PURPLE GOLD

A contemporary view of recycled water irrigation.

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Advanced sewage treatment takes raw sewage and converts it into clear, reclaimed water that looks as good to the human eye as any potable water. However, many "dissolved" solids (salts) still remain and are of concern if the water is to be used for irrigation.

Most of us are familiar with the term **Black Gold** as another name for oil, and we may have heard of **Blue Gold** used in some quarters in reference to water. World news increasingly delivers stories of water being "privatized" or of political fights between those who would commoditize it and those who believe access to clean water is a basic human right. Without question, humanity is polluting and wasting water even as its need for water grows with increasing population. Thus, just as it appears that wars today are fought over oil, future wars may be fought over water (for an excellent treatment of this topic, see *Blue Gold: World Water Wars*, a documentary film, as well as a book, by Barlow and Clarke).

Agronomists generally do not play the roles of economist, diplomat, or soldier. We can, however, try to educate, and sometimes the topics we broach have large consequences. The use of recycled or reclaimed water is, I believe, such a topic. And considering the critical water needs of today's world, I would like to assign to recycled water the term **Purple Gold**, after the color officially used to designate all equipment contacting it. Having worked with this resource for over 30 years, evaluating its potential for turfgrass and landscape irrigation, I have witnessed its quality increase significantly. As quality has increased, both the value and the use of recycled water have also risen dramatically. I believe recycled water, already deserving of the name **Purple Gold**, will be recognized as such society-wide in the near future. Already, in the face of increasingly common drought, habitat erosion, and the escalating cost of potable water, recycled water is the **Purple Gold** of urban landscape irrigation. In light of recycled water's importance, a review of its qualities and of the management practices needed to use it successfully is in order.

WATER DISTRIBUTION

Although three-quarters of the earth's surface is covered with water, only a minute fraction of all the water on earth is both readily available and of sufficient quality to be suitable for human use, including irrigation of agricultural crops and landscape plants. In fact, it is estimated that only 0.02% of all water on earth is fresh and immediately available — i.e., could be used with relative ease and with minimal energy input and expense. That small fraction of earth's water includes rain and snow-melt stored in lakes and reservoirs, as well as water available in rivers. More than 99% of earth's water is in its oceans or locked in polar ice caps and glaciers. Converting water from these sources to potable form is highly energy-dependent and expensive. Yet fresh surface

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and ground water together are being rapidly depleted due to industrial and agricultural use and direct human consumption. Population growth accelerates and exacerbates the potable water scarcity. Also, human activities continue to pollute much of earth's waters, contributing to potable water scarcity. It is estimated that by the year 2025, earth's population will pass 8 billion, with the great majority of the population living in large metropolitan areas. Most of the world's turfgrass (and other landscape plantings) is also in urban centers, where it competes with human consumption and food production for access to high-quality irrigation water.

Another piece of the world's water puzzle, drought is a serious and increasing problem in much of the world. In the United States and elsewhere over the past two decades, significant drought conditions occurred in various regions. During the same period, Americans migrated in large numbers to "desert" states. Housing developments in these arid regions, along with their attendant landscape sites (golf courses especially) have significantly increased the demand for water.

In most cases, turf and landscape irrigation is not a priority for municipalities during droughts. Severe restrictions on turfgrass and landscape irrigation during droughts are common, including complete shutdown of golf course or park irrigation. Irrigation with recycled water is therefore a viable means of coping with drought, water shortages, and/or the rising cost of potable water. Currently, large volumes of recycled water are used to irrigate golf courses, parks, roadsides, landscapes, cemeteries, athletic fields, sod production farms, and other landscape sites. Interest in recycled water irrigation also increases as more and better-quality treated sewage water becomes available.

Sewage treatment has become more effective at eliminating potential human pathogens. Historically, treated sewage water was used to irrigate crops not consumed directly by humans (e.g., pasture, fodder, fiber, and seed crops), fruits borne high enough on trees that they did not come into contact with irrigation water, and crops grown for processing (e.g. grapes for wine, tomatoes for ketchup, or cucumbers for pickling). Today, most sewage treatment plants produce high-quality recycled water suitable (as far as human-pathogen content is concerned) for additional uses such as golf courses, parks, athletic fields, and other urban landscape sites. In certain southwest desert areas of the United States, most golf courses (and associated landscapes) may use only recycled (or other degraded-quality) water for irrigation. In a larger context, recycled water is now the irrigation source for approximately 15% of U.S. golf courses and close to 35% of courses in southwestern states. These figures are rapidly increasing, as are those for all other commercial, institutional, and industrial sites irrigated with recycled water.

