In-Situ Remediation of Hydrocarbon Impacted Soil and Groundwater in Permafrost Terrain at a Remote Site. Tibbitt to Contwoyto Winter Road, Northwest Territories

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Principal Hydrogeologist
Acknowledgements

- Tibbitt to Contwoyto Winter Road Joint Venture
  Winter Road currently owned and operated by Mining companies De Beers Canada, Diavik Diamond Mines and Dominion Diamonds (formerly BHP Billiton)
- LL Allen Enterprises (Transportation Company)
- Arctic West Adjusters Limited (Insurer)
Overview

- Background
- Assessments conducted
- Remediation Action Plan (RAP) analysis
- Remediation: PermeOx injection
- Remediation performance evaluation
- Impact prediction to nearby lake
- Summary
What happened and Where

- March 9 2008: ~ 14,000 L of diesel released from transport truck at Portage 32 of the Tibbitt to Contwoyto Winter Road, Northwest Territories
Tibbitt to Contwoyto Winter Road

- Private Road: services mines and exploration activities
- First year of operation – 1982
- Total length 600 km – 87% on frozen lakes
- 65 overland portages, 35% of which have been upgraded with gravel / sand pads
- Three maintenance camps – Dome Lake, Lockhart Lake and Lac de Gras. Heck point at Meadows
- Season of operation – February / March
- Average operational days per year – 57 days
Emergency Response

- March 9, 2008 spill
- March 10, 2008 inspection by Indian and Northern Affairs Canada
- March 18 to March 24 2008
  Removed impacted snow.
  129,276 kg soil excavated and disposed in Yellowknife, Berm built around excavation pit (10 m x 5 m x 1 m deep).
Inspection/Excavation
Inspection/Excavation
Inspection/Excavation
Summer 2008 Assessment

License of Occupation of Winter Road issued by Federal Government, Aboriginal Affairs and Northern Development Canada (AANDC) (formerly Indian and Northern Affairs Canada). Site administered by AANDC.

Guidelines

Groundwater: Canadian Council of Ministers of the Environment (CCME), Canadian Water Quality Guidelines for Protection of Fresh Water Aquatic Life (FAL), 1999
Soils:
- 10 test pits 1 to 2 m depth
- Analysis: Benzene, Toluene, Ethylbenzene and Xylenes (BTEX) and PHC fraction F1 to F4
- F1, F2 and F3 exceeded guidelines

Groundwater:
- Eight monitoring wells installed using excavator
- Analysis: BTEX and PHC fraction F1, F2
- Petroleum hydrocarbons exceeded guidelines
2009 – 2011 Assessment/Delineation

- **2009:**
  - March: install 23 monitoring wells
  - Summer 2009: surface water and groundwater sampling

- **2010:**
  - March: install six monitoring wells (2.5 to 6.0 m depth)
  - Summer 2010: surface water and groundwater sampling

- **Summer 2011:**
  - Surface water and groundwater sampling, install four well points by lake (1.2 to 1.7 m depth)
  - Hydraulic conductivity testing and geologic mapping
  - Pathway assessment and remediation options analysis
2009 – 2011 Assessment/Delineation
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2009 – 2011 Assessment/Delineation
Granitoid bedrock with small scale quartz lined fractures. Granitoid blocks common (frost jacking?)

Bedrock tends to smooth from glacial scouring

No major faulting

Jointing most commonly parallel to lake

Low lying areas contain mix of silty, sandy gravelly sediment. Peat and other organics common.

Depth to groundwater 0.5 to 1.5 m below ground

Hydraulic conductivity $2 \times 10^{-4}$ to $3 \times 10^{-7}$ m/sec.

(mean $1.51 \times 10^{-5}$ m/sec)
2011 Geological Mapping
2011 Pathway Assessment

- No residential, commercial / industrial, agricultural activities in area
- Proximity of lake – natural areas land use appropriate as wildlife and freshwater aquatic pathways in this land use
- Exposure pathways and receptors under land use:
  - Soil contact: soil invertebrates, wildlife, and human
  - Soil and food ingestion: herbivores and human
  - Groundwater/surface water: aquatic life and human

Governing Pathways: soil contact by wildlife, FAL via surface water and groundwater
## 2011 Pathway Assessment

CCME – Applicable Guidelines
FAL (are more stringent than wildlife)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Guideline Value (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benzene</td>
<td>0.37</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.02</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>0.09</td>
</tr>
<tr>
<td>Xylene</td>
<td>-</td>
</tr>
<tr>
<td>F1</td>
<td>-</td>
</tr>
<tr>
<td>F2</td>
<td>-</td>
</tr>
</tbody>
</table>
2011 Remediation Options

