Evaluating Recycled Waters for Golf Course Irrigation

To avoid problems, analyze recycled water thoroughly before starting to use it to irrigate a golf course, and monitor it regularly thereafter.

BY M. ALI HARIVANDI

Throughout the United States and in many other parts of the world, an increasing number of golf courses use recycled municipal water for irrigation. Much of the recycled water used for irrigation contains high concentrations of dissolved salts that are potentially toxic to turfgrasses and other golf course plants. Consequently, chemical water analysis and periodic monitoring are key components of sound irrigation management at such sites.

Water analysis done by commercial laboratories provides data on many parameters, most of which are not of great significance for turfgrass irrigation. The most important parameters for this purpose are: total concentration of soluble salts (i.e., salinity); sodium (Na) content; relative proportion of sodium to calcium (Ca) and magnesium (Mg) (Sodium Adsorption Ratio, or SAR); chloride (Cl), boron (B), bicarbonate (HCO_3), and carbonate (CO_3) content; and pH. The following parameters are also often reported on a water test report and should be reviewed, although none by itself plays a major role in determining the suitability of a given recycled water for irrigation: nutrient content (nitrogen, phosphorus, and potassium), chlorine content, and suspended solids.

SALINITY

All recycled waters contain some dissolved mineral salts and chemicals. Some soluble salts are nutrients and thus are beneficial to turfgrass growth; others, however, may be phytotoxic or may become so when present in high concentrations. The rate at which salts accumulate to undesirable levels in a soil depends on their concentration in the irrigation water, the amount of water applied annually, annual precipitation (rain plus snow), and the soil's physical/chemical characteristics.

Water salinity is reported differently by different laboratories. It is reported quantitatively as Total Dissolved Solids (TDS) in units of parts per million (ppm), or milligrams per liter (mgL^{-1}), or reported as electrical conductivity (ECw) in terms of milimhos per centimeter ($mmhos\ cm^{-1}$), micromhos per centimeter ($\mu mhos\ cm^{-1}$), decisiemens per meter (dSm^{-1}), or siemens per meter (Sm^{-1}). Some labs may also report the individual components of salinity (e.g., sodium) in milliequivalent per liter ($meqL^{-1}$). The following equations may be used to convert results from one set of units to another, thus enabling comparisons of data from differently formatted reports:

(1) $1\ ppm = 1\ mgL^{-1}$

(2) $1\ mgL^{-1} = meqL^{-1} \times$ Equivalent Weight (see Table 1)

(3) $1\ mmhos\ cm^{-1} = 1\ dSm^{-1} = 1000 \mu mhos\ cm^{-1} = 0.1\ Sm^{-1}$

The relationship between ECw and TDS is approximately:

(4) ECw (in $mmhos\ cm^{-1}$ or dSm^{-1}) $\times$ 640 = TDS (in ppm or mgL^{-1})

Most waters of acceptable quality for turfgrass irrigation contain from 200 to 800 parts per million (ppm) soluble salts. Soluble salt levels above 2,000 ppm may injure turfgrass; recycled irrigation water with salt levels up to 2,000 ppm may be tolerated by some turfgrass species (Table 2), but only on soils with exceptional permeability and subsoil drainage. Good permeability and drainage allow a turfgrass manager to leach excessive salt from the rootzone by periodic heavy irrigations. Sand-based golf greens create the proper soil structure for this form of salinity management.

Table 3 lists the parameters that should be considered in evaluating irrigation water quality. As indicated, re-

Table 1
Conversion factors: mgL^{-1} and $meqL^{-1}$

Constituent	To Convert mgL^{-1} to $meqL^{-1}$	To Convert $meqL^{-1}$ to mgL^{-1}
	Multiply by	
Sodium (Na)	0.043	23
Calcium (Ca)	0.050	20
Magnesium (Mg)	0.083	12
Bicarbonate (HCO_3)	0.016	61
Carbonate (CO_3)	0.033	30
Chloride (Cl)	0.029	35

cycled water with ECw values above 0.7 dSm^{-1} (or 450 mgL^{-1}), present increased salinity problems. Only careful management will prevent deleterious salt accumulation in the soil if water with a high ECw is used for irrigation. Recycled water with an EC above 3 dSm^{-1} should be avoided or diluted with less saline water before use for irrigation. The salt tolerance of turfgrass and other plants is expressed in terms of the salt content of the soil rootzone [e.g., as indicated in Table 2, Kentucky bluegrass will tolerate soil salinity (ECe, indicating electrical conductivity of soil water extract) at levels up to 3 dSm^{-1}]. Therefore, soil physical characteristics and drainage, both important factors in determining rootzone salinity, must also be considered when deciding about the suitability of a given recycled irrigation water. For example, water with an ECw of 1.5 dSm^{-1} may be successfully used on grass grown on sandy soil with good drainage (and thus high natural leaching), but prove injurious within a very short period of time if used to irrigate the same grass grown on a clay soil or soil with limited drainage due to salt buildup in the rootzone.

