Estimating Times of Remediation Associated with Natural Attenuation

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Introduction

Project Funding and Support

- YO817 project
- Initiated by SOUTHDIV
- Funded by NAVFAC
- Supported by ARTT
In the late 1980s, it was becoming clear that microbial biodegradation limited contaminant transport in groundwater systems.

- Baedecker et al., 1988 (Bemidji, MN)
- Barker et al., 1987 (Borden field experiment). "Natural Attenuation of aromatic hydrocarbons in a shallow sand aquifer"
  - First use of term "natural attenuation"
  - Passive bioremediation, intrinsic bioremediation were other terms
How Should Regulatory Agencies Include Natural Attenuation Processes in Site-Specific Remediation Plans?

According to the U.S. EPA, monitored natural attenuation can be selected as a remedial strategy "only....where it will meet site remediation objectives within a timeframe that is reasonable compared to that offered by other methods."

EPA OSWER Directive, 1999
This brought up the issue of Time of Remediation (TOR)

How do you estimate times of remediation?

- In 1999, there was no clear approach to this problem.
Introduction

NAPL Mass

Dissolved Plume
There are many processes that contribute to contaminant removal (remediation by monitored natural attenuation) [RMNA] in groundwater systems, including:

1. Advection
2. Dispersion
3. Biodegradation
4. Sorption
5. NAPL Dissolution
Each of these components is summed in the solute-transport equation, which can then be solved for time (t).

\[
\frac{\partial C}{\partial t} = -v \frac{\partial C}{\partial x} + D \frac{\partial^2 C}{\partial x^2} - \frac{K_d \rho_b}{n} \frac{\partial C}{\partial t} - R_{bio} + R_{NAPL}
\]
Introduction

Historically, this approach has been difficult to utilize by project managers and regulators.

- Requires an in-depth knowledge of GW modeling.
- Such models can be difficult to use.
- Results are hard to analyze.
NAS is a Decision-Making Tool for Assessing Monitored Natural Attenuation and Estimating Cleanup Times

**NAS Main Menu**

- Start New Project
- Open Existing Project
- Save Current Project
- Print Data & Results
- Exit NAS
- About NAS
- Help Menu

**Facility Name:** Plattsburg AFB

**Site Name:** Fire training site 002

**Additional Description:** TCE

**Options:**
- Edit/Review Site Data
- Source Concentration Reduction / Time of Stabilization
- Contaminant Mass Removal / Time of Remediation
NAS is an interface that allows non-modelers to find solutions to the TOR problem

- Analytical Solutions for plume shrinkage questions
- Numerical Solutions for Time of NAPL Dissolution
- NAS prompts the user for required information, sets up the problem, and answers site-specific TOR questions.
NAS – Types of Problems and Source Contaminants

1. Chlorinated Ethenes
   - PCE or
   - TCE

2. Petroleum Hydrocarbons
   - BTEX
   - MTBE (optional)
   - Naphthalene (optional)
NA Screening Tools

Monitored Natural Attenuation (MNA)

Hydrogeology → Contaminant Data and History
Geochemical and Microbial Sorption

Proceed with MNA Feasibility Study for Site X?

YES → NO
NAS – A Tool for Decision-Making

Monitored Natural Attenuation (MNA)

Site Data

Min  Best Est.  Max

Is MNA an Appropriate Technology at Site X?

NAS

Point of Regulatory Compliance

Remediation Objectives

RITS Spring 2003: Estimating Times of Remediation Associated with Natural Attenuation
NAS – Questions Addressed

1. Is MNA an appropriate technology at Site X?

and

What degree of source remediation is required at Site X?

- Distance of Plume Stabilization
- Time of Plume Stabilization
- Time of NAPL Dissolution
NAS Example – Naval Submarine Base Kings Bay, GA

PCE Source (total chlorinated ethenes plume)
NAS Example – NSB Kings Bay, GA

Site Information

1. Enter the following hydrogeologic and aquifer properties.

<table>
<thead>
<tr>
<th>Property</th>
<th>Maximum</th>
<th>Average</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic Conductivity [ft/yr]</td>
<td>3600.0</td>
<td>1440.0</td>
<td>720.0</td>
</tr>
<tr>
<td>Hydraulic Gradient [ft/ft]</td>
<td>0.048</td>
<td>0.048</td>
<td>0.048</td>
</tr>
<tr>
<td>Weight Percent Organic Matter (loss on ignition) [%]</td>
<td>0.19</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td>Total Porosity [ft³/ft³]</td>
<td></td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Effective Porosity [ft³/ft³]</td>
<td></td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Contaminated Aquifer Thickness [ft]</td>
<td></td>
<td>20.0</td>
<td></td>
</tr>
</tbody>
</table>

\[ v = \frac{K}{Rn_e} i \]
1. Enter the date when field measurements for contaminant concentration were collected:

   **Month**: November  
   **Year**: 1999

2. Enter the number of monitoring wells sampled for contaminant concentration along the centerline of the plume:

   **Currently, contaminant concentration data is reported for 6 wells.**

3. Enter the well name (optional), distance downgradient of the source (required), and contaminant concentrations measured at each monitoring point.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Distance from Source [ft]</th>
<th>PCE [µg/L]</th>
<th>TCE [µg/L]</th>
<th>cis-DCE [µg/L]</th>
<th>VC [µg/L]</th>
</tr>
</thead>
<tbody>
<tr>
<td>KBA-34</td>
<td>1</td>
<td>3500</td>
<td>1000</td>
<td>BD</td>
<td>BD</td>
</tr>
<tr>
<td>usgs-3</td>
<td>110</td>
<td>2</td>
<td>511</td>
<td>1270</td>
<td>112</td>
</tr>
<tr>
<td>KBA-13</td>
<td>160</td>
<td>0.5</td>
<td>32.5</td>
<td>158</td>
<td>76</td>
</tr>
<tr>
<td>usgs-5</td>
<td>220</td>
<td>BD</td>
<td>BD</td>
<td>54</td>
<td>166</td>
</tr>
<tr>
<td>usgs-10</td>
<td>380</td>
<td>BD</td>
<td>BD</td>
<td>24</td>
<td>31</td>
</tr>
<tr>
<td>KBA-37</td>
<td>630</td>
<td>BD</td>
<td>BD</td>
<td>10</td>
<td>2</td>
</tr>
</tbody>
</table>

**NOTE:** The origin of the NAS coordinate system (0,0) is located immediately downgradient of the area and along the centerline of the plume.
1. Enter the time when the redox indicator field measurements were collected:
   - November 1999 (Collected at the same time as contaminant data.)
   - Collected at a different time than contaminant data
     
     Month: November  Year: 1999

2. NAS requires specification of dissolved oxygen (O2), ferrous iron (Fe2) and sulfate (SO4) at all redox well locations. Indicate which additional redox indicators were measured at your site:
   - Nitrate (NO3):  Yes  No
   - Manganese(II) (MN2):  Yes  No
   - Hydrogen Sulfide (H2S):  Yes  No
   - Methane(CH4):  Yes  No
   - Hydrogen (H2):  Yes  No

3. Number of redox indicators along the centerline of the plume.

Currently, redox indicator concentration data is reported for 6 wells.

4. Enter the well name (optional), distance downgradient of the source (required), and concentrations for indicators of redox potential measured at each monitoring point.

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Distance from Source [ft]</th>
<th>C2 (mg/L)</th>
<th>NO3 (mg/L)</th>
<th>Fe2 (mg/L)</th>
<th>SO4 (mg/L)</th>
<th>H2S (mg/L)</th>
<th>CH4 (mg/L)</th>
<th>H2 (nM)</th>
<th>Redox Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>KBA-34</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>5</td>
<td>2</td>
<td>SO4/C02-reducing</td>
</tr>
<tr>
<td>usgs-3</td>
<td>110</td>
<td>0</td>
<td>0</td>
<td>0.33</td>
<td>6.48</td>
<td>0</td>
<td>3.8</td>
<td>1.66</td>
<td>SO4/C02-reducing</td>
</tr>
<tr>
<td>KBA-13</td>
<td>160</td>
<td>0</td>
<td>0</td>
<td>0.24</td>
<td>3.27</td>
<td>0.577</td>
<td>5.1</td>
<td>1.55</td>
<td>SO4/C02-reducing</td>
</tr>
<tr>
<td>usgs-5</td>
<td>220</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
<td>0.385</td>
<td>5.6</td>
<td>0.5</td>
<td>Ferrogenic</td>
</tr>
<tr>
<td>usgs-10</td>
<td>380</td>
<td>0</td>
<td>0</td>
<td>0.41</td>
<td>10</td>
<td>1.5</td>
<td>6</td>
<td>0.81</td>
<td>Ferrogenic</td>
</tr>
<tr>
<td>KBA-37</td>
<td>630</td>
<td>0</td>
<td>0</td>
<td>0.3</td>
<td>10.2</td>
<td>0.1</td>
<td>0.3</td>
<td>0.3</td>
<td>Ferrogenic</td>
</tr>
</tbody>
</table>
Estimates Biodegradation Rate Constants
Introduction

Distance and Time of Stabilization
How long will it take?

