Groundwater Contaminant Plume Stability Analysis

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Ricker Plume Stability Analysis

- Background
- Ricker Plume Stability Analysis Methodology
- Example Site Analyses
- **Stable Groundwater Plume**: A groundwater plume is “stable” when data representative of the entirety of the plume demonstrates that the plume is not expanding and that, overall, concentrations of chemicals of concern (COC) are not increasing.

- **Shrinking Groundwater Plume**: A groundwater plume is “shrinking” when data demonstrates that the areal extent of the plume is decreasing and concentrations of COCs, overall, are decreasing.

- **Expanding Groundwater Plume**: A groundwater plume is “expanding” when either the physical extent of the plume is increasing or concentrations of COCs are increasing.
A condition where the plume is no longer expanding in size, AND the plume footprint is not moving.

Plume is at dynamic equilibrium

*Rate of chemical mass into the plume is equal to the rate of chemical mass lost from the plume*
Why Evaluate Plume Stability?

- An increasing plume could migrate to sensitive receptors
- Evaluate remedial progress
- Answer Environmental Indicator Code (EI) CA 750 – “Has the migration of contaminated groundwater stabilized?”
- Primary line of evidence when implementing MNA
  - “Historical groundwater ...data that demonstrate a clear and meaningful trend of decreasing contaminant mass and/or concentration over time...”
    - USEPA OSWER Directive 9200.4-17P
- Demonstrate low risk to close sites
How is Plume Stability Determined?

- **Qualitative Methods**
  - Concentration vs. Time Plots
  - Concentration vs. Distance Plots
  - Concentration Isopleth Maps

- **Statistical Methods**
  - Well by well trend analysis
    - Mann-Kendall
    - Linear Regression

- **Plume-Based Methods**
  - Plume Area
  - Plume Mass
  - Plume Center of Mass (COM)
  - Mass Flux
## How is Plume Stability Determined?

### Qualitative Methods

<table>
<thead>
<tr>
<th>Plume Stability Analysis Method</th>
<th>Probability of Significant Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Concentration vs. Time Plots</td>
<td>Trends in most wells visually stable and/or increasing</td>
</tr>
<tr>
<td>Concentration vs. Distance Plots</td>
<td>Moderate or no visual decrease in concentration along the plume centerline and generally stable trends in plots over time. Sentinel wells above DRCLs.</td>
</tr>
<tr>
<td>Concentration Isopleth Maps</td>
<td>Generally increasing plume size over time. Sentinel wells above DRCLs.</td>
</tr>
</tbody>
</table>
How is Plume Stability Determined?

- **Statistical Methods**
  
<table>
<thead>
<tr>
<th>Plume Stability Analysis Method</th>
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<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Mann-Kendall</td>
<td>Concentration trends in any relevant monitoring wells are statistically Increasing or Probably Increasing</td>
</tr>
<tr>
<td>Linear Regression</td>
<td>Increasing</td>
</tr>
</tbody>
</table>

### Mann-Kendall Trend Analysis Criteria

<table>
<thead>
<tr>
<th>Mann-Kendall Statistic</th>
<th>Confidence in Trend</th>
<th>Concentration Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>S&gt;0</td>
<td>&gt; 95%</td>
<td>Increasing</td>
</tr>
<tr>
<td>S&lt;0</td>
<td>&lt; 90%</td>
<td>No Trend</td>
</tr>
<tr>
<td>S&lt;0</td>
<td>&lt; 90% and COV &gt; 1</td>
<td>No Trend</td>
</tr>
<tr>
<td>S&lt;0</td>
<td>&lt; 90% and COV &lt; 1</td>
<td>Stable</td>
</tr>
<tr>
<td>S&lt;0</td>
<td>90-95%</td>
<td>Probably Decreasing</td>
</tr>
<tr>
<td>S&lt;0</td>
<td>0.95</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>

### Linear Regression Trend Analysis Criteria

<table>
<thead>
<tr>
<th>Ln Slope</th>
<th>Confidence in Trend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt; 90%</td>
</tr>
<tr>
<td>90-95%</td>
<td>Probably Increasing</td>
</tr>
<tr>
<td>&gt; 95%</td>
<td>Increasing</td>
</tr>
<tr>
<td>&gt; 95%</td>
<td>Decreasing</td>
</tr>
</tbody>
</table>
How is Plume Stability Determined?

