Remedial Goals Based on Mass Discharge

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  Naji Akladiss, Richard Lewis, Alec Naugle, Chuck Newell, Fred Payne, Hans Stroo, and others
ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance

- Host organization
- Network
  - State regulators
    - All 50 states, PR, DC
  - Federal partners
  - ITRC Industry Affiliates Program
- Academia
- Community stakeholders
- Wide variety of topics
  - Technologies
  - Approaches
  - Contaminants
  - Sites
- Products
  - Technical and regulatory guidance documents
  - Internet-based and classroom training

What is Mass Flux?

1. **Specific Discharge,** \( q = K \times i \) \( (L/ m^2/ \text{day}) \)

![Cross-Sectional Area](Image)  
\( q = K \times i \)
What is Mass Flux?

1. Specific Discharge, \( q = K \times i \) \( \text{L/m}^2/\text{day} \)

2. Average concentration, \( C_{\text{avg}} \) \( \text{g/L} \)

3. Mass Flux, \( MF = q \times C \) \( \text{g/m}^2/\text{day} \)
What is Mass Flux?

1. Specific Discharge, $q = K \times i$ (L/m$^2$/day)
2. Average concentration, $C_{avg}$ (g/L)
3. Mass Flux, $MF = q \times C$ (g/m$^2$/day)

Mass Discharge – Source or Plume Strength

Source Transect

Source: $Q$, $M_d$

Plume Transects

Plume
What is Mass Discharge?

Mass Discharge
\[ M_{d_i} = M_{F_i} \times A_i \]

Units: g/day or kg/year

Often people say: **Mass Flux**

When they mean: **Mass Discharge**
Mass Flux and Mass Discharge: Why Care?

- To augment concentrations, not replace them
- Allows targeted remediation strategies
  - Most flux is in a small fraction of the volume
- Provides meaningful performance metrics
  - Links partial treatment to risk reduction
- Recent advances in techniques

Advantages and Limitations

**Potential advantages**
- Improved conceptual site model (CSM)
- More representative attenuation rates, exposure assessment
- Improved remediation efficiency
- Reduced remediation timeframe

**Limitations**
- Uncertainty
- Cost
Mass Discharge as a Remedial Goal

- NAPL source zones
  - Complete restoration difficult
  - Concentration trends highly variable
- Realistic end goals?
- Influence on risk?

ITRC Overview Document

- Use and Measurement of Mass Flux and Mass Discharge
  
  www.itrcweb.org
Outline

1. DNAPL source depletion trends
2. Use and Measurement of Mass Flux / Mass Discharge
3. Defining realistic remedial goals
DNAPL Architecture Scenarios

Fresh Source

Free phase layer
Residual phase layer
Residual phase trail

Source Strength = Mass discharge from source zone (kg/year)

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DNAPL Architecture Scenarios

- **Fresh Source**
- **Aged Source**

- **High Source Strength**
- **Lower Source Strength**

DNAPL Architecture

- DNAPL architecture affects source depletion rates
  - Horizontal layers – SLOW
  - Vertical ganglia - FASTER
Back-Diffusion

Sand

Well

DNAPL

Diffusion Into Clay

Clay

Back-Diffusion Out of Clay

Sand

Well

Back-Diffusion

Clay
DNAPL Dissolution

- DNAPL dissolves naturally
  - Source strength as DNAPL volume
  - In-situ → Accelerate dissolution

Source Strength Reduction

- Natural Dissolution
- Pump-and-Treat (Q=7 gpm)
- Containment
- EISB

Time Since Start of Remediation (y)

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Use and Measurement of Mass Flux / Mass Discharge

Six Use Categories from Case Studies

1. Site Characterization
   - Baseline mass discharge
   - Identify hotspots
   - Attenuation rates
   - Low vs. high K
   - Multiple sources

2. Potential Impacts and Exposure Evaluation
   - Remedial action objectives (RAOs)
   - Technology selection
   - Remedial design
   - Performance
   - Optimization

3. Remediation Selection and Design

4. Performance Monitoring and Optimization

5. Compliance Monitoring

6. Site Prioritization
Increasing Use of Mass Flux and Mass Discharge

Rapid increase in use since 1995

Number of Case Studies


Over 61 Case Studies Documenting Mass Flux and Mass Discharge Use

Number of Case Studies

Site Characterization Potential Impact Remediation Compliance Monitoring Site Prioritization
Example: Prioritizing Treatment Zones

As the source is depleted, more mass remains in less permeable regions.
This preferential depletion may alter the priorities for remediation.

