EFFLUENT WATER: *Nightmare or Dream Come True?*

Effluent water is nothing to lose sleep over — you just need to understand the management challenges you face.

by MIKE HUCK, R. N. CARROW, AND R. R. DUNCAN

JUST THE THOUGHT of switching to effluent water (recycled, non-potable, wastewater, reclaimed) causes many green chairmen, directors of golf, and superintendents to lose sleep. Their sweet dreams of fast greens and flawless fairways quickly turn into nightmares of deteriorating turfgrass quality. When the subject of wastewater use is raised, stories are quickly told about courses losing their greens the first season while using effluent. These stories may or may not be true, but when they are, there were usually compounding reasons for problems. Often, no adjustments were made in management programs to compensate for differences in water quality between the present effluent and the former irrigation source.

Effluent is an alternative irrigation source that all golf course managers should readily embrace (Borchardt, 1999; Snow et al., 1994; Zupanic, 1999). While most effluent use is now voluntary, it is currently required in some regions. Such is the case in California, where Assembly Bill 174 was adopted in 1992 mandating the use of reclaimed water (where available) for all non-potable applications such as irrigation and industrial use. Water-sensitive Tucson and Phoenix, Arizona, and Las Vegas, Nevada, also impose their own unique restrictions. They offer incentives, limit the amount of potable water available, or require non-potable irrigation sources for new development projects.

Effluent water use for golf course irrigation continues to increase across the country. A survey conducted in 1978 reported 26 respondents then using recycled water (Snow, 1979). A recent survey conducted by the National Golf Foundation (NGF) reports approximately 13% of golf courses nationwide now use effluent irrigation sources, and this increases to 34% in the Southwest, where water availability is a constant issue (NGF, 1999). In many areas effluent use and associated management adjustments will be the *norm* within a few years.

In the eyes of the non-golfing public, we are wasting drinking-quality water when it is used for irrigating a golf course with typical irrigation rates from 250,000 to 1,000,000 gallons per day for an 18-hole golf course. The golf industry cannot disagree with this point and must recognize that using effluent water is good for our image. It also is good for the environment, as turfgrass sites can filter out and utilize nitrates and other nutrients as the water percolates through the thatch and soil profile, eventually to recharge groundwater. Effluent can also be good for the bottom line of the budget, depending on the water quality and price when delivered to the course. In the arid western states, water is a valuable resource and annual irrigation costs can range from \$100,000 to \$1,000,000 for 18 holes. Considering that effluent water is often negotiated for 80% or less of fresh (potable) water costs, the savings frequently offset increased management costs.

Whether effluent becomes a non-interruptible dream-come-true water supply or a nightmare of agronomic problems depends on many factors. Ultimately, success depends on proper agronomic management based on the individual site, soil, turfgrass cultivars, and effluent quality.

Agronomic and Environmental Issues

Use of effluent water requires consideration of several agronomic and environmental issues (Ayers and Westcot, 1985; Bond, 1998; Snow et al., 1994; Westcot and Ayers, 1985).

• *Water Quality* — The greatest difference between effluent and any other water source such as potable, lakes, wells, streams, or rivers is the quality of the water. Water quality assessment from a turfgrass irrigation suitability standpoint (human health issues will be discussed later) examines the water chemistry, or more simply stated, the types and quantities of dissolved or suspended constituents in the water. The quality of effluent, such as the amounts and types of dissolved salts included, will vary at every location and can change throughout the year. All effluent will have some level of salt and variable nutrient concentrations.

Many water reclamation plants offer customers periodic laboratory test results at no charge; however, these data are often incomplete for assessing irrigation quality. Therefore, it is extremely important to have samples (soil and water) analyzed regularly by an agricultural soil and water laboratory to develop comprehensive management plans that address specific needs of the individual site. *No single management program will be appropriate across the board for any two effluent users because of varying soil and water chemistry.*

Water quality should be tested for the chemical characteristics noted in Tables 1 and 2. Guidelines in these tables apply to effluent water as well as other water sources and are useful for predicting the potential for problems to arise with longtime use of a water source. Also, in Tables 1 and 2 are average water quality values and nutrient contents of effluent sources in California presented as examples of typical reclaimed water. Since effluent water quality may vary over time, recommended maximum contractual limits can be used to prevent the water quality from exceeding reasonable limits (Stowell, 1999).

• *Total Salinity* — The first concern when examining effluent water quality is to evaluate the salinity hazard. This will normally be reported as EC_w (electrical conductivity of water) or TDS (total dissolved salts). EC_w is reported in decisiemens per meter (dSm^{-1}) and TDS is reported in parts per million (ppm). For conversion purposes, 1.0 dSm^{-1} EC_w = 640 ppm TDS. A guide for evaluating the salinity hazard of an irrigation source is found in Table 1.

Buildup of total soluble salts (Na^+, Cl^-, SO_4^{-2}, K^+, Ca^{+2}, Mg^{+2}) in the rootzone: a) Inhibits turfgrass water uptake, thereby contributing to moisture stress. In severe cases, turfgrasses can exhibit drought stress symptoms while the soil still appears moist. b) Causes turfgrasses to lose color and fail to respond to nutrient applications (i.e., yellowing, browning, or purpling — varies with species). c) Increases the opportunity for direct salt toxicity to root tissues by excess levels of Na, Cl, or B. And d) enhances the potential for excessive uptake of salts into shoot tissues where leaf firing and tissue injury can occur. The latter two stresses are especially prevalent on sensitive trees/shrubs/flowers in the landscape and on salt-sensitive grasses.

Table 1
Guidelines for irrigation water quality: total salinity, Na permeability hazard, and ion toxicity problems. Also, average effluent water quality reported by Stowell (1999) and Asano et al. (1985).

Chemical Characteristics	Degree of Restriction on Use: None	Degree of Restriction on Use: Slight to Moderate	Degree of Restriction on Use: Severe	Average Effluent: Stowell, Calif.[c]	Average Effluent: Asano et al., Calif.[d]
General Water Characteristics					
• pH	---------- NA ----------			7.1	7.0
• Hardness (grains per gallon)	0-200	200-300	>300	—	220
• Bicarbonate (HCO_3)(mgL^{-1})	Depends on RSC Value			194	151
• Carbonate (CO_3)(mgL^{-1})	Depends on RSC Value			0	0
Total Salinity (Impact on Plant Growth)					
• EC_W(dSm^{-1}) (electrical conductivity)	<0.7	0.7-3.0	>3.0	1.1	2.0
• TDS (mgL^{-1})(mgL^{-1})[a] (total dissolved salts) (total soluble salts)	<450	450-2000	>2000	729	1266
Sodium Hazard (Na Permeability Hazard)					
• SAR_W or adj. SAR_W (meq L^{-1}) (sodium absorption ratio)				3.1	4.8
2:1 clay type	<6	6-9	>9		
1:1 clay type	<16	16-24	>24		
sand, EC_W > 1.5 dSm^{-1}	<16	16-24	>24		
sand, EC_W < 1.5 dSm^{-1}	<6	6-9	>9		
• SAR_W and EC_W Relationship on Water Infiltration into Soil					
SAR_W=0-3 and EC_W=	>0.7	0.7-0.2	<0.2		
SAR_W=3-6 and EC_W=	>1.2	1.2-0.3	<0.3		
SAR_W=6-12 and EC_W=	>1.9	1.9-0.5	<0.5		
SAR_W=12-20 and EC_W=	>2.9	2.9-1.3	<1.3		
SAR_W=20-40 and EC_W=	>5.0	5.0-2.9	<2.9		
• RSC (meq L^{-1}) (residual sodium carbonate)	<0	0 to 2.5	>2.5	-2.3	-1.8
Ion Toxicity (Soil Accumulation and Root Toxicity) (Sensitive Plants)[b]					
• Na (mg L^{-1})	0-70	70-210	>210	114	164
• Cl (mg L^{-1})	0-70	70-355	>355	130	147
• B (mg L^{-1})	<0.7	0.7-3.0	>3.0	.44	.90
Ion Toxicity (Foliage Contact) (Sensitive Plants)[b]					
• Na (mg L^{-1})	0-7	>70		114	164
• Cl (mg L^{-1})	0.100	>100		130	147
• HCO_3 (mg L^{-1}) (no direct toxicity, unsightly foliage deposit)	0-90	90-500	>500	194	151

Source: Westcott and Ayers (1985) and Eaton (1950)

[a]1 mg L^{-1} = 1 ppm

[b]Sensitive trees and shrubs. Turgrasses can tolerate levels above those noted for trees and shrubs.

[c]Stowell (1999). Average of effluent water used on six golf courses in Southern California.

[d]Asano et al. (1985). Average of water quality from six water treatment plants (advanced treatment) in California.