## Plume-Based Methods

<table>
<thead>
<tr>
<th>Plume Stability Analysis Method</th>
<th>Probability of Significant Risk</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Plume Area</td>
<td>Increasing or probably increasing trend in plume area.</td>
</tr>
<tr>
<td></td>
<td>Stable trend in plume area.</td>
</tr>
<tr>
<td></td>
<td>Decreasing or probably decreasing trend in plume area.</td>
</tr>
<tr>
<td>Plume Mass</td>
<td>Increasing or probably increasing trend in plume mass.</td>
</tr>
<tr>
<td></td>
<td>Stable trend in plume mass.</td>
</tr>
<tr>
<td></td>
<td>Decreasing or probably decreasing trend in plume mass.</td>
</tr>
<tr>
<td>Plume Center of Mass (COM)</td>
<td>Increasing or probably increasing trend in COM location.</td>
</tr>
<tr>
<td></td>
<td>Stable trend in plume COM location.</td>
</tr>
<tr>
<td></td>
<td>Decreasing or probably decreasing trend in plume COM location.</td>
</tr>
<tr>
<td>Mass Flux</td>
<td>Increasing or probably increasing trend in mass flux at any transect location.</td>
</tr>
<tr>
<td></td>
<td>Decreasing, probably decreasing, or stable trend in mass flux at each transect.</td>
</tr>
<tr>
<td></td>
<td>Decreasing or probably decreasing trend in mass flux at each transect.</td>
</tr>
</tbody>
</table>
Most Common Method to Evaluate Plume Stability

- **Well by well trend analysis**

  - “The primary concern in a stability demonstration is whether COC concentrations are increasing or decreasing at individual monitoring wells.”

  - “...a stable or shrinking condition can be identified by a stable or decreasing concentration trends over time. For this analysis, an overall plume condition was determined for each COC based on a statistical trend analysis of concentrations at each well...”

- Indiana RISC Technical Guide – Appendix 3

- AFCEE MAROS User’s Guide
Plume Stability - Existing Methods
- Naphthalene Plume
- 52 Wells
Other Common Method to Evaluate Plume Stability

- Evaluate plume contours over time
  - “One method of evaluating plume status is to plot plume concentrations from four or more events on the same figure.”

  - Washington Guidance on Remediation by Natural Attenuation
Plume Stability - Existing Methods

Figure D.1. Finding Plume Status Over Time
(5 µg/L Contour line of Benzene vs. Time)

From State of Washington Guidance on Remediation of Petroleum-Contaminated Ground Water By Natural Attenuation (Publication No. 05-09-091 [Version 1.0])
Plume Stability - Existing Methods

Carbon Tetrachloride Plume Average Concentration

Carbon Tetrachloride Plume Mass
Plume Stability - Existing Methods

- PCP Plume
- 11 Wells
Plume Stability - Existing Methods

PCP Plume Area Trend

Area (Acres)

Date

Oct-92  Jan-94  Apr-95  Jul-96  Sep-97  Dec-98  Mar-00  Jun-01  Sep-02  Nov-03  Feb-05  May-06  Aug-07  Oct-08

R² = 0.12
Plume Stability - Existing Methods

PCP Plume Average Concentration Trend

PCP Plume Mass Trend

Date

Oct-92 Jan-94 Apr-95 Jul-96 Sep-97 Dec-98 Mar-00 Jun-01 Sep-02 Nov-03 Feb-05 May-06 Aug-07 Oct-08

R² = 0.48

R² = 0.46
Ricker Plume Stability Analysis Method

- Effective method to evaluate trends in plume characteristics using visual and statistical methods.
  - Area
  - Average concentration
  - Mass
  - Location of plume center of mass
  - Mass Flux

- Efficiently assimilates large volume of historical data into concise and meaningful analysis
Ricker Plume Stability Analysis Method

- Excellent groundwater management tool
  - Termination of remediation systems where low risk is demonstrated
  - Basis for MNA
  - Monitor progress of remediation system

- Ricker Method Highlighted by USEPA Region IV
  - RCRA Showcase Pilot
    - [http://www.epa.gov/correctiveaction/showcase/rcra_pdf/r4_velsi.pdf](http://www.epa.gov/correctiveaction/showcase/rcra_pdf/r4_velsi.pdf)

Methodology

- Selection of indicator compound(s)
- Develop concentration isopleth maps
  - Each indicator compound
  - Each aquifer level (shallow, deep, etc.)
  - Plume boundary defined by MCL or site-specific level
- Methodology
  - Calculate plume stability characteristics
    - Area
    - Average concentration
    - Mass
    - Center of mass