Assessing the Suitability of Water (Quality) for Irrigation - Salinity and Sodium

J. W. Bauder[1], T.A.Bauder[2], R. M. Waskom[3], Thomas F. Scherer[4]

Introduction

The face of irrigated agriculture is changing with respect to water quantity and quality. In the not-to-distant past, neither irrigators nor agricultural crop advisors had to give much consideration to either the supply or the quality of irrigation water. Supplies of good-quality water, well-matched to crop irrigation, were plentiful, generally uncontested, and not necessarily closely monitored or regulated.

However, growing competition for and accountability of the use of water have contributed to increasing scrutiny about just how water is used, how much water is available to the public for non-agricultural uses, and what practices impact the quality of our nation's water resources. Correspondingly, irrigators in many watersheds and irrigation districts have had to face and respond with changing practices to increasing scrutiny about how to best manage available water resources. Along with that has come growing attention to the quality of water available for irrigation. In fact, growing competition for use of limited water supplies has been the impetus for some irrigators to consider using water previously thought to be of only marginal quality and suitability for irrigation.

Typically, qualities of irrigation water which deserve consideration include the salt content, the sodium concentration, the presence and abundance of macro- and micro-nutrients and trace elements, the alkalinity, acidity, and hardness of the water. Under some circumstances, the suspended sediment concentration, bacterial content, and temperature of irrigation water may also deserve attention.

Salinity – the amount of dissolved salt in water. All water used for irrigation contains some salt! This salt generally comes from weathering of soil, leaching of salts dissolved from geologic marine sediments into the soil solution or groundwater, and flushing of salts off of roads, landscapes and stream banks during and following precipitation events. Typically, groundwater contains more salt than surface water. Additionally, the amount of salt found in irrigation water generally is greater in arid and semi-arid areas than in humid and sub-humid areas.

Salinity – the amount of salt dissolved in water – directly affects plant growth, generally has an adverse effect on agricultural crop performance, and can also affect soil properties. Consequently, without knowledge of both soil and water salinity and correspondingly appropriate management, long-term irrigated crop productivity can decrease.

Salt is defined as a water-soluble compound resulting from the combination of an acid and a metal. Generally, we associate the terms saline, salt, and salinity with sodium chloride (NaCl), otherwise known as common table salt. However, salinity of irrigation water generally is a combination of numerous salts. The cations and anions most frequently found in irrigation water are: sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), chloride (Cl^-), sulfate (SO_4^{2-}), and bicarbonate (HCO_3^-). These salts are most often thought of by their common names (Table 1).

Table 1. Some salts commonly contributing to the salinity of water.

Salt	Symbol	Common Name
sodium chloride	NaCl	table salt
calcium chloride	$CaCl_2$	common de-icing agent
magnesium chloride	$MgCl_2$	common de-icing agent
sodium sulfate	Na_2SO_4	thenardite; Glauber's salt when hydrated
calcium sulfate	$CaSO_4$	gypsum
magnesium sulfate	$MgSO_4$	Epsom salt
sodium bicarbonate	$NaHCO_3$	baking soda
calcium carbonate	$CaCO_3$	limestone
calcium-magnesium carbonate	$CaMg(CO_3)_2$	dolomite

Salt accumulates and concentrates in soil when water evaporates from the soil surface, when plants use water, when leaching is not adequate to leach salts beyond the root zone, and/or when precipitation does not wash salts off the land surface. As water evaporates from a soil surface, or is used by plants, the water that is used or taken up by plants is essentially distilled or purified, leaving salts behind. In essence, water that is considered saline contains excessive amounts of soluble salts which can adversely affect the growth of plants.

Salts are composed of positively and negatively charged ions, which dissociate when salt is dissolved in water. The positively charged ions are cations, and the negatively charged ions are anions. The salinity of irrigation water can be determined directly by measurement of the concentration of all the dissolved salts in a water sample. This type of measurement is made by an analytical laboratory using equipment that will determine the concentration of each anion and cation; these concentrations are then added together to get the total dissolved solids (TDS) concentration. TDS is typically expressed as either milligrams/liter (mg/L) or parts per million (ppm), which for all practical purposes is the same as mg/L.

