Pacific Northwest NATIONAL LABORATORY

UNIVERSITY OF FLORIDA

Source Area Remediation in Complex Subsurface Conditions at Joint Base Lewis-McChord

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PNNL-SA-169812

Seminar Overview

Objective: Present a case study describing strategic monitoring approaches and remedies for source removal/control.

Take-aways from today's seminar:

Challenge: Trichloroethene NAPL in source area and large dissolved-phase groundwater plume in complex geology.

Approach: Apply multiple remedy elements to address source and dissolved phase plume. Mass flux can help determine source strength, guide remedy design, and provide performance monitoring.

Impact: Verification of thermal treatment performance. Implemented pump-and-treat source control. Both actions help decrease the overall remedy duration.

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Outline of Discussion

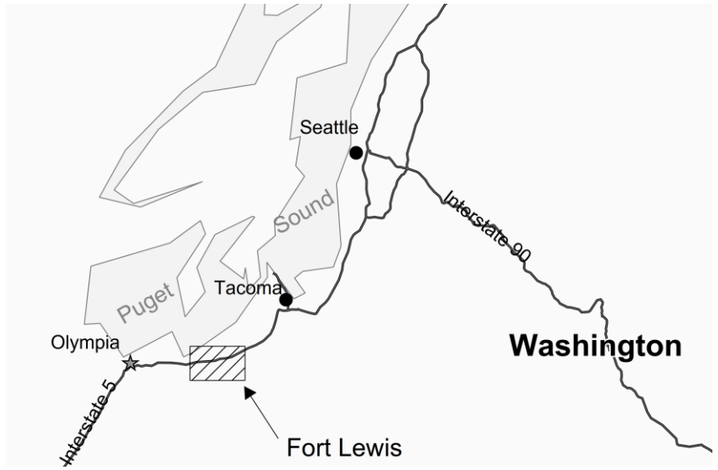
- Introduction to Joint Base Lewis McChord
  - Complex site with source area, multiple plumes and multiple treatment components
- Mass flux for remedy performance monitoring
  - What it is and example application
- Pump-and-treat for source control
  - Key element to overall remediation strategy

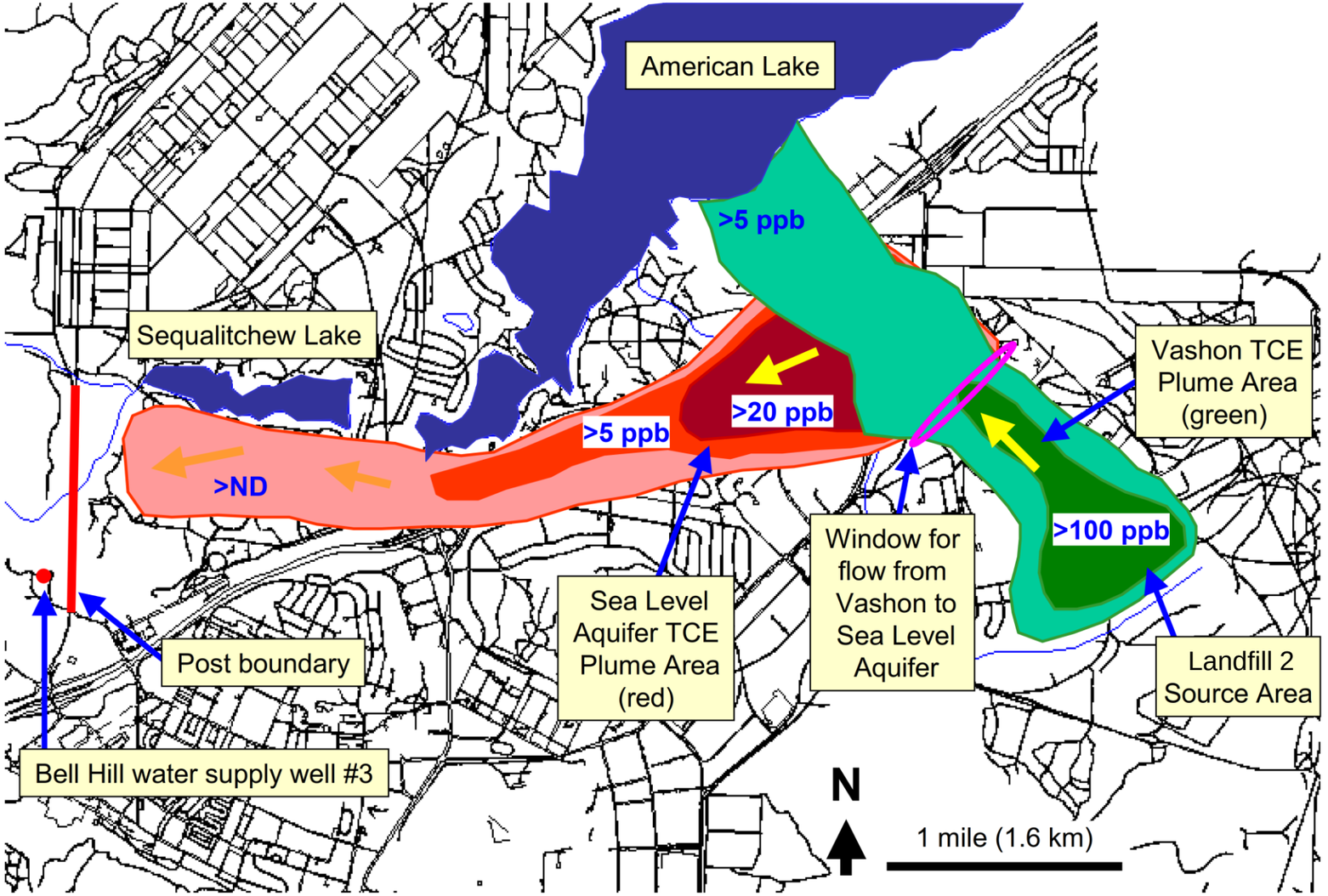
Joint Base Lewis McChord (Fort Lewis) Logistics Center

- Contaminated groundwater in the Logistics Center area
- Trichloroethene (TCE)
  - Historically used as a degreaser/solvent in equipment maintenance
  - Waste solvent disposed of in drums in Landfill 2
    - Formerly known as East Gate Disposal Yard (EGDY)
- Remedial investigations in 1980s and beyond
- Regulatory
  - Superfund National Priorities List in 1989
  - Record of Decision in 1990
  - Explanation of Significant Difference in 2001
- More site details in *Remedial Action Completion Report* (EPA, 2015)

