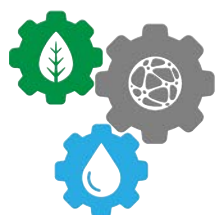




Evaluation Approaches for Transitioning from Active to Passive Remediation

September 23, 2020

Katie Muller and Mike Truex



REMPLEX
CENTER FOR THE REMEDIATION
OF COMPLEX SITES
@PNNL

U.S. DEPARTMENT OF
ENERGY **BATTELLE**

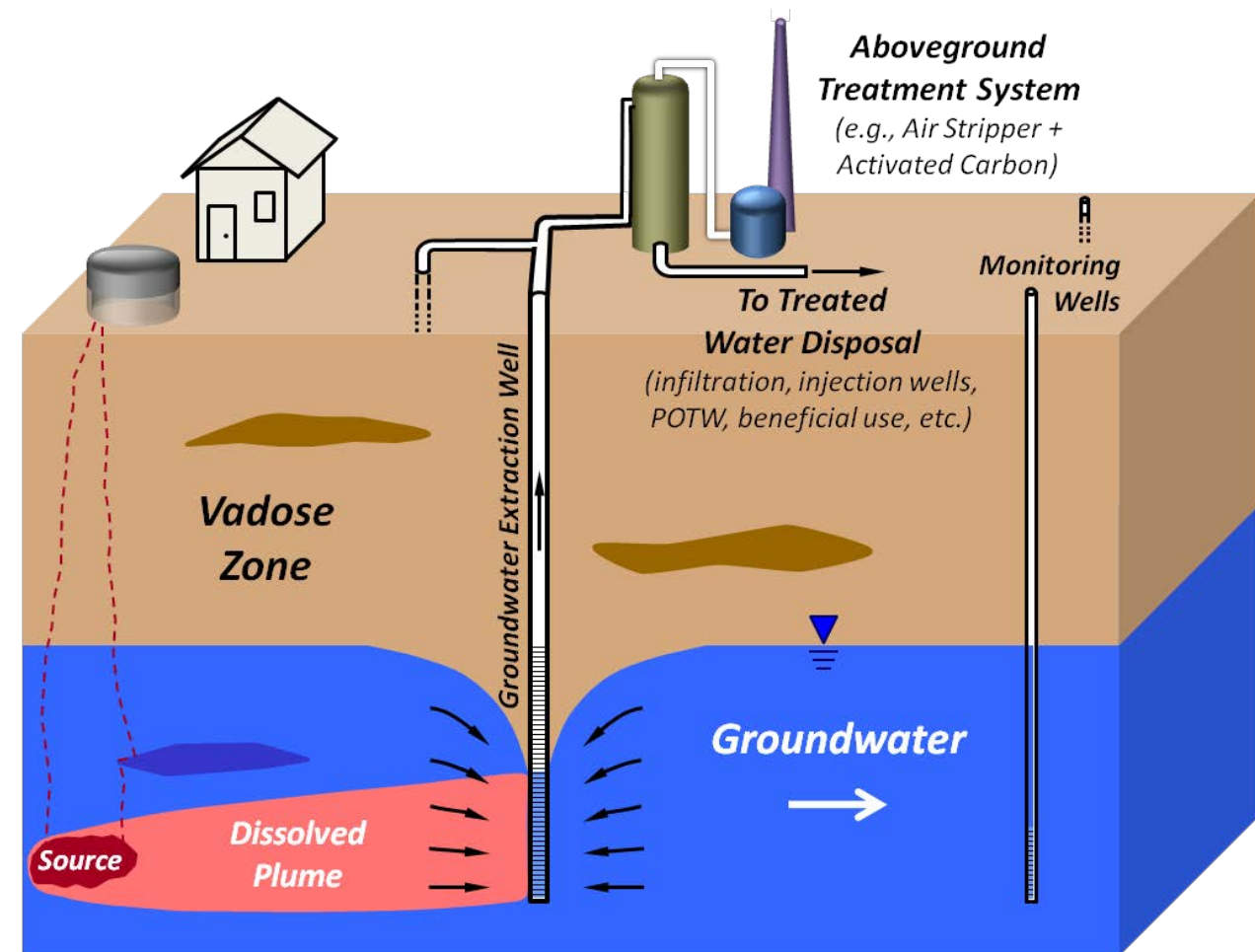
PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-156585



Outline

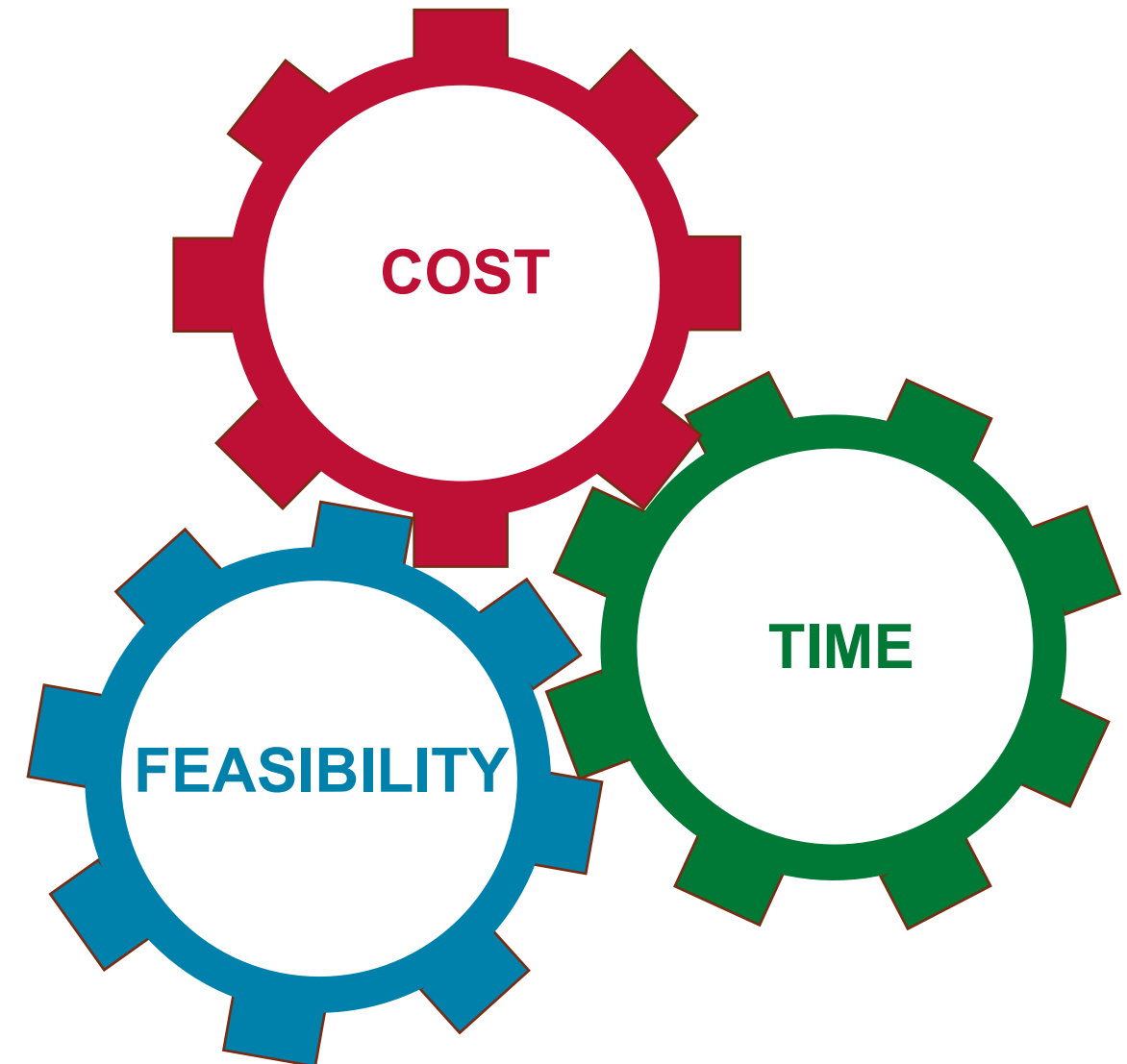
- 1) Transition Assessment Basics (Why, When and How)
- 2) Assessment Framework
- 3) Technical Justification
 - Tools and Methodology
- 4) Case Studies
- 5) After Transition



Why Transition from Active to Passive?

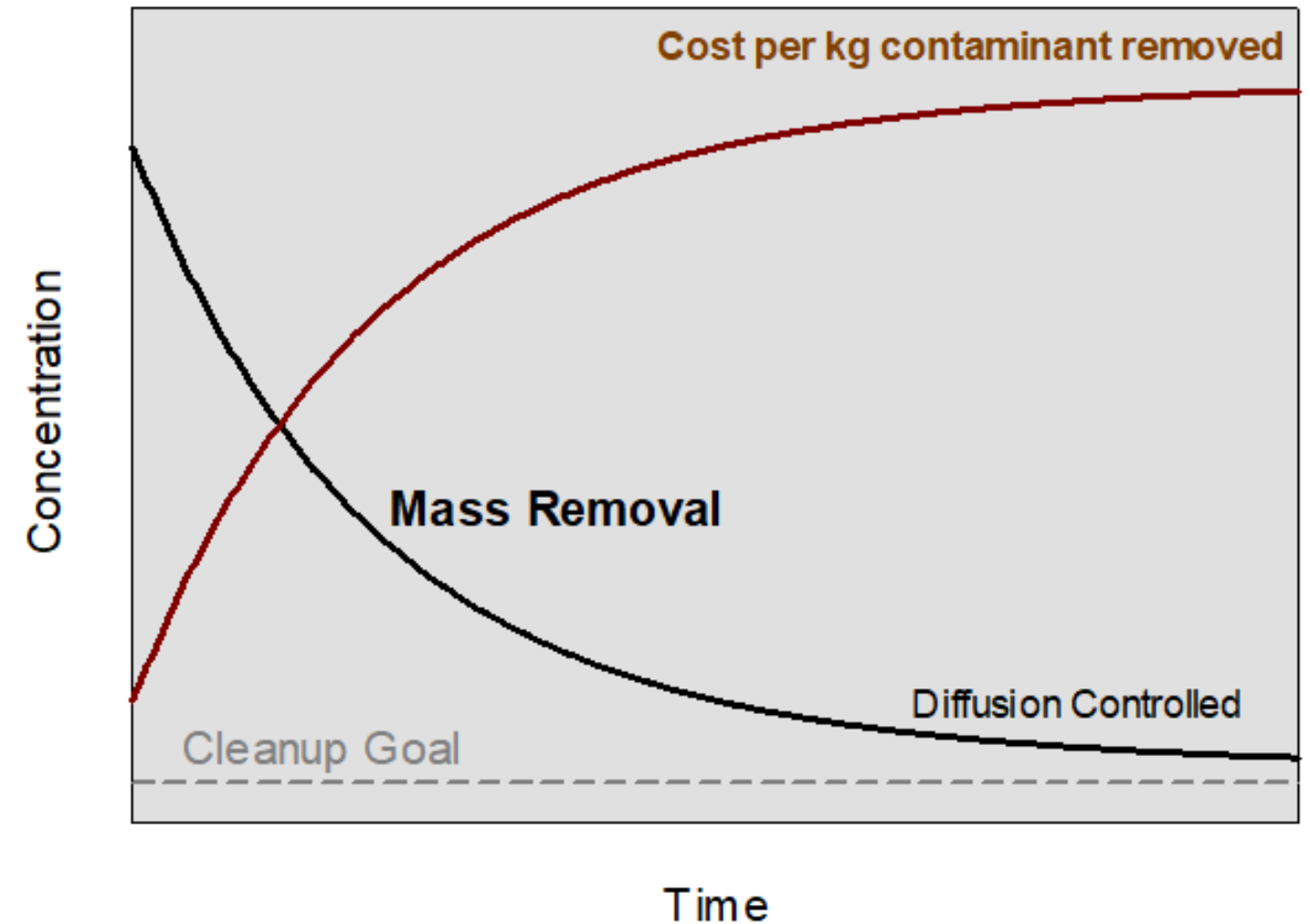
- Able to Manage Risk
 - ✓ Balance of time, cost, feasibility and potential risk
- Remaining mass may not constitute unacceptable risk
 - ✓ Mass removal does not necessarily equate to risk reduction

RISK MANAGEMENT



When to Consider a Transition Assessment?

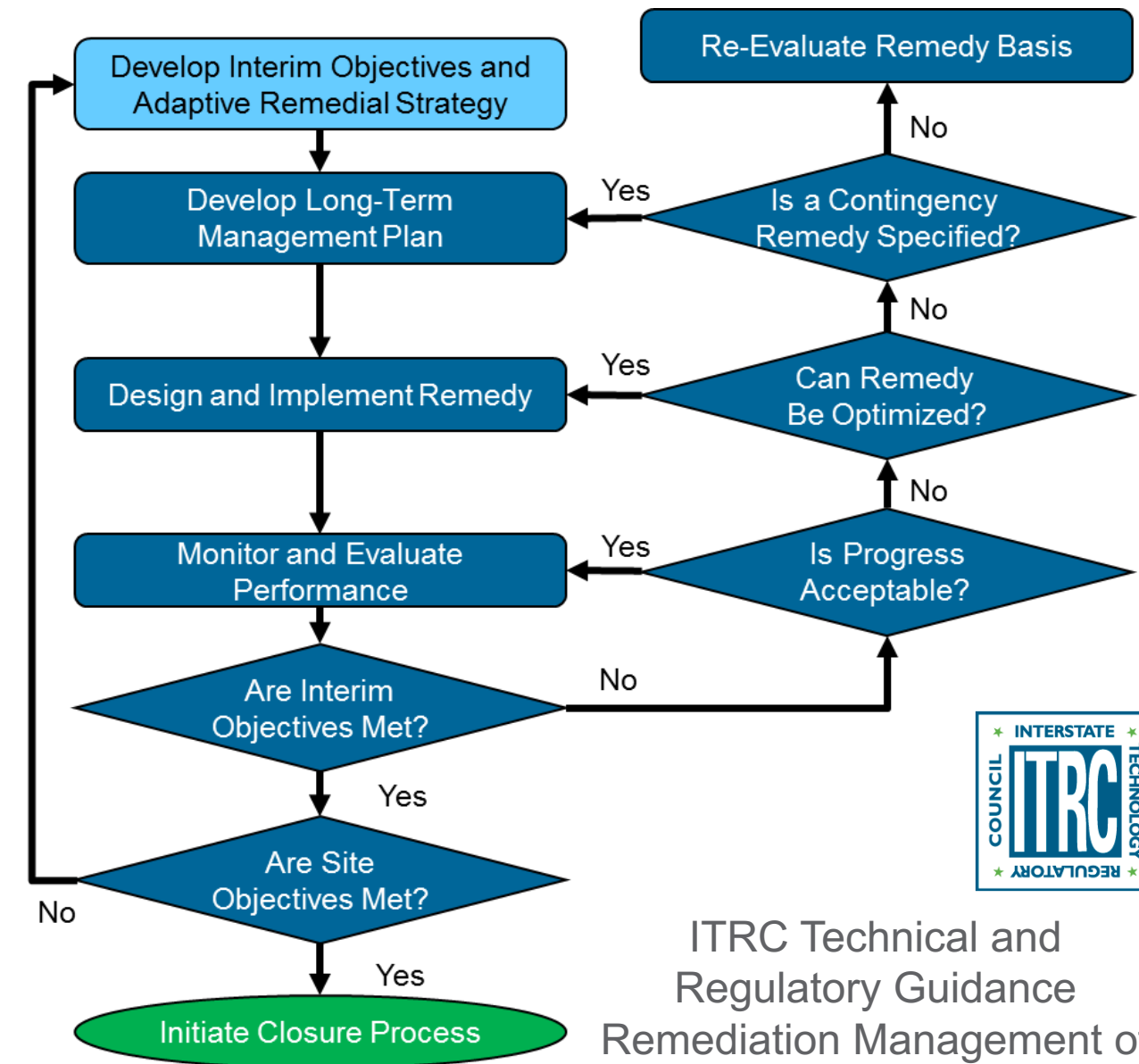
- Predetermined condition is reached
 - ✓ Source strength, plume behavior, etc.
- Asymptotic behavior under current remedy
- Current remedy has become impractical
- Conditions warrant a TI evaluation or development of alternative RAOs



