

Effective Use of Seawater Irrigation on Turfgrass

This article is the second in a three-part series on water quality, the first of which appeared in the November/December 1999 issue.

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THE PROBLEM: Availability of adequate water in terms of quality and quantity will be the number-one issue affecting turfgrass management in the 21st century.

Global demand for fresh potable water is doubling every 20 years. Irrigated areas have increased about 1% per year worldwide during the 1990s. During the past 30 years, the population of the United States has increased 52% while total water use has increased 300%. Renewable water resources per person decreased 50% between 1960 and 1998 in the United States. Another 50% reduction is projected by 2025. By 2000, 20% of all U.S. communities will experience water shortages in the form of water rationing or short-term cutoffs. Competition for potable water will force turfgrass managers to search for alternative water resources — from recycled wastewater to seawater.

Water is available in many different forms. Seawater (34,486 ppm salt) encompasses 96.5% of the total global water supply (Gleick, 1993). Fresh water reserves total 2.5%. Groundwater, which makes up 1.7% of the total global water supply, includes 55% saline and 45% fresh water. A total of 30.1% of fresh water comes from the groundwater.

Lake water reserves (0.013% of total water resources) include 0.006% of total saline and 0.007% of fresh water. Swamp water (0.0008% of total water reserves), river flows (0.0002%), glaciers plus permanent snow cover (1.74%), and ground ice/permafrost (0.022%) account for the remaining global water reserves.

Crop plants normally utilize 40-45% of the water applied through irrigation, with the remaining 55-60% lost as runoff, deep percolation, or evaporation/evapotranspiration. Turfgrasses are probably slightly more efficient in water use than most crop plants due to greater canopy coverage of the soil and their perennial nature.



Water is available in many different forms. The ability to irrigate a golf course with seawater has long been a dream. This dream will soon become a reality as turfgrass-quality ecotypes of seashore paspalum tolerant to ocean-level salt concentrations become commercially available.

The Dilemma

Water quality and availability have a dramatic influence on site-specific turfgrass management strategies, regardless of whether salt-laden effluent (recycled water), ocean water, or blends of the two sources are used as the water source. Saltwater intrusion is a major concern in coastal areas (Newport, 1997; Todd, 1997). Water withdrawal from coastal groundwater can contribute to degradation of water and soil quality. Renewal time for groundwater resources is estimated at 300 years (Gleick, 1993).

Salinization of irrigated land occurs when dissolved salts accumulate in the upper soil layers on naturally saline lands, on lands with poor drainage, in arid/semi-arid regions, or on lands utilizing salt-laden effluent (recycled water). The percentage of irrigated lands affected by salinization includes 20-25% in the United States, 13% in Israel, 30-40% in Egypt, 15% in China, and 15-20% in Australia (Gleick, 1993). The use of highly saline irrigation water greatly enhances the potential to degrade soil by salinization unless definite construction and management prac-

tices are followed. Accumulation of excess total salts (salinization) and sodium (sodic soil formation) in the soil is more rapid as irrigation water quality declines. *The dilemma confronting turfgrass managers is how to effectively use water of poor quality without causing excessive salt problems that will result in substantial decline in turfgrass quality and performance.*

Potential climatic changes will complicate water and salt management. Possible climatic changes projected globally from increasing CO₂ atmospheric levels include:

- 2-5°C increase in temperature;
- 0- to 32-inch increase in sea level;
- Precipitation increase of 7-15%;
- Direct solar radiation change -10% to +10%; 5-10% evapotranspiration increase (Woodward, 1992).

These climatic changes will significantly affect turfgrass management in the 21st century. Because of these changes, most recreational turf will possibly be mandated to be irrigated with nonpotable resources (California Assembly Bill 174, Oct. 1991). Desalination is one option as an alternative water resource, but cost comparisons and the volume of water produced are key considerations (California Coastal Commission, 1999).

Irrigating with Seawater

With the availability of ocean-level, salt-tolerant turf species, using seawater for irrigation becomes a viable option in turfgrass management. The focus of this article is to emphasize those critical issues that arise when this worst-case water option (i.e. seawater) is selected as the irrigation source. The basic principles are applicable to sites using salt-laden effluent.

Irrigating food crops, as well as turfgrass, with seawater requires that a number of basic guidelines be considered (Glenn et al., 1998):

1. Halophyte turfgrasses (salt-tolerant species such as seashore paspalum, saltgrass, or alkaligrass) and landscape plants should be planted.
2. Golf courses should be constructed on sandy, well-drained coastal sites for long-term sustainability.
3. Water should be available at sufficient volumes to leach salts, minimizing the concentration of salts in the rootzone and preventing dry down of the surface caused by evaporation and percolation. High leaching events are critical, and proper irrigation scheduling is essential to success. All irrigated

areas on the golf course, including roughs, surrounds, and mounds must be managed as primary areas.

