Remediation of Brine Spills- What Goes Wrong

Kerry Sublette

Sublette Consulting, Inc.

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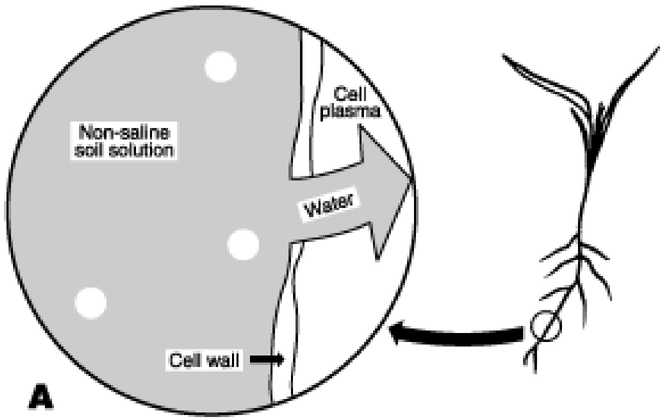
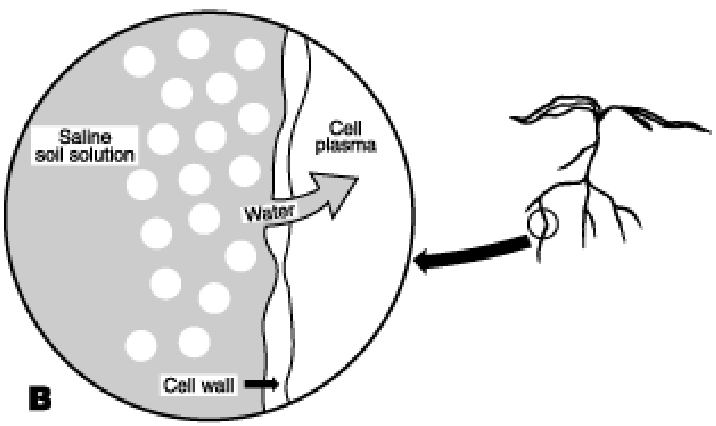
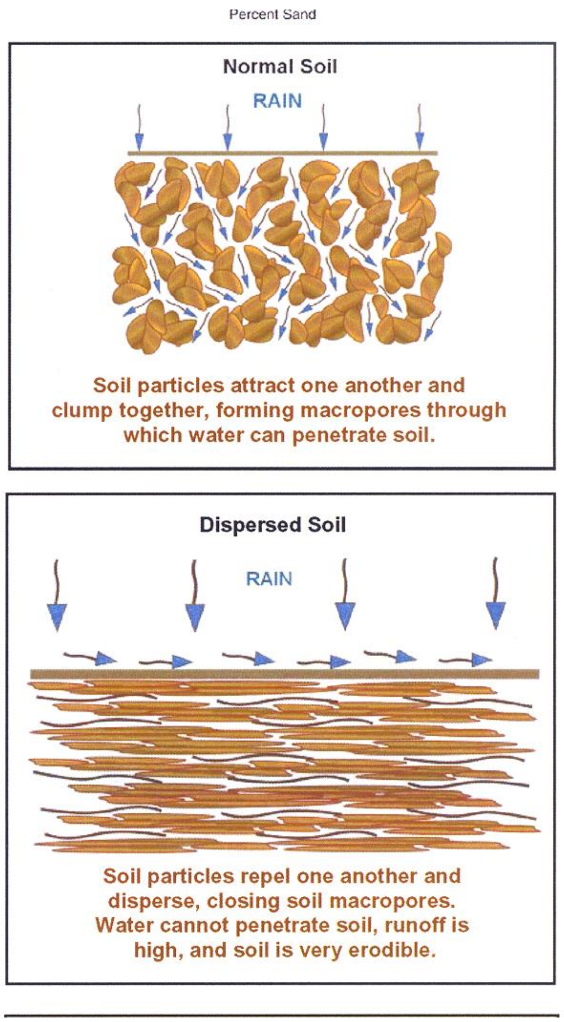
Spills of produced water or brine on soil result in two types of damage:





- 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.

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

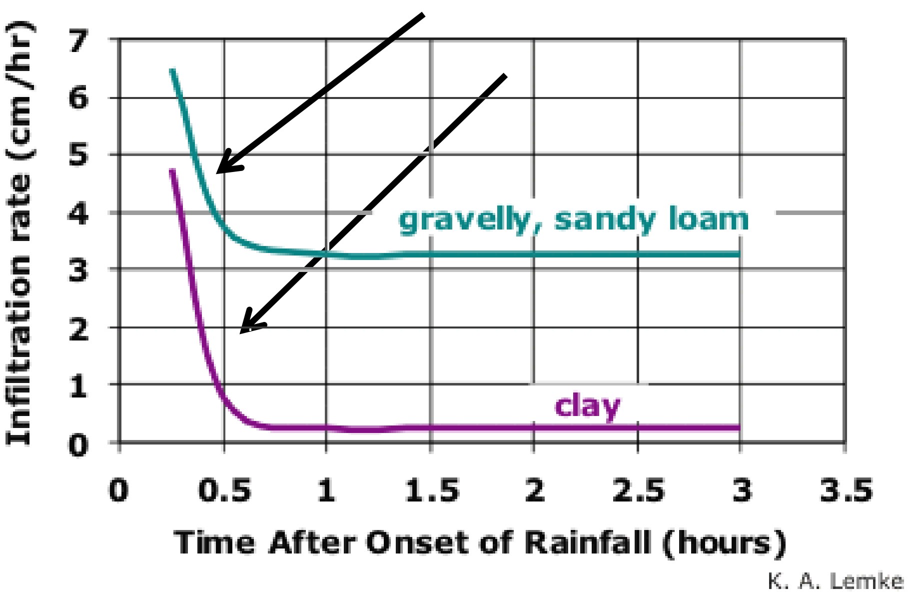
Remediation of a Brine Spill In Brief

- First response
  - Flushing and containment
- Reducing salinity
  - Breaking open the soil
  - Bulking agents
  - Fresh water
  - Drainage
- Reducing sodicity
  - Soluble calcium ion to reverse sodic reaction with clays
- Revegetation
  - Taking advantage of plant root systems

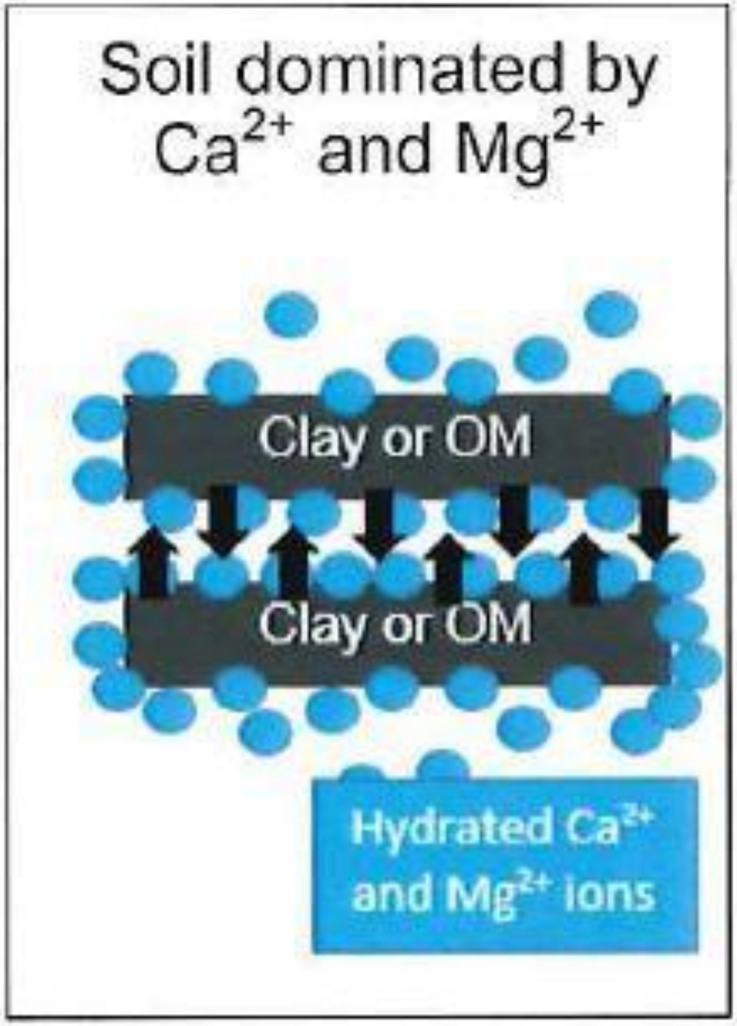
There are many ways for this process to go wrong

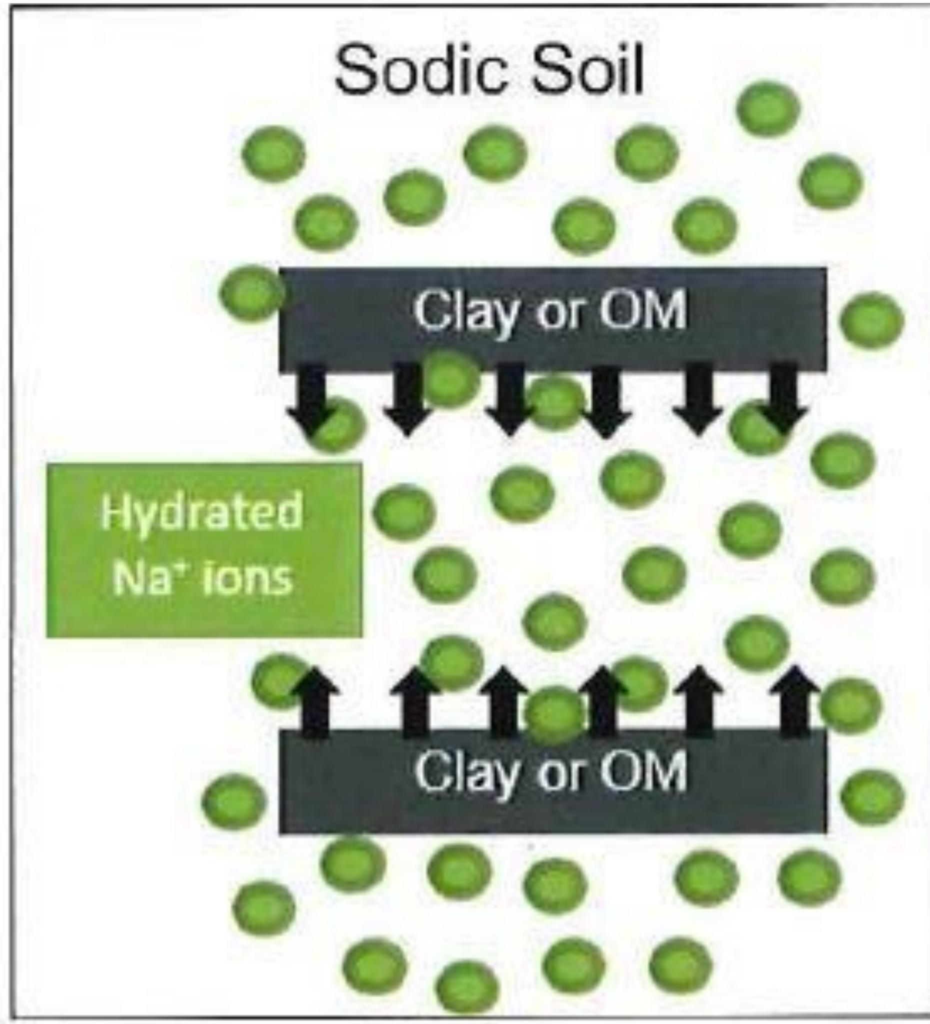
First response to a brine spill

- A typical method of first response: flushing with fresh water into a receiving body followed by disposal of salty water. There are two problems with this approach.



Capillary suction from dry soil can result if further damage

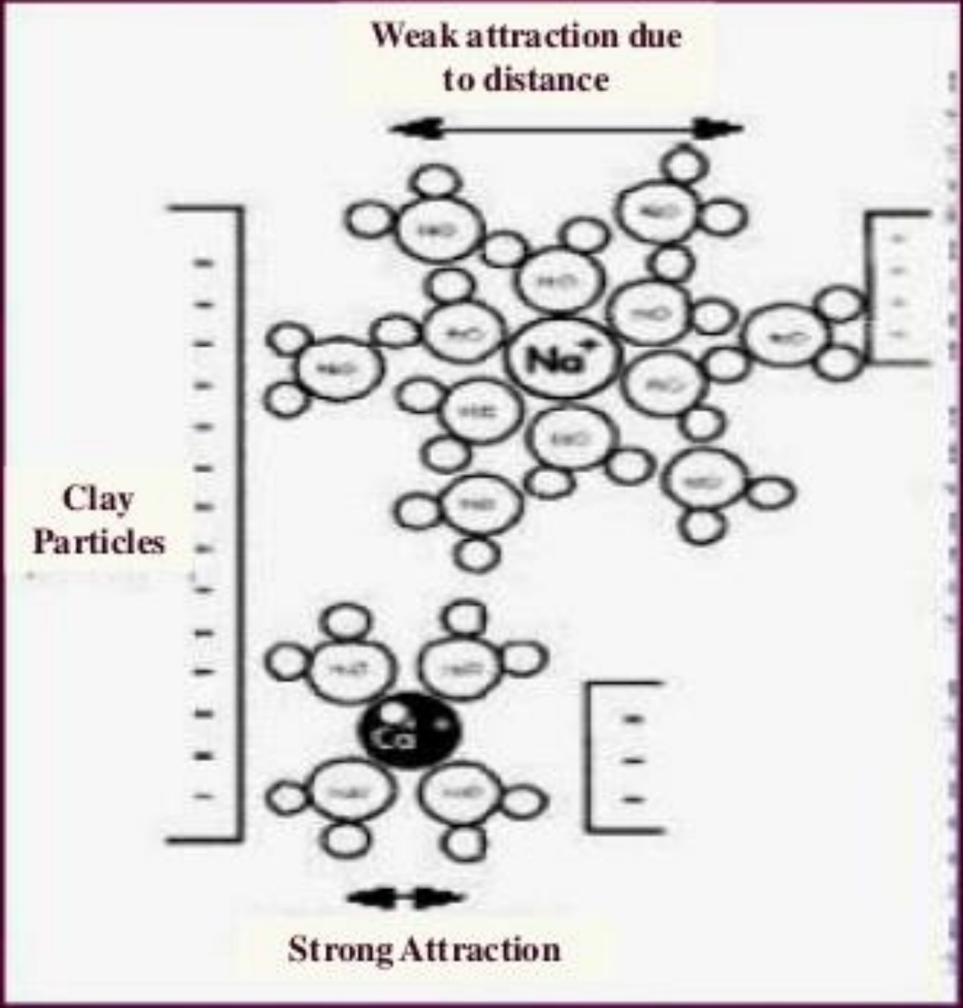




Clay platelets are negatively charged. Normally Ca^{+2} and Mg^{+2} keep them from repelling each other acting as kind of a clue holding clays in aggregates.

