Applications of Plume Stability Analysis in Risk Assessment for Contaminated Sites


October 12, 2018
Our vision

We strive to be the premier engineering solutions partner, committed to delivering complex projects from vision to reality for a sustainable lifespan.
Presentation Outline

› Brief overview of risk assessment
› How plume stability is used to support risk assessment
› Plume anatomy: shrinking vs expanding plumes
› Use of statistical analyses and trends
› Determining plume stability
› Examples of data and plumes and results of Plume Stability Analysis
Risk Assessment

› Site characterization requires collecting data to develop our understanding of the site & to support future site management plans
› Risk Assessment is understanding the three pillars: source, pathway, receptor.
› If risk is unacceptable, risk management measures are recommended.
› Stakeholders implement Risk Management Plans and follow up monitoring.
Relative Risk

› Primary Goal: to find a solution to manage risk that presents the best compromise of risk reduction / risk control and societal benefit.

› Secondary Goal: to find a balance between the ‘precautionary principle’ and evidenced-based risk management decision-making.
Problem Formulation
Overall Conceptual Site Model (CSM)

**Ecological Risk Assessment (ERA)**
- Problem Formulation (ECSM)
  - COPCs, sources, pathways, receptors
- Exposure Assessment
- Toxicity Assessment - Ecological TRV
- Risk Characterization

**Human Health Risk Assessment (HHRA)**
- Problem Formulation (HHCSM)
  - COPCs, sources, pathways, receptors
- Exposure Assessment
- Toxicity Assessment - Human Health TRV
- Risk Characterization

If risks are unacceptable

**Risk Management Plan**
Conceptual Site Models

Developing a CSM is a step-wise approach where data (available and needed) is reviewed, organized and presented in an accessible format:

› Establish your framework
› Know your impact
› Understand your receptors
› Assess data gaps to feed your CSM

There are many acceptable formats… choose one that is most appropriate for your audience.
Risk Assessment Methods

Problem Formulation
- Overall Conceptual Site Model (CSM)

Ecological Risk Assessment
- COPCs, sources, pathways

Toxicity Assessment
- Ecological TRV

Risk Characterization
- if risks are unacceptable

Risk Management Plan

Risk Assessment HHRA
- Problem Formulation (HHCSM)
- COPCs, sources, pathways, receptors

Exposure Assessment

Risk Characterization
- Human Health TRV

Receptor
Source
Pathway
Problem Formulation

› Identifying Chemicals of Potential Concern (COPC)
  › Measured in water and other media (soil, sediment, vapour, food)
  › Screening identifies COPC, with guidelines specific to receptors
› Selection of Receptors
  › Identifies who may be exposed to contaminants (workers, residents, visitors)
  › Identifies ecological receptors (plants, invertebrates, birds, mammals, amphibians, fish)
  › Rare ecological species are also considered
› Exposure Pathway Analysis
  › Identifies exposure pathways where receptors can be exposed to site impacts
› Human Health and Ecological Conceptual Site Model
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if risks are unacceptable

Risk Management Plan
Reasons to Conduct Plume Stability Analysis

› Provides quantified values to characterize plumes
› Supports risk analysis of the plume in relation to neighbouring properties
› Identifies if there are potential risks to sensitive receptors
› Answers key regulatory requirements of plume stabilization
› Can be used as an indicator for remediation performance
› Provides a line of evidence to support Monitored Natural Attenuation
› Can visually support closure for low risk sites.
Plume Anatomy

Direction of Plume Migration

Source

Non-Aqueous Phase Liquids

Dissolved Phase

Plume Front (or Nose, Tail)
Benzene Concentration at 0.046 mg/L, equal to ABT1 guideline in fine-grained soils
Detection Limit of 0.0005 mg/L

Plume Anatomy
Plume Anatomy

Source Well

Plume Centre Well

Plume Front Well
Plume Stability

Rate of Mass Gain Chemical Added into Plume

= 

Rate Mass Loss Chemical Loss from Plume

The interpolated data tells you if:

› Plume is, or is not, expanding or shrinking in size
› Plume footprint is, or is not, moving
How to Determine Plume Stability Classification

› Mann-Kendall is a non-parametric statistical procedure that predicts trends in individual wells over time.
› Provides confidence values for the calculated trend analysis.
› Mann-Kendall considers historical concentration data, including non-detectable concentrations.
› The tool also provides a basis for the modification and / or reduction of proposed risk management programs.
# Determining Plume Stability – Using Statistical Methods

