Understanding relationships between soil properties and shallow groundwater with spatial variability

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Outline

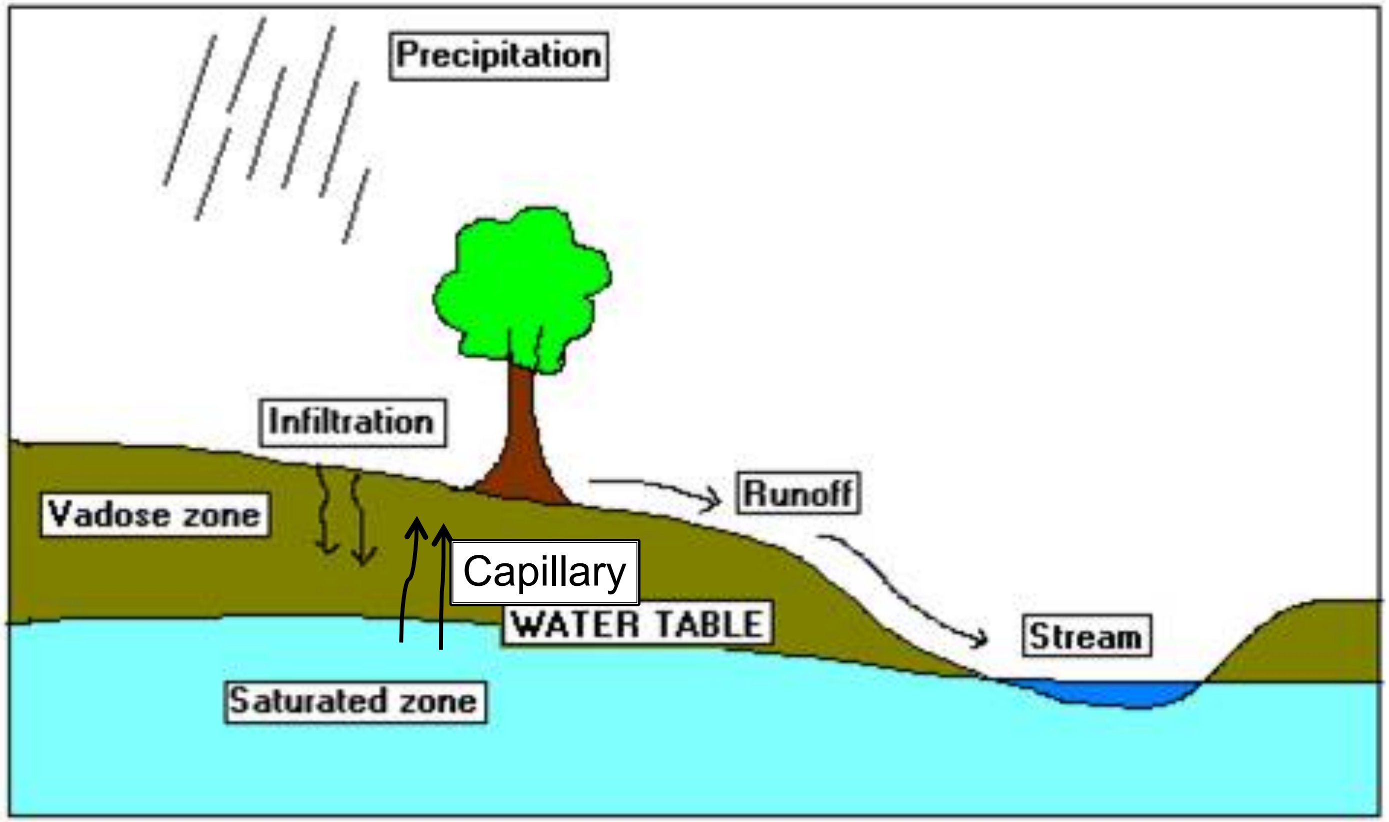
- Objectives of that study
- Soil & groundwater relationship in field
- Results analysis by Derby et al. (2012)
- PHREEQC analyses

Objectives of that study

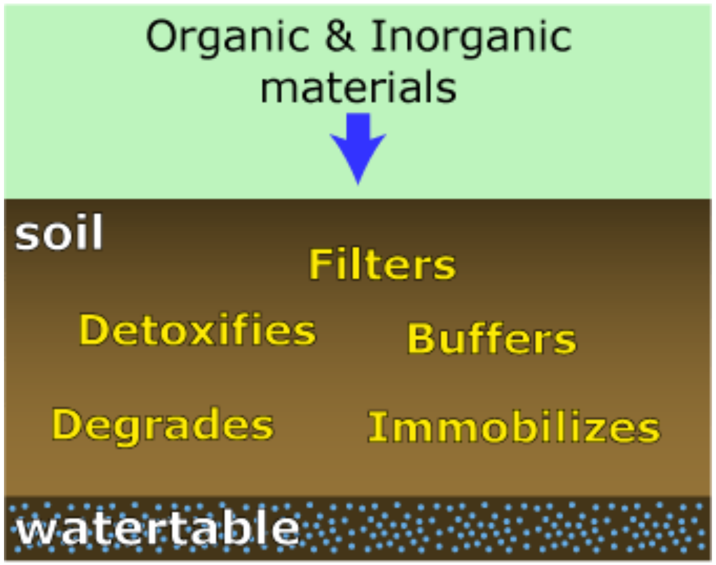
- Determine the relationships among soil properties (topography, WT, EC, texture, pH), soil and groundwater quality (EC, pH, DO, DOC, and major ions) data in field