4. Salts must be removed by drainage systems and be properly disposed of to prevent contamination of any potable groundwater under the site and to prevent soil salinization.

5. The cost of pumping from wells near the ocean is increased due to increasing irrigation demands (for proper leaching). Minimal water lifting is required, which offsets some of those costs.

6. Coastal aquatic sites are impacted (especially saltwater intrusion) and should be carefully monitored.

7. Maintenance costs may be 50% higher than in non-salt affected areas because of continuous application of amendments to minimize salt buildup and corrosion damage to maintenance, irrigation, and other equipment, requiring more frequent replacement.

8. Highly trained turfgrass managers are necessary because of the site-specific complexity of the salt-related problems.

9. Unnecessary traffic on turf should be reduced or eliminated to (a) offset the lack of wear recovery caused by growth reduction resulting from salt stress and (b) avoid compacting saturated soils that are frequently irrigated to field capacity in order to promote leaching.

Pre-Construction Considerations

Grass Selection

As we enter the new millennium and potable water becomes a more scarce resource, continued development of salt-tolerant species (turfgrass, trees, ornamentals, and other landscape plants) will become increasingly important for all recreational landscapes, including golf courses. Research funded by the USGA has resulted in the development of high-quality, environmentally friendly and ocean level salt-tolerant seashore paspalum turfgrasses for use on greens, tees, fairways, and roughs. This grass currently provides a unique opportunity in temperate and tropical climates to utilize alternative water resources for irrigation. Additional research and breeding efforts to improve salt tolerance of cool-season species (some private companies have made this a priority) will extend alternative water use to northern climates.

Irrigation with ocean water (34,486 ppm salt), brackish water (at salt concentrations < 34,000 ppm), seawater

blended with other nonpotable water resources, or salt-laden effluent is now feasible (Duncan and Carrow, 2000). The problem of saltwater intrusion into coastal aquifers that results in unintentional application of seawater onto golf courses, and coastal or low-land saltwater inundation from storm surges/salt deposition now can be addressed with the most salt-tolerant turfgrass (Carrow and Duncan, 1998). These extreme cases of the ultimate poor water quality require serious and diligent pre-construction, establishment, grow-in/post establishment considerations for successful turfgrass management. The site-specific nature of salinity-challenged environments causes the most complex and, often, most confusing situations involved in turfgrass management. Mistakes or omissions become readily apparent and amplified once the grass is planted and the turf responds to its environment.

Growth rates of all turfgrasses, including seashore paspalum, are reduced when exposed to increasing levels of salinity. Older bermudagrass (Tifway) and creeping bentgrass cultivars (Seaside, Seaside II, SR1020, and Mariner are better choices) will tolerate only about one-third ocean level salt, and therefore may be suitable for use with some effluent and/or brackish sources, depending on water quality. However, selected ecotypes of seashore paspalum can tolerate straight ocean water (TDS = 34,486 ppm salt, EC_w = 54 dSm⁻¹, SAR = 57.4 meq L⁻¹, Na = 10,556 ppm, Cl = 18,980 ppm, Mg = 1,304 ppm, Ca = 420 ppm, K = 390 ppm, SO₄ = 2,690 ppm, HCO₃ = 146 ppm). Landscape plants also must be able to tolerate high total salts and toxic Cl and Na levels. Careful planning and proper management are the keys to success when using seawater for irrigation on turfgrass.

Water Quality Assessment

Monitor water quality by location and over time, especially if the source is brackish or the water is obtained from a well subjected to saltwater intrusion where the salt water retreats during wet periods or encroaches during dry periods. Intrusion of salt water into a well head can occur abruptly and, consequently, regularly scheduled water quality testing will be necessary. If salt-laden effluent is used directly or blended with seawater, quality should be monitored over time. Relatively inexpensive electrical conduc-

tivity meters can be easily used by turf managers for on-site monitoring of total salinity. Seawater drawn from wells may be influenced by local soil conditions, such as those exhibiting higher bicarbonates (HCO_3^-), or from excessive levels of other components, such as heavy metals or boron or extremely low pH (<5.0) conditions where Al or Mn levels might be extremely high. Knowledge of water constituents and their fluctuation over time is essential for making management decisions.