## Calculation of Mann-Kendall S Statistic for Five Sampling Events

<table>
<thead>
<tr>
<th>Benzene (mg/L)</th>
<th>Event 1</th>
<th>Event 2</th>
<th>Event 3</th>
<th>Event 4</th>
<th>Event 5</th>
<th>TOTAL POINTS</th>
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<tr>
<td></td>
<td>13.95</td>
<td>42.08</td>
<td>33.90</td>
<td>33.67</td>
<td>18.05</td>
<td>+ 4</td>
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<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>- 3</td>
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<tr>
<td>Compare To Event 2</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>- 2</td>
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<tr>
<td>Compare To Event 3</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>- 1</td>
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<tr>
<td>Compare To Event 4</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>- 2</td>
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</table>

**Apparent Decreasing Trend**

\[ S = -2 \]
### Determining Plume Stability – Using Statistical Methods

<table>
<thead>
<tr>
<th>S Statistic</th>
<th>Confidence In Trend</th>
<th>Trend</th>
</tr>
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<tbody>
<tr>
<td>S &gt; 0</td>
<td>CF &gt; 95%</td>
<td>Increasing</td>
</tr>
<tr>
<td>S &gt; 0</td>
<td>95% ≥ CF ≥ 90%</td>
<td>Probably Increasing</td>
</tr>
<tr>
<td>S &gt; 0</td>
<td>CF &lt; 90%</td>
<td>No Trend</td>
</tr>
<tr>
<td>S ≤ 0</td>
<td>CF &lt; 90% and COV ≥ 1</td>
<td>No Trend</td>
</tr>
<tr>
<td>S ≤ 0</td>
<td>CF &lt; 90% and COV &lt; 1</td>
<td>Stable</td>
</tr>
<tr>
<td>S &lt; 0</td>
<td>95% ≥ CF ≥ 90%</td>
<td>Probably Decreasing</td>
</tr>
<tr>
<td>S &lt; 0</td>
<td>CF &gt; 95%</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>
Determing Plume Stability

<table>
<thead>
<tr>
<th>Evaluation Date</th>
<th>Facility Name</th>
<th>Conducted By</th>
<th>Job ID</th>
<th>Constituent</th>
<th>Concentration Units</th>
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</thead>
<tbody>
<tr>
<td>12-Oct-18</td>
<td>ABC Corporation</td>
<td>Sheila Duchek</td>
<td>9999</td>
<td>Contaminant of Concern</td>
<td>mg/L</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sampling Point ID</th>
<th>MW18-1A</th>
<th>MW18-1B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling Event</td>
<td>Sampling Date</td>
<td>Contaminant of Concern Concentration (mg/L)</td>
</tr>
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<td>37.1</td>
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<tr>
<td>2</td>
<td>12-Oct-18</td>
<td>41.9</td>
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<td>3</td>
<td>13-Oct-18</td>
<td>13</td>
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<td>4</td>
<td>14-Oct-18</td>
<td>5.1</td>
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<tr>
<td>5</td>
<td>15-Oct-18</td>
<td>11.5</td>
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<tr>
<td>6</td>
<td>16-Oct-18</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>17-Oct-18</td>
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<td>8</td>
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<td>9</td>
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<td>10</td>
<td>20-Oct-18</td>
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<tr>
<td>11</td>
<td>21-Oct-18</td>
<td>0.5</td>
</tr>
</tbody>
</table>
Determining Plume Stability
Determining Plume Stability

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<tr>
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<th>Value 1</th>
<th>Value 2</th>
</tr>
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<tr>
<td>1</td>
<td>11-Oct-18</td>
<td>37.1</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>12-Oct-18</td>
<td>41.9</td>
<td>8.49</td>
</tr>
<tr>
<td>3</td>
<td>13-Oct-18</td>
<td>4.3</td>
<td>10.2</td>
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<tr>
<td>4</td>
<td>14-Oct-18</td>
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<td>8</td>
<td>18-Oct-18</td>
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<td>19-Oct-18</td>
<td>1.85</td>
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<td>20-Oct-18</td>
<td>0.9</td>
<td>11.6</td>
</tr>
<tr>
<td>11</td>
<td>21-Oct-18</td>
<td>0.5</td>
<td>14.3</td>
</tr>
</tbody>
</table>

Coefficient of Variation: 1.27, 0.21
Mann-Kendall Statistic (S): .49, 29
Confidence Factor: >99.9%, 98.7%
Concentration Trend: Decreasing, Increasing
Determining Plume Stability

Graph showing concentration (mg/L) over sampling dates from 11/17 to 02/19.