Juvenile plants are more sensitive to salt injury than mature grasses, and a high salt content effluent can reduce establishment and survival rates of seedlings or sprigs. As an example, in regions where winter overseeding is practiced, increasing overseeding rates by 10-20% may be necessary to produce an acceptable quality turf when irrigating with salt-laden effluent water, as well as applying extra irrigation water for leaching of surface rootzone salts prior to and after seeding.

Practical experience has shown that established creeping bentgrass / *Poa annua* mixture greens can become difficult to manage when EC_W approaches 1.5 to 2.0 dSm^{-1} (soil ECe > 3.0 dSm^{-1}), while bermudagrass greens begin showing reduction in quality at higher salt contents, closer to the range of EC_W 4 to 15 (ECe 6 to 20 dSm^{-1}). A pure stand of creeping bentgrass falls somewhere between these ranges, with an exception being Seaside and some other cultivars (Table 4) that have been reported to tolerate an EC_W of 6.0 dSm^{-1} while being maintained at 3⁄16-inch mowing height. The actual point where turf decline begins is dependent on many factors such as: degree of leaching, physical soil properties, surface drainage, air and soil temperatures, humidity, irrigation system efficiency, specific management programs, and the skills of the turf manager.

Cool-season grasses are most susceptible to salinity stress in mid to late summer as they become weakened by high temperatures, especially when maintained at close mowing heights. Application of sufficient leaching water volume to prevent accumulation of soluble salts in the rootzone can allow grasses to grow well up to their threshold ECe levels or even somewhat above, but without leaching soil EC (ECe) soon increases to above the effluent EC_W level and salinity stress escalates. A delay in exercising this management strategy can result in salinity-induced root and shoot dessication with a rapid deterioration of turf quality.

• *Sodium Permeability Hazard* — The next great concern of effluent

Table 2
Guidelines for nutrients contained in irrigation water and quantities that may be applied per foot of irrigation water. Also, average effluent water quality reported by Stowell (1999) and Asano et al. (1985).

	Nutrient Content in Water in mg L^{-1} (or ppm)					Average Effluent	
Nutrient or Element	**Low**	**Normal**	**High**	**Very High**	**Conversion to lbs. per 1,000 sq. ft. of nutrient added for every 12" of irrigation water applied**	**Stowell, Calif.[c]**	**Asano et al., Calif.[d]**
N	<1.1	1.1-11.3	11.3-22.6	>22.6	11.3 ppm N = 0.71 lb. N per 1,000 sq. ft.	—	1.4
NO_3^-	<5	5-50	50-100	>100	50 ppm NO_3^- = 0.71 lb. N per 1,000 sq. ft.	—	6
P	<0.1	0.1-0.4	0.4-0.8	>0.8	0.4 ppm P = 0.057 lb. P_2O_5 per 1,000 sq. ft.	—	8
PO_4^-	<0.30	0.30-1.21	1.21-2.42	>2.42	1.21 ppm PO_4^- = 0.057 lb. P_2O_5 per 1,000 sq. ft.	—	24
P_2O_5	<0.23	0.23-0.92	0.92-1.83	>1.83	0.92 ppm P_2O_5 = 0.057 lb. P_2O_5 per 1,000 sq. ft.	—	18
K^4	<5	5-20	20-30	>30	20 ppm K = 1.5 lb. K_2O per 1,000 sq. ft.	26	15
K_2O	<6	6-24	24-36	>36	24 ppm K_2O = 1.5 lb. K_2O per 1,000 sq. ft.	31	18
Ca^{+2}	<20	20-60	60-80	>80	60 ppm Ca = 3.75 lb. Ca per 1,000 sq. ft.	64	59
Mg^{+2}	<10	10-25	25-35	>35	25 ppm Mg = 1.56 lb. Mg per 1,000 sq. ft.	23	16
S	<10	10-30	30-60	>60	30 ppm S = 1.87 lb. S per 1,000 sq. ft.	65	59
SO_4^{-2}	<30	30-90	90-180	>180	90 ppm SO_4^- = 1.87 lb. S per 1,000 sq. ft.	196	180
Mn	—	—	>0.2[b]	—		0.03	—
Fe	—	—	>5.0[a]	—		0.20	—
Cu	—	—	>0.2[a]	—		0.03	—
Zn	—	—	>2.0[a]	—		0.08	—
Mo	—	—	>0.01[b]	—		—	—
Ni	—	—	>0.2[a]	—		—	—

[a]These values are based on potential toxicity problems that may *arise over long-term use* of the irrigation water, especially for sensitive plants in the landscape — turfgrasses can often tolerate higher levels. For fertilization, higher rates than these can be applied as foliar treatment without problems.

[b]Based on Westcott and Ayers (1985) and Harvandi (1994).

[c]Stowell (1999). Average of effluent water used on six golf courses in Southern California.

[d]Asano et al. (1985). Average of water quality from six water treatment plants (advanced treatment) in California.

quality is the influence of sodium on soil structure. On fine-textured soils, Na causes structural deterioration, which reduces water infiltration/percolation/drainage and often causes low soil O_2 problems. While sand soils do not have structural aggregates to be broken down by the dispersive action of excess Na, any colloidal-size particles (colloidal clay or organic matter) in the sand profile are more likely to migrate downward and form a layer. In arid regions during prolonged dry periods, routine irrigation applications often cause particles to move to the depth of irrigation water penetration in sand mixes since Na keeps colloidal particles dispersed and more prone to migrate and eventually accumulate as a layer in the soil. Over time, this can lead to a less permeable zone and reduced water percolation, enhance the potential for a perched water table above this zone, and lead to black layer formation in response to low soil aeration. Poor soil water permeability that is induced by excess Na is especially serious if the effluent also contains appreciable salts since salt leaching is restricted.

Irrigation water is assessed for the potential to cause Na-induced water permeability problems by the use of: a) SAR_W-sodium adsorption ratio of

water, b) adjusted SAR_W — the SAR_W adjusted for the influence of HCO_3 (bicarbonate) and CO_3 (carbonate) on precipitation of Ca and Mg from the irrigation water and soil solution, thereby allowing Na to be dominate, and/or c) the RSC (residual sodium carbonate) value which uses Ca, Mg, HCO_3, and CO_3 concentrations. Carrow et al. (1999) or Carrow and Duncan (1998) have more detailed explanations for these parameters, but basic guidelines are presented in Table 1.

SAR_W is preferred for assessing the Na-induced permeability hazard when HCO_3 is <120 mg L^{-1} and CO_3^{-2} is <15 mg L^{-1}. Above these levels, adj. SAR_W and RSC values should be used since these include the influence of HCO_3, CO_3, Ca, and Mg or Na activity.

A note of caution: There are currently two methods used by laboratories to calculate adj. SAR. The first method was originally presented in the 1976 edition of Ayers and Wescot *Water Quality for Agriculture* and uses the formula Adjusted SAR = SAR (9.4 - pHc). This formula, according to the 1985 edition of the same publica-

Water is a valuable resource treated like gold in arid regions.

tion, is no longer preferred as it tends to over-predict the sodium hazard.

The currently recommended method of determining adjusted SAR uses the unadjusted SAR formula with a substituted value for calcium derived from a table where the ratios of calcium, carbonates, and bicarbonates are compared to the water EC_W. For more in-depth information regarding current methods for calculating adjusted SAR, refer to Hanson et al. (1999).

Sodium permeability hazard of effluent water is affected not only by the SAR_W (or adj. SAR_W) but also by a) EC_W or total salt content of the water. High EC_W or total salt concentration in the water inhibits the dispersing influence of Na. Thus, SAR_W and EC_W should be assessed together (Table 1), and b) soil type. Expanding clays (2:1 clays which exhibit cracking on drying), such as montmorillonite and illite, are much more susceptible to structural breakdown (at adj. SAR_W as low as 6) than are 1:1 clays (kaolinite, Fe/Al oxides which do not crack when drying) that can tolerate adj. SAR < 16 (Table 1). Particle migration by Na action can occur in sands at adj. SAR_W of near 6 when the effluent EC_W is < 1.5 dSm^{-1}. But, if the effluent contains appreciable salts (EC_W > 1.5 dSm^{-1}), migration may not occur until adj. SAR_W nears 16. Particle migration on sands as affected by Na is most likely to occur during grow-in when both water percolation rates and water application rates are high.

Infiltration and permeability problems can develop if the SAR or adjusted SAR is high. Gypsum, acid, or other soil/water treatments may be appropriate. For a more in-depth discussion of this subject, please refer to a previously published *Green Section Record* article titled "Treating the Cause, Not the Symptoms" by Carrow et al. (1999).

