Visual Bio Overview

by Grant R. Carey, Ph.D.
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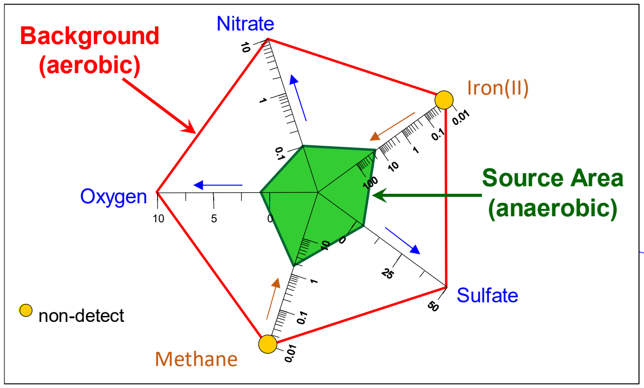
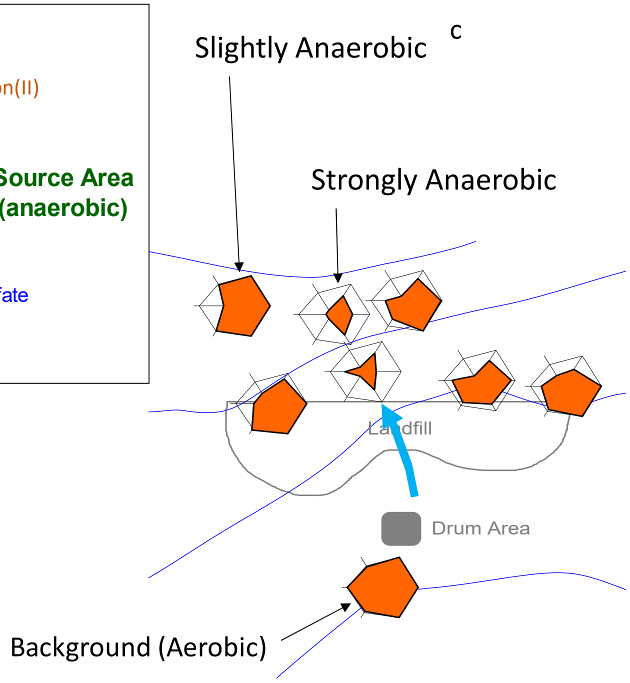
April 30, 2017





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Visual Bio Overview Outline

1. Attenuation concepts
2. Visual Bio for radial diagram maps

   2.1 Redox Radial Diagrams

   2.2 VOC Radial Diagrams

3. Case Studies
4. Summary

Attenuation Concepts

Section 1

Natural Attenuation Mechanisms

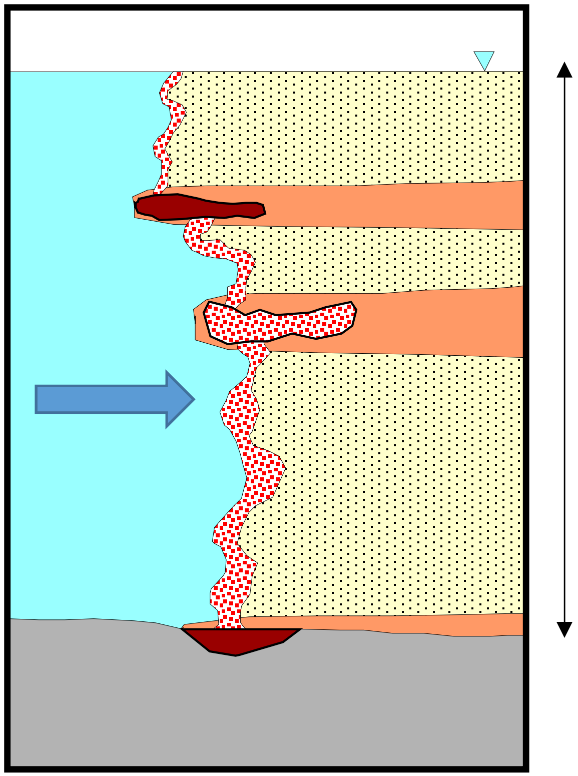
- There are two main processes by which natural attenuation may be protective at a site:

  1. Source depletion – concentrations decline with time;
  2. Plume attenuation – concentrations decline along the flow path downgradient from the source zone.

- Plume attenuation is most significant when biodegradation is occurring along the flow path. Other processes which influence plume attenuation include dispersion, abiotic degradation, and sorption when the plume is still advancing.

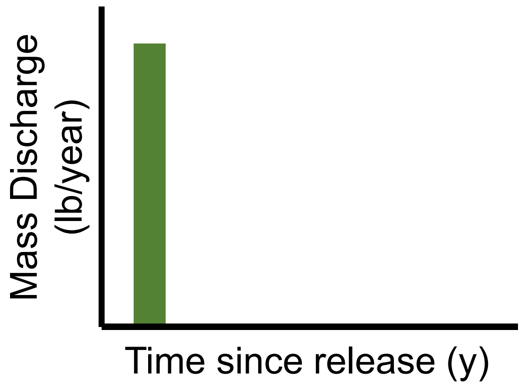
Mass Discharge (Source Strength) Trends

Fresh Source



Modified from Parker et al., 2003

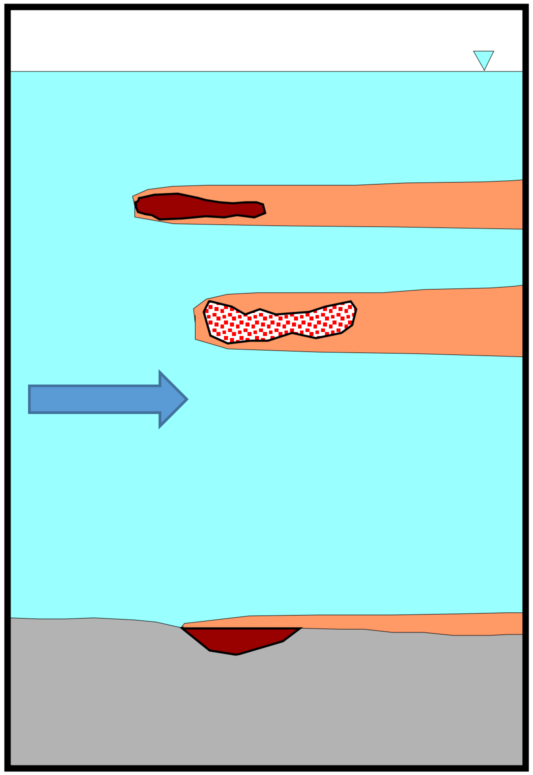
Mass discharge from source zone (kg/y)

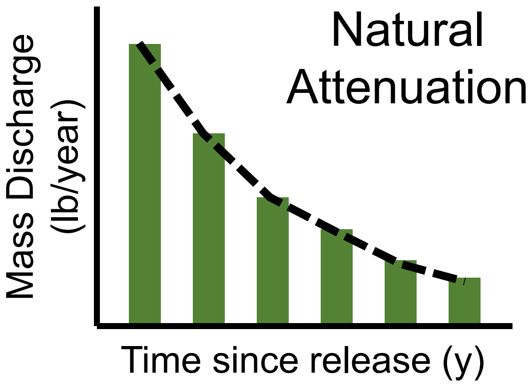


Mass Discharge (Source Strength) Trends

Aged Source

Typical source zone mass discharge = 1 to 100 kg/year





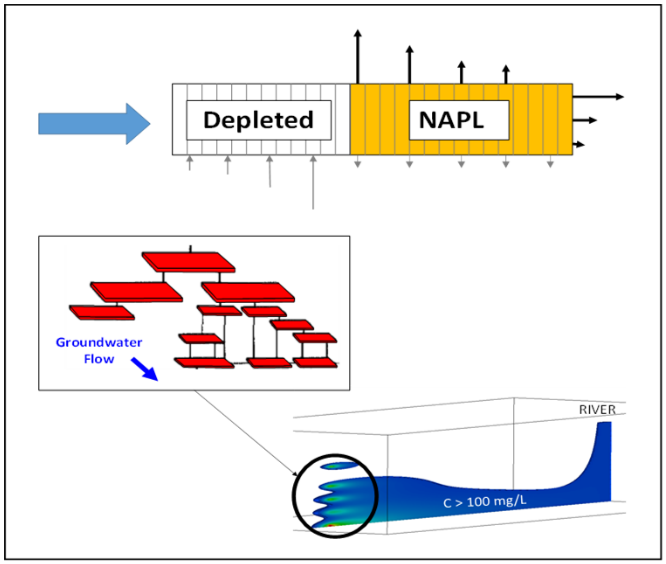
<u>Newell et al., 2006:</u>
Median TCE DNAPL half-life of 6 years

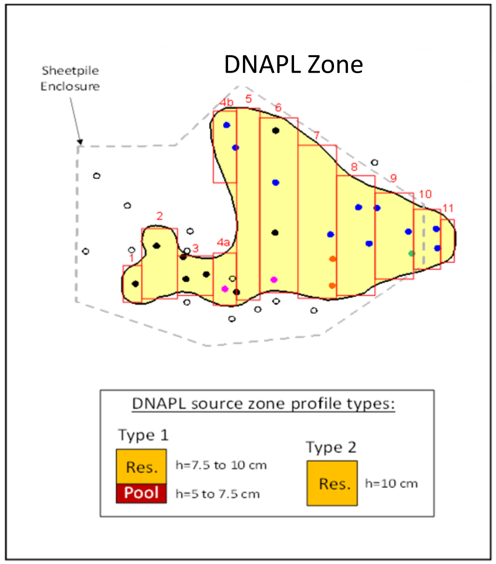
Mass discharge reduction 30x in 30 years

NAPL Depletion Model (NDM)

Estimating Timeframes for Natural and Enhanced NAPL Depletion

Free software and 4-hour short course download: www.porewater.com





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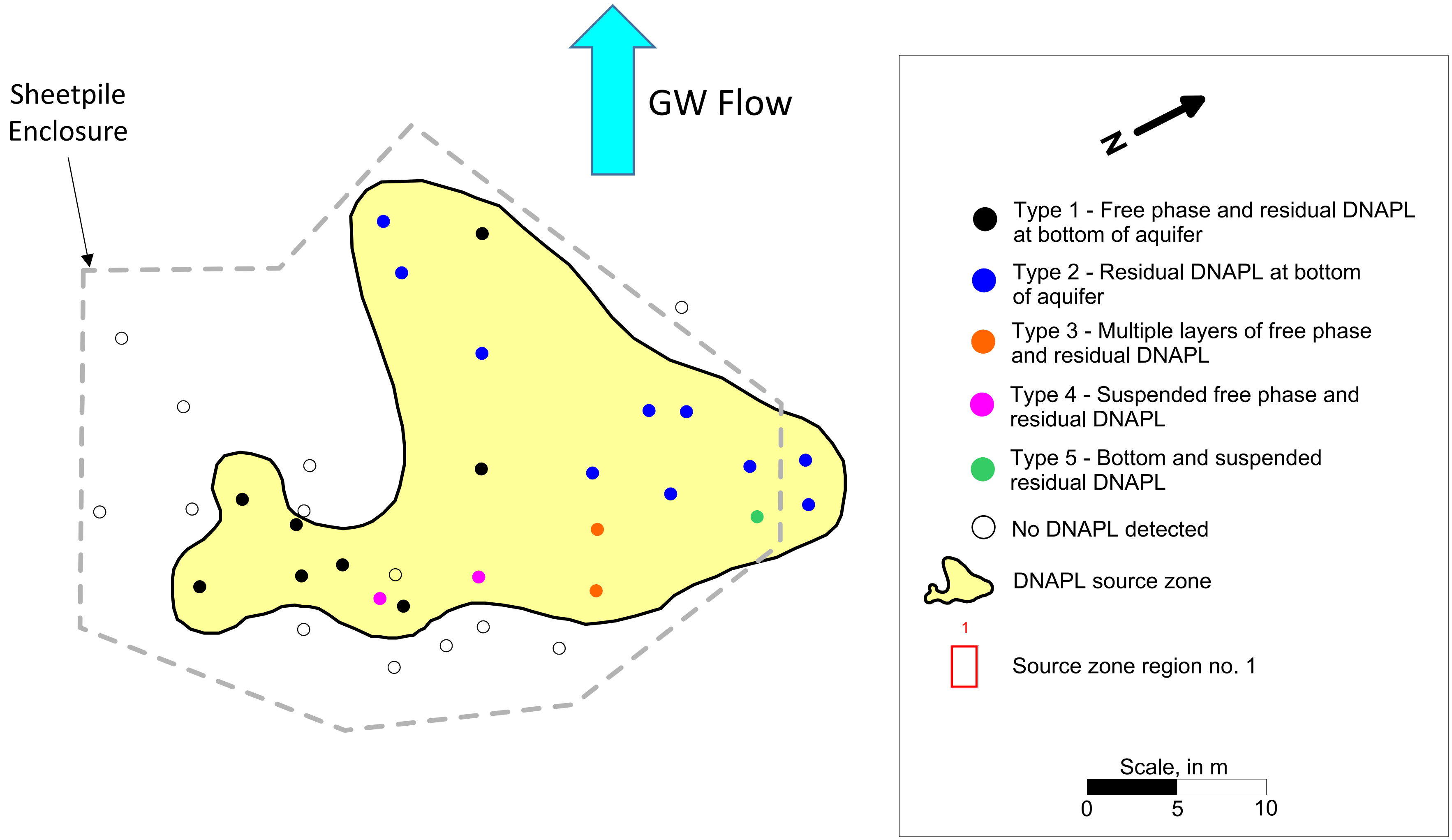
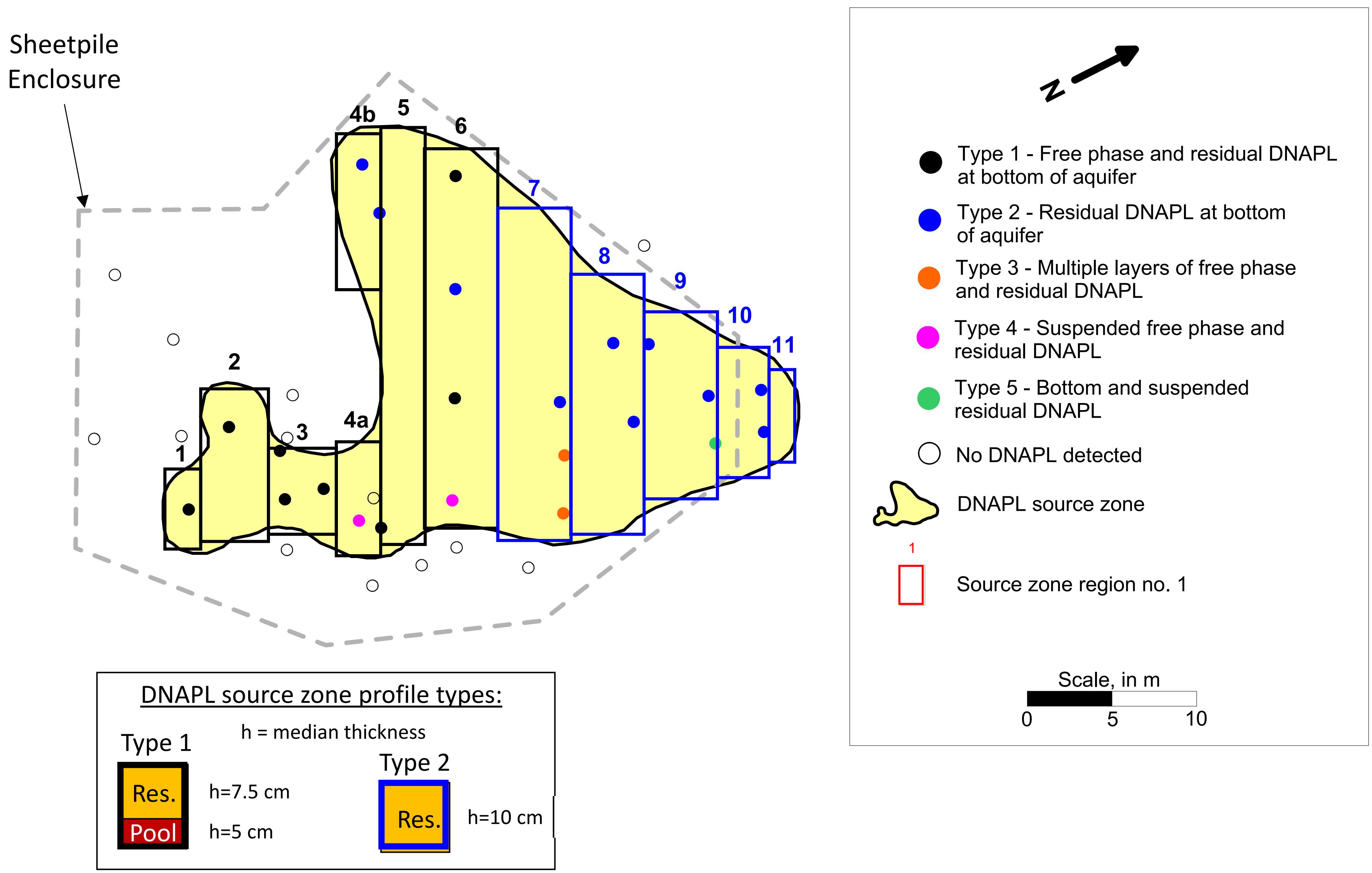
Case Study: Beth Parker et al. (2003) CT Site

