Remediation of Brine Impacted Soils

Sublette™
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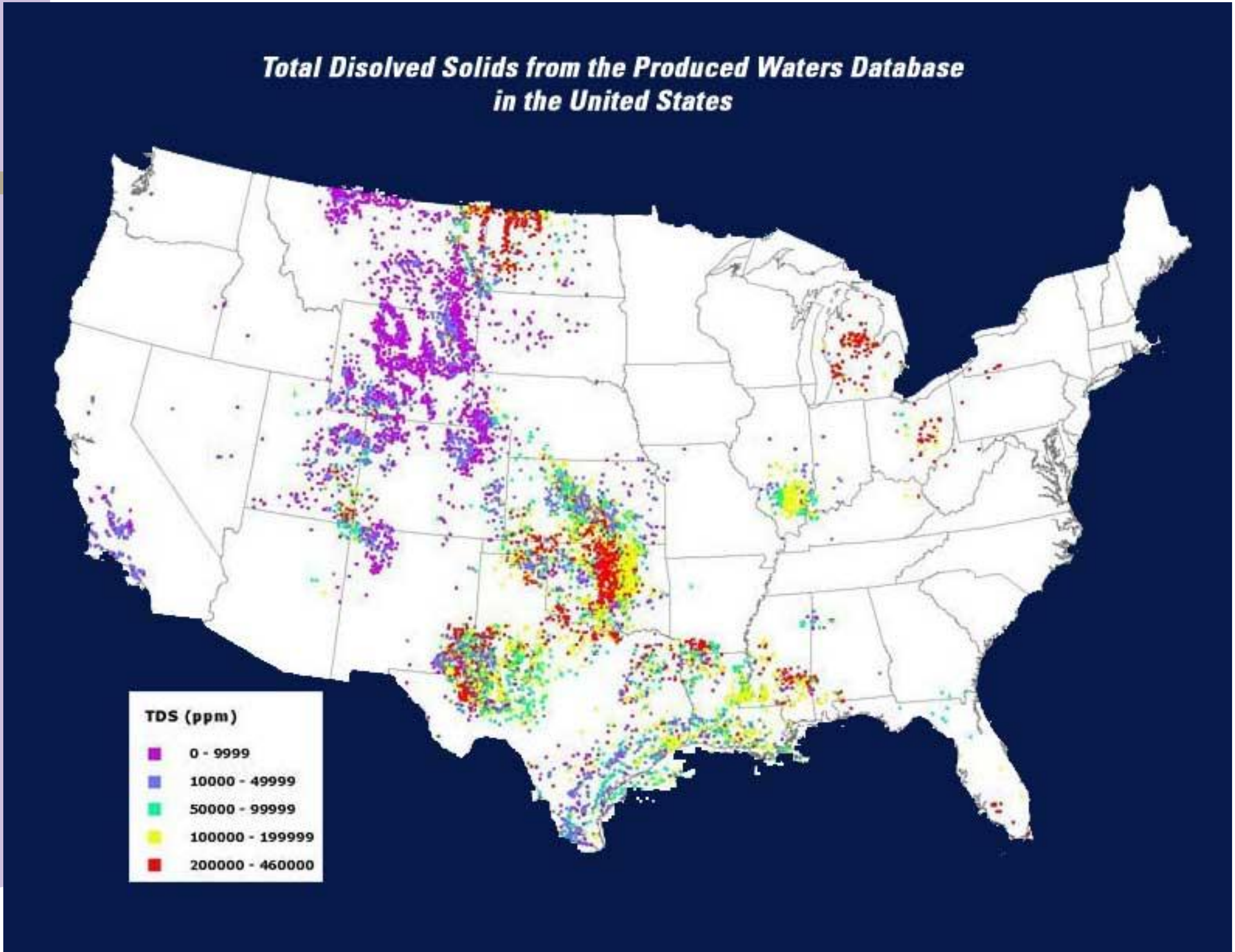
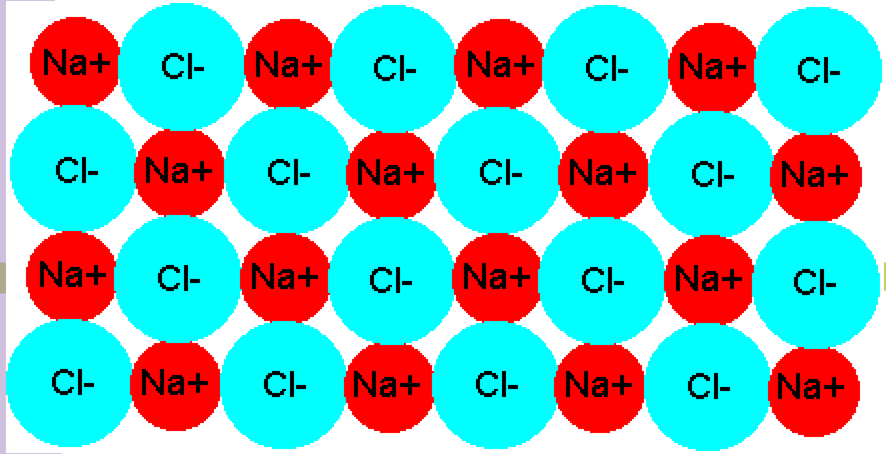
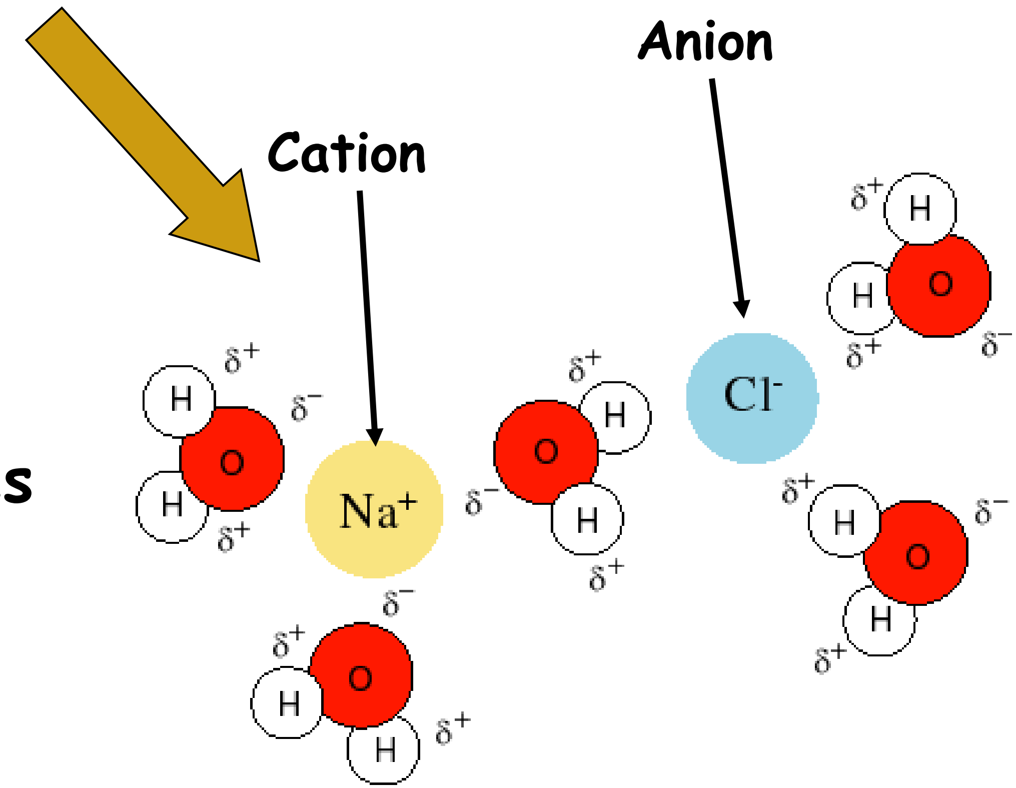
Most of the TDS (total dissolved solids) are salts





NaCl crystals



NaCl dissolves in water as ions

Principal cations and anions in produced water

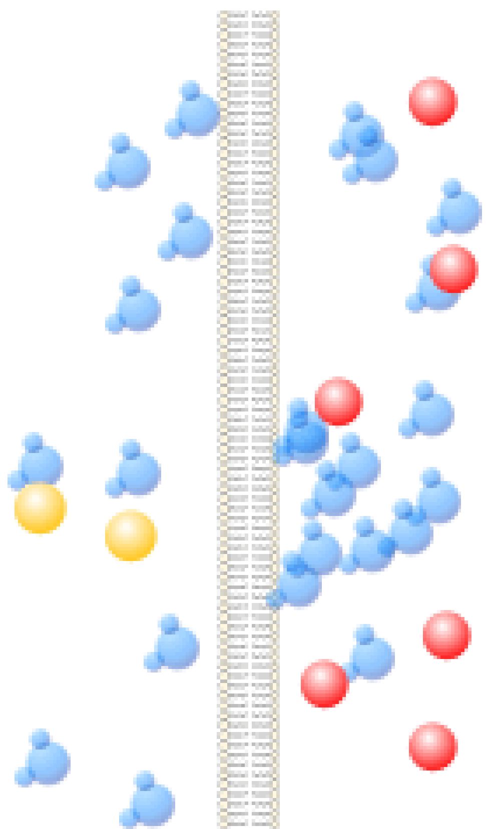
Most abundant cation → Na^+ (Sodium)

Most abundant anion → Cl^- (Chloride)

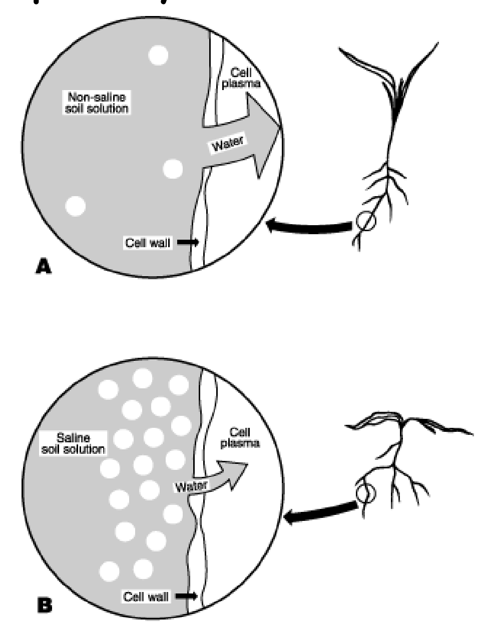
Cations	Anions
Na^+ Sodium	Cl^- Chloride
K^+ Potassium	HCO_3^- Bicarbonate
Ca^{+2} Calcium	SO_4^{-2} Sulfate
Mg^{+2} Magnesium	

Salt or sodium chloride (NaCl) is principally responsible for the excess salinity in brine impacted soil.

Spills of produced water or brine on soil result in two types of damage:

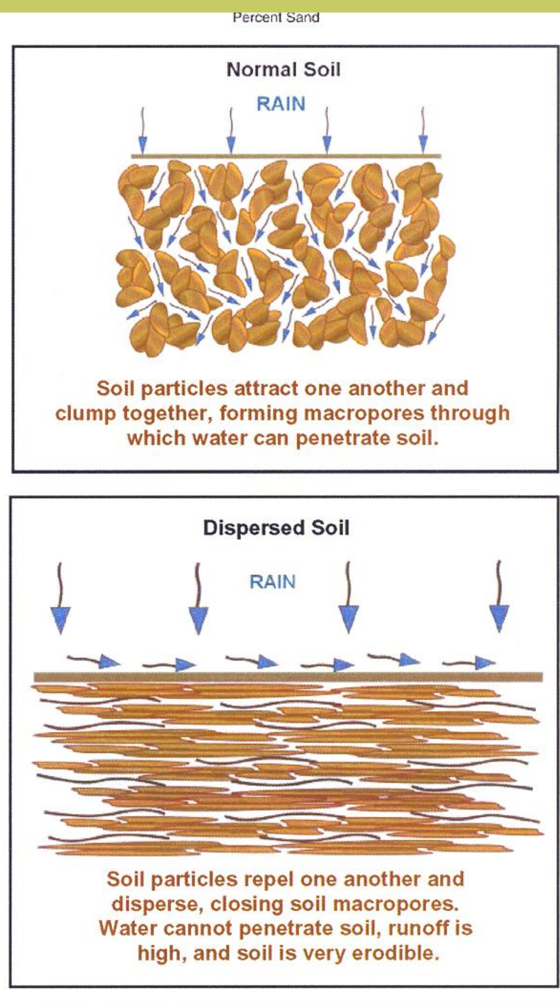


- Excess salinity
  - Creates an osmotic imbalance that reduces water uptake by plant roots. Plants can go into drought stress even though there is plenty of water in the soil.



Three days following a brine spill

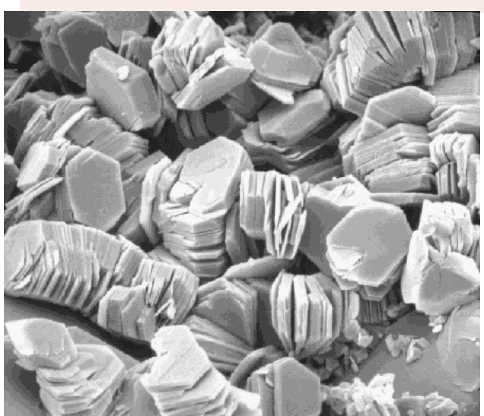
Spills of produced water or brine on soil result in two types of damage:

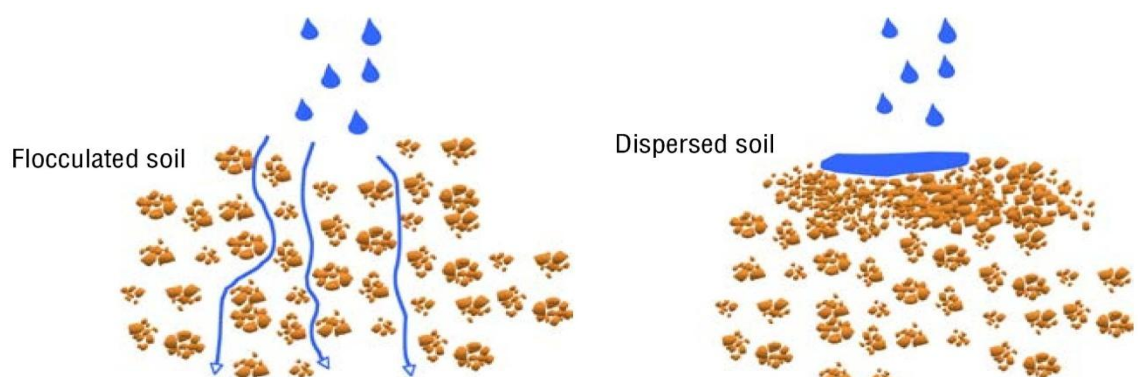


- Excess sodicity (an excess of sodium)
  - Destroys soil structure by dispersing clays
  - Produces a hardpan that will not transmit water
  - Erosion

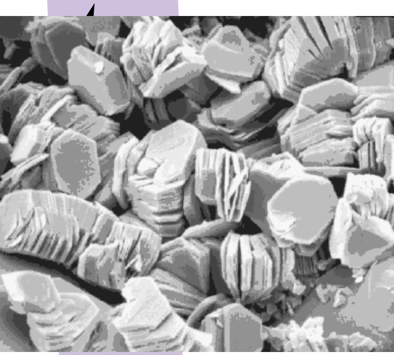
Both salinity and sodicity must be addressed in any successful remediation of a brine impacted site

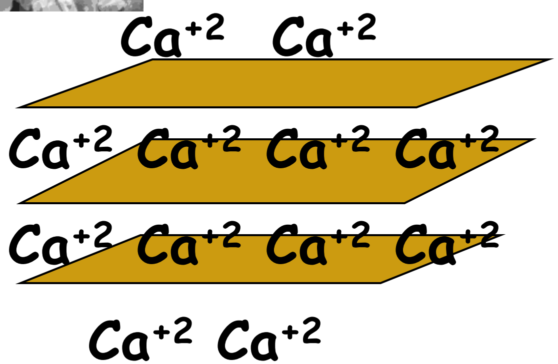
Clay dispersal in sodic soils



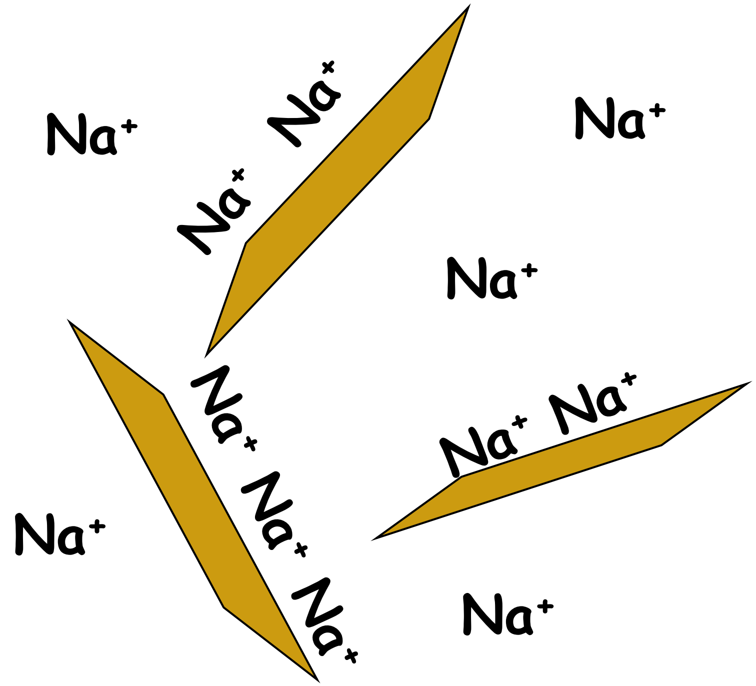


Sodicity and soil structure





Clay particles or platelets in soil are held together by Ca^{+2} ions



High concentrations of Na^{+} ions can displace the Ca^{+2} and cause the clay particles to disperse


Brine spill + 10 years


Brine spill + 60+ years

Key parameters in the remediation of brine impacted soils

- Electrical conductivity of a saturated paste extract of soil (EC) – units: dS/m, mS/cm, µS/cm, or mmhos/cm
- Sodium adsorption ratio of the saturated paste extract (SAR) – no units
- Cation exchange capacity of the soil (CEC) – units: meq/100 g of soil
- Exchangeable sodium percentage (ESP) – units: %

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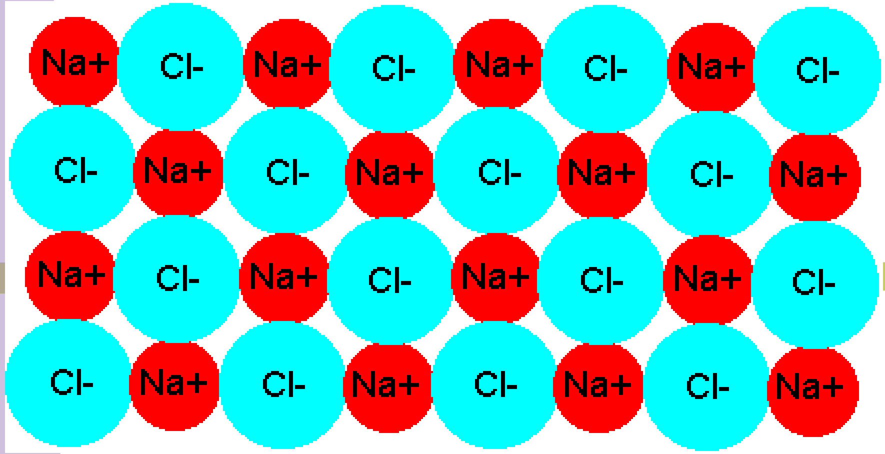
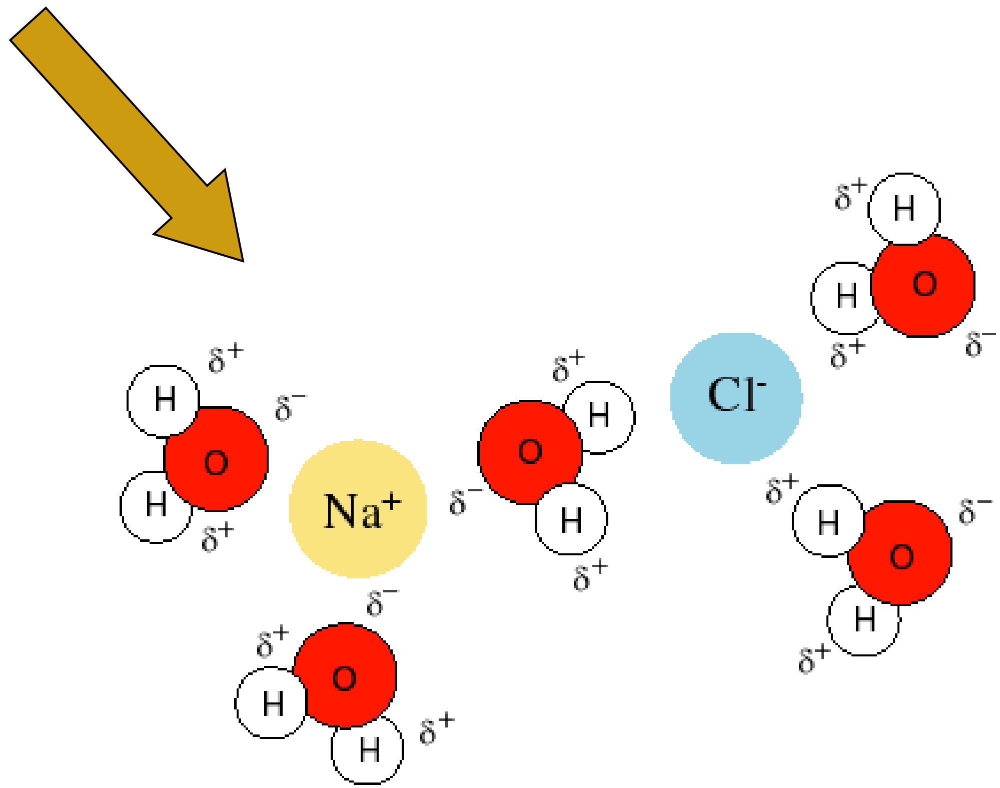
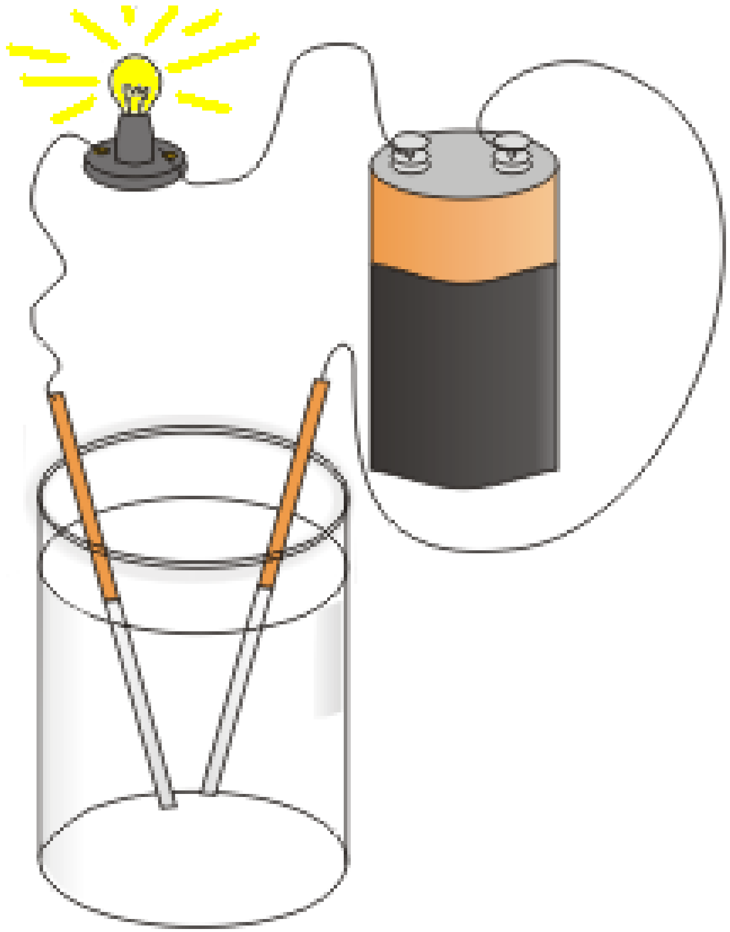


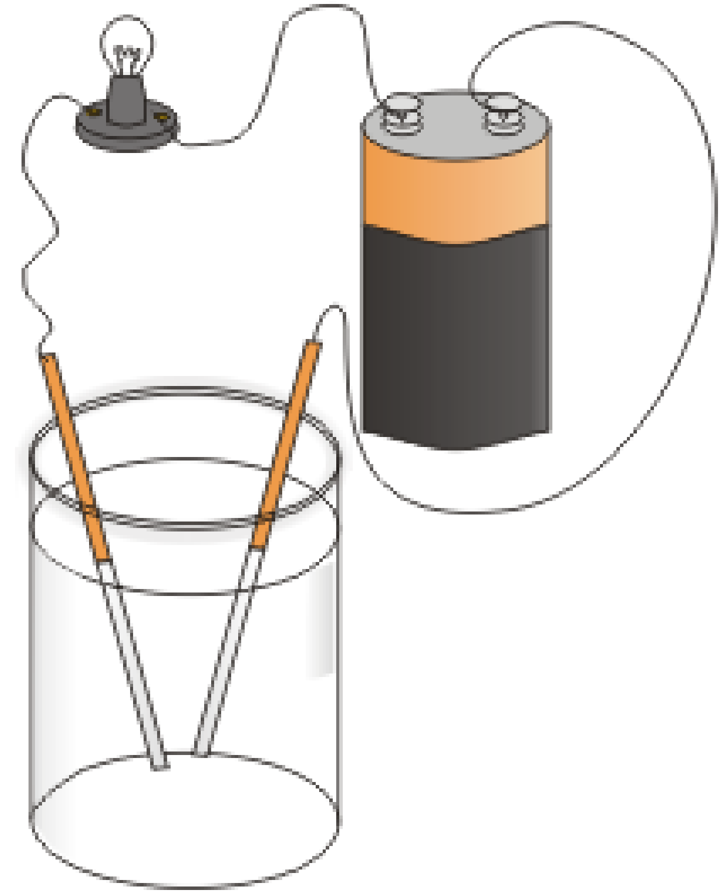
NaCl crystals

NaCl dissociates into ions in water making the water electrically conductive



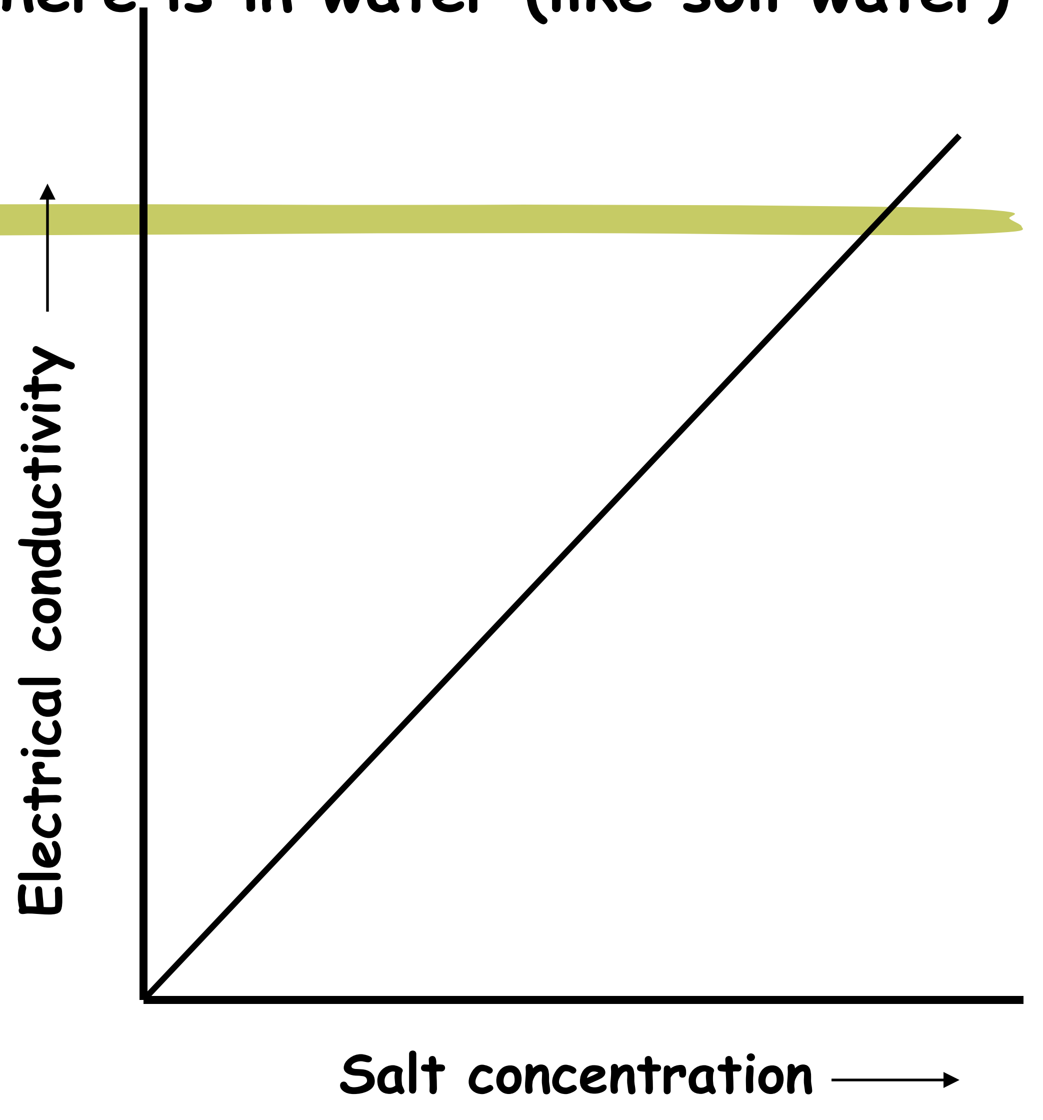


Salt solution



Pure water or solutions of compounds that do not dissociate into ions do not conduct electricity

Electrical conductivity is a measure of how much salt there is in water (like soil water)



Saturated paste electrical conductivity

(The standard way of reporting EC)

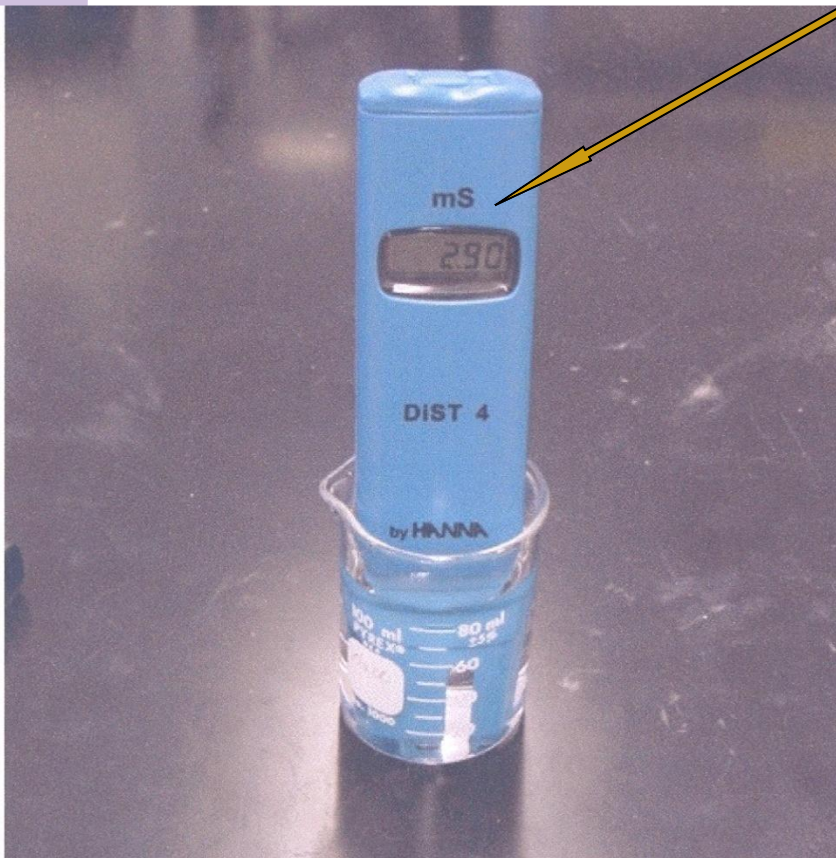
- Soil sample is moistened with distilled water until all the soil pores are filled without any standing water on the surface. When the soil is saturated the top of the soil will glisten.
- Extract water is recovered by vacuum filtration and the conductivity measured- this is the saturated paste EC.
- Saturated paste EC is proportional to the concentration of soluble salts in the soil
- Saturated paste EC reflects the salinity of the pore water when the soil is wet

Relationship between a saturated paste EC and EC of a 1:1 wt ratio (100 mL water + 100 g dry soil)

Soil Texture	USDA relationship between EC_s and $EC_{1:1}$ (mS/cm)
Coarse	$EC_s = 3.0(EC_{1:1}) - 0.06$
Medium	$EC_s = 3.0(EC_{1:1}) - 0.77$
Fine	$EC_s = 2.96(EC_{1:1}) - 0.95$

We can approximate a 1:1 wt. ratio of soil and water in the field

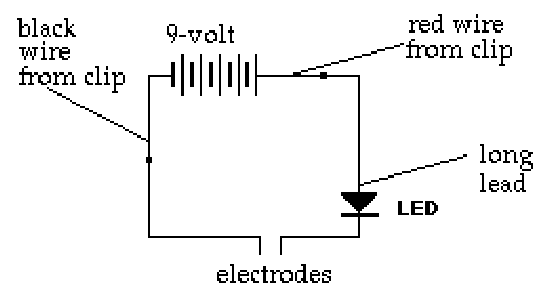
Measuring electrical conductivity



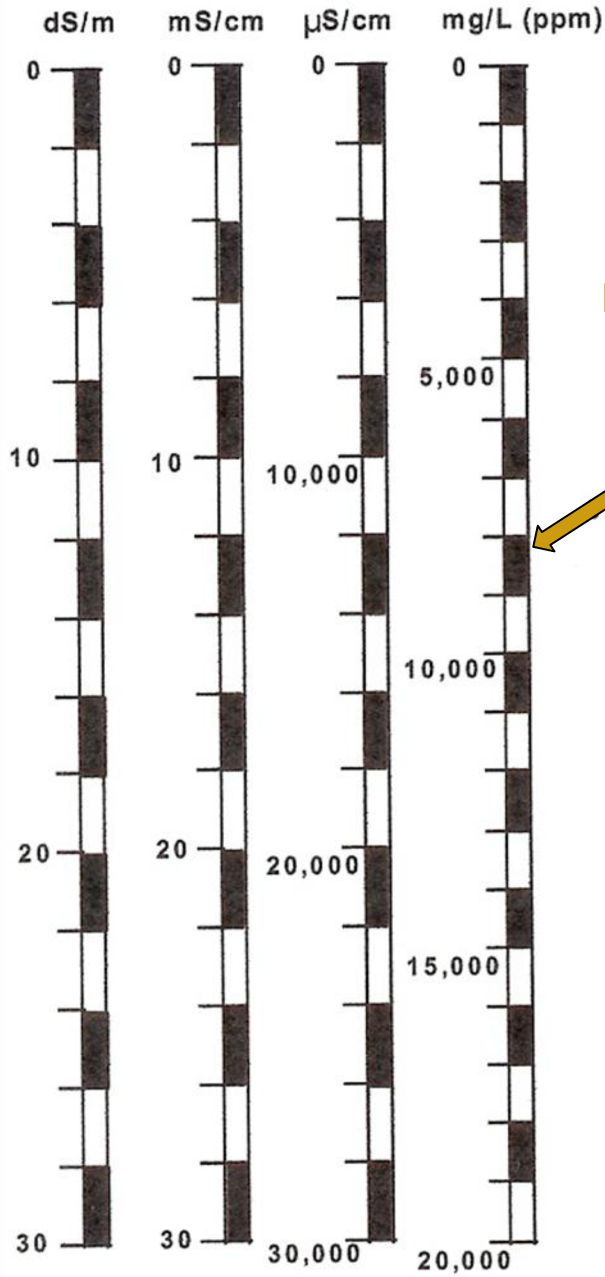
Field EC meter

EC is proportional to the concentration of soluble salts in the water

Typical units are dS/m, mS/cm, µS/cm, or mmhos/cm



Schematic of Conductivity Tester



mmhos/cm = mS/cm

Total Dissolved Solids (TDS)

Approximate relationships:

EC (mS/cm) X 640 = TDS (mg/L)

TDS (mg/L) X 0.61 = [Chloride], mg/L

If equal weights of dry soil and water are used to produce the extract, then this chloride concentration is also the chloride concentration in the soil in units of mg/kg.

Interpretation of electrical conductivity (EC) from saturated paste extract

EC (mS/cm)	Salt rank	Effect on Plants
0 - 2	Low	Very little chance of injury on all plants
2 - 4	Moderate	Sensitive plants and seedlings of others may show injury
4 - 8	High	Most non-salt tolerant plants will show injury; salt-sensitive plants will show severe injury
8 - 16	Excessive	Salt-tolerant plants will grow; most others show severe injury
16+	Very excessive	Very few plants will tolerate and grow

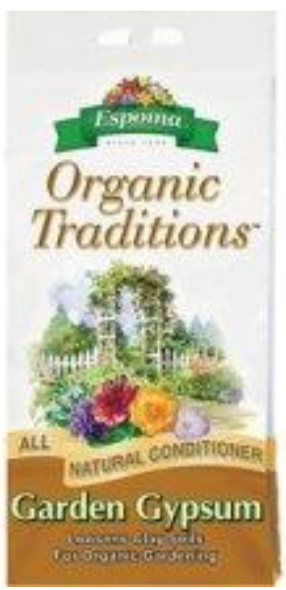
Interpretation of electrical conductivity (EC) from saturated paste extract

EC (mS/cm)	Approximate soil chloride* (mg/kg)
0 - 2	0 - 260
2 - 4	260 - 520
4 - 8	520 - 1040
8 - 16	1040 - 2080
16+	> 2080

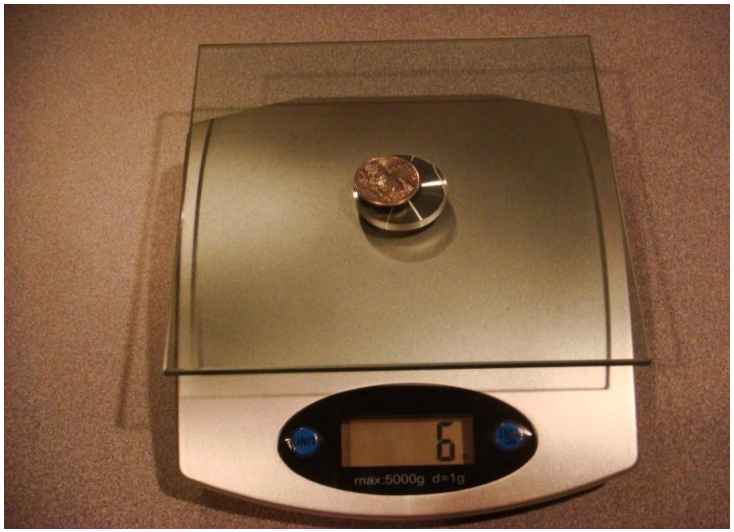
* Assumes dry soil and NaCl as only source of salinity

Alternate method for chloride concentration in soil

- Mix equal weights of soil and chloride extraction solution [saturated calcium sulfate or gypsum ($CaSO_4 \cdot 2H_2O$) solution]



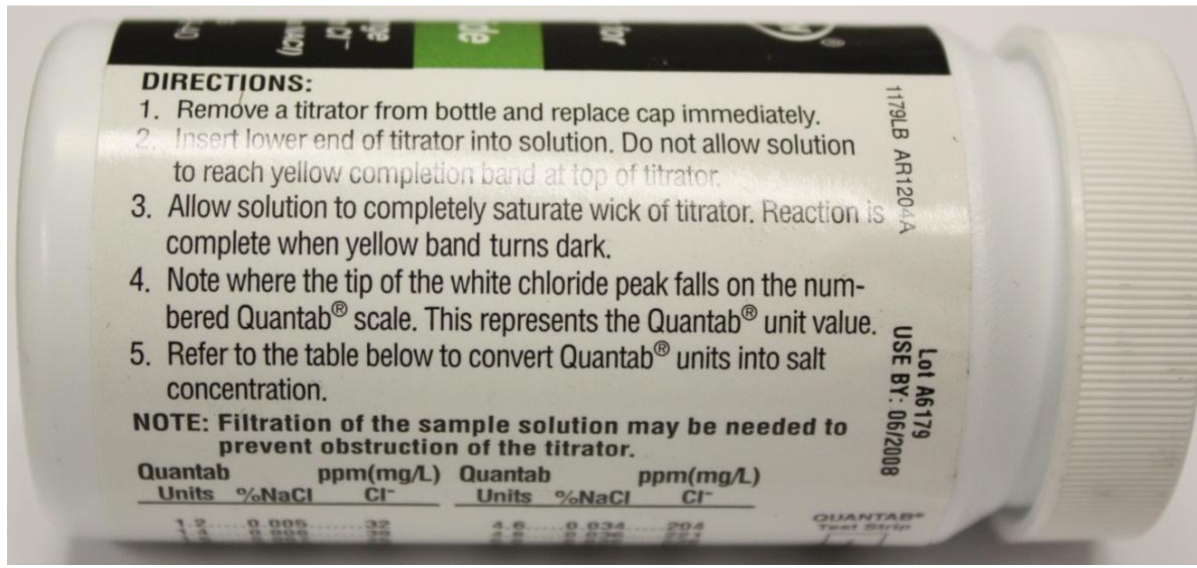
Chloride extraction solution: Mix gypsum with distilled water and stir. Allow undissolved gypsum to settle and pour off the clear solution. This is your extraction solution



Battery operated scale reading in grams available from WalMart for <$15

Thoroughly mix equal weights of soil and extraction solution

The chloride analysis uses test strips for chloride from Hach Chemical Co. (www.hach.com)

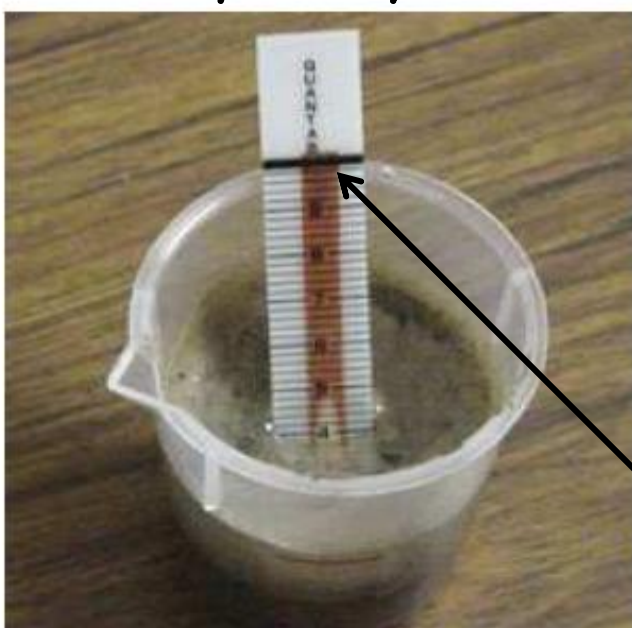


Also available in High Range 300 – 6000 ppm

Cost about $42

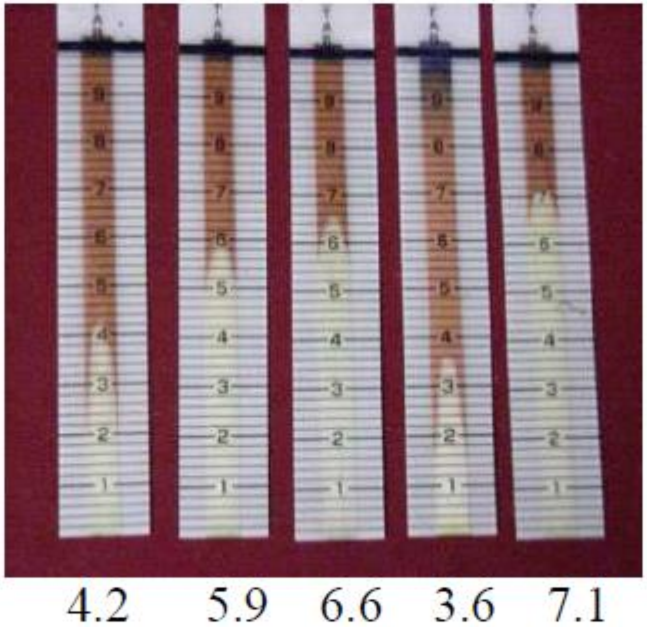
Allow soil to settle, the solution does not need to totally clarify

Drop in a test strip with the "Quantab" label up

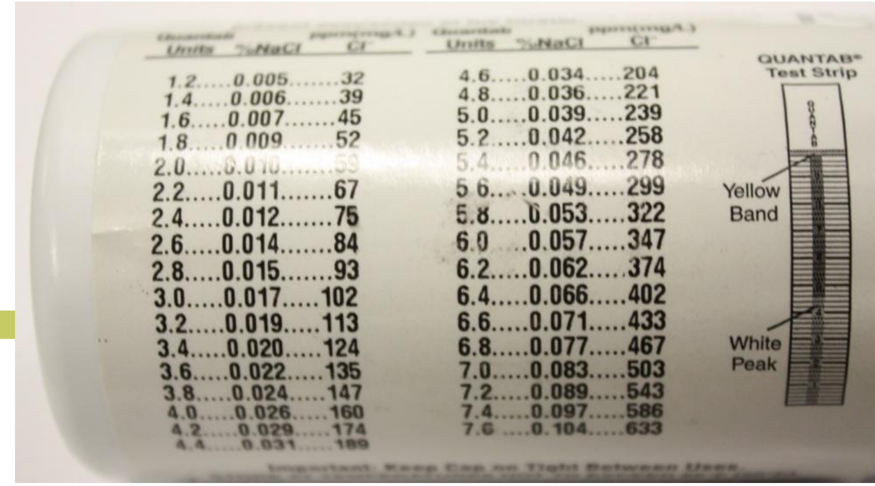


Water will begin to wick up the test strip. As it does chloride in the water will chemically react with an indicator in the brown strip turning whitish to indicate chloride.

Leave the test strip in the water until the strip across the top turns black

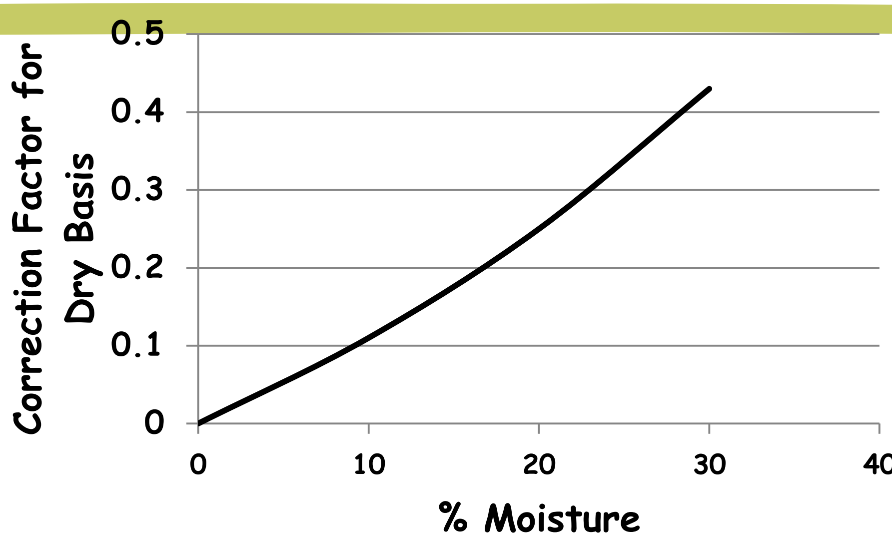


When the test incubation is concluded read on the test strip how far the tip of the white color has moved as shown above.



The table on the test strip bottle can convert the test strip reading into a chloride concentration in the extraction solution in mg/L. If you use equal weights of the soil and extraction solution to make this extract then this is also the chloride concentration in the soil in mg/kg

Chloride method correction



Dry soil as much as possible to minimize need for correction

The chloride concentration in the soil (in mg/kg) will be numerically equal to the concentration (mg/L) in the extraction solution if the soil extracted is dry. If it is moist then the chloride concentration in the soil will be underestimated. The chart above can be used to correct the soil chloride concentration to a dry basis is the % moisture can be estimate or measured. For moist soil multiply the results of your analysis by 1 + the correction factor read from the chart. For example if your analysis gives a chloride concentration of 700 mg/kg and the % moisture is about 15% then the chloride concentration on a dry basis is about (700) x (1 + 0.17) = 819 mg/kg

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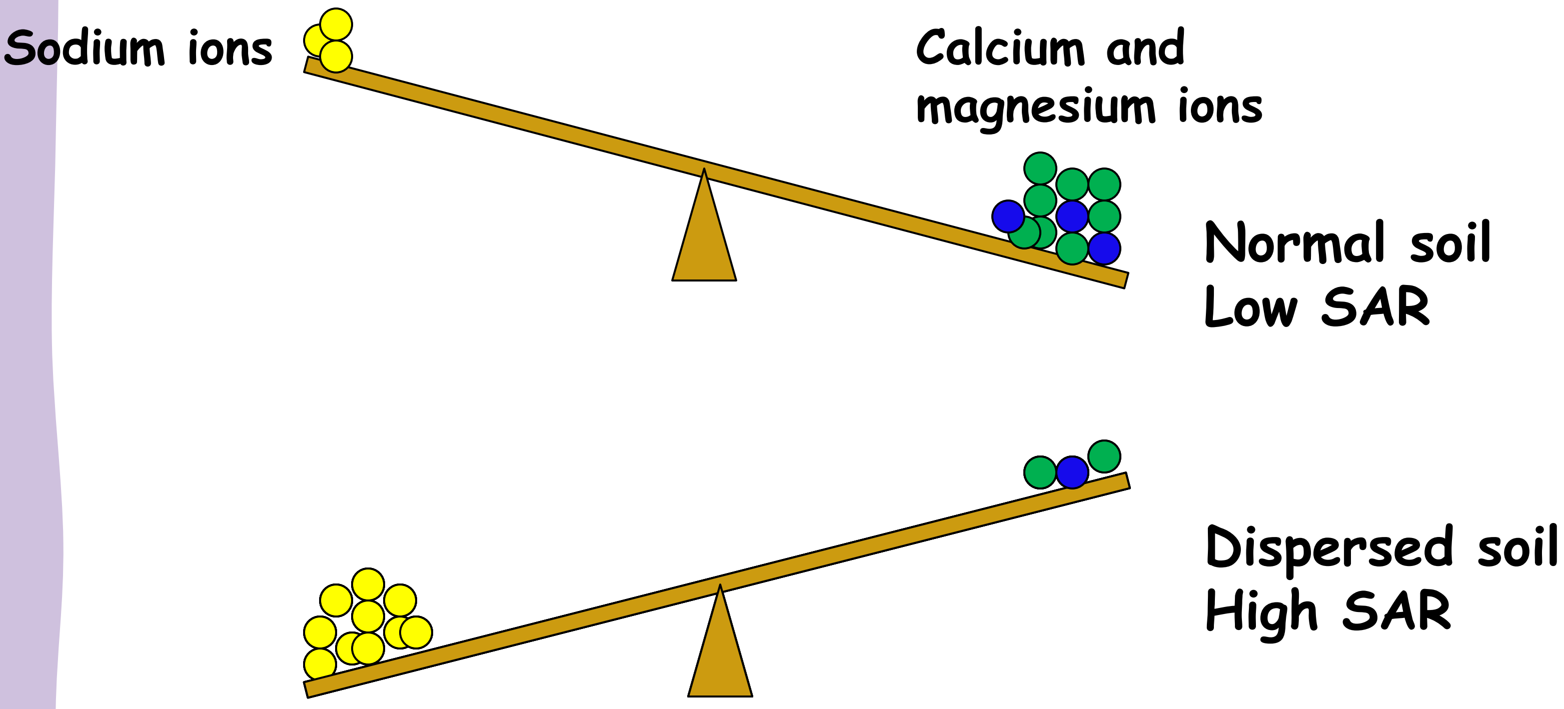
Sodium adsorption ratio (SAR)

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

Units are **meq/L**

SAR is typically measured by a laboratory analysis. There is no good way to determine SAR in the field.

The SAR is an index of sodicity – an excess of Na^+ in the soil compared to Ca^{+2} and Mg^{+2}


Sodium ions
Calcium and magnesium ions
Normal soil
Low SAR
Dispersed soil
High SAR

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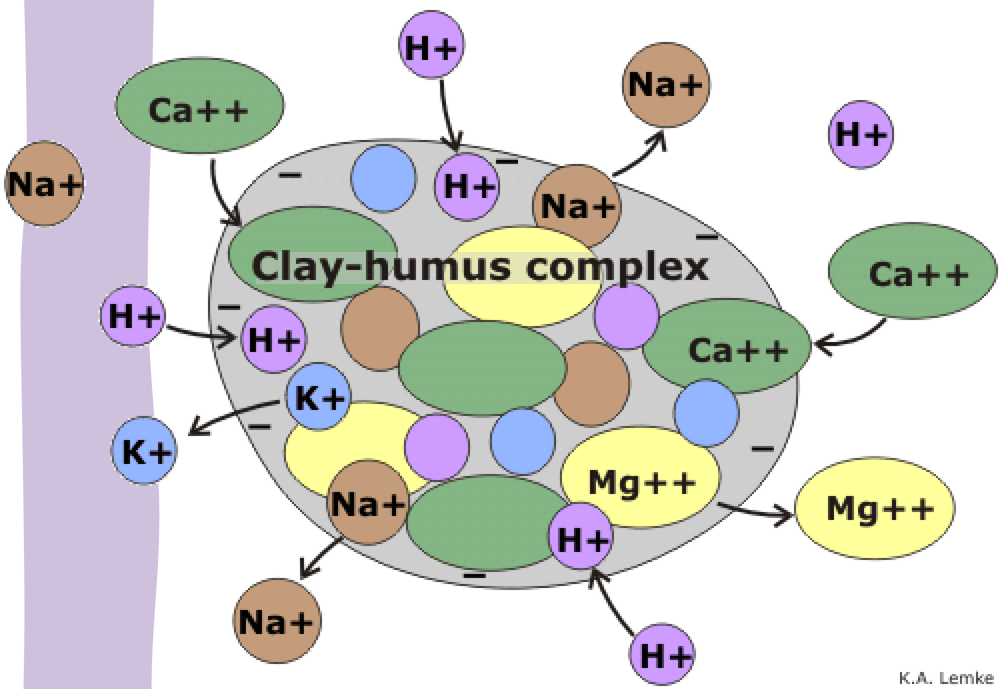
- Exchangeable sodium percentage (ESP) – units: %

Soil cation exchange sites are associated with clays and soil organic matter



The CEC of a soil is the number of cation adsorption sites per unit weight of soil

CEC is another parameter that must be done by laboratory analysis

CEC will be reported in units of milliequivalents (meq) per 100 g of oven dry soil.