When the clays are flooded with Na^{+}, the Ca^{+2} and Mg^{+2} are replaced with a lot of Na^{+}. Na^{+} has a large hydration shell pushing the clay platelets apart with less charge to hold the platelets together, the result is clay dispersion.

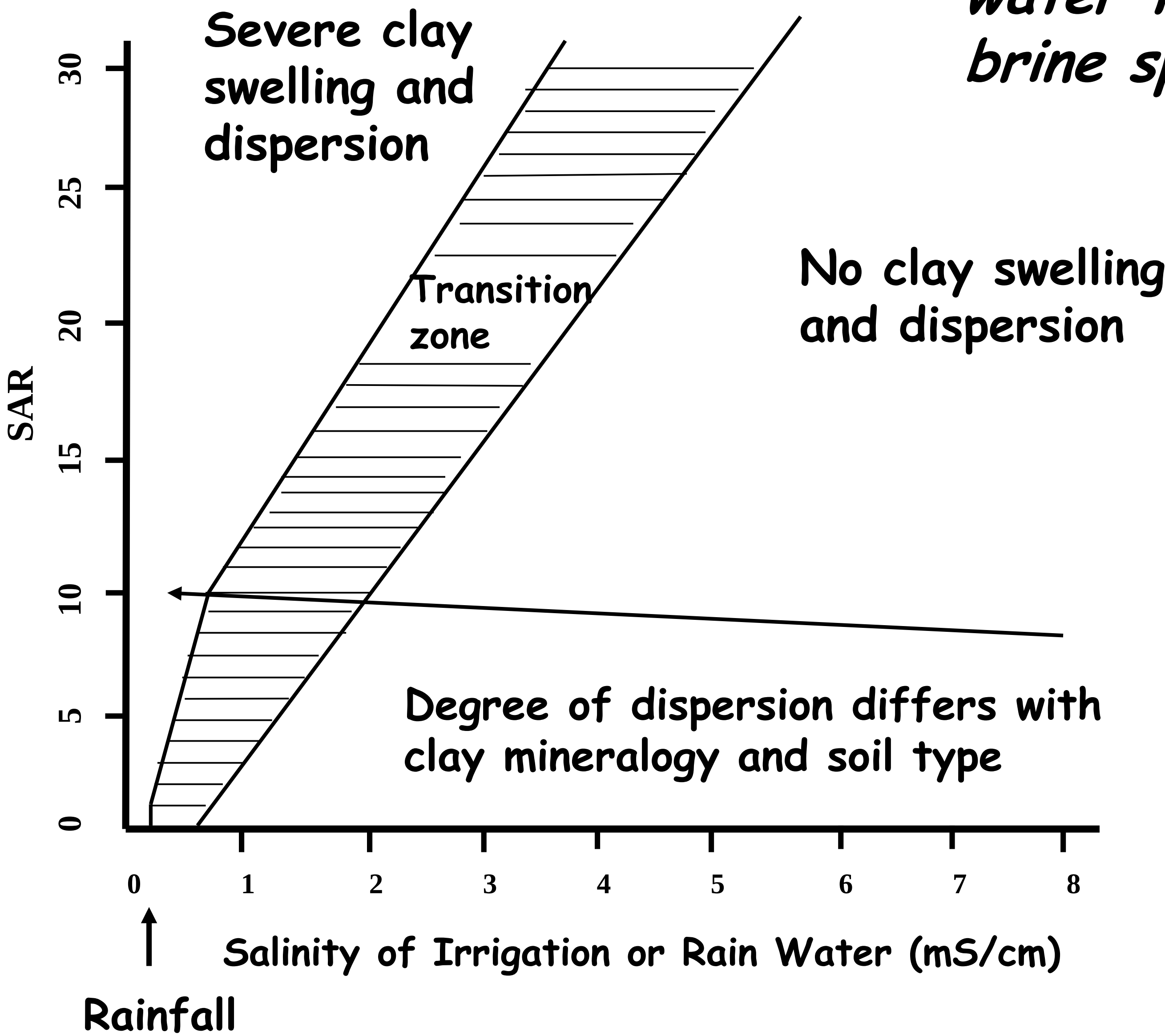
Dispersion Phenomenon



High level of hydration increases dispersion

High concentrations of salts in the environment inhibit hydration of the Na^{+} limiting dispersion

Never add fresh water to a recent brine spill

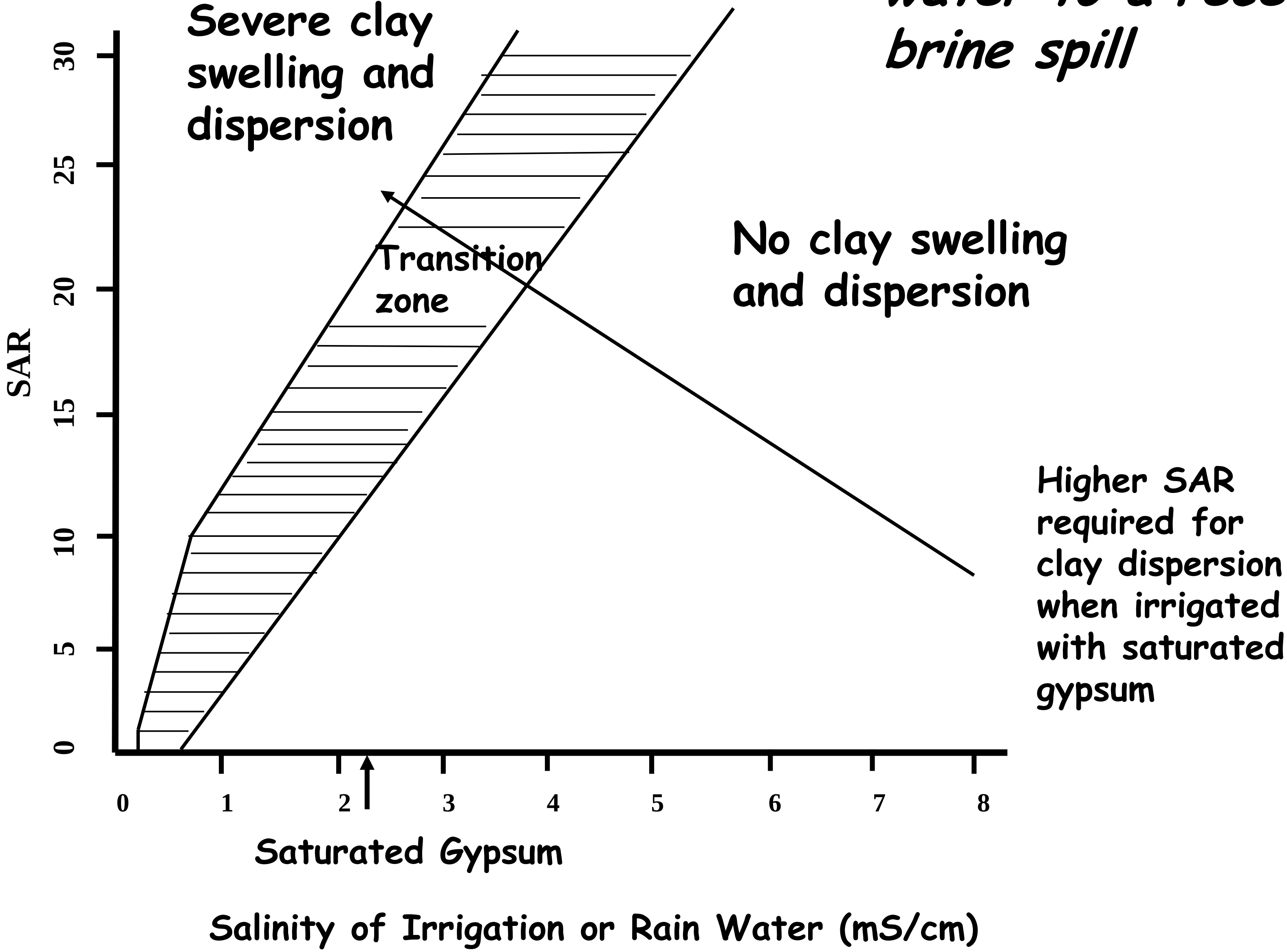


Upper zone of brine impacted soil: EC reduced as fresh water flows through

Flushing as a first response

- To prevent spreading contamination and causing clay dispersion:
  - Liberally spread fine-particle gypsum on the spill and the surface between the spill and the receiving body so that when water is applied dissolved gypsum keeps the EC of the upper soil profile at acceptable levels
  - Wet the soil between the spill and the receiving body to prevent capillary suction of salty water into clean soil

Never add fresh water to a recent brine spill



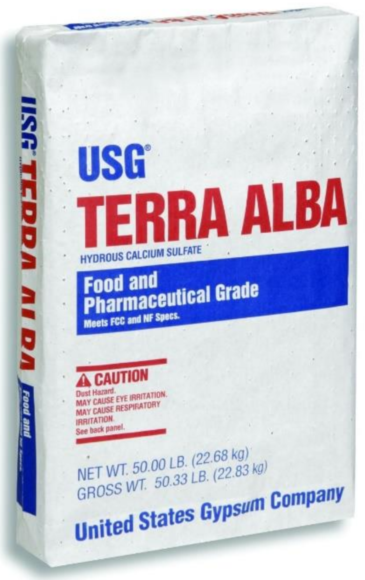
Minimizing effects of produced water spill on soil reduces cleanup costs

- Keep fine particle gypsum (gypsum flour) on hand and readily available
- Get lots of gypsum in the ground before it rains

Typical Particle Size Distribution

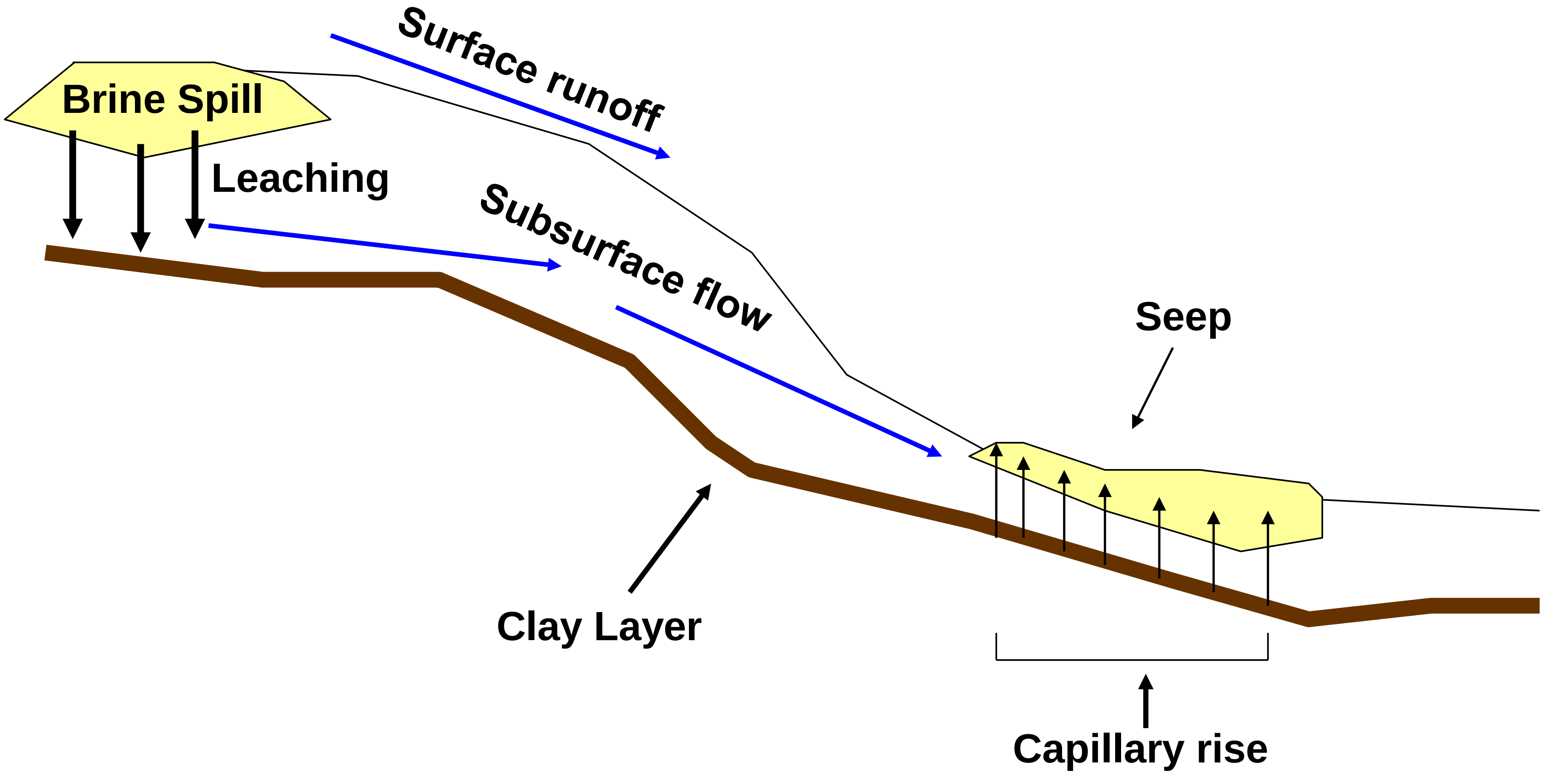
Particles Passing ASTM Sieves:

200 Mesh	100.0%
270 Mesh	98.4 %
325 Mesh	95.6 %
400 Mesh	88.4 %



Expect things to go from bad to worst if you don't do anything or don't do enough

