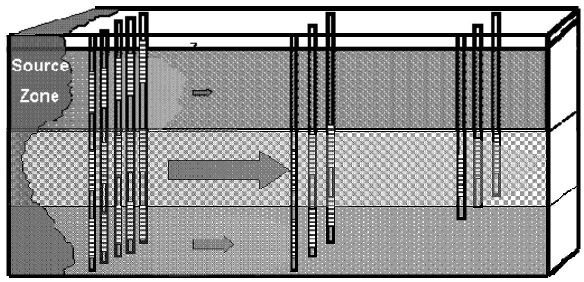
1

Welcome – Thanks for joining this ITRC Training Class

Use and Measurement of Mass Flux and Mass Discharge



An ITRC Technology Overview Document

Sponsored by: Interstate Technology and Regulatory Council (www.itrcweb.org)
Hosted by: US EPA Clean Up Information Network (www.cluin.org)

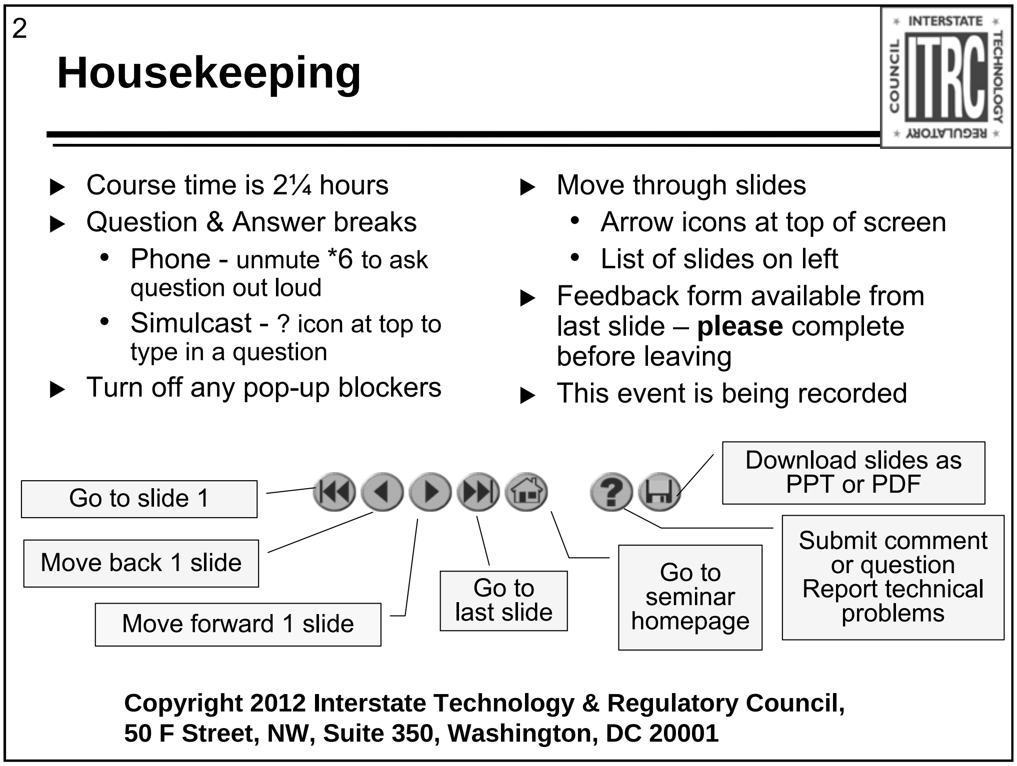
Most decisions at groundwater contamination sites are driven by measurements of contaminant concentration – snapshots of contaminant concentrations that may appear to be relatively stable or show notable changes over time. Decisions can be improved by considering mass flux and mass discharge. Mass flux and mass discharge quantify the source or plume strength at a given time and location resulting in better-informed management decisions regarding site prioritization or remedial design as well as lead to significant improvements in remediation efficiency and faster cleanup times. The use of mass flux and mass discharge is increasing and will accelerate as field methods improve and practitioners and regulators become familiar with its application, advantages, and limitations. The decision to collect and evaluate mass flux data is site-specific. It should consider the reliability of other available data, the uncertainty associated with mass flux measurements, the specific applications of the mass flux data, and the cost-benefit of collecting mass measurements.

The ITRC technology overview, Use and Measurement of Mass Flux and Mass Discharge (MASSFLUX-1, 2010), and associated Internet-based training provide a description of the underlying concepts, potential applications, description of methods for measuring and calculating, and case studies of the uses of mass flux and mass discharge. This Technology Overview, and associated Internet-based training are intended to foster the appropriate understanding and application of mass flux and mass discharge estimates, and provide examples of use and analysis. The document and training assumes the participant has a general understanding of hydrogeology, the movement of chemicals in porous media, remediation technologies, and the overall remedial process. Practitioners, regulators, and others working on groundwater sites should attend this training course to learn more about various methods and potential use of mass flux and mass discharge information.

ITRC (Interstate Technology and Regulatory Council) www.itrcweb.org

Training Co-Sponsored by: US EPA Technology Innovation and Field Services Division (TIFSD) (www.clu-in.org)

ITRC Training Program: training@itrcweb.org; Phone: 402-201-2419



Although I'm sure that some of you are familiar with these rules from previous CLU-IN events, let's run through them quickly for our new participants.

We have started the seminar with all phone lines muted to prevent background noise. Please keep your phone lines muted during the seminar to minimize disruption and background noise. During the question and answer break, press *6 to unmute your lines to ask a question (note: *6 to mute again). Also, please do NOT put this call on hold as this may bring unwanted background music over the lines and interrupt the seminar.

You should note that throughout the seminar, we will ask for your feedback. You do not need to wait for Q&A breaks to ask questions or provide comments using the ? icon. To submit comments/questions and report technical problems, please use the ? icon at the top of your screen. You can move forward/backward in the slides by using the single arrow buttons (left moves back 1 slide, right moves advances 1 slide). The double arrowed buttons will take you to 1st and last slides respectively. You may also advance to any slide using the numbered links that appear on the left side of your screen. The button with a house icon will take you back to main seminar page which displays our presentation overview, instructor bios, links to the slides and additional resources. Lastly, the button with a computer disc can be used to download and save today's presentation slides.

3

ITRC Disclaimer

- This material was sponsored by an agency of the United States Government. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof and no official endorsement should be inferred.
- The information in ITRC Products was formulated to be reliable and accurate. However, the information is provided "as is" and use of this information is at the users' own risk. Information in ITRC Products is for general reference only; it should not be construed as definitive guidance for any specific site and is not a substitute for consultation with qualified professional advisors.
- ITRC Product content may be revised or withdrawn at any time without prior notice.
- ITRC, ERIS, and ECOS make no representations or warranties with respect to information in its Products. ITRC, ERIS, and ECOS will not accept liability for damages of any kind that result from acting upon or using this information.
- ITRC, ERIS, and ECOS do not endorse or recommend the use of specific technology or technology provider through ITRC Products.

This material was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof and no official endorsement should be inferred.

The information provided in documents, training curricula, and other print or electronic materials created by the Interstate Technology and Regulatory Council (ITRC) ("ITRC Products") is intended as a general reference to help regulators and others develop a consistent approach to their evaluation, regulatory approval, and deployment of environmental technologies. The information in ITRC Products was formulated to be reliable and accurate. However, the information is provided "as is" and use of this information is at the users' own risk.

ITRC Products do not necessarily address all applicable health and safety risks and precautions with respect to particular materials, conditions, or procedures in specific applications of any technology. Consequently, ITRC recommends consulting applicable standards, laws, regulations, suppliers of materials, and material safety data sheets for information concerning safety and health risks and precautions and compliance with then-applicable laws and regulations. ITRC, ERIS and ECOS shall not be liable in the event of any conflict between information in ITRC Products and such laws, regulations, and/or other ordinances. ITRC Product content may be revised or withdrawn at any time without prior notice.

ITRC, ERIS, and ECOS make no representations or warranties, express or implied, with respect to information in its Products and specifically disclaim all warranties to the fullest extent permitted by law (including, but not limited to, merchantability or fitness for a particular purpose). ITRC, ERIS, and ECOS will not accept liability for damages of any kind that result from acting upon or using this information.

ITRC, ERIS, and ECOS do not endorse or recommend the use of specific technology or technology provider through ITRC Products. Reference to technologies, products, or services offered by other parties does not constitute a guarantee by ITRC, ERIS, and ECOS of the quality or value of those technologies, products, or services. Information in ITRC Products is for general reference only; it should not be construed as definitive guidance for any specific site and is not a substitute for consultation with qualified professional advisors.

4

ITRC (www.itrcweb.org) – Shaping the Future of Regulatory Acceptance

- Host organization
- Network
  - State regulators
    - All 50 states, PR, DC
  - Federal partners

    DOE DOD EPA
  - 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

The Interstate Technology and Regulatory Council (ITRC) is a state-led coalition of regulators, industry experts, citizen stakeholders, academia and federal partners that work to achieve regulatory acceptance of environmental technologies and innovative approaches. ITRC consists of all 50 states (and Puerto Rico and the District of Columbia) that work to break down barriers and reduce compliance costs, making it easier to use new technologies and helping states maximize resources. ITRC brings together a diverse mix of environmental experts and stakeholders from both the public and private sectors to broaden and deepen technical knowledge and advance the regulatory acceptance of environmental technologies. Together, we're building the environmental community's ability to expedite quality decision making while protecting human health and the environment. With our network of organizations and individuals throughout the environmental community, ITRC is a unique catalyst for dialogue between regulators and the regulated community.

For a state to be a member of ITRC their environmental agency must designate a State Point of Contact. To find out who your State POC is check out the "contacts" section at www.itrcweb.org. Also, click on "membership" to learn how you can become a member of an ITRC Technical Team.

5

ITRC Course Topics Planned for 2012 – More information at www.itrcweb.org

Popular courses from 2011

- Bioavailability Considerations for Contaminated Sediment Sites
- Biofuels: Release Prevention, Environmental Behavior, and Remediation
- Decision Framework for Applying Attenuation Processes to Metals and Radionuclides
- Development of Performance Specifications for Solidification/Stabilization
- LNAPL 1: An Improved Understanding of LNAPL Behavior in the Subsurface
- LNAPL 2: LNAPL Characterization and Recoverability - Improved Analysis
- LNAPL 3: Evaluating LNAPL Remedial Technologies for Achieving Project Goals
- Mine Waste Treatment Technology Selection
- Phytotechnologies
- Permeable Reactive Barrier (PRB): Technology Update
- Project Risk Management for Site Remediation
- Use and Measurement of Mass Flux and Mass Discharge
- Use of Risk Assessment in Management of Contaminated Sites

New in 2012

- Green & Sustainable Remediation
- Incremental Sampling Methodology
- Integrated DNAPL Site Strategy

2-Day Classroom Training:

- Light Nonaqueous-Phase Liquids (LNAPLs): Science, Management, and Technology

April 5-6, 2012 in Boston, MA

More details and schedules are available from www.itrcweb.org.

6

Meet the ITRC Instructors

Alex MacDonald
California Water Boards
Rancho Cordova, CA
916-464-4625
amacdonald@ waterboards.ca.gov

Tamzen Macbeth
CDM
Idaho Falls, ID
208-569-5147
macbethtw@cdm.com

Fred Payne
Arcadis
Charlotte, MI
248-376-5129
fpayne@arcadis-us.com

Alec Naugle
California Water Boards
Oakland, CA
510-622-2510
anaugle@ waterboards.ca.gov

Grant Carey
Porewater Solutions
Ontario, Canada
613-270-9458
gcarey@porewater.com

Alex MacDonald is a senior engineer in the technical support section of the Cleanup Unit at the Central Valley Regional Water Quality Control Board in Rancho Cordova, California. He has worked at the Water Quality Control Board since 1984. He primarily works on cleanup of the Aerojet site in Rancho Cordova, California and other nearby sites such as McClellan Air Force Base. Alex has also worked on cleanup at underground and above ground storage tanks sites; permitting and inspection of landfill and waste disposal to land sites; regulating application of biosolids sites; regulating NPDES sites that include wastewater treatment plants, power plants, industrial facilities, and groundwater treatment facilities; and permitting and inspecting dredging projects. Alex was a member of the ITRC Perchlorate team. Alex earned a bachelor's degree in Civil/Environmental Engineering from Stanford University in Palo Alto , California in 1977 and a master's degree in Civil/Environmental Engineering from Sacramento State University in Sacramento, California in 1987.

Tamzen Macbeth, Ph.D., is a senior environmental engineer at CDM in Idaho Falls, Idaho. She has worked for CDM since 2009. Previously, she worked for 7 years at North Wind Inc. Tamzen is an environmental engineer with an interdisciplinary academic and research background in microbiology and engineering. She specializes in the development, demonstration and application of innovative, cost-effective remedial technologies for contaminated groundwater. Specifically, she is experienced in all aspects of remedies for characterization and remediation of contaminated sites including DNAPLs, dissolved organic, inorganic, and radioactive contaminants under CERCLA and RCRA regulatory processes. She has expertise in a variety of remediation techniques, including in situ bioremediation, natural attenuation, in situ chemical oxidation, and thermal treatment. Her current work focuses on application of enhanced ISB and monitored natural attenuation in combination with other aggressive technologies such as in situ chemical oxidation and thermal remediation for effective treatment of groundwater plumes containing residual source areas. Since 2004, Tamzen has contributed to the ITRC as a team member and instructor for the ITRC's Bioremediation of DNAPLs team. Tamzen earned a bachelor's degree in Microbiology in 2000 and a master's degree in Environmental Engineering in 2002 both from Idaho State University in Pocatello, Idaho, and a doctoral degree from in Civil and Environmental Engineering in 2008 from the University of Idaho in Moscow, Idaho.