<table>
<thead>
<tr>
<th>Sampling Date</th>
<th>MW18-1A</th>
<th>MW18-1B</th>
</tr>
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<tbody>
<tr>
<td>11/17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/18</td>
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<tr>
<td>04/18</td>
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<td>05/18</td>
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<td>09/18</td>
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</tr>
<tr>
<td>12/18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/19</td>
<td></td>
<td></td>
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</tbody>
</table>

Parameters:
- Coefficient of Variation: 1.24 (MW18-1A) vs. 0.43 (MW18-1B)
- Mann-Kendall Statistic (S): -14 (MW18-1A) vs. 15 (MW18-1B)
- Confidence Factor: 84.0% (MW18-1A) vs. 85.9% (MW18-1B)
- Concentration Trend: No Trend (MW18-1A) vs. No Trend (MW18-1B)
Plume Status: Stable Plumes

Stable Trend

Concentration (mg/L)

Sampling Date

10/18 10/18 10/18 10/18 10/18 10/18 10/18 10/18
Plume Status: Shrinking Plumes

Graph showing decreasing trend in concentration over time.
Plume Status: Expanding Plumes
Plume Status: Shrinking
Plume Status: Expanding

Stable or Decreasing Trend

Stable or Decreasing Trend

Increasing Trend
Plume Status: Stable

Increasing Trend

Stable Trend

Stable Trend
More Methods to Determine Plume Stability

Qualitative Methods
› Concentration Temporal Trend Charts
› Concentration Spatial Trend Maps
› Concentration Isopleth Maps

Combined Methods
› Analyzing concentration trends in individual monitoring wells
› Plume characterization
› Assessing nonparametric statistical trends in plume characteristics, including area, average concentration, total mass.
Concentration Spatial Trend Maps & Isopleth Charts

Month of Year 2
Concentration Spatial Trend Maps & Isopleth Charts

Month of Year 3
Concentrations Temporal Trend Charts: Total Dissolved Solids

**TDS in REGMW13-01A: Aquifer-Surficial**

Mann-Kendall P.Value = 0.348; Half-Life > -5 Years

- **Detectable Data**
- **Linear Conc. Trend**
- **Threshold Limit**
Concentrations Temporal Trend Charts: Chloride

**Cl in MW13-04A: Aquifer-Surficial**

Mann-Kendall P.Value = 0.0763; Half-Life = -511 days

- Detectable Data
- Linear Conc. Trend
- Threshold Limit

![Graph showing temporal trend of chloride concentrations](image)
Determine Plume Stability – Combining Methods

› Plume Characterization
  › Understand the Conceptual Site Model
  › Understand the plume’s configuration
  › Understand the history of impact
    › Source removal
    › On-going remediation or monitored natural attenuation
    › Active operation

› Analyzing concentration trends in indicator wells;

› Assessing other plume characteristics
  › Plume area (qualitative methods)
  › Average concentration
  › Plume mass
  › Non parametric analysis on the above plume characteristics
Summary: Plume Stability as a Tool for Risk Assessment

- Risk Assessment is understanding the three pillars: source, pathway, receptor.
- If you can eliminate, isolate, or remove any of the three, there is no risk.
- Finding a solution to manage risk will present the best compromise between risk control and societal benefit.
- Plume Stability Analysis answers whether plumes are stable and/or decreasing.
- Understand the plumes’ anatomy to determine the status.
- Combined methods will support the Plume Stability Analysis.
- Use of statistics will support evidence-based decision-making.
- Can include concentration trending charts, isopleth maps, spatial concentration maps to reinforce Plume Stability Analysis.
Our values are the essence of our company’s identity. They represent how we act, speak and behave together, and how we engage with our clients and stakeholders.

**SAFETY**

We put safety at the heart of everything we do, to safeguard people, assets and the environment.

**INTEGRITY**

We do the right thing, no matter what, and are accountable for our actions.

**COLLABORATION**

We work together and embrace each other’s unique contribution to deliver amazing results for all.

**INNOVATION**

We redefine engineering by thinking boldly, proudly and differently.