1. Construction of Impermeable Barriers
2. Permeable Treatment Beds
3. Pump and Treat: Dissolved Phase Recovery
4. Soil Vapour Extraction System (SVE)
5. Air Sparging
6. Surface treatment (air stripping, granular activated carbon, gravity separation, reverse osmosis, etc.)
7. In-situ biological treatment
8. Chemical oxidation (e.g., PermeOx Plus)
2012 – 2013 Remediation – PermeOx Plus

- PermeOx Plus – calcium peroxide – CaO2
  \[ \text{CaO}_2 + 2\text{H}_2\text{O} \rightarrow \text{Ca(OH)}_2 + \text{H}_2\text{O}_2 \]
  \[ 2\text{H}_2\text{O}_2 \rightarrow \text{O}_2 + 2\text{H}_2\text{O} \]
- Contains 18% active oxygen
- Provides slow oxygen release
- Can be provided in dilute form to monitoring wells
- Can be mixed up to slurry of 45% by weight
- Factors controlling effectiveness of bioremediation
  - Presence of microbes
  - Nutrients
  - Electron donor (in aerobic metabolism oxygen) - limiting factor is often lack of oxygen
  - Hydraulic conductivity (HC)
2012 – 2013 PermeOx Dosing

- PermeOx mixed with Lake water, delivered to monitoring wells / PHC
- Left over PermeOx applied to excavation
- First dosing July 2012 (300 lbs) – 11.3 kg per 100 L water
- Subsequent dosing Sept 2012, July 2013, Sept 2013 (300 - 350 lbs) – 11.3 kg per 200 L water
Results

- 2009 to 2010: 16 wells exceeded guidelines for hydrocarbons
- 2011: 13 wells exceeded guidelines
- 2013: four wells exceeded guidelines for toluene
Performance Evaluation

Theoretical decrease (decay) of toluene and ethylbenzene by natural processes compared to observed concentrations.

Used first order decay equation (Aral and Taylor 2011):

\[ C_t = C_i e^{-\lambda T} \]

Where:

\( C_i \) = Initial PHC Concentration in July 2012 (mg/L).
\( C_t \) = Final PHC Concentration in September 2012 (mg/L).
\( \lambda \) = Decay constant of toluene and ethylbenzene (-/year). Derived from half-lives of toluene and ethylbenzene (0.288 year and 0.312 year, respectively).
\( T \) = Time (years) = 0.18 years (time between July and September sampling events)
## Performance Evaluation

<table>
<thead>
<tr>
<th>Monitoring Well</th>
<th>Toluene (mg/L)</th>
<th>Ethylbenzene (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Theoretical</td>
<td>Observed</td>
</tr>
<tr>
<td>MW09-04</td>
<td>0.18</td>
<td>0.17</td>
</tr>
<tr>
<td>MW09-08</td>
<td>0.16</td>
<td>0.039</td>
</tr>
<tr>
<td>MW09-18</td>
<td>0.0012</td>
<td>&lt;0.0004</td>
</tr>
<tr>
<td>MW09-19B</td>
<td>0.23</td>
<td>0.097</td>
</tr>
</tbody>
</table>

**Note:** ethylbenzene was non-detect during July and September 2012 at MW09-19B.
Potential Hydrocarbon Migration

Potential toluene concentration that could reach lake based on residual toluene concentration in 2013.