Fred Payne, Ph.D., is Vice President and Director, In Situ Remediation Services, at ARCADIS; his office is located in Novi, Michigan. He has worked for ARCADIS since 1999 and is responsible for the technical performance of soil and groundwater remedies at ARCADIS sites in the United States. He has more than 28 years environmental industry experience, encompassing a broad range of natural resource, wastewater, stormwater and hazardous waste management. Fred is a leader in the design and development of in situ reactive zone technologies for aquifer restoration. In 2005, he coauthored the book In Situ Remediation Engineering with Suthan S. Suthersan and he is the lead author for the book Remediation Hydraulics (2008). He is the inventor of six patented technologies used in the treatment of contaminated soils and groundwater that have been applied with great success at several hundred sites in the United States, Japan, and Europe. He is presently developing enhanced soil and groundwater remedial systems employing chemical oxidation and reduction, as well as biological methods for in-situ destruction of contaminants, with a focus on treatment of difficult compounds such as 1,4-dioxane, nitrosodimethylamine and hydrophobic organic compounds such as hexachlorobenzene and polychlorinated biphenyls. He is a member of the ITRC Bioremediation of DNAPLs team. Fred earned a bachelor's degree in biology/botany from Michigan State University (East Lansing, Michigan) in 1973, and master's and doctoral degrees in limnology from Michigan State University in 1977 and 1982, respectively.

Alec Naugle, P.G. is a Senior Engineering Geologist in the Groundwater Protection Division at the California Regional Water Quality Control Board, San Francisco Bay Region where he has worked since 1999. Alec leads a unit that oversees solvent and petroleum hydrocarbon cleanups at Department of Energy laboratories and closed military bases, many of which are undergoing conversion for civilian use. He is also co-chair of the Region's technical groundwater committee, which supports the Board's planning activities related to groundwater quality and beneficial use. Prior to joining the Board, Alec worked as a consultant on various military and private sites in California and the Northeast and as a regulator in the UST program. Alec has been a member of ITRC since 2000 participating in the Permeable Reactive Barriers, Enhanced Attenuation: Chlorinated Organics, and Integrated DNAPL Site Strategy teams. Alec earned a bachelor's degree in chemistry and geology from Marietta College in Marietta, Ohio in 1986 and a master's degree in groundwater hydrology from the University of California at Davis in 2001. Alec is a Registered Professional Geologist in California.

Grant Carey, P.Eng., is President of Porewater Solutions in Ottawa, Ontario, Canada, and has worked for Porewater Solutions since 2006. Grant has worked on over 300 sites across North America in the past 20 years, and is expert in site characterization and remediation, environmental forensics, and mathematical modeling. Grant has developed industry-leading software used for modeling and visualization of biogeochemical reactions in groundwater, and has published over 60 technical papers and short courses. Grant is currently participating on the ITRC Integrated DNAPL Source Strategy Team, and previously participated on the ITRC Enhanced Attenuation of Chlorinated Organics (EACO) Team. Grant earned a bachelors degree in Civil Engineering from Waterloo University in Ontario, Canada in 1993 and a masters degree in Civil Engineering from Carleton University in Ontario, Canada in 2001. Grant is currently completing his Ph.D. in Civil Engineering at the University of Guelph in Ontario, Canada. Grant is a Professional Engineer in Ontario, Canada.

7

What You Will Learn…

- What is mass flux and mass discharge
- Why these are useful metrics
- How mass flux and discharge can complement concentration-based measures
- What methods are available to measure mass flux and discharge
- How to calculate mass flux and discharge
- How existing site data may be used to estimate mass flux and discharge
- How to manage uncertainty
- Regulatory considerations with mass flux and discharge estimates

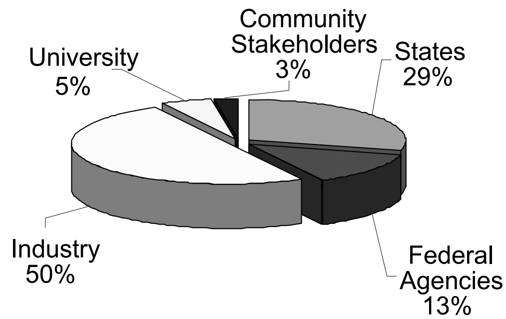
No associated notes.

8

ITRC Mass Flux Project

- Use and Measurement of Mass Flux and Mass Discharge (MASSFLUX-1, 2010)
- Other products
  - In Situ Bioremediation of Chlorinated Ethene: DNAPL Source Zones (BioDNAPL-3, 2008)
  - Integrated DNAPL Site Strategy (IDSS-1, 2011)
- www.itrcweb.org

Integrated DNAPL Site Strategy Team



No associated notes.

9

ITRC Technology Overview

- Use and Measurement of Mass Flux and Mass Discharge (ITRC MASSFLUX-1, 2010)
  - Concepts, measurement / estimation methods, and uses
  - Regulatory considerations
  - Case study review

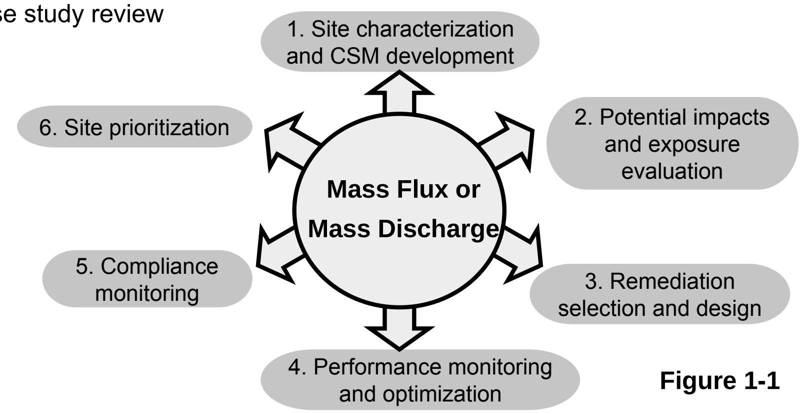


Figure 1-1

No associated notes.

10

Regulatory Considerations Associated with Mass Flux and Mass Discharge

- Precedent for use in a regulatory context
  - Federal Superfund
    - Signed Record of Decision (ROD) identifying a mass discharge interim goal was accepted in October 2009
  - Surface water regulations
    - Total Maximum Daily Loads (TMDL)
    - National Pollutant Discharge Elimination System (NPDES)
- Issues with regulatory acceptance
  - Complexity and uncertainty of mass flux measurements
  - How to relate mass flux to risk and exposure
  - Unclear how mass flux relates to standard regulatory metrics
    - e.g., Maximum Contaminant Levels (MCLs)

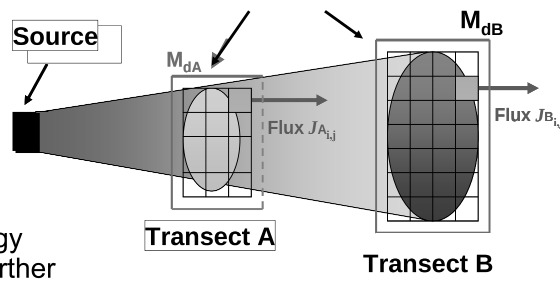
l NPDES permits you are required to report concentration and mass measurements

11

Questions to Consider

- Why should I estimate mass flux/discharge at my site?
- How do I calculate mass flux/discharge?
- What are the cost/benefits of using mass flux/ discharge?
- Can mass flux help measure compliance?
- Integrated DNAPL Site Strategy Tech-Reg Guidance (2011) further describes uses of mass flux/discharge estimates

Mass Discharge (M_d) = Sum of all Measures of Mass Flux x Area



$J_{A_{ij}}$= Individual mass flux measurement at Transect A

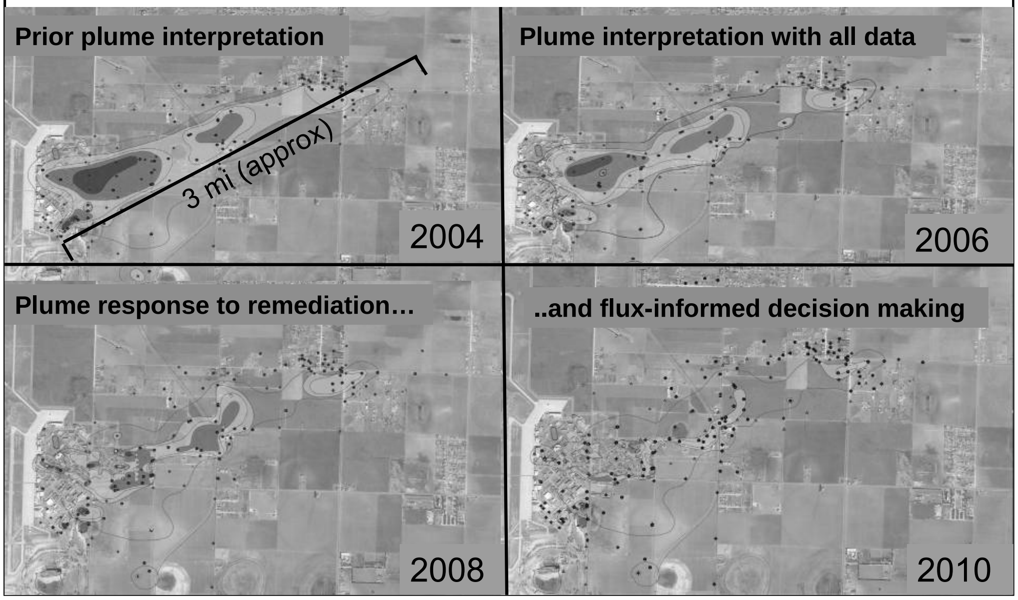
M_{dA}= Mass discharge at transect A (sum of all of the mass discharge estimates for each specific area [$J_{a_{ij}}$ x A])

No associated notes.

12

Case Studies: Real Life Application of Mass Flux

Case study from F. Payne, ARCADIS



Near the end of today's presentation we have several case studies that show how mass flux has been applied at several sites across the country to help remediate sites more efficiently. Pay attention to the presentation between now and then so you can see how to apply mass flux concepts that helped this site at Reese Air Force Base significantly address its groundwater contamination as shown by the shrinking plumes depicted here.

13

Course Roadmap

- ▶ Mass concepts
- ▶ Measurement methods
- ▶ Application
- ▶ Case studies
- ▶ Summary

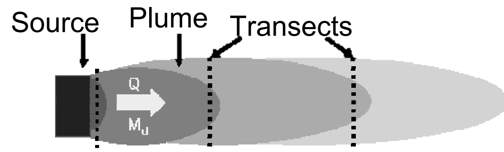


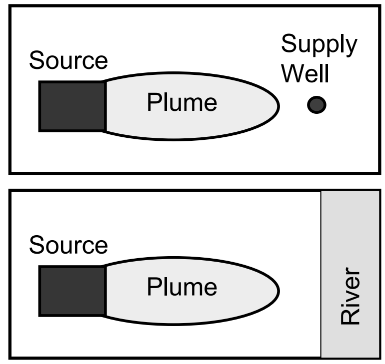
Figure 2-1

This section discusses the fundamental concepts of mass flux and discharge: the definitions, how these metrics compare to concentration data, how flux and discharge can be estimated, how flux and discharge change over time as sources and plumes evolve, and how flux and discharge can be valuable for site management.

Mass Flux and Mass Discharge: Why Care?

Better Understanding Yields Smarter Solutions!

- 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
- Basis for existing groundwater models
  - Already used but often ignored
- Recent advances in techniques



Downgradient Risk Due to Mass Discharge NOT Concentration

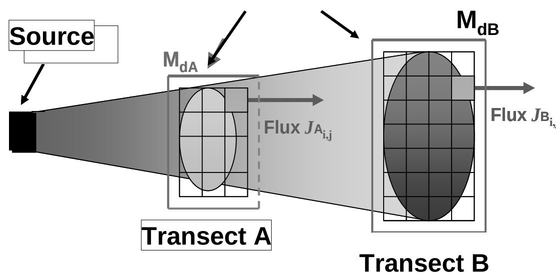
No associated notes.

15

Definitions

- Mass discharge
  - The total mass of any solute conveyed by a plume at a given location
  - M_d is a scalar quantity, expressed as mass/time
- Mass flux
  - The rate of solute mass moving across a specific defined area, usually a portion of the plume cross-section
  - Mass flux is a vector quantity, expressed as mass/time/area

Mass Discharge (M_d) = Sum of all Measures of Mass Flux x Area



$J_{A_{ij}}$= Individual mass flux measurement at Transect A

M_{dA}= Mass discharge at transect A (sum of all of the mass discharge estimates for each specific area [$J_{a_{ij}}$ x A])

Fundamental principles of contaminant hydrogeology. Terms are often confused – in particular, “mass flux” is often used for both concepts. Measures the total mass of contaminant, or other solute, in motion. Measuring mass flux identifies the variations in the mass and flow velocity across a plume.

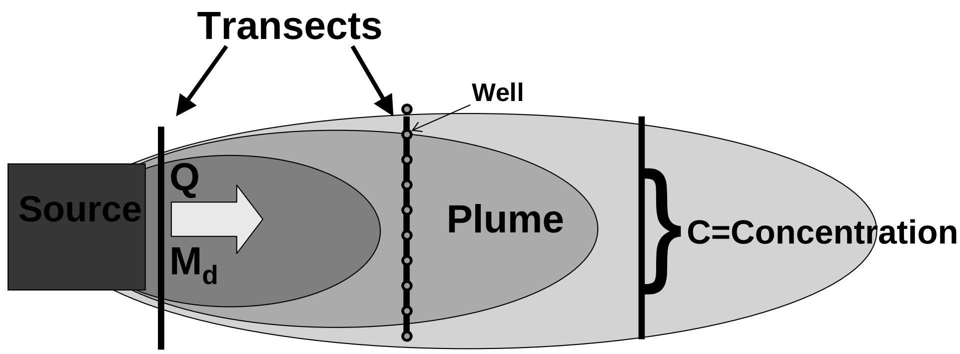
Excellent fundamental descriptions are given in:

R. B. Bird, W. E. Stewart, and E. N. Lightfoot. Transport Phenomena. Revised 2nd ed., 2007. John Wiley & Sons, Inc.

C.W. Fetter. Contaminant Hydrogeology. 2nd ed., 1999. Waveland Press, Inc.