After NAVFAC, 2012

How to Consider a Transition Assessment

- Adaptive management framework can be used for active to passive transition
 - ✓ Addresses uncertainties and enables interim actions
- Recent Guidance for Adaptive Site Management and End States
 - ✓ Remediation Management of Complex Sites (ITRC, 2017)
 - ✓ Groundwater Remedy Completion Strategy: Moving Forward with the End in Mind (EPA, 2014)
 - ✓ Groundwater Read Map- Recommended Processes for Restoring Contaminated Groundwater at Superfund Sites (EPA, 2011)
 - ✓ Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. (National Research Council (NRC), 2013)
- Technical Basis for Active to Passive Transition
 - ✓ Soil Vapor Extraction (Truex et al., 2013)
 - ✓ Pump and Treat (Truex et al., 2015, 2017)



Transition Assessment Framework

1. Refine Conceptual Site Model

- Determine dominant processes under passive conditions
- Identify key complexities at site
- Estimate uncertainties

2. Evaluate Site Objectives

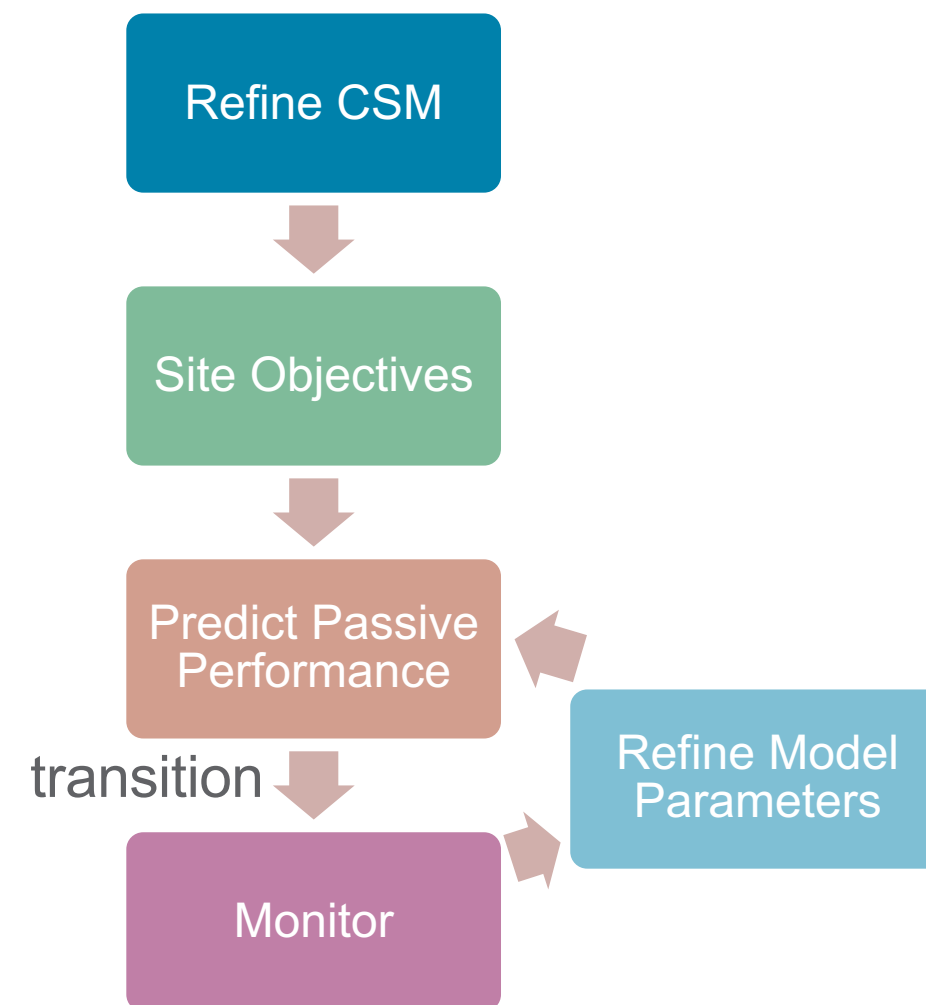
- Potential exposure pathways
- Remedial Action Objective concentrations
- Determine site constraints

3. Predict Passive Remedy Performance

- Quantify potential impact of remaining source material
- Estimate key fate and transport parameters

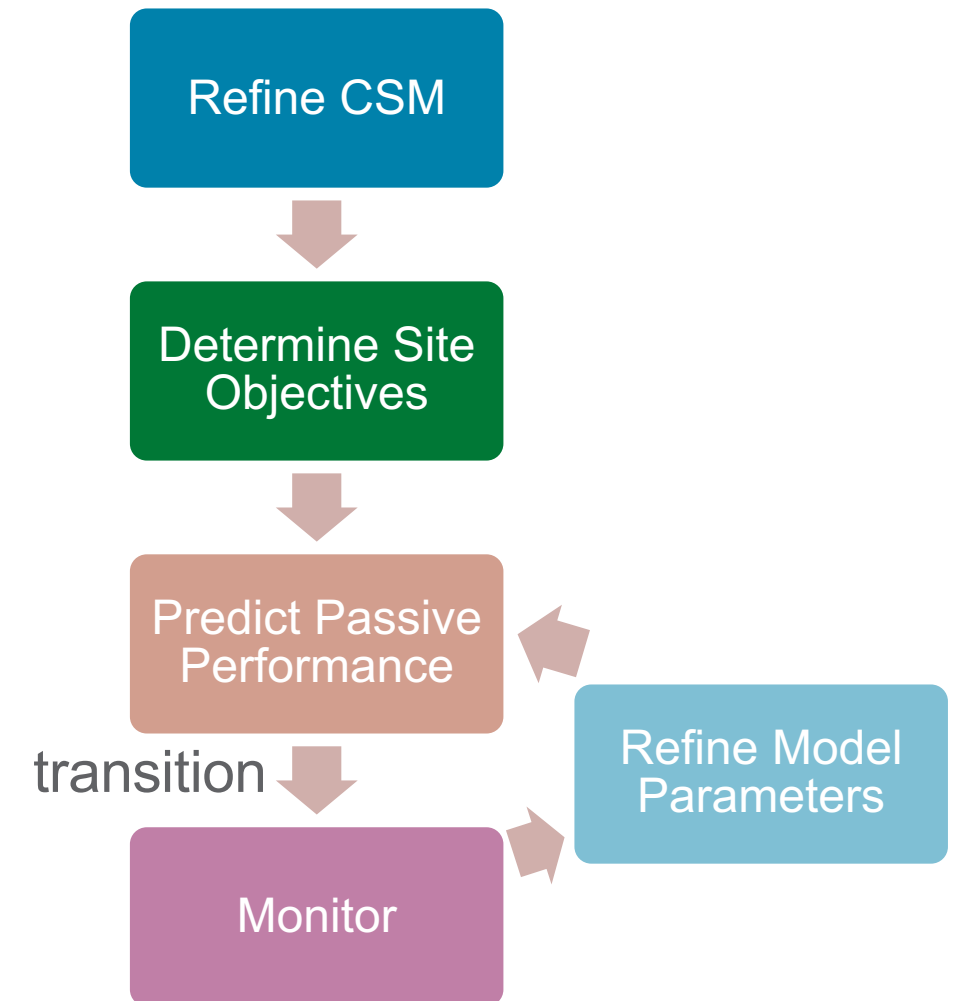
4. Monitor for Selected Performance Indicators

5. Refine and Update Model Parameters (if needed)



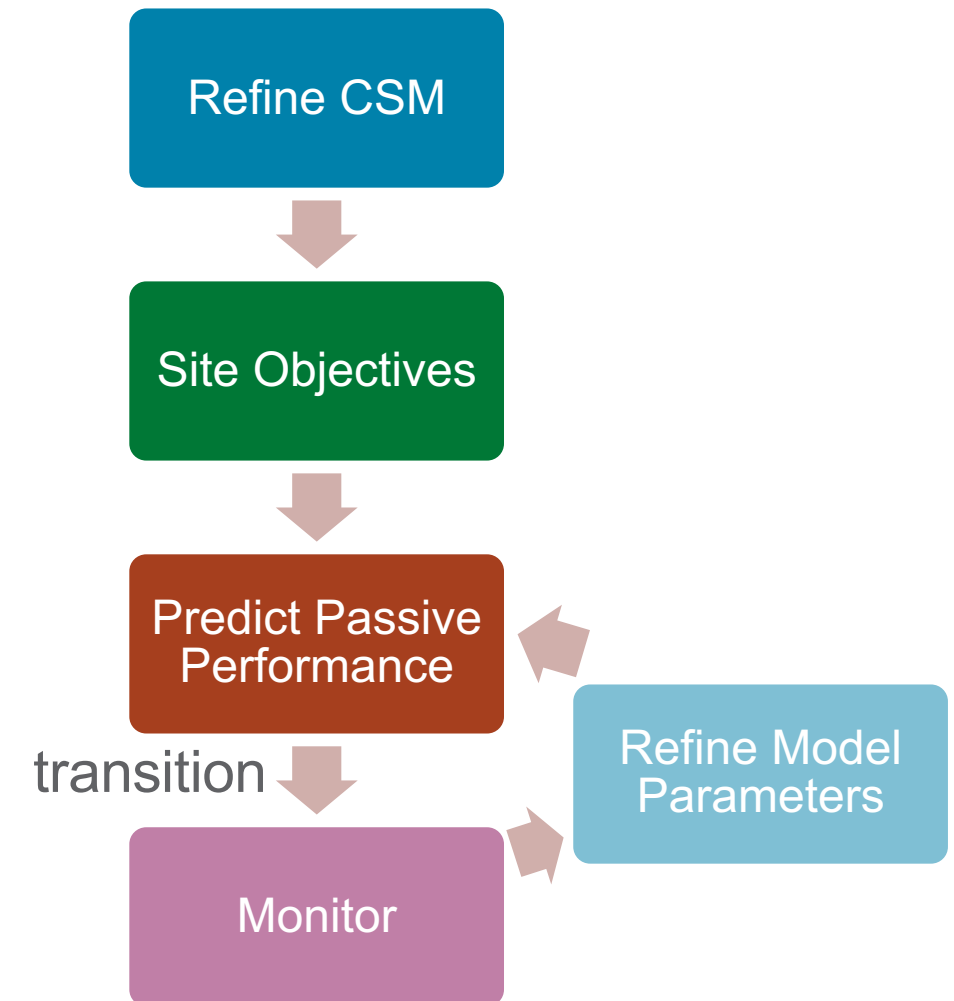
Transition Assessment Framework

1. Refine Conceptual Site Model
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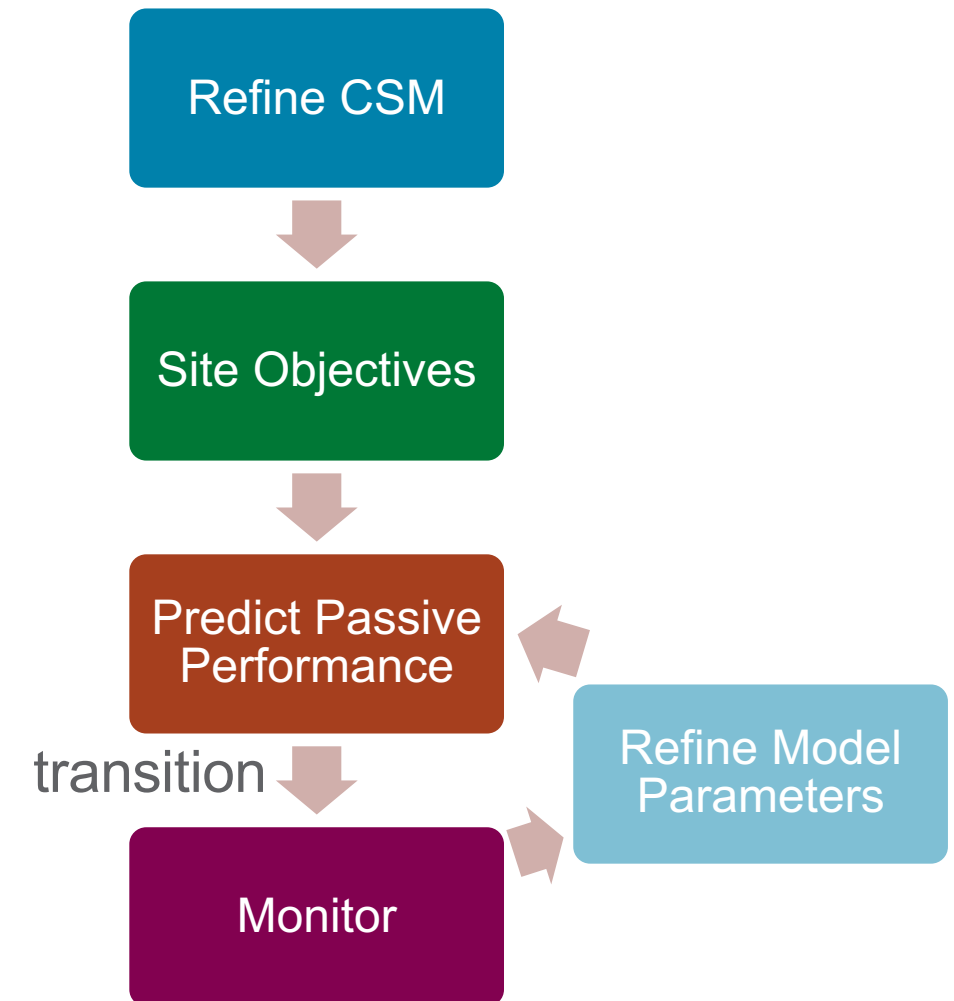
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Transition Assessment Framework

