to irrigate with potable water on putting greens and reserve the recycled water for fairways and rough areas. Soil conditions will also inform strategies for using recycled irrigation water. Sandy soils make it easier to leach salts and other contaminants through the rootzone, so parts of the course with better drainage could be preferred for recycled water use.

According to a water-use survey from the Golf Course Superintendents Association of America, recycled water accounted for 21% of U.S. golf course irrigation in 2020 – second only to wells (32%) and lakes or ponds (23%) (Shaddox et al., 2022). The southwestern and southeastern U.S. applied 87% of all recycled water used for golf course irrigation.

Recycled water is most commonly used for golf course irrigation in places where other water sources are expensive or limited.

Opportunities to expand use

Since nearly 90% of the recycled irrigation water applied to golf courses is in the southeastern and southwestern U.S., the greatest expansion opportunities might be in other geographic regions. However, demand for recycled water is greatest in locations where water is expensive or supplies are limited, so future growth may remain concentrated in the southwestern and southeastern U.S. Depending on the source, the quality of recycled water may be perfectly suitable for all turfgrass species. However, in many instances recycled water carries a salt load that may impact the growth of desirable turf, particularly cool-season species. Converting from cool-season to warm-season grasses, where well-adapted, would further expand opportunities for successful irrigation with recycled water.

It is important to note that the increasing prevalence of initiatives like direct potable reuse may eventually limit the amount of recycled water available for golf course irrigation, or at least make it more expensive.

HOW IS RECYCLED WATER MADE?

Municipal and industrial wastewater is treated at sewage water treatment plants and then typically discharged into rivers or directly into the ocean. When this water is diverted for non-potable reuse rather than discharged, it is classified as recycled water. Recycled water has also been called "reclaimed," "effluent" or "treated" water, but the terms "recycled" or "reused" are most commonly used by the EPA (Harivandi, 2011; U.S. EPA, 2024). There are multiple levels of recycled water treatment.

- **Primary treatment** involves screening and filtering organic and inorganic solids. This type of water is typically not suitable for irrigation.

- **Secondary treatment** removes organic matter with biological treatment. Most often, aerobic bacteria consume organic materials and produce simple nutrients. Secondary treatment is completed by disinfection, most often with chlorine, to kill pathogens and reduce odor before discharge or diversion for reuse. This treatment is the reason for the nutrient load and overall higher salinity of recycled water. Recycled water that has received secondary treatment is normally what would be used in golf course irrigation.

- **Tertiary treatment** may follow secondary treatment to remove nutrients and pathogens that may remain. This type of sanitation and processing can make water suitable for direct potable reuse and is typically not part of water treatment for reuse as irrigation.

BENEFITS

Water Conservation and Environmental Benefits

Recycled water typically replaces the use of potable or fresh water sources, except where recycled water is the only available water source. Conserving fresh water benefits wildlife and the environment, and allows prioritization for human consumption or other necessary commercial and agricultural uses. Irrigating with recycled water also reduces the discharge of wastewater into rivers, lakes or oceans.

Source of Fertilizer

The dissolved nutrients found in recycled water are a source of fertilizer for a golf course, which reduces the amount of fertilizer that needs to be purchased and applied by the maintenance team. Nutrients applied from irrigation with recycled water, especially nitrogen and phosphorous, should be quantified and considered in annual fertilizer program planning. While the nutrients contained in recycled water can be a benefit, they could also present challenges because of limitations with irrigation system uniformity, or simply because the amount and timing of the nutrient delivery may not match a superintendent's preferred program or plant needs.

Lower Cost and More-Reliable Supply

Recycled water can be cheaper than potable water and it may be less vulnerable to water restrictions. It is important to note that the demand for recycled water is increasing in many areas, especially where water is scarce. This is driving the cost of recycled water up, but it still remains a lower-cost option than potable water. The total savings over time is also heavily influenced by the infrastructure costs involved in connecting the golf course with a recycled water source, which is normally in the millions. Distance from the source and necessary treatment and storage once on-site are key factors in the total infrastructure investment. Another benefit is that in many instances recycled water arrives pressurized by the treatment facility, reducing pumping costs.

Public Perception

Using recycled water is generally viewed as a more sustainable practice by the public. Golf courses that use recycled water often display signs around their perimeter to let the community know about their efforts to conserve potable and freshwater sources and dispel any misperceptions about the golf course's water source. This can be especially important information during times of drought or restrictions in potable water use that affect the general public.

Placing signs about recycled water use around the perimeter of a golf course can highlight water conservation efforts that the community may not be aware of.

CONSIDERATIONS

Availability and Cost

In most cases, the opportunity for a golf facility to use recycled water depends on proximity to a utility that produces recycled water for customers. If recycled water is new to the golf course, special permitting may be required. Recycled water is typically more affordable than potable water, but there can be significant investment required to lay water conveyance infrastructure from the golf facility to the treatment plant or nearest connection point. These costs are typically estimated at $1 million to $2 million per mile.

There also are potential longevity concerns for golf course irrigation infrastructure when water quality is poor. Salts are very corrosive to pumps and other components that likely will require more frequent servicing and replacement.

The availability of recycled water is also subject to change. In some desert communities, volumes of recycled water are highest in winter when irrigation water arguably is least needed. There are also examples of golf courses losing access to recycled water entirely because of changes in the original source. Further, direct potable reuse of wastewater is already a reality in several southwestern U.S. cities and will likely expand, which will eventually influence the availability and cost of recycled water for golf course irrigation.

Water Quality

The first and most important task for a superintendent irrigating with recycled water is to collect and submit water quality samples. Samples should always be collected from the sprinkler heads, the input source and the irrigation lake if there is one. There may be discrepancies in water quality among these different locations, so it is important to identify any issues and develop an appropriate treatment plan. Samples can be collected in a soda or water bottle that has been triple-rinsed. After collecting the sample, the container should be properly sealed and labeled before shipping it to a lab for chemical analysis. If the recycled water comes from a municipal water treatment plant, the superintendent should regularly obtain water chemical analyses from the plant. It is recommended to test as often as monthly, at least for a few years, to determine how the water quality changes throughout the year.

The first and most important task for a superintendent irrigating with recycled water is to collect and submit water quality samples.

