Understanding relationships between soil properties and shallow groundwater with spatial variability

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Geochemistry 628
NDSU
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Outline

- Objectives of that study
- Soil & groundwater relationship in field
- Results analysis by Derby et al. (2012)
- PHREEQC analyses
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, $\text{NO}_3^-\text{N}$
  - 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
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 H2O 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 (Left top 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, $\text{HCO}_3^-$, and $\text{Na}^+$

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)

<table>
<thead>
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<th>5</th>
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Legend:
- △ Mg-HCO₃
- ○ Ca-HCO₃
- ★ Na-HCO₃
- □ Ca-SO₄
- X Irrigation
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

<table>
<thead>
<tr>
<th>Ion</th>
<th>Average Concentration (mg/L)</th>
<th>Average Annual Application Rate (kg/ha/year)</th>
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<td>NO₃⁻ – N</td>
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<td>&lt;0.1</td>
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<tr>
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<td>&lt;0.1</td>
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<td>Cl⁻</td>
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<tr>
<td>SO₄²⁻</td>
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<tr>
<td>Ca²⁺</td>
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<td>Mg²⁺</td>
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<td>Na⁺</td>
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<td>K⁺</td>
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Well A2

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<tr>
<td>pe</td>
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Well H7

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<td>redox</td>
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Solution 1

Solution 2

Solution 3
Irrigation meet GW variation

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<tr>
<th>Species</th>
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<td>HCO3-</td>
<td>3.27E-03</td>
<td>SO4-2</td>
<td>1.38E-03</td>
<td>HCO3-</td>
<td>1.73E-03</td>
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<td>SO4-2</td>
<td>1.04E-03</td>
<td>Ca+2</td>
<td>2.05E-03</td>
<td>SO4-2</td>
<td>1.31E-03</td>
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<tr>
<td>Ca+2</td>
<td>2.05E-03</td>
<td>NO3-</td>
<td>5.93E-05</td>
<td>Ca+2</td>
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<td>NO3-</td>
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<td>NO2-</td>
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</table>

- Irrigation water is dominated by \( \text{SO}_4^{2-}, \text{Ca}^{2+} \), and has low \( \text{NO}_3^- \).
- After mixing with GW (A2 low depression), the dominant anion is \( \text{HCO}_3^- \), \( \text{Ca}^{2+} \) did not change, total N increase while \( \text{NO}_3^- \) decreased by denitrification.
- After mixing with H7 (high water table), the dominant anion is \( \text{HCO}_3^- \), \( \text{Ca}^{2+} \) did not change, and amount of \( \text{NO}_3^- \) increased.
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(CO₃)₂) SI: -2.41 to 0.48, some undersaturated and some supersaturated
  - Aragonite (CaCO₃) SI: -1.27 to 0.21, some undersaturated and some supersaturated
Low vs. high elevation

<table>
<thead>
<tr>
<th>Well #</th>
<th>A2</th>
<th>Soil series</th>
<th>Stirium</th>
<th>WSElev (m)</th>
<th>395.48</th>
<th>WTD(m)</th>
<th>1.4</th>
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<td>H7</td>
<td></td>
<td>Hecla</td>
<td></td>
<td>WSElev (m)</td>
<td>397.76</td>
<td>WTD(m)</td>
<td>2.3</td>
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</table>

Low depression A2: Molality HCO3- = 6.53E-03
High elevation H7: Molality HCO3- = 3.46E-03

- Dominant anion is HCO3- for all wells related with pH
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.

### Previous work

- 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.
### Water quality under different soil series?

**Stirum**

<table>
<thead>
<tr>
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<th>Specific conductance</th>
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<tbody>
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<td>B3</td>
<td>8.081</td>
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**Letcher**

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</tbody>
</table>

**B3,4 & B5---Stirum**

**A7, 8, & B8---Letcher**

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.
Conclusions

- PHREEQC provides further information about the relationship between soil and shallow groundwater 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).