16

Mass Discharge: Source or Plume Strength



Across any Transect, a Contaminant Plume Conveys:

Groundwater Discharge, **Q** (e.g., L/day)

Contaminant **Mass Discharge**, $\mathbf{M_d}$ (e.g., g/day or kg/year)

$$\mathbf{M_d = Q \times C} \quad \textbf{(L/day x mg/L = mg/day)}$$

Figure 2-1

Transitioning into mass discharge—

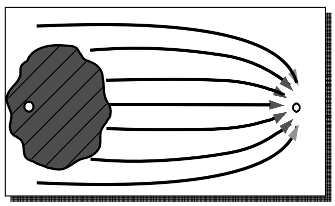
Mass discharge is equivalent to source or plume strength. Looking down on a plume, a transect immediately down gradient of the source measures the mass loading to the plume, which changes with time, and transects further downgradient measure the mass in motion. The difference in mass discharge with distance is the natural attenuation rate, in a plume that is stable.

17

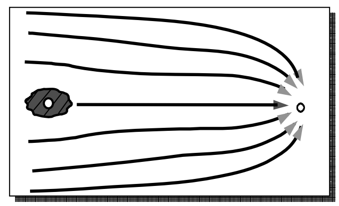
Mass Discharge and Concentration

- Concentration-based approach may not account for important site characteristics
  - Large vs. small releases
  - Pumping rate at the receptor well

Case A: Large Release
High Max. Conc. and High Md



Case B: Small Release
High Max. Conc. and Low Md



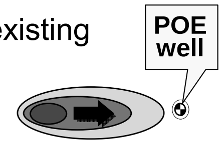
KEY POINT: **Evaluation of mass discharge (M_d) can increase understanding of site and be an important component of the site conceptual model**

No associated notes.

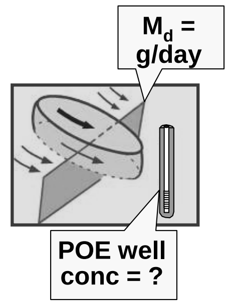
18

Mass Discharge vs. Traditional Approach

- ***Traditional Approach:*** Measure existing plume **concentrations** to assess
  - Impact on receptor wells
  - Natural attenuation rates
  - Remedial options



- ***Mass Discharge Approach:*** Define rate of **mass discharge** across specified cross-sectional areas of plume to assess
  - Impact on receptor wells
  - Natural attenuation rates
  - Remedial options



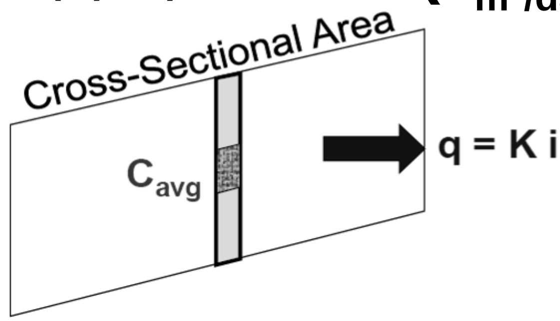
KEY BENEFITS: **Mass discharge approach sometimes offers a better understanding of potential risks and attenuation rates, and can lead to sounder remediation strategies.**

Mass discharge approach based on Einarson and Mackay (2001) ES&T, 35(3): 67A-73A

No associated notes.

What Is Mass Flux?

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



No associated notes.

Mass Flux Can Be Highly Variable

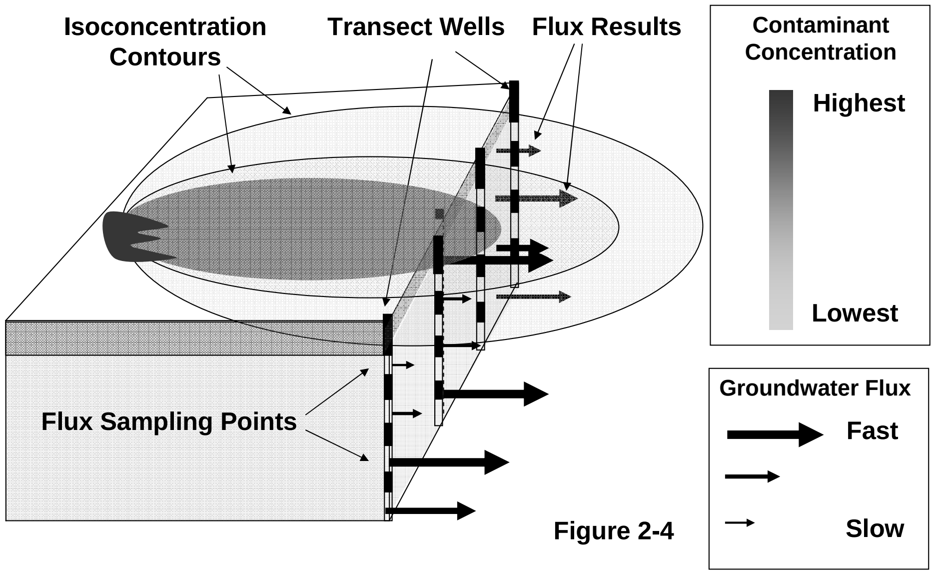


Figure 2-4

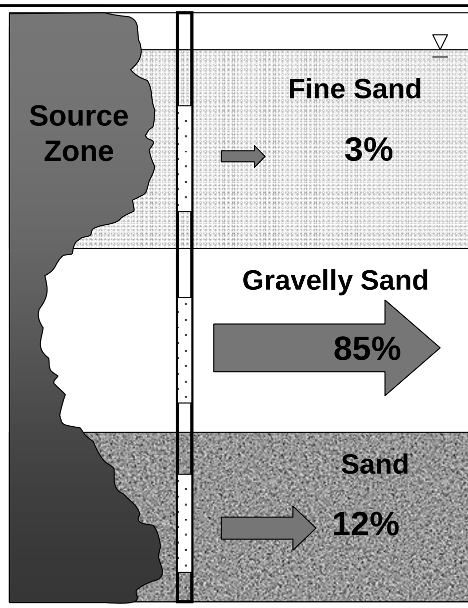
Both concentrations and groundwater velocity can vary dramatically over short distances. Both can also vary over time, seasonally and over longer time frames. The spatial variation in 3 dimensions is generally far more complex than typical representations of contaminant plumes suggest, and it can be important to understand these variations.

21

Mass Flux and Concentration

Figure 2

Mass Flux (*J*) = KiC



K = 1.0 m/day
i = 0.003 m/m
C = 10,000 μg/L
Mass Flux = 0.03 g/day/m^2

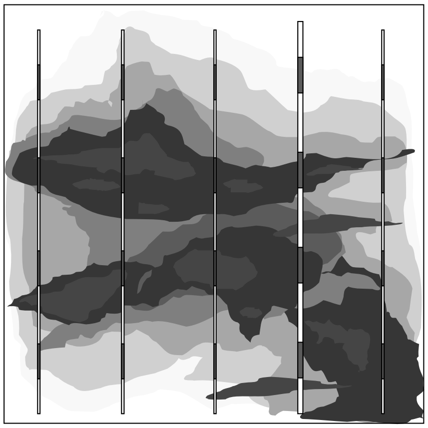
K = 33.3 m/day
i = 0.003 m/m
C = 10,000 μg/L
Mass Flux = 1 g/day/m^2

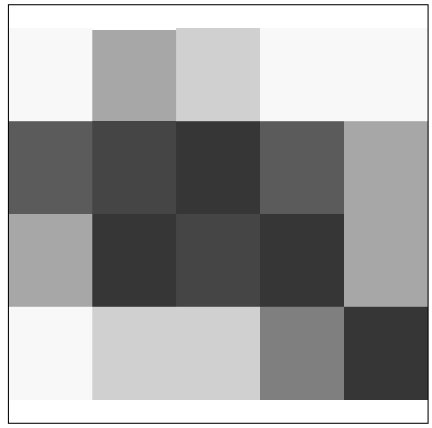
K = 5.0 m/day
i = 0.003 m/m
C = 10,000 μg/L
Mass Flux = 0.15 g/day/m^2

Illustrative example of an aquifer with identical concentrations and gradients in three sandy layers. But mass flux varies about 30-fold between layers, because the hydraulic conductivity varies, so that 85% of the flux is through only one layer. Even in unconsolidated aquifers, 80-90% of the mass flux may be through only 10-20% of the total plume volume.

Note that the groundwater and mass discharge are based on the Darcy velocity (Q=Ki) and not the seepage velocity (Vs=Ki/p), where p = porosity. The seepage velocity, which is the average fluid velocity within the pores, is faster than the Darcy velocity, which refers to the rate of movement of water through the entire area of a plane across the flow direction.

Interpolation



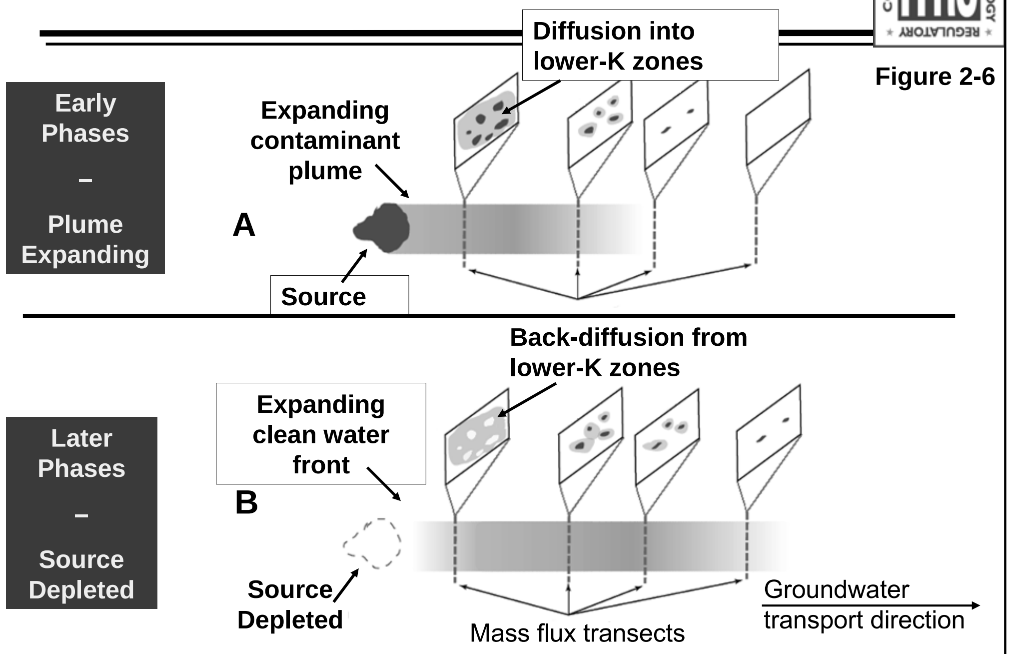


- Scale matters – what needs to be measured
- How to interpolate between highly variable data
- Most transects sample < 1% of the groundwater

No associated notes.

23

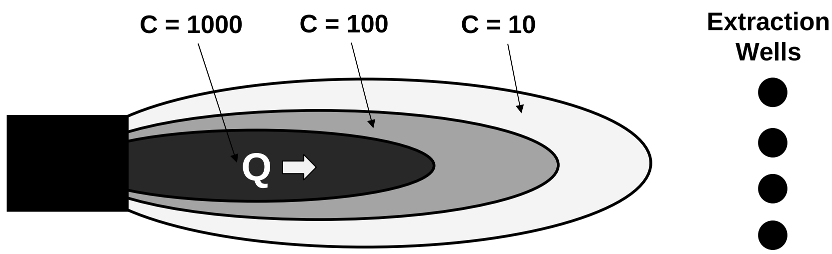
Mass Flux and Plume Evolution



In the early phases, most of the mass is in the transmissive zones.
Later, mass diffuses into the lower-permeability zones.
Finally, plumes are sustained by back-diffusion, with relatively little flux in higher-K zones.
Mass flux distribution indicates where to treat most mass and whether back-diffusion is a likely problem.

Mass Flux and Mass Discharge Are Not New Concepts

- Basis for source depletion and natural attenuation models
- Ex situ treatments based on loading rates (e.g., Lb/hr)
- EPA, 2002: review of 20 pump and treat (P&T) sites
  - 35% of treatment systems to be replaced because mass loading estimates were inadequate



Contaminant Loading = Q x C

EPA, 2002 reference: EPA 542-R-02-008a-u, November 2002, Pilot Project to Optimize Superfund-financed Pump and Treat Systems: Summary Report and Lessons Learned. More information available at http://www.epa.gov/tio/download/remed/rse/phase_ii_report.pdf

Uncertainty and its Management

- Uncertainty inevitable, but manageable
  - Similar uncertainty with concentration data
  - To successfully establish compliance goals consensus between stakeholders required
- Spatial heterogeneity and sample volumes
  - May need >> 1% (Li and Abriola, 2006)
- Source / Plume Boundary?
  - Hard to find and hard to define
- Solutions
  - Work Smart – Consider source architecture, plume evolution, hydrogeology, etc
  - Consider iterative investigation
  - Vertical variability is usually >> Lateral

No associated notes.