Another approach is to completely evaporate a sample of water from which the sediment has been filtered and determine the mass of the residue (salts) remaining in the container. This approach also results in determination of the TDS.

The dissociation of salt into anions and cations in water is what allows water containing salt to conduct electricity – something which distilled water does not do. Correspondingly, the salinity of water can be equated to and estimated from the ability of water to conduct electricity; saline water conducts electricity more effectively than water with little or no dissolved salt.

Most commonly, suitability of irrigation water, with respect to salinity, is assessed on the basis of the 'electrical conductivity' (EC) or 'specific conductance' of a water sample. This can be done either in a laboratory or with a relatively inexpensive, hand-held, battery-powered EC meter. The EC of irrigation water is often denoted as EC_w and is expressed as either millimhos/cm (mmhos/cm), micromhos/cm (umhos/cm) or deciSiemens/m (dS/m).

A few simple conversions allow for comparison of salinity values measured or reported by different units.

For example:

1 ppm = 1 mg/L for all practical purposes in dealing with salinity
1 ppm = 1 mg/kg (milligram per kilogram)
1 percent concentration = 10,000 ppm
1 mmolc/L = 1 meq/L
1 mmhos/cm = 1 dS/m
1 mmhos/cm = 1000 umhos/cm

Conversions:

TDS (ppm or mg/L) = 640 x EC_w (dS/m or mmhos/cm) when $EC_w < 5$ dS/m
TDS (meq/L) = 10 x EC_w (dS/m or mmhos/cm) when $EC_w < 5$ dS/m
TDS (ppm or mg/L) = 800 x EC_w (dS/m or mmhos/cm) when $EC_w > 5$ dS/m
EC_w (dS/m or mmhos/cm) = TDS (ppm or mg/L) / 640 when $EC_w < 5$
Note: < means 'less than'; > means 'greater than'.

The conversions of TDS to EC_w and vice-versa are merely approximations, since EC_w varies with ion composition and temperature; and the relationship between TDS and EC_w is not perfectly linear.

Not all labs report salt concentrations in the same units. Thus, it is often necessary to convert from one unit of measurement to another. Parts per million (ppm), milligrams per liter (mg/L), and milligrams per kilogram (mg/kg) are numerically equivalent and interchangeable. Another unit which is often reported, millequivalent weight, or meq/L, is a unit used to compare concentrations of ions with different atomic weights and charges. Equivalent weight is simply the atom-

Four principal units are used to express the concentration of salt in water.

1. grains per gallon; grains per gallon x 17.2 = parts per million

2. parts per million (ppm); 1 part of salt to 1 million parts of water. For all practical purposes – numerically equivalent to milligrams/liter (mg/L)

3. milligrams per liter (mg/l); 1 milligram of salt per kilogram (or liter) of solution

4. milliequivalents per liter (meq/L);a numerical expression of concentration of salt, based on the atomic weight of the ion divided by its valence; a measurement of charge concentration/liter

ic weight of an ion divide by its charge. To convert ppm, mg/L or mg/kg to meq/L , the ppm, mg/L or mg/kg value needs to be divided by the equivalent weight.

Ion	Symbol	Equivalent Weight* (g)
Calcium	Ca^{+2}	20
Magnesium	Mg^{+2}	12
Sodium	Na^{+}	23
Potassium	K^{+}	39
Bicarbonate	HCO_3^{-}	61
Carbonate	CO_3^{-2}	30
Chloride	Cl^{-}	35.5
Sulfate	SO_4^{-2}	48

*Note: A meq is 1/1000th of an equivalent

The conversions are as follows:

meq/L = ppm / equivalent weight

ppm = equivalent weight / meq/L

To calculate the total pounds of dissolved salts contained in an acre-foot of irrigation water, multiply TDS (ppm, mg/L, or mg/kg) by 2.72. For example, water having an EC_w of 1.15 mmhos/cm would contain [1.15 mmhos/cm x 640 mg/L/mmhos/cm x 2.72 pounds/mg/L] = 2002 pounds of dissolved salt per acre foot of water.