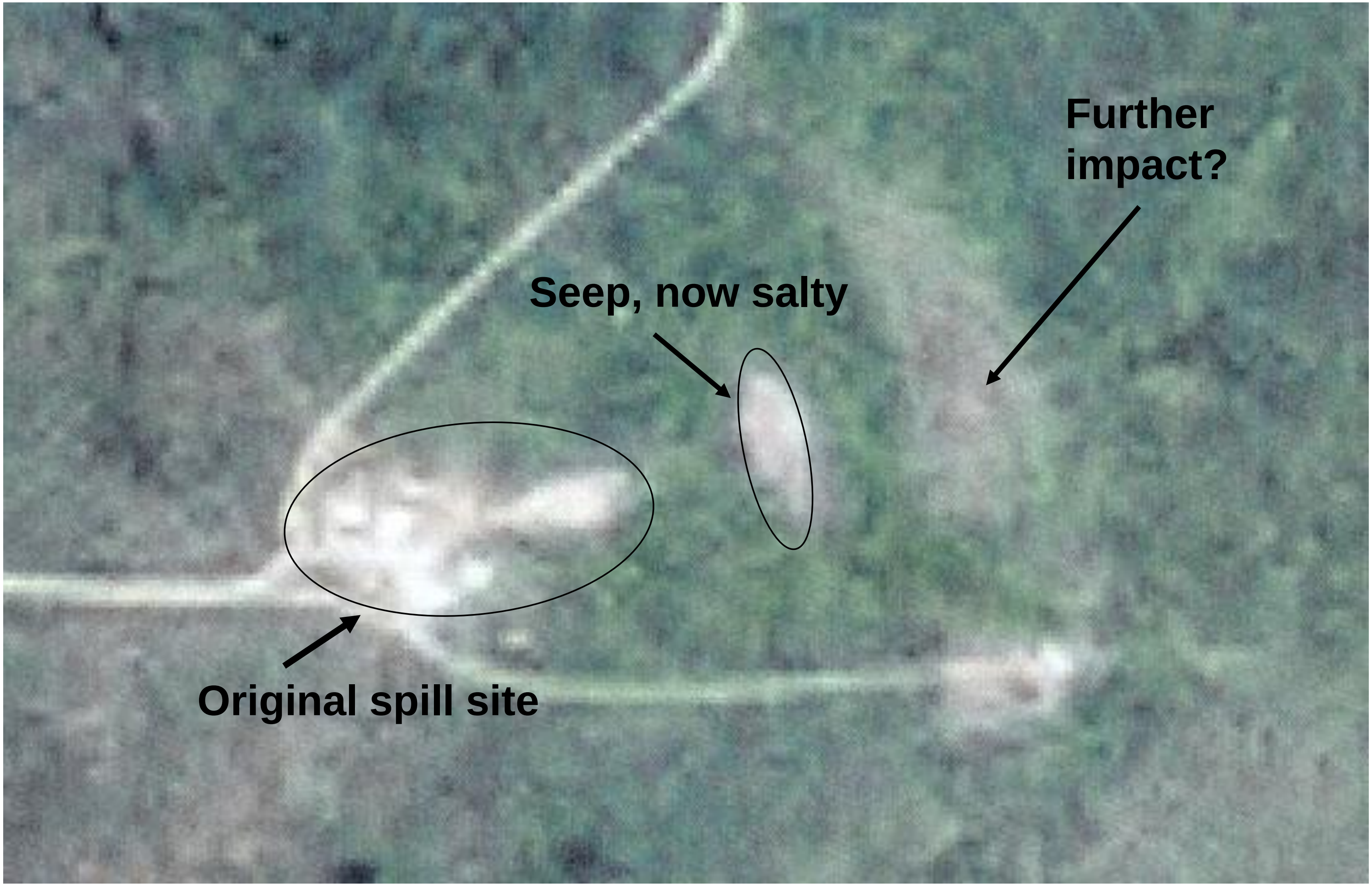
Site topography was an issue

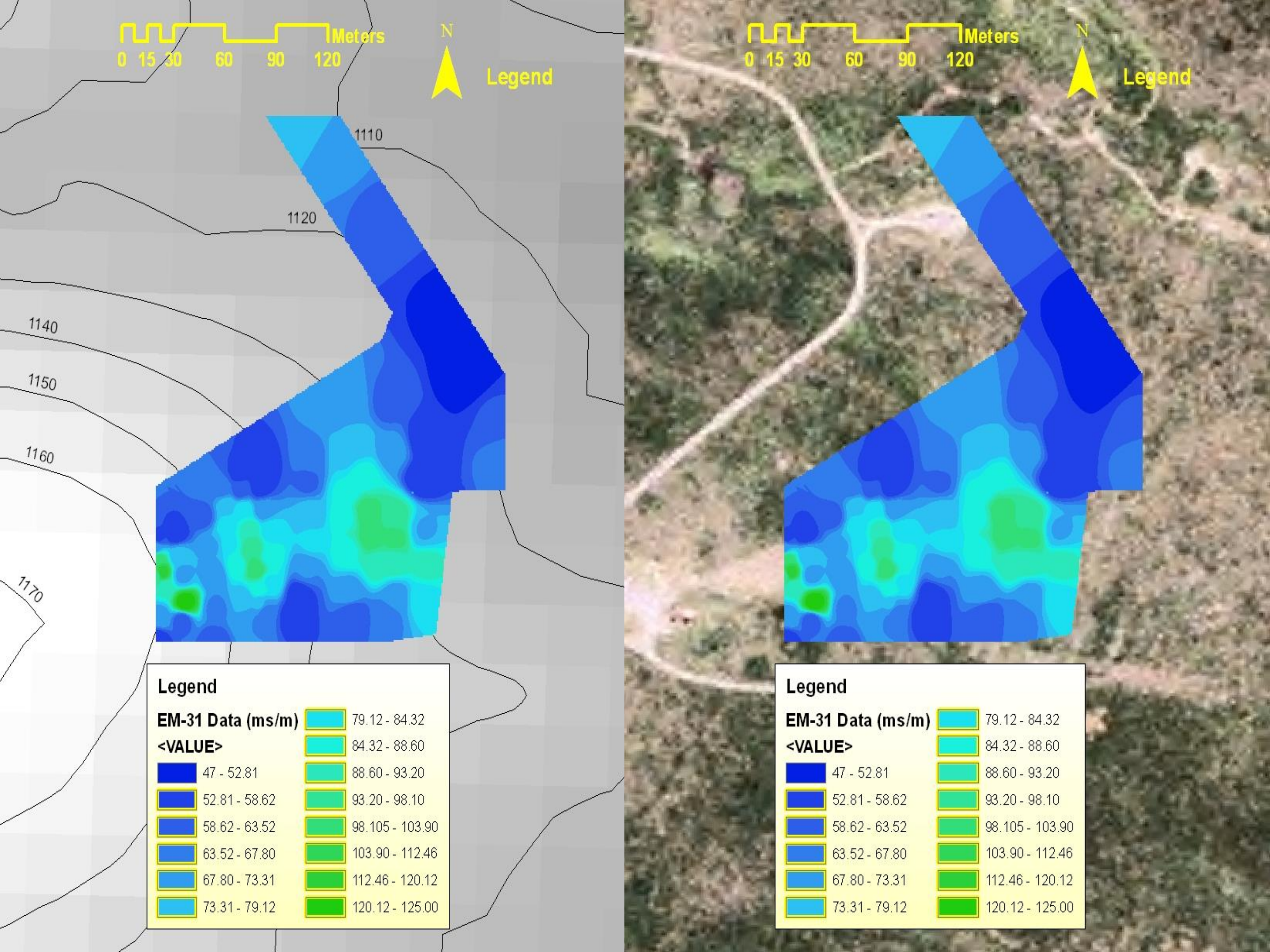


Recommended remediation method

- Ripping, tilling with hay and fertilizer application, calcium source
- 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 (once); no artificial drainage used, no calcium source

Google Earth





0 15 30 60 90 120 Meters
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Legend
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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

Metrics

- Salinity
  - Soil salinity is measured as a **saturated paste** EC
  - $EC_{sat\ paste} \approx 3 \times EC_{1:1}$
    - Assumes good contact and dry soils
- Sodicity
  - Sodium adsorption ratio (SAR)

$$SAR = \frac{[Na^{+}]}{\left[\frac{[Ca^{+2}] + [Mg^{+2}]}{2}\right]^{1/2}}$$

All units meq/L

Soil, Water & Forage Analytical Laboratory

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SOIL SALINITY REPORT

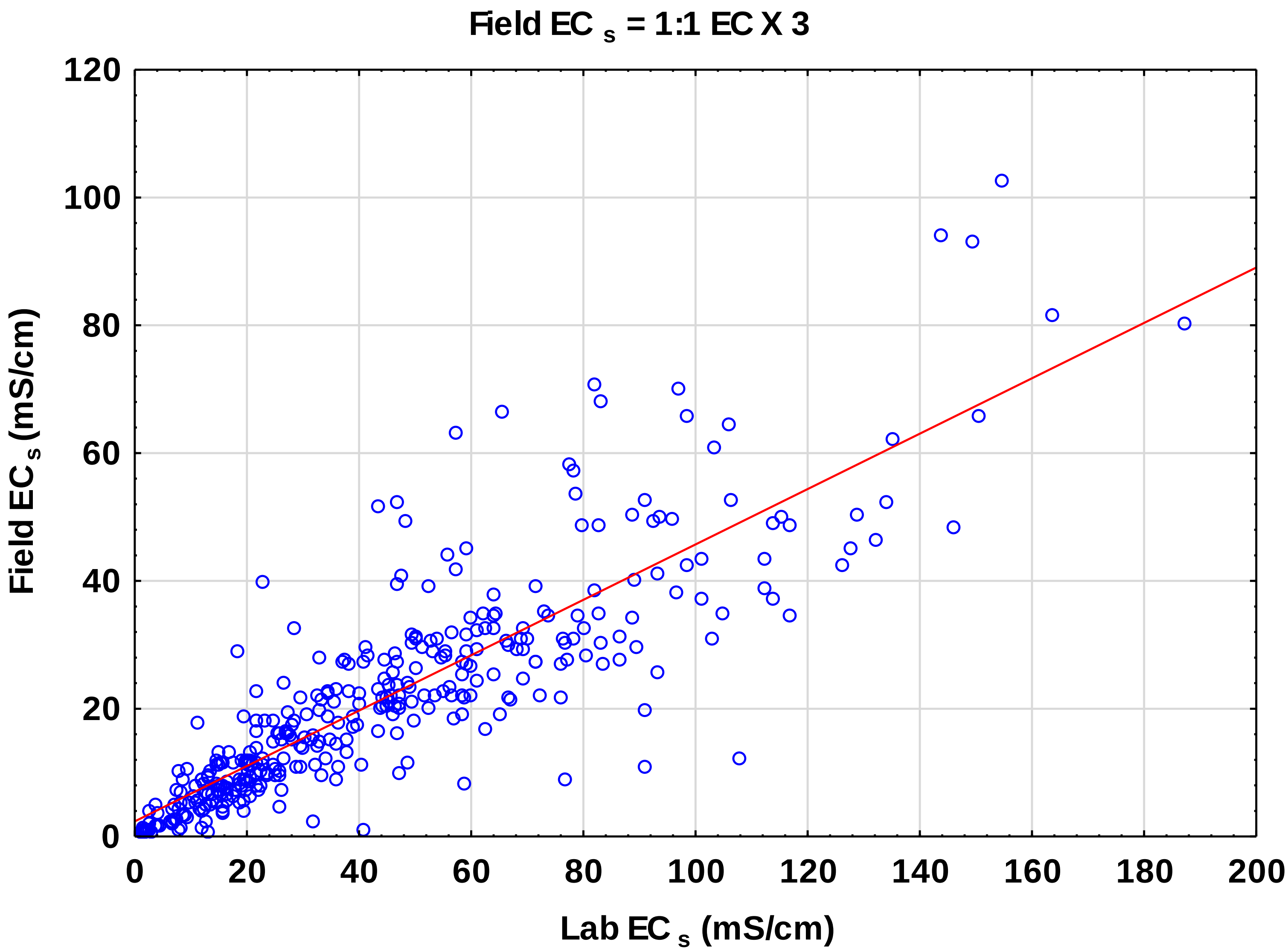
SUBLETTE CONSULTING, INC **8802 E. 98TH ST** **TULSA, OK 74133**	**Name :** **Location :**	**Lab ID No.: : 663008** **Customer Code :** **Sample No. : 805** **Received : 9/19/2012** **Report Date : 9/25/2012**

Test Results for Comprehensive Salinity(Saturated paste extraction)

---------- Cations ---------------		----------- Anions ------------		------------ Other --------------	
Sodium (ppm)	4922.1	Nitrate-N (ppm)	<1	pH	7.4
Calcium (ppm)	2914.9	Chloride (ppm)	13646.7	EC (μmhos/cm)	34900
Magnesium (ppm)	570.5	Sulfate (ppm)	622.4	Texture	Coarse
Potassium (ppm)	105	Boron (ppm)	0.3		
		Bicarbonate (ppm)	309.7		

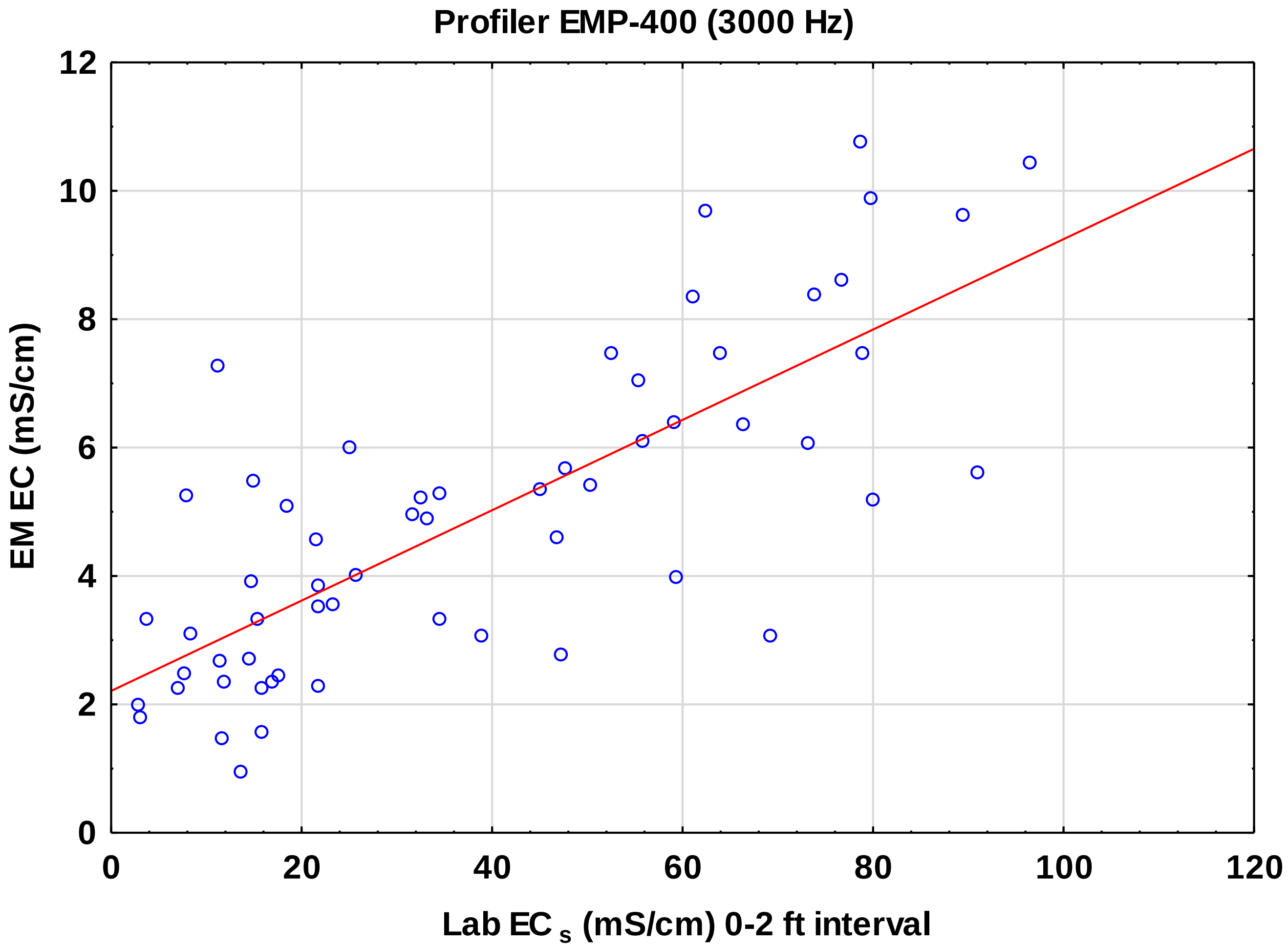
------------ Derived Values -----------------		-------- Derived Values (cont'd) --------------	
Total Soluble Salts (TSS in ppm)	23091.4	Exchangeable Sodium Percentage (ESP)	23.5
Sodium Adsorption Ratio (SAR)	21.8	Exchangeable Potassium Percentage (EPP)	6.1
Potassium Adsorption Ratio (PAR)	0.3		