26

Advantages and Limitations

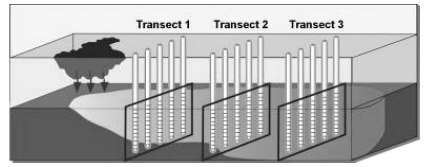
- Potential advantages
  - Improved conceptual site model (CSM)
  - More representative attenuation rates, exposure assessment
  - Improved remediation efficiency
  - Reduced remediation timeframe
- Limitations
  - Uncertainty
  - Cost

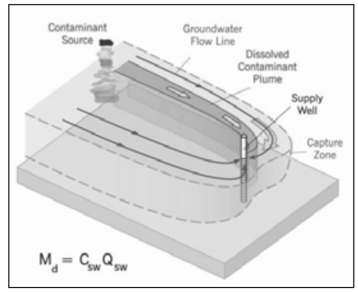
No associated notes.

27

Course Roadmap

- ▶ Mass concepts
- ▶ Measurement methods
- ▶ Application
- ▶ Case studies
- ▶ Summary



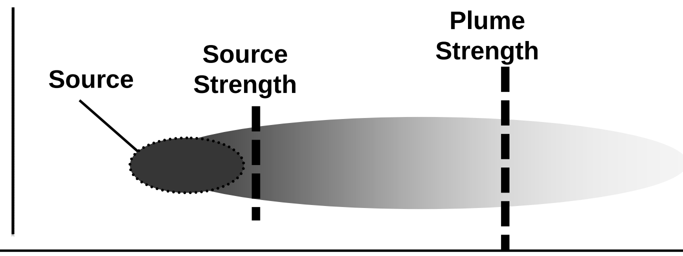


No associated notes.

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 Data (Isocontours) (Sect. 4.4)
- *Method 5*: Solute Transport Models (Sect. 4.5)

All methods are “ready to go”



No associated notes.

Calculating Mass Discharge: Transect Method Simple Example

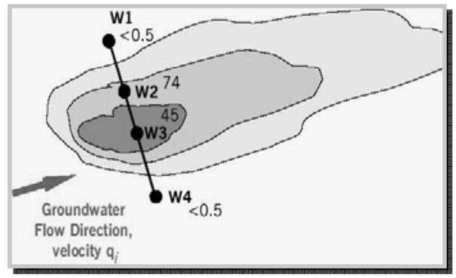
Nichols and Roth, 2004

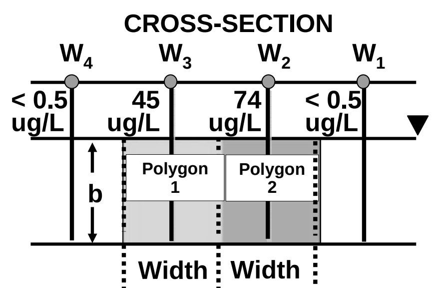
Step-by-step approach assuming uniform groundwater velocity

1. Characterize plume (C)
2. Characterize flow (q)
3. Draw transect: with simple approach, just build cross-sectional polygons ("window panes") for each well across flow
4. Determine area (W • b = A)
5. Multiply and sum together:

$$M_d = \Sigma (C_n \cdot A_n \cdot q)$$

M_d = Mass discharge
C_n = concentration in polygon n
A_n = Area of segment n





No associated notes.

30

Calculating Mass Discharge: Groundwater Darcy Velocity Term (q)

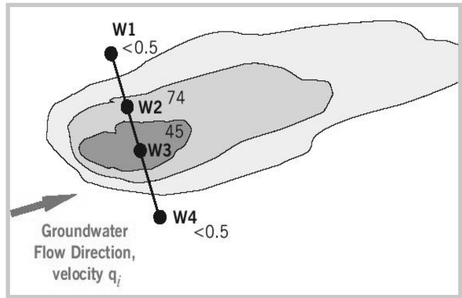
$$M_d = \Sigma (C_n \bullet A_n \bullet q_n)$$

Calculation of Darcy Velocity

$$q = K \bullet i$$

q = Groundwater Darcy velocity
i = Hydraulic gradient
K = Hydraulic conductivity*

- Hydraulic conductivity can be determined by pumping test, slug test, or estimated based on soil type
- Don't use porosity – hydraulic calculations for groundwater (such as Theis equation) don't rely on porosity



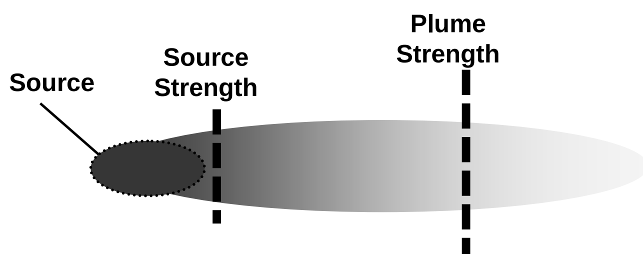
Variability in groundwater velocity - most applications of the transect method to date have assumed a uniform groundwater. Darcy velocity for the entire transect. However, different values for q may be used for different polygons if sufficient data are available.

No associated notes.

31

Building Transects: General Rules

- Can be permanent or temporary installations
- No special well or sampling points needed
- Can be based on longer single screen wells or multilevel observations
- Transect must be perpendicular or close to perpendicular to groundwater flow



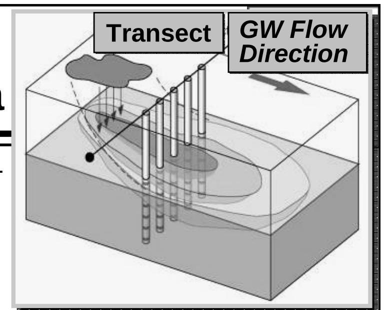
No associated notes.

32

Transect Method: Using High Resolution Data

Nichols and Roth, 2004

- Multi-level sampling means multiple level polygons
- Sum up all cells to get Mass Discharge (M_d) in units of
  - Grams per day (g/dy)
  - or
  - Kilograms per year (kg/yr)



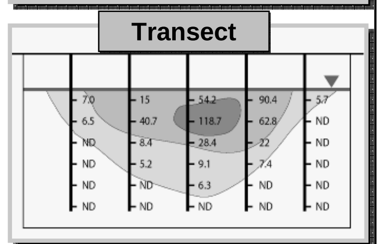


Figure 4-1

In this case

- **M_d = 488 g/dy**
- **or**
- **$M_{d\,=}$ 178 kg/yr**

	W_1	W_2	W_3	W_4	W_5
b_1	7.0	15	54.2	90.4	5.7
b_2	6.5	40.7	118.7	62.8	0
b_3	0	8.4	28.4	22	0
b_4	0	5.2	9.1	7.4	0
b_5	0	0	6.3	0	0
b_6	0	0	0	0	0

No associated notes.

33

How Many Points? Depends on Use

Information from Table 1.1

Remedial Applications	**Mass Flux Data Use**	**Relative Data Density Needed**
Active remediation or MNA	Estimate source strength	Low
	Estimate plume stability	High*
	Estimate mass balance-natural attenuation capacity	Medium to High*
Evaluate risk to receptor(s)	Estimate risks and exposures at various points of potential exposure	Low to Medium
Select appropriate technology	Determine remedial action objectives	Low to High
	Determine appropriate remedial technology(ies)	
Develop/optimize remedial design	Evaluate heterogeneities in source architecture	High
	Estimate source strength reductions necessary to transition technology (e.g., in situ biorem. or MNA)	Low
	Estimate distribution of contaminants	High
Evaluate remedial performance	Compare actual mass removal to design. Compare electron acceptors to electron donors	Low to High**
Evaluate compliance / LTM	Determine mass discharge or flux limits to achieve remedial goals	Low to Medium

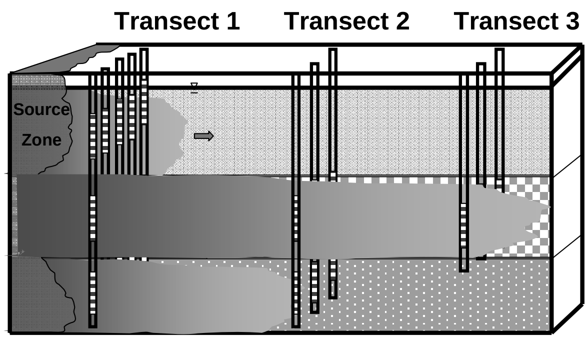
*If using multiple plume transects **Depending on system design and treatment volume(s)

No associated notes.

34

Use of Multiple Mass Transects

Design Tailored to Site Conditions and Goals



Mass Discharge *vs. Distance*

Mass Discharge *vs. Time*

For more info see: "EPA's Calculation and Use of First-Order Rate Constants – MNA" EPA/540/S-02/500

No associated notes.

35

Two Related Concepts

- Pre-characterization
  - One option is to use Membrane Interface Probes (MIPs) or some other screening tools to determine where mass discharge is located
  - Then design a mass discharge monitoring system with more focused sampling on high mass flux areas
- *Site characterization* is different than *long-term monitoring*

No associated notes.

36

Tools for Transect Method: High-Resolution Piezocone

- High-resolution piezocone, MIP (Kram et al, 2008)
- Plus computational/visualization package (slices)
- Still experimental

Shows mass flux in 2 or 3 dimensions

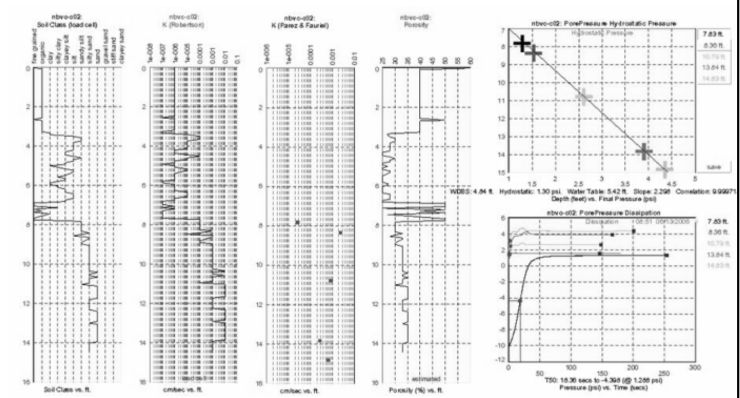
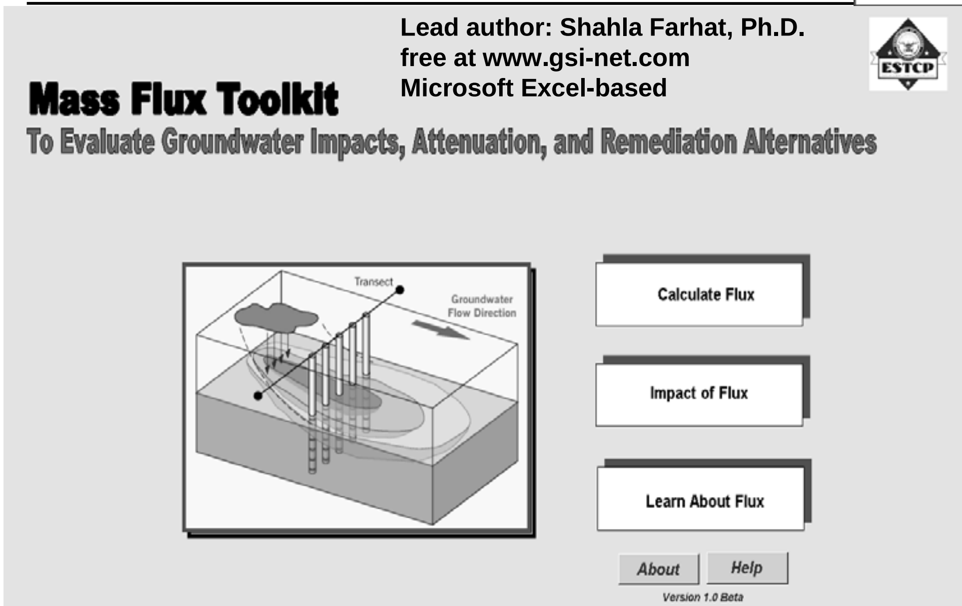


Figure 4-7

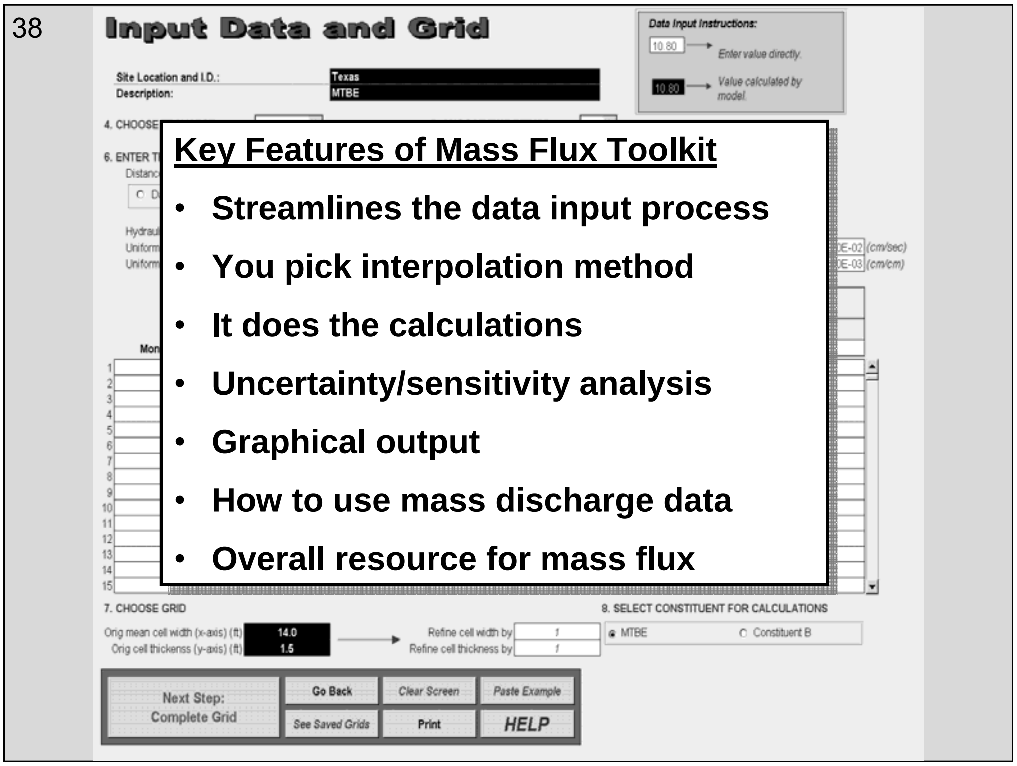
No associated notes.