The problem with salinity. Saline conditions restrict or inhibit the ability of plants to take up water and nutrients, regardless of whether the salinity is caused by irrigation water or soil water which has become saline because of additions of salty water, poor drainage, or a shallow water table. Plants uptake water through a process of 'osmo-regulation', wherein elevated salt concentration within plants causes water to move from the soil surrounding root tissue into the plant root. When the soil solution salinity is greater than the internal salinity of the plant, water uptake is restricted. The result is often a smaller plant than one not affected by salinity. Yield reduction may occur even where plant symptoms appear minimal. In situations of especially elevated salinity, plant tissue may die, thereby exhibiting necrosis at the leaf edges . Additionally, saline water may lead to concentrations of some elements which can be toxic to plants. Some examples of frequently occurring specific-ion toxicities include boron, sodium, and chloride.

Numerous guidelines for assessment of the salinity hazard of irrigation water have been published. A summary of guidelines is presented in Table 2. It is important to note that irrigation water hazard levels and soil salinity hazard levels are not equivalent.

Table 2. General guidelines for assessment of salinity hazard of irrigation water.

	Limitation		
	None	**Moderate**	**Severe**
EC_w[1,2,3] (mmhos/cm, dS/m)	< 0.75	0.75-3.0	> 3.0
TDS[2] (mg/L)	< 450	450-2000	>2000

[1] Schafer, W. M. 1983. Irrigation water quality in Montana. Montana State University Coop. Ext. Serv., Montguide MT8373.

[2] Miller, R. W., and D. T. Gardiner. 2001. Soils in our environment. 9th edition. Prentice Hall-Inc., Upper Sddle River, New Jersey 07458. ISBN 0-13-020036-0, Table 15-6. Source: Guidelines for Irrigation Water Quality – from Food and Agriculture Organization (FAO) guidelines.

[3] Western Fertilizer Handbook 1995. California Fertilizer Association. 1700 I Street, Suite 130, Sacramento, CA. 95814. ISBN 0-8134-2972-2. Note: no limitation ECw is 0.7 mmshos/cm

Sodicity – the amount of sodium, relative to the amount of calcium and magnesium. Sodic water is water with a high concentration of sodium, relative to the concentration of calcium and magnesium. Sodic water is not the same as saline water. Sodium adsorbs onto cation exchange sites of the soil, which causes aggregates of some soils to break down (disperse), leading to sealing of soil pores and a reduction in permeability to water flow. This typically only happens to soil with a relatively high percentage of smectite clay, which is a group of clay minerals that includes montmorillonite and bentonite. This type of mineral tends to swell when exposed to water. Once a clay-dominated soil disperses, the soil will either become anaerobic (lacking oxygen), saline, or compacted/consolidated.

The tendency for sodium to increase its proportion on the cation exchange sites at the expense of other types of cations (primarily calcium and magnesium) is estimated by the sodium adsorption ratio (SAR), which is the ratio of sodium concentration to the concentration of the square root of the average calcium plus magnesium concentration in either irrigation water or the soil solution (Miller and Gardiner, 2007).

$$SAR = \frac{Na^{+}\ \text{meq/L}}{\sqrt{\dfrac{(Ca^{++}\ \text{meq/L}) + (Mg^{++}\ \text{meq/L})}{2}}}$$

Numerically, SAR is:

It is important to remember that SAR values are calculated using meq/L.

Numerous references refer to sodicity problems associated with irrigation water as permeability. Complicating the issue of sodicity is the fact that at very low salinity levels (even though the ratio of sodium to calcium plus magnesium may be high), soil flocculation and aggregation (which occurs with any high salt concentration) is lost and permeability decreases. Thus, irrigation water which is very low in salt concentration (< 0.2 dS/m) accentuates poor permeability resulting from high SAR. This principle is illustrated in Table 3, which provides a summary of guidelines for assessment of sodium hazard of irrigation water (as applied to dispersive, smectite-rich soils).