Example of correlation between field and lab EC: heavy clay, high moisture content

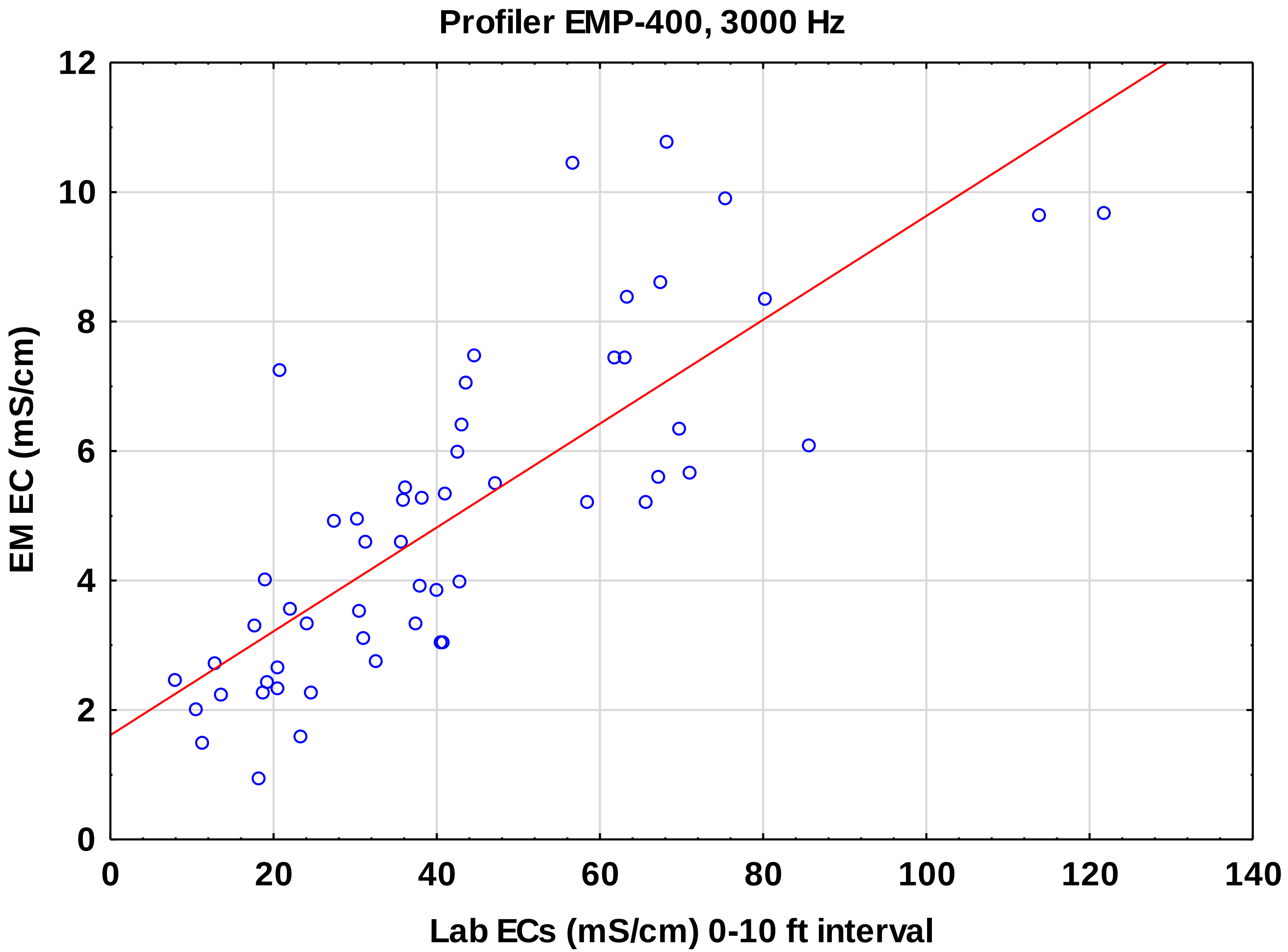


Geophysical surveys detect salt at depth

EMP EC correlates with lab EC_s but greatly underestimates actual soil EC_s



Geophysical methods tells you relative salt concentrations in the subsurface



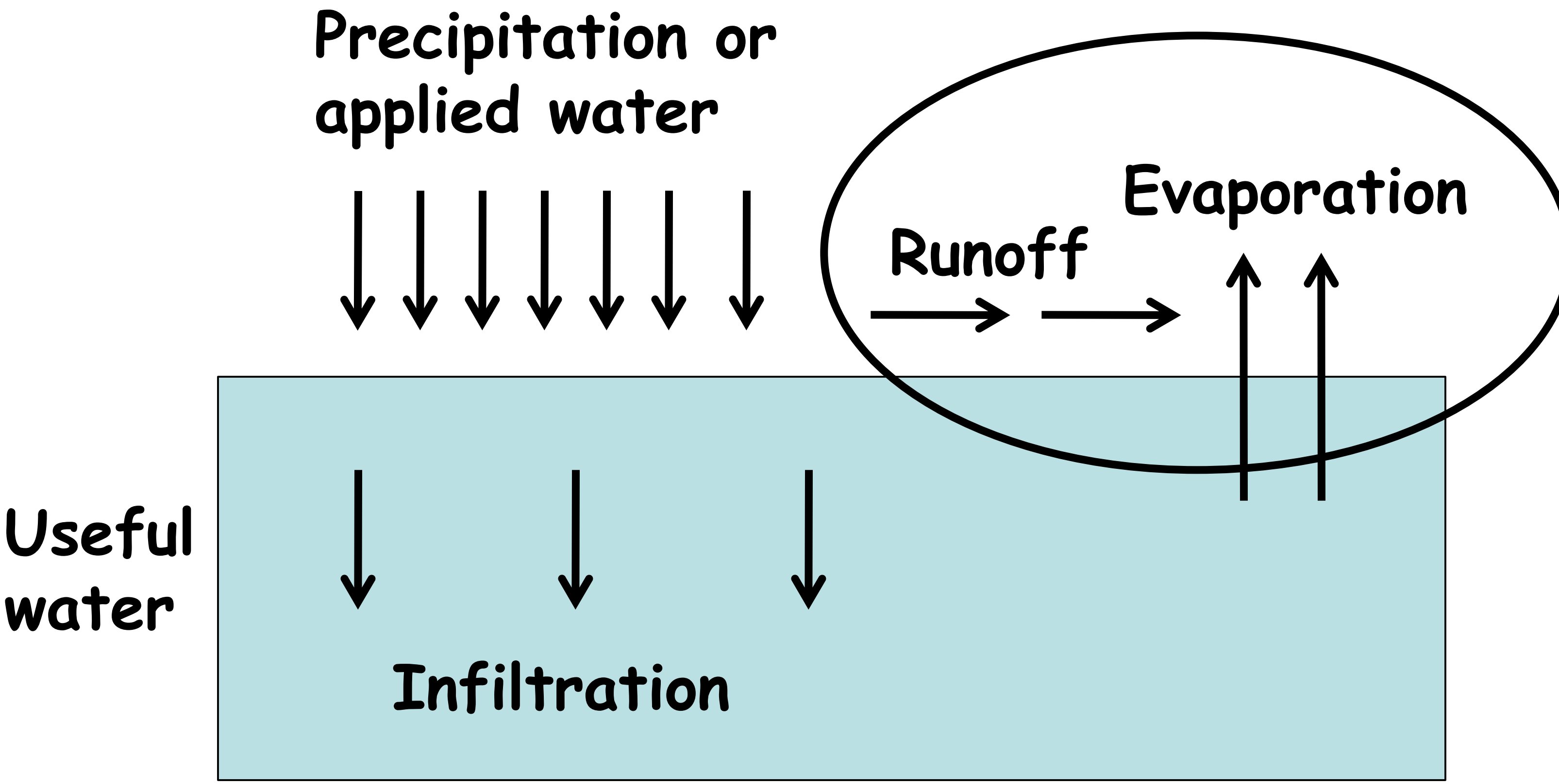
Water

- Soluble salts are transported by water – **No water no movement**
- How much water? A unit depth of water will remove about 80% of the salts from the same depth of contaminated soil.

Example: 12 in interval of contamination with an EC of 28 mS/cm

Leaching water (in)	% of salts leached	Approximate EC (mS/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.



Water

- Lots of water is required which means lots of time if you don't irrigate.
- Lots of organic matter in the soil improves permeability to water. A thick layer of mulch retains moisture and reduces evaporation.

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WATER QUALITY REPORT

SUBLETTE CONSULTING, INC **8802 E. 98TH ST** **TULSA, OK 74133**	**Name :** **Location :**	**Lab ID No.: : 668766** **Customer Code : 1392** **Sample No. : 1** **Received : 11/16/2012** **Report Date : 11/21/2012**

Test Results for Irrigation Water

---------- Cations ---------------		----------- Anions -------------		------------- Other --------------	
Sodium (ppm)	14	Nitrate-N (ppm)	10.6	pH	7.7
Calcium (ppm)	78	Chloride (ppm)	87	EC (µmhos/cm)	589
Magnesium (ppm)	12	Sulfate (ppm)	10		
Potassium (ppm)	3	Boron (ppm)	0.03		
		Bicarbonate (ppm)	115		

------------ Derived Values -----------------		-------- Derived Values(cont'd) --------------	
Total Soluble Salts (TSS in ppm)	388.7	Sodium Percentage	10.9 %
Sodium Adsorption Ratio (SAR)	0.4	Hardness (ppm)	243.9
Potassium Adsorption Ratio (PAR)	0.0	Hardness Class	Very Hard
		Alkalinity (ppm as CaCO3)	94.4

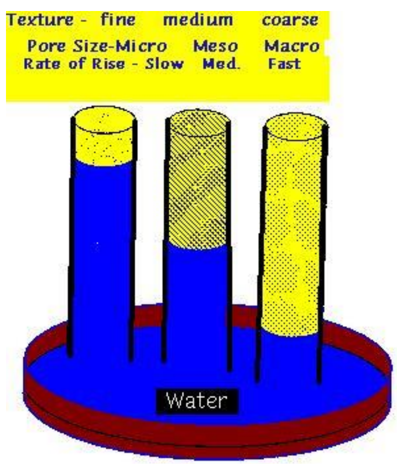
INTERPRETATION AND REQUIREMENTS FOR *Irrigation Water*

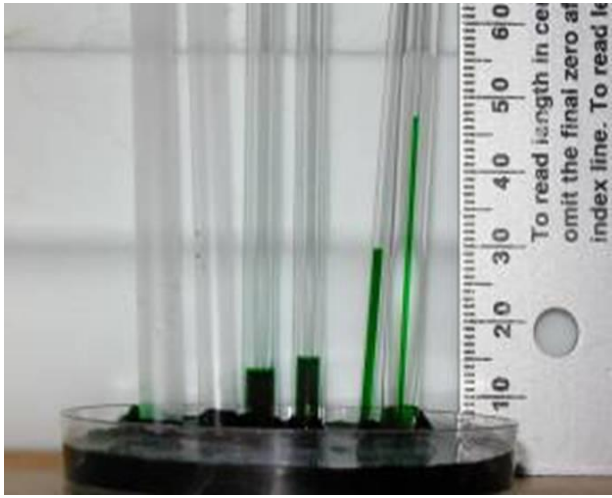
Water of this quality is suitable for use on most crops under most conditions. A problem may eventually arise with continued use of this water on very heavy soils where essentially no leaching occurs. If rainfall is sufficient, it will dilute the salts and reduce the hazard. If sodium is the main problem, gypsum can be used to help remedy the problem.

Signature

Capillary Migration?

- Capillarity can be described as the migration of soil moisture against the forces of gravity
  - Occurs in unsaturated soil environments
- Three contributing factors of capillary action
  - Pore size in the soil matrix
  - Surface tension of soil water
  - Wettability of soil mineral particles





Capillary Migration

- Capillary action causes the unexpected migration of brine within the soil
  - Has proven to negate remediation efforts
  - The same forces causing the vertical migration of brine also cause the LATERAL migration of brine
- Helps explain the persistence and growth of brine scars
- Brine components must be driven well beyond the plant root zone in the long term to allow revegetation

Guidance on estimated capillary rise

Handbook of Drainage Principles (OMAF, Pub. 73)

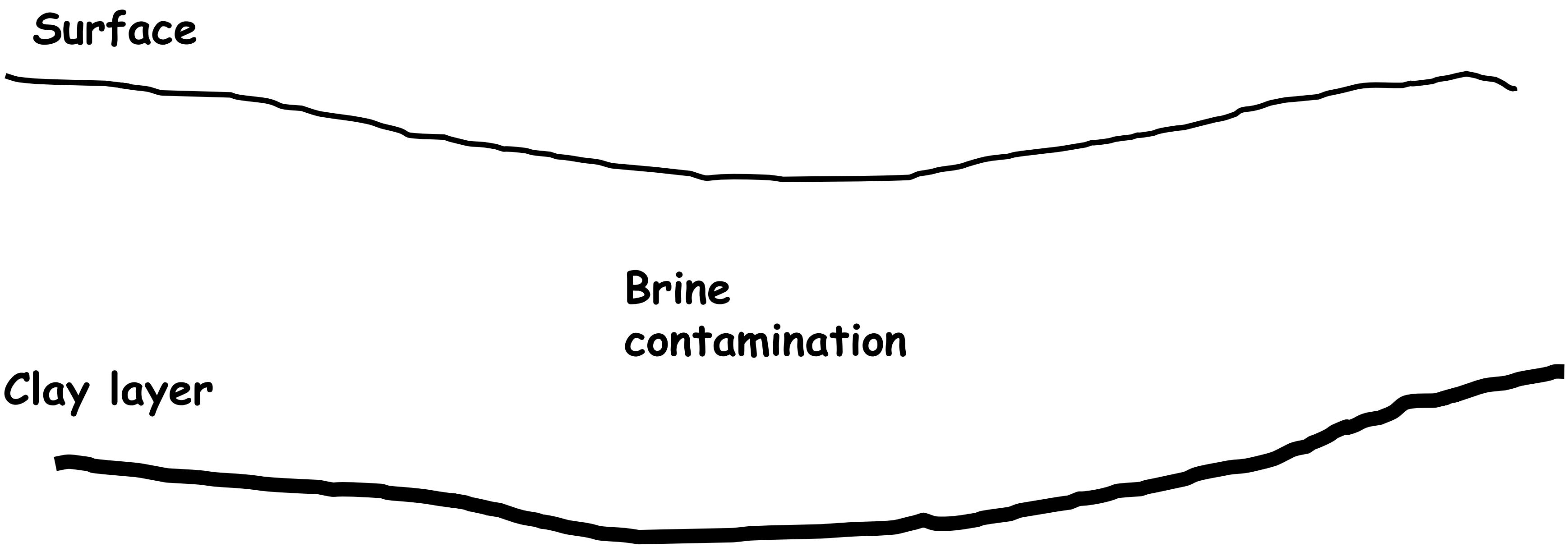
Soil type	Capillary rise (inches)
Very coarse sand	0.8
Coarse sand	1.6
Medium sand	3.2
Fine sand	6.8
Very fine sand	16.0
Silt	40.0
Clay	> 40.0

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

Drainage: the salt has to have somewhere to go

- What are the options?
  - Vertical drainage
    - Will it go deep enough?
    - Will it impact groundwater?
  - Lateral drainage
    - Will it cause additional damage?
    - Can I protect environmental receptors?