• *Specific Ion Problems* — Several specific salt ions contained in effluent may cause problems such as direct toxicities to root or shoot tissues or nutrient imbalances. These include:

1. *Bicarbonates and Carbonates.* High bicarbonates are relatively common in reclaimed water (Table 1). While HCO_3^- > 500 ppm can cause unsightly, but not harmful, deposits on foliage of plants, HCO_3^- or CO_3^{-2} levels that result in turf nutritional problems are not specific. Instead it is the imbalance of HCO_3^- and CO_3^{-2} with Na^+, Ca^{+2}, and Mg^{+2} that is most important. When $HCO_3^- + CO_3^{-2}$ levels exceed $Ca^{+2} + Mg^{+2}$ levels (in meq L^{-1}), the Ca^{+2} and Mg^{+2} are precipitated as insoluble lime in the soil and as scale in irrigation lines. Two problems can arise from excess lime precipitation (Carrow et al., 1999):

• If Na^+ is moderately high (> 150 ppm), removal of soluble Ca and Mg by precipitation into the relatively insoluble carbonate forms will leave Na^+ to dominate the soil CEC sites and potentially create a sodic (soil structural deterioration) condition. As noted in the previous section, HCO_3 at > 120 mgL^{-1} or CO_3 > 15 mgL^{-1} in conjuction with at least moderate Na levels are a potential cause for concern. The degree of Na permeability hazard can be determined by adj. SAR_W RSC values along with consideration of soil type and EC_W. High Na^+ on the CEC sites also will depress plant availability of Mg, K, and Ca. Acidification of irrigation water is the normal management option for this situation.

• On sandy soils, the precipitated calcite (lime) may start to seal some of the macropores and reduce water infiltration. With light, frequent irrigation, the surface may be the site of sealing. Under heavier, less frequent irrigation, a calcite layer may form deeper in the profile at the normal depth of irrigation water penetration. This problem is only somewhat serious under the combination of high HCO_3/CO_3 + high Ca and Mg + arid climate + sandy soil profile (Carrow et al., 1999). The sealing can be broken up by a combination of cultivation (aeration) and use of acidic fertilizers or elemental S. Since it is confined primarily to greens, acidifying the effluent water for a whole golf course would be an expensive option. In contrast, when high Na^+ is present and is a problem on all areas and soil types, irrigation water acidification is more feasible and beneficial. The RSC (residual sodium carbonate) value is used to determine the potential for this problem where RSC = $(HCO_3 + CO_3)$ - (Ca + Mg), in meq L^{-1} (Table 1).

2. *Toxicities from Excess Na, Cl, B.* While the guidelines for root toxicities or soil accumulation of these ions in Table 1 are most appropriate for sensitive trees and shrubs, excessive levels can cause turfgrass root deterioration, but usually at higher levels than noted in the table. *Excess Na^+* can displace Ca^{+2} in the cell walls and cell membranes of root tissues and cause root deterioration. As excess Na^+ displaces Ca^{+2} in root cell walls and membranes, these cells often start to leak their contents. Potassium can be lost by root cell leakage. Turfgrasses with low to moderate total salinity tolerance often are susceptible to this type of root injury, which then results in roots that are less efficient for nutrient and water uptake. Calcium in a relatively soluble form (not lime) in the root zone corrects this type of Na toxicity (i.e., in reality, a Ca^{+2} deficiency in the root tissues), especially when leaching removes the excess Na. Foliar application of Ca is not effective for Na-induced root toxicities since Ca is the least mobile nutrient and is not translocated from shoot to root tissues. However, grasses irrigated with effluent water containing high Na (>200 mg L^{-1}) but low Ca (<20 mg L^{-1}) may benefit from foliar Ca to limit Na replacement for Ca in shoot cell wall surfaces. This should be done on a limited trial basis to determine whether any visible response occurs, since this type of shoot injury on turfgrasses has not been documented.

High Cl does not cause direct turfgrass root tissue injury except at very high levels that are well above the guidelines in Table 1 for more sensitive plants. Instead, Cl inhibits water uptake as a salt and, thereby, nutrient uptake. Mowing of turf normally limits shoot injury from Cl accumulation in leaves by removal of the leaf tips.

Treatment of reclaimed water may leave excess residual chlorine (which is Cl_2), a highly reactive form. At greater than 1 mg L^{-1} residual chlorine, foliage damage can occur. After a few hours in a holding pond, Cl_2 dissipates into the air. Residual chlorine is normally listed as a separate item on a reclaimed water quality test since it is not the same as Cl^- ions.

Boron (B) toxicities can be a problem on turfgrasses, especially in arid regions. Injury is expressed as a leaf tip and margin chlorosis. Mowing of turfgrasses aids in reducing B accumulation in shoot tissues but at B soil levels > 6.0 mg kg^{-1} (saturated soil paste extract), injury may occur. Kentucky bluegrass is most sensitive at > 2.0 mg kg^{-1}. Irrigation water containing > 3.0 mg L^{-1} of B may result in soil accumulation. Except on acid sands, leaching of B is difficult and requires approximately three times the amount of water to leach this element than would be needed to remove an equivalent quantity of Cl or total salts (Ayers and Westcott, 1985).

• *Total Suspended Solids (TSS)* — Suspended solids (colloidal clay or organic particles) and dissolved organic matter are found in lower-quality effluent waters not receiving filtration. Some of these organic materials are humic substances such as fulvic acids and humic acids that have been observed to show both soil aggregating and anti-aggregating qualities. In addition to humic substances, dissolved organic matter also may contain hydrophilic substances such as proteins, polysaccharides, and other compounds (Levy et al., 1999). Irrigation with low-quality effluent waters high in organic matter load often results in a significant decrease of infiltration (hydraulic conductivity) by blocking water-conducting pores. The total effect on hydraulic conductivity is controlled by the quantity of organic matter and particle sizes of the suspended inorganic or organic solids. Unfortunately, no specific guidelines have been published for predicting the TSS hazard.

• *Nutrient Considerations* — In addition to the chemical characteristics in Table 1, a number of nutrients may be present in reclaimed water that can affect turfgrasses and landscape plants (King et al., 2000) (Table 2). The quantities of these nutrients have a major influence on environmental concerns and on turfgrass fertilization programs. Important considerations with respect to the macronutrients (N, P, K, Ca, Mg, S) and micronutrients (Fe, Mn, Ca, Zn, Mo, Ni, B) are found in Table 2.

Nitrogen, phosphorus, potassium, and various secondary and micronutrients are often contained in effluent. Like the salt content, the types and quantities of these nutrients will vary depending on the prior use of the water and level of reclamation treatment. What is most important is to monitor and track seasonal variations through regularly scheduled soil and water analyses and make adjustments in fertility programs accordingly. Specific nutrients are addressed in the following sections.

1. *Nitrogen*. The quantity of N added over time in the irrigation source will directly contribute to the nutritional needs of turfgrass and other landscape plants receiving irrigation. Thus, supplemental N-fertilization must be adjusted accordingly and turfgrasses should be used that can tolerate the N level applied. Some turfgrasses deteriorate rapidly when over-fertilized with N, especially those with low N requirements such as red fescues and centipedegrass. On golf greens, high N in the water may produce more growth than desired (expressed as excess clippings, scalping, slower putting speeds, thatch accumulation, greater succulence, and reduced hardiness), especially if the total annual N exceeds 4 to 6 lbs. N per 1,000 sq. ft. (*Poa annua* or creeping bentgrass) or 8 to 12 lbs. N per 1,000 sq. ft. (bermudagrass). Cool-season grasses receiving excess N during hot, dry summers are especially likely to deteriorate from over-fertilization. If irrigation water containing even 1.1 ppm N is stored in ponds, algae and aquatic plant growth may flourish. Barley straw is an effective management option (Gaussoin, 1999) to tie up NO_3^- in these water features and to reduce algae growth.

Effluent sources can pose a unique situation regarding N since a majority of this element is taken up by plants in the nitrate (NO_3^-) form. Total N loading

Table 3
Nitrification at various soil temperatures
(adapted from Western Fertilizer Handbook, 7th edition)

Soil Temperature	Time (Weeks)	Percent Nitrification[a]
75° F	2	100%
52° F	12	100%
47° F	12	77%
42° F	12	35%
37° F	12	5%

[a]Nitrification: conversion of ammonia - N to NO_3^- - N (nitrate) by nitrifying soil bacteria

in the soil is a possibility, especially when irrigation applications containing high amounts of organic and/or ammonium nitrogen are made during cool soil temperatures. A flush of growth can result after a rapid increase in soil temperature, such as after a warm spring rain. The conversion of ammonium and organic N to nitrate is shown in Table 3 based on time and temperature. Additionally, since N content within effluent water cannot be controlled, the possibility of developing excessive growth and disease problems can increase during weather conditions where the superintendent would normally withhold fertilizer. The severity of this problem will depend on the seasonal quantity of N contained in the water.

