SALINITY ASSESSMENT & BASIC CONCEPTS

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Useful references

- **Agricultural Salinity & Drainage**
  Hanson, Grattan & Fulton (2006). Ag & Natural Resources (ANR), Univ. California. Pub. #3375

- **FAO 29: Water Quality for Agriculture**
  FAO Irrigation & Drainage series
  [www.fao.org/DOCREP/003/T0234E/T0234E00.HTM](http://www.fao.org/DOCREP/003/T0234E/T0234E00.HTM)

- **FAO 48: Use of Saline Waters for Crop Production**
  Rhoades et al. (1992).
  FAO Irrigation & Drainage Series
Outline

- What is salinity?
- What is sodicity?
- Salinity units, conversions (and sodicity)
- Osmotic vs. Specific Ion Effects of salinity
- Salt tolerance rankings ⇒ Maas Hoffman tables
- Salinity Management
  - Leaching fraction (LF) and Leaching requirement (LR)
- Field Assessment
  - In-situ vs. traditional soil and water sampling
Common salinizing Constituents

- Sodium \((\text{Na}^+))\)
- Calcium \((\text{Ca}^{2+})\)
- Magnesium \((\text{Mg}^{2+})\)
- Chloride \((\text{Cl}^-)\)
- Sulfate \((\text{SO}_4^{2-})\)
- Bicarbonate \((\text{HCO}_3^-)\)

Cations

Anions

Boron \((\text{B})\), Carbonate \((\text{CO}_3^{2-})\), Nitrate \((\text{NO}_3^-)\), Potassium \((\text{K}^+)\)
Where does Salinity come from?

- **Parent Material of the soil**
  - Westside SJV: marine sediments
  - Eastside SJV- granitic materials, not contributing much salinity

- **Irrigation water**
  - Imperial Valley– Colorado River water has more salt
  - Westside SJV– a large volume of low salt canal water applied or now, a lesser volume of more saline well water applied.

- **Fertilizers and amendments**
- **Shallow groundwater**

- **Sea spray or seawater intrusion (coastal areas)**
Measuring salinity

- **Total Dissolved Solids (TDS) in ppm (= mg/L)**

- **Electrical conductivity (EC) in dS/m (= mmho/cm)**
  - “Saline soil” = EC > 4 dS/m (~ Soil Science Society of America)
  - *Preferred because MH salinity tolerance tables based on ECe.*

- EC = TDS x ~640 (for EC ≤ 5 dS/m)
- EC = TDS x ~800 (for EC 5 – 10 dS/m) or for Ca salts
- EC (drainage waters) = TDS x 740/840/920 for EC’s of ≤5, 5-10, >10 dS/m, respectively
Different types of EC

- \( EC_w = \) Electrical conductivity of a water

- \( *EC_e = \) EC of saturated soil paste extract

\[ EC_w \times \sim 1.3 \text{ to } 1.5^* = EC_e \]

*depends on soil texture, leaching fraction, frequency of irrigation

- \( EC_{sw} = \) EC of the soil water

  (nearly twice that of \( EC_e \))

- \( EC_a \) or \( EC_b = \) apparent (or bulk) soil conductivity

  (EM-38 or Veris soil mapping)

  (Decagon 5TE & Delta-T WET sensors)
Expected Soil Salinity (ECe) for Irrigation Water of given salinities (ECw):

\[ \text{ECe} = \text{ECw} \times 1.5 \quad (w/ \text{LF 15-20%}) \]
Sodicity

Condition of excess of sodium with respect to calcium and magnesium, in the presence or absence of salinity.

- **Soils**: measured either as:
  - ESP (exchangeable sodium). ESP > 15 = sodic soil condition
  - SAR (sodium adsorption ratio). SAR > 13 = """

\[
SAR^* = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad \text{*concs. in meq/L}
\]

- **Water**: high SAR (> 8-10)
Problem for soils. Sodium disperses clays (and O.M.), degrading soil structure and reducing infiltration.

