Aquatrols Guide to Assessing and Managing Turfgrass Salinity Issues in Irrigation Water and Soils

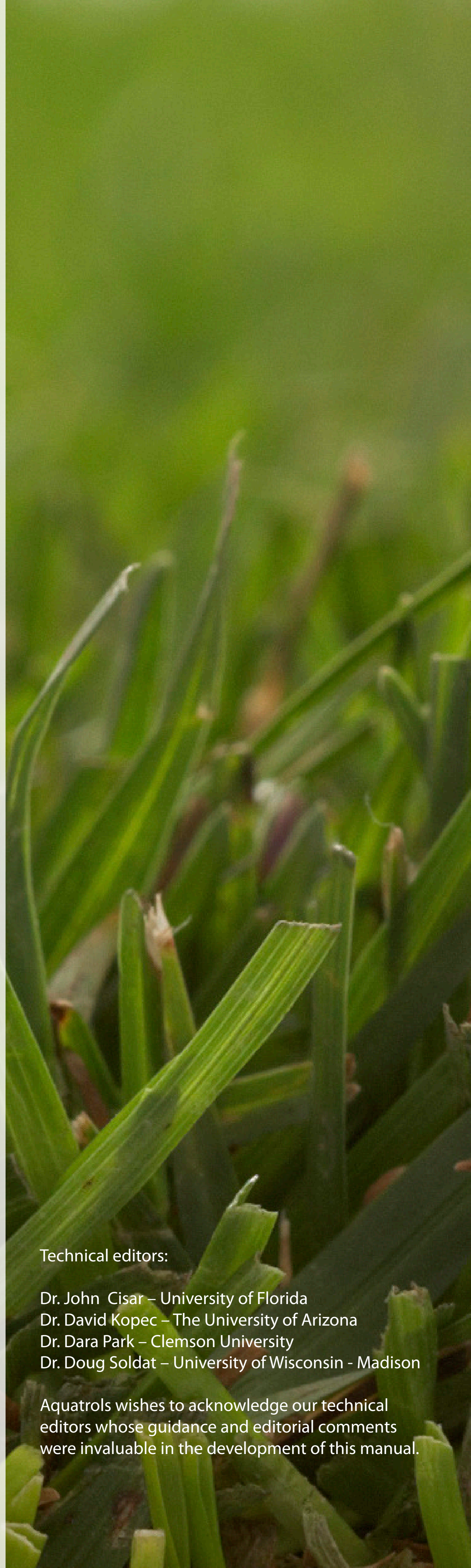
PURPOSE OF THIS GUIDE

The purpose of this guide is to simplify the often confusing, and sometimes contradictory information available today regarding water quality guidelines for turfgrass irrigation, and soil salinity and sodicity (sodium) issues in turfgrass soils. Poor irrigation water quality and salinity and sodium issues in the soil are related, as most soil salinity and sodium problems arise from using irrigation water that contains excessive soluble salts and/or sodium. In addition, salinity problems can also arise when evapotranspiration is consistently greater than water inputs as occurs in arid regions, or during extended periods of drought in non-arid regions.

This guide is not meant to be an all-inclusive reference on all irrigation water quality issues, there have been textbooks written to do that. Instead, it will focus primarily on soluble salts and sodium (the most common irrigation water quality problems) and will provide enough basic information to help you determine if you have a problem with soluble salts or sodium in your irrigation water and soils. It also briefly describes ions in irrigation water which can also sometimes be toxic to turfgrass or landscape plants. If you discover you have problems related to any of these issues, recommendations are provided.

THE IMPORTANCE OF TESTING

The only way to determine if your irrigation water is suitable for use on turfgrass is to have the water tested. The same goes for assessing potential salinity or sodium problems in soils – you must test the soil. However, there are literally dozens of tests that laboratories can run on water or soil samples to assess these potential issues and not all laboratories run the same tests or use the same interpretations. Be aware that some of these tests may not be appropriate or relevant for your climate or soil conditions. Before you begin any testing program, you need to determine the most appropriate tests and identify a laboratory that can do those tests for you. Initial testing will determine the status of your irrigation water and soil, and provide a baseline for making management recommendations. Continued periodic testing after management practices are implemented will show how well those management practices are working, and if changes to the initial recommendations need to be made.



Technical editors:

Dr. John Cisar – University of Florida
Dr. David Kopec – The University of Arizona
Dr. Dara Park – Clemson University
Dr. Doug Soldat – University of Wisconsin - Madison

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IRRIGATION WATER QUALITY AND SOIL TEST TERMS EXPLAINED

Before discussing irrigation water quality and soil testing, test result interpretations, and management of salinity, sodium or toxicity problems, it will be helpful to review the most important testing terms that will be discussed in this guide. These terms are commonly included in water quality and soil test reports.

B — **Boron** can be toxic to some turfgrass species at concentrations as low as two to four ppm in the soil. Irrigation water should contain less than one ppm if possible. Boron can be leached from sandy soils, but it accumulates and is more difficult to leach from fine-textured soils. It is more commonly a problem in landscape plants than in mowed turf.

Ca — **Calcium (Ca^{2+})** is the most important cation in fine-textured soils for the development of good soil structure as it is essential for flocculation of clay and organic particles. However, adding additional calcium to soils that are not low in calcium will not necessarily increase soil structure any further. Ca^{2+} is also very effective in displacing sodium (Na^+) from cation exchange sites in the soil. Therefore, calcium applications to sodium-affected soils are a key sodium management practice. Ca^{2+} concentration in irrigation water is a required variable in several water quality equations, including RSC, SARw, adj SARw and adj RNa.