HOW WATER IS RECYCLED

"Recycled water" refers to water that has undergone one cycle of (human)

In most cases where significant drought conditions occur, turf and landscape irrigation is not a priority for municipalities, resulting in parched stands of grass.

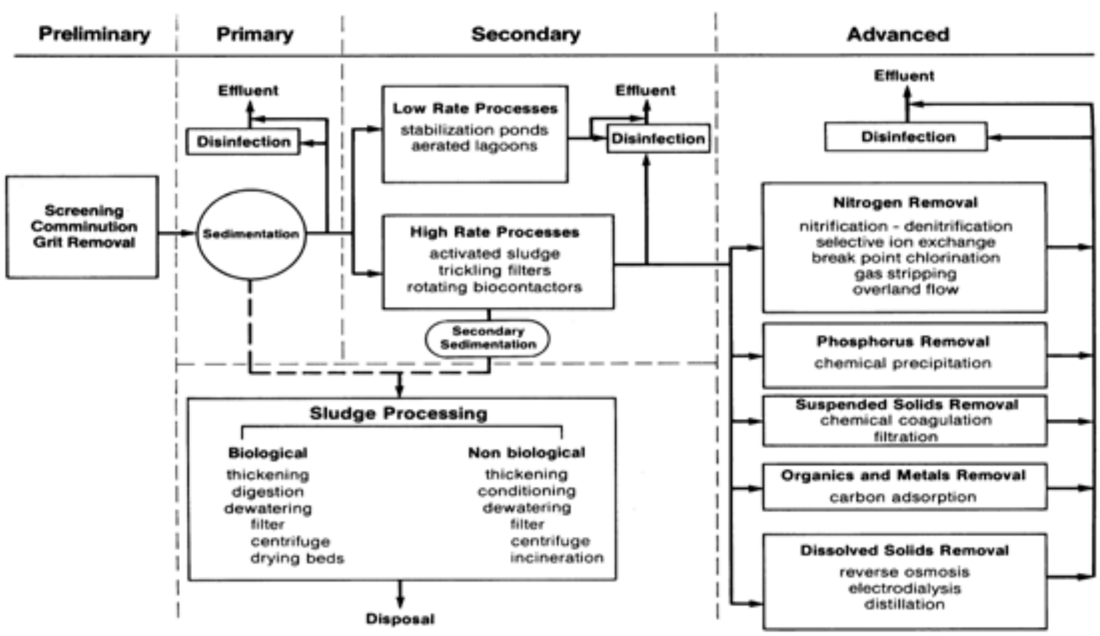
use and then received significant treatment at a sewage treatment plant to be made suitable for various reuse purposes, including turfgrass irrigation. Several other terms are also used for recycled water, among them: reclaimed water, reuse wastewater, effluent water, and treated sewage water. Depending on degree of treatment, recycled water is referred to as primary, secondary, or advanced (tertiary) treated municipal or industrial wastewater. Primary treatment is generally a screening or settling process that removes organic and inorganic solids from wastewater. Secondary treatment is a biological process in which complex organic matter is broken down to less-complex organic material, which is then metabolized by simple organisms that are later removed from the wastewater. Advanced wastewater treatment consists of processes that are similar to potable water treatment, such as chemical coagulation and flocculation, sedimentation, filtration, or adsorption of compounds by a bed of activated charcoal. Advanced treatment is often referred to as "tertiary treatment." Secondary and tertiary processes significantly reduce suspended matter and pathogenic organisms contained in effluent water. Urban sewage treatment employs sophisticated procedures and equipment to remove human-disease-causing organisms. Figure 1 presents a simplified schematic of the three levels of treatment.

Sewage treatment takes raw sewage with all of its suspended matter and pathogenic organisms and converts it into clear, reclaimed water that looks as good to the human eye as any potable water. In almost all cases, recycled water is thoroughly disinfected before leaving the treatment plant. Disinfection greatly reduces (or entirely eliminates) the human disease-causing organisms and expands the irrigation uses of recycled water.

