



PRAXIS

ENVIRONMENTAL TECHNOLOGIES, INC.

Thermally Enhanced Remediation

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Overview

- Definition of Thermal Enhancements
- State of the Industry with a Little History
- Challenges to “Success”
- Example Site – Residual Fuel
- Example Site – Submerged DNAPL
- Example Site – Accelerated SVE/Bioventing
- Combined Remedies
- Defining “Success”

Definition of Thermal Enhancement

- Introduction of energy into a contaminated subsurface to accelerate cleanup by conventional remedial technologies:
 - Vapor Extraction
 - Liquid Extraction
 - In Situ Destruction

GOAL: Accelerated risk elimination or reduction

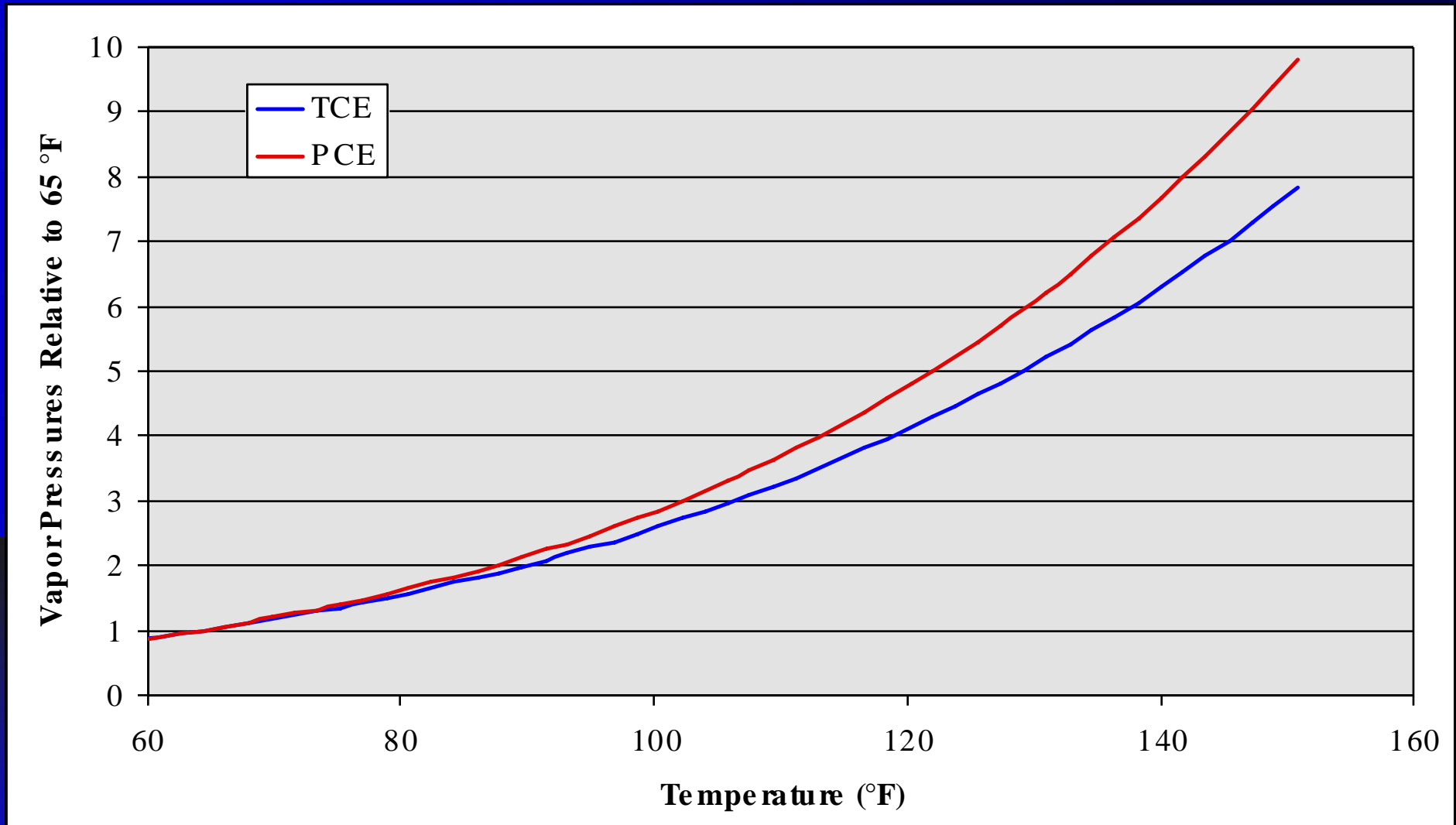
Thermal Enhancement Technologies

- Steam Injection
- Hot Air Injection
- Electrical Resistive Heating
- Conductive Heating
- Radio Frequency Heating
- Vitrification

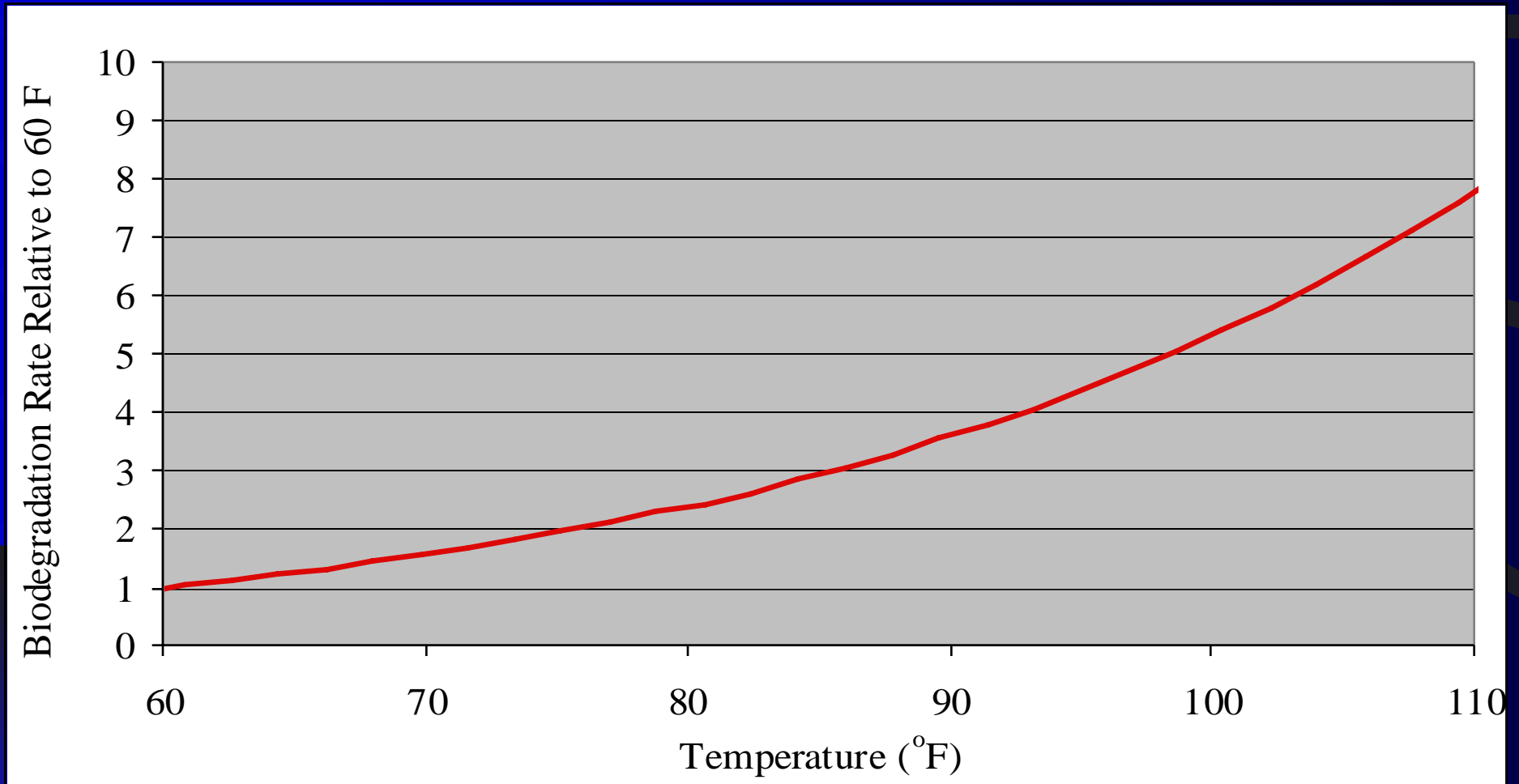
Enhancement Mechanisms

- Increased volatility
- Increased solubility
- Decreased adsorption
- Decreased viscosity
- Increased biological degradation rates
- Increased diffusion rates