CEC — **Cation exchange capacity** is the maximum quantity of total cations (positively charged ions) a soil can hold at a given pH to exchange with cations in the soil solution. CEC is expressed in units of meq/100 g of dry soil, and must be calculated correctly for the soil exchangeable sodium percentage (ESP) to be determined accurately. Special extraction methodology (elevated pH ammonium acetate) is required to correctly measure the CEC of soils containing free lime with pH > 8.

CO_3^{2-} / HCO_3^- — **Carbonate (CO_3^{2-})** and **bicarbonate (HCO_3^-)** anions in alkaline irrigation water or in the soil solution commonly react with calcium cations (Ca^{2+}) in higher pH soils and precipitate out as calcium carbonate ($CaCO_3$), also known as calcite or free lime. Less commonly, magnesium cations (Mg^{2+}) can also precipitate out of alkaline irrigation water or the soil solution in higher pH soils to form magnesium carbonate ($MgCO_3$). Either of these events will elevate the ESP of the soil, and increase the potential for sodium-induced soil deflocculation and a loss of soil structure. Carbonate and bicarbonate concentrations are factored into the adj SARw equation and the newer adj RNa equation.

Cl^- — **Chloride** is an anion commonly found in irrigation water and can be a major contributor to the overall salinity of water. Chloride is not particularly toxic to turfgrass, but many landscape plants are very sensitive to it.

Cl_2 — **Chlorine** is a gas usually only present in minor amounts in recycled water sources where chlorine-containing compounds are commonly used as a disinfectant. Residual chlorine levels above 5 mg/L can be toxic to turfgrass. Chlorine is generally unstable in water and will form chlorides. *Note: Do not confuse chlorine (Cl_2) with chloride (Cl^-).*

ECe — The **electrical conductivity** of a **soil extract**. It is a measure of salinity or the total soluble salts in a soil and is expressed in units of dS/m or mmhos/cm. When measured by a laboratory, it is most often determined using a saturated paste extract test. ECe can also be measured fairly accurately in the field using an EC meter in soils at the proper volumetric water content.

ECw The **electrical conductivity** of **water**. It is a measure of salinity in water and is expressed in units of dS/m or mmhos/cm. ECw is required to calculate the amount of water required for reclamation and maintenance leaching of soils with high salinity. It is also required for comparison to SARw, adj SARw or adj RNa to assess the potential of irrigation water to contribute to sodium-induced soil deflocculation and a loss of soil structure. In addition, it is used to assess the potential for loss of soil structure associated with the use of "ultra pure" (low salinity) irrigation water. Salinity is also reported by some labs as TDS (total dissolved salts) in units of mg/L or ppm. Convert TDS to ECw if ECw is not reported on an irrigation water quality test *(see Common Units of Measure and Conversion Factors)*.

ESP The **Exchangeable Sodium Percentage** of the soil. ESP equals the amount of exchangeable sodium in the soil (meq/100 g of soil), divided by the CEC of the soil (meq/100 g of soil) times 100. The higher the ESP, the greater the chance sodium will cause deflocculation of soil particles and loss of soil structure resulting in reduced permeability. Impact of high ESP will vary with soil texture and organic matter content, with fine-textured clay soils being most negatively affected and sandy soils being least negatively affected. "ESP" is often not reported directly as such on a soil test report, but it is equivalent to *exchangeable %Na* in the base saturation section or cation exchange section of a soil test report.

Excess carbonate / free lime (fizz test) A test used to determine the presence of free lime, also known as calcium carbonate ($CaCO_3$), or calcite in a soil. A dilute hydrochloric acid solution is poured onto a soil sample and if it fizzes and gas is given off, free lime is present. This test can be used to determine if the entire soil is calcareous, or if there is a layer of free lime at a certain depth in a non-calcareous soil, when a soil core is tested.

Mg **Magnesium (Mg^{2+})** is normally the second most abundant cation on soil cation exchange sites (calcium [Ca^{2+}] is normally the most abundant). Like calcium, it can also displace sodium cations (Na^+) from cation exchange sites in the soil. Mg^{2+} concentration in irrigation water is a required variable in several water quality equations, including RSC, SARw, adj SARw and adj RNa.

Na **Sodium** cations **(Na^+)** can cause deflocculation of soil particles and reduce permeability of fine-textured soils. The Na^+ concentration in irrigation water is required to determine SARw, adj SARw or adj RNa, and Na^+ concentration in the soil is needed to calculate soil ESP. High concentrations of sodium in irrigation water will also increase the total salinity of the irrigation water (ECw).

pH The negative logarithm of the hydrogen ion (H^+) concentration in an aqueous solution, and is a unitless measure of acidity or alkalinity of water or soil. The pH scale is from 0-14, 7.0 is neutral, less than 7.0 is acidic, and greater than 7.0 is alkaline. Very low or high pH of irrigation water or soil is a good indicator that other chemical properties of the water or soil may be negatively impacting soil structure or plant growth, and should be evaluated.

RSC **Residual sodium carbonate** is the sum of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) concentrations in irrigation water minus the sum of calcium (Ca^{2+}) and magnesium (Mg^{2+}) concentrations in irrigation water reported in meq/L. RSC is used to estimate the amount of calcium (CA^{2+}) and magnesium (Mg^{2+})cations in irrigation water that remain after precipitation with carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions to form calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$) in the soil. RSC values greater than 1.25 along with sodium (Na^+) concentration in excess of 100 ppm in irrigation water may indicate the potential for sodium accumulation in the soil. Test the soil and check ESP to determine if sodium levels in the soil are high enough to be problematic.

adj RNa The **adjusted sodium hazard**. This equation is very similar to the adj SARw equation referenced below, but it is preferred to adj SARw because it includes a better estimate of the effect of bicarbonate (HCO_3^-) anion concentration on calcium cation (Ca^{2+}) precipitation from irrigation water, and the degree of impact this may have on the potential of sodium cations (Na^+) in irrigation water to cause deflocculation of soils and a loss of soil structure resulting in reduced permeability. This is a newer equation however, and most testing laboratories are still not reporting it. The adj RNa value (if available) is most appropriate to use when irrigating alkaline soils (pH > 7.0) and using irrigation water with bicarbonate levels of 120 ppm or greater.