Where will the salt go?

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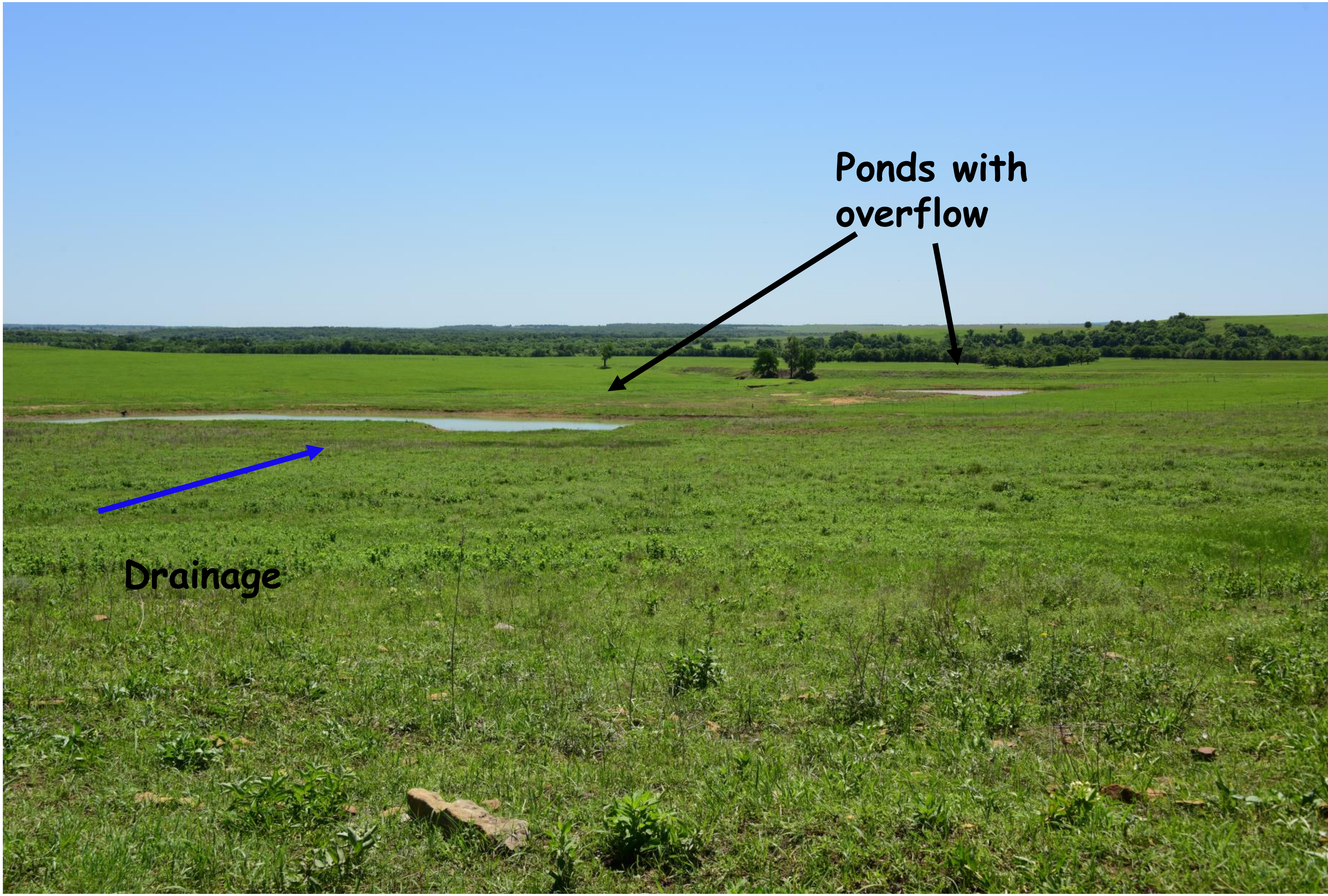
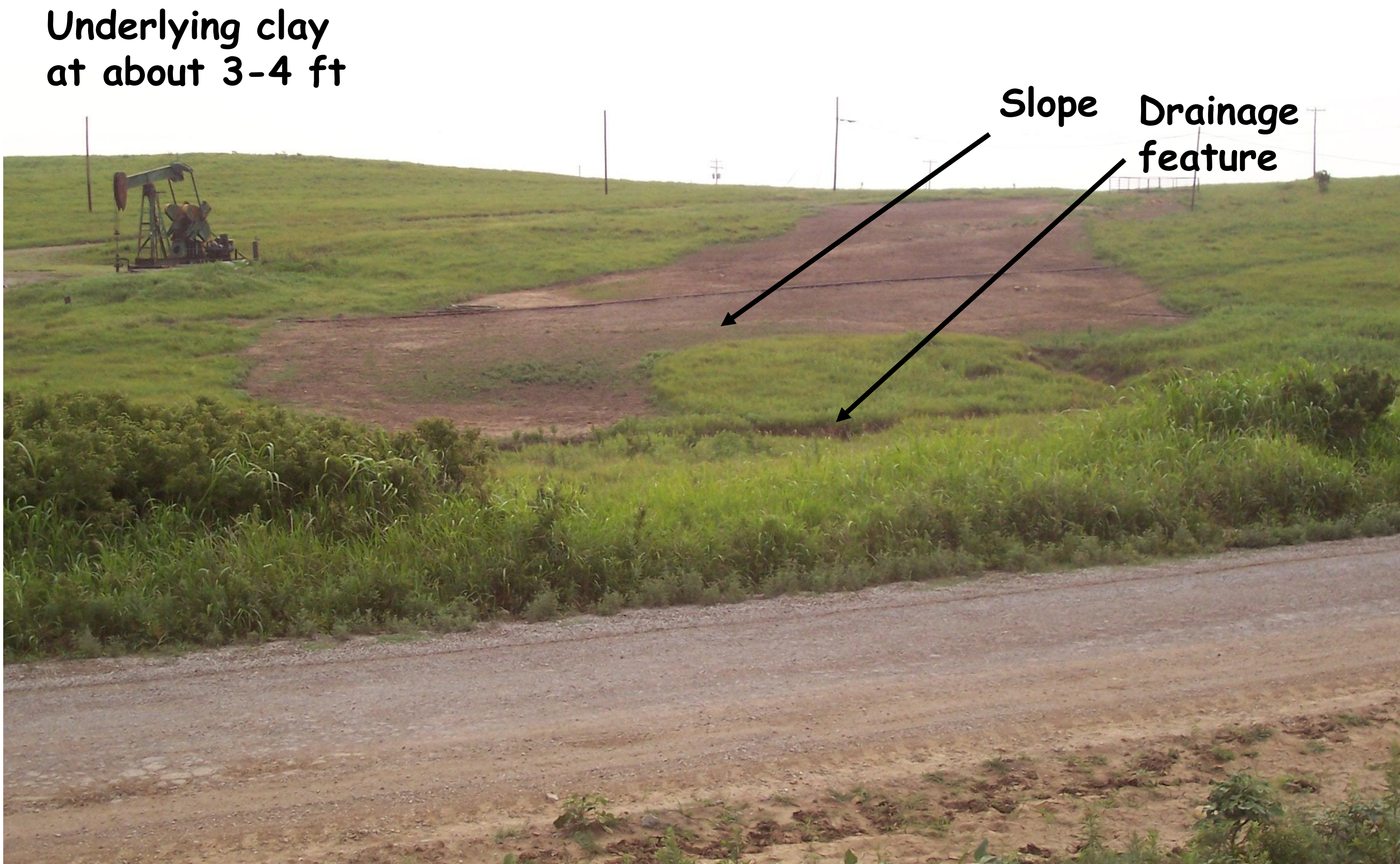
0 145 290 580 870 1,160
Meters
Legend

The salt has to have somewhere to go



Remediation using lateral drainage



7 months of treatment

20 months of treatment (June)

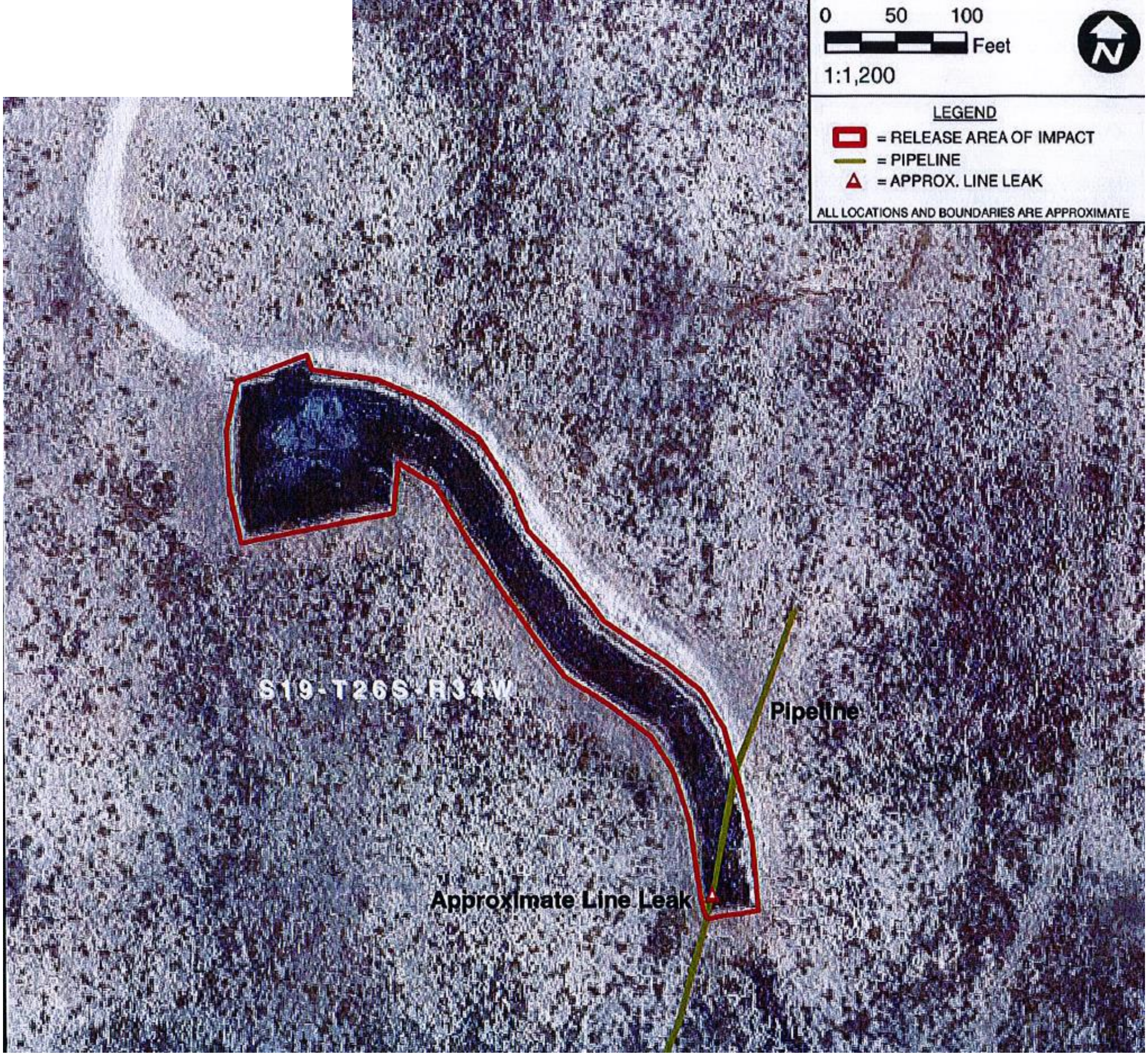
Factors affecting risk to groundwater from surface brine release

- Chloride mass
- Aquifer thickness
- Depth to groundwater
- Effective width of surface impact
- Annual precipitation
- Pan evaporation index
- Surface soil type top 3 ft
- Slope
- Vadose zone material (from 3 ft to aquifer)
- Hydraulic conductivity of aquifer

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
Hydraulic conductivity of aquifer	Affects dilution through mixing; faster groundwater flow rates mean more dilution of chloride
Effective width of surface impact	Greater spreading of spill results in greater dilution of salt when it reaches groundwater
Annual rainfall and evaporation index	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