2. *Phosphorus*. The limits on P in irrigation water are lower than other macronutrients because P is a limiting factor for algae and aquatic plants. Excessive P that reaches ponds, lakes, or streams can markedly increase growth of these problem plants. Thus, turfgrasses can easily tolerate annual P additions up to 2.0 lb. P_2O_5 per 1,000 sq. ft. from irrigation water, but aquatic plants would be greatly stimulated if this P-laden water reached streams or ponds. The combination of high N plus P would also be most detrimental in causing eutrophication (lack of dissolved O_2 in water). If steps are taken to prevent lake or stream water contamination by P from effluent irrigation sources, higher P levels can be tolerated. But if soil levels of P build up over time, P may reach waterways through leaching or runoff events. Buffer strips may be needed for transitioning into environmentally sensitive areas.

3. *Potassium*. Since recreational sites require ample K, any K in irrigation water is often viewed as beneficial. If K is high in reclaimed water, adequate Ca and Mg are normally available to prevent any nutrient imbalances, but excess K will contribute to overall total salinity. Effluent water high in total salts or Na require more leaching of the root zone mix, which can easily leach K from the soil and require supplemental K fertilization.

4. *Calcium*. Potential problems from high Ca were addressed in the section on "Bicarbonates and Carbonates." Turfgrass managers should be aware of the total Ca added by the water source since reclaimed water and even rainwater (1 to 8 ppm Ca) contain Ca. As noted in Table 2, effluent water with 60 ppm Ca would add 3.75 lb. Ca per 1,000 sq. ft per 12 inches irrigation water (equivalent to 16 lbs. $CaCO_3$). Thus, rainwater at 8 ppm Ca would add 0.50 lb. Ca per 1,000 sq. ft. (2.2 lb. $CaCO_3$ equivalent) per 12 inches rain. Some consultants have recommended foliar Ca or granular Ca fertilization to most turf sites in recent years. This is a questionable practice unless:

- Very high soil Na^+ (sodic soil) or Al^{+3} [excessively acid (pH < 4.8)] conditions exist. In both cases, these ions can replace Ca^{+2} from root tissues and soil CEC sites to the point where Ca^{+2} deficiency in the *root* tissues causes root deterioration. Even under these conditions, shoot tissue Ca deficiency symptoms have not been documented on turfgrass, and soil application of Ca is required — not a foliar Ca treatment since Ca does not translocate to the roots.
- As noted earlier, effluent with high Na (> 200 mg L^{-1}) and low Ca (< 20 mg L^{-1}) may reduce Ca in shoot tissues (this has not been determined on turf). Foliar Ca additions may be beneficial in this instance.
- Unusually high Mg additions may require Ca fertilization if a Ca source is not already required to control excess Na problems. However, the primary response from adding Ca is improved soil physical properties since Ca is a better soil colloid aggregating agent than Mg. Brackish or seawater can be high in Mg.
- Low pH (< 6.0) soils benefit from lime amendments to adjust pH to within pH 6.0-7.5 for better availability of nutrients in general, but Ca levels are still adequate for turfgrass nutrient needs even at very low pHs until the point of Al^{+3} toxicity arises. Plants do not require more than 2 to 6 lbs. of Ca per 1,000 sq. ft. to meet all nutritional needs. However, on acidic soils with pH < 5.5, a rapid greening response after lime or gypsum application is not unusual. This response is due to creating more favorable conditions for *Nitrosomonas* and *Nitrobacter* stimulation, which transform NH_4^+ into NO_3^-. Many grasses prefer NO_3^- and respond to enhanced NO_3^- availability (i.e., greening response). These soil bacteria activities are limited at low pH, primarily because of low Ca and not because of low pH or H^+ toxicity.

Problems that may occur from applying Ca when not required include a) the potential to enhance Mg or K deficiencies (two nutrients that can be deficient in turfgrasses), and b) causing confusion by emphasizing a problem that does not exist except in special cases. Ethical and economic issues may arise when recommending a nutrient amendment that is often added normally by irrigation sources in abundant quantity.

5. *Magnesium*. Most often Mg is present in effluent water at lower levels than Ca. Sometimes, however, Mg content will be relatively high, which can reduce Ca^{+2} on CEC sites and restrict K availability. In these cases (and when using seawater or brackish water), supplemental Ca may be needed to maintain adequate Ca for soil physical conditions and to counter Na^+ toxicities. Also, supplemental K will be necessary to maintain ample K nutrition.

More often than excess Mg, low Mg content in irrigation water or low Mg caused by the addition of high-Ca applications using irrigation water that has too much Na are problems. Another problem of increasing frequency is Mg deficiency induced by application of unneeded Ca on sandy sites. As with Ca, knowledge about Mg content and rates applied in the irrigation water are very useful in avoiding deficiencies or excessive Mg problems (Table 2).

6. *Sulfur.* Normally 2 or 3 lbs. S per 1,000 sq. ft per year is sufficient for turfgrass nutritional needs, and this amount is often provided by SO_4^{-2} content in water or with N, K, or Ca fertilizers. It is not unusual for SO_4^- content in reclaimed water to be 100 to 200 ppm. Irrigation water at 200 ppm SO_4^{-2} would supply 4.2 lbs. S per 1,000 sq. ft. per 12 inches water.

The primary problem of high SO_4^{-2} additions onto turfgrass sites occurs under anaerobic conditions, which transform SO_4^{-2} into reduced S. Reduced S can react with reduced forms of Fe and Mn to create FeS and MnS compounds in the soil that are contributors to black layer and result in further anaerobic conditions and sealing of soil pores. Thus, a high S level is normally not the initial cause of an anaerobic condition, but it will greatly amplify the condition and require a more aggressive cultivation program.

When SO_4^{-2} content is above desirable levels in irrigation water, the application of lime to the soil at low rates can "scrub" SO_4^{-2} from the system. As SO_4^{-2} reacts with Ca from the lime, gypsum ($CaSO_4$) is formed. In this form, S is much less soluble and is protected from becoming reduced. Application of 10 lbs. $CaCO_3$ per 1,000 sq. ft. provides about 3.8 lbs. Ca that can react with 9.1 lbs. SO_4^{-2}, which is equivalent to 3 lbs. S per 1,000 sq. ft. Thus, for every 3 lbs. elemental S (or the equivalent rate of 9.1 lbs. SO_4^{-2}) added with irrigation water, 3.8 lbs. Ca will remove the S through the process of gypsum formation. The Ca can come from the irrigation water itself, but if this is not sufficient, lime can be added to the soil surface to remove the remaining SO_4^{-2}.

7. *Iron (Fe).* The 5.0 mg L^{-1} guideline in Table 2 for Fe in irrigation water is not related to any potential toxic level but to continuous use that could cause a) precipitation of P and molybdenum (Mo) and contribute to deficiency problems for turfgrasses (P) or landscape plants (P or Mo), b) staining on plants, sidewalks, buildings, and equipment, c) potential plugging of irrigation pipes by anaerobic Fe sludge deposits, which can be a problem at > 1.5 mg L^{-1} Fe, and d) high continuous rates of Fe that may induce Mn deficiency or much less likely Zn and Cu deficiencies. On heavily leached sands, where Mn content is often low, this may become a problem. At 5.0 mg L^{-1} Fe, 12 inches of irrigation water would add 0.31 lb. Fe per 1,000 sq. ft., while a typical foliar application is 0.025 lb. Fe

A predominately Poa annua *putting surface shows typical signs of salt-related stress such as yellowing, thinning, and more vigorous growth within aerification holes.*

per 1,000 sq. ft. but in only 3 to 4 gal. water per 1,000 sq. ft. In most instances, Fe concentrations are low and turfgrasses will respond to foliar Fe. When total salinity is high, Fe plus a cytokinin as a foliar treatment is often beneficial, since salt-stressed plants exhibit low cytokinin activity. Increased cytokinin concentration can enhance root production in salt-stressed turf plants with low to moderate levels of salt tolerance.

In those rare cases where Fe is high enough in combination with sulfides to cause plugging of irrigation pipes and anaerobic sludge/iron bacterial slime deposits, iron should be oxidized to an insoluble form, precipitated and filtered before entering the irrigation system. Chlorinate to a residual of 1 mg/L chlorine, or mechanically aerate in an open pond to cause precipitation prior to filtration (Ayers and Westcott, 1985).

8. *Manganese (Mn).* Manganese can become toxic to roots of many plants. So use of water high in Mn (0.20 mg L^{-1}) can contribute to this problem, especially on poorly drained, acidic soils. Acidic, anaerobic conditions transform soil Mn into more soluble (i.e., toxic) forms. If effluent water is high in Mn, liming soil to pH 6.0 to 7.5 and providing good drainage greatly reduces the potential for Mn toxicities. At > 1.5 mg L^{-1} Mn in irrigation water, Mn can contribute to sludge formation within irrigation lines. Also, high Mn may inhibit Fe uptake and promote Fe deficiency. Supplemental foliar Fe would prevent this problem.