SARw & adj SARw The **sodium adsorption ratio** and **adjusted sodium adsorption ratio** of water. These equations are used to determine the potential for deflocculation of soil particles and reduced permeability caused by sodium in irrigation water. SARw compares ratios of sodium (Na^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) cation concentrations in irrigation water (meq/L). The adjusted SARw compares ratios of sodium, calcium and magnesium cation concentrations in irrigation water, and also factors the potential of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions to react with calcium cations to form calcium carbonate ($CaCO_3$) or to react with magnesium cations to form magnesium carbonate ($MgCO_3$). SARw is most appropriate to use when irrigating acidic soils (pH < 7.0) using irrigation water with bicarbonate levels less than 120 ppm. The adj SARw is most appropriate to use when irrigating alkaline soils (pH > 7.0) and using irrigation water with bicarbonate levels of 120 ppm or greater, when adj RNa is not available. Laboratories will usually report adj SARw or adj RNa, but not both.

TDS **Total dissolved salts**. This is a measure of salinity or the total dissolved or soluble salts in water and is expressed in units of mg/L or ppm. Salinity is also reported by many labs as ECw (electrical conductivity of water) in units of dS/m or mmhos/cm. ECw is the preferred measure of salinity for irrigation water quality testing because ECw is required for comparison to SARw, adj SARw or adj RNa to assess the potential of irrigation water to contribute to sodium-induced soil deflocculation and a loss of soil structure. ECw is also needed to assess the potential for loss of soil structure associated with the use of "ultra pure" (low salinity) irrigation water. Convert TDS to ECw if ECw is not reported on an irrigation water quality test *(see Common Units of Measure and Conversion Factors - page 18)*.

With all of the different test results on an irrigation water quality report, figuring out what it all means and what is really most important can be a bit overwhelming. But if you remember that the three primary problems with water used to irrigate turfgrass are (1) excessive salinity, (2) excessive sodium, and (3) potentially toxic ions, the number of test results you have to look for is relatively small. So if you focus on the test results that give you information to answer three main questions, interpreting an irrigation water quality test report can actually be quite easy.

Does your irrigation water contain high enough salinity that it might cause a water uptake problem in the soil for turfgrass species growing in that soil?

HOW TO FIND THE ANSWER:

Identify the ECw value on your irrigation water quality test report and compare it to the ECw value ranges in Table 1 to determine the likelihood of salinity levels being high enough to potentially cause a buildup of salinity levels in the soil. If ECw levels are medium to high, this warrants additional testing of soil salinity levels (ECe) and a review of the soil salinity tolerance of the turfgrass species you are growing (Table 2 - page 9).

Based on the salinity of your irrigation water, and the soil salinity levels the turfgrass species you are irrigating can tolerate, additional water may need to be applied with each irrigation event to maintain soil salinity levels low enough as to not restrict water uptake. This extra water is called the Leaching Requirement (LR), and is the minimum amount of water that must percolate through the root zone to keep salinity levels from building up over time *(see Management of Irrigation Water Quality Issues – High Irrigation Water Salinity - page 10)*.

Does your irrigation water contain a high enough concentration of sodium to cause soil deflocculation and a loss of soil structure, resulting in significantly reduced permeability in fine-textured soils?

HOW TO FIND THE ANSWER:

Identify SARw, adj SARw and adj RNa values on your irrigation water quality test report (if given). If you are irrigating fine-textured soils with a pH of 7.0 or less, compare ECw to SARw values in Table 1 or Chart 1 to determine the likelihood of whether sodium in the irrigation water will induce soil deflocculation.

If you are irrigating fine-textured soils with a pH greater than 7.0, compare ECw to adj SARw or adj RNa values in Table 1 to determine the likelihood of whether sodium in the irrigation water will induce soil deflocculation.

Does your irrigation water contain enough boron or chlorine to worry about boron (B) or chlorine (Cl_2) toxicity in turfgrass?

HOW TO FIND THE ANSWER:

Identify boron values on your irrigation water quality report and compare to the boron value ranges in Table 1 to determine the likelihood of boron causing root toxicity. Chlorine levels are not commonly reported on irrigation water quality reports. If using recycled water, obtain chlorine levels for your recycled water supplier and compare to chlorine levels in Table 1.

Table 1. Likelihood of soil or turfgrass problems related to salinity, sodium, bicarbonate or toxic ions in irrigation water.