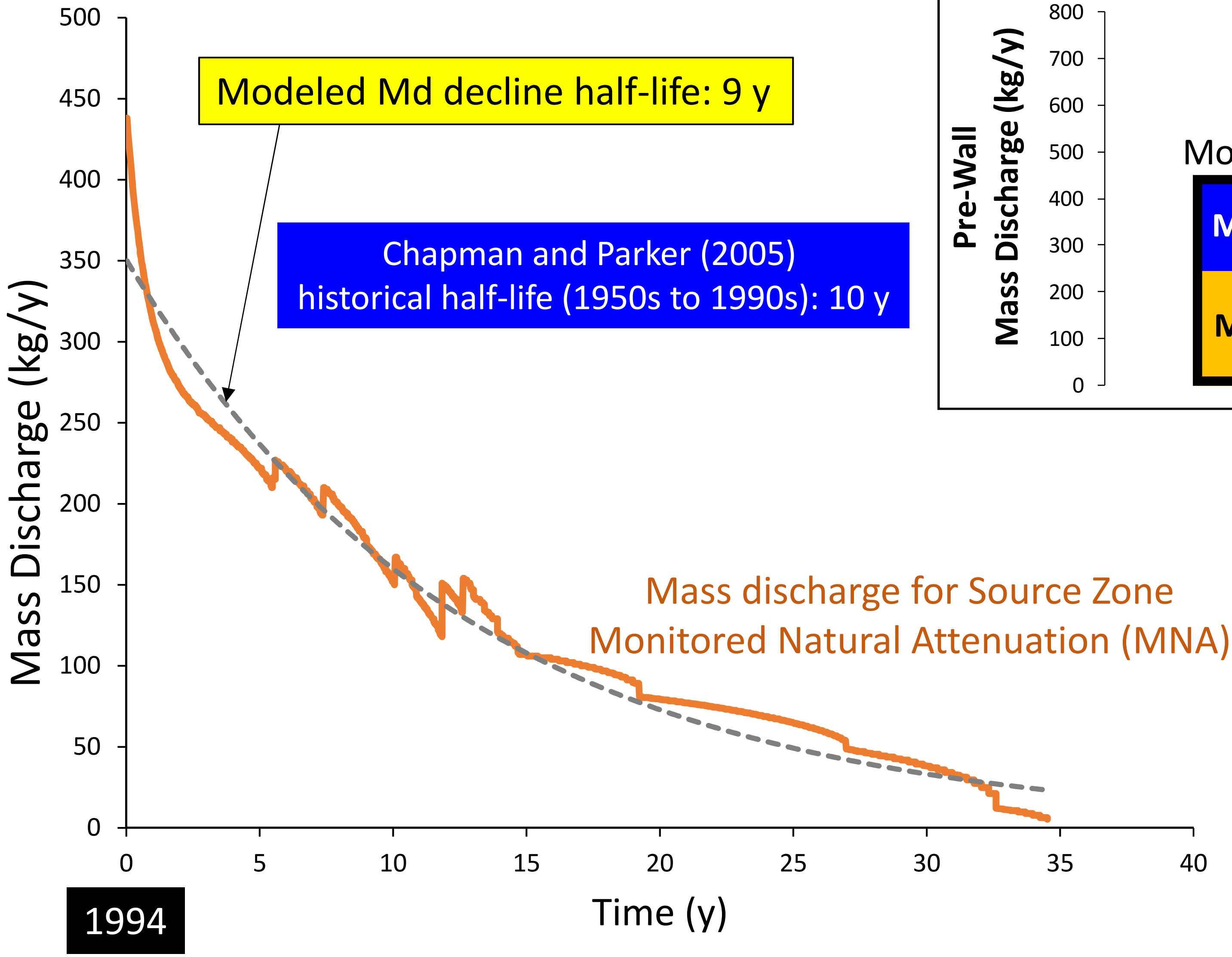


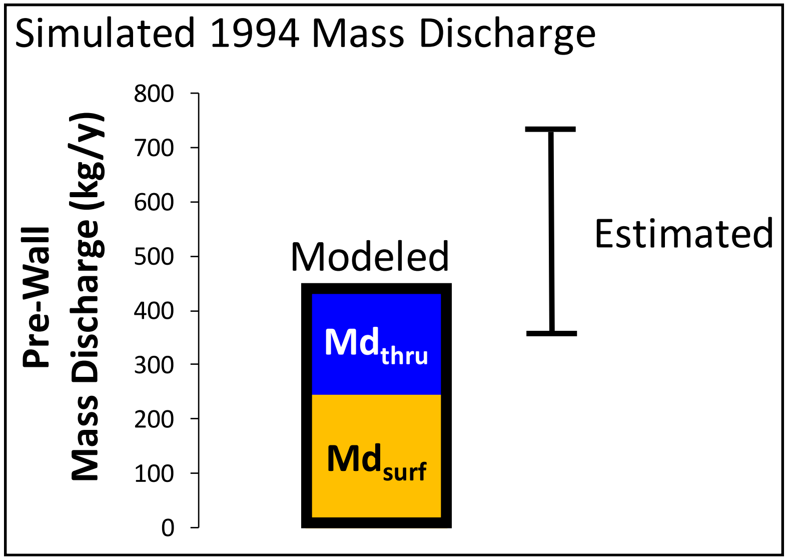
Data summarized in Stewart (2002) and Parker et al. (2003)

DNAPL Sub-Zones



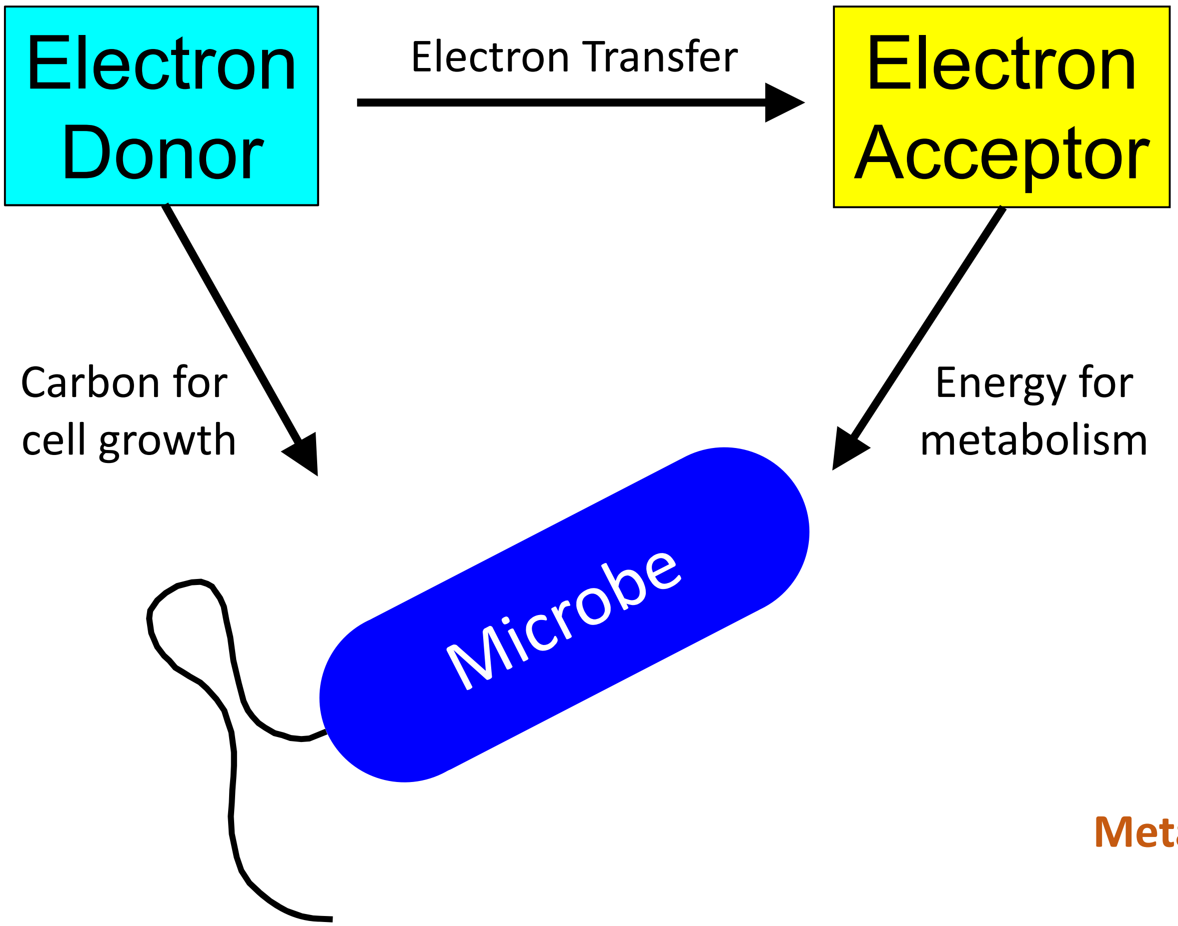
Source Depletion: Modeled vs. Estimated Half-Life





Md = Mass discharge

Biogeochemical Processes



Inorganic Electron Acceptors:

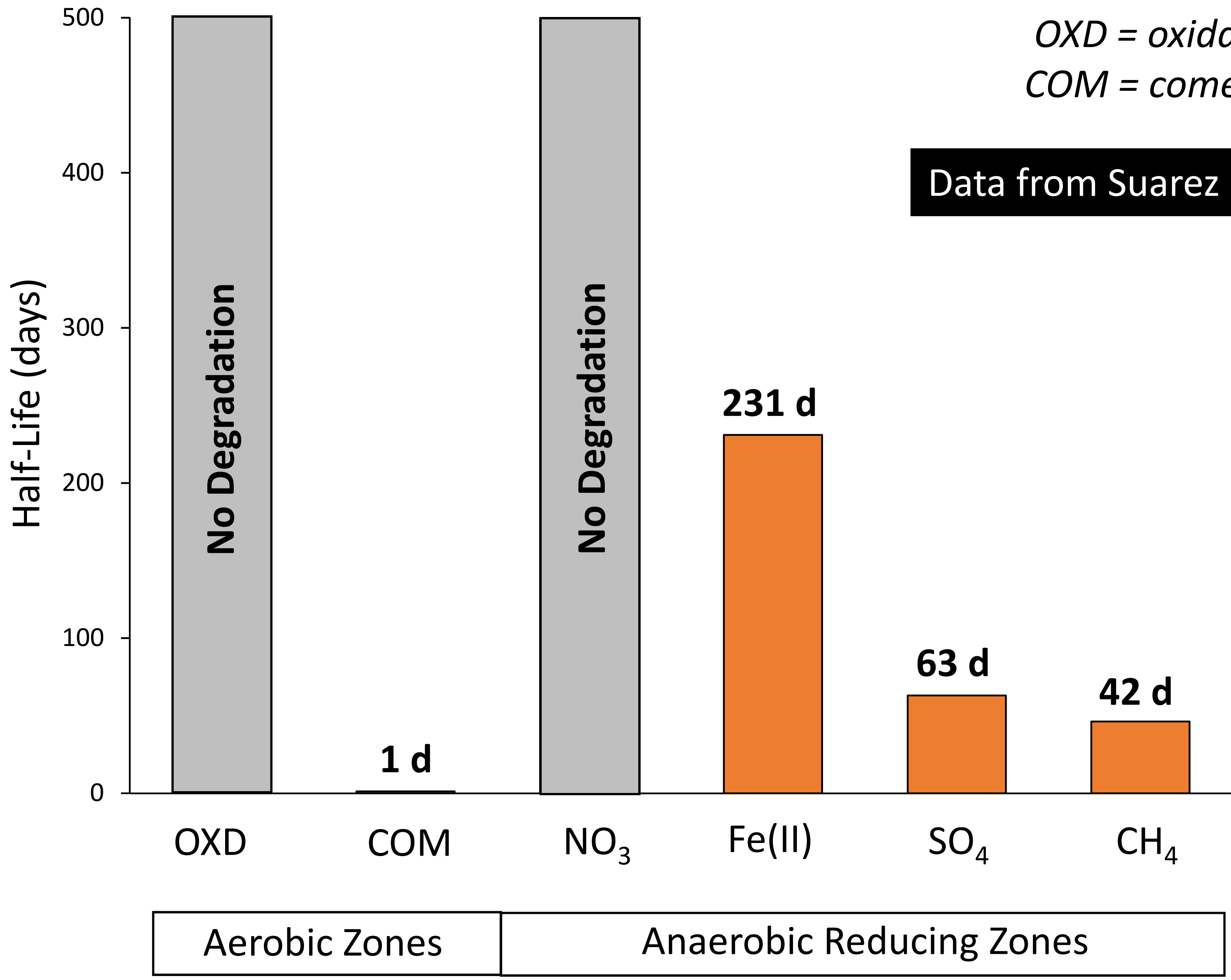
- O_2
- NO_3
- $Mn_{(s)} \rightarrow Mn^{2+}$
- $Fe_{(s)} \rightarrow Fe^{2+}$
- SO_4
- $CO_2 \rightarrow CH_4$

Metabolic Byproducts

Plume Biogeochemical Processes

- Typical concentration trends during biodegradation
  - Electron acceptors (oxygen, nitrate, sulfate) decline
    - At some sites, sulfate may increase due to dissolution of sulfate-bearing minerals during geochemical changes associated with biodegradation. Sulfate reduction is typically still occurring, even with an increase in sulfate concentrations.
  - Metabolic byproducts (manganese, iron, methane) increase
  - Naturally-occurring arsenic may be temporarily co-dissolved into groundwater with iron. (This arsenic is typically sorbed into iron coatings on sand grains in aerobic aquifers.) Arsenic will later co-precipitate with iron when mixed with oxygen.