The Irrigation System

Irrigation system design efficiency includes sprinkler head spacing for uniform coverage, nozzle size tailored to soil texture (percolation rate, e.g., fine-textured soils may require low application rates), and individual sprinkler head control to ensure flexible scheduling. Pulse irrigation is essential on soils with low infiltration and percolation or with poor or slow drainage characteristics since it can be difficult to effectively manage and match precipitation rates of large turf sprinklers to the infiltration rates in these salt-challenged soils. Pulse irrigation provides water to the turf at a rate up to runoff and then stops to allow for infiltration/percolation, followed by repeated cycles. The intermittent application of water throughout a daily irrigation cycle via pulse irrigation provides for:

1. Maximum leaching of excess salts.
2. Minimal buildup of excess Na, which causes soil structural breakdown (sodic soil conditions).
3. Minimal bicarbonate precipitation and sealing at the surface of sandy soil profiles caused by light, frequent irrigation.

The number-one management requirement of all salt-affected turfgrass sites is leaching to remove excess salts or to prevent sodium and chloride accumulation. The leaching requirement (LR) is the quantity of water required to maintain a moist soil profile with consistent net downward movement of salts below the turfgrass root-zone that is over and above turf evapotranspiration (ET). Turfgrass ET can be high due to coastal winds or high temperatures, especially during establishment when soil evaporation is excessive. Total saltwater needs include $\text{LR} + \text{ET} + \text{correction for irrigation design inefficiency}$. Total water use could average 30-50% higher using



Commercially available, putting green quality seashore paspalum tolerates low mowing heights and ocean-level salt concentrations in the irrigation water.

ocean water compared to non-salt affected situations.

The additional volumes of water needed to leach salts delivered by seawater or other poor-quality recycled or brackish water can require special consideration when designing the hydraulic capacity of the irrigation system. Pipe sizes need to be increased to avoid excessive flow velocities that cause subsequent water hammer and fatiguing damage to PVC components. Inadequate pipe sizing will result in a longer window for total operating time, resulting in sprinklers operating before dusk and after dawn, interfering with both maintenance operations and golf play. A general rule of thumb when designing the irrigation system is that no greater than an 8-hour window of operation should be needed to irrigate the golf course at maximum ET while including the proper leaching fraction.

A "dual" mainline irrigation system to allow irrigation of salt-sensitive areas (cool-season grass putting greens, clubhouse landscape areas) with a better-quality water also is an option. Another alternative is a system of multiple storage lakes that allow blending of alternative water sources for leaching. Under either of these scenarios, reverse osmosis could be incorporated into the system to supply water for occasional leaching, blending, or management of salt-sensitive areas. Any of these options should be included in the design phase on a cost-effective basis.

A dual irrigation system would prove beneficial for:

1. Blending seawater with wastewater to dilute the total salts and high Na^+ levels (improve overall quality).
2. Irrigation of golf greens with reduced salt-laden sources (such as reverse-osmosis water).
3. Use of alternative water resources during periods of high volume leaching.

4. Application of fertilizer or other amendments through the irrigation system.

Desalinization is one option as an alternative water resource, but cost comparisons and volume of water produced are key considerations (California Coastal Commission, 1999).

Corrosion of irrigation hardware and other equipment exposed to ocean water also is a major concern and should be addressed within the design specifications. Plastic pipe and sprinklers are naturally preferred where feasible. Where steel components are normally specified, epoxy coating, high-grade stainless steel (Austenitic) or ductile iron fittings on PVC mains should be investigated for improved longevity and economic feasibility. Custom manufacturing using seawater-resistant nonferrous metal blends and marine or reclaimed water grade equipment and paint also may be options for consideration. Components exposed to salty sprinkler spray (wetting and drying cycles) will deteriorate more rapidly than those that are always submerged. Items such as controller cabinets should be manufactured from stainless steel or plastic and be maintained in a relatively watertight condition to inhibit corrosion of internal electrical components and connections. It also is imperative that all buried wiring splices are made with the highest-quality waterproof-type connections. Another option would be to install a radio-operated control system (such as OSMAC from Toro and FREEDOM from Rainbird) that eliminates the need for hard wiring of a low-voltage signal loop between the computer central control and the satellites. This type of system would eliminate a number of additional and potentially troublesome electrical connections that are prone to failure under highly saline conditions.