Introduction

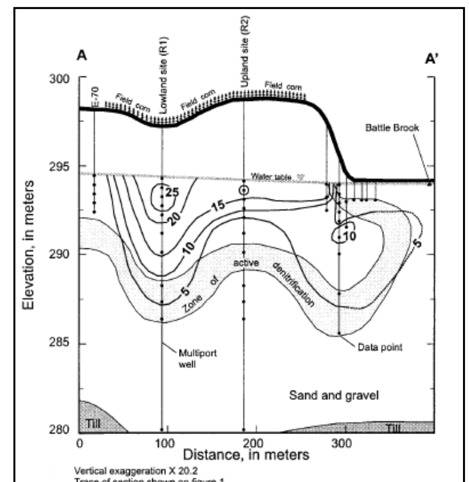
- Soil, groundwater, and land surface are interacted



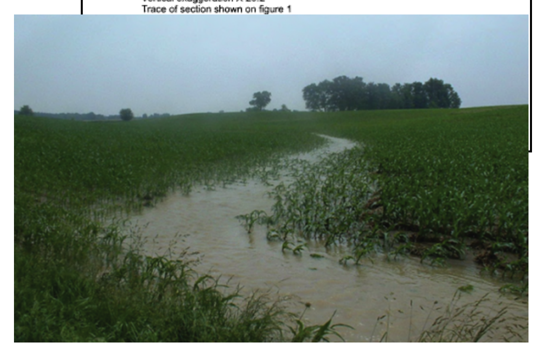
Function of soils



- Agricultural nonpoint source (NPS) pollution is the leading source of water quality impacts (EPA)
- Activities: sediment, nutrients, pesticides, and salts

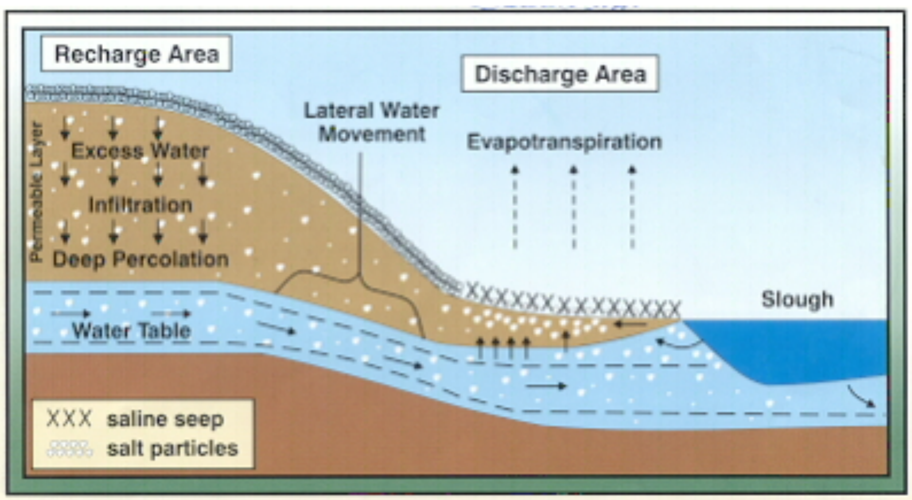


- Groundwater chemical analysis from agriculture field affected by soil topography
  - Example, NO_3^-–N
  - Lowland > Upland by depression focused events



Groundwater

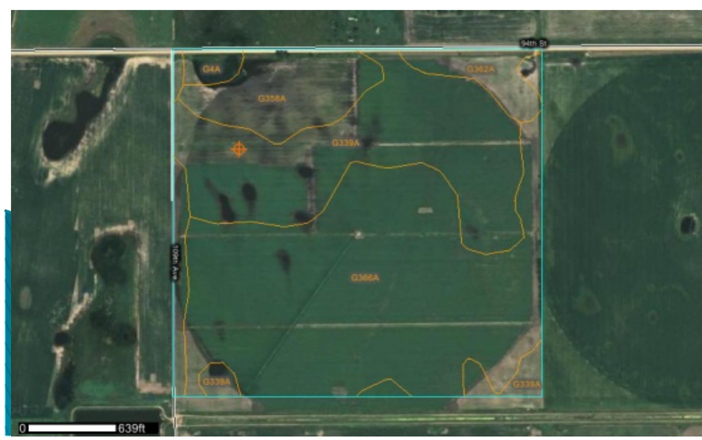
- Capillary and precipitation of salts from shallow water table in depression areas
  - Soil EC increase, saline/sodic soils
  - Subsequent recharge dissolve salts and transport to water table
- Help develop surface management and improve GW quality