Mass Flux \( (J) = \text{KiC} \)

- **Residual Source**
  - Fine Sand 75%
  - Gravelly Sand 5%
  - Sand 15%

**Fine Sand Zone**

- \( K = 1.0 \text{ m/day} \)
- \( i = 0.003 \text{ m/m} \)
- \( C = 1,000 \mu\text{g/L} \)
- Mass Flux = 37.5 mg/d/m²

**Gravelly Sand Zone**

- \( K = 33.3 \text{ m/day} \)
- \( i = 0.003 \text{ m/m} \)
- \( C = 50 \mu\text{g/L} \)
- Mass Flux = 5 mg/d/m²

**Sand Zone**

- \( K = 5.0 \text{ m/day} \)
- \( i = 0.003 \text{ m/m} \)
- \( C = 500 \mu\text{g/L} \)
- Mass Flux = 7.5 mg/d/m²

Source Treatment Goal

- **MW-1**, **MW-2**, **MW-3**

**Risk is proportional to source strength.**
Source Treatment Goal

Concentration trends difficult to predict due to high uncertainty.
Predicting source strength reduction has less uncertainty.

Interim Compliance Metric

<table>
<thead>
<tr>
<th>Source Strength</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Single metric</td>
<td>- Multiple points</td>
</tr>
<tr>
<td>- Easier to predict (“average”)</td>
<td>- Difficult to predict (point-specific)</td>
</tr>
<tr>
<td>- Limited use for compliance</td>
<td>- Accepted for compliance</td>
</tr>
<tr>
<td>- Direct risk indicator</td>
<td>- Partial risk indicator</td>
</tr>
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</table>

- Intra-Site Comparison

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Five Methods for Mass Discharge

- **Method 1**: Transect Method (Sect. 4.1)
- **Method 2**: Well Capture/Pumping Methods (Sect. 4.2)
- **Method 3**: Passive Flux Meters (Sect. 4.3)
- **Method 4**: Using Existing Isocontour Data (Sect. 4.4)
- **Method 5**: Solute Transport Models (Sect. 4.5)

ITRC 2010 Case Study Review

Minimum = 0.00029 kg/y
25th Percentile = 1.3 kg/y
Median = 10.2 kg/y
75th percentile = 52 kg/y
90th percentile = 201 kg/y
Maximum = 680 kg/y

Geometric mean = 7.7 kg/y
Alameda Naval Station, CA

- 80% of mass in 7% of transect area
- 90% of mass occurs where $C > 20,000$ ug/L

Data Source: Einarson and MacKay, 2001

Source Strength as Interim Goal

Well 12A Site, Washington

• FFS evaluation:
  – If Source strength (Md) reduced by 90% with active treatment, MNA will be sufficient to achieve compliance in GW

• Mass flux and mass discharge
  – Performance metric $\Rightarrow$ treatment efficiency
  – Interim target for transitioning from active treatment to MNA
EISB at Reese Air Force Base

Prior plume interpretation

3 mil (approx)

Plume interpretation with all data

2004

2006

Plume response to remediation...

...and flux-informed decision making

2008

2010

Defining Realistic Remedial Goals
Source Strength Reduction

Before Treatment

After Treatment

McGuire et al., 2006

- 147 wells at 59 sites (42 full-scale)
  - Up to 4 wells in source zone per site

Median Reduction in Parent CVOC Concentration

<table>
<thead>
<tr>
<th>Technology</th>
<th>Reduction</th>
<th>(n)</th>
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<tr>
<td>All technologies</td>
<td>92%</td>
<td></td>
</tr>
<tr>
<td>EISB</td>
<td>95%</td>
<td>26</td>
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e.g. McGuire et al., 2006, Ground Water Monitoring and Remediation, 26(1): 73-84.
McGuire et al., 2006

### Performance Statistics for Parent Compound Concentrations

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McGuire et al., 2006

### Median Parent CVOC Concentration Reduction Over Time

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<th>Time Period</th>
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<td>Immediately following treatment</td>
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**McGuire et al., 2006**

**Median Parent CVOC Concentration Reduction Over Time**

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**Other Studies**

**Sale et al., ESTCP, 2008**

“Well-implemented in situ remediation projects are likely to reduce source zone groundwater concentrations by about one to possibly two orders of magnitude (90-99% reduction) from pretreatment levels.”
What about your Site?

• Review broad performance ranges at other sites
  – E.g. ESTCP: DNAPL Technology Evaluation Screening Tool

• Site-specific limiting factors?

Summary

• Mass discharge is beneficial as a performance metric
  – Empirical data from other sites
  – More realistic remedial goals
  – Directly related to risk reduction