Site Overview

- Site location
- Reference features
- TCE plumes
- Conceptual model elements

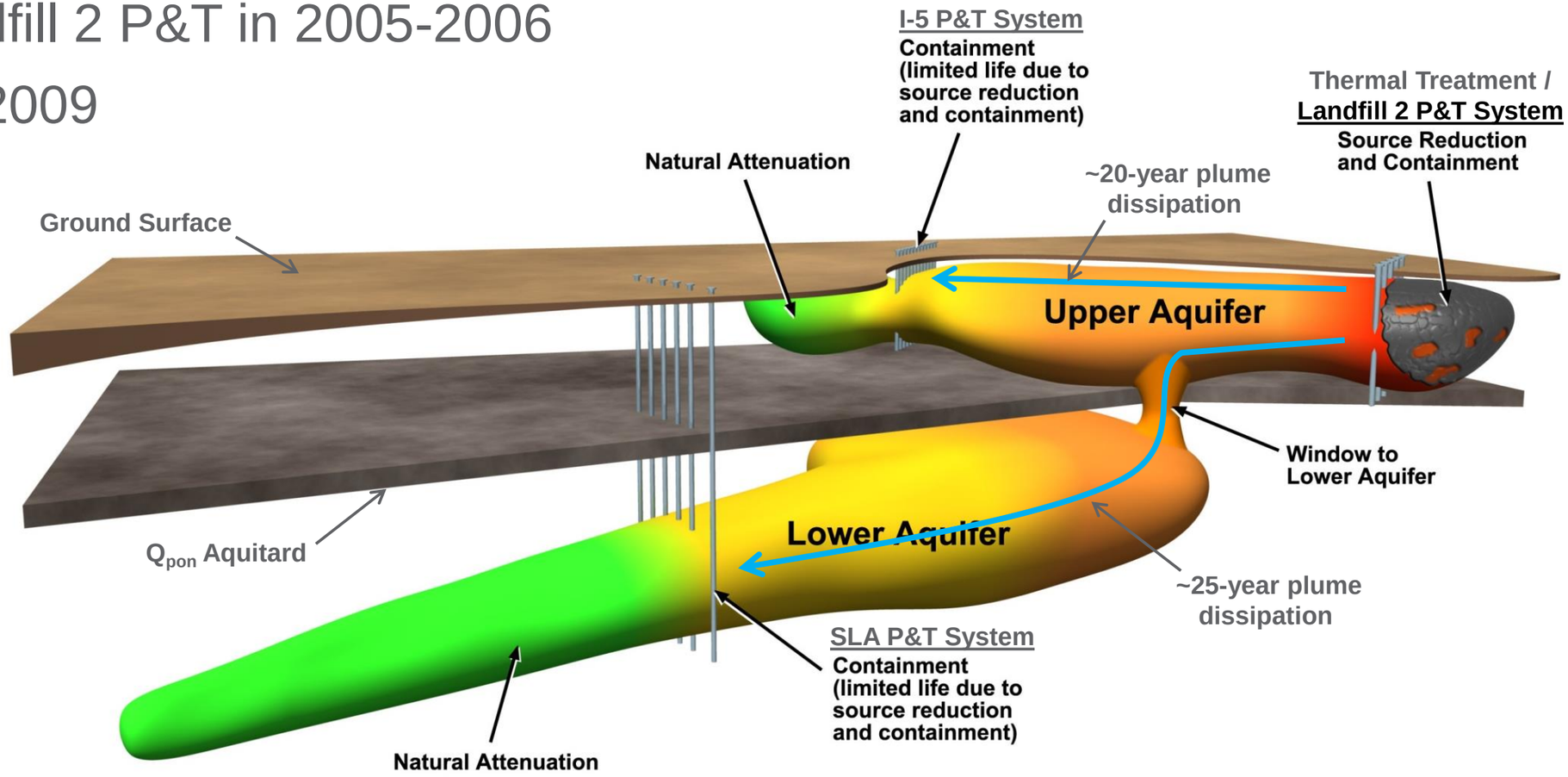




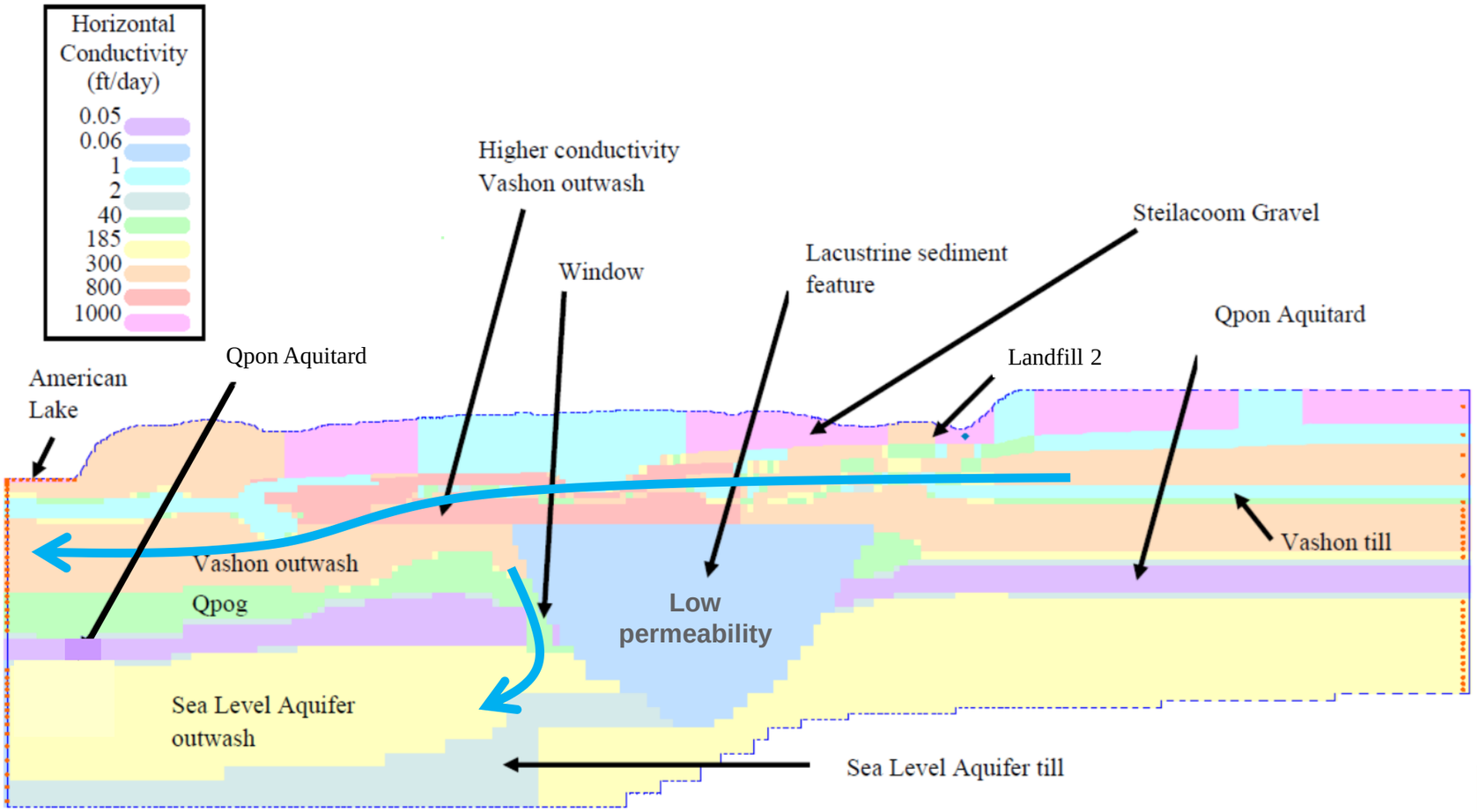
Truex et al. 2006

Conceptual 3D Depiction of Logistics Center Trichloroethene Plumes

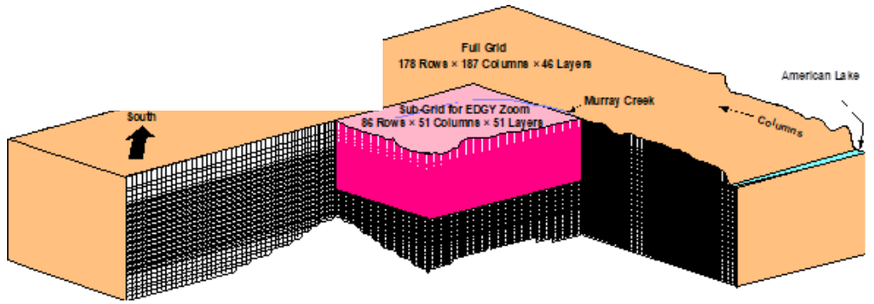
- Landfill 2 and I-5 P&T since mid-1990s
- Source removal in 2001
- Upgrade of Landfill 2 P&T in 2005-2006
- SLA P&T since 2009
- Thermal treatment
  - NAPL Area 1 in 2003-2004
  - NAPL Area 2 in 2005
  - NAPL Area 3 in 2006-2007



JBLM Logistics Center Cross Section and Modeling



- Complex geology
  - Outwashes, tills, lacustrine
- Window from upper to lower aquifer
- Represented in a numerical model
  - Used for remedy assessment and design



Truex et al. 2006

Landfill 2 Source Treatment Summary

- NAPL area treatment – only way to significantly reduce source lifetime and overall cost
- Without source treatment, Landfill 2 P&T would continue for ~500 years
  - Does not meet installation goal for groundwater cleanup
  - Lifecycle cost of >$60M (constant dollar)
- Preferred remedy includes thermal treatment
  - Thermal treatment new funds required = $12M
  - Residual contamination P&T remediation lifetime ~ 40 years
  - Landfill 2 P&T lifecycle cost of ~$6M (constant dollar)
- Effect on source flux
  - Estimated 95% reduction in flux possible

Flux Measurements in Granular Deposits

- Applying mass flux and mass balance concepts
- Example using Joint Base Lewis McChord thermal treatment area
- Work on flux measurement presented here represents efforts of a large collaborative research group supported through a number of funding agencies

DoD EPA DOE SERDP
Strategic Environmental Research and Development Program

ESTCP
Environmental Security Technology Certification Program

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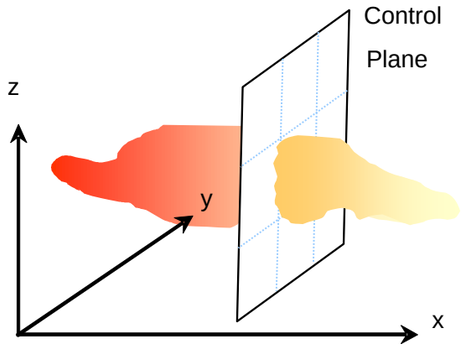
Flux-Based Concepts



$$M_D = \sum_{k=1}^{n} J_k A_k$$

$$J_k = C_k q_k$$

$$q_k = Ki$$

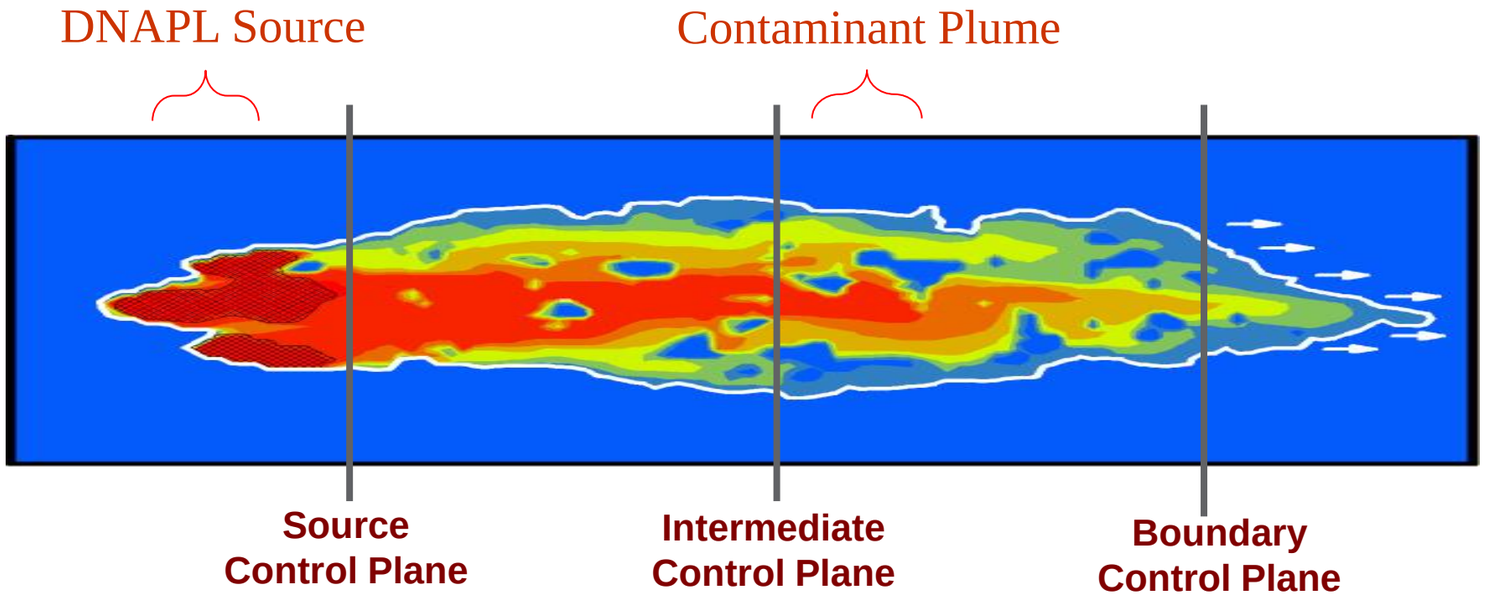
$$A_k = \Delta x_k \Delta z_k$$

M_D = Mass Discharge [MT^{-1}]

J = Mass flux [ML^2T^{-1}]

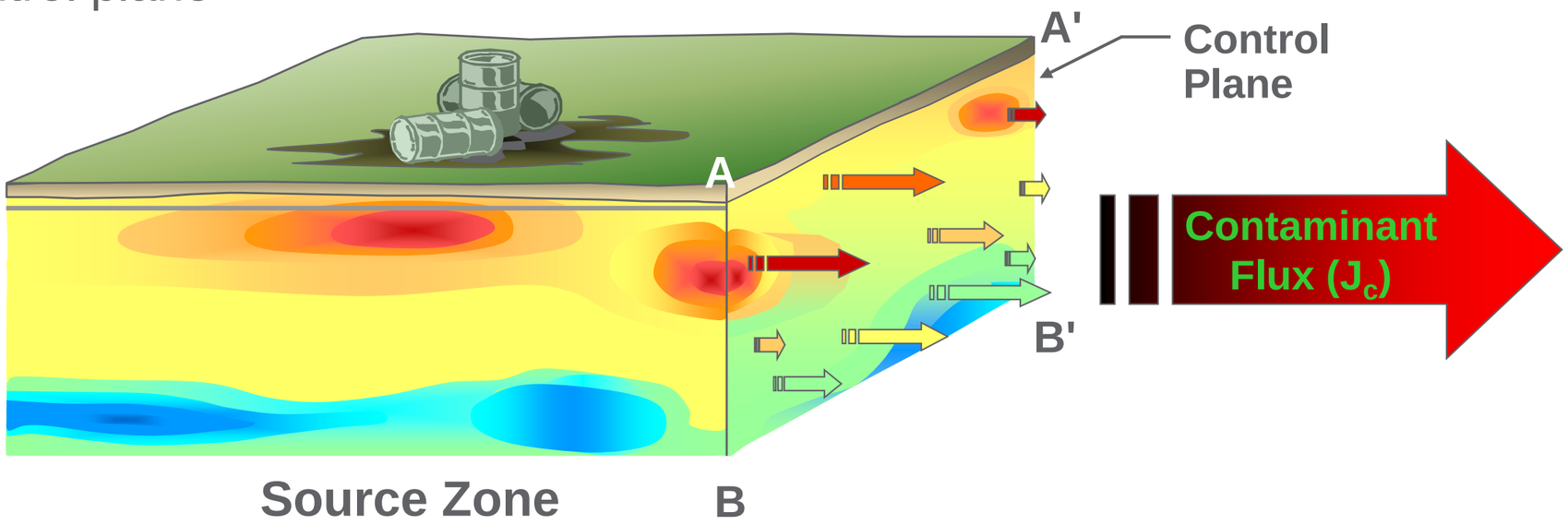
C = Concentration [ML^{-3}]

q = Groundwater flux [LT^{-1}]

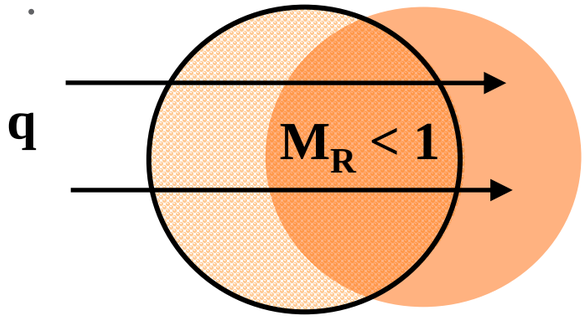


Flux Based Site Characterization

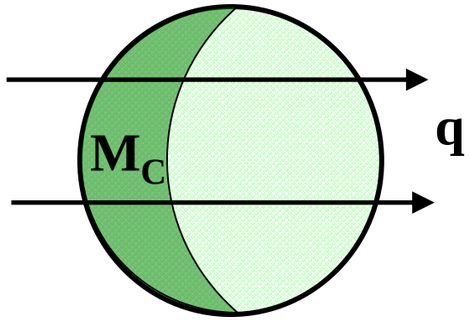
- Is knowledge of pre- and post-mass in the source zone critical?
- Because of the difficulties measuring mass in source zones, may want to consider an alternative approach to characterization
- Look at the source zone characteristic that has a direct link to plume response – mass flux/discharge
  - Downgradient control plane



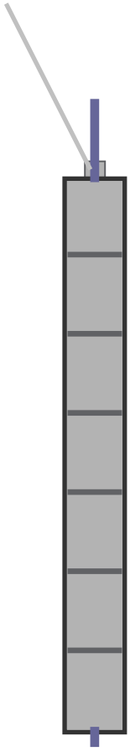
Passive Flux Meter – Groundwater & Contaminant Fluxes

