Using Mass Balance to Assist in Determining Remedial Options

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Presentation Outline

- Introduction.
- Example Site.
- Mass Balance.
- Calculations.
- Outcomes.
Introduction

• Investigating site for 6 years.
• Spent approximately $400k on investigation and remediation.
• Have good understanding of CSM.
• Use mass balance calculations to gain a greater understanding of contamination distribution and help guide future management options.
Example Site – Current Situation

- Operational service station.
- Located on small NZ city in a mixed commercial / residential area.
- Down-gradient landuse is all commercial.
- Site had a history of leaks.
- Significant soil contamination was identified during a fuel system upgrade in 2004.
Example Site: CSM - Geology

- Alluvial Deposits - interbedded sequence of silts and sands (some clays) that extend to depths of at least 10 m.
Example Site – CSM: Geology

Site

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Example Site: CSM - Geology
Example Site: CSM - Geology
Example Site: CSM - Hydrogeology

- Groundwater at an average depth of 4.5 m bgl.
- Fluctuates between 0.30 and 1.2 m
- Flows in a northerly direction.
- Possibly influenced by a paleo-channel or attributed to monitoring well locations.
Example Site: CSM - Hydrogeology
Example Site: CSM - Contaminant Conditions

- Consists of petroleum hydrocarbon – petrol.
- SPH plume:
  - Currently approximately 9000 litres.
  - Covering 900 m².
- Dissolved phased benzene (2 mg/l) plume extends 120 m from boundary.
Example Site: CSM - Contaminant Conditions

- Soil-gas: BTEX concentration in soil-gas at 0.5, 1 and 2 m bgl all below laboratory detection limits.

Remediation

- 417 tonnes of impacted soil removed during upgrade works.
- SPH recovery system has recovered 3,400 L.
Example Site - CSM

Benzene 2 mg/l contour (ANZECC 80%)
Example Site: CSM - Contaminant Conditions
Example Site: Risk Assessment

• Little or No Risk to:
  - Building occupants, even in buildings located over SPH
  - Groundwater users - none

• Potential Risks to:
  - Subsurface excavations workers
  - Subsurface utility workers
  - Redevelopment
Mass Balance

• Calculate the mass of benzene moving through the dissolved phased plume to gain an greater understanding of benzene migration and time required for the plume to degrade.
Mass Balance 101

Known Mass Release

\[ \text{Mass}_{\text{released}} = \sum \text{Mass}_{\text{partitions}} \]

- Very Static View.
- More meaningful mass-balance exercise is based on rates of change of a mass in a more dynamic model that includes advective flow into and out of the model and transformation that occurs. Therefore:

\[ \text{Mass}_{\text{in}} + \text{Mass}_{\text{gen}} = \text{Mass}_{\text{out}} + \text{Mass}_{\text{stored}} \]
Mass Balance 101

Mass\textsubscript{in} = Rate at which contaminant mass is entering the model. Mass flux through the up gradient face.

Mass\textsubscript{gen} = Transformation i.e. PCE to TCE.

Mass\textsubscript{out} = Rate at which contaminant mass is leaving the model. Mass flux through the down gradient face.

Mass\textsubscript{stored} = If steady state then rates of sorption and desorption about same resulting in zero mass storage.
Mass Balance 101

- Mass of benzene (kg) moving across each transect per year.
Mass Balance - Transects

- Transect 1 (122 m x 2 m)
- Transect 2 (80 m x 2 m)
- Transect 3 (63 m x 2 m)
Mass Balance: Calculations

- Mass through each transect = \( \sum (C_w \times V_c \times \text{ratio}) \)

Where:
- \( C_w \) = contaminant concentration (kg/m\(^3\))
- \( V_c \) = contaminant velocity (m/yr)
- Ratio = ratio that well concentration represents transect.
- \( V_c = V_s / R_f \), where
  - \( V_s \) = seepage velocity, and
  - \( R_f \) = retardation factor
Mass Balance: Assumptions

• Groundwater flow rates are assumed to be uniform across cross-section.

• Steady state, therefore rates of sorption and desorption about the same.