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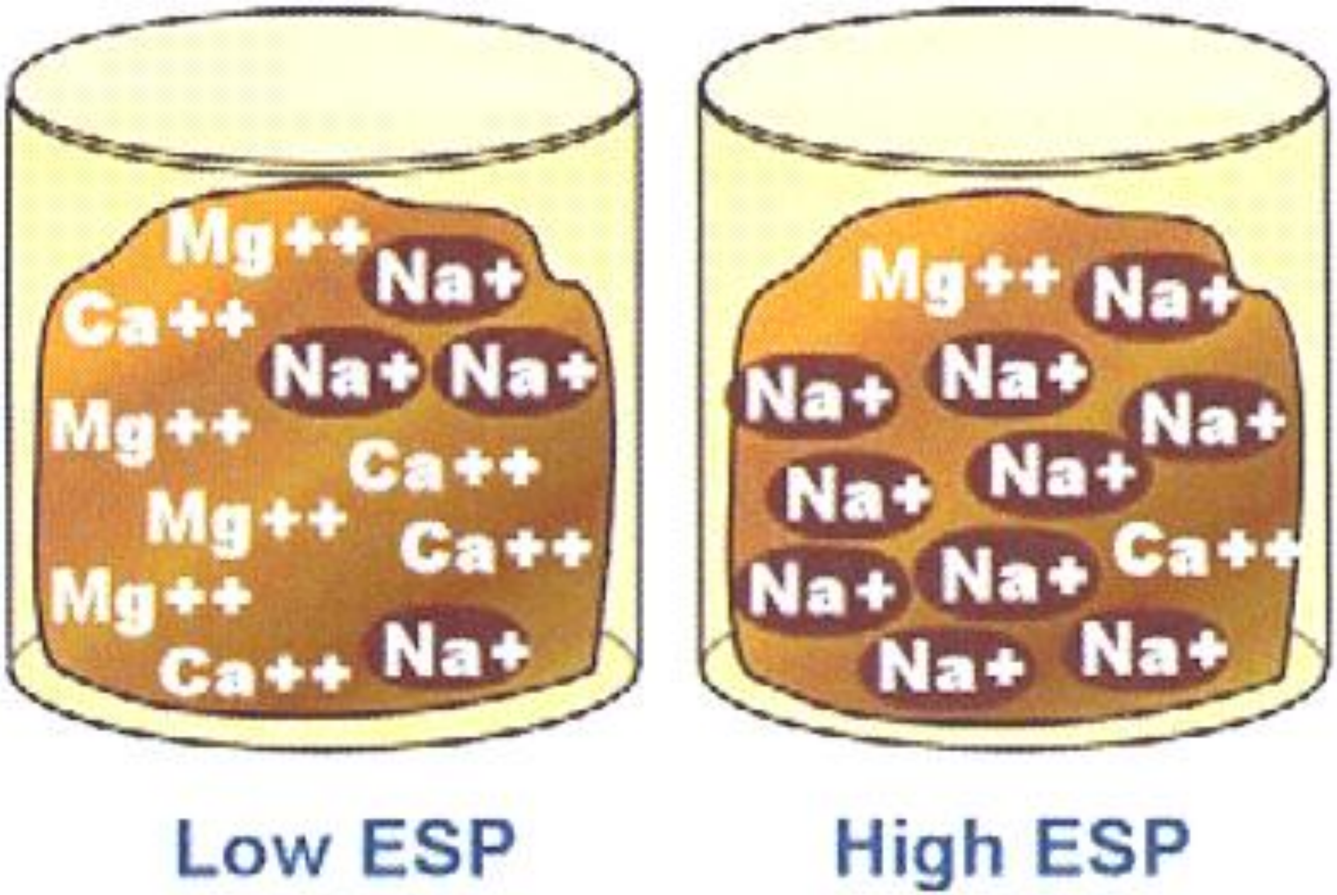
The ESP is the fraction of the cation adsorption sites occupied by Na^+



Exchangeable sodium percentage (ESP)

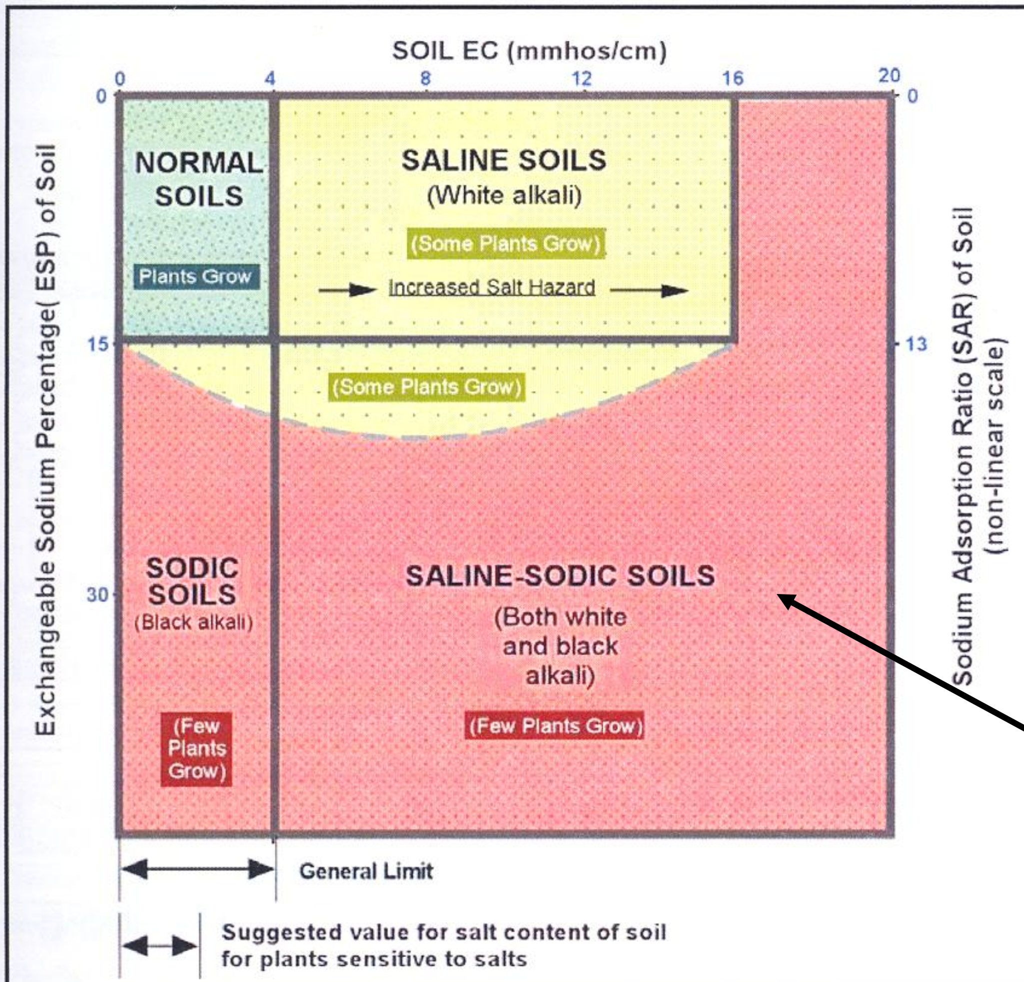
- ESP is frequently estimated from the SAR

$$ESP\ (\%) = \frac{100\,[-0.0126 + 0.01475(SAR)]}{1 + [-0.0126 + 0.01475(SAR)]}$$

Any laboratory reporting SAR for a soil will likely also report the ESP.

The effects of salinity and sodicity on plant growth

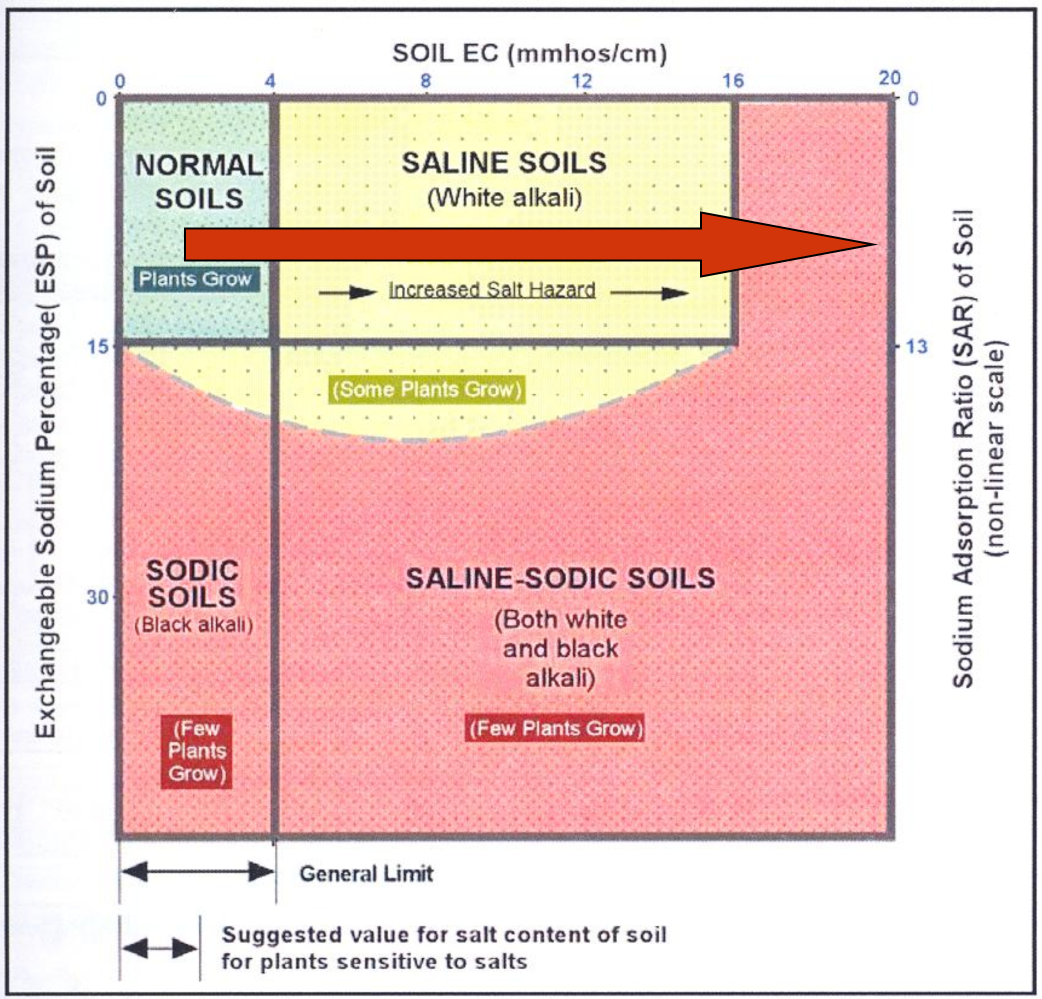
susceptible to erosion.



Soil Classification Based on ESP (%) (Y-Axis) and EC (mmhos/cm) (X-Axis) (API Publication 4663); adapted from Donahue et al., 1983).

Very few plants grow

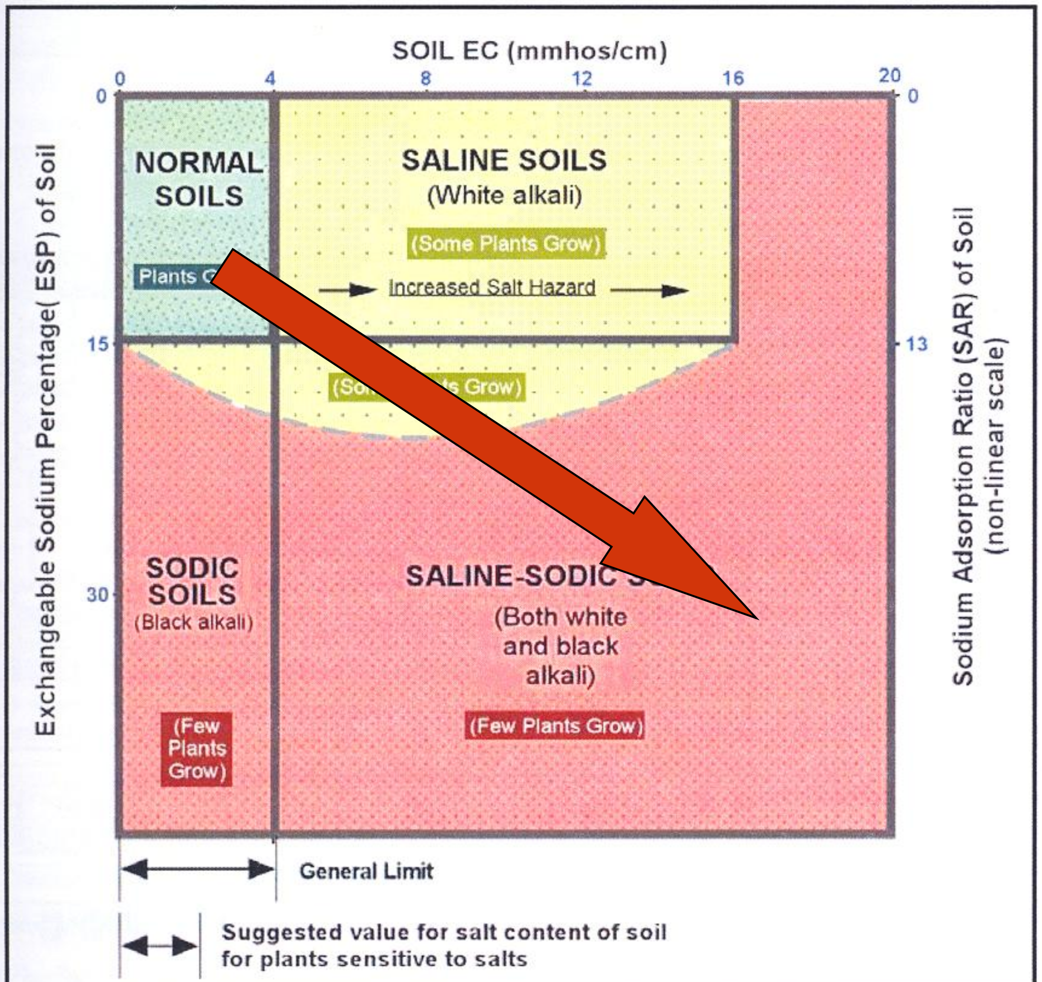
Immediate effect of brine spill on EC and SAR



Soil Classification Based on ESP (%) (Y-Axis) and EC (mmhos/cm) (X-Axis) (API Publication 4663); adapted from Donahue et al., 1983).

Effect of brine spill on EC and SAR over time

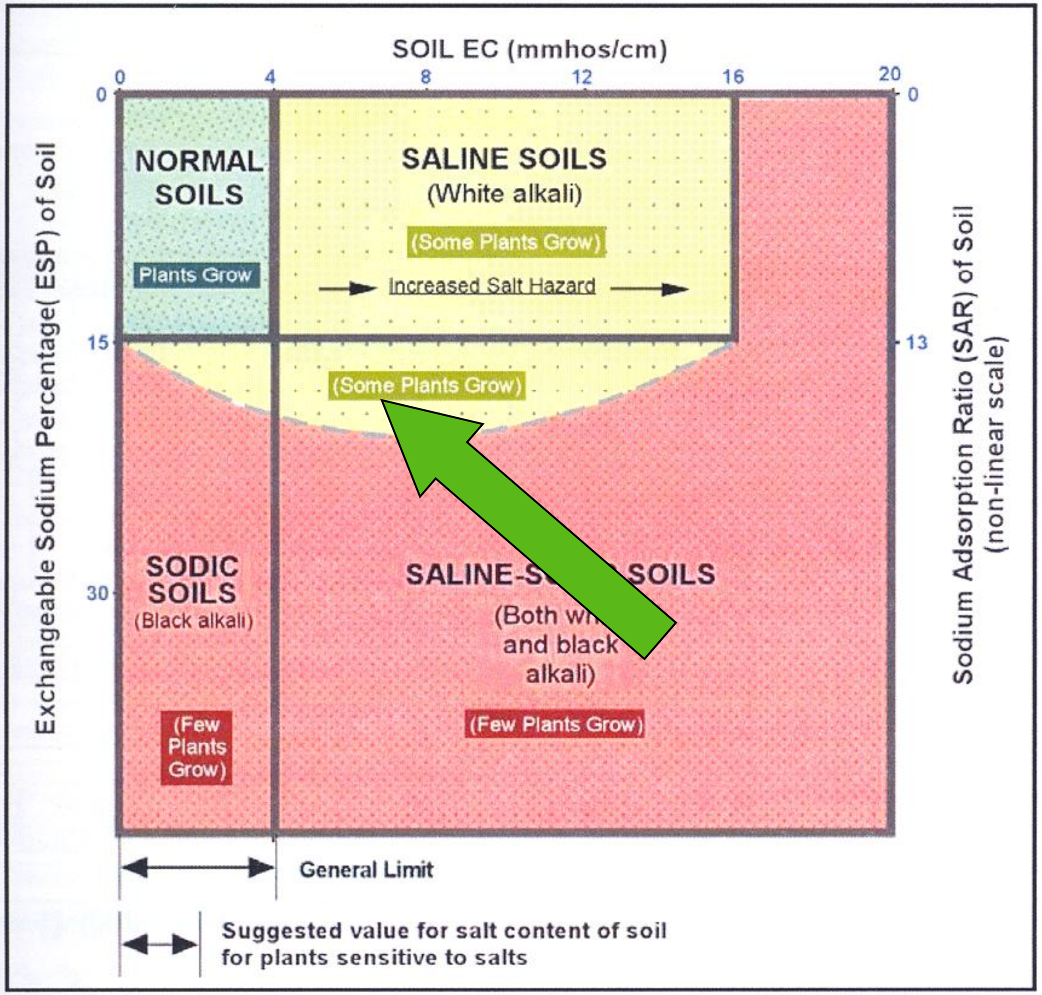
susceptible to erosion.



Soil Classification Based on ESP (%) (Y-Axis) and EC (mmhos/cm) (X-Axis) (API Publication 4663); adapted from Donahue et al., 1983).

Remediation of a brine spill must reduce salinity and sodicity

susceptible to erosion.



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For information on salt-tolerant plants go to:

http://www.ussl.ars.usda.gov/pls/caliche/Halophyte.query

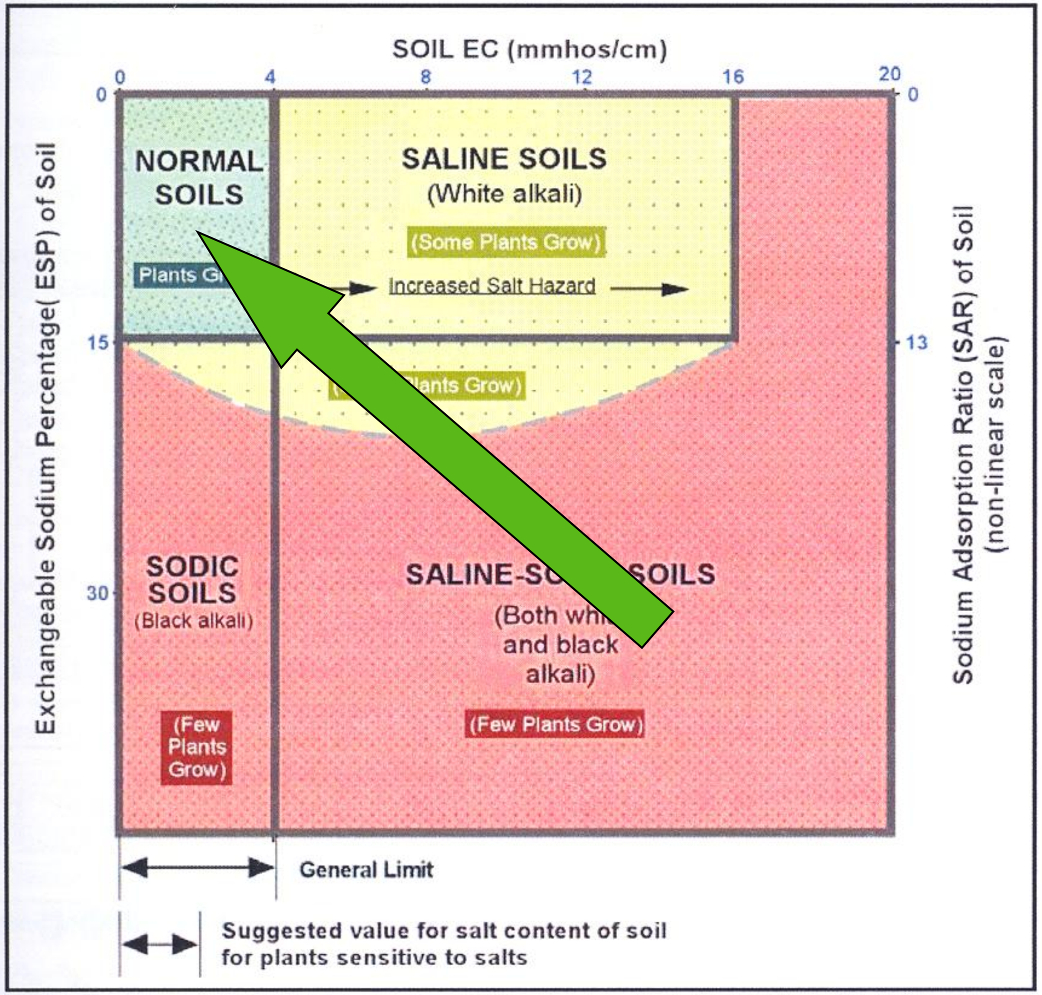
Halophyte DataBase

Salt - Tolerant Plants & Their Uses

by N.P. Yensen

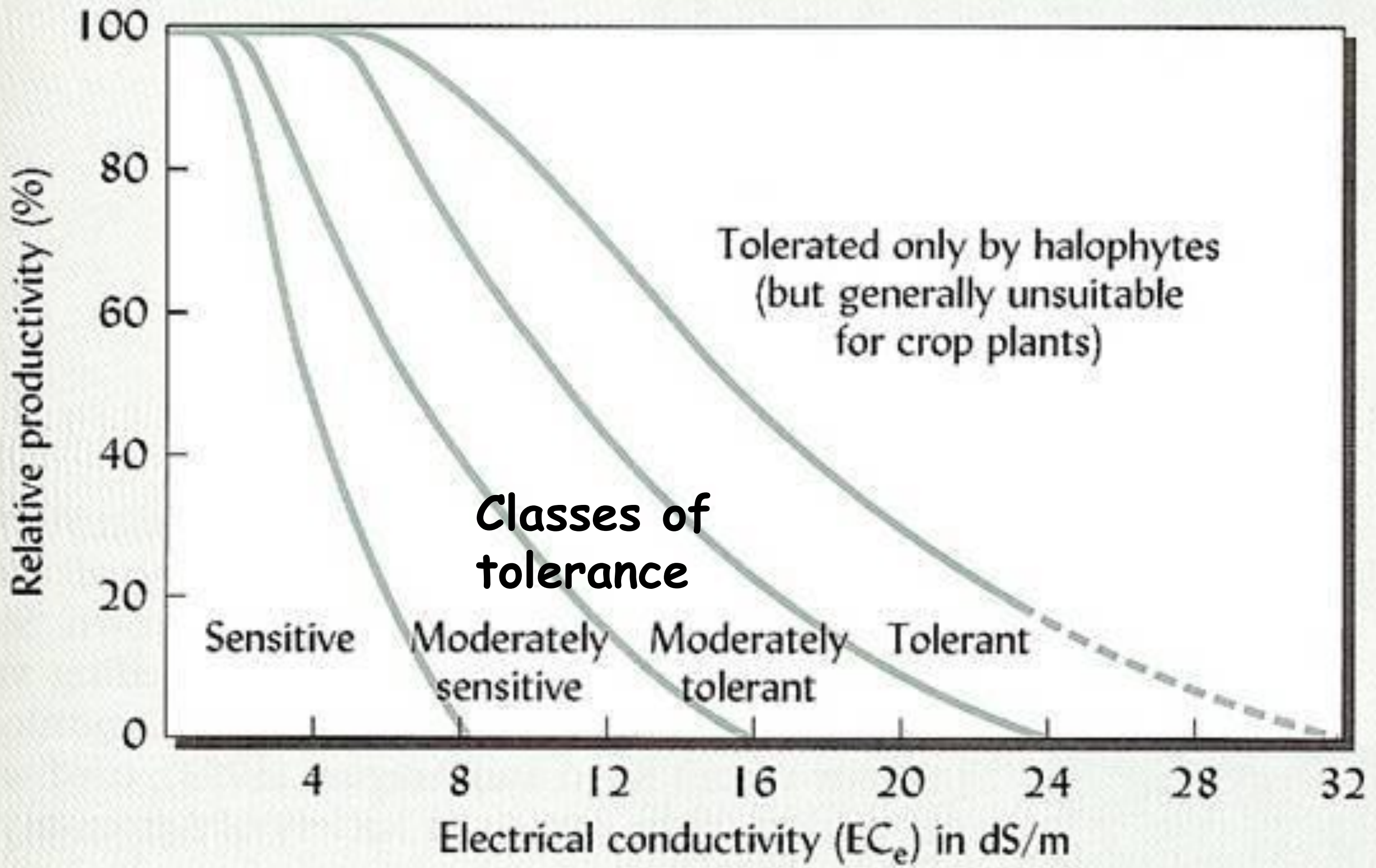
Remediation of a brine spill must reduce salinity and sodicity

susceptible to erosion.

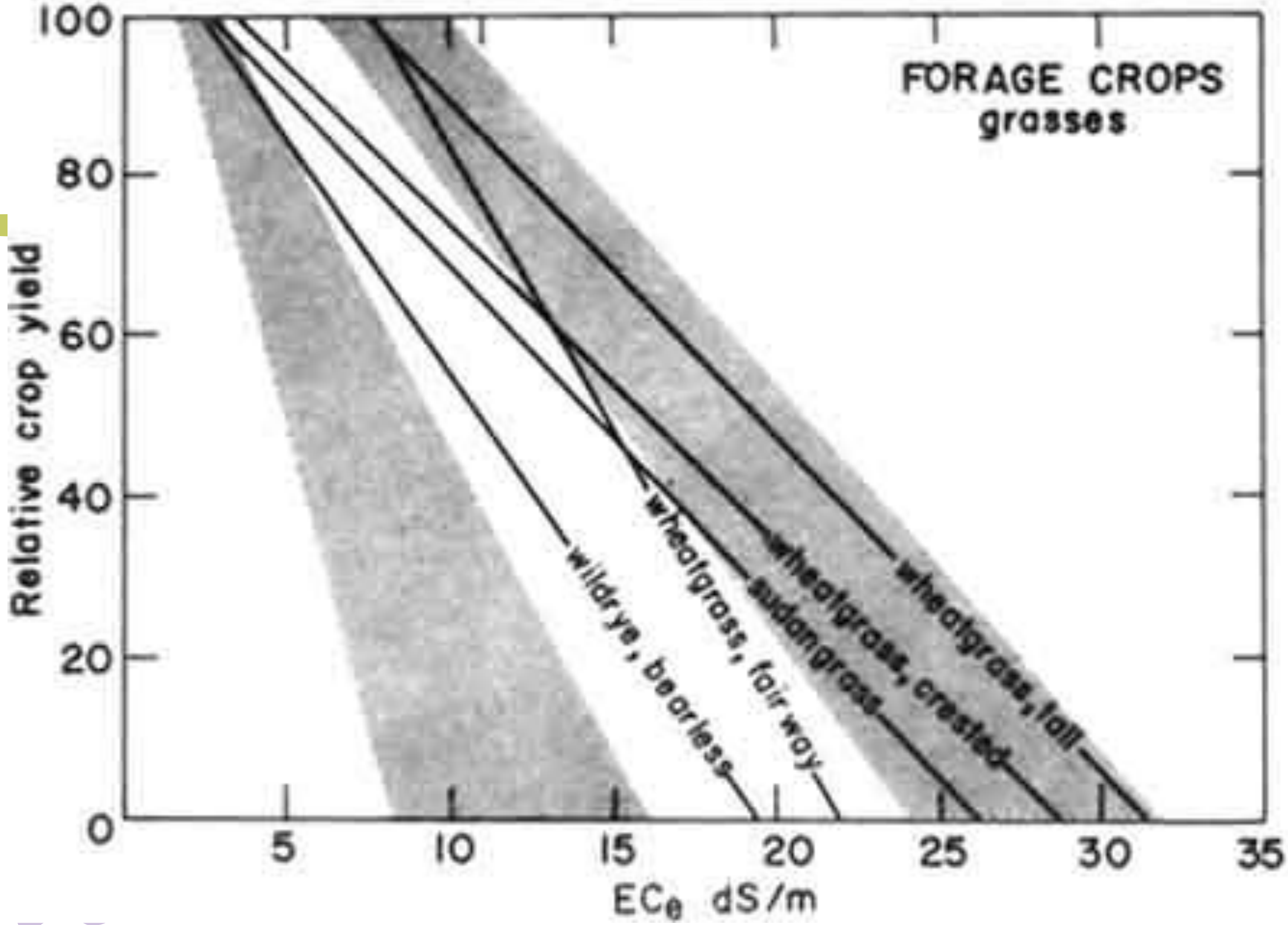


Soil Classification Based on ESP (%) (Y-Axis) and EC (mmhos/cm) (X-Axis) (API Publication 4663); adapted from Donahue et al., 1983).

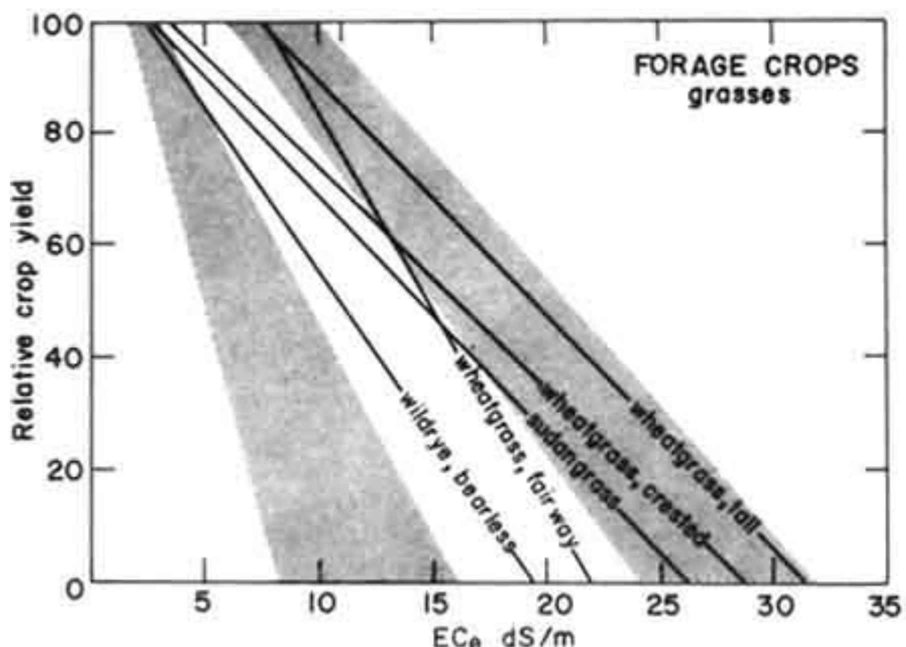
Effect of salinity on plant productivity



Rule of Thumb: the EC which produces 50% reduction in biomass production in mature plants will be approximately the maximum EC that can be tolerated by young plants and germinating seeds


FORAGE CROPS
grasses
Relative crop yield
100
80
60
40
20
0
5
10
15
20
25
30
35
ECe dS/m
wildrye, beardless
wheatgrass, fairway
sudangrass
wheatgrass, crested
wheatgrass, tall

More charts like this for other crops and forage plants are in the Appendix



Sensitivity to salinity generally increases with temperature and other stressors

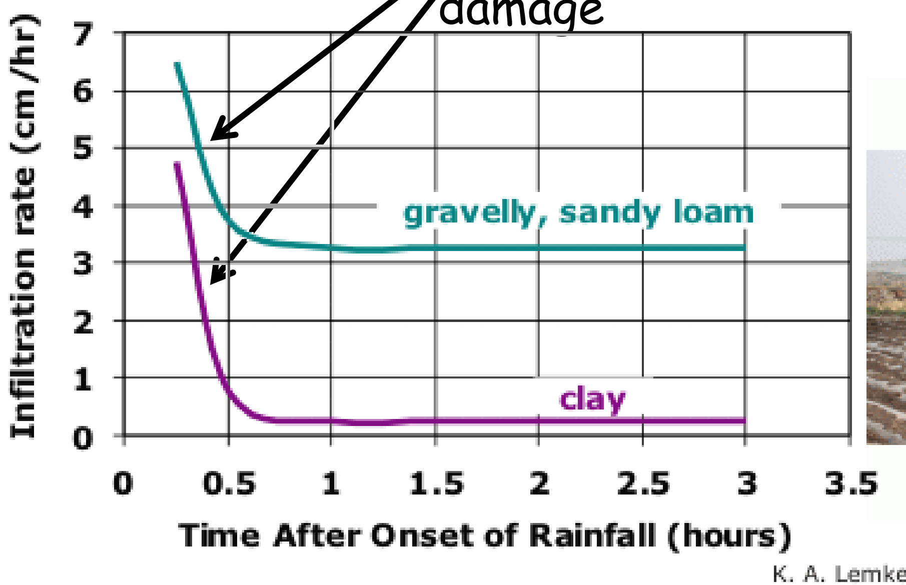
Table 15 RESPONSE OF THREE CROPS TO SALINITY IN SAND CULTURES AT TWO LOCATIONS

Crop	Solution salinity at which 25% yield reduction was observed dS/m	
	Cool location	Hot location
Bean pods	4.0	3.0
Garden beetroots	11.1	6.6
Onion bulbs	12.5	3.3

First response to a brine spill

- Flushing with fresh water into a receiving body followed by disposal of salty water
  - Soak the area between the spill and the receiving body with fresh water **before** flushing

Capillary suction from dry soil can result if further damage



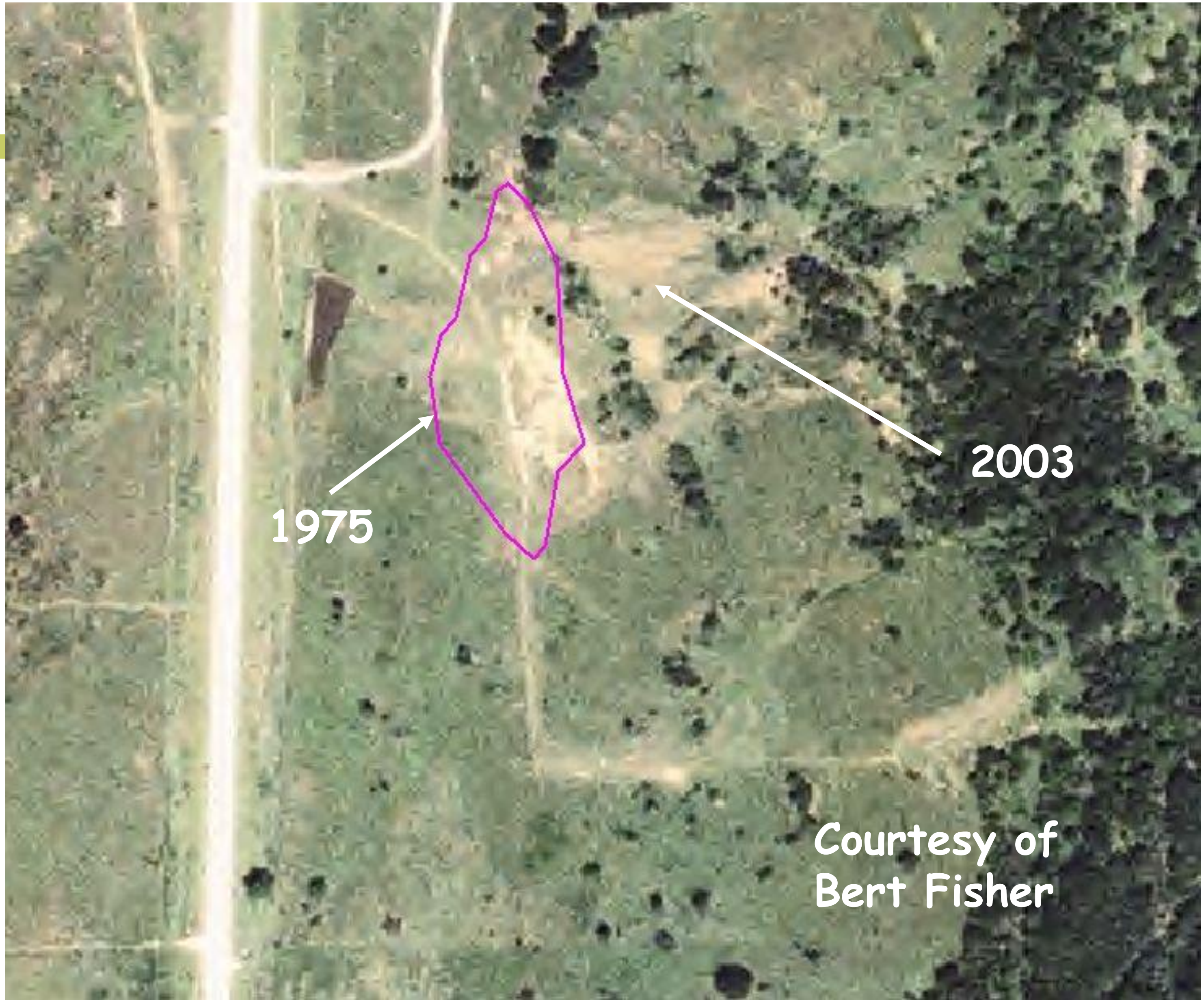
Dam a drainage ditch

or

Push up an earthen dam downgradient

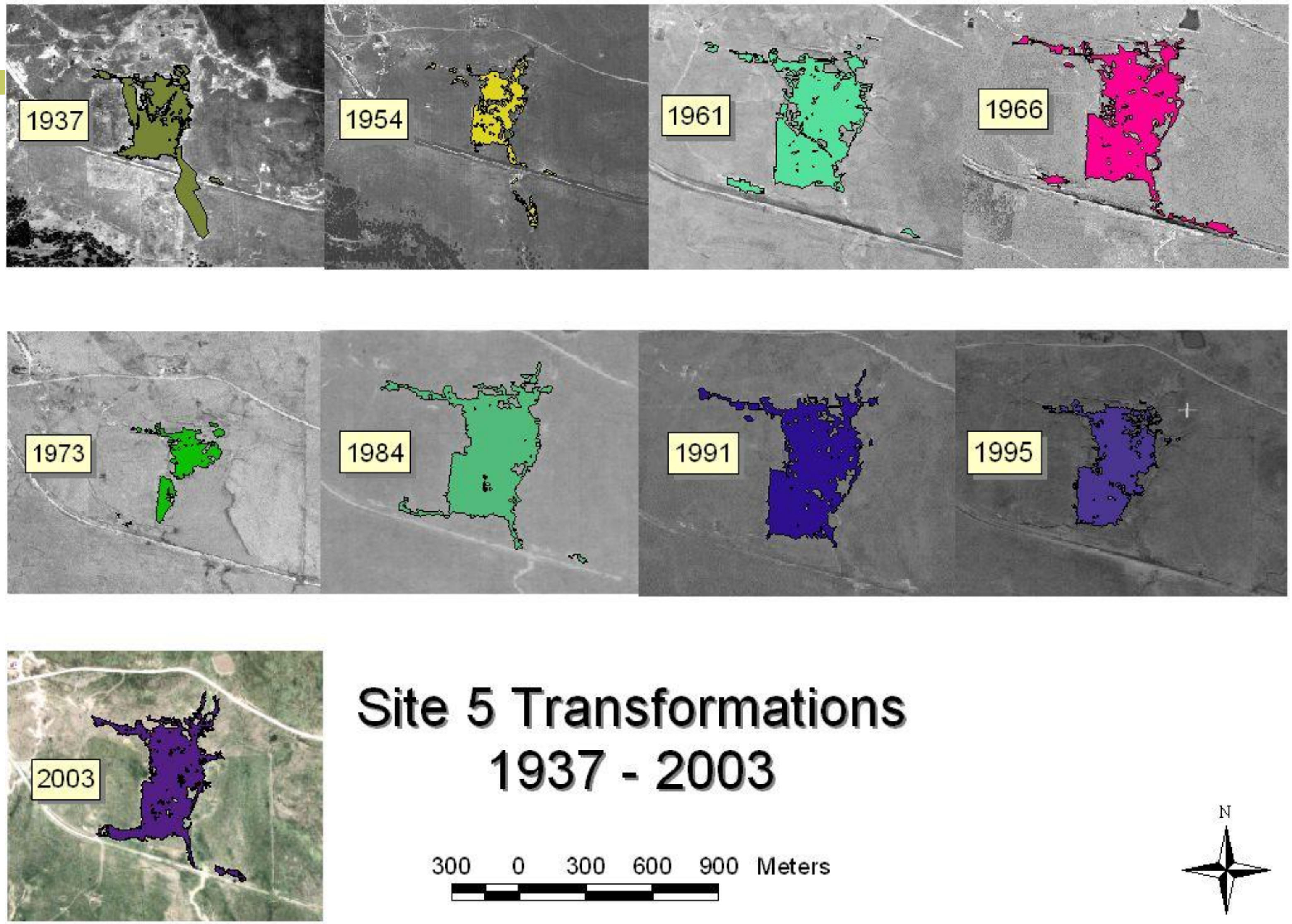
Vacuum truck to recover fluids

Brine spills will generally not heal by themselves

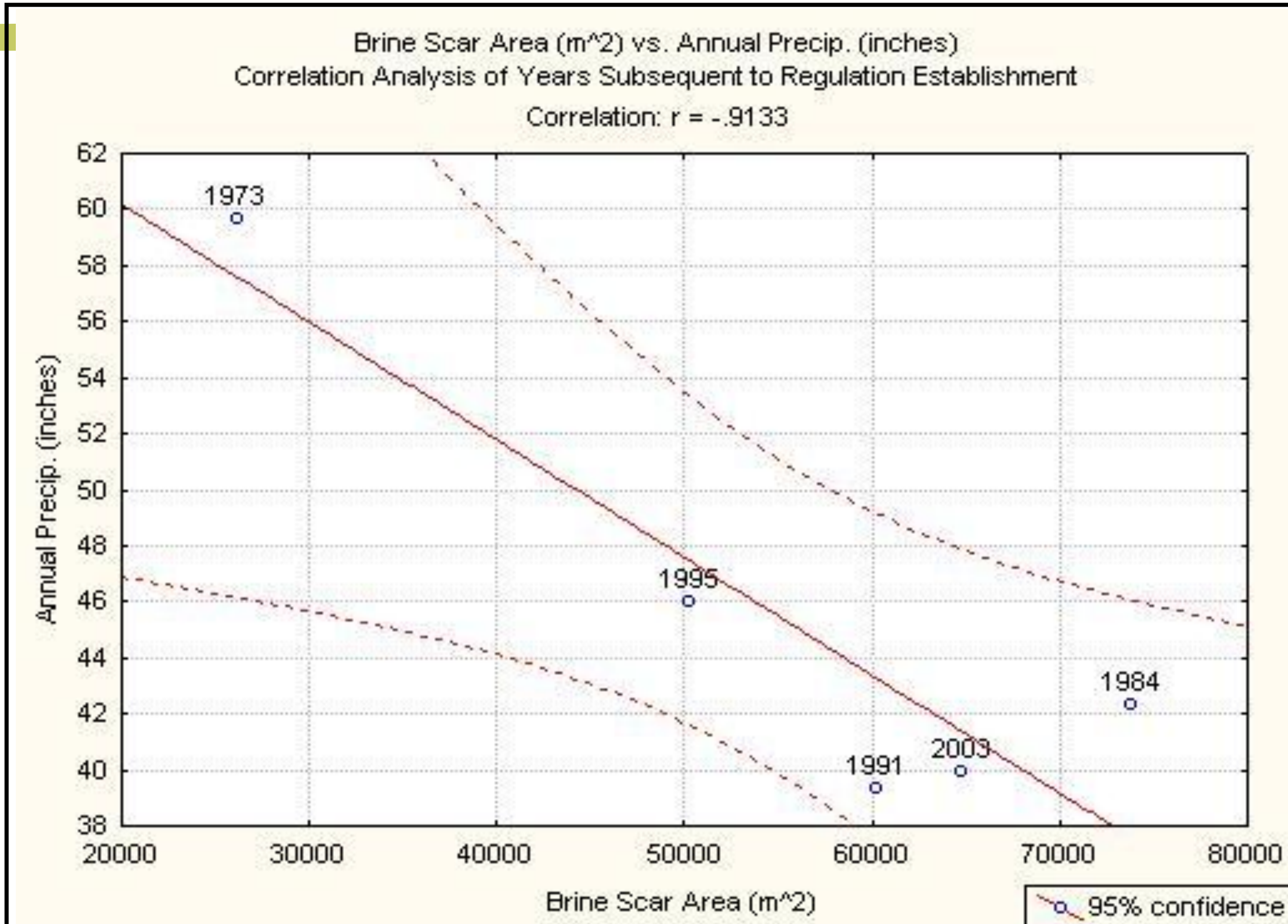



Historic brine scar

Rainfall and movement of brine components



Brine scar area vs. annual precipitation since 1973

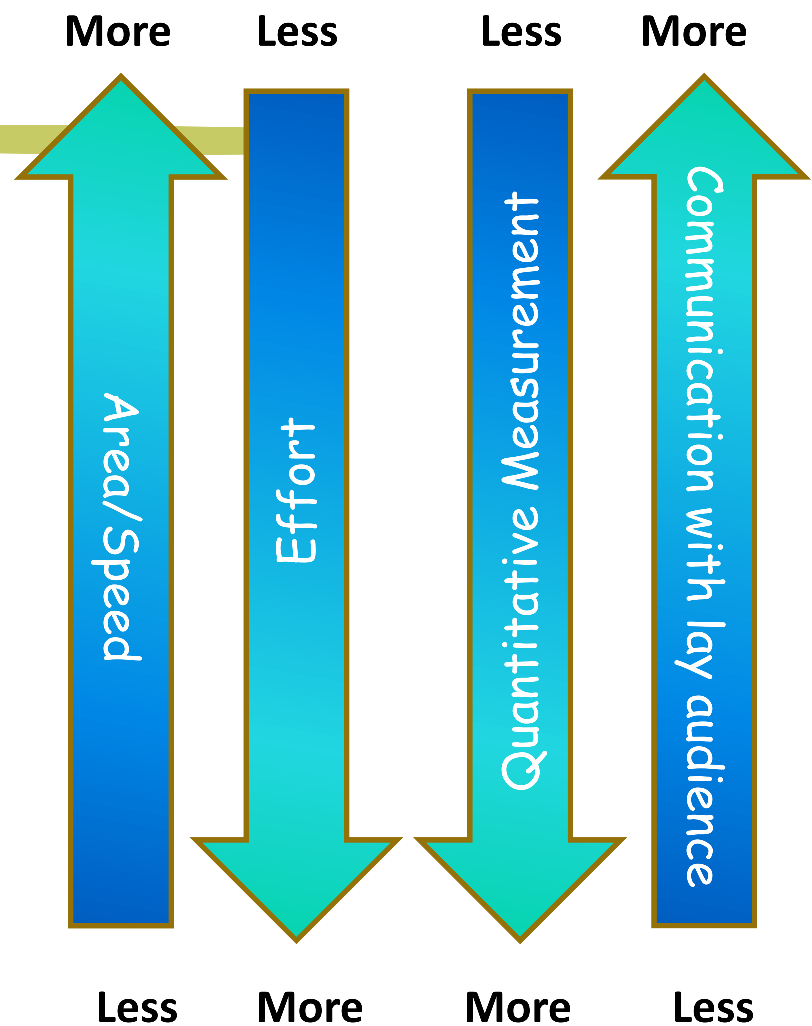


Remediation of Brine Spills

Recognizing and documenting brine damage

Site assessment tools

- Visual indicators
  - Vegetation damage
  - Salt tolerant vegetation
  - Corrosion
  - Haloclastic weathering
  - Salt crusts
  - Erosion
- Field screening techniques
  - Field kits for chlorides
  - EC
- Soil sampling/lab analysis
- Geophysical investigation
  - EM Survey

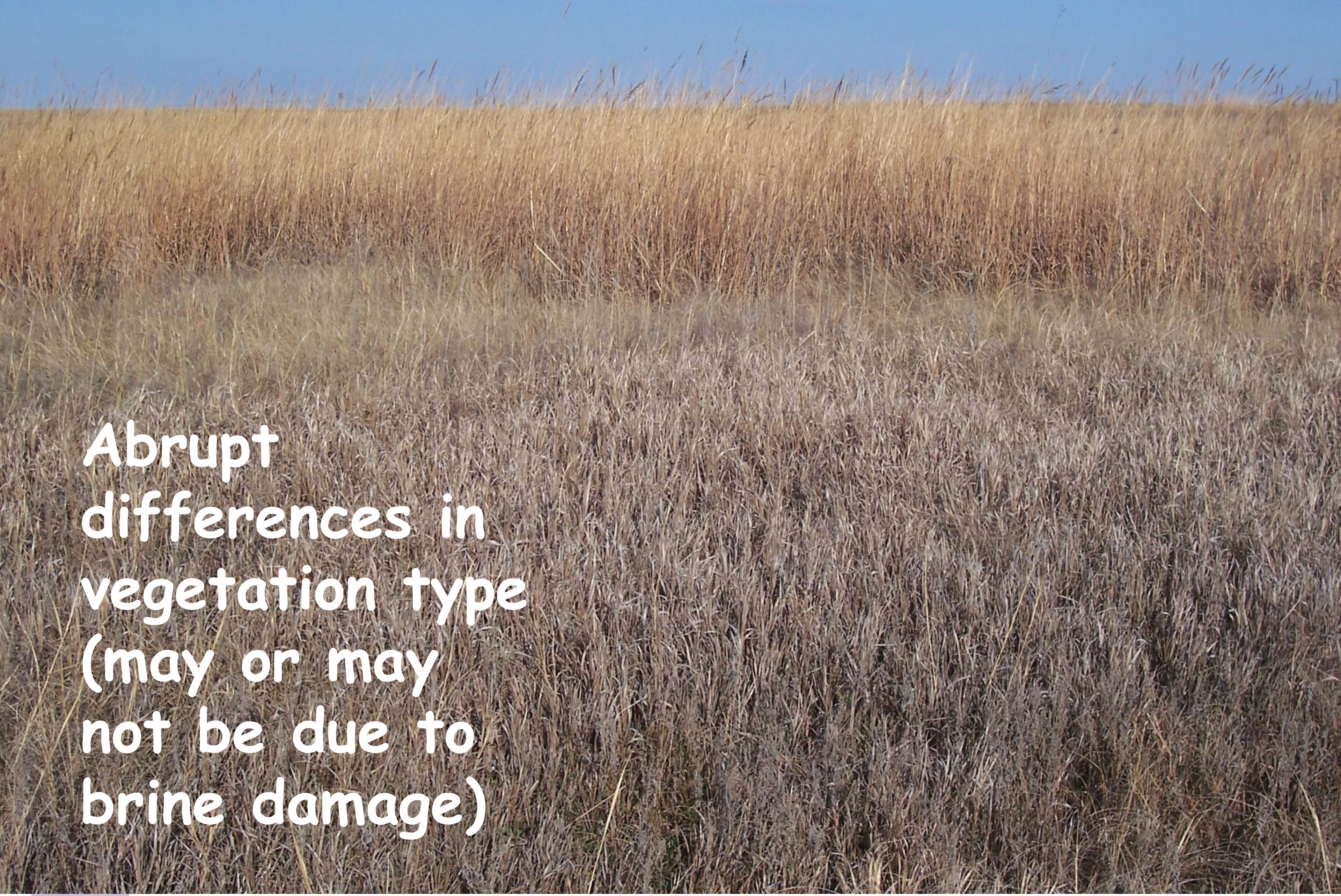


Courtesy of Bert Fisher

Recent brine spill


Vegetation kill


Abrupt differences
in vegetation type


Abrupt differences in vegetation type (may or may not be due to brine damage)


Loss of vegetation


Loss of
vegetation

Vegetation damage

Vegetation damage


Loss of
vegetation


Loss of vegetation
and erosion

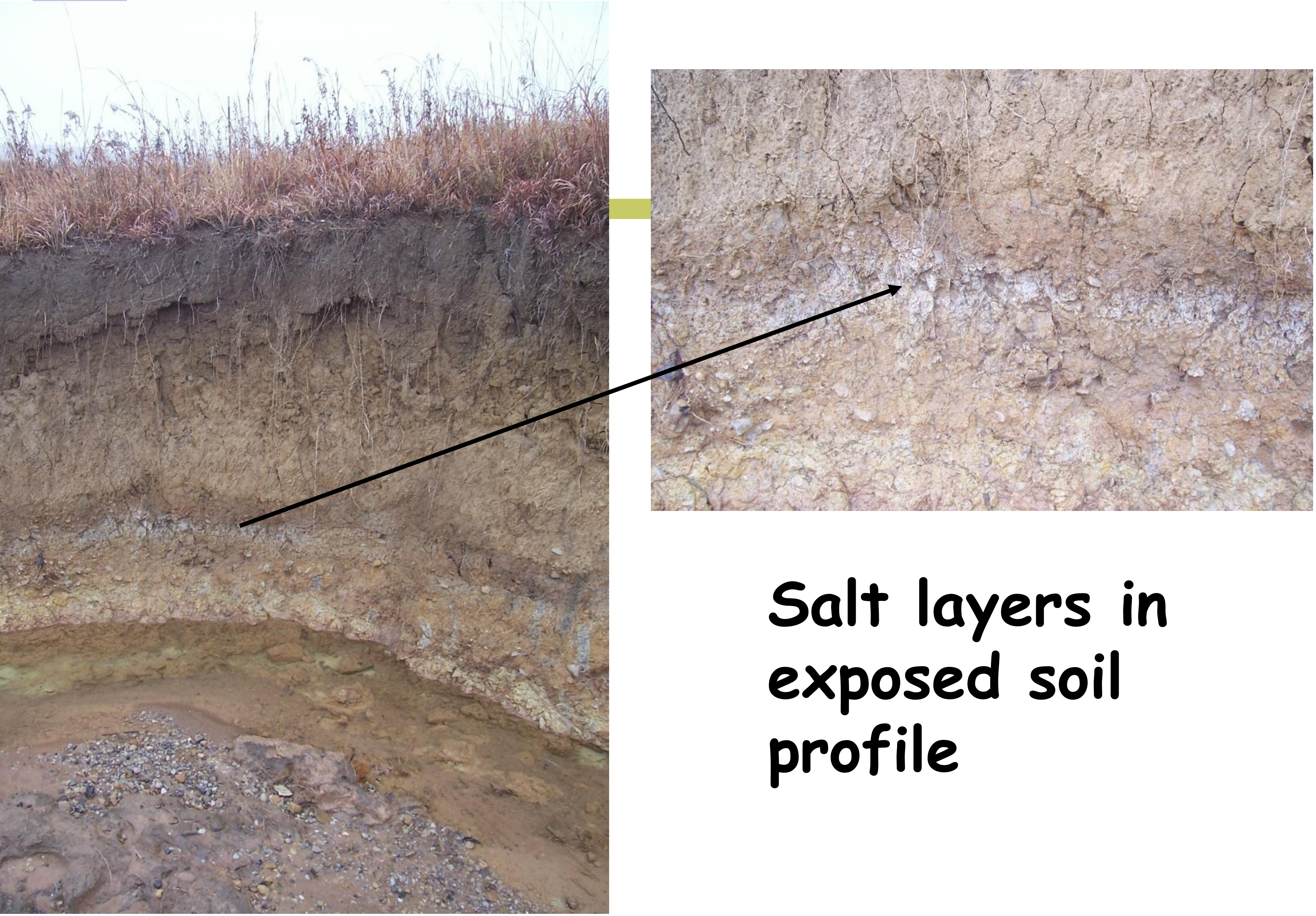

Loss of vegetation
and erosion


Erosion


Erosion

Corrosion

Salt crusts



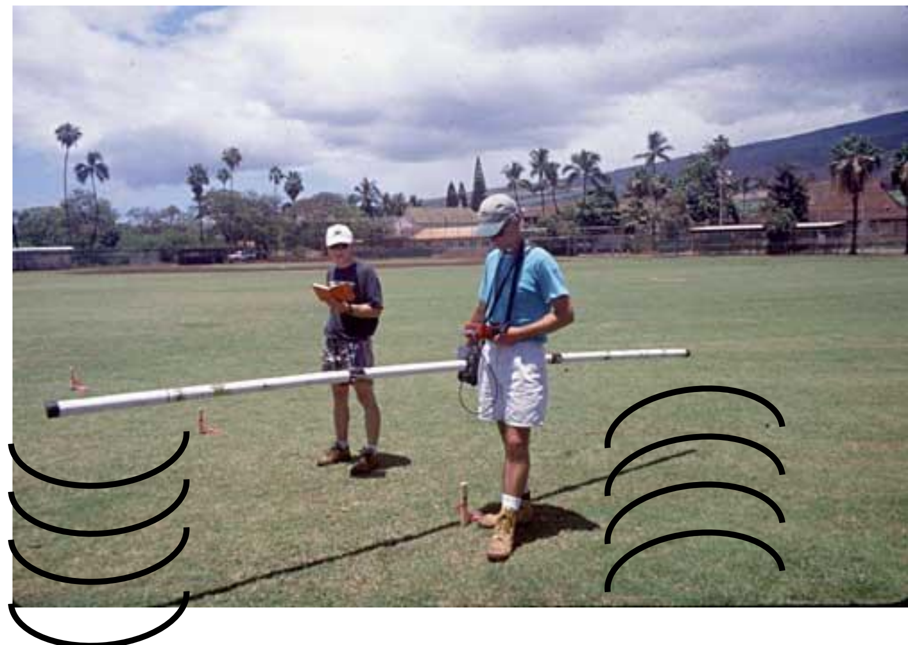
Salt layers in exposed soil profile

Haloclastic weathering

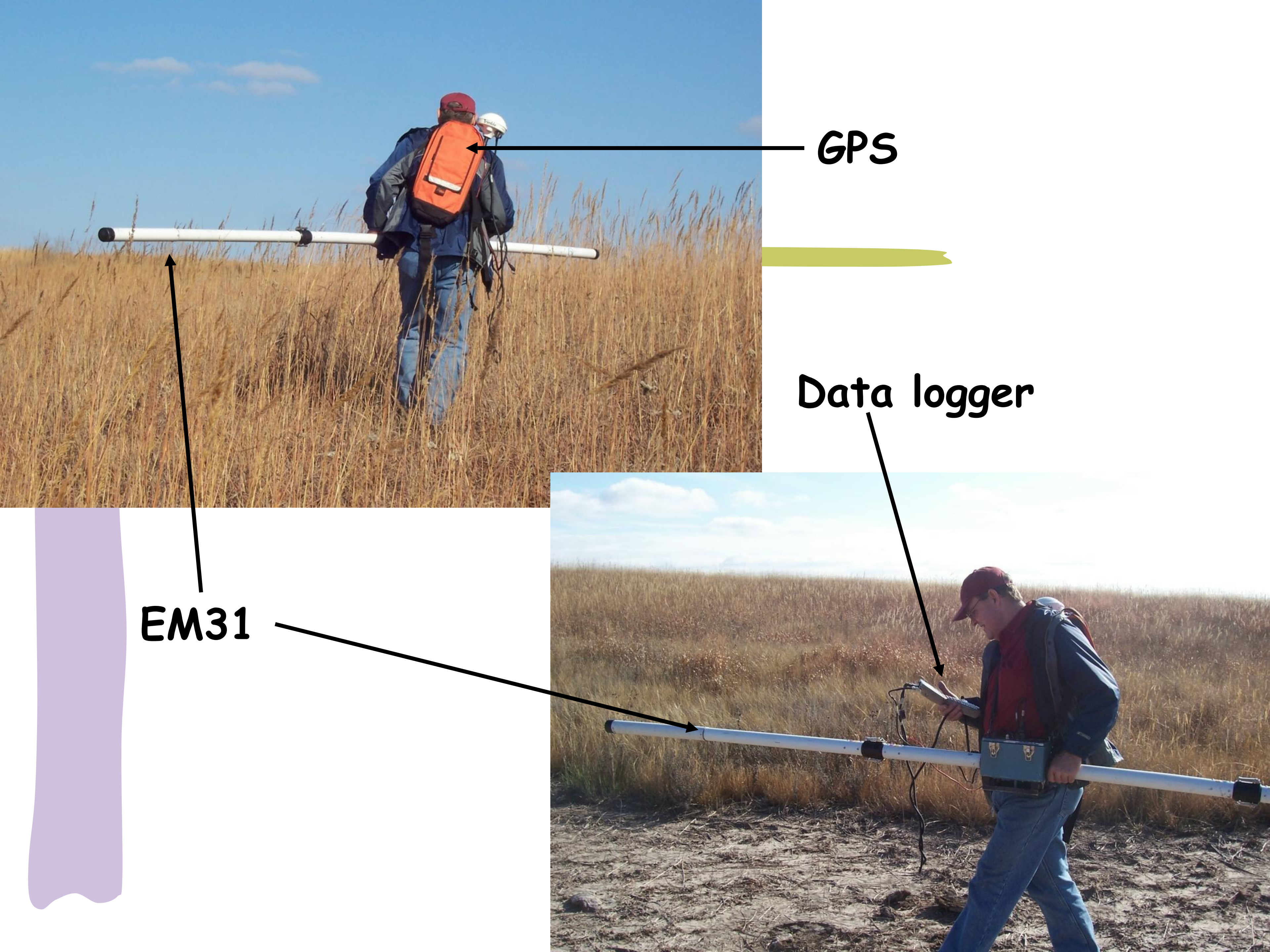
Salt tolerant vegetation

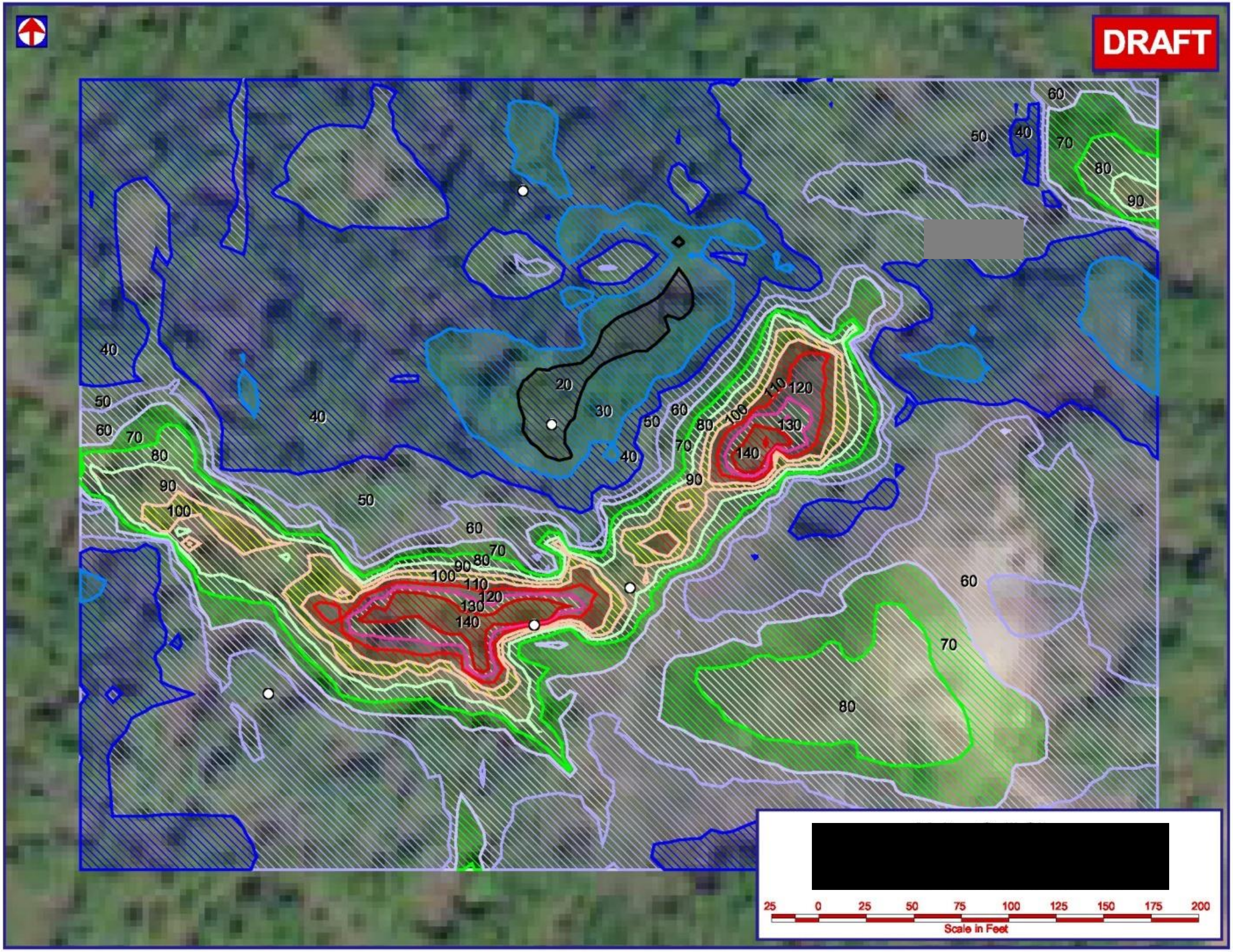
Electomagnetic induction profiling (EM)

