Remediation of Brine Spills- What We Learn from What Goes Wrong

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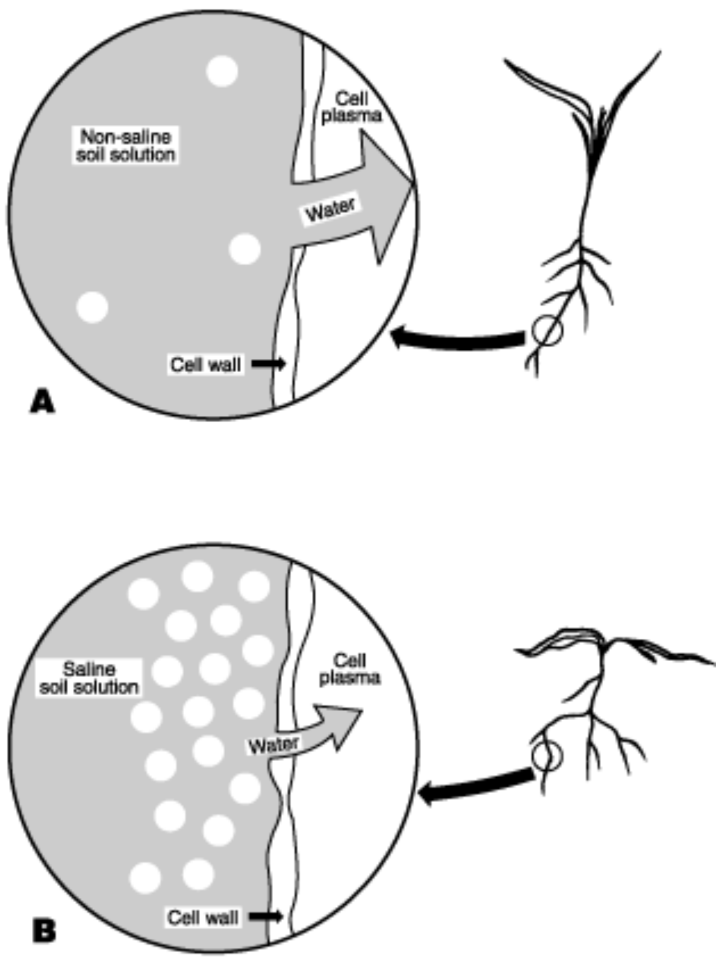
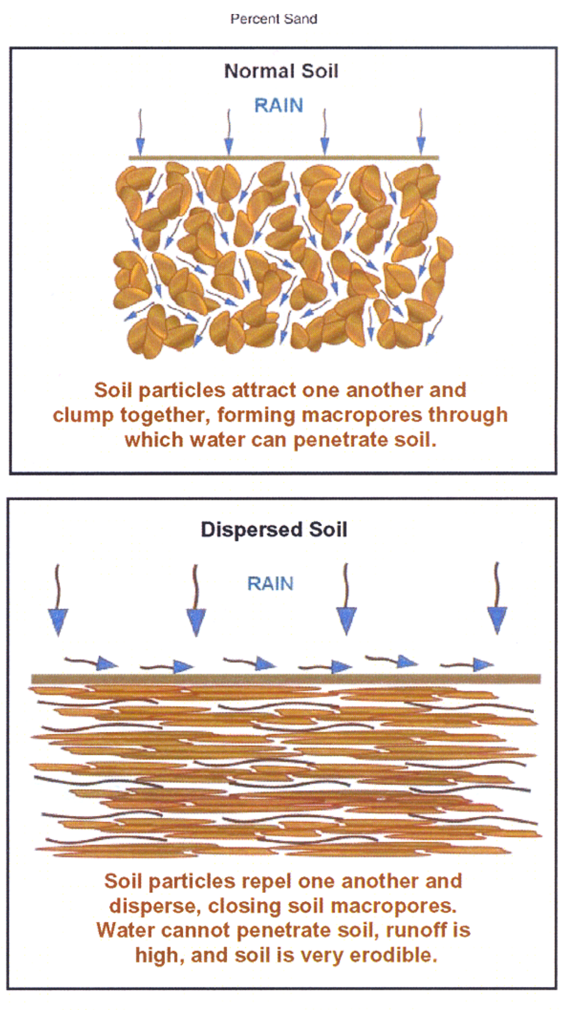
Spills of produced water or brine on soil result in two types of damage:



- 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

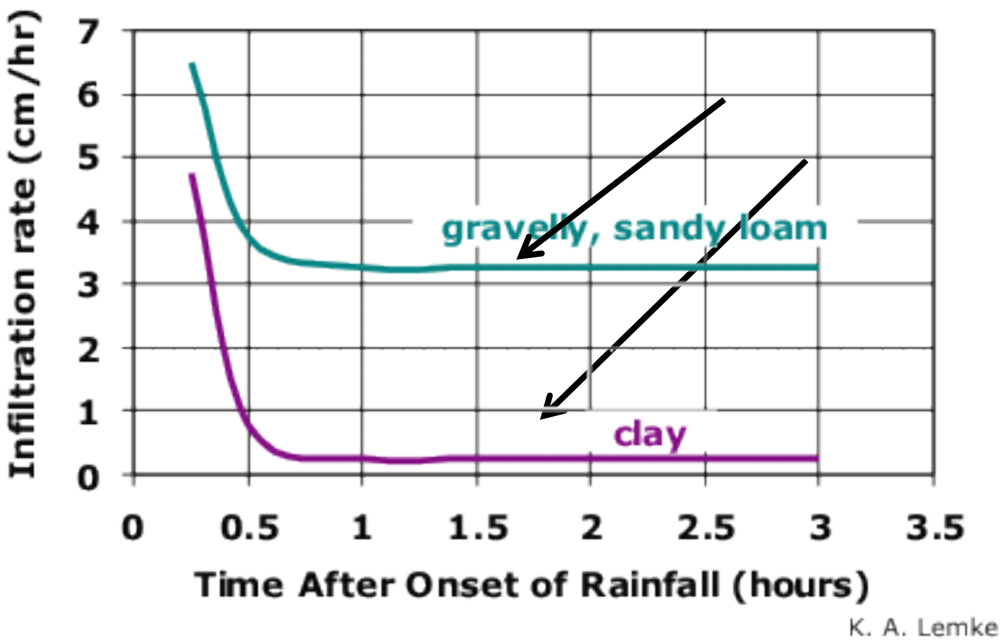
Remediation of a Brine Spill In Brief

- 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 (even recommended by some regulators): flushing with fresh water into a receiving body followed by disposal of salty water. There are two problems with this approach.

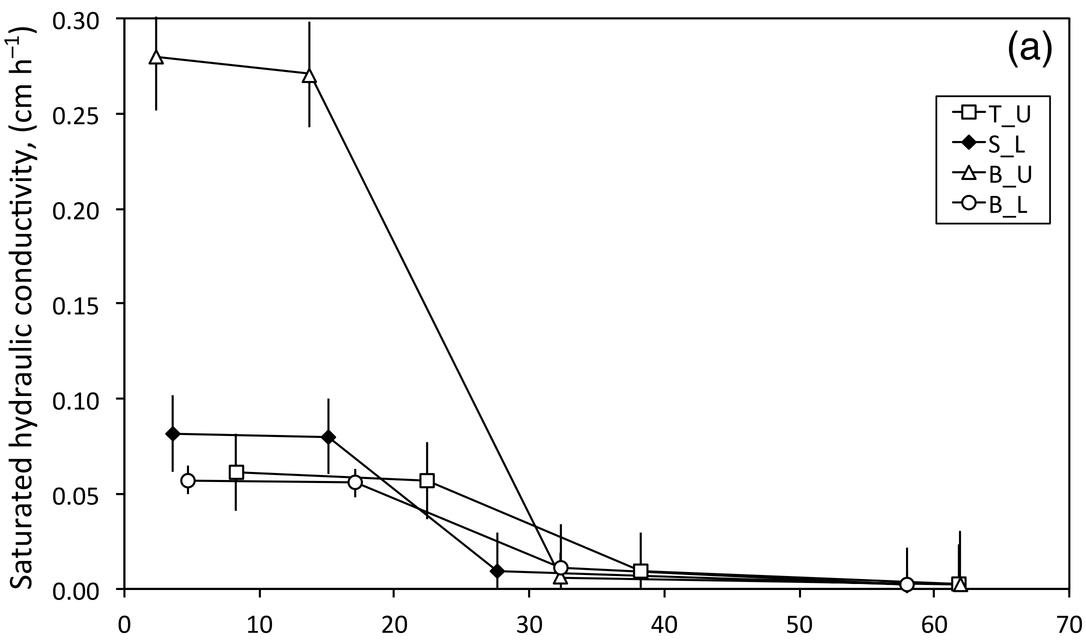


Capillary suction from dry soil can result if further damage

First response to a brine spill

- Fresh water on a brine spill accelerates dispersal of clays and results in severe reductions in soil permeability

Derby, *et al.* (2016), "Effects of oil field brine wastewater on saturated hydraulic conductivity of smectitic loam soils", Can. J. Soil Sci 96: 496-503



Pre – distilled water to steady state flow

BR – One pore volume of produced water (no change in hydraulic conductivity)

Post 1, 2 – distilled water to steady state flow (large decrease in hydraulic conductivity)

First response

- To prevent spreading contamination and causing clay dispersion:
  - Collect all standing water to prevent infiltration
  - Do not flush with fresh water
  - Initiate remediation, including incorporation of fine particle gypsum deep into the soil, **before it rains**
    - Inhibits clay dispersal
    - Restores proper cation balance in soil

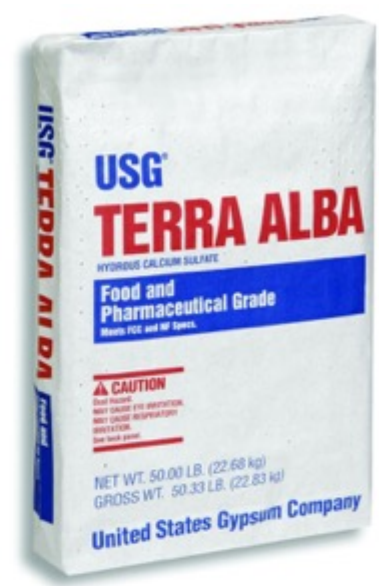
Minimizing effects of produced water spill on soil reduces cleanup costs