Potential Problem	Test Conducted	Likelihood of Soil or Turfgrass Problems		
		Low	Medium	High
high salinity	ECw (dS/m or mmhos/cm)	< 0.7*	0.7 - 3.0*	> 3.0*
sodium-induced soil deflocculation	SARw, adj SARw or adj RNa 0 - 3**	ECw > 0.7	ECw 0.2 - 0.7	ECw < 0.2
	SARw, adj SARw or adj RNa 3 - 6**	ECw > 1.2	ECw 0.3 - 1.2	ECw < 0.3
	SARw, adj SARw or adj RNa 6 - 12**	ECw > 1.9	ECw 0.5 - 1.9	ECw < 0.5
	SARw, adj SARw or adj RNa 12 - 20**	ECw > 2.9	ECw 1.3 - 2.9	ECw < 1.3
	SARw, adj SARw or adj RNa 20 - 40**	ECw > 5.0	ECw 2.9 - 5.0	ECw < 2.9
calcite formation	Bicarbonate (HCO_3^-) (mg/L or ppm)	< 90***	90 - 500***	> 500***
root ion toxicity	Boron (B) (mg/L or ppm)	< 0.5	0.5 - 2.0	> 2.0
	Chloride (Cl^-) (mg/L or ppm)****	< 70	70 - 355	> 355
	Chlorine (Cl_2) (mg/L or ppm)	< 1.0	1.0 - 5.0	> 5.0
	Sodium (Na^+) (SARw)****	< 3.0	3.0 - 9.0	> 9.0

Reference: Modified from Westcott, D.W. and R.S. Ayers. 1984. Irrigation water quality criteria. In G.S. Pettygrove and T. Asano (eds.) Irrigation with Reclaimed Municipal Wastewater – A guidance manual. Report No. 841-1wr. California State Water Resources Control Board, Sacramento, CA; and from D.S. Farnham et. Al. 1985. Water Quality: Its Effects on Ornamental Plants. University of California Division of Agriculture and Natural Resources Publication 2995.

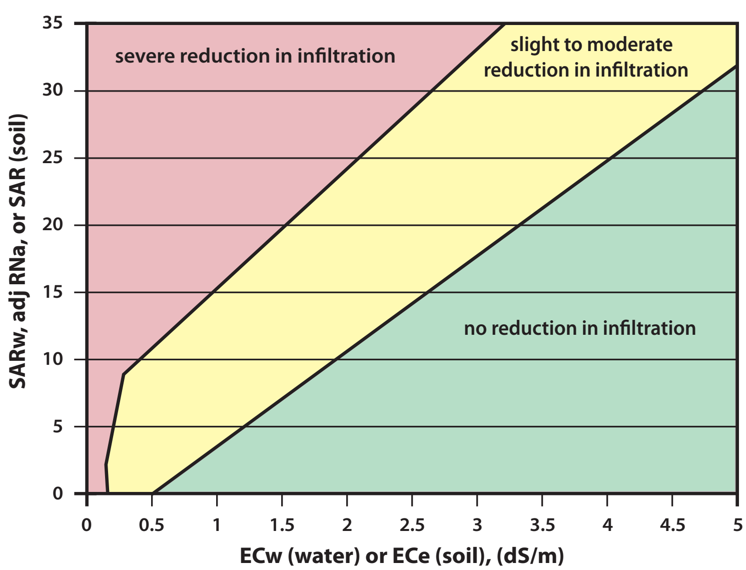
* Salinity tolerance varies greatly among turfgrass species. If medium to high salinity levels are found, this warrants monitoring of soil salinity levels (ECe) and comparing to the soil salinity tolerance of the turf species you are growing (Table 2) to determine if you have a potential water update problem from soil salinity.

** For irrigation water applied to soils with a pH of 7.0 or less, compare SARw to ECw. For irrigation water applied to soil with a pH greater than 7.0, compare adj SARw or adj RNa to ECw.

*** Likelihood of bicarbonate forming calcite and reducing permeability when sodium levels in irrigation water are low, or in non-arid regions with non-alkaline soils is being studied. *See further explanation in "THE DEBATE: Bicarbonate in Irrigation Water".*

**** Chloride and sodium toxicity is not common in turfgrasses, but these levels of may be toxic via root absorption to landscape plants. Chloride levels of more than 100 mg/L or ppm and sodium levels of more than 70 mg/L or ppm may also cause foliage damage on sensitive landscape plants.

Chart 1. Sodium permeability hazard of irrigation water as influenced by ECw.



Reference: From: Oster, J.D. and F.W. Schroer. 1979. Infiltration as influenced by irrigation water quality. *Soil Sci. Soc. Am. J.* 43: 444-447.

THE DEBATE:

Bicarbonate in Irrigation Water

High salinity, high sodium, and potential ion toxicity from irrigation water are problems that are all commonly agreed upon by turfgrass managers and turfgrass researchers alike.

However, the issue of whether medium to high bicarbonate levels in irrigation water (see Table 1) are a concern if sodium levels in the irrigation water are low, or in non-arid areas of the country with non-alkaline soils, is much less clear. There are anecdotal reports that high bicarbonate levels in irrigation water may reduce soil infiltration rates in non-arid regions during extended dry or drought conditions.

The hypothesis for this idea argues that bicarbonate anions (HCO_3^-) and calcium cations (Ca^{2+}) precipitate out as calcium carbonate ($CaCO_3$), or calcite, when the soil dries and these tiny calcite mineral deposits can partially plug pore spaces in the soil resulting in reduced infiltration rates. On the other hand, chemical equilibrium simulation software predicts bicarbonate anions and calcium cations only precipitate out as calcium carbonate, or calcite, in alkaline soils.

Ongoing research investigating these questions will hopefully settle this debate. Until then, testing for free lime layer formation using an excess carbonate or "fizz" test may be a useful tool to identify whether a calcite layer, significant enough to reduce infiltration rates, has actually formed in soils irrigated with irrigation water containing high bicarbonate levels.

Irrigation water quality testing is a good first step, because whatever is in your irrigation water will end up in your soil. If irrigation water quality test results indicate a potential problem with excessive salinity, excessive sodium, or toxic ions, you should test your soil for these same issues. However, irrigation water quality issues do not always result in problems in the soil, especially in non-arid regions with high precipitation rates and well drained soils, which allows natural leaching of salts past the root zone. So, if irrigation water quality tests indicate a potential problem, it is critical to test the soil to verify if there is a soil-related problem.