- EM instruments work by generating an electromagnetic field in a transmitter coil which induces electric currents in soil below the surface
- These electric currents in the soil generate a secondary electromagnetic field which is detected and measured in a receiver coil in the instrument
- This is an EM31. The transmitter and receiving soils are at opposite ends of the tube
- The depth of exploration is determined by the distance between the coils and the orientation of the instrument (horizontal or vertical)

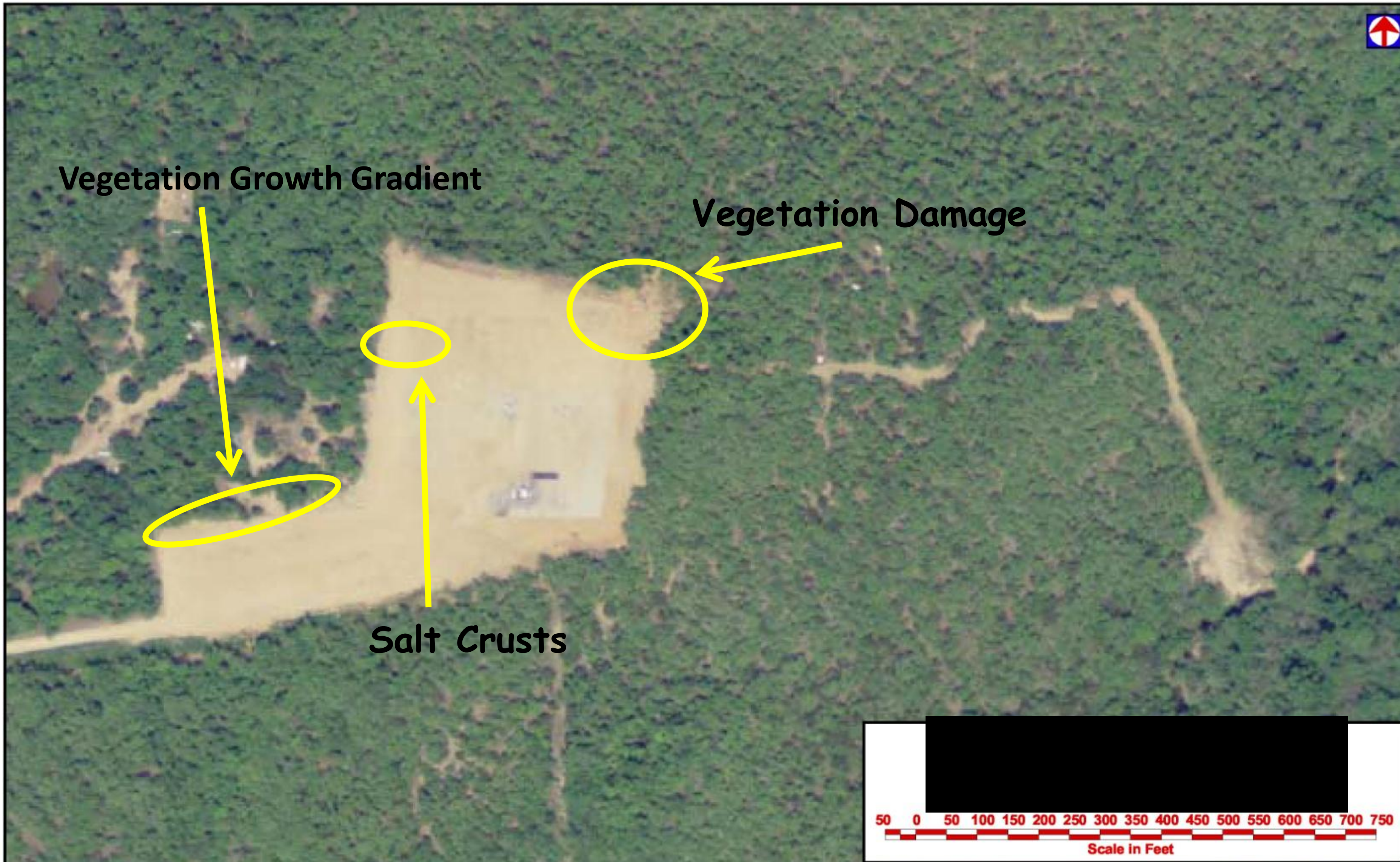


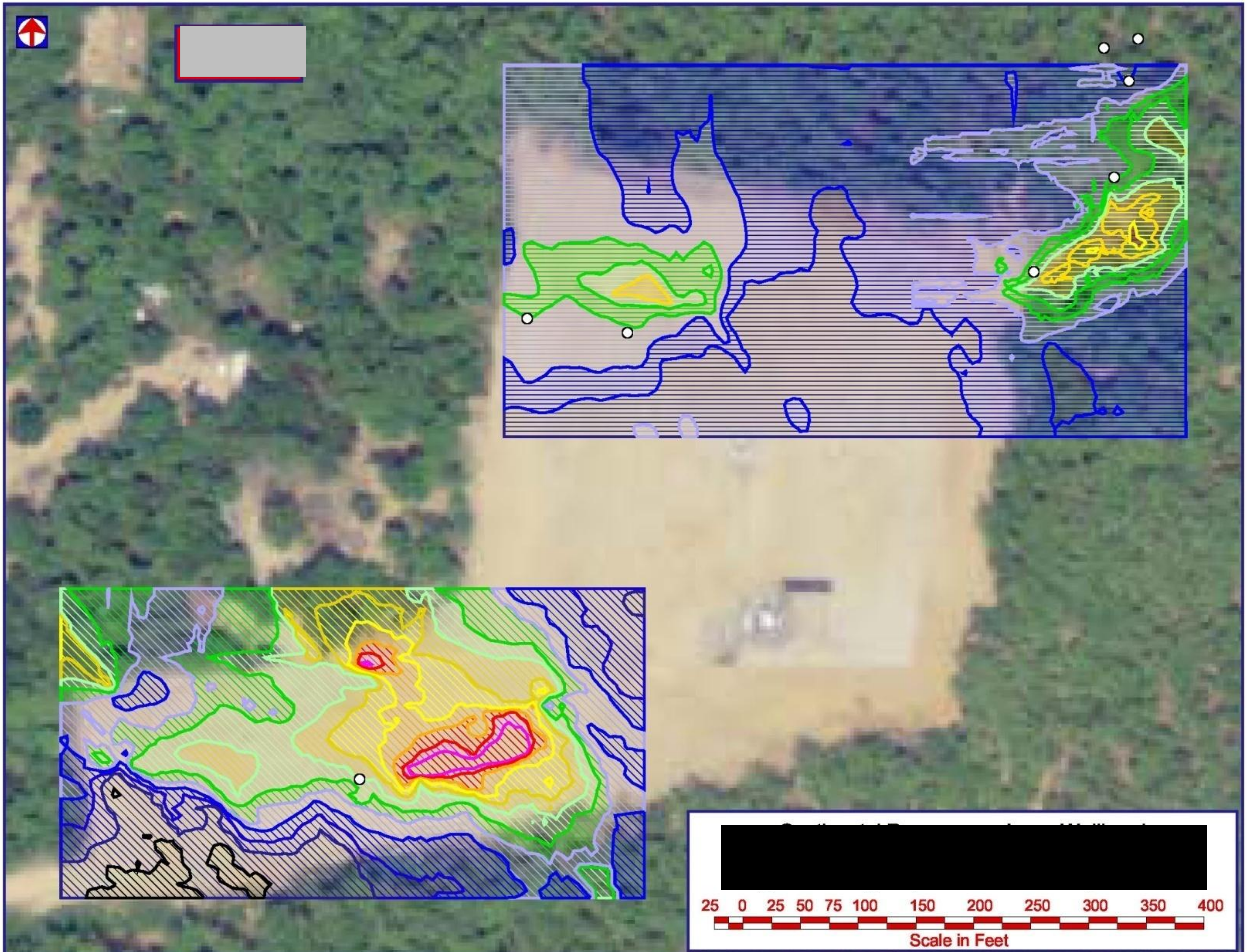
EM31


GPS
Data logger
EM31


DRAFT
20
30
40
50
60
70
80
90
100
110
120
130
140
[redacted]
25 0 25 50 75 100 125 150 175 200
Scale in Feet

Recent drill site




[redacted]
25 0 25 50 75 100 150 200 250 300 350 400
Scale in Feet

Using EMP to find the source of salt contamination


Dead trees

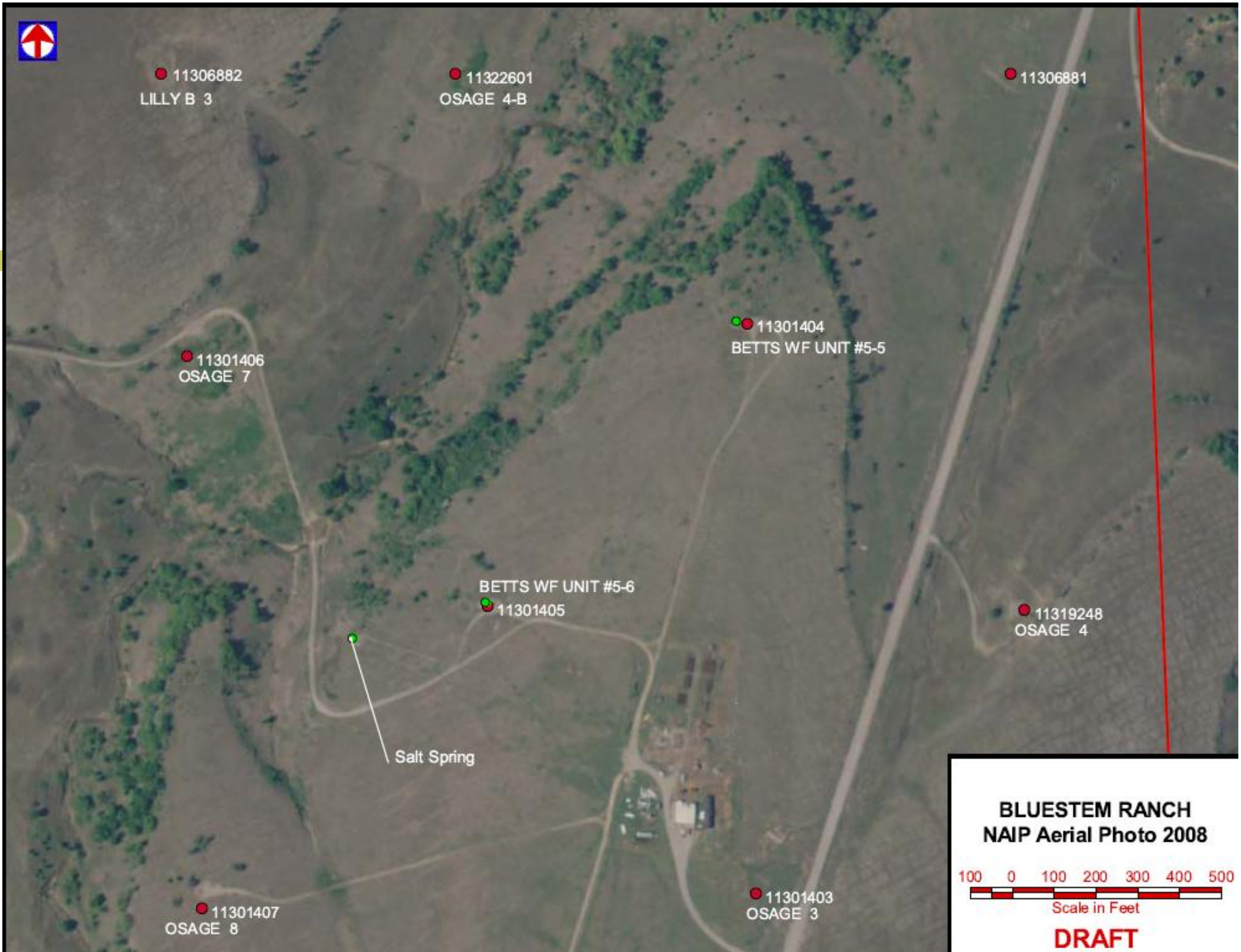

15% increase in EC

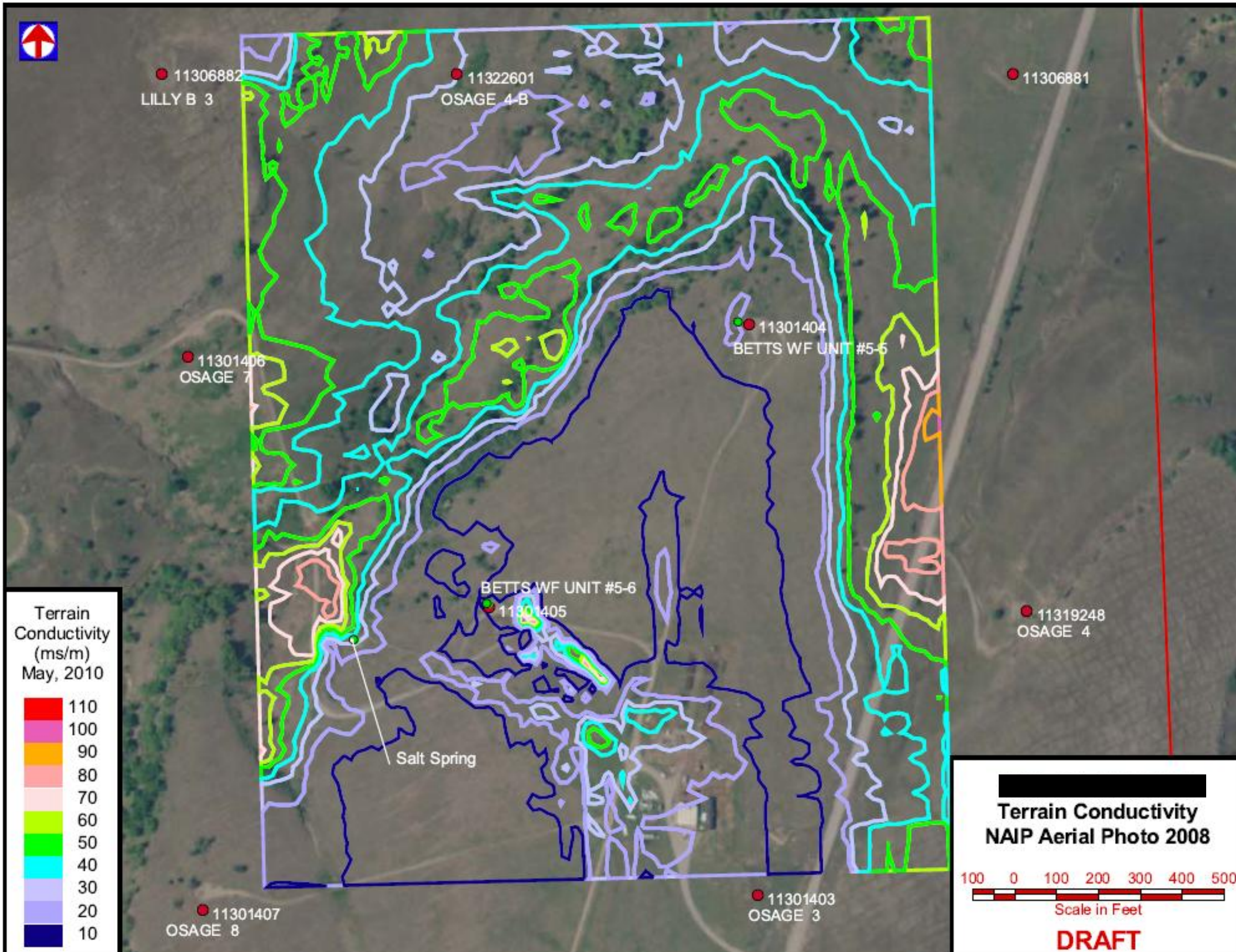
Analysis of seep water

---------- Cations ----------		---------- Anions ----------		---------- Other ----------	
Sodium (ppm)	1518	Nitrate-N (ppm)	< 1	pH	7.8
Calcium (ppm)	332	Chloride (ppm)	2807	EC (µmhos/cm)	8950
Magnesium (ppm)	52	Sulfate (ppm)	14		
Potassium (ppm)	13	Boron (ppm)	0.16		
		Bicarbonate (ppm)	314		

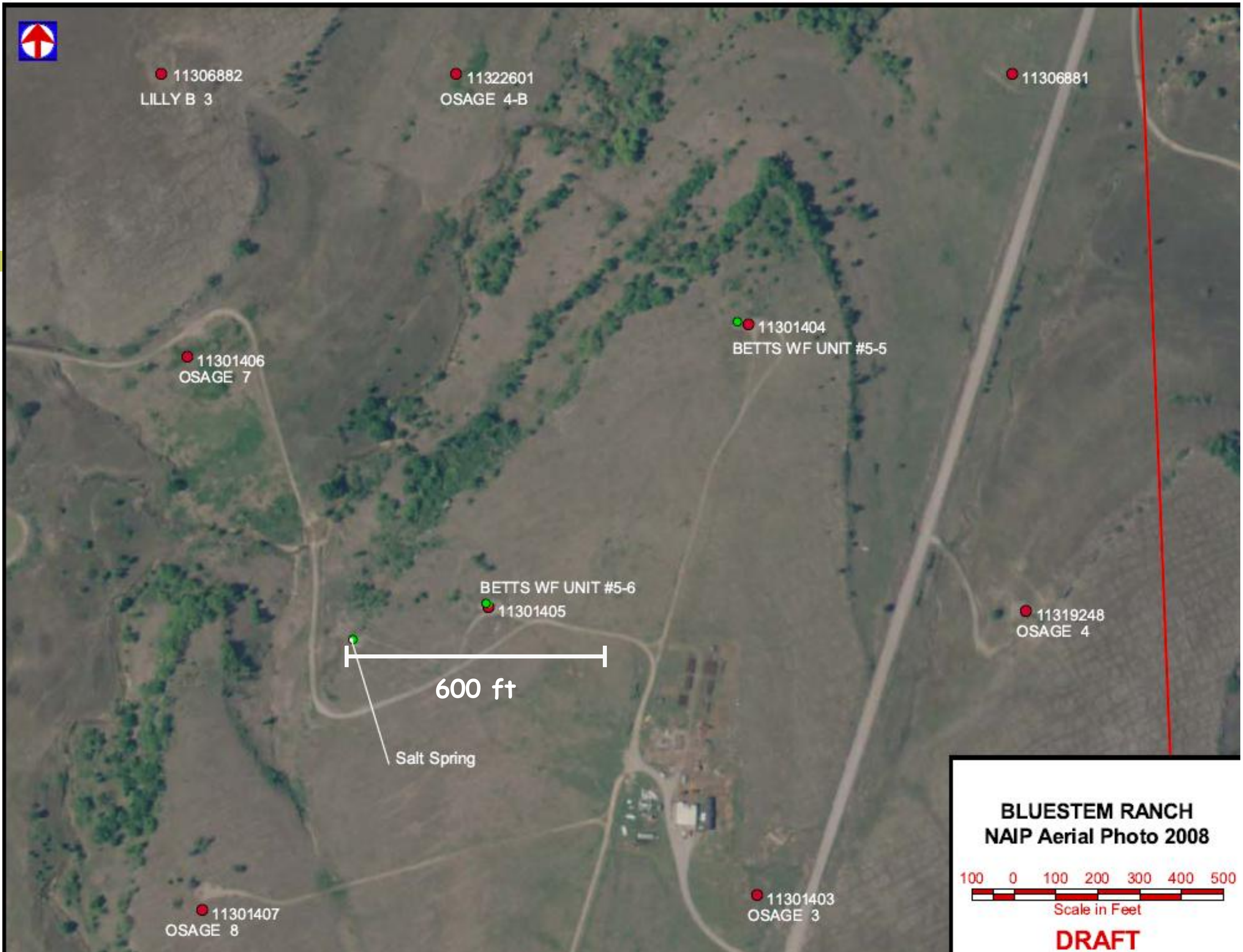
---------- Derived Values ----------	
Total Soluble Salts (TSS in ppm)	5907
Sodium Adsorption Ratio (SAR)	20.5
Potassium Adsorption Ratio (PAR)	0.1

-------- Derived Values(cont'd) --------	
Soduim Percentage	76.0%
Hardness (ppm)	1042
Hardness Class	Very Hard
Alkalinity (ppm as CaCO3)	257

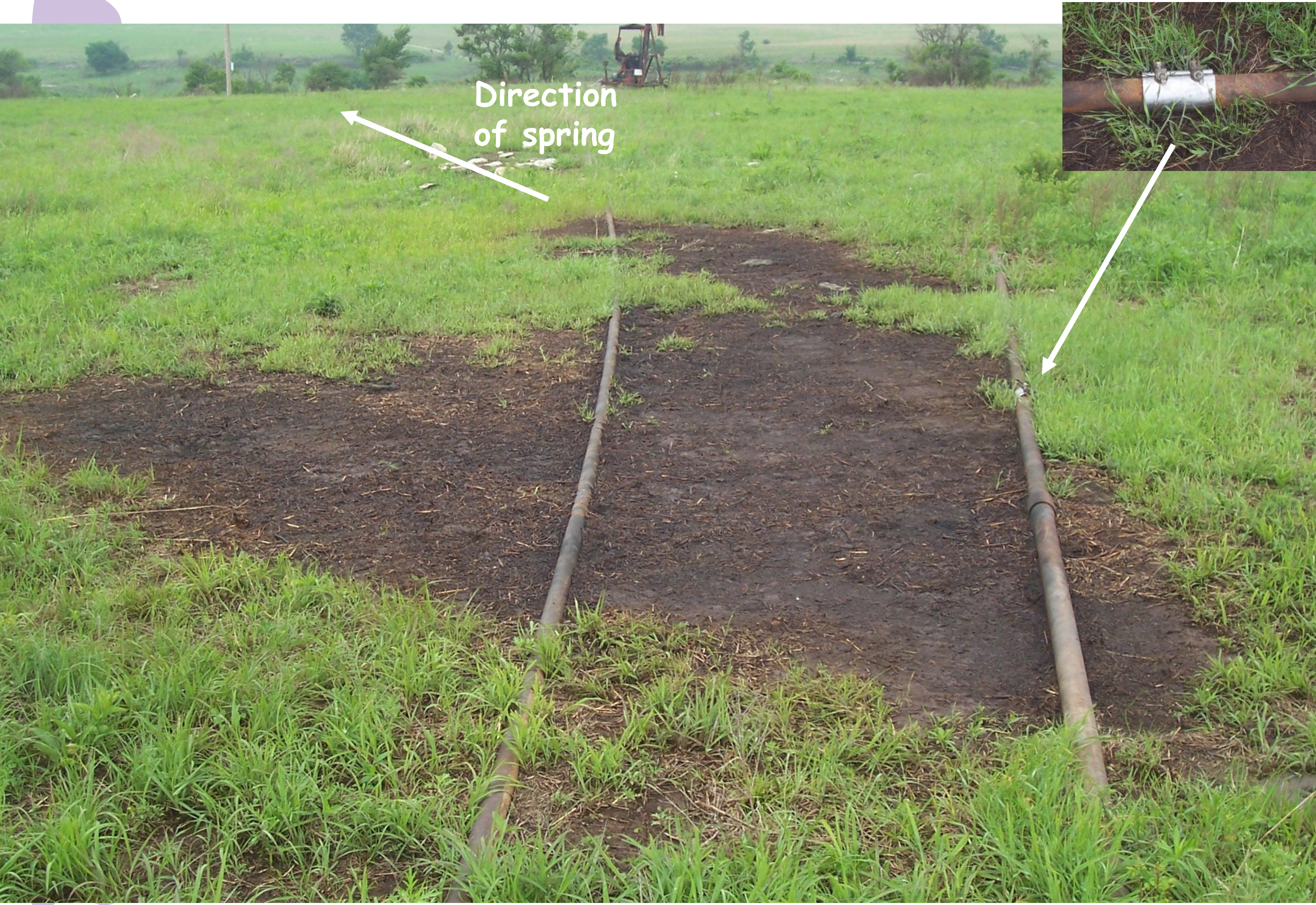

11306882
LILLY B 3
11322601
OSAGE 4-B
11306881
11301404
BETTS WF UNIT #5-5
11301406
OSAGE 7
BETTS WF UNIT #5-6
11301405
11319248
OSAGE 4
Salt Spring
11301407
OSAGE 8
11301403
OSAGE 3
BLUESTEM RANCH
NAIP Aerial Photo 2008
100 0 100 200 300 400 500
Scale in Feet
DRAFT



11306882
LILLY B 3
11322601
OSAGE 4-B
11306881
11301406
OSAGE 7
11301404
BETTS WF UNIT #5-6
BETTS WF UNIT #5-6
11301405
11319248
OSAGE 4
Salt Spring
11301407
OSAGE 8
11301403
OSAGE 3
Terrain Conductivity (ms/m) May, 2010
110
100
90
80
70
60
50
40
30
20
10
[redacted]
Terrain Conductivity
NAIP Aerial Photo 2008
100 0 100 200 300 400 500
Scale in Feet
DRAFT



11306882
LILLY B 3
11322601
OSAGE 4-B
11306881
11301404
BETTS WF UNIT #5-5
11301406
OSAGE 7
BETTS WF UNIT #5-6
11301405
11319248
OSAGE 4
600 ft
Salt Spring
BLUESTEM RANCH
NAIP Aerial Photo 2008
100 0 100 200 300 400 500
Scale in Feet
DRAFT
11301403
OSAGE 3
11301407
OSAGE 8


Direction
of spring

What defines remediation?

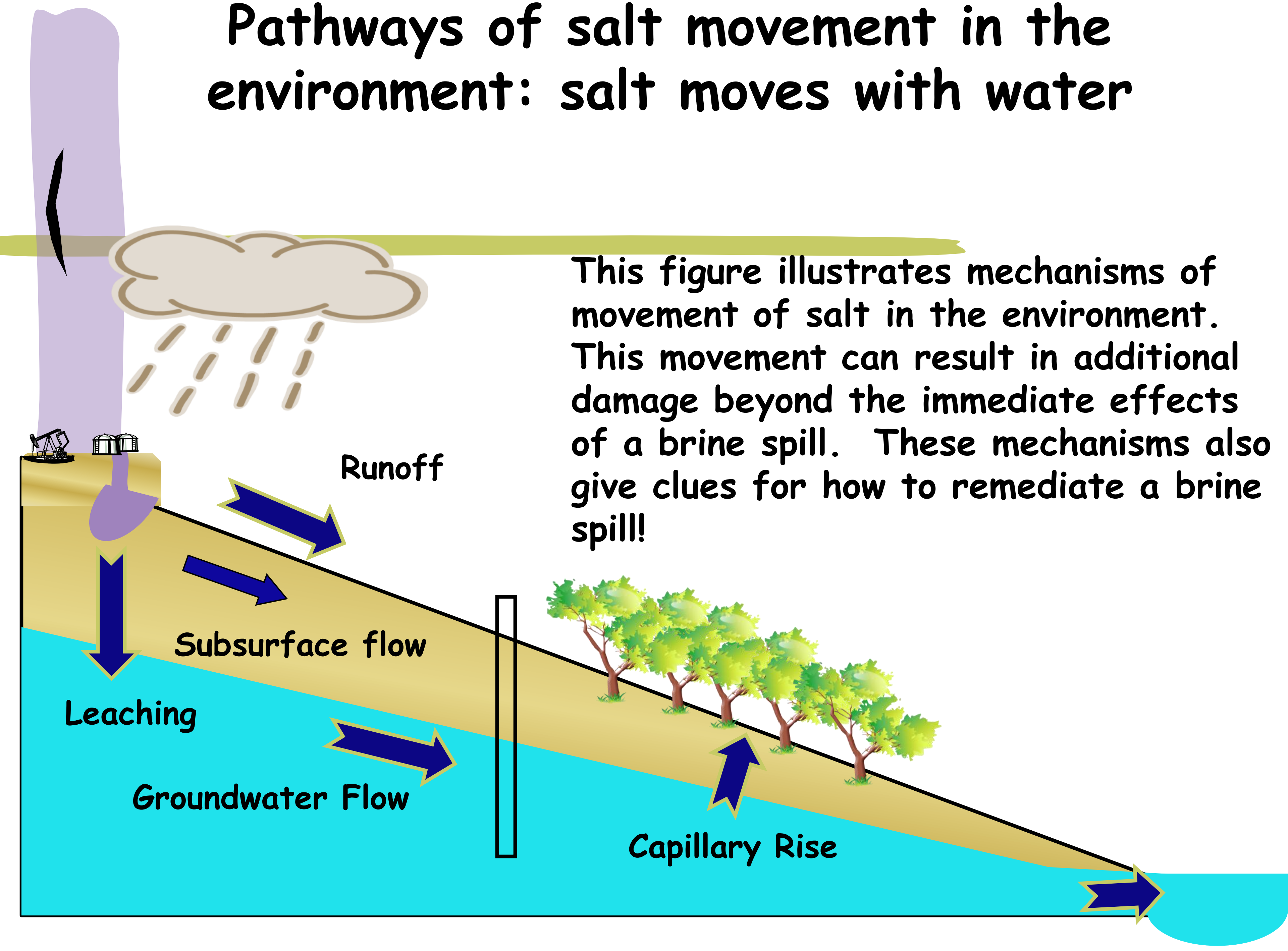

The site of a produced water release at a wellhead

Are these sites remediated?

- The regulator (in this case the BIA) says yes because it is revegetated
- The landowner says no, he wants native grass back suitable for cattle grazing
- A jury agreed with the landowner and awarded damages (cost of remediation) plus plaintiff's attorney fees
- This case was won with pictures only!

Remediating a brine spill is all about water and drainage.

Pathways of salt movement in the environment: salt moves with water



This figure illustrates mechanisms of movement of salt in the environment. This movement can result in additional damage beyond the immediate effects of a brine spill. These mechanisms also give clues for how to remediate a brine spill!

Basic principles in the remediation of brine spills

- Salt concentrations in the plant root zone must be reduced to acceptable levels in the **long term** to allow growth of desired plants
  - **It's easy to flush salt from soil in the short term – the challenge is in making sure it doesn't come back! Remember capillary suction?**

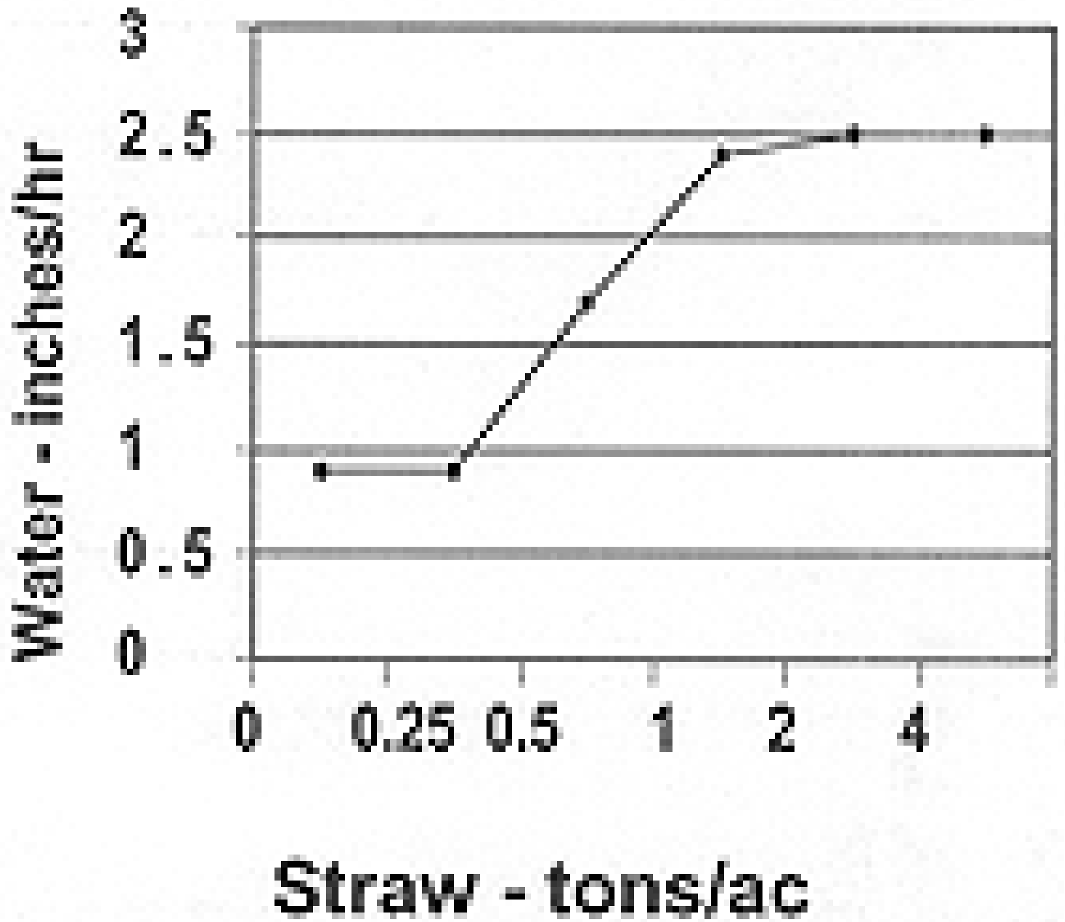
Basic principles in the remediation of brine spills, cont.

- Soluble salts are transported by **water**
  - **No water, no movement**
  - Therefore, remediation requires contact of **water** with salt and **drainage** to convey salt away from the root zone
  - Both the **quantity and quality** (EC and SAR) of irrigation water are important to the outcome of any remediation effort

Basic principles in the remediation of brine spills, cont.

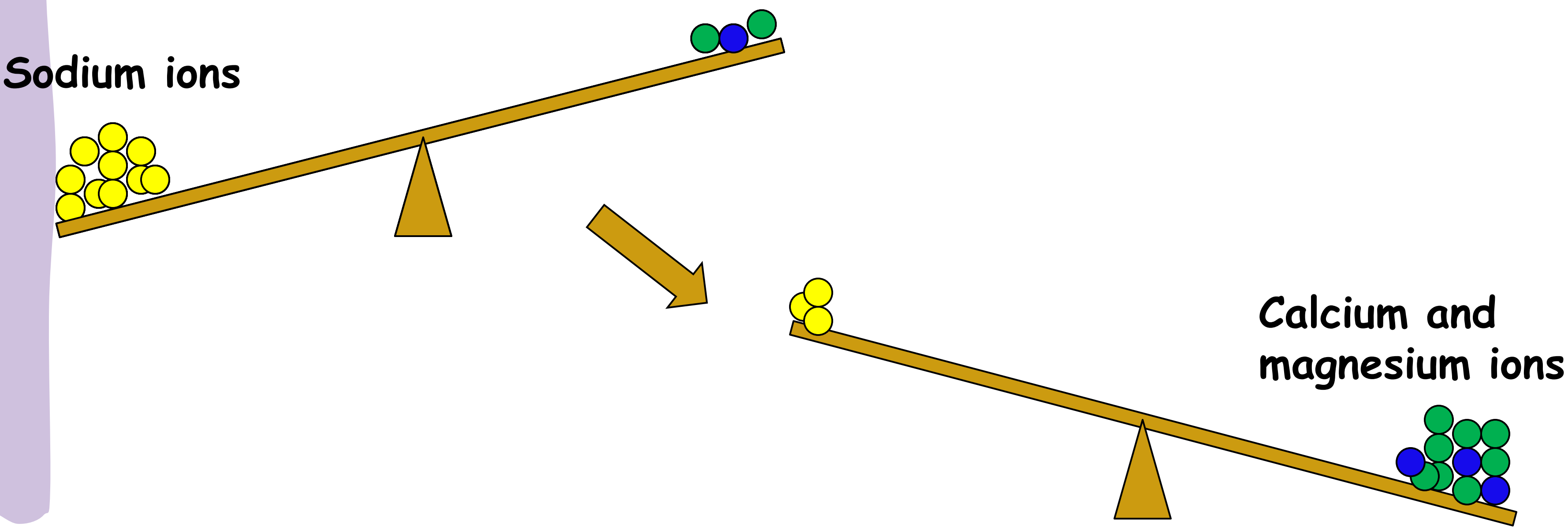
- The rate of movement of water through the soil and, therefore, the rate at which salts can be carried out of the root zone, is determined by the permeability of the soil
  - Permeability must be addressed in the short term and the long term
    - In the **short term** we must mechanically open the soil and prop it open with bulking agents (organic matter) to maintain a porous structure to allow the transport of water

Basic principles in the remediation of brine spills, cont.



Basic principles in the remediation of brine spills, cont.

- In the **long term** we must rebuild soil structure
  - Reverse sodicity by restoring the proper exchangeable cation status
  - Generate the natural glue that holds particles together



Basic principles in the remediation of brine spills, cont.

- Salts (as salty water) are carried upward in the soil profile by capillary suction; therefore, salts must be driven deep enough that they do not rise into the plant root zone
- All soluble salts are affected by leaching
  - Leaching to remove produced water salts also removes beneficial nutrients (particularly N)

Basic principles in the remediation of brine spills, cont.

- Once salinity and sodicity damages have been alleviated revegetation is required to prevent erosion and restore productivity
  - Successful revegetation is dependent on
    - preparation of a proper seedbed
    - choosing the right plants (seeds) for the climate
    - addressing any nutrient deficiencies in the soil
    - maintaining proper moisture conditions while new plants get established

Basic elements in the remediation of brine spills, the tool box

- Water (irrigation and/or rainfall)
  - Providing a sufficient quantity of water
  - Providing water of sufficient quality
  - Minimizing runoff and maximizing infiltration
- Drainage
  - Where can the salt go?
  - Facilitating movement of salts from the site in a responsible manner
  - Taking advantage of natural drainage patterns
  - Artificial drainage
- Leaching of salts and restoring soil structure
  - Facilitating contact of water with salt
  - Maintaining soil permeability
  - Restoring the proper exchangeable cation status
- Revegetation
  - Seedbed preparation
  - Soil fertility
  - Reseeding
  - Moisture

Basic elements in the remediation of brine spills, the tool box

- **Water (irrigation and/or rainfall)**
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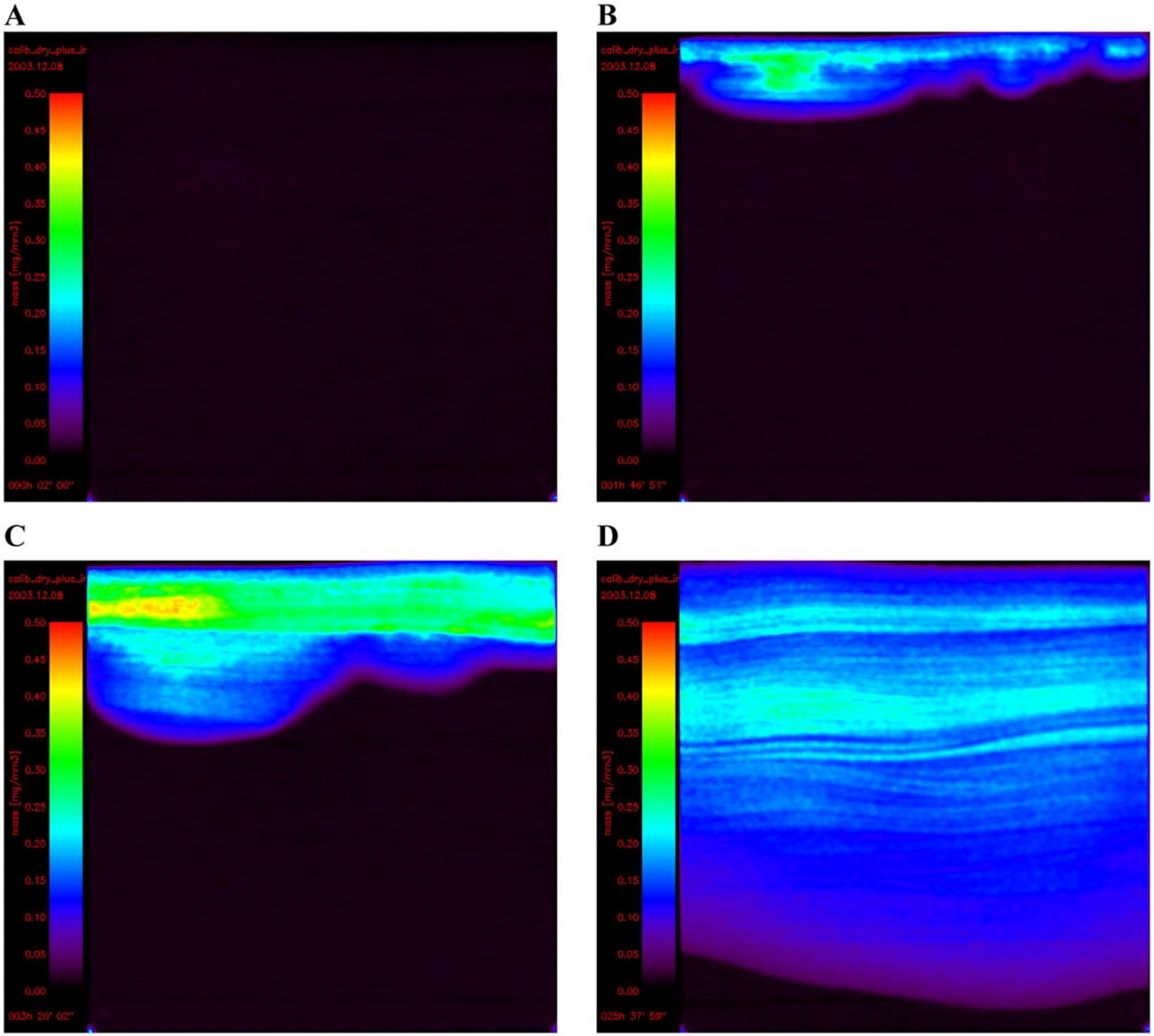
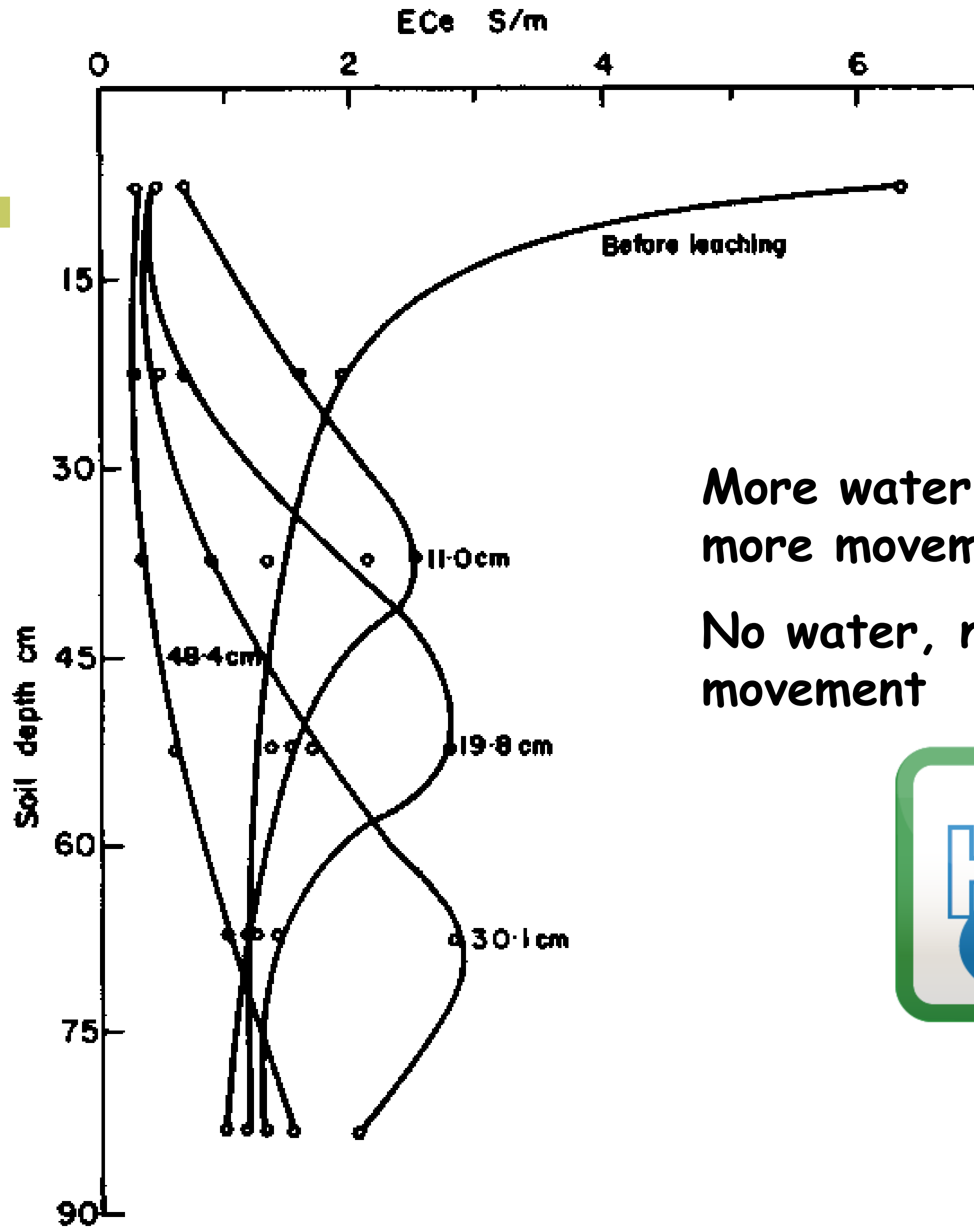
  - Seedbed preparation
  - Soil fertility
  - Reseeding
  - Moisture



Increasing volumes of applied water result in deeper penetration of water; if the water is dissolving salt in the soil, increasing the volume of applied water results in more movement of salt in the soil profile

Driving salts down in the soil profile with water



More water, more movement

No water, no movement

Calculating water requirements

- A dilution model can estimate minimum water requirements

$$d_{iw} = kd_s(EC_o/EC_t)$$

where:

d_{iw} = depth of drainage water required (inches)

d_s = thickness of impacted layer of soil (inches)

k = drainable porosity (%/100)

EC_o = initial soil EC

EC_t = target EC after treatment (< 4 mS/cm)

Drainable porosity depends on soil texture and structure

Soil Texture	Drainable Porosity (% by vol.)
clays, clay loams, silty clays	3-11%
well structured loams	10-15%
sandy	18-35%

Sample calculation of water requirements

- Medium textured soil (k = 0.15)
- Average EC_o:
  - 0-1 ft 28 mmhos/cm (mS/cm)
  - > 1 ft 4 mmhos/cm
- EC_t = 4 mS/cm

Sample calculation of water requirements

$$d_{iw} = kd_s(EC_o/EC_t)$$

$$d_s = 12 \text{ inches}$$

$$\text{average } EC_o = 28 \text{ mS/cm}$$

$$d_{iw} = (0.15)(12 \text{ inches})(23/4) = 12.6 \text{ inches}$$

This is the amount of water that has to drain through the contaminated zone to potentially mobilize the salt out of the plant root zone.

Rule of thumb calculation of water requirements to leach 1 ft of soil

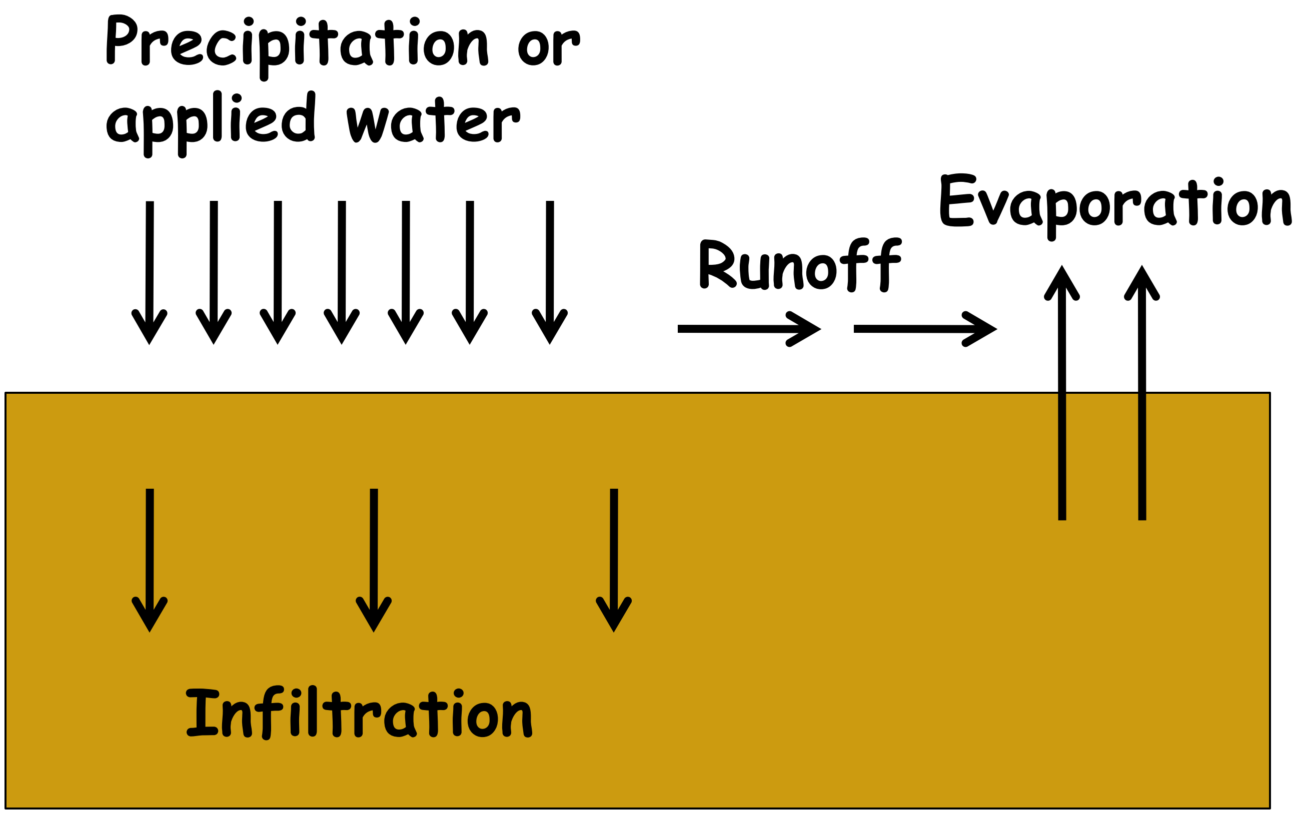
- 6" of water will leach about 50% of the salts
- 12" of water will leach about 80% of the salts
- 24" of water will leach about 90% of the salts
- A unit depth of irrigation water will remove about 80% of the salts from a unit depth of impacted soil

Sample calculation of water requirements using rule of thumb

- Average EC_o: 28 mmhos/cm in top 12"

Leaching water (in)	% of salts leached	Approximate EC (mmhos/cm) after leaching
6	50	14
12	80	5.6
24	90	2.8

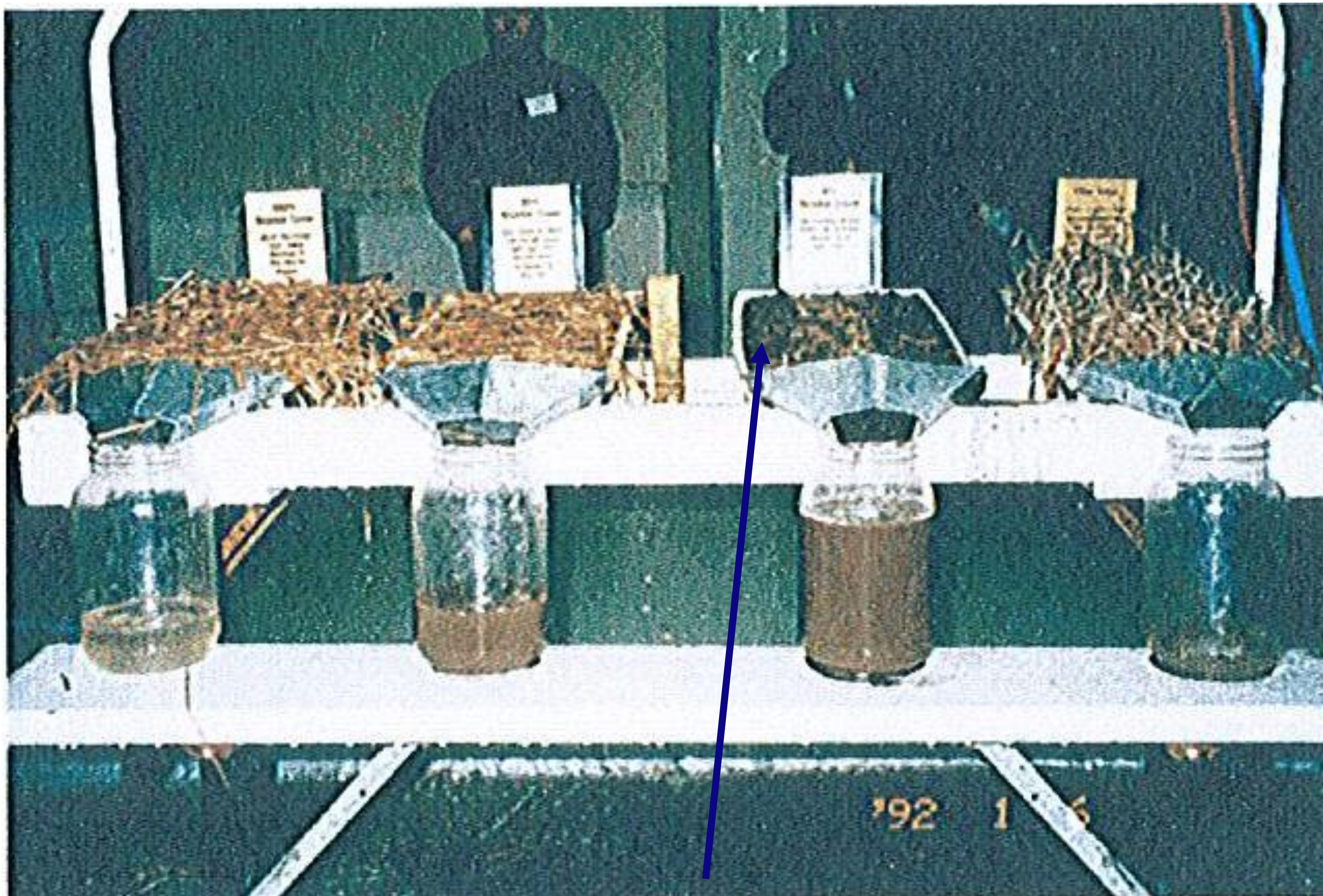
Remediation of brine spills will require more than the calculated amount of water to be applied because of runoff and evaporation.