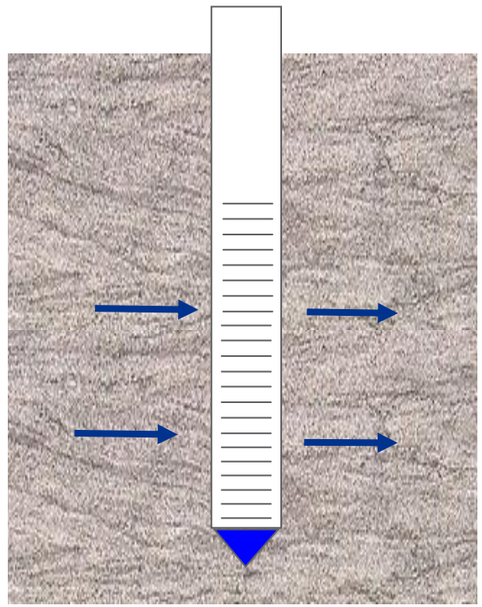


Displaced resident tracers for groundwater flux



Captured contaminants for contaminant fluxes





Hatfield et al., 2004 JCH

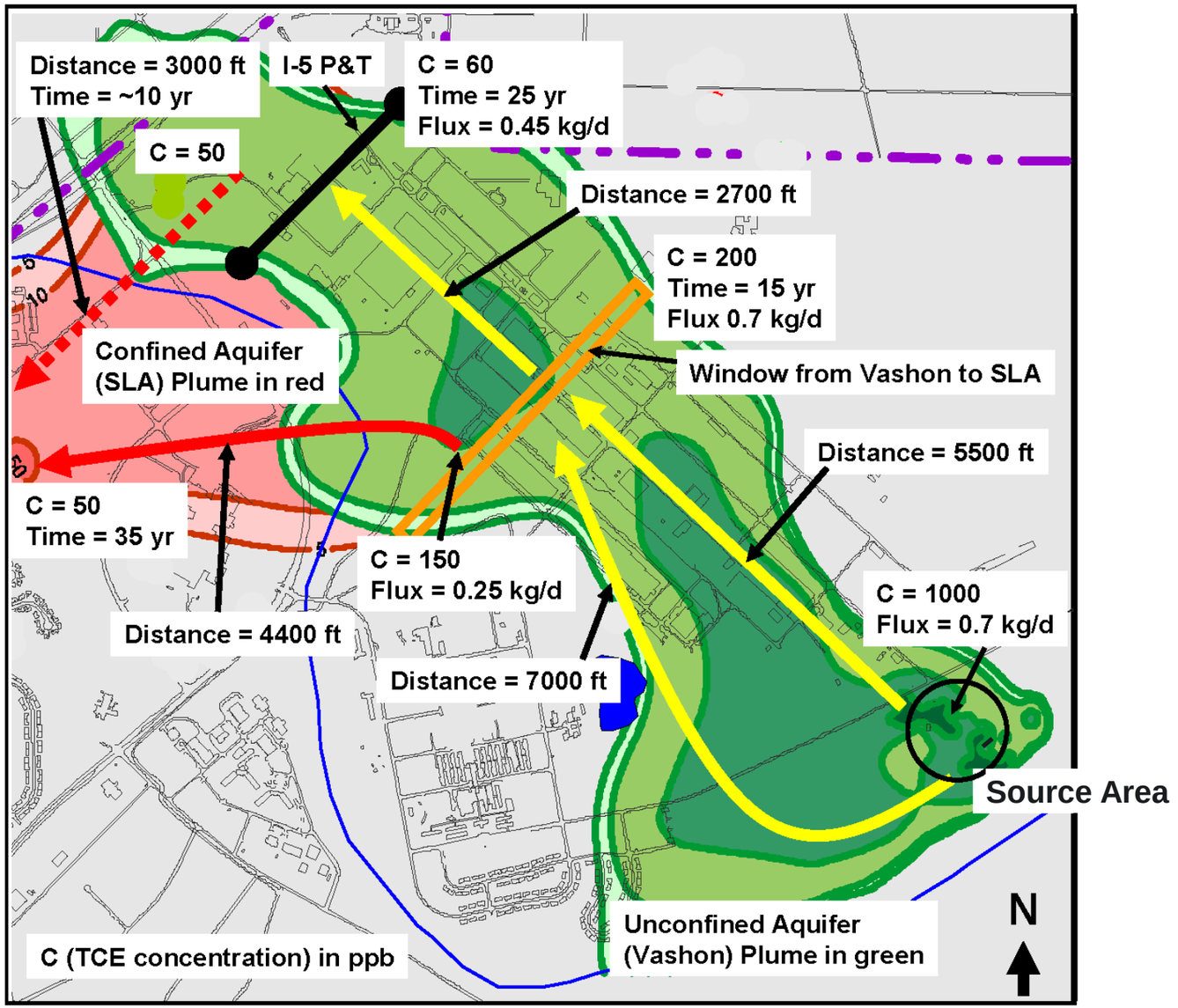
Example Site for Flux Based Assessment – Joint Base Lewis McChord

- TCE source zone area defined (3 major NAPL zones)
- Treated the first (upgradient) zone with resistive heating (TRS)
- Measured mass flux using passive flux meters and integral pump test in November 2003
- Site heating from December 2003 to August 2004
  - Average site temperature reached 97 °C
- Post-remediation flux June 2006

- SERDP project in collaboration with the EPA lab in Ada, OK
  - Lynn Wood and Michael Brooks

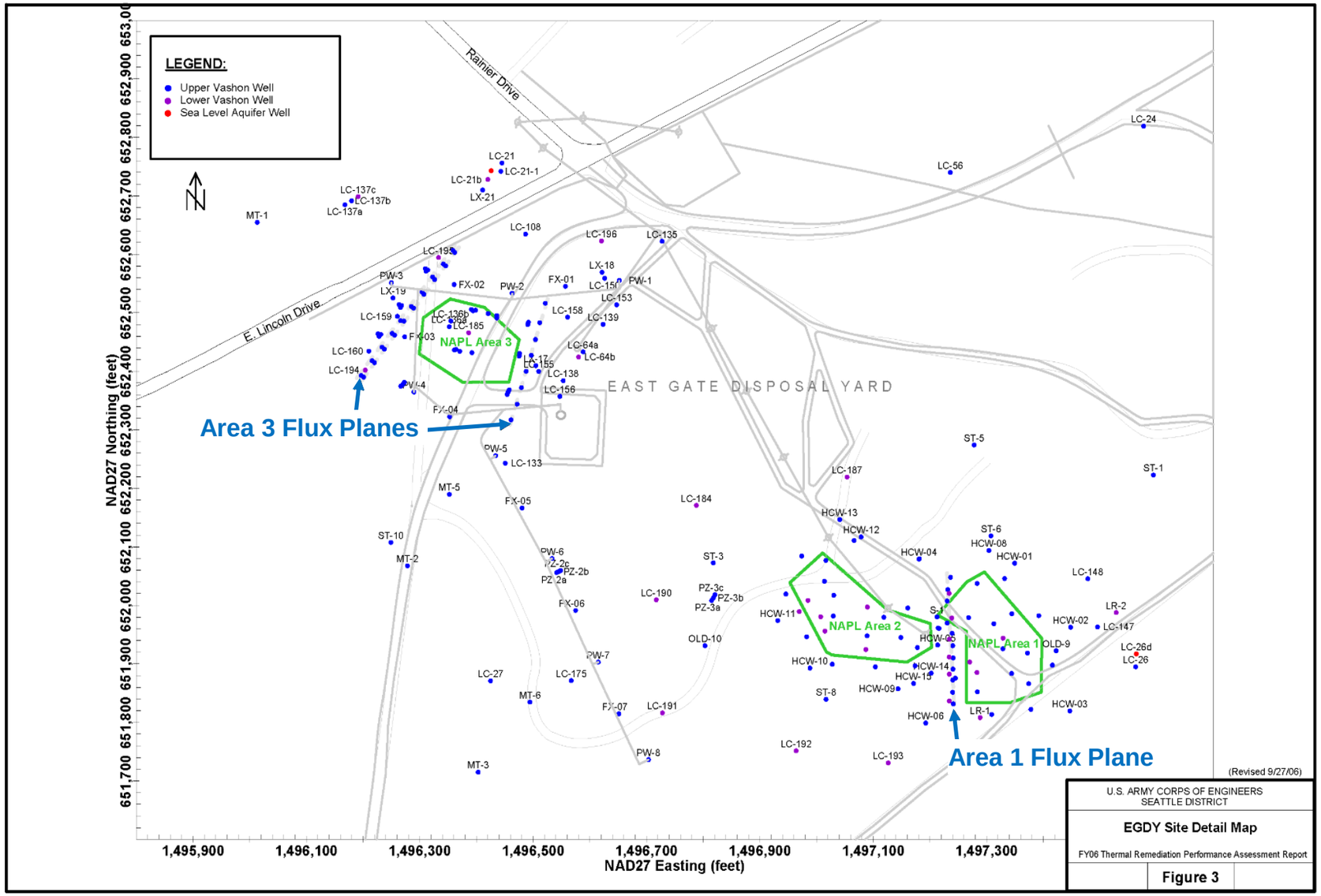
Dissolved-phase TCE Plume

- In 2003, prior to thermal remediation



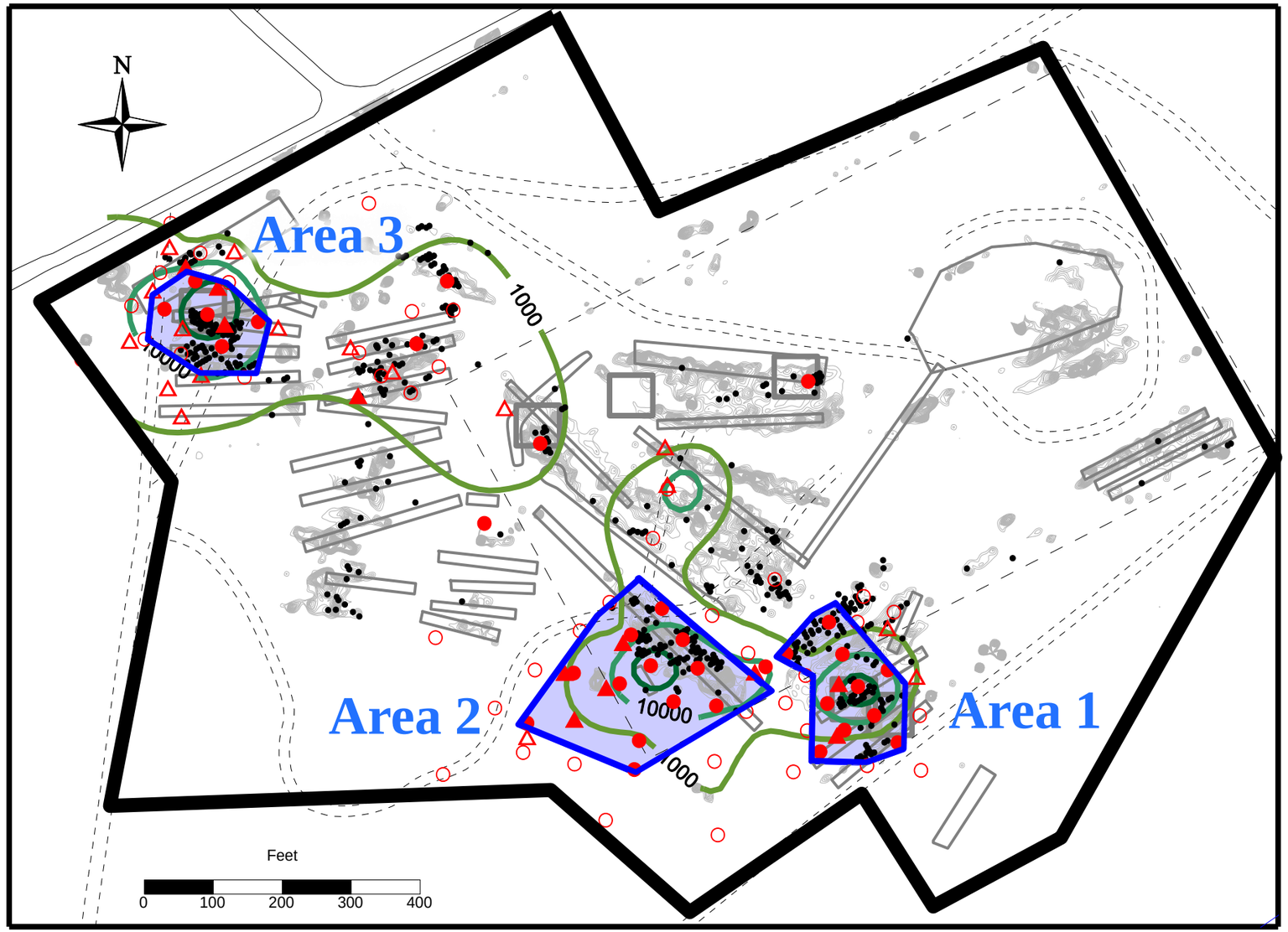
Landfill 2 (EGDY) NAPL Thermal Treatment Areas

