Sections 5 & 6

Site Characterization and Lines of Evidence

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Overview – Section 5

- **Site Characterization**
  - Conceptual site model
  - Aquifer characteristics
    - Hydraulic conductivity/gradient
    - Porosity
    - Organic carbon content
  - Contaminant spatial & temporal distribution
    - Plume geometry
    - Seasonal trends
    - Perturbations

Overview – Section 6

MNA Lines of Evidence

- **Primary**: Plume characteristics
  - Plume behavior (shrinking/stable/expanding)
  - Contaminant trends
    - Spatial/graphical analysis
    - Statistical tests
    - Mass flux/discharge
- **Secondary**: Geochemical characteristics
  - Organic
  - Inorganic

Overview – Section 6

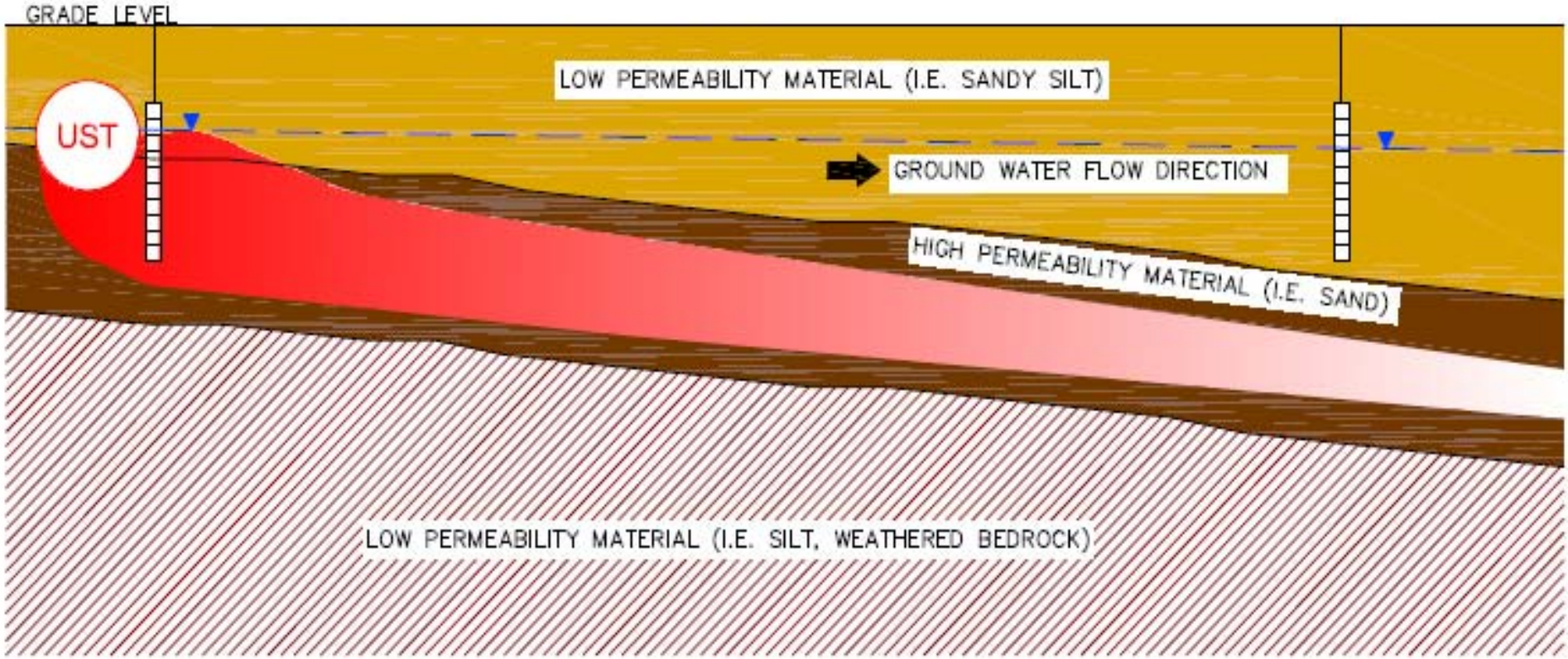
- MNA Lines of Evidence
  - **Tertiary**: Microbiological & isotopic studies
    - MBTs
    - CSIA
- Protective ground water remedies with non-decreasing levels of ground water contamination
  - Attachment 2 of RAO guidance

Site Characterization - CSM

- Conceptual Site Model (CSM)
  - Technical guidance document available
  - Not a required submittal
  - Written or illustrative representation of the physical, chemical and biological processes that control the transport, migration and potential impacts to receptors.