Highly sandy soils are very desirable since leaching is much easier on sands compared to fine-textured soils that have lower infiltration/percolation/drainage rates. Additionally, sandy soils that drain more rapidly will return to playable conditions in less time following leaching and will resist compaction from maintenance equipment and other traffic when wet. Continuous paved cart paths and cart restrictions on the turf also are recommended to minimize traffic damage from stresses due to:

1. The reduction of turf growth and recovery from wear caused by salt accumulation.

2. Excess compaction when traffic occurs on saturated soils following regular leaching events.

Salt Disposal

The golf course design must include plans for environmentally sound disposal of leached salts (and/or brine if reverse osmosis is used) when seawater is to be used for irrigation. The primary considerations involve:

1. Avoidance of salt accumulation below the turfgrass rootzone in an increasingly concentrated form. Eventually, this zone of salt accumulation will rise to the soil surface and cause catastrophic injury to all plants and their root systems.

2. Prevention of leachate or salt seepage into a potable water source or freshwater off-site area, or contamination by saltwater intrusion due to excessive removal from the good water source.

Both considerations involve proper land surface contouring and adequate deep-tile drainage lines (3-5 feet) with outlets either directly into the ocean or into a carefully constructed and impervious well or holding pond. The 34,486 ppm of total salts in seawater is equivalent to 2,153 lbs. of salt per 1,000 square feet per foot of seawater applied. Deep coarse sands (>0.50 mm) with high percolation rates (>10 inches per hour) are strongly preferred when seawater is used for irrigation.

Long-Term Maintenance Costs

Seawater irrigation requires proactive management to minimize the constant threat of saline-sodic soil conditions and their resulting impact on turfgrass performance. Increased budgeting needs include:

1. Extra chemicals (gypsum, acids, lime, micronutrient fertilizers, highly

soluble fertilizers) that will be needed continuously and periodically at high rates. Some of these added costs are offset by reduced needs for herbicides and other pesticides and a less expensive water source.

2. Cultivation equipment (both surface and subsurface types) to maintain water movement for efficient leaching of salts through soils. Fine-textured soils will require much more aggressive cultivation programs than sandy soils. The effectiveness of a cultivation operation is typically reduced by one-half on high-Na sites and cultivation frequency must be increased. Both deep (10-12 inches) and shallow (3-5 inches) aeration practices are essential for proper salt leaching. Deep-tine cultivators include Verti-drain, Soil Reliever, Aerway Slicer, and Deep-drill. The Yeager-Twose Turf Conditioner is less effective for deep cultivation (i.e. > 7 inches), but has excellent chemical injection capabilities (capable of applying 80-90 lbs. gypsum per 1,000 square feet at a 7- to 8-inch depth). The Hydroject units also can be used to enhance seawater irrigation percolation into the soil profile.

3. Extra irrigation equipment. The corrosive nature of the high salts in ocean water will require constant monitoring and more frequent replacement of certain components like sprinkler heads and irrigation pumps. Injector systems can occasionally be used to treat seawater. Acidification (H_2SO_4 , N-phuric acid, or urea sulfuric acid, sulfur dioxide generator) to aid in the formation of gypsum ($CaSO_4$) in the soil by reaction with surface-applied lime ($CaCO_3$) is one method of supplying considerable Ca^{2+} to replace Na^+ on soil cation exchange sites (CEC). The excess Na combines with the available SO_4 from the acids to form Na_2SO_4 , which then can be leached.

Another method of supplying high levels of Ca^{2+} ions to counter high Na^+ levels in seawater is a gypsum injector linked with the irrigation system. $CaCl_2$, $Ca(NO_3)_2$, or other highly soluble amendments can be added with this unit. Although seawater contains relatively low HCO_3^- (146 ppm), water that is pumped from ground wells near the ocean can occasionally contain levels exceeding 550 ppm, which would benefit from acidification to remove the excess bicarbonates. This removal releases the Ca and Mg in the water to counteract the excessive Na in the seawater. Additional lakes, pumps, and piping for blending, dual irrigation

systems, and desalinization/reverse osmosis equipment will raise ongoing long-term maintenance costs.

4. Accelerated equipment replacement schedules for maintenance equipment and course accessories are commonly required on sites with saline irrigation sources. Daily exposure to salt-laden irrigation spray, exudation water, and runoff deteriorates metal components on mowing equipment, utility vehicles, and course accessories such as signs, benches, and ball-washers (much like the corrosion on automobiles in northern climates caused from salting and deicing highways). Undercoating and rustproofing treatment of undercarriages on all equipment is recommended. A potable water source also should be used when washing equipment after every use to slow the corrosion process.

5. *The turf manager must be well trained in order to maintain high-quality turf.* Salt-related problems are site-specific and very complex because of multiple environment/turf interactions.