- Nonaqueous phase TCE
  - Thermal treatment areas 1, 2, & 3



Logistics Center Plume Source Zone

- 3 Areas for Remediation



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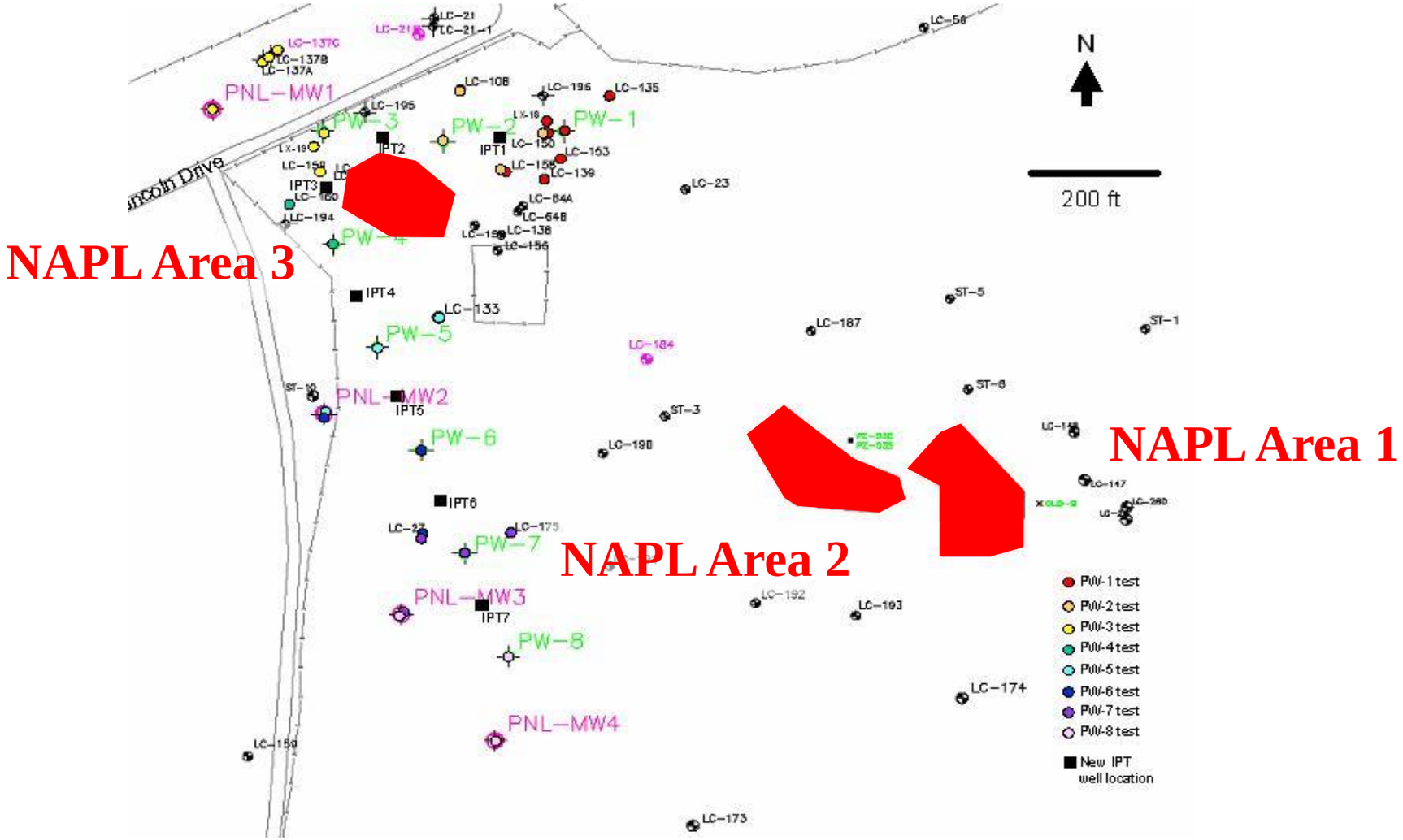
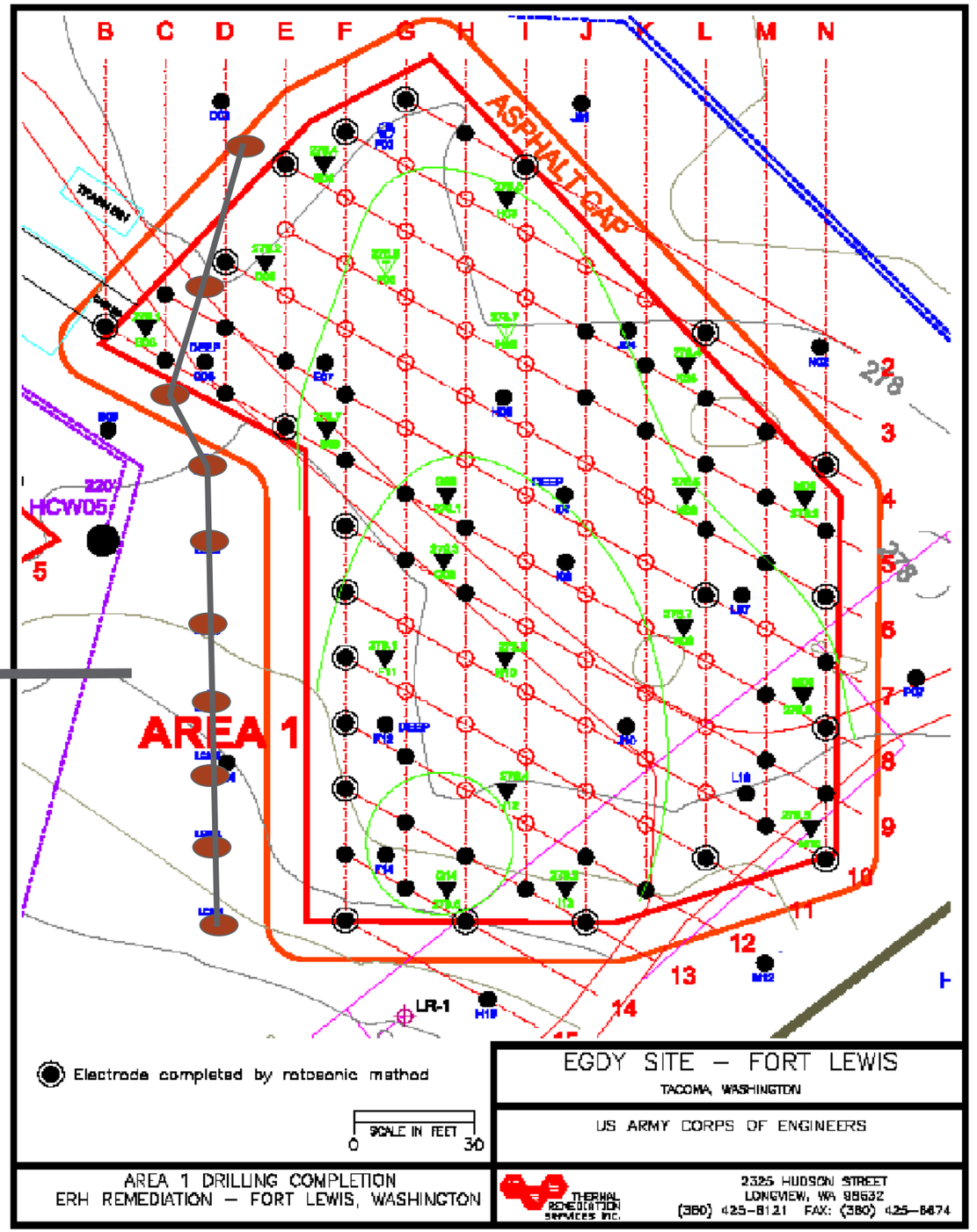
Source Zone Detail



NAPL Area 1

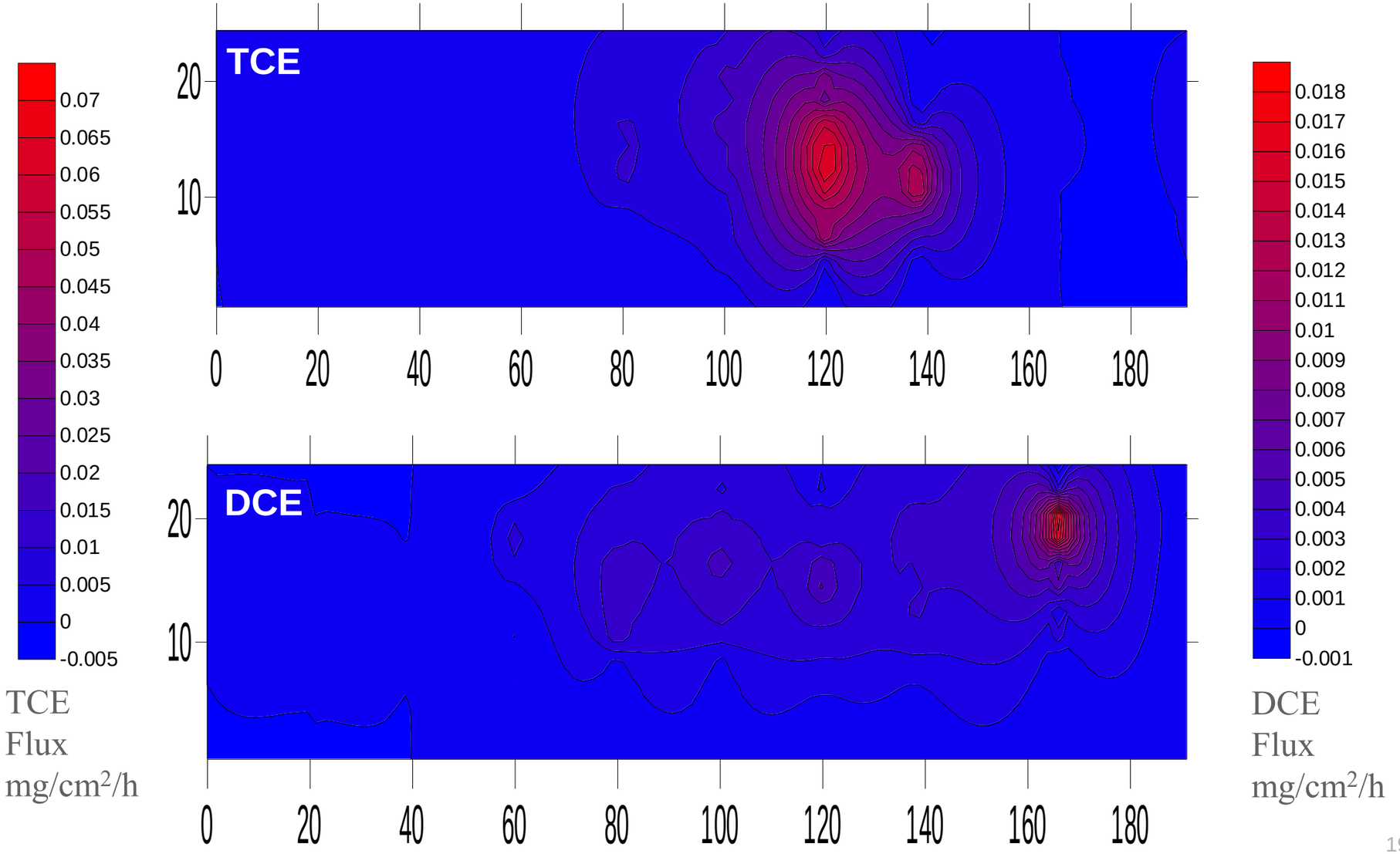
Groundwater flow direction

Flux well transect



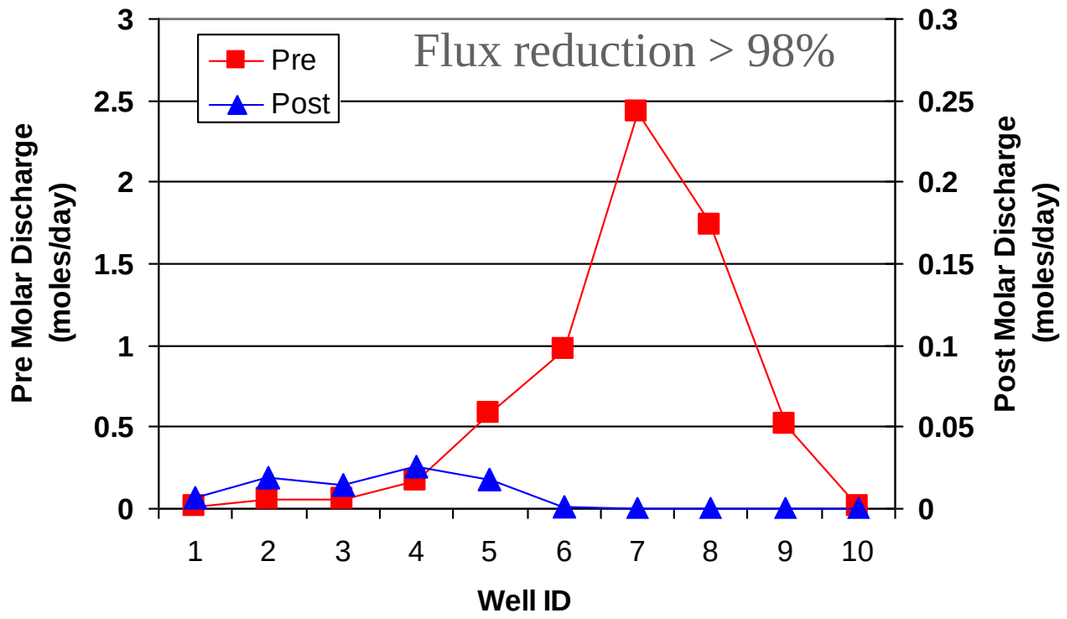
JBLM Shallow Transect Mass Flux

- 0.75 kg/d TCE
- 0.15 kg/d DCE



Recent Field Studies

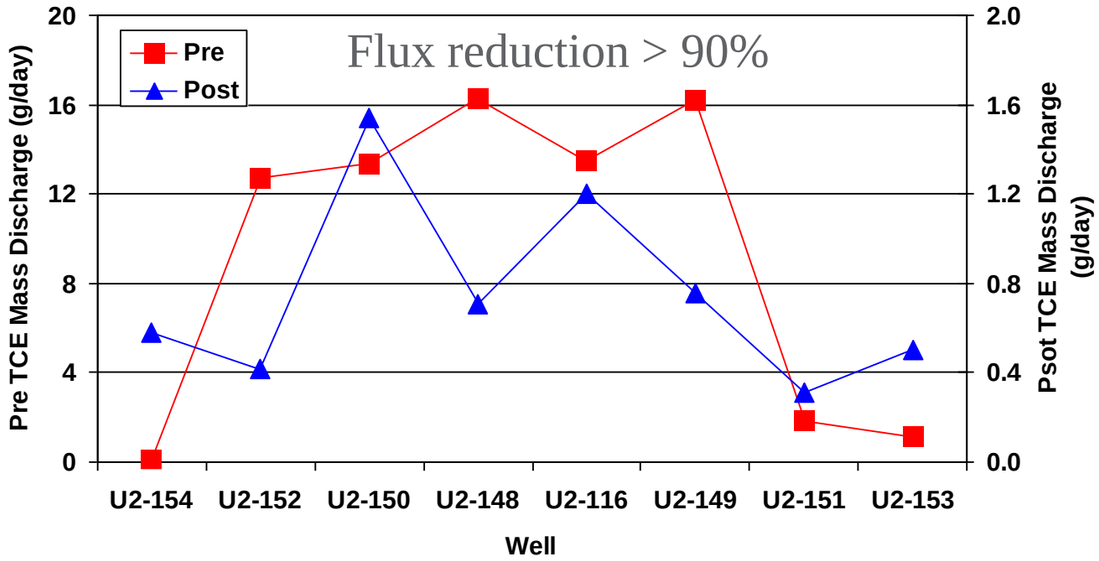
JBLM Thermal Remediation



Note difference in magnitude on pre and post Y-axis scales.

