# Water Quality for Irrigated Agriculture - Salinity/Sodicity Focus

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# Overview

- Terminology
- Background
- Parameters of concern
- Impacts
- Management

# Factors Influencing Salinity

**Geology**: weathering of primary minerals, marine sediments, etc

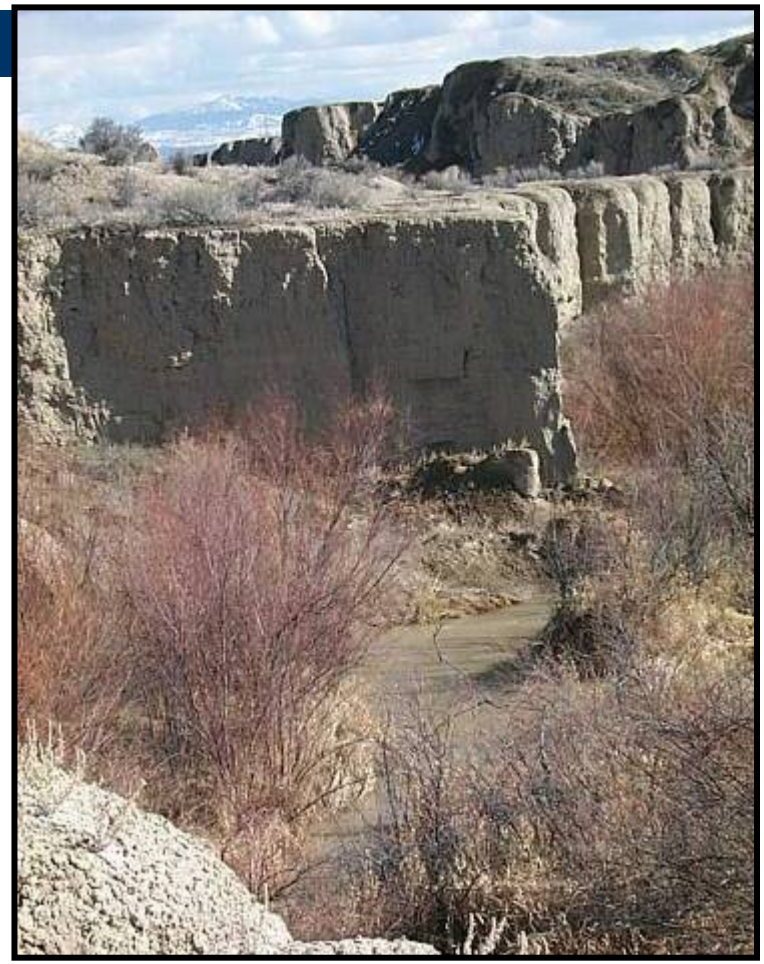
**Climate**: evaporation exceeds precipitation

**Irrigation**: water with moderate to high TDS or SAR

**Water table**: near soil surface

**Human activity**: mines, production plants, or high urban activity

**Soil drainage**: poor



# Irrigation Water Quality

- All waters used for irrigation contain varying amount of salts
- Salinization of soil and water is inevitable in climates where ET > precipitation
- Thus, drainage, either natural or artificial is essential to manage salts
- Key to sustainable irrigated agriculture in arid/semi-arid climates

# Terminology

- **Salinity** - total salt content
  - **Electrical Conductivity ($EC_w$)**
  - **Electrical Conductivity of saturated paste extract ($EC_{e\ or\ sat}$)**
  - 1 dS/m = 1 mmho/cm = 1000 µmho/cm
  - **Total Dissolved Solids (TDS):** mg/L or ppm

# Terminology

- **Sodicity** (sodic) - high sodium content
  - **SAR**: sodium adsorption ratio
  - **$SAR_{adj}$:** adjusted SAR
  - **ESP**: Exchangeable sodium percentage (soil)
- **pH** – acidic (<7.0), basic (>7.0), alkaline (> 7.8)

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

Na, Ca, and Mg concentrations must be expressed as meq/l

# Definitions

| Definitions | |
|---|---|
| **Abbrev.** | **Meaning** |
| mg/L | milligrams per liter |
| meq/L | milliequivalents per liter: mg/l ÷ atomic wt. ÷ charge |
| ppm | parts per million |
| dS/m | deciSiemens per meter |
| µS/cm | microSiemens per centimeter |
| mmho/cm | millimhos per centimeter |
| TDS | total dissolved solids |

# Conversions

| Component | To Convert | Multiply By | To Obtain |
|---|---|---|---|
| Water nutrient or TDS | mg/L | 1 | ppm |
| Water salinity hazard | 1 dS/m | 1 | 1 mmho/cm |
| Water salinity hazard | 1 mmho/cm | 1,000 | 1 µmho/cm |
| Water salinity hazard | EC (dS/m) for EC <5 dS/m | 640 | TDS (mg/L) |
| Water salinity hazard | EC (dS/m) for EC >5 dS/m | 800 | TDS (mg/L) |
| Water $NO_3N$, $SO_4$-S, B | ppm | 0.23 | lb per acre inch of water applied |

# General Irrigation Water EC Classifications

| Classes of water | TDS | Electrical Conductivity |
|---|---|---|
| | (mg/l) | (dS/m)* |
| Class 1, Excellent | <1,000 | ≤0.25 |
| Class 2, Good | | 0.25 - 0.75 |
| Class 3, Permissible[1] | 1,000 – 2,000 | 0.76 - 2.00 |
| Class 4, Doubtful[2] | | 2.01 - 3.00 |
| Class 5, Unsuitable[2] | >2,000 | ≥3.00 |

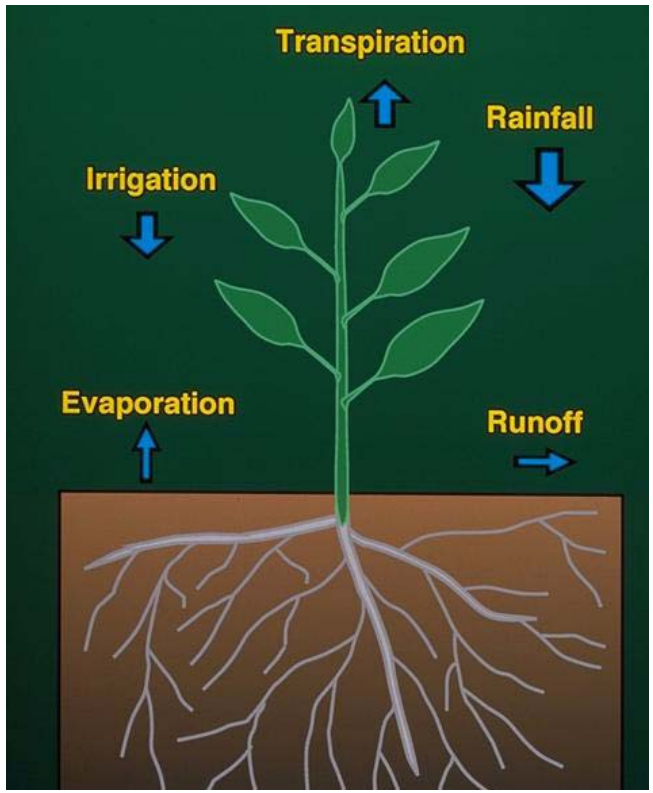
*dS/m at 25ºC = mmhos/cm
[1]Leaching needed if used.
[2]Good drainage needed and sensitive plants will have difficulty obtaining stands.