Sand Capping and Drainage

If saline-sodic soil is dredged from an ocean bay and added as the topsoil for the turfgrass rootzone, several practices are suggested to alleviate the high total salts and excess Na that cause considerable soil structural deterioration:

1. Deep-tine (10-14 inches) aerate and apply 200-600 lbs. gypsum per 1,000 square feet to the soil surface and rototill into the top six inches. Higher rates may be needed for heavier clay soils.

2. Apply an additional 200 lbs. gypsum per 1,000 square feet to the surface and cap with two inches of coarse sand. Till into the top 1 or 2 inches of soil.

3. Cap with an additional six inches of coarse sand. The more coarse the sand (especially 0.5 to 1.0 mm range and none exceeding 2.0 mm), the better the rate of percolation and the faster the leaching with less volume of seawater irrigation. Coarse sand in the 1.0 to 2.0 mm range should probably not exceed 10-20% (by volume) of the total coarse sand to minimize damage to golf clubs and maintenance equipment.

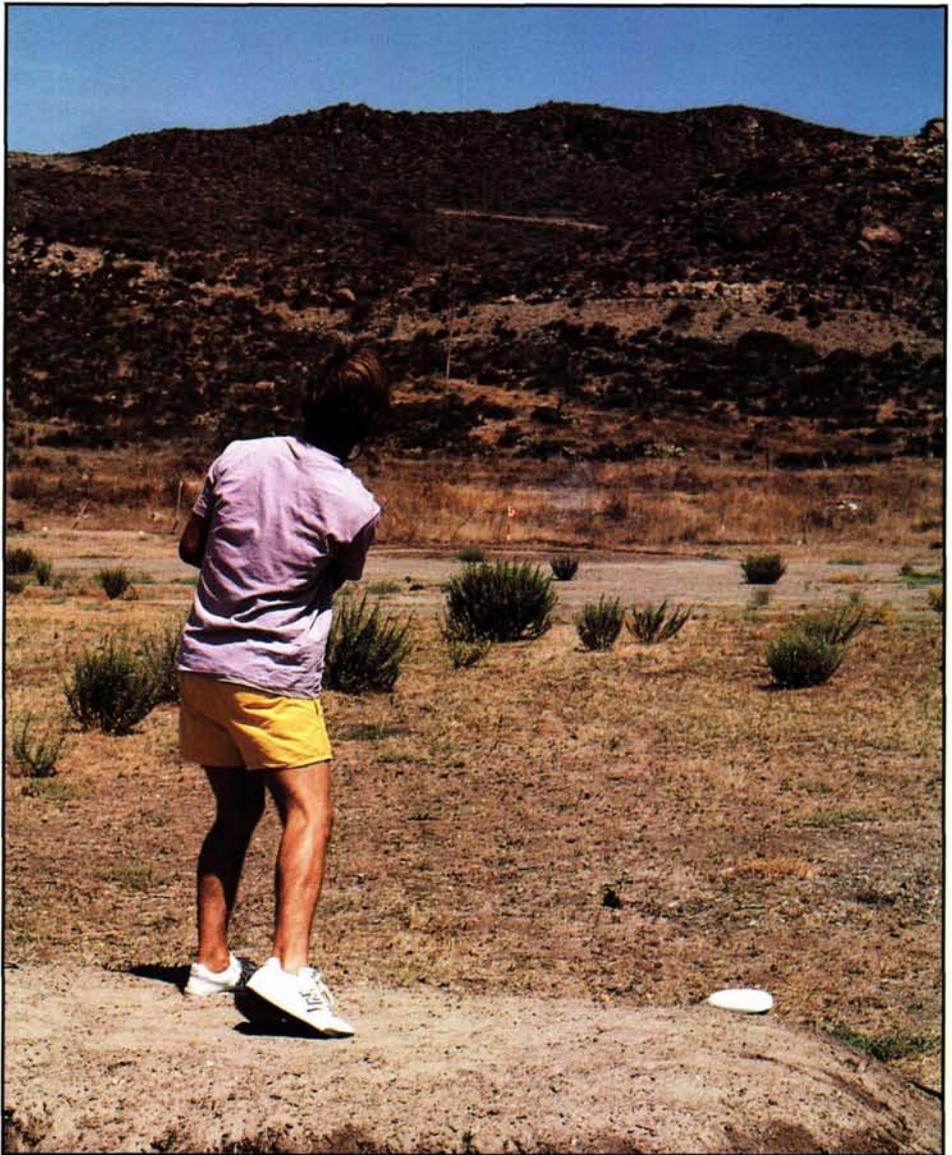
If fine-textured soils that are high in silt and clay content have low infiltration and percolation rates, application of a 6- to 12-inch coarse sand layer (cap) over the existing soil will

enhance the leaching effectiveness in the rootzone and help maintain water infiltration by reducing surface soil compaction. Incorporating 4-5% organic matter into the coarse sand prior to capping will (a) provide improved water-holding capacity, (b) help maintain a moist soil profile for a longer time frame compared to straight sand with no organic matter, and (c) minimize or slow down upward movement of salts concentrated below the rootzone when surface evaporation demands exceed seawater application rates.