Relative risk to groundwater

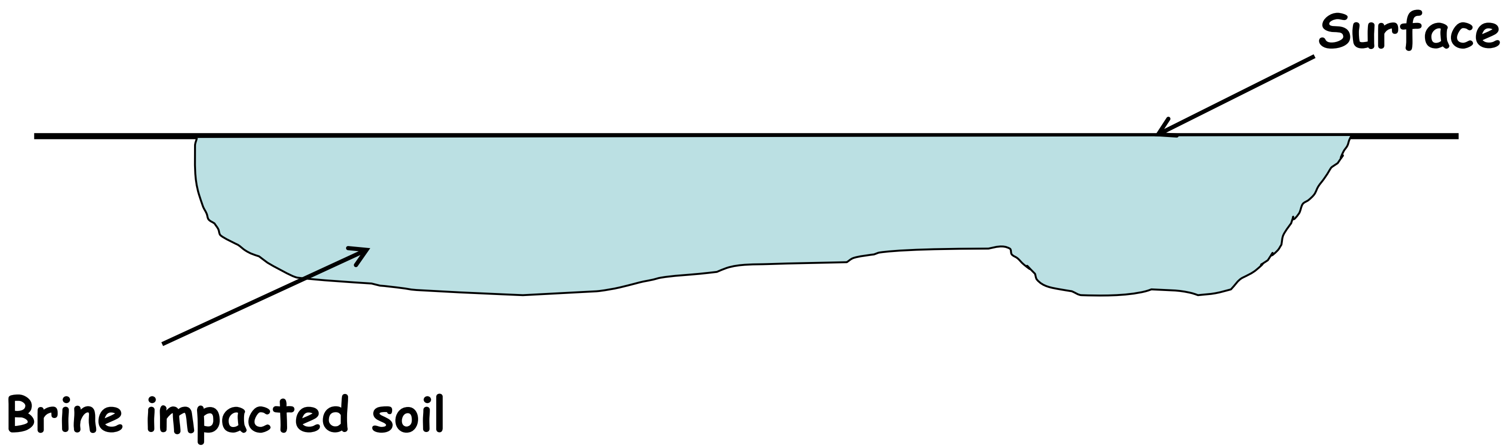
Parameter	Relative risk factor
Chloride mass	10
Aquifer thickness	7
Depth to groundwater	3
Effective width of surface impact	3
Annual precipitation	2
Pan evaporation index	2
Surface soil type top 3 ft	4
Slope	1
Vadose zone material (3 ft to aquifer)	5
Hydraulic conductivity of aquifer	4



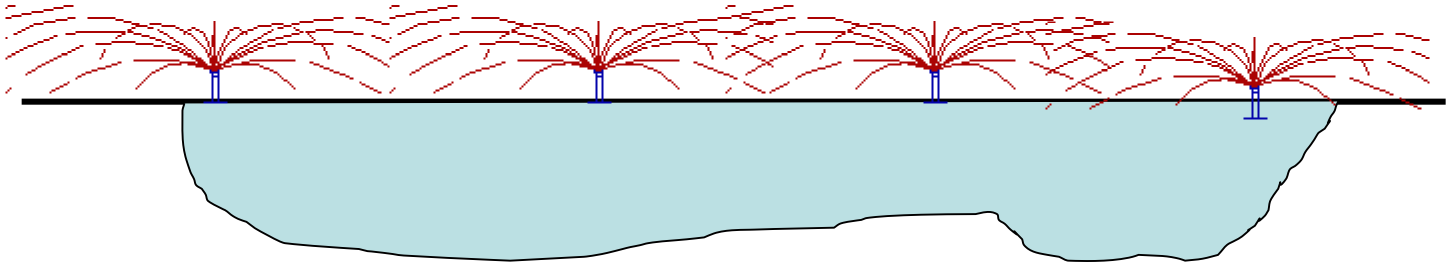
0
50
100
Feet
1:1,200
LEGEND
= RELEASE AREA OF IMPACT
= PIPELINE
= APPROX. LINE LEAK
ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE
S19-T26S-R34W
Pipeline
Approximate Line Leak

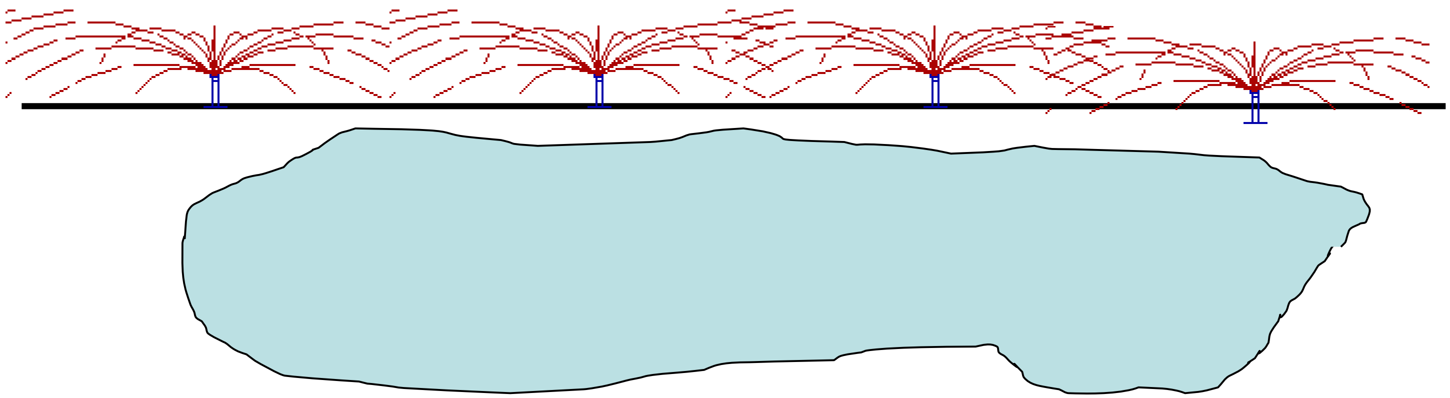
- Site characteristics argue for vertical migration of salts below the root zone
  - Clay lens below root zone are protective of groundwater
  - Sandy soil minimizes potential for capillary suction
  - Low recharge rate minimizes movement of salt in the subsurface under natural rainfall conditions
  - Deep groundwater results in spreading and therefore dilution of any salt that gets to the aquifer
  - High hydraulic conductivity results in rapid dilution of any salt reaching the aquifer
- Irrigation required to drive salts below the root zone