Tools for Transect Method: Calculator

Lead author: Shahla Farhat, Ph.D.
free at www.gsi-net.com
Microsoft Excel-based

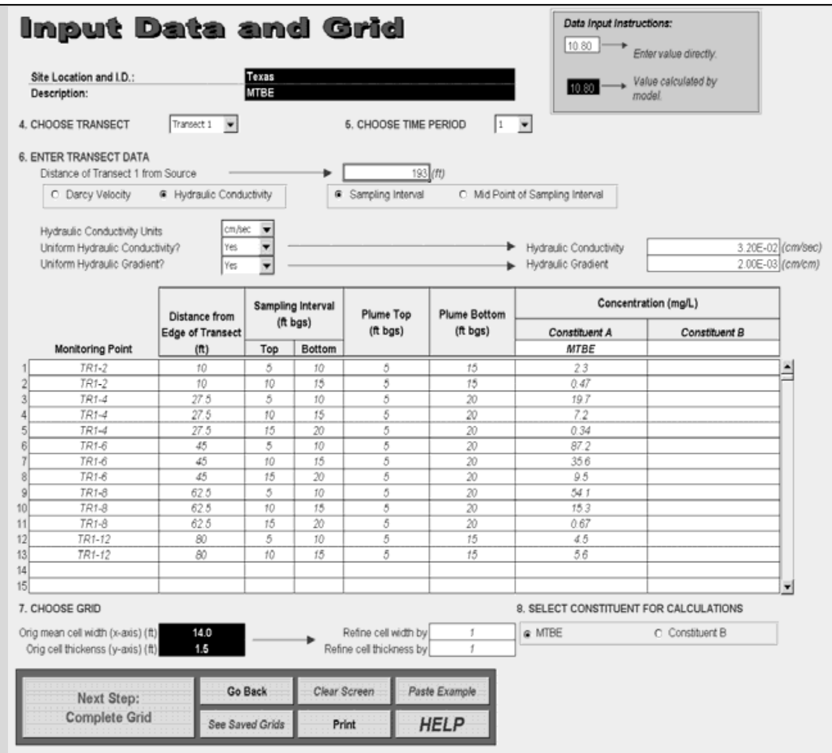


No associated notes.



No associated notes.

39



Input Data and Grid

Data Input Instructions:

10.80 → Enter value directly.

10.80 → Value calculated by model.

Site Location and I.D.: Texas

Description: MTBE

4. CHOOSE TRANSECT: Transect 1

5. CHOOSE TIME PERIOD: 1

6. ENTER TRANSECT DATA

Distance of Transect 1 from Source → 193 (ft)

○ Darcy Velocity ◉ Hydraulic Conductivity

◉ Sampling Interval ○ Mid Point of Sampling Interval

Hydraulic Conductivity Units: cm/sec

Uniform Hydraulic Conductivity?: Yes → Hydraulic Conductivity 3.20E-02 (cm/sec)

Uniform Hydraulic Gradient?: Yes → Hydraulic Gradient 2.00E-03 (cm/cm)

	Monitoring Point	Distance from Edge of Transect (ft)	Sampling Interval (ft bgs) Top	Sampling Interval (ft bgs) Bottom	Plume Top (ft bgs)	Plume Bottom (ft bgs)	Concentration (mg/L) Constituent A MTBE	Concentration (mg/L) Constituent B
1	TR1-2	10	5	10	5	15	2.3	
2	TR1-2	10	10	15	5	15	0.47	
3	TR1-4	27.5	5	10	5	20	19.7	
4	TR1-4	27.5	10	15	5	20	7.2	
5	TR1-4	27.5	15	20	5	20	0.34	
6	TR1-6	45	5	10	5	20	87.2	
7	TR1-6	45	10	15	5	20	35.6	
8	TR1-6	45	15	20	5	20	9.5	
9	TR1-8	62.5	5	10	5	20	54.1	
10	TR1-8	62.5	10	15	5	20	15.3	
11	TR1-8	62.5	15	20	5	20	0.67	
12	TR1-12	80	5	10	5	15	4.5	
13	TR1-12	80	10	15	5	15	5.6	
14								
15								

7. CHOOSE GRID

Orig mean cell width (x-axis) (ft): 14.0 → Refine cell width by: 1

Orig cell thickenss (y-axis) (ft): 1.5 → Refine cell thickness by: 1

8. SELECT CONSTITUENT FOR CALCULATIONS

◉ MTBE ○ Constituent B

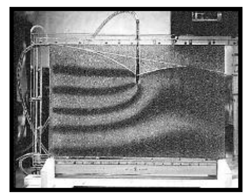
Next Step: Complete Grid | Go Back | Clear Screen | Paste Example | See Saved Grids | Print | HELP

No associated notes.

40

Method 1 – Transects Advantages and Limitations

- Advantages
  - Commonly used – many applications
  - Direct measurement
  - Extension of accepted technology
- Limitations
  - High resolution data can be costly
  - Calculations can be time consuming



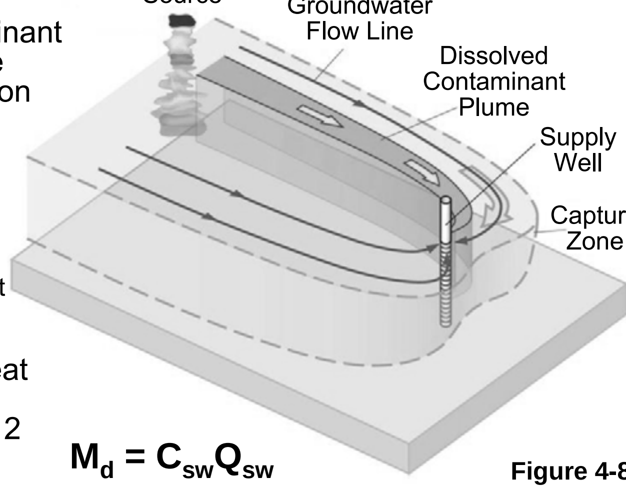
No associated notes.

41

Method 2 – Well Capture/Pump Tests

Nichols and Roth, 2004

- Instead of plume flowing downgradient you capture the contaminant plume and measure flow, concentration on surface, but
  - Pumping should not induce dissolution at the source
  - Pumping needs to reach steady state
  - High confidence that plume has been captured
- Some pump and treat (P&T) systems can be ideal for Method 2



$$M_d = C_{sw}Q_{sw}$$

Figure 4-8

No associated notes.

42

Well Capture Mass Discharge Calculation

Nichols and Roth, 2004

Figure 4-8

Measure Q, C_{well} from well

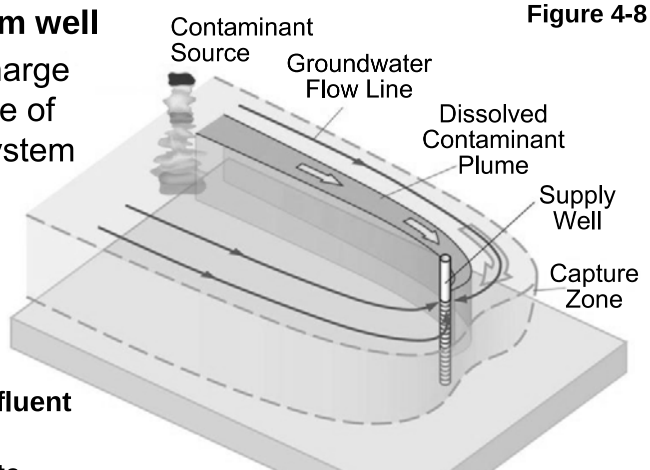
Calculate mass discharge based on total capture of plume by pumping system

$$M_d = Q \times C_{well}$$

M_d = Mass discharge (grams per day)

C_{well} = concentration in recovery well effluent (grams per liter)

Q = Well pumping rate (liters per day)



$$\frac{\text{gram}}{\cancel{\text{liter}}} \times \frac{\cancel{\text{liters}}}{\text{day}} = \frac{\text{grams}}{\text{day}}$$

No associated notes.

More Sophisticated Version Method 2

- ▶ Integral Pump Tests (IPT)
  - Steady state flow conditions, but handles changing heterogeneous concentrations in plume

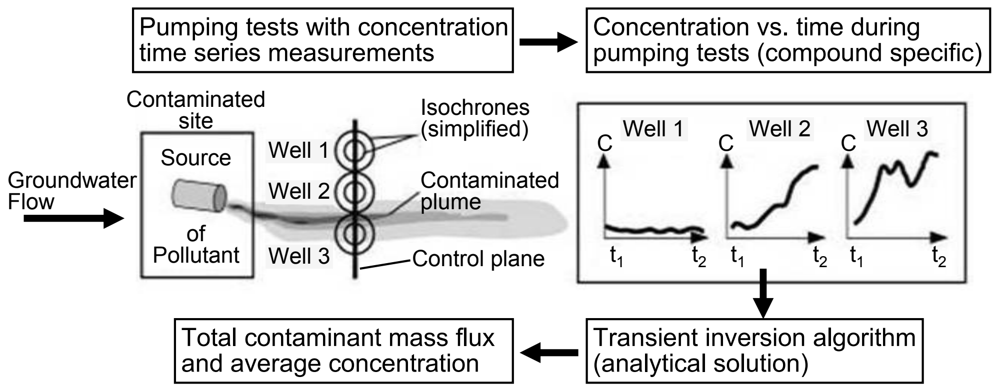


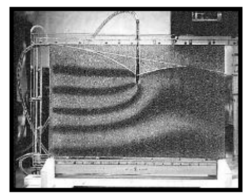
Figure 4-9. Estimating Mass Flux Using Integral Pump Test Series Data

No associated notes.

44

Well Capture Methods Advantages and Limitations

- Advantages
  - Fewer wells
  - Better integration of flow and concentration data
  - Can use existing pumping system
- Limitations
  - No mass flux data
  - Large volumes of water that need disposal/treatment
  - Possible to change plume characteristics
  - Difficult to assure full plume capture

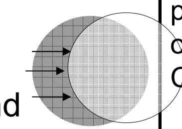


No associated notes.

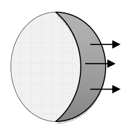
45

Method 3 – Passive Flux Meter

- Permeable sorbent
  - Accumulates contaminant based on flow and concentration



- Soluble tracers
  - Loses tracer based on groundwater velocity and flux convergence calculations



1. Contaminant adsorbed onto passive flux meter over time to get Concentration

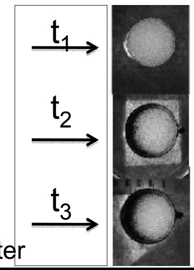
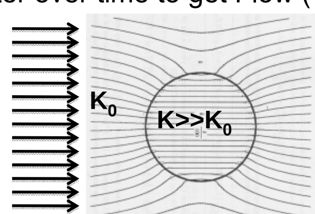


Photo: Dye intercepted in a meter

2. Tracer desorbs from passive flux meter over time to get Flow (Q)



Groundwater Flowlines

Source: Hatfield and Annable

No associated notes.

Passive Flux Meter

Installation

Sampling

Vendor: http://www.enviroflux.com/pfm.htm

No associated notes.

47

Passive Flux Meter
Advantages and Limitations

- Advantages
  - "One stop shop" for both flow and concentration
  - Easy to install in the field
  - No waste generated
  - Vendor available to implement this method
- Limitations
  - Some method-specific issues (lower measurement in pushed wells, slight biodegradation of tracer at one site, competitive sorption under some conditions)
  - Relies on well convergence calculations

No associated notes.

Method 4 – Use Existing Data (Transect Based on Isocontours)

- Uses existing well network and plume map
- Combine with flow data

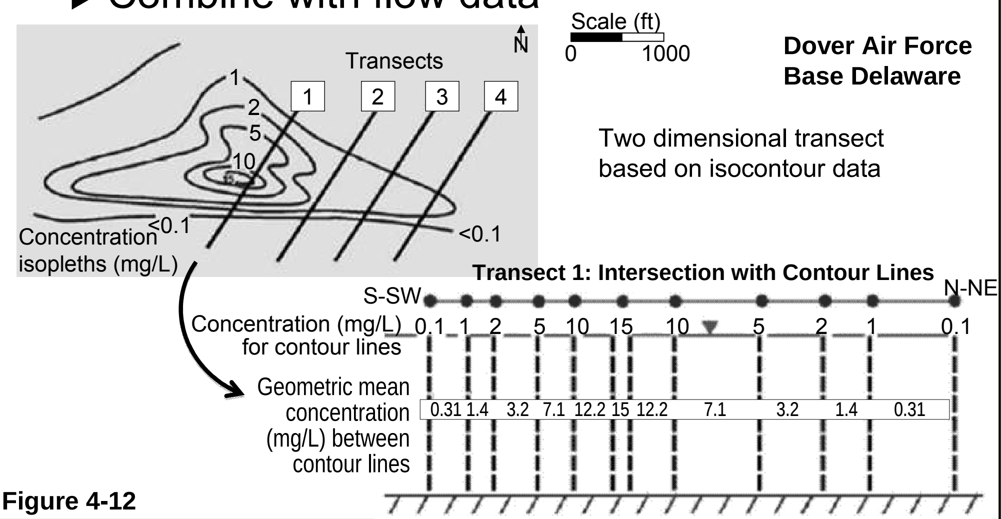
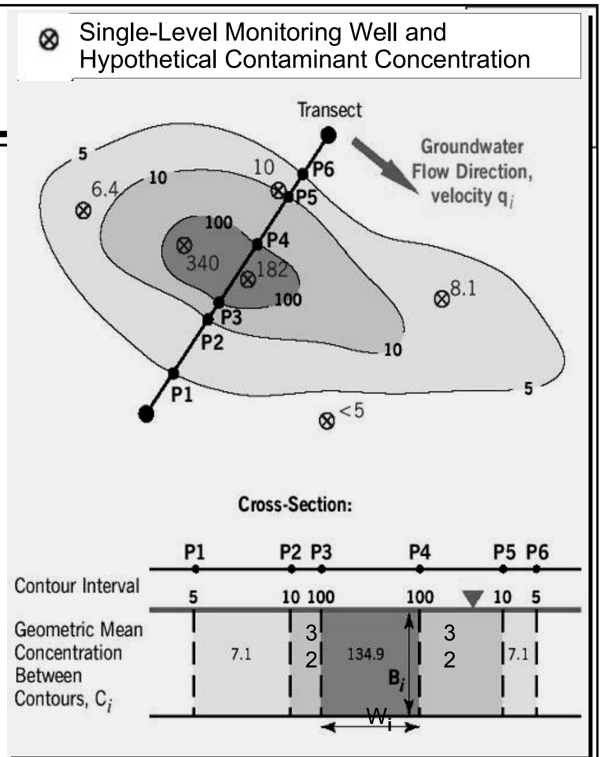


Figure 4-12

No associated notes.