Salinity, sodium hazard, carbonates and bicarbonates, and nutrient levels should be the focus of examination on water quality reports. Other water quality issues include pH and toxicity from other elements. The following is a summary of the most common water quality issues when it comes to using recycled water for golf course irrigation.

Salinity

A common misconception is that sodium (Na) or sodium chloride (NaCl) are the only potential salt issues in irrigation water. In reality, all ions and ionic compounds are salts and there are several ways that “salts stress” can affect turfgrass and other plants. High total salinity is the most common type of salt stress. Salinity is expressed either as the electrical conductivity of water (ECw) or soil (ECe), and it is measured in deciSiemens per meter (dS/m). How well a solution can conduct electricity increases with higher concentrations of dissolved salts. In soil science, a higher dS/m value generally means higher salinity, which can affect plant growth negatively. An EC value of 1 dS/m is approximately equal to 640 parts per million (ppm) of total dissolved solids (TDS). TDS represents the total concentration of dissolved substances in water – including salts, minerals and organic matter. It is usually measured in parts per million or milligrams per liter (mg/L). TDS is a broader measure than EC because it includes all dissolved components, not just those that contribute to electrical conductivity. High TDS levels can indicate poor water quality, which may mean the water is unsuitable for drinking or irrigation.

The general risk thresholds for salinity can be found in Table 1. ECe is almost always higher than ECw because the salts dissolved in irrigation water accumulate in soil over time. Sometimes, salinity is also reported as TDS and expressed in ppm. However, the relationship between the two measurements is not linear, which is why the preferred unit of measurement is EC.

Table 1. Risk thresholds for key water-quality criteria.

	Low Risk	Medium Risk	High Risk	Very High Risk
Salinity Hazard (ECw; dS/m)	<0.75	0.75-1.50	1.50-3.00	>3.00
Sodium Hazard (SAR)	<10	10-18	18-26	>26
Carbonates (CO_3^{2-}; ppm)	0-120	120-180	180-600	>600
Bicarbonates (HCO_3^-; ppm)	0-15	15-90	90-500	>500

Sources: Ayers & Wescott, 1985; Richards, 1954; Harivandi et al., 1992

As a reference, ocean water has a salinity of around 55 dS/m, which translates to more than 35,000 ppm. Salinity hazards start when ECw is higher than 0.75 dS/m. The first visible symptom of turfgrass impacts from salinity is a reduction in growth. Additional stress may appear similar to drought symptoms. Excessive salts hinder water uptake by the roots, causing leaf firing and wilting. Salinity in soil can be managed with two main strategies – selecting turf species that have a higher tolerance for salinity and leaching salts through the rootzone with an occasional heavy irrigation event. Salinity in the water itself water can be managed through water purification (reverse osmosis) or dilution with fresh water.

Sodium hazard

The presence of total sodium in irrigation water is important and its concentration in relationship to calcium (Ca) and magnesium (Mg) is of higher importance. This ratio is called the sodium absorption ratio (SAR). The higher the sodium, the higher the SAR. Conversely, the higher the calcium and magnesium, the lower the SAR. Calcium and magnesium are crucial for the stabilization of soil structure. When SAR increases above five, sodium could displace calcium bound to soil colloids. When sodium is left to dominate in the soil, it may break down soil structure, depending on the soil texture. In sand-based systems with little to no clay, soil dispersion from high sodium is not a concern. A high SAR can disperse or deflocculate soils with appreciable amounts of clay. Sodic soils are those that have high sodium in relation to calcium and magnesium – i.e., soils that have a SAR higher than 13. High-clay soils have higher cation exchange capacity (CEC) and are at higher risk for deflocculation. The most classic symptom of deflocculation is a "sealed" soil that has little to no water permeability and is a very difficult growing environment. Other symptoms include the presence of surface algae or black layer formation in the soil profile.

Once the soil has deflocculated and sealed, it will be extremely difficult to reclaim. Repeated aeration to break the sealed layer followed by the application of calcium-based amendments (particularly gypsum) and high-volume leaching will be needed. It is crucial to note that gypsum and other calcium-based products will work only for the reclamation of sodic soil and not for salinity management (Choudhary & Kharche, 2018). Gypsum, which is calcium sulfate ($CaSO_4$), is a salt. So, its application will increase soil salinity rather than decrease it.

Carbonates and bicarbonates

Carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) are often present in recycled and well water and could affect sodium permeability hazard. However, the typical concern is when sodium in water is also high. Bicarbonates are more common and are the main concern, primarily because there is a chance of increasing soil pH. Some also worry about high bicarbonates reducing soil permeability, but this hasn't been demonstrated without high soil sodicity. The concern is that CO_3^{2-} and HCO_3^- can bind with calcium and magnesium, forming insoluble calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). When calcium and magnesium are bound, sodium will attach to negatively charged sites of soil colloids and potentially induce sodium permeability hazard resulting in soil dispersion and poor soil permeability.

For turfgrass irrigation, high bicarbonate levels are associated with values exceeding 350 ppm. However, just like sodium, it is not the levels of carbonates and bicarbonates dissolved in water that are most important, but their relative concentration to calcium, magnesium and sodium. To account for their influence in irrigation water when bicarbonate concentration is > 120 mg/L, the adjusted SAR has been proposed (adj SAR). In this formula, calcium concentration is replaced by Ca_x, which is a factor that comes from a table of HCO_3^- versus ECw.

To determine the negative impacts of bicarbonates on soil, Residual Sodium Carbonate (RSC) is calculated (Eaton, 1950).

$$RSC=(HCO_3+ CO_3)-(Ca+Mg)$$

Water with RSC values lower than 1.25 ppm is considered safe for golf course irrigation; values between 1.25 and 2.50 ppm are marginal, and RSC values above 2.50 ppm indicate that most of the calcium and magnesium in the water will precipitate as calcium and magnesium carbonate, leaving sodium to dominate the soil exchange complex. How rapidly the sodium accumulation occurs depends on the sodium level in the irrigation water. A solution for managing carbonates and bicarbonates in recycled water is acidification of the water, which is discussed later.

pH

In general, very high or low pH values in irrigation water are a concern and should be treated accordingly. On most occasions, pH falls into a neutral range around 7.0. Any fluctuation from this value should be considered a warning sign of potential issues.