Table 2

The relative tolerances of turfgrass species to soil salinity (ECe).

Sensitive (<3 dSm^{-1})	**Moderately Sensitive (3 to 6 dSm^{-1})**	**Moderately Tolerant (6 to 10 dSm^{-1})**	**Tolerant (>10 dSm^{-1})**
Annual Bluegrass	Annual Ryegrass	Perennial Ryegrass	Alkaligrass
Colonial Bentgrass	Creeping Bentgrass	Tall Fescue	Bermudagrasses
Kentucky Bluegrass	Fine-Leaf Fescues	Zoysiagrasses	Seashore Paspalum
Rough Bluegrass	Buffalograss		St. Augustinegrass

From: M.A. Harivandi, J. D. Butler, and L. Wu. 1992. Salinity and turfgrass culture. In: *Turfgrass*. D. V. Waddington, R. N. Carrow, and R. C. Shearman (eds.) pp. 207-229. Series No. 32, American Society of Agronomy, Madison, Wisconsin, USA.

Table 3

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	dSm^{-1}	<0.7	0.7 to 3.0	>3.0
TDS	mgL^{-1}	<450	450 to 2,000	>2,000
Soil Water Infiltration				
Evaluate using EC_w (dSm^{-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	$meqL^{-1}$	<3	>3	—
	mgL^{-1}	<70	>70	—
Chloride (Cl)				
Root Absorption	$meqL^{-1}$	<2	2 to 10	>10
	MgL^{-1}	<70	70 to 355	>355
Foliar Absorption	$meqL^{-1}$	<3	>3	
	mgL^{-1}	<100	>100	
Boron (B)	mgL^{-1}	<1.0	1.0 to 2.0	>2.0
Miscellaneous Effects				
Bicarbonate (HCO_3)	$meqL^{-1}$	<1.5	1.5 to 8.5	>8.5
	mgL^{-1}	<90	90 to 500	>500
pH	—	normal range:	6.5 to 8.4	
Residual Chlorine	mgL^{-1}	<1.0	1 to 5	>5

Adapted by: M.A. Harivandi from: Westcot, D.W., and R. S. Ayers. 1984. Irrigation water quality criteria. In: Pettygrove, G. S., and T. Asano (eds.). *Irrigation with reclaimed municipal wastewater* — A guidance manual. Report No. 841-1wr. California State Water Resources Control Board, Sacramento, California; and from: Farnham, D. S., et al. 1985. *Water Quality: Its effects on ornamental plants*. University of California Cooperative Extension Leaflet 2995. Div. of Agric. Nat. Resources, Oakland, California.

Table 2 is a general guide to the salt tolerance of individual turfgrasses. As indicated, soils with an ECe below 3 dSm^{-1} are considered satisfactory for growing most turfgrasses. Soils with an ECe between 3 and 10 dSm^{-1} can successfully support only a few salt-tolerant turfgrass species.

SODIUM

Sodium content is another important factor in recycled irrigation water quality evaluation. Plant roots absorb sodium and transport it to leaves, where it can accumulate and cause injury. Thus, symptoms of sodium toxicity resemble those of salt burn on leaves. Recycled irrigation water with high levels of sodium salts can be particularly toxic if applied to plant leaves by overhead sprinkler, since salts can be absorbed directly by leaves. Sodium toxicity is often of more concern on plants other than turfgrasses, primarily because accumulated sodium is removed every time grass is mown. Among grasses grown on golf courses, annual bluegrass and bentgrass are the most susceptible to sodium phytotoxicity. In their case, mowing may not provide protection, since grasses are generally cut very shot (a stress in itself), and any sodium accumulation will comprise a large proportion of the small quantity of remaining leaf tissue.

Table 3 provides general guidelines for assessing the effect of sodium in

Weak, thin turf is the result of salt accumulation in heavy soils due to use of recycled irrigation water.

irrigation water. As indicated in the table, the level of sodium tolerated by non-turf plants varies with irrigation application method. Most landscape plants will tolerate up to 70 ppm (mgL^{-1}) sodium when irrigated by overhead sprinkler.

SAR (SODIUM ADSORPTION RATIO)

Although sodium can be directly toxic to plants, its most frequent deleterious effects on plant growth are indirect due to its effect on soil structure. It is this latter effect that is most often of concern to golf course superintendents and other professional managers of intensively used turfgrasses.

When irrigation is applied to soil, the best indicator of sodium effect is a recycled water's Sodium Adsorption Ratio (SAR), a value that should be provided in all laboratory water analyses. Although, in general, water with an SAR below 3 is considered safe for turf and other ornamental plants (Table 3), SAR is an important enough factor in water evaluation to merit thorough understanding.