- 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

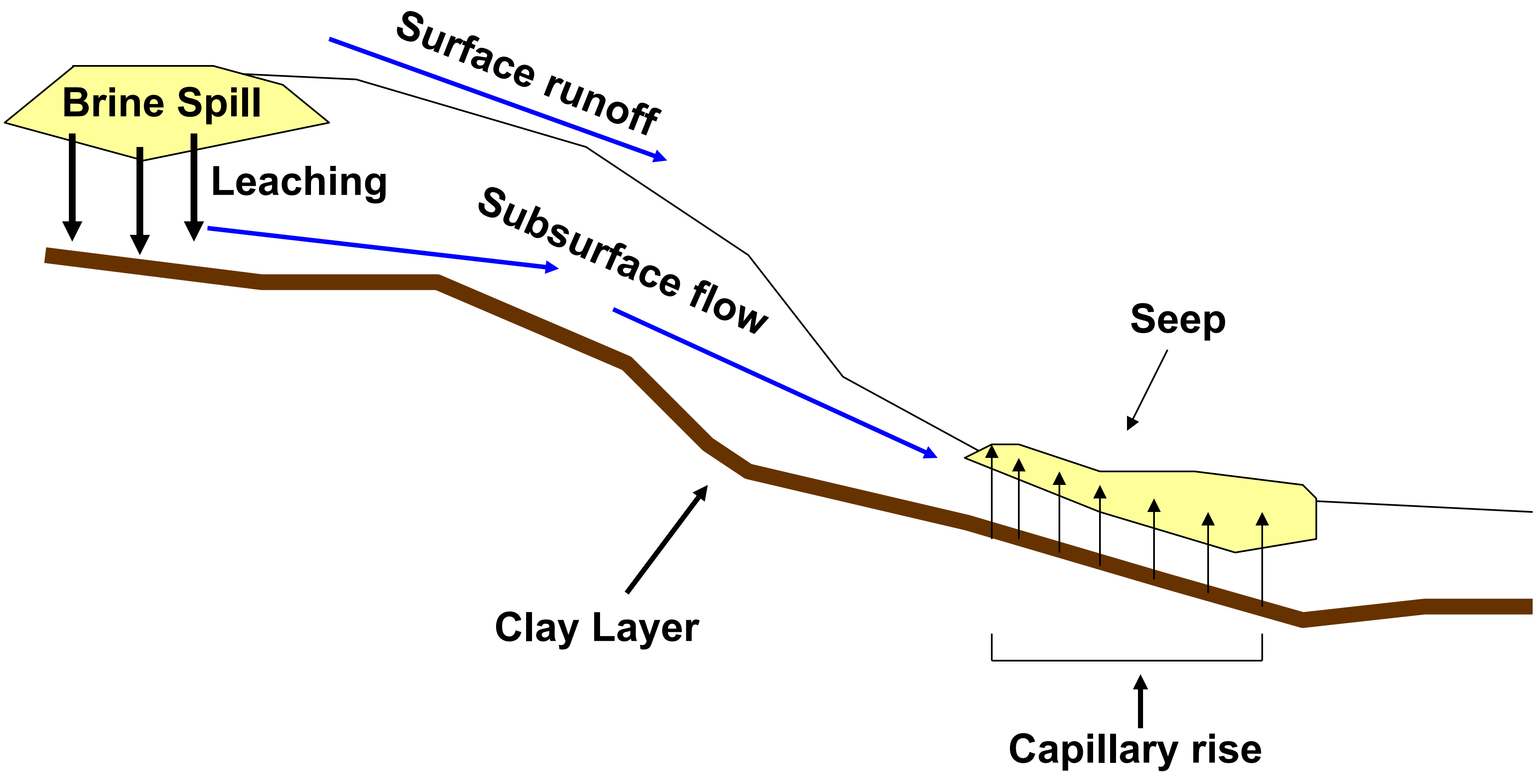
Particles Passing ASTM Sieves:

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

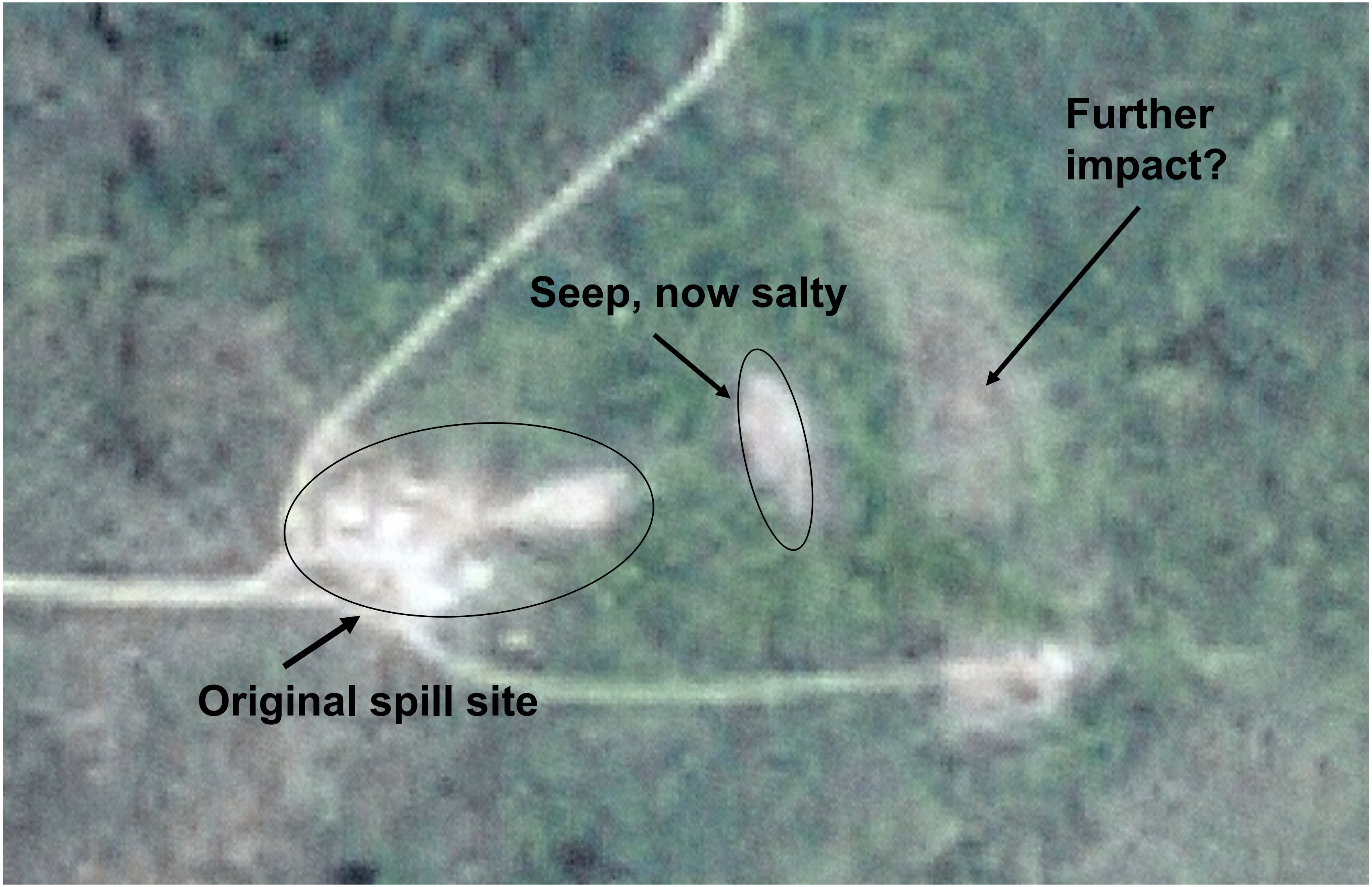
Site topography was an issue

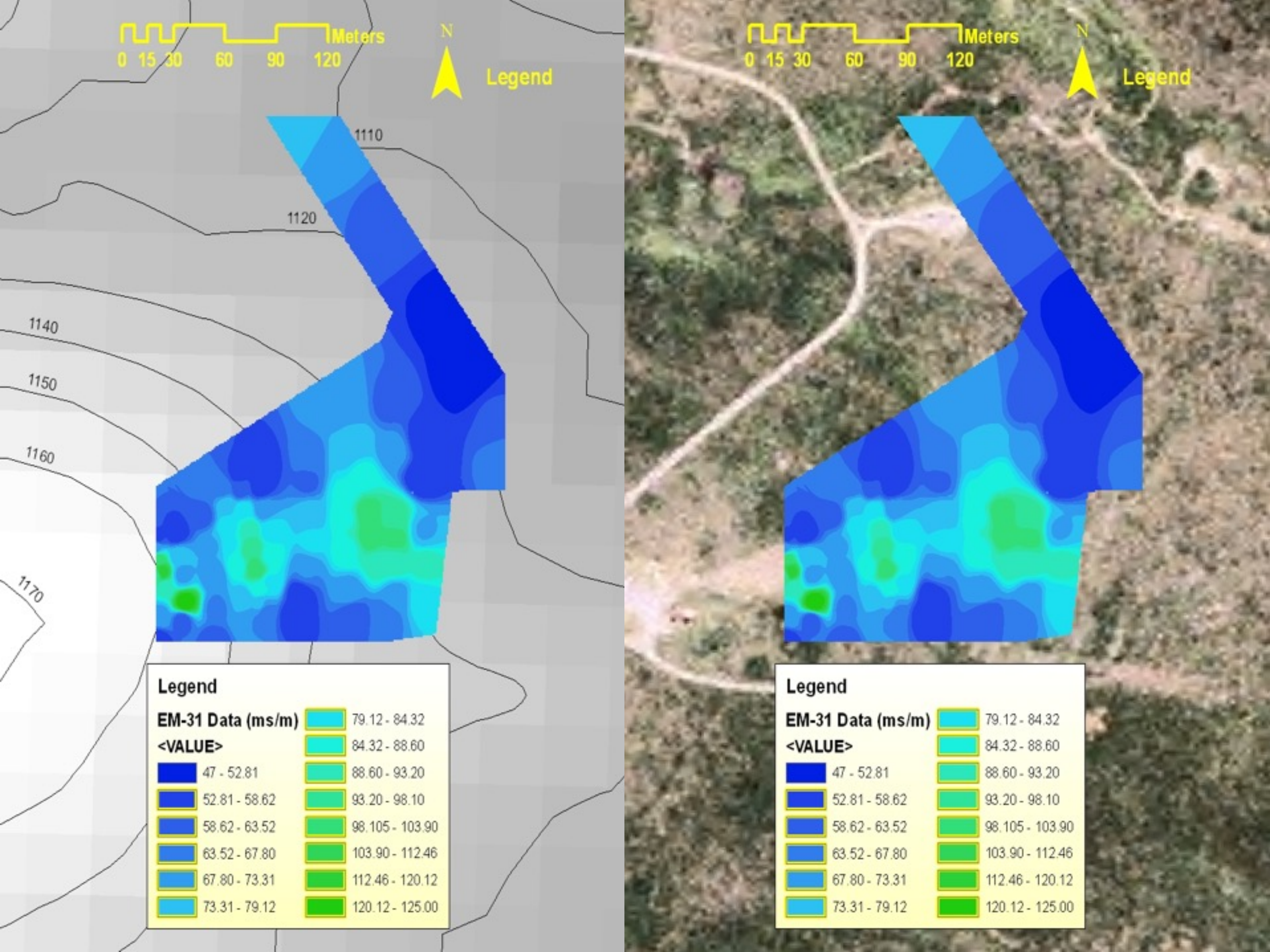


Recommended remediation method

- 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
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

