Effect of Steam-Related Heave on Groundwater-Surface Water Interaction

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Outline

- Satellite Monitoring to measure heave
- Groundwater-Surface Water monitoring program
- Use of heat as tracer to estimate GW/SW interaction
- Results to date
- Next Steps
Satellite Monitoring to Assess Surface Heave

Satellite monitoring

Reservoir Monitoring with Radar Satellite Images

Measured uplift

Steam injection to mobilize bitumen
Jackfish Heave Displacement
0 to >20 mm/year
Groundwater - Surface Water Monitoring Installations
Monitoring Stations at J1 (Pad B)
Monday Creek
Monitoring Stations at J2 (Pad BB) Unnamed Creek
Monitoring Well Installations: Streambed / Streambank

- Thermocouple Sensors
- Pressure Transducer
- Electrical Conductivity probe
Groundwater Monitoring Wells and telemetry installation
Stream Bed Monitoring
Some background theory...

Using Heat as a tracer to estimate GW/SW interaction
Temperature variability in SW-GW

Seasonal temperature signals

Diurnal temperature signals
Temperature fluctuation vs. depth

- Frequency (e.g., diurnal, seasonal)
- Thermal parameters of the sediments
- Groundwater velocity (magnitude and direction)
Using temperature to assess GW Flux

- Temperature signal is more attenuated in gaining streams (GW discharge)

- Temperature signal propagates deeper in losing streams (GW recharge)
Advantages of using Heat as a tracer

- Intrinsic to the System

Molina-Giraldo et al. 2011
Advantages of using Heat as a Tracer

• Temperatures can be continuously measured

• Heat can be used to estimate GW-SW flux direction and magnitude

• Heat can be used jointly with hydraulic head to estimate hydraulic conductivity
Modelling Heat to determine Groundwater Flux

Heat transport in porous media can be expressed by the 1D partial differential equation:

\[
\frac{\partial T}{\partial t} = \frac{\lambda_m}{C_m} \frac{\partial^2 T}{\partial x^2} - q \frac{C_w}{C_m} \frac{\partial T}{\partial x}
\]

- **Transient term**
- **Conduction**
- **Forced convection**

\( T \): temperature \([\degree C]\),
\( q \): Darcy velocity \([\text{m/s}]\),
\( \lambda_m \): the bulk thermal conductivity \([\text{W/m/\degree C}]\),
\( C_m \): volumetric heat capacity of the porous medium \([\text{J/m}^3/\degree C]\) and
\( C_w \): volumetric heat capacity of water \([\text{J/m}^3/\degree C]\).

Data and Results
Temperature profile vs time in Streambed

a) Raw Temperature Data

- Surface water
- Sensor 1 (8 cm below streambed)
- Sensor 2 (28 cm below streambed)
- Sensor 3 (48 cm below streambed)

Absolute Temperature [°C]

07/31/13 08/10/13 08/19/13 08/29/13 09/07/13 09/17/13 09/26/13 10/06/13 10/15/13 10/25/13
Sinusoidal components of water temperature fluctuation

b) Sinusoidal components

- Sensor 1 (8 cm below streambed)
- Sensor 2 (28 cm below streambed)
- Sensor 3 (48 cm below streambed)
Vertical seepage flux (1D Analytical Solution)

Vertical Darcy Velocity (m/day)

Sensor 1 (8 cm below streambed)
Sensor 2 (28 cm below streambed)
Sensor 3 (48 cm below streambed)
Precipitation vs. Water Levels

- Precipitation
- Water levels in bank, piezometers, and creek
Project Summary - Next Steps

- Heat monitoring is a leading edge approach to monitor SW-GW interaction

- Long term monitoring will identify any heave-related effects on groundwater surface water interaction

- First full year round of dataset collection: August 2014

- Project timeline: 5 years