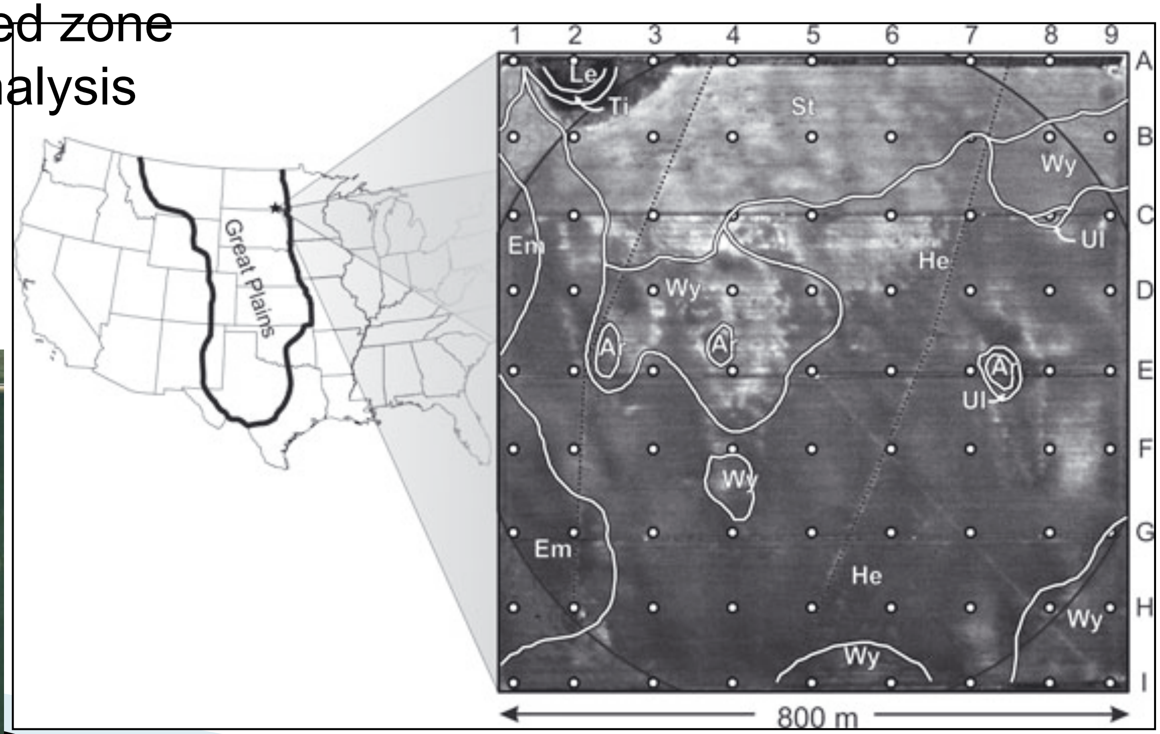


Research Site

- The field is under pivot sprinkler irrigation
- Topography of field is gently sloping, and numerous small depressions 50-100m wide (<1m lower than surrounding areas of field)
- Different soil series in the field (loamy fine sand and fine sandy texture)
- 80 grid shallow GW monitoring wells (9 wells on each transect by every 100m) were installed in 1989 and 1992