Adjusted SAR (SAR_{adj})

The presence of or introduction of bicarbonate and carbonate ions in the irrigation water increases the permeability hazard as quantified by SAR. Irrigation of calcium-rich or magnesium rich soil with water containing carbonate or bicarbonate ions will form insoluble calcium and magnesium carbonate (limestone, dolomite), thereby reducing the concentration of calcium and magnesium applied to the SAR calculation. This consideration in the calculation of SAR results in the adjusted SAR (SAR_{adj}) being greater than the SAR, thereby providing a truer index of the sodicity of the water and the risk of dispersion. Most SAR_{adj} values of irrigation waters are about 10 to 15 percent greater than the unadjusted SAR. Additionally, irrigation water with a low salt concentration and a high SAR will contribute to reduced permeability of dispersive soils eventually. It is important to know if you are dealing with SAR or SAR adjusted when interpreting results.

Table 3. Guidelines for assessment of sodium hazard of irrigation water based on SAR and EC_w[2], when applied to soils containing more than 30% smectite clay.

	Limitation		
	None	**Moderate**	**Severe**
	EC_w (dS/m)		
When SAR = 0-3 and EC_w	>0.7	0.2-0.7	< 0.2
When SAR = 3-6 and EC_w	> 1.2	0.3-1.2	< 0.3
When SAR = 6-12 and EC_w	> 1.9	0.5-1.9	< 0.5
When SAR =12-20 and EC_w	> 2.9	1.3-2.9	< 1.3
When SAR = 20-40 and EC_w	>5.0	2.9-5.0	< 2.9

[2]Modified from Miller and Gardiner (2007), Table 15-6, page 452. Source: R. S. Ayers and D. W. Westcot. 1989. Water Quality for Agriculture, Irrigation and Drainage Paper 29, rev. 1, Food and Agriculture Organization of the United Nations, Rome.

Dealing with salinity in irrigation water:

1. irrigate only well-drained soils

2. irrigate more frequently and determine leaching requirement. (See references 3,4 for explanation of of LR)

3. minimize contact with plant leaves

4. plant salt-tolerant crops

5. avoid irrigation to seedlings and young plants

Managing irrigation water with salt or sodium.

Leaching of salt below the crop root zone is essential for sustainable irrigated agriculture. With reasonably good irrigation practices on well-drained soils, including periodic leaching either with ample irrigation water or with precipitation, the average salt content of the saturated soil extract will be about 1.5 times the salt content of the irrigation water . Where water is less plentiful, evaporation and transpiration are relatively high, and leaching is less frequent, the saturated soil extract may have a salt concentration three or more times that of the irrigation water – due almost exclusively to the concentrating effect of salt as water either evaporates from the soil or is transpired by the growing crop. Consequently, as a basic guideline, the amount of water – quantity and frequency of availability – needs to be increased as the salinity level of the irrigation water increases.

Managing irrigation water with elevated sodium concentration is somewhat more challenging – due to the complexity of interactions between clay particles, sodium and salt concentration of the irrigation water, and rainfall . As a basic guideline, efforts should be made to avoid applying irrigation water with SAR greater than 6[3] to irrigated soils with more than 30% smectite clay. It is reasonable to expect that severe problems will occur on these soils if the SAR exceeds 9. Generally speaking, poorer quality water (higher salinity x SAR) can be used to irrigate sandy, well-drained soils with good drainage than can be used to irrigate soils having relatively high clay contents.

Reducing sodium-related permeability problems:

1. apply a source of soluble calcium

2. reduce the pH and bicarbonate in the irrigation water (acidify) by adding sulfuric acid

3. incorporate elemental sulfur into soil where free lime is present

Source: Western Fertilizer Handbook, pg. 41-42

Authors

[1/]J. W. Bauder – Professor, Montana State University, Bozeman, MT,
[2/]T.A.Bauder – Extension Water Quality Specialist, Colorado State University, Fort Collins, CO,
[3/]R. M. Waskom – Director, Colorado Water Institute, Colorado State Univesity, Fort Collins, CO
[4/]Thomas F. Scherer – Extension Agricultural Engineering Specialist, North Dakota State University, Fargo, ND

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[2]Miller, R. W., and D. T. Gardiner. 2007 Soils in our environment. 9th edition. Prentice Hall-Inc., Upper Sddle River, New Jersey 07458. ISBN 0-13-020036-0, Table 15-6, page 452. Source: R. S. Ayers and D. W. Westcot. 1989. Water Quality for Agriculture, Irrigation and Drainage Paper 29, rev. 1, Food and Agriculture Organization of the United Nations, Rome.

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