- Indicate significant decrease in mass discharge from source zones after DNAPL mass depletion

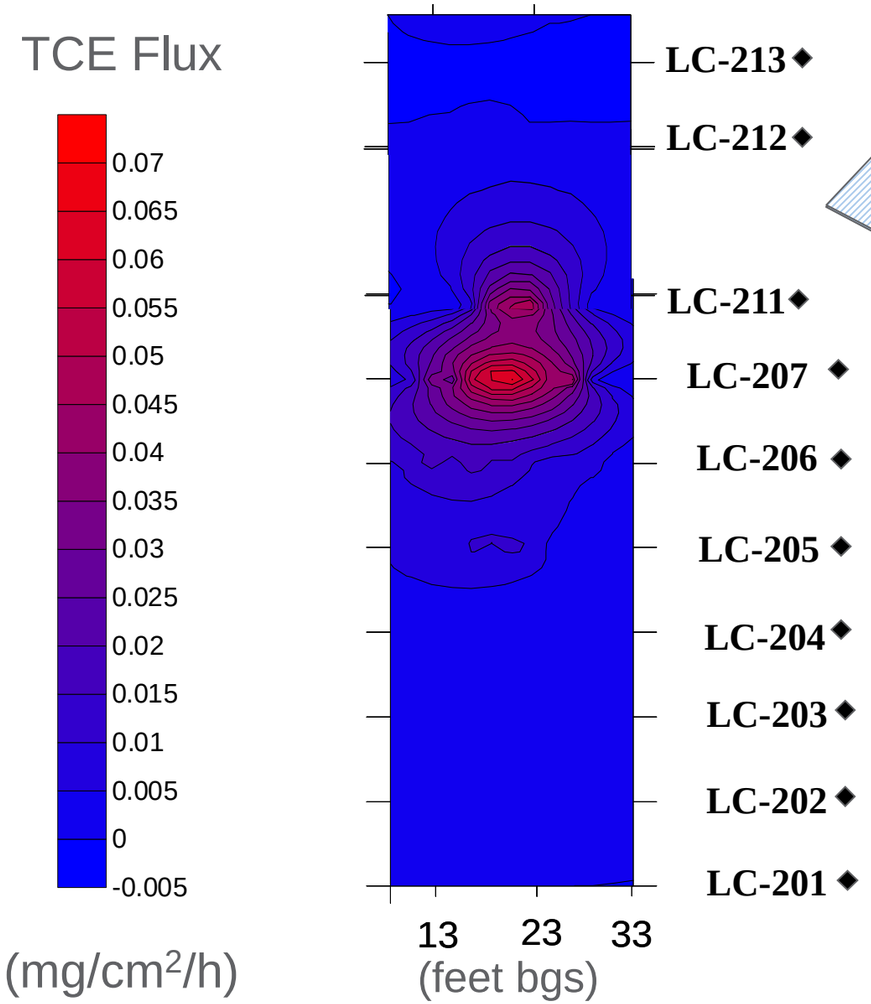
Hill AFB Surfactant Remediation

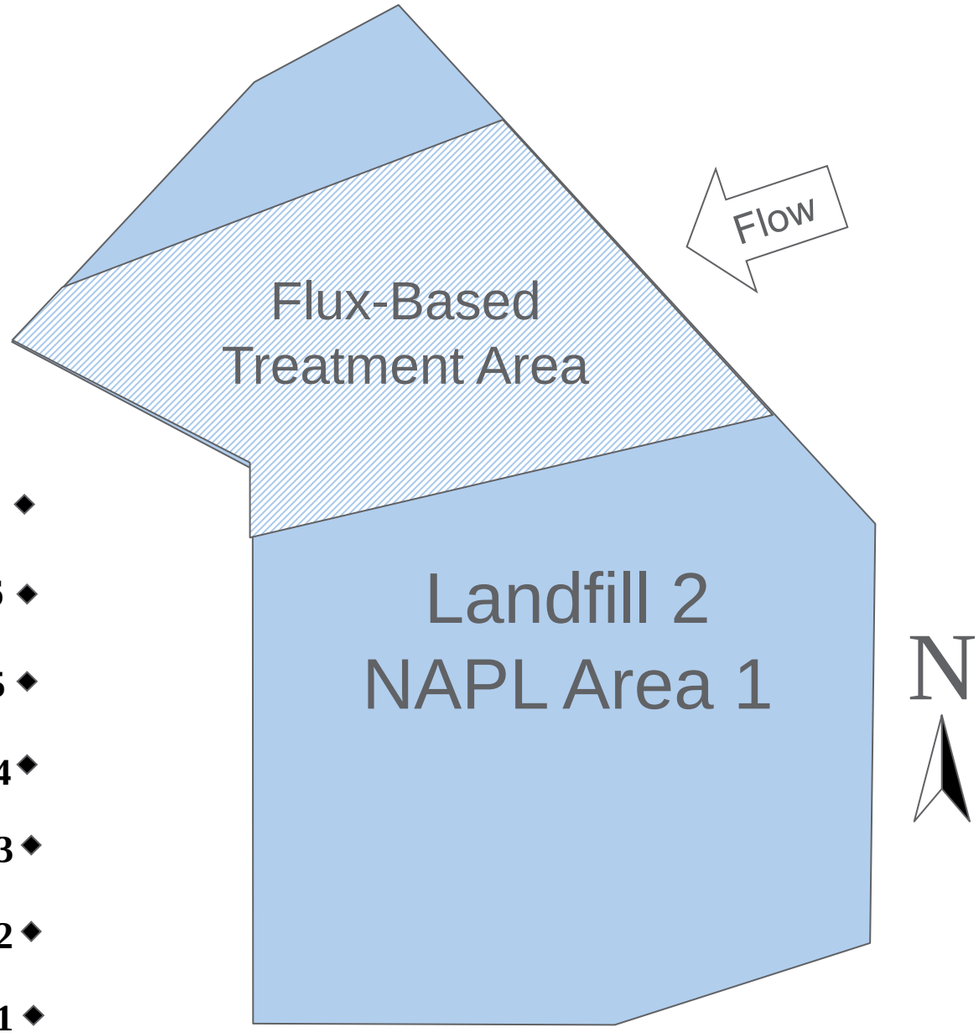


Brooks et al., 2008 JCH

Area 1 TCE Flux

- Thermal Treatment
- Cost ≈ $4M
- Flux cost ≈ 2%





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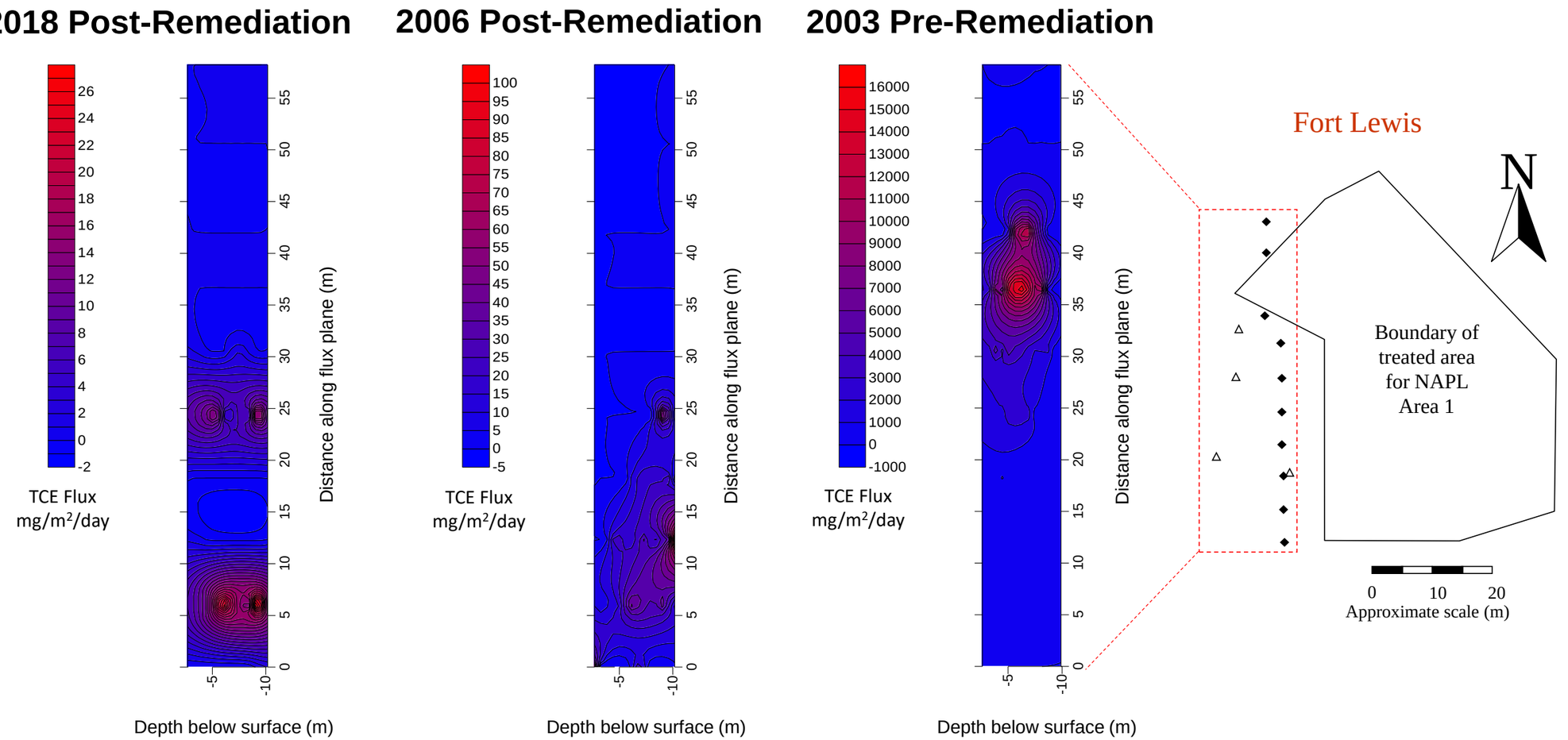
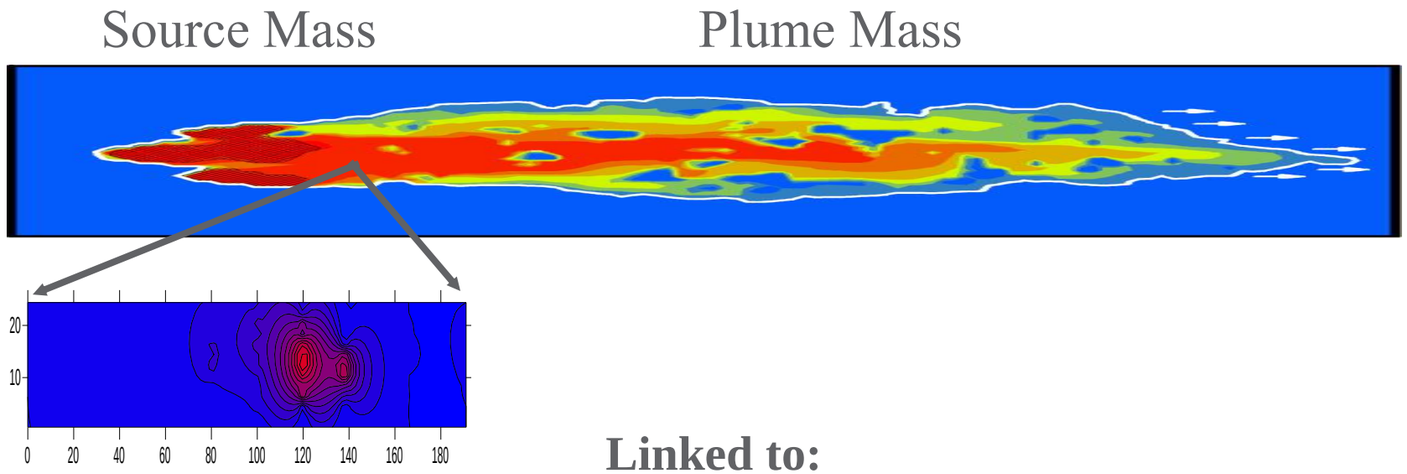
Comparison of Pre-remedial and Post-remedial TCE Mass Flux

- Significant decrease in flux magnitude
- Shift in spatial distribution



Site Mass Balance Components

- Quantified using all available historic site data
- Source strength functions can be linked to site mass balance