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

Oklahoma State University Division of Agricultural Sciences and Natural Resources
045 Agricultural Hall
Stillwater, OK 74078
E-mail: soiltesting@okstate.edu
Website: www.soiltesting.okstate.edu

SOIL SALINITY REPORT

SUBLETTE CONSULTING, INC
8802 E. 98TH ST

TULSA, OK 74133

Name :

Location :

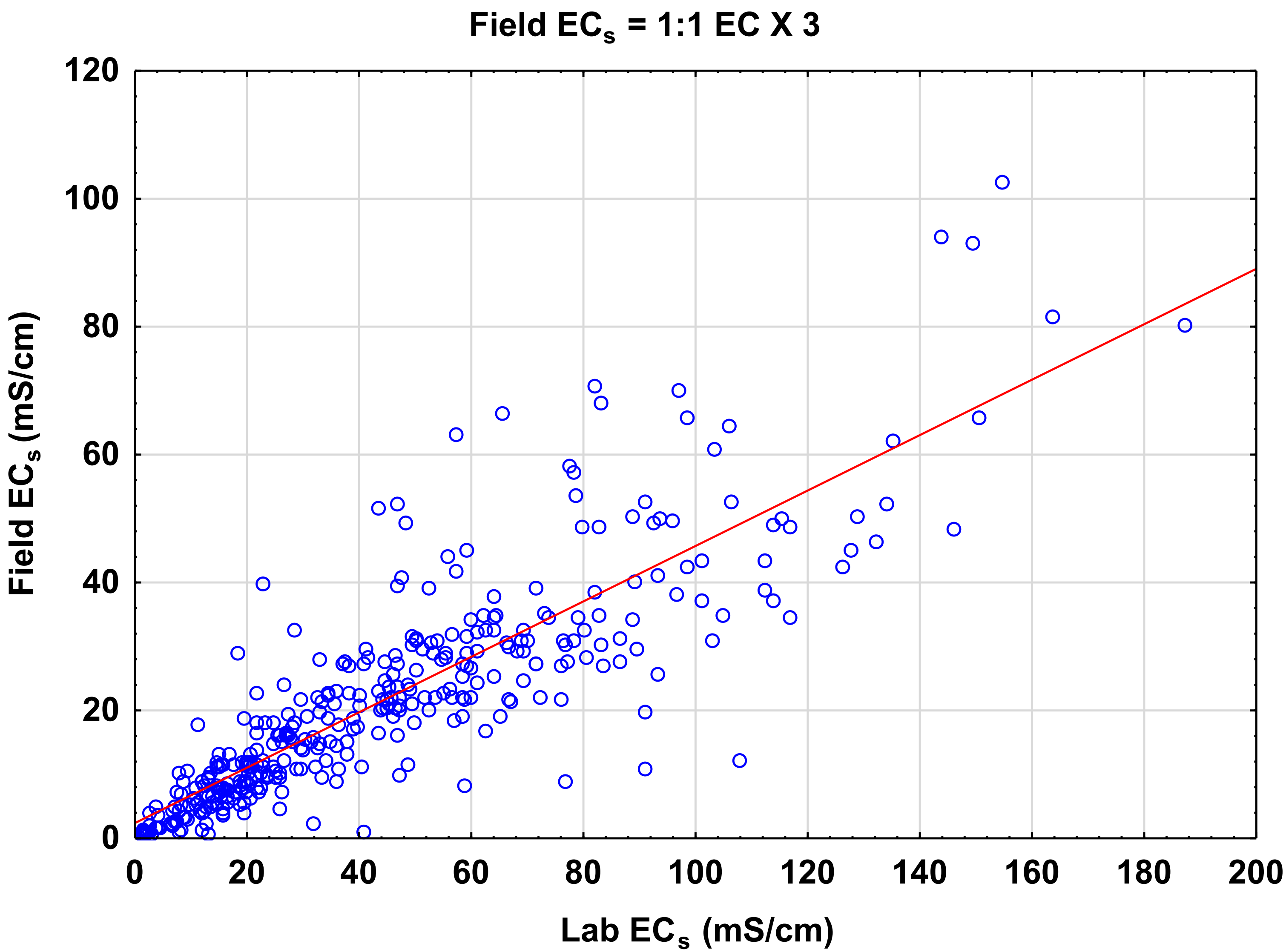
Lab ID No.: : 663008
Customer Code :
Sample No. : 805
Received : 9/19/2012
Report Date : 9/25/2012

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



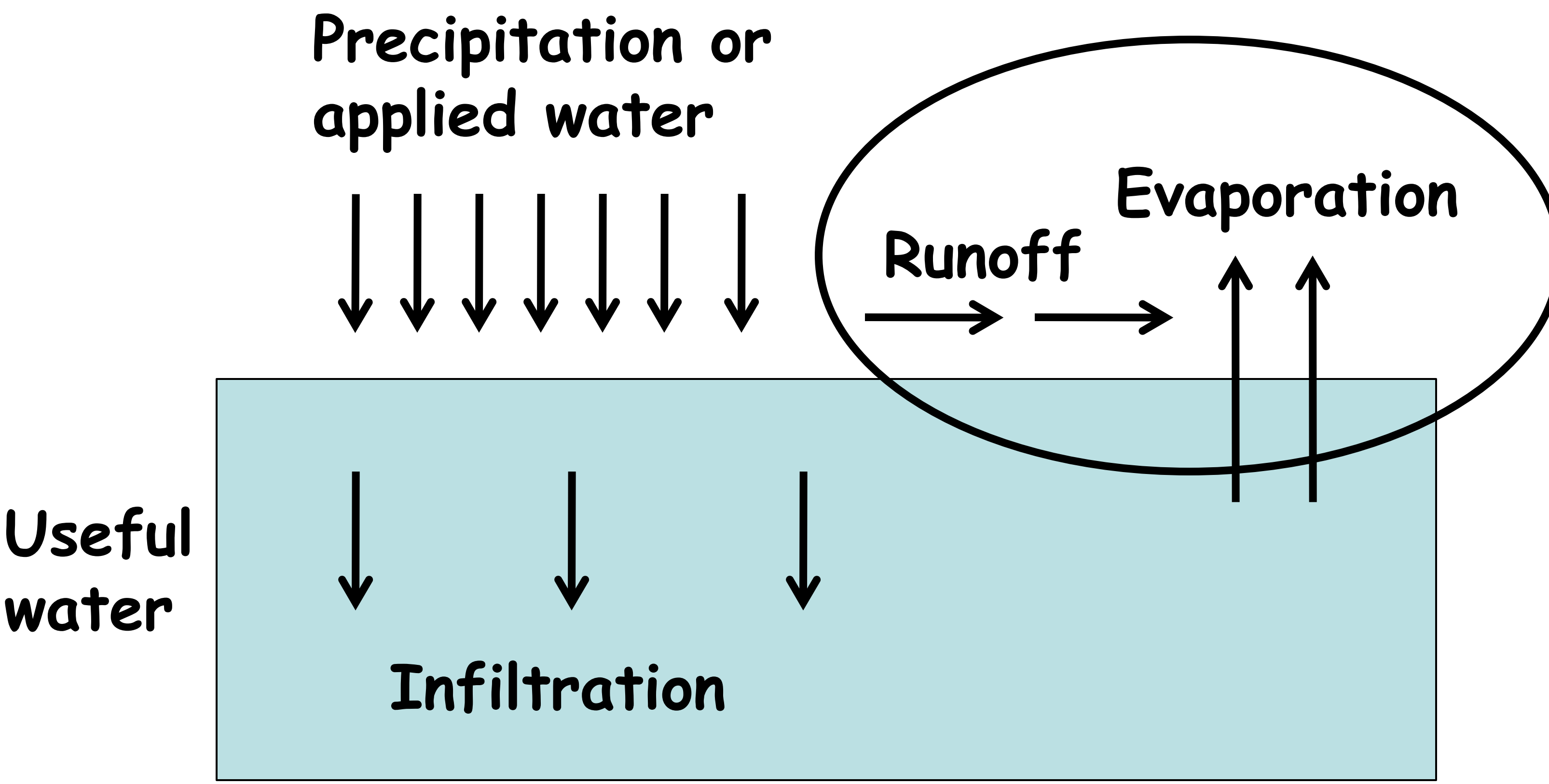
Water

- 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

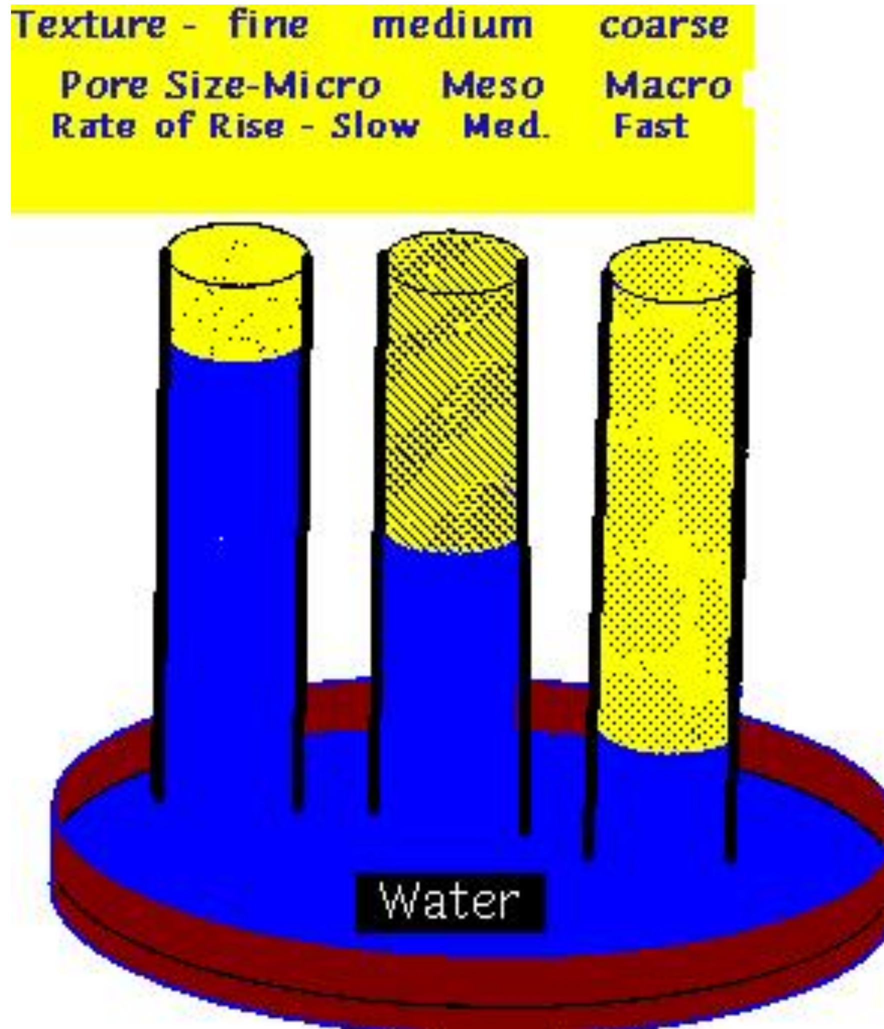
INTERPRETATION AND REQUIREMENTS FOR *Irrigation Water*