# Irrigation water is a major source of salts for many fields

- For every 1 ppm there is 0.23 lbs per acre inch water
- Irrigation water example:
  - Total Dissolved solids (TDS) = 1000 mg/l (EC = 1.6 dS/m)
  - 1000 mg/l x 0.23 = 230 lb/acre inch
  - Seasonal Irrigation (24 inches)
  - 230 x 24 inches = ***5520 lb salt / acre***

# Salinity Impacts

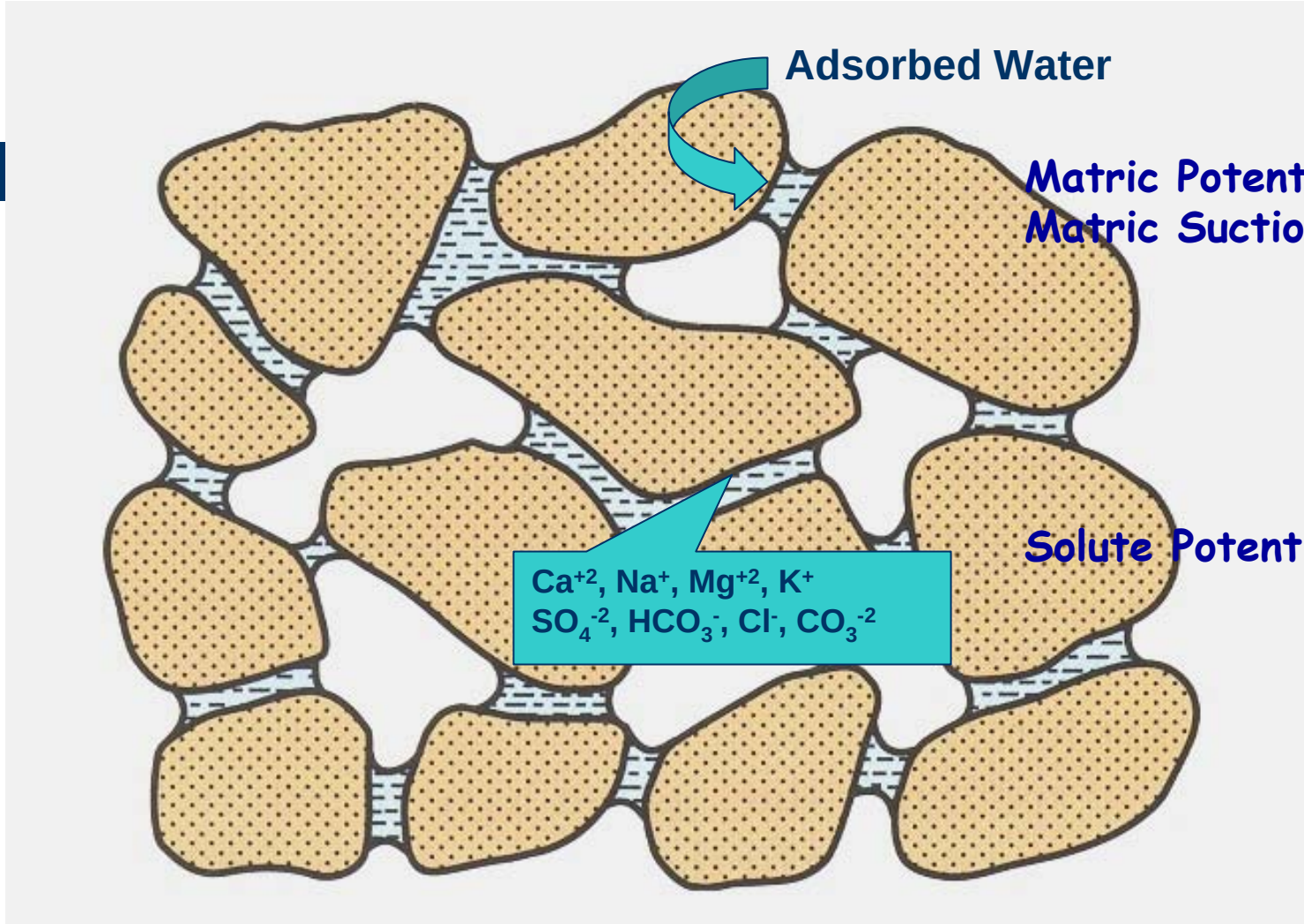
- Plants only transpire "pure" water
- Salts in irrigation water remain in soil – if not leached



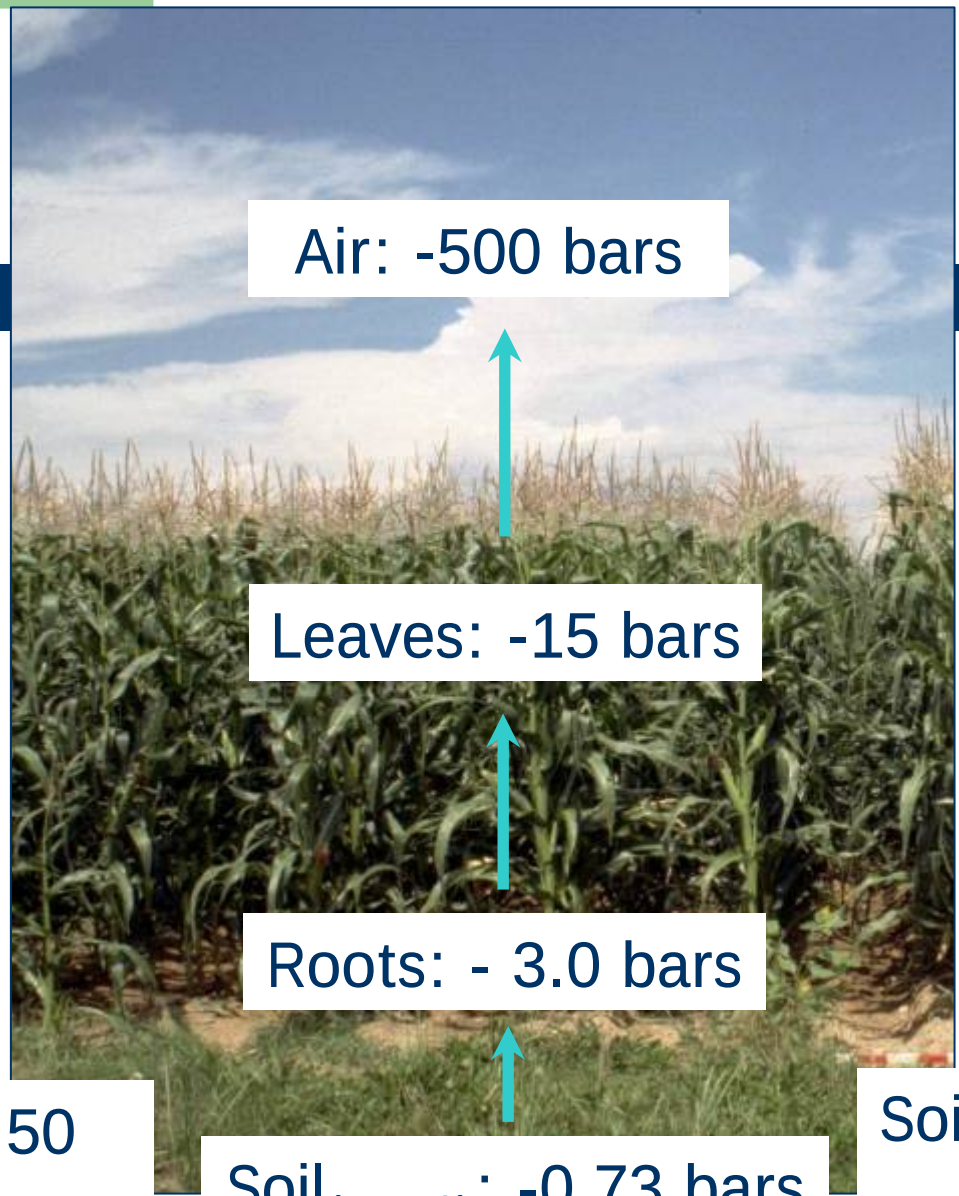
# Salinity Impacts

- Plant
  - Physiological drought
  - Increased osmotic potential of soil
  - Specific ion toxicity
  - Leaf burn
  - Nutrient uptake interferences