Source Strength (derived from current flux measurements or estimates)

Linked to:
Source Mass Estimate

Or

Plume Mass Estimate

Source Strength Function $M_D(t)$

historical concentration data

JBLM Entire Source Zone (2005 conditions)

1.5 kg/day → 5,400 kg → $M_D(t)$ [$\Gamma = 0.7$]

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Site Mass Balance

- Estimating a mass balance for entire JBLM Landfill 2 site
  - Far more complicated task
  - Not a consistent flux record for the site as a whole
- However, pump-and-treat data can be used
  - Provides a rudimentary estimate
  - Based upon contaminant mass removed after thermal treatment ended (post-remediation)

Year	TCE Mass Removed (lb)	TCE Mass Removed (kg)
2007	329	149.23
2008	246	111.58
2009	129	58.51
2010	141	63.96
2011	108	48.99
2012	119	53.98
2013	71	32.21
2014	61	27.67
2015	85	38.56
2016	85 *	38.56 *
2017	85	38.56
Total	1459	662

* No data available – assumed same as 2015 and 2017

Site Mass Balance

- Historical TCE mass removed by pump-and-treat system
- Used with exponential decay source model
- Combinatorial optimization framework
- Determined optimal decay rate (k) and initial 2007 (post-remedial) source mass (M_{post})
- Minimized sum of the squared differences between observed and model-calculated mass removed values over a ten-year period (2007 to 2017)

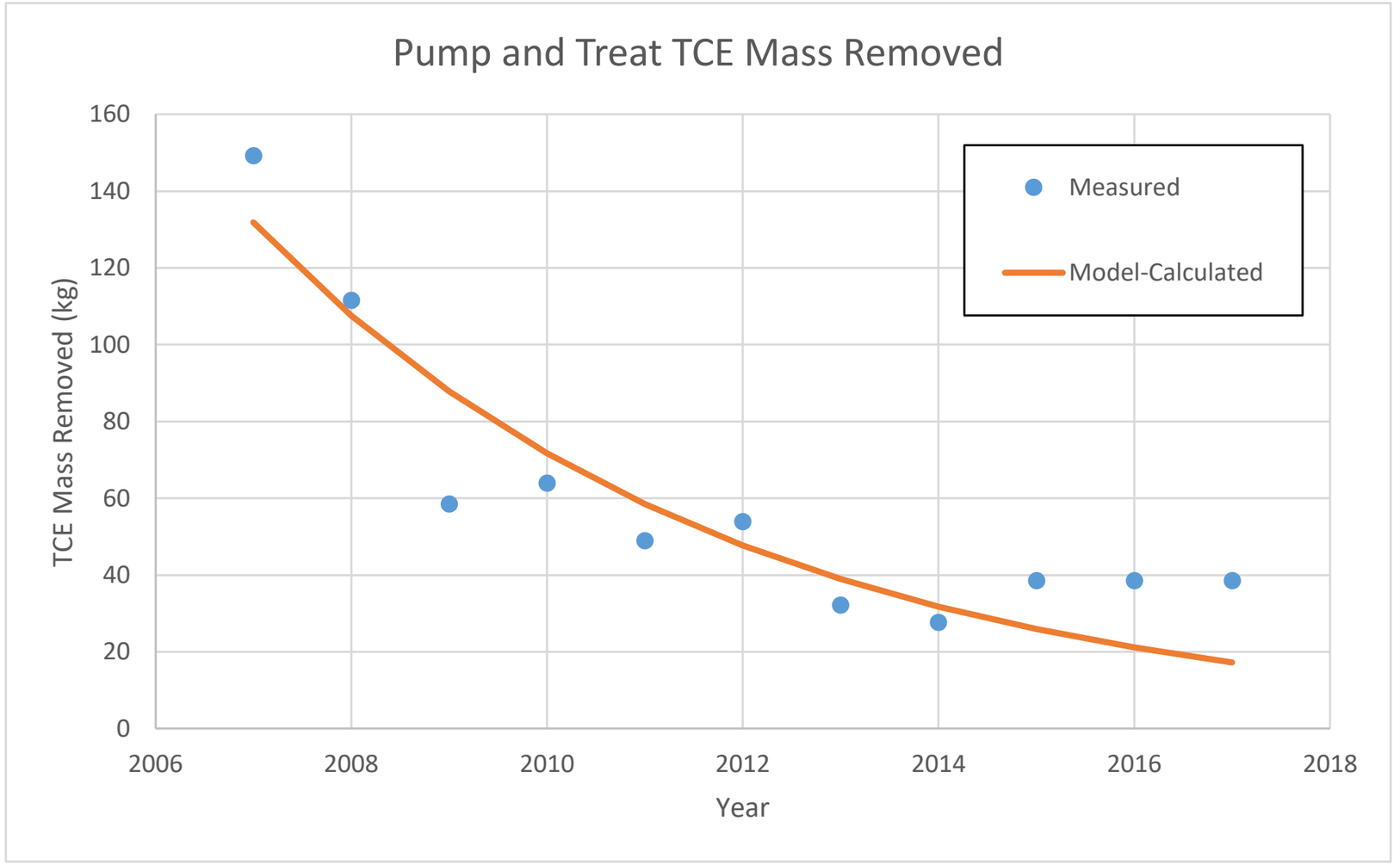
Optimal parameters

$k = 0.000556853$

$M_{post} = 161.60$ kg

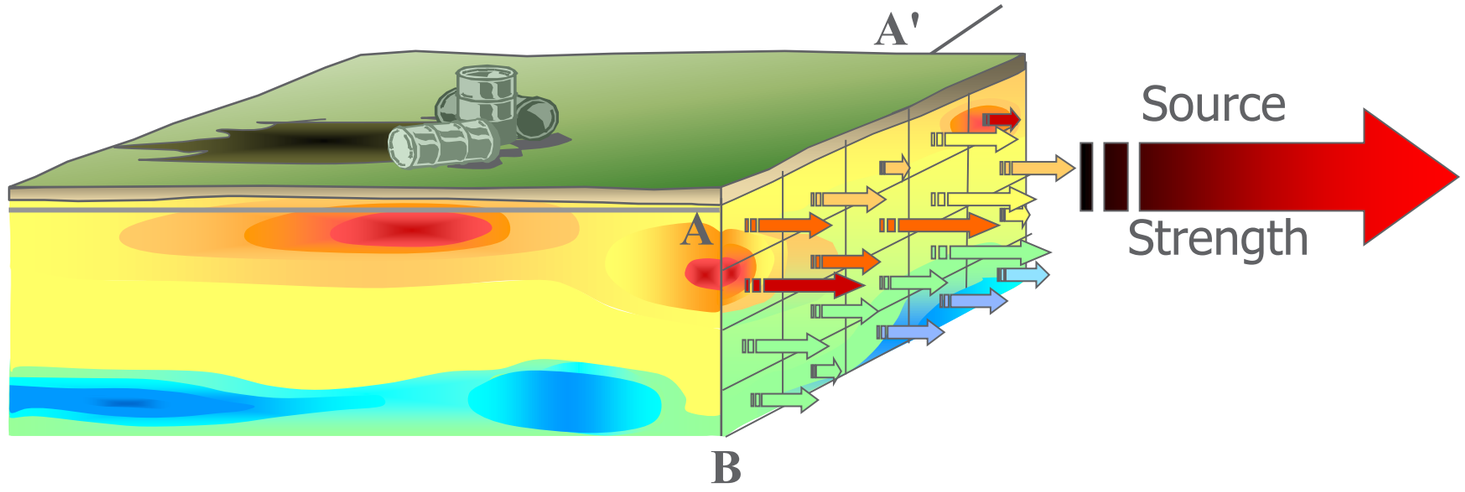
Site Mass Balance

- Comparison of measured and model-calculated TCE mass removed by pump-and-treat



Mass Flux Summary

- Linking mass depletion and mass flux at field scales can aid in site management
- Flux distribution may have utility in remedial design
- Passive Flux Meters provide a means to simultaneously measure spatial distribution of mass and Darcy flux



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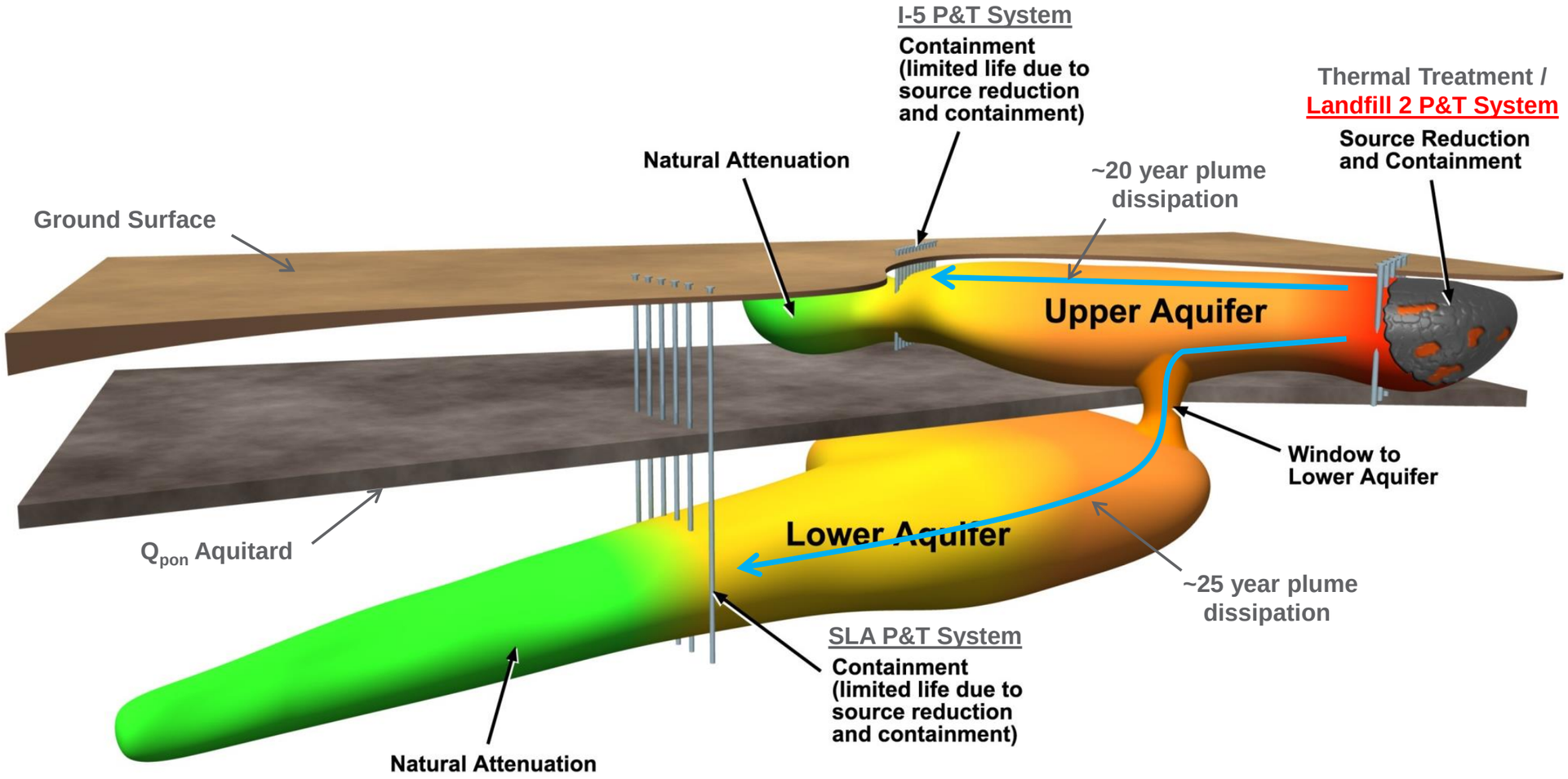
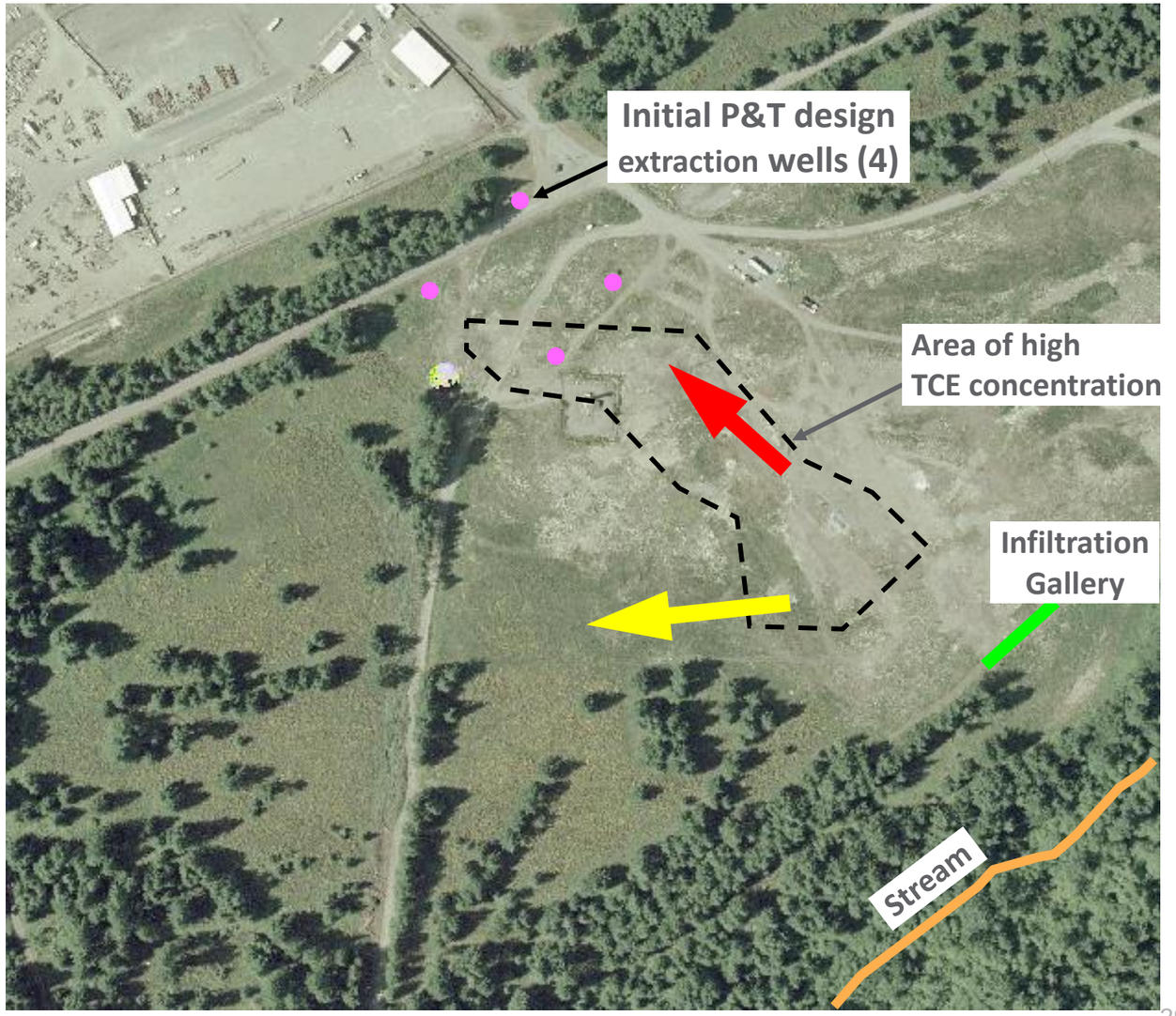
Redesign of Landfill 2 P&T System for Source Control