Wind + high temperatures + exposed sandy surfaces during establishment and early grow-in can place very high evaporative demands on the overall turfgrass system. *Heavy leaching at night to keep the salts moving downward followed by periodic seawater applications during the heat of the day in an effort to maintain uniform soil moisture and prevent upward movement of concentrated salts are the key irrigation maintenance practices for successful establishment and grow-in of turf with seawater irrigation.*

One additional alternative — a fairway system with full drainage — could be considered. The concept involves creating the world's largest USGA green by letting the subsoil seal with excess Na^+ (creating a lake bottom) and installing a subsurface drainage system below the sand cap. The drainage system allows collection and disposal of the salt-laden drainage water, if engineered correctly, and also protects any potable groundwater or aquifers in the immediate area. Construction costs are initially higher, but savings in deep aeration, gypsum applications, and associated labor to perform these maintenance operations could conceivably pay for the drainage system over a six-year period.

For example, approximately 2,378 lbs. gypsum (23% Ca) per 1,000 square feet must be applied for every 12 inches of seawater irrigation to counter the high Na^+ concentration. In deep sands with < 2-3% silt and clay, the gypsum rate can be reduced by 50-70%. However, sand-capped sites still require the higher gypsum rates to maintain non-sodic conditions in the subsoil. For practical purposes, assume the golf course covers 100 acres and the gypsum costs \$100 per ton, or about \$2,178 per month (at 100 lbs. per 1,000 square feet per month, or about \$5,180 per acre-foot of seawater). Assuming a 7,000-yard course and \$6.00 per linear foot for solid perforated pipe including



As we enter the new millennium and fresh water becomes increasingly more scarce, alternative water supplies and salt-tolerant turfgrasses for golf become a much better option than the "other" alternative.

main drains and occasional drain basins, 30-foot lateral spacing would cost about \$997,000 and 20-foot lateral spacing would cost about \$1,432,800 initially for the fairway drainage. If the gypsum rates could be reduced to 50% for treating the sand cap (instead of keeping the subsoil draining) and utilizing subsurface drainage, the system could pay for itself relatively quickly. With heavy rains from monsoons, hurricanes, or tropical storms, this drainage system would be extremely beneficial for rapid removal of excess water.

Establishment

All turfgrass and landscape plants are more sensitive to high-salt problems during initial root formation and early establishment. Besides the high-salt impact on the root system, the turfgrass

growth rate will be reduced, prolonging the grow-in period. Additionally, salt accumulation on the soil surface occurs very rapidly when seawater is used for irrigation unless appropriate management practices are used. Proper management techniques can minimize the need for an expensive replanting. Factors to consider include:

1. *Reduction of total salts for establishment.* Seawater has a total salinity level of $\text{EC}_w = 54 \text{ dSm}^{-1}$. Total salts will only be reduced below 54 dSm^{-1} (a) after a heavy rainfall or prolonged rainy period, (b) by use of better-quality water sources (effluent, brackish, reverse-osmosis water), or (c) by blending with lower salt-containing water sources.

2. *Alleviation of Na-induced soil physical problems in the surface zone.*

Aggressive deep and shallow aeration, gypsum application, cultivation, top-dressing, and leaching are key management options. Gypsum applications should always be made immediately following aeration to avoid creating a Na⁺-affected layer deeper in the soil profile.

3. *Maintenance of a uniformly moist soil profile.* Preventing the soil surface EC_e from rising above 54 dSm⁻¹ when seawater is the sole source of irrigation water will require:

(a) *Keeping the salts moving* — a continuous program of supplying sufficient water volume is necessary to maintain net downward movement of salts away from the rootzone and soil surface, and to prevent them from rising back up by capillary/absorptive water movement.