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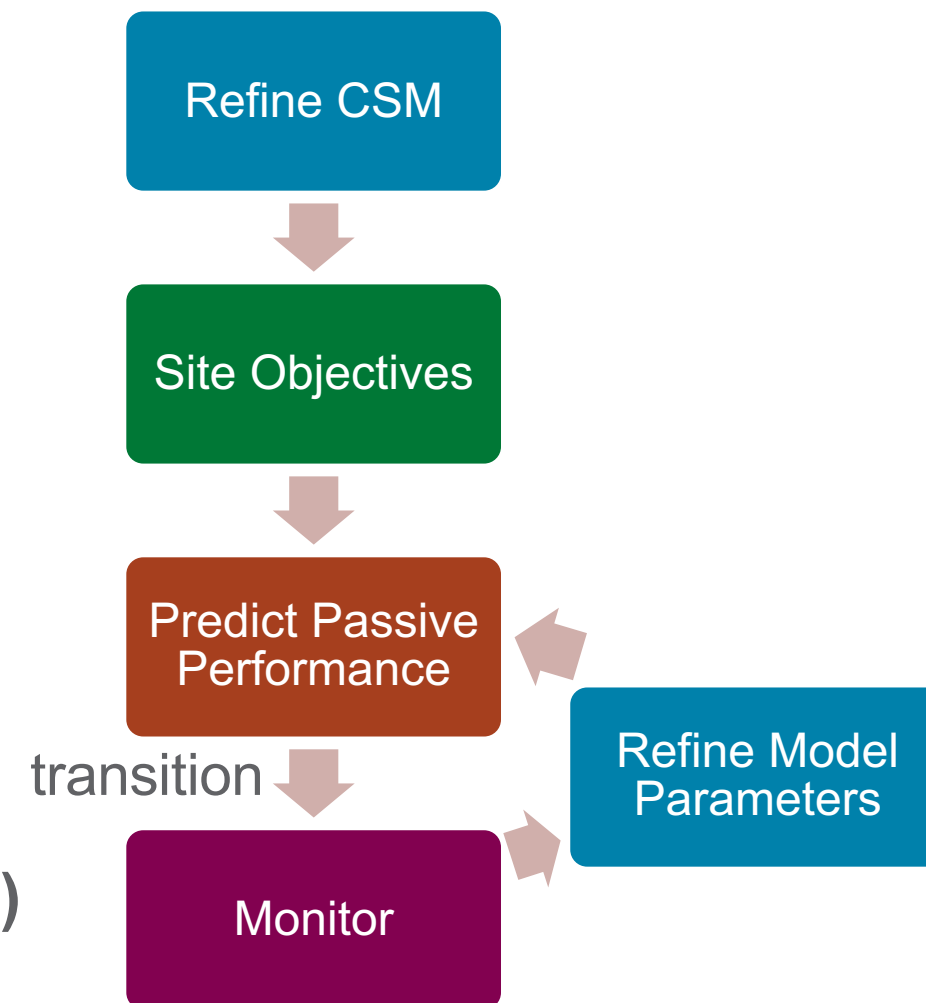
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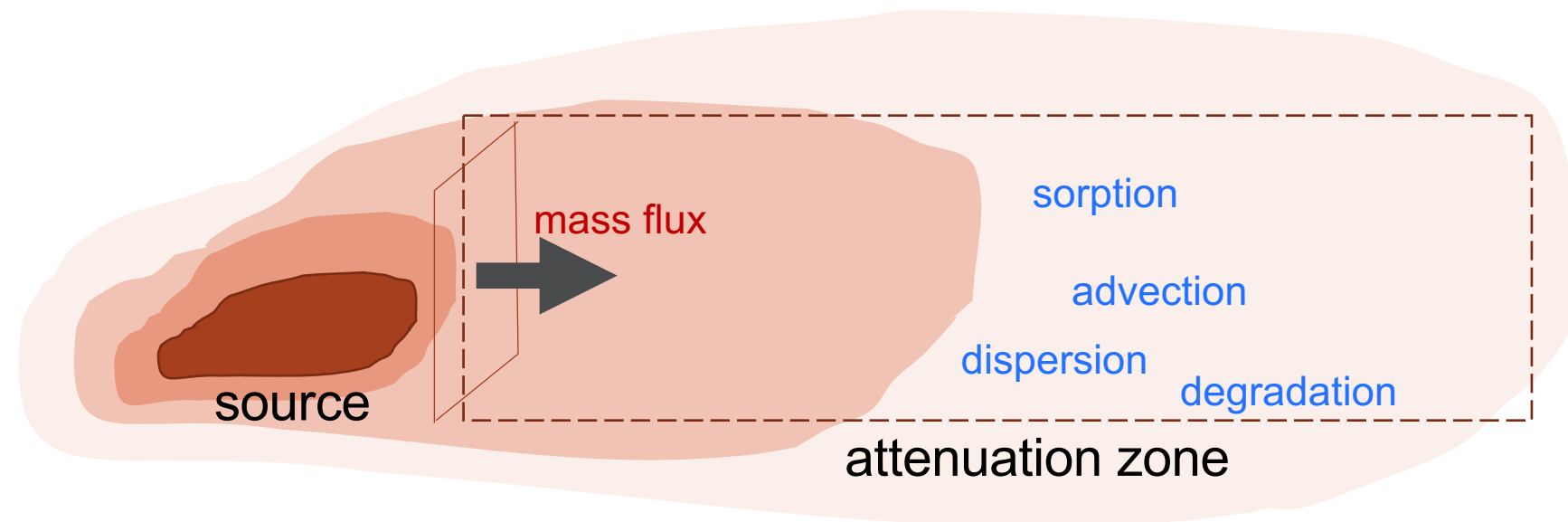
4. Monitor for Selected Performance Indicators

5. Refine and Update Model Parameters (if needed)



Relating Mass Estimates to Potential Site Impacts

Balance **source** and **attenuation** rates



Decision Tools:

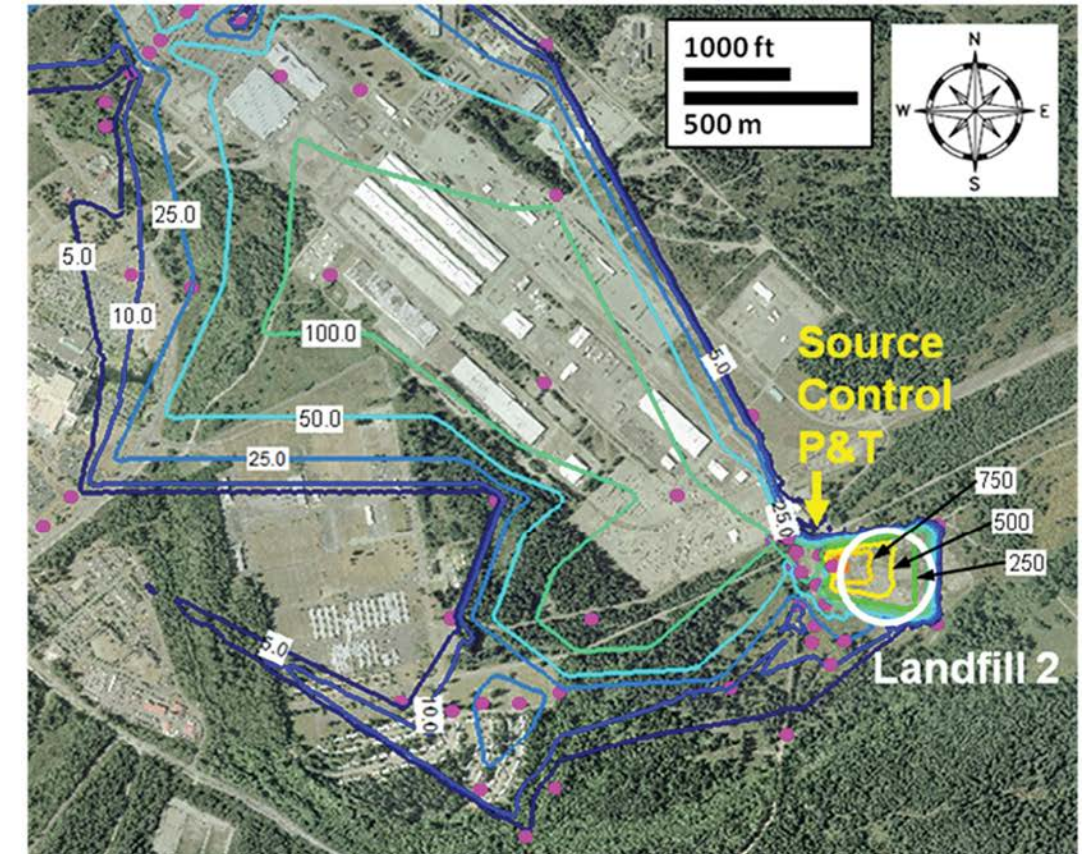
- Contaminant Concentrations and Trends
- Contaminant Mass Discharge
- Attenuation Rates and Capacity
- Fate and Transport Assessment
- Comparison to Threshold Concentration (RAO)

Quantifying Source: Mass-In-Place

- Inventory of contaminant mass
 - Form (aqueous, sorbed, NAPL, gaseous, etc.)
 - Location (depth, saturated, unsaturated, different aquifers, aquitards, and porous medias)

Methods:

- Volume x Concentration Estimation
- Isoconcentration Contours



TCE Isoconcentration Contours

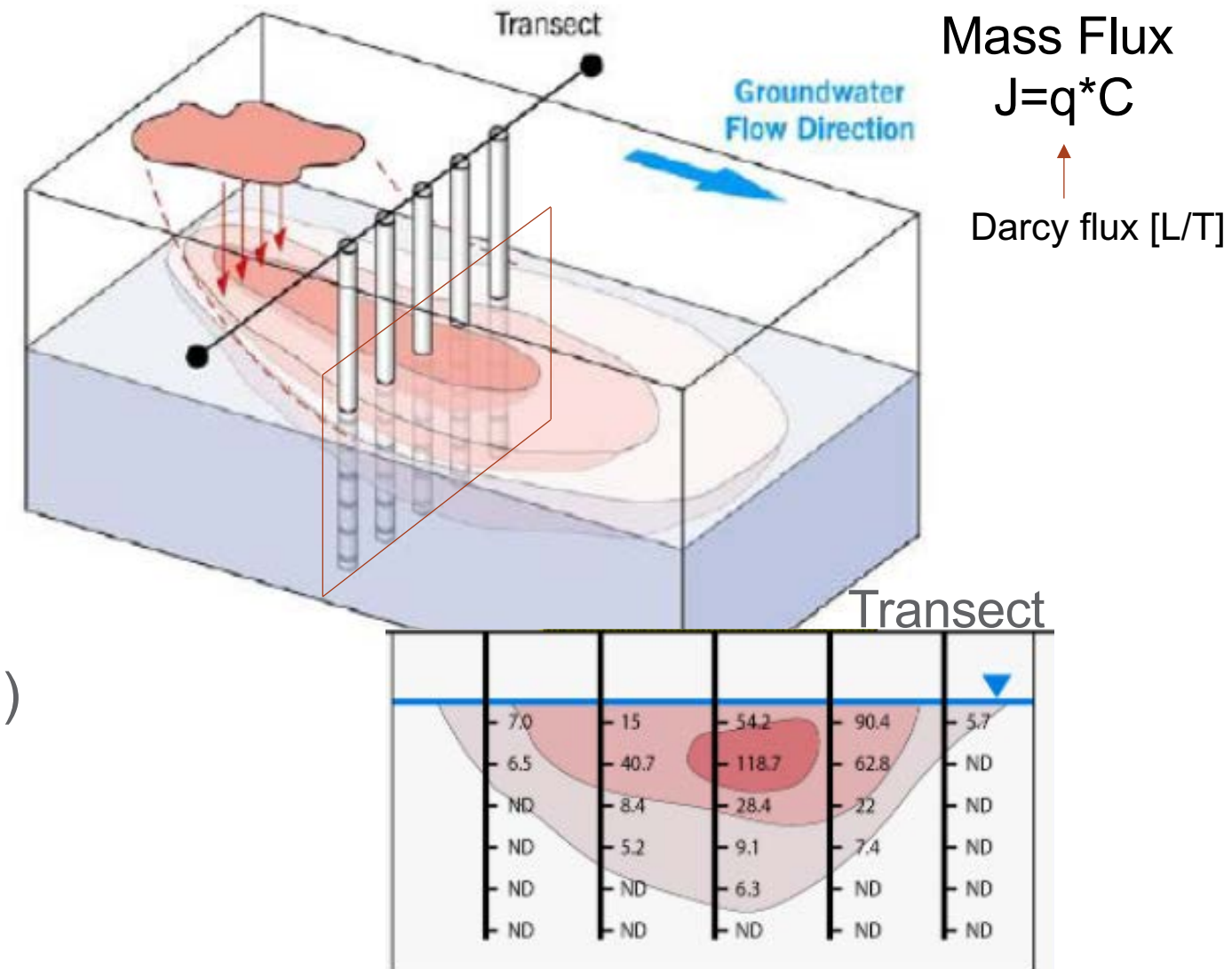
Truex et al 2017

Quantifying Source: Mass Discharge

- Mass discharge is the mass of COC per time [M/T]
- Mass flux mass per area per time [M/L²/T]

Methods:

- Transect Method ($M_d = \sum C_i \cdot A_i \cdot q_i$)
 - ✓ Increasing complexity
 - Variable groundwater velocity
 - Variable conc with depth (multilevel sampling)
- Pump tests (can use existing P&T systems)
- Passive flux samplers
- Rebound testing

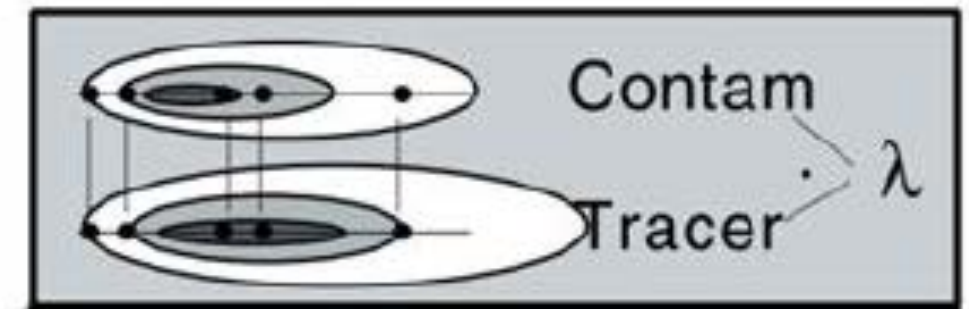
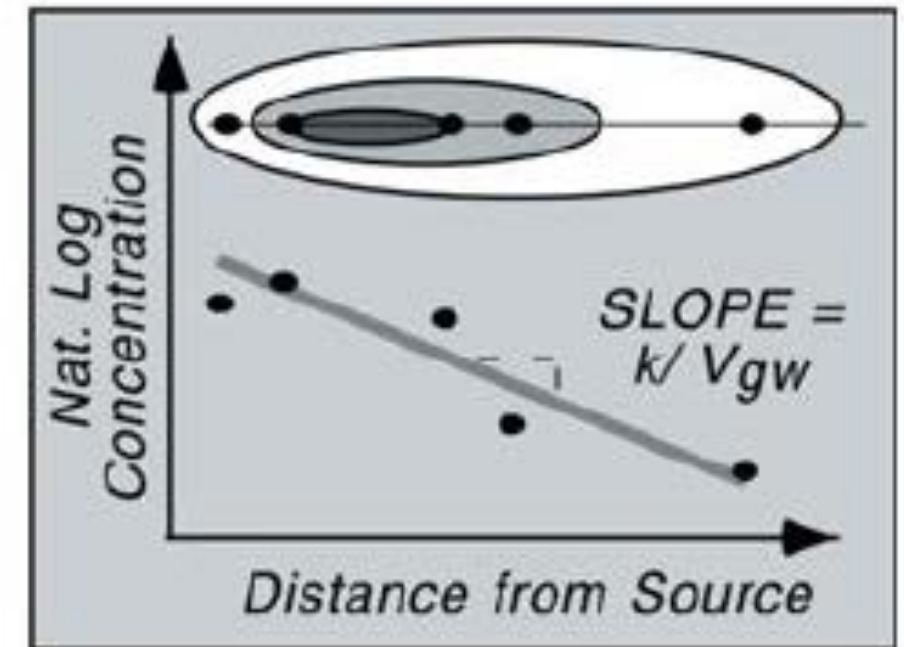