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

Beware of Capillary Migration

- Capillary suction moves salty leachate against the force of gravity
  - Height of capillaries inversely proportional to pore size
  - Capillary suction brings salt from depth into the root zone



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)

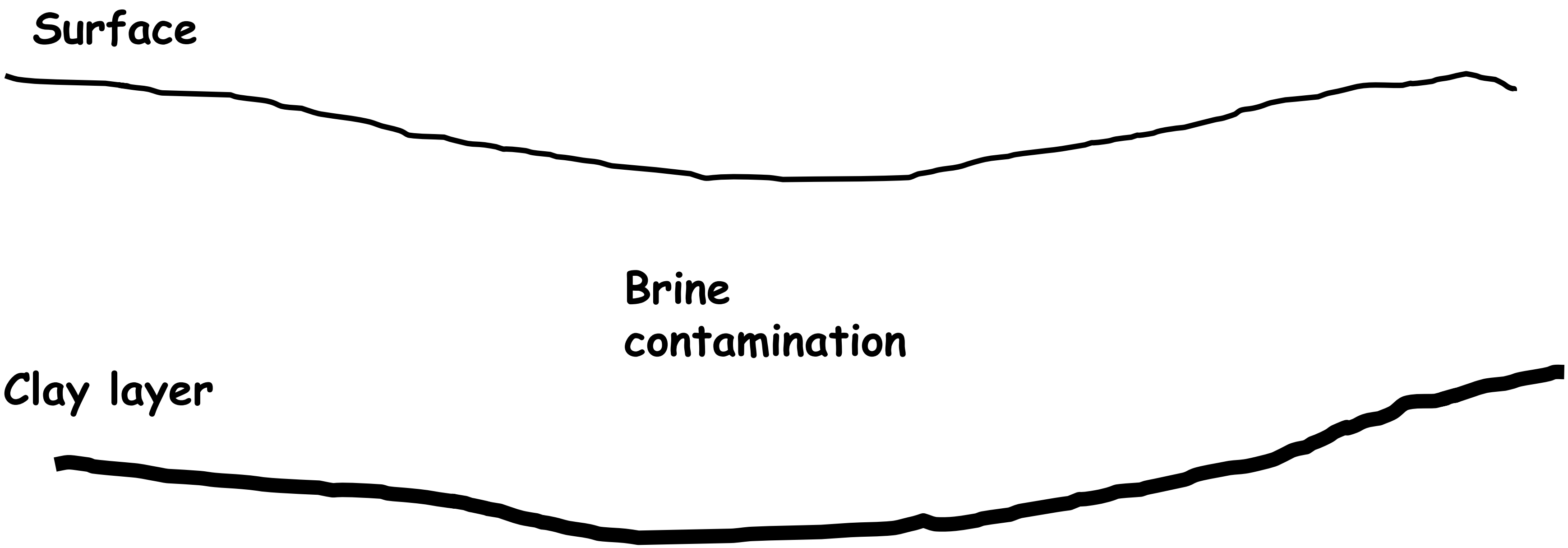
Soil type	Capillary rise (inches)
Very coarse sand	0.8
Coarse sand	1.6
Medium sand	3.2
Fine sand	6.8
Very fine sand	16.0
Silt	40.0
Clay	> 40.0

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

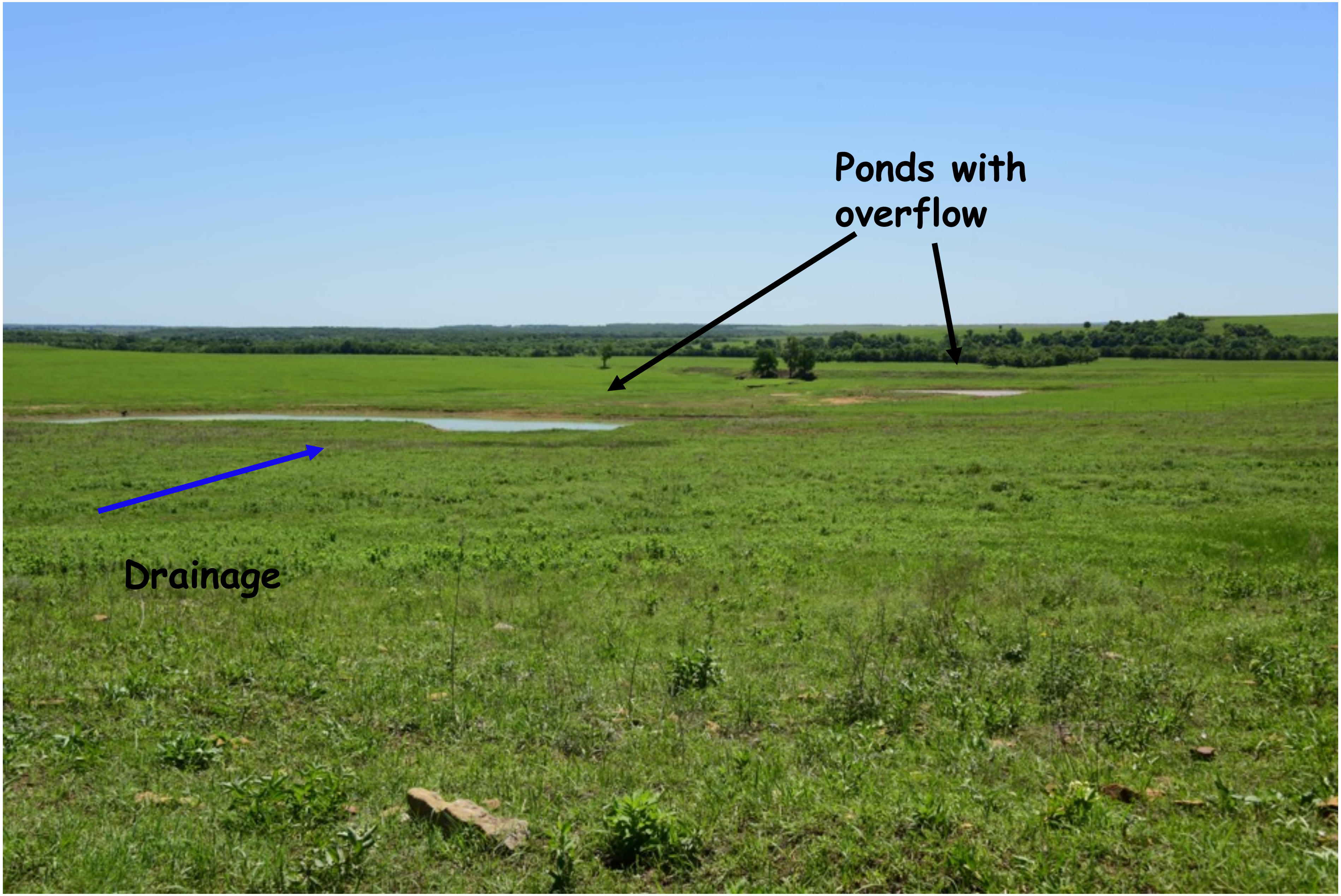
- What are the options?
  - Vertical drainage
    - Will it go deep enough?
    - Will it impact groundwater?
  - Lateral drainage
    - Will it cause additional damage?
    - Can I protect environmental receptors?
  - Ultimately choices are isolation, collection for disposal (drain systems), or dilution

Where will the salt go?




Site 5
N
Meters
0 145 290 580 870 1,160
Legend

The salt has to have somewhere to go



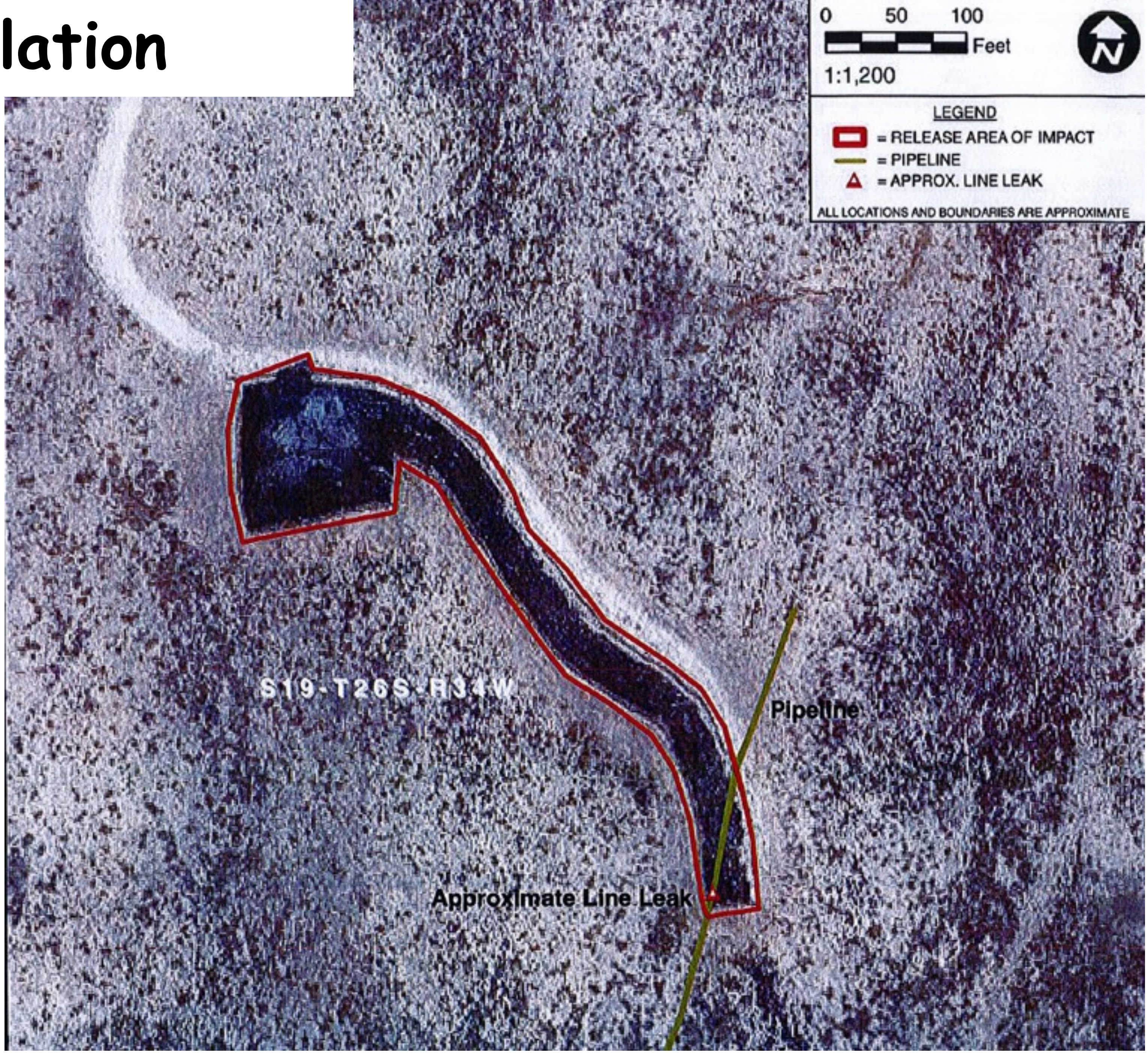
Remediation using lateral drainage

Underlying clay
at about 3-4 ft

7 months of treatment

20 months of treatment (June)