However, "dissolved" solids (salts) still remain and are of concern if the water is to be used for irrigation. It is technically possible to remove all of the dissolved salts from sewage water, using techniques such as reverse osmosis. Reverse osmosis, in fact, is used on a small scale at a few golf courses to remove almost all dissolved solids from water. However, the expense is such that very few treatment plants in the world currently use it. Therefore, most of the recycled water available for irrigation is only tertiary treated and may contain high concentration of salts.

Turfgrass is particularly well suited to irrigation with recycled water. Among landscape plants, turfgrasses can absorb relatively large amounts of nitrogen and other nutrients often found in elevated quantities in recycled water, a characteristic that may greatly decrease the odds of groundwater contamination by recycled water. Equally important, turgrass plantings are generally permanent and their growth is continuous, providing a stable need for continuously produced recycled water. Presently, most of the turfgrass irrigated with recycled water grows on golf courses. However, recycled water irrigation is increasing on sports fields, in parks, on many

Figure 1
Generalized flow sheet for wastewater (sewage) treatment



Source: Asano, T., et al. 1984. Municipal wastewater: treatment and reclaimed water characteristics. In Pettygrove and Asano (eds.) Irrigation with Reclaimed Municipal Wastewater — A Guidance Manual. Report No. 84-1 wr. Calif. State Water Resources Control Board, Sacramento, Ca.

industrial and institutional landscapes, and on sod production farms.

Most municipalities require signage (usually colored **purple**) to inform the public of the presence of recycled water. These efforts are intended to prevent anyone from ingesting or otherwise using the water directly, to avoid any risk, however slight, of contact with human pathogens. The color **purple** is now broadly accepted as the official color for recycled water conveyance equipment. Almost all irrigation system components are now available in **purple,** including pipes, sprinkler heads, valves, and irrigation boxes.

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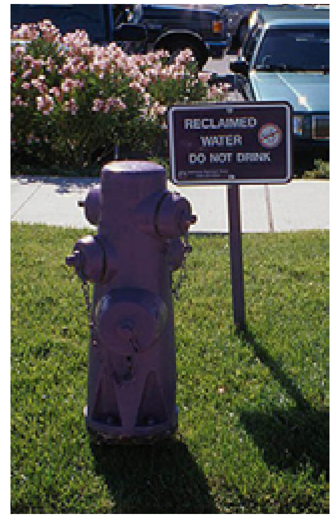


Presently, most of the turfgrass irrigated with recycled water grows on golf courses, sports fields, and parks. However, recycled water irrigation is increasing on other urban common spaces.

POTENTIAL CHALLENGES

Despite sound reasons for using recycled water for turfgrass irrigation, there are legitimate concerns about possible injury to turfgrass and other landscape plants due to the salt content and other characteristics of reclaimed water. During irrigation, dissolved salts and other chemical constituents move with water into the plant rootzone. Recognizing the problems that may arise from this and understanding their remedies allow turfgrass managers to make use of this valuable irrigation resource, the **Purple Gold**, in spite of potential challenges.

Recycled waters usually contain higher amounts of dissolved salts than most other irrigation water sources. Salt accumulation in the soil is the most common concern. Ordinarily, a long period of irrigation passes before salt builds up in the soil enough to actually injure plants. Besides saline irrigation water, insufficient natural precipitation, inadequate irrigation, and poor drainage all increase the likelihood of creating saline soil conditions.

Generally, salinity becomes a problem for turfgrass when the total quantity of soluble salt in the rootzone is high. The rate at which salts accumulate to these levels in a soil depends on their concentration in the irrigation water, the amount of water applied annually, annual precipitation, and the soil's physical and chemical characteristics. Once rootzone salinity builds to harmful levels, several problems may occur. Salinity may inhibit water absorption by plant roots (due to the high osmotic potential of the soil water solution) and cause plants to appear drought stressed despite the presence of adequate water within the rootzone. For such osmotic stress symptoms, the term *physiological drought* is often used. High salinity can also cause some ions (e.g., sodium) to be absorbed by the plant in high enough quantities to cause tissue burn or to compete with other essential elements, creating nutritional imbalances. In most cases, injury caused by high water/soil salinity is due to a combination of these factors.

If the amount of water applied to turf (irrigation plus precipitation) is higher than evapotranspiration and drainage is provided, then salt movement is downward. Conversely, salt movement is upward if evapotranspiration exceeds water applied. In the latter case, salt drawn to the surface gradually accumulates to levels toxic to turfgrasses and other plants. Diagnosing water/soil salinity problems always begins with chemical analysis of the irrigation water and soil.