49 **Calculating Mass Discharge from Isocontours**



Plume Contour Data

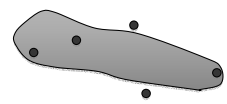
1. Get isocontours from existing plume map
2. Build transect using points where isocontours intersect transect line (you can add actual wells if close to contour)
3. Apply Transect Method (Method 1) Calculations

Nichols and Roth, 2004

No associated notes.

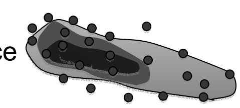
Isocontour Method Advantages and Limitations

- Advantages
  - Does not need special field study. Can use existing, historical data from existing monitoring system
  - Limited additional expense
- Limitations
  - Wide range of opinion about usefulness of this method
  - Can be inaccurate if plume map is built with only a few wells. For example consider:
    - Gas station site with 5 wells throughout entire plume: **not likely** to provide high quality mass flux/mass discharge data



versus

    - Well characterized site with 40 wells in source zone: **likely** to provide higher quality data

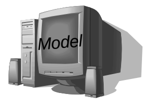


No associated notes.

51

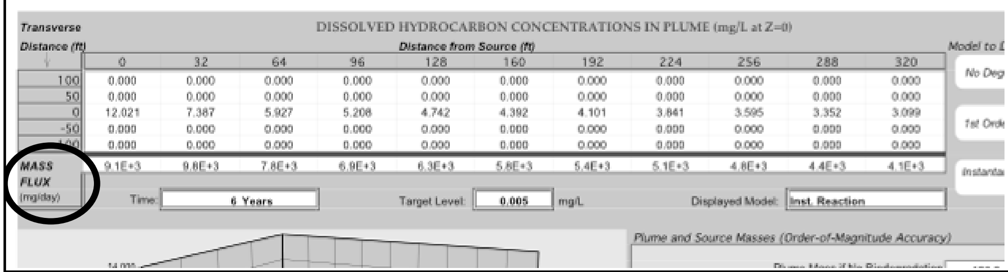
Measurement Method 5 – Computer Models

- Using computer models



Models Integrate Flow and Concentration

1. Calibrate model
2. Get flow and concentration data across transect
3. Example Below from BIOSCREEN



DISSOLVED HYDROCARBON CONCENTRATIONS IN PLUME (mg/L at Z=0)

Transverse Distance (ft) / Distance from Source (ft)	0	32	64	96	128	160	192	224	256	288	320
100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	12.021	7.387	5.927	5.208	4.742	4.392	4.101	3.841	3.595	3.352	3.099
-50	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
-100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
MASS FLUX (mg/day)	9.1E+3	9.8E+3	7.8E+3	6.9E+3	6.3E+3	5.8E+3	5.4E+3	5.1E+3	4.8E+3	4.4E+3	4.1E+3

Time: 6 Years Target Level: 0.005 mg/L Displayed Model: Inst. Reaction

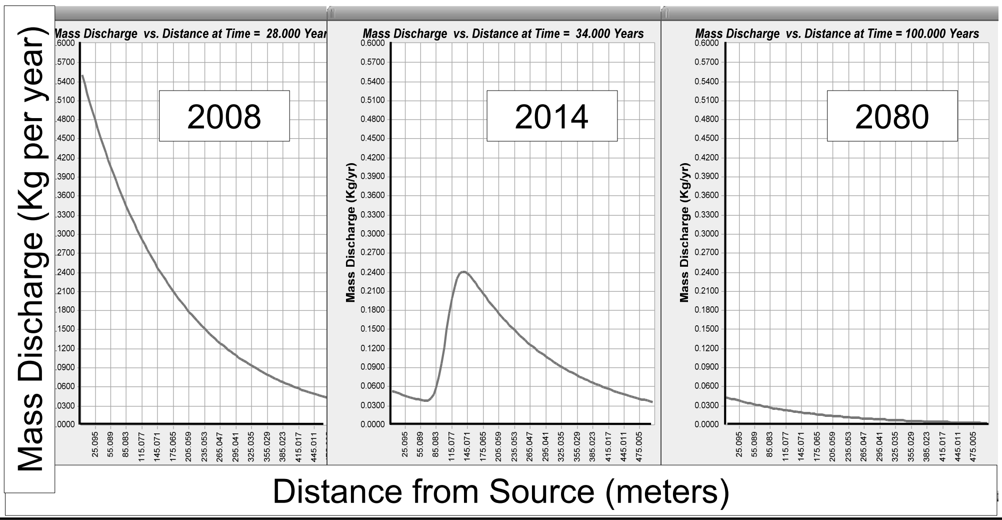
No associated notes.

52

REMChlor Model of Source Remediation

Source: Ron Falta, Clemson Univ.

Remove 90% of mass in 2010.
REMchlor shows mass discharge vs. distance in future years



No associated notes.

53

Measurement Method 5
Models with Mass Discharge

Model	Model application and type
BIOSCREEN	**Fuel Hydrocarbon MNA, Analytical**
BIOCHLOR	**Chlorinated Solvent MNA, Analytical**
BIOBALANCE	**Chlorinated Solvent MNA, Analytical**
MODFLOW/MT3DMS	**General. Numerical**
MODFLOW/RT3DMS	**General, Sequential Degradation, Numerical**
MODFLOW/MT3D	**General. Numerical**
MODFLOW/RT3D - rtFlux	**General. Numerical**
REMChlor ***New!***	**Hydrocarbon, Chlorinated Solvent**

From Table 4-3

No associated notes.

54

Computer Model Method Advantages and Limitations

- Advantages
  - Does not need special field study. Can use existing, historical data from existing monitoring system
  - Models are designed to combine flow, concentration data
- Limitations
  - Helpful to have experience/training in using models
  - Need good data – both flow and concentration data
  - Amount of data depends on what information is being used for
    - For example - need absolute or relative number?
    - Table 1.1 in Guide (shown under Transect Section) provides more detail

No associated notes.

55

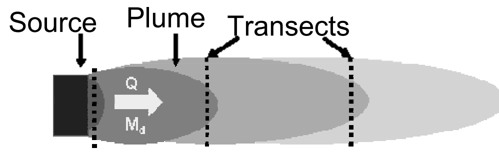
Five Methods for Mass Discharge

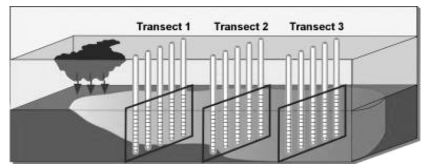
- *Method 1:* Transect Method (Sect. 4.1)
  - Commonly used. Based on familiar technology
- *Method 2:* Well Capture/Pumping Methods (Sect. 4.2)
  - Many pump and treat systems doing this now.
- *Method 3:* Passive Flux Meters (Sect. 4.3)
  - New technology, easy to install, one device for flow and concentration
- *Method 4:* Using Existing Data (Isocontours) (Sect. 4.4)
  - Uses existing data. Cost effective, but requires good monitoring network.
- *Method 5:* Solute Transport Models (Sect. 4.5)
  - Combines flow and concentration data. Helpful to have experience

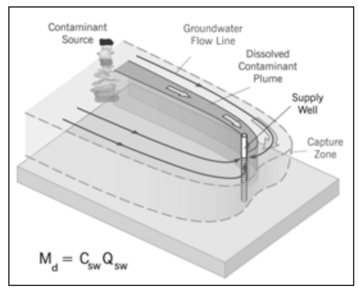
No associated notes.

Question and Answer

- ▶ Mass concepts
- ▶ Measurement methods
- ➡ Question and answer break
- ▶ Application
- ▶ Case studies
- ▶ Summary







No associated notes.

Course Roadmap

- Mass concepts
- Measurement methods
- Application
- Case studies
- Summary

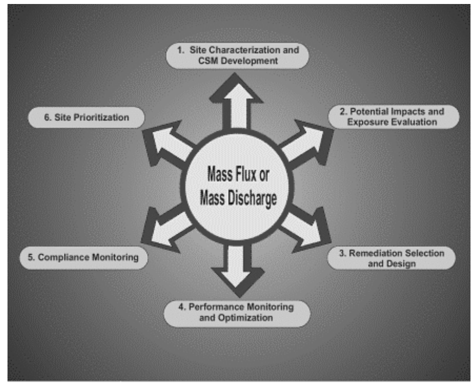


Figure 1-1

No associated notes.

Six Use Categories from Case Studies

1. Site Characterization
2. Potential Impacts and Exposure Evaluation
3. Remediation Selection and Design
4. Performance Monitoring and Optimization
5. Compliance Monitoring
6. Site Prioritization

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

- Remedial action objectives (RAOs)
- Technology selection
- Remedial design
- Performance
- Optimization

•Based on review of case studies we identified five categories of mass flux and mass discharge “uses”:

•Some categories, like “site characterization” and “remediation” are fairly broad and encompass several sub-categories

•And it should be noted that some sub-categories of “site characterization” may occur after a remedy has been selected, but there is reason to suspect things are working as planned due to incomplete site characterization, so the site characterization uses don’t necessarily happen in the beginning.

1.Site Characterization

2.Potential Impact Assessment

3.Remediation

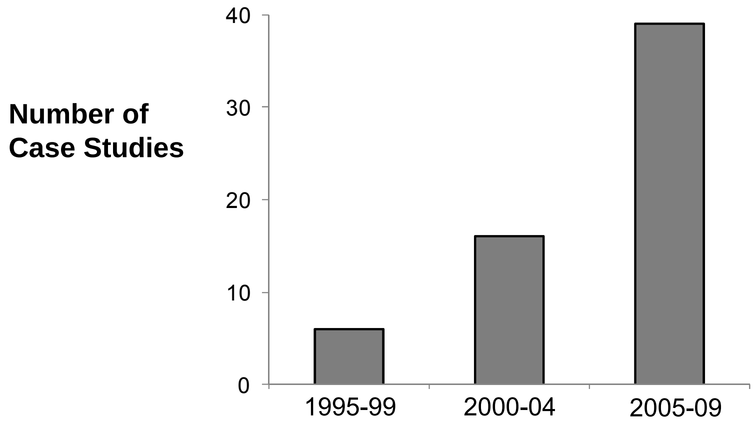
4.Compliance Monitoring

5.Site Prioritization

59

Increasing Use of Mass Flux and Mass Discharge

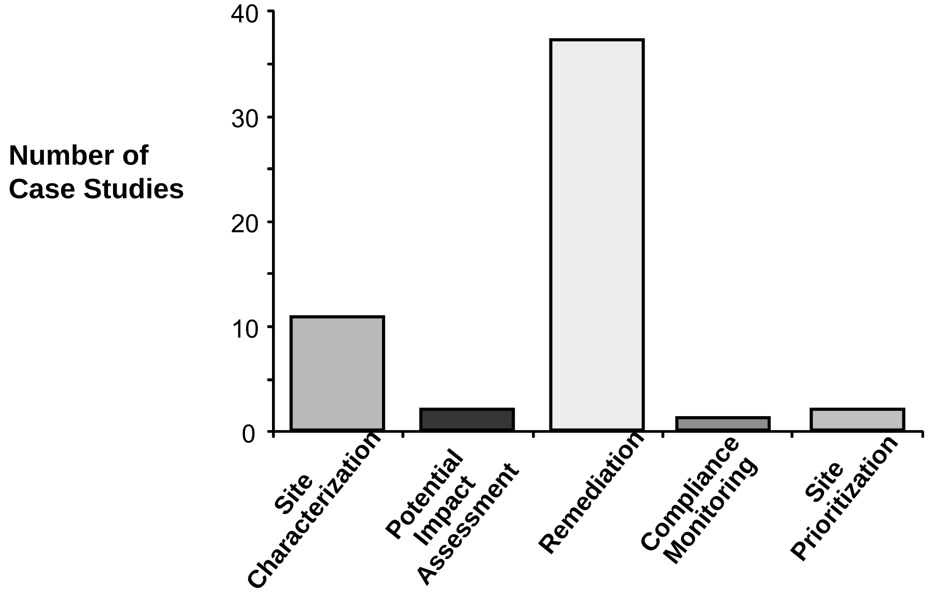
Rapid increase in use since 1995



No associated notes.