Isolation

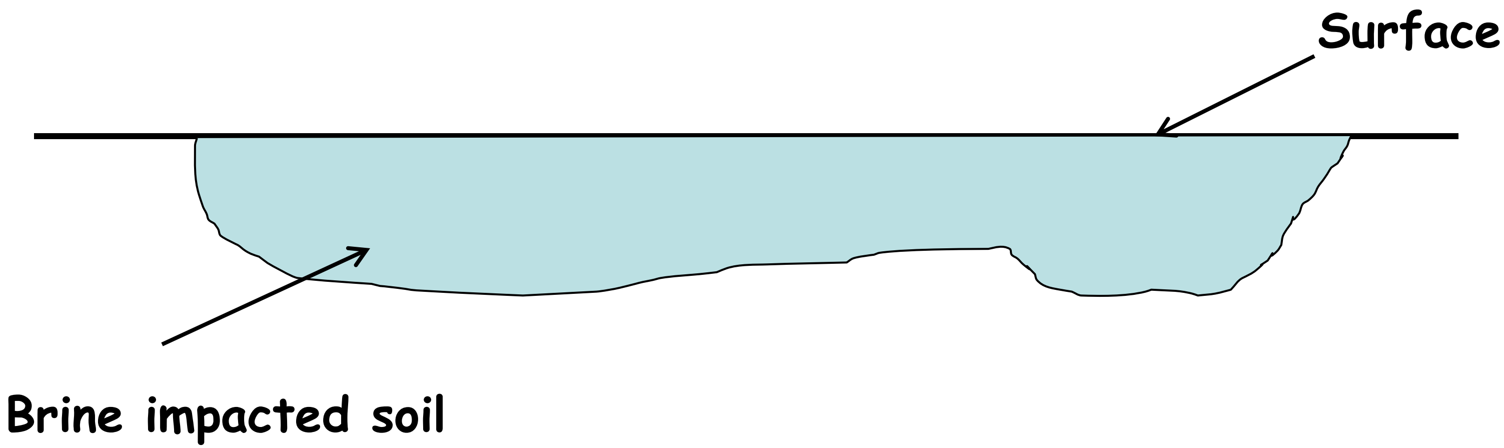


0
50
100
Feet
1:1,200
N
LEGEND
= RELEASE AREA OF IMPACT
= PIPELINE
= APPROX. LINE LEAK
ALL LOCATIONS AND BOUNDARIES ARE APPROXIMATE
S19-T26S-R34W
Pipeline
Approximate Line Leak

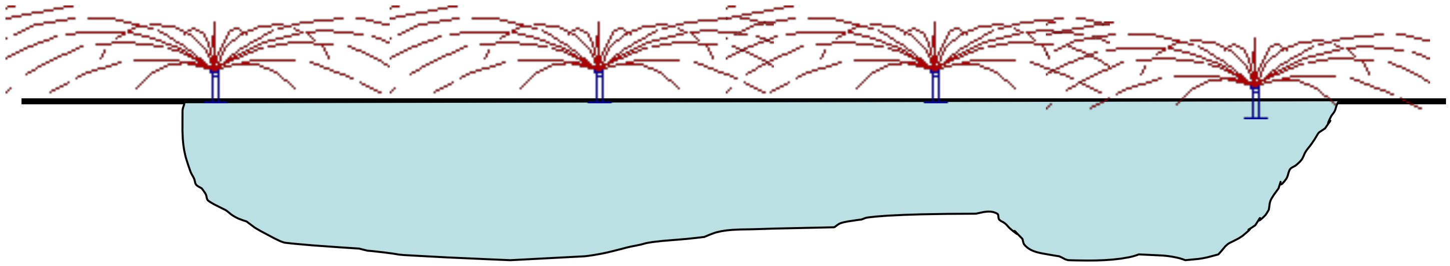
Isolation

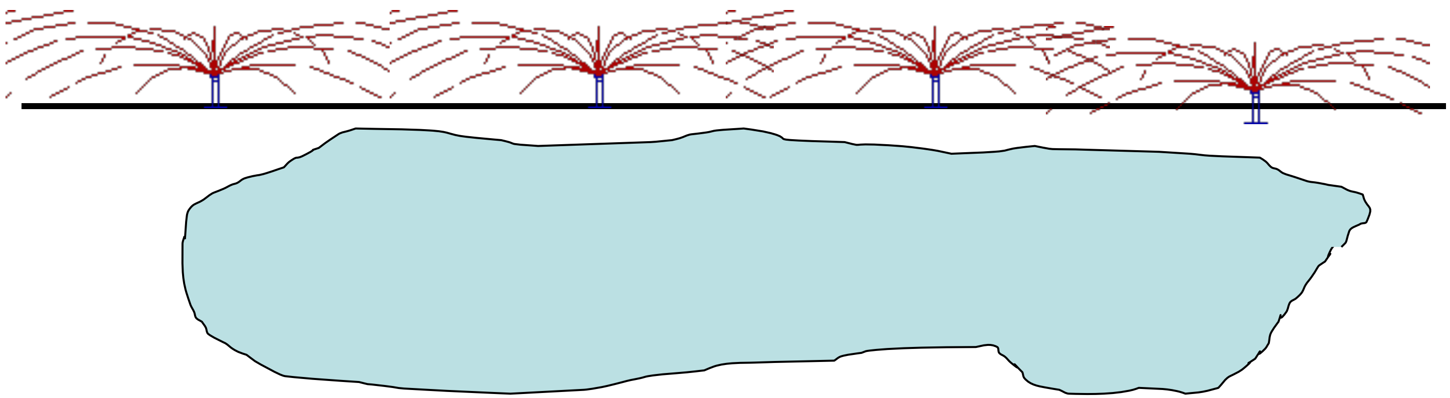
- Site characteristics argue for vertical migration of salts below the root zone
  - Clay lens below root zone are protective of groundwater
  - Sandy soil minimizes potential for capillary suction
  - Low recharge rate minimizes movement of salt in the subsurface under natural rainfall conditions
  - 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