Minimizing runoff and evaporation make the most of any water applied to the site

- Avoid watering under conditions which produce high rates of evaporation
  - Sunny and hot
  - Low humidity
  - Windy
- A surface cover of organic mulch reduces runoff and evaporation

Simulated 60 mm/hr rain



Bare soil

Note the significant reduction in runoff and increase in infiltration of rainfall with an organic mulch on the soil

Making the most of irrigation water: Infiltration rates are greatest when the soil is dry

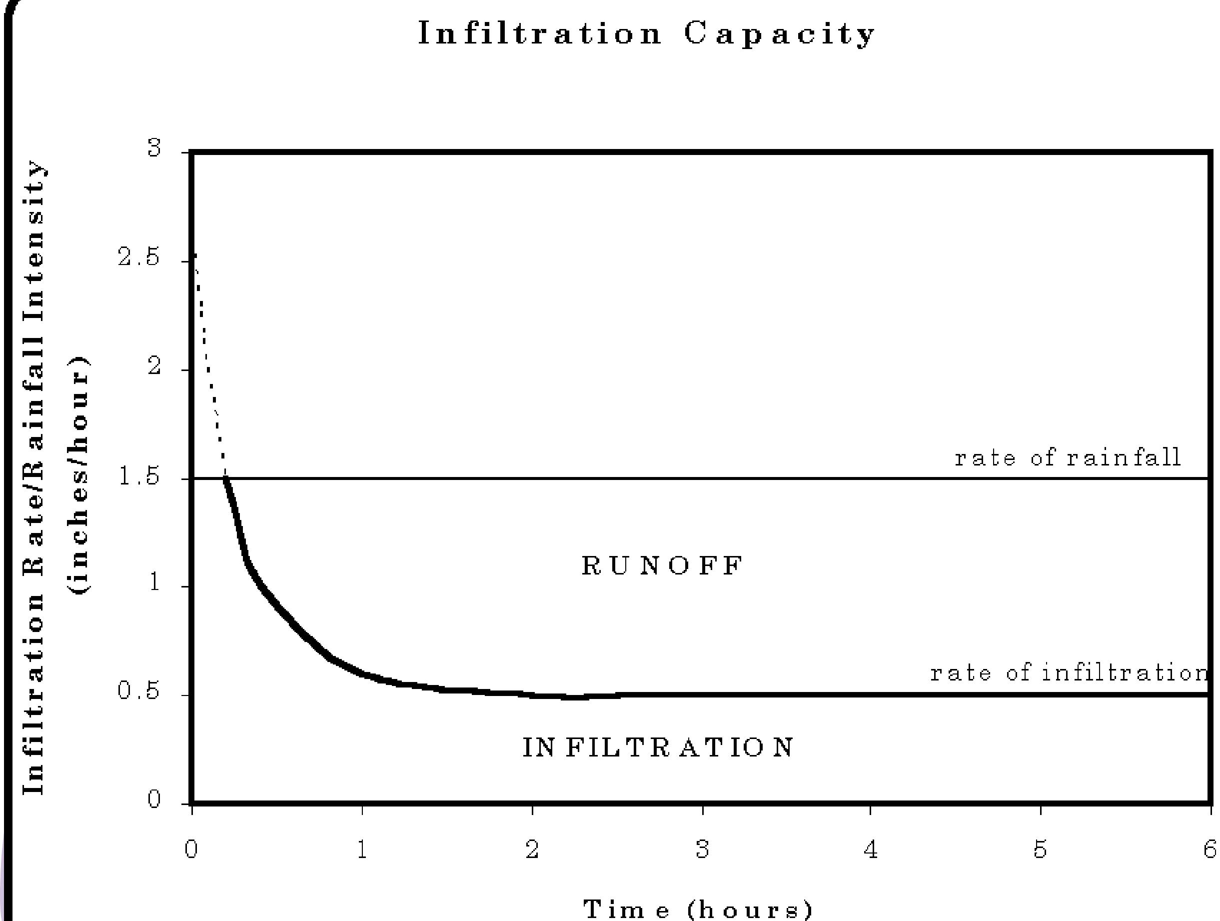
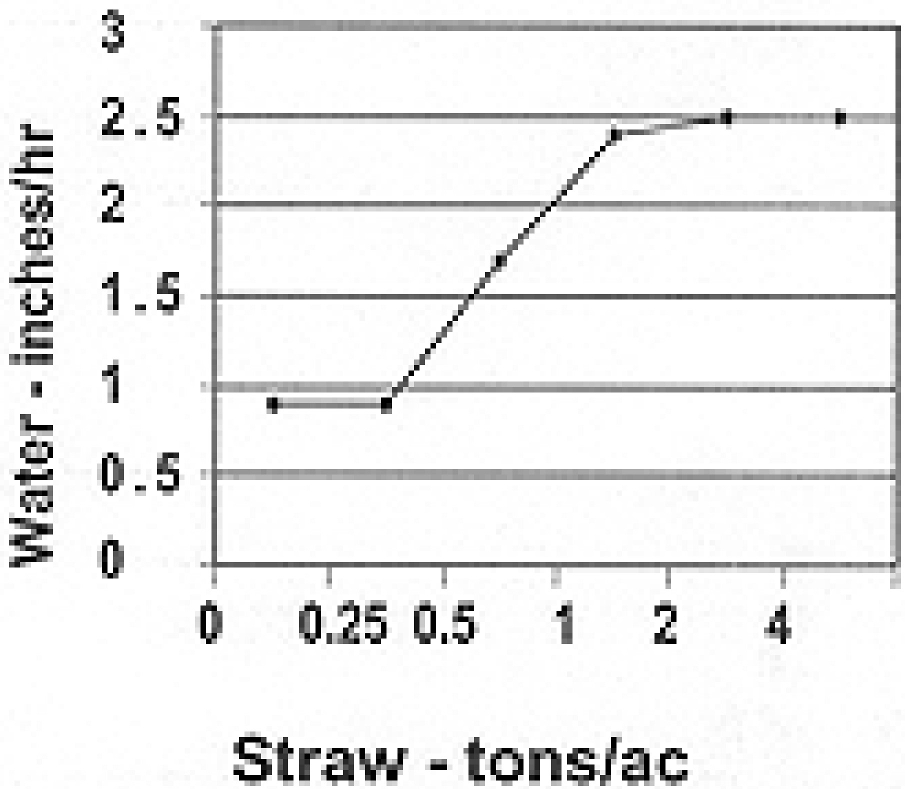


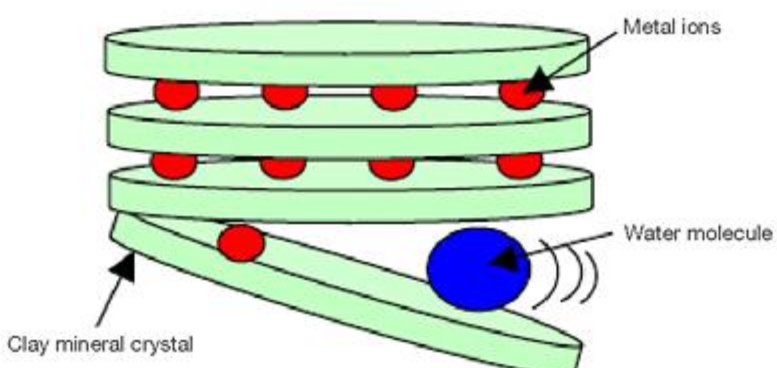
Figure 2

Pulsed irrigation with sprinkler application works best to deliver water at depth



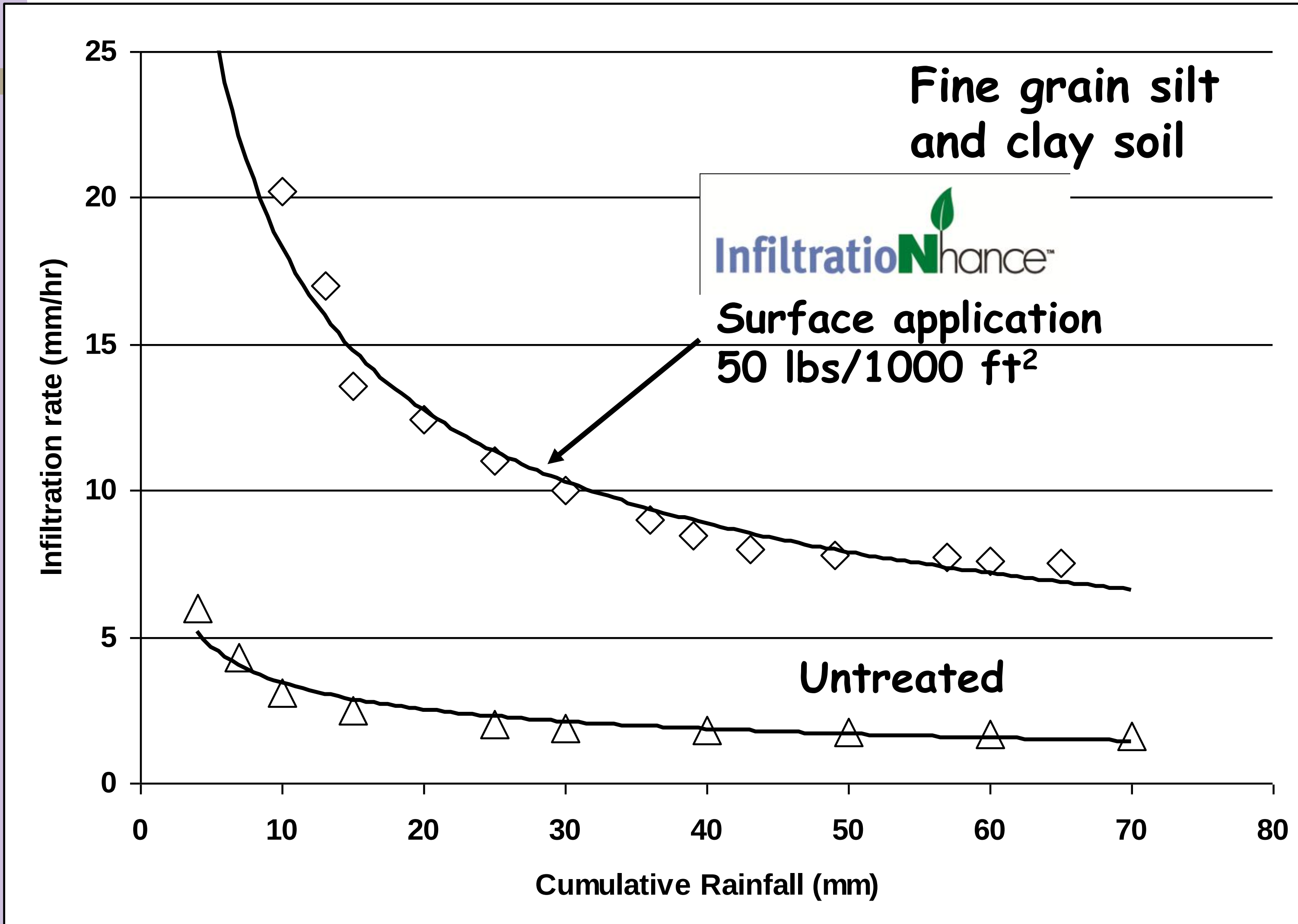
Greater fraction of macropores results in greater infiltration rates; bulking agents like organic matter help a lot!

Remember those swelling clays?

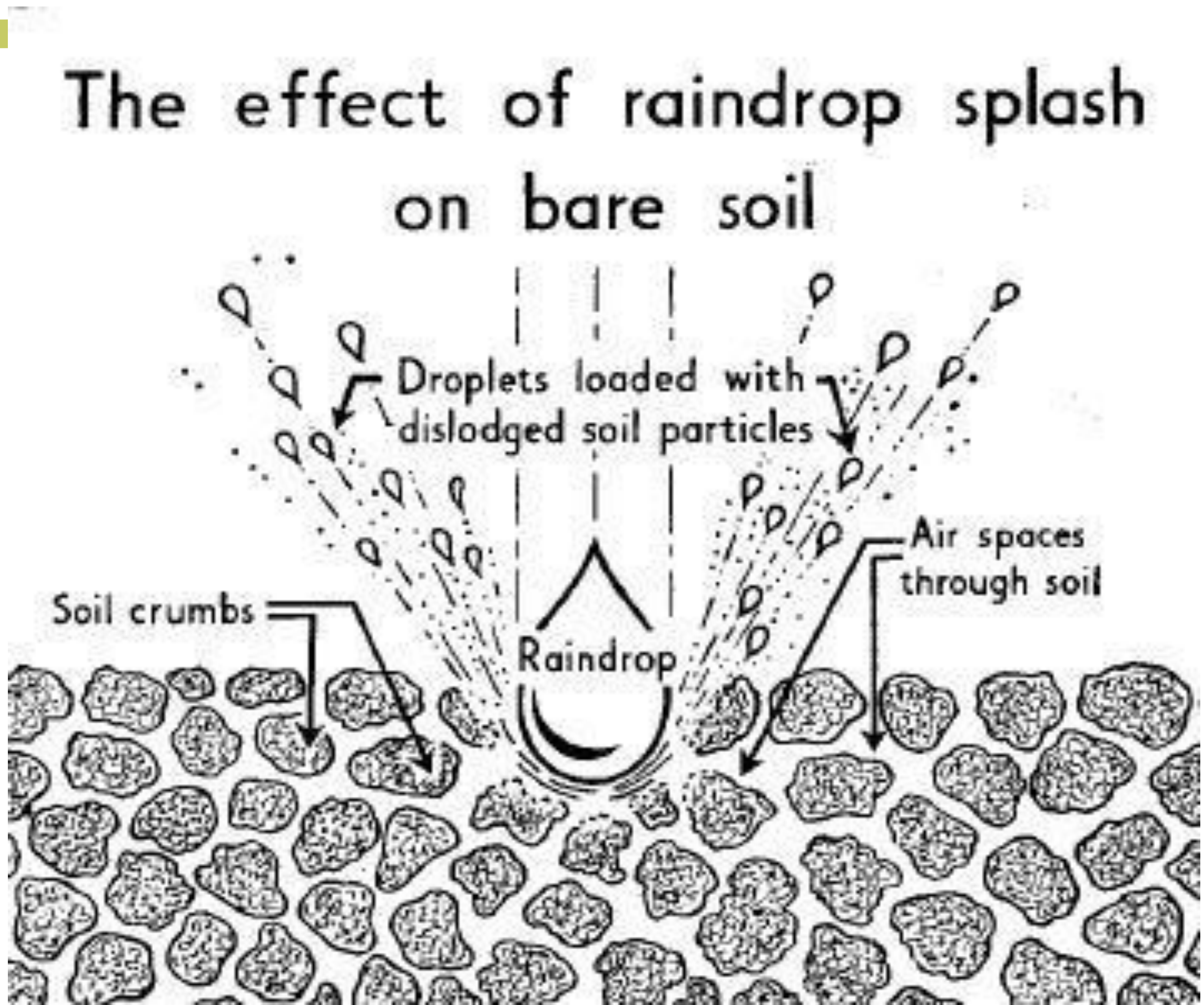


Swelling clays seal off the surface decreasing infiltration and increasing runoff!

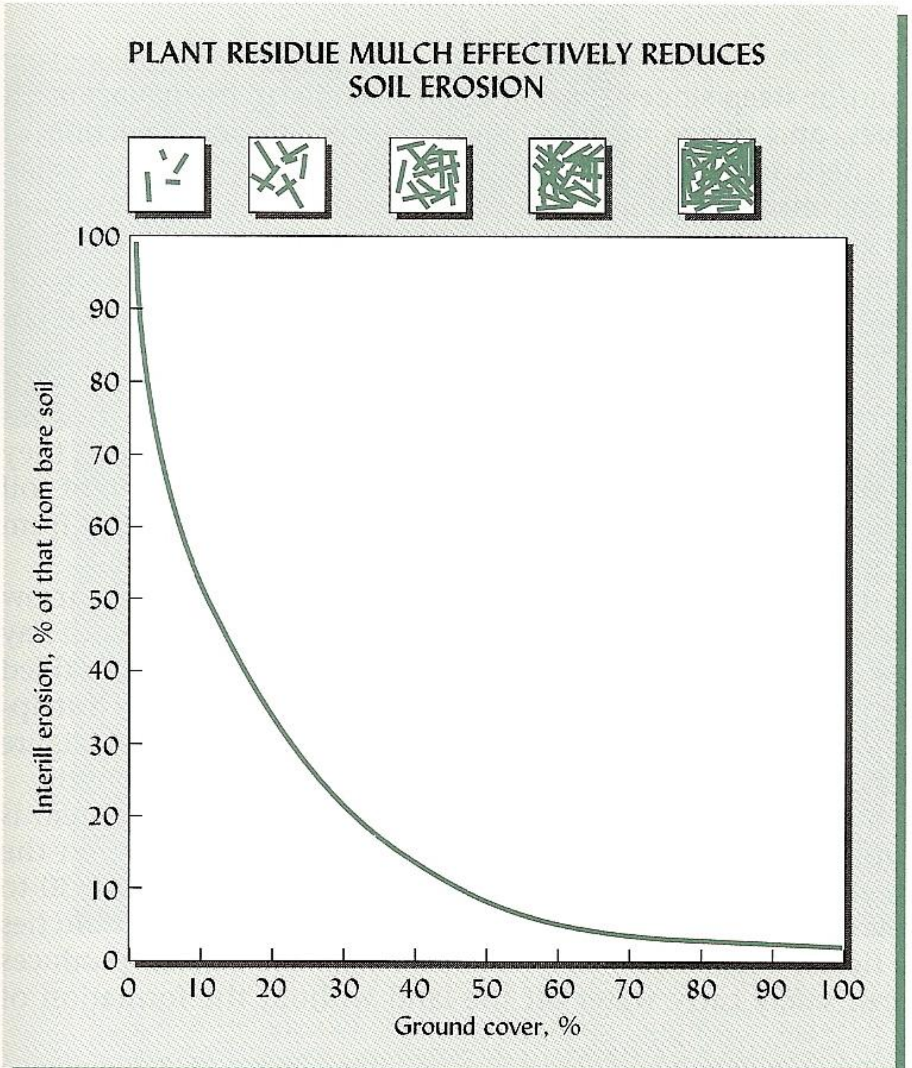
Surface application of electrolyte source inhibits swelling and maintains good rates of water infiltration into the soil



Remember the effect of rain drops on soil infiltration and the formation of soil crusts



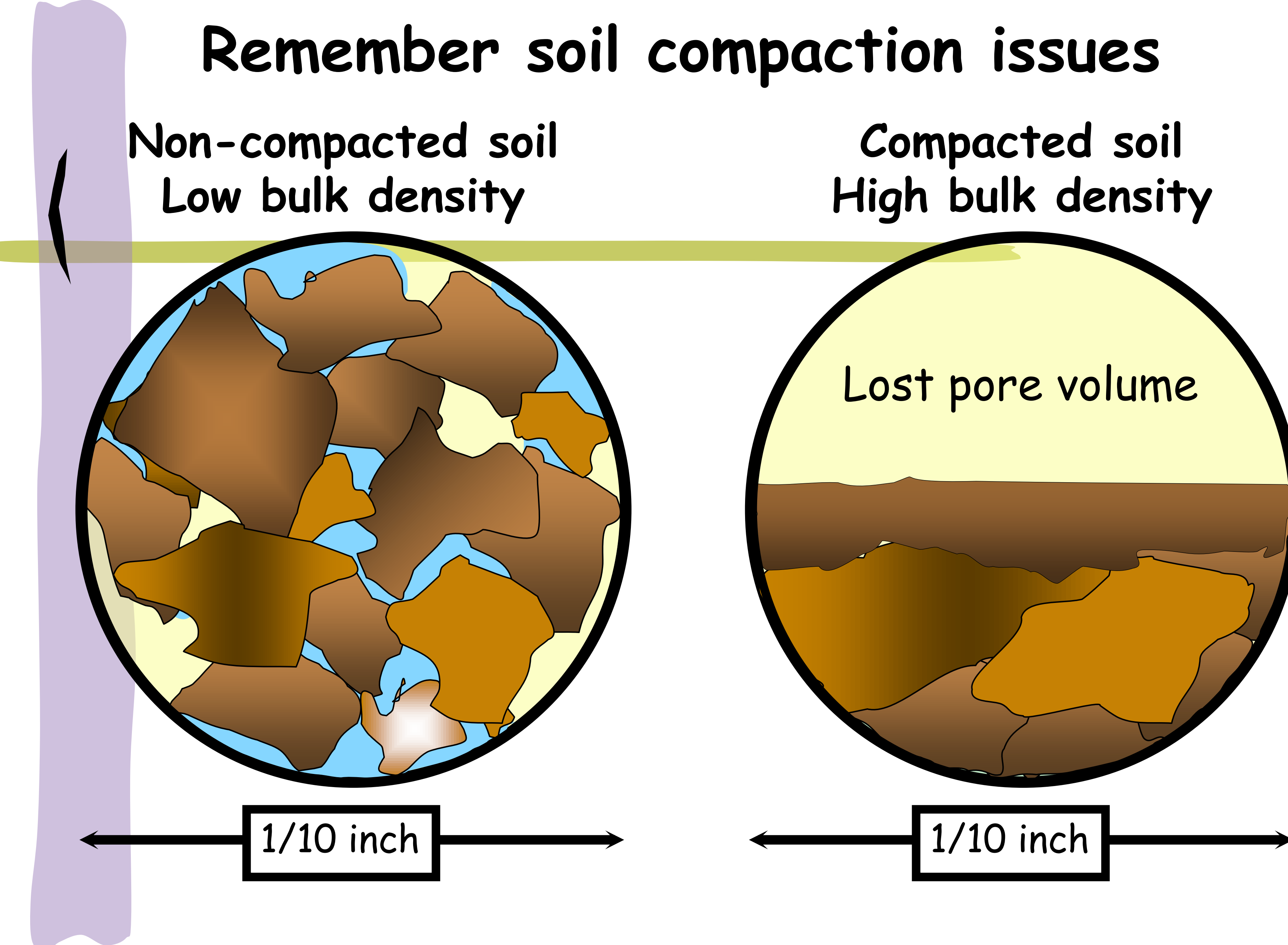
The solution: Surface dressing of organic matter reduces crusting and erosion



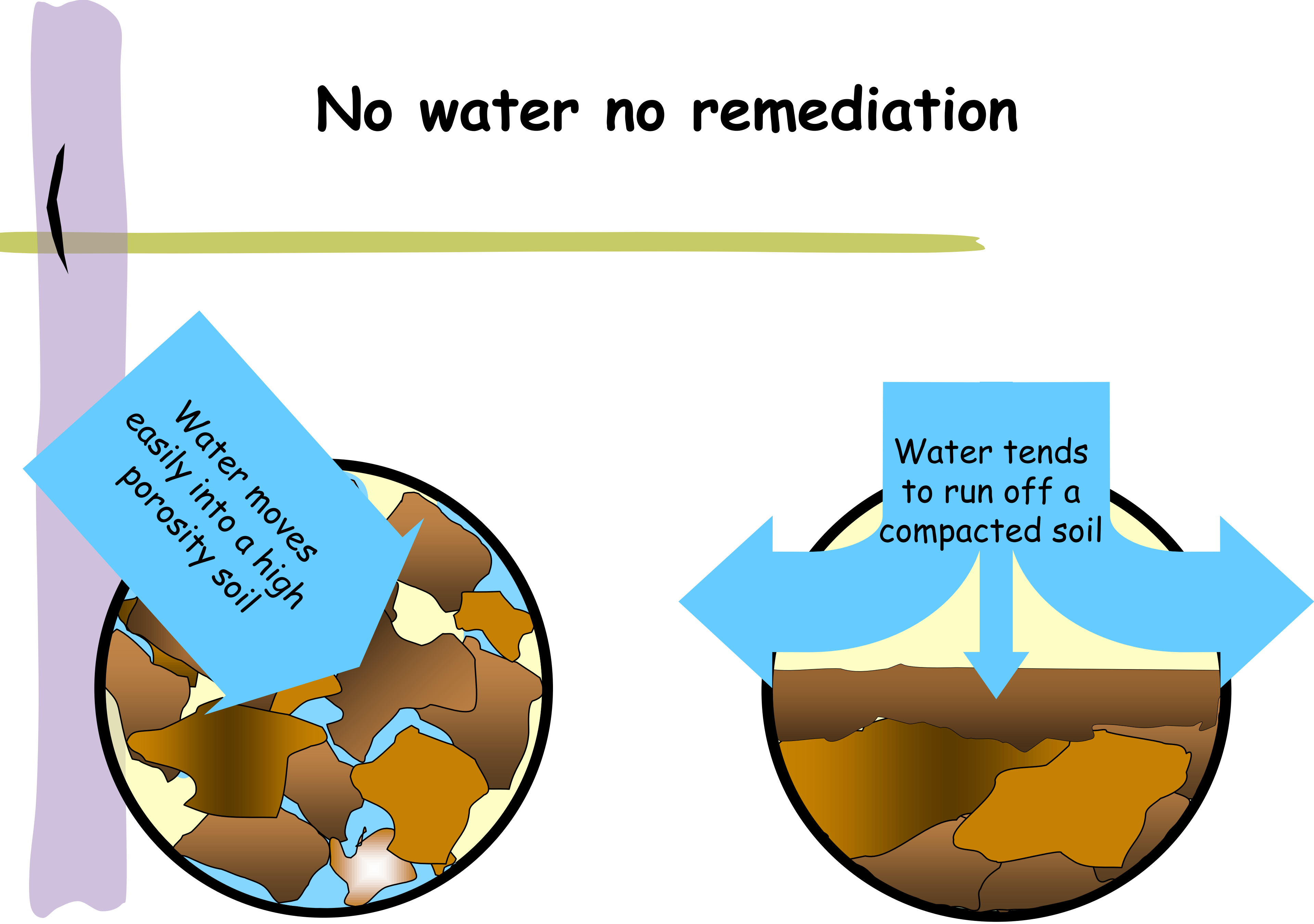
Use a thick layer; we get other benefits and we don't have to worry about oxygen penetration with brine remediation

FIGURE 17.11 Reduction in interrill erosion achieved by increasing ground cover percentage. The diagrams above the graph illustrate 5, 20, 40, 60, and 80% ground cover. Note that even a light covering of mulch has a major effect on soil erosion. The graph applies to interrill erosion. On steep slopes, some rill erosion may occur even if the soil is well covered. [Generalized relationship based on results from many studies]

Remember soil compaction issues



No water no remediation

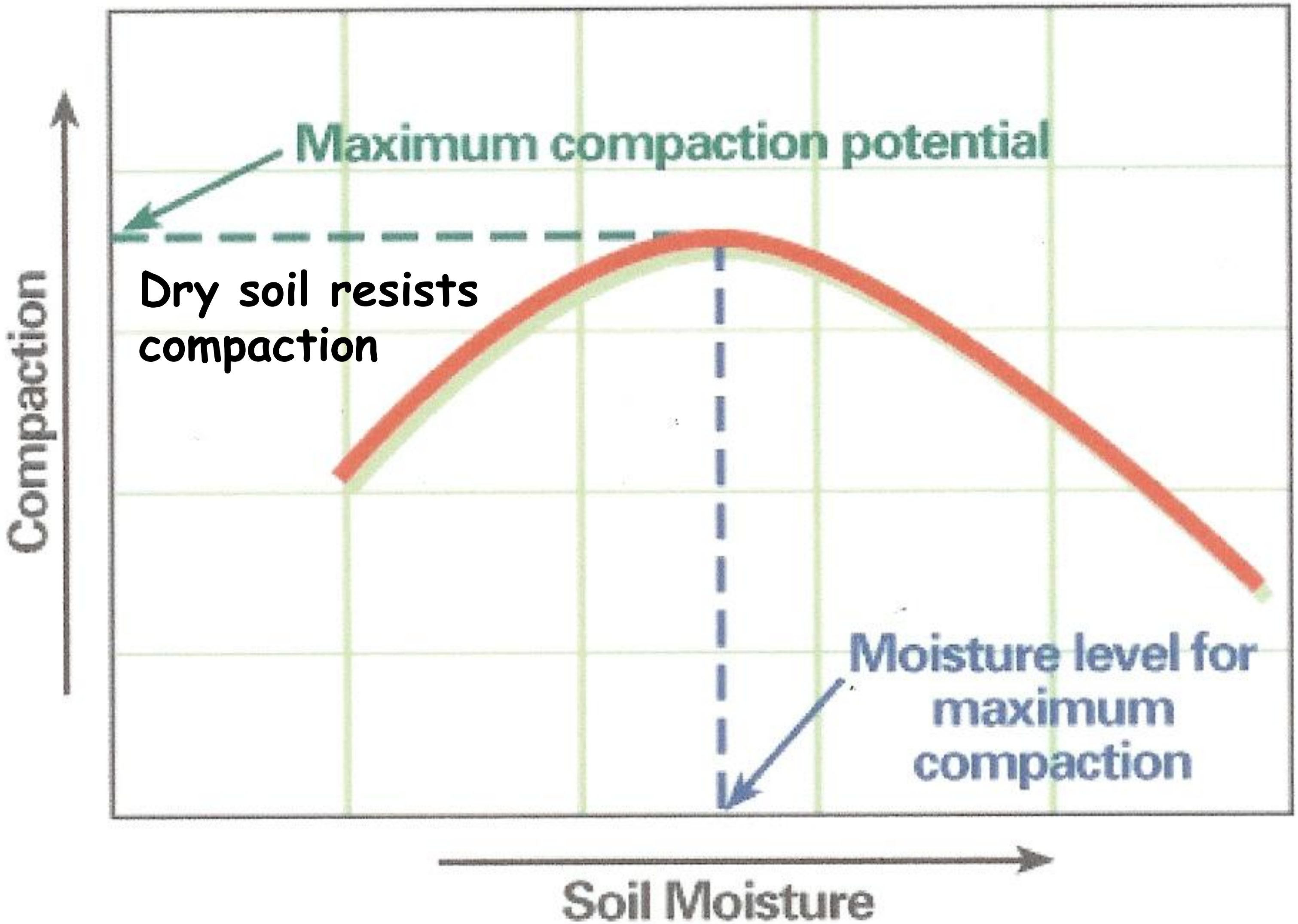


The enemy

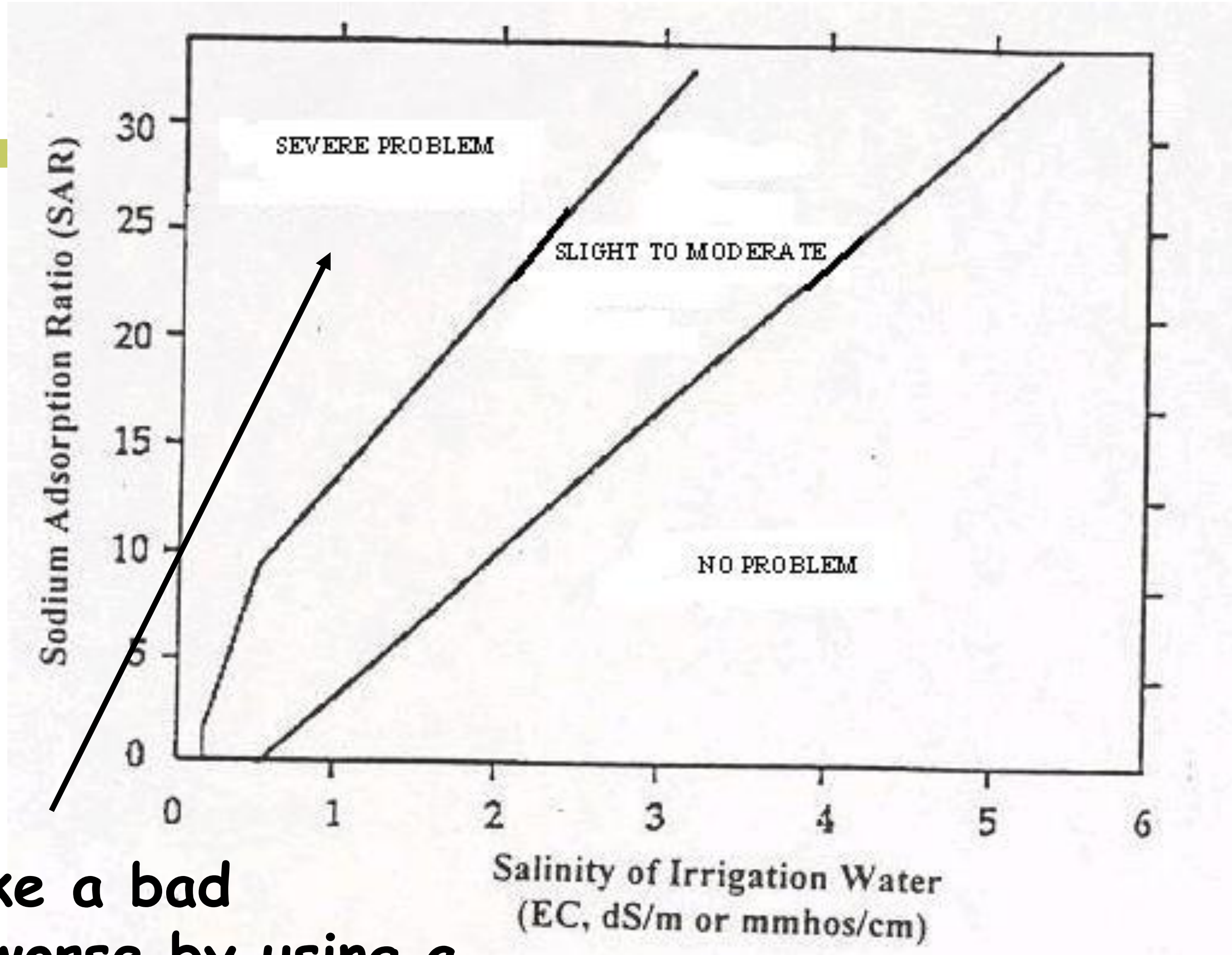
The problem

The solution: Fence the site!

Work the site only when dry



Irrigation water quality



Don't make a bad situation worse by using a high SAR irrigation water

Basic elements in the remediation of brine spills

- Water (irrigation and/or rainfall)
  - Providing a sufficient quantity of water
  - Providing water of sufficient quality
  - Minimizing runoff and maximizing infiltration
- **Drainage**
  - **Where can the salt go?**
  - **Facilitating movement of salts from the site in a responsible manner**
  - **Taking advantage of natural drainage patterns**
  - **Artificial drainage**
- Leaching of salts and restoring soil structure
  - Facilitating contact of water with salt
  - Maintaining soil permeability
  - Restoring the proper exchangeable cation status
- Revegetation
  - Seedbed preparation
  - Soil fertility
  - Reseeding
  - Moisture

Drainage, Drainage, Drainage

Any attempt to leach salt without adequate drainage is not only doomed to failure but will actually make things worse!!!!

Where can the salt go?

- What are the options?
  - Vertical drainage
    - Any impediments to vertical migration?
    - Will it go deep enough? How deep is deep enough?
    - Will it impact groundwater?
  - Lateral drainage
    - Will it cause additional damage?
    - Can I protect environmental receptors?

Vertical drainage

Is there an impermeable layer in the soil that will prevent vertical drainage?

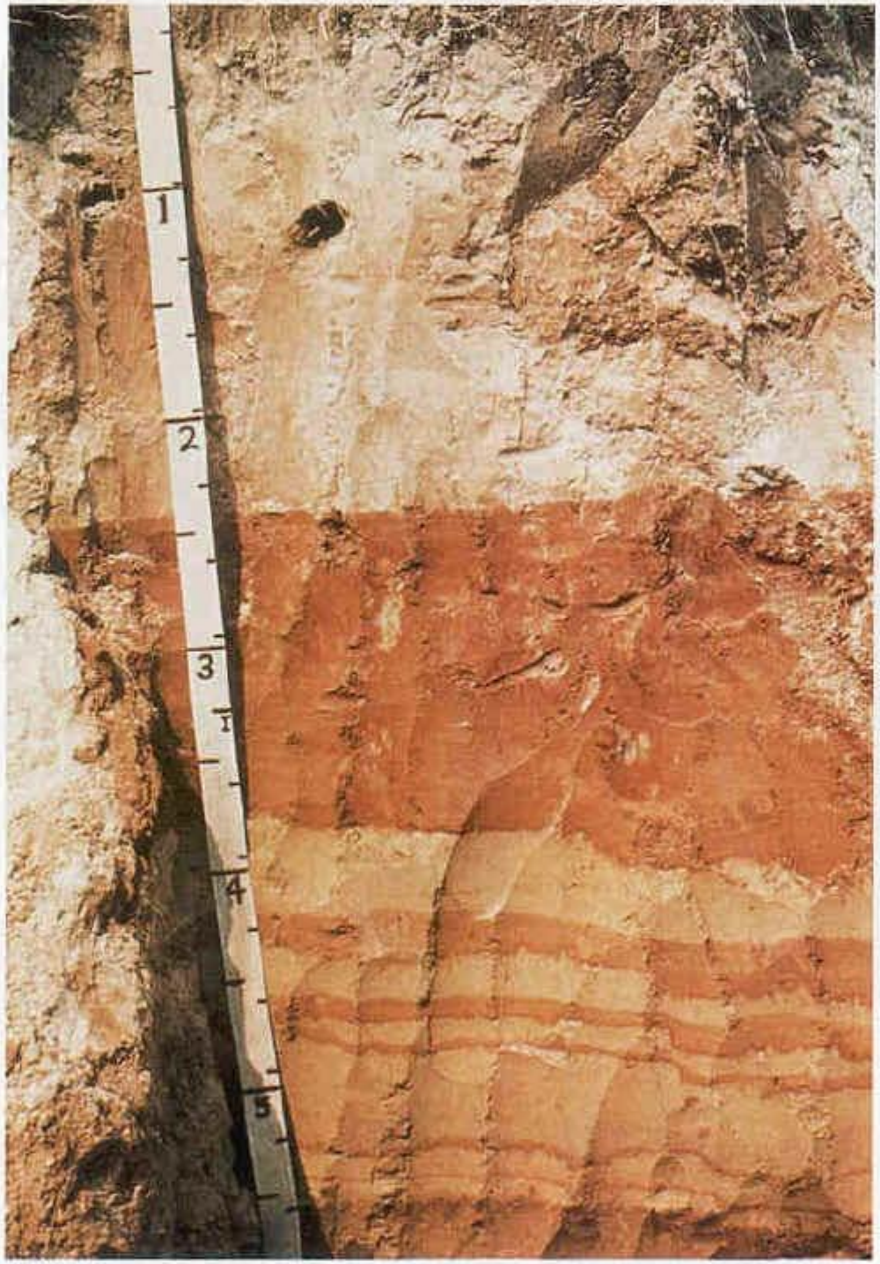
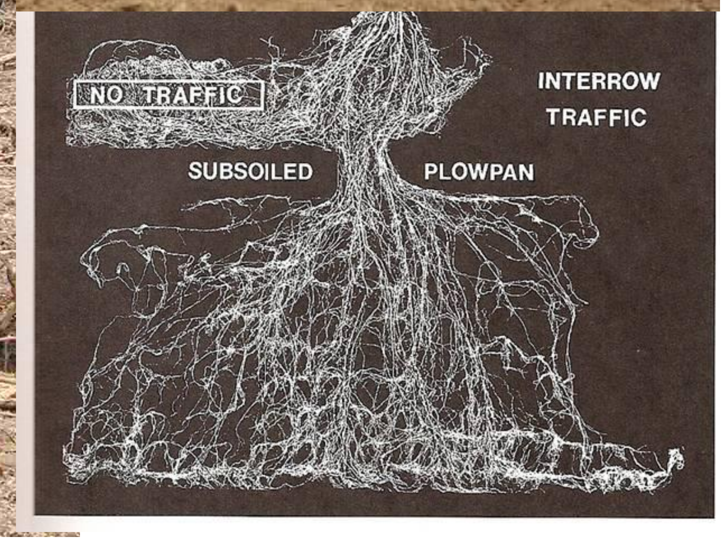
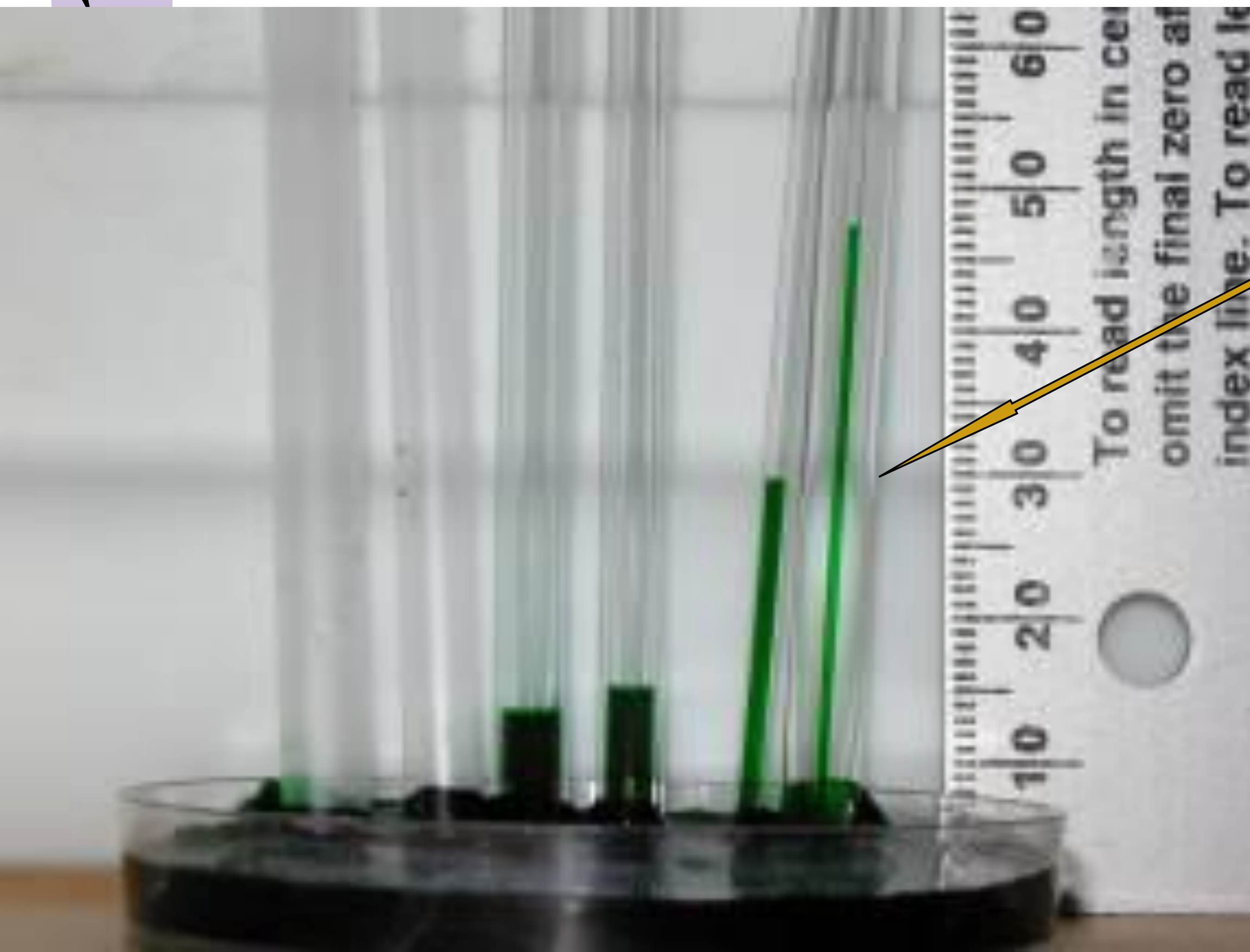


Photo 31.—Lamellae below an argillic horizon.

Soil profile modification – breaking through an impermeable layer to allow vertical drainage



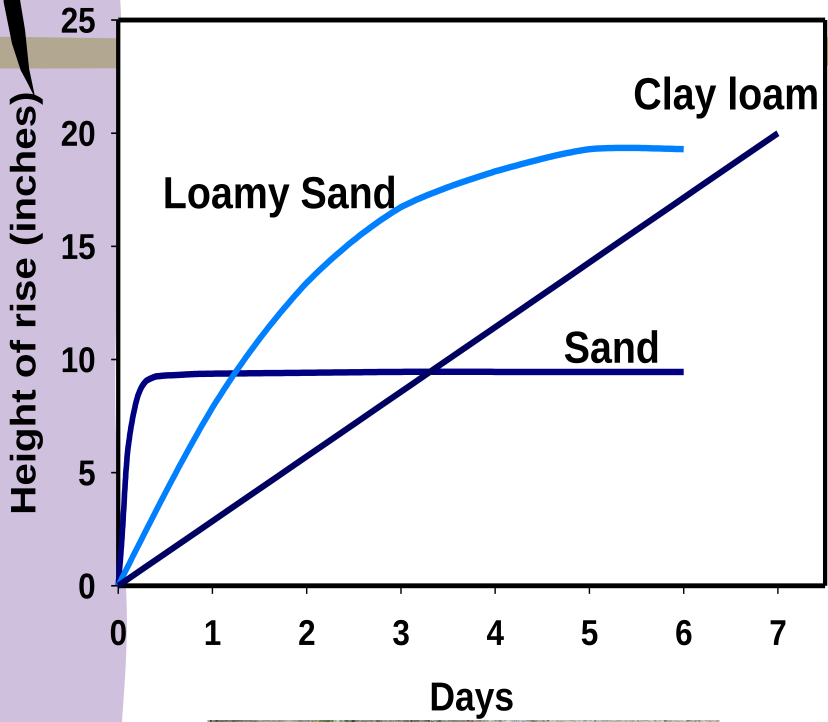
Capillary suction can result of vertical rise of saline water

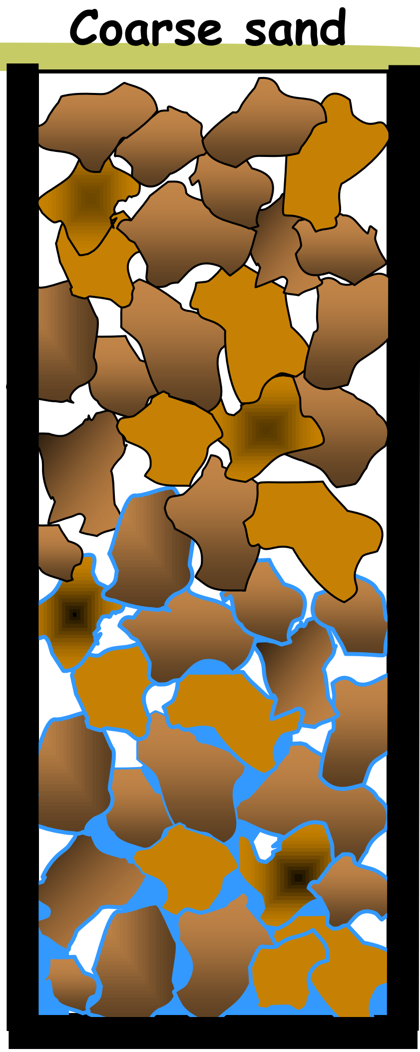


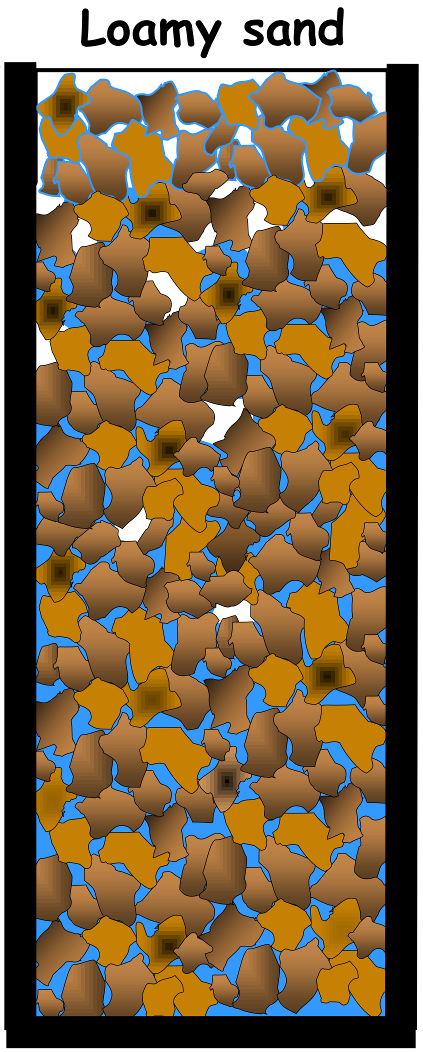
Greatest capillary rise is seen in smallest pores

Capillary must be in contact with water

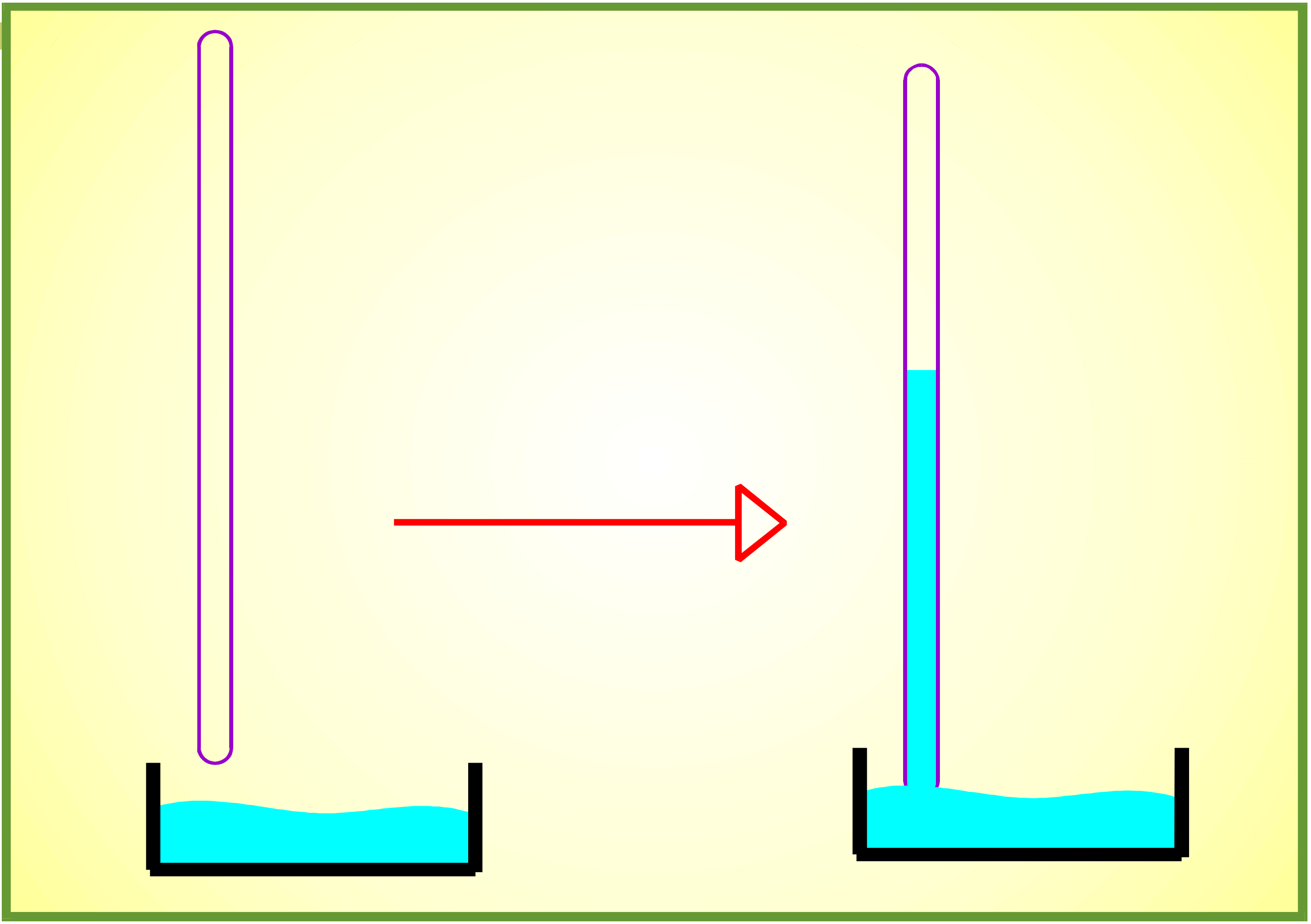
Rate and height of matrix flow depends on soil pore size

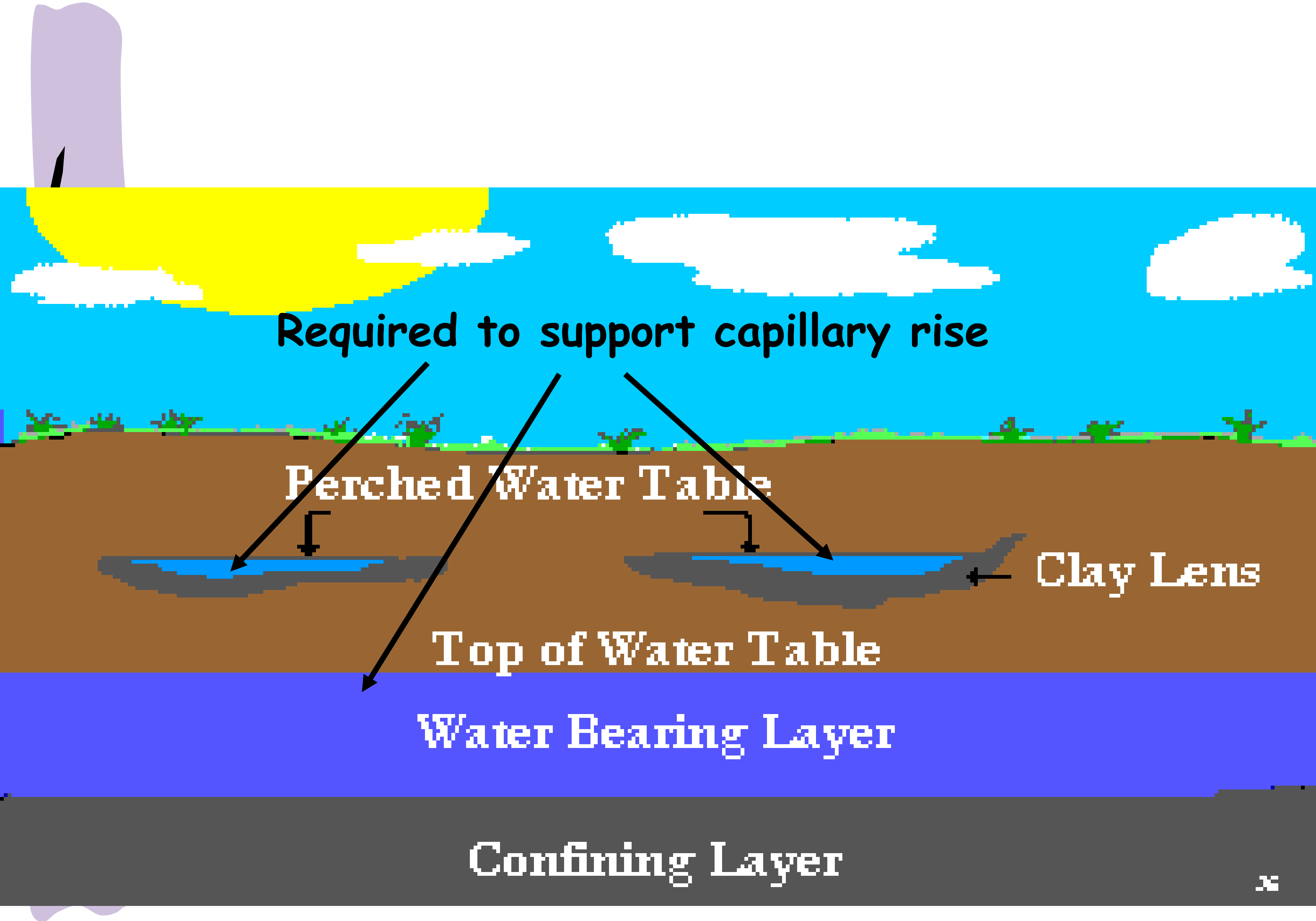






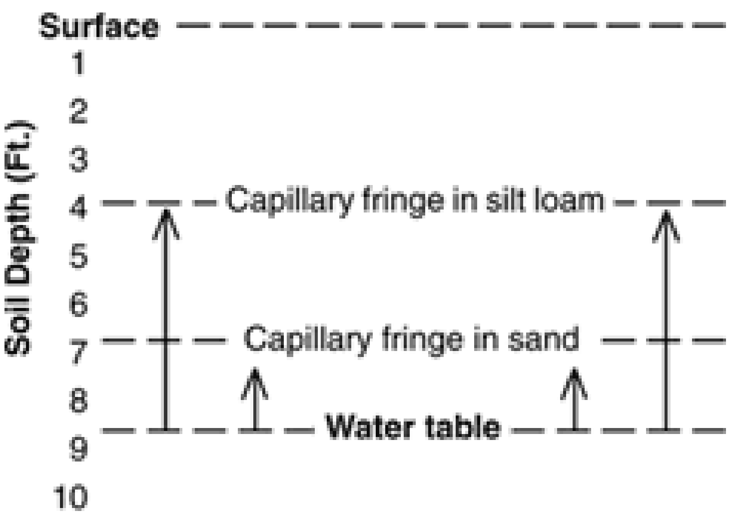
Saturated soil required to support capillary



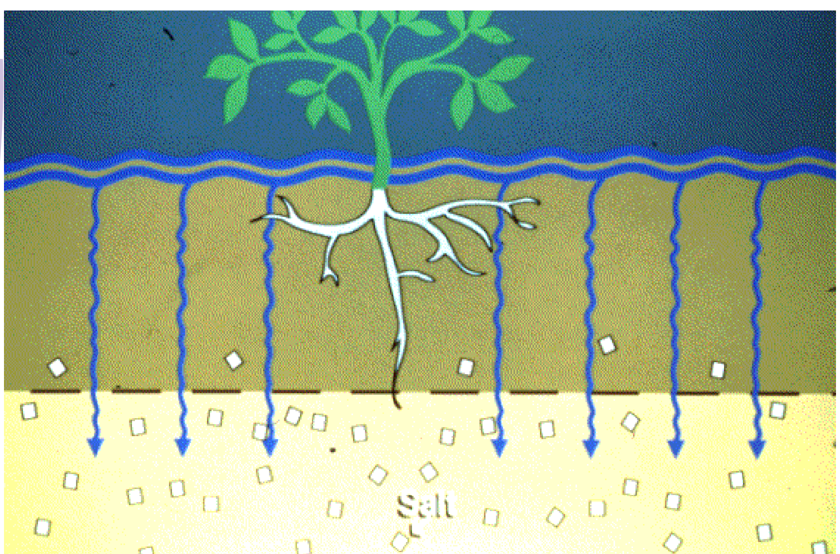


Required to support capillary rise
Perched Water Table
Clay Lens
Top of Water Table
Water Bearing Layer
Confining Layer

How deep must the salt be before capillary rise will not result in vertical movement of salt into the root zone?