Other toxic elements and compounds

Recycled water may contain other elements or compounds apart from the ones already mentioned that can be problematic for turf growth and soil health if present in large quantities. These include chloride, chlorine and boron. Chloride can be more problematic for trees and shrubs than turfgrasses. Concentrations of chloride above 355 ppm are toxic to roots, and concentrations higher than 100 ppm can cause foliar burns and necrosis. Chlorine has similar issues as chloride, but its presence is rare and mostly associated with pool or sanitary water. Boron is phytotoxic to plants at very low concentrations (1 to 2 ppm) and will cause leaf burns on trees and shrubs. Turfgrass will show signs of boron toxicity at 10 ppm.

Nutrient content

Specific ion toxicity is seldom a problem for turfgrass managers as turfgrass gets regularly mowed, removing potential toxic ion accumulation. However, specific ion toxicities could be a problem for trees and landscape plants that might be planted near turfgrass. Still, some of the nutrients dissolved in recycled water might be absorbed by turfgrass, so it is important to account for nutrients from recycled water in the overall turfgrass management plan. More research is needed to fully understand any potential issues surrounding nutrients present in recycled irrigation water. Nutrients that are not adsorbed to soil or absorbed by turfgrass roots may leach into surface water and/or groundwater. Superintendents should check soil tests and observe turfgrass health when recycled water is used as a source of irrigation, adjusting fertilization accordingly to avoid soil nutrient overload.

Excess nitrogen in irrigation water can lead to turf decline, especially in putting greens in hot climates. High levels of nitrogen applied with irrigation water during periods of active growth can lead to excess clippings, scalping, elevated thatch and organic matter, and increased disease susceptibility.

Table 2. Nutrients supplied by recycled water.

Nitrogen Concentration in Reclaimed Water (mg/L N or ppm N)	Nitrogen Applied (lb N per 1,000 square feet)							
	Inches of Reclaimed Water Applied for Irrigation							
	1	5	10	20	30	50	100	150
1.0	<0.1	<0.1	0.1	0.1	0.2	0.3	0.5	0.8
2.0	<0.1	0.1	0.1	0.2	0.3	0.5	1.0	1.6
3.0	<0.1	0.1	0.2	0.3	0.5	0.8	1.6	2.3
5.0	<0.1	0.2	0.3	0.5	0.8	1.3	2.6	3.9
10.0	0.1	0.3	0.5	1.0	1.6	2.6	5.2	7.8
20.0	0.1	0.5	1.0	2.1	3.1	5.2	10.4	15.6
30.0	0.2	0.8	1.6	3.1	4.7	7.8	15.6	23.4

Phosphorus Concentration in Reclaimed Water (mg/L P or ppm P)	Phosphate Applied (lb P_2O_5 per 1,000 square feet)							
	Inches of Reclaimed Water Applied for Irrigation							
	1	5	10	20	30	50	100	150
.10	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1	0.2
.25	<0.1	<0.1	<0.1	0.1	0.1	0.1	0.3	0.4
.50	<0.1	<0.1	0.1	0.1	0.2	0.3	0.6	0.9
.75	<0.1	<0.1	0.1	0.2	0.3	0.4	0.9	1.3
1.0	<0.1	0.1	0.1	0.2	0.4	0.6	1.2	1.8
2.0	<0.1	0.1	0.2	0.5	0.7	1.2	2.4	3.6
5.0	0.1	0.3	0.6	1.2	1.8	3.0	6.0	8.9

Source: Martinez et al., 2011.

Rapid Blight Disease

Recycled irrigation water can create conditions that promote a disease called rapid blight in susceptible turfgrasses. Rapid blight is caused by the slime mold *Labyrinthula terrestris* (Olsen, 2007) and primarily affects cool-season grasses such as annual bluegrass, rough bluegrass and perennial ryegrass. Creeping bentgrass and creeping slender red fescue are more tolerant, and perennial ryegrass cultivars with increased salt tolerance have also been shown to be less susceptible to rapid blight (Kerrigan et al., 2012). Warm-season grasses are typically asymptomatic hosts, but can be an inoculum source for susceptible grasses. Rapid blight is particularly problematic in areas where turf is irrigated with saline water and where soil salinity levels are high. Outbreaks can occur at a range of temperatures during dry conditions with water or soil salinities from 1.0 to 3.5 dS/m and are most common with warmer temperatures stressful to cool-season hosts (Tredway et al., 2023). Some of the key symptoms of rapid blight disease are the presence of small, irregularly shaped yellow, brown or straw-colored patches that can quickly expand and coalesce into larger areas of dead turf. The best way to manage rapid blight is by managing soil salinity through leaching and water quality monitoring. There also are tolerant cultivars of susceptible cool-season grasses. Limiting winter overseeding of warm-season grasses will reduce disease. Few chemical pesticides are effective for the control of rapid blight.

Pyraclostrobin, trifloxystrobin and mancozeb offer preventive control, with the best control having been observed from a tank-mixture of pyraclostrobin and mancozeb (Tredway et al., 2023). However, even these products are ineffective under high disease pressure.

Soil Types

Soil type plays a role in any potentially negative impacts from using recycled water for irrigation. Clay soils present a higher risk of deflocculation compared to sand-based soils. Therefore, areas of a golf course with high-clay native soil need more attention. Sand-based putting greens or sand capped tees and fairways are usually less of a concern. Soils containing any type of layering that restricts water flow are very difficult to manage with water containing high salinity or sodium because leaching is very difficult.

Turfgrass Salinity Tolerance

Several studies have investigated the salinity tolerances of turfgrass species and cultivars. This information should be considered as a reference or starting point for superintendents that may have to irrigate with recycled water. Most studies have been conducted in greenhouse settings and in isolation from other stresses. In field conditions, salinity is only one of many potential stressors and environmental factors can exacerbate salinity issues. Nevertheless, research tells us that cool-season turfgrass species are, with the few exceptions listed earlier, less tolerant of salinity than warm-season turfgrass species. Therefore, where possible, warm-season species are always preferred when water quality is a concern. In general, warm-season species are more salt tolerant than cool-season species. However, intraspecific variabilities, such as cultivar differences, exist within turfgrass species. Seashore paspalum is the most salt-tolerant turfgrass species that can be used for golf. However, its drought resistance is not as high as that of bermudagrass. Among cool-season species, alkaligrass, tall fescue and certain creeping bentgrass species are the most salt tolerant. Annual bluegrass and Kentucky bluegrass are among the most salt-sensitive species.