Plant Health:
-- Indirect effect: poor aeration and distribution of water. Tough surface crust, hard for seeds to germinate

-- Nutritional: negative impact on Ca nutrition. High pH reduces availability of P and cationic micronutrients.
San Luis Rio Colorado delta area: saline-sodic, cracking clay soils
High SAR (& low EC) water infiltrates poorly

- **Ideal zone**
- **Severe Reduction in Infiltration**
- **Slight to Moderate Reduction in Infiltration**
- **No Reduction in Infiltration**

Sodium Adsorption Ratio

EC of Irrigation Water (dS/m)
## Classification of Soils (or water)

<table>
<thead>
<tr>
<th></th>
<th>Salinity (ECe) (dS/m)</th>
<th>Sodicity (SAR)</th>
<th>pH</th>
<th>Physical Condition of Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Non-saline</strong></td>
<td>&lt; 4</td>
<td>&lt; 13</td>
<td>&lt; 8.5</td>
<td>Normal</td>
</tr>
<tr>
<td><strong>“Saline”</strong></td>
<td>&gt; 4</td>
<td>&lt; 13</td>
<td>&lt; 8.5</td>
<td>Normal</td>
</tr>
<tr>
<td><strong>“Saline-sodic”</strong></td>
<td>&gt; 4</td>
<td>&gt; 13</td>
<td>&lt; 8.5</td>
<td>Some degradation</td>
</tr>
<tr>
<td><strong>“Sodic”</strong></td>
<td>&lt; 4</td>
<td>&gt; 13</td>
<td>&gt; 8.5</td>
<td>Poor</td>
</tr>
</tbody>
</table>

Proper management requires proper determination of the soil condition: saline, saline-sodic, or sodic
Salinity affects plant growth and performance due to:

- Osmotic effects - more immediate
- Specific ion effects (Na & Cl-), longer term effect
  - Ion toxicities
  - Nutritional disorders
Salinity effects on plants: osmotic

Salt-stressed Lettuce

Celery

0 4 8 12

Cotton at increasing salinity

Salinity
Salinity effects on plants: specific ion (Na⁺, Cl⁻)

Strawberry: chloride toxicity
Crop choice (MH salinity tolerance tables)

Planting position

Choice of irrigation water

Leaching*

Subsurface Drainage*
### MH Salinity tolerance tables

Most vegetables are sensitive (S) or moderately sensitive (MS). The table below shows the salt tolerance of various vegetables and fruit crops.

<table>
<thead>
<tr>
<th>Crop</th>
<th>Threshold Salinity (A)</th>
<th>Slope (B)</th>
<th>Rating*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artichoke</td>
<td>6.1</td>
<td>11.5</td>
<td>MT</td>
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<td>Asparagus</td>
<td>4.1</td>
<td>2.0</td>
<td>T</td>
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<td>Bean, Common</td>
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<td>19.0</td>
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<td>Bean, Mung</td>
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<td>S</td>
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<td>Beet, red</td>
<td>4.0</td>
<td>9.0</td>
<td>MT</td>
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<td>Broccoli</td>
<td>2.8</td>
<td>9.2</td>
<td>MS</td>
</tr>
<tr>
<td>Brussels sprouts</td>
<td></td>
<td></td>
<td>MS</td>
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<tr>
<td>Cabbage</td>
<td>1.8</td>
<td>9.7</td>
<td>MS</td>
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<tr>
<td>Carrot</td>
<td>1.0</td>
<td>14.0</td>
<td>S</td>
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<td>Cauliflower</td>
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<td>6.2</td>
<td>MS</td>
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<tr>
<td>Celery</td>
<td>1.8</td>
<td>12.0</td>
<td>MS</td>
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<td>Corn, sweet</td>
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<td>MS</td>
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<td>Cowpea</td>
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<td>MS</td>
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<td>Kohlrabi</td>
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<td>MS</td>
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<td>1.0</td>
<td>8.4</td>
<td>MS</td>
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<tr>
<td>Okra</td>
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<td>MS</td>
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<td>S</td>
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<td>Pea</td>
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<td>Spinach</td>
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<td>7.6</td>
<td>MS</td>
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<td>Squash, zucchini</td>
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<td>10.5</td>
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<td>Strawberry</td>
<td>1.0</td>
<td>33.0</td>
<td>S</td>
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<td>Sweet potato</td>
<td>1.5</td>
<td>11.0</td>
<td>MS</td>
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<td>Tomato</td>
<td>2.5</td>
<td>9.9</td>
<td>MS</td>
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<td>Tomato, cherry</td>
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<td>9.1</td>
<td>MS</td>
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<td>0.9</td>
<td>9.0</td>
<td>MS</td>
</tr>
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<td>Turnip, greens</td>
<td>3.3</td>
<td>4.3</td>
<td>MT</td>
</tr>
<tr>
<td>Watermelon</td>
<td></td>
<td></td>
<td>MS</td>
</tr>
</tbody>
</table>