Site Characterization – CSM

Example of Incomplete Characterization



NOTE: BOTH WELLS OPEN FROM 5 TO 15' BELOW GRADE SURFACE

Site Characterization - Aquifer Characteristics

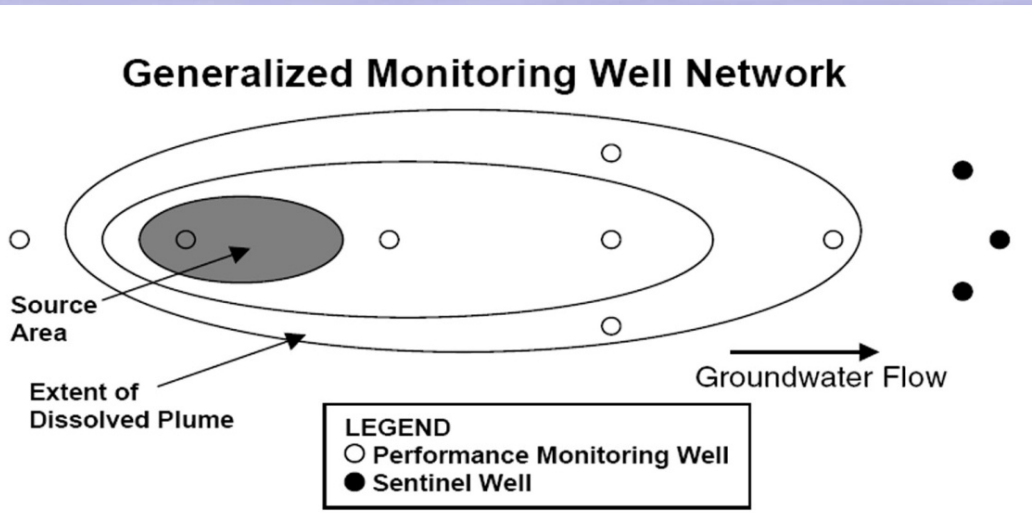
- Basic data needed for evaluation of contaminant transport
  - Seepage velocity
  - Fate and transport modeling
- Aquifer characterization (Appendix D)
  - Hydraulic conductivity (field: slug tests)
  - Hydraulic gradient (field: WL measurements)
  - Porosity (literature or field measurements)
  - Organic carbon content (f_{oc} literature or field)

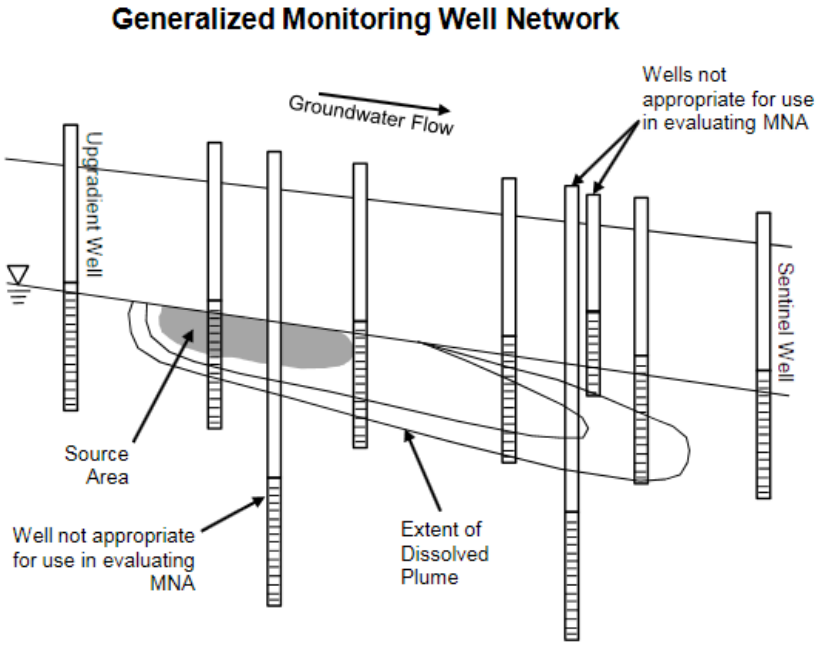
Site Characterization – Spatial & Temporal Distribution

Characterize Contaminant Plume

- **High Resolution Screening Techniques**
  - Membrane Interface Probe (MIP)
  - Ultraviolet Optical Screening Tool (UVOST)
- **Monitoring Well Array**
  - Lateral
    - Upgradient, source area, longitudinal along plume, transverse across plume
  - Vertical
    - Stratigraphy, “diving plume”, “back diffusion”

Site Characterization – Spatial & Temporal Distribution





Source: Missouri DNR 2007, and others

Site Characterization – Spatial & Temporal Distribution

- Characterize seasonal variability
  - Eight rounds of monitoring well sampling
    - Includes 4 quarterly rounds
  - Performed **after** active remediation complete
- Identify “Perturbations”
  - Pumping
  - Surface waters
  - Tidal influences