Natural Attenuation Rates and Capacity

- Estimate processes that reduce downgradient concentrations
 - Advective, dispersive mixing, sorption, abiotic/biotic degradation and transformations

Methods:

- Sampling of multiple downgradient wells along the flow path
- Tracer/Push-Pull Tests
- Compound Specific Isotope Analysis (CSIA)
- Microbial Analysis



EPA 2002

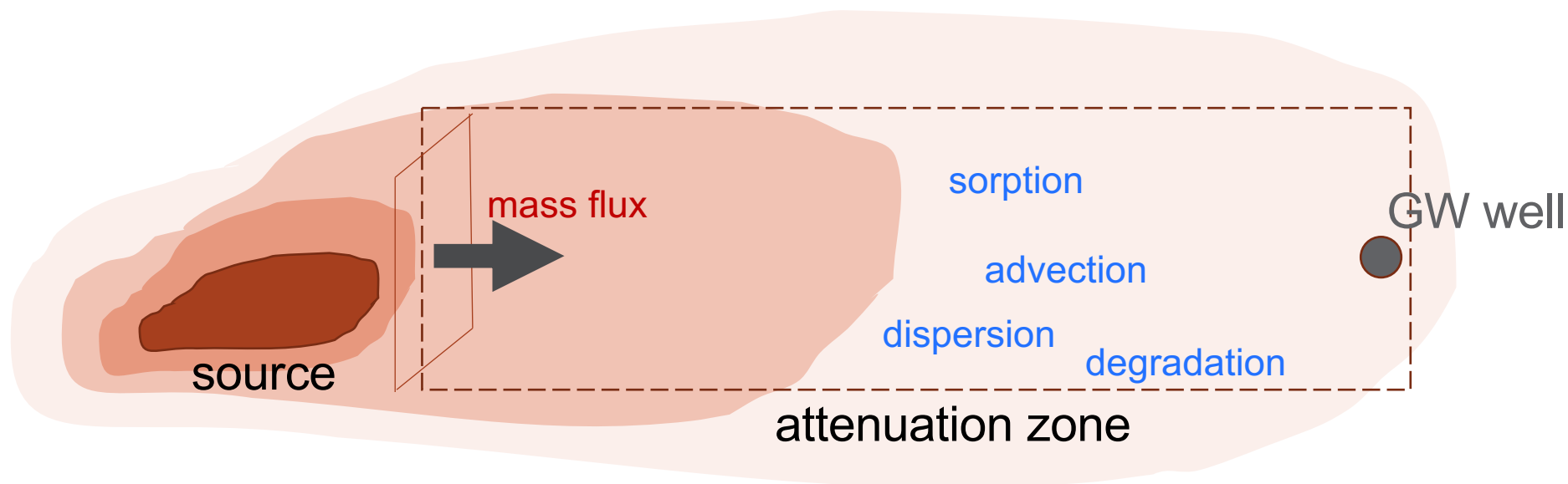
Estimating Impacts

Put **Source** and **Attenuation** estimates together

- Threshold-concentration
 - ✓ mass discharge – attenuation < RAO?

$$\text{Threshold Conc} = C_{RAO} + k \frac{x}{v_{COC}}$$

$$v_{COC} = \frac{\frac{q_{ambient}}{n}}{R_{COC}}$$



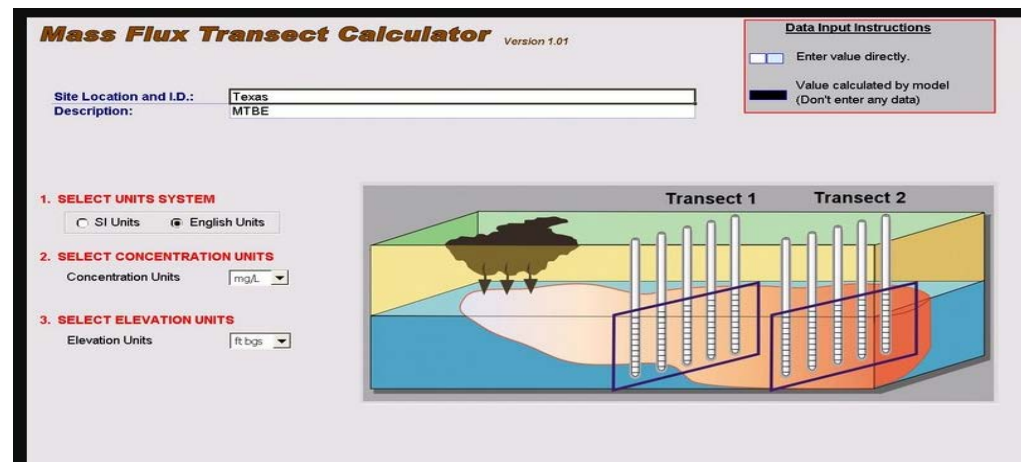
- Fate and transport assessments

Software Tools

Mass Flux Toolkit (GSI, ESTCP)
<https://www.gsi-net.com/en/software/free-software/mass-flux-toolkit.html>

SourceDK (GSI, 2011)
https://clu-in.org/products/dst/DST_Tools/SourceDK.htm

Matrix Diffusion Toolkit (GSI, 2012)
<https://www.gsi-net.com/en/software/free-software/matrix-diffusion-toolkit.html>



Mass Flux Transect Calculator Version 1.01

Site Location and ID.: Texas
Description: MTBE

1. SELECT UNITS SYSTEM
SI Units English Units

2. SELECT CONCENTRATION UNITS
Concentration Units mg/L

3. SELECT ELEVATION UNITS
Elevation Units ft bgs

Data Input Instructions
Enter value directly.
Value calculated by model (Don't enter any data)

Transect 1 **Transect 2**



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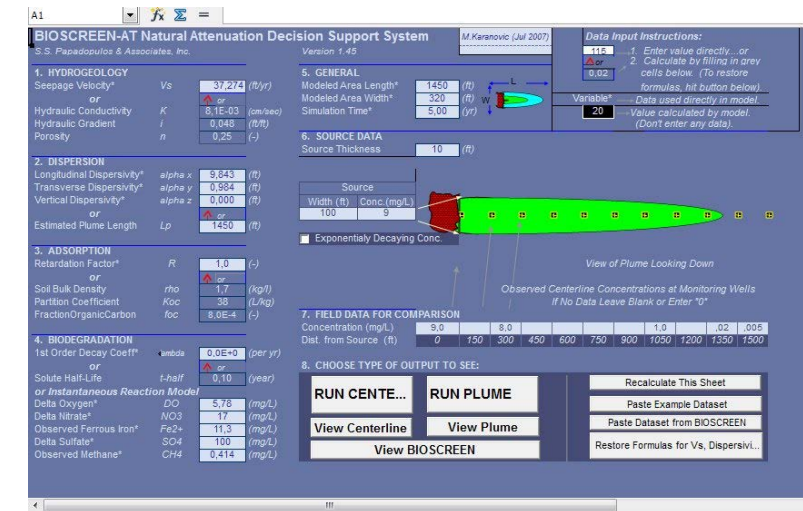
Natural Attenuation Software (NAS)
<https://www.nas.cee.vt.edu/index.php>

BIOCHLOR (chlorinated solvents)
<https://www.epa.gov/water-research/biochlor-natural-attenuation-decision-support-system>

BIOSCREEN (Petroleum Hydrocarbons) (EPA, 1997, 2002)
<https://www.epa.gov/water-research/bioscreen-natural-attenuation-decision-support-system>

REMChlor/REMFuel
<https://www.epa.gov/water-research/remediation-evaluation-model-chlorinated-solvents-remchlor>

Fate and Transport Models
✓ STOMP, MODFLOW, MT3D, RT3D



BIOSCREEN-AT Natural Attenuation Decision Support System Version 1.42

1. HYDROGEOLOGY
Seepage Velocity* Vs 3.224 (ft/yr)
Hydraulic Conductivity K 8.1E-03 (cm/sec)
Hydraulic Gradient i 0.048 (ft/ft)
Porosity n 0.25 (-)

2. DISPERSION
Longitudinal Dispersivity* alpha x 9.843 (ft)
Transverse Dispersivity* alpha y 0.984 (ft)
Vertical Dispersivity* alpha z 0.000 (ft)
Estimated Plume Length Lp 1450 (ft)

3. ADSORPTION
Retardation Factor* R 1.0 (-)
Soil Bulk Density rho 1.7 (kg/L)
Partition Coefficient Koc 38 (L/kg)
Fraction Organic Carbon foc 8.0E-4 (-)

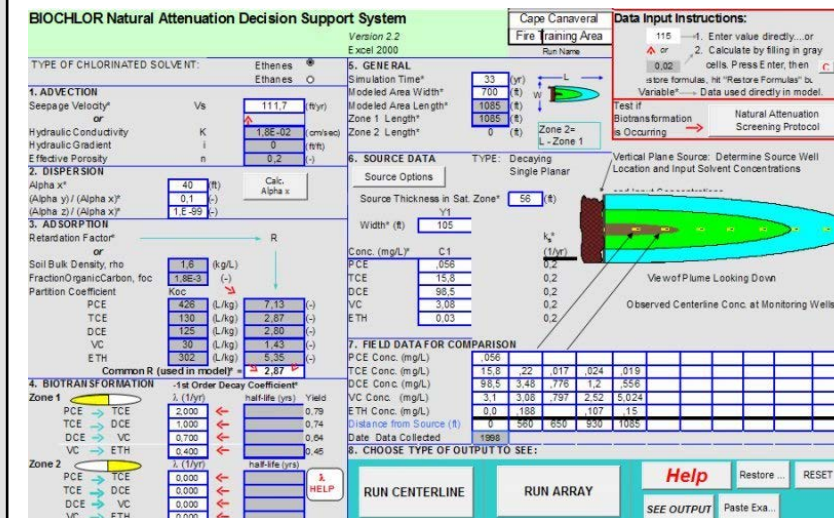
4. BIODEGRADATION
1st Order Decay Coeff* lambda 0.0E+0 (per yr)
Solute Half-Life t-half 0.10 (year)
or Instantaneous Reaction Model Delta Oxygen DO 5.78 (mg/L)
Delta Nitrate NO3 17 (mg/L)
Observed Ferrous Iron Fe2+ 11.3 (mg/L)
Delta Sulfate SO4 100 (mg/L)
Observed Methane CH4 0.414 (mg/L)

5. GENERAL
Model Area Length* 1450 (ft)
Model Area Width* 320 (ft)
Simulation Time* 5.00 (yr)

6. SOURCE DATA
Source Thickness 10 (ft)

7. FIELD DATA FOR COMPARISON
Concentration (mg/L) 9.0 150 300 450 600 750 900 1050 1200 1350 1500
Dist. from Source (ft) 0 150 300 450 600 750 900 1050 1200 1350 1500

8. CHOOSE TYPE OF OUTPUT TO SEE:
RUN CENTE... RUN PLUME
View Centerline View Plume
View BIOSCREEN



BIOCHLOR Natural Attenuation Decision Support System Version 2.2
Excel 2000

TYPE OF CHLORINATED SOLVENT: Ethanes
1. ADVECTION
Seepage Velocity* Vs 111.7 (ft/yr)
Hydraulic Conductivity K 1.8E-02 (cm/sec)
Effective Porosity n 0.2 (-)

2. DISPERSION
Alpha x* 40 (ft)
Alpha y* 0.1 (ft)
Alpha z* 1E-59 (ft)

3. ADSORPTION
Retardation Factor* R 1.0 (-)
Soil Bulk Density rho 1.8 (kg/L)
Fraction Organic Carbon, foc 1.8E-3 (-)
Partition Coefficient Koc 425 (L/kg)
PCE 130 (L/kg)
TCE 125 (L/kg)
VC 30 (L/kg)
ETH 302 (L/kg)

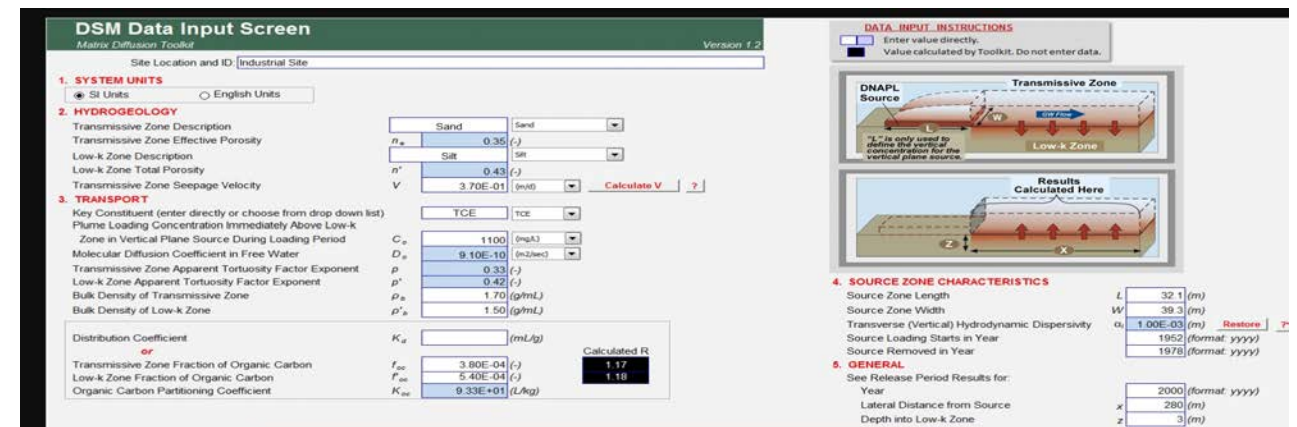
4. BIOTRANSFORMATION
Common R (used in model) 2.87 (-)
Zone 1
PCE TCE 2.000 (-)
TCE DCE 1.000 (-)
DCE VC 0.700 (-)
VC ETH 0.400 (-)
Zone 2
PCE TCE 6.000 (-)
TCE DCE 6.000 (-)
DCE VC 6.000 (-)
VC ETH 6.000 (-)

5. GENERAL
Simulation Time* 33 (yr)
Model Area Width* 700 (ft)
Model Area Length* 1085 (ft)
Zone 1 Length* 0 (ft)
Zone 2 Length* 0 (ft)

6. SOURCE DATA
Source Options TYPE: Decaying Single Planar
Source Thickness in Sat. Zone* 56 (ft)
Width* (ft) 105
Conc. (mg/L)* C1 0.056
PCE 0.056
TCE 15.8
DCE 98.5
VC 3.08
ETH 0.03

7. FIELD DATA FOR COMPARISON
PCE Conc. (mg/L) 15.8 22 017 024 019
TCE Conc. (mg/L) 3.1 3.08 797 2.52 5.024
DCE Conc. (mg/L) 98.5 3.48 778 1.2 556
VC Conc. (mg/L) 0.0 188 107 15
ETH Conc. (mg/L) 0.03 0.03 0.03 0.03 0.03