Enhancement Mechanisms



Enhancement Mechanisms



Barriers to Widespread Usage

- Expensive with an uncertain outcome
 - extended operating period, in general
 - highly dependent on characterization
- Lack of “recipes”
 - P&T, SVE, MNA have much guidance
 - ISCO has some guidance
 - Thermal has almost none
- Proprietary: Primes vs Vendors

Challenges: Above Ground

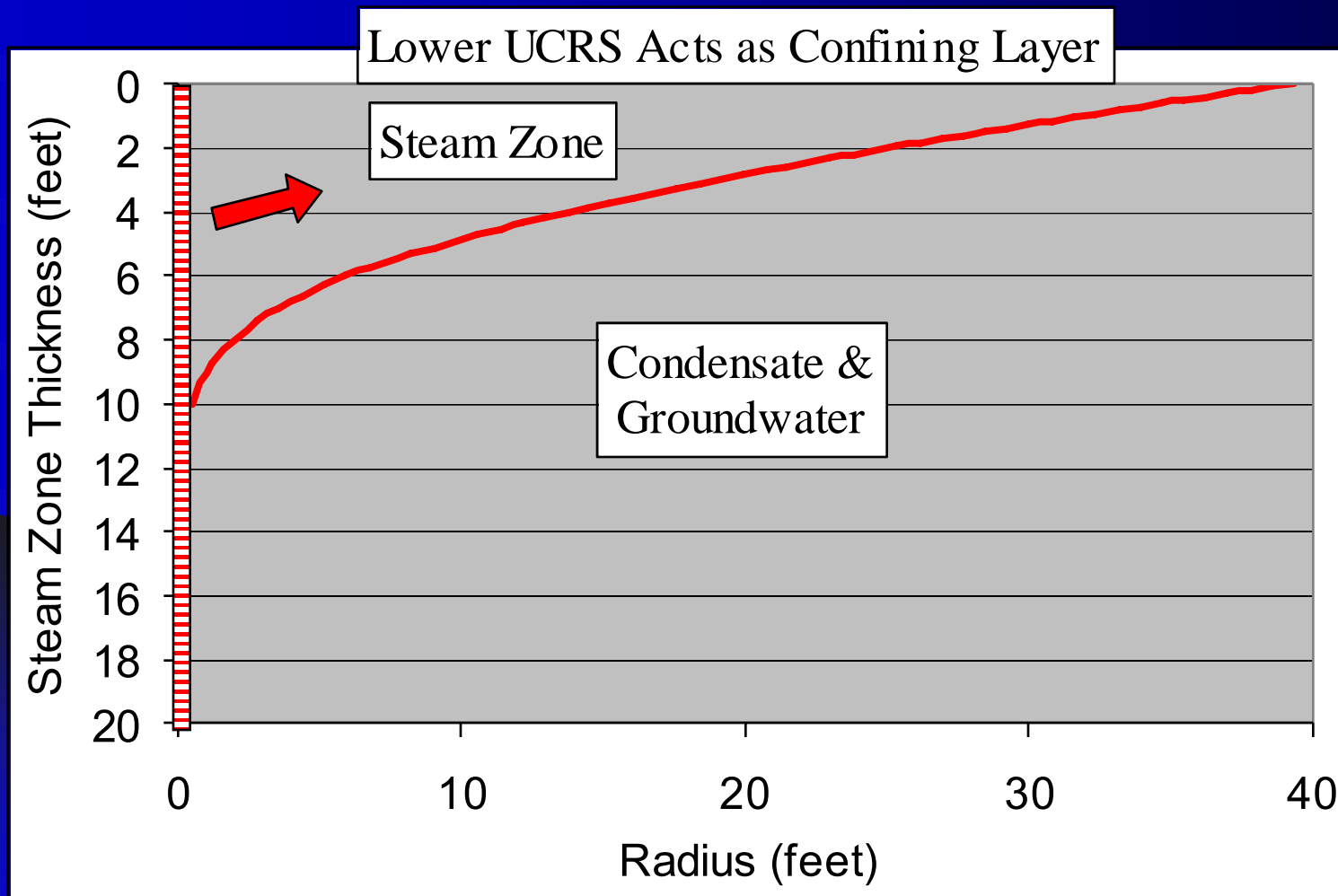
- What if the enhancement works extremely well during extraction?
 - huge, overwhelming slug of contaminants
 - treatment system must be designed for max
- Staging: Treat in cells or all together
- Availability of utilities
- What's the risk of killing an operator?