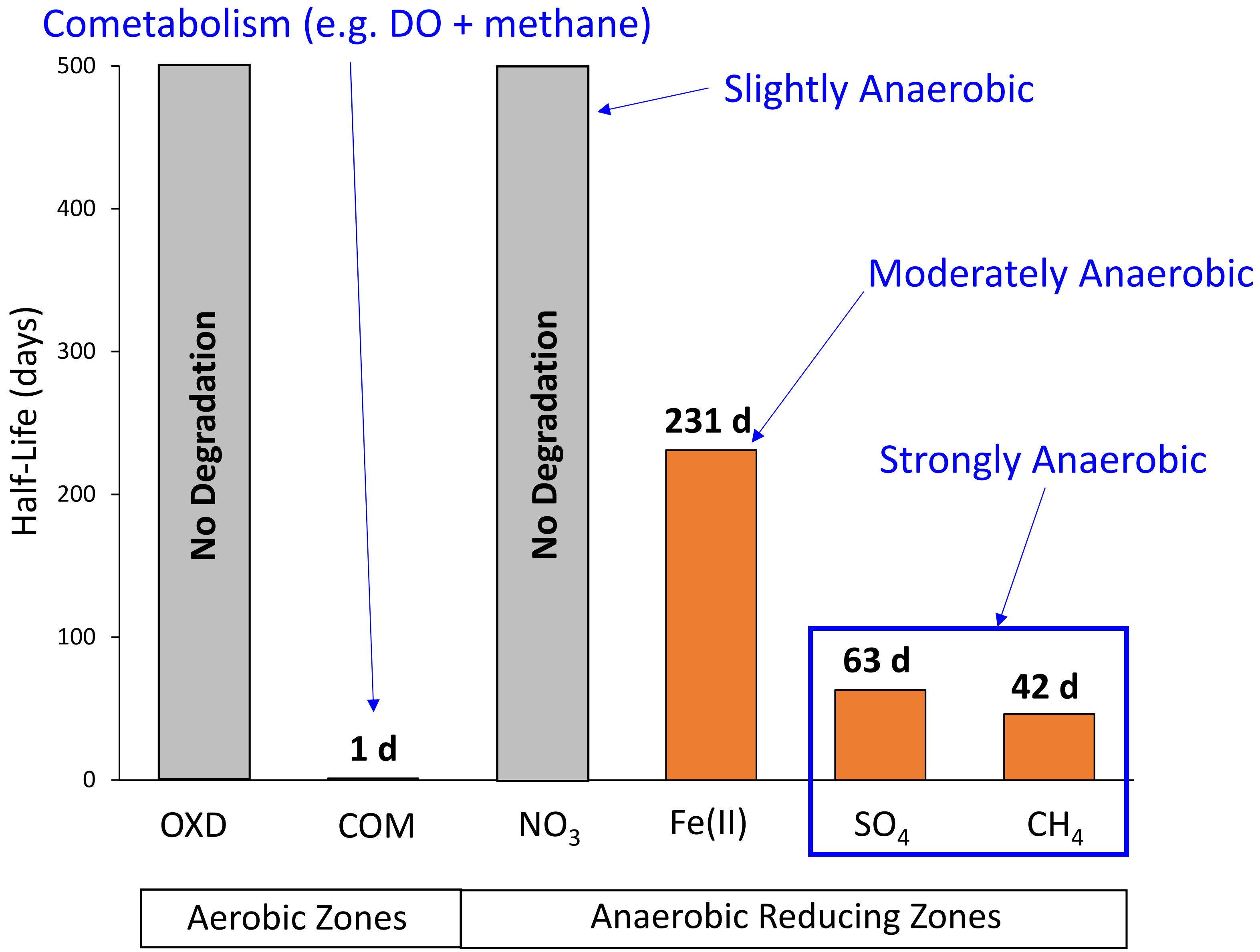
TCE Mean Degradation Half-Life by Redox Zone



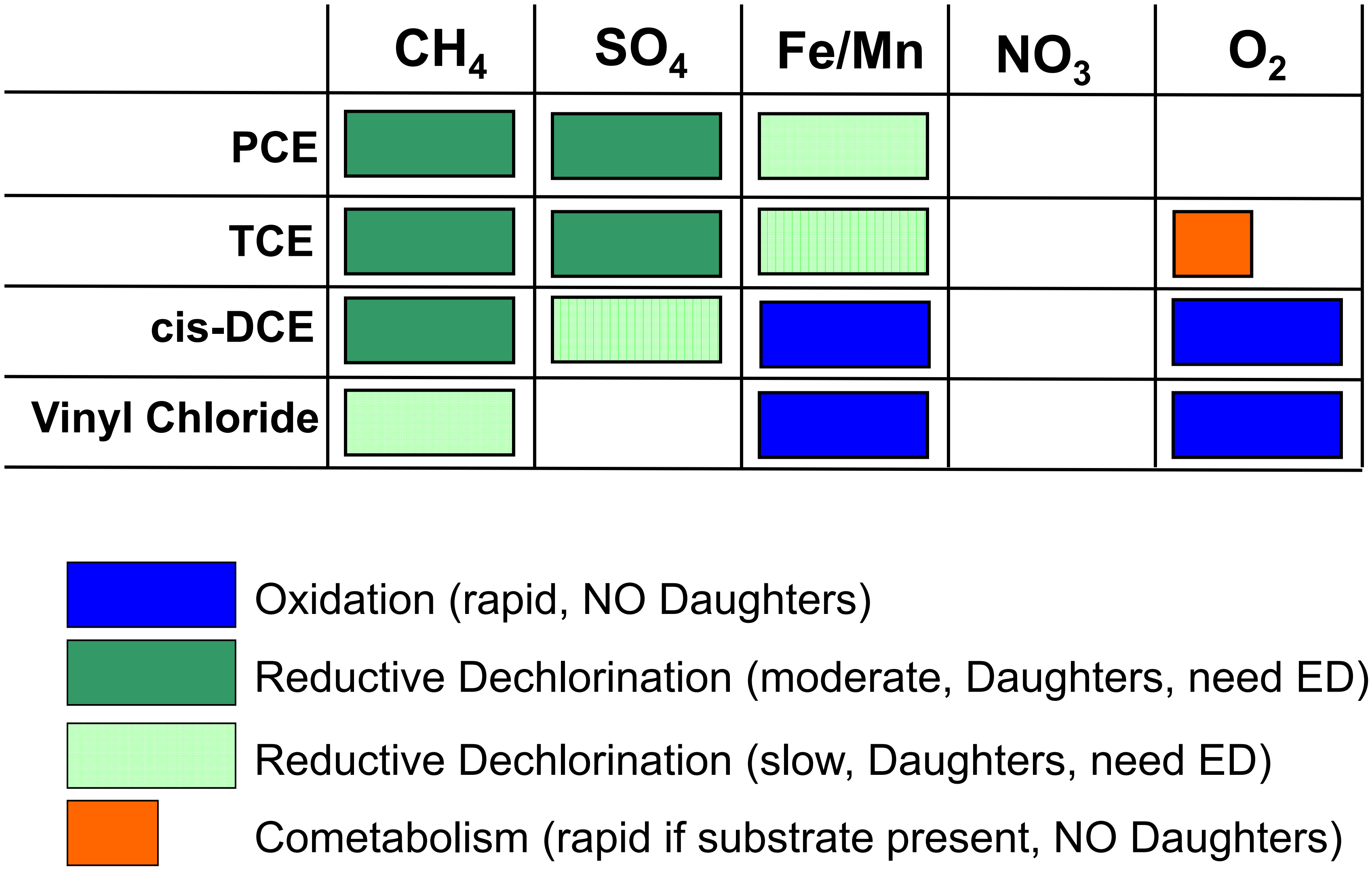
OXD = oxidation
COM = cometabolism

Data from Suarez and Rifai, 1999

TCE Degradation Half-Life by Redox Zone



Example of Redox-Dependent Rates



Redox-Dependent VOC Biodegradability

- Parent VOCs (PCE, TCE, 111-TCA)
  - Aerobic cometabolism – when chemicals like methane or toluene are present to stimulate rapid degradation
  - Otherwise need moderately or strongly anaerobic conditions
- Daughter products (e.g. 12-DCE, VC, 11-DCA, 11-DCE)
  - May undergo oxidation (without daughters) under aerobic or moderately anaerobic conditions
  - Undergo reductive dichlorination under moderate to strongly anaerobic conditions

Natural and Enhanced Degradation

- Analysis requires:
  - Delineation of major redox zones
  - Illustration of parent to daughter product ratios at wells
  - Illustration of trends along flowpath
    - Decreasing parent and increasing daughter products?
  - Illustration of trends over time across the entire site
- Applicable to natural and enhanced attenuation

Visual Bio for Radial Diagram Visualization

Section 2

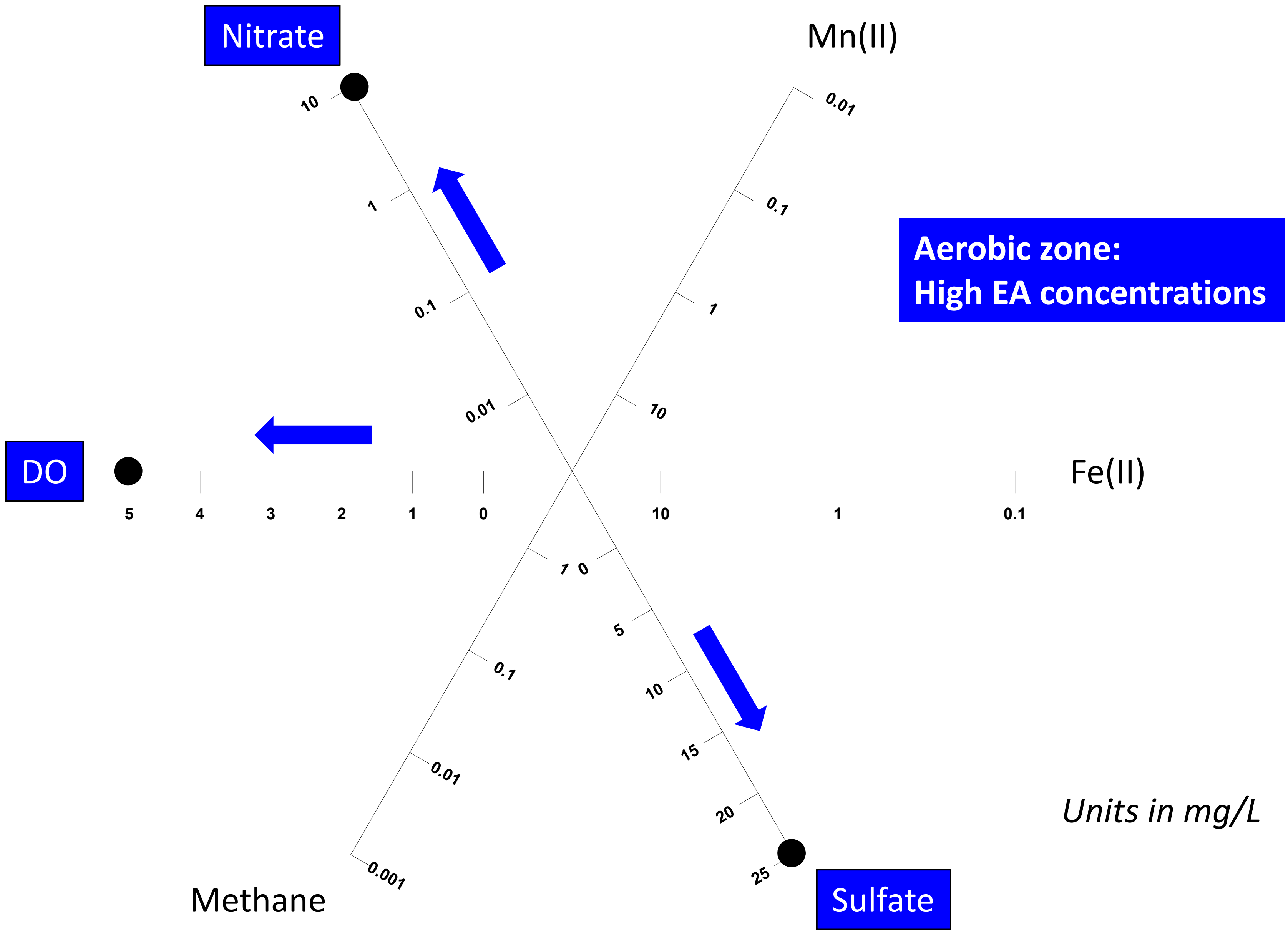
Development History

- 1998/99 – SEQUENCE and the Remediation ToolKit developed with funding from Conestoga-Rovers & Associates (now called GHD)
  - Originally sold by Waterloo Hydrogeologic
- 2002 – software ownership changed and is no longer available
- Visual Bio – new public domain tool released in spring 2017
  - Simple code using text files, Surfer used for graphics
  - Beta version available upon request

Redox Radial Diagrams

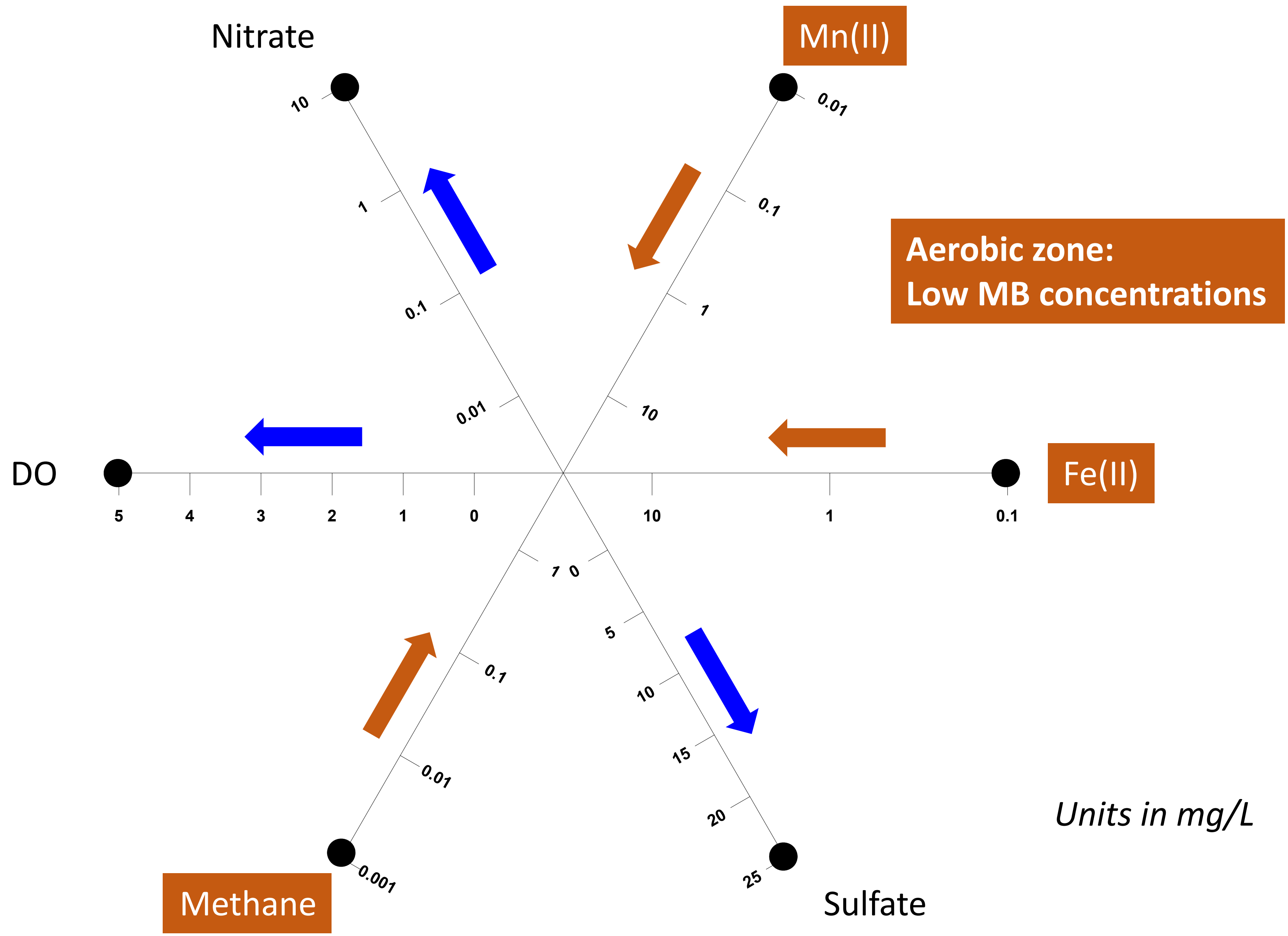
Section 2.1

Redox Diagram: Electron Acceptors (EA)



