Assessment of Plume Stability in Monitored Natural Attenuation Assessments Using the Centre of Mass and Total Plume Mass Approach

Samuel Mohr & Kate Naude
Presentation Outline

- The sustainable remediation approach
- Methods for assessing plume stability
- Case study:
  - Site setting
  - Plume area and mass calculations
  - Plume centre of mass
- Conclusions
ERM’s Sustainable Remediation Approach

Is remediation really needed?

Minimise footprint of remediation

**OBJECTIVE**

- Project Definition
  - System boundaries
  - Stakeholder identification
  - Environmental, social & economic indicators
  - Maximise site reuse, materials & resources

- Planning Brownfield
  - Integration of land use and contamination
  - Social benefits
  - Systematic planning
  - Technical project planning
  - Community / stakeholder engagement

- Site Investigation
  - Robust conceptual site model
  - Dynamic & real-time work strategies
  - Triad approach
  - High resolution site characterisation

- Risk Assessment
  - Site specific risk assessment
  - Incorporation of site specific chemistry, soil properties
  - Vapour data
  - Bioavailability
  - Toxicity testing

- Remedial Options Approval
  - Tool box qualitative/quantitative
  - Multi criteria analysis
  - Cost benefit analysis
  - Life cycle analysis
  - Carbon footprinting
  - Net environmental benefit analysis
  - Community/stakeholder engagement

- Remediation Implementation
  - Green remediation
  - Construction best management practices

- Remediation Optimisation
  - Continuous optimisation of system throughout project process
  - Optimisation of existing systems

**GOAL**

- Green Remediation
- Minimise footprint of remediation
Monitored Natural Attenuation (MNA) has been steadily gaining popularity as a plausible remediation strategy over the past two decades.

Three main criteria for adopting an MNA approach:

- **Criteria 1**: NA processes must be demonstrated to an acceptable level of confidence.
- **Criteria 2**: The intended land uses must not adversely affect the NA processes.
- **Criteria 3**: Identified receptors will be protected in the short and long term, and minimal expansion of the plume over the remedial timeframe.
Methods For Assessing Plume Stability

Graphical Analysis
- Concentration isopleth maps
- Concentration vs distance
- Concentration vs time

Statistical Analysis
- Mann Kendall Analysis
- Mann Whitney U-test

<table>
<thead>
<tr>
<th>Mann-Kendall Results</th>
<th>0-8 Quarter Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MW1</td>
<td>Decreasing</td>
</tr>
<tr>
<td>MW2</td>
<td>Stable/No Trend</td>
</tr>
<tr>
<td>MW3</td>
<td>Stable/No Trend</td>
</tr>
<tr>
<td>MW4</td>
<td>Decreasing</td>
</tr>
<tr>
<td>MW5</td>
<td>Increasing</td>
</tr>
</tbody>
</table>

MW1 - TCE

MW2 - TCE
Site Setting

- Operational petrochemical facility
- Sand dominated sediments to 6m bgl, followed by dense clay
- Groundwater at 1-2m bgl, groundwater flow in a westerly direction
- Large gasoline spill in 2011

A site investigation and remediation programme was initiated which included:

- **Plume delineation & monitoring well installation,**
- **Product recovery well installation & passive skimming; and**
- **Groundwater monitoring of the plume & surrounding area**
Plume Area and Mass Calculation

Apr 2013

Oct 2014

Oct 2015

Oct 2016
Plume Area and Mass Calculation

- Isopleth maps were generated as 3 dimensional surfaces
- Plume threshold value is set and a grid volume report is generated giving:
  - Planar area (m²)
  - Grid volume (µg/L•m²)

\[
\text{Average } [C] = \frac{\text{Grid Volume (µg/L • m²)}}{\text{Planar Area (m²)}}
\]

\[
\text{Actual Avg } [C] = \text{Average } [C] + \text{Plume Threshold } [C]
\]

\[
\text{Plume Mass (kg)} = \frac{[\text{Planar Area}] \times [\text{Actual (} C \text{)}] \times [b] \times [n_{eff}] \times \left[\frac{1000L}{m^3}\right]}{1E + 9µg/kg}
\]
## Plume Area and Mass Calculation

### Average Benzene Concentration

![Graph showing average benzene concentration over time](image)

### Benzene Plume Mass

![Graph showing benzene plume mass over time](image)

### Table: Parameter Analysis

<table>
<thead>
<tr>
<th>Parameter</th>
<th>$R^2$</th>
<th>Regression Line Slope</th>
<th>95% Lower Confidence Limit</th>
<th>95% Upper Confidence Limit</th>
<th>Trend Analysis Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concentration</td>
<td>0.69</td>
<td>-1.3</td>
<td>-2.44</td>
<td>-0.32</td>
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<tr>
<td>Mass</td>
<td>0.88</td>
<td>-0.06</td>
<td>-0.08</td>
<td>-0.04</td>
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<tr>
<td>Area</td>
<td>0.77</td>
<td>-4.6</td>
<td>-7.47</td>
<td>-1.72</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>
Plume Centre of Mass

- The plume centre of mass (COM) is essentially the geometric centre (or centroid) of the plume.
- Plume COM is generated from Surfer grid files.
- Grid file data (X,Y,Z) is filtered to remove all node points which are less than the defined threshold (Z) value.

\[
\text{COM}(X) = \frac{\sum X \times Z}{\sum Z} \quad \text{COM}(Y) = \frac{\sum Y \times Z}{\sum Z}
\]

Typical Plume COM behaviour:
- **Expanding plume** - migrates downgradient.
- **Shrinking plume** – migrates up-gradient (back towards source).
- **Stable plume** – minimal lateral movement.
Plume Centre of Mass
Conclusions

- Total mass approach is a useful tool within the MNA toolbox to demonstrate that natural attenuation processes occurring within a plume
- Centre of Mass approach is a useful method to provide a meaningful assessment of plume stability
- Data generated from the case study supports the position that MNA is an appropriate and sustainable approach to employ at the site
- As always, there are limitations…
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