Challenges: Below Ground

- Where are the contaminants?
- How to get energy where it's wanted
- Adverse contaminant migration
- Control
 - how to keep energy and mobilized contaminants where they belong
- Can cleanup be attained reasonably?

Challenges: Below Ground

Gravity Override During Steam Injection

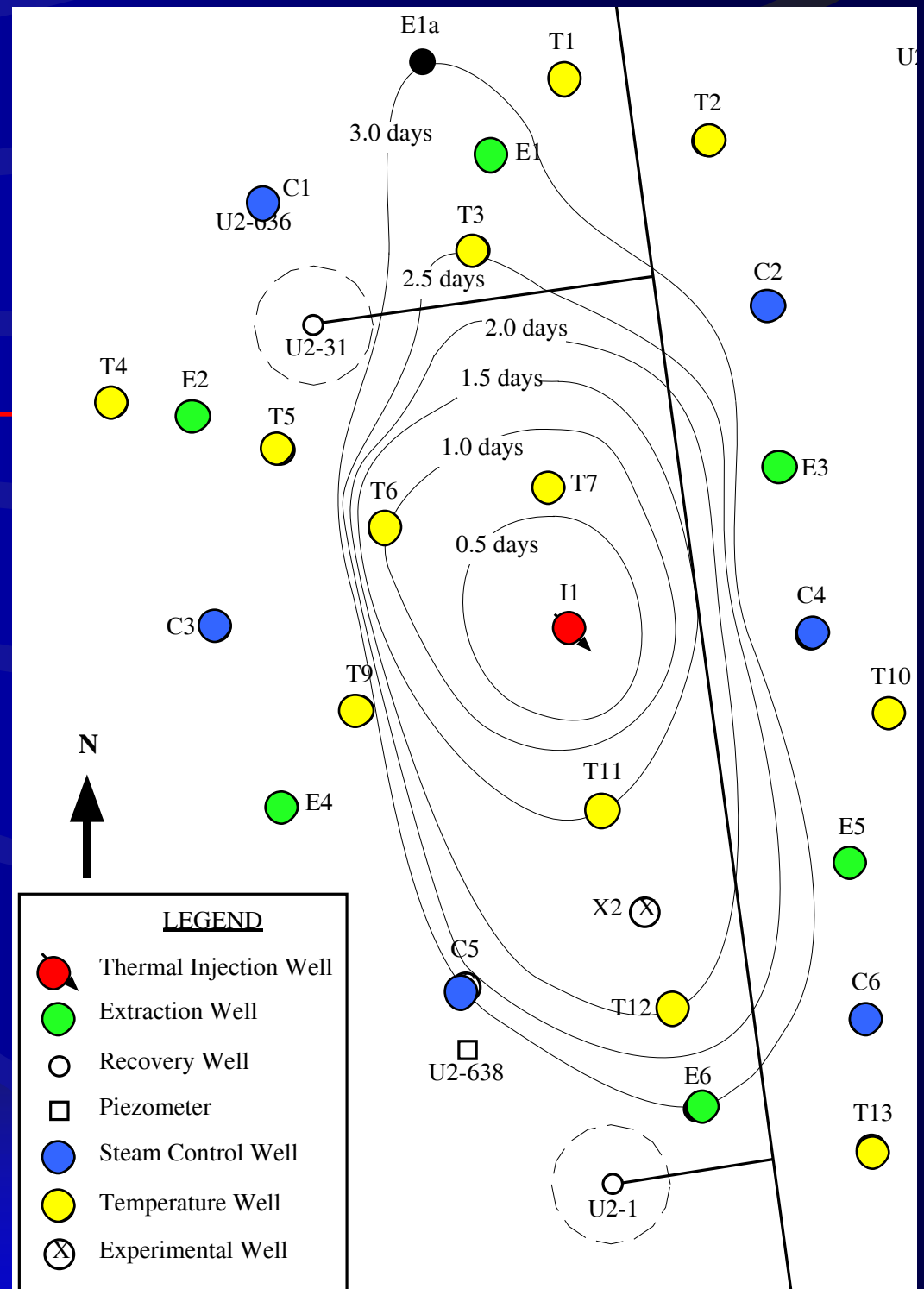


Note: Calculation graciously provided by Baron van Lookeren

Example – Submerged DNAPL

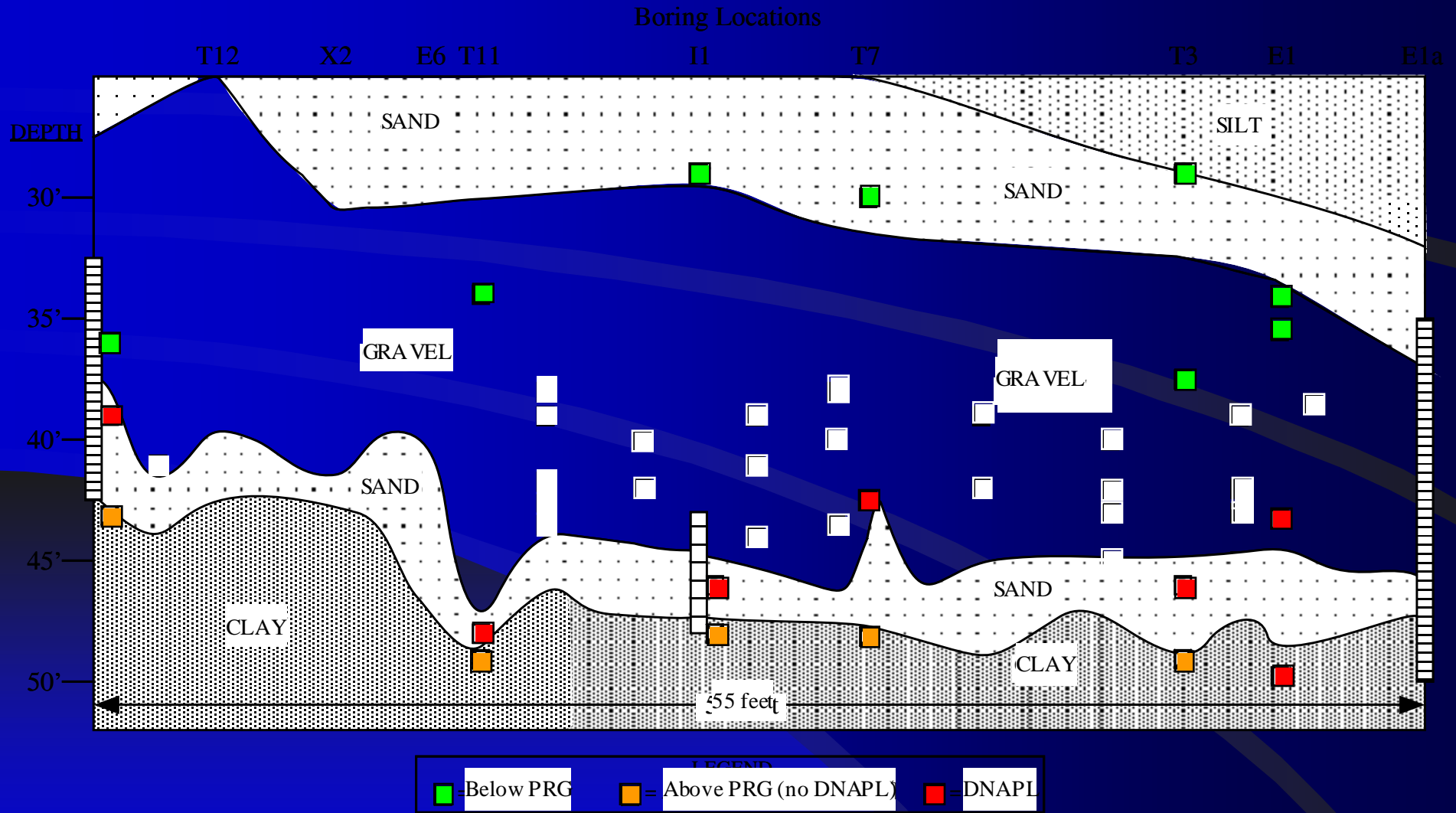
Hill AFB Operable Unit 2:

- TCE, PCE
- DNAPL pooled at bottom of a saturated channel



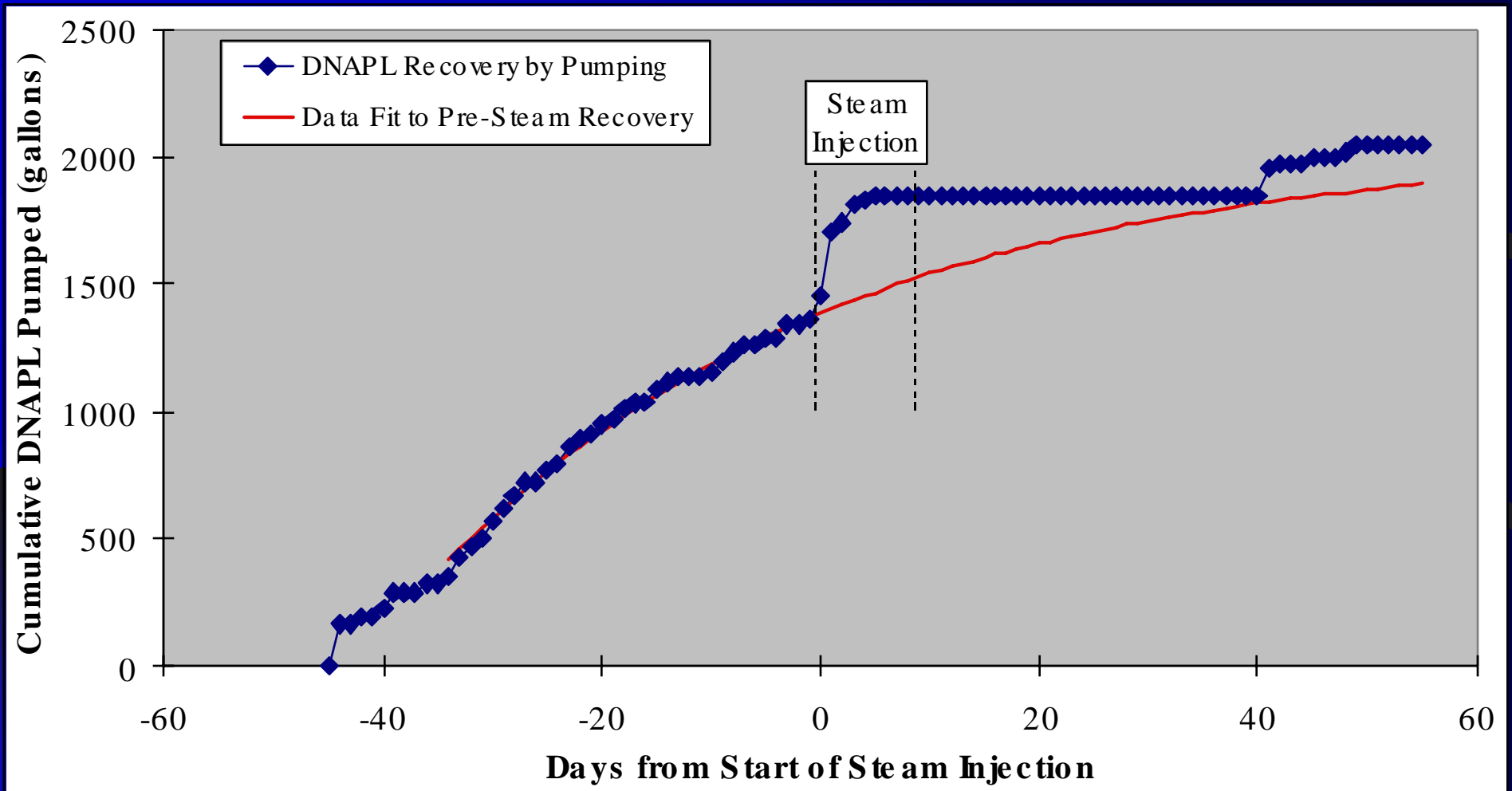
Example – Submerged DNAPL