9. *Copper (Cu), Zinc (Zn), Nickel (Ni).* The irrigation water levels in Table 2 are based on potential to develop toxicities on sensitive landscape plants over time. Turfgrasses can tolerate relatively high rates due to mowing of leaf tips where these elements tend to accumulate. Unusually high Cu and Zn could inhibit Fe or Mn uptake and thereby induce deficiencies of these nutrients, even on grasses.

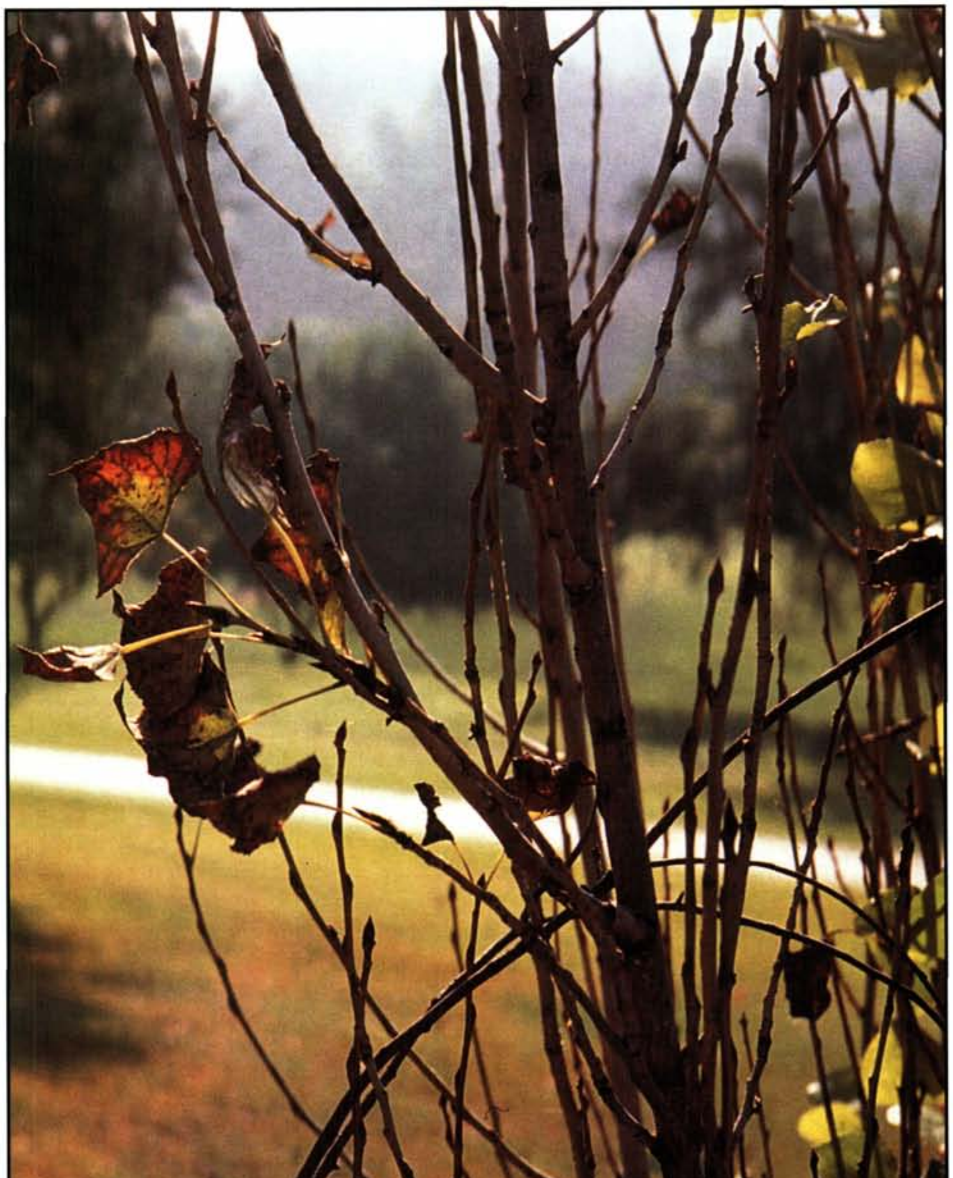
10. *Molybdenum (Mo).* Molybdenum toxicity would be very unlikely in turf plants, but livestock feeding on grasses high in Mo can be affected. Mo deficiency can occasionally occur on low-pH sites.

11. *Other Trace Elements.* Reclaimed water may contain excessive levels of some elements. These are reported by Westcott and Ayers (1985) and Snow (1994). These elements would not directly influence turfgrass nutrition, but they would be of concern for toxicities on some landscape plants. Little is known regarding heavy metals effects on turf; however, because of the risk to human health, vegetable or herb gardens used by club restaurants should be protected from receiving any effluent spray or irrigation. Local regulations may require a minimum setback or buffer area irrigated by potable water in these cases.

12. *Water pH.* The water pH can alter soil surface pH and thatch pH over time. Soil nutrients are most plant available at soil pH 6.0 to 7.5. However, the chemical constituents that cause irrigation water to exhibit a pH outside of this range are more important than pH by itself.

• *Monitoring* — Monitoring soil salinity accumulation is recommended to establish threshold limits to determine when to leach. It is difficult to recover from salinity damage once turf begins to decline and, therefore, leaching should ideally be performed before damage is visible. This is especially critical during the heat of summer with sensitive cool-season species.

Monitoring can be performed by a) collecting and submitting samples to a soil laboratory, b) visual examination of turfgrass salt stress symptoms, or c) on-site measurements of soil electrical conductivity with a low-cost handheld meter (Stowell, 1999). The on-site method is preferred as it allows immediately available data to the superintendent when determining the need



Leaves of sensitive trees and ornamental species show salt stress symptoms of scorching, discoloration, curling, and burning.

Table 4

Tolerance of turfgrasses to total salts or total salinity. Salinity values are for soil surface conditions (ECe) where ECe is approximately equal to 1 to 1.5X the effluent EC_w under good leaching programs.

Salinity Tolerance Class[a], ECe (dSm^{-1})	Grass
Very Sensitive (<1.5)	Annual bluegrass Colonial bentgrass Rough bluegrass Centipedegrass
Moderately Sensitive (1.6-3.0)	Kentucky bluegrass Most zoysia spp.
Moderately Tolerant (3.1-6.0)	Creeping bentgrass Fine-leaf fescues Bahiagrass Buffalograss Blue grama Annual ryegrass
Tolerant (6.1-10.0)	Seaside bentgrass[b] Common bermudagrass Tall fescue Zoysia matrella (some) Zoysia japonica (some) Perennial ryegrass Kikuyu Wheatgrasses
Very Tolerant (10.1 to 20.0)	Hybrid bermudagrasses (some) St. Augustinegrass Salt grass Alkaligrass (Fults, Salty)
Superior Tolerance (>20.0)	Seashore paspalum (some)

[a]The plant classification values and rankings are based on those traditionally used for all plants (Carrow and Duncan, 1998). The exception is the "Superior Tolerance" class, which is added to classify grasses that are true halophytes with salinity tolerances well above most plants.

[b]Other potential cultivars include Seaside II, SR 1020, and Mariner.

to leach (Vermeulen, 1997). Inspection ports installed into drain outlets of greens allow collecting and sampling drainage leachate for total salt content.

• *Drainage and Leaching.* There was once an old saying that when building a golf course one should use ample amounts of both common sense and drainage. If not much of the first was used, then that much more of the second is required. This statement goes double when using effluent water. Ample water is needed to leach soluble salts. Positive surface drainage is the key to avoiding puddles from forming and hence algae layer problems from developing. Even a properly constructed USGA green will be plagued with these black, leather-like surface layers if there are "birdbaths" in the surface that collect water. Surface, internal (soil), and subsurface drainage are necessities on greens supporting salt-sensitive, closely cut turf. Additional drainage may be required on tees and throughout low-lying areas of fairways, depending on the turf species' salt tolerance and internal drainage characteristics.

• *Cultivation Programs and Leaching* — Poor quality effluent in conjunction with poor internal water drainage and/or heavily thatched turf may require intensive cultivation programs to keep salts moving downward. Aeration frequency should be increased particularly in spring and early summer. Early season coring of greens with hollow tines followed by backfilling with sand topdressing performs a dual function of:

1. Creating additional channels for water to infiltrate when leaching during the summer stress period.

2. Initiate deep root development prior to the onset of summer heat and salt stress.

Spring/early summer also is the time of the season when deep aeration treatments would be preferred for similar reasons. Frequent cultivation, from mid through late summer, with less aggressive techniques like high-pressure water injection, slicing, spiking, star or quad-tines may also be required. This will keep the surfaces open to exchange gases and accept large volumes of water applied to leach. If salts are allowed to accumulate in the surface one or two inches by mid to late summer from light, frequent irrigation, leaching before cultivation may be necessary or the water will flow through the cultivation holes without removing salts between holes. Non-disruptive cultivation also helps manage and avoid black layer development. Light topdressing after cultivation is acceptable, providing the turf is not under heat or salt stress, but it is often avoided if the greens show any amount of stress. Or topdressing can be applied at a light rate a few days before or after cultivation during stress periods.