# Osmotic Potential



# Salinity Impacts to Crop Water Use

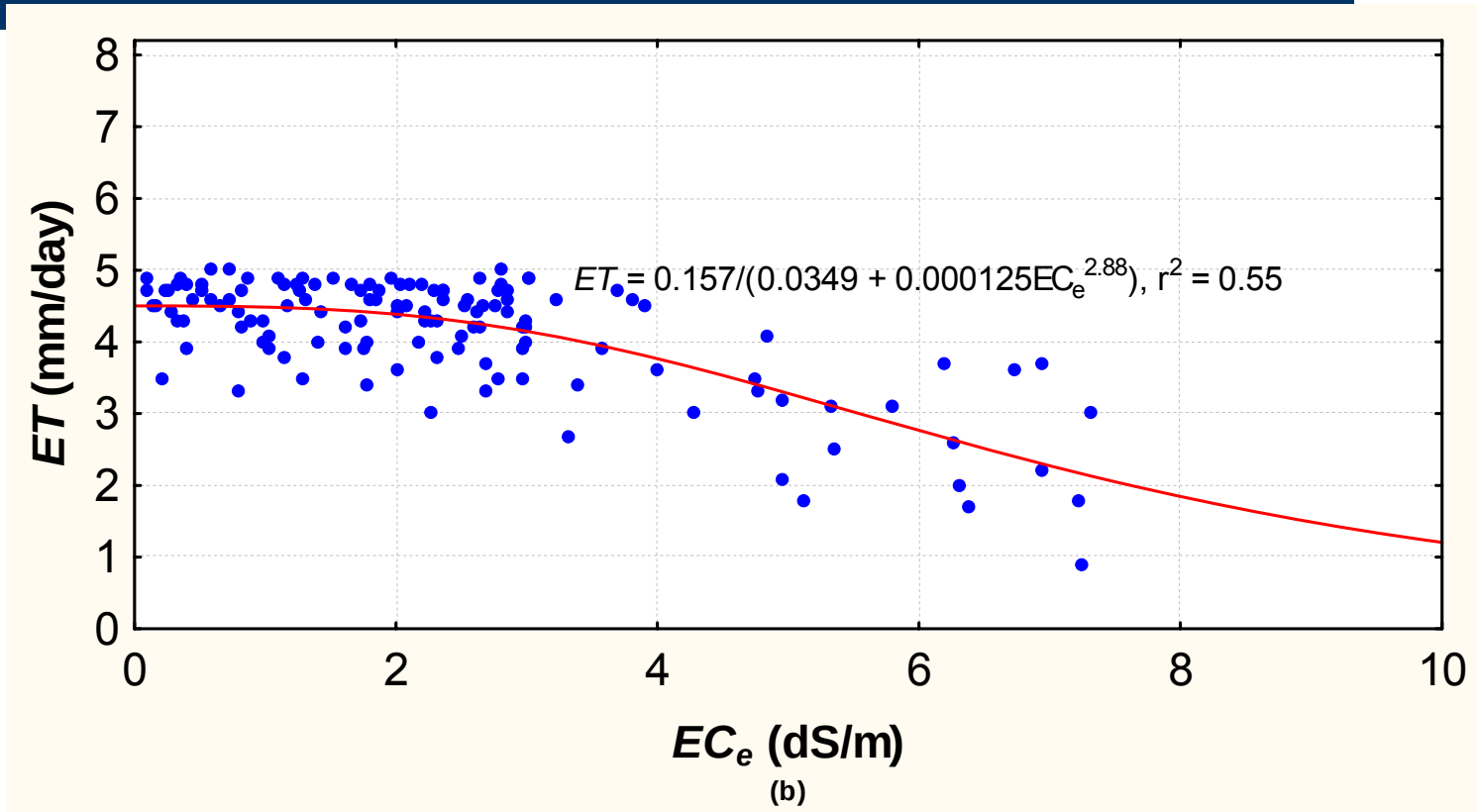



Soil @ field capacity,
86 deg. F,
50% RH

Soil(ec 2.0): -1.50 bars

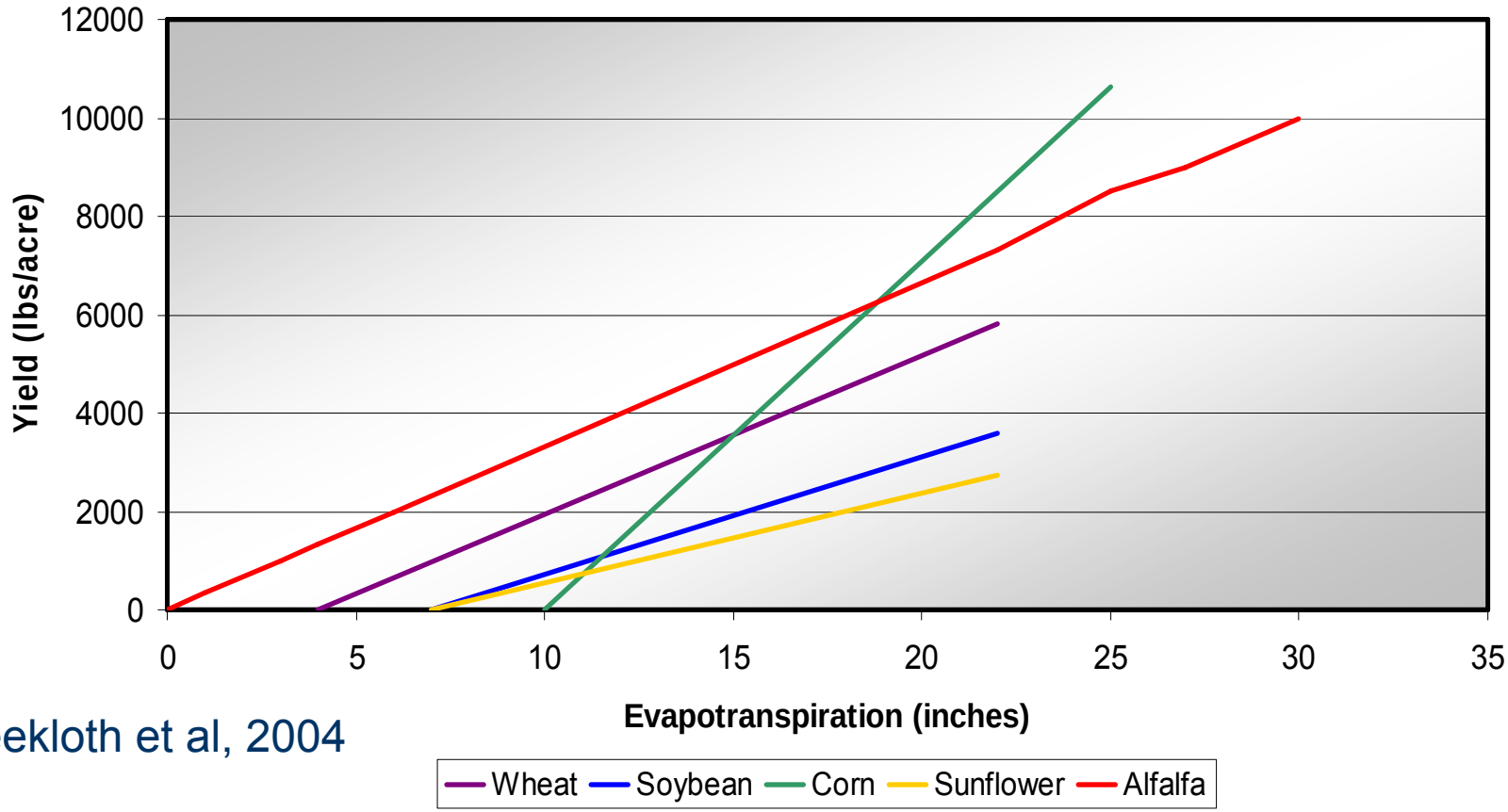
Soil(ec 4.0): -3.15 bars

# Background – ET vs. Salinity




Estimated crop ET versus *ECe* measured with EM-38s; (Gates et al. 2006).