Table 3. Relative salinity tolerance among turfgrass species.

Sensitive (<3 dS/m)	Moderately Sensitive (3 to 6 dS/m)	Moderately Tolerant (6 to 10 dS/m)	Tolerant (>10 dS/m)
Annual bluegrass	Annual ryegrass	Perennial ryegrass	Alkaligrass
Bahiagrass	Buffalograss	Creeping bentgrass (cultivars Mariner and Seaside)	Bermudagrass
Carpetgrass	Creeping bentgrass	Coarse-leaf (Japonica type) Zoysiagrasses	Fine-leaf (Matrella type) Zoysiagrasses
Centipedegrass	Slender creeping, red, and Chewings fescue	Tall fescue	Saltgrass
Colonial bentgrass			Seashore paspalum
Hard fescue			St. Augustinegrass
Kentucky bluegrass			
Rough bluegrass			

Source: Harivandi et al., 1992. Note that salinity tolerance may vary among cultivars within a particular species.

Landscape Plants

Landscape plants and trees often show signs of stress from water quality issues earlier than turfgrass. Salinity stress on these plants is often mistaken for drought symptoms – their leaves will start to burn and eventually the vegetation will die. When adding or replacing landscape plants and trees on a golf course that uses recycled water, it is important to verify that selected plants can tolerate higher salinity levels in the irrigation water and soil.

Soil Sensor Functionality

Salinity can have a huge impact on the accuracy of soil moisture sensors. Since ECe influences the speed at which electrical signals travel, some sensors could display inaccurate soil moisture readings. This is particularly true for older soil moisture sensors. Newer devices utilize a different methodology for measurements and are calibrated for higher salinity levels than are commonly found in recycled water (Serena et al., 2017). If an older soil moisture sensor seems to be unreliable after converting to recycled water, consider investing in a newer model. Newer sensors also often provide salinity index (ECe) readings as well.

SOLUTIONS FOR MANAGING SALINITY

Using salt-tolerant turfgrass species and landscape plants is a good strategy for managing the salinity that is common in recycled water. However, even courses that have salt-tolerant species will need management strategies to avoid long-term reductions in turf quality. The following are some primary techniques that courses can use to minimize the impact of high salinity in irrigation water.

Leaching

Leaching is the practice of applying irrigation in a quantity designed to move salts and other contaminants through the soil and out of the turfgrass rootzone. The amount of water required for successful leaching is over and above turfgrass requirements. If soil water infiltration is adequate, the additional water will carry salts beyond the rootzone. If the soil is very poorly drained, attempts at leaching may be futile. Most golf courses rely on rainy seasons to leach the salt accumulated in the soil during the year. Courses can optimize the leaching power of rainfall by aerating and applying wetting agents in advance to help the downward movement of water and salts.

Leaching water can be applied as part of regular irrigation (maintenance leaching) or as a large irrigation event when soil salinity reaches a critical threshold as a flushing event (reclamation leaching). In either case, the theoretical amount of irrigation water required for leaching can be calculated if the EC of the water is known as well as the threshold EC of the turf species being grown. Leaching requirements (LR) are calculated as:

$$LR = \frac{ECw}{(5\ ECe - ECw)}$$

Where ECw is the salinity of irrigation water, and ECe is the soil salinity threshold at which turfgrass loses quality (Maas, 1990).

This formula was originally introduced in the 1970s and remains valid, but it has the major limitation of assuming that the leaching requirement is consistent throughout the year. In reality, leaching requirements vary during the year based on the weather, changing salt content in recycled water and a range of other factors. This equation gives you the ability to estimate how much more water you will need for leaching based on the salt concentration of the water and the tolerance of the turf, but adjustments may be needed in practical application.

It may be difficult to determine a detrimental ECe threshold across the various turfgrass species and cultivars that are often present on a golf course. As an example, assuming an ECe threshold of 6 for perennial ryegrass, the leaching requirement when ECw is 4.2 dS/m[1] would be 16%. However, in a practical situation under field research conditions, this amount of maintenance leaching has been shown to be insufficient (Schiavon et al., 2017).

Another challenge with a maintenance leaching approach is that consistently applying even 20% more irrigation is often impractical because of the potential impact on playing conditions. Putting greens and other sand-based soils drain better and can accommodate more water without saturated conditions, but that is not necessarily the case with heavier soils or parts of the course that drain poorly. This amount of additional irrigation water would reduce even putting green firmness and the waterlogged conditions elsewhere could be unbearable.

Reclamation leaching is a better strategy for many golf courses.

The capacity of the irrigation system can also be the limiting factor to an approach relying on maintenance leaching. An irrigation system has limited pumping and flow capacity and therefore can only accommodate deep irrigation on a percentage of the course during an evening irrigation cycle. The system would need to run for several hours to apply the leaching requirement in soaking cycles. About 6 inches of water are necessary to reduce soil salinity by 50%. The irrigation systems at most golf courses apply less than an inch of water per hour, which means seven or eight hours of watering would be necessary, at minimum. More time would be required to accommodate a cycle-soak schedule that allows water to absorb into the soil rather than running off and pooling. For these reasons, maintenance leaching isn't commonly used, especially in larger areas and with native soils.

Reclamation leaching is a better strategy for many golf courses. Research showed that the traditional approach to maintenance leaching has the tendency to overestimate the requirement, resulting in excessive and unnecessary water use (Corwin et al., 2007). In-ground sensors or portable EC meters can be used to monitor salt accumulation until leaching is needed. An additional advantage of a portable meter is the ability to measure salt concentration at different depths. When a predetermined threshold is reached, heavy irrigation can be applied where needed to leach salts and reduce ECe. This is a more efficient and effective approach to leaching that will end up requiring less water to achieve the desired results. By monitoring ECe with portable meters, it's common for golf courses only to have four or five leaching events annually, and only where needed, resulting in water savings and better playing conditions (B. Whitlark, personal communication, July 26, 2024).

Considerations for Effective Leaching

Seasonal changes and turfgrass leaching requirements

Leaching requirements can vary significantly with seasonal changes and the type of grass being grown. For instance, under overseeding conditions, ryegrass generally requires more leaching than bermudagrass during the summer season. The difference in water needs is critical to consider when managing salt levels in the soil to ensure optimal grass health.