Site Characterization – Spatial & Temporal Distribution

- Design long term monitoring array
  - Subset of characterization array
  - Complex site
    - Upgradient, source area, plume longitudinal, plume transverse, plume fringe, sentinel
  - Simple/Area constrained site
    - Source area, plume fringe, sentinel
    - Source area, plume fringe/sentinel

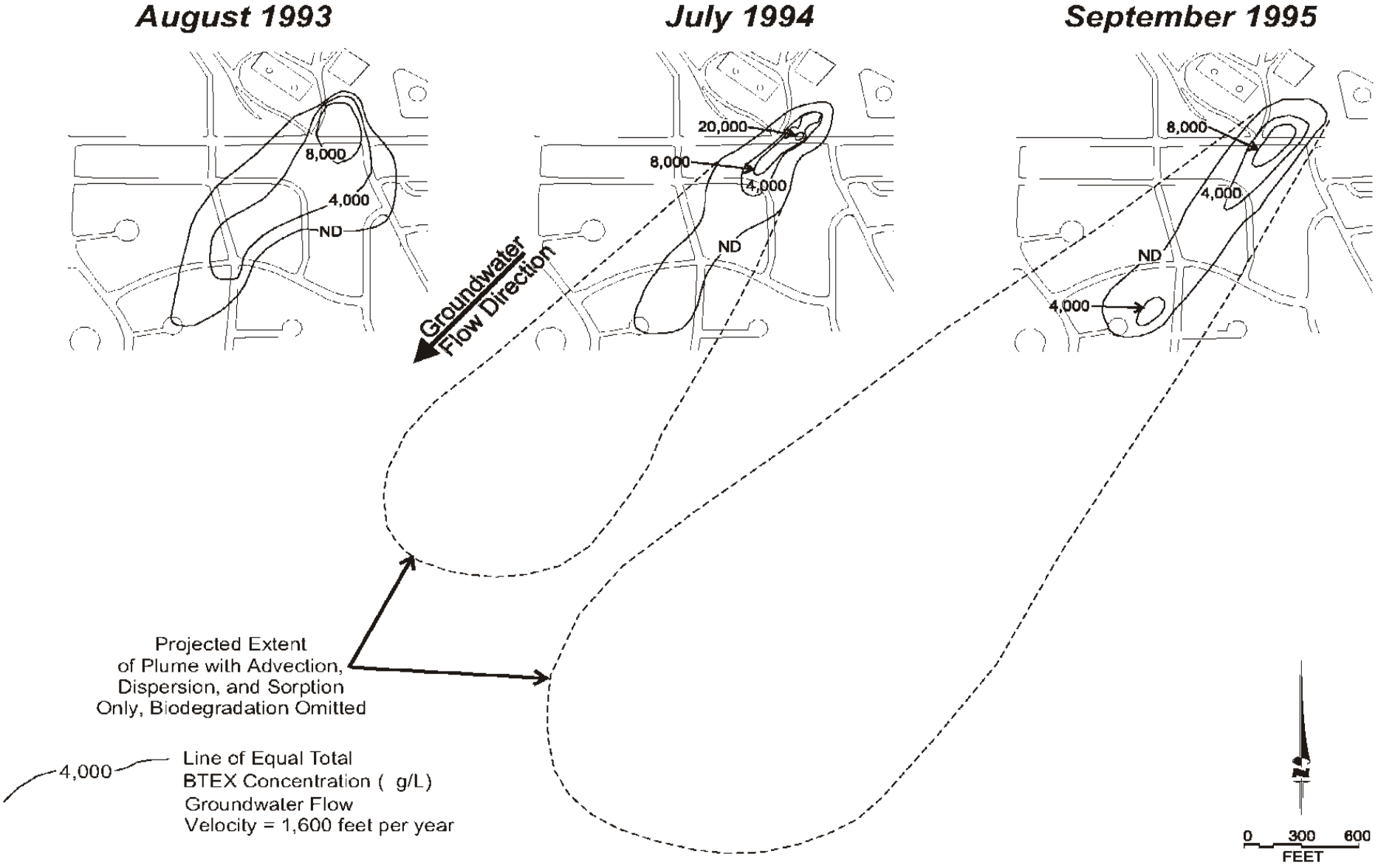
Lines of Evidence - Primary

MNA effectiveness is determined primarily by decreasing contaminant concentrations over time in conjunction with a stable or receding ground water plume.