# Background - Yield vs. Evapotranspiration




Schneekloth et al, 2004

# Crop Impacts

Salinity Tolerance

More E.C.

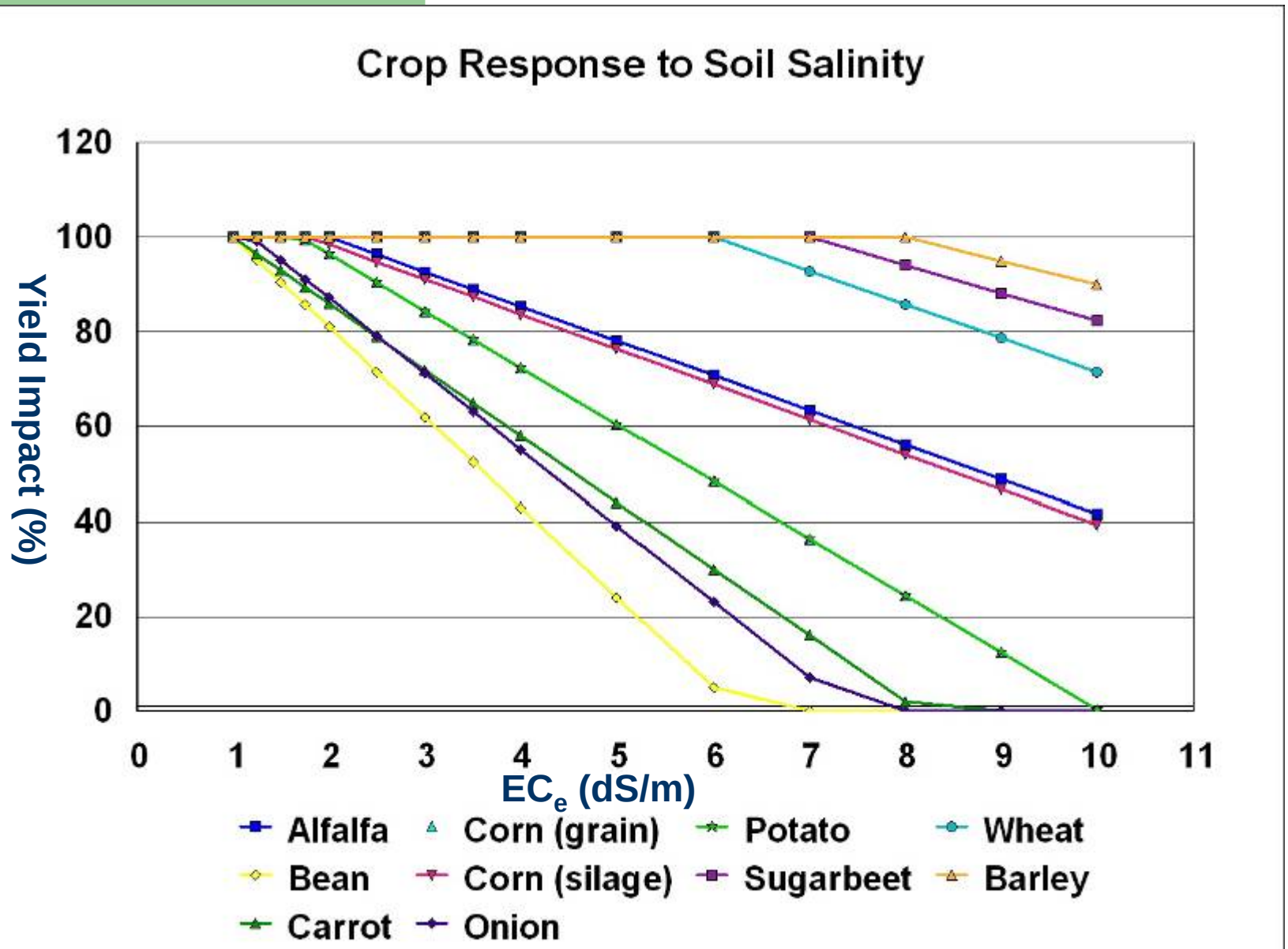
Less E.C.

**Forage crops**

**Field crops**

**Vegetables**

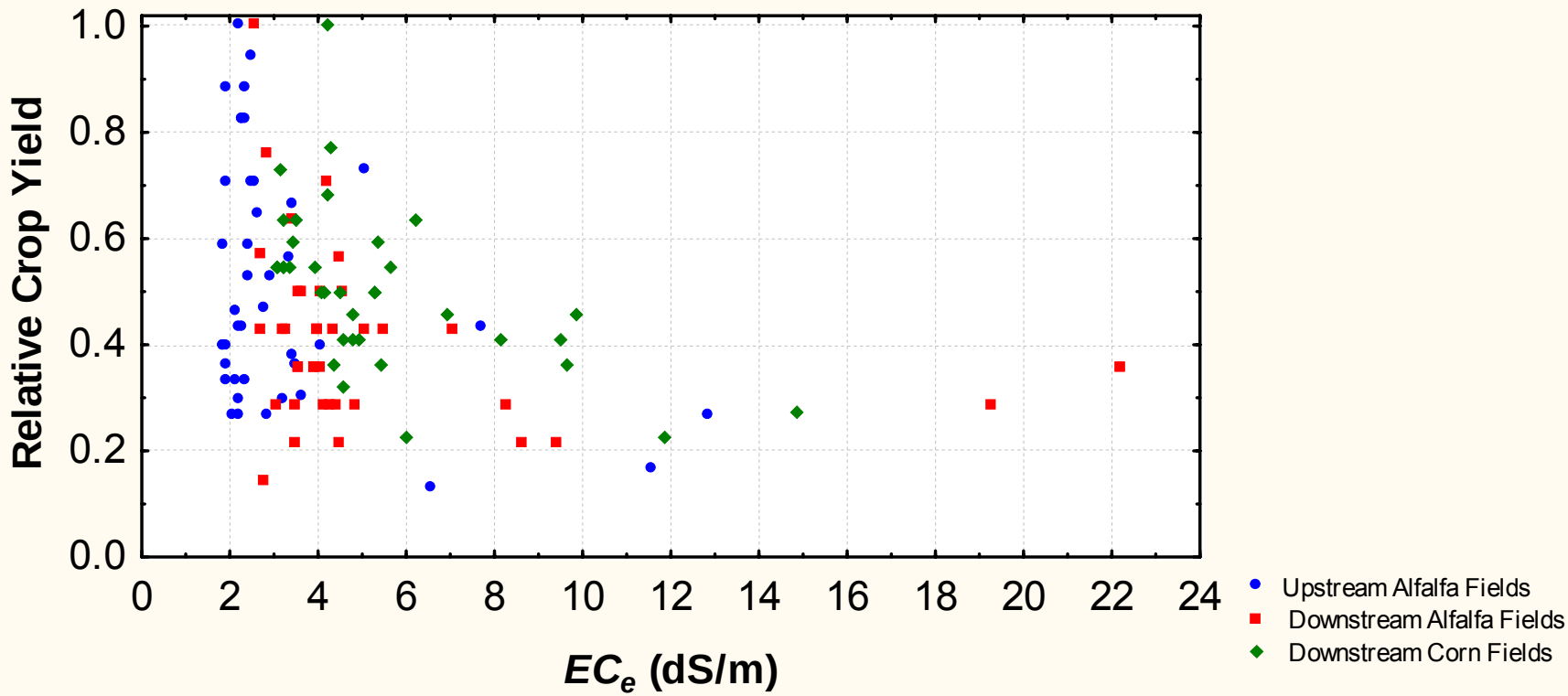
**Fruits**


Crop Response to Soil Salinity
Yield Impact (%)
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
8
9
10
11
ECe (dS/m)
Alfalfa
Corn (grain)
Potato
Wheat
Bean
Corn (silage)
Sugarbeet
Barley
Carrot
Onion