Portable direct EC meter

A portable direct EC meter is an essential tool for effective leaching. It allows for real-time monitoring of soil salinity levels, enabling timely adjustments to irrigation practices. By measuring the salinity of the soil directly, superintendents can make informed decisions to prevent salt buildup and maintain healthy turf.

A portable EC meter is an essential tool for making decisions about leaching.

Low salt-index fertilizer

Using fertilizers with a low salt index is another key consideration. Fertilizers with a high salt index can contribute to the accumulation of salts in the soil, making leaching more challenging. Some fertilizers with low salt index are ammonia and urea. Fertilizers with high salt index are sodium nitrate, calcium nitrate and ammonium thiosulfate. Opting for low salt-index fertilizers helps minimize the risk of salt stress on the turf.

Dual-system irrigation lines

Having a dual-system irrigation line (potable and recycled) can significantly enhance the leaching process. Using potable water for leaching events will flush salts from the soil in a shorter time frame and with less water compared to using recycled water.

Portable micro irrigation systems

Utilizing a portable micro irrigation system is an effective strategy to increase the leaching fraction (Whitlark, 2023). These systems allow for the localized application of larger amounts of water with minimal runoff, which makes them ideal for targeting areas that need more-intensive leaching. Typically, these systems use small spray heads, which allow for high uniformity and a higher precipitation rate.

Portable micro sprinklers can be a great tool for leaching salts because they can apply larger amounts of water with minimal runoff.

Importance of aeration

Aeration is a critical practice in turf management, particularly for enhancing the effectiveness of leaching. However, as the soil gets aerated it loses more water, which increases the amount of water required for flushing. Proper timing and frequency of aeration can help maintain soil porosity, allowing for better water infiltration and salt leaching.

Venting for soil compaction

Venting involves using small solid tines to create holes and channels in compacted soils to allow for air and water movement. This practice is essential for improving soil structure and facilitating the leaching of salts. By alleviating soil compaction, venting helps water move more freely through the soil profile.

Gypsum and calcium applications

While gypsum and calcium applications are common practices, they are often overused and their benefits are not always well quantified. Instead of relying heavily on these amendments, focusing on improving drainage and incorporating sand topdressing can provide more sustainable long-term benefits for salt management and soil health.

Wetting agents

The application of wetting agents has been proven to assist with water movement and salinity management (Gross, 2019). Wetting agents reduce soil water repellency, allowing for more uniform water distribution and better leaching of salts.

Deep and infrequent irrigation

Deep and infrequent irrigation is generally more effective for leaching salts than light and frequent watering, provided the soil can accommodate deep watering. This approach to irrigation encourages deeper root growth and more efficient use of water, reducing the risk of salt buildup and promoting overall turf health.

Acidification of Water

To counteract the effect of CO_3^{2-} and HCO_3^-, acidification of irrigation water, particularly with sulfuric acid (H_2SO_4), hydrochloric acid (HCl), carbonic acid (H_2CO_3) or products like N-pHuric acid ($CH_4N_2O_4S$) may be needed. The amount of acid needed is a function of the carbonate or bicarbonate concentration and the expected pH. Typically, this is calculated in a lab with titration. Acidifying is typically recommended when carbonates and bicarbonates concentration is higher than calcium and magnesium concentration, and when RSC and adjusted SAR are higher than 1.25 and 6.0, respectively. Acidification has been shown to reduce bicarbonate accumulation in the water and potentially in the soil; to date, no improvement in saturated hydraulic conductivity has been demonstrated. The benefits of acid injection on plant health have not been proven and are often associated with nutrient imbalance (Sevostianova & Leinauer, 2023). Acidification may enhance nutrient availability within the rhizosphere, but the turf benefits have been difficult to define quantitatively. In essence, bicarbonate concentration in the soil becomes an issue only when sodium is elevated.

When irrigating with water high in carbonate and/or bicarbonate, it is common to see a white residue in areas with bare ground. The residue is often visible around drip irrigation emitters in landscape areas. While this may appear menacing and potentially harmful to plants, these white residues only indicate the presence of bicarbonates and are not harmful to the vegetation, especially in the absence of high sodium content in the water. Seeing white residues left behind from irrigation water does not necessarily mean that you need to acidify the water to maintain healthy turf and landscape plants.

The high risk when handling these acids and the potential for injuries is another aspect to consider. It is often best to hire a skilled contractor to handle the acid and service the injection system. Carbonic acid is a safer alternative for injection because of its low corrosivity and it can be used in an automated process of injection. Another alternative is a sulfur burner. Sulfur burners use the hydraulic pressure in the irrigation system to burn pure elemental sulfur. The mixture results in a liquid sulfurous acid (H_2SO_3) that is typically directly injected into an irrigation lake. The sulfurous acid is non-caustic and once it contacts the water in the irrigation lake, it rapidly accumulates an oxygen atom, producing sulfuric acid. This method has not only been effective in reducing water pH but has proven to help produce clearer water in irrigation ponds and lakes.

Gypsum

Gypsum (calcium sulfate) plays a significant role in managing soil salinity, particularly in soils with high sodium. Sodium can cause soil particles to disperse, leading to poor soil structure, reduced permeability and impaired plant growth. Gypsum can help counteract these negative effects by providing a source of calcium. When gypsum is applied to the soil, the calcium ions (Ca^{2+}) in the gypsum replace the sodium ions (Na^{+}) on the soil, which can then be leached.

Gypsum applications may be needed to displace sodium from colloid binding sites. Repeated applications, over months or even years are often necessary to ameliorate sodic soils. Soils with very poor infiltration likely will not benefit from gypsum addition and leaching. The limiting factor in such soils is the physical constraints rather than the high SAR. Ameliorating these types of soils will require soil modification, such as sand topdressing or sand capping, in addition to drainage installation rather than calcium or other soil amendment additions.

In a recent study on bermudagrass grown in a sand cap, gypsum applications were able to decrease SAR compared to the nontreated control, but the researcher mentioned that the reduction was minimal and insufficient to make an agronomic impact (Wherley et al., 2021). The authors suggested that other agronomic strategies are more beneficial than gypsum application.

