Groundwater flow and residence time – Twin Cities metropolitan area

Estimating vertical travel times to upper bedrock aquifers

Bob Tipping – MGWA Spring Conference, April 19, 2012
Questions asked by resource managers

• “What’s the quality of water in my area?”
• “Is it getting worse or better?”
• “If we change our use patterns, what are the consequences?”
What is the problem?

• The spatial and temporal variability in groundwater composition and flow is largely unrecognized and undocumented.

• These problems are compounded in urban areas, where the effects of pumping, natural and human induced changes in recharge and a wide variety of pollution impacts make things more complicated.
• what is the composition, spatial distribution and hydraulic characteristics of unconsolidated materials overlying bedrock aquifers?

• what is the spatial distribution of vertical gradient that drives the downward movement of groundwater through these deposits?

Not a new approach: Larson-Higdem and others, 1975; incorporated into Ruhl and others, 2002; MN Department of Natural Resources, 1991
<table>
<thead>
<tr>
<th>code</th>
<th>Texture Description</th>
<th>$K_{\text{max}}$ (ft/day)</th>
<th>$K_{\text{min}}$ (ft/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>loam to clay loam</td>
<td>3.0E-3</td>
<td>1.0E-3</td>
</tr>
<tr>
<td>2</td>
<td>loam to sandy loam</td>
<td>2.0E+1</td>
<td>1.0E-1</td>
</tr>
<tr>
<td>3</td>
<td>loam, silt rich; silt and clay</td>
<td>2.0E-2</td>
<td>3.0E-4</td>
</tr>
<tr>
<td>4</td>
<td>loam to sandy clay loam</td>
<td>2.0E+1</td>
<td>1.0E-1</td>
</tr>
<tr>
<td>5</td>
<td>sand and gravel</td>
<td>5000</td>
<td>100</td>
</tr>
<tr>
<td>6</td>
<td>fine sand</td>
<td>30</td>
<td>0.3</td>
</tr>
<tr>
<td>7</td>
<td>sandy silt</td>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>8</td>
<td>loam to clay loam - deep</td>
<td>3.0E-5</td>
<td>1.0E-5</td>
</tr>
<tr>
<td>9</td>
<td>loam to sandy loam - deep</td>
<td>2.0E-1</td>
<td>1.0E-3</td>
</tr>
<tr>
<td>10</td>
<td>loam, silt rich; silt and clay - deep</td>
<td>2.0E-4</td>
<td>3.0E-6</td>
</tr>
<tr>
<td>11</td>
<td>loam to sandy clay loam - deep</td>
<td>2.0E-1</td>
<td>1.0E-3</td>
</tr>
</tbody>
</table>

Corresponds to fields "K_class," and "K_class_sgpg," as code specifies range of expected hydraulic conductivity in feet/day. Reference to "deep" in codes 8-11 are for point depths greater than 60 feet from land surface, estimated to be 2 orders of magnitude lower hydraulic conductivity than equivalent textures in shallow settings.
Harmonic mean of vertical hydraulic conductivity from the regional water table to the bedrock surface
Regional water table – modified OPCJ March 2008 synoptic surface
Regional water table – modified OPCJ August 2008 synoptic surface
gradient = \frac{\text{delta } h}{L}

Kz saturated mean calculated only over distance L
Calculated time of travel from water table to the bedrock surface, in years.

- Red: coarse-grained
- Green: coarse- to fine-grained
- Blue: fine-grained

Bedrock:
- Gray: Platteville Formation
- Brown: St. Peter Sandstone
- Blue: Prairie du Chien Group
- White: Bedrock stratigraphically lower than the Prairie du Chien Group
C. elevation of open-hole top
bedrock wells with detectible tritium

D. digital elevation model for marking base
elevation for recent waters
elevation of open-hole top
Quaternary wells with sr/(ca+mg) ratios greater than 0.001
elevation of open-hole top
Jordan wells with sr/(ca+mg) ratios greater than 0.001
Flowmeter measurement downward gradient from Prairie du Chien to Jordan.
The bar chart shows the percentage of total distribution with chloride (Cl) concentrations at different elevations (feet above msl). The categories are:

- **Cl less than 5 mg/l**
- **Cl between 5 and 50 mg/l**
- **Cl greater than 50 mg/l**

**Elevation (feet above msl):**
- 900: 70% (70% of the total, 70% of the total, 0%)
- 850: 64% (28% of the total, 32% of the total, 0%)
- 800: 65% (41% of the total, 22% of the total, 22%)
- 750: 22% (22% of the total, 0% of the total, 22% of the total)
- 700: 28% (14% of the total, 14% of the total, 24% of the total)
- 650: 32% (16% of the total, 16% of the total, 24% of the total)
- 600: 41% (21% of the total, 10% of the total, 20% of the total)

**Count:**
- X-axis represents the count with values ranging from 0 to 300.
Conclusions

• Gradient matters!
• Distribution of geologic materials in unconsolidated material is complex, but not without regional patterns.
• Chemical and isotopic data help refine conceptual models of groundwater flow by providing information on residence time and groundwater pathways