# Impacts to Landscapes/Garden

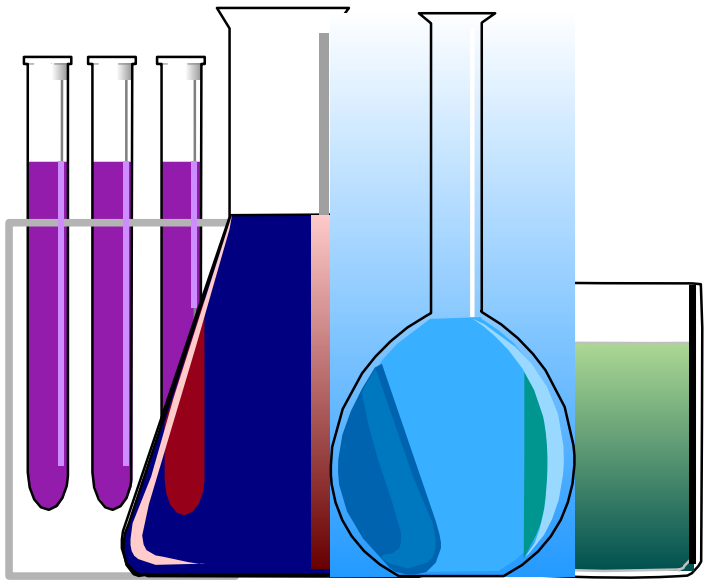
# Salinity Impacts are Site Specific

## Relative Yield vs. Salinity




(Gates et al 2006)

# Irrigation Water Quality – Specific Ion Concerns and Toxicities



# Sodium ($Na^+$)

- Soil – sodicity
  - Crusting
  - Reduced infiltration
  - Lower hydraulic conductivity
  - Higher pH impacting nutrient uptake/imbalances
- Plant –
  - Stunted plants
  - Toxicity and leaf burn potential

# General Sodium Irrigation Water Classifications

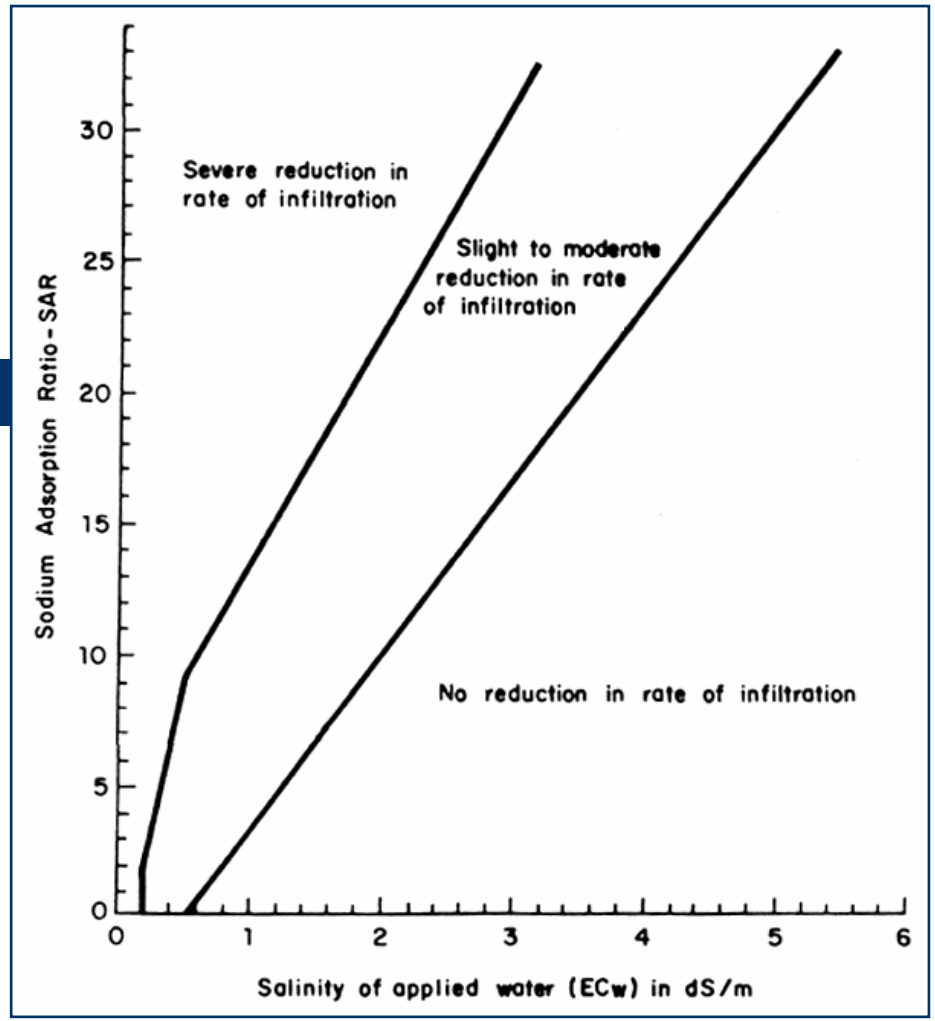
| SAR values | Sodium hazard of water | Comments |
|---|---|---|
| 1-9 | Low | Use on sodium sensitive crops must be cautioned. |
| 10-17 | Medium | Amendments (such as gypsum) and leaching needed. |
| 18-25 | High | Generally unsuitable for continuous use. |
| ≥26 | Very High | Generally unsuitable for use. |
| Note: Actual impacts of SAR to soil/crop system are very site specific and these values should be used as guidelines only. | | |

# EC and SAR

**The hazard of irrigation water sodium on soil infiltration *must* be determined from the SAR/EC interaction.**

**As EC increases relative to SAR, infiltration problems are reduced.**

**Rainfall or sprinkler irrigation with non-saline water on soils previously irrigated with sodic water can increase the infiltration problem.**




Ayers and Westcott, 1985

***Point: Irrigating with water with a lower EC than the soil can cause more infiltration problems at high SAR.***

# Chloride ($Cl^-$)

- Contributes to EC
- Essential in low amounts
- Sensitive crops affected at high concentration
- Leaf burn potential under sprinkler
- Burn higher with daytime irrigation

# Chloride tolerance criteria

| Chloride (ppm) | Effect on Crops |
|---|---|
| Below 70 | Generally safe for all plants. |
| 70-140 | Sensitive plants show injury. |
| 141-350 | Moderately tolerant plants show injury. |
| Above 350 | Can cause severe problems. |

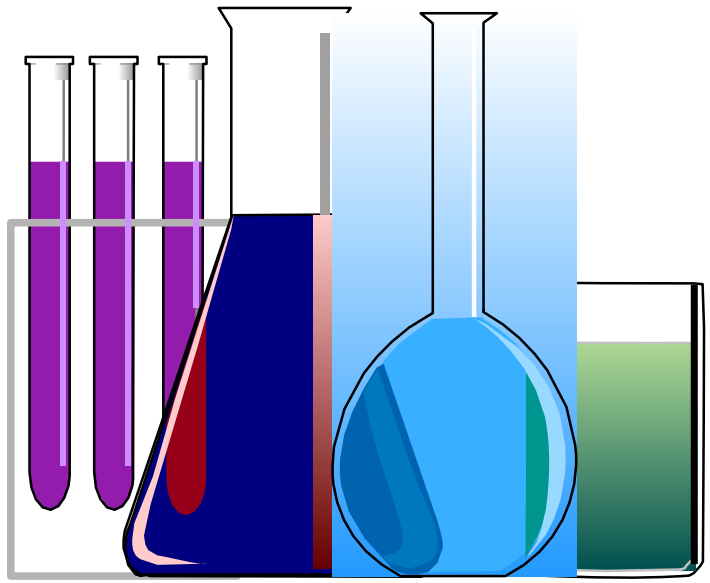
Chloride tolerance of selected crops. Listing in order of increasing tolerance: (low tolerance) dry bean, onion, carrot, lettuce, pepper, corn, potato, alfalfa, sudangrass, zucchini squash, wheat, sorghum, sugar beet, barley (high tolerance). Source: Mass (1990) Crop Salt Tolerance. Agricultural Salinity Assessment and Management Manual. K.K. Tanji (ed.). ASCE, New York. pp 262-304.