Depends on soil texture, i.e., average soil pore size



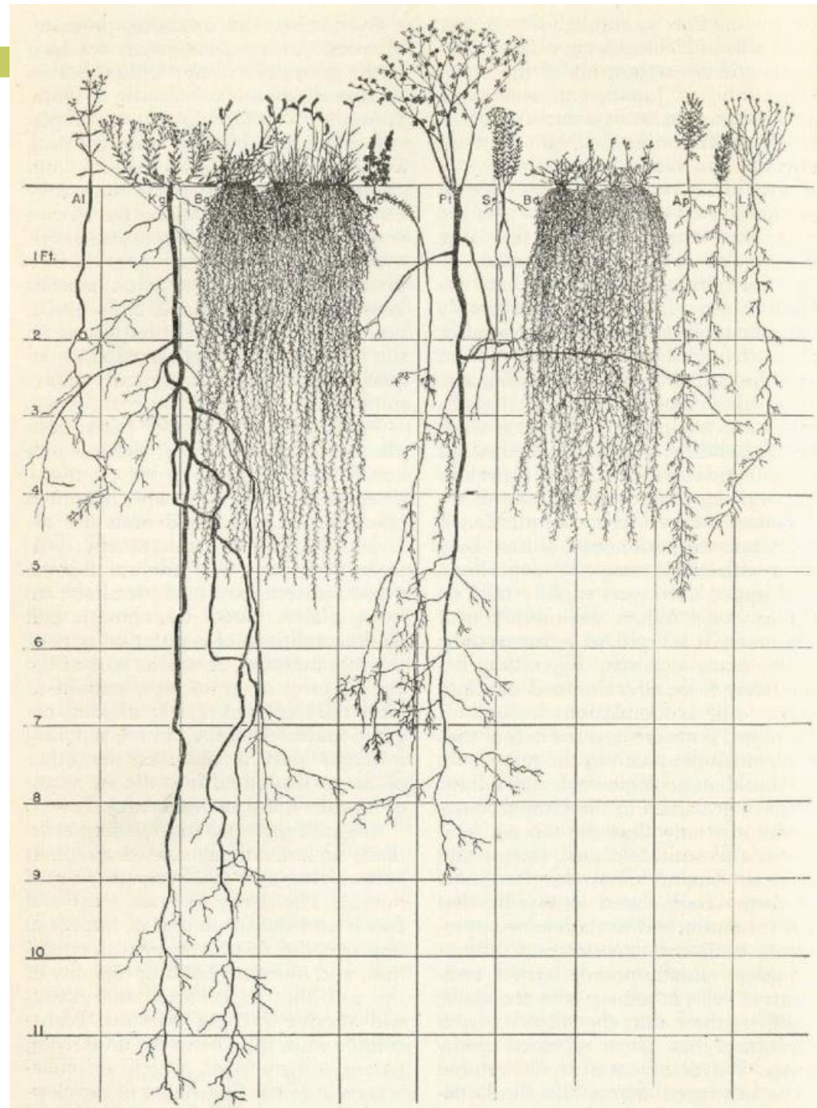
Guidance on estimated capillary rise

Handbook of Drainage Principles (OMAF, Pub. 73)

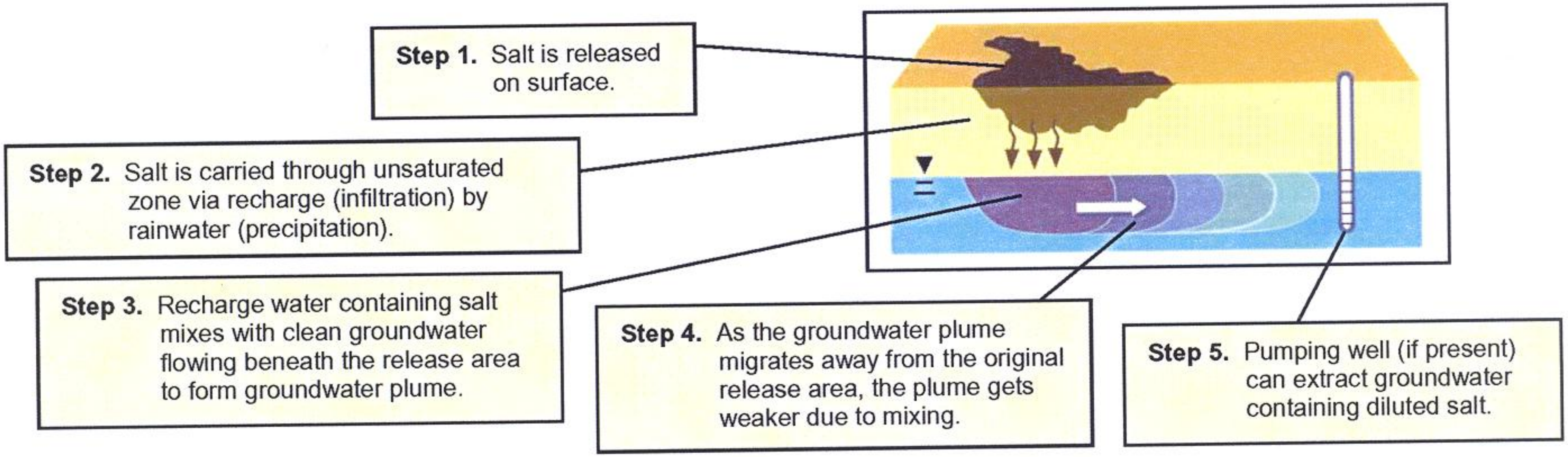
Soil type	Capillary rise (inches)
Very coarse sand	0.8
Coarse sand	1.6
Medium sand	3.2
Fine sand	6.8
Very fine sand	16.0
Silt	40.0
Clay	> 40.0

Depending on soil texture salt must be moved at least this far out of the root zone of desired vegetation

The depth of the root zone depends on the type of vegetation



Brine impacts to groundwater – potential consequences of vertical transport of salt



API Publication 4758 (2006)

DRASTIC model for predicting potential for groundwater impact

- D = **Depth** to aquifer
- R = **Recharge** rate
- A = **Aquifer** permeability
- S = **Soil** type
- T = **Topography**
- I = **Impact** of the vadose zone
- C = hydraulic **Conductivity** of the aquifer

Aller, L., Bennett, T., Lehr, J.H., Petty, R.J., Hackett, G., 1987. DRASTIC: A standardized system for evaluating ground water pollution potential using hydrogeologic settings. US Environmental Protection Agency, Report 600/2-85/018, Washington.

DRASTIC model for predicting potential for groundwater impact

- DI = DRASTIC Index = $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$

where r = rating and w = weight

DI	Vulnerability level
> 140	Very high
120 - 140	High
100 - 120	Medium
< 100	Low

Depth to groundwater (D)
Weight = 5

Depth (ft)	Rating
0 - 5	10
5 -15	9
15 - 30	7
30 - 50	5
50 - 75	3
75 - 100	2
100+	1

Net recharge (R)
Weight = 4

Rate (in/yr)	Rating
0 - 2	1
2 - 4	3
4 - 7	6
7 - 10	8
10+	9

Aquifer medium (A)
Weight = 3

Aquifer	Rating
Glacil till	5
Bedded sandstone, limestone, shale	6
Sandstone	6
Limestone	6
Sand and gravel	8
Basalt	9
Karst limestone	10

Soil (surface) type (S)
Weight = 2

Soil	Rating
Thin or no soil	10
Gravel	10
Sand	9
Aggregated clay	7
Sandy loam	6
Loam	5
Silty loam	4
Clay loam	3
Non-aggregated clay	1

Topography (T)
Weight = 1

Slope (%)	Rating
0 - 2	10
2-6	9
6-12	5

Impact of vadose zone (I)
Weight = 5

Vadose matrix	Rating
Karst limestone	10
Basalt	9
Gravel	8
Gravel - sand	7
Sand - gravel	6
Sand	5
Clay – sand - gravel	4
Clay - sand	3
Clay	2

Hydraulic conductivity (C)
Weight = 3

gpd/ft^2	Rating
1 - 100	1
100 - 300	2
300 - 700	4
700 - 1000	6
1000 - 2000	8
2000+	10

Sample calculation brine spill SW Kansas

Variable	Value	Rating	Weight	Total score
D	150 – 200 ft	1	5	5
R	0.4 – 1 in.	1	4	4
A	Sand/gravel	8	3	24
S	Sand	9	2	18
T	2-6 %	9	1	9
I	Sand	8	5	40
C	100 – 300 gpd/ft^2	2	3	6
			Total	**106**

DRASTIC model for predicting potential for groundwater impact

- DI = DRASTIC Index = $D_rD_w + R_rR_w + A_rA_w + S_rS_w + T_rT_w + I_rI_w + C_rC_w$
  where r = rating and w = weight

DI	Vulnerability level
> 140	Very high
120 - 140	High
100 - 120	Medium
< 100	Low

Modeling Study of Produced Water Release Scenarios

API Publication Number 4734
January 2005

Relative effects of vadose zone, aquifer, and brine release factors on the maximum chloride concentration (C_{max}) in groundwater and the time of arrival of the maximum concentration (T_{max})

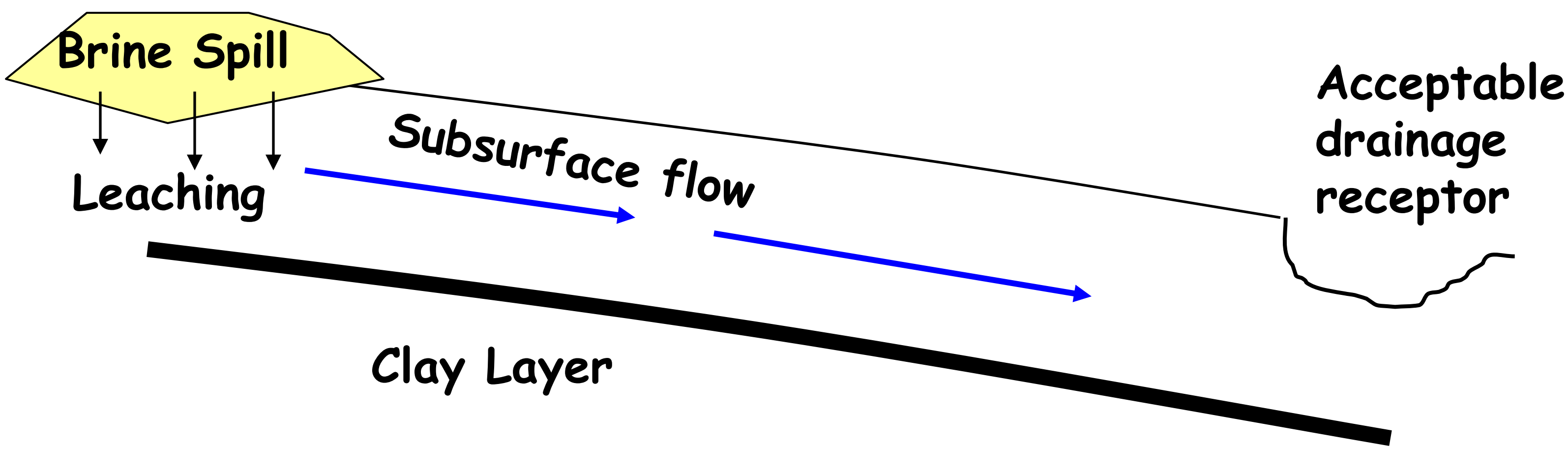
Factor	Relative effect on C_{max}	Relative effect on T_{max}
Chloride mass	100	46
Aquifer thickness	67	4
Soil texture	43	93
Groundwater flow rate	42	6
Dispersion length	32	6
Climate	25	100
Depth to groundwater	22	91
Volume of brine released	20	0

Factor	Effect
Chloride mass	More salt means more impact
Aquifer thickness	Affects dilution through mixing; thicker aquifers mean more dilution of chloride
Soil texture	Affects rate that chloride migrates downward in the vadose zone; faster transport means less dilution of the chloride in groundwater
Groundwater flow rate	Affects dilution through mixing; faster groundwater flow rates mean more dilution of chloride
Dispersion length	Greater spreading of spill results in greater dilution of salt when it reaches groundwater
Climate	Water infiltration from rainfall; more rain faster transport of salt downward in the vadose zone and less dilution of the chloride in groundwater
Depth to groundwater	Greater depths to groundwater can result in more dispersion of salt as it is transported downward and more dilution of chloride in groundwater

A few last word about vertical drainage

- In arid areas irrigation water or rainfall may never reach groundwater (little or no surface recharge)
  - Salt driven down in the soil profile may stay at a level below the root zone for decades or more
- Surface vegetation withdraws water from the subsurface reducing recharge to groundwater
  - Revegetation of impacted sites is protective of groundwater

Lateral drainage: Using the impermeable layer for moving salt



Using natural drainage patterns: An impermeable layer becomes a salt highway

Drainage

Taking advantage of natural drainage patterns

- When using natural drainage patterns “dilution is the solution to brine pollution”.
- The objective with this approach is to cause salts to leach from the impacted site **slowly enough** and over a **long enough period of time** that salt concentrations in downgradient receptors (pristine soils, surface waters, groundwater) are never high enough to create environmental problems (such as vegetation stress, measurable effects on aquatic life, degradation of drinking water quality, etc.)

Drainage

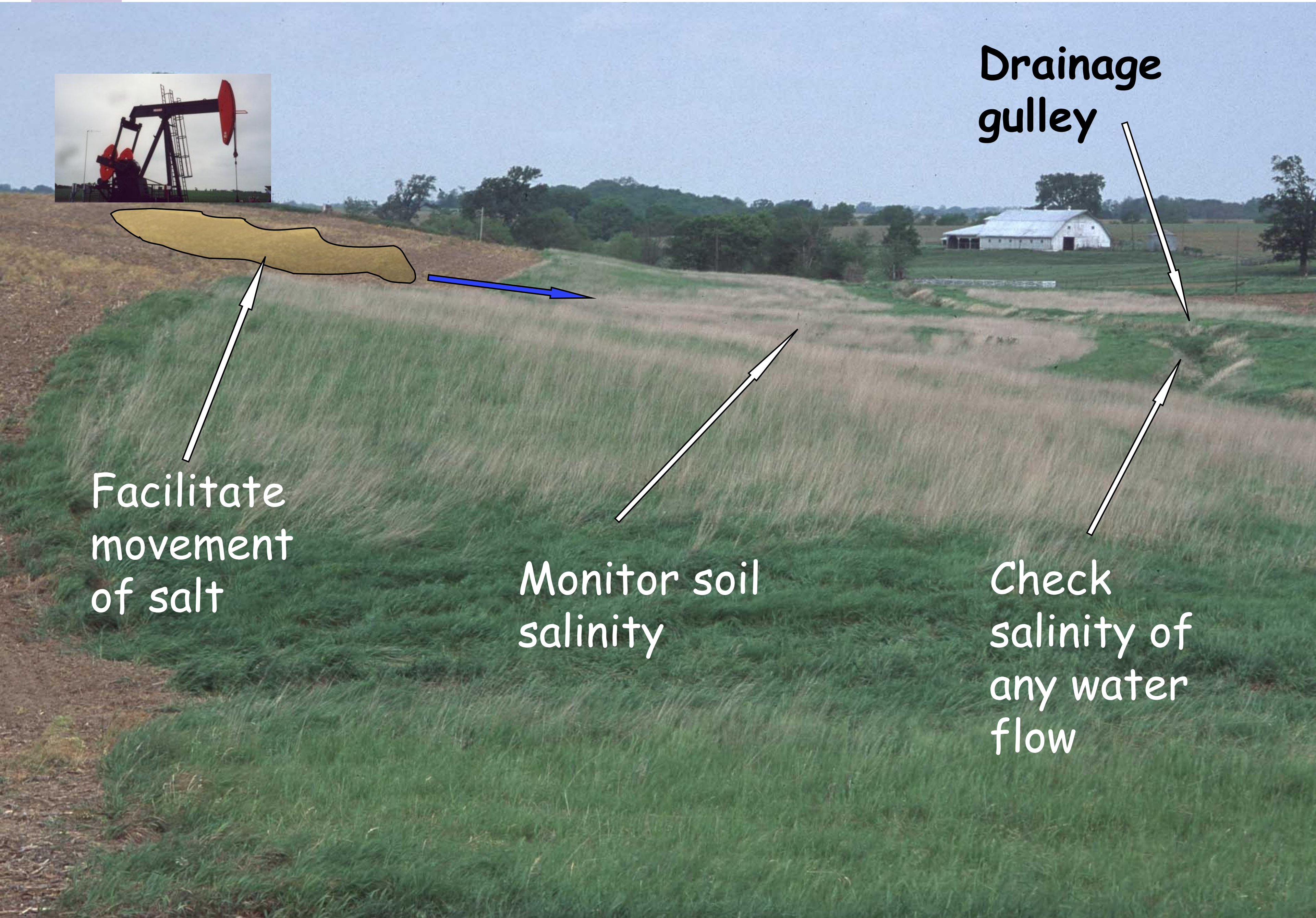
Taking advantage of natural drainage patterns

- There must be a commitment to monitor downgradient!
  - Soil profile from the surface to any impermeable layer
  - Surface water
  - Signs of vegetation stress

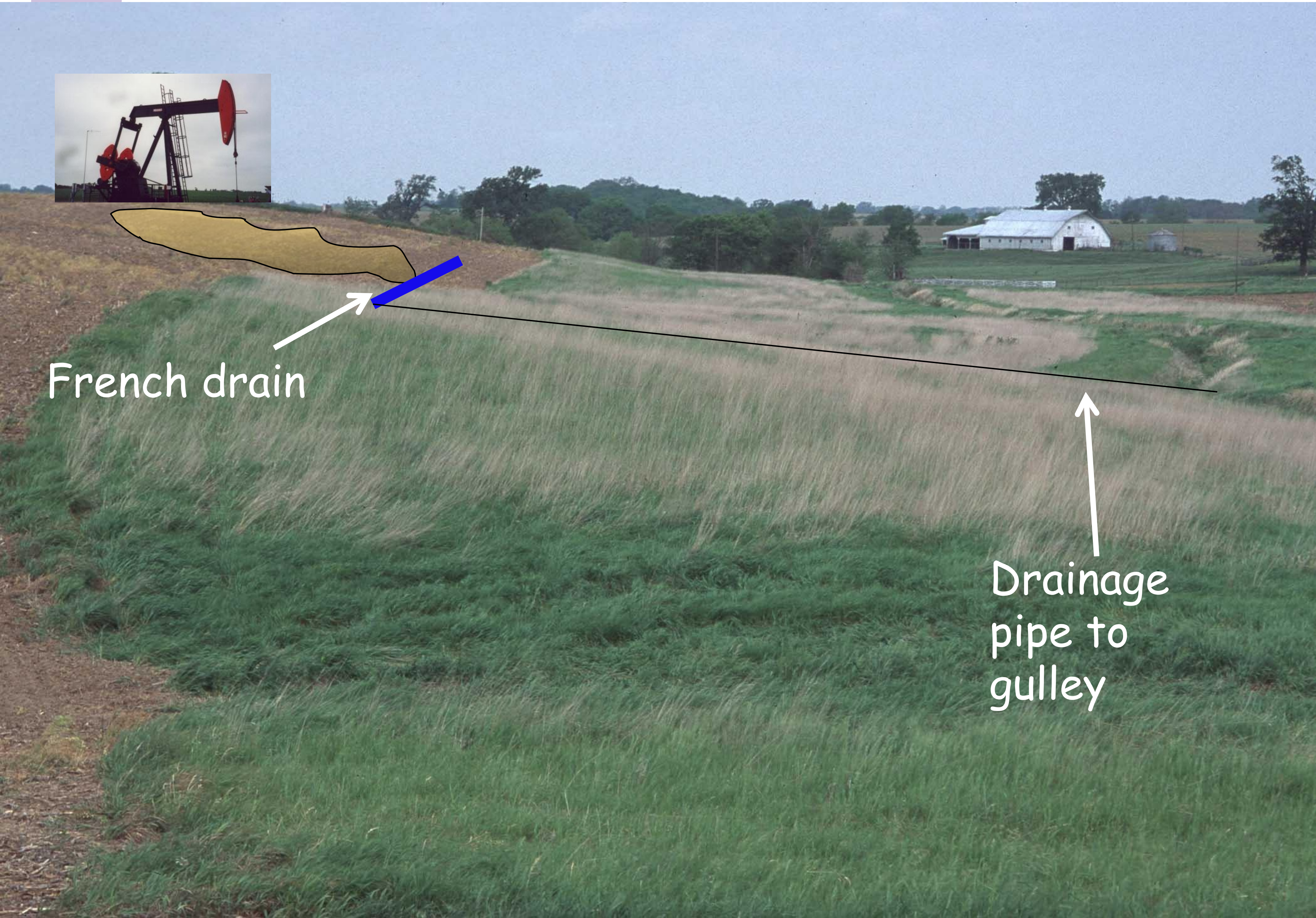
Lateral drainage takes advantage of natural drainage patterns

Lateral drainage takes advantage of natural drainage patterns

Lateral drainage takes advantage of natural drainage patterns

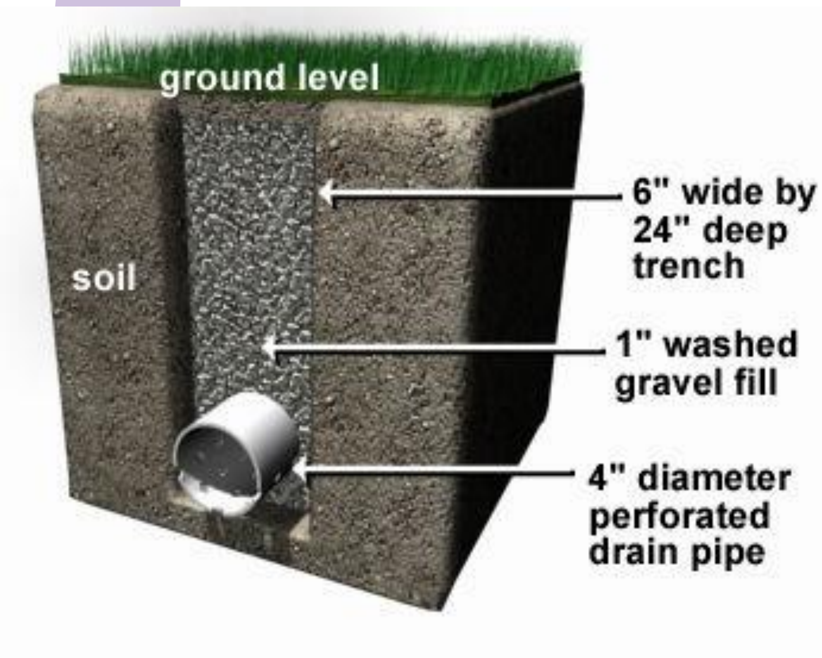


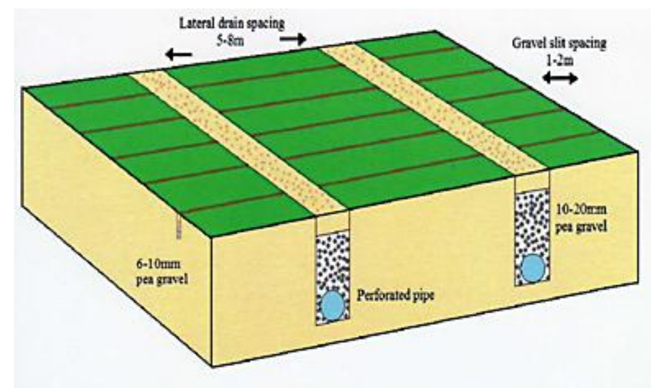
What do we do if the salt moves too fast?



What if there is insufficient natural drainage or there is no safe place for leachate to drain?

- Install subsurface ("tile") drainage
  - Collect and dispose of leachate

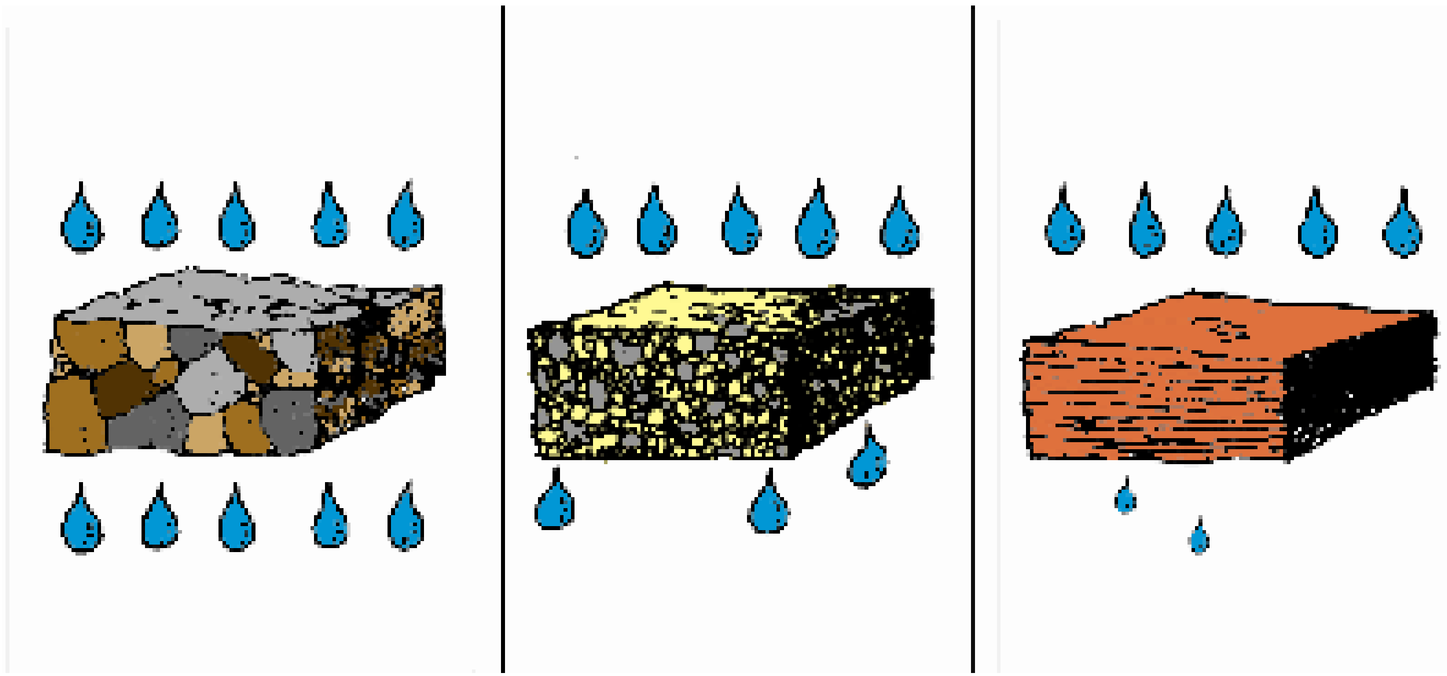




Basic elements in the remediation of brine spills

- Water (irrigation and/or rainfall)
  - Providing a sufficient quantity of water
  - Providing water of sufficient quality
  - Minimizing runoff and maximizing infiltration
- Drainage
  - Where can the salt go?
  - Facilitating movement of salts from the site in a responsible manner
  - Taking advantage of natural drainage patterns
  - Artificial drainage
  - Erosion control
- **Leaching of salts and restoring soil structure**
  - **Facilitating contact of water with salt**
  - **Maintaining soil permeability**
  - **Restoring the proper exchangeable cation status**
- Revegetation
  - Seedbed preparation
  - Soil fertility
  - Reseeding
  - Moisture

To facilitate contact of water with salt we need to increase soil permeability



Increasing permeability

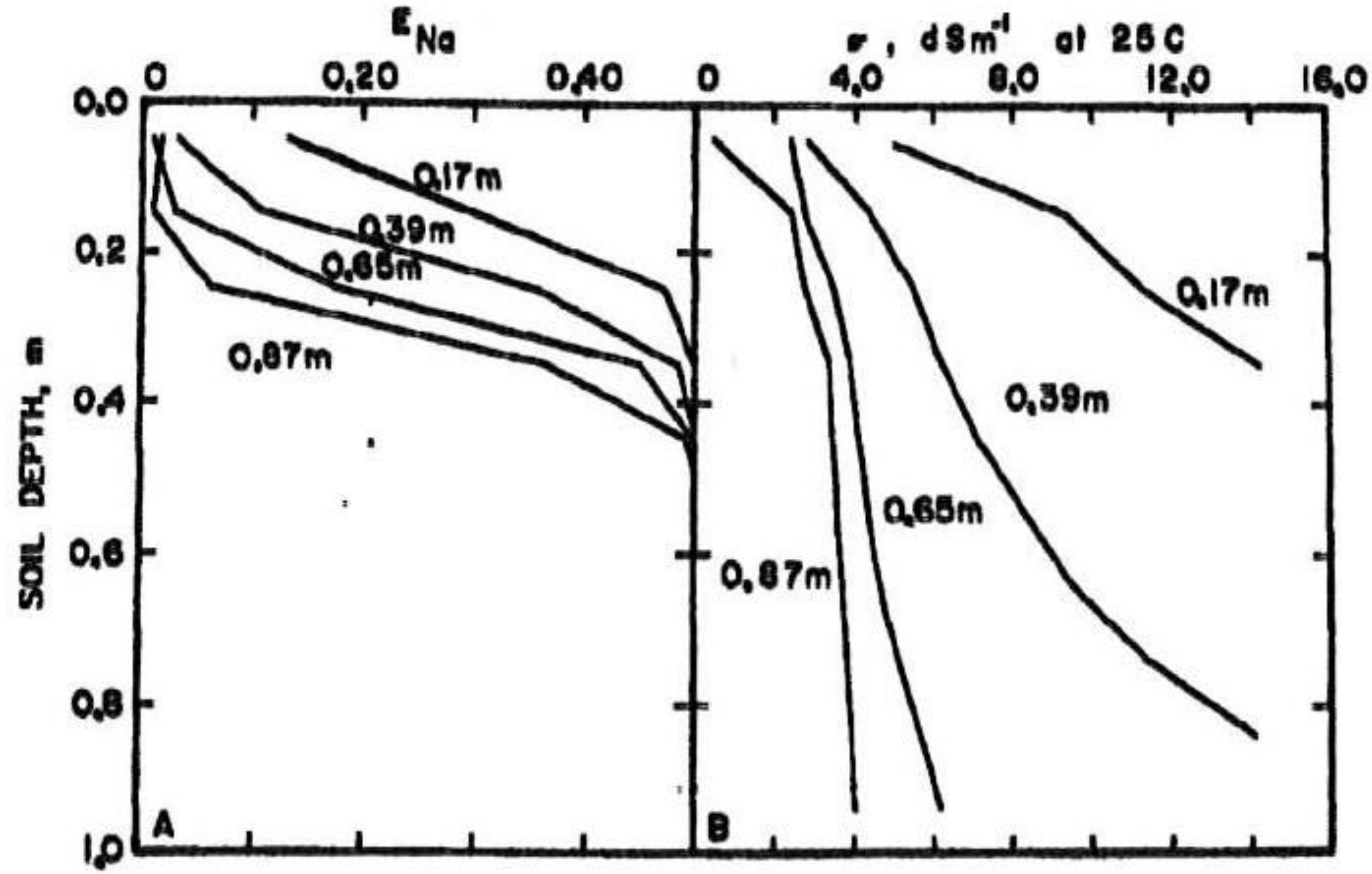
- Mechanical loosening of the soil
- Soil amendments to prop open the soil
  - Biodegradable organic matter
    - Hay
    - Stimulates soil biota and nutrient cycling which aids in revegetation
    - Biodegradation of hay improves soil structure by enhancing aggregate formation which in turn improves soil permeability

Hay application

Hay

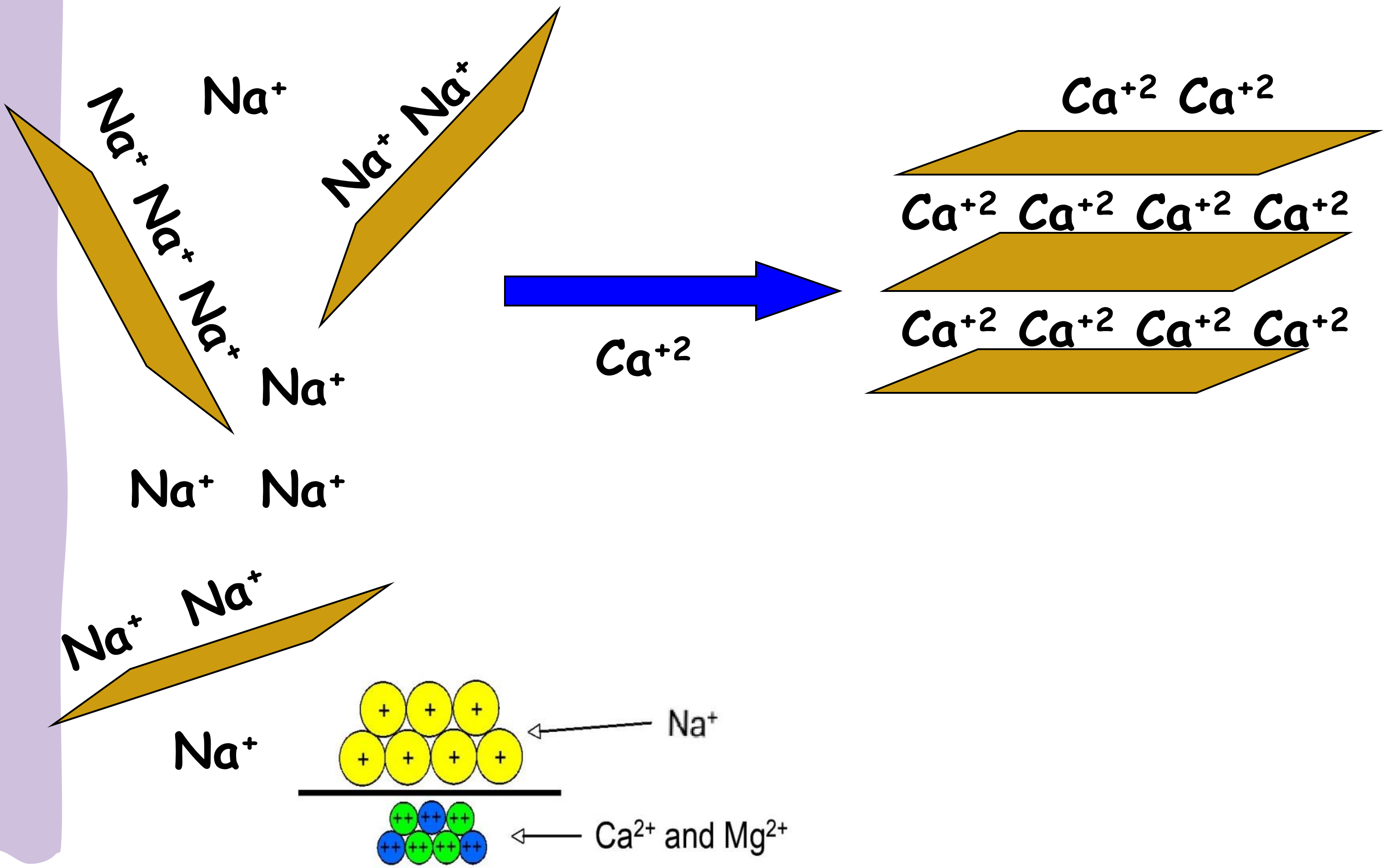
- Cultivate in about five 50-lb bales per 1000 ft^2
- Repeat as necessary to maintain good soil structure
- A top dressing of hay can help protect the soil surface from dispersing during a rainfall or watering event

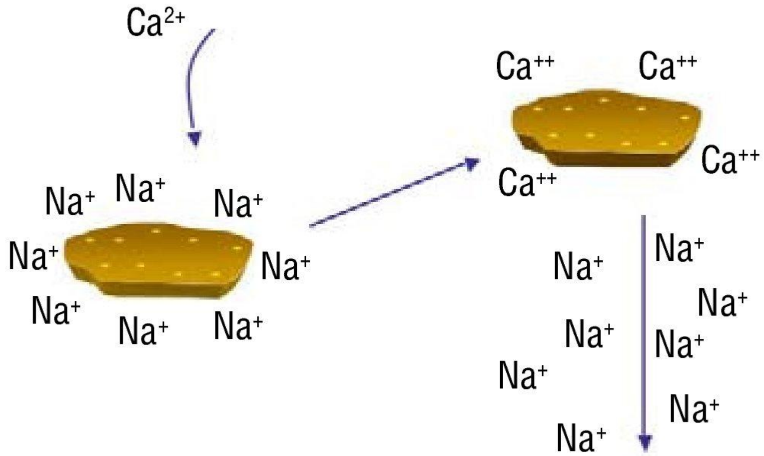
Leaching of a saline-sodic soil (CEC 20 meq/100 g)



Mechanically propping the soil open will facilitate leaching of the salt but will not restore lost soil structure due to sodicity

Calcium is required to fight sodicity





Ca2+
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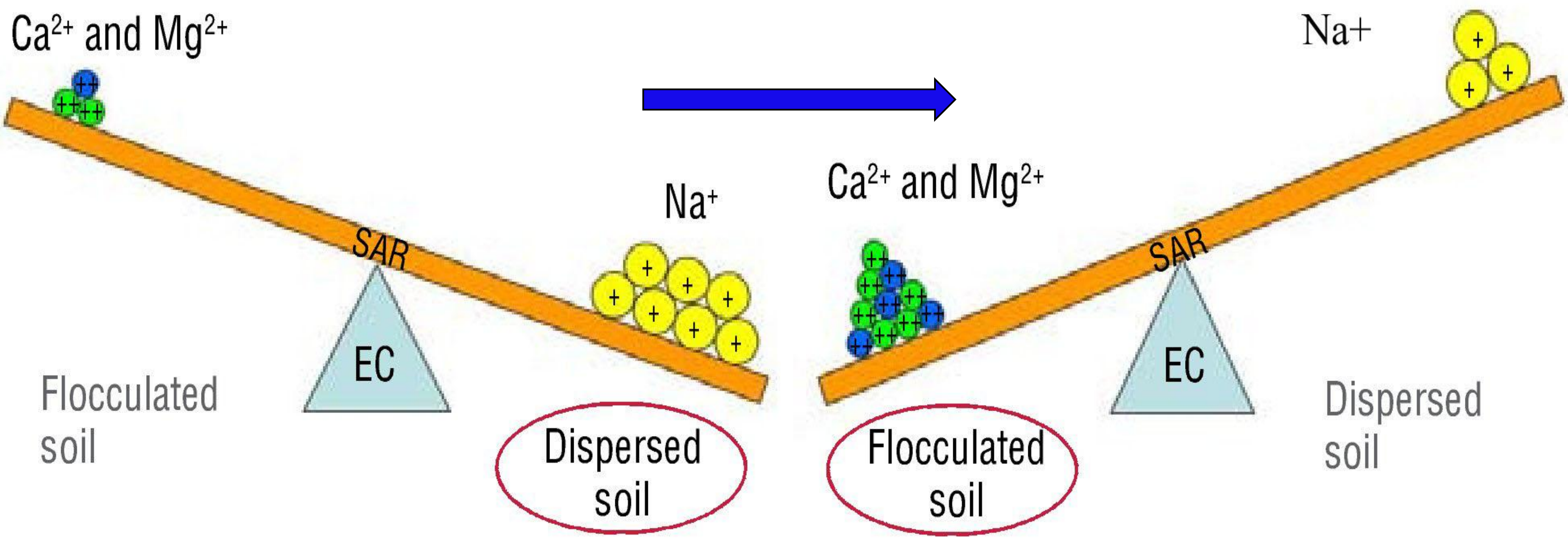
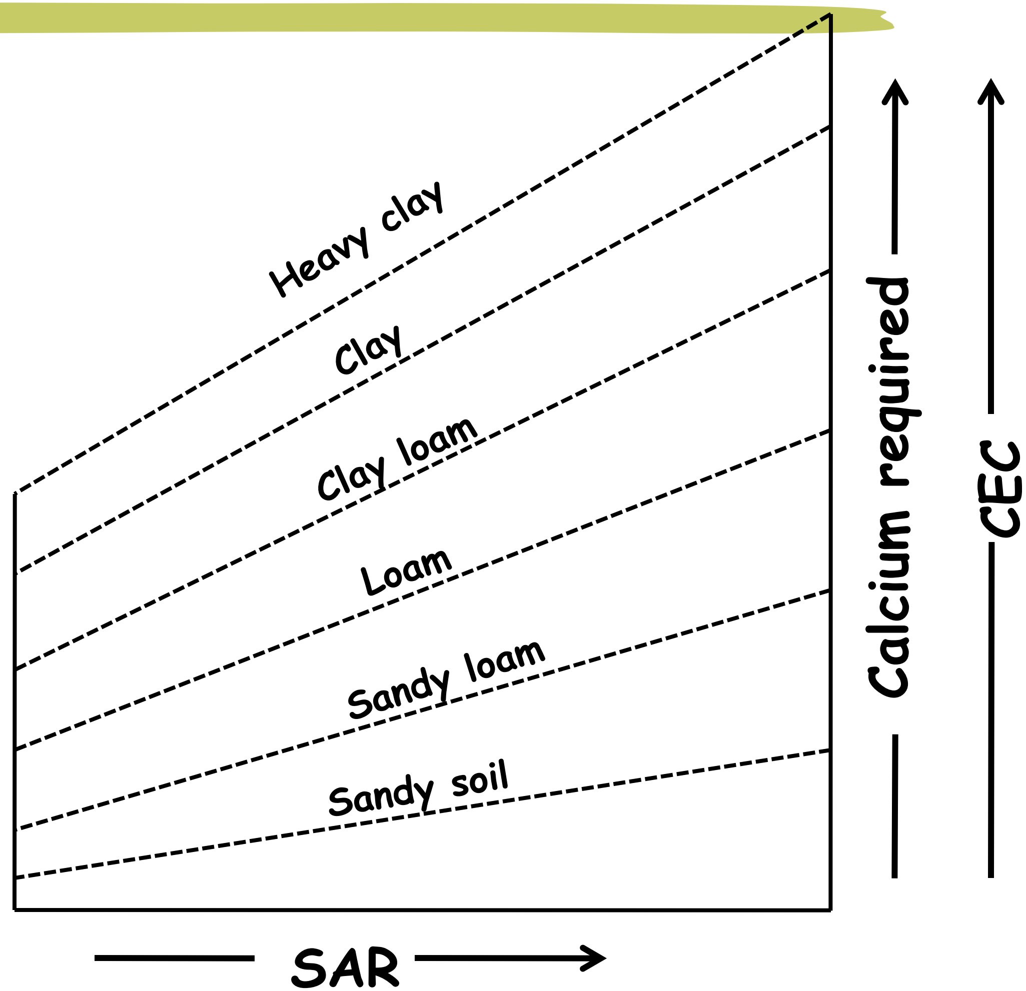


Ca2+ and Mg2+
Na+
SAR
EC
Flocculated soil
Dispersed soil
Na+
Ca2+ and Mg2+
SAR
EC
Flocculated soil
Dispersed soil

How much calcium?



Chemical amendments for replacement of exchangeable sodium

Choice of chemical amendments will depend on soil classification as defined by the table below:

Soil Classification	Abundance of $CaCO_3$
I	yes
II	no

How can you tell if there is an abundance of $CaCO_3$ in your soil?

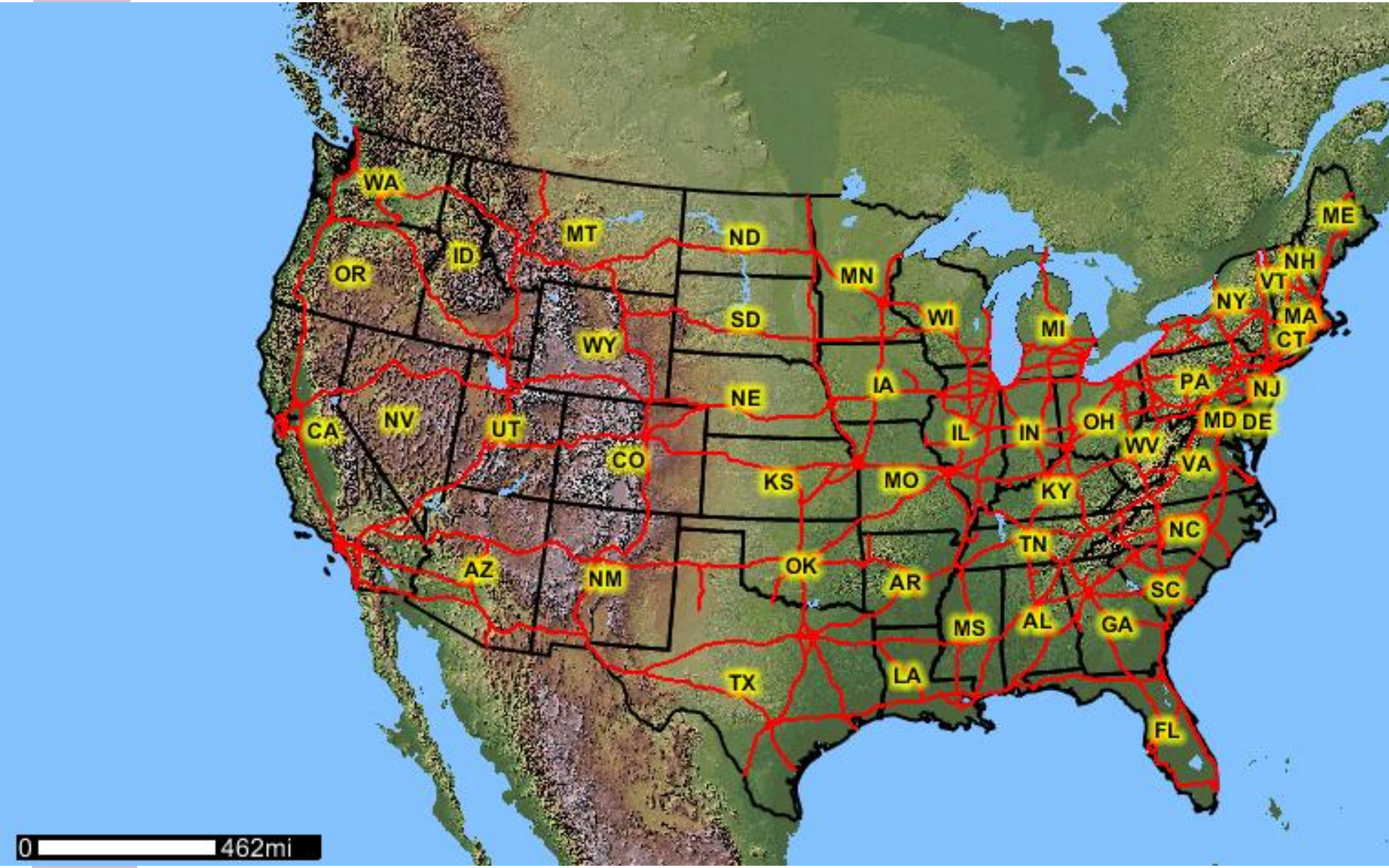
- Fizz test*
  - Add 2-3 drops of muriatic acid to dry soil (crush to break up any aggregates)
  - If the soil fizzes, $CaCO_3$ is present (the fizzing is the release of carbon dioxide resulting from the chemical reaction of the acid with $CaCO_3$)
    - Vigorous fizz: > 5% $CaCO_3$
    - Moderate fizz: 2-3% $CaCO_3$
    - Light fizz: < 1% $CaCO_3$

***Caution, generates heat**

How can you tell if there is an abundance of $CaCO_3$ in your soil?