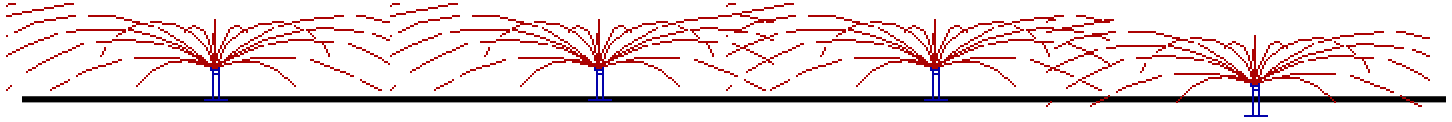
Remediation strategy for this site

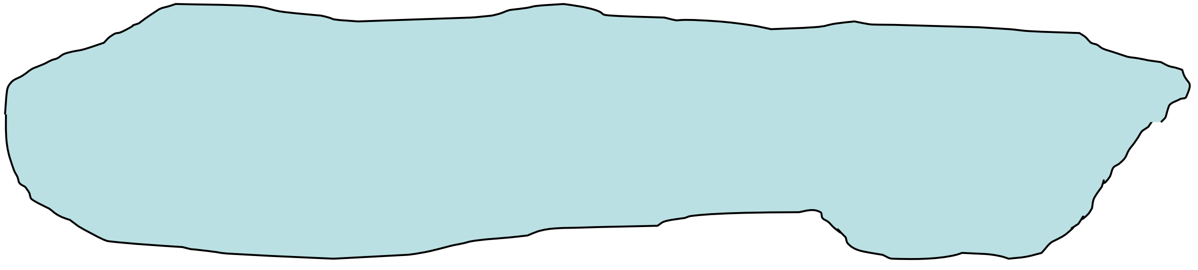


Incorporate calcium, irrigate to push brine well below root zone

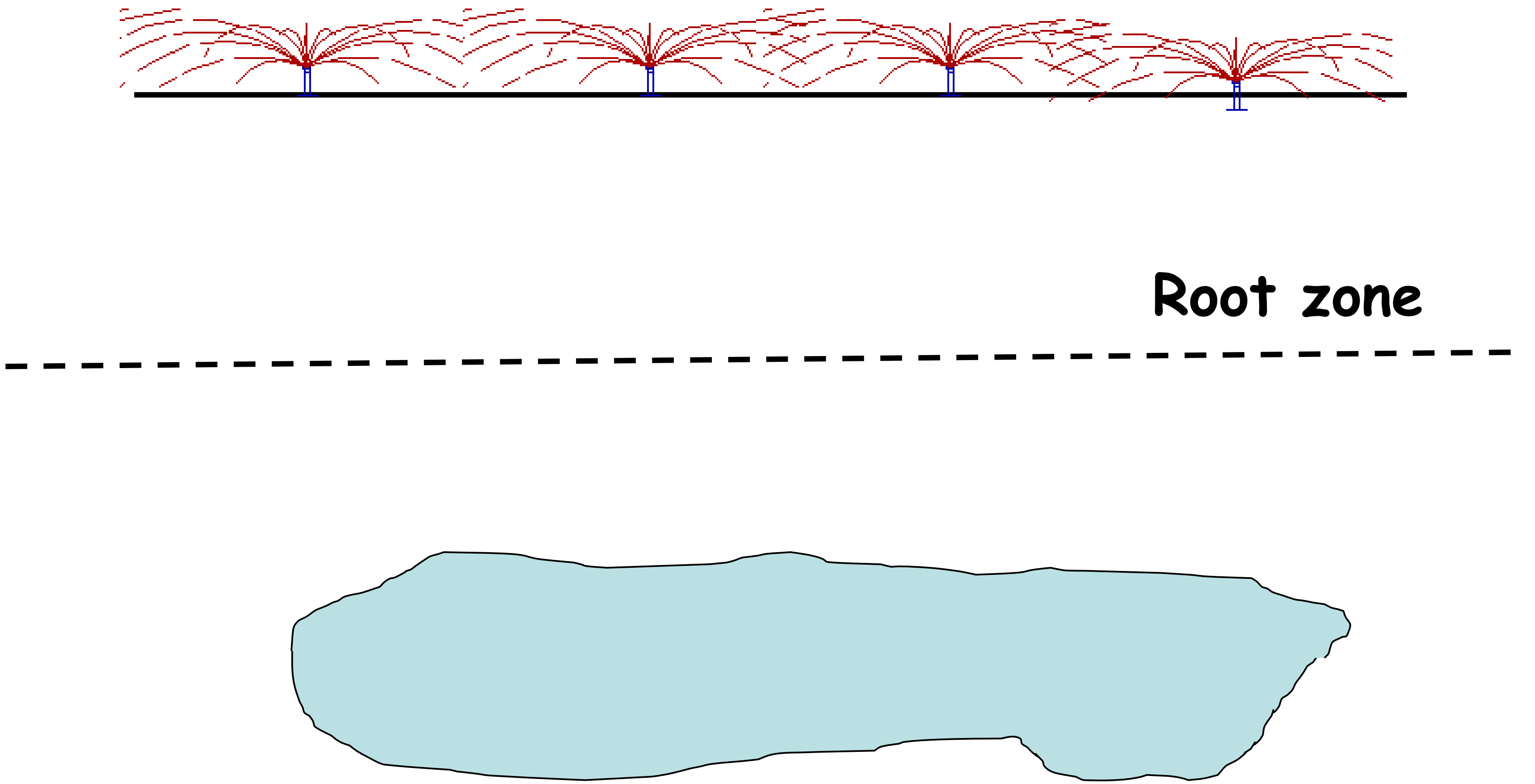




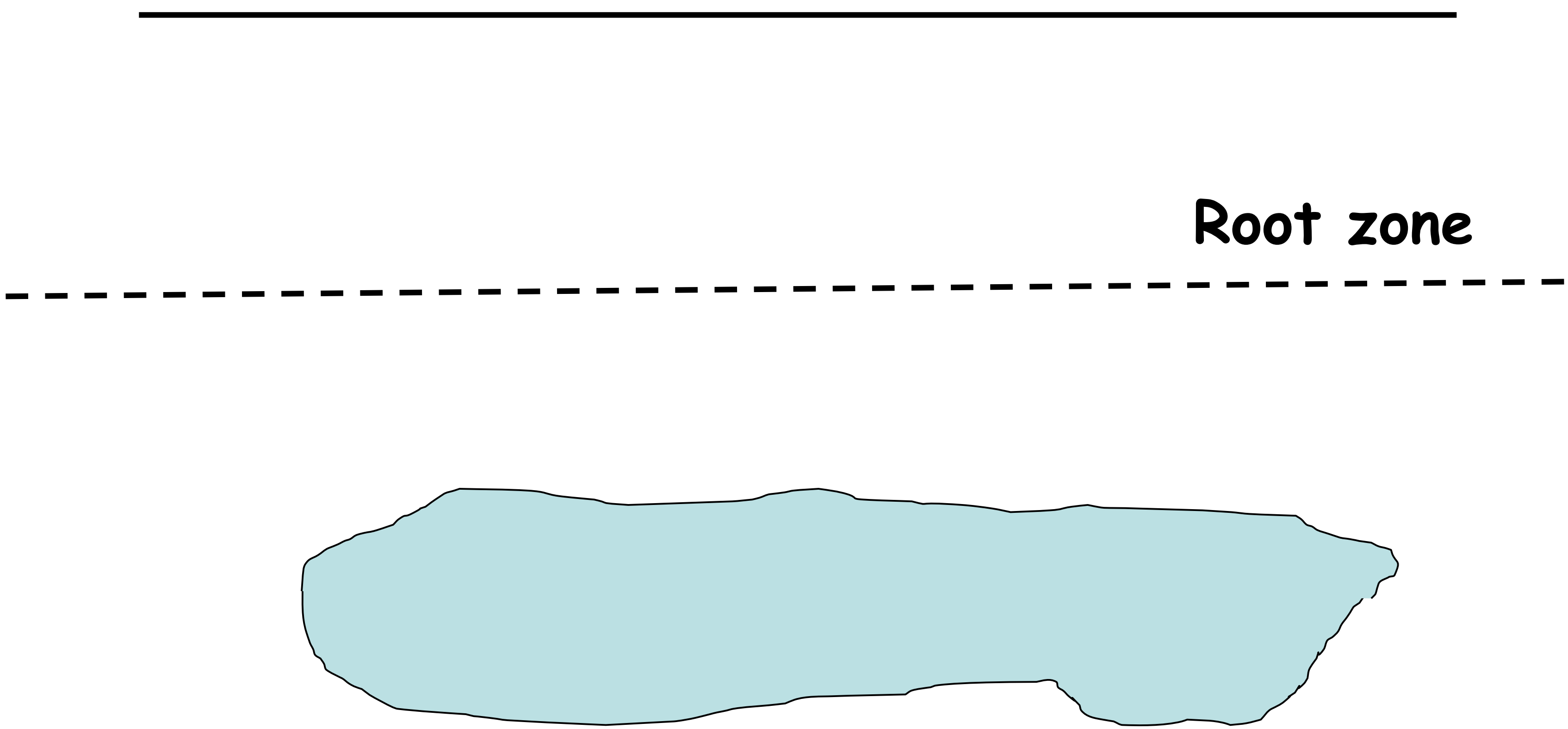




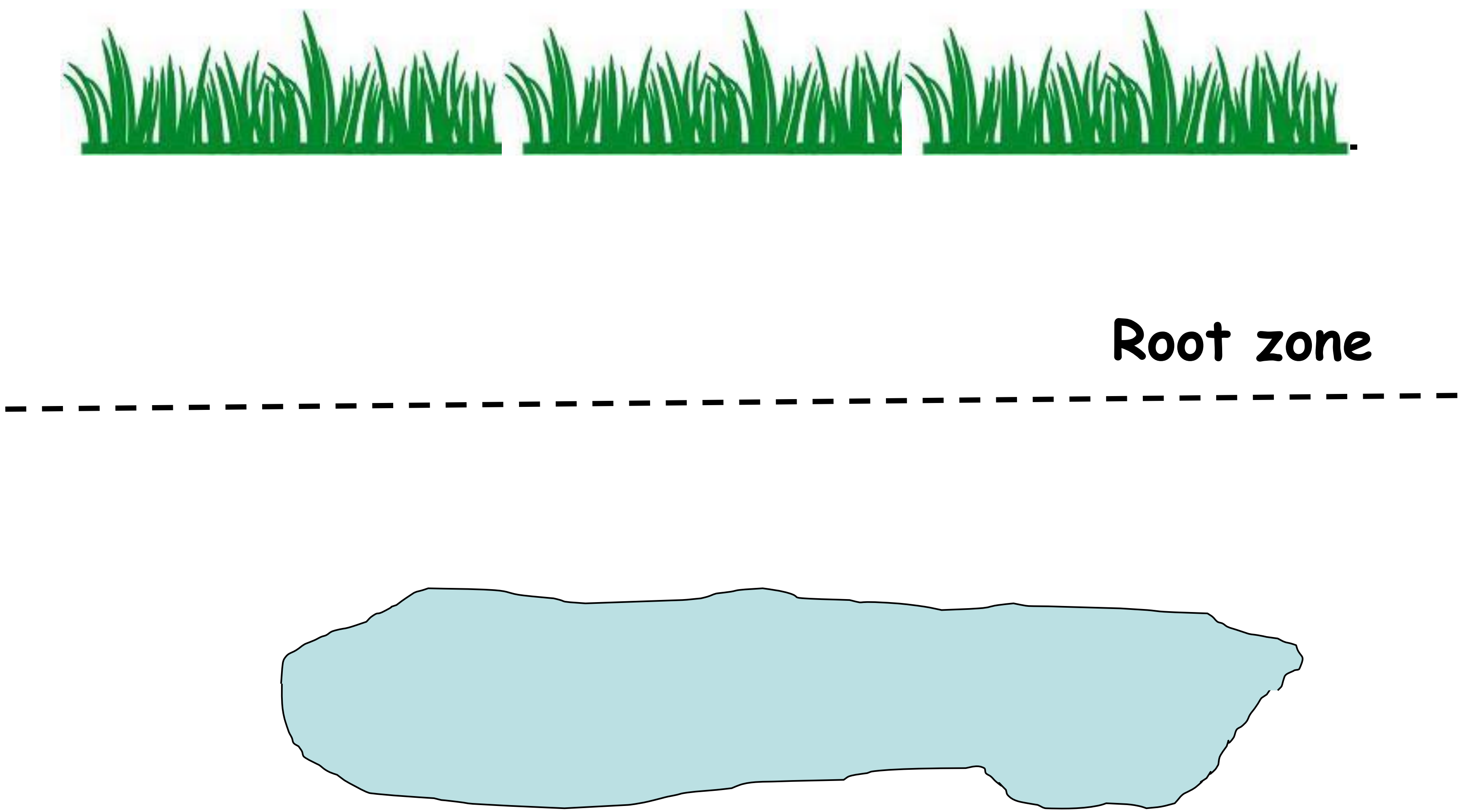
Move salt low enough in soil profile that capillary suction will not bring it back into the root zone.



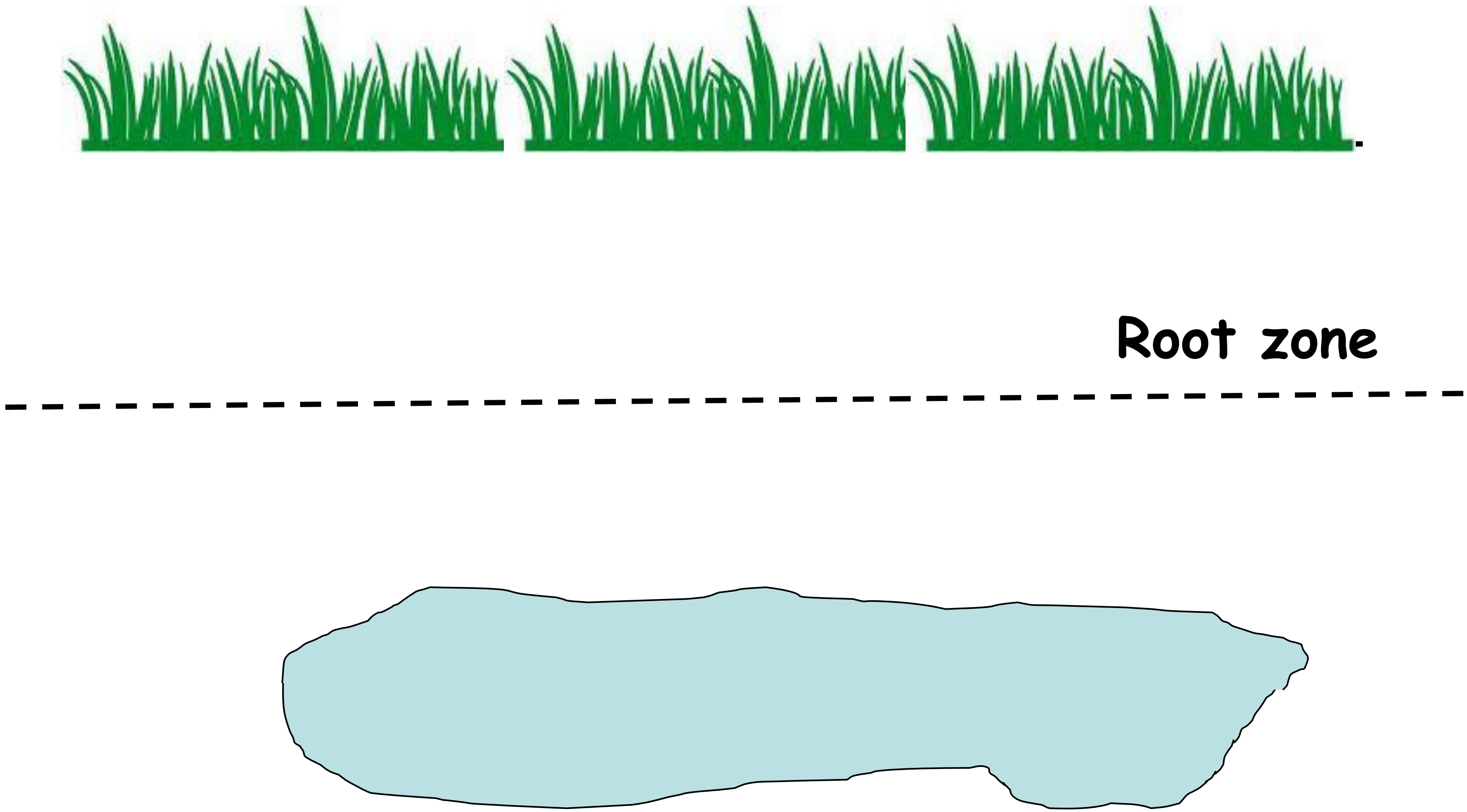
Withdraw heavy irrigation; seed, fertilize, and provide just enough water to establish vegetation cover



When vegetation established irrigate only enough to keep vegetation healthy; when plants mature withdraw artificial water

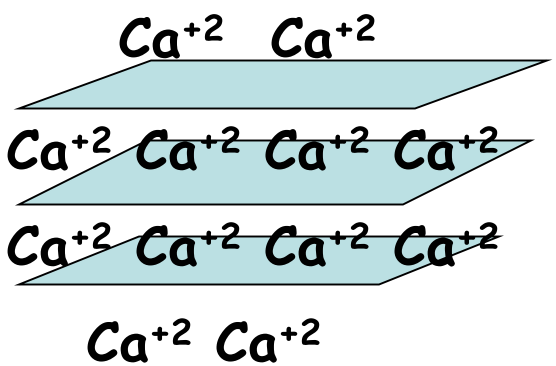


Evapotranspiration further decreases net recharge to aquifer further slowing any downward movement of brine

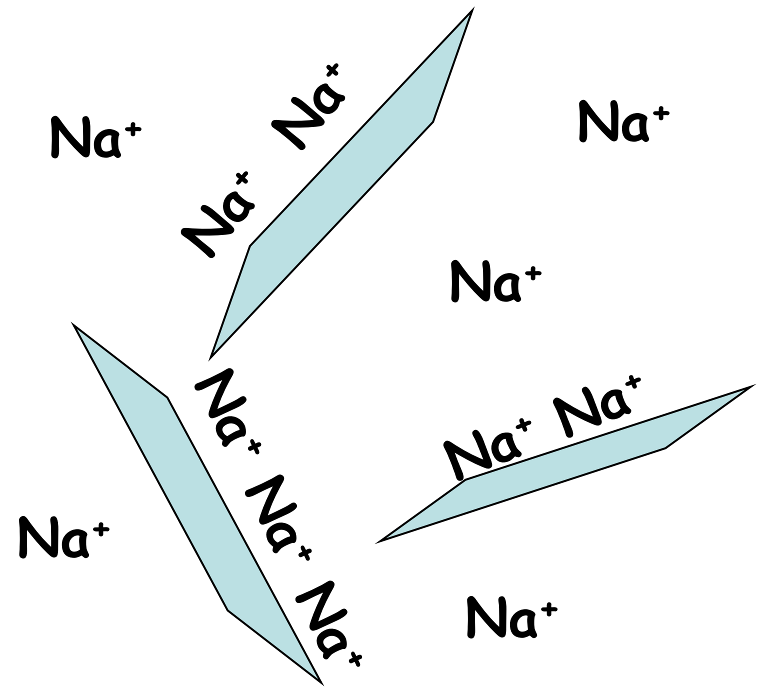


After 7 months of treatment

Sodicity and soil structure

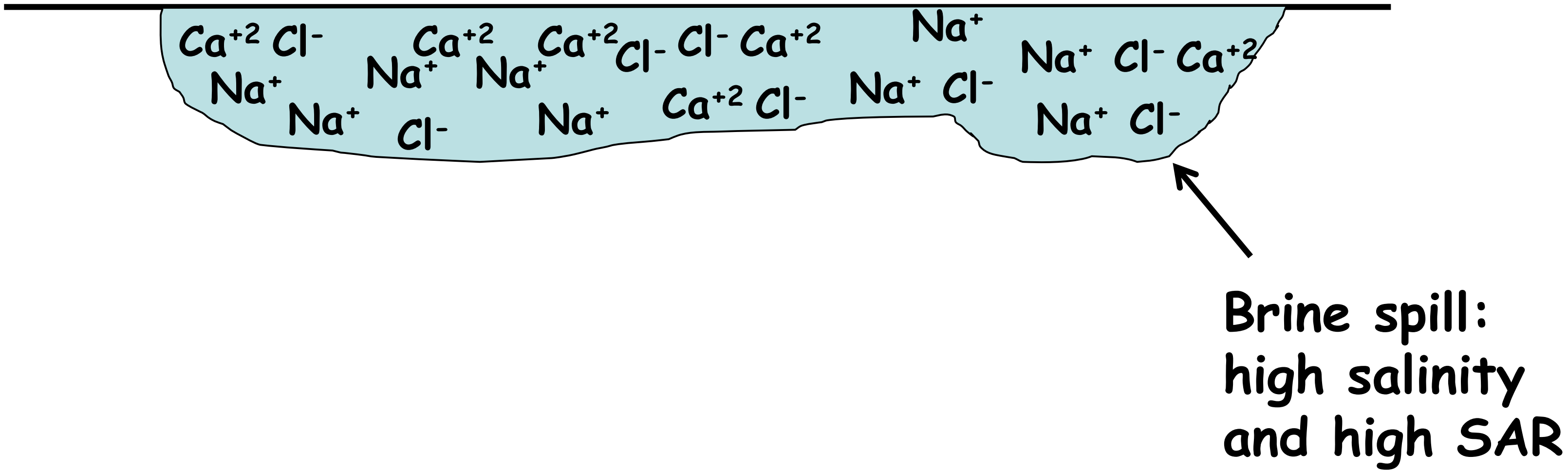


Clay particles or platelets in soil are held together by Ca^{+2} ions

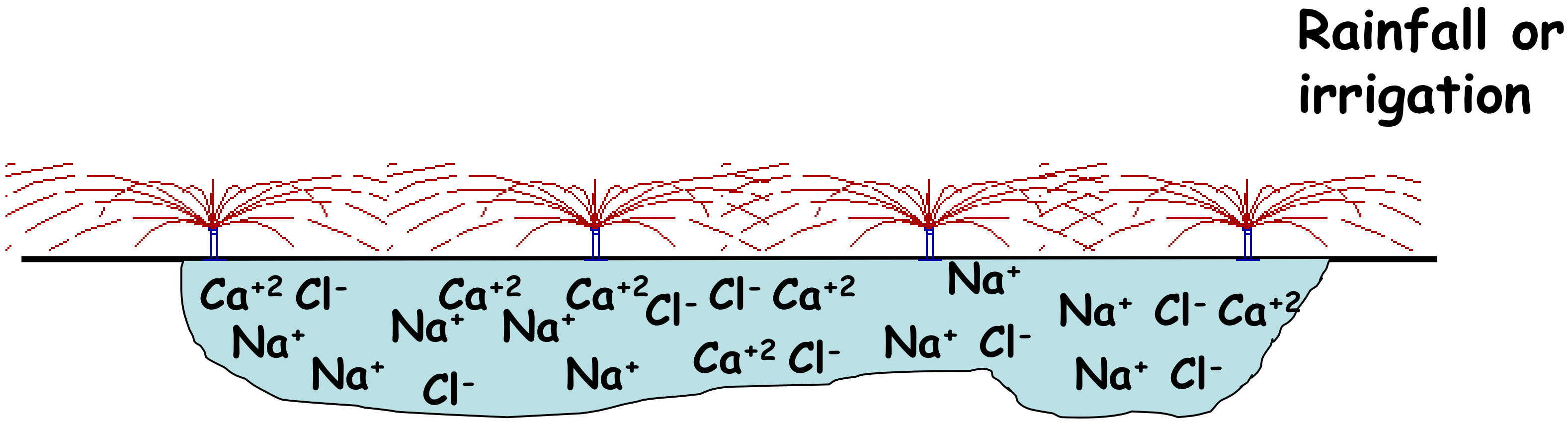


High concentrations of Na^{+} ions can displace the Ca^{+2} and cause the clay particles to disperse