* S = sensitive; MS = moderately sensitive; MT = moderately tolerant; T = tolerant
Salinity Response Curve (slope & threshold)
**Crop salt tolerance**

**RY = 100% - slope (ECe - threshold ECe)**

- Lower threshold, but low slope
  - Compensates

- Higher threshold, but higher slope

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**Average Rootzone Salinity (ECe)**

- Strawberry
- Lettuce
- Berry
- Broccoli
- Artichoke
- Asparagus

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*Maas and Grattan, 1999*

*Slide from Steve Grattan, UC Davis*
Crop Salt Tolerance in Gypsiferous Soils
(may tolerate an ECe substantially higher than their threshold value*)

*when preparing the saturated paste, some of the gypsum, not normally soluble, goes into solution, ↑’ing the ECe

Slide from Steve Grattan, UC Davis.
### Table 9-1  Salinity Thresholds for Crop Yield Reduction Due to Salinity of the Saturation Extract (ECe) or Irrigation Water (ECw), and Salinity Levels Corresponding to 90% and 50% Yields

<table>
<thead>
<tr>
<th>Crop</th>
<th>Threshold</th>
<th>90% Yield</th>
<th>50% Yield</th>
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<tbody>
<tr>
<td></td>
<td>ECe</td>
<td>ECw</td>
<td>ECe</td>
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<tr>
<td>Alfalfa</td>
<td>2.0</td>
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<td>1.0</td>
<td>2.0</td>
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<td>Barley</td>
<td>8.0</td>
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<td>10.0</td>
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<td>Bean</td>
<td>1.0</td>
<td>0.7</td>
<td>1.5</td>
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<tr>
<td>Bermuda grass</td>
<td>6.9</td>
<td>4.6</td>
<td>8.5</td>
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<tr>
<td>Blackberry</td>
<td>1.5</td>
<td>1.0</td>
<td>2.0</td>
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<td>Broccoli</td>
<td>2.8</td>
<td>1.9</td>
<td>3.9</td>
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<td>Carrot</td>
<td>1.0</td>
<td>0.7</td>
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<td>Corn</td>
<td>1.7</td>
<td>1.1</td>
<td>2.3</td>
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<tr>
<td>Cotton</td>
<td>7.7</td>
<td>5.1</td>
<td>9.6</td>
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<tr>
<td>Cucumber</td>
<td>2.5</td>
<td>1.7</td>
<td>3.3</td>
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<td>Date palm</td>
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<td>6.8</td>
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<td>Flax</td>
<td>1.7</td>
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<td>2.5</td>
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<td>Grape</td>
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<td>1.0</td>
<td>2.5</td>
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<td>Onion</td>
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<td>Orange</td>
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<td>3.5</td>
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<td>1.7</td>
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<td>Rice</td>
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<td>Sorghum</td>
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<td>7.4</td>
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<td>Tall fescue</td>
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<td>Tall wheatgrass</td>
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<td>9.9</td>
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<td>3.5</td>
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<td>Wheat</td>
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<td>Zucchini</td>
<td>4.7</td>
<td>3.1</td>
<td>5.8</td>
</tr>
</tbody>
</table>


Salinity tolerance tables based on: -- ECe or ECw -- 100% yield or less
For some crops, tolerance to salinity may be less if sprinkling

<table>
<thead>
<tr>
<th>Sodium or chloride concentration (meq/l) susceptibility level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5</td>
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<tr>
<td>Almond</td>
</tr>
<tr>
<td>Apricot</td>
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<tr>
<td>Citrus</td>
</tr>
<tr>
<td>Plum</td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
</tr>
</tbody>
</table>

Hansen & Grattan (2006), Ag Salinity & Drainage Manual
Leaching Fraction (LF)

LF = volume of water that drains below the rootzone / volume of water that infiltrates into the soil

But how do we measure this???

Slide from Steve Grattan, UC Davis
Salinity distribution in relation to various leaching fractions

Same irrigation water ECw

Soil Depth

High LF

Low LF

ET

40%

30%

20%

10%

ECe

Slide from Steve Grattan, UC Davis
Leaching Requirement (LR)

Letey (CA-ASA, 2011): the minimum LF required over a growing season for a particular quality of water to achieve maximum yield of a given crop and has a specific quantitative value. More relevant to maintenance leaching)

\[
LR = \text{minimum amount of water, in excess of irrigation requirement, needed to leach salts through a water-saturated soil and ensure proper salt balance.}
\]

- Expressed as the decimal fraction* of the water needed to wet the soil (bring to FC) that must be applied additionally.