8. CHOOSE TYPE OF OUTPUT TO SEE:
RUN CENTERLINE RUN ARRAY
Help Restore ... RESET
SEE OUTPUT Paste Exa...



DSM Data Input Screen Version 1.2

Site Location and ID: Industrial Site

1. SYSTEM UNITS
SI Units English Units

2. HYDROGEOLOGY
Transmissive Zone Description
Transmissive Zone Effective Porosity n* 0.35 (-)
Low-k Zone Description
Low-k Zone Total Porosity n* 0.43 (-)
Transmissive Zone Seepage Velocity V 3.70E-01 (m/d)
Calculate V

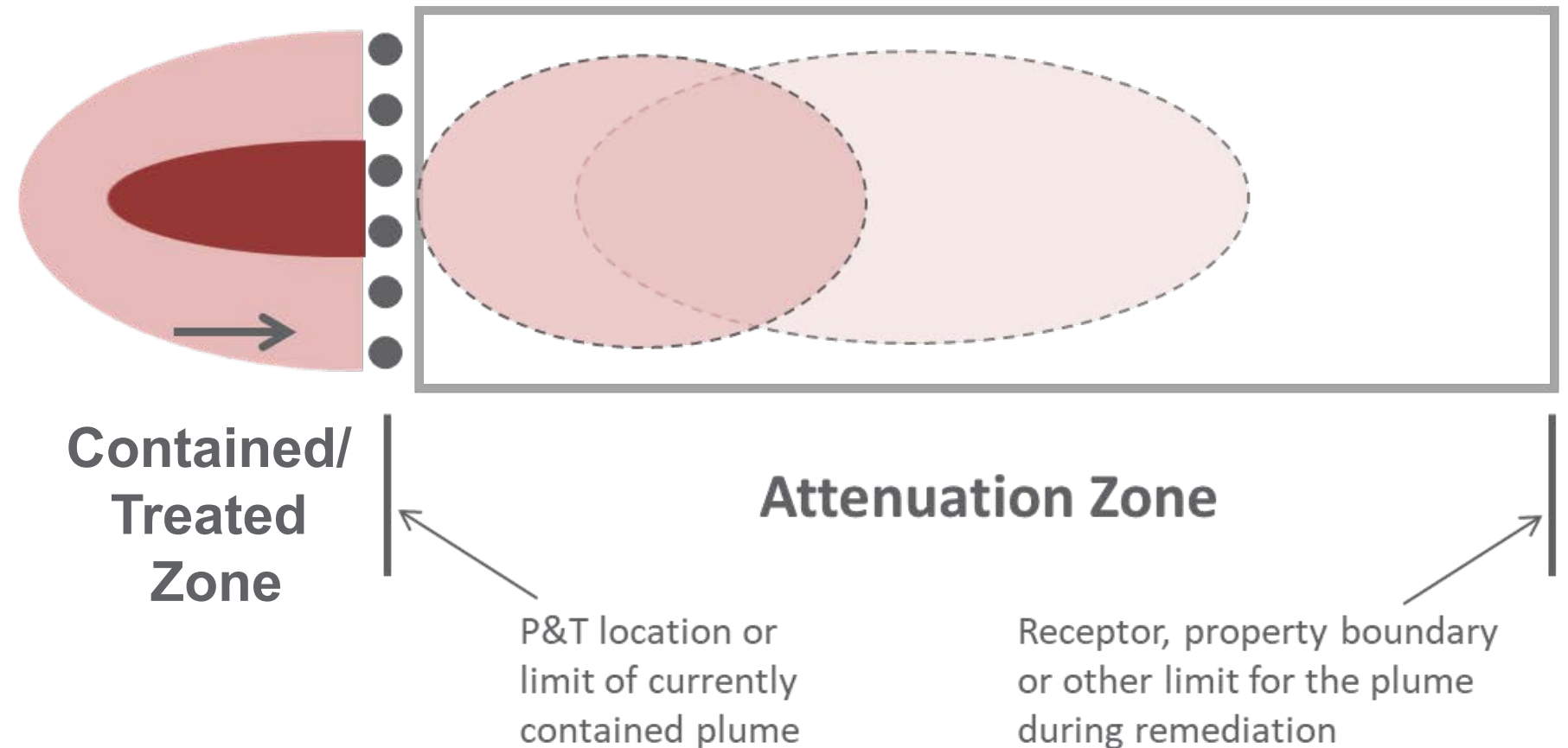
3. TRANSPORT
Key Constituent (enter directly or choose from drop down list)
Plume Loading Concentration Immediately Above Low-k Zone in Vertical Plane Source During Loading Period
Molecular Diffusion Coefficient in Free Water D* 1100 (mg/L)
Transmissive Zone Apparent Tortuosity Factor Exponent p* 0.33 (-)
Low-k Zone Apparent Tortuosity Factor Exponent p* 0.42 (-)
Bulk Density of Transmissive Zone rho* 1.70 (g/mL)
Bulk Density of Low-k Zone rho* 1.50 (g/mL)

4. SOURCE ZONE CHARACTERISTICS
Source Zone Length L 32.1 (m)
Source Zone Width W 39.3 (m)
Transverse (Vertical) Hydrodynamic Dispersivity alpha 1.00E-03 (m)
Source Loading Starts in Year 1962 (format: yyyy)
Source Removed in Year 1978 (format: yyyy)

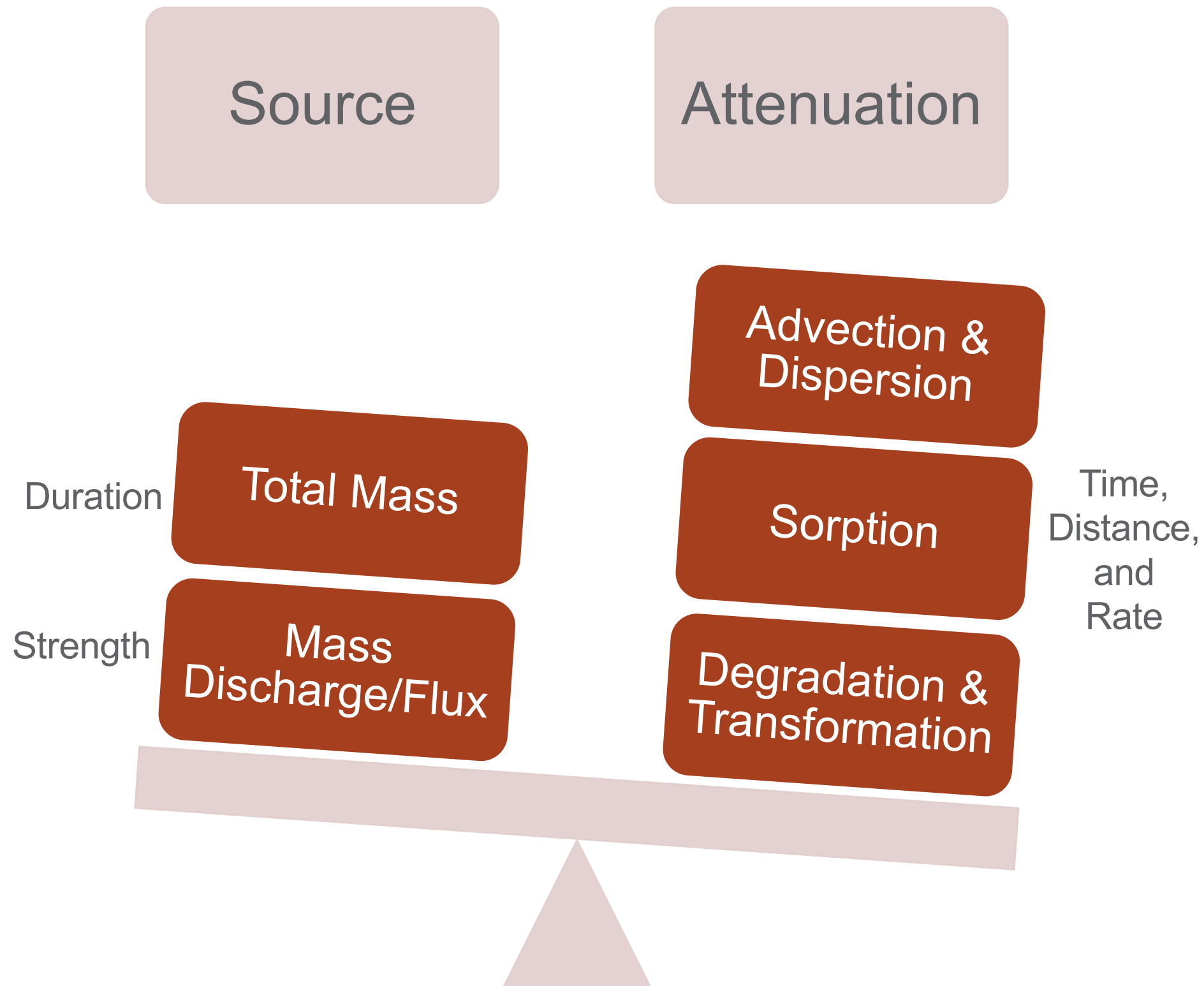
5. GENERAL
See Release Period Results for:
Year 2000 (format: yyyy)
Lateral Distance from Source x 280 (m)
Depth into Low-k Zone z 3 (m)

Active/Passive Transition Considerations

- Transient conditions after transition
- Contaminants in contained/treated zone must be balanced by attenuation
- Define size of attenuation zone and timeframe
- Need for verification of transition

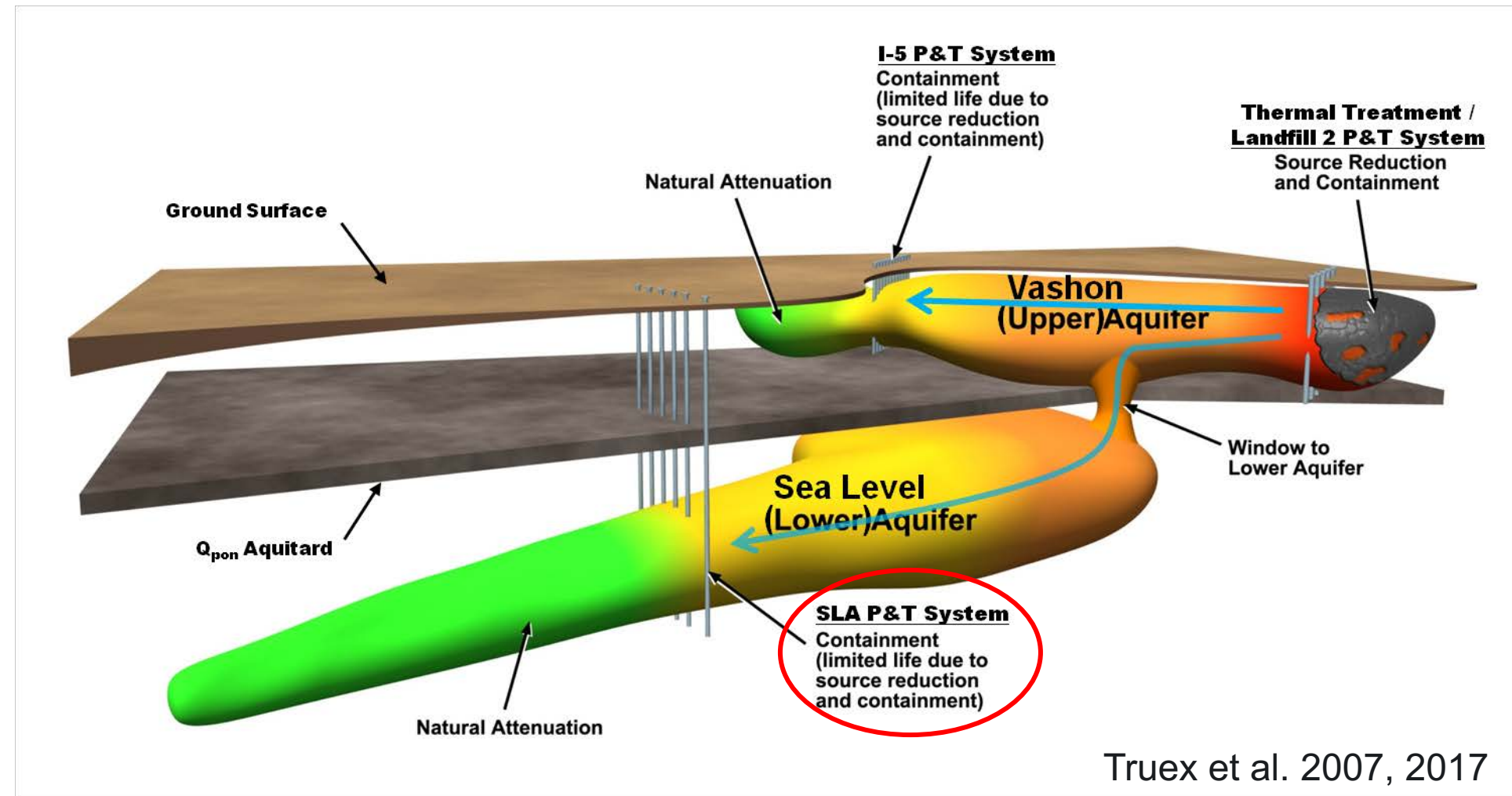


Compare Contaminant Contribution against Aquifer Attenuation Capacity



Case Study

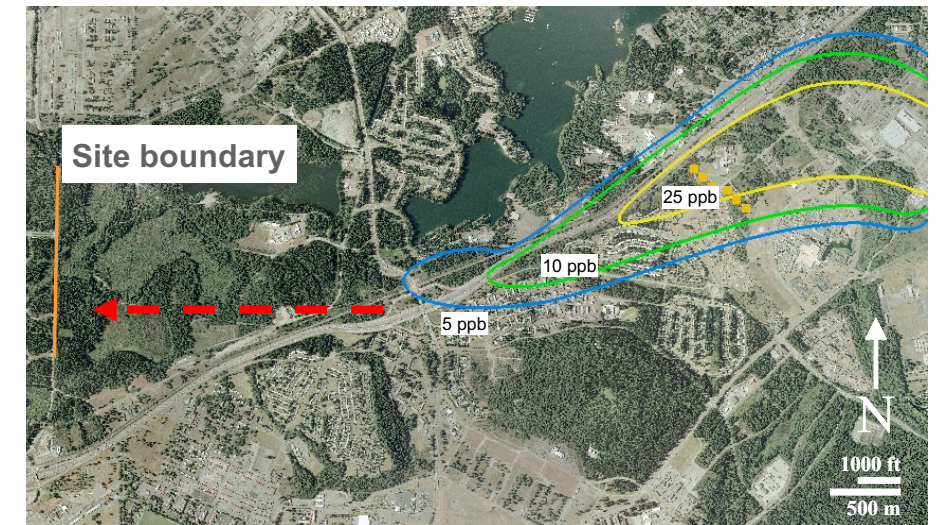
- Joint Base Lewis McChord
- System of P&T and source treatment
- Example: Sea Level Aquifer
 - Upgradient flux cut off
 - How long to P&T before transition to natural attenuation