Water salinity is reported differently by different laboratories. It may be reported as electrical conductivity (ECw) in terms of deci Siemens per meter (dS/m), or as Total Dissolved Solids (TDS) in either parts per million (ppm) or milligrams per liter (mg/L).

Generally, waters of acceptable quality for turfgrass irrigation have electrical conductivities of less than 0.7 dS/m (Table 1). Waters with soluble salt levels above 3 dS/m may injure turfgrass and are not recommended for irrigation. Recycled irrigation water with salt levels up to 3 dS/m may be tolerated by some turfgrass species, but only on soils with good permeability and subsoil drainage, which allow a turfgrass manager to leach excessive salt from the rootzone by periodic heavy irrigations.

For agronomic purposes, in addition to salinity, recycled waters must also be evaluated for their sodium, chloride, boron, bicarbonate, and nutrient content, as well as pH and suspended matter. Each of these elements affects plant growth. Managers can request that labs test their samples for the specific elements they know are likely to cause injury to plants. With test results in hand, managers use published guidelines to determine if their conditions are problematic and, if so, in what way.

Sodium content is as important to recycled water quality as salinity. Although sodium can be directly toxic to plants, its most frequent deleterious effects on plant growth are indirect through its effect on soil structure. The high sodium content common to recycled water can cause deflocculation (dispersion) of soil clay particles or breakdown of soil structure, reducing soil aeration and water infiltration and percolation. Waterlogging and soil compaction are common results of excess sodium. In such conditions, direct sodium toxicity may also eventually occur. The sodium (Na) hazard of recycled water is measured by the Sodium Adsorption Ratio (SAR), generally calculated as shown here:

$$\mathbf{SAR} = \frac{Na}{\sqrt{\dfrac{Ca + Mg}{2}}}$$

Because calcium (Ca) and magnesium(Mg) flocculate clay particles, while sodium disperses them, the ratio of these elements to each other in irrigation water provides a measure of likely soil permeability resulting from irrigation with a particular water. That said, the effect of sodium on soil particle dispersion (i.e., permeability) is counteracted by high electrolyte (soluble salts). Thus, the likely effect of a particular irrigation water on soil

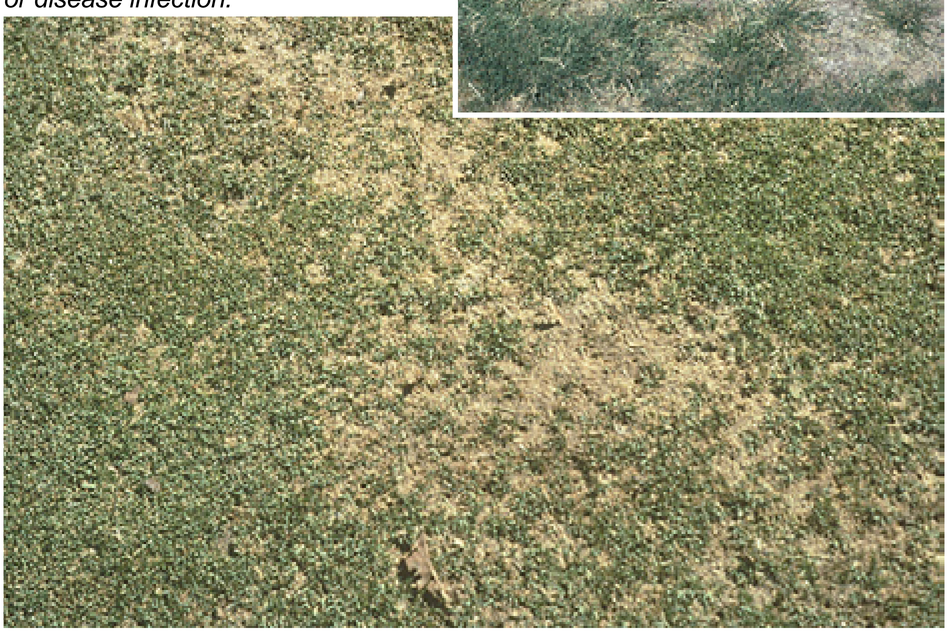
Table 1
Guidelines for the interpretations of recycled water quality for irrigation