(b) *Maintaining moist soil profile conditions between irrigation events* so that salts do not concentrate in the soil solution or rise by capillary action from below the surface zone. *If the salts move down at EC_e = 54 dSm⁻¹ and concentrate, high evaporation in sandy soils can bring the salts back to the surface at EC_e > 54 dSm⁻¹ and kill the young turf seedlings.*

Light, frequent seawater irrigation at establishment or on mature turf without adequate leaching will result in rapid surface resalinization and subsequently lead to turfgrass failure even with the most tolerant turfgrass cultivars. Scheduling high leaching events at night will minimize competition from wind and the high evaporative

daytime demands when using seawater. On sands, the nighttime leaching event should be sufficient to move surface salts (i.e. the wetting front in the soil profile) to at least 12 inches and on fine-textured soils to at least 16-20 inches depth. This will minimize capillary rise of more concentrated salts back to the surface and into the turfgrass rhizosphere. This heavy leaching event may be done over two nights on fine-textured soils if percolation rates are low. Seawater irrigation scheduling during the day should be frequent enough to maintain a continuous and uniformly moist soil profile with minimal surface drying. A monthly gypsum application of 100-200 lbs. per 1,000 square feet can be surface-applied as a sodic-soil preventative strategy when using seawater for irrigation.

4. *Adequate initial fertilization and careful monitoring of micronutrients with continuous leaching events.* A spoon-feeding approach (frequent applications, 1/10 to 1/2 rates) is necessary on seawater-irrigated sites, with total annual fertilizer nutrients applied at 1.5 to 2.0 times that used on areas irrigated with non-salt-laden water. While higher annual rates of fertilizer are required, the rates per application are similar to non-salt-affected sites, but the frequency is greater. Use of highly soluble fertilizers and fertigation through a well-designed irrigation system is very beneficial.

Adequate phosphorus (2-3 lbs. P₂O₅ per 1,000 square feet) should be applied to the surface at planting to promote

establishment. Soil test analysis will reveal the need for additional nutrients in conjunction with nutrients supplied by the seawater. High leaching events can deplete micronutrient (Fe, Mn) levels, and careful monitoring is necessary on a continuous basis. Potassium, Ca, and Mg also are subject to leaching losses and should be monitored closely.

Post-Establishment/Mature Turf

The use of seawater for turfgrass irrigation produces two very important results that significantly impact management strategies:

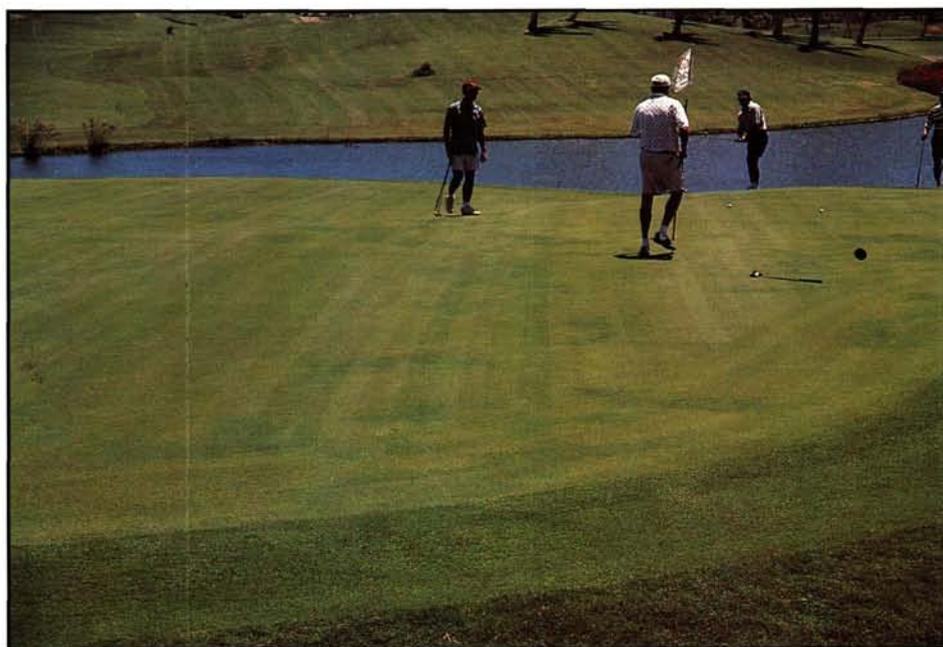
1. *Seawater supplies additional nutrients that require adjustment in fertilization protocols,* and chemicals that are applied to replace excess Na⁺ on soil CEC sites necessitate additional nutritional adjustments (Table 1).

- *All ions in Table 1 contribute to overall high total salts,* with Na⁺ and Cl⁻ ions contributing the most salts because of total quantity. As long as adequate irrigation water is applied, chloride is easily leached. Excess chloride can detrimentally affect nitrate uptake.