Truex et al. 2007, 2017

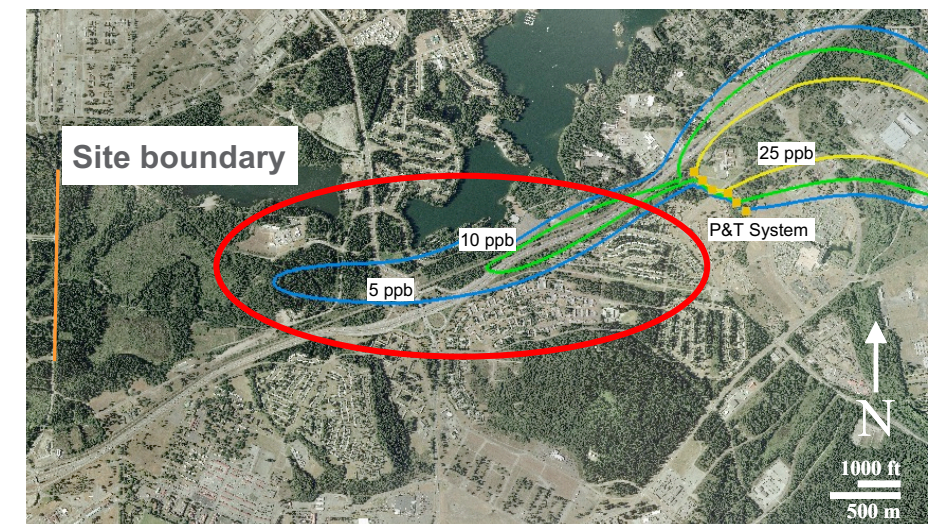
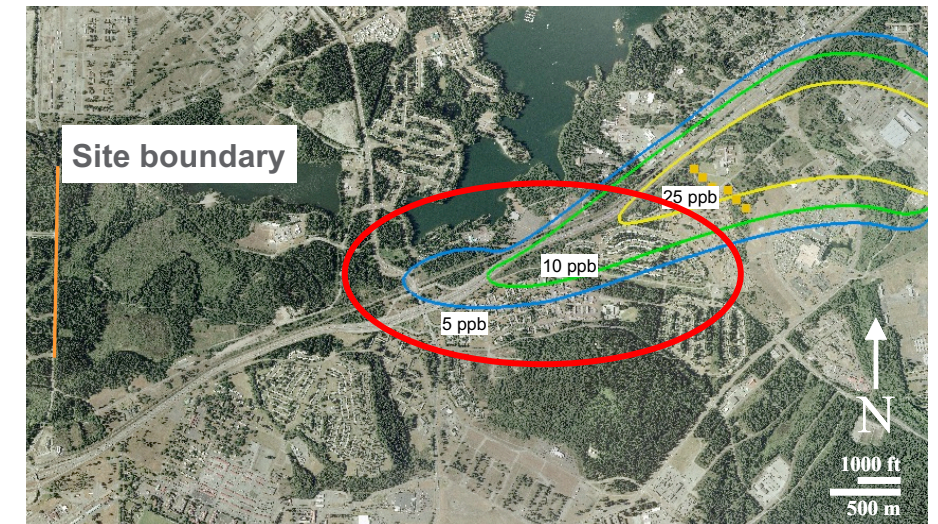
Case Study

- Remedy considered an attenuation zone and evaluation of active/passive transition for the P&T/NA system in the SLA
- Top figure, plume just before initiating P&T
- Bottom figure, estimated plume at end of P&T just before transition



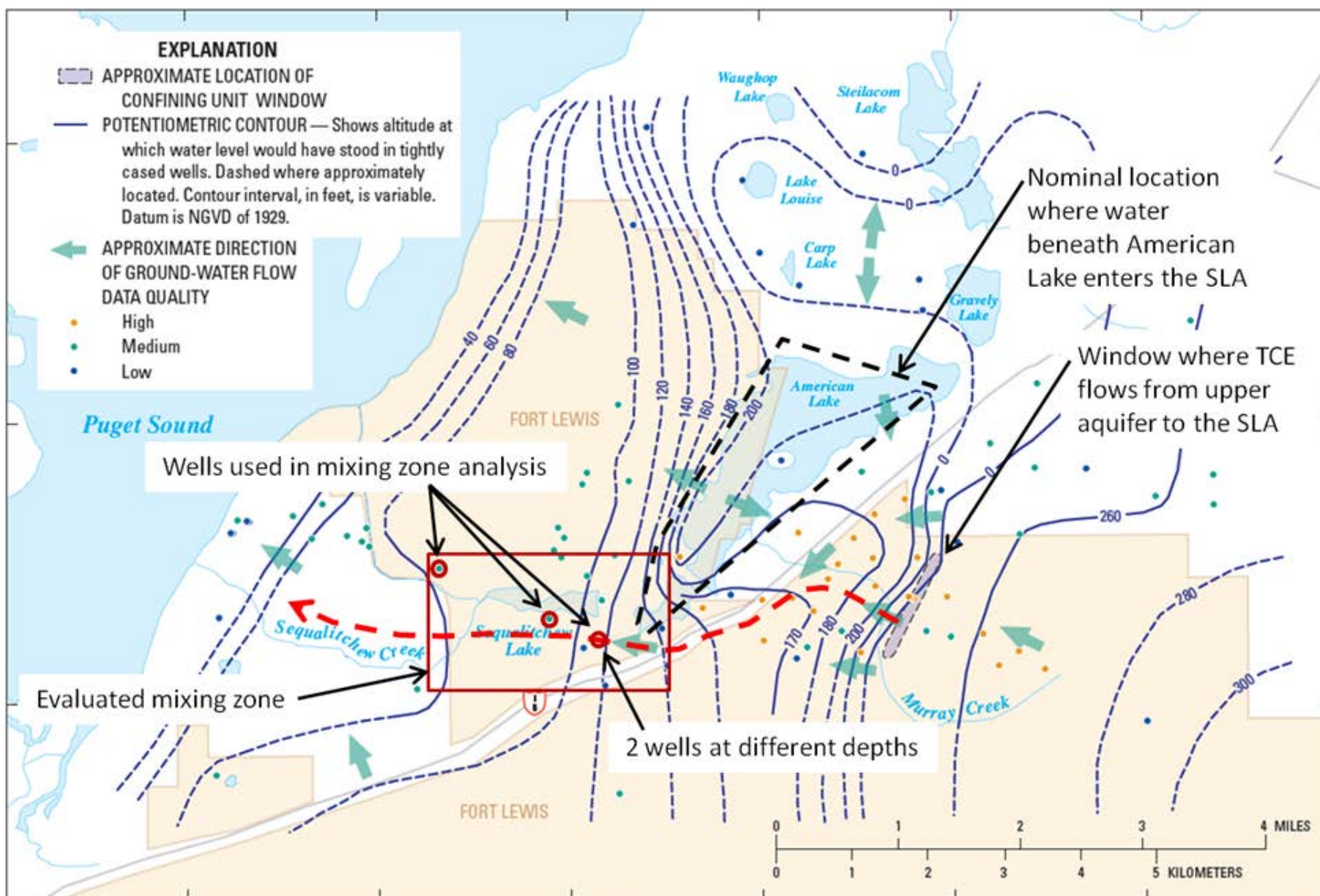
Case Study

- Prior to P&T, evaluated attenuation processes and plume migration to estimate attenuation rate
- Threshold concentration = $C_{RAO} / [e^{(-k \times t)}] = 20 \text{ ppb}$
- Predictive modeling estimates
- Initial verification through monitoring of downgradient plume natural attenuation during P&T



Case Study

- Accounting for attenuation processes and spatial aspects of the system through modeling

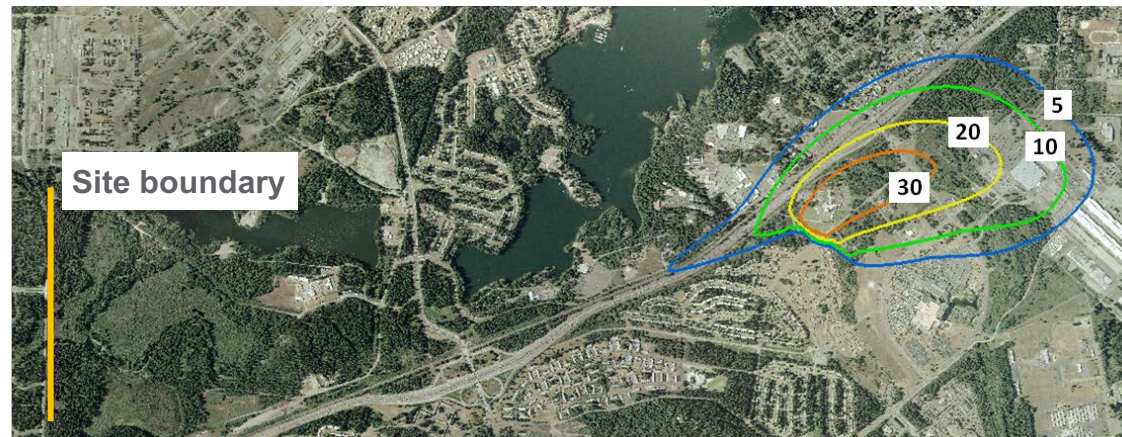


Case Study

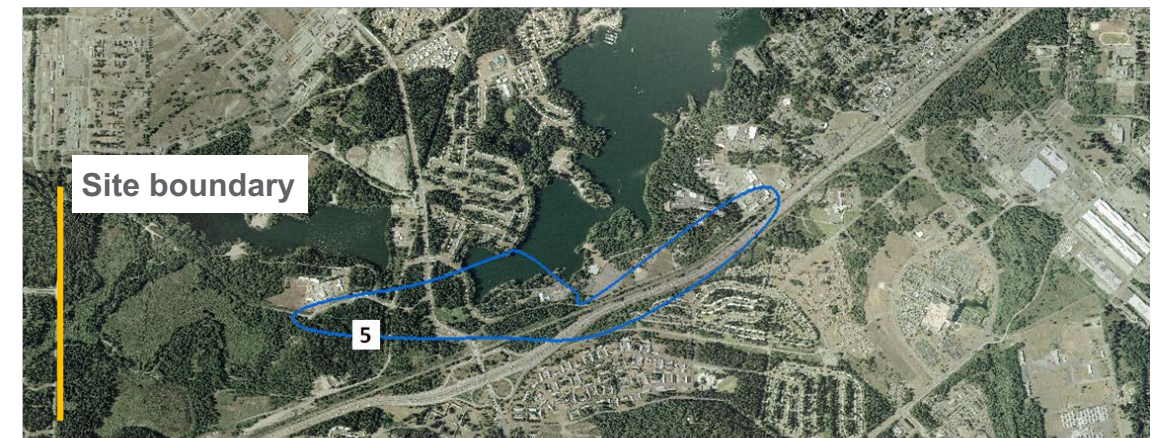
~20 years of pumping

~28 years of pumping

At transition

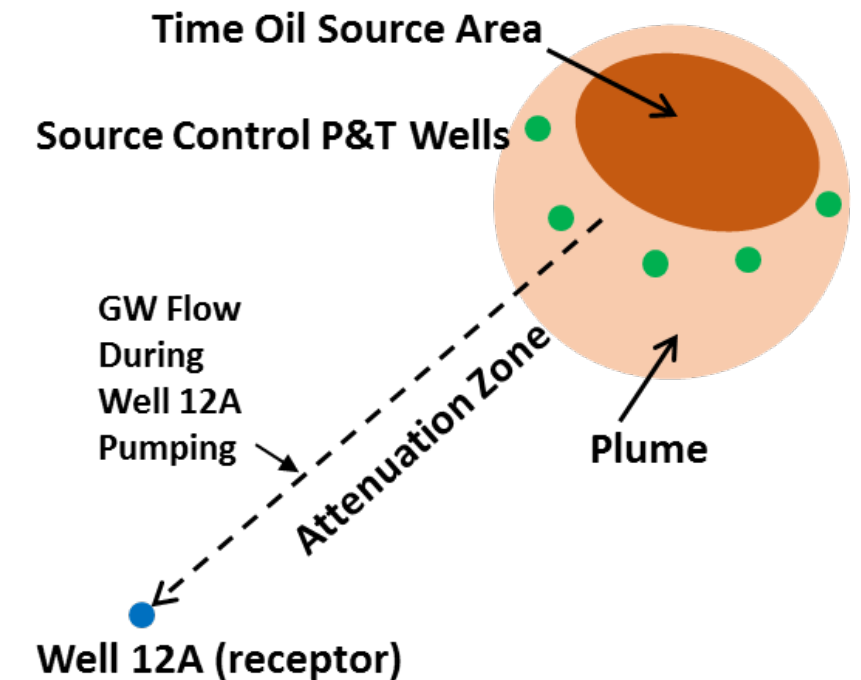


Max. plume
extent



Transition Criteria

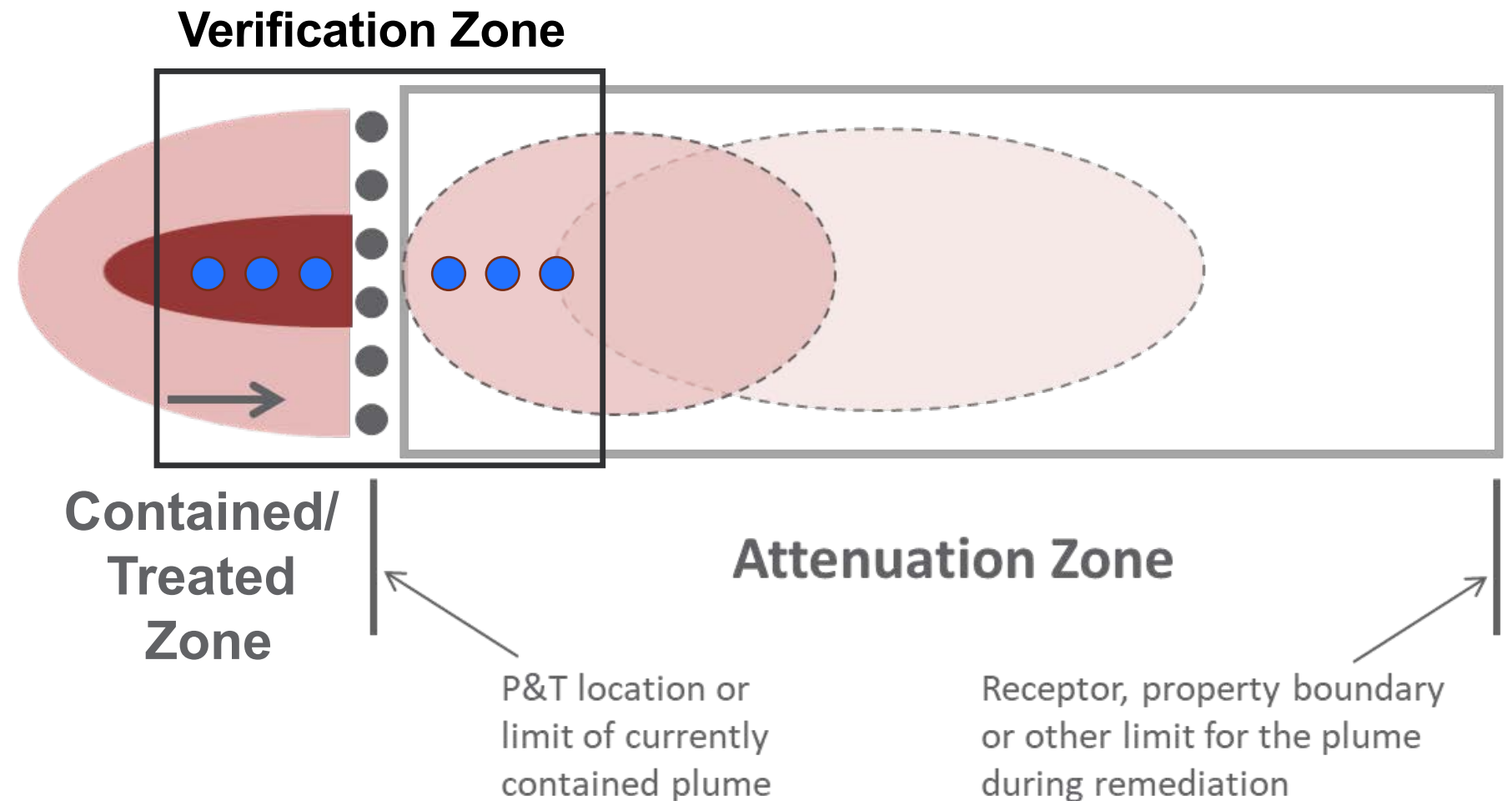
- Threshold Concentrations or Mass Discharge
- Identify P&T timeframe, threshold concentration, mass discharge reduction goal, and timeframe for plume/source in relation to selected attenuation zone
- Document transition criteria
 - Setting of interim goals in ROD
 - Verification/reassessment