Initial Soil Concentrations



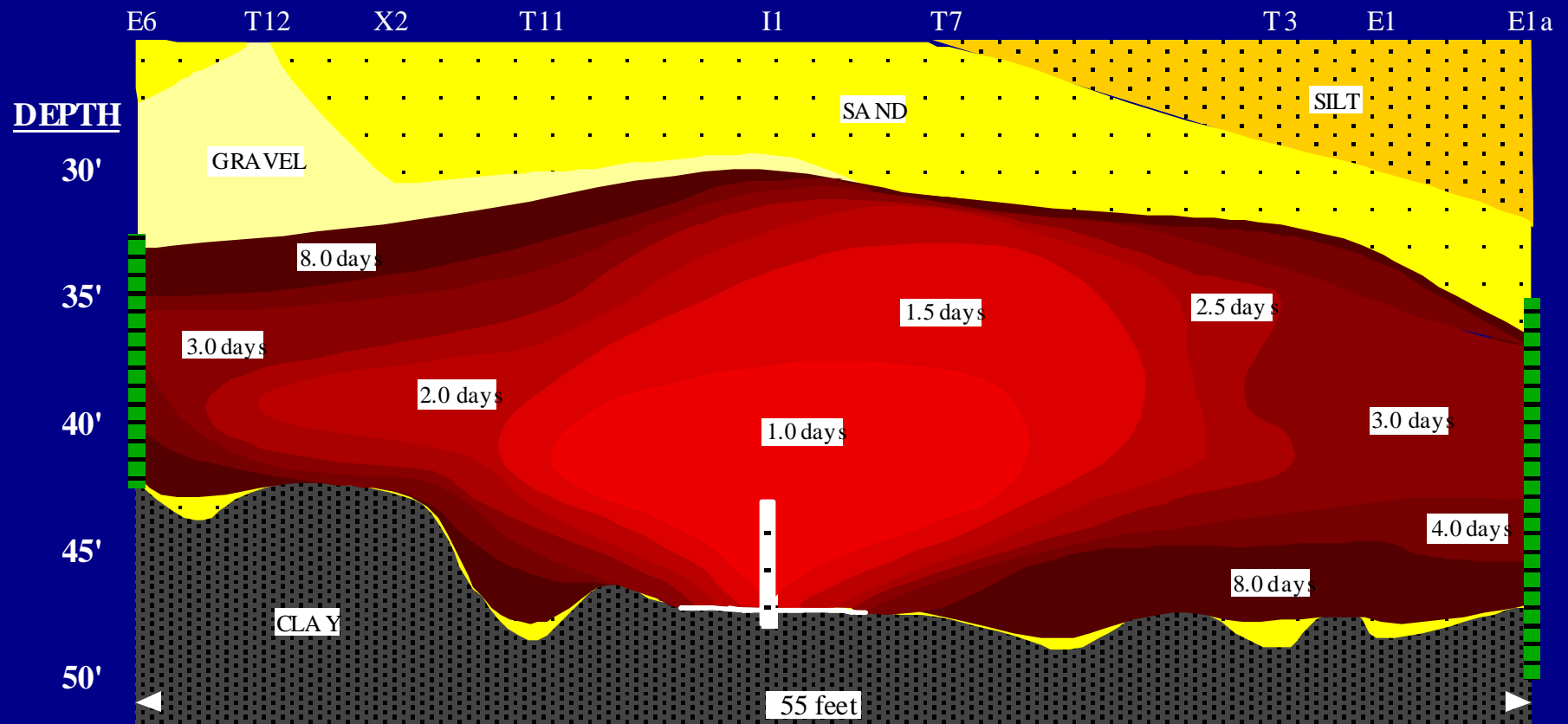
Example – Submerged DNAPL