Potential Irrigation Problems	Units	Degree of Restriction on Use: None	Slight to Moderate	Severe
Salinity				
EC_w	dS m^{-1}	<0.7	0.7 to 3.0	>3.0
TDS	mg L^{-1}	<450	450 to 2,000	>2,000
Soil Water Infiltration				
(Evaluate using EC_w (dS m^{-1}) and SAR together:				
If SAR = 0 to 3 and EC_w =		>0.7	0.7 to 0.2	<0.2
If SAR = 3 to 6 and EC_w =		>1.2	1.2 to 0.3	<0.3
If SAR = 6 to 12 and EC_w =		>1.9	1.9 to 0.5	<0.5
If SAR = 12 to 20 and EC_w =		>2.9	2.9 to 1.3	<1.3
If SAR = 20 to 40 and EC_w =		>5.0	5.0 to 2.9	<2.9
Specific Ion Toxicity				
Sodium (Na)				
➢ Root Absorption	SAR	<3	3 to 9	>9
➢ Foliar Absorption	meq L^{-1}	<3	>3	—
	mg L^{-1}	<70	>70	—
Chloride (Cl)				
➢ Root Absorption	meq L^{-1}	<2	2 tp 10	>10
	mg L^{-1}	<70	70 to 355	> 355
➢ Foliar Absorption	meq L^{-1}	<3	>3	
	mg L^{-1}	<100	>100	
Boron (B)	mg L^{-1}	<1.0	1.0 to 2.0	>2.0
pH	—	Normal Range:	6.5 to 8.4	

Under saline recycled water irrigation, injury to landscape plants other than turf often appears on lower foliage due to its direct contact with irrigation water.

(Right) Turfgrasses have varying degrees of tolerance to salinity. Research funded by organizations aims to develop highly salt-tolerant turfgrasses (e.g., salt grass).

(Below) In early stages of salt buildup under saline recycled water irrigation, the stress caused by salinity may leave thinned, weak grass vulnerable to other stresses like heat, drought, or disease infection.



permeability is best gauged by assessing the water's SAR in combination with its ECw. Note that for recycled waters high in bicarbonate, some laboratories "adjust" the calculation of SAR (yielding a number called "adjusted SAR" or "Adj. SAR") because soil calcium and magnesium concentrations are affected by a water's bicarbonate. In simplest terms, Adj. SAR reflects the water content of calcium, magnesium, sodium, and bicarbonate, as well as the water's total salinity. The combined effect of water ECw and SAR on soil permeability is shown in Table 1. The table provides general guidelines only, since soil properties, irrigation, climate, species salt tolerance, and cultural practices all interact with water quality and plant growth. In general, water with an SAR below 3 is safe for turf and other ornamental plants. Recycled waters with an SAR above 9 can cause severe permeability problems when applied to fine-textured (i.e., clay) soils over a period of time. Coarse-textured (i.e., sandy) soils experience less severe permeability problems and can tolerate an SAR of this magnitude. Golf course greens and sports fields with high-sand-content rootzone mixes, for example, can be irrigated successfully with high-SAR water because their drainage is good.

Recycled waters usually contain a wide variety of other elements in small concentrations. Some of these elements are toxic to turfgrasses and other plants if they accumulate in the soil to sufficient levels. The most common toxicities are due to accumulations of sodium, chloride, and boron. Plant roots absorb sodium and transport it to leaves, where it can accumulate and cause injury. Symptoms of sodium toxicity resemble those of salt burn on leaves. Sodium toxicity is often of more concern on plants other than turfgrasses, primarily because accumulated sodium is removed every time grass is mowed.

Chloride (Cl), in addition to contributing to the total soluble salt content of irrigation water, is another ion that may be directly toxic to landscape plants. Although not particularly toxic to turfgrasses, it affects many trees, shrubs, and ground covers. In sensitive plants, chloride toxicity causes leaf margin scorch in minor cases and total leaf kill and abscission in severe situations. Fortunately, chloride salts are quite soluble and thus may be leached from well-drained soils with good subsurface drainage.

Recycled water may also contain boron (B), a micronutrient essential for plant growth in very small quantities. Injury from excess B is most obvious as necrosis on the margins of older leaves. Turfgrasses are more tolerant of boron than any other plants grown in the landscape. Table 1 provides general guidelines for assessing the effect of sodium, chloride, and boron in irrigation water.

pH, a measure of acidity, is valued on a scale of 0 to 14. Water pH is easily determined and provides useful information about water's chemical properties. Although seldom a problem in itself, a very high or low pH indicates that water needs evaluation for other constituents. On the pH scale, pH 7 represents neutral (i.e., water with a pH of 7 is neither acidic nor alkaline.) Moving from pH 7 to pH 0, water is increasingly acidic; moving from pH 7 to pH 14, water is increasingly basic (or "alkaline"). The desirable *soil* pH for most turfgrasses is 5.5 to 7.0; the pH of most irrigation *water*, however, ranges from 6.5 to 8.4. Depending on the soil on which grass is grown, an irrigation water pH range of 6.5-7 is desirable. Recycled water with a pH outside the desirable range must be evaluated for other chemical constituents.