• *Supplementary/Dual Sprinkler Systems* — Leaching with the stationary in-ground pop-up systems can be performed provided there is good distribution uniformity that promotes uniform leaching, and multiple start times can be scheduled to avoid runoff. Performing a catch-can test to visually examine application uniformity will show coverage deficiencies. Performing the leaching process over two to three evenings also has been reported as more successful than saturating the turf in one night. A targeted ¾ to 1 inch of water is applied each night.

It may be difficult to avoid excessively wet surrounds and greenside bunkers when leaching with stationary full-circle sprinklers. This becomes a more severe problem in coastal areas with low E.T. (evapo-transpiration) rates. Under conditions of poor distribution, poor internal soil drainage, and/or low E.T. rates, many superintendents substitute portable landscape or orchard sprinklers with low-precipitation rates for leaching instead of in-ground systems (Gross, 1999). This allows precise placement of water on the green surface to avoid saturating surrounds and bunkers. The sprinklers are simply turned on after dark and allowed to run until sunrise.

In the most severe cases of poor quality effluent, dual irrigation systems are installed utilizing two mainlines, one supplying potable water exclusively to the greens and another providing effluent to the remainder of the course. This can greatly reduce leaching requirements and putting green salt stress. Finally, it is important to avoid leaching a) immediately following fertilizer application to avoid nutrient/nitrate leaching, and b) when heat and humidity are ideal for disease development. The loss of turf from salt stress is slower than from disease activity; however, salt stressed turf is more susceptible to disease damage.

• *Species Tolerance* — The selection of salt-tolerant trees, shrubs, and turf (Table 4) species during construction will make management much easier. On an established property (retrofit project), this matter can present problems. Sensitive trees, shrubs, and flowers may require replacement. An inter-seeding program for turf areas may be needed to increase tolerant cultivars in the turfgrass sward. Raising cutting heights slightly, although often unpopular with golfers, also can increase salinity tolerance of greens; the old saying "slow grass is better than fast dirt" applies when irrigating greens with effluent water.

Salinity tolerance guidelines in Table 4 are based on soil salinity (ECe). Under good leaching conditions, soil ECe will usually be equal to EC_W or up to 1.5x higher. But without leaching, surface soil ECe can increase dramatically above that of effluent water EC_W. Thus, a creeping bentgrass that can tolerate ECe of 3 dSm^{-1} may do well with effluent up to $EC_W = 3$ dSm^{-1} as long as leaching prevents soil ECe from rising above this value.

Several current projects sponsored by the USGA Green Section research program are investigating salt stress mechanisms and salt tolerance of turfgrass species. In the future these projects will lead to additional cultivars of turfgrasses tolerant of high salts and suitable for golf. Your local Green Section agronomist and university extension turfgrass specialist should be contacted to provide salt-tolerant plant lists and turfgrass recommendations adapted to your climate. Certain cultivars within a species often perform better than others (Table 4).

Regulatory Issues

Note: Regulations regarding effluent water vary considerably between agencies. The following discussions highlight many different regulations but cannot be considered all-inclusive. It is important to contact the appropriate local agency monitoring effluent water use to determine what standards are required for each specific site.

• *Cross Connection* — Human health concerns are the heart of effluent water regulation no matter what agency has developed them. The greatest concern is cross connection; in other words, the accidental contamination of a potable supply with effluent. This could lead to an unknowing person consuming tainted water. There are two primary ways that this could take place.

First would be an accidental direct connection of an effluent pipe to a potable line. To avoid this possibility, most regulatory agencies require new effluent installations to clearly identify any and all lines with either purple colored pipe; burial tape marked "reclaimed, recycled, or effluent water"; or stenciling of pipe at specified distances with the same verbiage. The California-Nevada Section of the AWWA (American Water Works Association) first adopted purple to designate any non-potable water sources. This has since become the recognized standard in most regions of the country.

An annual cross connection inspection of effluent-using sites is usually performed by the regulating agency. This can involve a 24-hour drain-down of the clubhouse potable systems to assure they are not directly connected to the effluent irrigation system.

A second way that effluent could contaminate a drinking source is through back-siphoning into a potable irrigation system. A simultaneous chain of events would have to take place in order for this to occur, but nonetheless it is possible. They include:

1. A pump failure or line break causes a loss of pressure and drainage of the potable supply line, creating a negative pressure (vacuum) at a potable irrigation system's point of connection (POC).
2. A remote control valve for the potable system is open, allowing effluent drainage to siphon backwards into the sprinkler head past the POC and into the potable supply.
3. When the potable system is again pressurized, contaminated water could then be delivered to drinking taps.

To avoid contamination problems, anti-backflow devices, such as an RPPD (reduced pressure principle device), double check valves, or anti-siphon valves are installed at the point of connection between all potable sources and irrigation systems. The RPPD delivers the highest level of anti-siphon protection and is normally required at each potable POC at sites using effluent water. Biannual testing of backflow devices by certified personnel is usually required to maintain effluent irrigation permits.

• *Line Separation* — Regulations vary considerably regarding the separation distance required between potable and effluent delivery lines. Depending on local codes, between 12 inches and 10 feet horizontal and a minimum of 12 inches vertical separation are normally required.

• *Employee Training* — The superintendent is normally responsible for maintaining required records and abiding by all local regulations. All maintenance staff who come in contact with or work around effluent water must also be trained to understand the a) proper procedures used, b) rules and regulations, and c) basic cross connection and backflow principles and procedures applying to effluent water use.

• *Inspections* — Part-circle perimeter sprinkler heads tend to fall out of adjustment over time, and a monthly self-inspection of perimeter sprinklers is required in some jurisdictions to make certain effluent water is not leaving the permitted property. The superintendent must submit a monthly report to the controlling agency. Annual or semiannual walk through site inspections with health department officials and/or water department inspectors also are generally required.

• *Plan Submission* — Copies of blueprints also are requested by some regulatory agencies for their files. This allows the agencies to have a permanent record of any effluent distribution/irrigation lines should public utilities crossing the golf course require repairs, etc.

• *Public Notification* — Signs, tags, and informational messages on irrigation equipment are often required to inform employees, golfers, and the general public that effluent water is used. In most cases there is a minimum wording requirement such as: "Caution — Effluent Irrigation Water, No Swimming — Do Not Drink." Most agencies allow additional wording that conveys a more positive message such as: "In the interest of water conservation this facility irrigates with effluent water. Please do not drink or swim in lakes." In addition to the minimum wording requirements, regulations often dictate a minimum letter size on

Creeping bentgrass is surviving within aerification holes surrounded by a white crust of accumulated salt.

such signs to assure visibility from a reasonable distance.

Areas and components where posting/notification is often required include:

- Lakes
- Control satellites
- Scorecards
- Property perimeters
- Remote-control valves
- Hose bibs
- Quick-coupler valves (also may require locking lids and/or specially threaded keys)
- Delivery pipe (identified by purple color, burial tape, or stenciled identification as specified by regulatory agency)

• *Operational Guidelines* — Most agencies impose strict operational guidelines regarding how and when automatic irrigation may operate. Examples include:

- Unattended automatic irrigation may only operate between 9:00 PM and 6:00 AM.
- Runoff or puddling is not allowed.
- Compliance failures with operational guidelines will result in the termination of service.
- System shutdown required when wind exceeds 15 mph.

Such restrictions can cause operational problems when the need to apply water during the day arises. Touchup irrigation, watering in of chemical or fertilizer applications, and establishment of seed or sprigs require an employee present to observe operating sprinklers and protect unknowing individuals from accidentally coming into contact with effluent. This requires additional labor where in the past an unattended syringe cycle performed the job. Where winter overseeding of bermudagrass is practiced and multiple daytime irrigations are needed, course closure throughout the germination period becomes necessary to promote good seedling establishment and avoid violations.

• *Miscellaneous Requirements* — Other miscellaneous restrictions and monitoring programs have been required to protect adjoining properties, groundwater, etc. Examples include:

- Minimum lake lining thickness of 40 mil.
- Verification of E.T. (evapotranspiration) versus application.
- Setbacks or a buffer zone between effluent use and housing/property lines, edible crops, potable wellheads, freshwater lakes, streams, and rivers. Distances ranging from 50 to 1,000 ft. have been reported.
- Protection of drinking water (coolers, fountains, etc.) on the golf course from over-spray.
- Minimum daily use requirements.