Unlike soil salinity, using gypsum and calcium amendments to manage carbonates and bicarbonates remains questionable, especially in sandy soils. A recent study conducted at the University of Florida's Fort Lauderdale Research and Education Center has shown that gypsum applications were not an effective method to ameliorate salinity in sandy soils, nor did these amendments improve turfgrass performance when applied to bermudagrass mowed at fairway height on a sandy soil that was irrigated with a water source high in bicarbonates and had a granular application of sodium chloride to increase salt content in the soil (Sierra & Schiavon, 2023).

Drainage

Successful leaching only happens with great drainage. For instance, most putting green rootzones are constructed primarily with sand and contain a robust subsurface drainage system, so leaching can be highly effective with only short-term impacts on playability. Consider adding drainage lines in areas of the course where salt is an issue. This will help flush and move salts from the profile, particularly in compacted soils. Drainage will also be beneficial when seasonal precipitation occurs.

In very poor soil conditions, drain lines will improve conditions immediately above and adjacent to the drain lines, but may not alleviate salinity problems in between the lines. In such cases, a more extensive approach may be necessary. Some courses have removed wide expanses of soil in areas where they plan to install drainage and replaced the existing soil with a sand cap or other material that allows for better drainage and an improved ability to flush salts (Whitlark, 2014).

Cultivation and Management Practices

Cultivation practices can help manage thatch and soil compaction, both of which impede water movement and increase the risk of salt accumulation when irrigating with recycled water. Hollow- or solid-tine aeration is particularly beneficial to disrupt compacted soil and improve water movement. Tools for linear decompaction, drill-and-fill aeration, and many other machines can also be used to temporarily mitigate soil compaction, with benefits that can last six to eight weeks. But they do not modify soil physical properties, at least not enough to meaningfully improve soil water infiltration in very poorly drained soils. If soil modification is needed, then consider sand topdressing.

Aeration can loosen compacted soil and improve water movement, which helps with leaching salts from the rootzone.

Modify the Rootzone

Incorporating sand into the rootzone through aeration or sand topdressing is the most beneficial practice for salt management (Whitlark, 2014). Sand in the rootzone helps reduce soil compaction and decreases bulk density. It increases the infiltration rate, increases total porosity and decreases the percentage saturation of the soil at field capacity. Working sand into the rootzone through topdressing and aeration provides a uniform layer of distributed soil particles and dilutes organic matter. Sand does not adsorb and retain salt, which facilitates water movement and leaching.

Sand topdressing at rates ranging from 60-100 tons per acre per year is a viable strategy to improve soil water infiltration. This strategy typically requires five to six years of continued sand application to realize quantifiable results. Once an amended layer 3-4 inches deep has accumulated, annual sand application rates can be reduced, but not omitted altogether.

Incorporating sand with aeration or other equipment is also beneficial. If the soils are especially poor, solid-tine rather than hollow-tine aeration is suggested in the initial five to six years of a sand topdressing program so as to avoid bringing the poor soil to the surface. Once a 3-4 inch layer of amended sand rootzone has been applied, courses often shift to shallow hollow-tine aeration to recycle the sand at the surface.

There is also an option to rototill sand into the native soil layer as part of a renovation or regrassing project. This may work well if the native soil does not contain excessive clay or organic matter. This tactic can create worse conditions if the resulting rootzone mix is more widely graded (a wider mixture of sand, silt and clay) than before because excess clay can seal up the new mixture. When considering some form of rototilling sand into native soil, it is critical to work with an accredited soil testing laboratory to evaluate the mixture's performance.

Sand-capping is another form of rootzone modification. This has several benefits for managing playing conditions, salt content and soil moisture. However, it requires careful consideration and working closely with a physical soil testing laboratory to avoid creating problems (Whitlark, 2022).

Tilling sand into heavier native soil during a renovation can improve water infiltration and salt management. Be sure to work with a physical soil testing lab to evaluate the potential performance of the mixture before moving forward.

Blending Potable Water

Recycled water or other saline water can be blended with potable water to dilute the concentration of salts. This can often be done by mixing two or more water sources in the irrigation lake. It can also be done by using different rates of each water source depending on the season and the status of turfgrass health.

Reverse Osmosis

Especially salty water can be purified with reverse osmosis. Although an option for recycled water, reverse osmosis is more common when irrigating from an impaired well. This is typically done with a process that utilizes semipermeable membranes to remove impurities from the water. Water is pressurized and forced across these membranes, leaving the salts behind in a concentrated brine solution. Water exiting the reverse osmosis process is clean of salts and can be used for irrigation. However, ultraclean water can be just as harmful as water high in sodium. Some amount of salts, preferably calcium and magnesium, need to be added to reverse osmosis water to raise the EC to at least 0.3 dS/m and preferably a range between 0.4-0.6 dS/m. Reverse osmosis systems are a very effective way to remove salts, however they are very expensive and costly to maintain. The membranes need frequent replacement and servicing. Additionally, disposing of the concentrated brine solution is another challenge and often requires a permit.

Soil Amendments

Gypsum applications have previously been described as facilitating the release of sodium and reducing its detrimental effects by replacing it with calcium. In other circumstances, acid applications will be beneficial where soil carbonates are present or when bicarbonates and carbonate in the irrigation water are high in relation to sodium.

Elemental sulfur and sulfur-containing fertilizers are also beneficial for managing salinity by making calcium already present in the soil more soluble. Similarly, fertilizers with an acid reaction (urea and ammonium sulfate) will be beneficial.

Other amendments such as soil surfactants, silicon or biostimulants have not been proven to help in alleviating salinity (Li et al., 2019). Similarly, some weak acids and organic acids have yet to be proven effective in managing salinity.

IMPLEMENTATION

Acquiring Recycled Water

The first step in using recycled water is finding a source, often a municipal supplier. Then there will likely be an extensive process to navigate permitting to use recycled water for irrigation. If a source is identified and there are no legal barriers to use, determine the water quality to evaluate its suitability and whether the recycled water would need to be treated or blended with higher-quality water sources for golf course irrigation. Evaluate corrosion potential of the recycled water and its possible effect on irrigation system infrastructure. You will also have to calculate expected costs of connecting to a recycled source and any additional infrastructure that may be needed to support using recycled water on-site, like a treatment facility.

Connecting to a recycled water source is often a complex and expensive process. This course had to invest in an on-site treatment facility to use recycled water effectively.