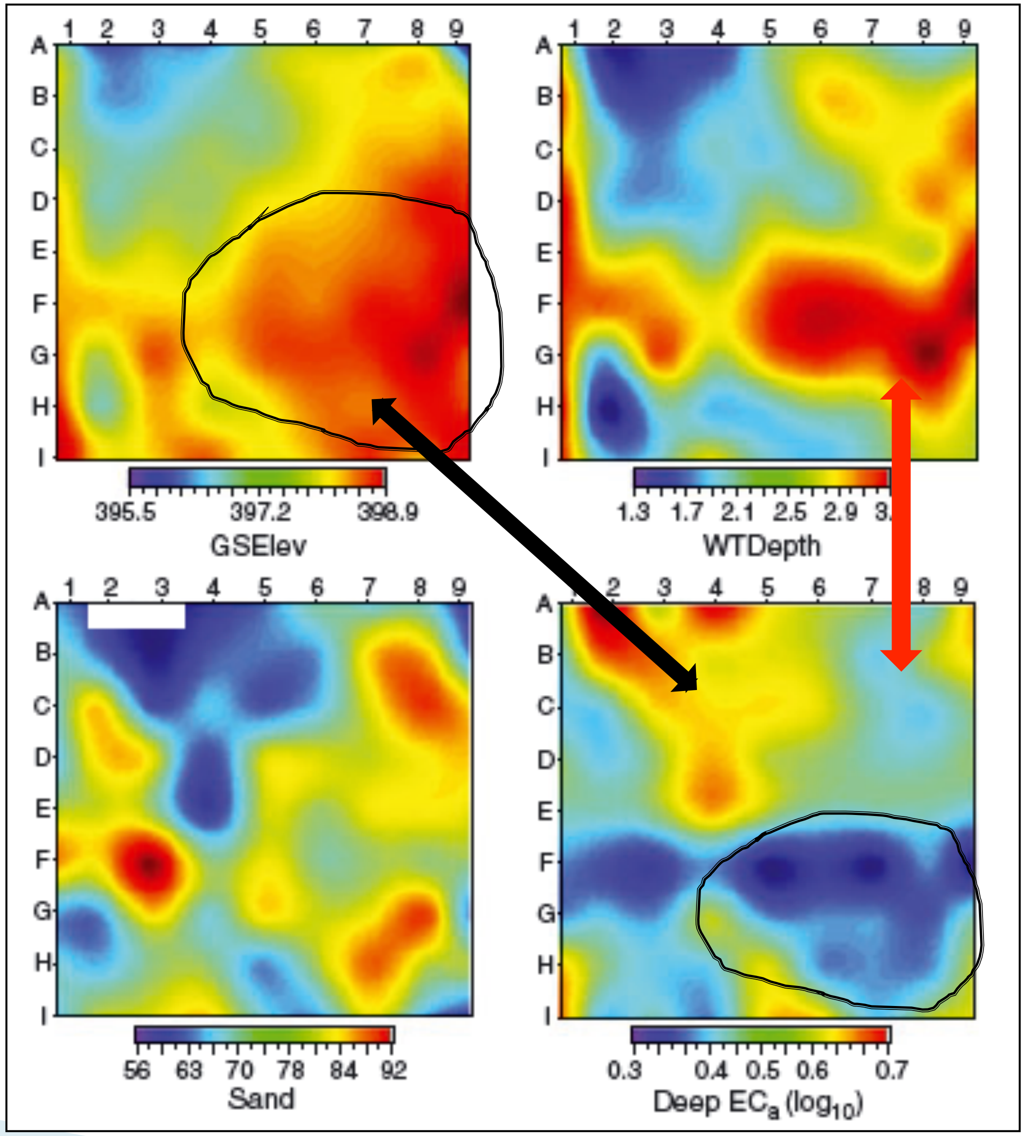
- Sample H_2O the upper 0.3-0.6m of the saturated zone
- Soil core is taken for analysis





Ground surface and soils is related in spatial pattern (previous)

- Statistically related by PASSaGE2, PCA, Inverse distance method, AqQA
- Soil EC is inversely corresponding with GSElev (Lefttop vs. right bottom graph)
- Soil EC is also related with WTDepth