- *Excess Na⁺ will rapidly cause a severe sodic-soil condition (soil structural deterioration) unless high quantities of Ca⁺² ions are added* to replace Na⁺ on the CEC sites and sufficient water is added to leach the ion away from the turfgrass root system. A sodic-soil situation is much more serious on fine-textured soils than on sands. At least 547 lbs. elemental Ca⁺² per 1,000 square feet or 2,378 lbs. gypsum (23% Ca) per 1,000 square feet must be applied for every 12 inches of seawater irrigation to counter the high Na⁺ concentration. In deep sands with < 2-3% silt and clay, the gypsum rate can be reduced by 50-70%. Sand-capped sites will still require the higher gypsum rates to maintain non-sodic conditions in the underlying soil, unless a complete subsurface drainage system has been included (discussed in sand-capping section).

- Additional highly soluble Ca sources could include CaCl₂ or Ca(NO₃)₂, which could be applied through injector systems. Lime (CaCO₃) can be applied to the soil to react with SO₄⁻² in the seawater to form gypsum. Approximately 170 lbs. lime per 1,000 square feet per 12 inches seawater irrigation is needed to react with 168 lbs. SO₄⁻² in the seawater.

- A 3:1 to 8:1 ratio of Ca:Mg is preferred in irrigation water. Ca deficiency may occur below 3:1 and Mg deficiency



As the bermudagrass succumbs to high salt levels, seashore paspalum (lighter color) fills in the putting green.

Table 1
Quantity of nutrients applied with typical seawater irrigation

Ion	lbs./1,000 sq. ft. per 12 inches seawater	meq L ⁻¹	ppm	% of Cations
Ca ⁺²	26.2	21.0	420	3.5
Mg ⁺²	81.4	106.8	1,304	17.9
K ⁺	24.3	9.9	310	0.8
Na ⁺	659	458.8	10,556	76.9
SO ₄ ⁻²	168	56.0	2,690	—
Cl ⁻	1,185	534.6	18,980	—
HCO ₃ ⁻	9	2.4	146	—
CO ₃	<1	—	—	—
N			11.5	—
P			0.06	—
Mo			0.01	—
Fe			0.002	—
Mn			0.0002	—

above 8:1. The 1:5 ratio of these two elements in seawater is usually not a problem since large quantities of Ca are applied as an amendment to replace Na⁺ when using seawater for irrigation. If extra Mg is needed, dolomitic lime can be used as a slow-release Mg source, or a soluble Mg source can be applied by fertilization.

• Even though 24.3 lbs. K is applied per 1,000 square feet per 12 inches seawater irrigation, *high Na⁺ suppresses K⁺ uptake*. A routine spoon-feeding program with KNO₃ or K₂SO₄ is recommended. On sand-capped areas or well-drained deep sands, adding 5% by weight of medium to coarse zeolite (0.25-1.00 mm diameter) will enhance selective retention of K⁺ ions.

2. *High leaching requirements will enhance the leaching of all nutrients.*

• N-P-K fertilizers should be applied in a spoon-feeding approach at 1.5 to 2.0 times annual rates (compared to sites with good-quality water).

• Slow-release fertilizers applied frequently in 1/10 to 1 lb. per 1,000 square feet per application increments can be used as the base fertilization with fertigation of water-soluble sources used to supplement turfgrass nutrition. Spot fertilization of wear/traffic areas with granular, quick-release, soluble fertilizers may be necessary.

• The micronutrients Fe and Mn may require extra foliar applications at 0.025 Fe and 0.013 lbs. Mn per 1,000 square feet every two to three weeks. Additional granular applications may be needed several times per year. A good micronutrient fertilizer should be

applied at the recommended rate, but 1.5-2.0 times more frequently.

Summary

Seawater irrigation on turfgrass is feasible with:

- Highly salt-tolerant turf species.
- Coarse, sandy soil profiles.
- Irrigation strategies that keep salts moving with regular leaching events and keep the soil profile uniformly moist to minimize concentrated salts from rising into the rootzone.
- Good surface and subsurface drainage design.
- Environmentally safe disposal of excess salts.
- Careful nutrient management and continuous monitoring.
- The entire course must receive high-level management.

Pros for Using Seawater Irrigation

- Non-interruptible supply of irrigation water during shortages/droughts/rationing.
- Reduced water costs when compared to “purchased” potable or recycled water.
- Reduced pumping costs compared to similar quality brackish wells.

Cons for Using Seawater Irrigation

- Higher ongoing maintenance costs: cultivation (labor, replacement tines, equipment repairs), amendments, equipment replacement (undercoatings), salt/brine/drainage disposal.
- Higher construction costs: sand capping, additional drainage, enhanced irrigation systems, reverse-osmosis equipment.

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