*So... ...LR is a number between 0 and 1.
Example: irrigating with **1.4 dS/m water**, your tomato crop requires 36 in. of water and from MH salinity tolerance tables, threshold ECe is 2.5 dS/m

1) \[ LR = \frac{EC_w}{(5 \times EC_e) - EC_w} \times 100 \]
   \[ = \frac{1.4}{(5 \times 2.5) - 1.4} \times 100 = 0.126 \]

2) **Total water needed (AW):**
   \[ AW = \frac{ET}{1 - LR} \]
   \[ = \frac{90 \text{ cm}}{1 - 0.126} = 103 \text{ cm} \]
“Assumes that the level of soil **salinity** is not excessive and does not change very much with time”.

“**Objective**: apply sufficient water so that soil salinity does not change appreciably with time”

Source: Ag Salinity Manual, pg. 95
*if salinity affects the crop to the extent that ET is reduced, then just applying the normal crop water requirement may result in some leaching of the profile.
Yield Response– combined salinity & water stress (Shani et al., 2005. JEQ)

Water requirement of melons & corn under “non-saline” irrigation was ~1.0 potential evaporation ($E_o$, Class A Pan) vs. 0.6 $E_o$ under saline irrigation
Leaching recommendations are being reconsidered. Some experts now feel that we may not have to apply as much as water as the present guidelines suggest. Applying less water for leaching, could help to reduce nitrate leaching.
**Assessment Tools**

*In-situ (real time) measurement*
- Soil vol. water content, EC, temp. sensors (Decagon 5TE, Delta-T WET sensor)
- Soil solution (suction lysimeters)
- EM-38 (ECa)

*“Traditional”*
- Soil Testing (traditional)
- Tissue testing
- Water testing
In-situ soil salinity monitoring

Decagon 5TE

Sensor: ~$250
+datalogger: $500 (direct download)
: $1,000 (cellular)

Dynamax: Delta-T
WET sensor

Sensor: $1400 (sensor) + ~$700 (datalogger)
or kit $2300 (sensor, hand-held meter, cables, software)
Accuracy: to 300 mS/m (= 3 dS/m, low!)

Measure volumetric water content (VWC), temperature and “bulk EC” (ECb; σb).
Software converts bulk EC to pore water EC (ECp; σp which is our ECsw)

Some use the bulk soil EC readings. Others use factory calibrations (mineral vs. organic soil) or their own conversions to get pore water EC.

How do we get to saturated paste EC (ECe)?
- Not easy: calibrate by taking soil samples and develop an equation to convert ECb (raw readings) to ECe, similar to ground-truthing done for EM-38 soil maps.

Advantage: real-time monitoring of salinity in soil

Disadvantage: do not have guidelines based on pore water (soil water) EC. Cannot measure in highly saline soils
EM-38 soil mapping
(hand-held or mobile rig)

Measures bulk or “apparent” soil EC ($EC_a$).

Ground-truthing: pull soil samples to determine if mapping soil salinity, clay content, other properties... or a combination. Convert $EC_b$ to $EC_e$. 
EM-38 soil mapping  
(hand-held or mobile rig)

- Good for assessing degree of spatial variability in soil salinity and where to focus leaching efforts, but if salinity is low in the soil, may also be measuring differences in clay or moisture content.

- Expensive instrument (>\$15,000). Commercial services available.

- Short rotations: may not be feasible to get frequent readings..... go with traditional soil sampling?
### Soil test report - saline

**Location:** Salinas, CA 93902

**Date:** 09/24/99

**Submitted By:** Ranch

**Copy To FAX:** 09/28/99

<table>
<thead>
<tr>
<th>Option</th>
<th>SP</th>
<th>pH_s</th>
<th>EC_e (x10^3)</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Cl</th>
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</tr>
</tbody>
</table>

**Nutrients (ppm):**
- B: 0.2 (54 99 170)
- NO₃-N: 0.2 (90 91 200)
- PO₄-P: 0.2 (26 100 140)
- AA: 0.1 (155 100 140)
- K: 2.1 (2.7 2.4 1.9)
- H₂SO₄: 2.1 (2.7 2.4 1.9)

**Remarks:** Not affected by sodicity
Good candidate for gypsum
- or soil sulfur, if free lime present in the soil
**Water Test Report (non-saline)**