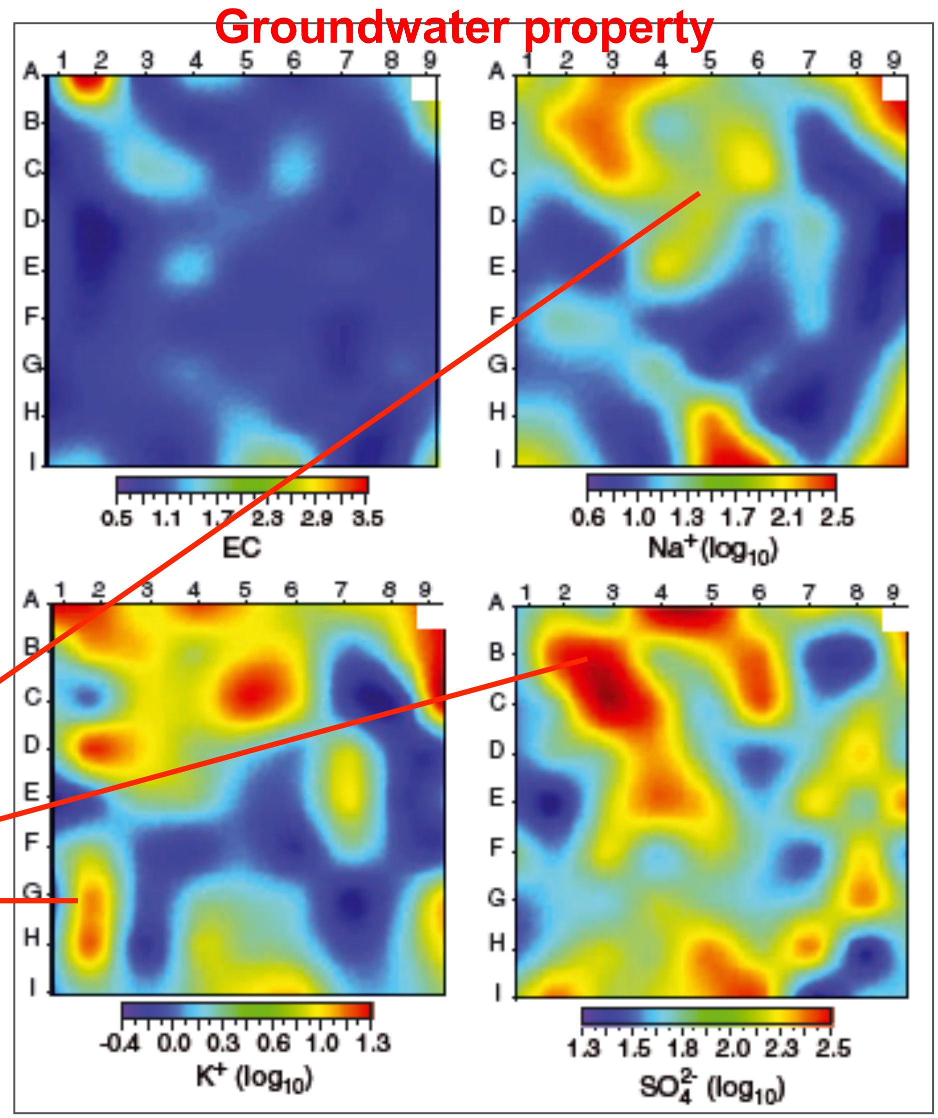


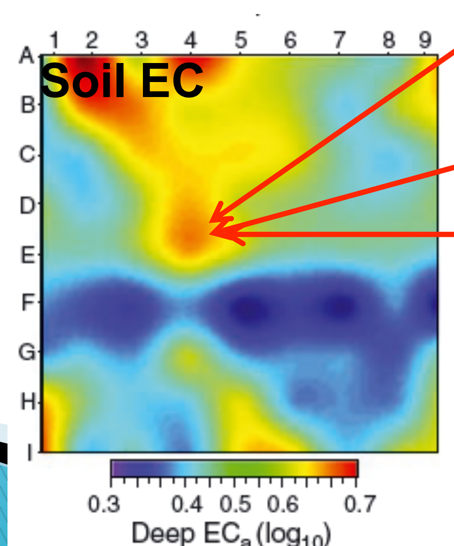
Shallow groundwater interact with soil

(previous)

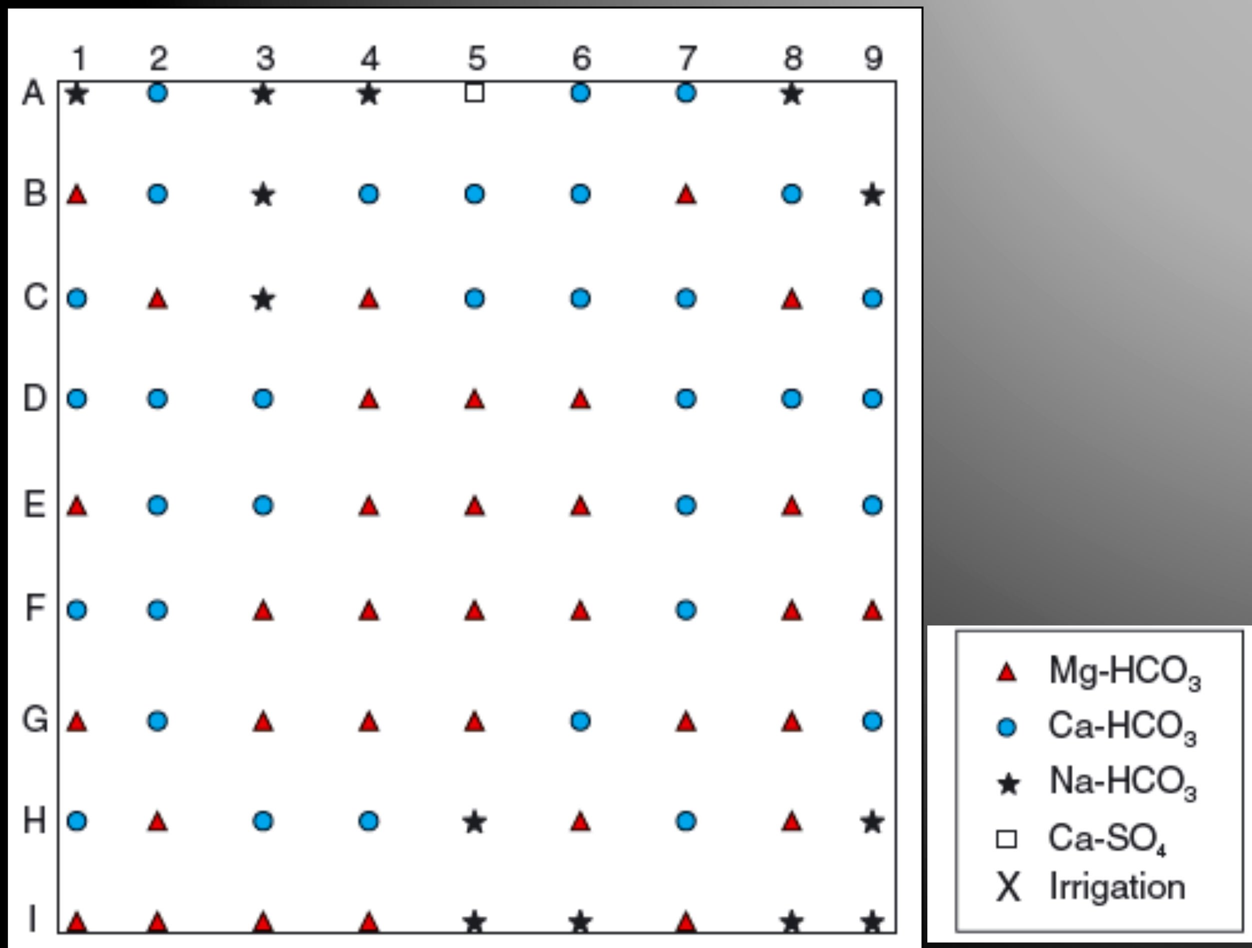
High soil EC areas are found by from shallow groundwater where it has high EC, HCO_3^-, and Na^+