The high sodium content common to recycled water can cause deflocculation or breakdown of soil clay particles, reducing soil aeration and water infiltration and percolation. In other words, soil permeability is reduced by a recycled irrigation water high in sodium. The likely effect of particular irrigation water on soil permeability can be best gauged by the water's SAR in combination with the ECw (Table 3).

Generally, recycled water with an SAR above 9 can cause severe permeability problems when applied to fine-textured (i.e., clay) soils over a period of time. In coarse-textured (i.e., sandy) soils, permeability problems are less severe and an SAR of this magnitude can be tolerated. Golf greens constructed with high-sand-content rootzone mixes, for example, can be successfully irrigated with high-SAR water because their drainage is good.

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 the 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. Other labs are adjusting the SAR value using a newly introduced method and report the adjusted value as R_{NA}.

INTERACTION OF SALINITY AND SAR

Salts and sodium do not act independently in the plant environment. The effect of sodium on soil particle dis-


Application of salty recycled water has caused burn and necrosis of leaf margins.

persion (and therefore permeability) is counteracted by high electrolyte (soluble salts) concentration; therefore, a water's sodium hazard cannot be assessed independently of its salinity. The combined effect of water ECw and SAR on soil permeability is given in Table 3. Note that the table provides general guidelines only. Soil properties, irrigation management, climate, a given plant's salt tolerance, and cultural practices all interact significantly with recycled water quality in the actual behavior of soils and plant growth.

BICARBONATE AND CARBONATE

The bicarbonate, and to a lesser degree carbonate, content of recycled irrigation water also deserves careful evaluation. Recycled waters, as well as well waters, are especially prone to containing excessive bicarbonate levels. Substantial bicarbonate levels in irrigation water can increase soil pH and may affect soil permeability. In addition, bicarbonate content may make itself obvious during hot, dry periods, when evaporation may cause white lime ($CaCO_3$) deposits to appear on leaves of plants irrigated by overhead sprinklers.

Although high levels of bicarbonate in water can raise soil pH to undesirable levels, it is bicarbonate's negative impact on soil permeability that is more often a concern. As mentioned above, the bicarbonate ion may combine with calcium and/or magnesium and precipitate as calcium and/or magnesium carbonate. This precipitation increases the SAR in the soil solution because it will lower the dissolved calcium concentration.

Table 3 indicates tolerable levels of bicarbonate in irrigation waters. The bicarbonate hazard of recycled water may be expressed as Residual Sodium Carbonate (RSC), calculated as follows:

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

In this equation, concentrations of ions are expressed in $meqL^{-1}$ [see Equation (2) and Table 1 for conversions]. Generally, recycled water with an RSC value of 1.25 $meqL^{-1}$ or lower is safe for irrigation, water with an RSC between 1.25 and 2.5 $meqL^{-1}$ is marginal, and water with an RSC of 2.5 $meqL^{-1}$ and above is probably not suitable for irrigation.

pH (HYDROGEN ION ACTIVITY)

The pH is a measure of water's acidity and alkalinity and is measured in pH units. The scale ranges from 0 to 14, with pH 7 representing 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"). pH units are on a logarithmic scale, which means that there is a tenfold change between each whole pH number. Thus, a water with pH 8 is 10 times more basic than a water with pH 7, and 100 times more basic than a water with pH 6. Water pH is easily determined and provides useful information about the water's chemical properties. Although seldom a problem in itself, a very high or low pH warns the user that the water needs evaluation for other constituents. The desirable *soil* pH for most turfgrasses is 5.5 to 7.0; the pH of most *irrigation waters*, however, ranges from 6.5 to 8.4. Depending on the soil on which the grass is grown, an irrigation water pH range of 6.5-7 would be desirable. Recycled water with a pH outside the desirable range must be carefully evaluated for other chemical constituents.

CHLORIDE

In addition to contributing to the total soluble salt concentration of irrigation water, chloride (Cl) may be directly toxic to plants grown on a golf course. Although chloride is not particularly toxic to turfgrasses, many trees, shrubs, and ground covers are sensitive to it.

Chloride is absorbed by plant roots and translocated to leaves, where it accumulates. In sensitive plants, this accumulation leads to necrosis — leaf margin scorch in minor cases, total leaf kill and abscission in severe situations. Similar symptoms may occur on sensitive plants if water high in chloride is applied by overhead sprinklers, since chloride can be absorbed by leaves as well as roots. Turfgrasses tolerate all but extremely high levels of chloride as long as they are regularly mowed.

Chloride salts are quite soluble and thus may be leached from well-drained soils with good subsurface drainage.