The bicarbonate (HCO_3) and, to a lesser degree, carbonate (CO_3) content of recycled irrigation water also deserves careful evaluation. Recycled waters are especially prone to excessive levels of bicarbonate. High bicarbonate levels in irrigation water increase soil pH and may affect soil permeability; combining with calcium and/or magnesium, bicarbonate precipitates as calcium and/or magnesium carbonate, both of which increase the SAR of the soil solution. As noted previously, high SARs can lead to reduced soil permeability. To determine the negative impact of the bicarbonate content of recycled water, it is not reported as meq/L (milliequivalent per liter) of HCO_3, but as Residual Sodium Carbonate (RSC). RSC is calculated from the equation shown below, in which concentrations of all ions are expressed in meq/L.

$$RSC = (HCO_3 + CO_3) - (Ca + Mg)$$

Generally, recycled water with an RSC value of 1.25 meq/L or lower is safe for irrigation, water with an RSC between 1.25 and 2.5 meq/L is marginal, and water with an RSC of 2.5 meq/L and above is probably not suitable for irrigation.

Recycled water can also be high in nutrients, whose economic value may be an important consideration. Nitrogen, phosphorus, and potassium, all of which are essential to turfgrass growth, are the primary nutrients present in most recycled waters. Even if the quantities of nutrients in a given recycled water are small, they are efficiently used by turfgrass because they are applied frequently and regularly. In most cases, turf obtains all the phosphorus and potassium and a large part of the nitrogen it needs from recycled water. Sufficient micronutrients are also supplied by most recycled

At some sites, especially golf courses, where recycled water is used for irrigation, creative water features are incorporated into the landscape design to control algae growth in ponds.

Wherever recycled water is used for irrigation, good drainage is essential. Drainage can be natural or can be improved by installation of tile drains.

waters. Water chemical analysis must therefore be thoroughly evaluated to determine the kind and amount of each nutrient applied through irrigation; the turf's fertility program can then be adjusted accordingly. Most agricultural testing laboratories will provide the nutritional contents of recycled water upon request.

Suspended solids in recycled water may include inorganic particles such as clay, silt, and other soil constituents, as well as organic matter such as plant material, algae, bacteria, etc. These materials do not dissolve in water and thus can be removed only by filtration. The suspended solids in tertiary treated (advanced) recycled water are negligible and not a cause for concern. However, if secondary treated recycled water is used for irrigation, suspended solids should be monitored. In addition to plugging irrigation equipment, solids can fill air spaces between sand particles, reducing infiltration and drainage, and increasing compaction. Since these effects vary considerably with type of solid, irrigation system, and soil, it is difficult to standardize suspended solid values for irrigation water. Overall, the complexity and variability of irrigation waters and systems make effective filtration the most sensible approach to controlling hazards posed by suspended solids in any water.

Recycled water quality varies significantly among sewage treatment plants as well as on a seasonal basis, and it must be analyzed individually and regularly. There are very few recycled water sources that are absolutely unsuitable for turfgrass irrigation. Furthermore, the nature and magnitude of potential problems with a specific water will depend on its interaction with climate and soil chemistry and physics.

Soil physical characteristics and drainage both play important roles in determining a rootzone's ability to handle salinity. For example, water with an ECw of 1.5 dS/m may be successfully used on grass grown on sandy soil with good drainage and high natural leaching, but may prove injurious within a very short time if it is used to irrigate the same grass grown on a clay soil or soil that has limited drainage because of salt buildup in the rootzone. Consequently, soil characteristics must be evaluated along with water quality to determine if irrigation-induced problems are likely. Fine-textured soils (clays) are more likely to accumulate salts than coarse-textured soils (sands). Also, layering in the rootzone that interferes with drainage (and therefore salt leaching) can lead to water-induced plant injury despite irrigating with seemingly acceptable recycled water. In other words, lack of drainage leads to salt buildup. Soils already saline or sodic are obviously more likely to contribute to salinity injury due to recycled water irrigation, regardless of their drainage characteristics. Application of excessive fertilizer can also contribute to the salt load and may create salinity problems where the salt load from recycled water alone may not be high enough to cause damage.