For all kinds of soil data check out:

http://websoilsurvey.nrcs.usda.gov/app/



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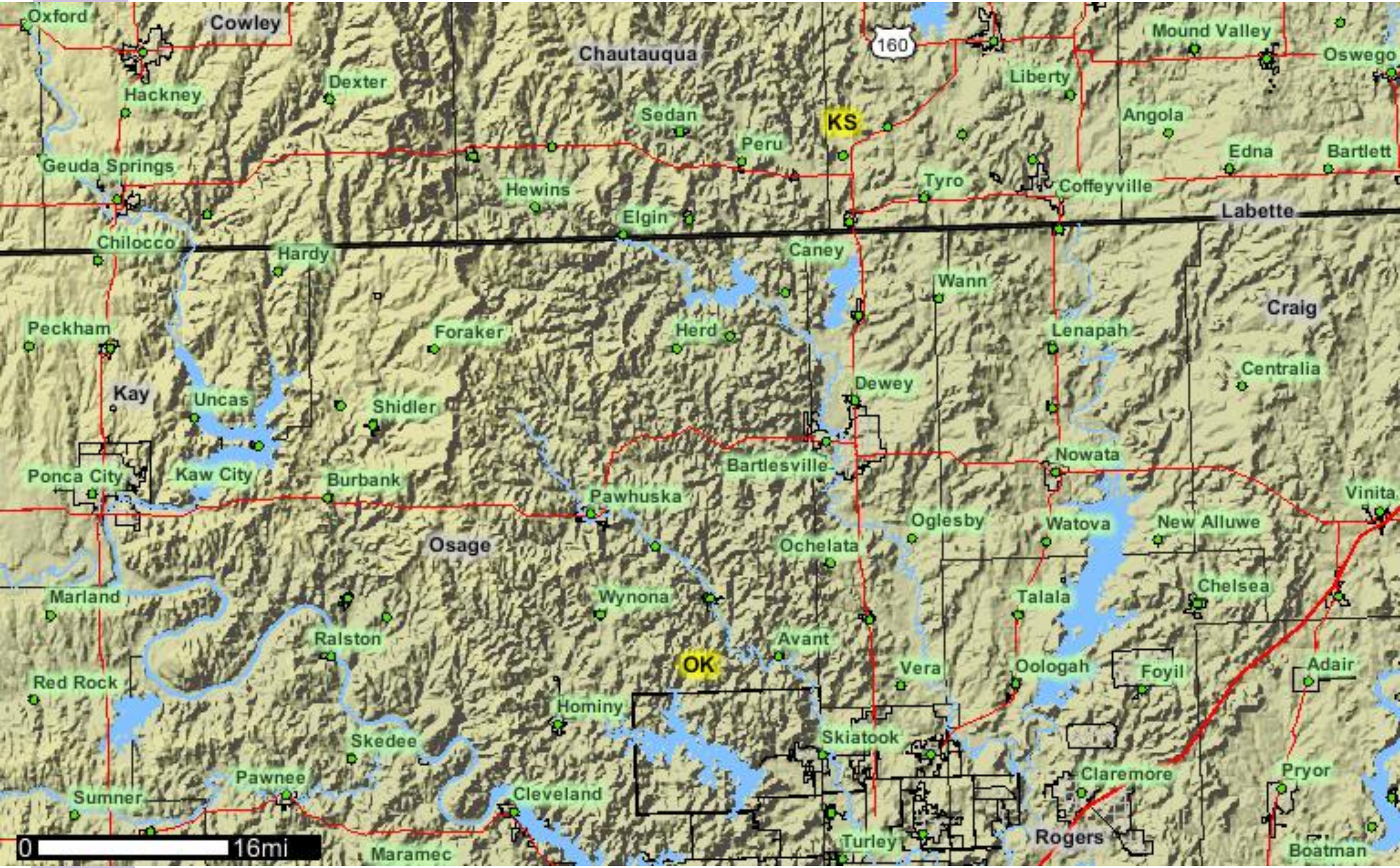
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Mound Valley
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Liberty
Dexter
Hackney
Sedan
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Angola
Peru
Edna
Bartlett
Geuda Springs
Tyro
Hewins
Coffeyville
Elgin
Labette
Chilocco
Hardy
Caney
Wann
Craig
Peckham
Foraker
Herd
Lenapah
Centralia
Kay
Uncas
Shidler
Dewey
Nowata
Ponca City
Kaw City
Burbank
Bartlesville
Pawhuska
Vinita
Oglesby
Watova
New Alluwe
Osage
Ochelata
Chelsea
Marland
Wynona
Talala
Ralston
Avant
OK
Vera
Oologah
Foyil
Adair
Red Rock
Hominy
Skiatook
Skedee
Claremore
Pryor
Pawnee
Sumner
Cleveland
Turley
Rogers
Boatman
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16mi
Maramec


OK
Osage
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47ft

Chemical amendments by class
Class I

- **Calcium amendments may not be needed**
- Enough calcium ($CaCO_3$, calcium carbonate) may already be available to displace sodium from clays if solubilized (producing Ca^{+2}) by reacting with acid sources
  - Increasing acidity (to lower pH):
    - Elemental sulfur
    - Aluminum sulfate [$Al_2(SO_4)_3$]
    - Ferrous sulfate ($FeSO_4$)

The common agricultural acid forming amendments form gypsum in the soil

- Elemental sulfur

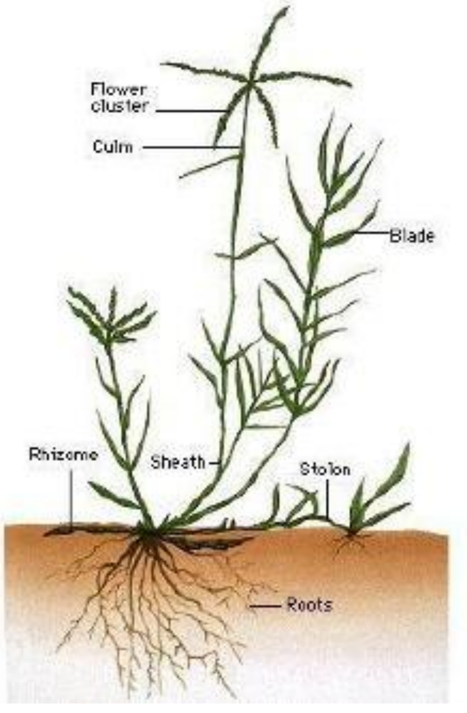
  Soil bacteria

  - S → H_2SO_4 (sulfuric acid)
  - Sulfuric acid + $CaCO_3$ → $CaSO_4$

- Aluminum sulfate [$Al_2(SO_4)_3$] and ferrous sulfate ($FeSO_4$) both form $CaSO_4$ in soil from $CaCO_3$

Nature's chemistry for fighting sodicity

Plant roots release organic acids into the soil which chemically react with $CaCO_3$



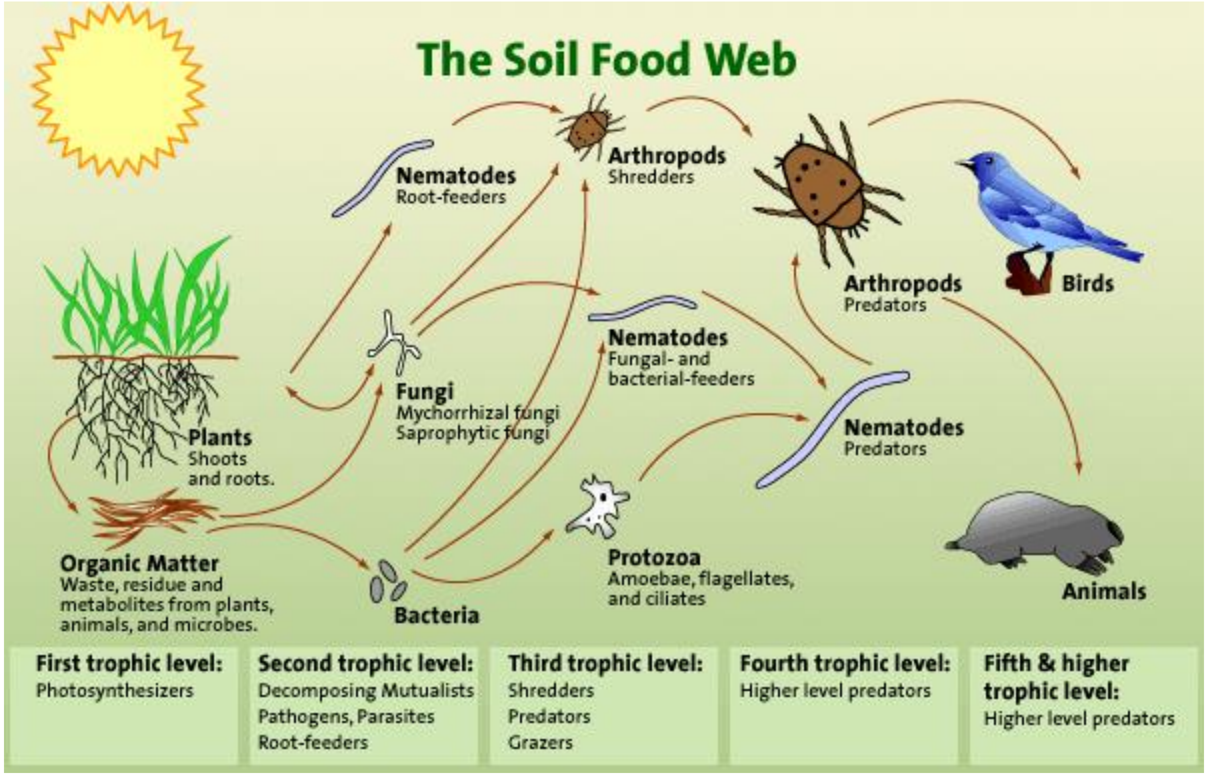
$$CaCO_3 + RCOOH \rightarrow\!\!> Ca^{+2} + RCOO^{-} + CO_2\uparrow$$

Organic acids mimic natural chemistry

Ca++Nhance™

Organic acids also stimulate microbial growth

- Immobilizes nutrients in the soil preventing loss by leaching
- Builds soil nutrient pools
- Stimulates growth of soil animals



Chemical amendments for replacement of exchangeable sodium

Choice of chemical amendments will depend on soil classification as defined by the table below:

Soil Classification	Abundance of $CaCO_3$
I	yes
II	no

Chemical amendments by class
Class II

- Source of calcium (Ca^{+2}) required
  - Calcium nitrate [$Ca(NO_3)_2$], calcium chloride ($CaCl_2$)
    - Provide high concentrations of soluble Ca^{+2} but easily leached out of the soil because of their high water solubility
      - Not much more effective that fresh water
    - Calcium nitrate cannot be used over shallow groundwater
  - Gypsum (calcium sulfate, $CaSO_4$)
    - Mined as agricultural amendment
    - Can be problematic
  - Limestone (calcium carbonate, $CaCO_3$) + acid former
    - Such as $CaCO_3$ + organic acids

Ca++Nhance™

Gypsum issues: Macro and micro composition of mined gypsum

Component	Units (ppm = mg/kg)	Mined gypsum [Average (std dev)]
Calcium (Ca)	%	19.1 (2.2)
Magnesium (Mg)	%	1.35 (0.3)
Sulfur (S)	%	19.2 (0.2)
Boron (B)	ppm	9.4 (0.9)
Iron (Fe)	ppm	1045 (148
Manganese (Mn)	ppm	14.6 (2.9)
Phosphorus (P)	ppm	30.6 (7.6)
Insoluble residue	%	12.9 (8.1)

Washington State University

Gypsum issues: Plant Nutrients

Major Nutrients

- Nitrogen
- Phosphorus
- Potassium
- Calcium
- Magnesium
- Sulfur

Micronutrients

- Boron
- Iron
- Manganese
- Zinc
- Copper
- Chloride
- Molybdenum

Mobile vs. immobile nutrients

- Mobile nutrients: N, S, B, Cl
  - Found primarily in the soil solution
- Immobile nutrients: K, Ca, Mg, Fe, Zn, Mn, Cu, Mb
  - Found primarily associated with soil particles and soil organic matter

Gypsum issues: Gypsum mobilizes certain immobile nutrients

- Gypsum mobilizes Mg^{+2} and K^{+}
  - In one test of the surface application of gypsum resulted in a leaching losses of 71% of soil Mg^{+2}
    - Ritchey et al. (1999): Center for Applied Energy Research, University of Kentucky
  - Wheat plants grown in gypsum treated soils have been shown to be seriously deficient in Mg^{+2}
    - Zaifnejad et al. (1996): Crop Science **36**, 968

How much gypsum is required to replace a given amount of exchangeable sodium?

$$\frac{(ESP_{now} - ESP_{required}) \times CEC \times 1720}{\% \text{ Gypsum}} =$$

lbs gypsum/acre/6"

How much gypsum is required to replace a given amount of exchangeable sodium? cont.

- Sample calculation:
  - ESP_{now} = 50%
  - $ESP_{required}$ = 10%
  - CEC = 30
  - % gypsum = 90%

$$\frac{(50 - 10) \times 30 \times 1720}{90} = \text{22,933 lbs/acre/6" increment}$$

or

527 lb/1000 ft^2

How much water is required to convert that gypsum to soluble Ca^{+2}?

$$\frac{527 \text{ lbs } (454.6 \text{ g/lb})}{2.5 \text{ g/L}(28.3 \text{ L/ft}^3)} = 5891 \text{ ft}^3$$

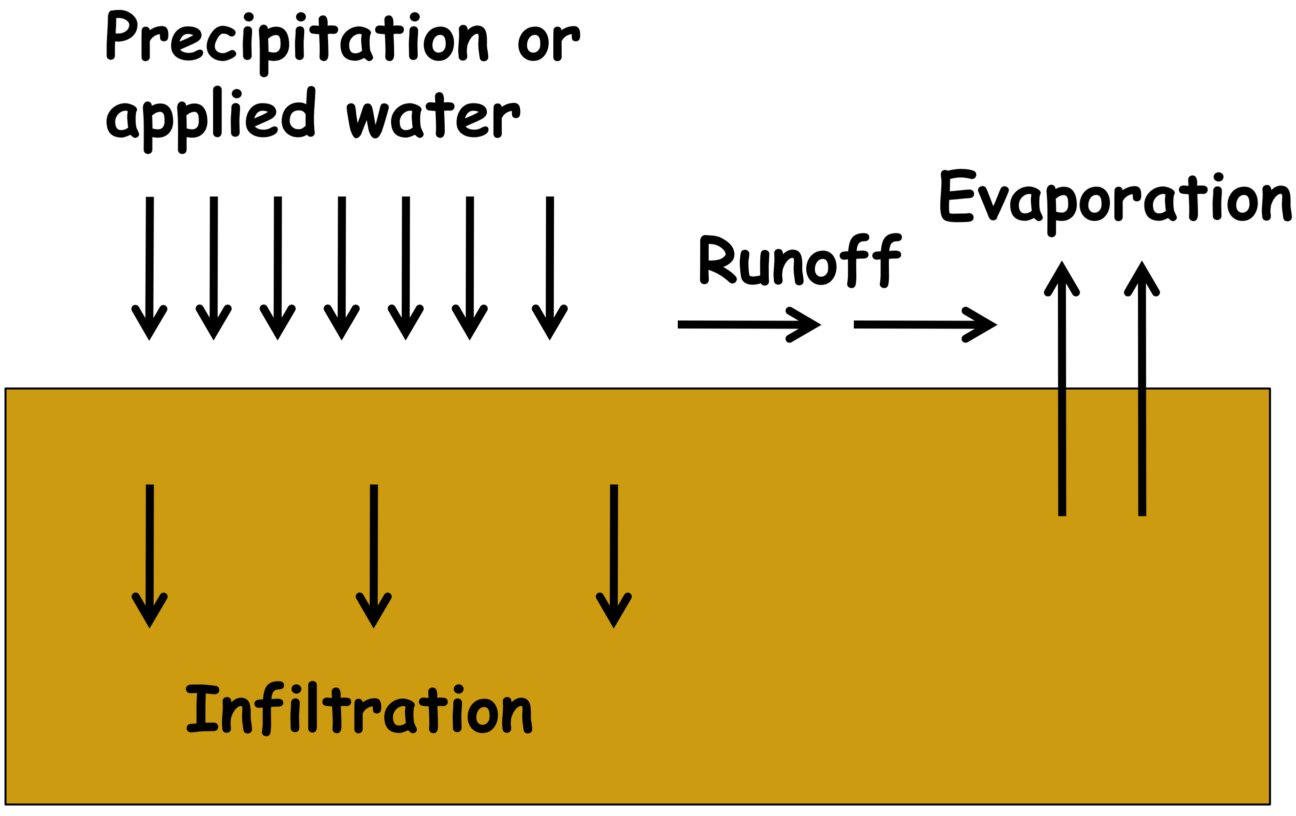
$$\text{Inches of water} = \frac{3386 \text{ ft}^3 (12 \text{ inches/ft})}{1000 \text{ ft}^2}$$

$$= 40.6 \text{ inches}$$

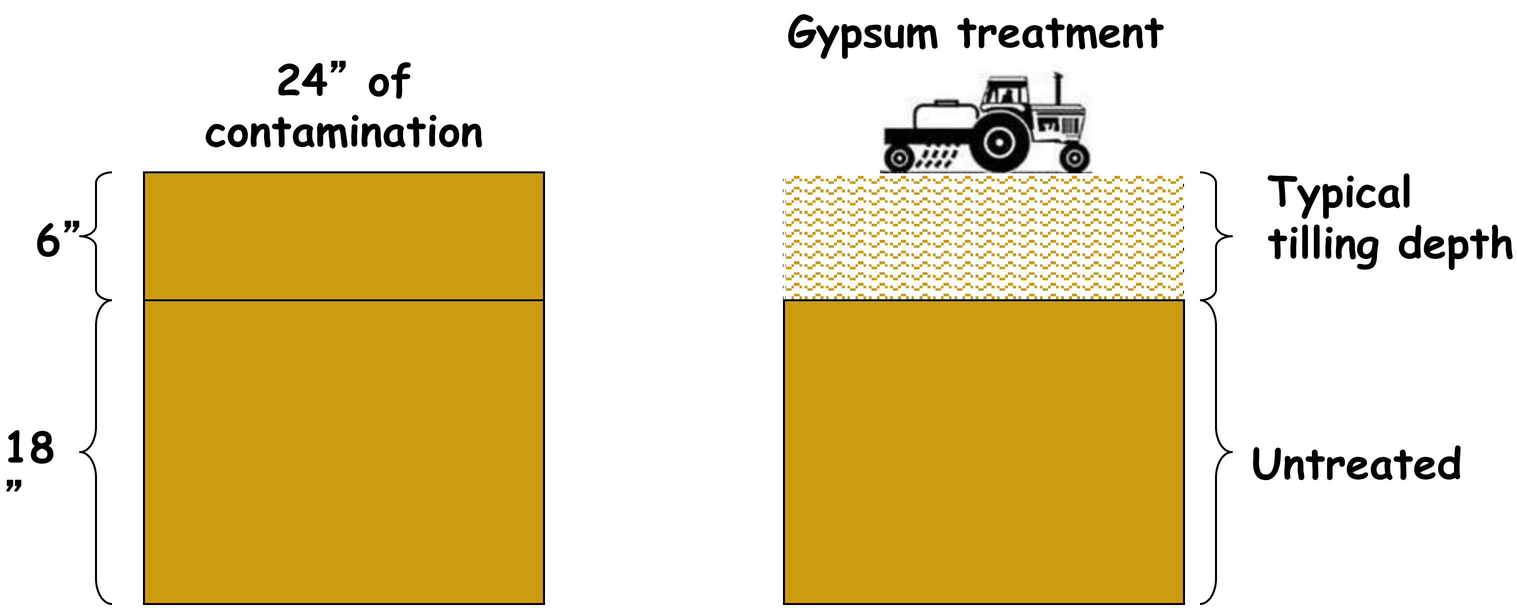
How much water for greater depths of contamination?

Increment thickness treated	lbs gypsum per 1000 ft^2	Inches of infiltration water required
6	527	40.6
12	1054	81.2
18	1581	121.8
24	2108	162.4

Remediation of brine spills will require more than the calculated amount of water to be applied because of runoff and evaporation.



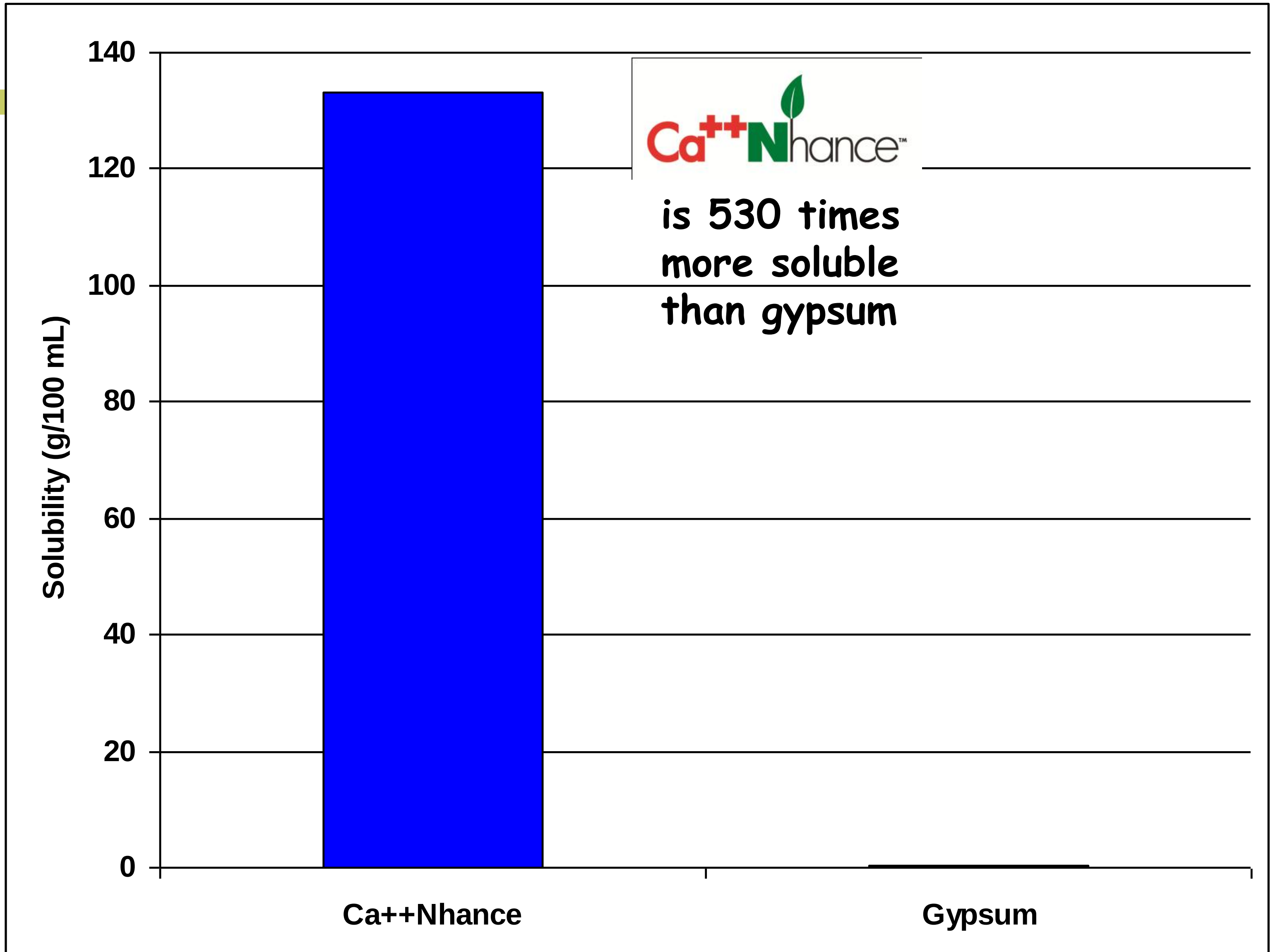
Due to the low solubility of gypsum, gypsum is typically effective only within the depth to which it is incorporated into soil



Sulfate in the soil can render gypsum totally ineffective

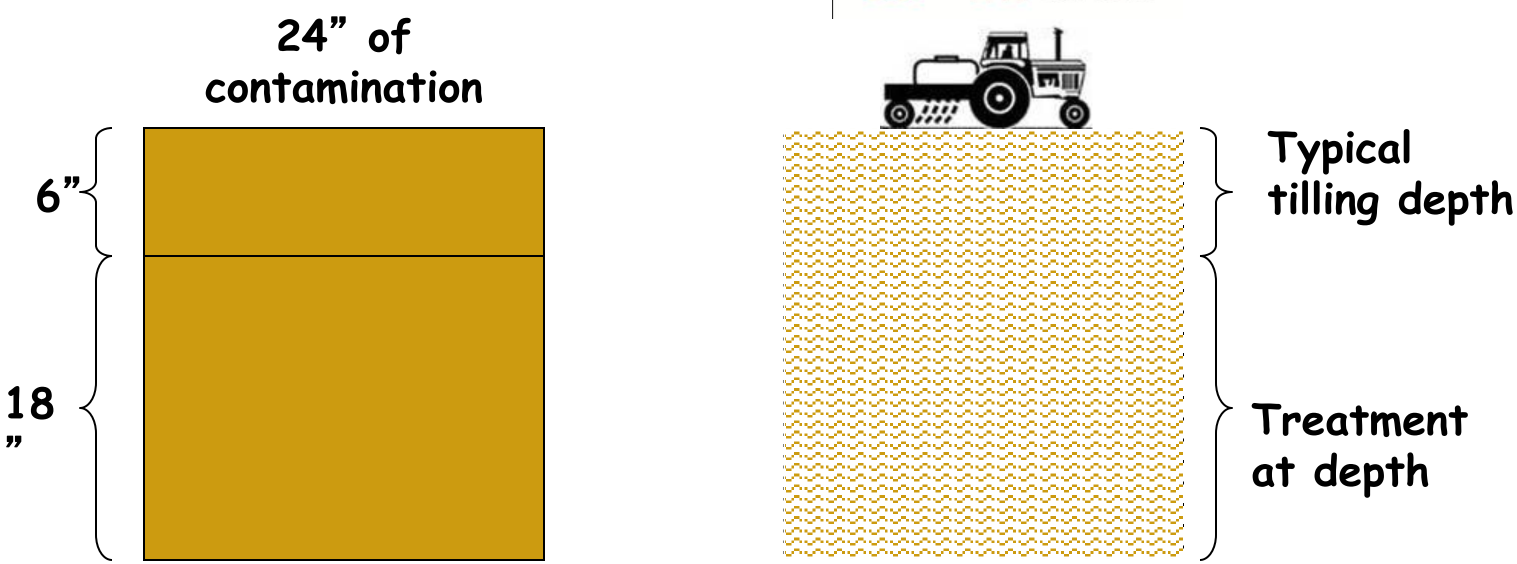
- It's called the common ion effect
- Sulfate in the soil reduces gypsum solubility and, therefore, availability of soluble calcium

Solubility of organic acids vs. gypsum

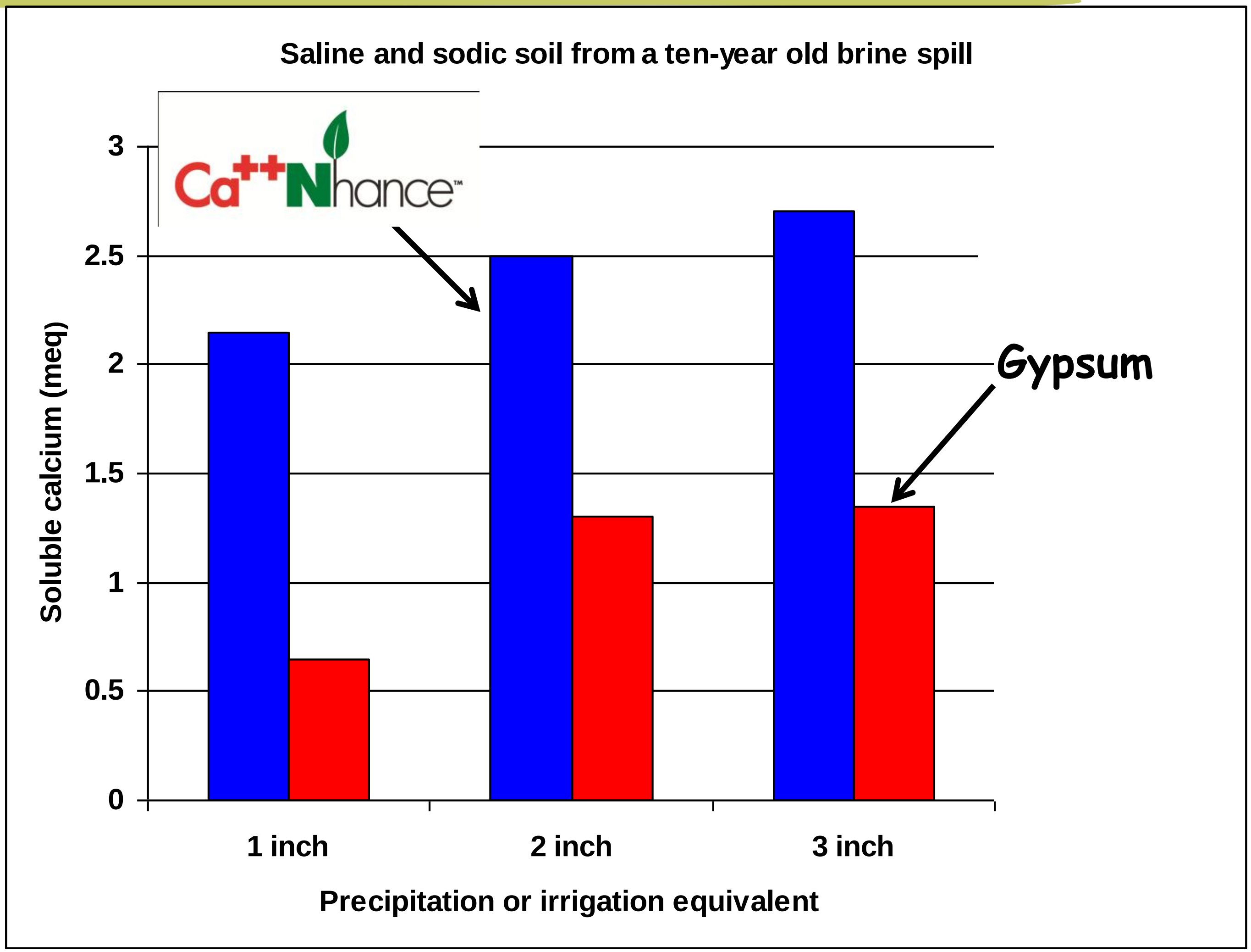


The much higher solubility of organic acids results in deeper penetration into the soil profile treating sodicity below tillage depth

Ca++Nhance™



Generation of soluble calcium in brine-impacted soil by organic acids and gypsum

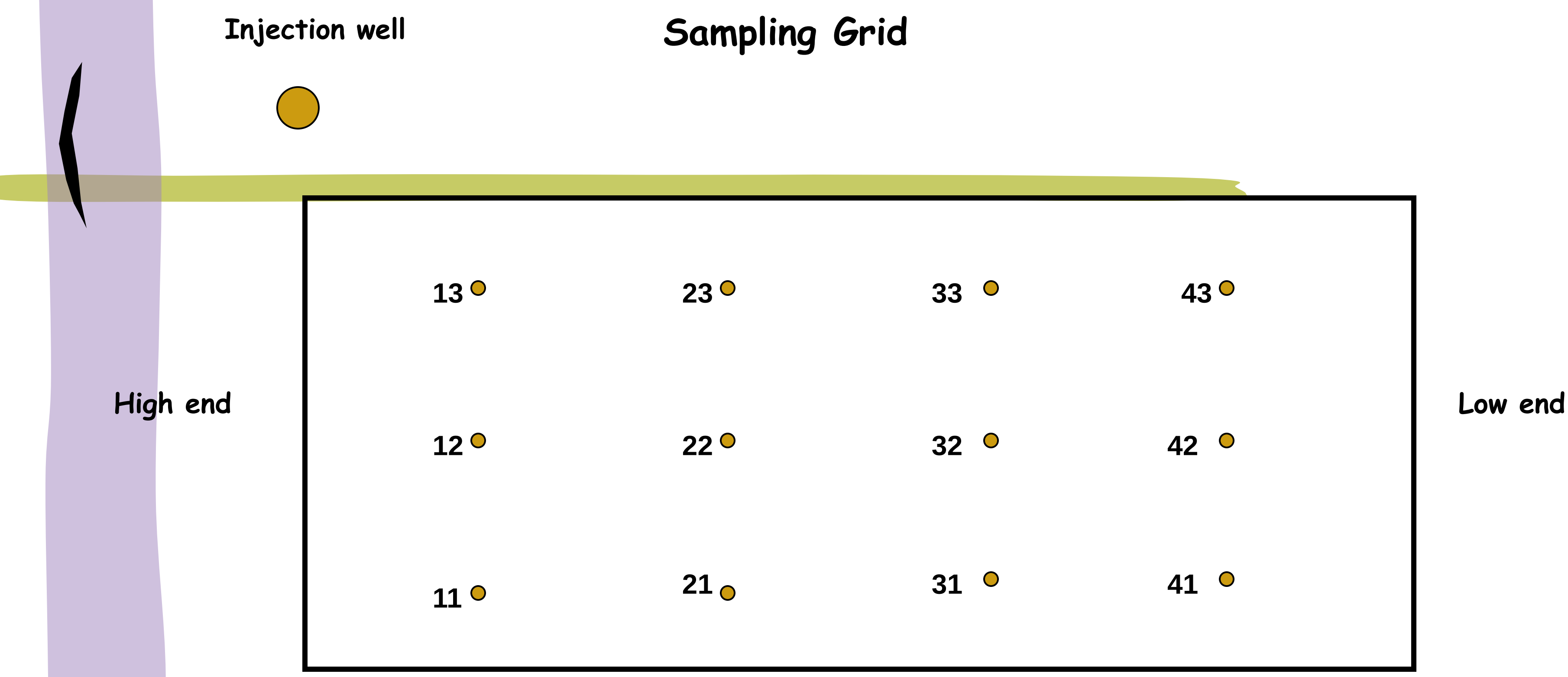


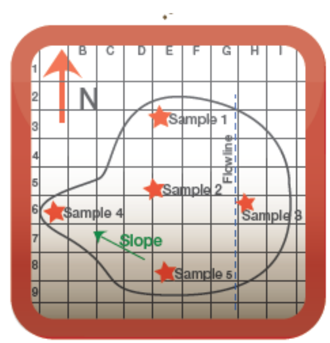
Brine spill remediation protocol

- Establish remediation goals with regulator and landowner
  - Type of vegetation
  - Required EC and SAR
  - Timeframe
  - Can the landowner provide equipment, hay, etc.?
- Site investigation and characterization
  - Has the source been removed?
  - How bad is the problem?
    - EC, SAR, and maybe CEC
      - 0-6 inches
      - 6-12 inches
      - 12-24 inches
      - Deeper?
  - Site map and photos

Osage County Remediation Site

Sampling Grid

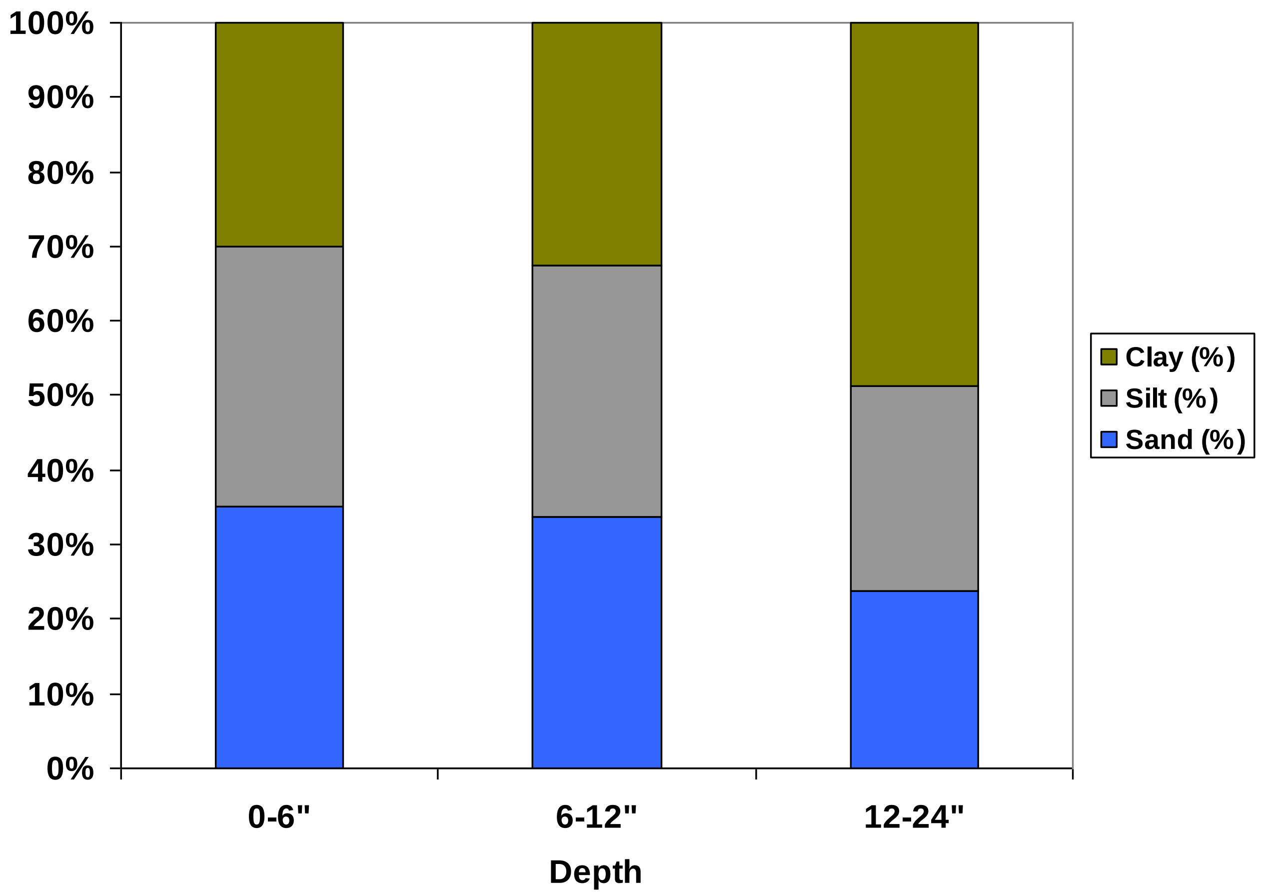




Photos to document site conditions

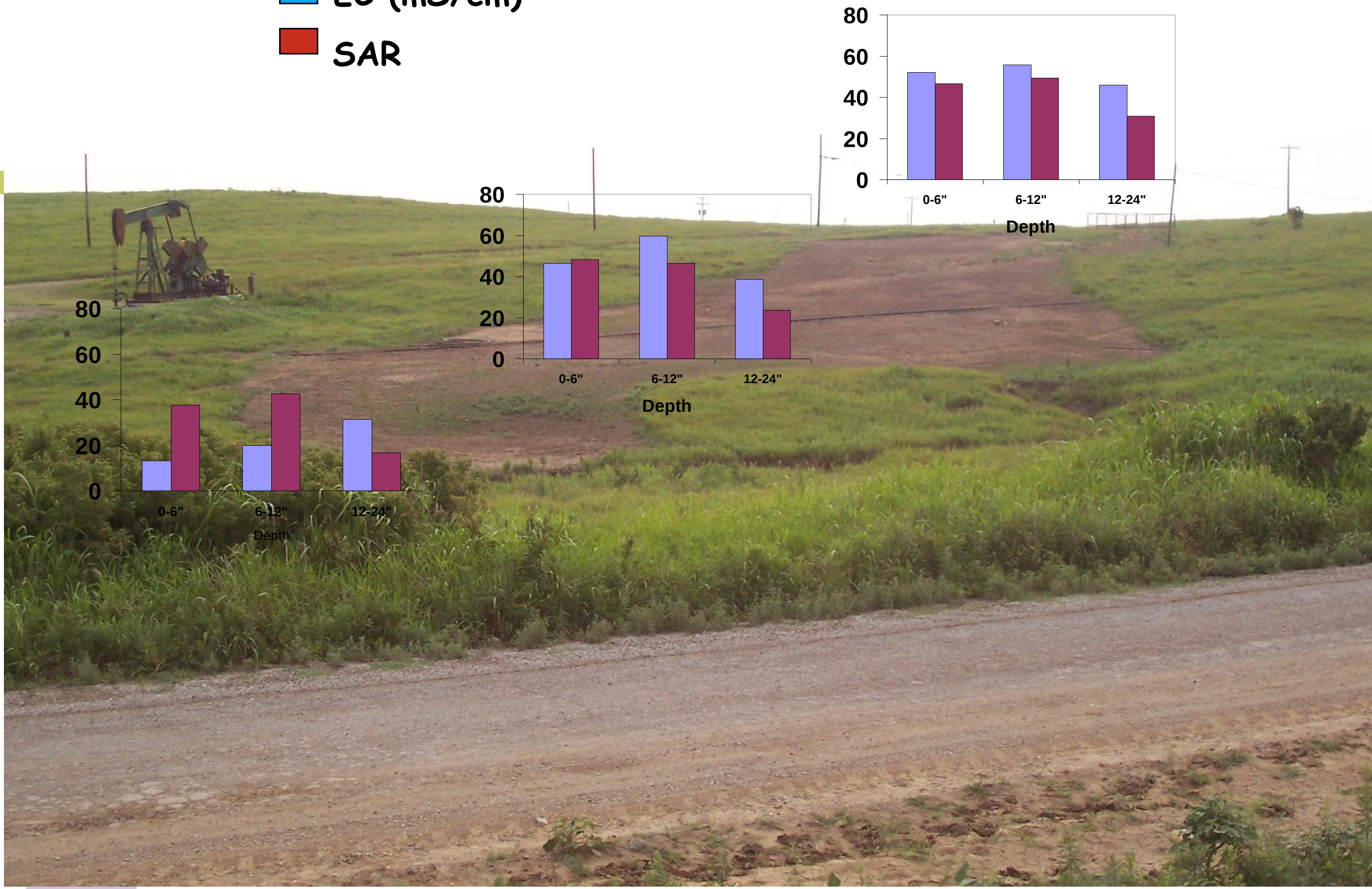
Photos to document sampling locations

Typical texture profile for pictured site



EC (mS/cm)

SAR


80
60
40
20
0
0-6"
6-12"
12-24"
Depth
80
60
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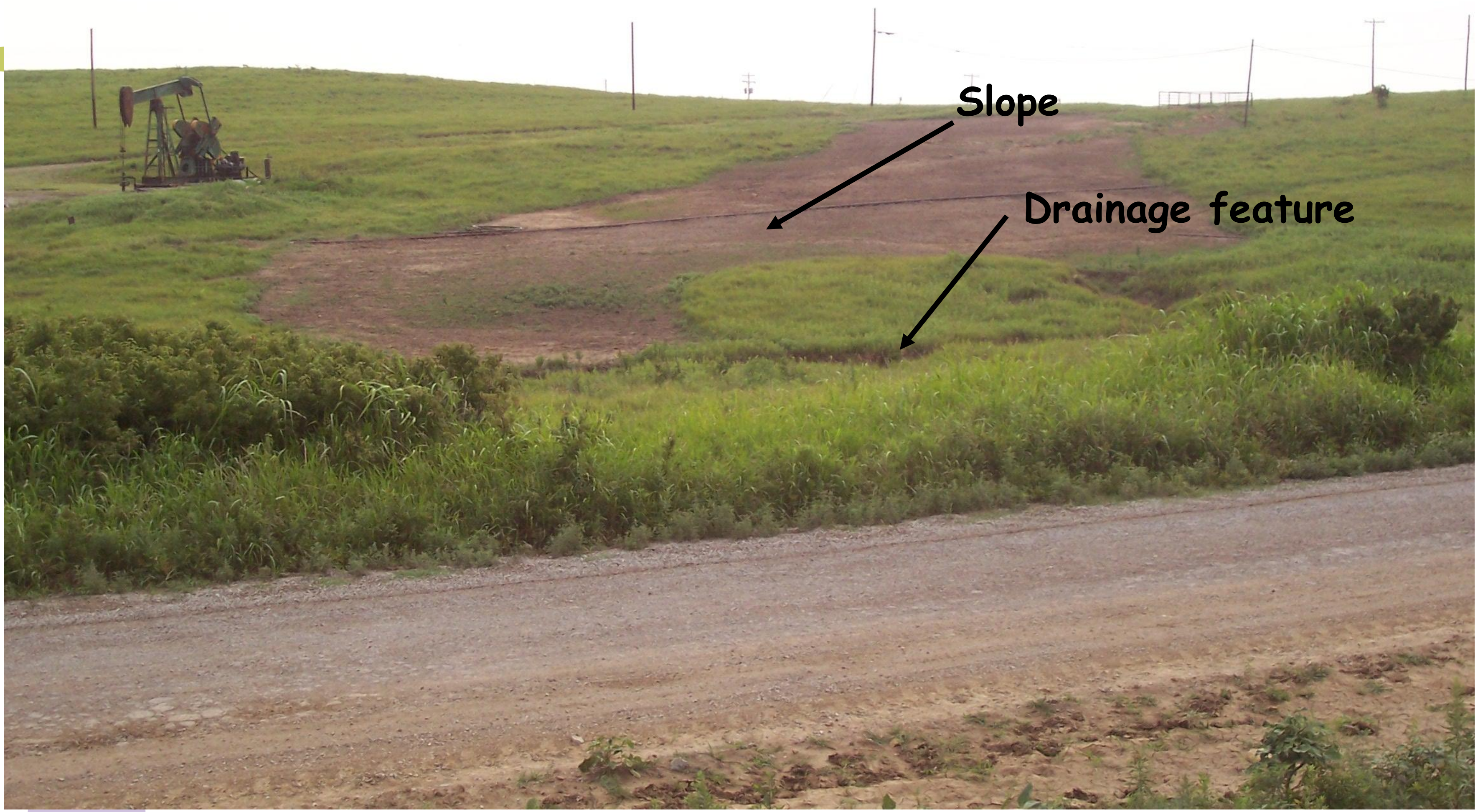
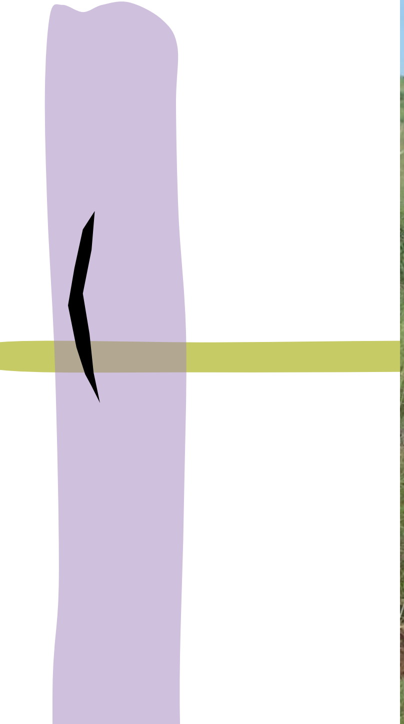
20
0
0-6"
6-12"
12-24"
Depth
80
60
40
20
0
0-6"
6-12"
12-24"
Depth

Brine spill remediation protocol

- Site investigation and characterization, cont.
  - What are the drainage possibilities?
    - Look for impermeable layers
    - Vertical vs. lateral?
    - Soil profile modification?
    - Artificial drainage?

Photos to document key site features






Brine spill remediation protocol

- Site investigation and characterization, cont.
  - What amendments will be necessary? Source?
  - Is there calcium carbonate in the soil?
  - Will erosion control be required?
  - Swelling clays?
  - Source and quality of water?

Swelling clays

Brine spill remediation protocol

- Site preparation
  - Eliminate high spots (less infiltration on high spots means less leaching)
  - Perform soil profile modification if necessary
  - Rip the site to 24-36 inches to open up the soil
  - Install drainage system if necessary
  - Incorporate biodegradable organic matter and till in **as deep as possible but at least to 6 inches**
  - Add calcium source and/or acid formers and till in **as deep as possible but at least to 6 inches**
  - Erosion control




Initial ripping of brine impacted soil

Incorporating hay

Adding organic acid remediation amendment

Tilling in remediation amendment and hay

Brine spill remediation protocol

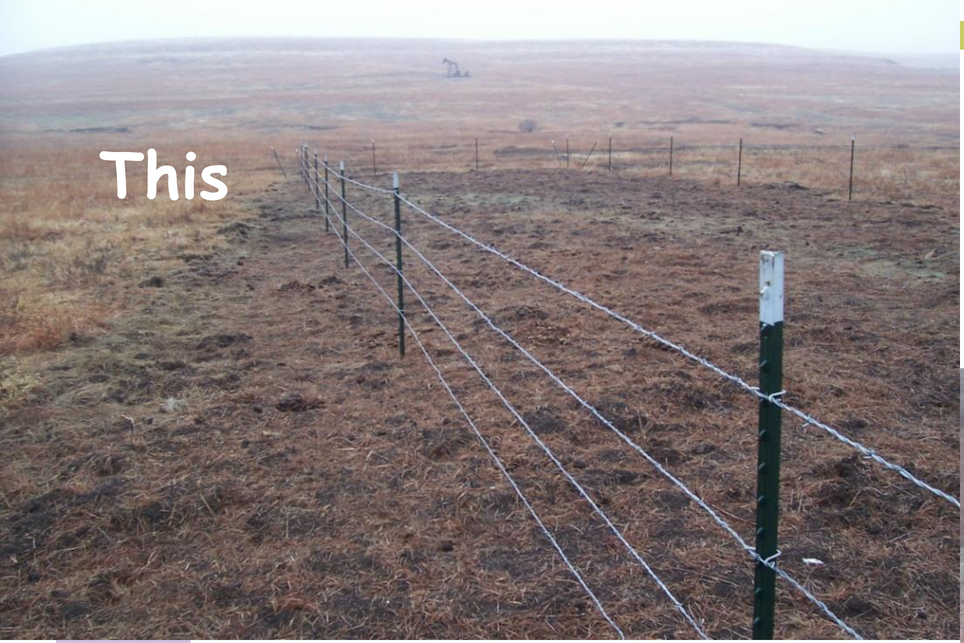
- Site preparation, cont.
  - Surface treatment for swelling clays
  - Add top dressing of organic matter
  - Install irrigation system if necessary
- Site maintenance
  - Check irrigation system for coverage; monitor quantity of irrigation water applied or rainfall received
  - Look for signs of reduced drainage (ponding, excessive runoff); correct as required
  - Monitor EC and SAR semi-annually during the first 1-2 years
    - 0-6 inches
    - 6-12 inches
    - 12-24 inches
    - Deeper?

Surface application of clay swelling agent

InfiltratioNhance™

Top dressing of hay to retain moisture

Fence the site if there is livestock in the area



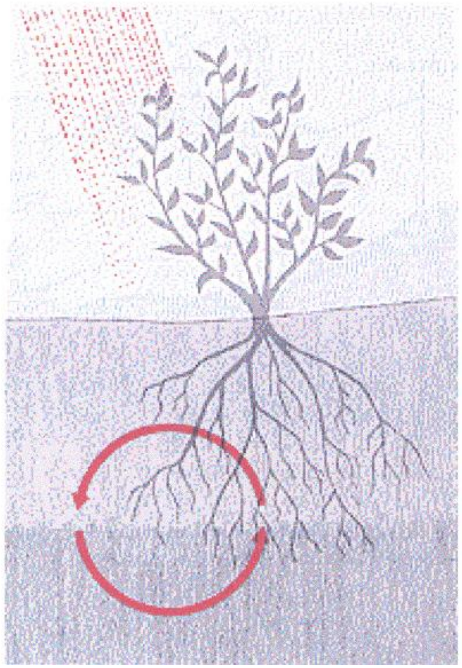
Livestock damage

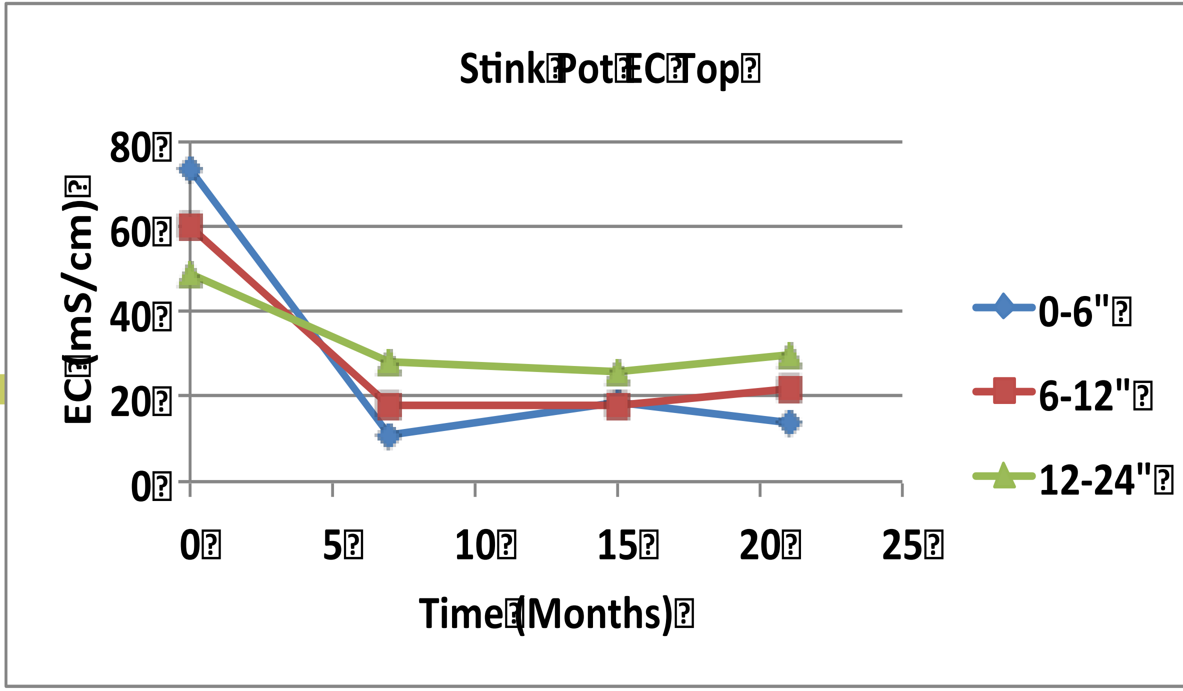
Brine spill remediation protocol

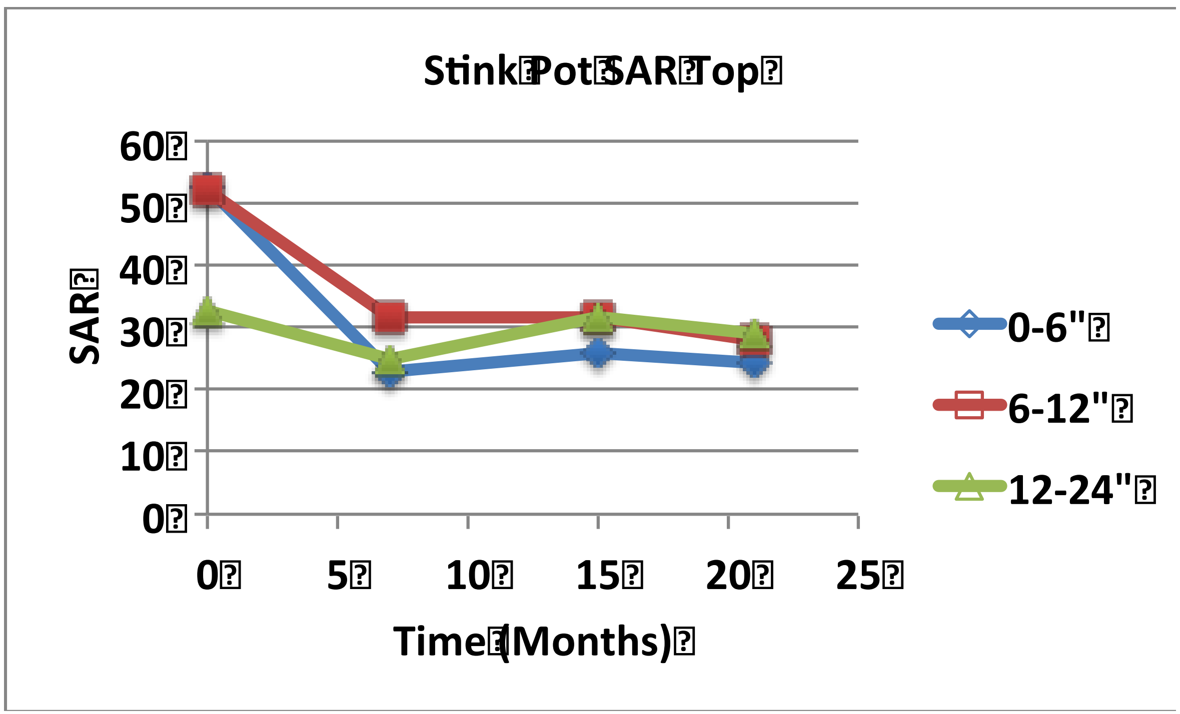
- Till the site as necessary to maintain permeability
  - reapply clay swelling agent if applicable
  - reapply top dressing of organic matter after each tilling
- Till in more organic matter if there are obvious changes in permeability or if EC reduction slows significantly
- Reapply calcium source and/or acid formers if SAR reduction slows significantly
- Remember nothing happens when its not raining or you are not irrigating

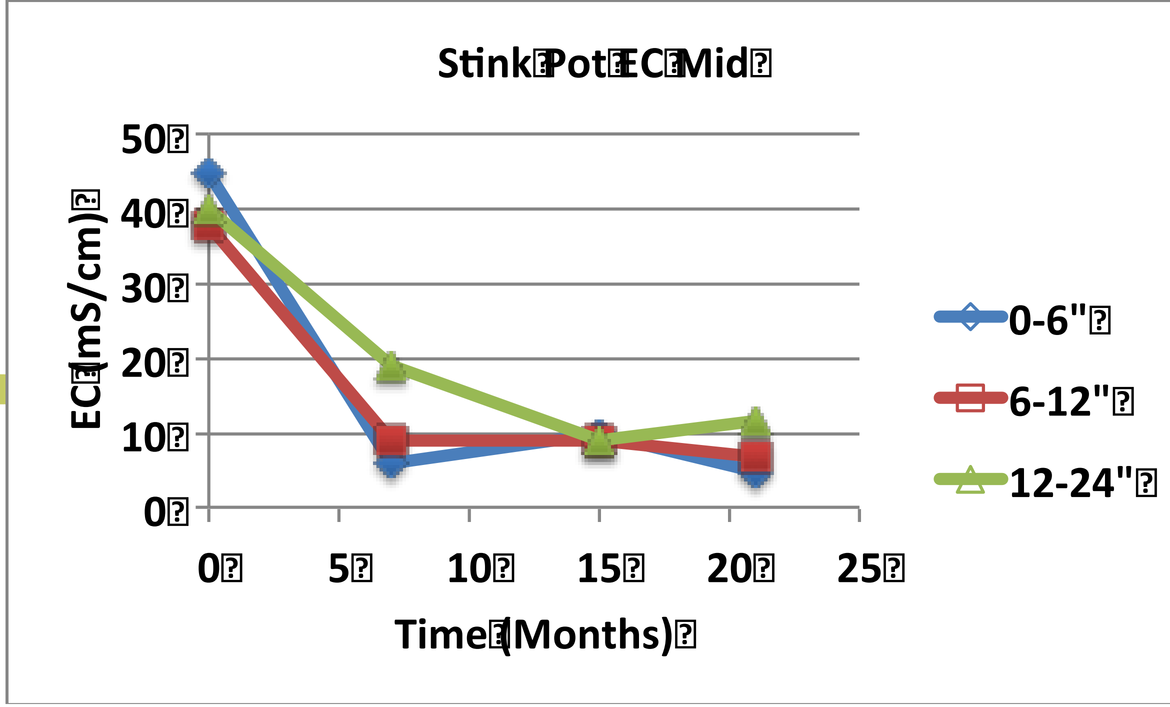
Brine spill remediation protocol

- If any part of the site begins to naturally revegetate do not disturb the vegetation; this applies to any stand of vegetation with a percent coverage of > 70%
  - stops loss of topsoil
  - stimulates soil biota
  - root system increases infiltration
  - Roots also release acids which solubilizes calcium (from natural or amended calcium carbonate) and further reduces sodicity
- Revegetation

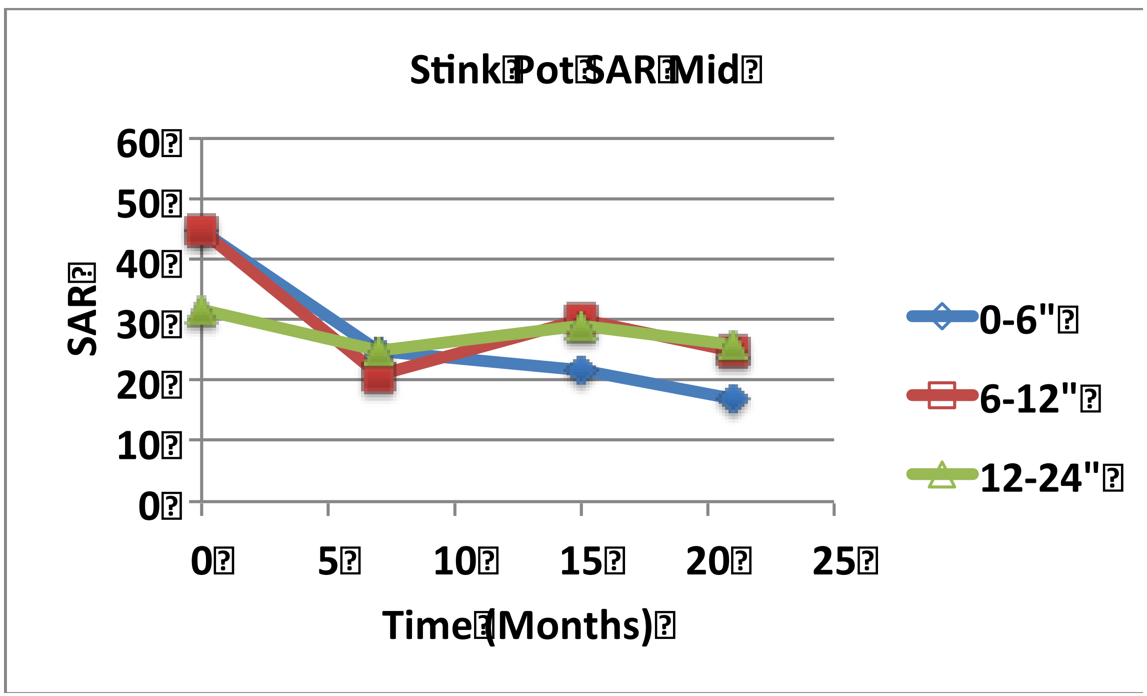



Stink Pot EC Top
80
60
40
20
0
EC (mS/cm)
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"