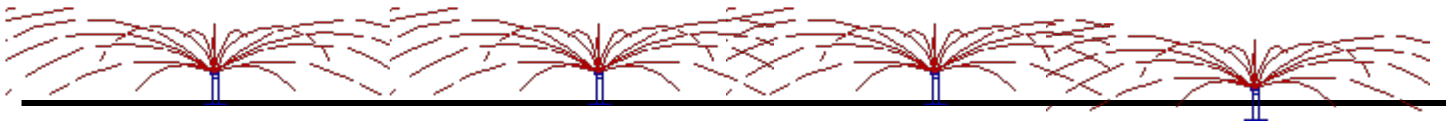
Remediation strategy for this site

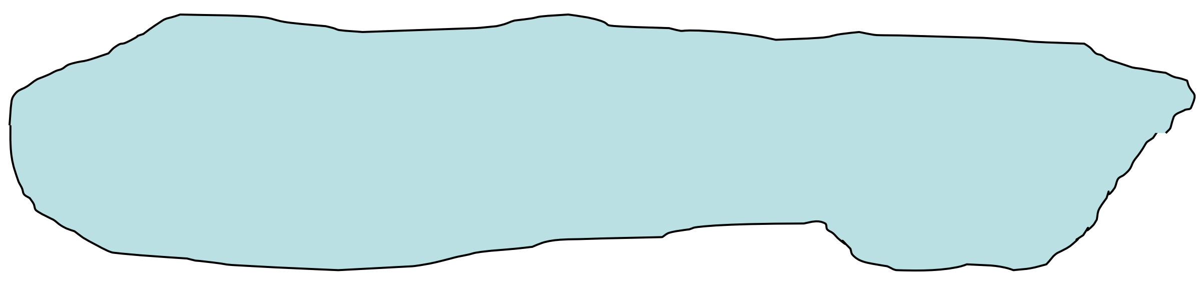


Incorporate calcium, irrigate to push brine well below root zone

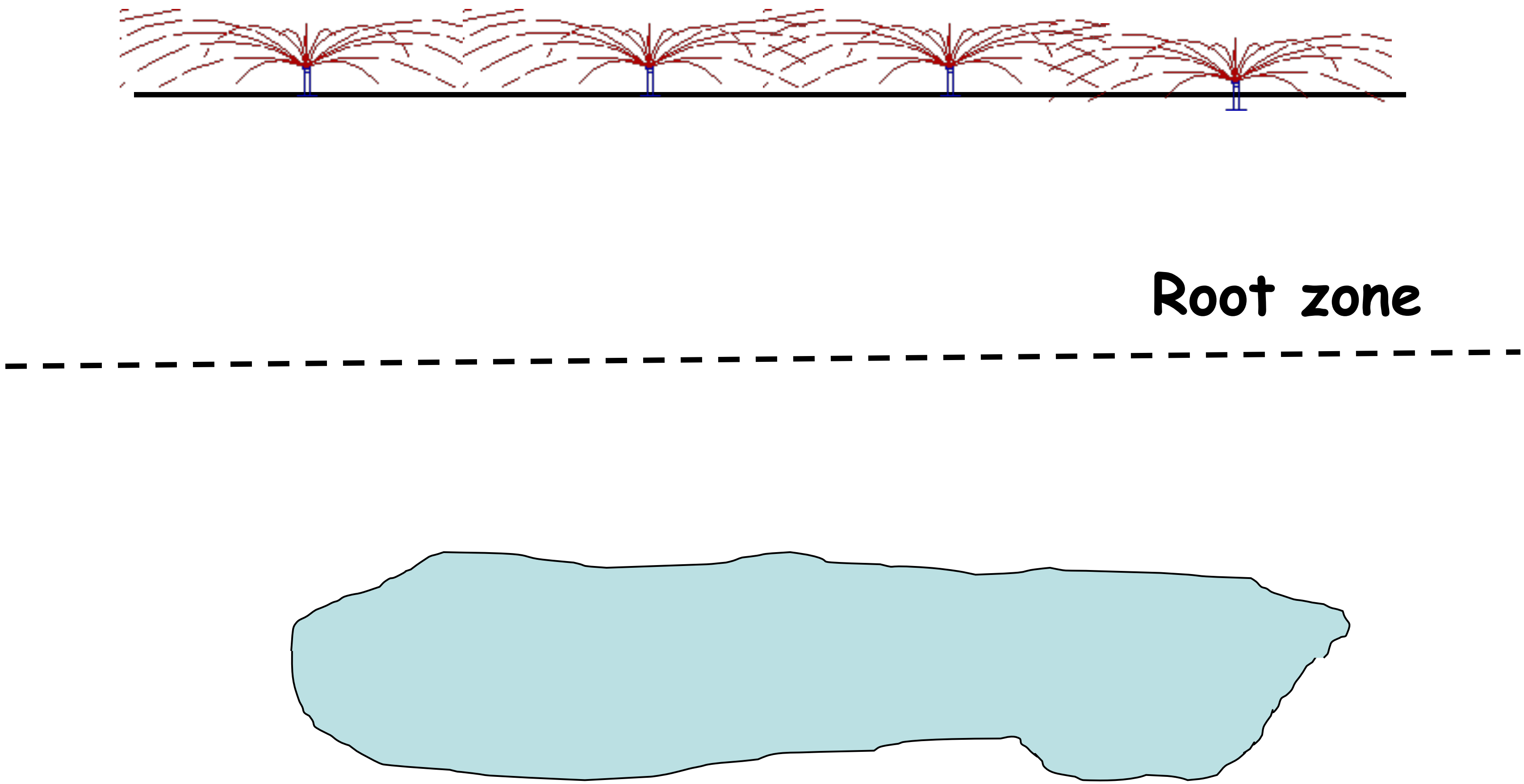




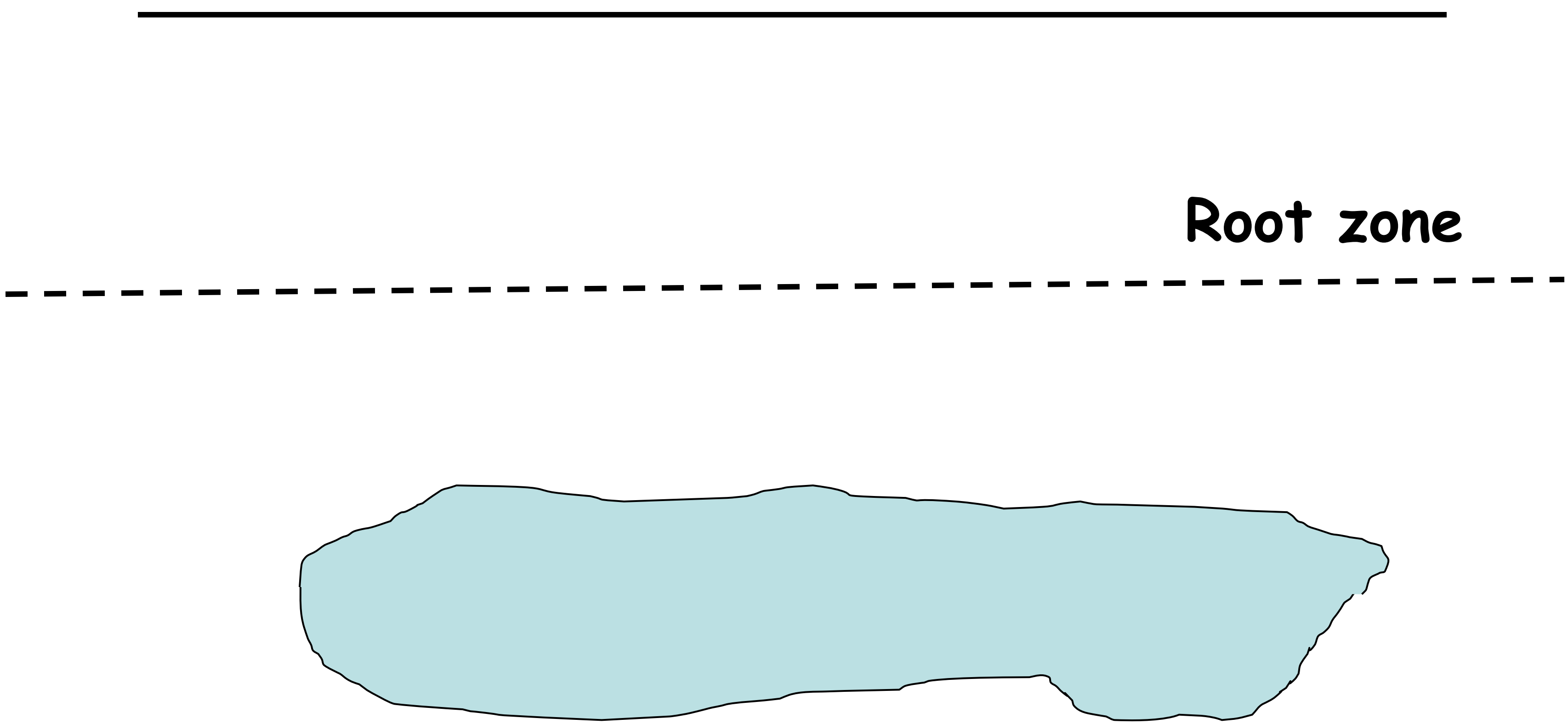




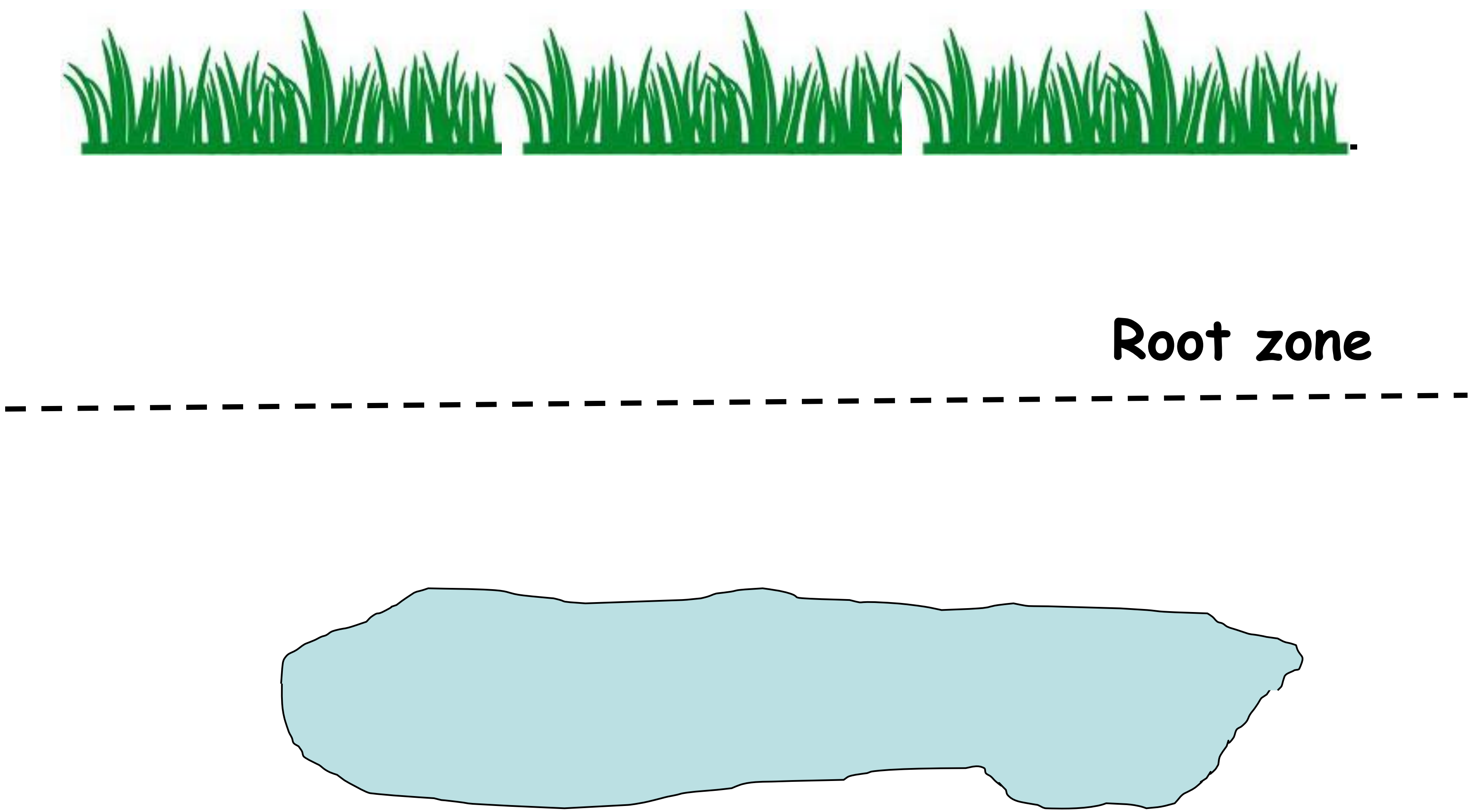
Move salt low enough in soil profile that capillary suction will not bring it back into the root zone.



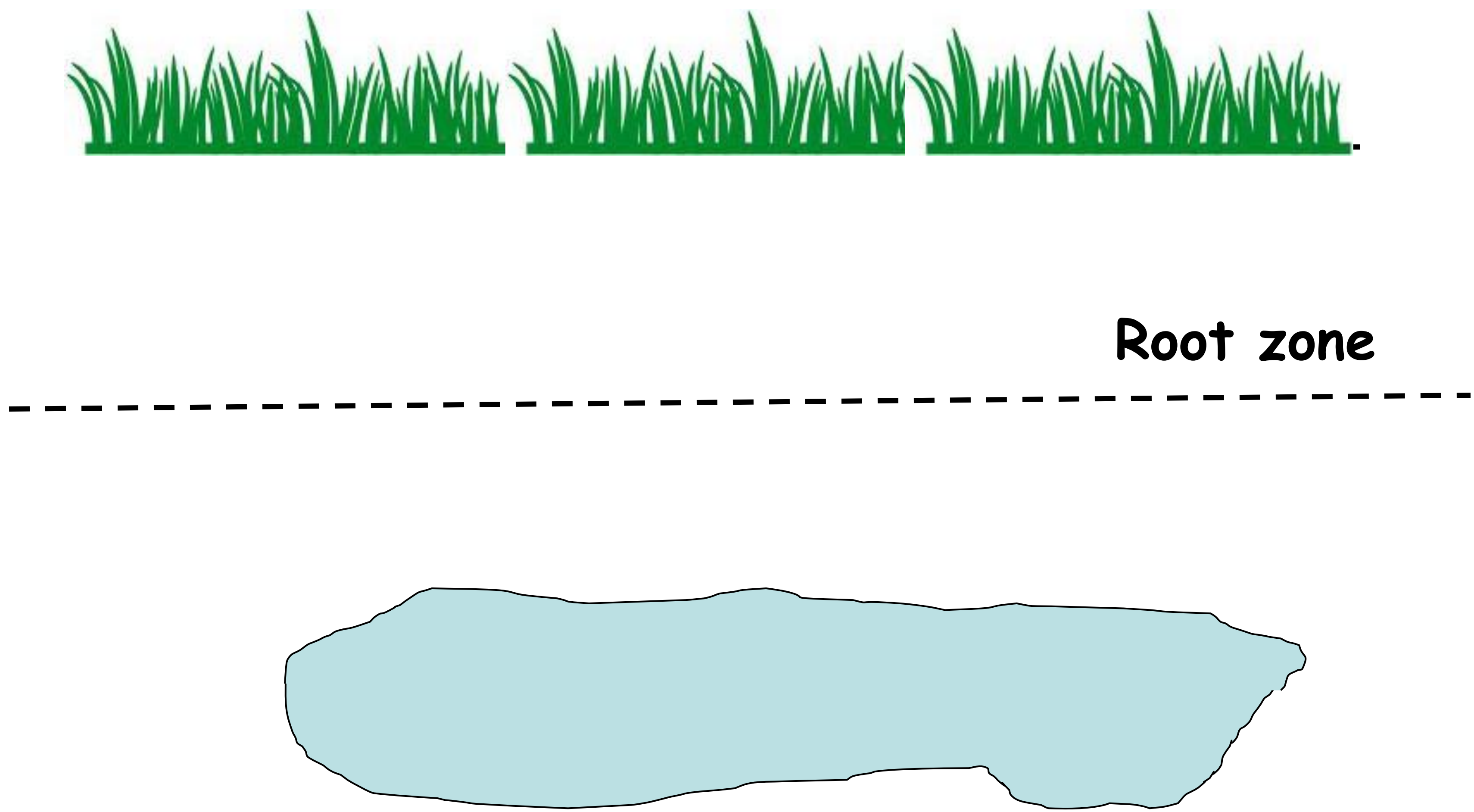
Withdraw heavy irrigation; seed, fertilize, and provide just enough water to establish vegetation cover