• Where product is present then assumed benzene concentration equal to effective solubility (59 mg/l)?
Benzene Mass Balance: Example Calculation (MW21 on T2)

Calculation for T2 (monitoring data collected on July 2008)

- T2 Seepage Velocity = 19.48 m/yr.
- T2 Contaminant Velocity = 9.50 m/yr (Rf = 2.1).
- MW21 had a benzene concentration of 8.1 mg/l (0.0081 kg/m\(^3\)).
- Mass through MW21 = 0.0081 \times 9.50 = 0.077 kg/m\(^2\)/yr.

<table>
<thead>
<tr>
<th>Well</th>
<th>Mass (kg/m(^2)/yr)</th>
<th>Portion of Transect Represented by Well</th>
<th>Benzene Flux (kg/m(^2)/yr)</th>
<th>Cross Section Area of Transect (m(^2))</th>
<th>Mass Through Transect (kg/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW13</td>
<td>0.035</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MW21</td>
<td>0.077</td>
<td>0.25</td>
<td>0.032</td>
<td>160</td>
<td>5.12</td>
</tr>
<tr>
<td>MW24</td>
<td>0.015</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MW29</td>
<td>1.2 \times 10^{-4}</td>
<td>0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Example Site:
Benzene Mass Across Each Transect (kg/yr)

<table>
<thead>
<tr>
<th>Date</th>
<th>T1*</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jun 05</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan 06</td>
<td>37</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apr 06</td>
<td>40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jul 06</td>
<td>25</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Oct 06</td>
<td>28</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Feb 07</td>
<td>29</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Sept 07</td>
<td>28</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Jul 08</td>
<td>27</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Mar 09</td>
<td>25</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Jul 10</td>
<td>33</td>
<td>2</td>
<td>4</td>
</tr>
</tbody>
</table>

* Includes a well with SPH
Benzene Mass Across Each Transect (kg/yr)

Mass Benzene (kg/yr)

Date

Jan-04  May-05  Oct-06  Feb-08  Jul-09  Nov-10

Benzene kg/yr

0  5  10  15  20  25  30  35  40  45

T1 Flux (kg/yr)
T2 Flux (kg/yr)
T3 Flux (kg/yr)
How Long for Plume to Degrade

- Estimate approximately 9,000 litres of product in ground.
- Analysis shows benzene concentration in the product ranges between 1.2 to 1.8 %.
- Therefore 108 and 162 litres of benzene in product.
How Long for Plume to Degrade

- Mass in kilograms of benzene is 95 to 142 kg.
- Average flux of 2 kg/yr will take between 48 and 71 years for benzene to leach out of product.
- Does not allow form evaporative loss of contaminant.
## Possible Remedial Options

<table>
<thead>
<tr>
<th>Possible Remedial Option</th>
<th>Mass SPH Removed</th>
<th>Time for benzene to leach from remaining SPH</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNA*</td>
<td>None</td>
<td>48 – 71 years</td>
</tr>
<tr>
<td>SPH Removal*</td>
<td>20% 1,800 L</td>
<td>38 – 57 years</td>
</tr>
<tr>
<td>SVE / Sparging /MPE**</td>
<td>90% 8,100 L</td>
<td>5 – 7 years</td>
</tr>
</tbody>
</table>

* Passive recovery system
### Possible Remedial Options

<table>
<thead>
<tr>
<th>Possible Remedial Option</th>
<th>Risk Reduction</th>
<th>Time Reduction</th>
<th>Estimated Total Costs (NPV$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNA*</td>
<td>No</td>
<td>No</td>
<td>$315k</td>
</tr>
<tr>
<td>SPH Removal*</td>
<td>No</td>
<td>Yes</td>
<td>$390k</td>
</tr>
<tr>
<td>SVE / Sparging /MPE**</td>
<td>Yes</td>
<td>Yes</td>
<td>$700k</td>
</tr>
</tbody>
</table>

* Not allowing for cost for off site liability claims
** No vapour treatment
Issue - Problem

Due to limited risk – preferred option to legalise discharge and monitor.

Regulator Questions:

1. Do we have any idea how long might this amount of SPH may remain as a problem that needs managing if we rely on natural attenuation processes only?

2. Would a purpose-designed SPH recovery system result in a significant shortening of that time, or is this hard to determine?
References

• Gibbs and Santillan (1999) Performing Contaminant Mass Balances for Remedy Assessment