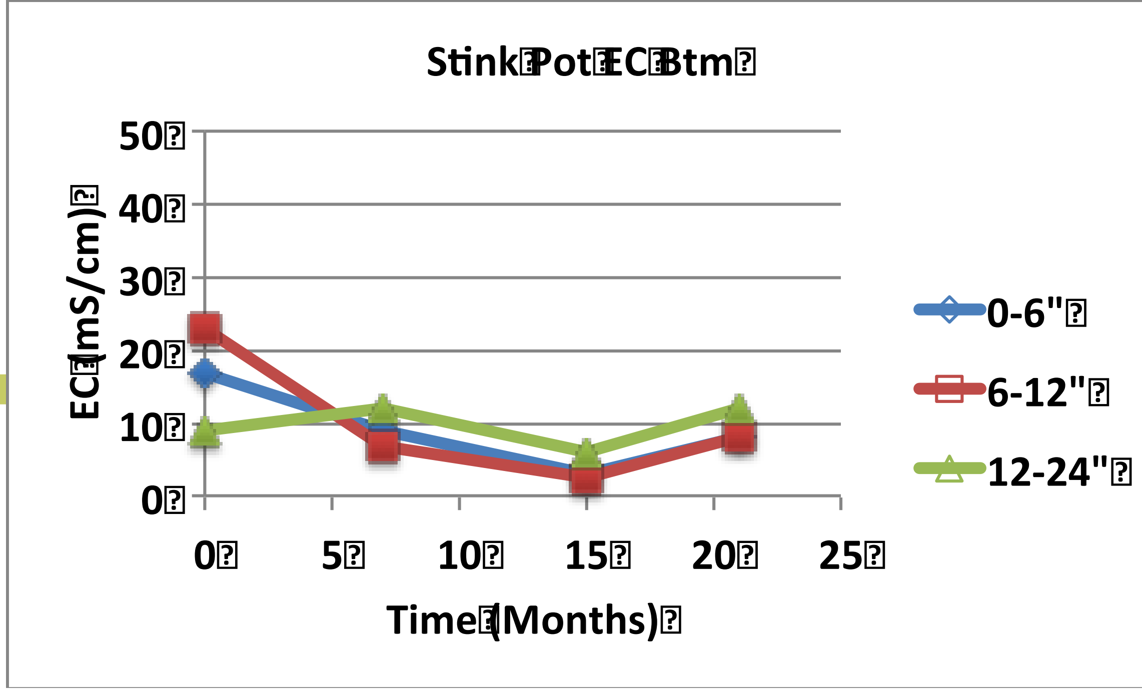

Stink Pot SAR Top
60
50
40
30
20
10
0
SAR
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"



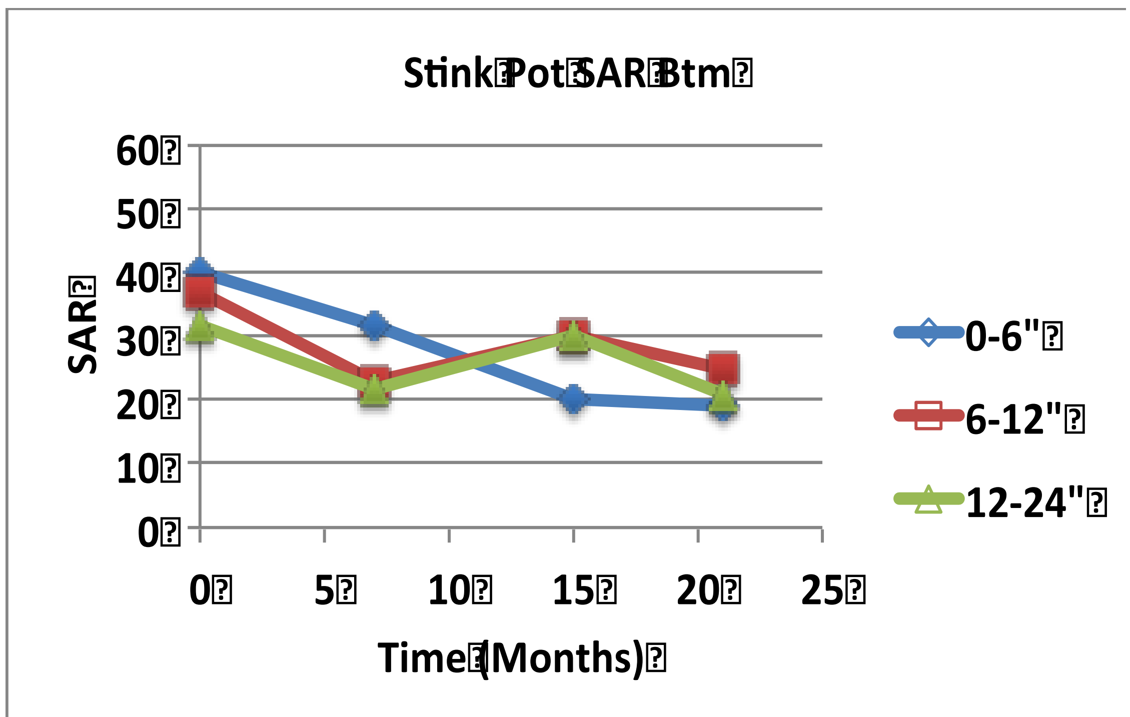
Stink Pot EC Mid
50
40
30
20
10
0
EC (mS/cm)
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"



Stink Pot SAR Mid
60
50
40
30
20
10
0
SAR
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"

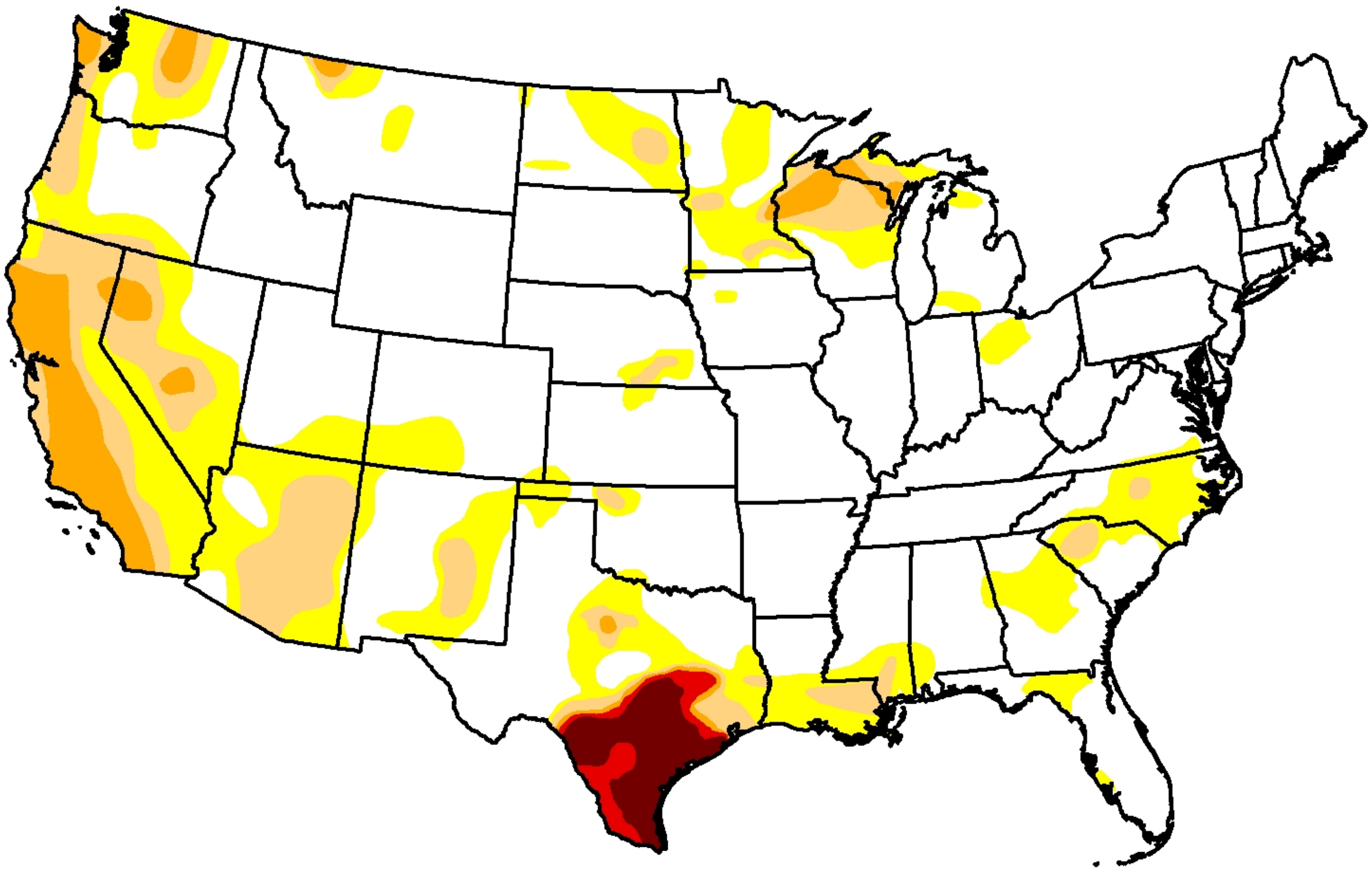


Stink Pot EC Btm
EC (mS/cm)
50
40
30
20
10
0
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"

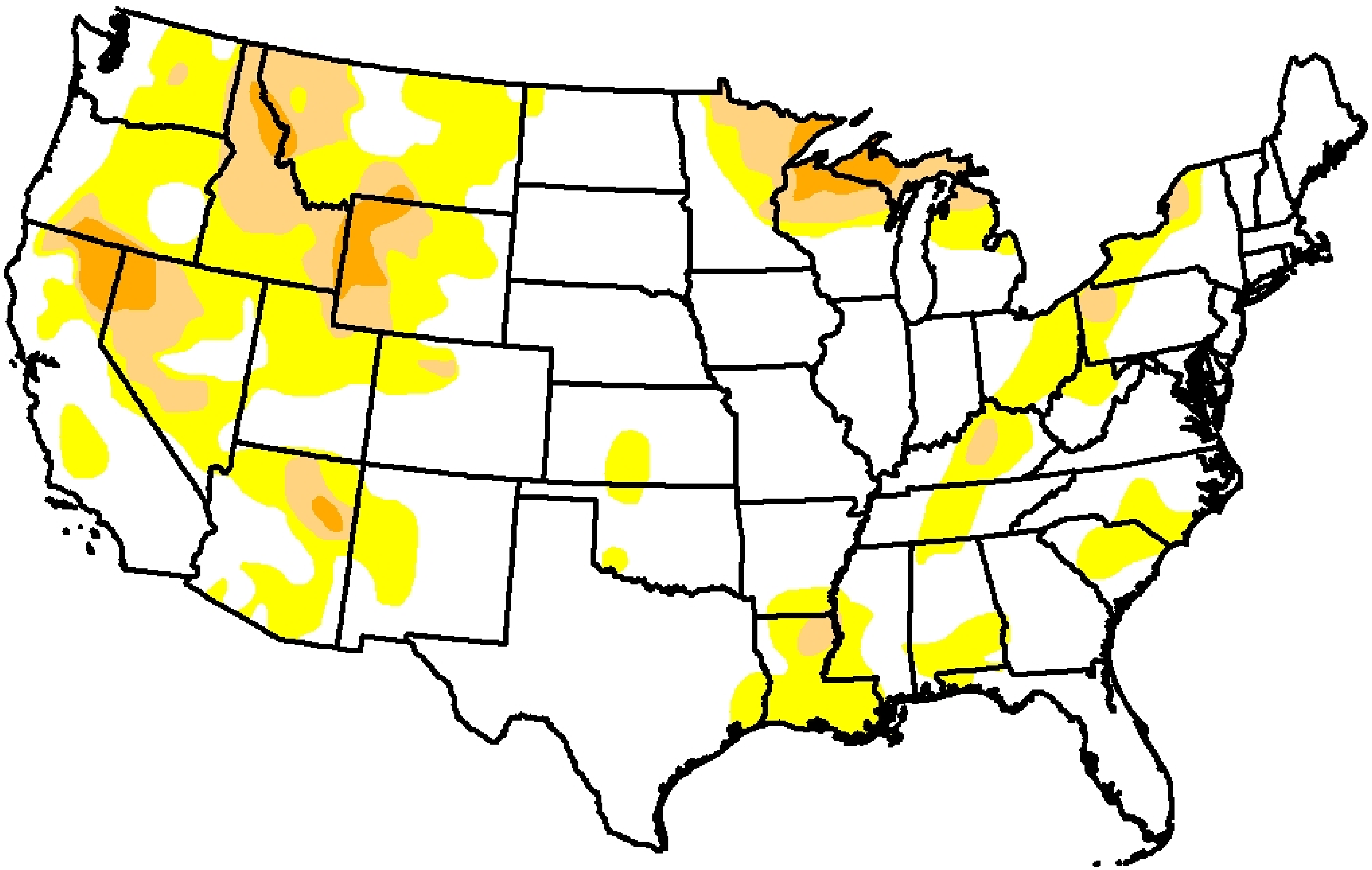


Stink Pot SAR Btm
SAR
60
50
40
30
20
10
0
0
5
10
15
20
25
Time (Months)
0-6"
6-12"
12-24"

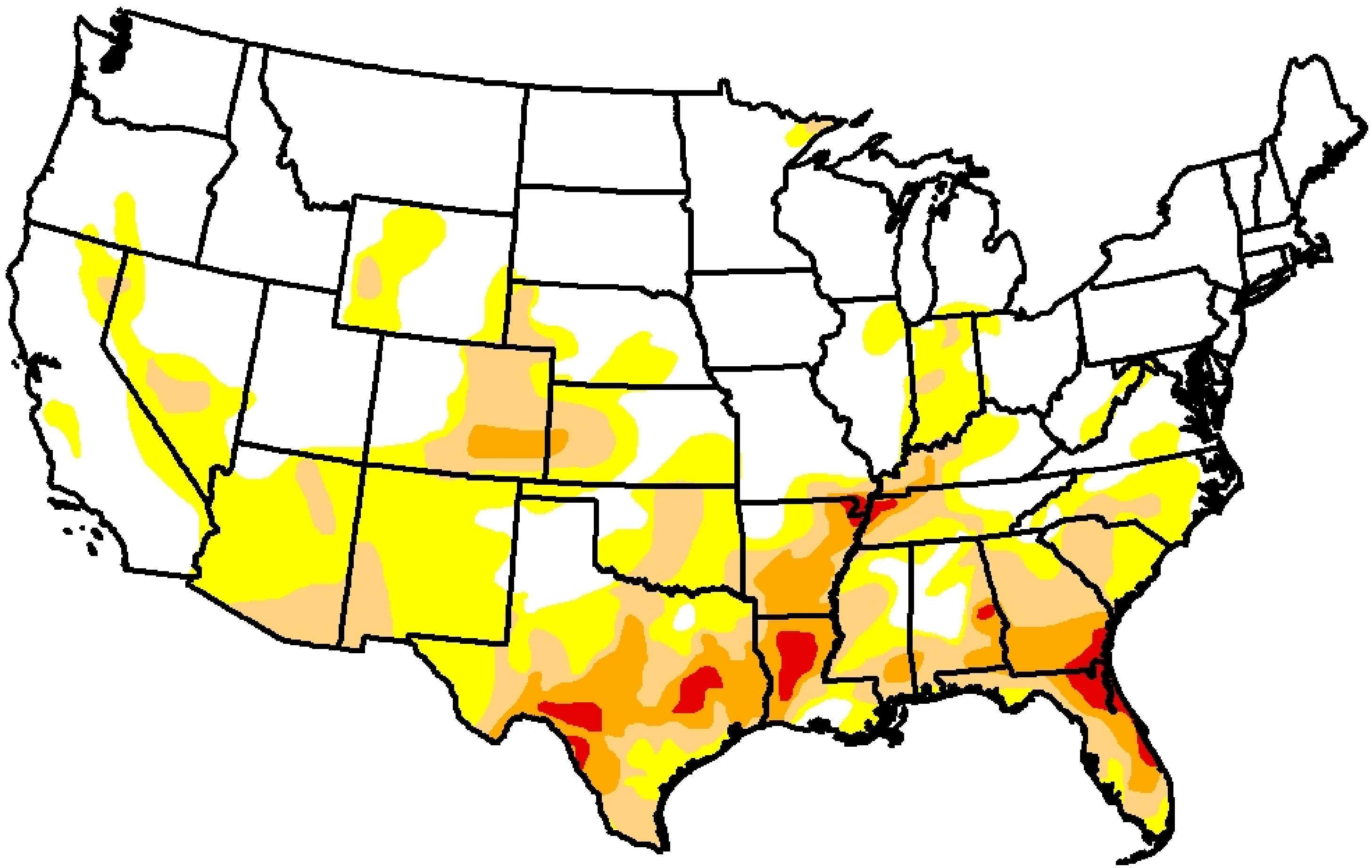
September 2009 (start up)



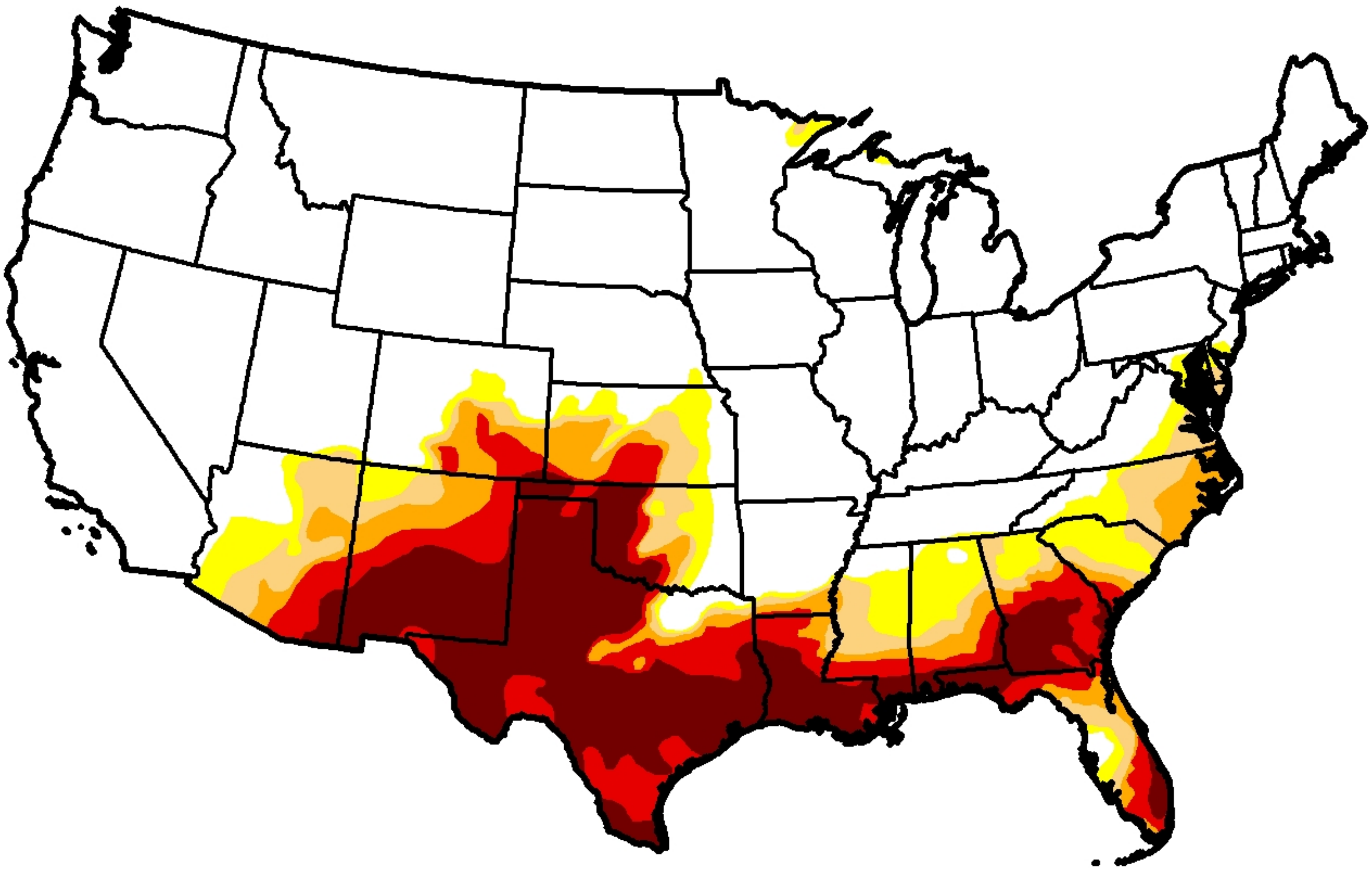
April 2010



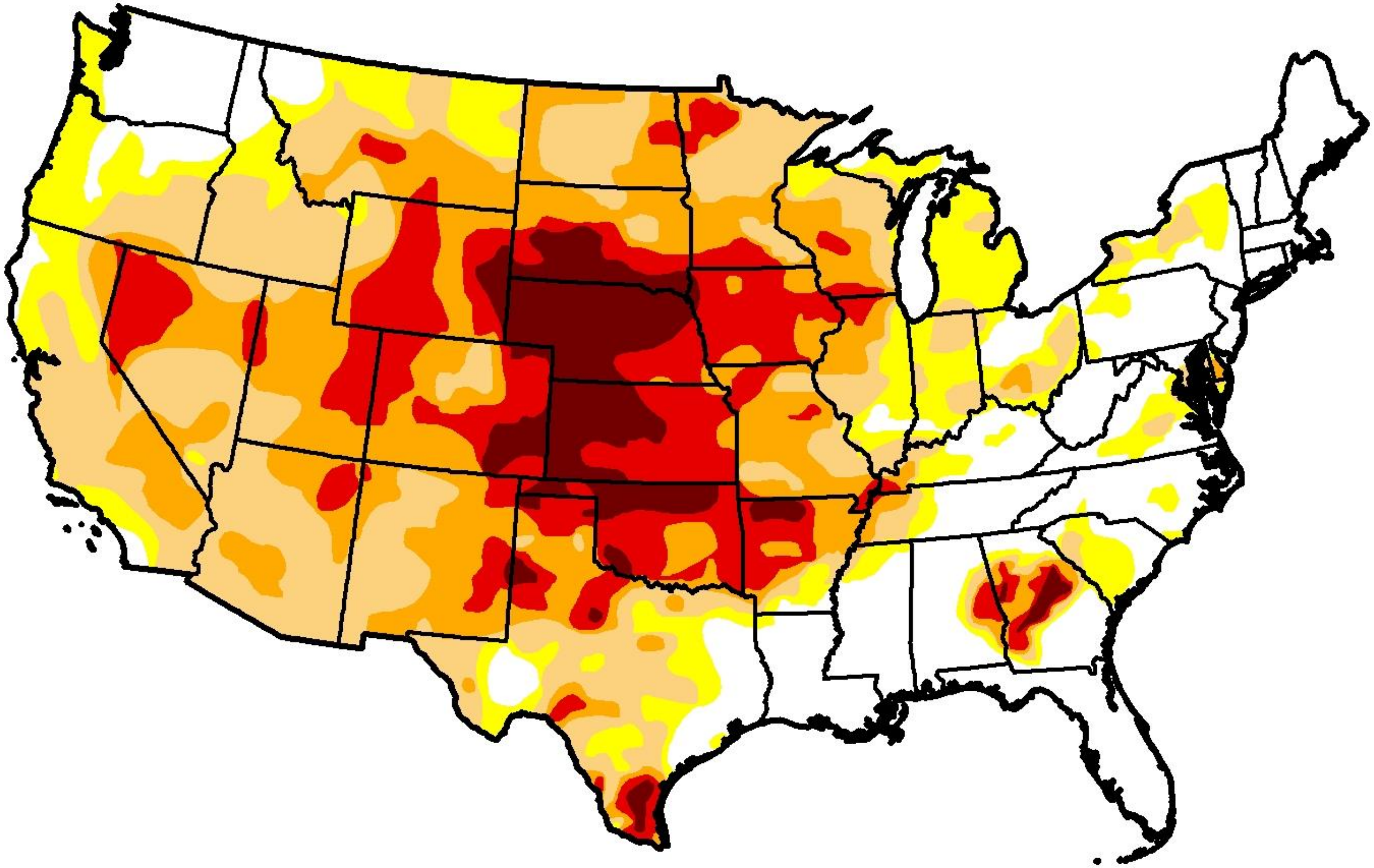
December 2010



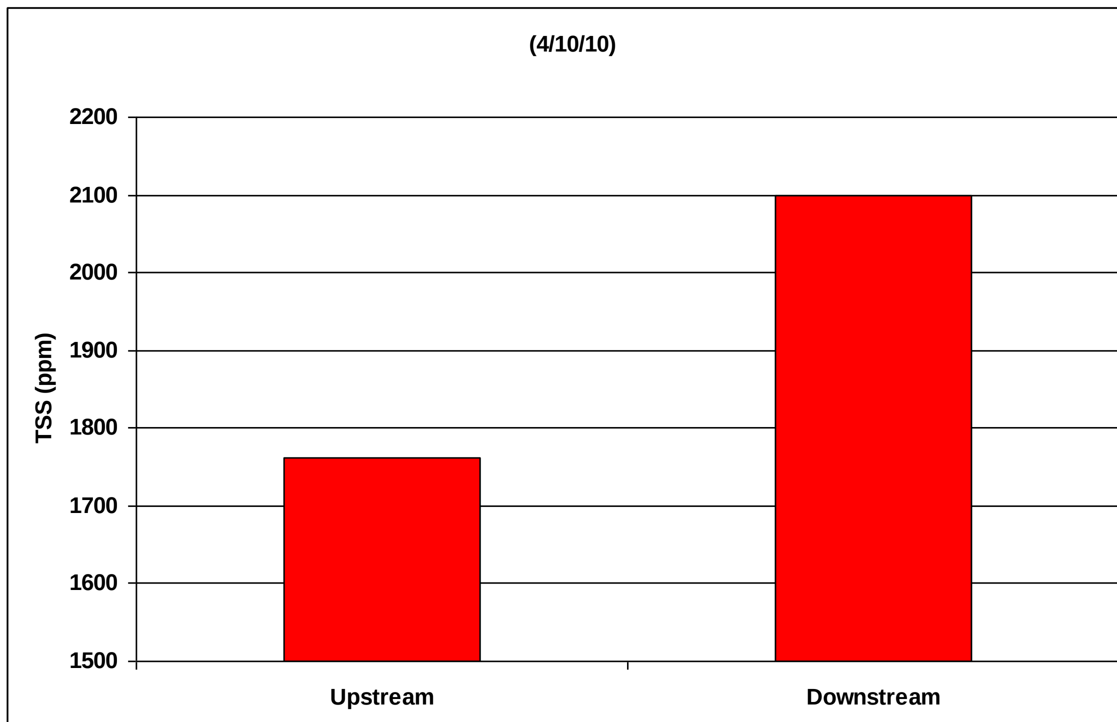
June 2011



October 2012



4 lb salt/d for every 1 gal/min flow



7 months of treatment, May

7 months of treatment, May

7 months of treatment, May

9 months of treatment (July)

Field brome:

Cool season grass

12” root system

No salt tolerance

9 months of treatment (July)

9 months of treatment (July)

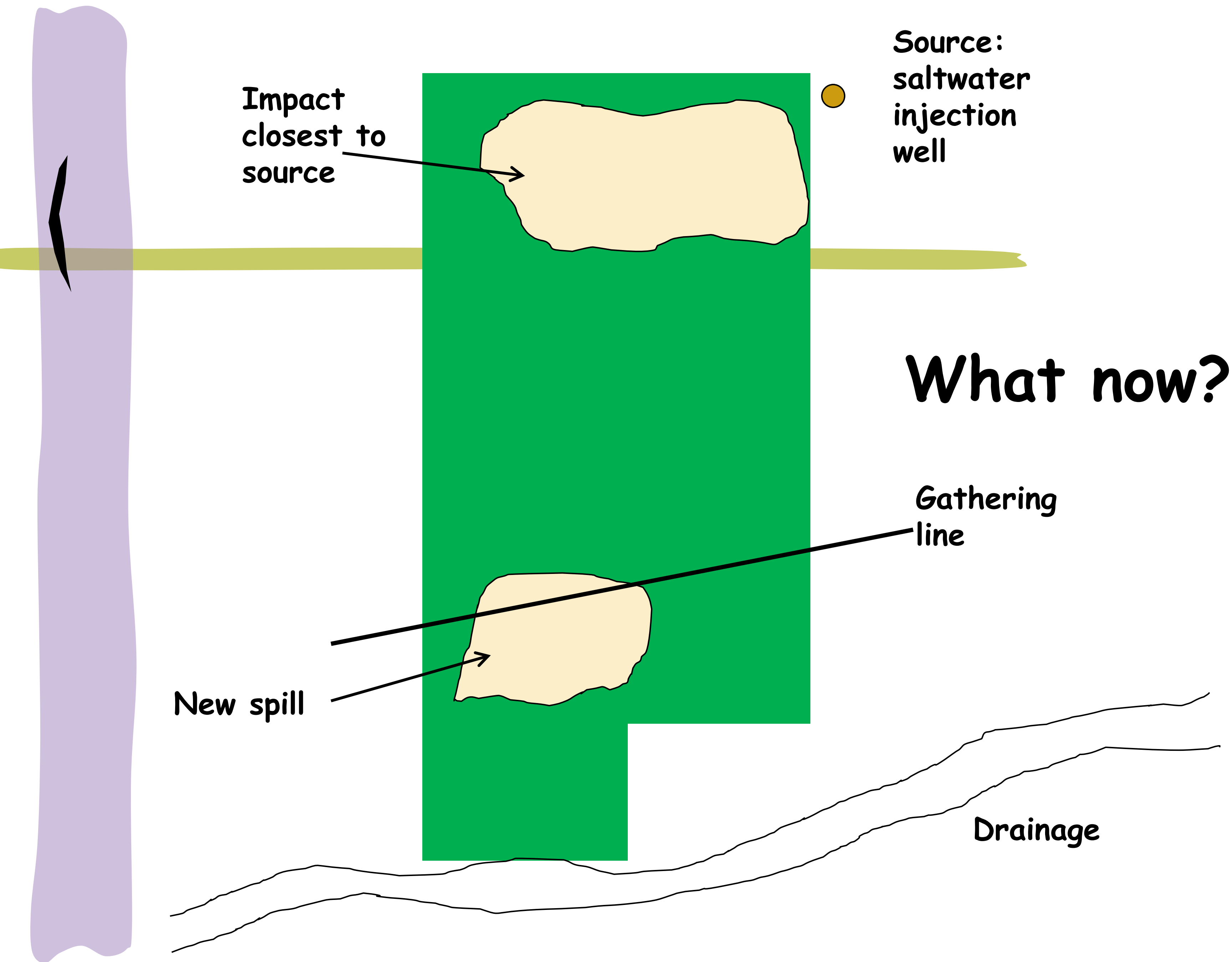
9 months of treatment (July)

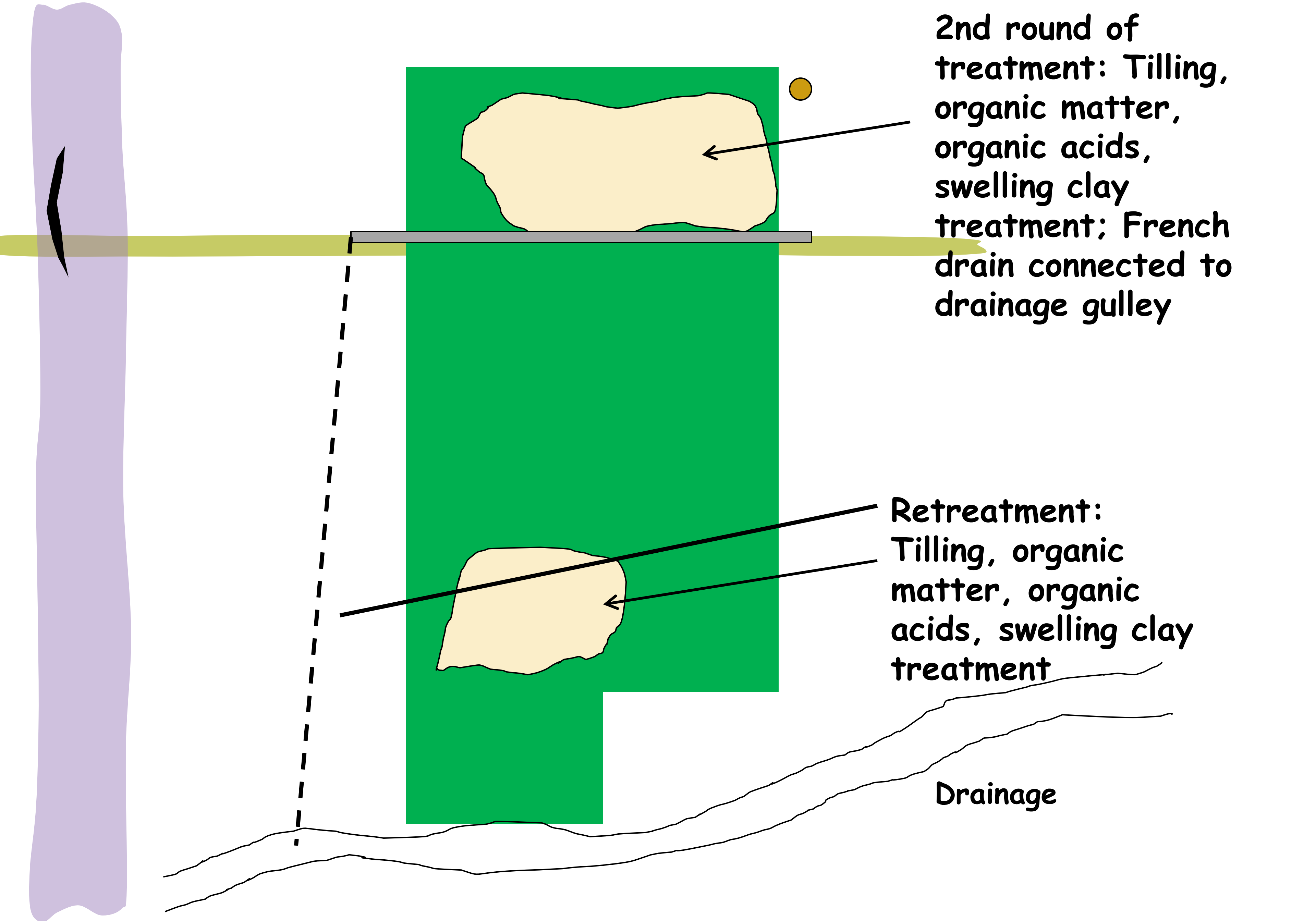
20 months of treatment (June)

20 months of treatment (June)

20 months of treatment (June)

20 months of treatment (June) a new spill


Source:
saltwater
injection
well
Impact
closest to
source
What now?
Gathering
line
New spill
Drainage


2nd round of treatment: Tilling, organic matter, organic acids, swelling clay treatment; French drain connected to drainage gulley
Retreatment: Tilling, organic matter, organic acids, swelling clay treatment
Drainage

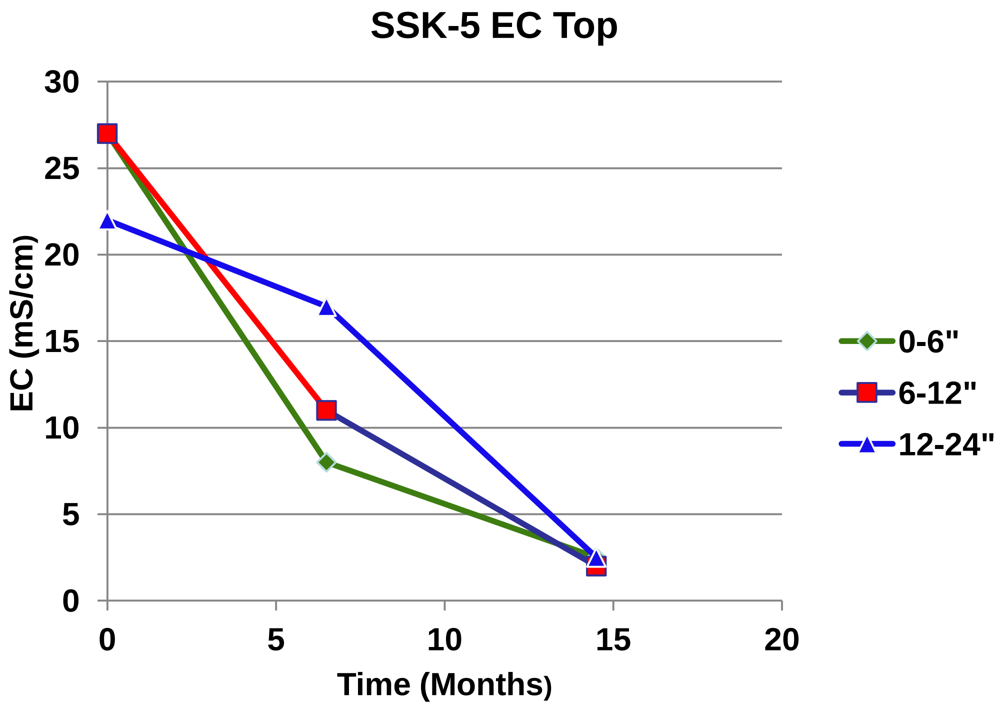
Another site in Osage County


KOMATSU

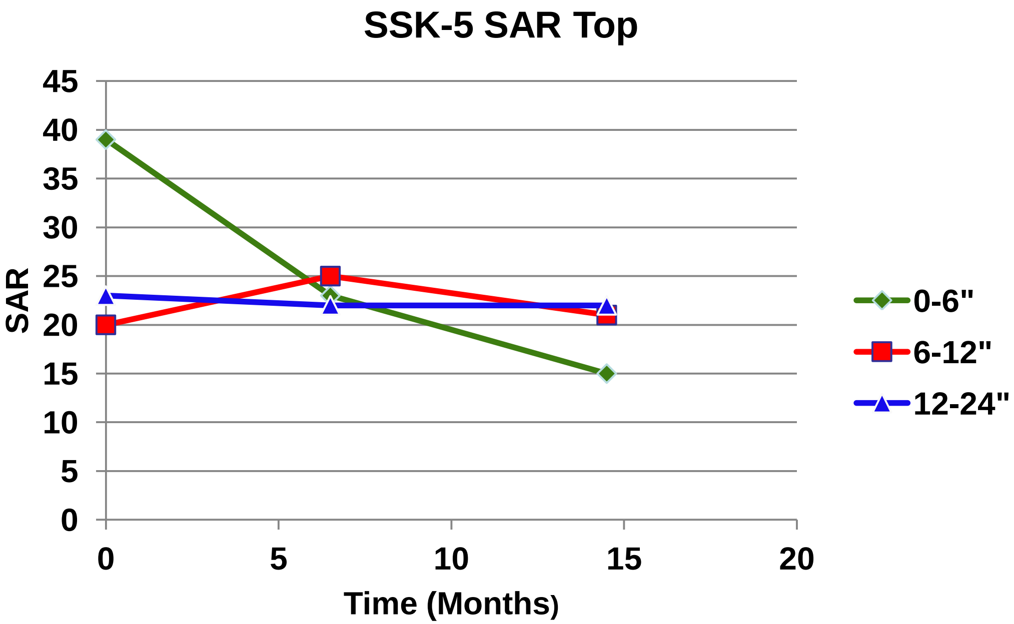
KOMATSU
61EX

E3154

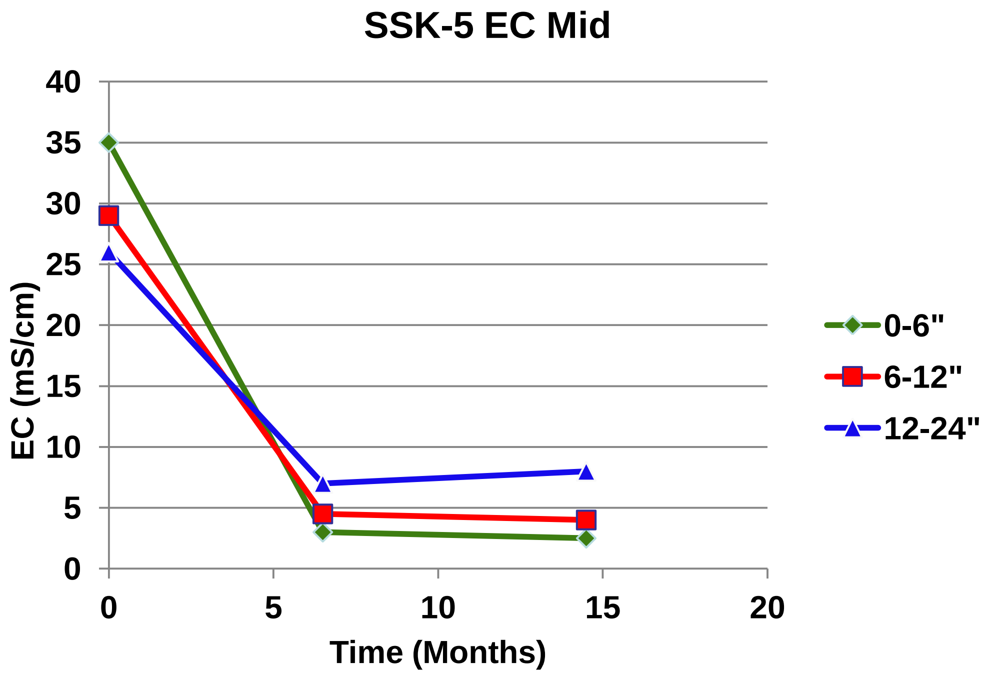


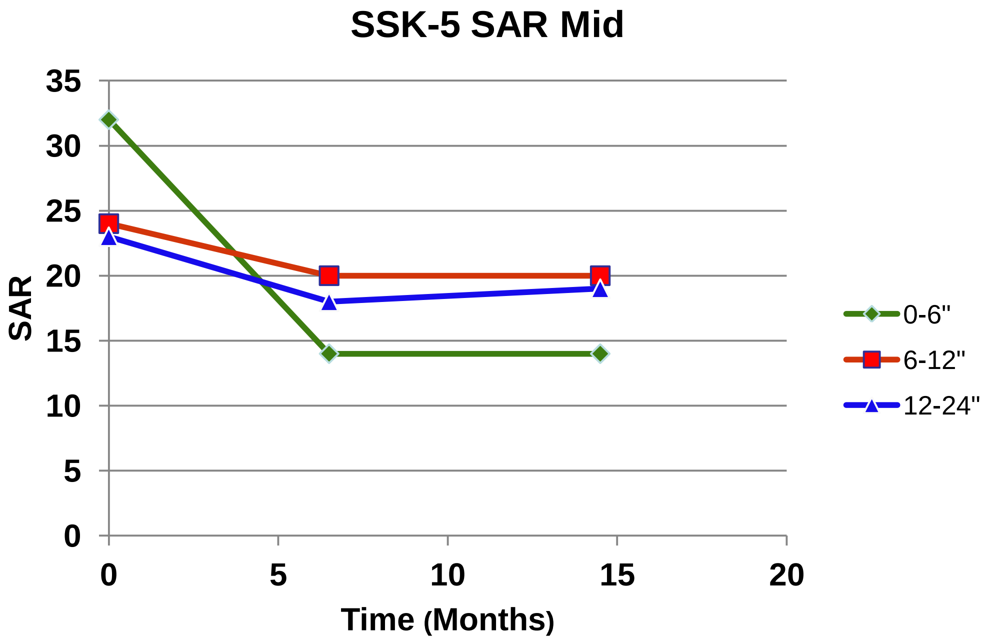



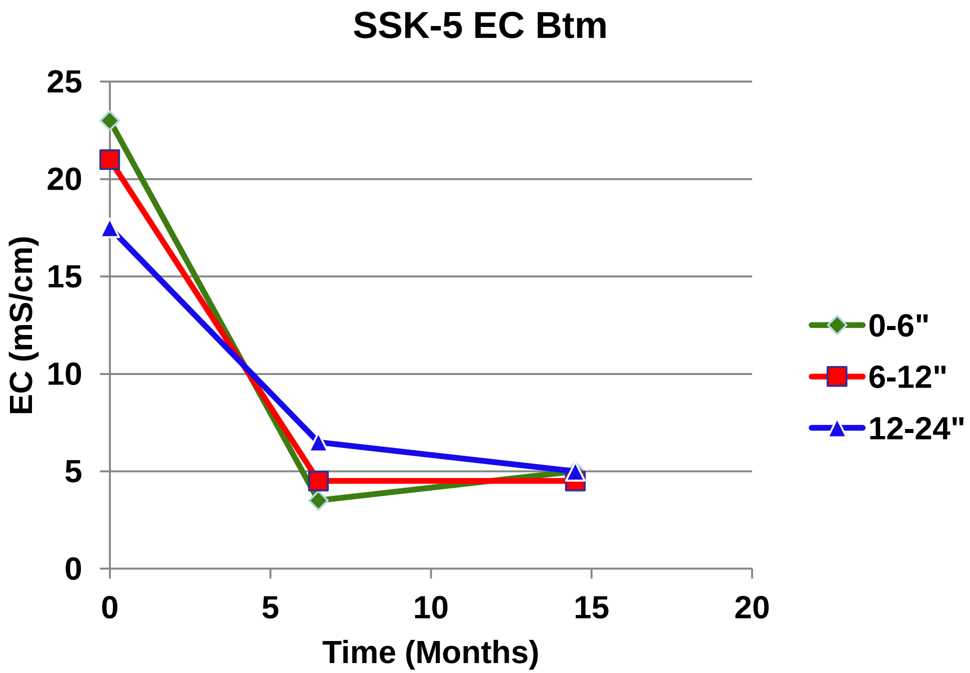
SSK-5 EC Top
EC (mS/cm)
30
25
20
15
10
5
0
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"

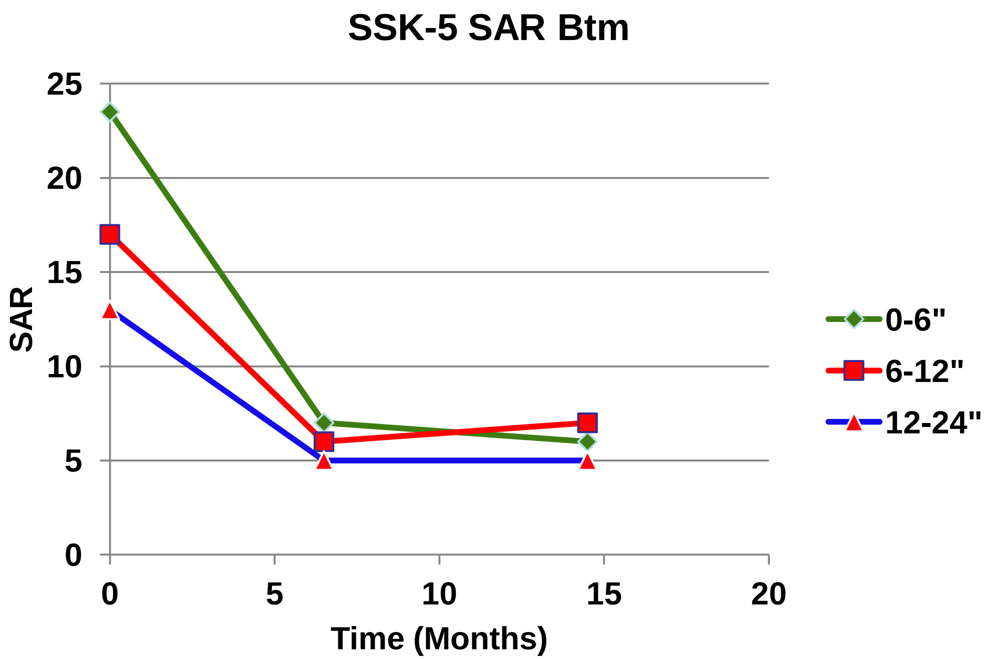


SSK-5 SAR Top
SAR
45
40
35
30
25
20
15
10
5
0
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"


SSK-5 EC Mid
EC (mS/cm)
40
35
30
25
20
15
10
5
0
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"


SSK-5 SAR Mid
SAR
35
30
25
20
15
10
5
0
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"

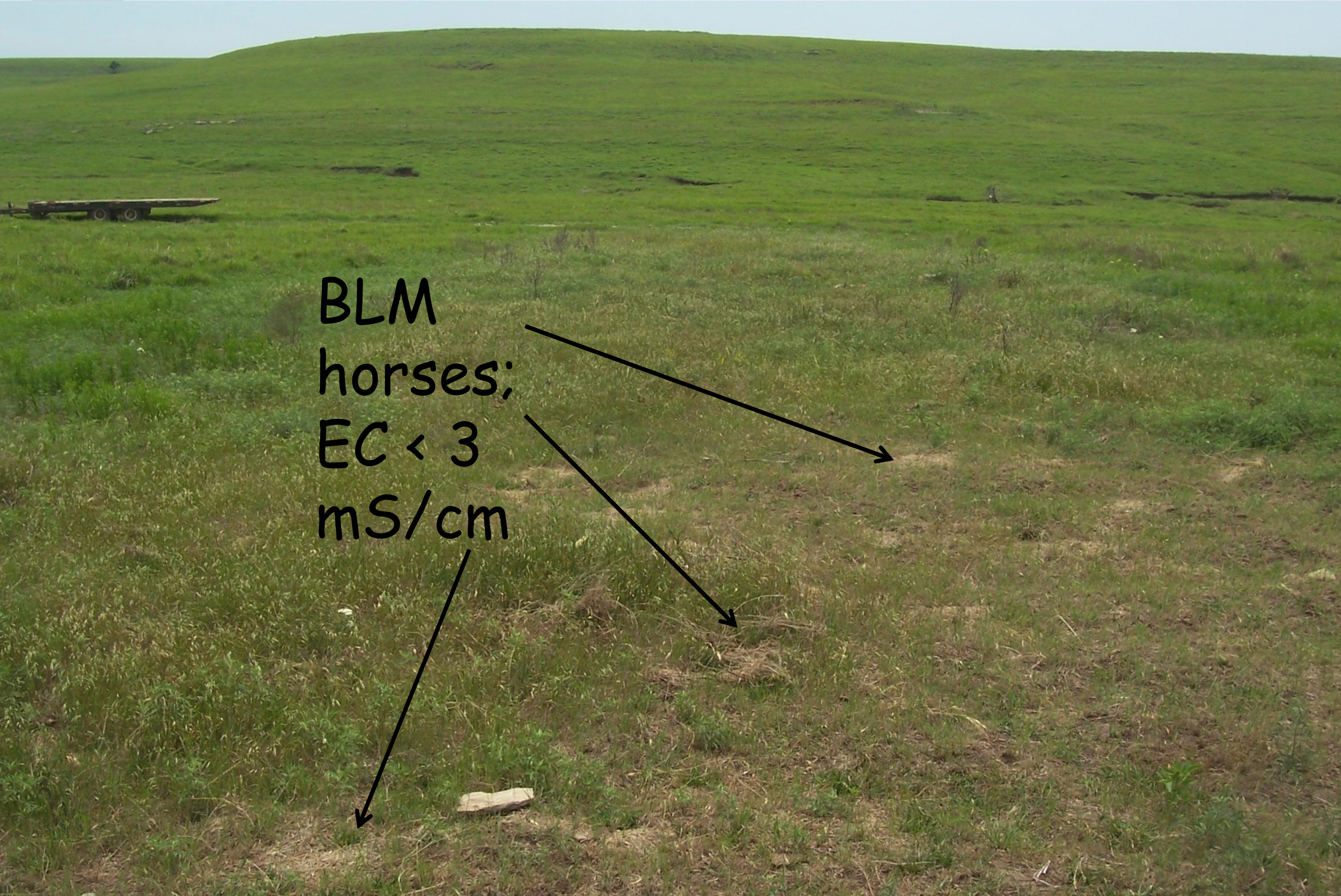

SSK-5 EC Btm
EC (mS/cm)
0
5
10
15
20
25
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"


SSK-5 SAR Btm
SAR
0
5
10
15
20
25
0
5
10
15
20
Time (Months)
0-6"
6-12"
12-24"