Like an irrigation water quality report, all the test results on a soil report can be a bit overwhelming too. However, if you focus on the soil test results that give you information to answer simple questions about potential salinity, sodium, and toxic ion problems in the soil, interpreting soil test reports can be relatively easy as well.

Does your soil contain a high enough concentration of salinity that it might cause a water uptake problem for turfgrass species growing in that soil?

HOW TO FIND THE ANSWER:

Identify the ECe value on your soil test report and compare to the ECe value ranges in Table 2 for the turfgrass species you are growing. Turfgrass species vary greatly in their tolerances to soil salinity. Some turfgrass species and cultivars are very sensitive to soil salinity while others are fairly tolerant. The ECe values on a soil test report should come from a *saturated paste extract test*. This value is sometimes reported by testing laboratories as *salinity ECe*. Be sure the lab you choose does perform the saturated paste extract procedure and specifically request that test when you submit a soil sample for salinity testing.

For fine-textured soils, does your soil contain a high enough concentration of sodium to cause soil deflocculation and a loss of soil structure, resulting in significantly reduced permeability?

HOW TO FIND THE ANSWER:

Identify the Exchangeable Sodium Percentage (ESP) value on your soil test report and compare it to the ESP value ranges in Table 3. ESP is often reported as exchangeable %Na in the base saturation section or cation exchange section of a soil test report*. Remember, sodium-induced soil deflocculation and the associated loss of soil structure is a problem in fine-textured soils with high silt and clay content, not in sands. In arid regions, it is important to keep ESP values below 10 in fine-textured soils.

* *Do not use salinity sodium values reported in units of meq/L, this is not ESP. ESP is always reported on a percentage basis.*

Does your soil contain enough boron or chlorine to worry about boron (B) or chlorine (Cl_2) toxicity in turfgrass?

HOW TO FIND THE ANSWER:

Identify the boron concentration on your soil test report. Boron levels as low as two to four ppm can be toxic to some turfgrass species. Chlorine concentrations in the soil are usually not reported on soil tests because chlorine is a gas and doesn't persist long in the soil. Avoid chlorine toxicity in the soil by using irrigation water low in chlorine (see Table 1).

Table 2. Relative tolerances of turfgrass species to soil salinity levels, and ECe levels at which salt stress symptoms may first appear.

Sensitive (<3 dS/m)	**Moderately Sensitive** (3 - 6 dS/m)	**Moderately Tolerant** (6 - 10 dS/m)	**Tolerant** (> 10 dS/m)
Annual bluegrass Colonial bentgrass Kentucky bluegrass Rough bluegrass	Annual ryegrass Creeping bentgrass Fine-leaf fescues Buffalograss	Perennial ryegrass Tall fescue Zoysiagrass	Alkaligrass Bermudagrass Seashore paspalum St. Augustinegrass

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

Table 3. Potential of sodium concentration in soil to reduce permeability as a function of ESP.

Sodium Hazard*	**Approximate Exchangeable Sodium Percentage**
None to slight (arid regions)** None to slight (non-arid regions)**	< 10 10 - 15
Light to moderate	15 - 30
Moderate to high	30 - 50
High to very high	50 - 70
Extremely high	> 70

Reference: Modified from: Ayers R.S. and Westcott D.W. 1985. Water quality for agriculture. Irrigation and Drainage Paper 29, Rev. 1. FAO, Rome. 174 pp.

* Impact of sodium will vary with soil texture and organic matter content of soil, with high clay soils being most negatively affected and sandy soils being least negatively affected.

** Reducing ESP to less than 10% in arid regions is desirable, while reducing ESP to less than 15% in non-arid regions is usually satisfactory during non-drought conditions. Reduce ESP to less than 10% in non-arid regions as well during drought conditions on non-sandy soils.

The following cultural practices and product recommendations for irrigation water quality issues are only required if associated salinity, sodium or toxic ion problems have been verified to be present in the soil.

High Irrigation Water Salinity *(ECw – Table 1)*

- Use reverse osmosis or blend irrigation water with another water source lower in soluble salts to reduce overall salinity to less than 2 dS/m.
- Use salt tolerant turfgrass species or cultivars.
- Leach the soil to move soluble salts below the root zone during each irrigation event to keep salinity levels from building up over time. Be sure to use the proper Leaching Requirement (LR) when you irrigate to maintain soil salinity levels at or below the maximum soil salinity tolerance of turfgrass species you are irrigating. The leaching requirement is the minimum amount of water that must percolate through the root zone to keep soil salinity levels at an existing, acceptable level, so this type of leaching can be viewed as maintenance leaching.
- If soil salinity levels have exceeded tolerance levels for the turfgrass you are irrigating, ***reclamation leaching*** must be performed prior to initiating a maintenance leaching program *(see High Soil Salinity - Management of Soil Salinity, Sodium & Ion Toxicity Problems - page 15)*.

Aquatrols Product Recommendations:

- Use an **Aquatrols surfactant** to improve the uniformity and effectiveness of your maintenance leaching program.
- Apply **AquaPlex amino** to improve turfgrass water uptake, and reduce physiological drought and other related salt stresses.

The Leaching Requirement (LR) equation:

$$\frac{\mathbf{ECw}}{\mathbf{5\ ECe - ECw}} \mathbf{\times 100}$$

where:

ECw = electrical conductivity of irrigation water from an irrigation water quality report (dS/m)
ECe = maximum soil salinity the turfgrass you are irrigating can tolerate (dS/m) *(see Table 2)*

Here is an example of how to use the leaching requirement equation:

Assume: (1) a water quality test report shows the ECw of your irrigation water is 2 dS/m and (2) you are growing Kentucky bluegrass that can't tolerate soil salinity of more than 3 dS/m (ECe from Table 2 - page 9). Insert these numbers into the LR equation and you get:

2 / ([5 x 3] – 2) X 100, or 15.4%.