Units in mg/L

Redox Diagram: Metabolic By-Products (MB)

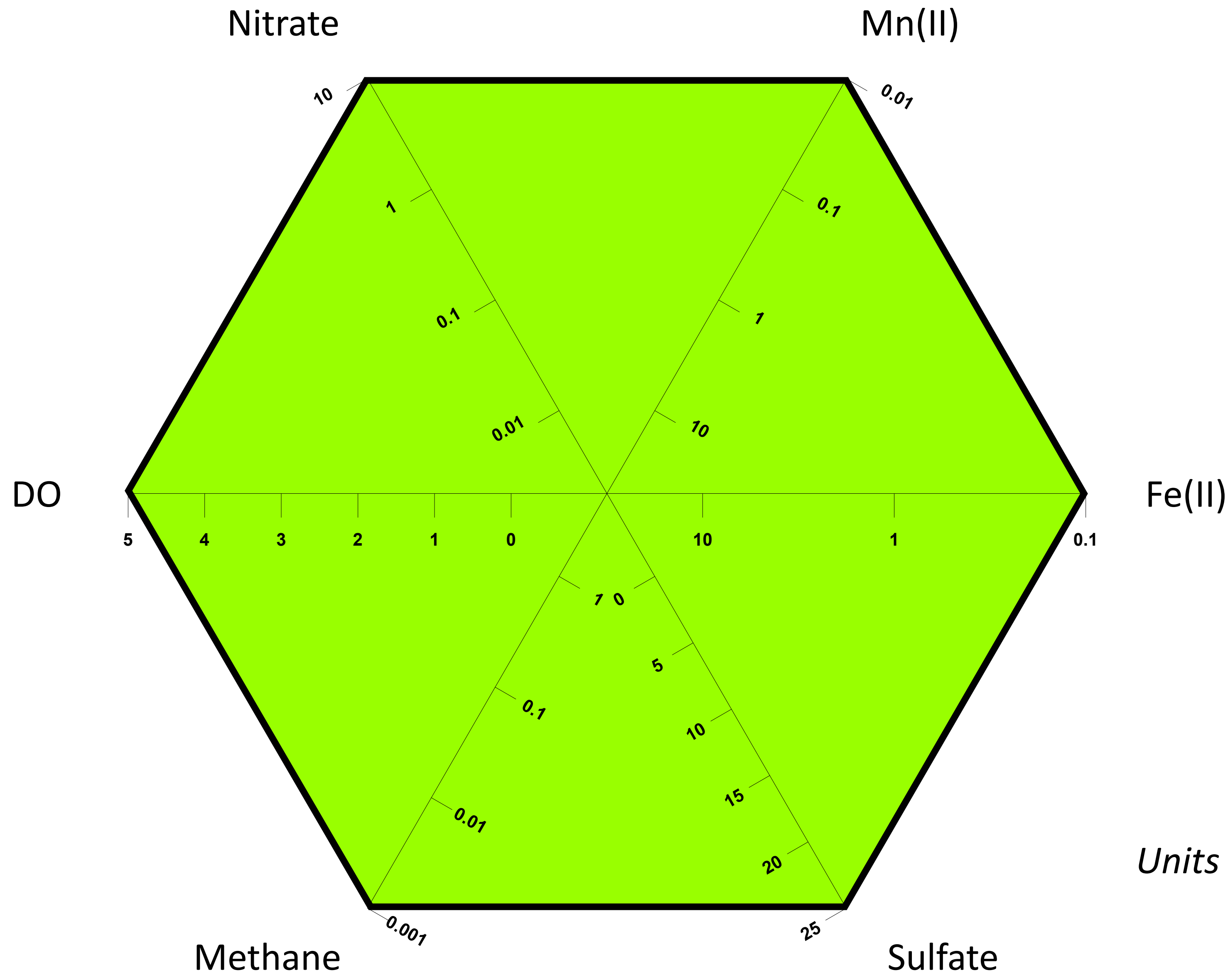


Units in mg/L

Redox Radial Diagrams

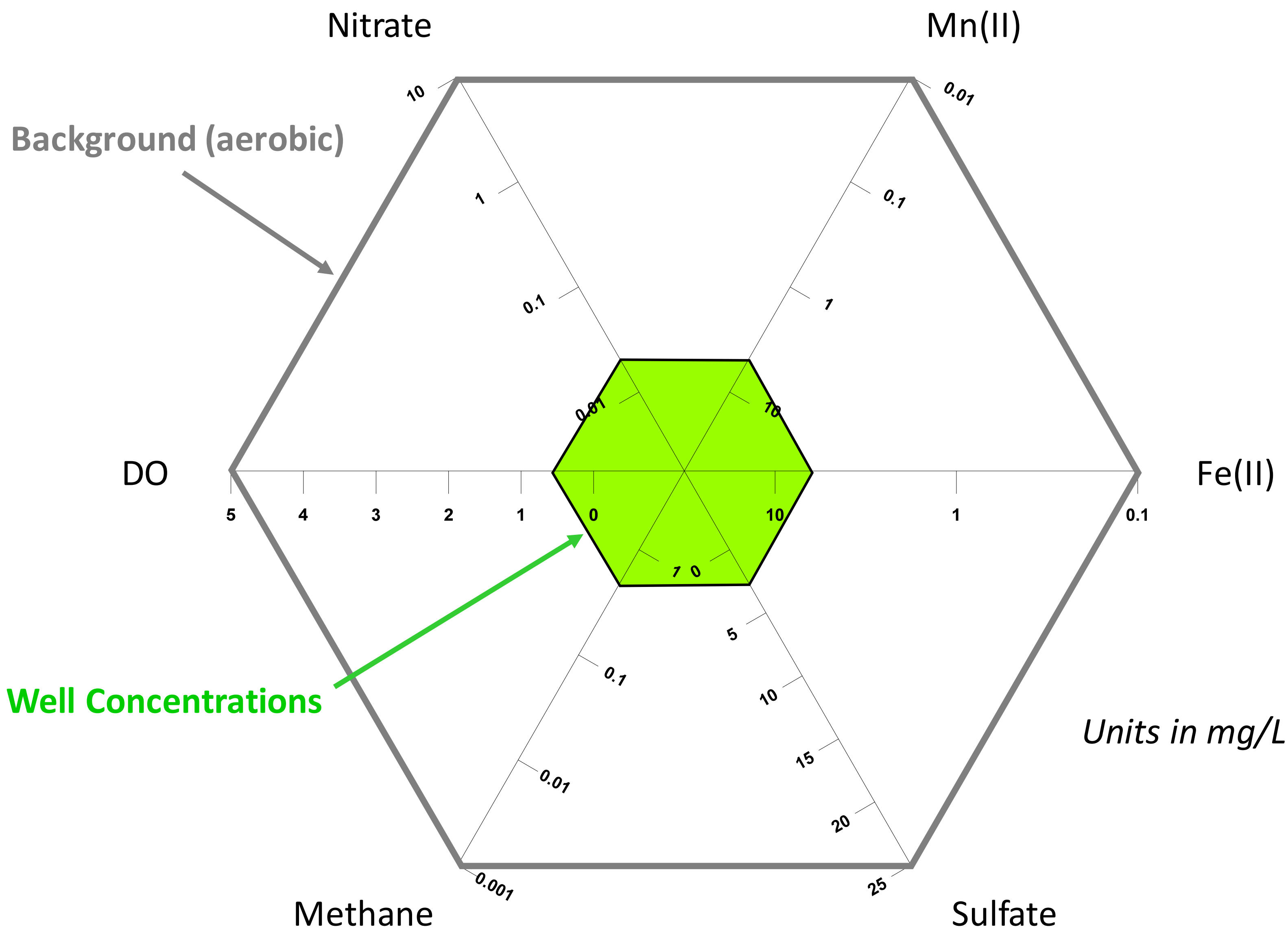
- Key functionality in Visual Bio allows for different directions of concentrations on each axis, relative to the center of the radial diagram
  - Electron acceptor axes
    - Concentrations increase **away from** the center of the diagram
    - Background aerobic concentrations plot at outer extent of axes
  - Metabolic byproduct axes
    - Concentrations increase **towards** the center of the diagram
    - Background aerobic concentrations also plot at outer extent of axes

Redox Diagram: Aerobic (Background)

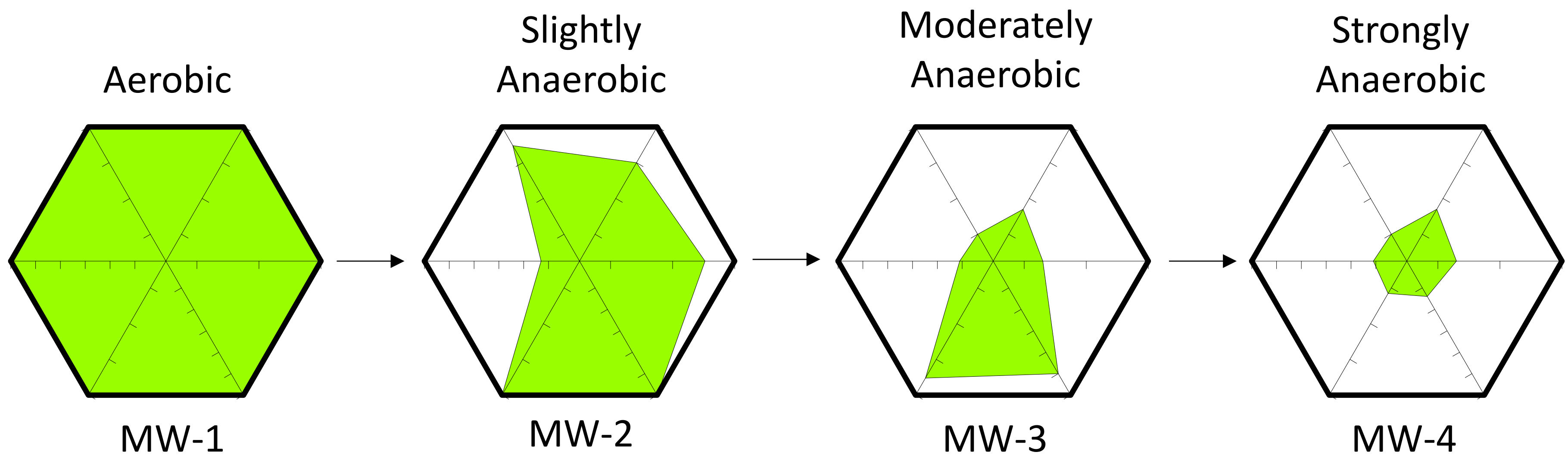


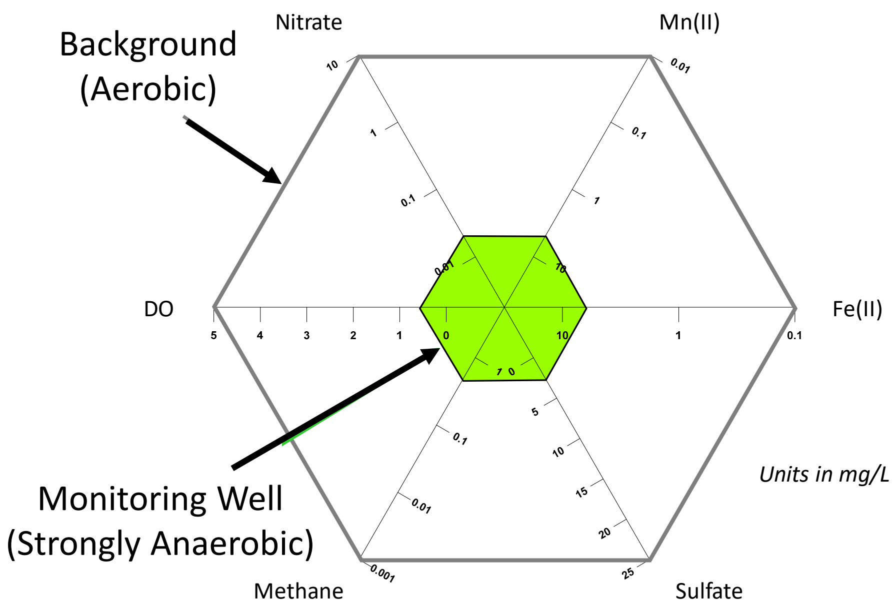
Units in mg/L

Redox Diagram: Strongly Anaerobic at Well



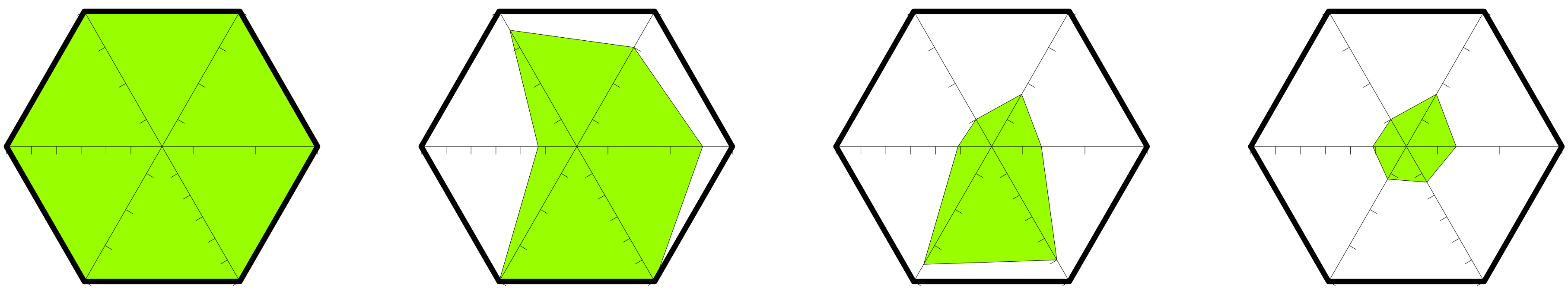
Redox Zone Transition





Redox Zone Transition

Aerobic | Slightly Anaerobic | Moderately Anaerobic | Strongly Anaerobic

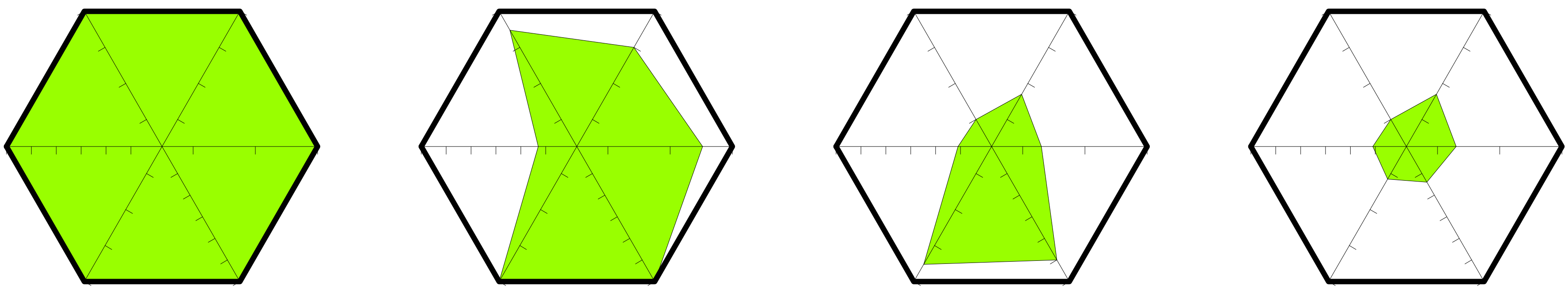


Radial diagrams are ideal for plotting inter-relationships between redox indicators at each monitoring well.