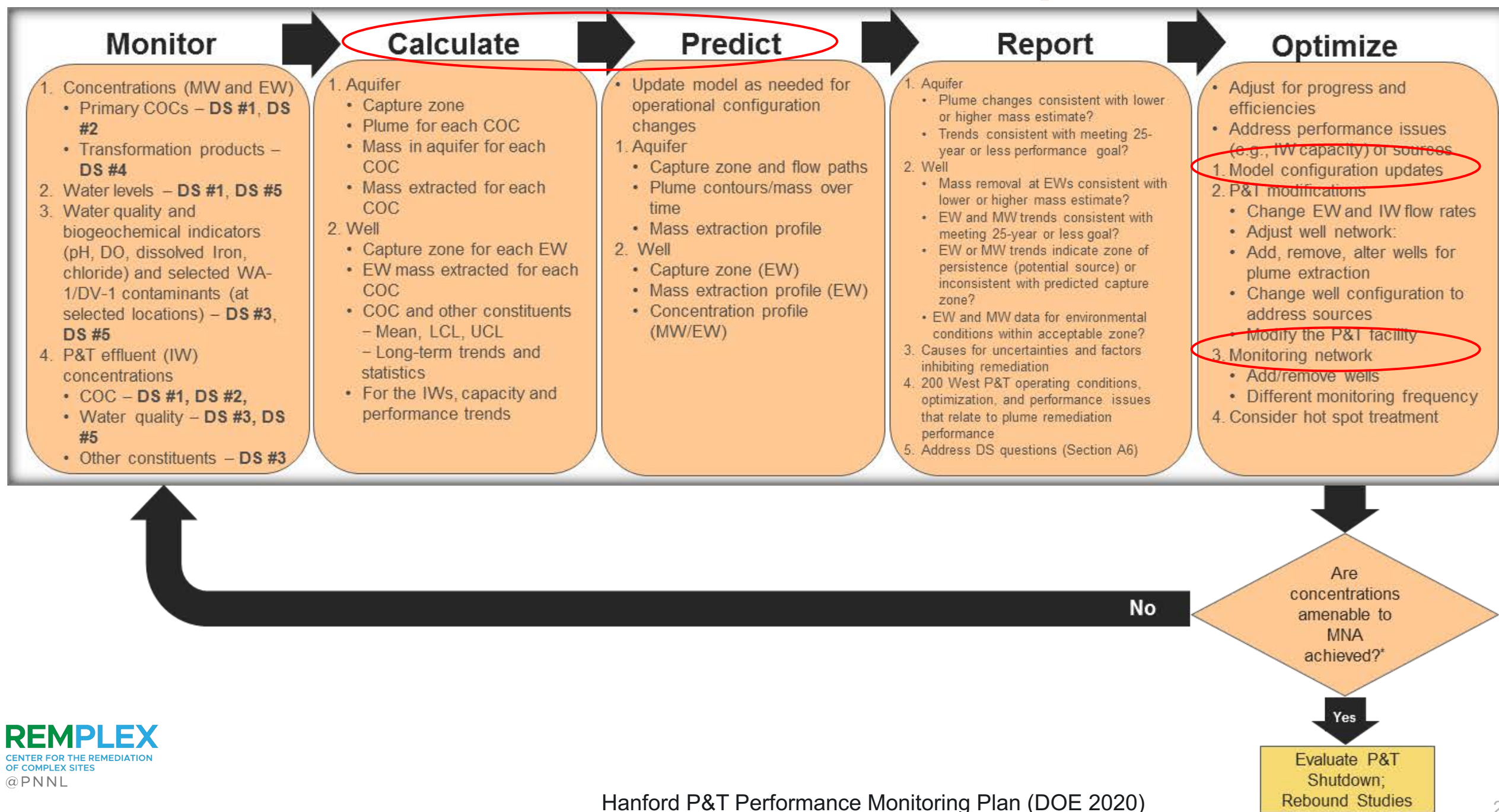
Truex et al. 2017

Verification Approaches

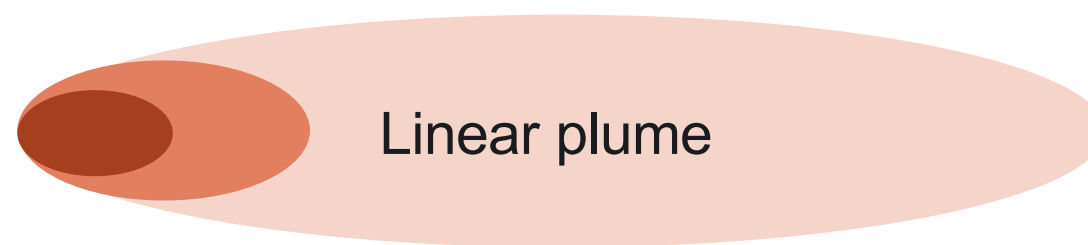
- Active remedy performance assessment
 - Active zone
 - Downgradient zone
- Staged verification
 - rebound testing
- Post-transition verification
 - contingency actions



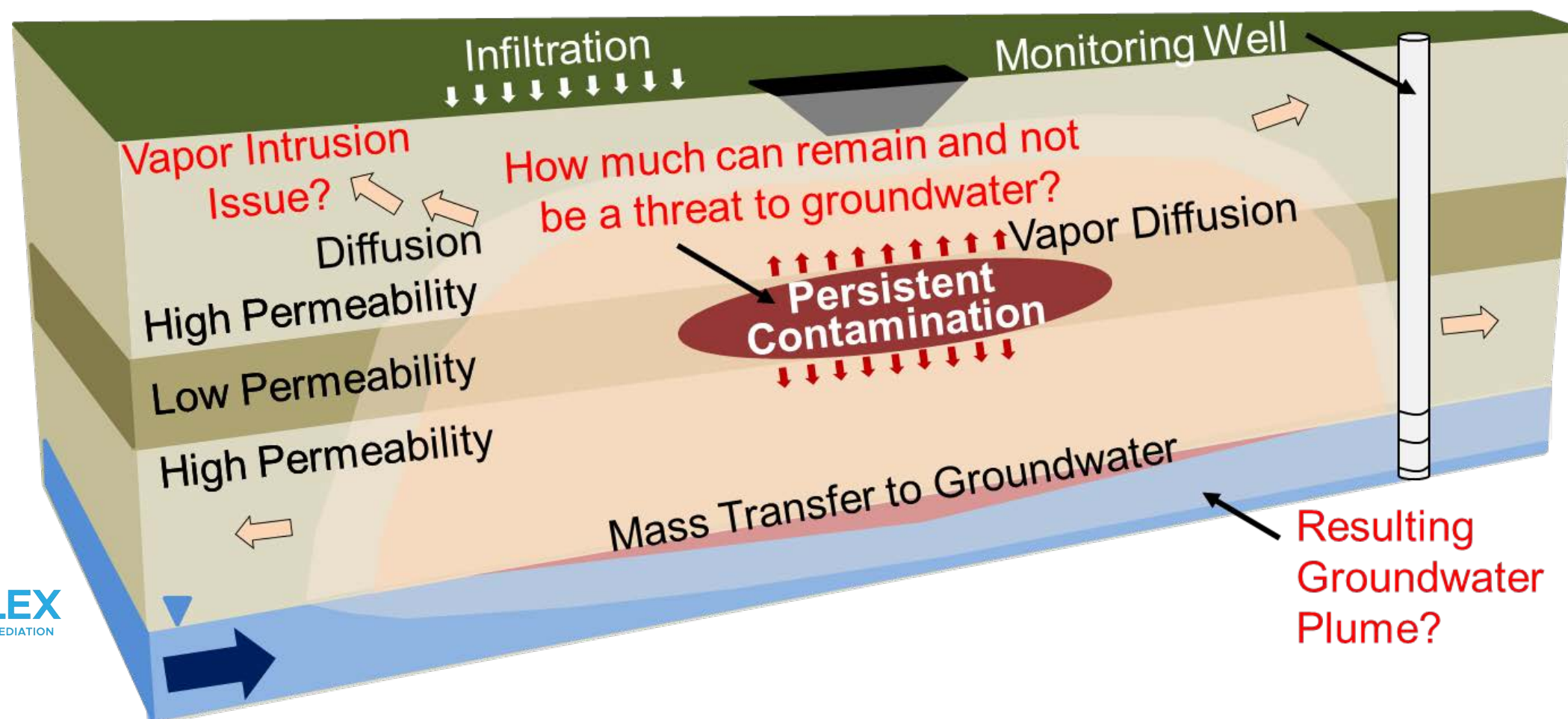
Performance Assessment Example



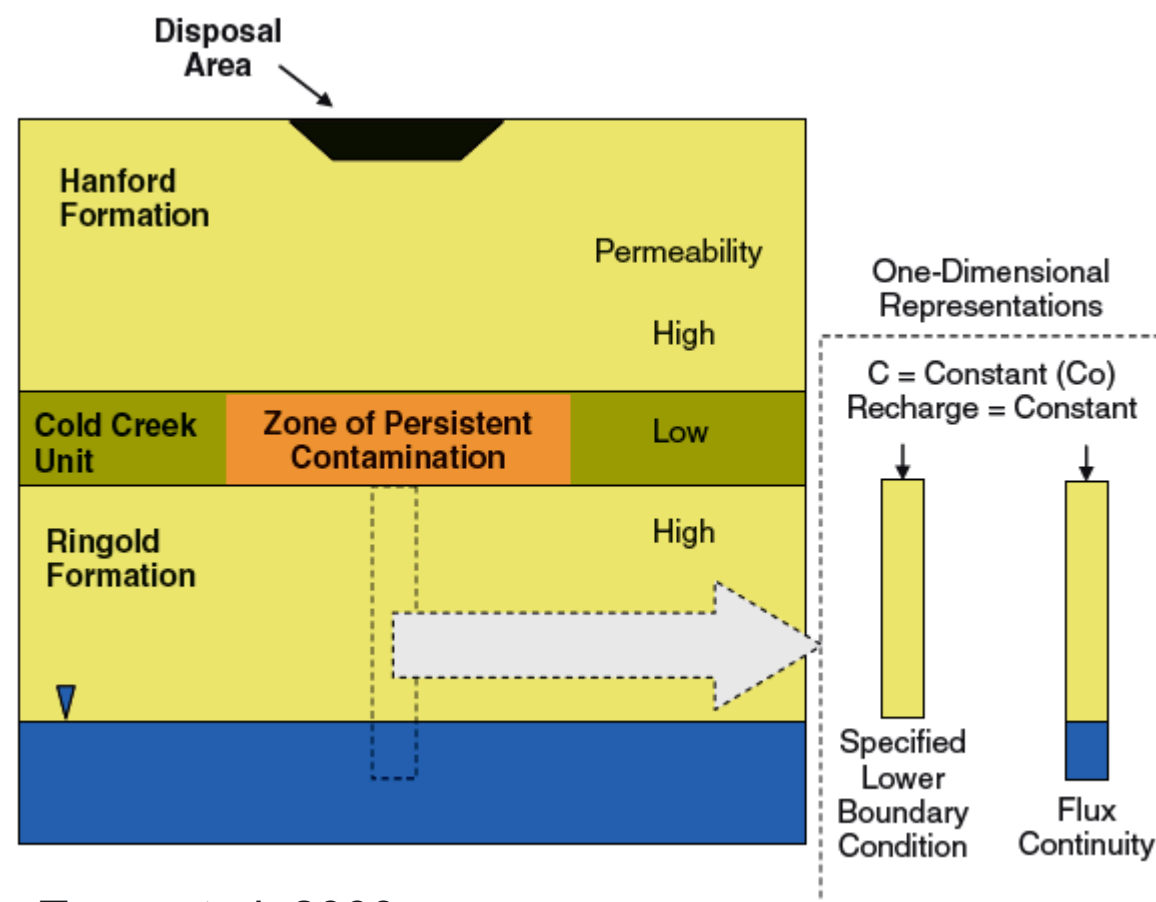
Source/Groundwater and 3D Considerations



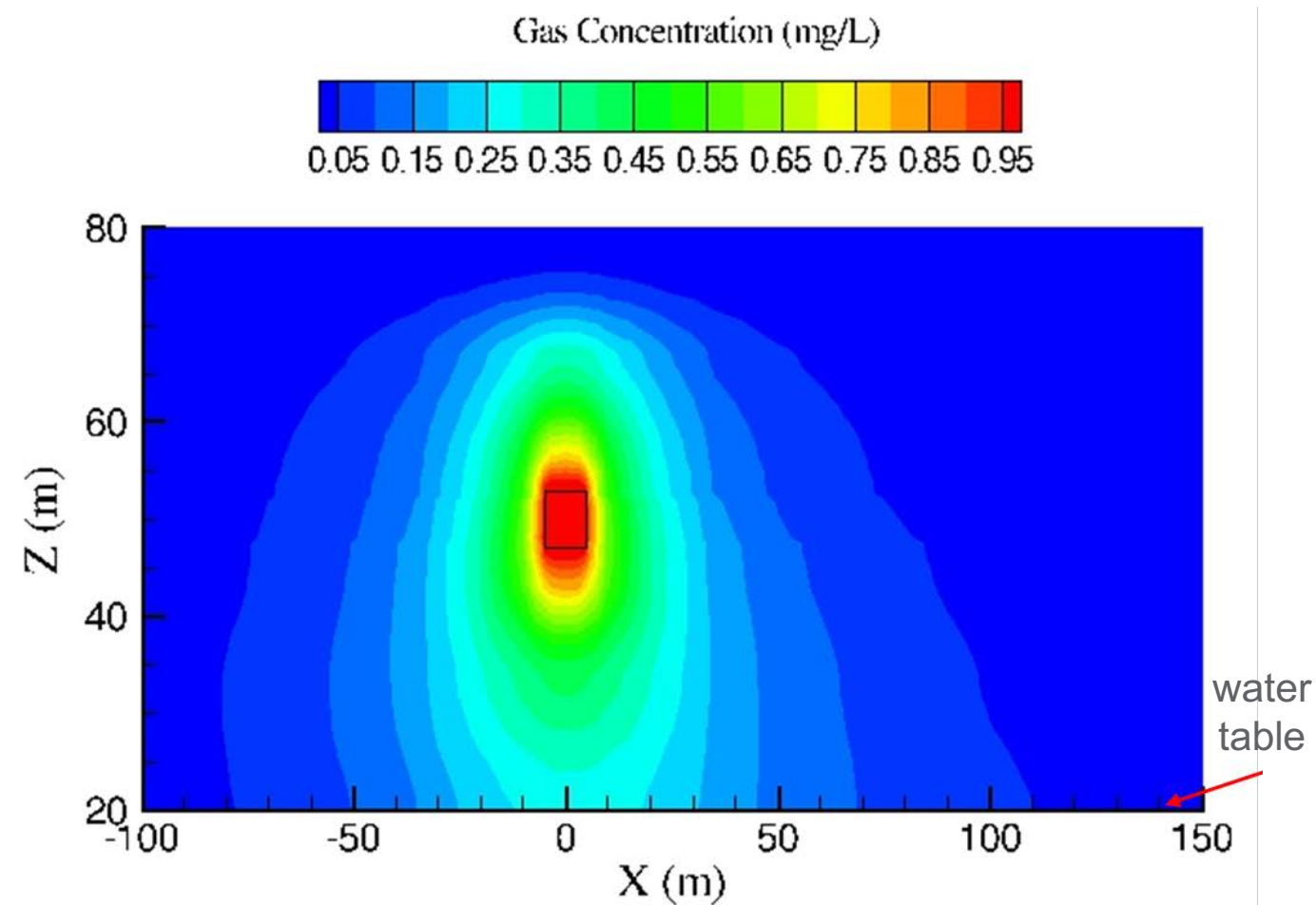
VS.