- Use Alberta Environment’s (AENV) steady state model for contaminant migration from the groundwater table beneath the source to the lake receptor (AENV Tier 1 and 2 Guidelines).
- Dilution Factor 4 (DF4) = concentration beneath source / concentration at receptor (accounts for dispersion and biodegradation).
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Value</th>
<th>Rational for parameter selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Darcy velocity</td>
<td>m/year</td>
<td>75.69</td>
<td>maximum K and max. hydraulic gradient (0.01) of wells along GW flow path</td>
</tr>
<tr>
<td></td>
<td>m/year</td>
<td>389.78</td>
<td>maximum K and max. hydraulic gradient (0.0515) of wells along GW flow path</td>
</tr>
<tr>
<td></td>
<td>m/year</td>
<td>389.78</td>
<td>maximum K and max. hydraulic gradient (0.0515) of wells along GW flow path</td>
</tr>
<tr>
<td>Water Table depth</td>
<td>m</td>
<td>4.59</td>
<td>Conservative based on maximum water level for September 2013</td>
</tr>
<tr>
<td>Distance to source</td>
<td>m</td>
<td>90</td>
<td>distance between monitoring well MW09-19B and receptor along &quot;interpreted&quot; GW flow direction</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>170</td>
<td>distance between monitoring well MW09-08 and receptor along &quot;interpreted&quot; GW flow direction</td>
</tr>
<tr>
<td></td>
<td>m</td>
<td>180</td>
<td>distance between monitoring well MW09-04 and receptor along &quot;interpreted&quot; GW flow direction</td>
</tr>
<tr>
<td>Source concentration</td>
<td>mg/L</td>
<td>0.011</td>
<td>September 2013 toluene concentration in monitoring Well MW09-19B</td>
</tr>
<tr>
<td></td>
<td>mg/L</td>
<td>0.012</td>
<td>September 2013 concentration in monitoring Well MW09-08</td>
</tr>
<tr>
<td></td>
<td>mg/L</td>
<td>0.064</td>
<td>September 2013 concentration in monitoring Well MW09-04</td>
</tr>
<tr>
<td>Tot. soil porosity</td>
<td></td>
<td>0.36</td>
<td>Value for coarse soil [Tier 2 Guidelines]</td>
</tr>
<tr>
<td>Dry soil bulk density</td>
<td>(g/cm³)</td>
<td>1.7</td>
<td>Value for coarse soil [Tier 2 Guidelines]</td>
</tr>
<tr>
<td>Org. C partition coeff.</td>
<td>mg/g</td>
<td>234</td>
<td>Value for Toluene [Tier 2 guidelines]</td>
</tr>
<tr>
<td>Decay halflife of cont.</td>
<td>years</td>
<td>0.288</td>
<td>Value for Toluene [Tier 2 guidelines]</td>
</tr>
<tr>
<td>Fraction org. carbon</td>
<td>(g/g)</td>
<td>0.005</td>
<td>Value for coarse soil [Tier 2 Guidelines]</td>
</tr>
<tr>
<td>Source width Perp. to GW flow</td>
<td>m</td>
<td>30</td>
<td>Conservative assumed to be entire width (based on vertical distance between most northern and most southern monitoring well with exceedances) perpendicular to groundwater flow</td>
</tr>
</tbody>
</table>
## Dilution Factor 4 (DF4) and Surface Water Receptor Estimation

<table>
<thead>
<tr>
<th>Chemical of Potential Concern (CoPC)</th>
<th>Toluene Tier 1 Guideline (mg/L)</th>
<th>Scenario</th>
<th>Measured Concentration at Source (mg/L)</th>
<th>Estimated Concentration at Receptor (mg/L)</th>
<th>DF4</th>
<th>A</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Toluene</td>
<td>0.002</td>
<td>Scenario 1</td>
<td>0.011</td>
<td>8.65E-10</td>
<td>1.27E+10</td>
<td>-16.09</td>
<td>0.83</td>
<td>-0.83</td>
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<tr>
<td></td>
<td></td>
<td>Scenario 2</td>
<td>0.012</td>
<td>3.18E-13</td>
<td>3.77E+10</td>
<td>-23.59</td>
<td>0.44</td>
<td>-0.44</td>
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<tr>
<td></td>
<td></td>
<td>Scenario 3</td>
<td>0.036</td>
<td>4.06E-13</td>
<td>8.87E+10</td>
<td>-24.40</td>
<td>0.42</td>
<td>-0.42</td>
</tr>
</tbody>
</table>

### Notes:

#### Scenario Descriptions

- **Scenario 1**: Based on monitoring well MW09-19B with Toluene exceedance and at a distance of 90 m from surface water receptor
- **Scenario 2**: Based on monitoring well MW09-08 with Toluene exceedance and at a distance of 170 m from surface water receptor
- **Scenario 3**: Based on monitoring well MW09-04 with Toluene exceedance and at a distance of 180 m from surface water receptor

Exceedances based on September 2013 toluene concentrations

See justification pf parameters on Table 4(b)
Summary

- March 9 2008: ~ 14,000 L of diesel spilled
- Excavation and removal of impacted snow and soils
- Hydrocarbon assessment and delineation, geological mapping, testing, pathway assessment, RAP development
- 2011: 13 wells exceeded guidelines
- 2012 to 2013: remediation using PermeOx
- 2013: Four wells exceeded guidelines for toluene
  - Actual concentrations less than predicted
  - Impact prediction: no adverse effects to lake predicted
  - Regulator accepted reduced groundwater sampling going forward
Questions

Contact
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