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

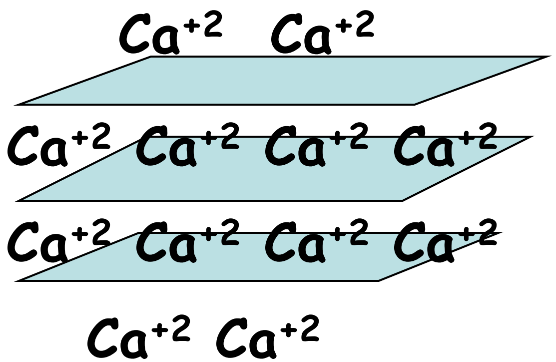


Evapotranspiration further decreases net recharge to aquifer further slowing any downward movement of brine

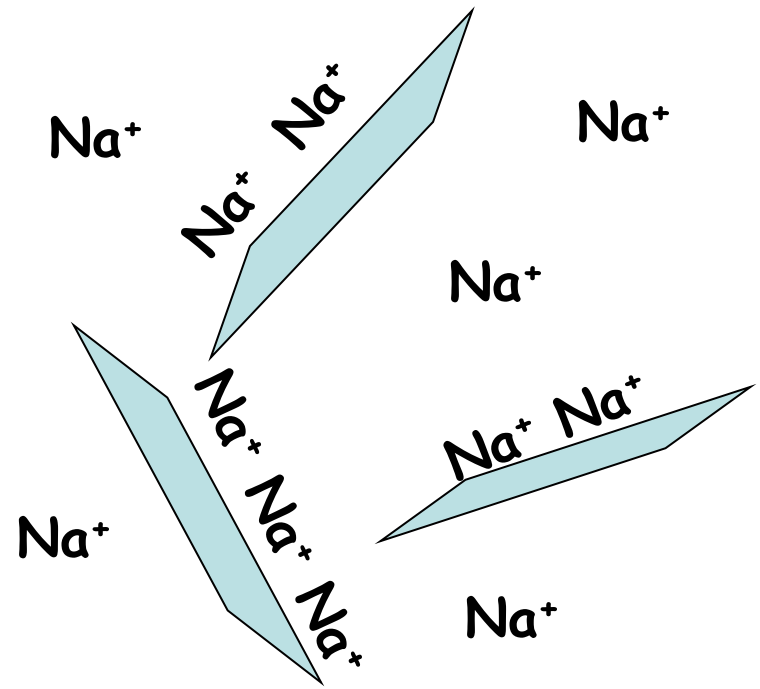


After 7 months of treatment

Sodicity and soil structure

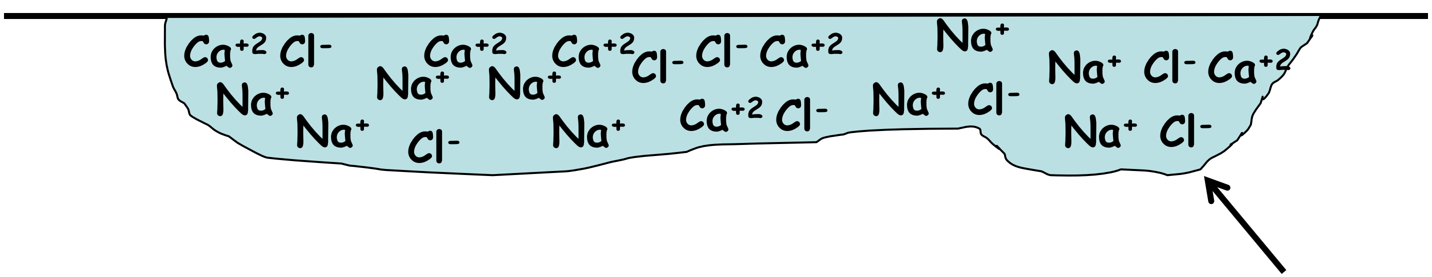


Clay particles or platelets in soil are held together by Ca^{+2} ions



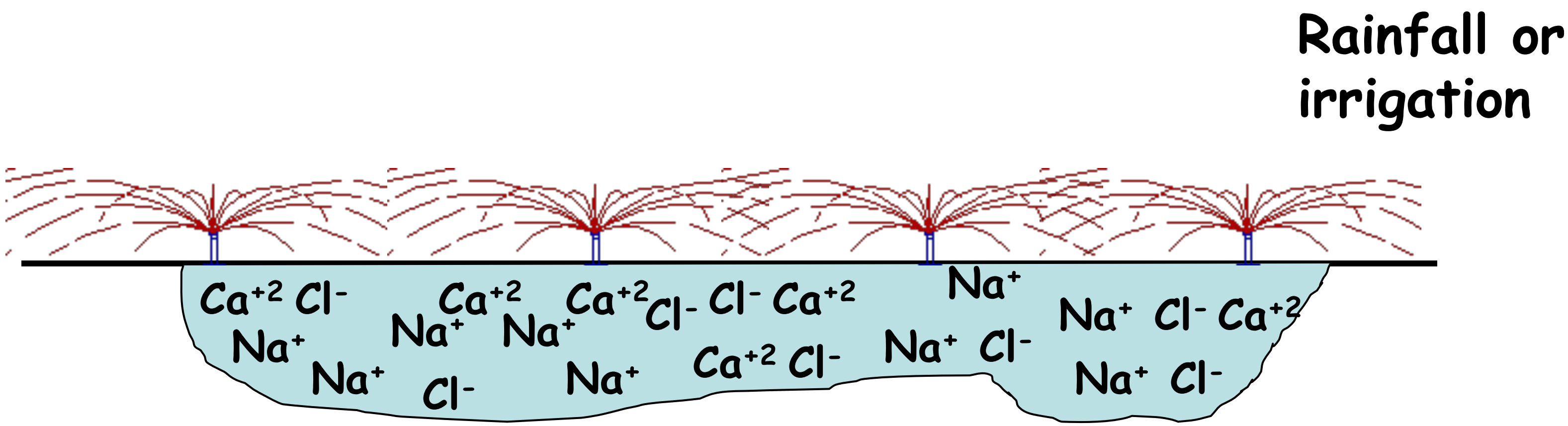
High concentrations of Na^{+} ions can displace the Ca^{+2} and cause the clay particles to disperse