Dimensionality of Situation and Transport



Truex et al. 2009

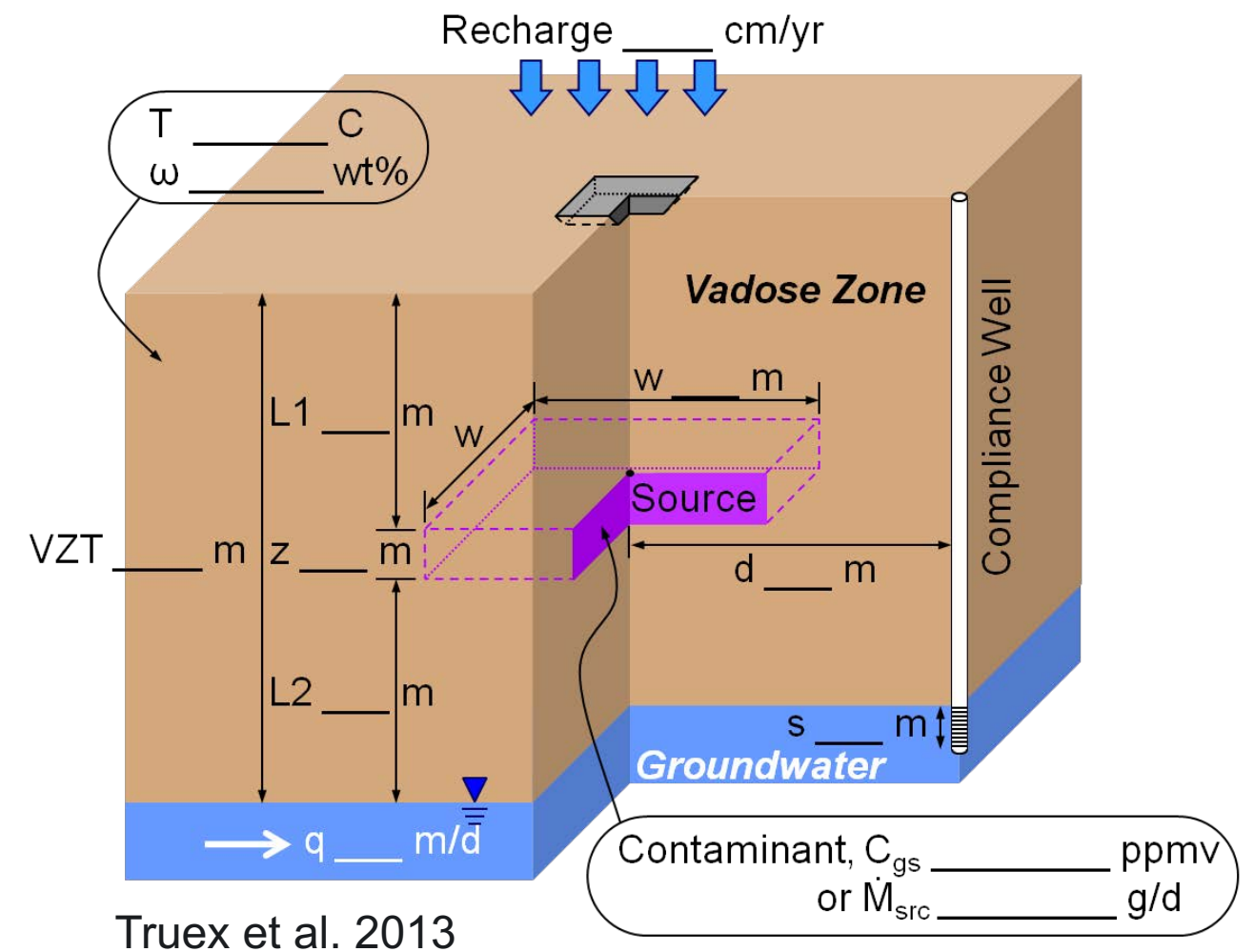


Oostrom et al. 2010

Conceptual Site Model and Quantitative Assessment

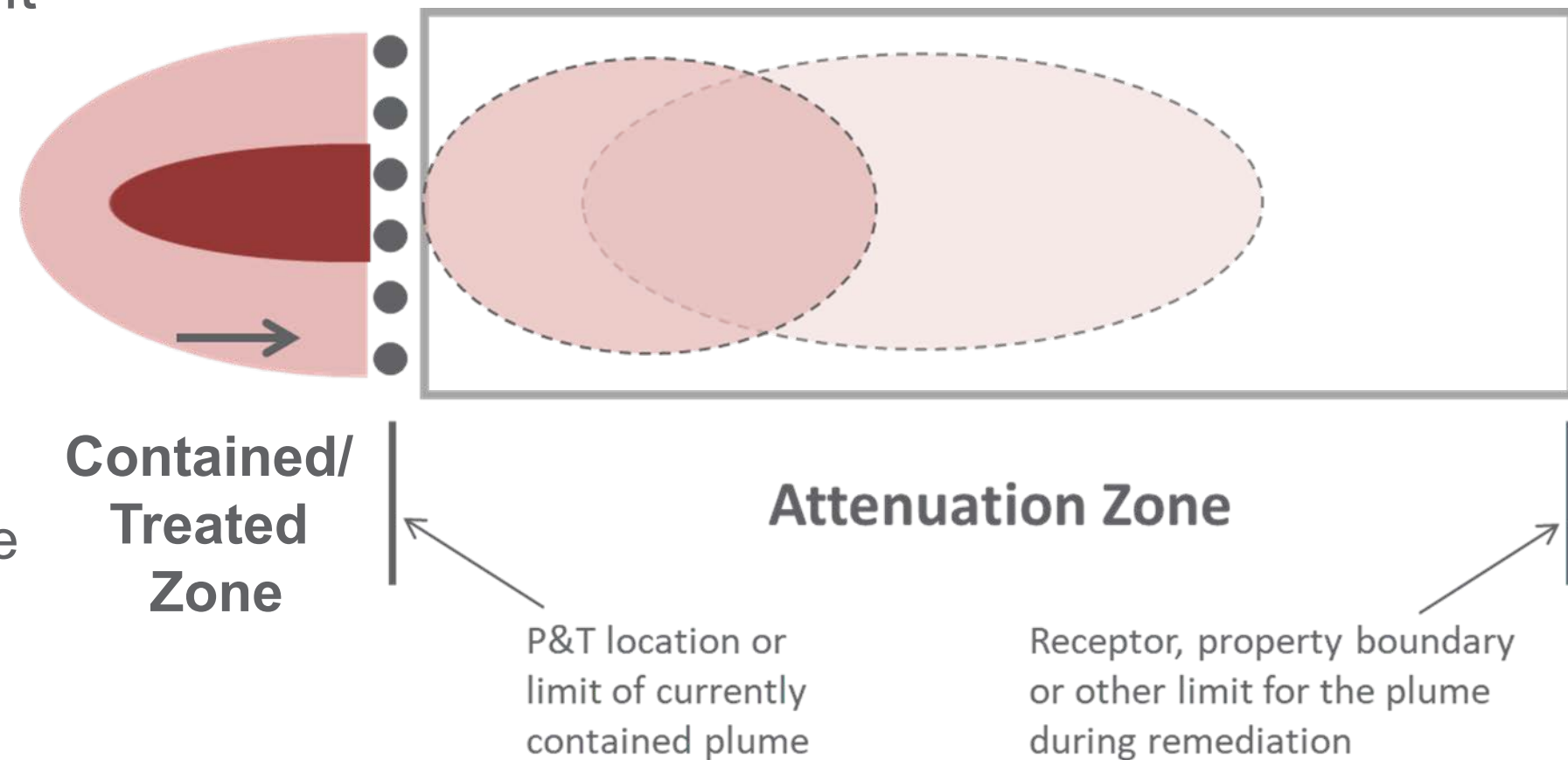
- Analysis approach needs to consider CSM elements and complexity of transport
- Consider CSM refinement during active remediation
- Identify controlling features and processes
- Identify sufficient analyses and appropriate verification

Example SVE Analysis Approach



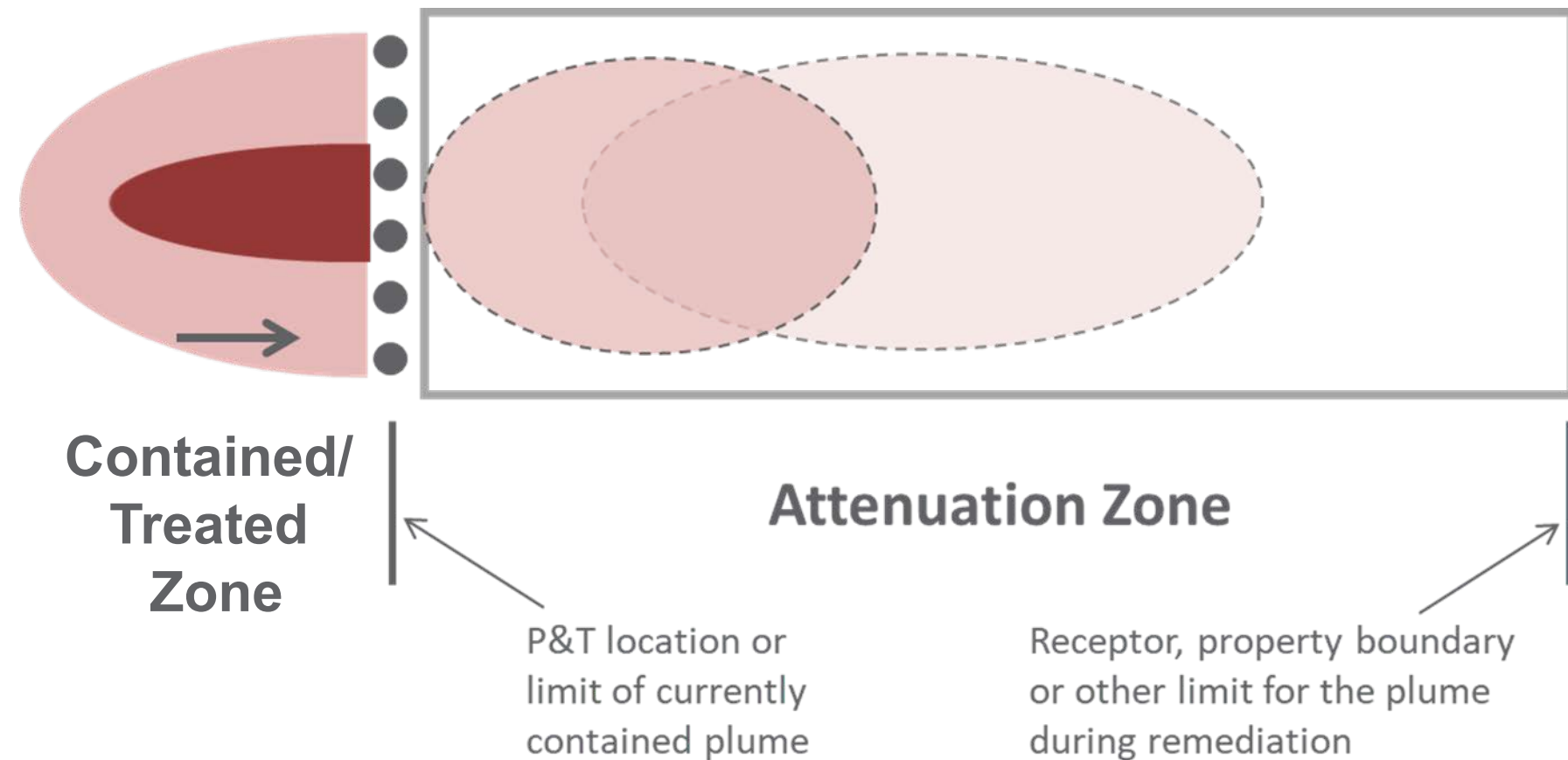
Other Active/Passive Transition Considerations

- Adaptive Site Management
 - Organizes active-passive transition within overall remediation management
- Time and space
 - Is there a zone where you can afford to have contamination during remediation and allow time to reach ultimate concentration goal?



Other Active/Passive Transition Considerations

- Time and Space
 - May need additional considerations when lingering sources are present – extended time, ARAR waivers
- Contingency actions for passive elements
 - e.g., as identified in the MNA directive
- Passive monitoring elements to evaluate changing conditions



Thank you

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Mike Truex
mj.truex@pnnl.gov



References

- DOE. 2020. Performance Monitoring Plan for the 200-ZP-1 Groundwater Operable Unit Remedial Action. DOE/RL-2009-115, Revision 3. Department of Energy Richland Operations Office, Richland, WA.
- EPA. 2014. Groundwater Remedy Completion Strategy: Moving Forward with the End in Mind.
- EPA. 2011. Groundwater Read Map- Recommended Processes for Restoring Contaminated Groundwater at Superfund Sites.
- EPA. 2002. Calculation and Use of First-Order Rate Constants for Monitored Natural Attenuation Studies. EPA/540/S-02/500.
- ITRC. 2017. Remediation Management of Complex Sites.
- Nichols, E., and T. Roth. 2004. "Flux Redux: Using Mass Flux to Improve Cleanup Decisions," L.U.S.T.Line 46 (March). Lowell, Mass.: New England Interstate Water Pollution Control Commission. www.neiwpcc.org/lustline/lustline_pdf/LustLine46.pdf.
- National Research Council (NRC). 2013. Alternatives for Managing the Nation's Complex Contaminated Groundwater Sites. National Academies Press, Washington, D.C.

References cont.

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