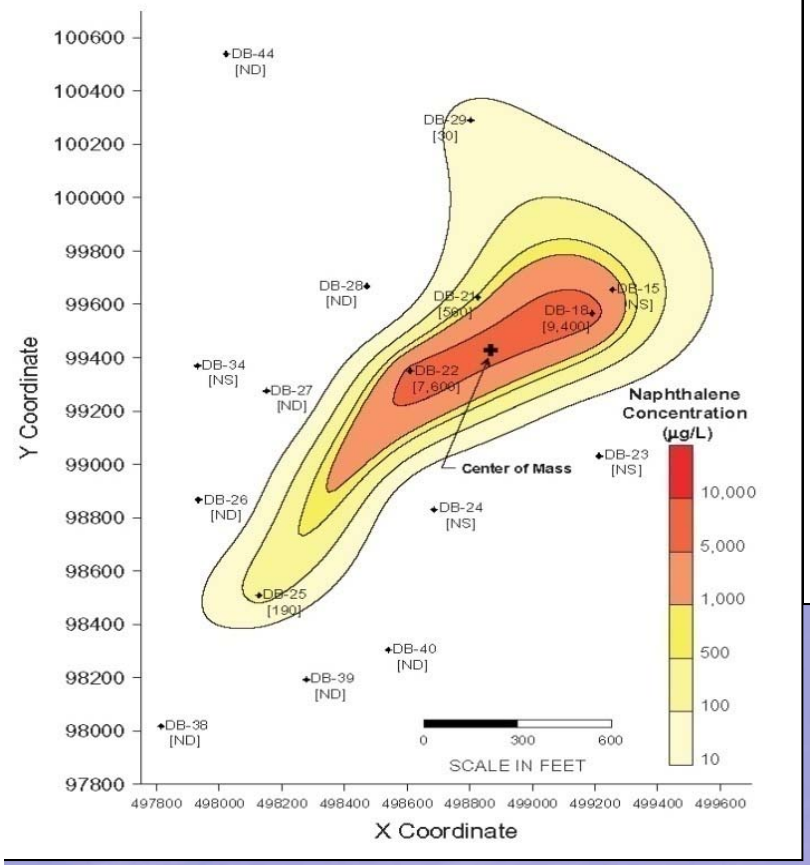
Lines of Evidence - Primary

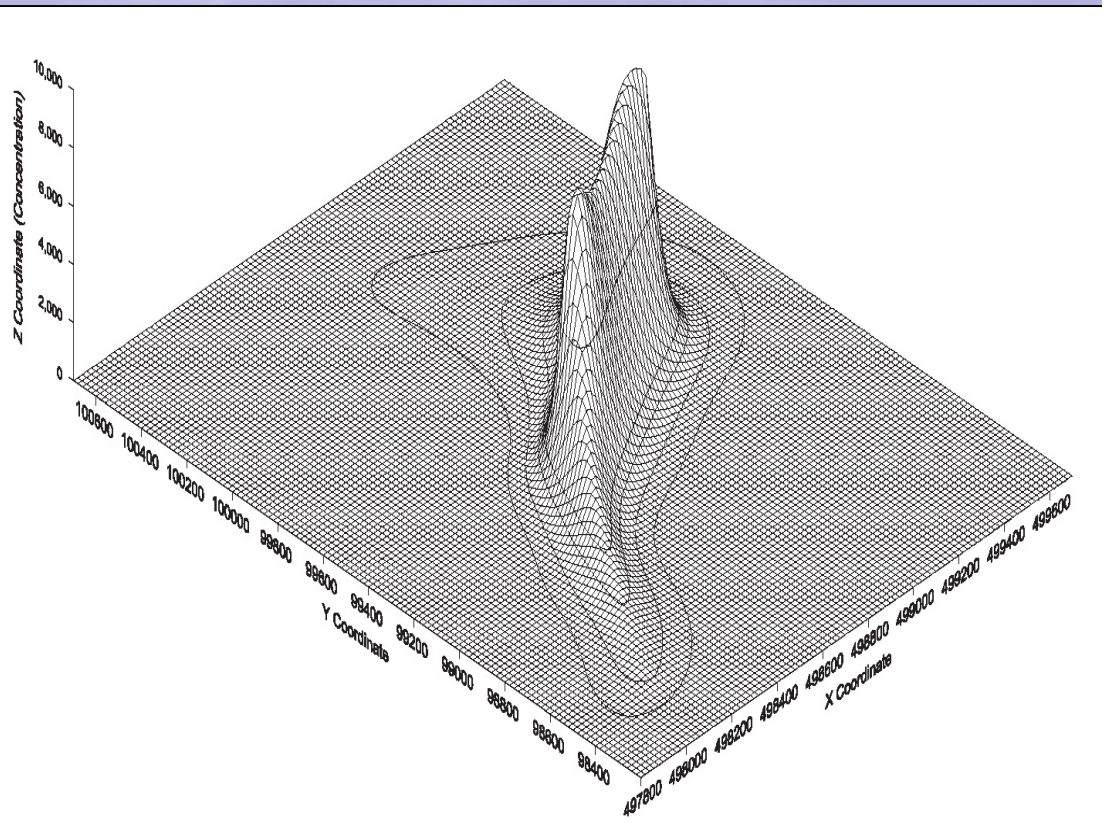
- Plume behavior
  - Shrinking or stable, vs. expanding
- Contaminant trends
  - Spatial analysis
    - Comparison of projected vs. actual plume migration
      - Analytical: AT123D, BIOChlor, REMChlor
      - Numerical: MODFLOW/MT3DS
    - Calculation of contaminant plume mass
      - Contour map “volumes” (Ricker, 2008)
      - **Appendix C**