Using Recycled Water for Irrigation

Once recycled water is in use, its quality must continually be evaluated to manage potential issues. Recycled water quality can change throughout the year, so ongoing testing will be needed. Testing should determine the amount of ECw (or TDS), SAR, HCO_{3-} and CO_3^{2-}, as well as nutrient levels.

Golf courses should also develop a complete picture of the soils on their property to know which areas have the greatest risk of problems with recycled water use. If you suspect high spatial variability, collect several soil samples and send them for complete performance analysis including soil texture, hydraulic conductivity and porosity. While sending soil samples for textural analysis, a soil salinity test may be recommended. Several labs offer a soil salinity package that includes the most important chemical analyses.

Once the water analysis is received, check all the parameters. Is there any hazard? If yes, where does it come from? Does the soil testing show sodic or saline-sodic conditions? If salinity is the main issue with the water source but Na, HCO_{3-} and CO_3^{2-} are not, maintenance leaching with regular irrigation is one approach. A better solution would be to monitor salt and proceed with reclamation leaching when the concentration is above the threshold. For leaching to be most effective, distribution uniformity of the irrigation system must always be maximized. Inconsistent application of water may result in leaching only certain zones while others see salt accumulation.

Gypsum or calcium-based product applications are needed only when sodium needs to be displaced from soil colloids. In sand-based rootzones, gypsum applications are likely unnecessary or should be applied at a lower rate and more sporadically than would be desired in heavy soils. Gypsum should be watered into the soil after application. Foliar calcium fertilizer applications are seldom needed, nor are they effective for managing recycled water use. Calcium should be applied to the soil to displace sodium and calcium is absorbed by turfgrass roots rather than leaves, so foliar applications will have little to no benefits for turfgrass health. If the soil has already been deflocculated and sealed, break the crust with cultural practices before applying gypsum. Deep cultivation may be necessary – e.g., 6 inches deep or more – if a black layer has formed below the rootzone.

Amendments like wetting agents can help with water infiltration into the soil profile. However, they should not be relied upon if the soil has deflocculated or in soils with poor hydraulic conductivity. In these situations, wetting agents will not increase soil permeability.

If the golf course is being renovated, adding drainage and potentially modifying the rootzone can improve the long-term effectiveness of recycled water use. Sand capping will help with water percolation, but subsurface drainage is also necessary to remove water from the rootzone. When sand capping, select a material with air-filled porosity from 18%-30% and capillary porosity from 15%-25%. Sand capping 2-4 inches deep is sufficient to increase turf quality (Wherley et al., 2021). Renovations are also an opportunity to convert playing surfaces to grasses that can better tolerate the recycled water quality.

TIPS FOR SUCCESS

Develop a strong relationship with water providers.

Developing a strong relationship with water providers and maintaining proactive communication with them is crucial for ensuring the continuous availability or recycled water. This collaboration allows golf course managers to stay informed about seasonal water availability, quality and any regulatory changes, enabling them to adapt their practices accordingly. By working closely with water providers, golf courses can advocate for fair and effective recycled water use policies, implement conservation measures under drought, and ensure a reliable supply that meets both their needs and conservation efforts.

Monitor water quality.

Obtaining water quality reports regularly and conducting in-house tests for validation are a crucial aspect of using recycled water successfully. A course should understand the water quality prior to connecting with a recycled source so they can plan for necessary management. It is also important to recognize that recycled water quality and characteristics change throughout the year. Regular water quality monitoring ensures that the irrigation water meets the required standards, preventing potential damage to the turf and surrounding environment. In-house tests provide an additional layer of verification, enabling course managers to promptly detect and address any issues, such as contamination or nutrient imbalances.

Monitoring recycled water tests regularly for dissolved salt content, sodium hazard, bicarbonates and nutrients is essential for maintaining turf health and playability. High levels of these elements can lead to soil degradation, reduced water infiltration and/or turfgrass toxicity. By ensuring these characteristics are within acceptable limits, golf course superintendents can optimize irrigation practices, promote healthy turf growth and minimize the risk of environmental impact.

Use soil sensors to track salt content.

Accurate and properly calibrated soil salinity sensors are crucial for managing a golf course irrigated with recycled water because they provide real-time data on salt content in the soil. This information allows superintendents to make precise irrigation decisions, ensuring that the soil salinity remains below the desired threshold. Different parts of the course will accumulate salts differently based on soil characteristics and many other factors. In-ground sensors in representative locations can be one part of data collection, but a portable EC meter is valuable for sampling around the property and getting a complete picture of salt content in the soil at different depths. The more targeted a course can be with flushing and other management strategies, the better.

Beware of the dry spell.

During dry periods, pay close attention to irrigation practices as salt accumulation in the rootzone can become a significant issue. When natural rainfall is scarce, reliance on irrigation increases and the salts present in recycled water can build up in the soil due to higher evapotranspiration. This salt accumulation can be detrimental to turfgrass quality by increasing the osmotic pressure and hindering water uptake by turf roots, leading to poor playing conditions. Proper management, including monitoring soil salinity levels and employing techniques like deep watering, is essential to prevent and mitigate these negative effects during dry weather.

Optimize irrigation system performance.

Ensuring that the irrigation system is working properly and distributes water as uniformly as possible is critical when using recycled water. Proper irrigation management ensures that all areas of the course receive uniform water distribution, preventing over or underwatering that can lead to uneven salt accumulation. Uniform distribution and proper system function is also important when it comes time to flush salts from the rootzone.

Consider a potable water line.

Having an additional irrigation line with potable or fresh water is an asset for leaching events and salt management when irrigating a golf course with recycled water. Potable water and fresh water have lower salt content, which means less water is necessary to flush salts out of the rootzone. This helps to prevent soil salinization and ensures optimal growing conditions for the turf. Some courses that use recycled water broadly may also want to irrigate sensitive areas like greens with potable water depending on the turf species and various other factors.

Account for nutrients in the recycled water.

When irrigating a golf course with recycled water, it is crucial to account for the nutrients present in the effluent water when making fertilizer calculations. Recycled water often contains significant amounts of nutrients such as nitrogen and phosphorus, which contribute to the nutritional needs of the turfgrass. This is particularly true in the summer, when higher amounts of water are being applied. By factoring in these nutrients, golf course managers can optimize fertilizer applications, preventing over-fertilization and minimizing the risk of environmental impacts.