Location	DO (mg/L)	Nitrate (mg/L)	Mn(II) (mg/L)	Fe(II) (mg/L)	Sulfate (mg/L)	Methane (mg/L)
Aerobic	5	10	<0.01	<0.1	25	<0.001
Slightly Anaerobic	0.3	3	0.1	0.3	25	<0.001
Moderately Anaerobic	0.1	<0.01	2	5	18	0.01
Strongly Anaerobic	0.1	<0.01	2	5	2	0.7

Quantifying Redox Zone Based on Polygon Areas

Aerobic	Slightly Anaerobic	Moderately Anaerobic	Strongly Anaerobic



100%	**58%**	**24%**	**7%**
>60%	50-60%	20-49%	<20%

$$\text{Relative Redox Area (RRA)} = \frac{\text{Area of monitoring well polygon}}{\text{Area of reference polygon (Aerobic)}}$$

Note – Intervals for redox zones are site-specific.

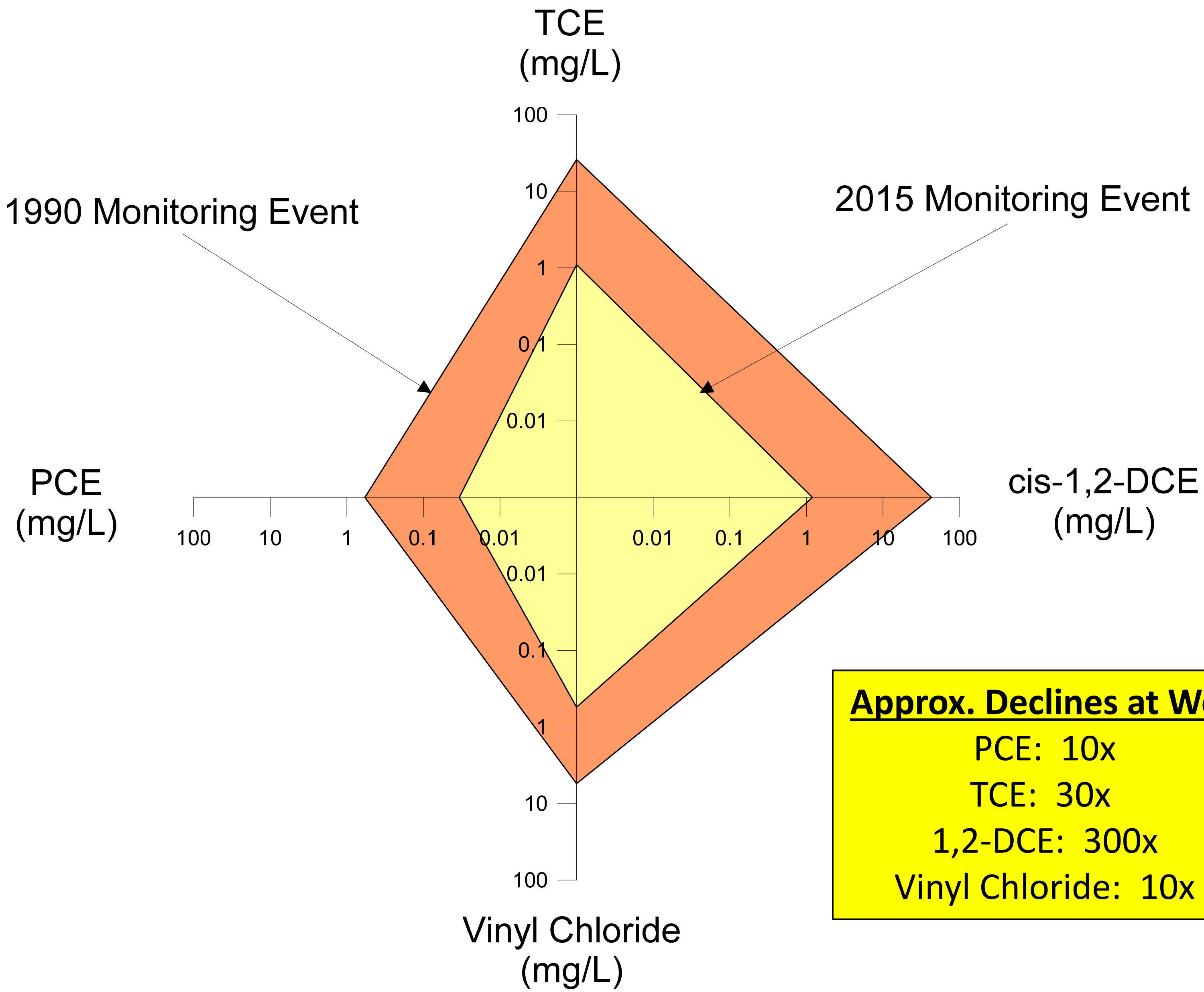
VOC Radial Diagrams

Section 2.2

Typical VOC Trend Analysis

- Evaluate changes over time and distance for multiple VOCs in groundwater, such as:
  - PCE, TCE, 12-DCE, vinyl chloride
  - 111-TCA, 11-DCA, 11-DCE, and chloroethane
  - Benzene, toluene, ethylbenzene, total xylenes
- Temporal trends based on difference between early and recent monitoring events