This means you must apply 15.4% more irrigation water than the ET replacement value in order to keep soil salinity (ECe) below the 3 dS/m threshold for Kentucky bluegrass for each irrigation event.

Ultra Pure Water

- This is the opposite problem of high salinity in irrigation water. Some irrigation water sources are considered to be "ultra pure" because they contain almost no soluble salts. Problems can begin when ECw is less than 0.4 dS/m.
- Ultra pure water has the potential to reduce soil infiltration on some fine-textured soils by "stripping" calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations near the soil surface, resulting in a loss of soil structure often described as "crusting" in a thin layer right at the soil surface. It is thought that hydrogen ions (H^+) in ultra pure water can displace calcium (Ca^{2+}) and magnesium (Mg^{2+}) cations, but infiltration problems from irrigating with ultra pure water are far from universal and this phenomenon is not completely understood, so additional research is needed. Ultra pure water problems are much more common in Canada, California, snow-packed mountainous areas and in arid regions of the western United States than other areas of the country.
- If ultra pure water seems to be reducing infiltration, inject gypsum, fertilizer or blend effluent water to the ultra pure water to raise the ECw to at least 0.4 dS/m, or apply granular gypsum or salt-based fertilizers to the soil to supply a source of soluble salts.
- Use physical soil cultivation to break up the thin layer of soil "crusting" near the soil surface.

Aquatrols Product Recommendations:

- If granular gypsum is applied, use **Catrisal ST** to increase solubility of the gypsum.

Sodium-Induced Soil Deflocculation
(ECw vs. SARw, adj SARw or adj RNa – Table 1)

- Inject gypsum through irrigation system or apply granular gypsum to the soil to provide calcium cations (Ca^{2+}) which will displace sodium cations (Na^+) from cation exchange sites.
- Leach the soil to move displaced sodium cations below the root zone.
- Use physical soil cultivation to break up soil compaction caused by loss of soil structure.

Aquatrols Product Recommendations:

- If soils contain appreciable amounts of free lime (based on excess carbonate or "fizz test" results), **Blast Injectable** or **Blast Sprayable** can dissolve the calcium carbonate ($CaCO_3$) and release additional calcium cations (Ca^{2+}), which will help displace sodium cations (Na^+) from soil cation exchange sites.
- Apply **Catrisal ST** to increase solubility of applied gypsum.
- Use an **Aquatrols surfactant** to aid leaching of displaced sodium (Na^+) cations below the root zone.

High Bicarbonate & Sodium-Induced Soil Deflocculation *(Table 1)*

- If irrigation water has high bicarbonate (HCO_3^-) levels and a high likelihood of sodium-induced soil deflocculation, and if adj SARw or adj RNa is two to three units higher than SARw, treating the irrigation water with acid to lower the pH will reduce bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) levels in the irrigation water. The acid lowers the pH of the irrigation water and increases the hydrogen ion (H^+) concentration, and the hydrogen ions react with many of the carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) anions converting them into carbon dioxide (CO_2) and water (H_2O). When bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentration in irrigation water is reduced in this manner, more calcium cations (Ca^{2+}) and magnesium cations (Mg^{2+}) in the irrigation water will be available to compete with sodium (Na^+) on cation exchange sites in the soil.
- Apply granular gypsum to the soil to provide additional calcium cations (Ca^{2+}) which will displace sodium cations (Na^+) from soil cation exchange sites.
- Leach the soil to move displaced sodium cations (Na^+) below the root zone.
- Use physical soil cultivation to break up soil compaction caused by loss of soil structure.

Aquatrols Product Recommendations:

- An alternative to preventative acid treatment of irrigation water to lower pH, bicarbonate anion (HCO_3^-) and carbonate (CO_3^{2-}) anion concentrations is a curative treatment of the soil once or twice a month with **Blast Injectable** or **Blast Sprayable**. Either **Blast** product will dissolve calcium carbonate ($CaCO_3$) deposits that form in the soil when calcium cations (Ca^{2+}) react with bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) anions in irrigation water, and will release additional calcium cations (Ca^{2+}) into the soil solution to help displace sodium cations (Na^+) from cation exchange sites.
- Apply **Caltrisal ST** to increase solubility of applied gypsum.
- Use an **Aquatrols surfactant** to aid leaching of displaced sodium cations below the root zone.

Ion Toxicity *(Boron, Chloride, Chlorine or Sodium – Table 1)*

- Avoid using irrigation water containing more than one to two ppm boron (B) or five ppm or more chlorine (Cl_2) on turfgrasses if possible.
- Blend irrigation water with another water source that contains less boron or chlorine.
- Avoid using irrigation water with greater than 10 ppm chloride (Cl^-) or a SARw greater than three to prevent chloride or sodium root injury on sensitive woody ornamentals. In arid regions, native tree and shrub species may tolerate irrigation water with chloride (Cl^-) levels of 150 ppm or more. Check with your state university extension office for chloride and sodium root and foliage tolerances of landscape trees and shrubs in your area.

Aquatrols Product Recommendations:

- Use an **Aquatrols surfactant** to improve the uniformity and effectiveness of toxic ion leaching.