Sodic or salt-affected soils is formed in snowmelt spring with subsequent evapotranspiration in summer in shallow depression areas





Spatial distribution of water facies (previous)



PHREEQC--objectives

- The relationship between groundwater and soil were demonstrated statistically related but is not explained in detail
- Potential mechanism of irrigation water reaction with shallow groundwater
- GW speciation with soil surface elevation? Why dominant anion is $HCO3^{-}$, and major facies?
- Soil series effect (i.e. N contamination) on GW

Example Data Input

Irrigation water

Average Concentrations and Annual Application Rates of Ions Supplied in the Irrigation Water on the 53.4-ha Irrigated Portion of the Field for 1991 and 1992

	Average Concentration (mg/L)	Average Annual Application Rate (kg/ha/year)
$NO_3^- - N$	1.4	1
$NO_2^- - N$	<0.1	<0.1
$NH_3^- - N$	<0.1	<0.1
$PO_4^{3-} - P$	<0.1	<0.1
Cl^-	49	35
SO_4^{2-}	174	125
Ca^{2+}	82	59
Mg^{2+}	41	29
Na^+	83	60
K^+	11	8

Solution 1

Well A2

```
temp        25
pH          7
pe          4
redox       pe
units       mg/l
density     1
N(5)        0.13
N(-3)       0.13
S(6)        86.85
Cl          36.32
Alkalinity 358.9
C           427.33
Ca          104.3
Mg          30.9
Na          49.05
K           13.15
O(0)        1.08
P           0.14
water      1 # kg
```

Solution 2

Well H7

```
temp        25
pH          7
pe          4
redox       pe
units       mg/l
density     1
N(5)        24.38
N(3)        0.13
N(-3)       0.15
P           0.01
S(6)        163.5
Cl          29.2
Alkalinity 181.3
C           234.84
Ca          128.1
Mg          42.9
Na          4.45
K           1.5
O(0)        3.83
water      1 # kg
```

Solution 3

Irrigation meet GW variation

Irrigation water		Mix irrigation with A2		Mix with H7	
Species	Molality	Species	Molality	Species	Molality
		HCO3-	3.27E-03	HCO3-	1.73E-03
SO4-2	1.38E-03	SO4-2	1.04E-03	SO4-2	1.31E-03
Ca+2	1.84E-03	Ca+2	2.05E-03	Ca+2	2.34E-03
NO3-	1.00E-04	NO3-	5.93E-05	NO3-	9.31E-04
		N2	4.46E-21	N2	5.06E-19
		NO2-	7.28E-17	NO2-	4.60E-16

- Irrigation water is dominated by SO_4^{2-}, Ca^{2+}, and has low NO_3^-,
- After mixing with GW (A2 low depression), the dominant anion is HCO_3^-, Ca^{2+} did not change, total N increase while NO_3^- decreased by denitrification
- After mixing with H7(high water table), the dominant anion is HCO_3^-, Ca^{2+} did not change, and amount of NO_3^- increased
- INTERACTION

Why dominant type is Ca,Mg-HCO3 type?