Example #1: Temporal Changes at A Monitoring Well



<u>Approx. Declines at Well</u>

PCE: 10x

TCE: 30x

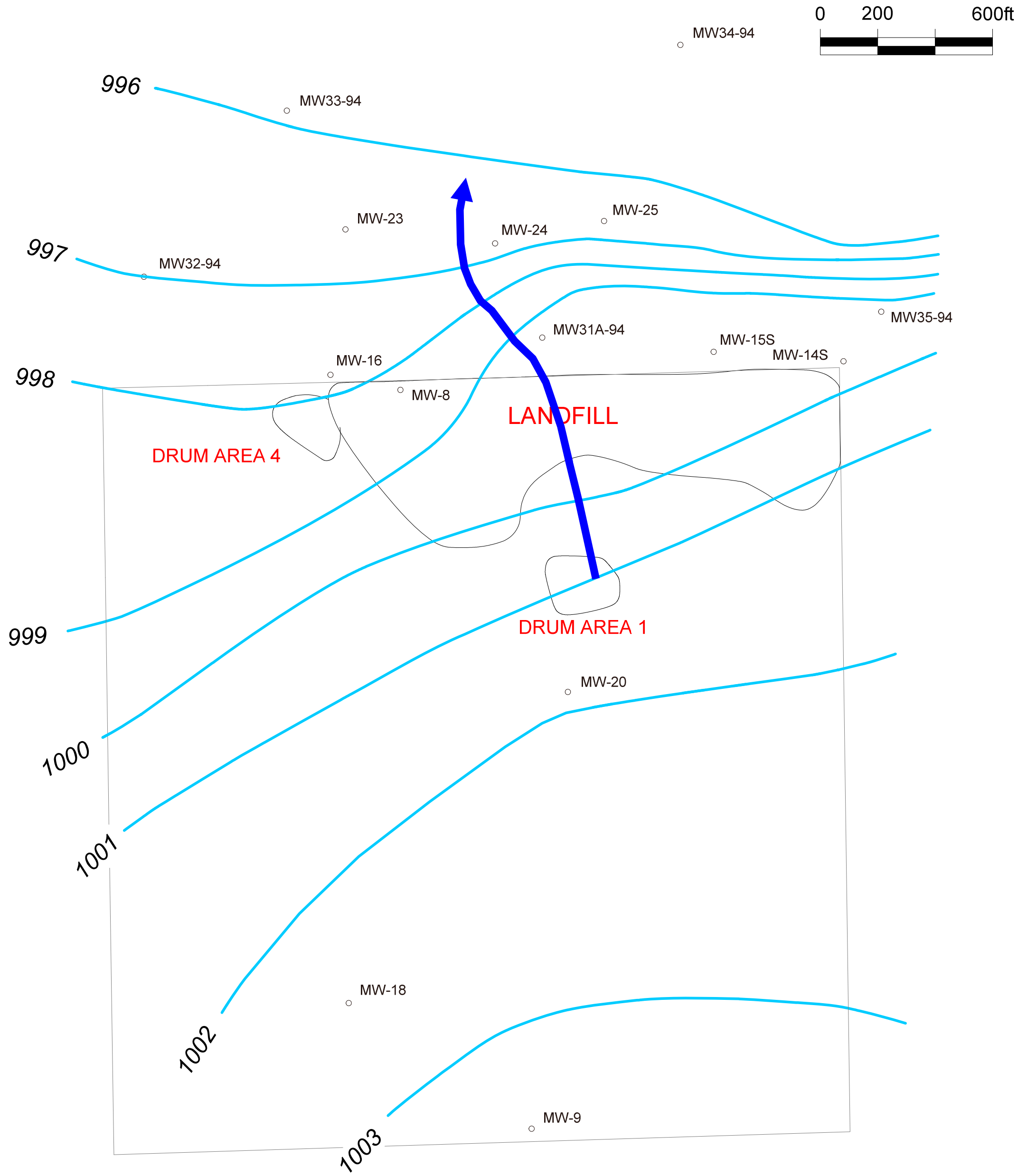
1,2-DCE: 300x

Vinyl Chloride: 10x

Case Studies

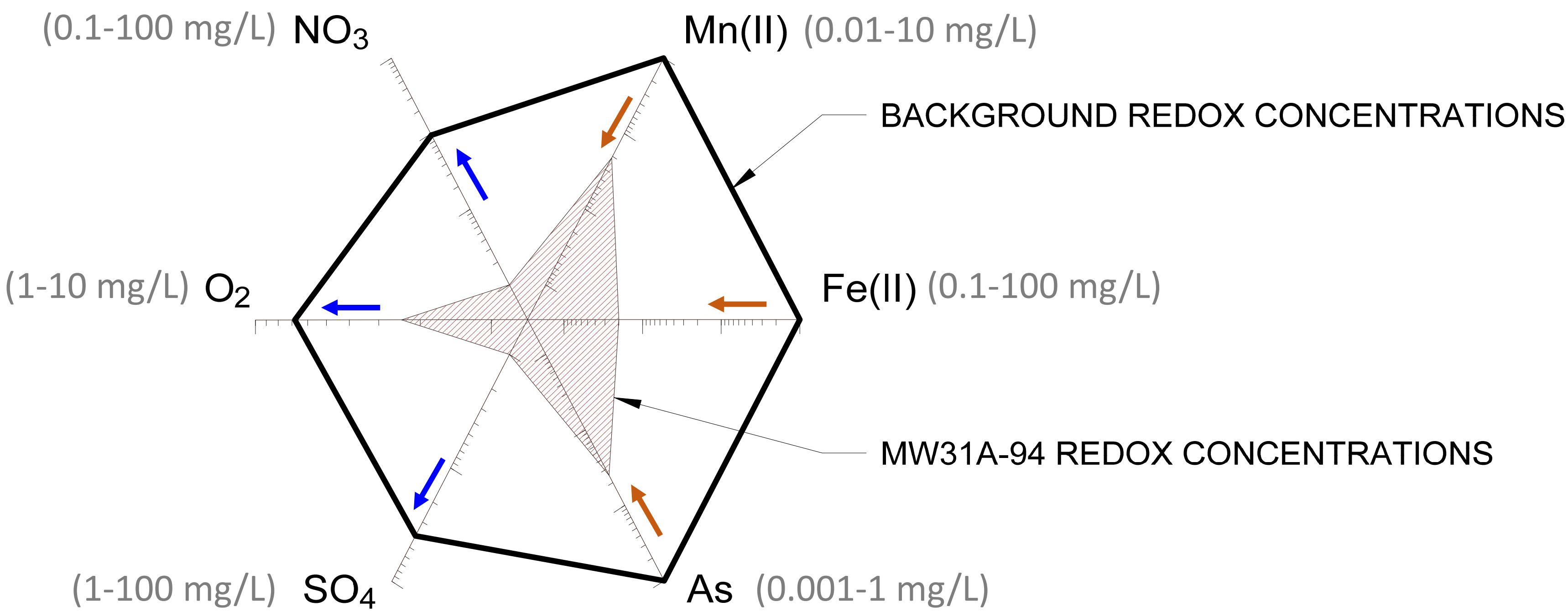
Section 3

Case Study #1 – Landfill Superfund Site



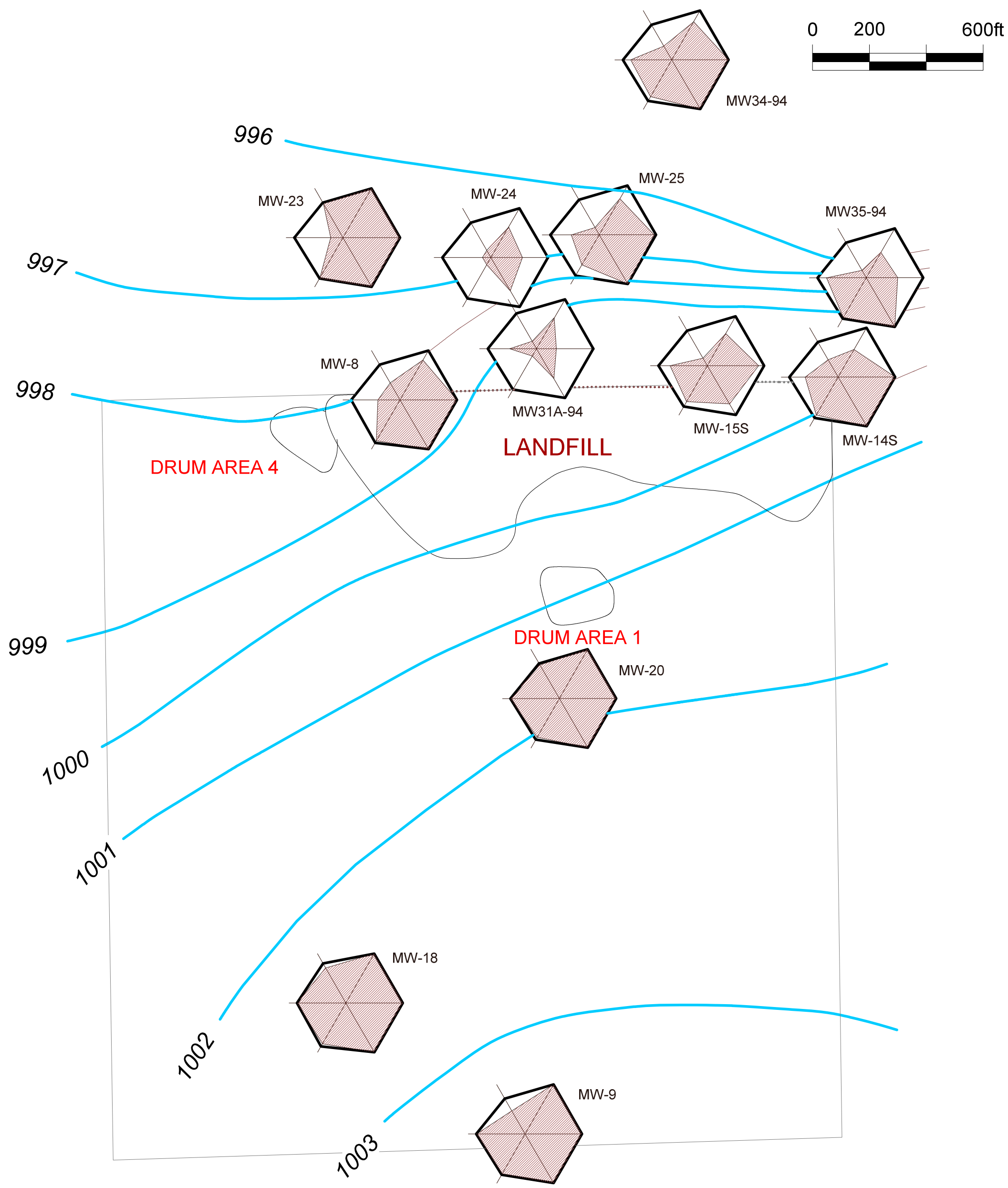
Carey et al., 1996

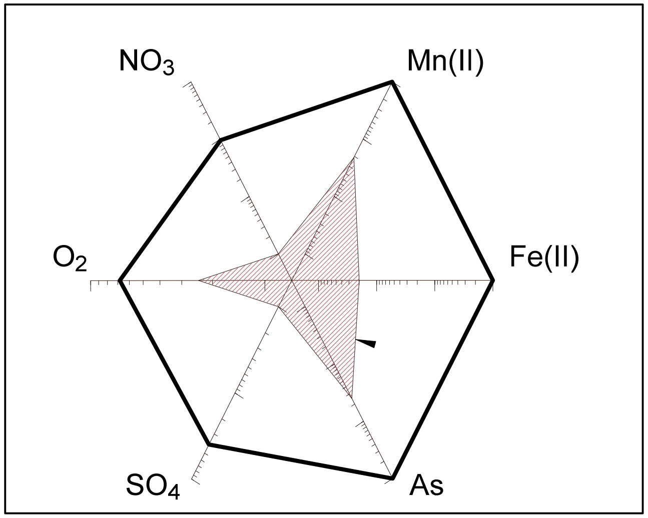
Redox Radial Diagram



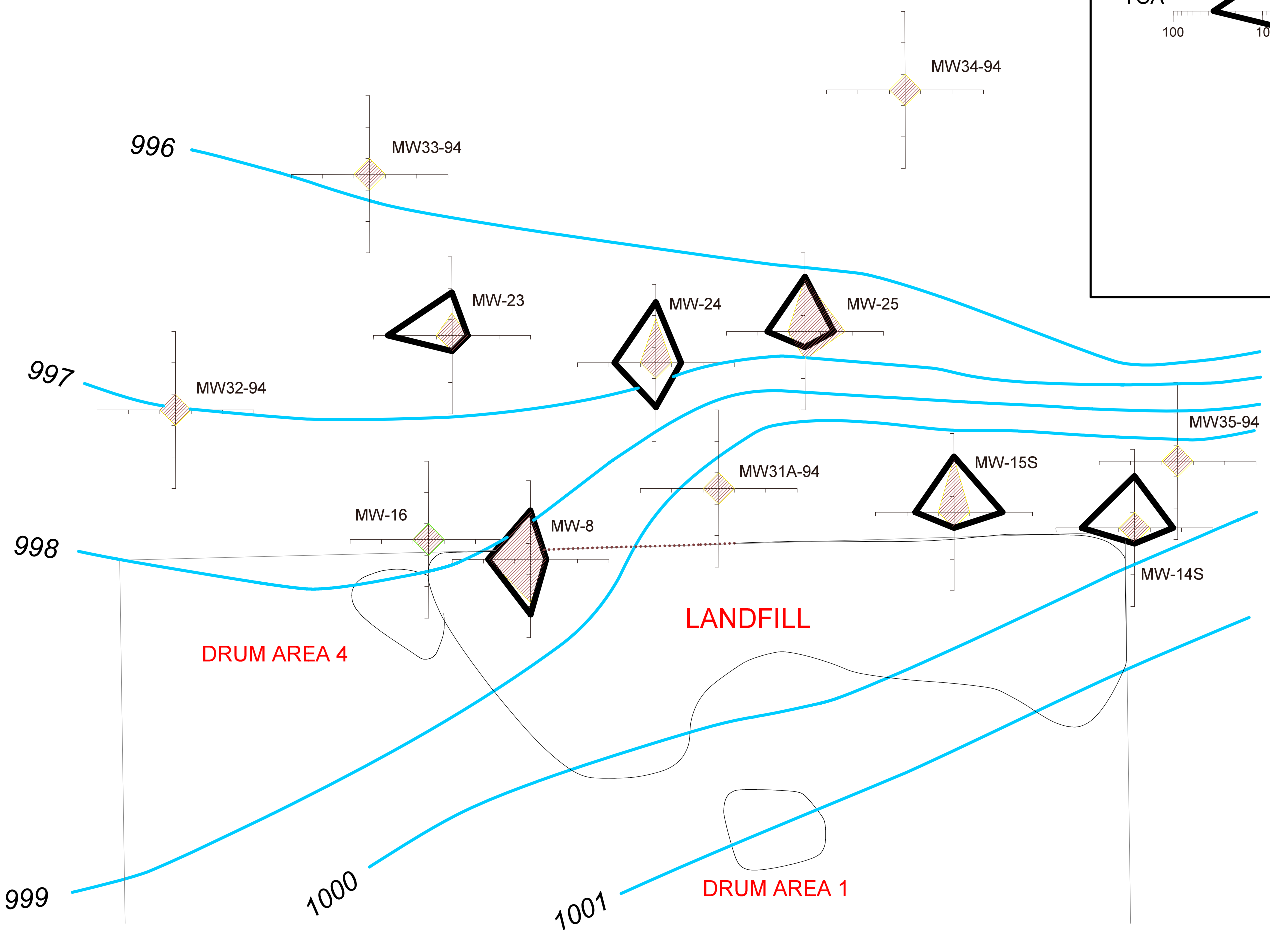
- Designed for evaluation of arsenic (As) and iron (Fe) correlation
  - Arsenic is often naturally-occurring, and may be temporarily mobilized during the reductive dissolution of iron minerals

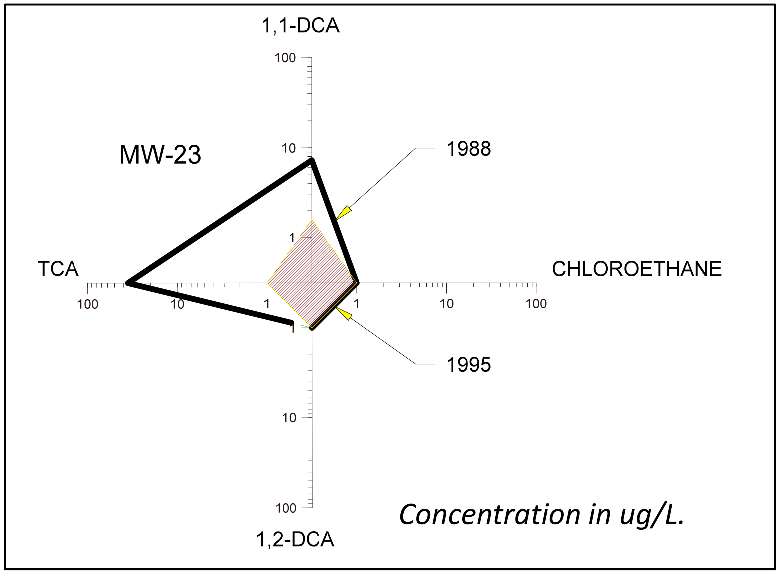
Redox Radial Diagram Map





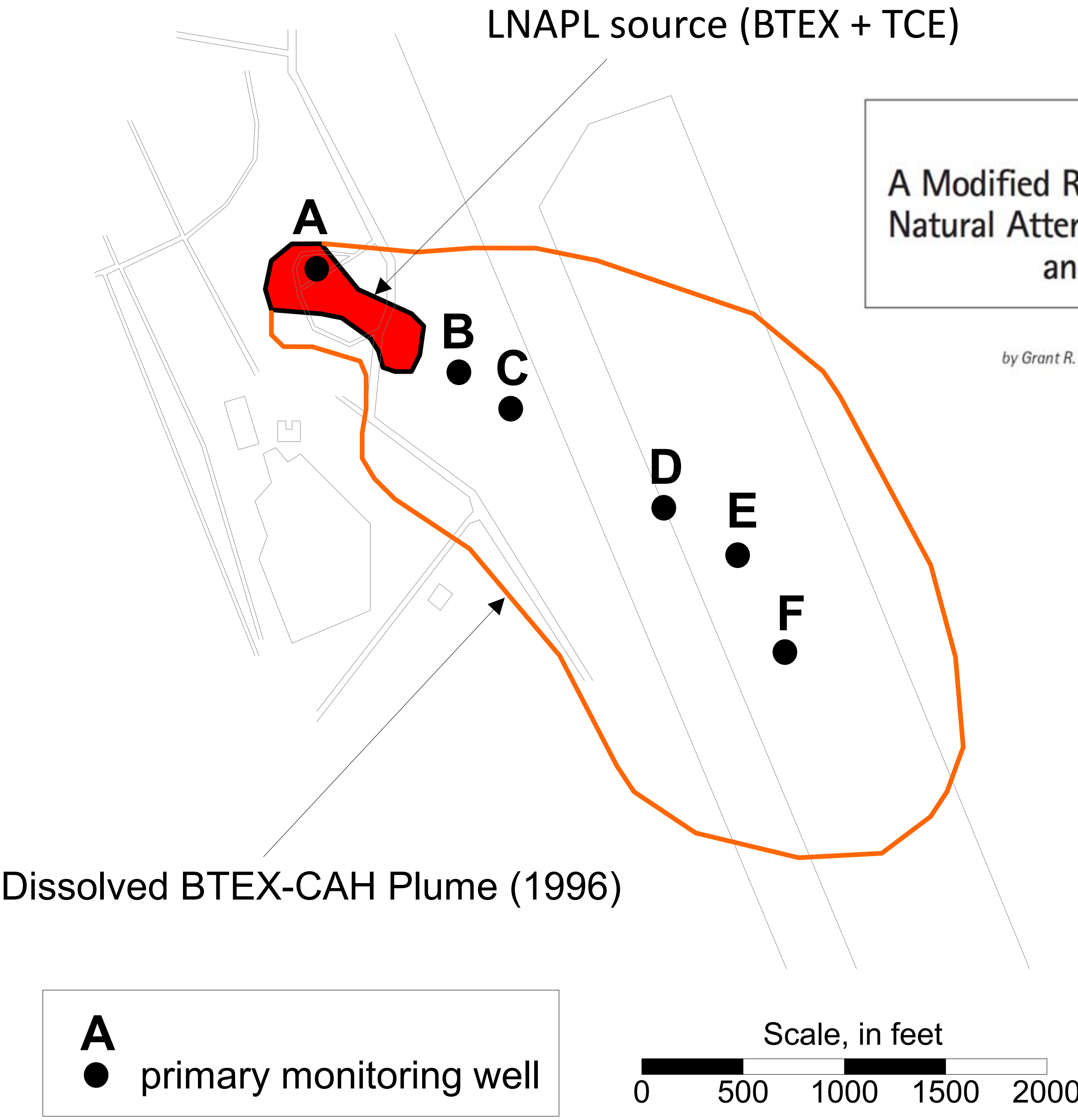
VOCs Map – Concentration versus Time





Case Study #2 – Plattsburgh AFB

Carey et al., 2003



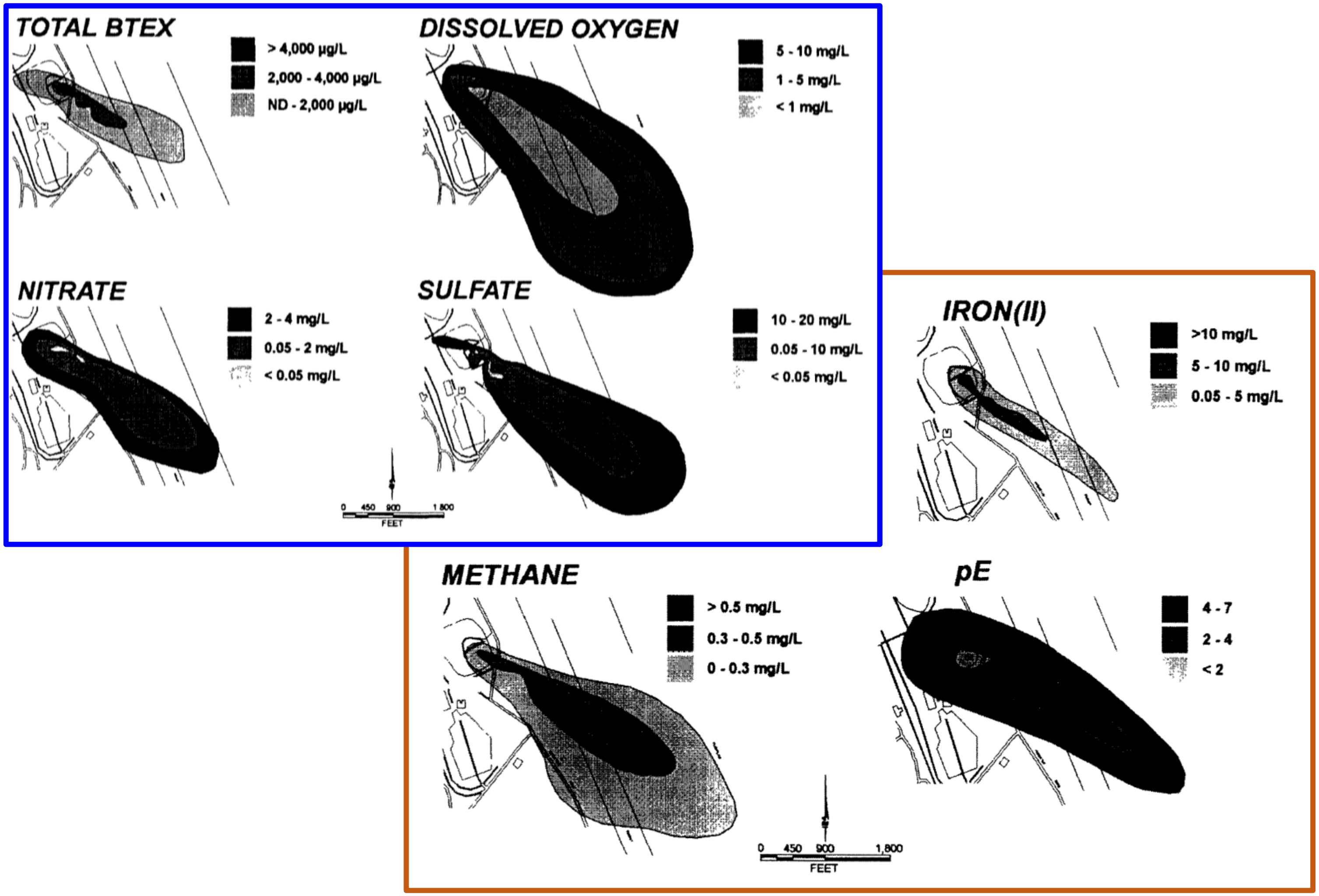
Ground Water Monitoring & Remediation

A Modified Radial Diagram Approach for Evaluating Natural Attenuation Trends for Chlorinated Solvents and Inorganic Redox Indicators