7 months of treatment, May

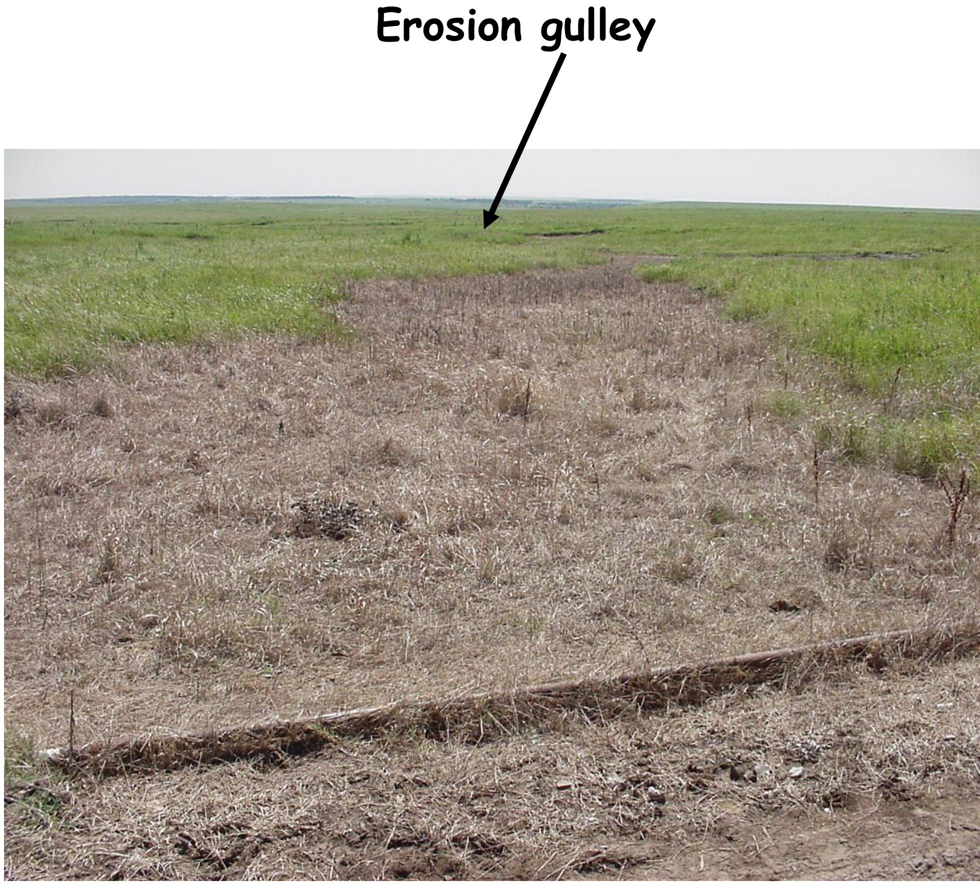
7 months of treatment, May

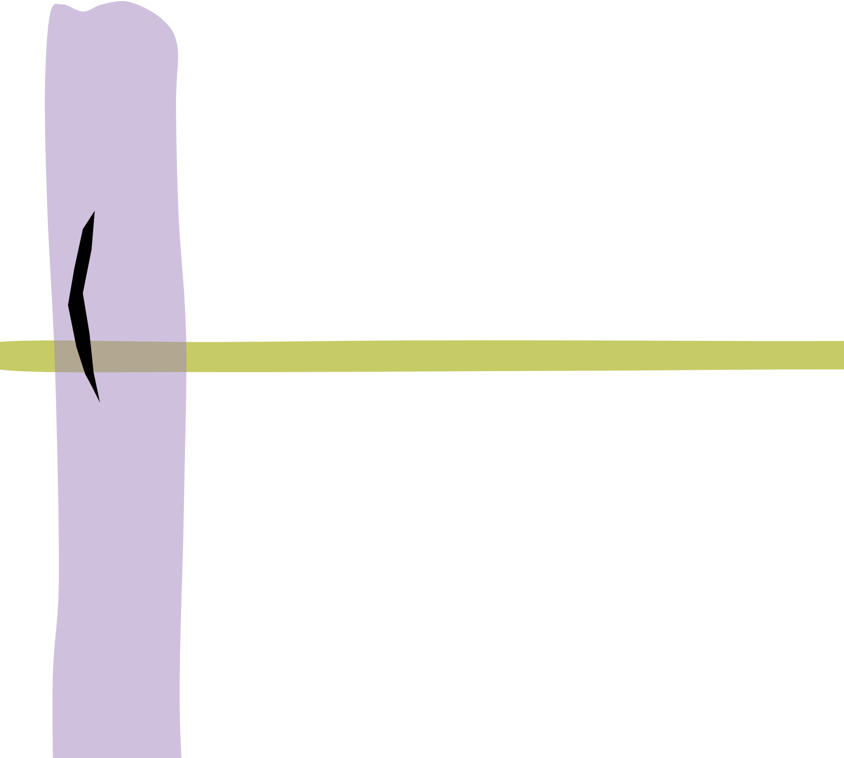
19 months of treatment, June

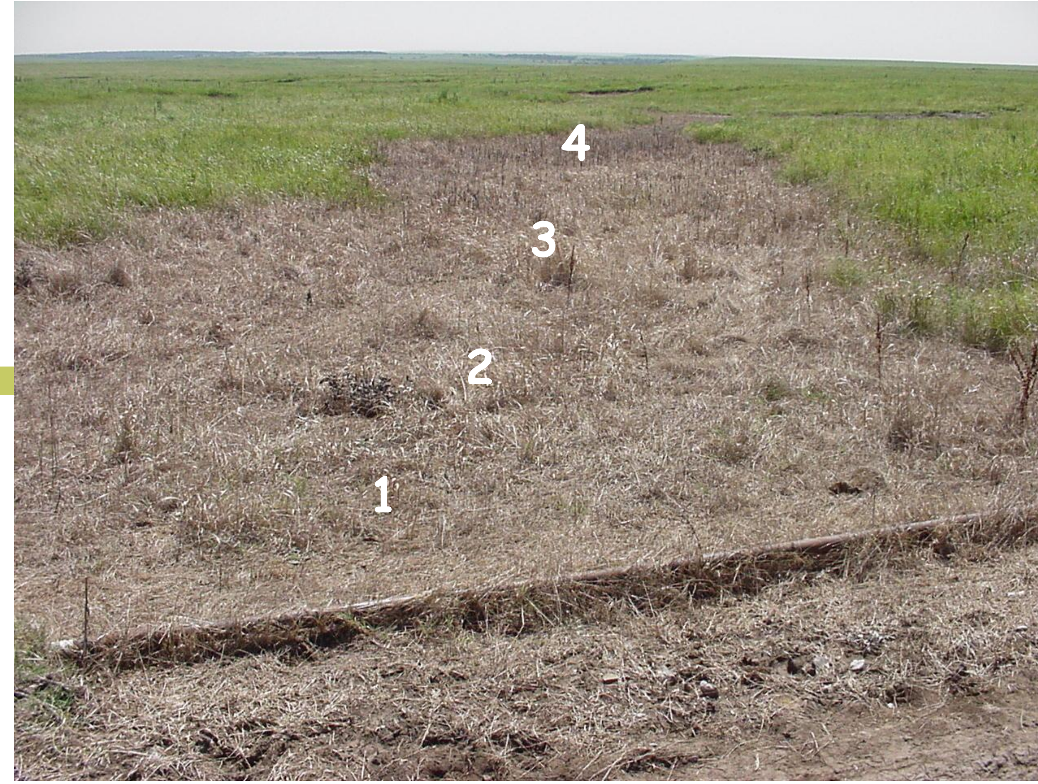


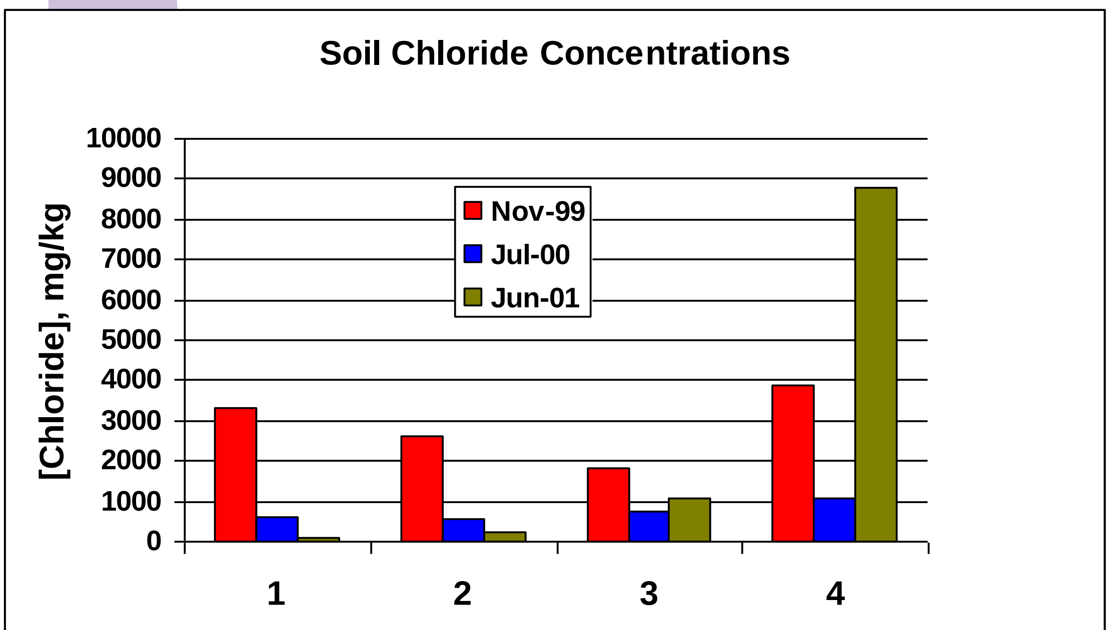
An older case study – Remediation of brine spill using lateral drainage

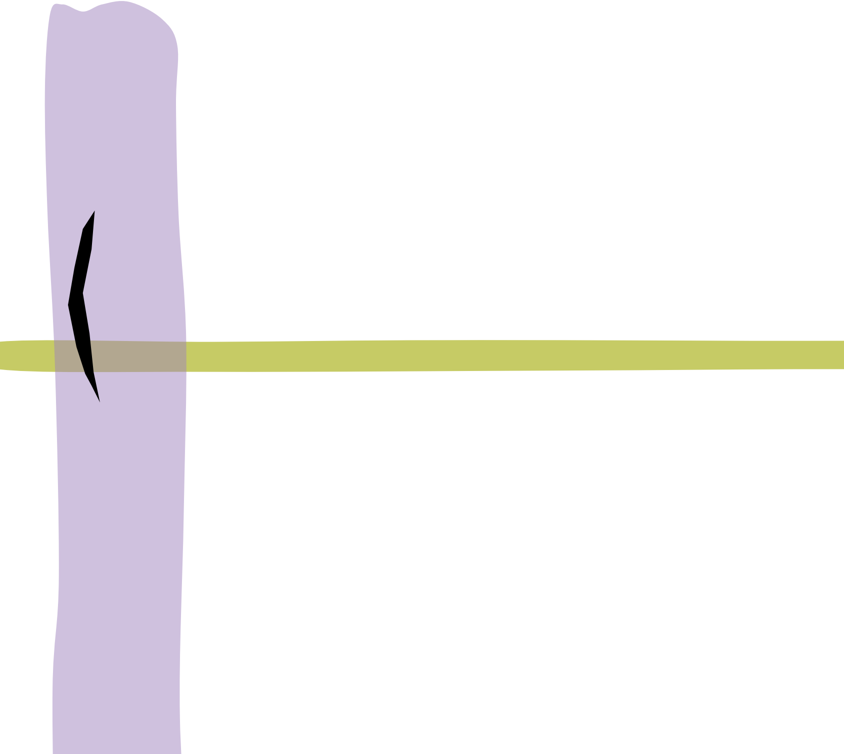
- Rupture of a salt water line in July 1999 in Osage County, OK
- Underlying clay layer at about 3 ft; site slopes to natural drainage
- Class I soil
- Hay and fertilizer tilled in November 1999
- Natural precipitation

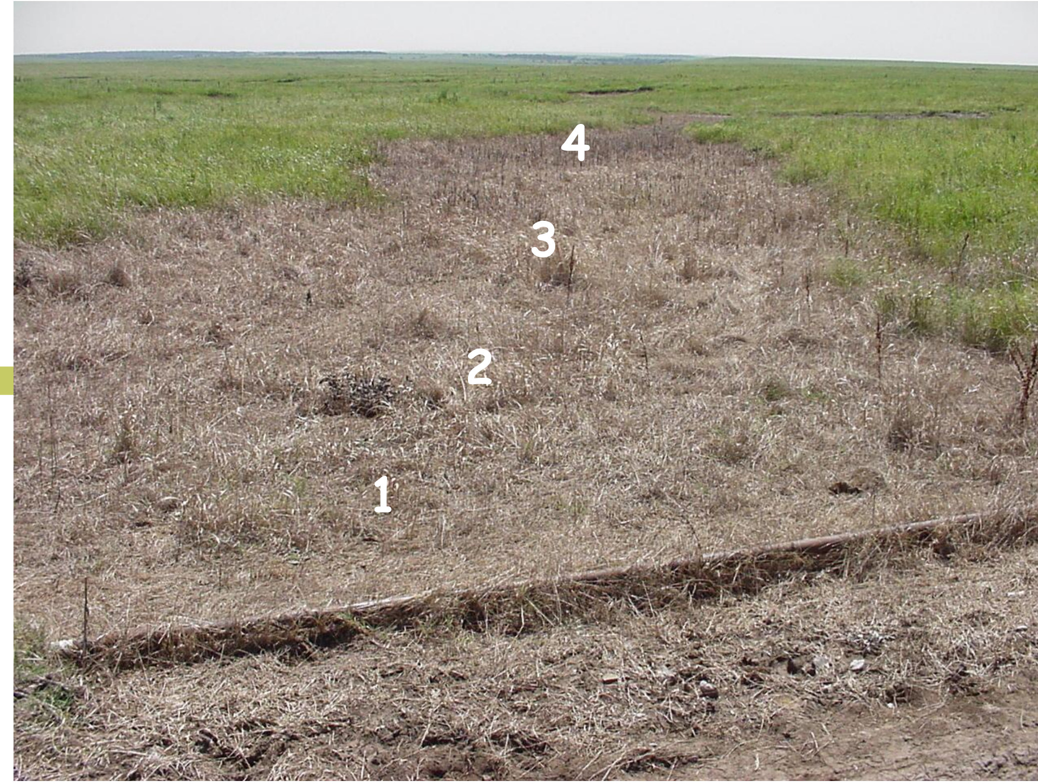


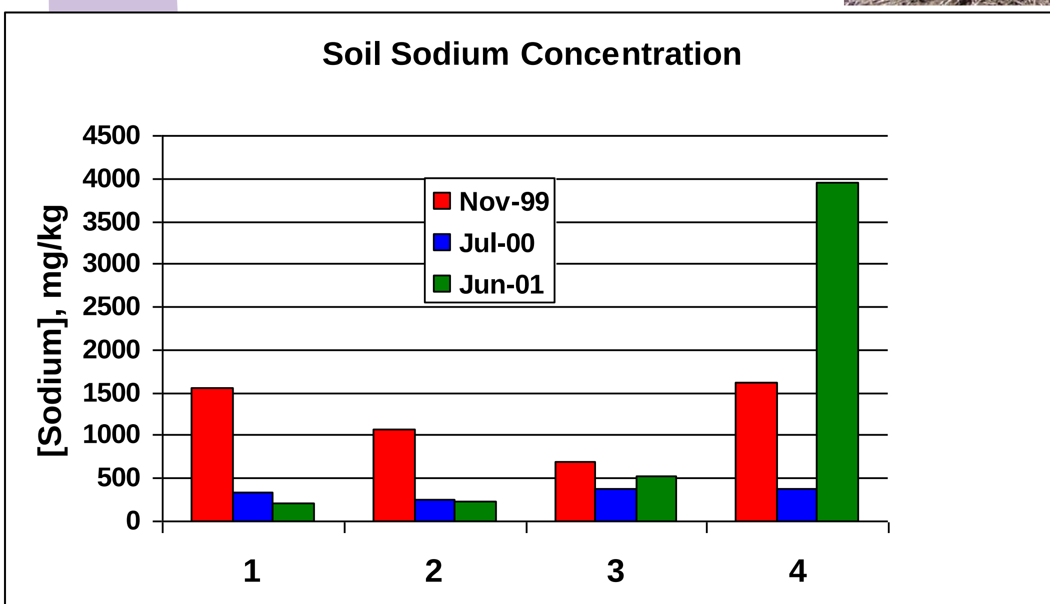



4
3
2
1


Soil Chloride Concentrations
[Chloride], mg/kg
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Nov-99
Jul-00
Jun-01
1
2
3
4




4
3
2
1


Soil Sodium Concentration
[Sodium], mg/kg
4500
4000
3500
3000
2500
2000
1500
1000
500
0
Nov-99
Jul-00
Jun-01
1
2
3
4

Late spring 2000; a good crop of ragweed

Late spring 2001; still some ragweed but lots of grasses

Late spring 2001; a closer look

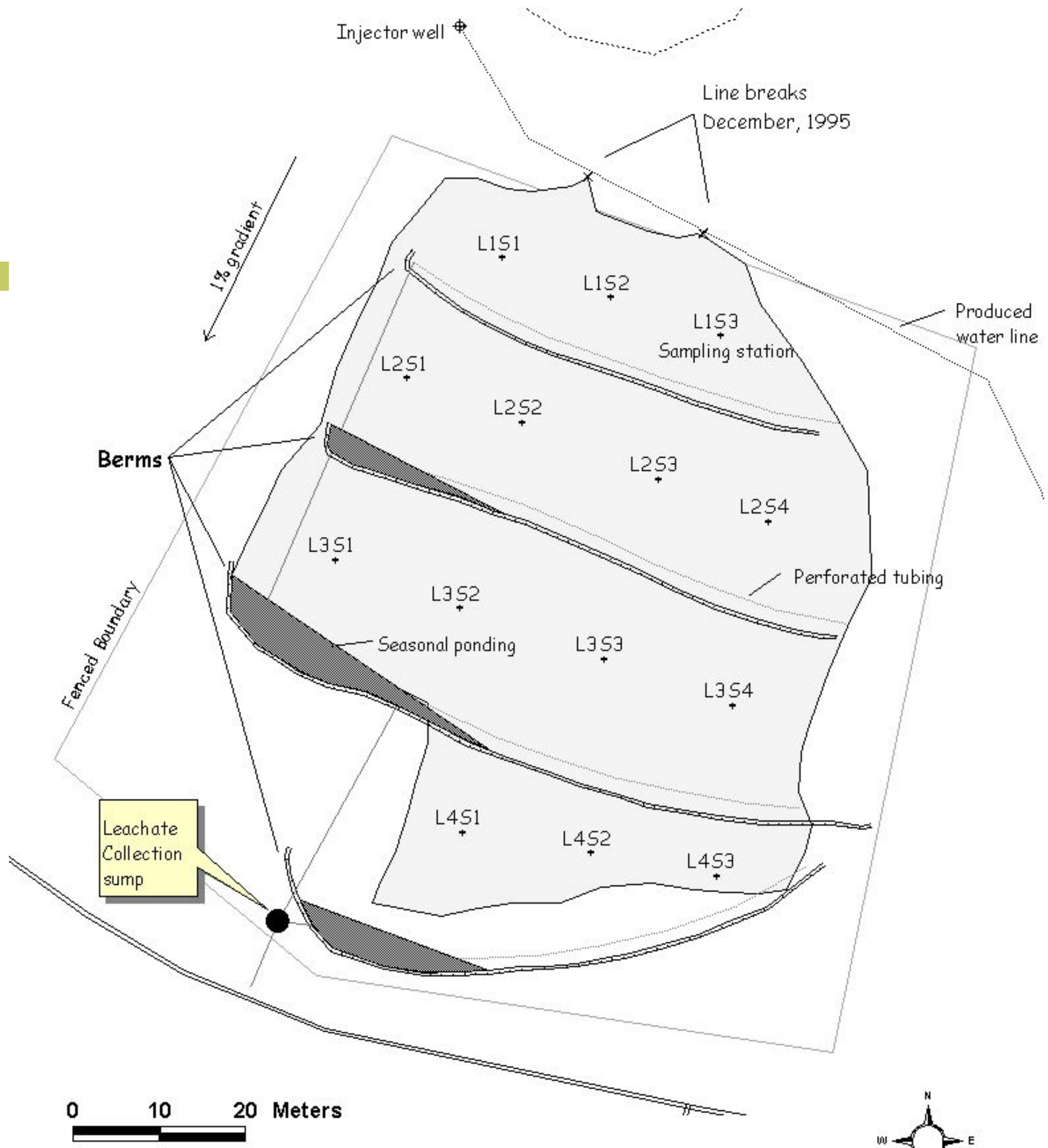
Another older case study – Remediation of a brine spill using a subsurface drain

- Rupture of a salt water line in December 1995 in Osage County, OK; about two acres impacted
- Essentially untreated for two years*
- Underlying clay layer at about 3 ft
- Site drained to a farm pond 600 yds away
- All aquatic life in pond killed

*Producer and landowner tried a number of commercial products for brine spills with no success

Remediation of a brine spill using a subsurface drain

- Drainage was a major issue
- Installed subsurface drains above clay layer (at about 3 ft)
  - French drain pipe in gravel bed
  - Drained to underground sump
  - Operator pumped leachate to salt water storage tank each day
- Installed berms downgradient of each subsurface drain to increase penetration of rainfall into the soil
- Tilled in hay and fertilizer in January 1998
- Cost $7,000 for materials



Injector well
Line breaks
December, 1995
1% gradient
L1S1
L1S2
L1S3
Sampling station
Produced
water line
L2S1
L2S2
Berms
L2S3
L2S4
L3S1
Perforated tubing
L3S2
Fenced Boundary
Seasonal ponding
L3S3
L3S4
L4S1
L4S2
L4S3
Leachate
Collection
sump
0 10 20 Meters
N
W
E
S

Fig. 4

Sodium Ion Concentration (ppm)

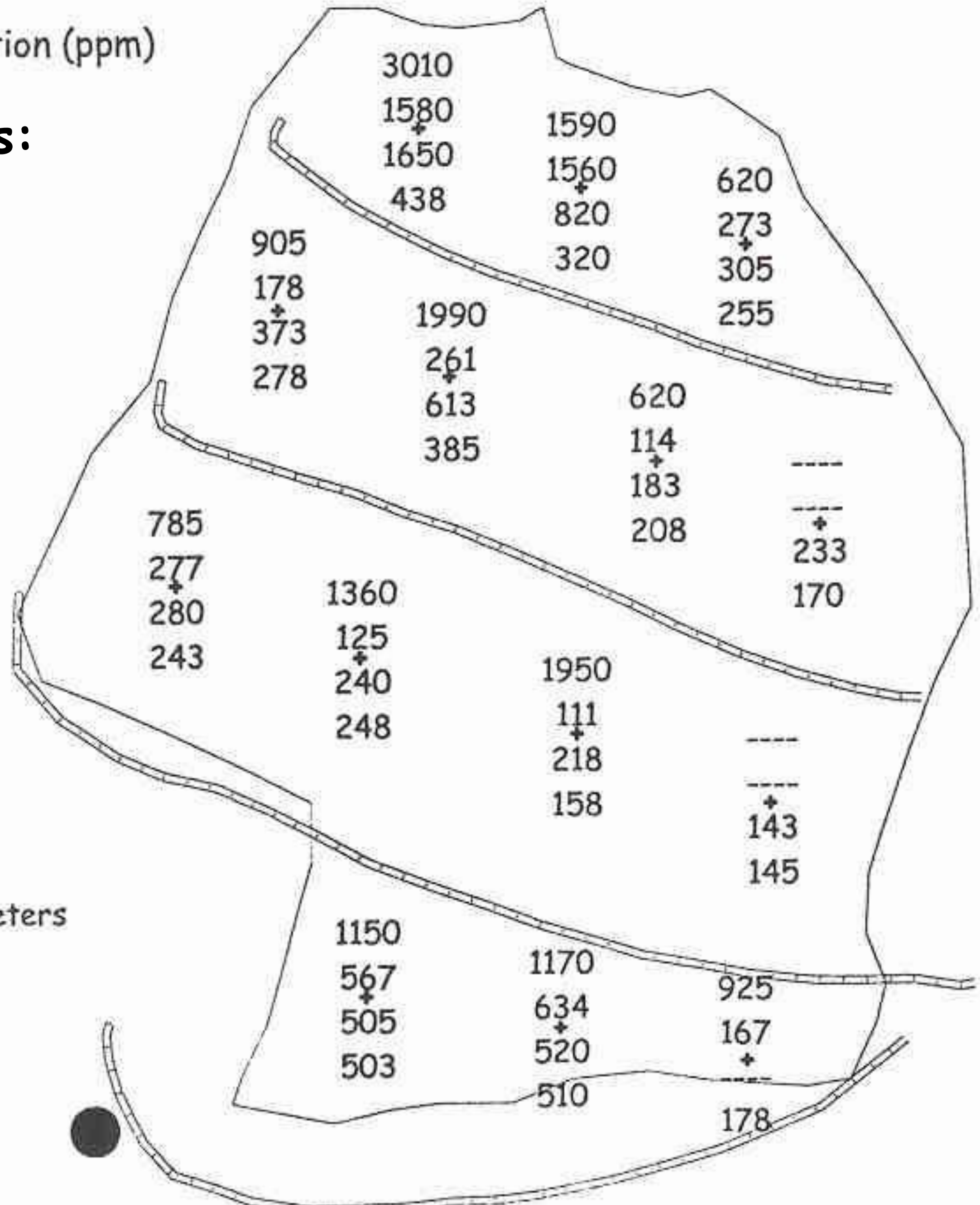
Sampling dates:

2/98

3/99

7/00

5/01



Chloride Ion Concentration (ppm)

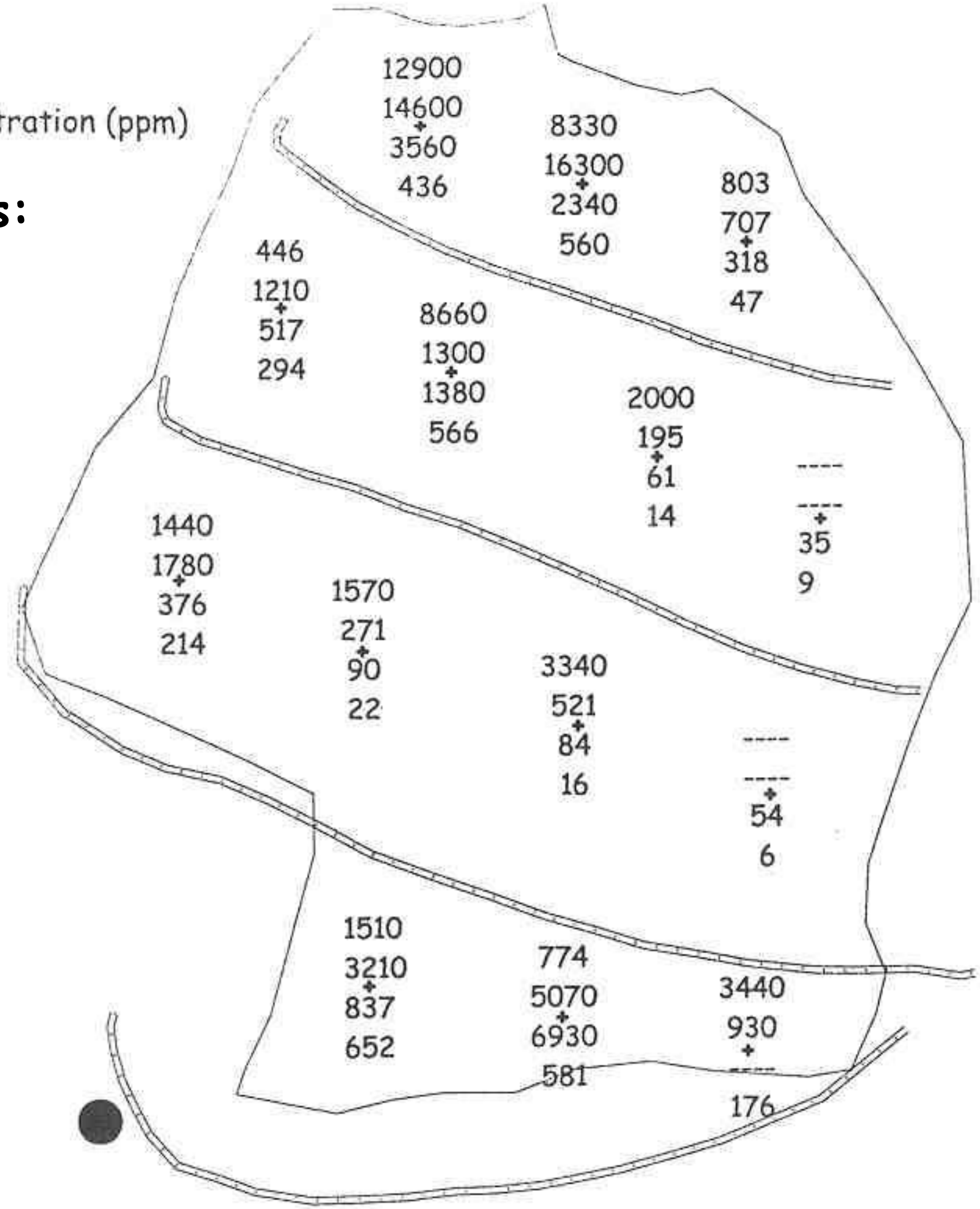
Sampling dates:

2/98

3/99

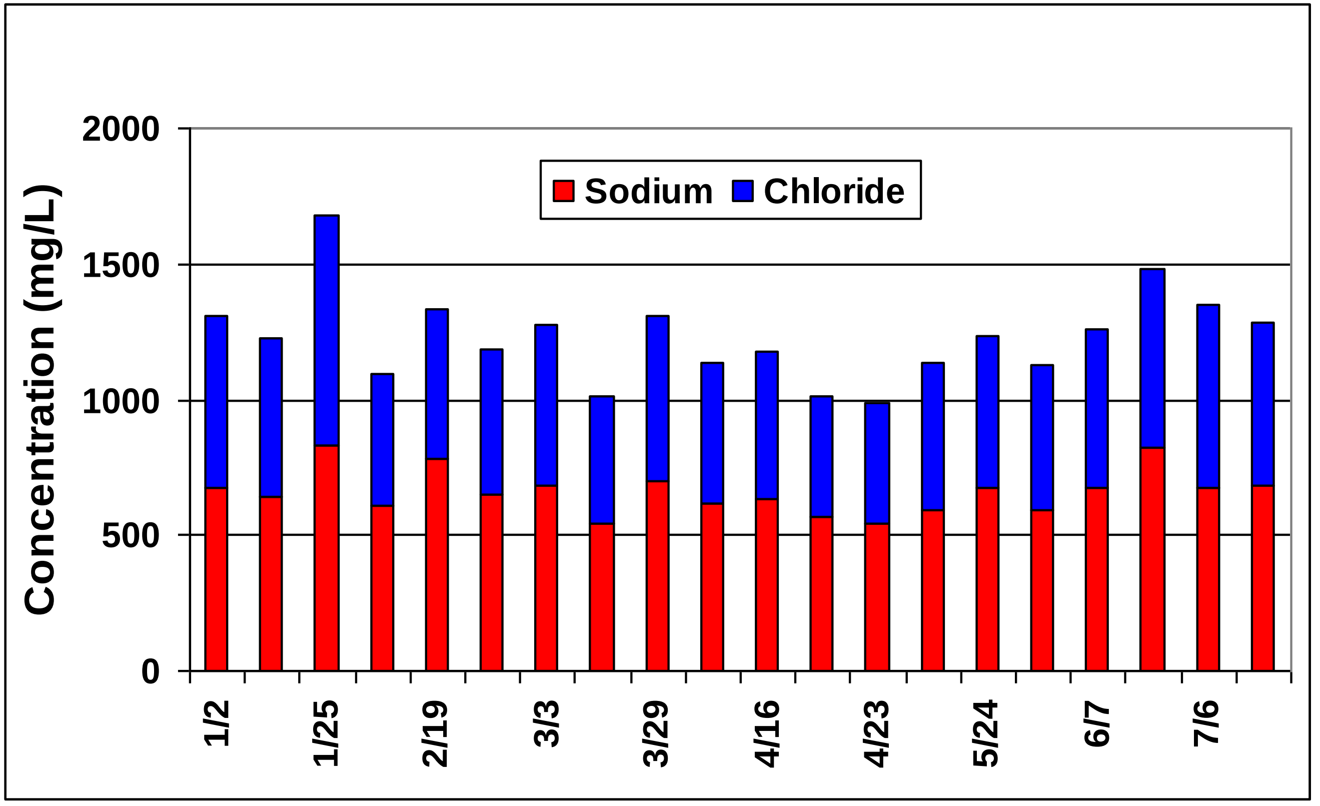
7/00

5/01



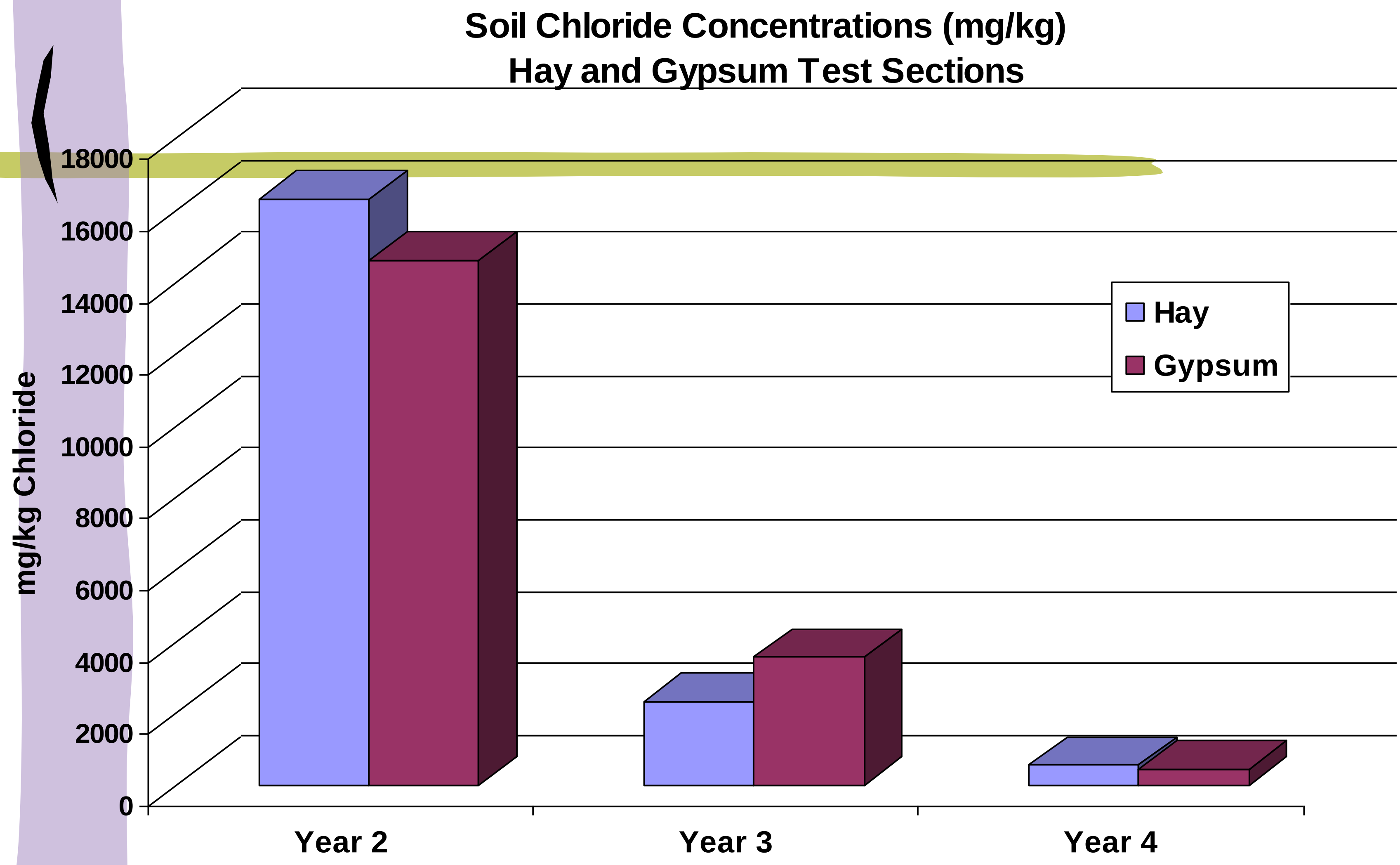
Leachate characteristics – first 6 months

- About 7000 bbl collected
- Salt concentrations 1000-1700 mg/L

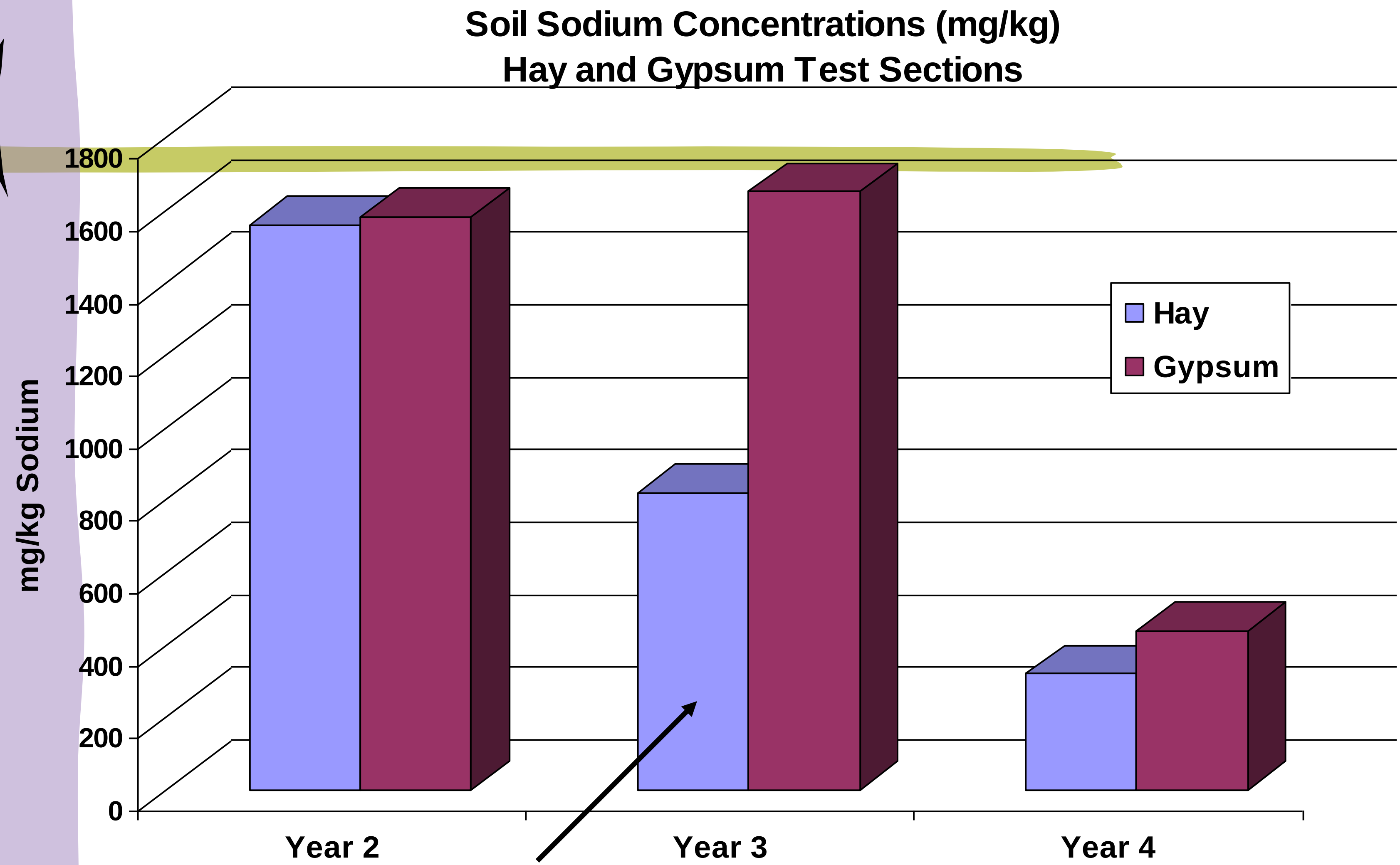


An interesting observation

- In year 2 the effects of the addition of more hay vs. gypsum application were compared in the two most contaminated sections nearest the source which were not showing any signs of revegetation (upper left in previous diagrams):
- Observations:
  - Faster sodium removal with hay
  - Faster revegetation with hay – section with hay was two years ahead of the section treated with gypsum- this is a soil fertility effect!



Soil Chloride Concentrations (mg/kg)
Hay and Gypsum Test Sections
mg/kg Chloride
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Year 2
Year 3
Year 4
Hay
Gypsum



Organic acids solubilized calcium from calcium carbonate in the soil without negative effects of gypsum on plant growth

Early spring 1998

Late spring 1999; good crop of ragweed, some bare spots still

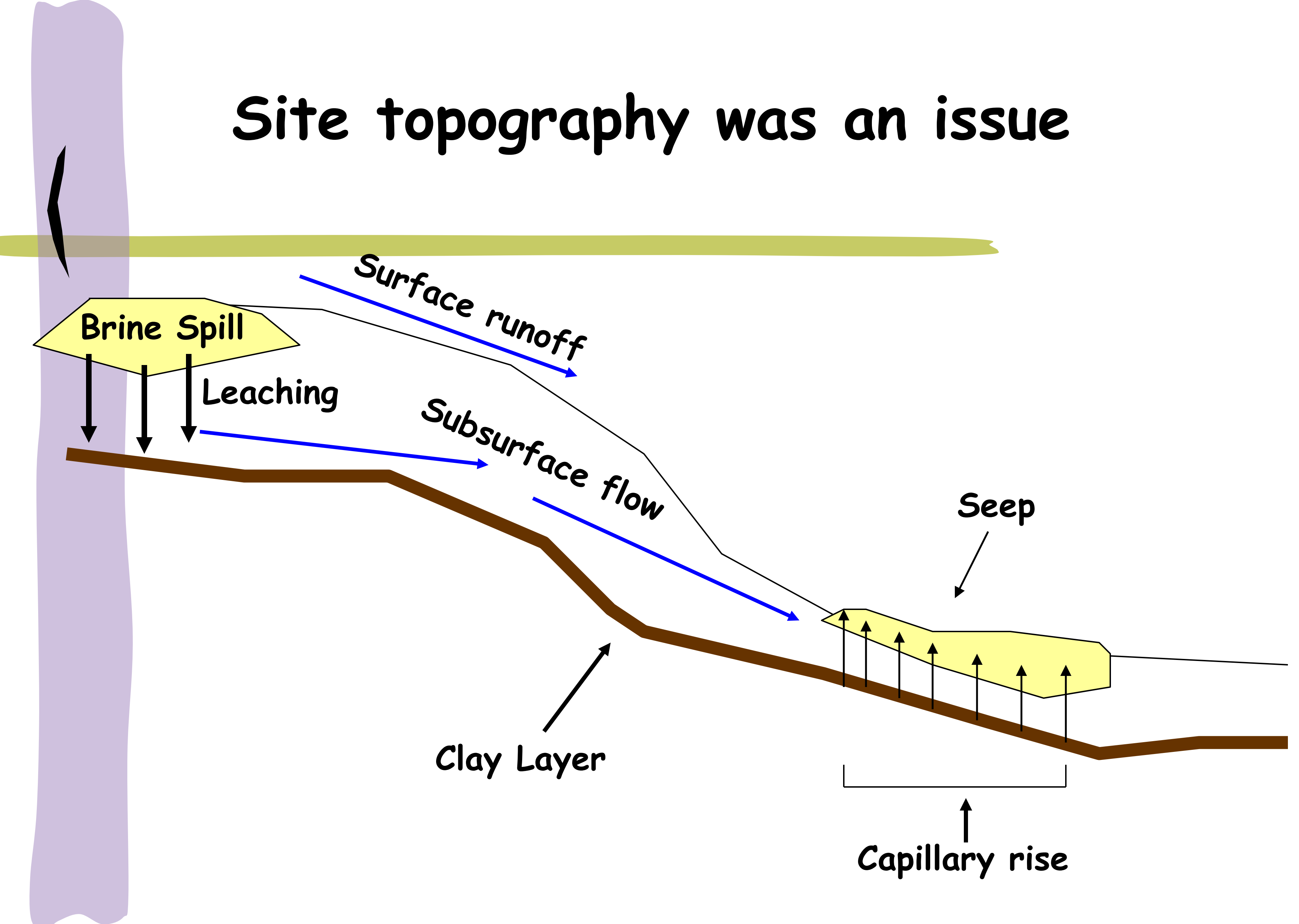
Spring 2000; lots of ragweed but lots of grasses too!

Spring 2002; opened by landowner to bison grazing

Spring 2002; a closer look – lots of grass!

Case study in what not to do

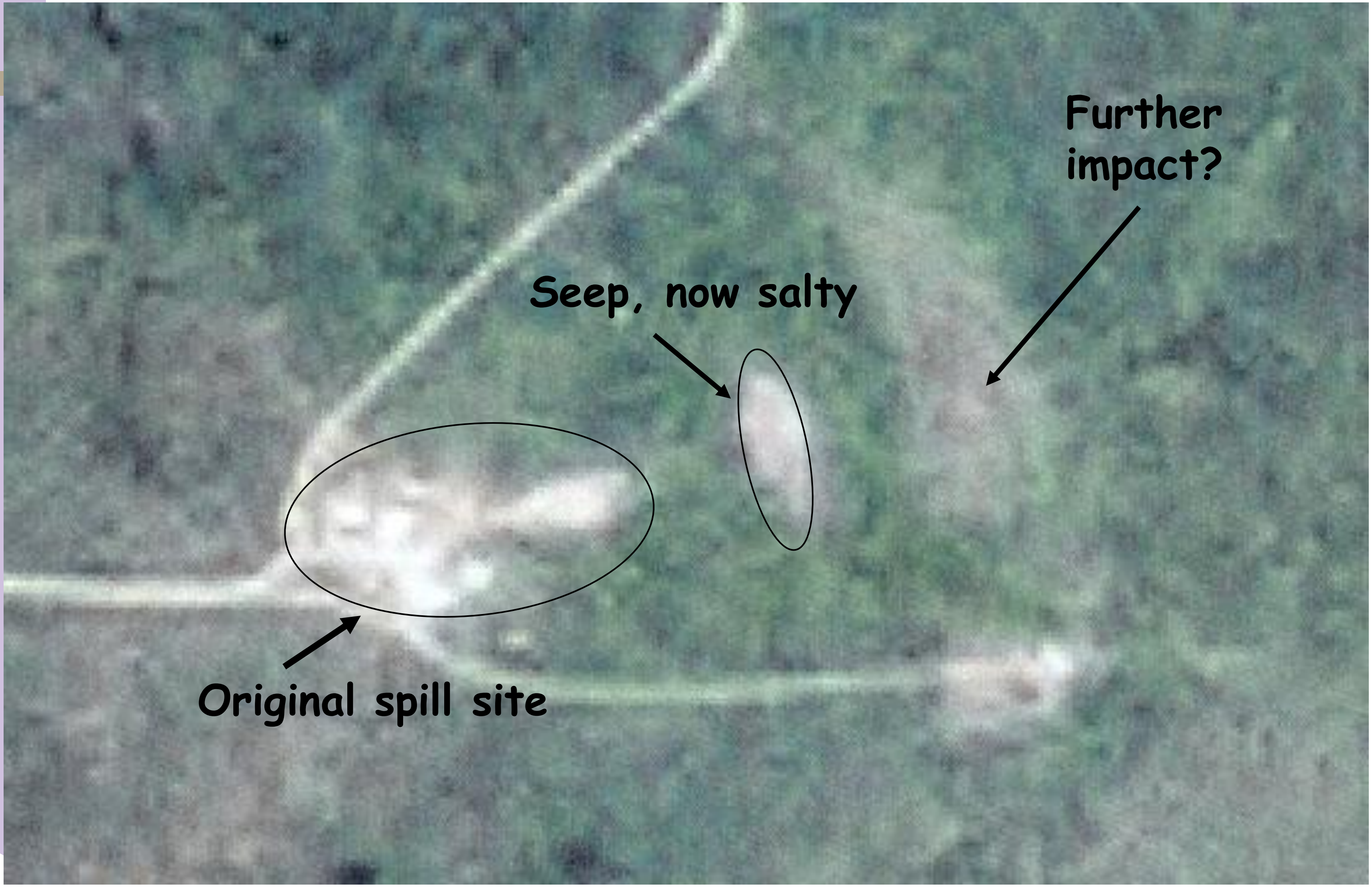
Site topography was an issue

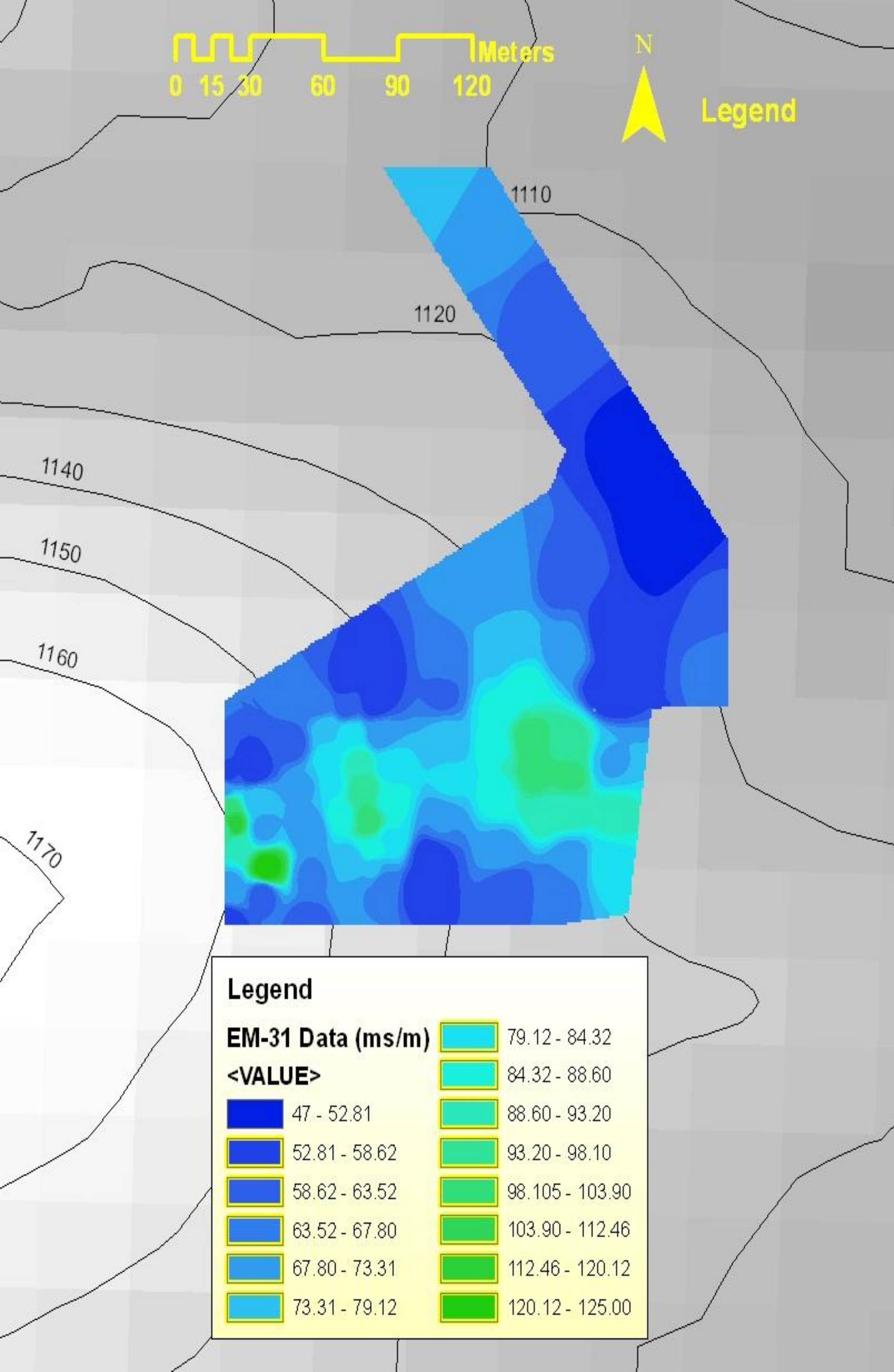


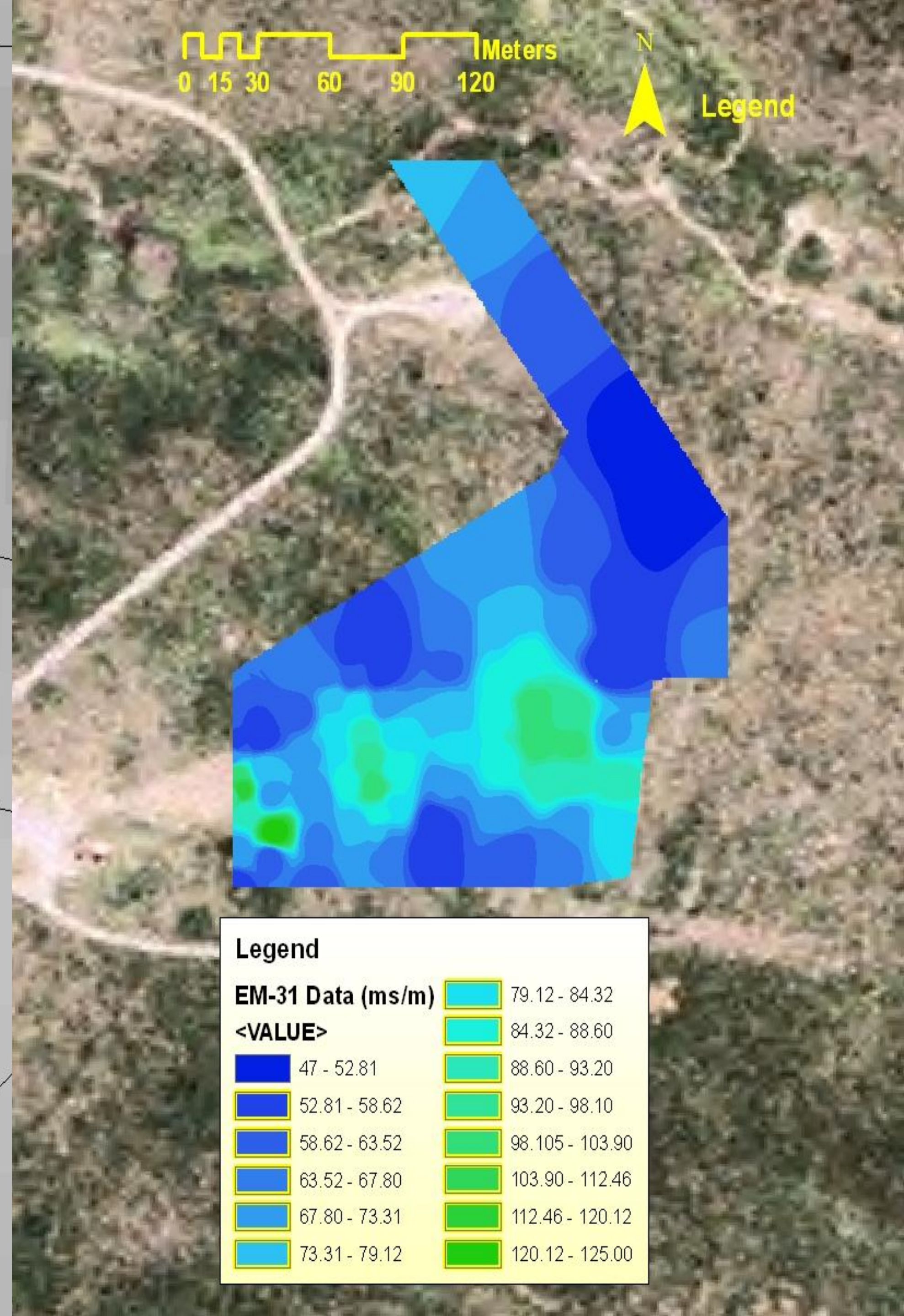
Recommended remediation method

- Ripping, tilling with hay and fertilizer application
- Subsurface drain at the bottom of the spill
  - Predicted that the salt was going to continue down slope and pool
- Only hay and fertilizer application with tilling was done; no artificial drainage used

Google Earth 2004




0 15 30 60 90 120 Meters
N
Legend
1110
1120
1140
1150
1160
1170
Legend
EM-31 Data (ms/m)
<VALUE>
47 - 52.81
52.81 - 58.62
58.62 - 63.52
63.52 - 67.80
67.80 - 73.31
73.31 - 79.12
79.12 - 84.32
84.32 - 88.60
88.60 - 93.20
93.20 - 98.10
98.105 - 103.90
103.90 - 112.46
112.46 - 120.12
120.12 - 125.00


0 15 30 60 90 120 Meters
N
Legend
Legend
EM-31 Data (ms/m)
<VALUE>
47 - 52.81
52.81 - 58.62
58.62 - 63.52
63.52 - 67.80
67.80 - 73.31
73.31 - 79.12
79.12 - 84.32
84.32 - 88.60
88.60 - 93.20
93.20 - 98.10
98.105 - 103.90
103.90 - 112.46
112.46 - 120.12
120.12 - 125.00

Costs of remediation

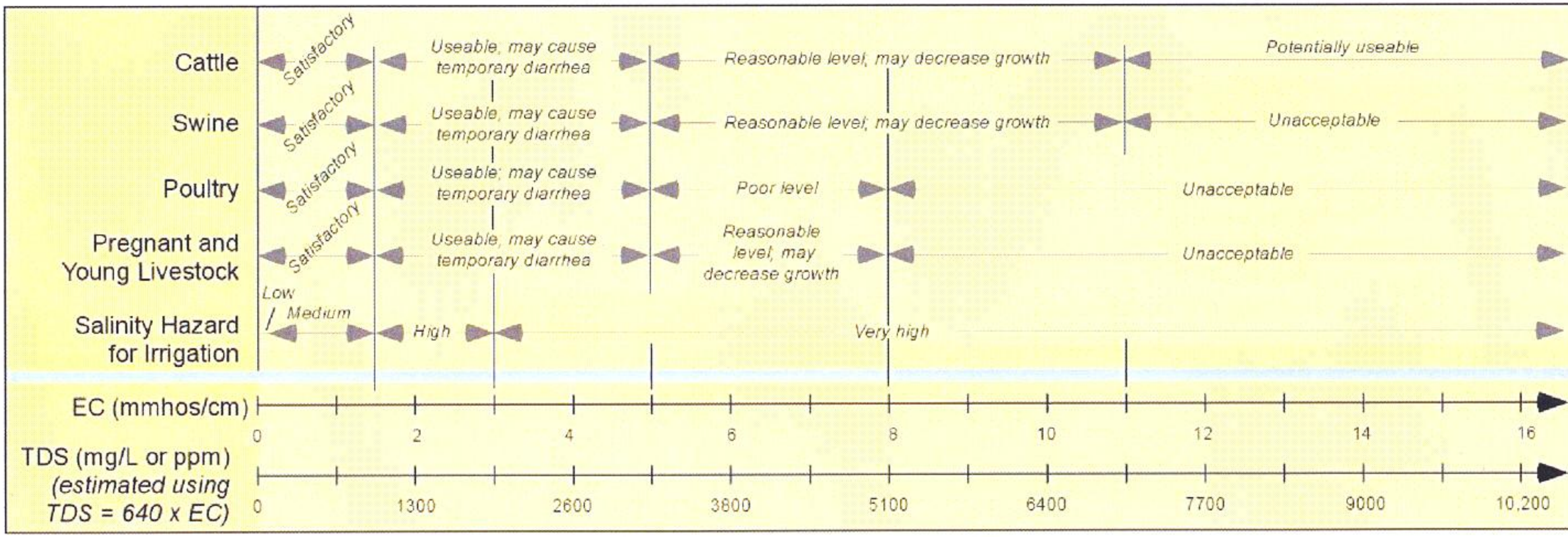
- Costs are highly variable depending on
  - Size of spill
  - Salt mass loading
  - Depth of contamination
  - Soil types
  - Drainage requirements
  - Water availability
  - Etc., etc.
- Compare to dig and haul at about $\$50/yd^3$
  - 0.5 acres excavated to 2 ft, disposal and replacement with clean soil, about $85,000
  - You still have to revegetate!

Impact of brine on surface waters

- Chloride is not toxic so maximum permissible chloride levels in water are typically determined by restriction in beneficial use
  - Drinking water: chlorides > 250 mg/L produce a salty taste
  - Protection of aquatic life
    - Criteria for exposure developed by EPA
      - Acute exposure < 860 mg/L
      - Chronic exposure < 230 mg/L
  - Agricultural uses
    - Irrigation quality standards (salinity and SAR)
    - Specific ion effects
    - Health effects on livestock

Specific ion effects for irrigation water

	Restrictions on use		
Species	None	Slight - moderate	Severe
Chloride (mg/L)	< 142	142 - 355	> 355
Boron (mg/L)	< 0.7	0.7 – 3.0	>3.0


Cattle
Satisfactory
Useable, may cause temporary diarrhea
Reasonable level, may decrease growth
Potentially useable
Swine
Satisfactory
Useable, may cause temporary diarrhea
Reasonable level, may decrease growth
Unacceptable
Poultry
Satisfactory
Useable; may cause temporary diarrhea
Poor level
Unacceptable
Pregnant and Young Livestock
Satisfactory
Useable, may cause temporary diarrhea
Reasonable level, may decrease growth
Unacceptable
Salinity Hazard for Irrigation
Low
Medium
High
Very high
EC (mmhos/cm)
0
2
4
6
8
10
12
14
16
TDS (mg/L or ppm) (estimated using TDS = 640 x EC)
0
1300
2600
3800
5100
6400
7700
9000
10,200