Lines of Evidence - Primary



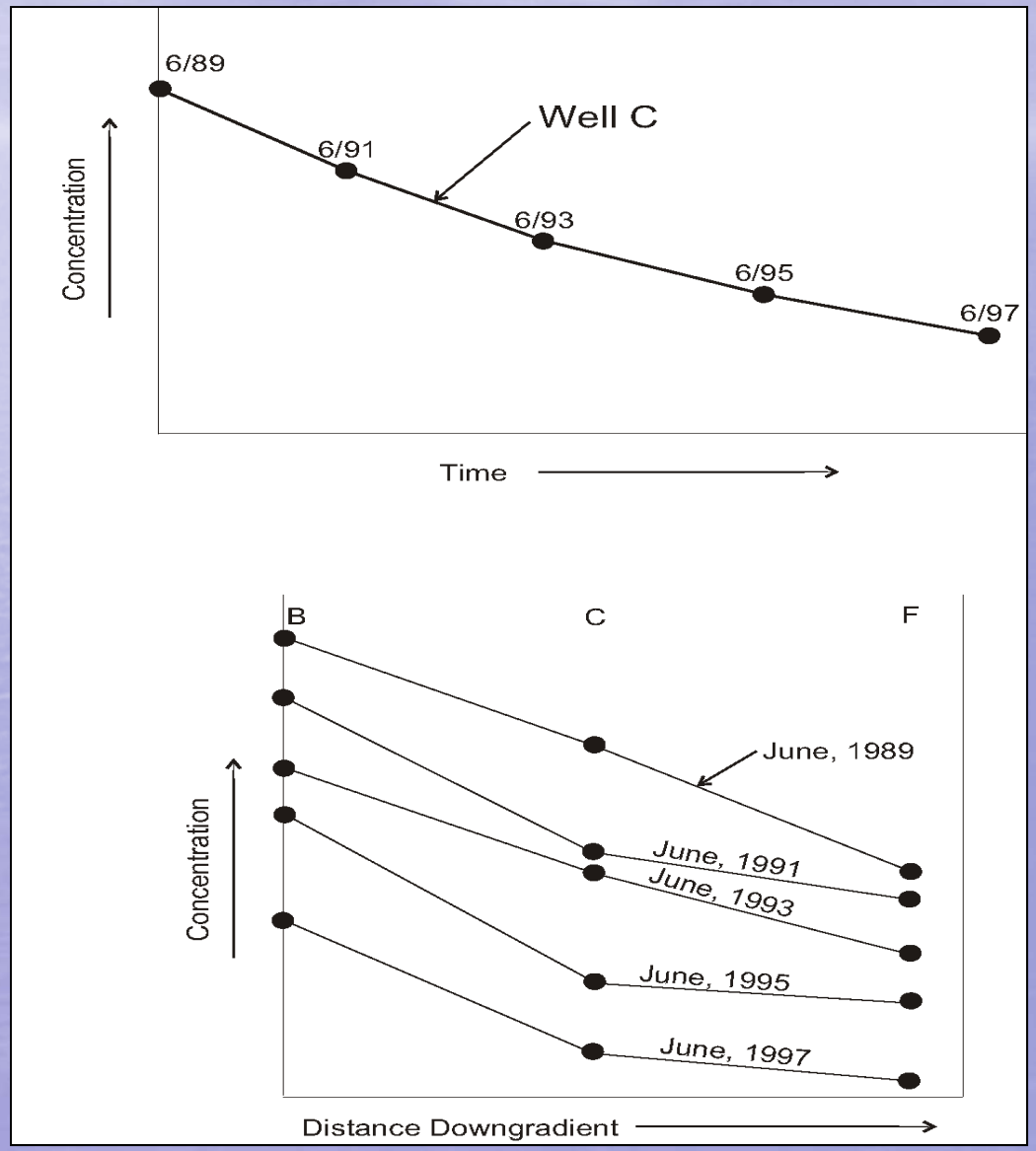
Lines of Evidence - Primary





Ricker, 2008

Lines of Evidence - Primary



Graphical Analysis

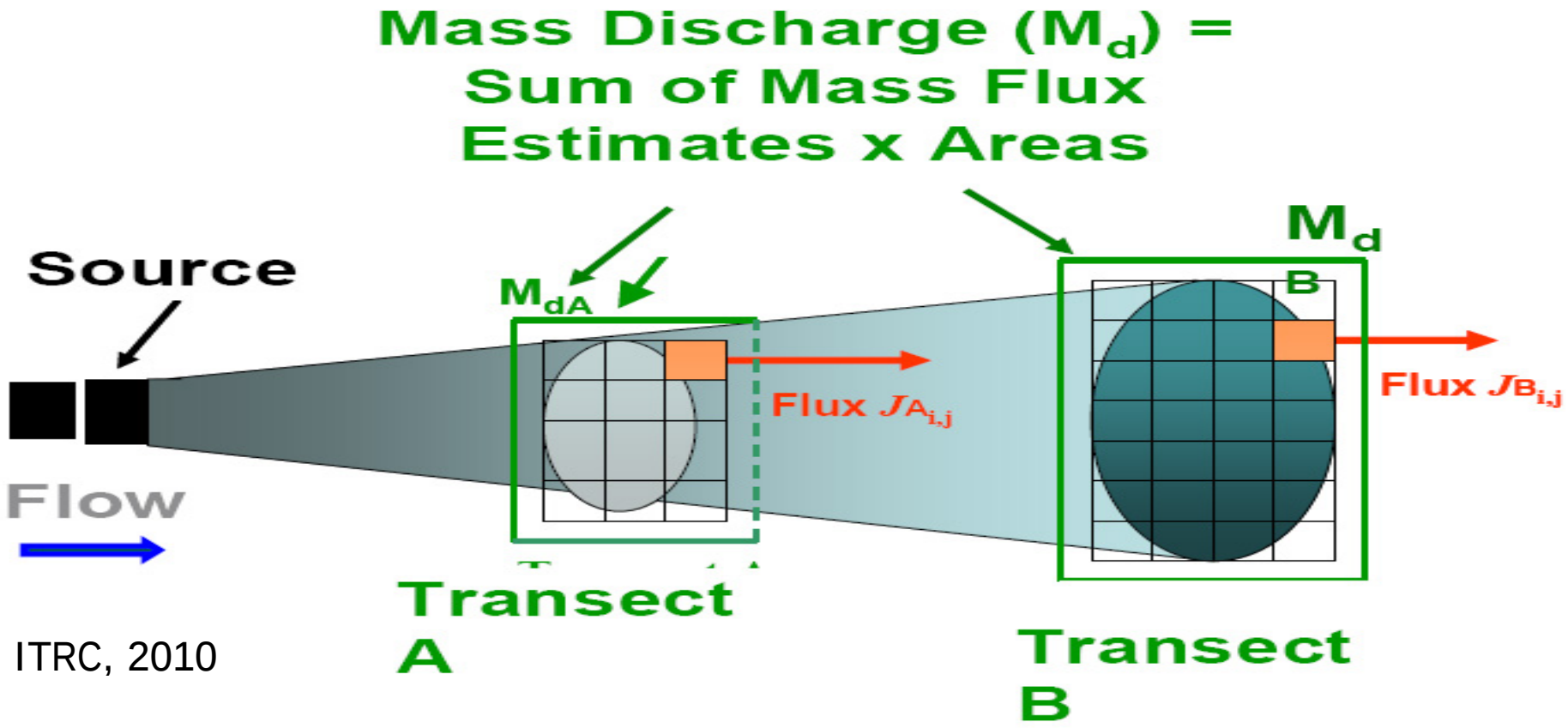
Lines of Evidence - Primary

- Statistical Tests
  - Regression analysis (linear, exponential, etc.)
  - Non-parametric tests:
    - Mann-Kendall (Seasonal Kendall Test)
    - Mann-Whitney (Tech Regs)
    - Sen Test
  - Additional examples, references and guidance in **Appendix E**

Lines of Evidence - Primary

Mass Flux and Mass Discharge

– **Appendix C**



ITRC, 2010

Lines of Evidence - Secondary

- Geochemistry
  - Organic compounds
    - Biodegradation: Microorganisms obtain energy by transferring electrons from electron donors to electron acceptors.
      - Electron donor compounds
      - Electron acceptor compounds
      - Metabolic by-products
  - Inorganic compounds
    - Adsorption, precipitation, decay

Secondary Lines of Evidence - Geochemistry

Organic Compound Biodegradation

- **Electron Donors**: Electron donor compounds are relatively reduced and include fuel hydrocarbons and native organic carbon (TOC)
- **Electron Acceptors**: Electron acceptor compounds are relatively oxidized and include DO, nitrate, ferric iron (III), manganese (IV), sulfate, and in some cases chlorinated aliphatic hydrocarbons (PCE, TCE)
- **Metabolic By-Products / Indicators**: VFAs, CAH degradation products, methane, chloride, CO_2