Effect of leaching on salinity vs sodicity

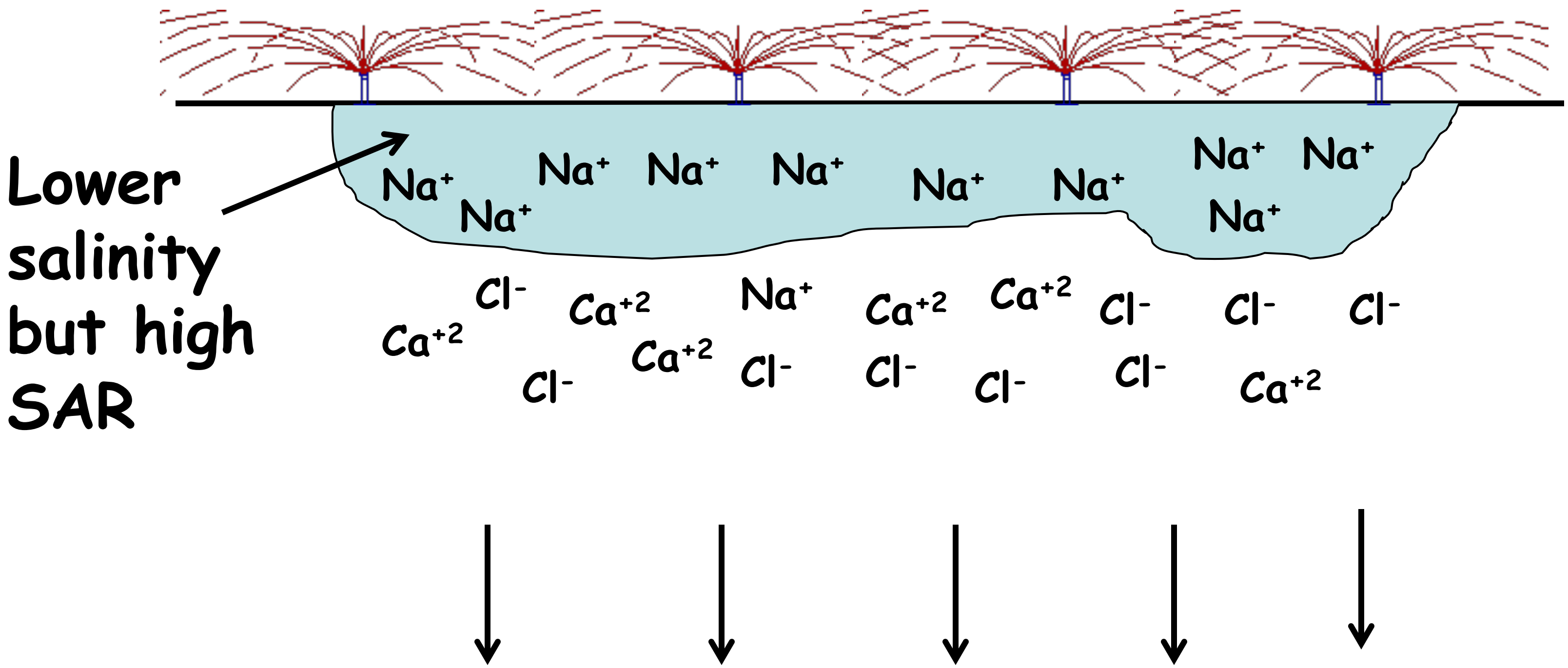


Brine spill:
high salinity
and high SAR

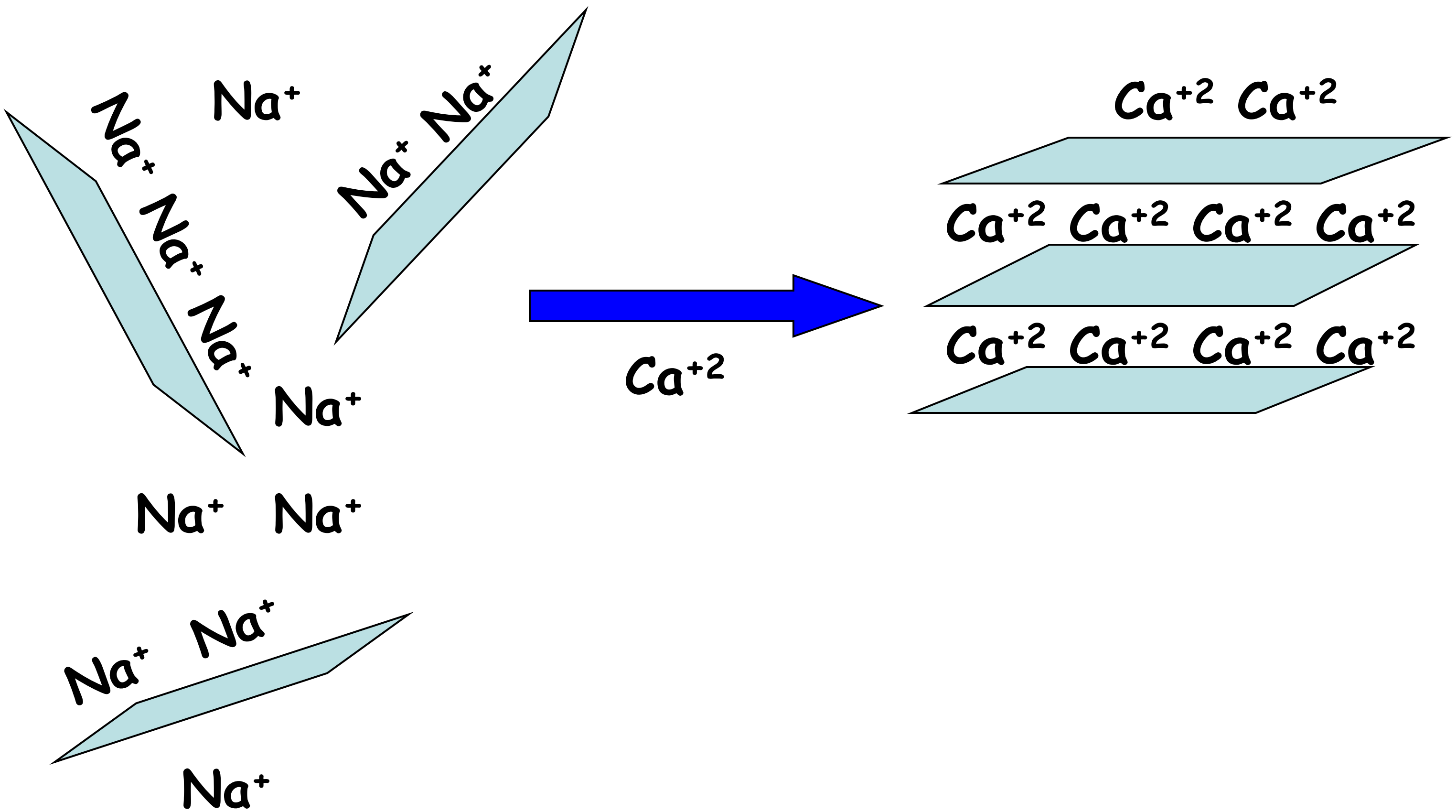
Effect of leaching on salinity vs sodicity



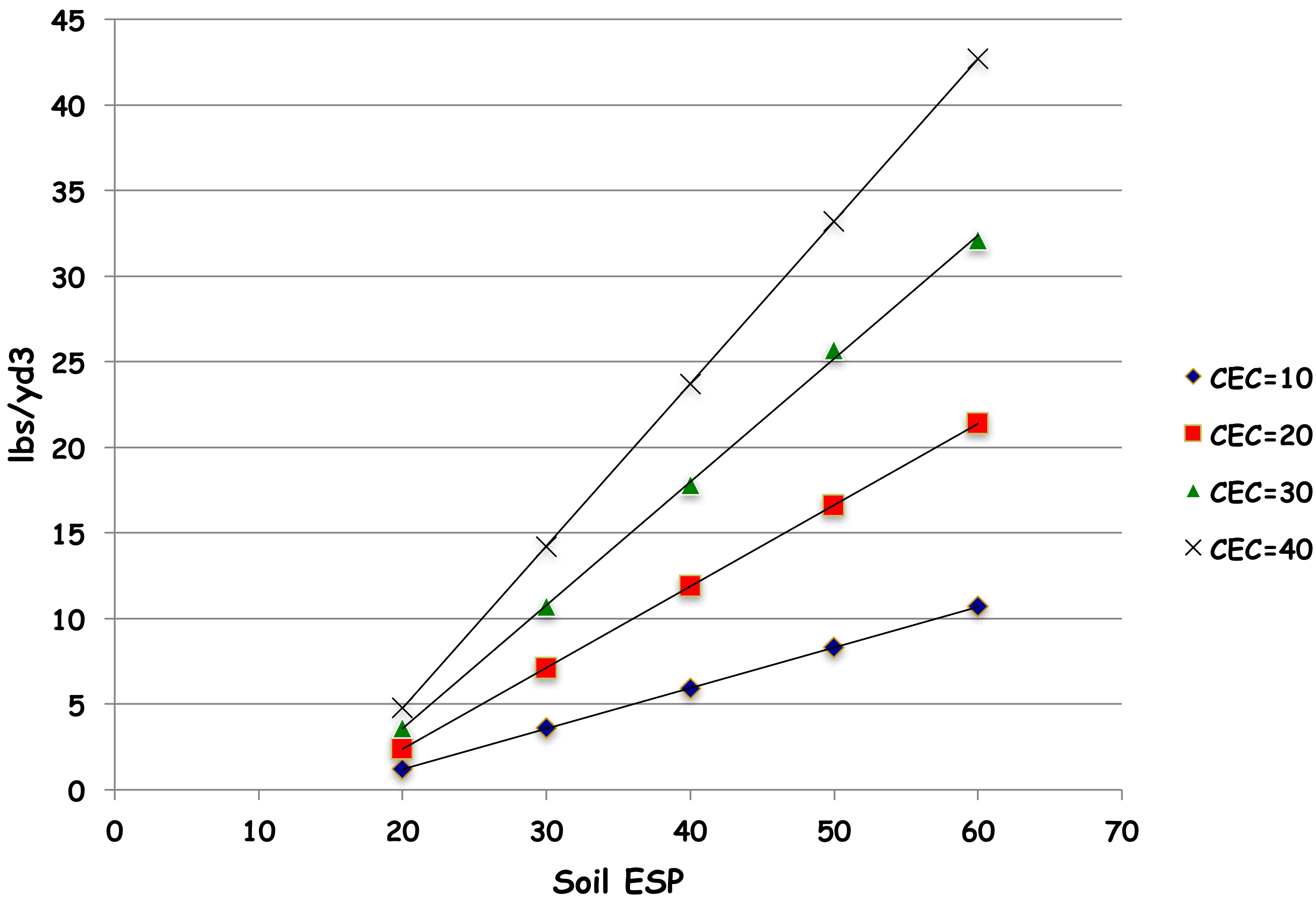
Effect of leaching on salinity vs sodicity



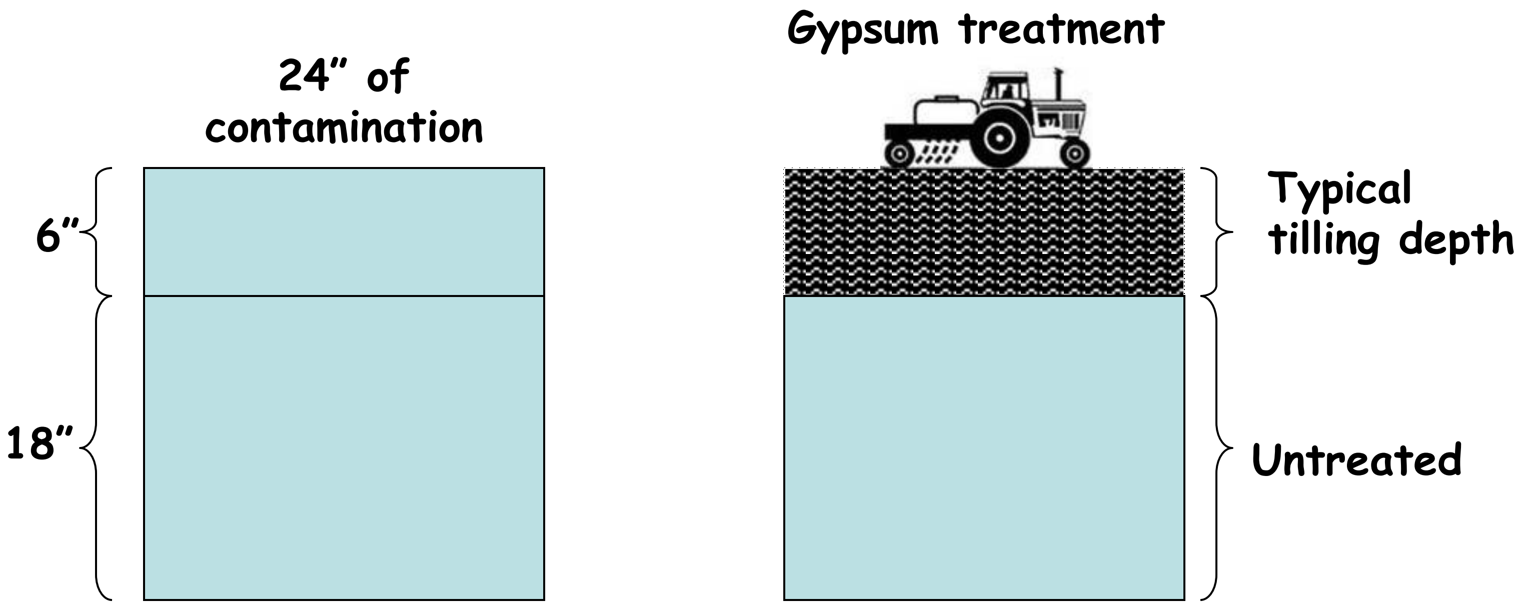
Calcium is required to fight sodicity



Gypsum application rates



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