POTENTIAL SOLUTIONS

If water salinity, sodium, and other chemical components are potential problems, management is key to agronomic success. Following is a list of management practices that can be used to address potential recycled water irrigation challenges.

Select salt-tolerant turfgrass species. If salinity problems are expected with recycled water irrigation, salt-tolerant grass species should be considered for planting. Salt tolerance of turfgrasses is usually expressed in relation to the salt content of the soil. Table 2 provides a general guide to the salt tolerance of individual turfgrasses, based on ECe values (electrical conductivity of soil water extract). Grasses are listed in columns indicating the highest levels of salt at which they perform adequately. As indicated, soils with an ECe below 3 dS/m are considered satisfactory for growing most turfgrasses; soils with an ECe between 3 and 10 dS/m can support a few moderately salt-tolerant turfgrass species, while soils with an ECe higher than 10 dS/m will support only very salt-tolerant grasses.

Apply extra water to leach excess salts below the turfgrass rootzone. Extra irrigation water needed to leach salts below the turfgrass rootzone, thus preventing salt buildup to toxic levels, is referred to as the *leaching*

Table 2
Relative tolerances of turfgrass species to saturated soil paste extract salinity (ECe)

Sensitive (<3 dS/m)	**Moderately Sensitive (3-6 dS/m)**	**Moderately Tolerant (6-10 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 (Japanica type) Zoysiagrasses	Fineleaf (Matrella type) Zoysiagrasses
Centipedegrass	Slender Creeping, Red, and Chewings Fescues	Tall Fescue	Saltgrass
Colonial Bentgrass			Seashore Paspalum
Hard Fescue			St. Augustinegrass
Kentucky Bluegrass			
Rough Bluegrass			

requirement or *fraction* and is calculated with the formula shown below:

$$LR = \frac{EC_W}{5\,(EC_e) - EC_W}$$

(Leaching Requirement)

A leaching requirement is based on the recycled water's salt content and the salt tolerance levels of the grass (expressed in ECe) at the site. For example, if a turfgrass species with salt tolerance of not more than 2.5 dS/m is irrigated with a recycled water with an electrical conductivity of 1.2 dS/m, 10% more water than is dictated by evapotranspiration (ET) alone must be applied to leach salts out of the rootzone.

$$LR = \frac{1.2}{5\,(2.5) - 1.2} = \frac{1.2}{11.3} = 0.10$$

Any changes in a system's input, such as rainfall, can affect the amount of water that must be applied for leaching. As the Leaching Requirement increases (and therefore more salt leaching occurs), salt accumulation in the rootzone decreases. As a result, highly saline recycled water may be used successfully for irrigation in high rainfall areas, while the same water may cause severe salinity damage to turfgrasses in arid and semi-arid locations.

Provide drainage. Clearly, successful leaching requires adequate drainage. In all cases where recycled water is used for irrigation, good drainage is essential. Drainage can be natural or can be improved by installing tile drains. An example of a site where drainage must be improved: a golf course with greens built on modified native soils (i.e., push-up greens) converting to recycled water for irrigation. The course can either rebuild greens on a sand-based rootzone mix or install an effective drainage system to provide for salt leaching. The objective is to keep percolated saline water below the turfgrass rootzone.

Modify management practices. Certain management practices may alleviate the deleterious effects of salinity. On golf greens, especially, reducing or removing accumulated surface organic matter (thatch) is crucial under recycled water irrigation. Thatch and mat layers stop the flow of water (and salts) through the soil and impede leaching of salts. On golf greens with a uniform rootzone profile, drainage is often adequate for salt leaching. However, if a given golf green rootzone profile indicates excessive organic matter (thatch) accumulation or, worse, the existence of a layering problem within the soil profile, then every effort must be employed to remove thatch or eliminate layering prior to the initiation of recycled water irrigation. Aeration (particularly useful on golf course greens and sports fields) punches through impermeable layers, facilitating faster and better water movement through the soil profile. Aerators remove soil cores at regular intervals. Cores should be removed from the soil surface of golf greens and similar specialty turf, and holes should be topdressed with sand. Often, just spreading sand over the aerated surface fails to fill the holes. Sweeping, brushing, or blowing sand into the holes left by aeration ensures optimum sand application. Holes should be filled all the way to the soil surface to provide channels for water percolation through the layers of sand/organic matter.