Use foliar fertilization if leaching salts is not possible.

In the event of drought, or when water is limited and leaching irrigation cannot be applied, it is advisable to switch to foliar fertilization to sustain turfgrass quality (Schiavon & Baird, 2018). Water and nutrients move from the soil to the roots via osmosis and increasing the salt concentration of the solute makes it harder for the plant to absorb water and nutrients. Foliar fertilization may provide temporary relief to the turf until rainfall or irrigation is available to flush salts from the rootzone. However, in drought conditions plants need water more than fertilizers, so it may be advisable to hold off on applying fertilizer until normal conditions are restored.

Keep an eye on seasonal variation in water characteristics.

Nutrient concentrations in recycled water can fluctuate throughout the year due to seasonal changes, varying water sources, and treatment processes. This is especially true in regions where the population changes drastically throughout the year, as is the case in places with many seasonal residents. Calculating fertilizer offsets for golf course irrigation must account for these variations to ensure optimal turf health and environmental responsibility. By conducting frequent water tests and watching for any nutrient changes, golf course managers can adjust fertilizer applications more precisely.

BMP CASE STUDIES

"Irrigating With Recycled Water"

USGA Green Section Record, 2020

The University of Louisville Golf Club in Kentucky faced water supply challenges, leading them to seek a cost-effective solution. They decided to use recycled water from a local treatment plant to ensure water availability at a lower cost. Monthly testing of soil and water samples helped maintain turf health despite higher salt levels in the recycled water. During dry spells, some minor issues arose, but the recycled water feed has proven effective.

"Flow Sensor Technology Improves Water Quality and Reduces Cost"

USGA Green Section Record, 2018

The Moorings Country Club in Florida uses both recycled and on-site lake water for irrigation. The lake water is less expensive and of higher quality than the recycled water, but its supply is limited. The recycled water is a valuable resource, particularly during droughts, but it is more expensive and has a higher salt content. Using a combination of both water sources during dry periods produced better results at a lower cost than relying solely on recycled water. Flow sensor technology enabled the course to achieve a precise blend of the two water sources for irrigation.

"Using Recycled Water for Irrigation"

USGA Green Section Record, 2017

Ivanhoe Club, a 27-hole golf facility near Chicago, uses recycled water for irrigation. The course vents greens and applies wetting agents in advance of rain events to help flush out salts. Despite the challenge of scheduling these activities, the recycled water supply is valuable and consistent, especially in dry periods.

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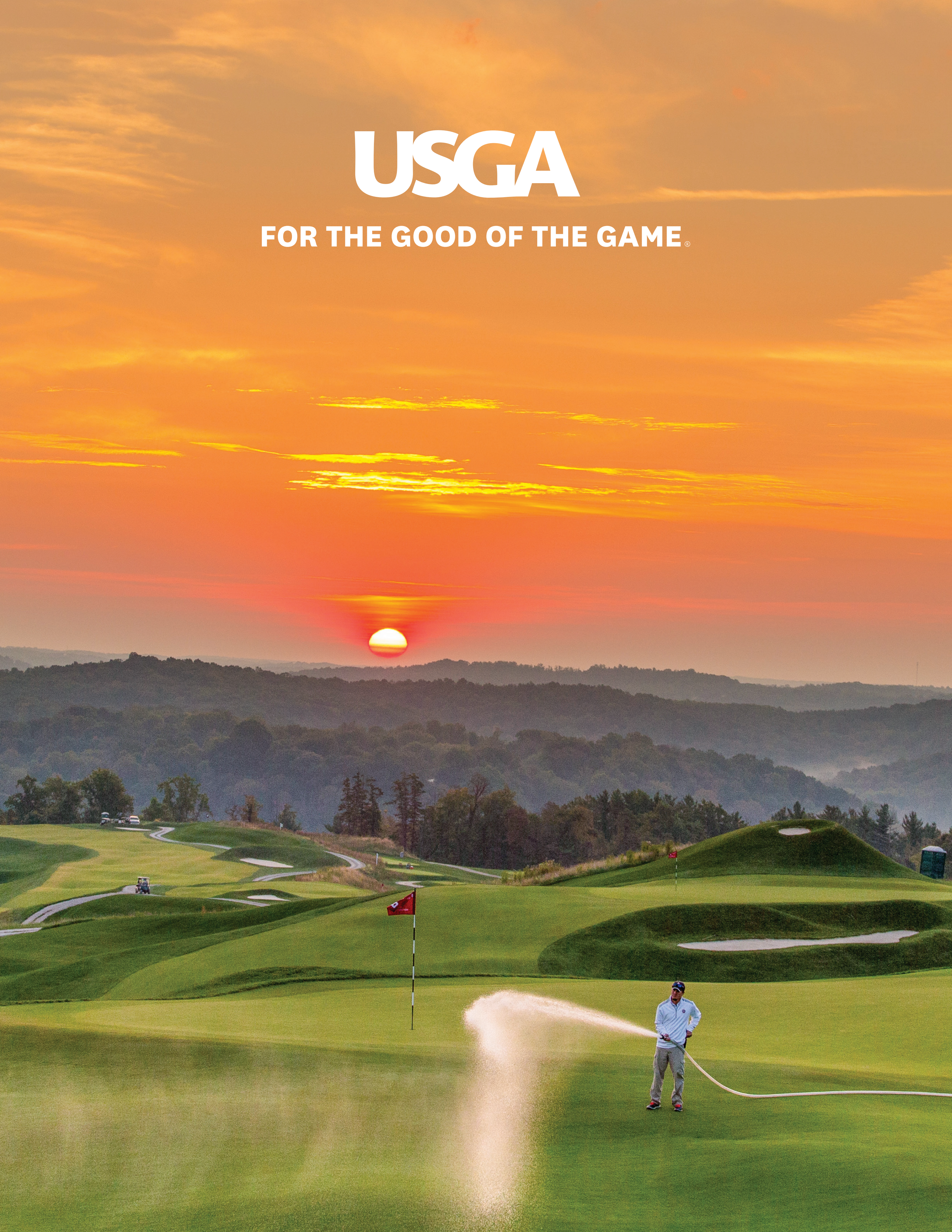
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