# Boron (B)

- Essential in low amounts (alfalfa)
- Toxic to sensitive crops (>1.0 to 2.0 ppm)
- Fertility Sufficient in low concentrations
- 24 inches of 0.50 ppm = 2.7 lb B / acre

# pH, Carbonate, and bicarbonate (alkalinity)

- pH > 8.5
- High $HCO_3^-$ cause $Ca^{2+}$ & $Mg^{2+}$ to form insoluble minerals leaving Na.
- Will exacerbate sodic soil conditions



# Nitrate-nitrogen ($NO_3$-N)

- Fertility issue
- Can be significant N source in some basins:
  - S. Platte
  - San Luis Valley
  - Arkansas
- Generally managed with N fertilizer program
- Should be credited toward fertilizer rate

# Plant impacts – uptake interferences

- High pH affects
  - P,
  - Fe,
  - and Zn availability
- Elevated Na can induce Ca and/or Mg deficiency

# Colorado Ground Water Quality Examples – Median Values

| Dissolved Constituent | High Plains | S. Platte Alluvial | Arkansas Alluvial | Laramie-Fox Hills * |
|---|---|---|---|---|
| | ---------- mg / l ---------- | | | |
| Calcium | 47 | 158 | 283 | 4.2 |
| Sodium | 15 | 147 | 220 | 270 |
| Bicarbonate | 155 | 368 | 334 | 640 |
| Chloride | 4.4 | 80 | 72 | NA |
| TDS | 311 | 1,305 | 2,333 | 662 |
| N | 111 | 96 | 159 | NA |

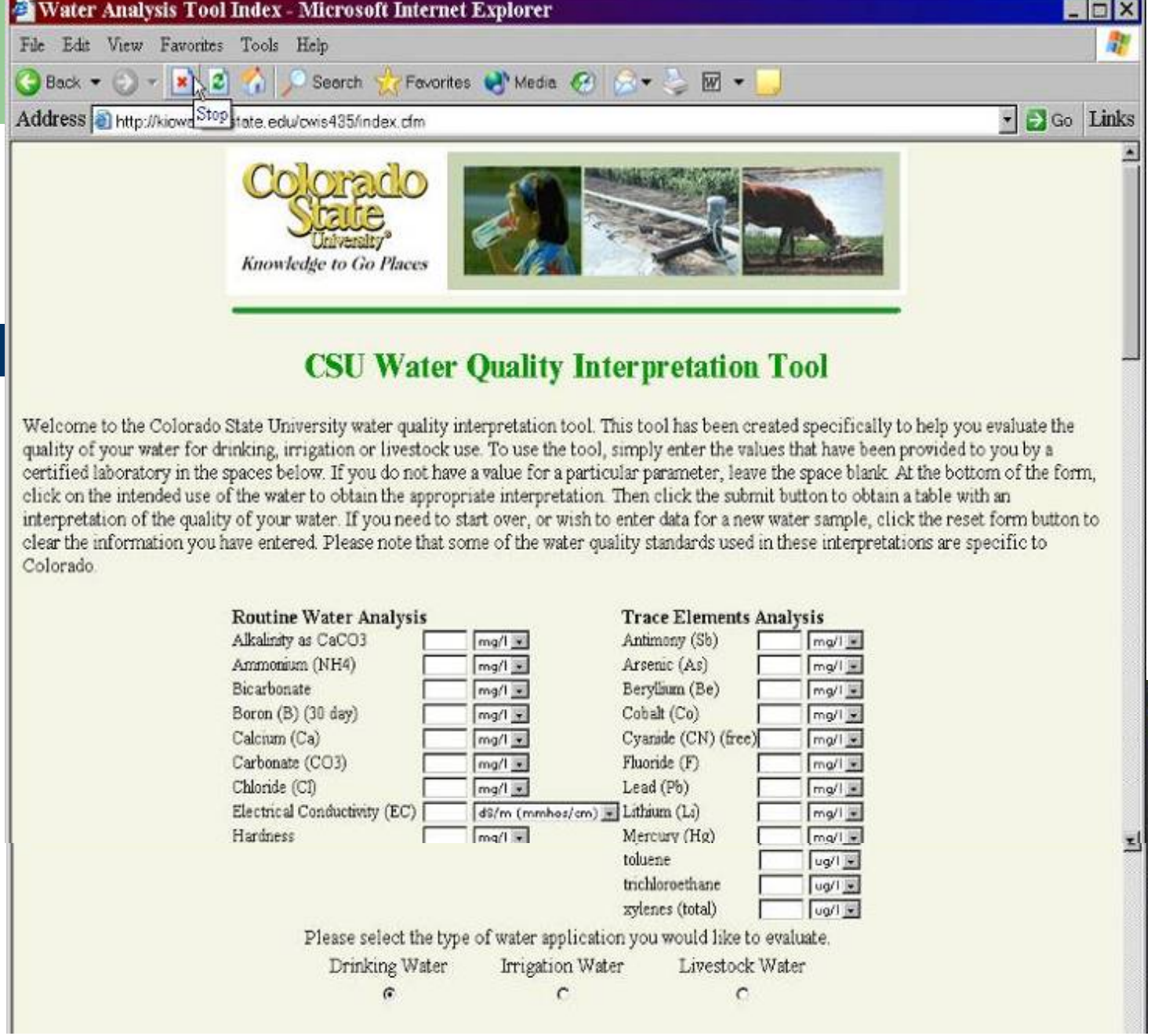
*From: Ground Water Atlas of Colorado, Colo. Geological Survey

# Colorado Surface Water Quality Examples

| Dissolved Constituent | Lower S. Platte | Lower Arkansas** | Rio Grande |
|---|---|---|---|
| | ---------- mg / l ---------- | | |
| Calcium | 30-70 | 45 - 420 | 5 – 12 |
| Sodium | | 30 - 635 | 2 – 6 |
| Bicarbonate | 60 – 120 | 75 - 740 | 20 – 50 |
| Sulfate | 40 – 160 | 160 - 790 | 2.6 – 6.0 |
| Chloride | 20 - 120 | 10 - 165 | <1.5 |
| TDS | 500 – 1,200* | ~600 -3,600 | 32 – 60 |

*From: USGS NWIS at Del Norte

**Gates, et al, 2006

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Water Analysis Irrigation

# Interpretations of Irrigation Water Quality

| Test Name:a | Lab Result: | Interpretation: | Excellent: | Satisfactory: | Objectionable: |
|---|---|---|---|---|---|
| **1) Routine Water Analysis** | | | | | |
| Alkalinity as CaCO3 | Not tested | Not interpreted | | 0-400 mg/l *** | >400 mg/l *** |
| Ammonium (NH4) | Not tested | Not interpreted | | No guideline | |
| Bicarbonate | Not tested | Not interpreted | | No guideline | |
| Boron (B) | Not tested | Not interpreted | 0 mg/l *** | 0.1-2.0 mg/l *** | >2.0 mg/l *** |
| Calcium (Ca) | 200 mg/l | No guideline | | No guideline | |
| Carbonate (CO3) | Not tested | Not interpreted | | No guideline | |
| Chloride (Cl) | Not tested | Not interpreted | <20 mg/l ** | 20-350 mg/l ** | >350 mg/l ** |
| Electrical Conductivity (EC) | 2.0 dS/m (mmhos/cm) | Satisfactory | <0.25 dS/m | 0.25-2.00 dS/m *** | >2.00 dS/m *** |
| Hardness | Not tested | Not interpreted | | No guideline | |
| Magnesium (Mg) | Not tested | Not interpreted | | No guideline | |
| Nitrate (NO3-N) | 10 mg/l | Satisfactory | | <35 mg/l *** | >35 mg/l *** |
| Nitrite (NO2-N) | Not tested | Not interpreted | | No guideline | |
| Nitrate + Nitrite (Total) | Not tested | Not interpreted | | No guideline | |
| pH | Not tested | Not interpreted | 7-7.5 *** | 6.5 - 6.99 or >7.5 to <8.5 *** | <6.5 or 8.5 - 14 *** |
| Potassium (K) | Not tested | Not interpreted | | No guideline | |
| SAR | Not tested | Not interpreted | | | |
| Sodium (Na) | 50 mg/l | Satisfactory | | <350 mg/l *** | >350 mg/l *** |
| Sulfate (SO4) | Not tested | Not interpreted | | No guideline | |
| Total Dissolved Solids (TDS) | Not tested | Not interpreted | <1000 mg/l *** | 1000 - 2000 mg/l *** | >2000 mg/l *** |