Initial Landfill 2 P&T Design

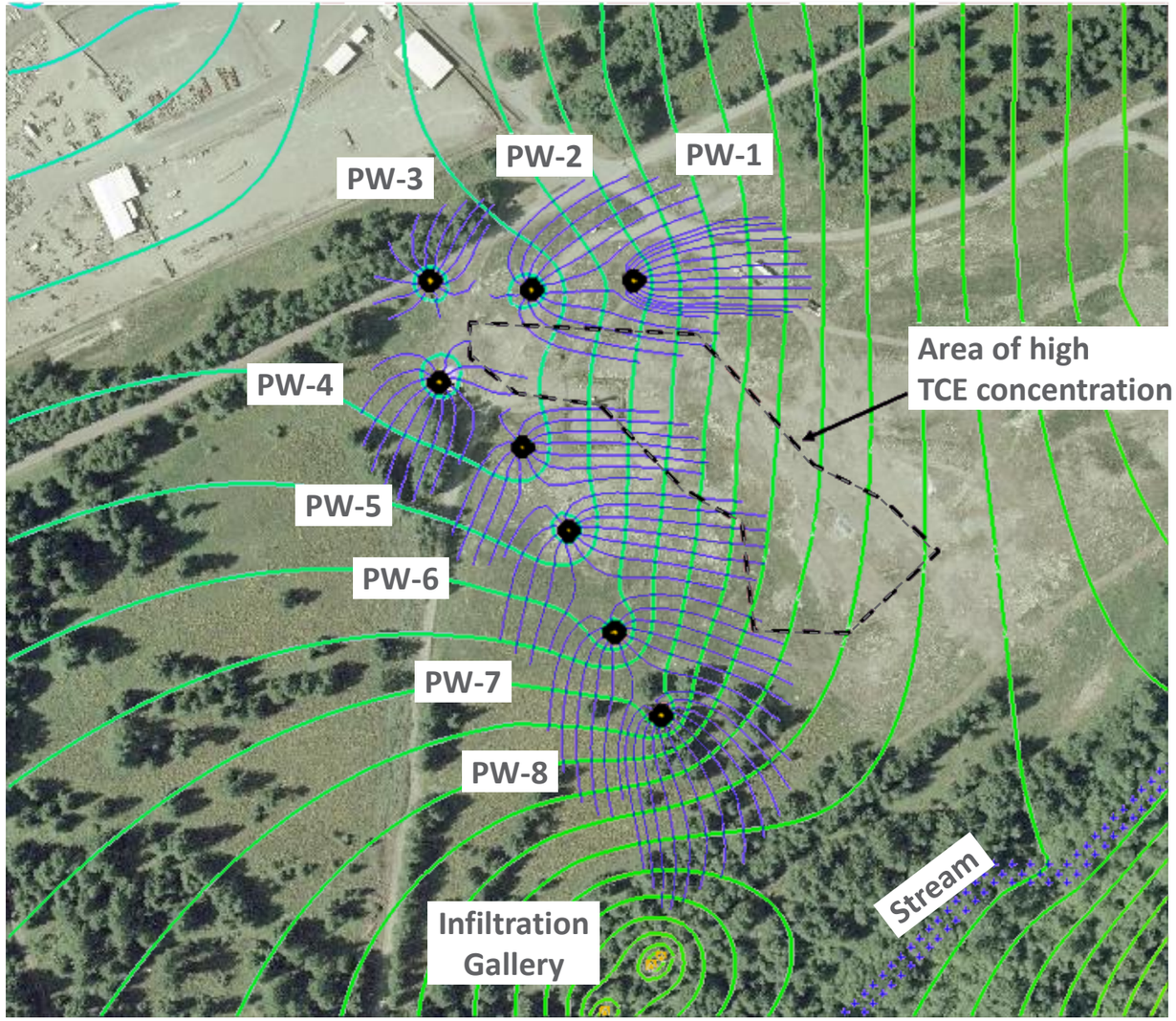
- Initial conceptual site model (CSM)
  - Plume axis and hydraulic gradient in initial CSM (red arrow)
- Initial P&T system
  - 4-spot P&T extraction wells
  - Infiltration gallery upgradient/west of NAPL Area 1
- Refined CSM
  - Seasonal hydraulic changes and drainage to adjacent stream
  - Lateral hydraulic gradient component (yellow arrow)
- Needed improved capture



Truex et al. 2017

Landfill 2 P&T Upgrade

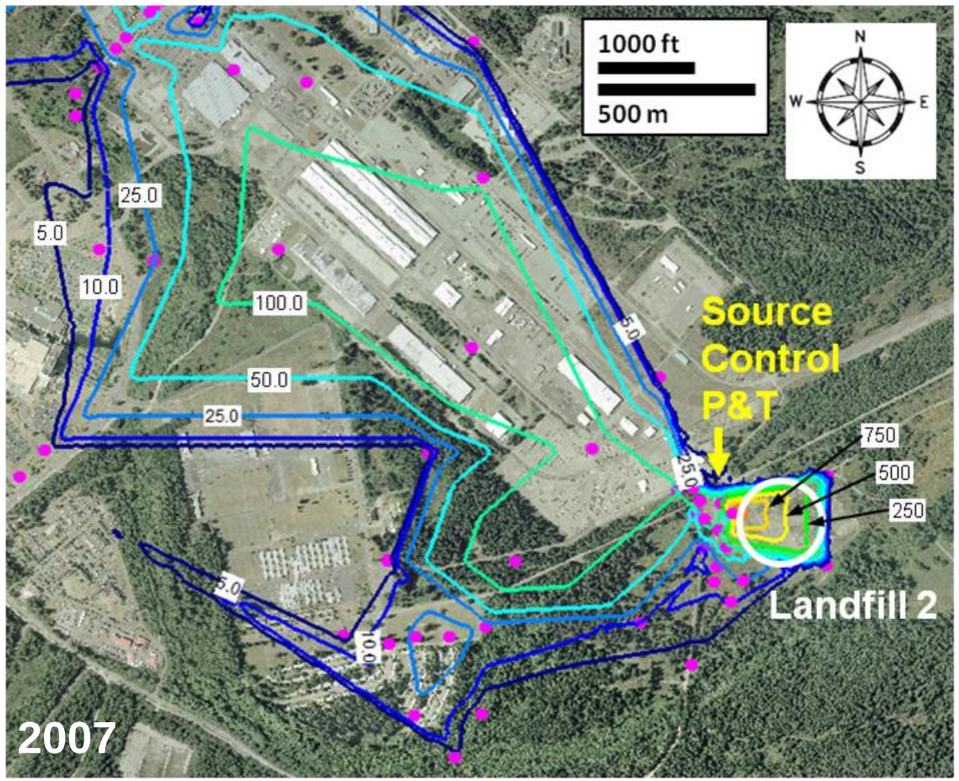
- System re-design
  - Used numerical model for design and predictions
  - 8 extraction wells in "V" or dogleg design
  - Moved infiltration gallery
- Predicted groundwater capture pathlines (blue lines)
- Hydraulic head contours (green lines)

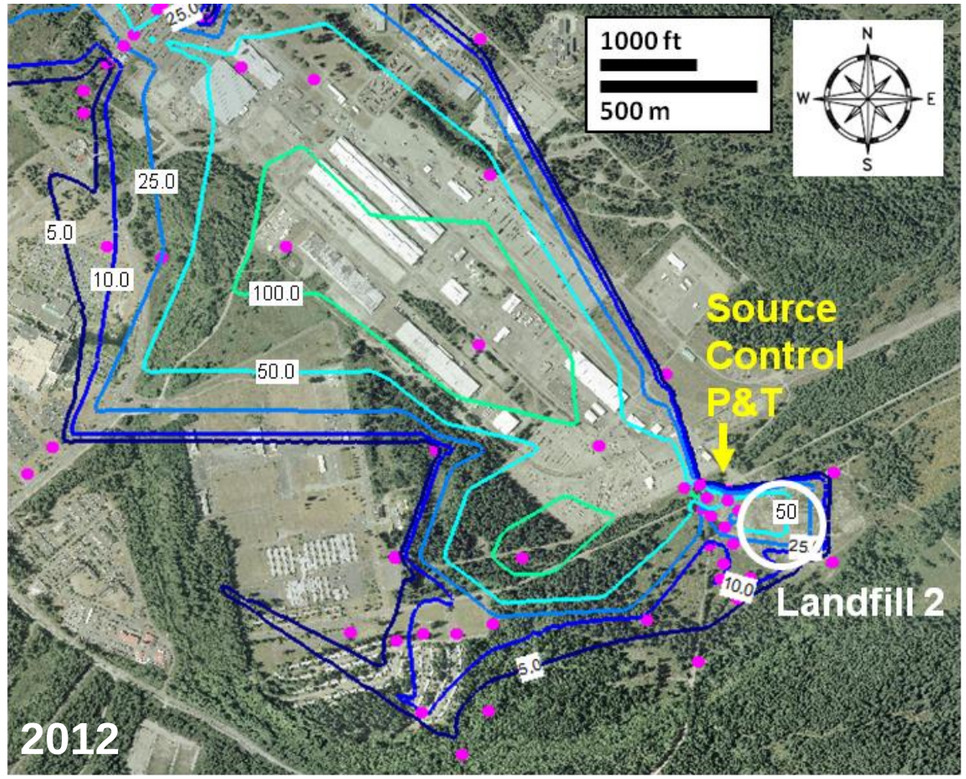


Truex et al. 2017

First Five Years of Updated Landfill 2 Source Control P&T

- Updated Landfill 2 source control P&T initiated in 2006
- Interpolated TCE concentration data (µg/L) in Vashon Aquifer