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Modify the rootzone mixture. Where turfgrasses are grown on soils with minimal natural drainage (e.g., heavy clay soils, soils with a hard pan or clay pan) and recycled irrigation water is high in salts or sodium, total modification of the rootzone mixture may be necessary. Sand-based golf greens or sports fields generally drain well and can tolerate recycled waters that may be too saline for irrigation on heavy clay or compacted soils.

Blend irrigation waters. Frequently, poor-quality water can be used for irrigation if better-quality water is available for blending. The two waters can be pumped into a reservoir to mix them before irrigation. Although the resulting salinity will vary according to the type of salts present and climatic conditions, water quality should improve in proportion to the mixing ratio. For example, when equal volumes of two waters, one with an ECw of 1 dS/m and the other with an ECw of 5 dS/m are mixed, the salinity of the blend should be approximately 3 dS/m. Deleterious effects of sodium/bicarbonate may be reduced by blending poor-quality water with less-sodic (waters with elevated sodium/

Applying soil and water amendments such as gypsum (calcium sulfate), calcium chloride, sulfur, and sulfuric or N-phuric acids can reduce the negative effects of sodium and other salts. There are many different amendments and equipment available to effectively inject them into an irrigation system.

bicarbonate contents), better-quality water. Although the resulting sodicity will vary according to the amount of sodium/bicarbonate present in the two waters, water quality will improve in proportion to the mixing ratio.

Use amendments. Applying soil and water amendments, such as gypsum (calcium sulfate), calcium chloride, sulfur, and sulfuric or N-phuric acids, can aid in reducing the negative effects of sodium and bicarbonte. They may also help with improving water/soil pH and partially help with salinity control. These amendments increase the soil supply of calcium, either directly, as in the case of gypsum and calcium chloride, or indirectly, as in the case of sulfur and sulfuric or N-phuric acids. Sulfur and sulfur-containing fertilizers applied to soils naturally high in calcium may make calcium more soluble. Once available, calcium can then replace sodium on clay particles, preventing excess sodium accumulation. Subsequent leaching will flush sodium salts out of the rootzone. The amount of sulfur amendment required depends on a soil's sodium content, SAR of the irrigation water, the quantity of water applied, soil texture, and type of amendment.

The impact of bicarbonate on pH may also be reduced by applying an acidifying fertilizer, such as ammonium sulfate, as part of a regular fertilization program, or by acidification of the irrigation water. In some cases, water with high residual sodium carbonate may require acidification with sulfuric, N-phuric acid (a type of urea-sulfuric acid), or phosphoric acids, or by use of a sulfur burner (which produces sulfurous acid).

Amendments may be applied directly to the turfgrass/soil or injected into the irrigation system. Acidification of water by acid injection requires unique measurements and equipment. A turfgrass manager must work closely with a consulting laboratory to determine whether acidification is required and, if it is, how it may best be accomplished. The same care is required for use of a sulfur burner. In general, however, the sulfurous acid produced by a burner is not as caustic as sulfuric acid.

There are many advantages to treating recycled water with direct injection of amendments into the irrigation system, among which are:

- More effective than surface application (gradual and frequent application)
- No disruption in site use
- Reduced labor
- No dust problems
- Reduced burn potential of sulfur
- Reduced risk of "overdose"
- Reduced pH and salinity fluctuations

There are also potential disadvantages to direct injection:

- Material more expensive
- Equipment and maintenance expensive
- Danger of handling acids
- Irrigation efficiency and uniformity must be optimal
- Segregation of areas are not possible (e.g., greens versus fairways in golf courses)

CONCLUSION

As human population grows and fresh water becomes increasingly scarce, recycled water is a viable alternative to costly, limited potable water for irrigating turfgrass sites. Recycled water is often better tolerated by turfgrasses than by other landscape plants; simultaneously, turfgrass venues (golf courses, parks, cemeteries, green belts, campus grounds, sports fields, and sod production farms), with their large expanses and trained maintenance staffs, are particularly well-suited to incorporate recycled water in their irrigation programs. Urban population growth ensures an expansion of turfgrass sites for a variety of recreational and functional uses, and this means that irrigation with **Purple Gold** will be a permanent part of our urban landscape schemes.

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