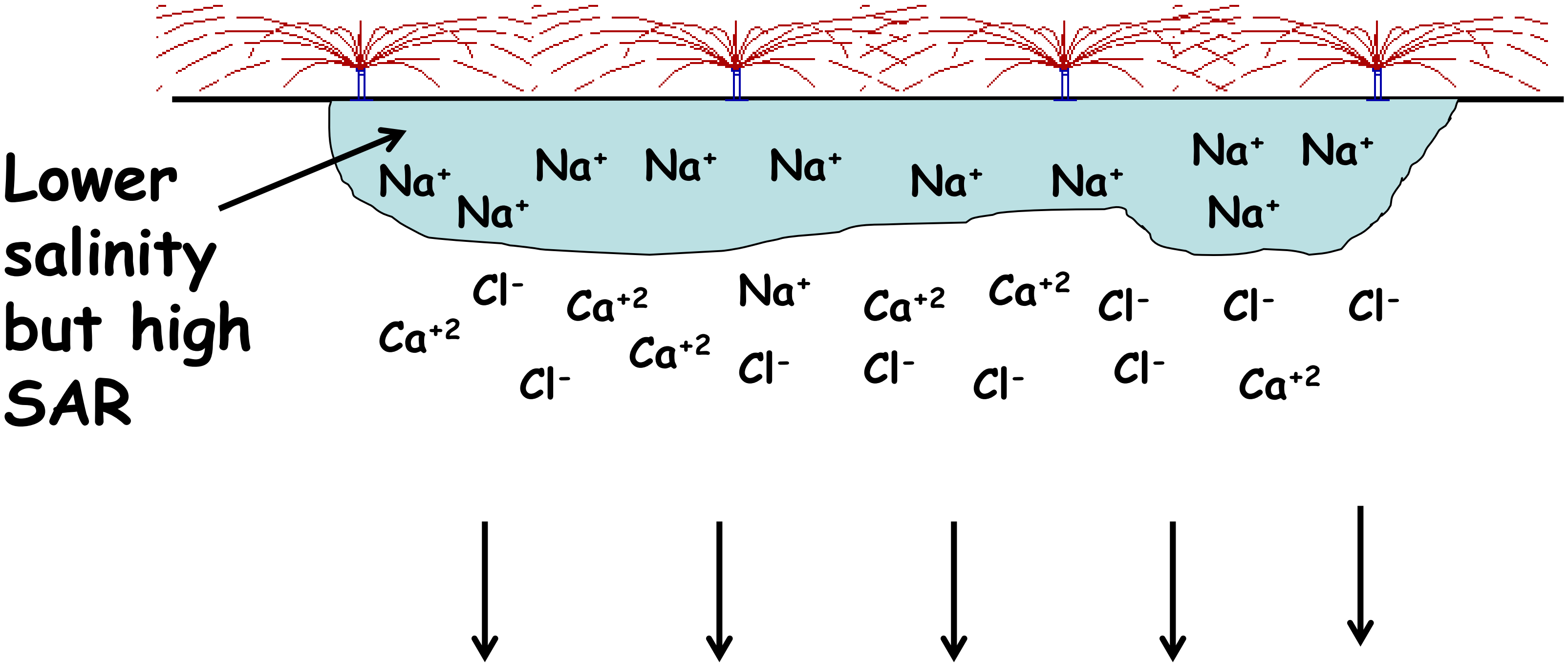
Effect of leaching on salinity vs sodicity



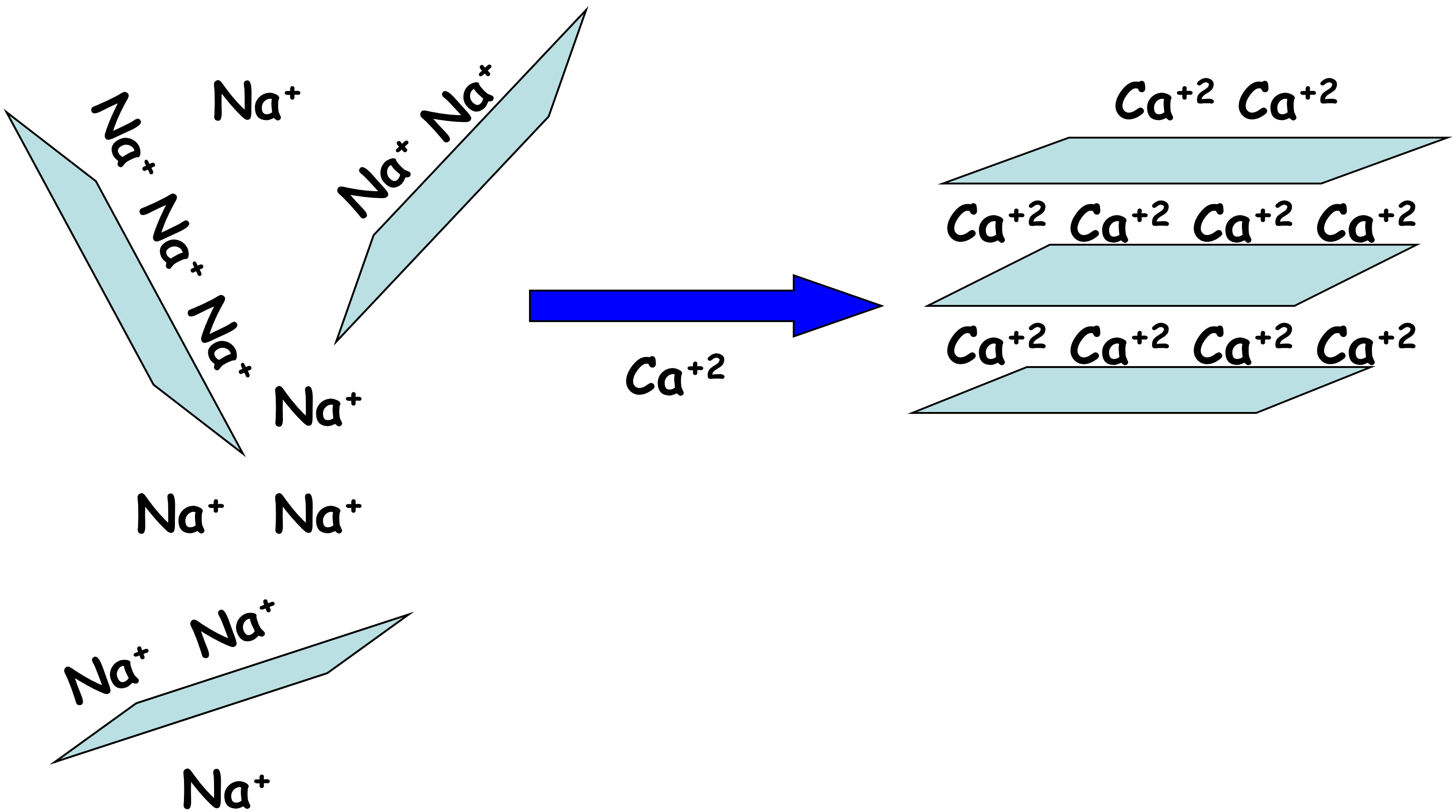
Effect of leaching on salinity vs sodicity



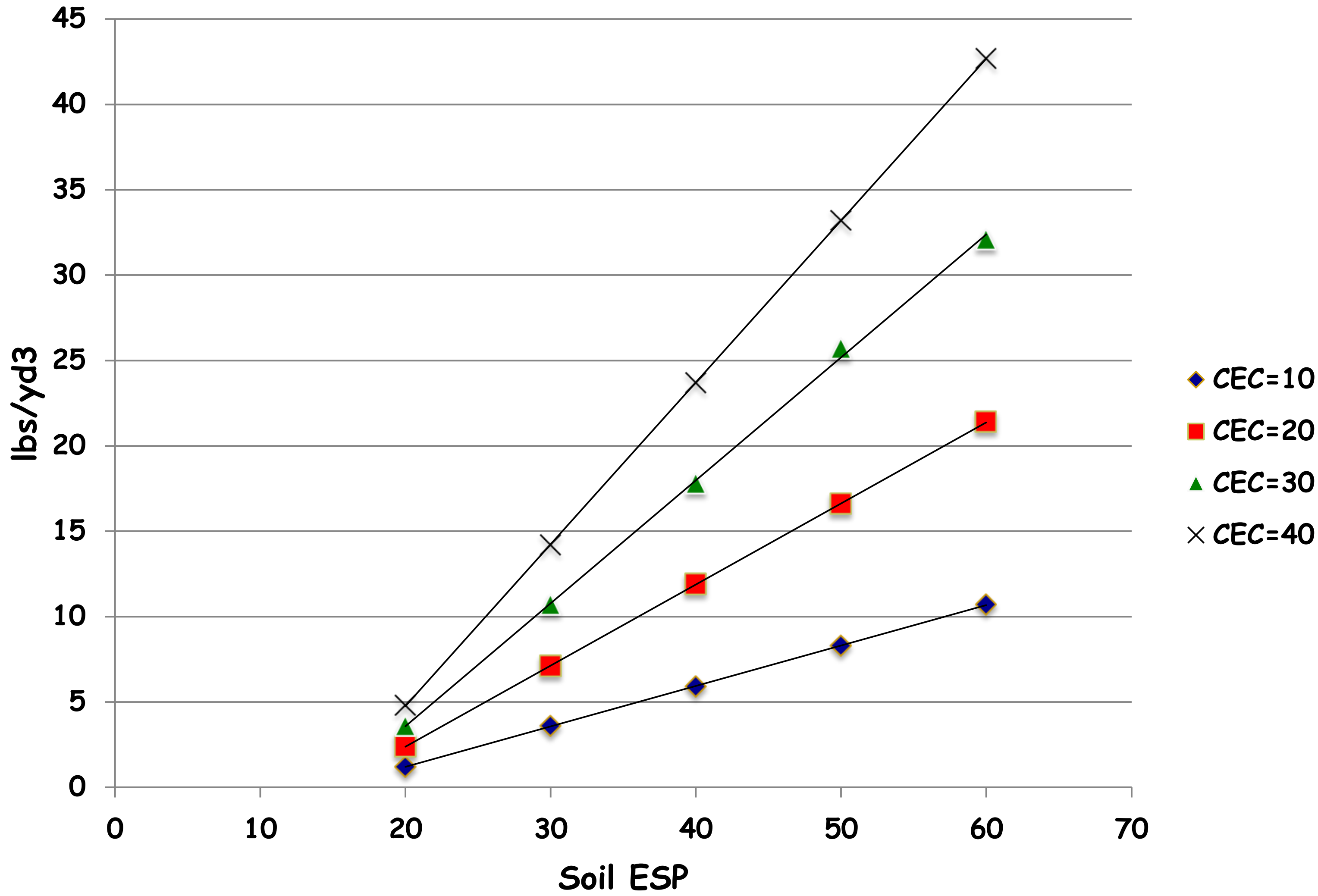
Effect of leaching on salinity vs sodicity



Calcium is required to fight sodicity

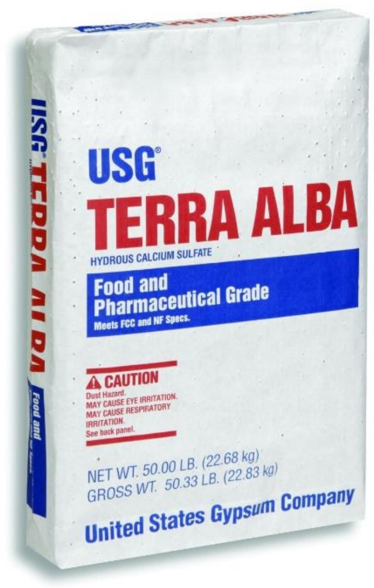


Gypsum application rates

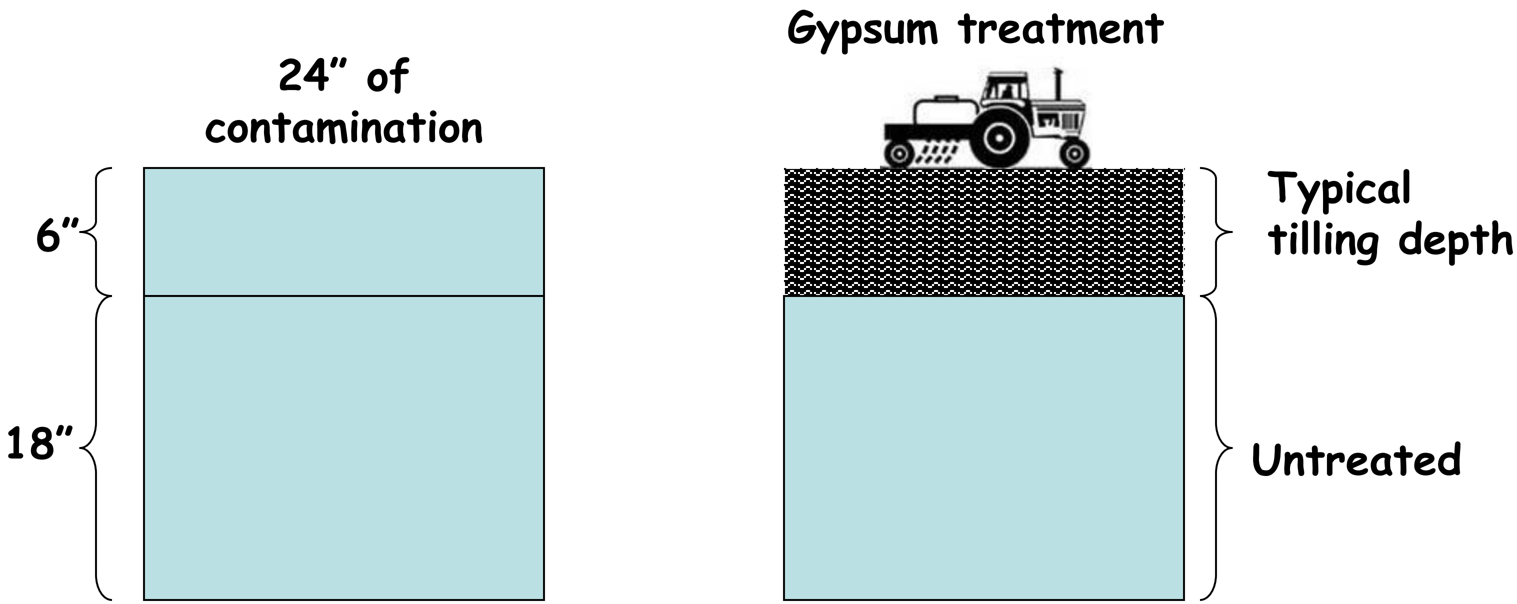


If you use gypsum remember that particle size is important

Use 400 mesh solution grade gypsum



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




DEERE


Any Questions?
SCENIC
TURNOUT
AHEAD