District-Scale Geothermal Exchange Fields

Modeling and Monitoring Results

Matthew Harper¹, Christopher Choi¹, David Hart², and James Tinjum³

(1) Biological Systems Engineering, UW-Madison
(2) Wisconsin Geological and Natural History Survey
(3) Geological Engineering, UW-Madison
Outline

- Project Objectives and Justification
- Site Description
- Site Characterization
- Modeling Results
- Monitoring Results
- Future Work
- Q&A
Objectives

- Determine the effect, if any, geothermal heat exchange systems have on groundwater quality
- Use a combination of monitoring data and modeling results to predict short and long term environmental risks
Justification

- Temperature has a positive effect on scorodite ($\text{FeAsO}_4 \cdot 2\text{H}_2\text{O}$) dissolution
- Core samples indicate arsenic is present on site
- Arsenic has harmful short and long term health effects
Site Description

- To date, Epic Systems Corporation has installed over 5,500 boreholes
- Within each a fluid circulates to transfer energy
- Epic is cooling dominant; i.e. more heat is transferred to the ground than from it, causing a year over year temperature increase
Site Description

Arial View of Epic Campus, looking south. (John Hart, State Journal Archives)
Site Description
Site Characterization

Arsenic vs. Depth - Epic Core 4

XRF Measurements (Clay and Hart, 2014)
Site Characterization

Arsenic vs. Depth - Epic Core 2

XRF Measurements (Clay and Hart, 2014)
Modeling Results

- Computational fluid dynamics allows us to solve the PDE’s that govern heat transfer.
- In order to reduce computational time, we have verified that using 2D models as “slices” of 3D models will not introduce significant errors.
Comparison

- 3D
- 2D

Temperature °C vs. y distance [m]
Borefield Scale

- Apply design data as a heat generation source to the field area

![Diagram of Computational Domain with Borefield Area and Surrounding Formation dimensions.]
Design Inputs

Borefield#3

<table>
<thead>
<tr>
<th>Month</th>
<th>W/m^3</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.1</td>
</tr>
<tr>
<td>2</td>
<td>-0.1</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
</tr>
<tr>
<td>4</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>0.3</td>
</tr>
<tr>
<td>6</td>
<td>0.4</td>
</tr>
<tr>
<td>7</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>0.6</td>
</tr>
<tr>
<td>9</td>
<td>0.5</td>
</tr>
<tr>
<td>10</td>
<td>0.4</td>
</tr>
<tr>
<td>11</td>
<td>0.3</td>
</tr>
<tr>
<td>12</td>
<td>0.2</td>
</tr>
</tbody>
</table>
Results

- **Temperature [°C]**
- **Time [years]**

Graph showing temperature over time for two scenarios:
- **q=0 m/d** (black line)
- **q=0.03 m/d** (blue line)
Results

Temperature contours for conduction only (left) and with advection (right) for a Darcy’s velocity of 0.3 m/day
Management Strategies

- Even under idealized conditions, ground temperatures still increase over 10°C
- Epic currently practices passive management; when a field temperature is too high, the field is temporarily shut down
- More active management may be needed for both the efficiency and sustainability of the system
Monitoring Results

- Currently 2 of the 5 planned monitoring wells are installed
- Each has shallow and deep piezometers and a blank for fiber optic installation
- Water samples prior to full-field activation for background levels

Example monitoring well installation. Horizontal distance greatly exaggerated.
Monitoring Results

- Samples taken Aug. 27th and 28th, 2014
- Shallow and deep aquifer sampled at north and east wells