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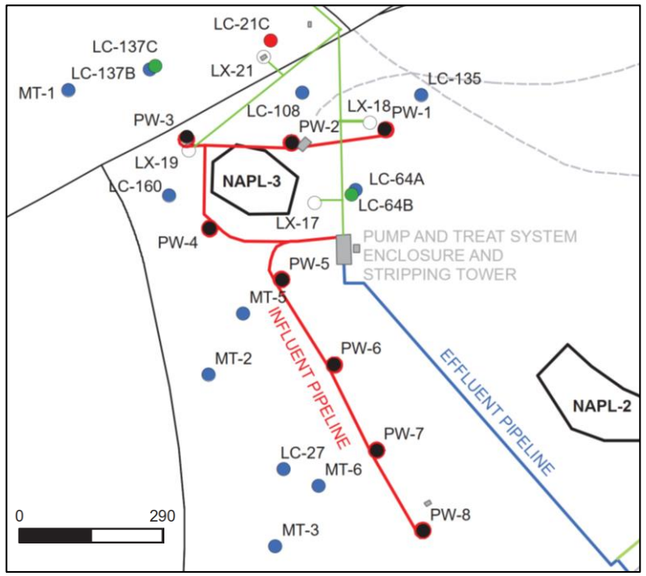
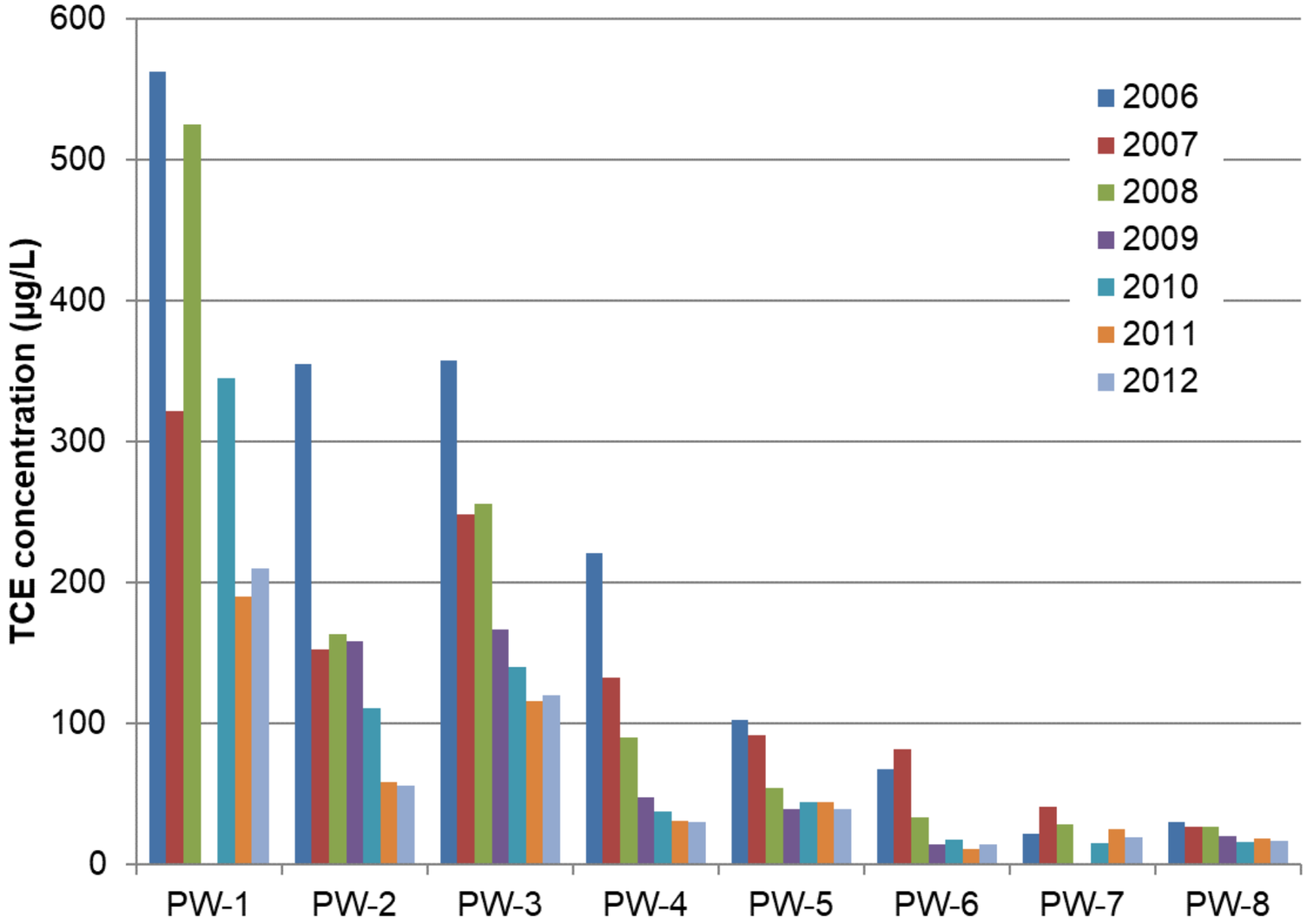
Truex et al. 2017

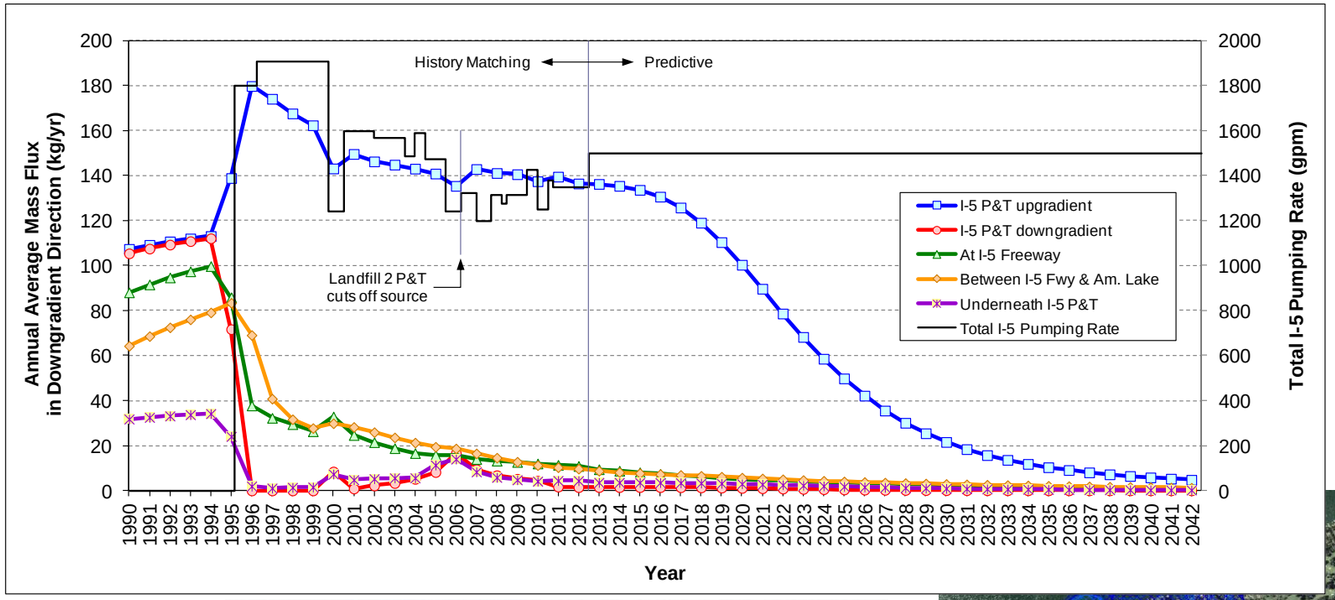
Landfill 2 P&T Data

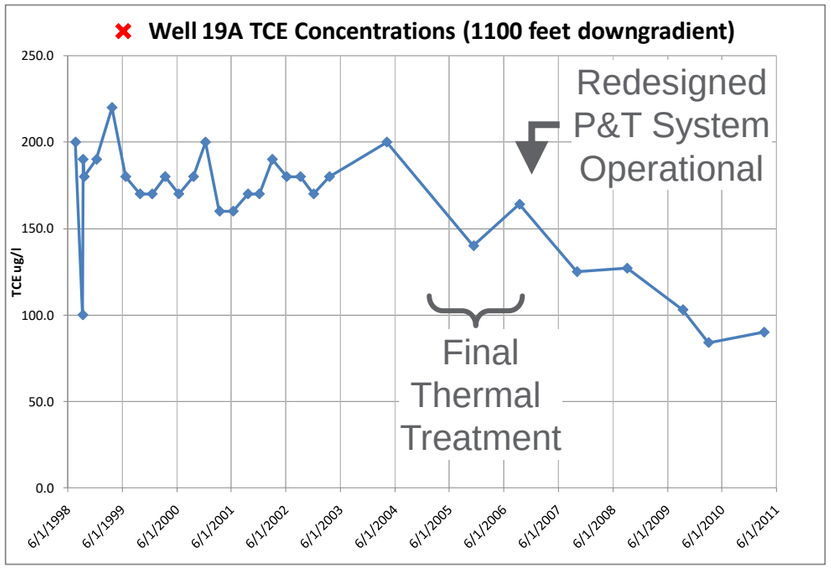
- Average concentrations over time at extraction wells

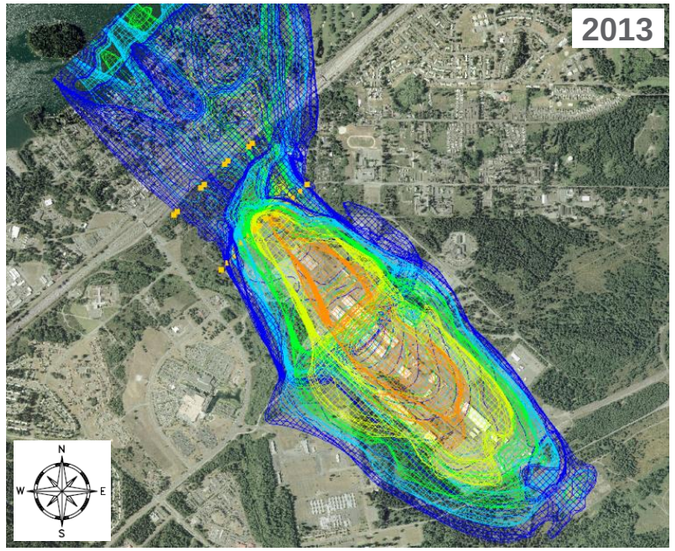


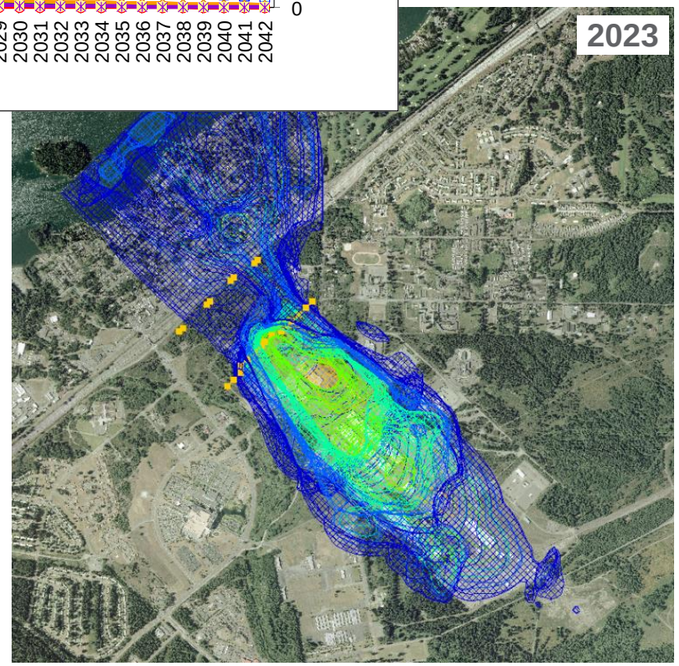


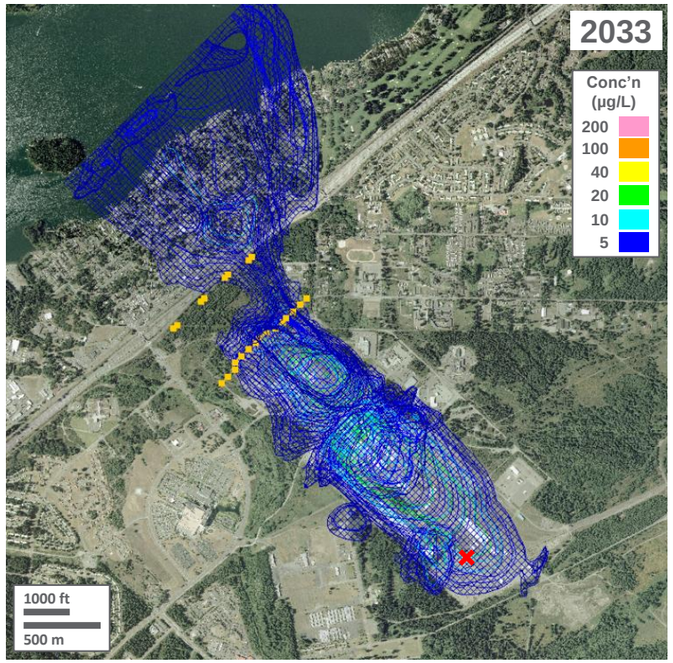
Impact on Downgradient Vashon TCE Plume











Summary

- Thermal treatment significantly diminished the source
- Pre- and post-treatment mass flux was quantified
  - Provided data to assess treatment performance
  - Approach provides information for treatment design and site management
  - Passive flux meters – concurrently measure spatial distribution of mass and Darcy flux
- P&T still needed for source control of residual TCE
- P&T design was updated to better control the source area
  - Updated conceptual site model → needed P&T re-design
  - Complex groundwater flow led to dog-leg design
  - Data indicate performance is favorable
    - Plume is being detached from source area
    - Majority of source capture is at PW-1 through PW-5

Impact and Broader Application

- The conceptual site model will evolve over time as additional data is acquired
  - Complex sites often require significant characterization
  - Here, seasonal changes in hydraulic gradient and flow direction were important
- Mass flux is useful for understanding:
  - Source strength
  - How to design source treatment or source control
  - Remedy performance
- Source control is key to minimizing overall remedy duration at JBLM
- These approaches and tools can apply to many sites
  - PNNL and U.S. Army Corps of Engineers pump-and-treat guidance (Truex et al., 2015)
  - Passive flux meters (Hatfield et al., 2004)

References

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