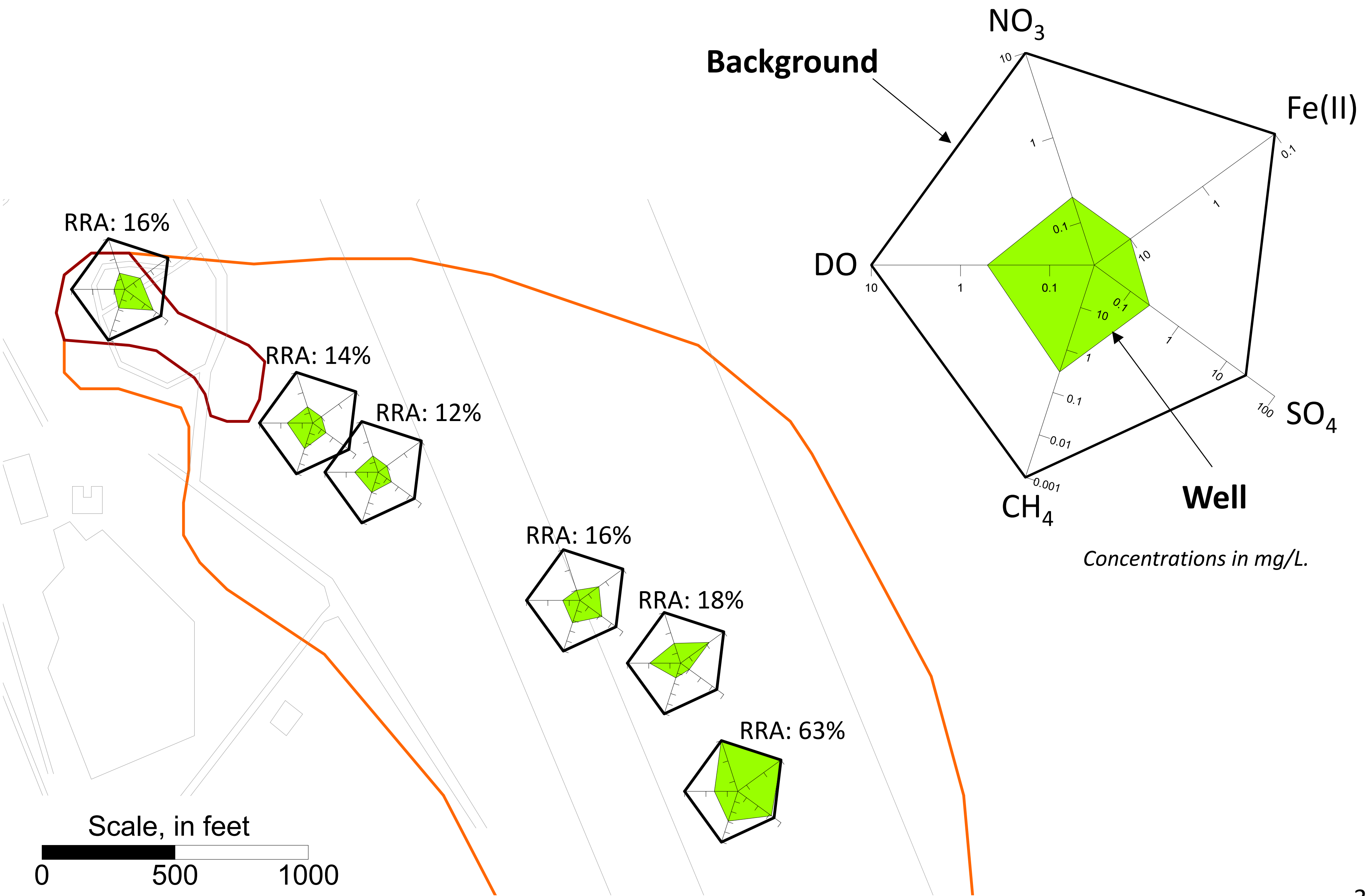
by Grant R. Carey, Paul J. Van Geel, Todd H. Wiedemeier, and Edward A. McBean

Redox Indicator Contours

Wiedemeier et al., 1996



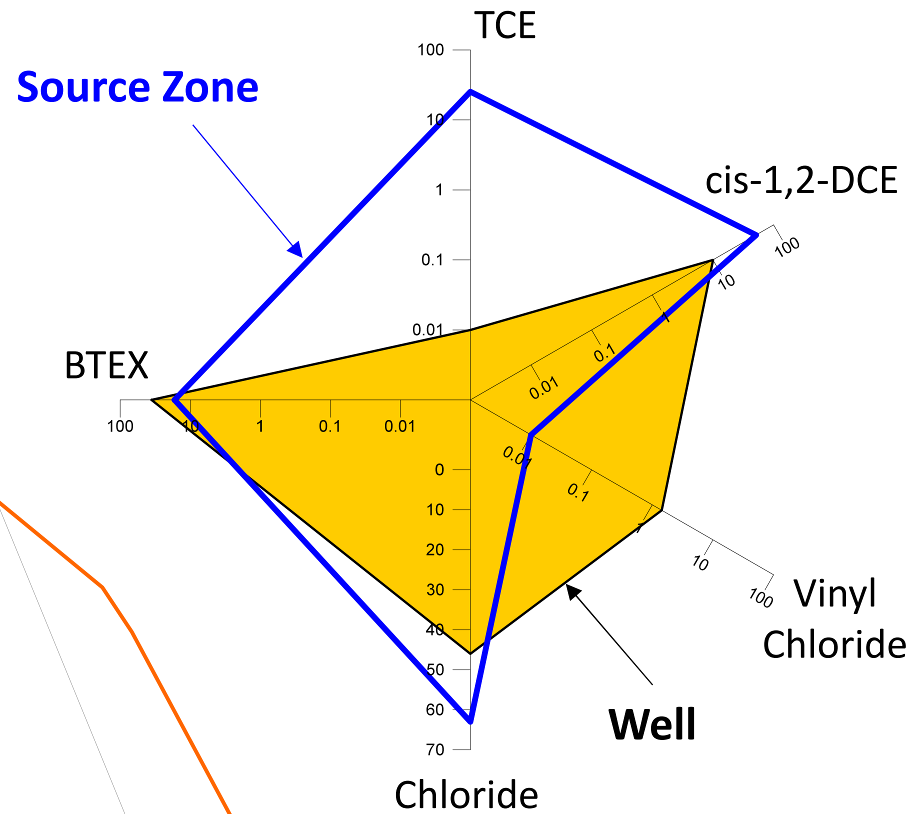
Plattsburgh AFB Redox Diagram Map



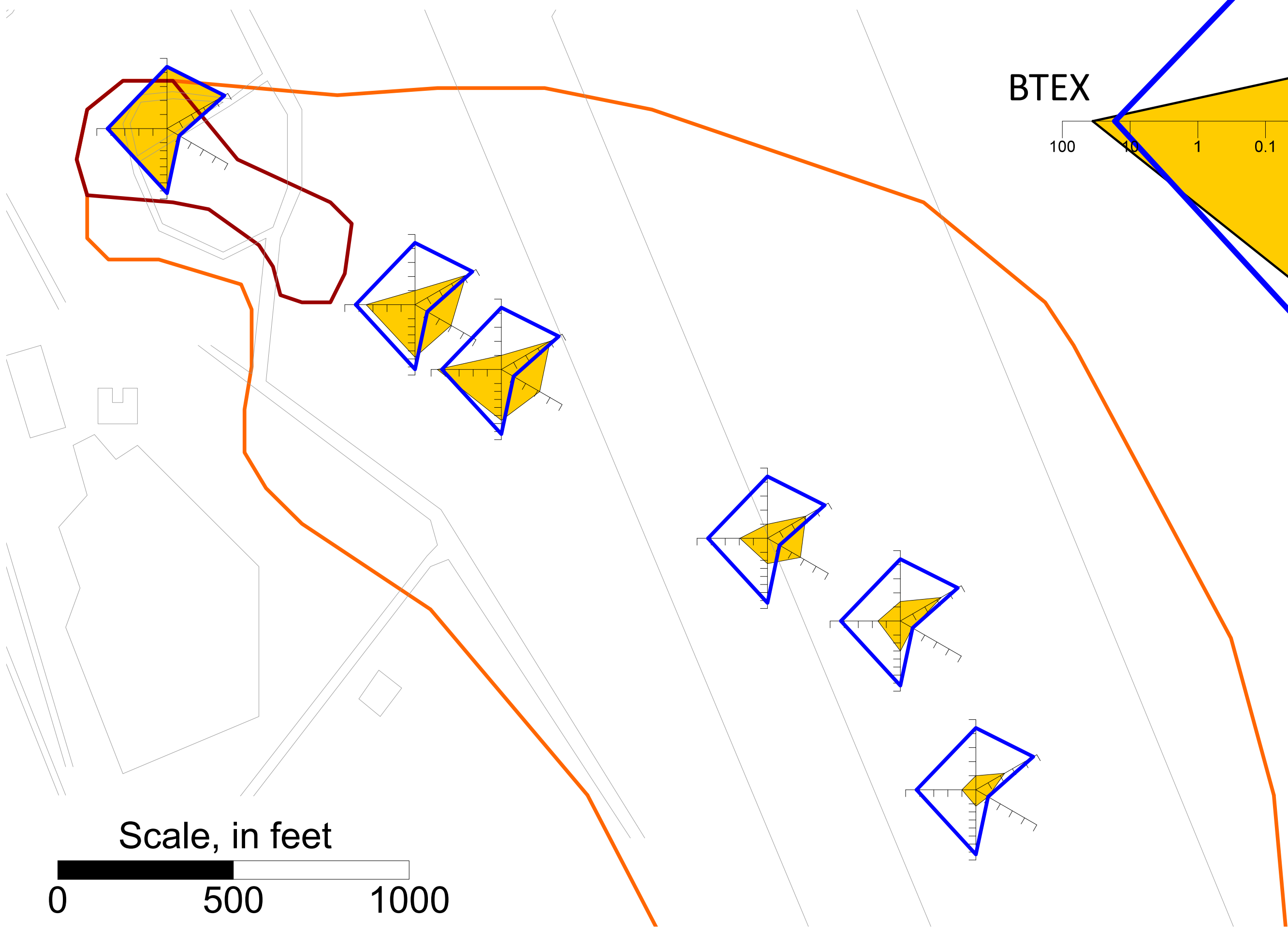
Plattsburgh AFB VOC Diagram Map

MNA lines of evidence:

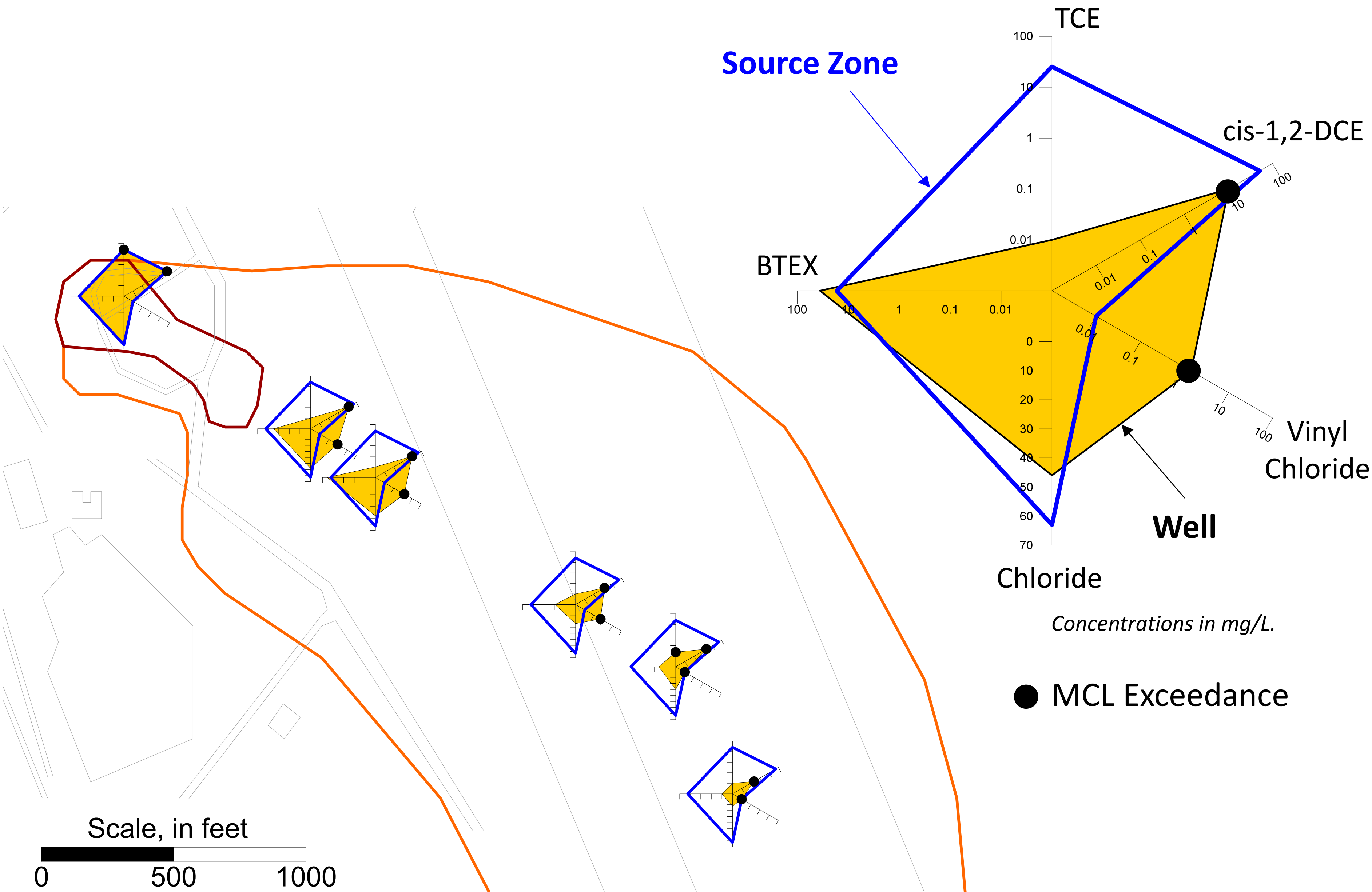
- **Declining parent C vs. distance**
- **Increasing daughter product C vs. distance**
- **Change from aerobic to strongly anaerobic**