<table>
<thead>
<tr>
<th>Lab #</th>
<th>Site</th>
<th>Nitrogen</th>
<th>Alkalinity</th>
<th>Chloride</th>
<th>Arsenic</th>
<th>Calcium</th>
<th>Copper</th>
<th>Iron</th>
<th>Potassium</th>
<th>Magnesium</th>
<th>Manganese</th>
<th>Sodium</th>
<th>Phosphorus</th>
<th>Lead</th>
<th>Sulfate</th>
<th>Zinc</th>
</tr>
</thead>
<tbody>
<tr>
<td>474-14-1</td>
<td>East PZ-D</td>
<td>0.3</td>
<td>320</td>
<td>2.8</td>
<td>0.005</td>
<td>60.49</td>
<td>&lt;0.002</td>
<td>0.090</td>
<td>0.090</td>
<td>42.581</td>
<td>0.01</td>
<td>3.2</td>
<td>0.043</td>
<td>&lt;0.005</td>
<td>15.4</td>
<td>0.005</td>
</tr>
<tr>
<td>474-14-2</td>
<td>North PZ-S</td>
<td>12.3</td>
<td>340</td>
<td>37.8</td>
<td>0.005</td>
<td>82.55</td>
<td>&lt;0.002</td>
<td>0.100</td>
<td>1.77</td>
<td>43.711</td>
<td>0.003</td>
<td>26.3</td>
<td>1.595</td>
<td>&lt;0.005</td>
<td>22.7</td>
<td>0.002</td>
</tr>
<tr>
<td>474-14-3</td>
<td>North PZ-D</td>
<td>0.2</td>
<td>312</td>
<td>&lt;0.5</td>
<td>&lt;0.004</td>
<td>54.75</td>
<td>&lt;0.002</td>
<td>0.07</td>
<td>1.18</td>
<td>40.38</td>
<td>0.007</td>
<td>3.5</td>
<td>0.13</td>
<td>&lt;0.005</td>
<td>10.90</td>
<td>&lt;0.002</td>
</tr>
<tr>
<td>474-14-4</td>
<td>North PZ-S</td>
<td>12.5</td>
<td>348</td>
<td>38.0</td>
<td>0.007</td>
<td>82.08</td>
<td>&lt;0.002</td>
<td>0.52</td>
<td>1.78</td>
<td>42.96</td>
<td>0.006</td>
<td>29.0</td>
<td>1.81</td>
<td>&lt;0.005</td>
<td>23.10</td>
<td>0</td>
</tr>
<tr>
<td>474-14-5</td>
<td>East PZ-S</td>
<td>11.2</td>
<td>336</td>
<td>39.5</td>
<td>0.005</td>
<td>85.06</td>
<td>0.03</td>
<td>0.89</td>
<td>6.15</td>
<td>44.59</td>
<td>0.011</td>
<td>34.3</td>
<td>0.74</td>
<td>&lt;0.005</td>
<td>27.3</td>
<td>0.01</td>
</tr>
</tbody>
</table>
**Highlighted Results**

- Results typical for the area, with significantly higher Nitrate, Chloride, Sodium, and Sulfate levels in the shallow aquifer
- All samples show arsenic levels below EPA guidelines (<10 ppb)

<table>
<thead>
<tr>
<th>Site</th>
<th>Nitrogen, Nitrate</th>
<th>Chloride</th>
<th>Phosphorus</th>
<th>Arsenic</th>
</tr>
</thead>
<tbody>
<tr>
<td>East PZ-S</td>
<td>11.2</td>
<td>39.5</td>
<td>0.74</td>
<td>0.005</td>
</tr>
<tr>
<td>East PZ-D</td>
<td>0.3</td>
<td>2.8</td>
<td>0.043</td>
<td>0.005</td>
</tr>
<tr>
<td>North PZ-S</td>
<td>12.5</td>
<td>38.0</td>
<td>1.81</td>
<td>0.007</td>
</tr>
<tr>
<td>North PZ-D</td>
<td>0.2</td>
<td>&lt;0.5</td>
<td>0.13</td>
<td>&lt;0.004</td>
</tr>
</tbody>
</table>

All values mg/L
Future Work

- Drill and install 3 additional monitoring wells, nested to determine groundwater flow
- Continue collecting groundwater samples to establish background levels; after full field activation, additional samples will be used to monitor contaminant levels
- Quantify temperature effects on arsenic release and develop a coupled temperature and mass transport model for long term predictions of risk
- Develop and test management strategies to achieve lower, steady borefield temperatures
Acknowledgements

- Epic Systems Corporation and associated contractors (Bertram Drilling, Morse, MEP Associates, General Heating and Cooling, TEEL Plastics)
- Funding from the Wisconsin Groundwater Coordinating Council
Questions?