(Primary Standard)
CL (Secondary Standard)
ber Limit Guideline

# IRRIGATION WATER ANALYSIS

SOURCE: Well #3

***"Routine Package"***

| | Results | Results | |
|---|---|---|---|
| Conductivity | 2500 | µmhos/cm | (E.C. x 1,000,000) |
| pH | 8.3 | | |
| | **mg/L** | **meq/L** | |
| Calcium | 325 | 16.22 | |
| Magnesium | 14.7 | 1.21 | |
| Sodium | 45 | 1.96 | |
| Potassium | 2.9 | 0.07 | |
| Carbonate | 38.5 | 1.28 | |
| Bicarbonate | 40 | 0.66 | |
| Chloride | 62.4 | 1.76 | |
| Sulfate | 350.0 | 7.29 | |
| Nitrate | 0.6 | 0.01 | |
| Nitrate-Nitrogen | 0.1 | 0.01 | |
| Boron | 0.13 | | |
| Pounds of Sulfate per acre foot | 311 | | |
| Pounds of Nitrate per acre foot | 0.37 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| SAR | 0.8 | Salinity Hazard | Medium | Sodium Hazard | low | |

**Customer Sample ID** SW Ranch

**Sample Date/Time:** 2/15/06 7:42 AM

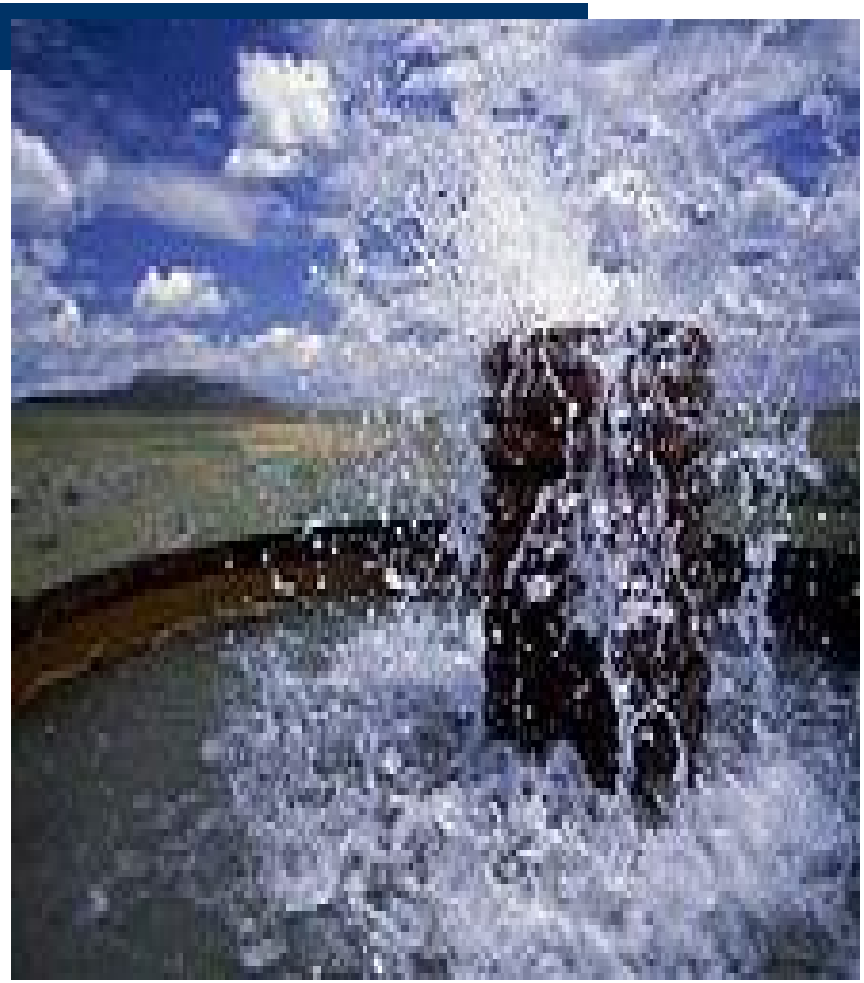
**Lab No.** 06022112-06

| Test (units) | Sample Result | Suggested Levels - Irrigation Use |
|---|---|---|
| Bicarbonate (mg/L) | 479.1 | - |
| Carbonate (mg/L) | < 0.1 | - |
| Total Alkalinity (mg/L as CaCO3) | 392.7 | 0-100 |
| Chloride (mg/L) | 56.69 | 0-140 |
| Nitrate Nitrogen (mg/L) | < 0.07 | 5+ |
| Phosphate - Ortho (mg/L) | 0.31 | 0.2-15 |
| Sulfate (mg/L) | 0.03 | 24-240 |
| | | |
| Ammonia Nitrogen (mg/L) | 0.10 | - |
| Copper - Total (mg/L) | 0.04 | 0-0.2 |
| Iron - Total (mg/L) | 1.557 | 2-5 |
| Potassium - Total (mg/L) | < 0.1 | 0.5-10 |
| Calcium - Total (mg/L) | 4.6 | 40-120 |
| Calcium Hardness (mg/L as CaCO3) | 11.5 | - |
| Magnesium - Total (mg/L) | 1.4 | 6-24 |
| Sodium - Total (mg/L) | 222.9 | 0-50 |
| | | |
| Boron (mg/L) | 0.19 | 0.2-0.8 |
| pH (units) | 8.64 | - |
| Salinity (umhos/cm @ 25c) | 1010 | 0-1500 |
| Sodium Adsorption Ratio (units) | 23.4 | 0-4 |

# CMB and Water Quality?

**The common signature of product water is a wide range in salinity and very high sodicity**

**Biogenic methane – Primarily sodium bicarbonate.**



Source: J. Bauder, MSU

# Chemical Changes in due to Coal Bed Methane Product Water When discharged

**For example – sodium bicarbonate-rich product water is discharged to a stream:**

- **the salt (EC, TDS) concentration of the water will increase**
- **the soluble calcium concentration will decrease, and**
- **the SAR will increase.**

$$Na(HCO_3)_2 + Ca \rightarrow CaCO_3(\text{calcite or limestone}) + Na + H_2O + CO_2$$

Source: J. Bauder, MSU

# Soil Chemical Changes Resulting from Irrigation with Water Co-Produced with Coalbed Natural Gas

Girisha K. Ganjugunte, George F. Vance, and Lyle A. King, Journal of Environmental Quality, 2005