- The dominant HCO3 type is related with the possible minerals reaction
- The PHREEQC output of the wells
  - CaSO4 SI: -2.64 to -1.17 <0, undersaturated
  - Gypsum SI: -2.39 to -0.91<0, undersaturated
  - Calcite SI: -1.12 to 0.36, some undersaturated and some supersaturated
  - Dolomite ($CaMg(CO_3)_2$) SI: -2.41 to 0.48, some undersaturated and some supersaturated
  - Aragonite ($CaCO_3$) SI: -1.27 to 0.21, some undersaturated and some supersaturated

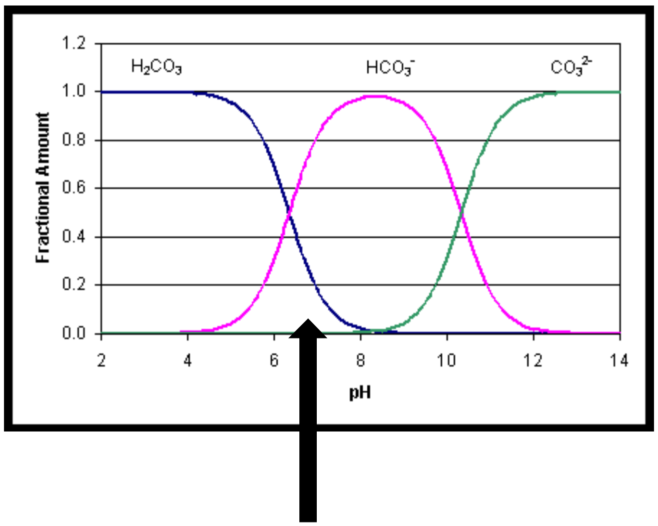
Low vs. high elevation

Well #	**A2**
Soil series	**Stirium**
WSElev (m)	**395.48**
WTD(m)	**1.4**

Well #	**H7**
Soil series	**Hecla**
WSElev (m)	**397.76**
WTD(m)	**2.3**

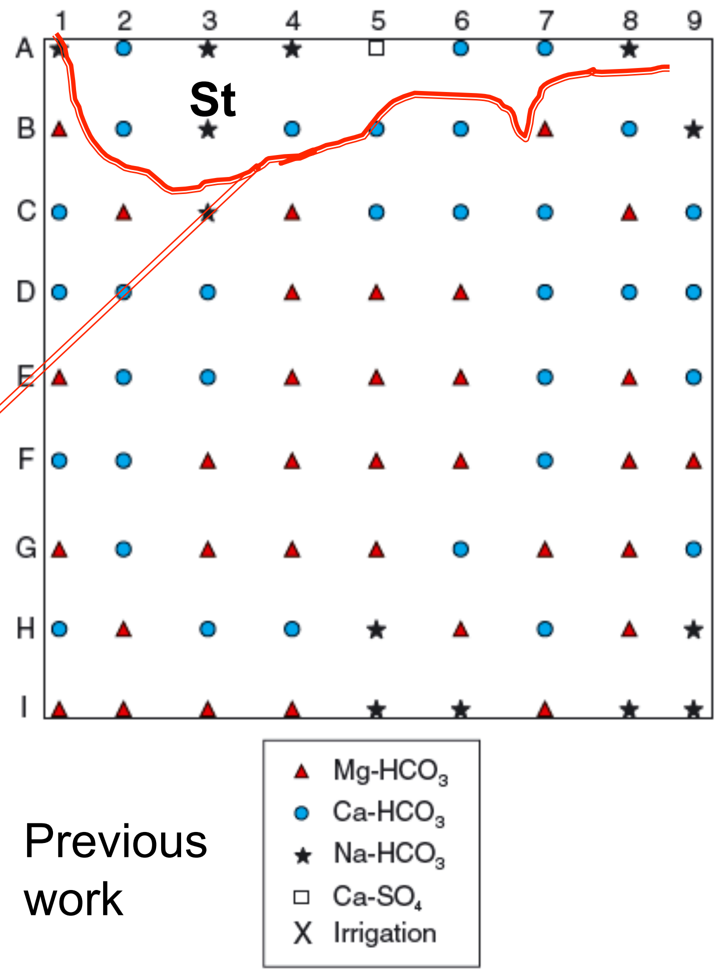
A2	
pH	8.26
pe	4
I	1.34E-02
H7	
pH	7.443
pe	4
I	1.45E-02

Low depression A2: Molality HCO_3^- =6.53E-03
High elevation H7: Molality HCO_3^- =3.46E-03