Posting to notify golfers of effluent water use is commonly required. Note that at this site in California all signs must be in both English and Spanish.

• Monitoring systems to observe pH, nitrates, orthophosphate, ammonia-N, coliform bacteria, biological oxygen demand (BOD), turbidity, chlorine residual, other changes in groundwater, freshwater streams, lakes, monitoring wells, etc. (Snow et al., 1994).

Management Costs

Compliance with the various regulatory issues addressed in the previous section often requires additional expenditures beyond that needed for use of potable water. Additional management costs or savings may also arise and these are noted below.

• *Amendment Programs* — Residential water softeners use rock salt (sodium chloride), while public water treatment facilities often use soda ash (sodium carbonate) to reduce calcium and magnesium scaling problems. Both add sodium along with carbonates, bicarbonates, or chloride to the effluent that cannot be removed in the reclamation process. Because of this, many water districts in the Southwest that use reclaimed water for irrigation have banned residential water softener use; however, the effort is somewhat futile when water softener salts can be purchased in local grocery stores. In some locations, the use of KCl in place of NaCl for water softeners is being proposed (Wu et al., 1995). More stringent regulations are needed along with research to evaluate different salts that are less harmful to soil structure and plant growth.

The increased sodium concentration in the water may require adding calcium (gypsum, calcium chloride, etc.) to the soil or water. If carbonates and/or bicarbonates are high, water acidification could be required. These situations all add costs to maintaining the golf course and could be negotiating points when bargaining for effluent water.

• *Equipment Deterioration* — Much like road salt deteriorates automobile bodies in northern climates, effluent water high in salts accelerates the corrosion of many metals. The use of plastics, corrosion-resistant galvanized steel, and stainless steel are recommended along with providing potable water at the equipment wash rack area. The life expectancy of mowing equipment, utility vehicles, metal fencing, irrigation controller cabinets, and course accessories (metal benches, ball washers, trash cans, etc.) all will be reduced from the daily exposure to more saline runoff and guttation water. Maintenance and repair of equipment, especially corrosion-prone electrical safety switches, increase.

• *Retrofit Costs* — Costs for retrofitting hardware when preparing to accept effluent may include: upgrading backflow prevention devices, informational signage, tags to properly identify hose bibs and remote control valves, replacement of quick couplers, etc.

• *Overseeding Costs* — Courses that overseed dormant bermudagrass will be forced to close to perform daytime irrigation at establishment, causing a loss of revenue. Additional seed (10-20%) can be required to provide acceptable turf quality dependent on salinity of the water.

• *Water Savings* — Effluent costs are often reduced (15 percent or more that of potable) and can offset some other costs; however, leaching requirements may raise the annual quantity of water used. This reduced cost trend may also reverse as demands for all water continue to increase and additional uses and demand are created for effluent in the new millennium.

• *Fertilizer Savings* — Some fertilizer savings can be expected with the nutrients added by the effluent. The actual amount will vary at each site and seasonally. It is again recommended to monitor nutrient additions through frequent soil and water analysis.

• *Other Costs* — Often the requirement for backflow device testing increases from one to two times per year. Additional laboratory testing of soil and water should be included in the budget as well as monitoring equipment costs (Stowell, 1999). While effluent water costs are usually 85% or less of potable sources, agreements on long-term prices should be determined to insure a consistent cost savings on the basic water costs. It is the cost savings in the purchase price that will aid in offsetting additional management/ equipment costs that arise from effluent use. Additionally, the contract should include a) definitions of the maximum acceptable water quality limits, b) delivery guarantees with access to potable water during pump or delivery line repair periods, and c) stipulations to avoid the required use of effluent water when irrigation is not needed, such as in rainy periods or dormancy periods (Stowell, 1999). It is unreasonable for a turfgrass facility to be required to take a certain quantity of effluent water when it is not needed. This transfers excess storage and disposal requirements from a government unit to a private user. These issues ultimately become economic costs if they are not dealt with in the contract.

Other Considerations

• *Fertilizer Selection* — Fertilizer selection must be considered when developing programs to manage salinity, especially where sensitive species are grown, and if effluent contains appreciable nutrients. Soluble, quick-release products have much higher salt indexes (burn potential) than slow-release or organic fertilizers (Table 5). Selecting products with a lower salt index during the summer months can help reduce the overall salt load placed on turfgrasses and soils at a time when ET rates are high. Using a "spoon-feeding" approach of low fertilizer rates on a more frequent basis is another approach. If the effluent contains ample levels of a nutrient, fertilization may be omitted for the particular nutrient.

• *Ornamental Lakes and Irrigation Reservoirs* — Effluent presents many lake management challenges as aquatic weeds and algae proliferate in nutrient-rich water. Small ornamental ponds are particularly problematic when water temperatures rise. They become stagnant with strong odors developing as aquatic plants die and consume dissolved oxygen. Little is known about irrigating with water low in dissolved oxygen and its effect on the turfgrass environment. Some suggest that water low in dissolved oxygen may contribute to anaerobic problems developing sooner than normal. Aeration will reduce odors and increase dissolved oxygen, but can also cause foaming, thus becoming an aesthetic problem. Antifoaming agents are usually effective, but they are short lived and therefore expensive.

Chemical controls for algae and aquatic weeds are available but become an ongoing expense. Another potential problem can arise with the continuous application of copper-based products. Over several years, the repeated cycle of aquatic weed and algae blooms followed by copper-based chemical control can develop an organic sludge on the lake bottom; the sludge may accumulate a high copper content, becoming a hazardous waste. Straw bales are an effective biological control of filamentous algae but appear ineffective in managing planktonic varieties (Gaussoin, 1999).

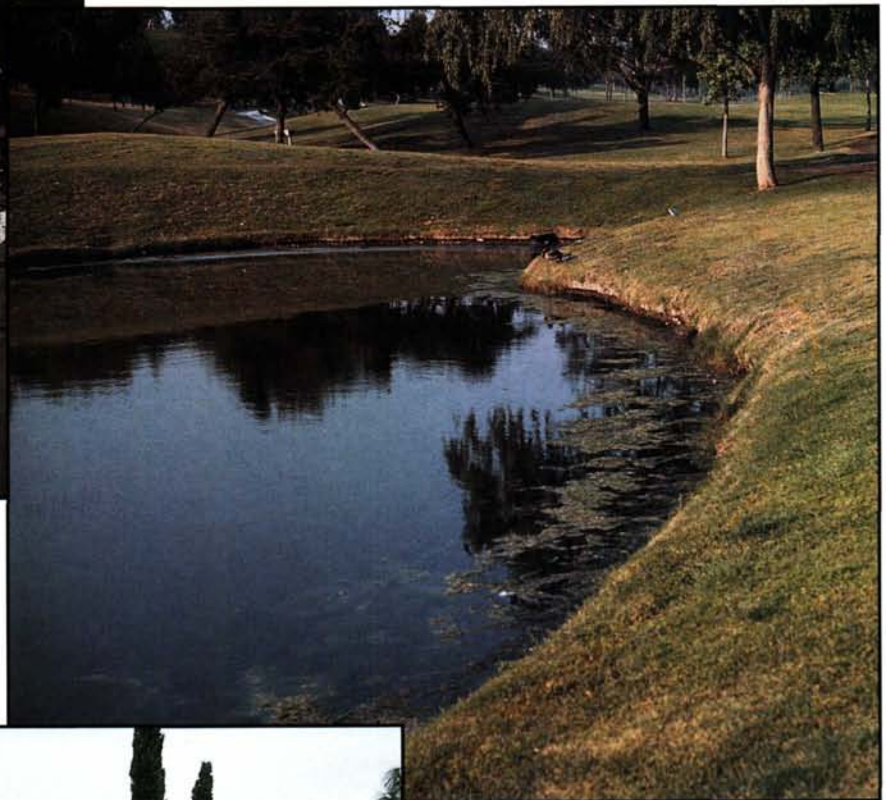
Irrigation reservoirs usually present less of a management problem because of the regular turnover of water. A direct connection of the irrigation system to the effluent supply can eliminate the irrigation reservoir requirement and problems associated with managing lakes; however, there then must be a backup system in place to supply water in the event that the reclamation plant is shut down for emergency service. Limiting the total number of lakes in a new design to only the irrigation reservoir will limit management problems. A well-designed lake system can minimize problems. Points to consider include:

• Size lake to promote rapid turnover of water; the fresher the water, the fewer the problems.