Lines of Evidence - Secondary

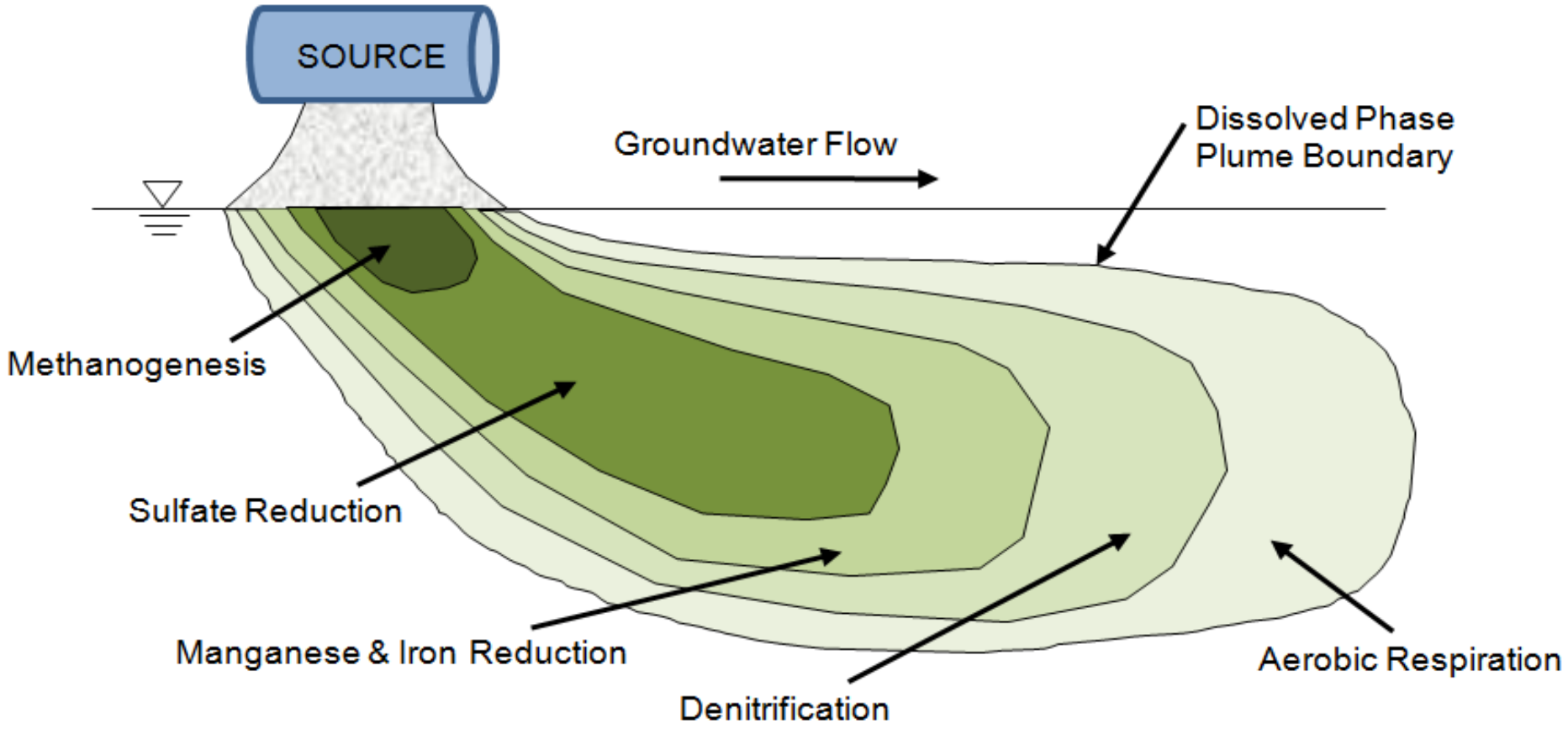
Geochemistry

Organic Compound Biodegradation

- **Fuel hydrocarbons** (= electron donor)
  - Electron acceptor limited (usually adequate supply)
    - Aerobic: DO -> Anaerobic: Nitrate -> Iron (III) -> Sulfate -> Methanogenesis (CO_2-EA -> Methane)
- **Chlorinated aliphatic hydrocarbons** (PCE, TCE, DCE)
  - Reductive dechlorination (**Appendix A**):
    - Electron donor (TOC) limited: CAH used as electron acceptor, and Cl atoms removed and replaced by H
    - Primarily anaerobic process (best under sulfate reducing and methanogenic conditions)

Lines of Evidence - Secondary

Conceptualization of TEA Zones in Groundwater Contamination Plume



Lines of Evidence - Secondary

Geochemistry

- Inorganic Compounds
  - **Appendix A**
    - Adsorption
      - ❖Reactive minerals, organic matter, ion exchange, pH
    - Precipitation
      - ❖Nucleation, crystal growth, co-precipitation (redox, pH)
  - Radioactive decay

Lines of Evidence - Tertiary

Microbiological Tools (MBTs)

