Spatial and Seasonal Variations of Water Movement in the Vadose Zone at Salt-Impacted Sites

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Acknowledgments

- Dr Tai Wong initiated this study
- Some material is based on internal reports by Douglas Haney
Outline

- Introduction
- Methodology
- Case study
- Summary
Significance of Vadose Zone

- **Vadose Zone**
- **Salt Impact**
- **Root Zone**
- **Shallow Groundwater**
- **DUA**
Regulatory Approaches

- **Alberta Tier 1 default values**
  - Recharge to groundwater: 60 mm/year for coarse-grained soil and 12 mm/year for fine-grained soil
  - No uptake rate is defined

- **Alberta Tier 2 approach - Soil Salinity Tool (SST)**
  - Estimated recharge (downward) and discharge (upward) rates for different climate sub-regions and different soil (fine or coarse)
  - In Central Parkland sub-region
    - discharge = 1 mm/y and recharge = 6 mm/y for fine soil
    - discharge = 1 mm/y and recharge = 27 mm/y for coarse soil
Questions Regarding Regulatory Approaches

- Should we use these constant recharge/discharge rates for site-specific assessments (Tier 2C)?
- Can we reasonably estimate site-specific recharge/discharge rates based on the data typically available?
- How significantly do the different rates could affect the assessment of salt contamination at a site?
Hydrus-1D


- Features
  - Water flow under unsaturated and unsaturated conditions
  - Soil retention curve (Van Genuchten model)
  - Surface evapotranspiration, surface runoff, and root uptake
  - Contaminant transport, vapour movement, and heat transferring
  - More ...
Model for Root Water Uptake

- Roots help transport water back to the surface
  - Evapotranspiration

- Feddies model
    - Actual uptake based on a stress reduction of the potential

- Van Genuchten (VG) Model (1992)
  - An S-shape function for stress reduction of the potential
Model for Root Water Uptake

Feddes Model

\[ S(h) = \alpha(h)S_p \]

\[ T_p = 1 \text{ mm d}^{-1}, \quad T_p = 5 \text{ mm d}^{-1} \]

<table>
<thead>
<tr>
<th>Crop</th>
<th>(h_1)</th>
<th>(h_2)</th>
<th>(h_{3, \text{high}})</th>
<th>(h_{3, \text{low}})</th>
<th>(h_4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potatoes</td>
<td>-10</td>
<td>-25</td>
<td>-320</td>
<td>-600</td>
<td>-16000</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>-10</td>
<td>-25</td>
<td>-320</td>
<td>-600</td>
<td>-16000</td>
</tr>
<tr>
<td>Wheat</td>
<td>0</td>
<td>-1</td>
<td>-500</td>
<td>-900</td>
<td>-16000</td>
</tr>
<tr>
<td>Pasture</td>
<td>-10</td>
<td>-25</td>
<td>-200</td>
<td>-800</td>
<td>-8000</td>
</tr>
<tr>
<td>Corn</td>
<td>-15</td>
<td>-30</td>
<td>-325</td>
<td>-600</td>
<td>-15000*</td>
</tr>
</tbody>
</table>
Van Genuchten (VG) Model

\[ \alpha(h) = \frac{1}{\left(1 + \frac{h}{h_{50}}\right)^p} \]
Case Study
Site Description

- Zoned for agriculture
- Soil mainly composed of silt with sand lenses \((K = 3.1 \times 10^{-7} \text{ m/s})\)
- Water table: 5 m below grade
Site Description

- Vegetation: grass onsite with canola cropland in surrounding areas
SST Assessment

- SST Tier 2A conducted to determine the guidelines of chloride
- SST results based on infiltration rate estimated for “Central Parkland” sub-region
  - Discharge (upward) = 1 mm/year
  - Recharge (downward) = 6 mm/year
HYDRUS 1D Model

- Depth of Root Zone
- Silt Loam
  - $K=3.1\times10^{-7}$ m/s
- Observation Points
- Groundwater Table
HYDRUS Scenarios