<table>
<thead>
<tr>
<th></th>
<th>EC (dS/m)</th>
<th>Ca (meq/L)</th>
<th>Mg (meq/L)</th>
<th>Na (meq/L)</th>
<th>SAR</th>
<th>SAR</th>
<th>Cl (meq/L)</th>
<th>CO₃⁺ HCO₃ (meq/L)</th>
<th>SO₄ (meq/L)</th>
<th>B (mg/L)</th>
<th>NO₃⁻-N (mg/L)</th>
<th>Fe (mg/L)</th>
<th>Mn (mg/L)</th>
<th>pH</th>
<th>L.I.</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL→→</td>
<td>0.01</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.01</td>
<td>0.10</td>
<td>0.02</td>
<td>1.0</td>
<td>-2.0</td>
<td>2.0</td>
</tr>
<tr>
<td>SM→→</td>
<td>2510 B</td>
<td>3120 B</td>
<td>3120 B</td>
<td>3120 B</td>
<td>Calc</td>
<td>Calc</td>
<td>2320 B</td>
<td>3120 B</td>
<td>3120 B</td>
<td>3120 B</td>
<td>4500 H B</td>
<td>2330 B</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>EPA→→</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>300.0</td>
<td>300.0</td>
<td>300.0</td>
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</tr>
</tbody>
</table>

**General Ag Levels**

- **Low**
  - Total Salts <0.50
  - Calcium <4.00
  - Magnesium -
  - Sodium -
  - SAR -
  - Adjusted -
  - Chloride -
  - Bicarbonates -
  - Sulfate -
  - Boron -
  - Nitrate -
  - Iron -
  - Manganese -
  - pH <6.5
  - Langelier Index < -0.5

- **Normal**
  - Total Salts 0.60-1.50
  - Calcium 5.00-10.00
  - Magnesium 1.1-5.0
  - Sodium <4.0
  - SAR 0.1-4.0
  - Adjusted 0.1-4.0
  - Chloride 0.1-1.5
  - Bicarbonates 0.1-2.5
  - Sulfate 0.1-5.0
  - Boron 0.01-0.40
  - Nitrate 0.1-5.0
  - Iron <0.20
  - Manganese <0.20
  - pH 6.8-7.9
  - Langelier Index 0.0-0.5

- **High for Sensitive Crops**
  - Total Salts 1.51-2.20
  - Calcium >10.00
  - Magnesium >5.0
  - Sodium 4.1-7.0
  - SAR 4.1-9.0
  - Adjusted 4.1-9.0
  - Chloride 1.6-3.5
  - Bicarbonates 2.5-3.5
  - Sulfate -
  - Boron 0.41-0.59
  - Nitrate 5.1-7.0
  - Iron 0.21-0.40
  - Manganese 0.21-0.40
  - pH 8.0-8.4
  - Langelier Index 0.6-0.7

- **High for Tolerant Crops**
  - Total Salts >2.20
  - Calcium -
  - Magnesium -
  - Sodium >7.0
  - SAR >9.0
  - Adjusted >9.0
  - Chloride >3.5
  - Bicarbonates >3.5
  - Sulfate -
  - Boron >0.60
  - Nitrate >7.0
  - Iron >0.40*
  - Manganese >0.40*
  - pH >8.4
  - Langelier Index >0.9*

**Notes:**
- Red = High
- Green = Slow Low
- Orange = Slow High
- Blue = Low

Many of the above parameters need specific adjustment for crops, uses, irrigation procedures, etc. Check report for specifics.

When sodium is greater than calcium (or high SAR), the water is considered sodic or "alkali".

Note: High & Low levels are based on consultant interpretation of the situation, including plant varieties, age, soil type, irrigation system, etc., when information is available.

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Sum of cations (or anions) in meq/L ÷ 10 = EC (dS/m)

Cations = 0.74 + 0.09 + 0.4 = 1.23

1.23/10 = 0.123
Conclusions

- Salinity is always a concern in irrigated agriculture.
- Drought periods reduce drainage problems....but shift to irrigation with well water or other non-conventional waters can result in higher salinity in the applied water.
- Drought and irrigation water scarcity will force us to utilize irrigation waters previously deemed “unsuitable” for irrigation. Ayars and Westcot (FAO 29) guidelines may be too conservative?
- Tools available for in-situ monitoring, but difficult to relate bulk soil EC (or pore water EC) ⇒ saturation paste (ECe), the basis of our salinity tolerance rankings. Will have to familiarize ourselves with another set of numbers.
"From the standpoint of salinity management & Ag sustainability, better that more water & salt leaves the basin.

From the standpoint of water quality, the reverse.

-- J. van Schiflgarde, 1990."