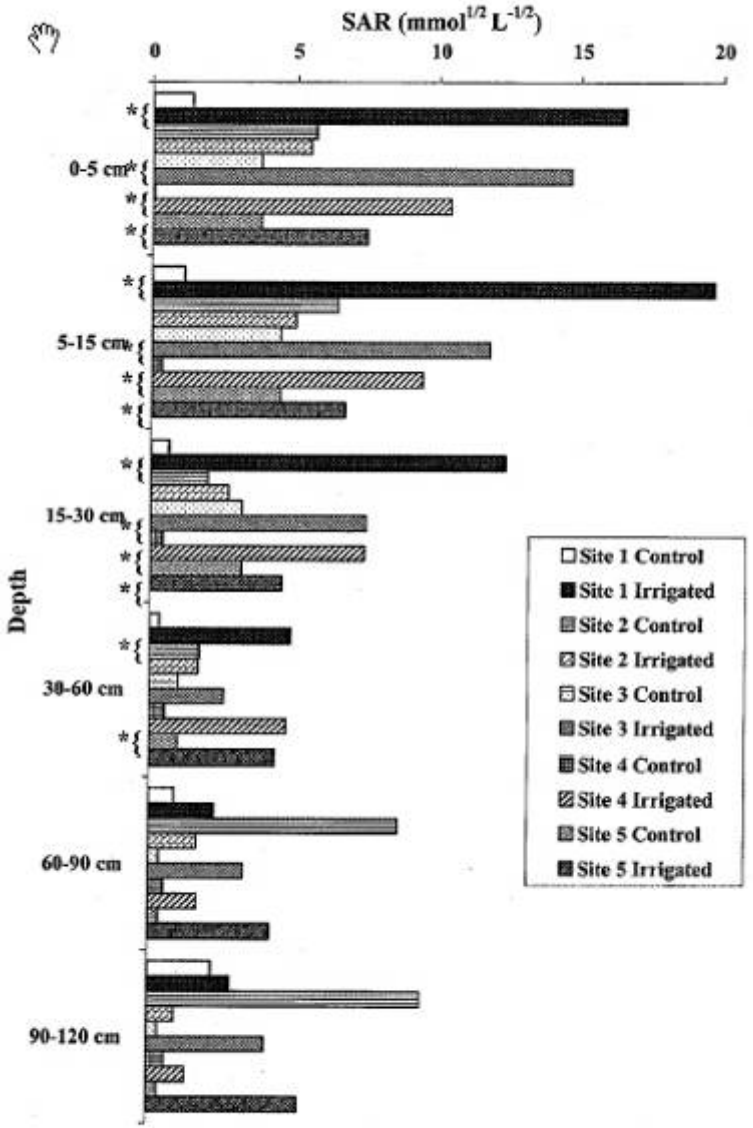



Fig. 4. Mean sodium adsorption ratio of soil saturated paste extracts ($SAR_e$) values of irrigated and control sites. Significant differences between irrigated and control samples at the 0.05 probability level are noted with asterisks.

**EC and SAR of CBNG produced water were greater than those recommended for irrigation on the study sites**

**EC and SAR of the soil saturated paste extract in the 0-30 cm depth for most sites following irrigation were significantly greater than the controls**

**Irrigation resulted in a significant accumulation of sodium**

**“Results of this study suggest CBNG waters used for irrigation in northwestern PRB, Wyoming, are generally unsuitable for direct land application.**

**Table 4. Selected chemical properties of coalbed natural gas (CBNG) water samples.**

| pH | EC | SAR | | Ca | Mg | Na |
|---|---|---|---|---|---|---|
| | dS $m^{-1}$ | $mmol^{1/2}$ $L^{-1/2}$ | | mg $L^{-1}$ | | |
| | | | Site 1 | | | |
| 8.2 ± 0.1 | 2.9 ± 0.9 | 30.9 ± 2.1a† | | 12.8 ± 7.1 | 30.0 ± 0.3 | 888 ± 7.80a |
| | | | Site 2 | | | |
| 8.0 ± 0.5 | 2.0 ± 0.4 | 24.2 ± 4.9ab | | 11.8 ± 3.4 | 7.0 ± 1.1 | 392 ± 68.6b |
| | | | Site 3 | | | |
| 7.9 ± 0.9 | 2.2 ± 0.3 | 32.8 ± 5.9a | | 9.9 ± 6.7 | 4.7 ± 0.5 | 485 ± 19.5b |
| | | | Site 4 | | | |
| 7.7 ± 0.3 | 2.9 ± 1.2 | 17.2 ± 2.2b | | 11.9 ± 2.9 | 16.4 ± 5.0 | 378 ± 5.10b |
| | | | Site 5 | | | |
| 8.0 ± 0.5 | 2.0 ± 0.4 | 24.2 ± 4.9ab | | 11.8 ± 3.4 | 7.0 ± 1.1 | 392 ± 68.6b |

† Means followed by the same lowercase letter are not significantly different from other values in that column at the 0.05 probability level.

# Management Options

- Crop selection
- Irrigation
  - Management
  - Controlled leaching
  - System adjustments
- Soil
  - Drainage
  - Tillage/compaction
  - Amendments – ***sodic problems only***
- Continued monitoring

# Diagnosis – Understanding the Problem(s)

- Salinity problems are usually present before yield impacts measured

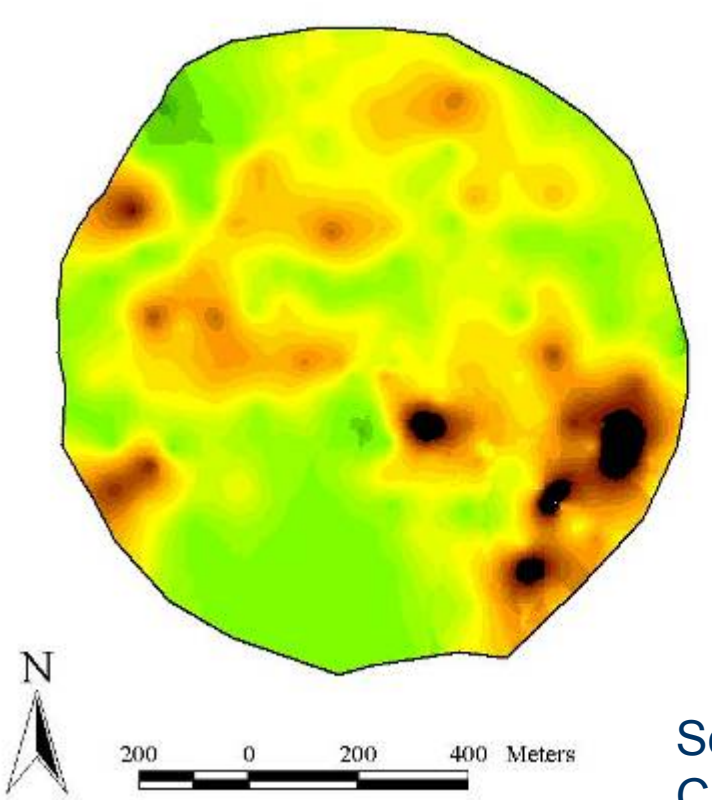
# Field Diagnosis

| Problem | Potential symptoms |
|---|---|
| saline soil | • white crust on soil surface<br>• water stressed plants, species changes<br>• leaf tip burn |
| saline irrigation water | • leaf burn<br>• poor growth<br>• moisture stress |
| sodic soil | • crusting or hardsetting<br>• low infiltration rate; runoff and erosion<br>• dark powdery residue on soil surface<br>• stunted plants with leaf margins burned |
| saline-sodic soil | • generally, same symptoms as saline soil |
| high pH | nutrient deficiencies manifesting as:<br>• stunted yellow plants<br>• dark green to purplish plants |

# Generalized Classification of Salt-Affected Soils

| Classification | Electrical Conductivity (dS/m) | Sodium Adsorption Ratio (SAR) | Soil pH |
|---|---|---|---|
| Saline | >4.0 | <13 | <8.5 |
| Sodic | <4.0 | ≥13 | >8.5 |
| Saline-Sodic | >4.0 | ≥13 | <8.5 |
| High pH | <4.0 | <13 | >7.8 |

# Diagnosis – Understanding Salinity Problem




- Salinity varies spatially, with depth and with time
- Routine fertility soil sample generally not adequate to fully describe and monitor salinity problem

Source, Louis Garcia, CSU

# Diagnosis – Understanding Salinity Problem

- Irrigation water analysis essential for proper diagnosis
- Understand changes in source, time

# Summary

- Most Colorado irrigation water contains some level of salt
- Concentration and type of salt should direct management adjustments
- Using saline/sodic irrigation water can decrease productivity and crop choices
- Using saline/sodic water will increase cost of production for most cropping systems
- Salinity/sodicity impacts are site specific

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