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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