60

Over 61 Case Studies Documenting Mass Flux and Mass Discharge Use



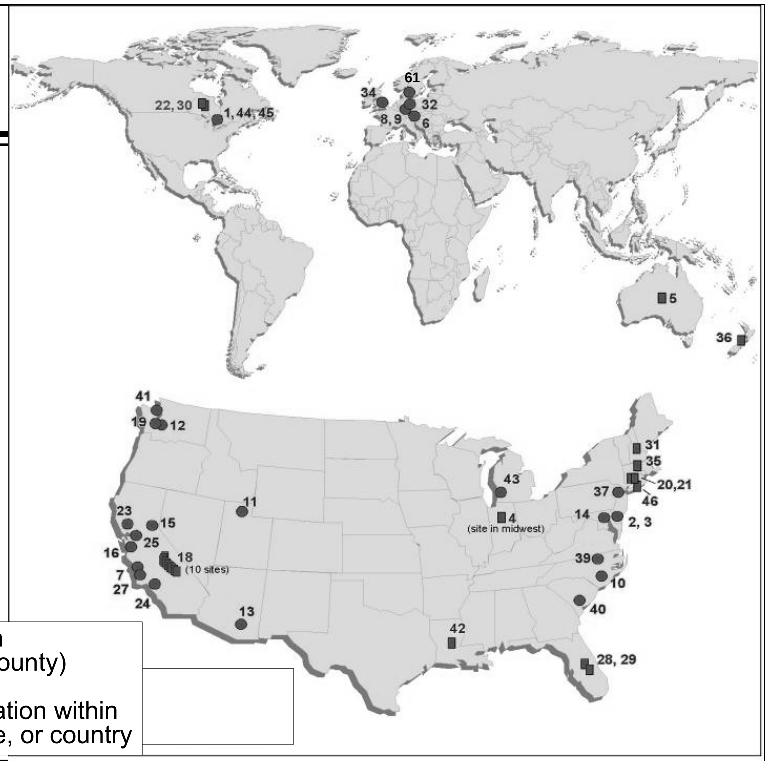
The use of Mass Flux and Mass Discharge is increasing, as the chart shows

Includes all “use” categories:

1. Site Characterization
2. Potential Impact Assessment
3. Remediation
4. Compliance Monitoring
5. Site Prioritization

61

Where Mass Discharge Has Been Used



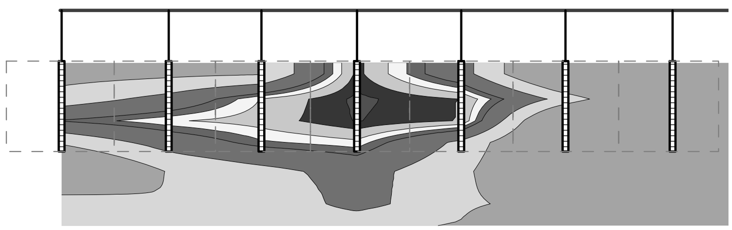
1 Specific location (known city or county)

5 Unspecified location within a state, province, or country

No associated notes.

Reasons for Increased Use

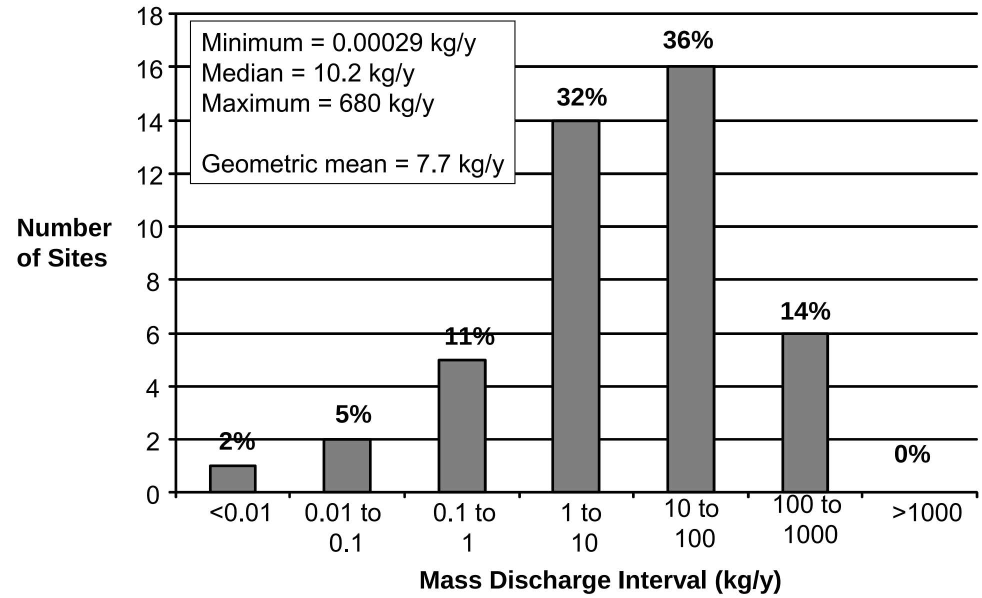
- New studies → heterogeneous mass flux from source zones (e.g. Guilbeault et al., 2005)
- Improved monitoring techniques
- Recent focus on improving remediation efficiency
- New databases comparing technology performance based on source strength reduction



No associated notes.

63

Frequency of Sites with VOC/SVOC Mass Discharge Ranges



No associated notes.

64

Mass Discharge Calculations for Various Sites

Site	Contaminant	Mass Discharge (g/d)	Reference
Sampson County, NC	MTBE	0.6 - 2	(Borden et al, 1997)
Vandenberg AFB, CA	MTBE	4 - 7	Unpublished
Unnamed Site	MTBE	4	Unpublished
Elizabeth City, NC	MTBE	7.6	Wilson, 2000
St. Joseph, MI	TCE	167	(Semprini et al, 1995)
Dover AFB, DE	CVOCs	630	(RTDF 1998)

Table adapted from Einarson and Mackay (2001) ES&T, 35(3): 67A-73A

No associated notes.

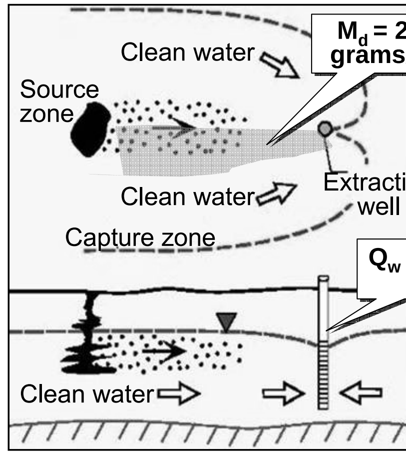
65 # Using Mass Discharge: Estimating Well Impacts

Einarson and Mackay, 2001

Use mass discharge of plume to predict constituent of concern concentration in downgradient water supply well

$$C_{well} = M_d \div Q_{Well}$$

C_{well} = Concentration in extraction well
Q_{well} = Pumping rate for extraction well

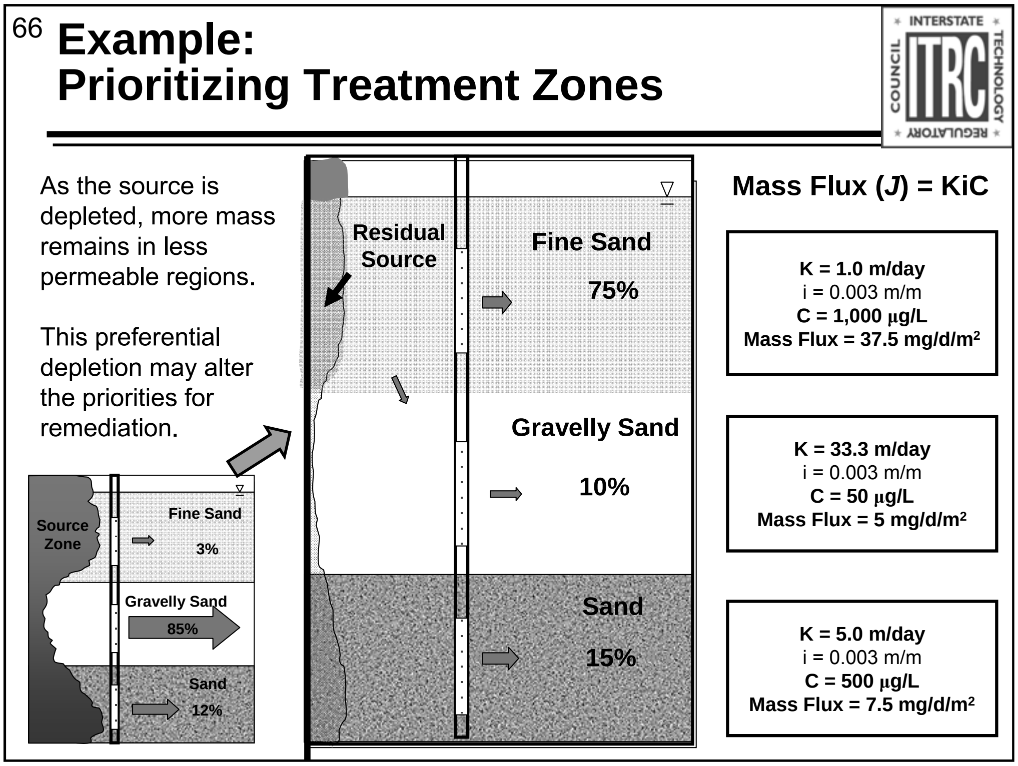


M_d = 2 grams/day

Q_w = 600 gpm

$$2\ \text{g/day} \times \frac{1}{600\ \text{gpm}} \div 1440\ \text{min} \times \frac{1\ \text{gal}}{3.79\ \text{L}} \times \frac{10^6\ \text{ug}}{\text{g}} = < 1\ \text{ug/L}$$

No associated notes.



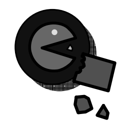
Illustrative example of an aquifer with a depleted source, and back diffusion can largely sustain a plume in the transmissive zones. Total discharge is much lower than originally (45 mg/day/m^2, as compared to 1,180 mg/day/m^2 – see slide 23). But now the concentrations remain higher in the less depleted zones and

67

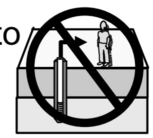
Mass Flux/Discharge Applications

1. Site Characterization
2. Potential Impacts and Exposure Evaluation
3. Remediation Selection and Design
4. Performance Monitoring and Optimization
5. Compliance Monitoring
6. Site Prioritization

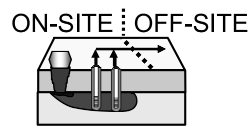
- Shows
  - Effect of natural attenuation

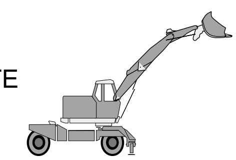


- Quantifies
  - Potential impacts to wells and streams



- Guides
  - Where remediation is needed





No associated notes.

68

Regulatory Precedence

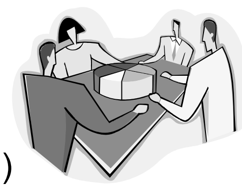
- Federal Superfund…signed Record of Decision (ROD) identifying a mass discharge interim goal [Well 12A site, WA, Oct 2009]
- Surface water regulation (e.g., Total Maximum Daily Loads (TMDL), National Pollutant Discharge Elimination System (NPDES)) is based on mass discharge
- Groundwater extraction gives estimate of mass discharge over capture zone
- Natural attenuation relies on mass discharge reduction

l NPDES permits you are required to report concentration and mass measurements

69

Regulatory Acceptance – Needs

- More familiarity with mass flux and mass discharge concepts, methods, and uncertainties
- Better understanding of how mass flux and mass discharge relates to
  - Risk
  - Compliance
  - Typical regulatory metrics (e.g., concentration-based standards)

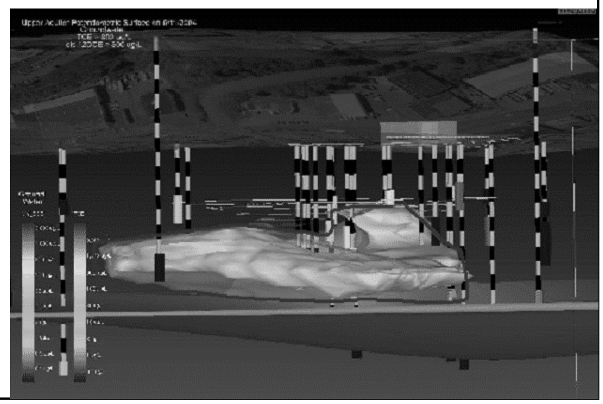


l NPDES permits you are required to report concentration and mass measurements

70

Course Roadmap

- Mass concepts
- Measurement methods
- Application
- Case studies
- Summary



So far we've heard very useful information about how mass flux and mass discharge can be used to support site characterization and remediation, and amount some of the interesting methods for estimating mass flux and mass discharge.

Even though the use of these mass data isn't new, the frequency of use of mass data has grown rapidly in the past few years. To gain some insights on how these data are being used across the industry, we conducted a detailed review of about 65 case studies where mass flux or discharge were estimated.

The results of this detailed review are included in tables in an appendix at the back of the Overview document, including a summary of site-specific mass discharge estimates with different methods, value added to the site through the use of mass, numbers and spaces between wells when used with the transect method, etc.

What we're going to do now is review several case studies that demonstrate how estimating mass flux and discharge can add value at some of your own sites.

71

Frequency of Method Applications

Mass Flux and Mass Discharge Measurement/Estimation Method	No. Sites Where Applied
Transects with groundwater sample collection	41
Integral Pump Test(s)	7
Transects with passive flux meters	5
Isoconcentration contours	2
Mass Balance	2
Solute Transport Model	1

This table lists the frequency that various methods were used to estimate mass flux and discharge in the published case studies.