High Soil Salinity *(ECe – Table 2)*

Sometimes soil salinity levels (ECe) are found to be above the threshold level for the turfgrass species you are irrigating when soil testing is first initiated. This can occur in arid regions if a maintenance leaching program has not been established. It also can occur in non-arid regions during drought conditions as salts that are normally leached out of the soil by significant rain events build up in the soil during dry weather. In either case, soil salinity levels must be lowered to acceptable levels as soon as possible. This is commonly referred to as **Reclamation Leaching**, and requires a greater quantity of water to be applied than the Leaching Requirement (LR) equation described previously. **Reclamation Leaching** must be performed prior to beginning a maintenance leaching program using the Leaching Requirement equation if the soil salinity is above the threshold level. The amount of water needed for **Reclamation Leaching** can be determined by using the equation from Rhoades and Loveday (1990) - ***see opposite page.***

Aquatrols Product Recommendations:

- Use an **Aquatrols surfactant** to improve the uniformity and effectiveness of Reclamation Leaching (if needed) and your maintenance leaching program.
- Apply **AquaPlex amino** to improve turfgrass water uptake, and reduce physiological drought and other related salt stresses.

High Exchangeable Sodium Percentage *(ESP – Table 3)*

- Apply granular gypsum to the soil to provide calcium cations (Ca^{2+}) which will displace sodium cations (Na^{+}) from cation exchange sites.
- For arid regions, use Table 4 below to determine how much gypsum to apply per 12 inch soil depth to lower the ESP below 10%, based on the ESP value and soil texture. In non-arid regions, lower ESP below 15%.
- A particle size analysis test is required to accurately determine soil texture for use in Table 4.
- Leach the soil to move displaced sodium cations (Na^{+}) below the root zone.
- Use physical soil cultivation to break up soil compaction caused by loss of soil structure.

Aquatrols Product Recommendations:

- Apply **Caltrisal ST** to increase solubility of applied gypsum.
- If soils contain appreciable amounts of free lime, **Blast Injectable** or **Blast Sprayable** can dissolve the calcium carbonate ($CaCO_3$) and release additional calcium cations (Ca^{2+}), which will help displace sodium cations (Na^{+}) from soil cation exchange sites.
- Use an **Aquatrols surfactant** to aid leaching of displaced sodium cations below the root zone.

Table 4. Estimated gypsum requirements to reduce ESP below 10%.

Soil Texture	Clay Content	Initial Exchangeable Sodium Percentage (ESP)				
		15%	20%	30%	40%	50%
	%	Tons per acre				
Sand, loamy sand	0 - 15	0.5 - 2	0.7 - 3	1 - 4	2 - 5	3 - 8
Loams	15 - 55	2 - 3	3 - 4	4 - 6	5 - 8	7 - 10
Clays	> 55	3 - 4	4 - 6	6 - 8	8 - 11	10 - 14+

Reference: Carrow, R.N., and R.R. Duncan. 1998. Salt-Affected Turfgrass Sites: Assessment and Management. John Wiley & Sons.

The Reclamation Leaching equation: $\mathbf{D_w = k \times D_s \times (EC_{eo} - EC_w) / (EC_e - EC_w)}$

where:

- $\mathbf{D_w}$ = depth of water to apply (feet)
- $\mathbf{D_s}$ = depth of soil to be declaimed (feet)
- $\mathbf{EC_e}$ = final soil salinity desired (dS/m)
- $\mathbf{EC_{eo}}$ = original or initial excessive soil salinity prior to leaching (dS/m)
- $\mathbf{EC_w}$ = irrigation water salinity (dS/m)
- **k** = factor that varies with soil type and water application method (efficiency of irrigation system)

For sprinkler irrigation applied by pulse irrigation that results in unsaturated flow conditions by allowing drainage for one to two hours (sands) or two to eight hours (fine-textured soils) between a pulse irrigation event, with repeated pulse events until the total quantity of water necessary for leaching is applied, use:

k = 0.05 for high sand content soils > 95% sand (i.e. <5% silt + clay content)*
k = 0.10 for all other soils*

For continuous ponding or continuous sprinkler irrigation that results in saturated flow conditions with water applied to keep soils saturated during leaching, use:

k = 0.10 for sandy soils
k = 0.30 for fine-textured soils
k = 0.45 for organic soils

Reference: Modified from: Rhoades, J.D. and J. Loveday. 1990. Salinity in irrigated agriculture. In B.A. Stewart and D.R. Nielsen (Eds.). *Irrigation of Agricultural Crops*. Agronomy No. 30. Amer. Soc. Of Agron., Madison, WI.

***** Adjustments to "k" value for high-sand content greens are based on experience of Carrow, Huck and Duncan in: Duncan, R.R., R.N. Carrow, and M.T. Huck. 2009. Turfgrass and Landscape Irrigation Water Quality: Assessment and Management. CRC Press.

Here is an example of how to use the Reclamation Leaching equation to determine the quantity of water needed for reclamation leaching (D_w) using pulse irrigation:

Assume:

1. A USGA specification golf green with a 12 inch root zone and four inches of gravel over the drain tile (D_s = 16 inches or 1.33 feet)
2. The turfgrass species is creeping bentgrass with a soil salinity tolerance of 6 dS/m, so this is the maximum soil salinity desired after reclamation leaching (EC_e = 6 dS/m) *(see Table 2 - page 9)*
3. The sand root zone mix in the green has an excessive soil salinity of 12 dS/m (E_{co} = 12 dS/m)
4. The irrigation water that will be used for leaching in pulses has a salinity of 3 dS/m (EC_w = 3 dS/m)
5. The sand root zone mix contains over 95% sand (k = 0.05)

Enter the variables above into the reclamation leaching equation:

$D_w = k \times D_s \times (EC_{eo} - EC_w) / (EC_e - EC_w)$

$\mathbf{D_w}$ = 0.05 x 1.33 x (12 – 3) / (6 – 3) = 0.20 feet or **2.4 inches**

In this case, the total quantity of water to apply in pulse irrigation events to lower the soil salinity from 12 dS/m to 6 dS/m in reclamation leaching is 2.4 inches.