Table 5
Salt Index (relative effect of fertilizer materials on the soil solution). Higher salt index values indicate a greater potential for fertilizer burn or increasing salt load.[a]

Material	Salt Index	Partial Salt Index per Unit of Plant Nutrient
Ammonium Nitrate	104.7	2.99
Ammonium Phosphate (11-48-0)	26.9	2.442
Ammonium Sulfate	69.0	3.253
Calcium Carbonate	4.7	0.083
Calcium Nitrate	52.5	4.409
Calcium Sulfate	8.1	0.247
Diammonium Phosphate	29.9	1.614 (N)
Dolomite (Calcium/Magnesium Carbonate)	0.8	0.042
IBDU[b]	5.0	0.161
Methylene urea (40% N)[d]	24.6	0.61
Milorganite[c]	0.042	0.007
Monoammonium Phosphate	34.2	2.453 (N)
Polymer/Polymer Coated Urea	24.5	0.647
Potassium Chloride 50%	109.4	2.189
Potassium Chloride 60%	116.3	1.936
Potassium Chloride 63%	114.3	1.812
Potassium Nitrate	73.6	5.336 (N)/ 1.580 (K2O)
Potassium Sulfate	46.1	0.853 (K2O)
Sodium Chloride (Water Softener Salts)	153.8	2.899 (Na)
Sulfur Coated Urea (38% N)[d]	24.5	0.647
Sulfate of Potash - Magnesia (Sulpomag)	43.2	1.971 (K2O)
Superphosphate 16%	7.8	0.487
Superphosphate 20%	7.8	0.39
Superphosphate 45%	10.1	0.224
Superphosphate 48%	10.1	0.21
Urea	75.4	1.618
Ureaform (40% N)[d]	6.1	0.163

[a]Adapted from Western Fertilizer Handbook - 7th Edition.
[b]Data provided by ParEx.
[c]Data provided by the Milwaukee Metropolitan Sewerage Company.
[d]Data provided by the Scotts Company.



Lake management is often more difficult with effluent water. Various problems with algae, foaming, and aquatic weeds can develop.

• Line lakes to allow easy maintenance and cleaning following draindown.

• Include electrical service and equipment to aerate and circulate water.

• Provide adequate lake depths (at least > 5 feet) to keep water temperature cooler.

• Position supply inlets and pump outlets at opposite ends of the lake to promote circulation and avoid developing stagnant areas.

• *Climate* — The local climate has a large influence on management. Areas of the country that receive high rainfall may not require regular leaching with the irrigation system unless a drought occurs. Arid regions will require more close management and scheduled leaching events to manage sodium and salinity accumulations.

Summary and Conclusions

Effluent water has both advantages and disadvantages related to regulatory, agronomic, economic, and operational issues. The greatest advantage of effluent is the aspect that the supply should not be interrupted by a drought. The disadvantages vary depending on costs, water quality, and regional/state/local operational restrictions that may be imposed. Summary points to remember include:

• Consider water quality for irrigation suitability (total salinity, Na permeability hazard, specific ion toxicities).

• Consider nutrient content effects on the fertilization program.

• Consider the climate and annual rainfall, especially the potential for prolonged extreme events.

• Provide positive surface drainage (greens, tees, fairways).

• Provide good internal drainage (greens and tees).

• Provide subsurface drainage (greens, tees, fairways).

• Regularly monitor soil and water chemistry (in-house and with laboratories).

• Select salt-tolerant species of turfgrasses, trees, and ornamentals.

• Adjust cultural programs as necessary (mowing heights/frequency, cultivation, etc.).

• Avoid storing excess quantities of effluent in lakes.

• Budget appropriately.

• Comply with local regulations.

The thought of using effluent is most definitely nothing to lose sleep over. Whether effluent water becomes an agronomic nightmare or not will be like many other things in life — it's what you make of it! The problems are manageable if prudent decisions are made during construction and when developing maintenance programs. Success cannot be guaranteed, but with a well-thought-out maintenance plan, the potential for failure should not keep you awake at night, and your dreams of having an adequate irrigation supply during the next drought could come true! You can have high-quality turf using effluent.

References

Ayers, R. S., and D. W. Westcott, 1985. *Water Quality for Agriculture.* FAO Irrigation and Drainage Paper 29, Rev. 1. Food and Agriculture Organization of the United Nations, Rome, Italy.

Bond, W. J. 1998. Effluent irrigation — an environmental challenge for soil science. Aust. J. Soil Res. 36:543-555.

Borchardt, J. 1999. Reclaiming a resource. Golf Course Management, Vol. 67, No. 1, p. 268-272, 276-278.

California Assembly Bill 174 (October) 1991. Water Resources — reclaimed water — nonpotable use. In Statutes of 1991-1992 Regular Session. State of California Legislative Counsel's Digest. Chapter 553. p. 2321-2322.

California Fertilizer Association. 1980. *Western Fertilizer Handbook — 7th Edition.* Interstate Printers & Publishers, Inc., Danville, Ill.

Carrow, R. N., and R. R. Duncan. 1998. *Salt-Affected Turfgrass Sites: Assessment and Treatment.* Ann Arbor Press, Chelsea, Mich.

Carrow, R. N., R. R. Duncan, and M. Huck. 1999. Treating the cause, not the symptoms — irrigation water treatment for better infiltration. USGA Green Section Record 37 (6): 11-15.

Duncan, R. R., and R. N. Carrow. 2000. *Seashore Paspalum: The Environmental Turfgrass.* Ann Arbor Press, Chelsea, Mich.

Feil, K., K. Kubick, R. Waters, R. Wong. 1997. *Guidelines for the On-Site Retrofit of Facilities Using Disinfected Tertiary Recycled Water.* California-Nevada Section American Water Works Association, Ontario, Calif.

Gaussoin, R. 1999. Algae control in ponds with barley bales: on-site results in Nebraska. Center for Grassland Studies 5 (2):3.

GCSAA. 1993. *64th International Golf Course Conference Proceedings.* GCSAA Education Department, Lawrence, Kan.

Ross, P. 1999. Flood your greens — not your bunkers. USGA Green Section Record, Vol. 27, No. 3, p. 26.

Hanson, B., S. R. Grattan, and A. Fulton. 1999. *Agricultural Salinity and Drainage:* Div. of ANR Pub. 3375, University of California, Davis, Calif.

King, K. W., J. C. Balogh, and R. D. Harmel. 2000. Feeding turf with wastewater. Golf Course Management. 68 (1): 59-62.

Levy, G. J., A. Rosenthal, J. Tarchitzky, I. Shaneberg, and Y. Chen. 1999. Soil hydraulic changes caused by irrigation with reclaimed wastewater. Journal of Environmental Quality. 28:1658-1664.

NGF. 1999. *Operating and Financial Performance Data of 18-Hole Golf Facilities.* NGF, Jupiter, Fla.

Pepper, I. L., and C. F. Mancino. 1994. Irrigation of turf with effluent water. *In* M. Pessarakli (ed.) *Handbook of Plant and Crop Stress.* Marcel Dekker, Inc., New York, N.Y.

Snow, J. T. 1979. Questionnaire on recycled water. USGA Green Section Record. Vol. 27, No. 3, p. 13.

Snow, J. T., K. S. Erusha, M. Henry, M. P. Kenna, C. H. Peacock, and J. R. Watson. 1994. *Wastewater Reuse for Golf Course Irrigation.* Lewis Publishers, Boca Raton, Fla.

Stowell, L. 1999. Pointers on reclaimed water contract negotiations — Pace Pointers (June). Web page (www.pace.ptri.-com).

Vermeulen, P. H. 1997. Know when to over-irrigate. USGA Green Section Record. Vol. 35, No. 5, p. 16.

Waddington, D. V., R. N. Carrow, and R. C. Shearman. 1992. *Turfgrass — ASA Monograph #32.* American Society of Agronomy, Madison, Wis.

Westcott, D. W., and R. S. Ayers. 1985. Irrigation water quality. *In* Pettygrove, G. S., and T. Asano (eds.) *Irrigation With Reclaimed Municipal Wastewater — A Guidance Manual.* Lewis Publishers, Boca Raton, Fla.

Wu, L., J. Chen, H. Lin, P. Van Mantgem, M. A. Harivandi, and J. Harding. 1995. Effects of regenerate wastewater irrigation on growth and ion uptake of landscape plants. J. Envir. Hort. 13 (2): 92-96.

Zupancic, J. 1999. Reclaimed water: challenges of irrigation use. Grounds Maintenance, Vol. 34, No. 3, p. 33-85.

MIKE HUCK *is an agronomist with the USGA Green Section Southwest Region. Formerly a golf course superintendent, he managed two facilities irrigated with effluent for more than 10 years and is regarded by his peers as a valuable source of information on the subject.*

DR. ROBERT N. CARROW *(turfgrass stress physiology and soil physical and chemical stresses), and* DR. RON R. DUNCAN *(turfgrass genetics/breeding, stress physiology) are research scientists in the Crop and Soil Science Department, University of Georgia, Georgia Experimental Station at Griffin.*