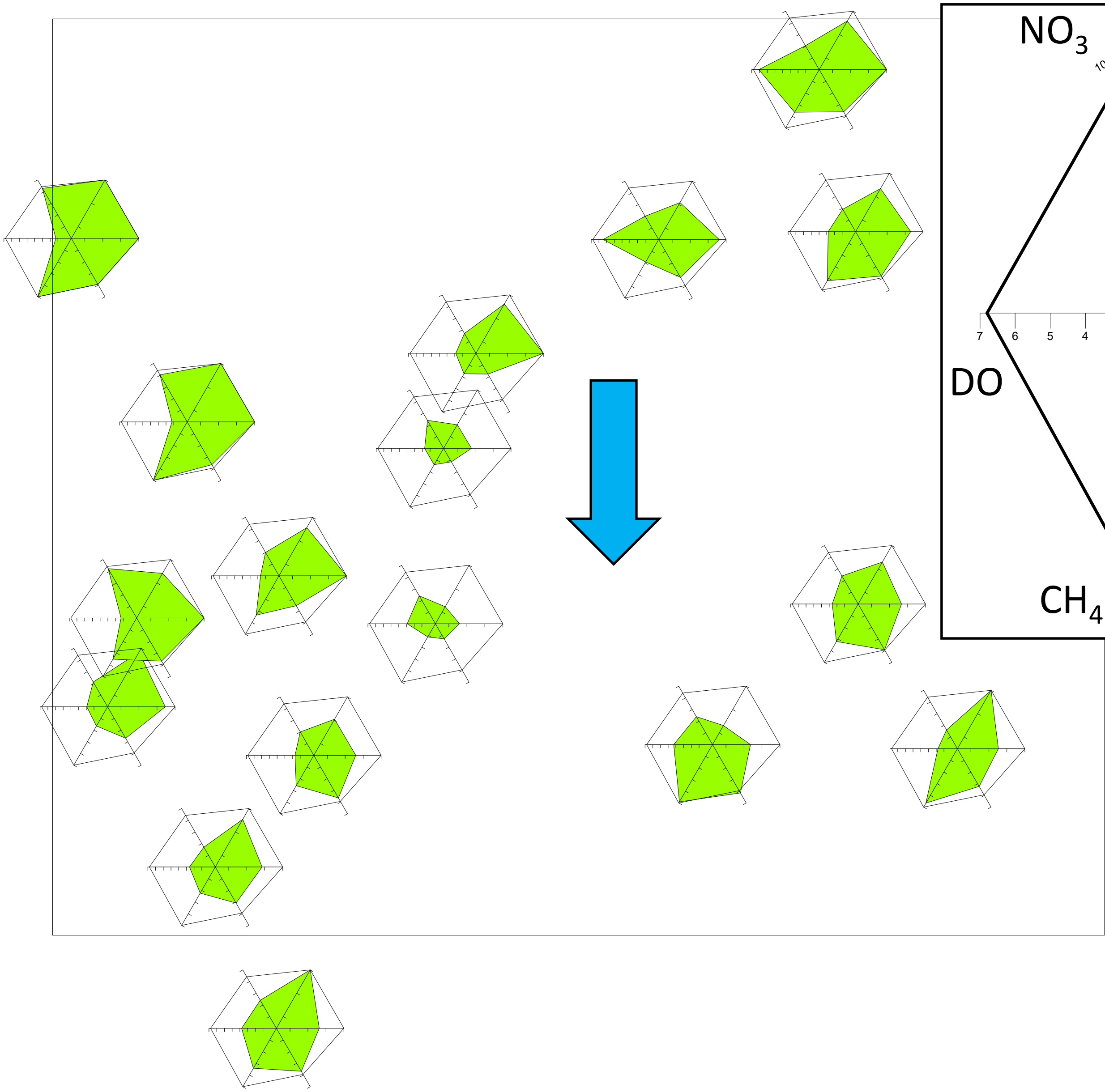
Concentrations in mg/L.

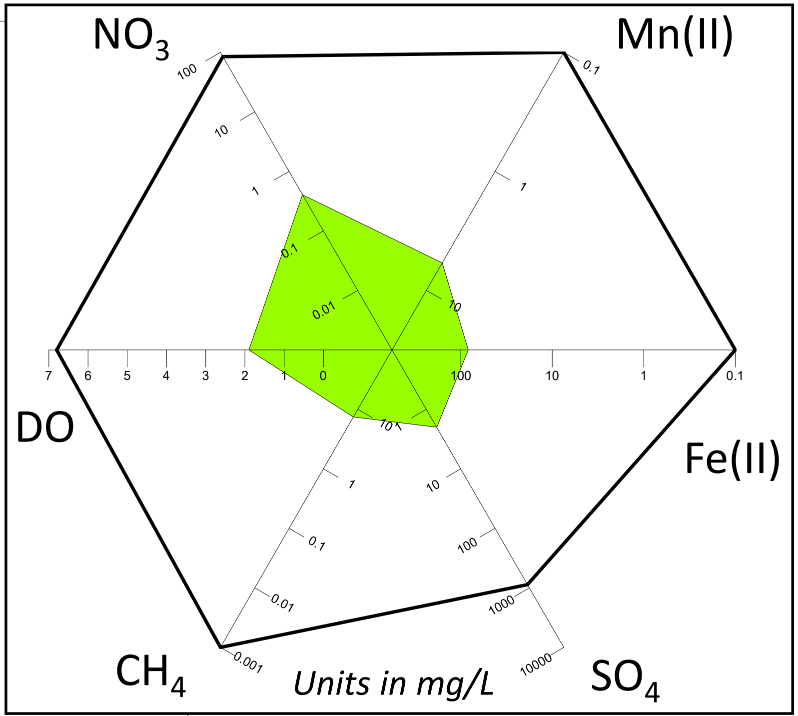


Plattsburgh AFB VOC Diagram Map

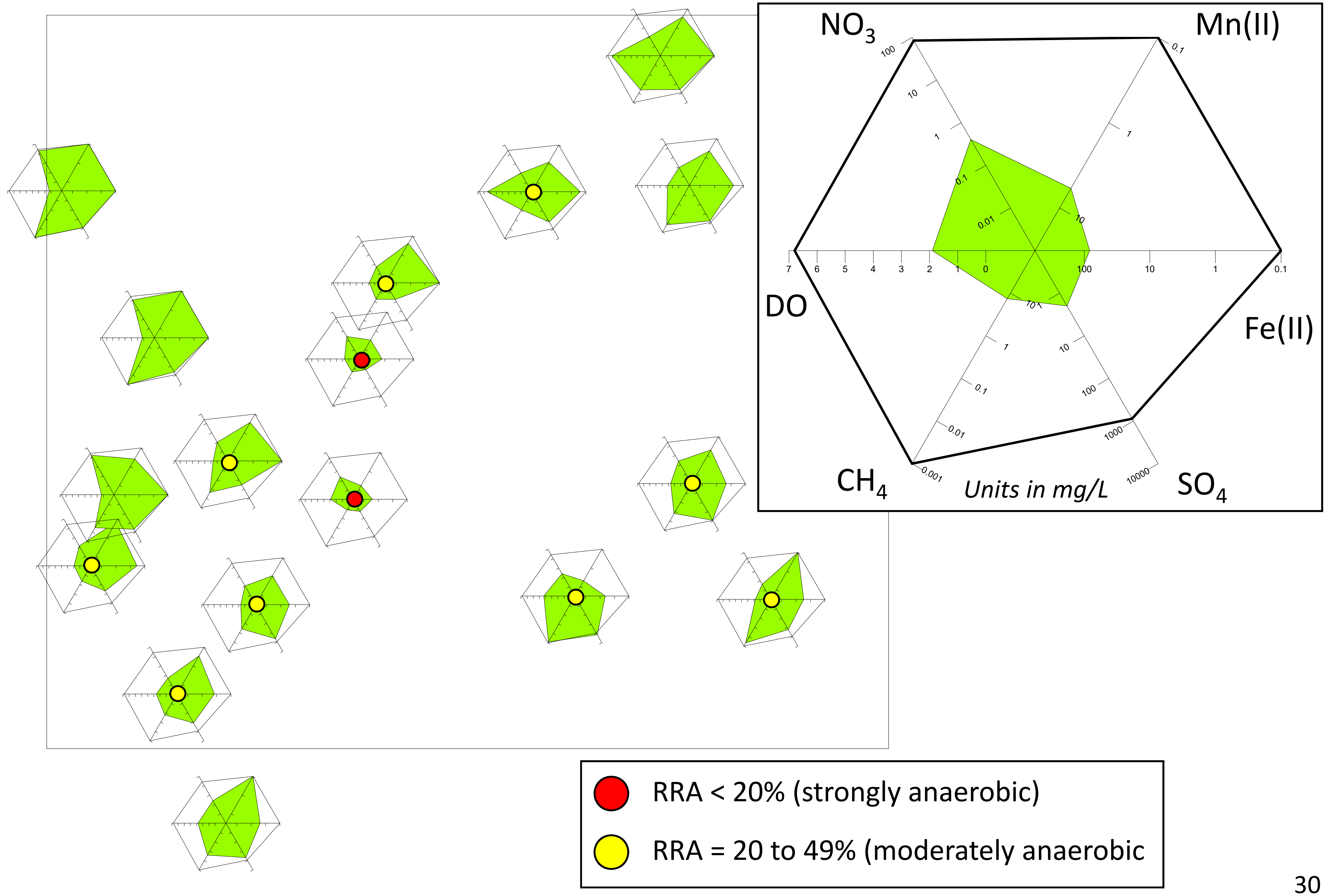


Case Study #3 - Redox Diagrams

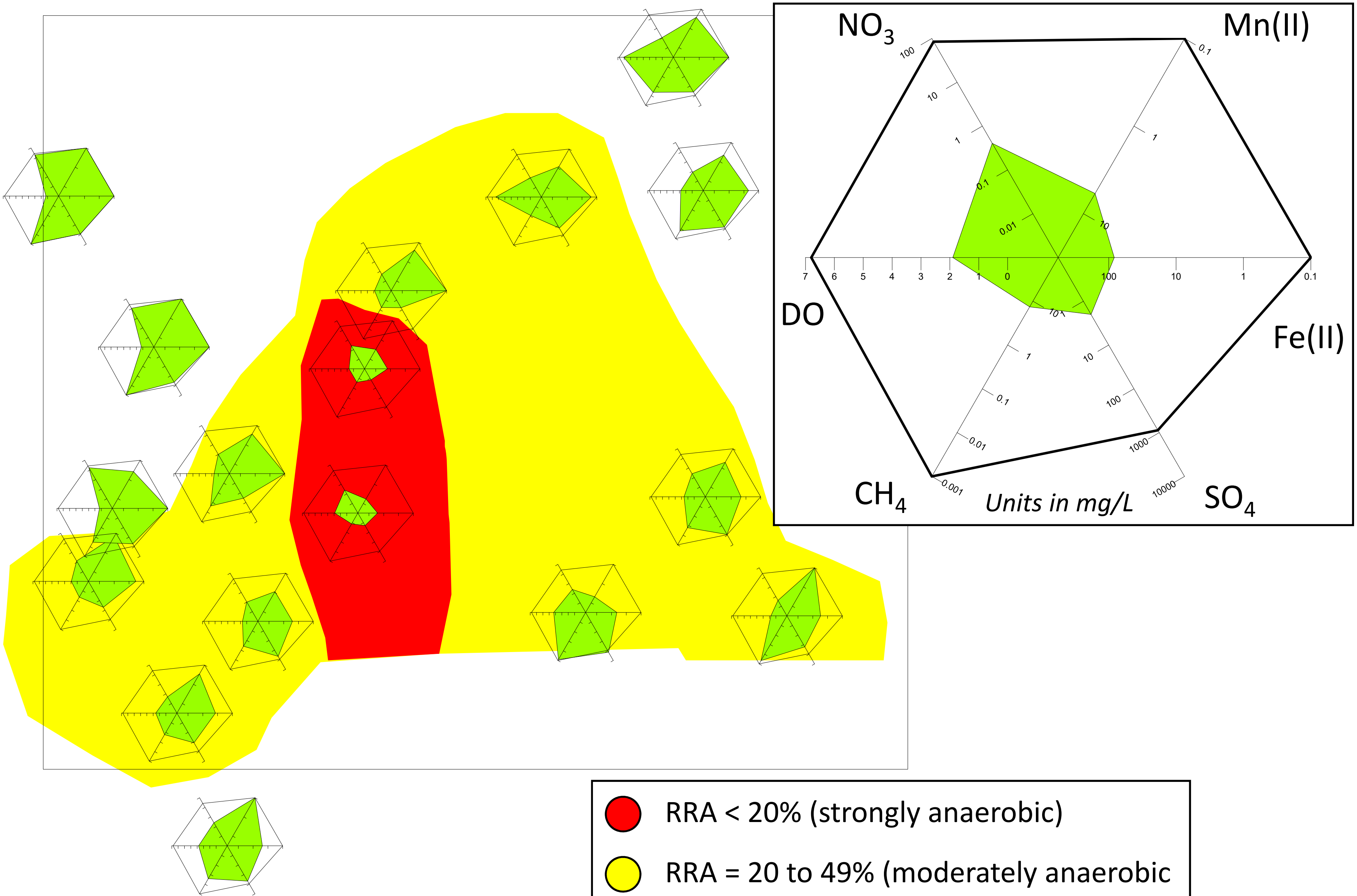




Relative Redox Area (RRA)



Relative Redox Zones



Summary

Section 4

Advantages of Visual Bio

- Powerful visualization tool for illustrating where biodegradation is occurring in groundwater and where cleanup exceedances occur
  - Graphical approach allows less technical professionals to clearly see the efficacy of natural and enhanced attenuation
- Can review spatial and temporal trends for multiple chemicals on a single map
- Relative to individual contour maps for each chemical, radial diagram maps are less subjective and easier to prepare
- Quantitative redox zone evaluation applicable at some sites, which allows for simple delineation of zones where VOCs are most likely to biodegrade

Key Functionality for Radial Diagrams

- Axes can increase in concentration away from, or towards the origin of the radial diagram
- Each axis has option of log or arithmetic scale
- Multiple events as data series, and/or reference series that are uniform across all wells

  e.g. background redox indicators, or source zone VOCs

- Option to shade in one or more data series
- Symbols to represent non-detects, and/or MCL exceedances

Visual Bio - Public Domain Software

- Available for FREE download in May 2017
- Simple tool (text input files)
  - Golden Surfer used to create radial diagram maps
- Classroom and online training available

More info:

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