As indicated in Table 3, recycled irrigation water with a chloride content above 355 mgL^{-1} is toxic when absorbed by roots, while a chloride content higher than 100 mgL^{-1} can damage sensitive ornamental plants if applied to foliage.

CHLORINE

Municipal recycled water may contain excessive residual chlorine (Cl_2), a potential plant toxin. Chlorine toxicity is almost always associated only with recycled waters that have been disinfected with chlorine-containing compounds. Chlorine toxicity will occur only if high levels of chlorine are sprayed directly onto foliage, a situation likely to occur only where recycled water goes straight from a treatment plant to an overhead irrigation system. Free chlorine is very unstable in water; thus, it will dissipate rapidly if stored for even a short period of time between treatment and application to plants. As indicated in Table 3, residual chlorine is of concern at levels above 5 mgL^{-1}.

BORON

Boron (B) is a micronutrient essential for plant growth, though it is required in very small amounts. At even very low concentrations (as low as 1 to 2 mgL^{-1} in irrigation water), it is phytotoxic to most ornamental plants, capable of causing leaf burn (Table 3). Injury is most obvious as a dark necrosis on the margins of older leaves. Turfgrasses are generally more tolerant of boron than any other plants grown on a golf course; however, they are more sensitive to boron toxicity than to either sodium or chloride. Most will grow in soils with boron levels as high as 10 ppm.

NUTRIENTS

Recycled waters always contain a range of micro (trace) elements sufficient to satisfy the need of most turfgrasses. They may also contain enough macro (major) nutrients (i.e., nitrogen, phosphorus, and potassium) to figure significantly in the fertilization program of large turfed areas.

Most laboratories test recycled water for nutrient content and often report nutrients in "lb./acre ft. of water applied." The economic value of these nutrients can be substantial. Even where the quantities of nutrients are low, because they are applied on a regular basis, the nutrients can be used very efficiently by plants. If the laboratory report does not include the lb./acre ft. of nutrients, the following conversion formula can be used to determine this value for any nutrient contained in irrigation water:

(6) lb./acre ft. of nutrient = nutrient content (mgL^{-1} or ppm) $\times$ 2.72.

SUSPENDED SOLIDS

Suspended solids (SS) in irrigation water refers to 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, an essential step for most irrigation systems in which plugged sprinkler head openings and/or valves reduce system efficiency and life.

The suspended solids in domestic municipal water sources are negligible and not a cause for concern. However, suspended solids should be monitored in wells, canals, and especially lakes or ponds storing recycled water used for irrigation. Nitrogen and phosphorus in recycled water can lead to algae growth in storage lakes during the winter. Such growth can pose a major concern when the water is introduced into an irrigation system. In addition to the mechanical problems they present for irrigation systems, suspended solids and algae can seal a soil surface, especially on sand-based golf greens and sand bunkers. Solids can fill in air spaces between sand particles, reducing infiltration and drainage, and increasing compaction. Since these effects vary considerably with type of solid, irrigation system, and turfgrass soils, it is difficult to formulate acceptable suspended solid values for irrigation water. The complexity and variability of irrigation waters and systems make effective filtration the most sensible approach to controlling hazards posed by suspended solids and algae in recycled water.

INTERPRETING WATER QUALITY HAZARD

As the preceding indicates, recycled water quality must be analyzed on an individual basis. There are very few recycled water sources that are absolutely unsuitable for turfgrass irrigation. While the discussion presented here can be used as a general guide to help turfgrass managers determine whether a water quality problem exists, the precise natureand magnitude of a potential problem may require more than water analysis. Climate, soil chemistry and physics, use patterns, and turf quality expectations will all contribute both to any problem and to any potential remedies.

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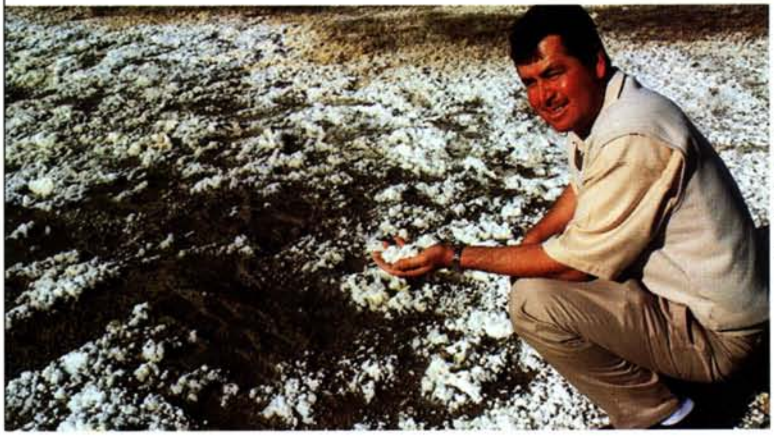

An extreme example of a salty crust on an area where the turf has disappeared.