Free Lime Layer Formation

- If a free lime or calcium carbonate ($CaCO_3$) layer in non-calcareous soils forms due to irrigating with high bicarbonate (HCO_3^-) water for an extended period of time with little to no rainfall, it is possible this layer could reduce permeability. Verify existence of the layer by doing an excess carbonate test (fizz test).
- Use physical soil cultivation to break up free lime layer near the surface.

Aquatrols Product Recommendations:

- An application of **Blast Injectable** or **Blast Sprayable** one or twice a month can help dissolve this free lime or calcium carbonate layer and improve permeability.

Ion Toxicity (Boron, Chloride, Chlorine or Sodium)

- Leach the soil to move boron (B) below the root zone. Boron binds tightly to the soil, and requires twice as much water to carry it below the root zone as do soluble salts (Harivandi et al., 1992). Leaching conducted periodically during the season, and regular removal of leaf tips (where boron naturally accumulates) by mowing can make boron toxicity manageable.
- Leach the soil to move chloride (Cl^-) or sodium (Na^+) below the root zone for susceptible woody ornamentals. Turfgrasses generally are fairly tolerant of chloride in the soil, although chloride contributes to total soil salinity.
- Chlorine (Cl_2) is a gas and doesn't persist long in the soil, so chlorine levels are not tested for in soils. Contact your recycled water supplier for chlorine levels in your irrigation water if you suspect chlorine toxicity is possible.

Aquatrols Product Recommendations:

- Use an **Aquatrols surfactant** to improve the uniformity and effectiveness of toxic ion leaching.

Table 5. Summary of cultural practices and Aquatrols products to use for irrigation water quality and soil salinity, sodium and ion toxicity problems.

	CULTURAL PRACTICES AND AQUATROLS PRODUCTS TO USE TO HELP MANAGE PROBLEMS									
IRRIGATION WATER QUALITY PROBLEMS	Reverse osmosis or blend with better quality water	Use reclamation leaching and/ or maintenance leaching	Use an Aquatrols surfactant to improve leaching	Physical soil cultivation	Use more salt tolerant turf species or cultivars	Inject gypsum or fertilizer, or blend in effluent water	AquaPlex amino	Blast Injectable	Blast Sprayable	Caltrisal ST
ultra pure water				●		●				
high bicarbonate & sodium-induced soil deflocculation		●	●	●				●	●	●
turf root toxicity	●	●	●							

SOIL SALINITY, SODIUM OR TOXICITY PROBLEMS	Reverse osmosis or blend with better quality water	Use reclamation leaching and/ or maintenance leaching	Use an Aquatrols surfactant to improve leaching	Physical soil cultivation	Use more salt tolerant turf species or cultivars	Soil apply granular gypsum	AquaPlex amino	Blast Injectable	Blast Sprayable	Caltrisal ST
high salinity	●	●	●		●		●			
high ESP		●	●	●		●				●
high ESP + high free lime in soil		●	●	●		●		●	●	●
free lime layer formation				●				●	●	
turf root toxicity	●	●	●							

COMMON UNITS OF MEASURE AND CONVERSION FACTORS

Symbol	Meaning	Units
ECe ECw	Electrical conductivity (soil) Electrical conductivity (irrigation water)	dS/m mmhos/cm µmhos/cm
TDS	Total dissolved salts (irrigation water)	mg/L ppm
CEC	Cation exchange capacity (soil)	meq/100 g dry soil
SARw	Sodium adsorption ratio (irrigation water)	–
adj SARw	Adjusted sodium adsorption ratio (irrigation water)	–
adj RNa	Adjusted sodium hazard (irrigation water)	–
ESP	Exchangeable sodium percentage (soil)	–

Unit Conversions

1 dS/m = 1 mmhos/cm = 1000 µmhos/cm
1 mg/L = 1 ppm

TDS (mg/L or ppm) = ECw (dS/m) x 640 → (when ECw < 5 dS/m)
TDS (mg/L or ppm) = ECw (dS/m) x 800 → (when ECw > 5 dS/m)
TDS (lbs/ac-ft) = TDS (mg/L or ppm) x 2.72

ECw (dS/m) = TDS / 640 → (when TDS < 3200 mg/L or ppm)
ECw (dS/m) = TDS / 800 → (when TDS > 3200 mg/L or ppm)

Ion Concentration Conversions

	To convert mg/L to meq/L, multiply mg/L by:	To convert meq/L to mg/L, multiply meq/L by:
Bicarbonate (HCO_3^-)	0.016	61
Calcium (Ca^{2+})	0.050	20
Carbonate (CO_3^{2-})	0.033	30
Magnesium (Mg^{2+})	0.083	12
Sodium (Na^+)	0.043	23

EQUATIONS TO ASSESS SODIUM HAZARD IN IRRIGATION WATER

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

$$\textbf{adj SAR} = SAR\,[1 - (8.4 - pH_c)]$$

$$\textbf{adj RNa} = \frac{Na}{\sqrt{\frac{Ca_x + Mg}{2}}}$$

where:

Na = sodium in irrigation water (meq/L)

Mg = magnesium in irrigation water (meq/L)

Ca = calcium in irrigation water (meq/L)

Ca_x = a modified calcium value based on irrigation water salinity (ECw), HCO_s /Ca ratio (meq/L) and estimated partial pressure of CO_2 in the surface of the soil (PCO_2 = 0.007 atmospheres). Ca_x can be found in Table 11 at: http://www.fao.org/docrep/003/t0234e/T0234E04.htm

pH_c = theoretical pH of the irrigation water in equilibrium with $CaCO_3$

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Aquatrols®

1273 Imperial Way • Paulsboro, NJ 08066 USA
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