Source Area Removal, 1998

Collapsed Contaminant Plume, At remediation Goal
2005? 2050?
1. Enter the distance from the contaminant source to the nearest downgradient point of compliance (POC).

   Distance to POC  \(220.0\) [ft]  More Info on POC >>

2. Enter an estimate for the width of the contaminant source.

   Contaminant Source Width  \(30.0\) [ft]

3. Enter the regulatory compliance concentration (RCC) at the POC, and calculate the Time of Stabilization (TOS) and Source Concentration Target.

<table>
<thead>
<tr>
<th>RCC [(\mu g/L)]</th>
<th>Source Conc.</th>
<th>TOS [years]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Well</td>
<td>Current</td>
</tr>
<tr>
<td>Total Chl. Eth.</td>
<td>2.0</td>
<td>Calculate</td>
</tr>
</tbody>
</table>

More Info on RCC >>  Return to Main Menu
NAS Simulation of KBA-13A

**NSB Kings Bay Case Study**

**NAS Simulation of KBA-13A**

![Graph showing NAS Simulation of KBA-13A](image)

- **Total Chlorinated Ethenes (g/L)**
  - Time (years): 0 1 2 4
  - Total Chlorinated Ethenes (g/L): 0 100 200 300 400 500 600

- **Legend**:
  - ▲ NAS Simulation
  - ● Observed Chlorinated Ethenes
Time of NAPL Dissolution (TNAD)
How long will it take?

PCE Source Area
Emplaced 1960

Source PCE
Fully Dissolved
2005?
2050?
Factors Affecting NAPL Dissolution

NAPL Properties

- NAPL mass
- Residual saturation
- Contaminant mass fraction
- Physical properties of NAPL components
- NAPL dissolution coefficient ($k_{NAPL}$)
- Source geometry
For these two cases and with all things being equal, except the orientation of the source relative to the groundwater flow direction, would source geometry influence TOR?

If the answer is yes, which case would result in the greater TOR?
NAPL Dissolution

Mass = 128 kg (gasoline), $Sr = 0.115$, Vol = 42 gal, $k = 3.0 \, d^{-1}$
1a. Specify how you wish to enter the estimated NAPL mass in the source area.

- **Average only.**

b. Fill in the chart below.

<table>
<thead>
<tr>
<th>NAPL Mass [lb]</th>
<th>NAPL Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>550.0</td>
<td>4.53e-02</td>
</tr>
</tbody>
</table>

2a. Specify how you wish to evaluate the impact of source removal on time of remediation.

- **Estimate TOR for 3 NAPL Mass Removal Plans.**

b. Fill in the chart below.

<table>
<thead>
<tr>
<th>% NAPL Removed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan 1</td>
</tr>
<tr>
<td>25</td>
</tr>
</tbody>
</table>

3. Specify the maximum time of analysis for TOR (up to 100 years).

- **Maximum Time of Analysis** 25 [years]
Choose Contaminant

PCE

% NAPL Removed

75
50
25

Time of Remediation (years)

NAPL Mass Estimate

550.0 lb
Conclusions

- The TOR problem is difficult but not unsolvable
- The NAS is a tool designed to facilitate TOR estimates
- NAS predictions are in line with monitoring data
- NAS has been used to reach regulatory closure of sites
NAS and SEAM-3D Software

- Acquiring NAS and SEAM-3D
  - NAS can be downloaded from: [http://www.cee.vt.edu/nas/](http://www.cee.vt.edu/nas/)
  - SEAM-3D is part of Groundwater Modeling System (GMS) maintained by DoD

- Two-Day In-Depth Training for NAS
  - Southwest Division, July 22-23; Southern Division, August 5-6
  - Sign up through Engineering Service Center (ESC)
NAVFAC Points of Contact

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