- Meteorological Datasets:
  - Environment Canada
    - Climate normals (Humidity, Wind)
    - Daily climate data (Precipitation, Temperature)
    - Net Radiation (paid data set)

- Two scenarios:
  - “Average” Dataset
  - Low Radiation, High Precipitation (LRHP)
## HYDRUS Scenarios

<table>
<thead>
<tr>
<th></th>
<th>Average</th>
<th>LRHP (low radiation, high precipitation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precipitation (mm yr(^{-1}))</td>
<td>374.4 (2009)</td>
<td>621.1 (2007)</td>
</tr>
<tr>
<td>Radiation (MJ m(^{-2})d(^{-1}))</td>
<td>3.83 (1967-2005)</td>
<td>3.38 (1969)</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>1.72 (2009)</td>
<td>1.16 (1969)</td>
</tr>
<tr>
<td>Wind Speed (km/day)</td>
<td>308.1 (2009)</td>
<td>308.1 (2009)</td>
</tr>
<tr>
<td>Humidity (%)</td>
<td>79.7 (2009)</td>
<td>79.7 (2009)</td>
</tr>
</tbody>
</table>
HYDRUS Scenarios

- **Vegetation**
  - **Vegetated**
    - Root Uptake functions (Feddus Model) based on available values for pasture, corn and potatoes
  - **Bare soil (no vegetation)**
HYDRUS Results

Average climate
Vegetation: default values for pasture

- N1 = Immediately below root zone
- N2 = Recharge to groundwater
- Negative values indicate downward flux
HYDRUS Results

Average climate
Vegetation: default values for corn/potatoes
N1 = Immediately below root zone
N2 = Recharge to groundwater
Negative values indicate downward flux
HYDRUS Results

Average climate
No vegetation

N1 = Immediately below root zone
N2 = Recharge to groundwater
Negative values indicate downward flux
## HYDRUS Summary

<table>
<thead>
<tr>
<th>Root Uptake Type</th>
<th>Discharge to root zone (mm/year)</th>
<th>Recharge to groundwater (mm/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>3.7 / 3.6</td>
<td>3.6 / 3.7</td>
</tr>
<tr>
<td>Corn or Potatoes</td>
<td>3.7 / 3.7</td>
<td>3.7 / 3.7</td>
</tr>
<tr>
<td>No Root Uptake</td>
<td>-31 / -163</td>
<td>-40 / -163</td>
</tr>
</tbody>
</table>

- Values for average climate / for LRHP
- Negative values indicate downward flux
Alberta Environment default constant values may differ significantly from the “true” site conditions.
HYDRUS Summary

- Different flux estimations change assessment of salt migration
  - For a site with crop, downward migration of salt could be minimal
  - For a site with -12 mm/y recharge to DUA, the chloride guidelines could be overestimated by 3 times if the default -6 mm/y is used
- Even with the same average flux, salt can migrate different with constant flux than with seasonal varying flux
HYDRUS Transport (Example 1)

- Depth of Root Zone
- Salt-Impacted Zone (ConC=1)
- Groundwater Table
HYDRUS Transport (Example 1)

- Relative concentration to root zone
- Constant upward flux = 1 mm/y

- Relative concentration to root zone
- Seasonally varying upward flux = 1 mm/y on average
HYDRUS Transport (Example 1)

Relative concentration to groundwater

Constant downward flux = 6 mm/y

Relative concentration to groundwater

Seasonally varying downward flux = 6 mm/y on average
Summary

- Water fluxes in vadose could vary significantly from site to site even under the same climate condition.
- Different root water uptake rates could be the most important one among a number of other factors.
- Using constant recharge/discharge rates does not represent possibly significant difference between sites and may overestimate or underestimate salt migration at the site.
Challenges remain how to determine site-specific water fluxes

- Not feasible to conduct field measurements at typical salt contaminated sites
- A more practical solution could be providing representative climate datasets in different regional and representative parameters values (used in Feddes model or VG model) for typical vegetation/crop types
- Possibly calibrated against seasonal water level changes