- Dominant anion is HCO_3^- for all wells related with pH

Example output: Spatial distribution of water facies in WT and roles on soil



Previous work

A2

Species	SI
Anhydrite	-1.84
Aragonite	1.19
Calcite	1.33
CH4(g)	-74.96
CO2(g)	-2.67
Dolomite	2.49
Gypsum	-1.62
H2(g)	-24.52
H2O(g)	-1.51
Halite	-7.35
Hydroxyapatite	4.51
NH3(g)	-7.88
O2(g)	-1.58

H7

Phase	SI
Anhydrite	-1.5
Aragonite	0.19
Calcite	0.33
CH4(g)	-67.9
CO2(g)	-2.13
Dolomite	0.54
Gypsum	-1.28
H2(g)	-22.89
H2O(g)	-1.51
Halite	-8.49
Hydroxyapatite	-1.88
NH3(g)	-8.61
O2(g)	-1.03

- Calcite, dolomite, and aragonite hydroxyapatite are supersaturated which provide Ca, CO3 for major CaHCO3 type in this location
- Cations (Ca and Na, HCO3) in WT capillary rise to horizon of soil, and demonstrate why the stirum Letcher have Bk and Btn horizon
- Result in a higher ECa in A2 (3.47) than H7 (0.85) in topographic low areas with shallow GWT to surface

Stirum

Letcher

Water quality under different soil series?

Well #	pH	pe	Specific conductance	I
			uS/cm	
B3	8.081	4	1395	1.93E-02
B4	8.009	4	750	1.17E-02
B5	8.1	4	890	1.36E-02
Mix	8.042	12.43	1010	1.48E-02

B3 Phase	SI	B4 Phase	SI	B5 Phase	SI	MIX Phase	SI
Anhydrite	-1.52	Anhydrite	-1.9	Anhydrite	-1.8	Anhydrite	-1.69
Aragonite	0.93	Aragonite	0.87	Aragonite	0.95	Aragonite	0.9
Calcite	1.08	Calcite	1.02	Calcite	1.1	Calcite	1.04
CH4(g)	-73.3	CH4(g)	-72.7	CH4(g)	-73.5	CH4(g)	-140.4
CO2(g)	-2.4	CO2(g)	-2.45	CO2(g)	-2.5	CO2(g)	-2.42
Dolomite	2.05	Dolomite	1.93	Dolomite	2.22	Dolomite	2.03
Gypsum	-1.3	Gypsum	-1.68	Gypsu			
H2(g)	-24.2	H2(g)	-24	H2(g)			
H2O(g)	-1.51	H2O(g)	-1.51	H2O(g			
Halite	-6.73	Halite	-8.08	Halite			
NH3(g)	-8.13	Hydroxyapa	1.4	NH3(g			
O2(g)	-1.51	NH3(g)	-8.23	O2(g)			
		O2(g)	-1.34				
						O2(g)	-1.3
						Sulfur	-106.3

Well #	pH	pe	Specific conductance	I
			uS/cm	
A7	8.094	4	1214	1.82E-02
A8	8.023	4	1561	2.08E-02
B8	4.428	4	1022	1.43E-02
Mix	6.648	13.89	1269	1.79E-02

A7 Phase	SI	A8 Phase	SI	B8 Phase	SI	Mix Phase	SI
Anhydrite	-1.64	Anhydrite	-1.79	Anhydrite	-5.77	Anhydrite	-1.88
Aragonite	1.18	Aragonite	1.06	Aragonite	-4.39	Aragonite	-0.43
Calcite	1.32	Calcite	1.2	Calcite	-4.25	Calcite	-0.29
CH4(g)	-73.38	CH4(g)	-72.74	CH4(g)	-42.29	CH4(g)	-139.61
CO2(g)	-2.41	CO2(g)	-2.34	CO2(g)	-0.64	CO2(g)	-1.12
Dolomite	2.56	Dolomite	2.29	Dolomite	-8.42	Dolomite	-0.62
Gypsum	-1.42	Gypsum	-1.57	Gypsum	-5.55	Gypsum	-1.66
					16.86	H2(g)	-41.07
					1.51	H2O(g)	-1.51
					7.23	H2S(g)	-139.42
					11.67	Halite	-7.1
					1.03	N2(g)	-13.29
						NH3(g)	-65.35
						O2(g)	-1.05
						Sulfur	-104.23

3 minerals are supersaturated in Stirum vs. all undersaturated in Lethcer; different soil may result in different water properties
High N in groundwater from fertilization runoff or infiltration into GWT > normal GW

B3,4 &B5---Stirum

A7, 8,&B8---Letcher

Conclusions

- PHREEQC provides further information about the relationship between soil and shallow ground water relationship with topography

- Errors from unfamiliar with PHREEQC, irrigation water would change when going through soil and meeting with shallow groundwater (mix function is not accurate in some case)