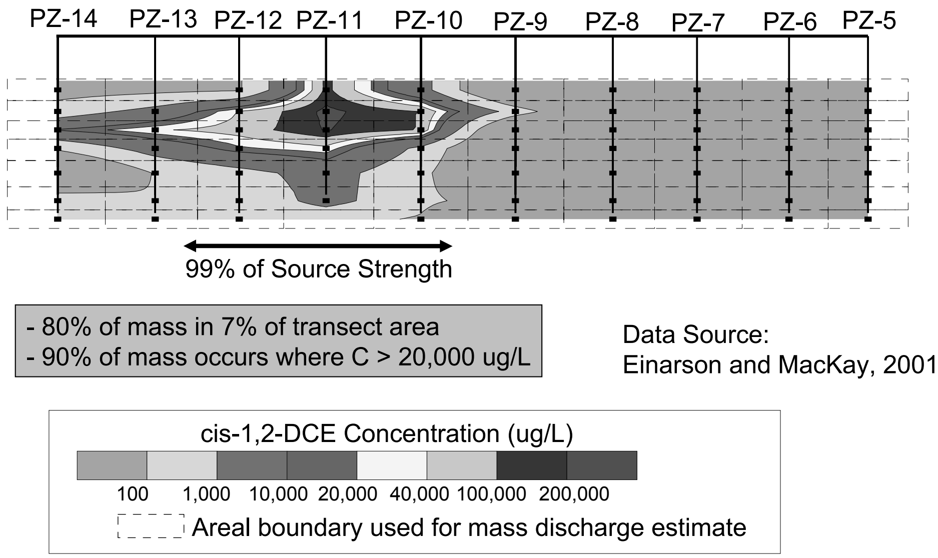
We can see from this table that the most common method for estimating mass discharge is the use of transects with the collection of groundwater samples. This method is probably the most common because it's relatively simple to apply in the field.

From the published case studies, we have seen more recent use of integral pump tests to estimate mass discharge at transects, as well as passive flux meters.

Many of these reported case studies were specifically intended to compare methods for mass flux estimation or performance of an in-situ treatment technology.

72

Example No. 1 Characterization and CSM Alameda Naval Station, CA



The data for this site were published in a class mass flux paper written in 2001 by Einarson and MacKay and published in Environmental Science & Technology.

This contour map shows the distribution of concentrations of cis-1,2-DCE in a transect that is approximately 30 meters in length.

These data show the same trend that we have seen in other sites where high resolution monitoring has been conducted.

And more than 80% of the mass is situated in less than 7% of the transect.

Over 99% of the mass is situated in less than 30% of the transect cross-sectional area.

Identifying the core of the plume mass such as was done at this site can help to focus remediation and monitoring efforts which may result in substantial cost and time savings.

73

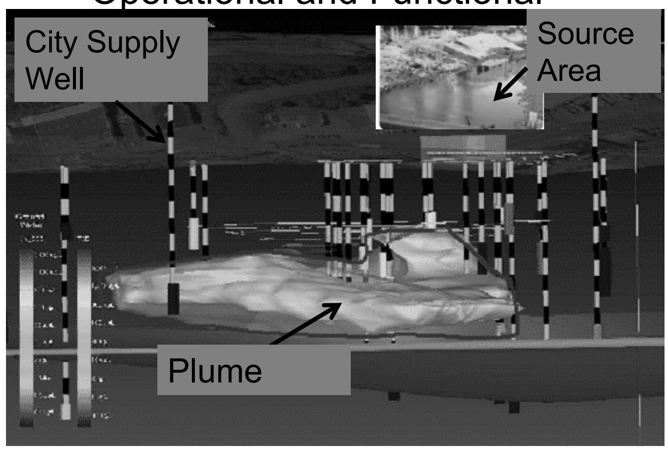
Example No. 2 – Mass Discharge (Md) as an Interim Remedial Goal Compliance

Mass flux and mass discharge

Focused Feasibility Study evaluation: Reduce source strength (Md) by 90%, MNA sufficient to achieve compliance

ROD amendment: Multi-component remedy- reduce source discharge Md by 90% & transition

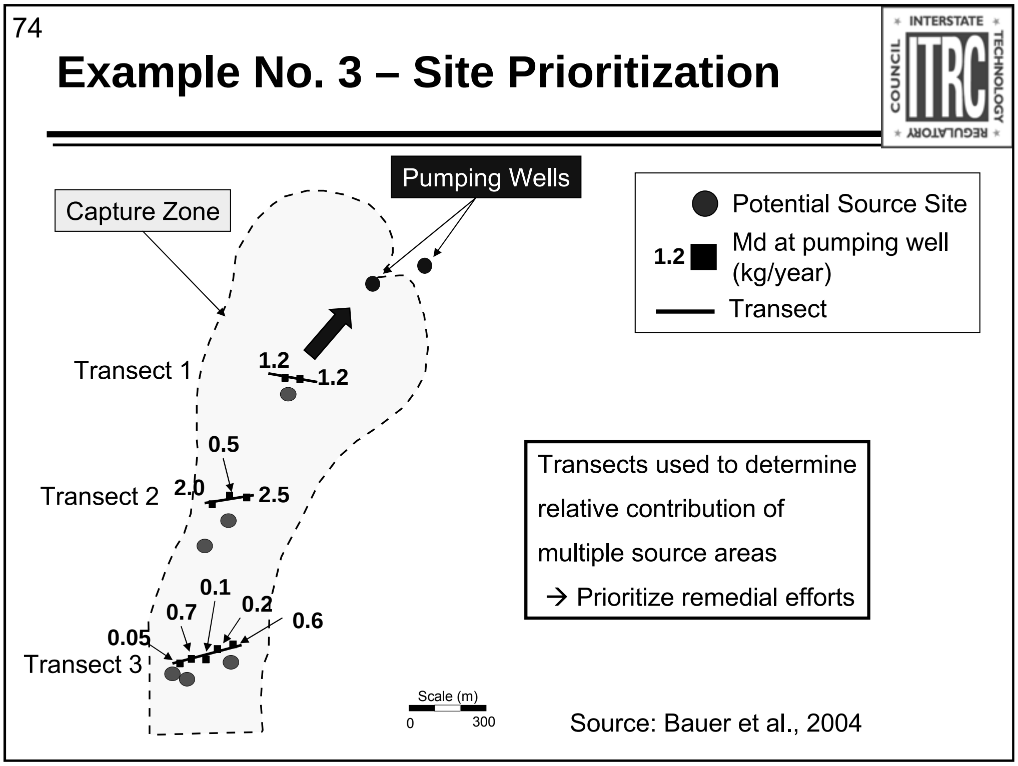
- **Well 12A Superfund Site, WA**
  - Performance metric → remedy Operational and Functional



Next we'll talk about the Well 12A Superfund Site in Washington where mass discharge was negotiated as an interim remedial goal.

As part of the Focused Feasibility Study, groundwater modeling determined that a reduction in source strength of 90%, which represents an order of magnitude decrease, would be sufficient for compliance to be achieved through MNA.

So here's an example of a site where mass flux and mass discharge are being used not only as a performance metric to evaluate treatment efficiency, but also as a decision guide for when to transition from active treatment to MNA.



Our third example is a regional basin with a commingled PCE plume that was created as a result of multiple source sites throughout the basin.

The red symbols indicate locations of potential sources contributing to the commingled PCE plume in the basin.

The yellow zone represents the capture zone for the regional supply wells shown here in blue.

The purpose of mass discharge monitoring was to evaluate which sites required further investigation and remediation, and which sites required no further action.

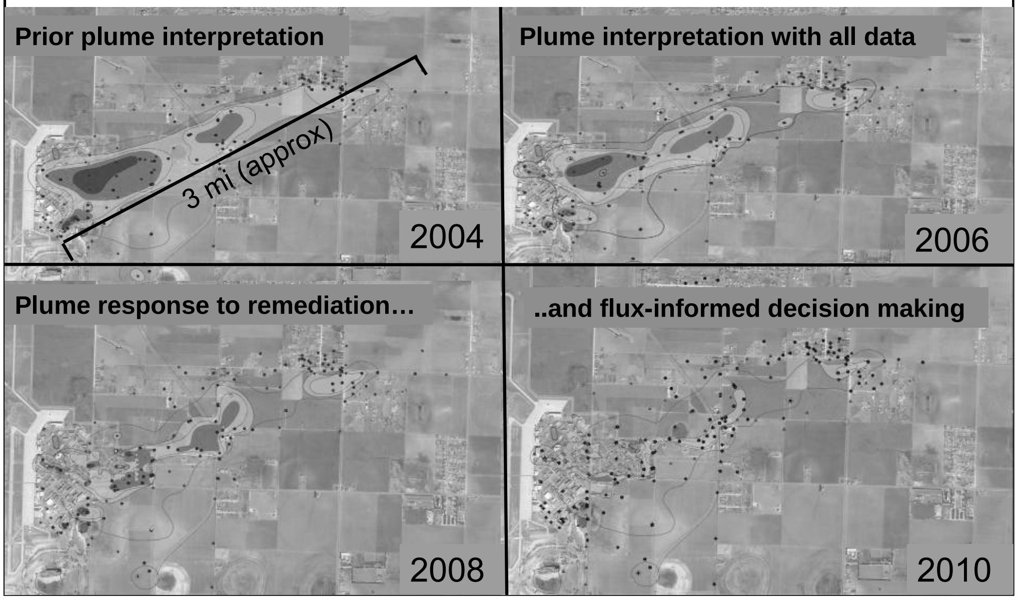
In the basin, multiple transects of pumping were installed downgradient of specific sites. The southern transect had a negligible mass discharge, so it was decided that these potential source sites in the south were not a priority for further investigation.

This example where sources at multiple sites are prioritized, is analogous to what we see at larger sites where multiple source zones exist. At these large sites, we can use a similar approach to prioritize which source zones need immediate treatment, and which can either be designated as a lower priority or requiring no further action.

75

Mass Flux to Target Remediation: Reese Air Force Base

Case study from F. Payne, ARCADIS



The fourth example, Reese AFB, is really interesting. This example was provided by Fred Payne at Arcadis.

Here’s a site that back in 2004 had a 3-mile long TCE plume. Response to remediation had stagnated.

When Arcadis became involved, they recognized that more characterization of the source zone was needed to define how the mass was distributed.

This enhanced characterization of mass flux in the source zone resulted in the decision to focus active bioremediation where mass was highest in the source zone.

The enhanced mass flux characterization was also used to optimize the use of groundwater extraction wells to accelerate mass removal from the source zone.

This is an example of what Fred appropriately calls “Flux-informed decision-making”, where the mass flux distribution was used to improve the efficiency of the remediation effort.

Through this effort the mass in the plume has been reduced by a factor of ten and is still decreasing today.

76

Course Roadmap

- Mass concepts
- Measurement methods
- Application
- Case studies
- Summary

No associated notes.

77

Mass Flux and Mass Discharge Summary

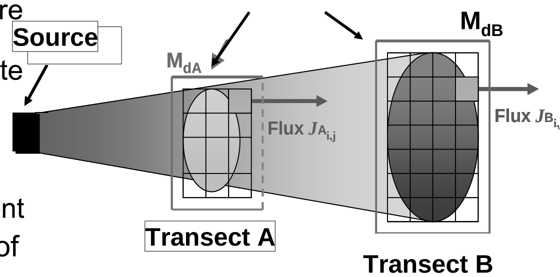
- Estimating mass may
  - Improve conceptual site models
  - Enhance remedial efficiency
  - Refinement of exposure assessment
- More effective site management
- Can use historical data and existing monitoring networks in some cases
- Can enhance compliance measurements

No associated notes.

Questions to Consider

- Why should I estimate mass flux/discharge at my site?
  - Characterization, exposure assessment, remedy selection, optimization, site prioritization, compliance
- How do I calculate mass flux/discharge?
  - Figure 2-2 of the document
- What are the cost/benefits of using mass flux/discharge?
  - Life cycle cost reduction, targeted remediation
- Can mass flux help measure compliance?
  - Mass reduction

Mass Discharge (M_d) = Sum of all Measures of Mass Flux x Area



$J_{A_{ij}}$= Individual mass flux measurement at Transect A

M_{dA}= Mass discharge at transect A (sum of all of the mass discharge estimates for each specific area [$J_{a_{ij}}$ x A])

No associated notes.

Additional ITRC Projects

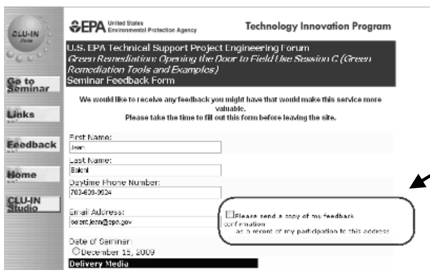
- Integrated DNAPL Site Strategy Technical and Regulatory Guidance (IDSS-1, 2011)
  - Further describe uses of mass flux and mass discharge estimates
  - Cleanup strategy
  - Goals and objectives
  - Treatment trains
  - Monitoring
- New ITRC Project started in 2012: DNAPL Site Characterization

No associated notes.

80

Thank You for Participating

- ▶ **Question and answer break**
- ▶ **Links to additional resources**
  - http://www.clu-in.org/conf/itrc/ummfmd/resource.cfm
- ▶ **Feedback form – *please* complete**
  - http://www.clu-in.org/conf/itrc/ummfmd/feedback.cfm



Need confirmation of your participation today?

Fill out the feedback form and check box for confirmation email.

Links to additional resources:
http://www.clu-in.org/conf/itrc/ummfmd/resource.cfm

Your feedback is important – please fill out the form at:
http://www.clu-in.org/conf/itrc/ummfmd/feedback.cfm

The benefits that ITRC offers to state regulators and technology developers, vendors, and consultants include:

✓Helping regulators build their knowledge base and raise their confidence about new environmental technologies

✓Helping regulators save time and money when evaluating environmental technologies

✓Guiding technology developers in the collection of performance data to satisfy the requirements of multiple states

✓Helping technology vendors avoid the time and expense of conducting duplicative and costly demonstrations

✓Providing a reliable network among members of the environmental community to focus on innovative environmental technologies

How you can get involved with ITRC:

✓Join an ITRC Team – with just 10% of your time you can have a positive impact on the regulatory process and acceptance of innovative technologies and approaches

✓Sponsor ITRC's technical team and other activities

✓Use ITRC products and attend training courses

✓Submit proposals for new technical teams and projects