Techniques that target biomarkers (nucleic acids, proteins, etc.) to provide information about organisms and processes relevant to the assessment & remediation of contaminants

- Identify & quantify ribosomal DNA of *Dehalococcoides* (genus of solvent degrading organisms)
- TCE and vinyl chloride reductase genes
- Microbiological community structure and diversity

Lines of Evidence - Tertiary

- Compound Specific Isotope Analysis (CSIA)
  - Powerful tool to assess/validate biodegradation
    - Organic Carbon (C^{13}/C^{12}) and Chlorine (Cl^{37}/Cl^{35})
    - Oxygen (O^{18}/O^{16}) and Hydrogen (H^{2}/H)
  - Hydrocarbons contain molecules with both heavier and lighter isotopes
  - During biodegradation, molecules with lighter isotopes are consumed preferentially by microorganisms

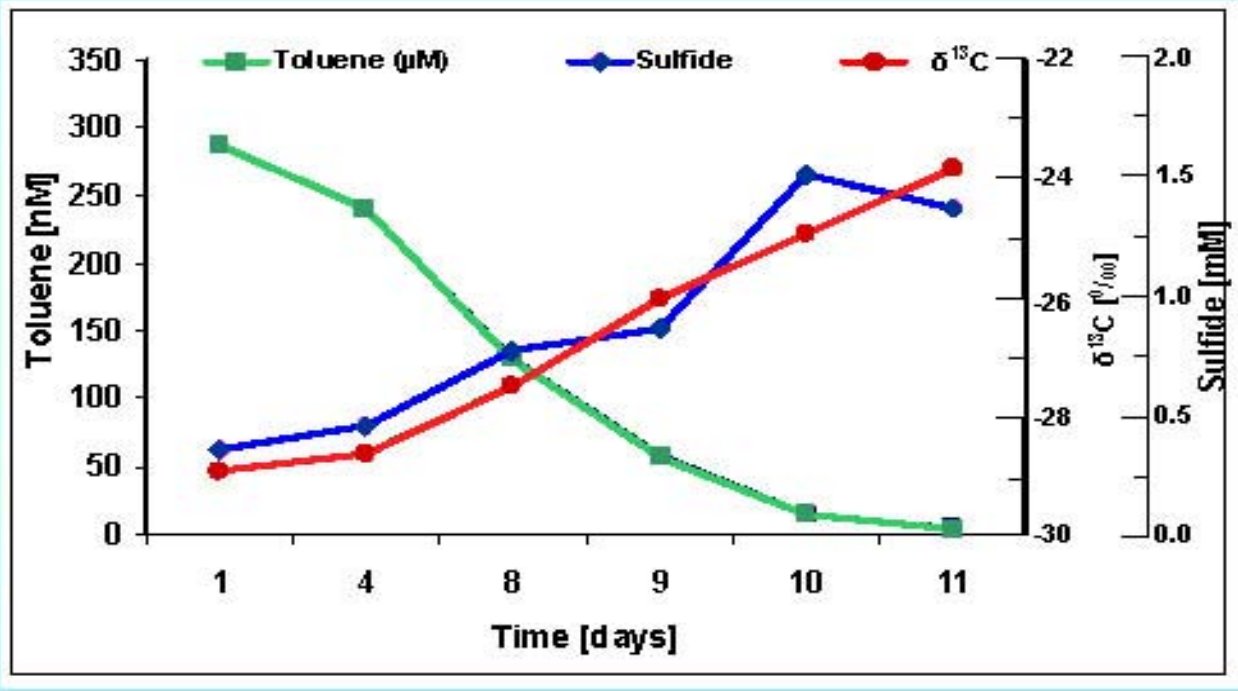
Lines of Evidence - Tertiary

- Compound Specific Isotope Analysis (CSIA)
  - Biodegradation results in “enrichment” of residual hydrocarbon with heavier isotopes (fractionation)
  - No fractionation occurs through processes of dilution, volatilization and sorption
  - Recent advances in analytical methods have significantly reduced cost & TAT
  - **Appendix B**

Lines of Evidence - Tertiary

Anaerobic Degradation of Toluene under Sulfate Reducing Conditions with Strain TRM1,

Meckenstock, et al., 1999.



Source: Microseeps, Inc.

Protective Ground Water Remedies with Non-Decreasing Levels of Ground Water Contamination

"Guidance for the Issuance of Response Action Outcomes" (RAO) Attachment 2

6 Criteria:

- Concentration cap
- No receptors are impacted or threatened
- All sources of ground water contamination have been identified and remediated
- Site is a candidate for a natural remediation program pursuant to N.J.A.C. 7:26E-6.3(e)
- Analytical data set is representative of ground water elevation fluctuations (seasonal, tidal, etc.)
- Minimum 8 rounds data collected

Questions?