DNAPL Recovery by Pumping



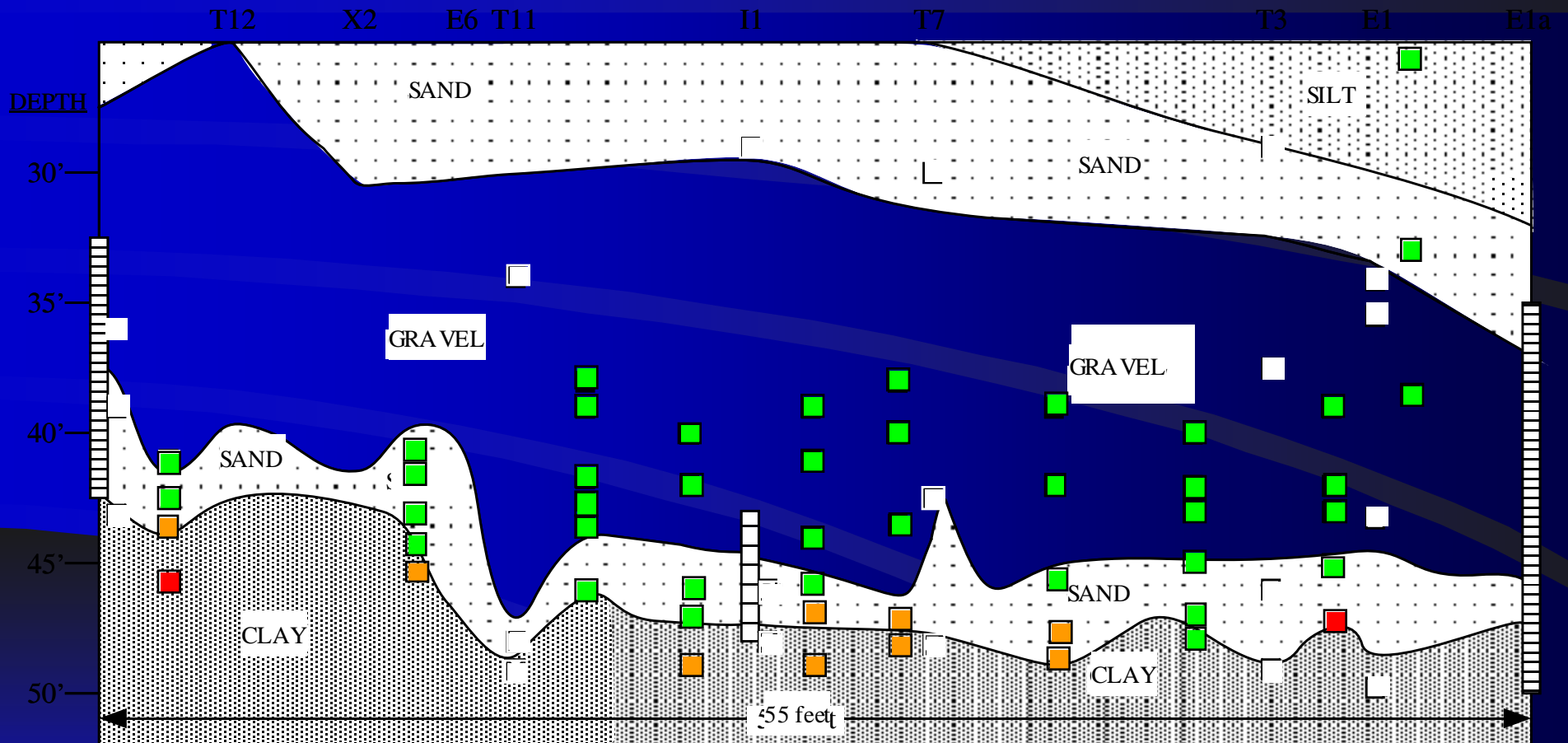
Example – Submerged DNAPL

Steam Zone Cross-Sections



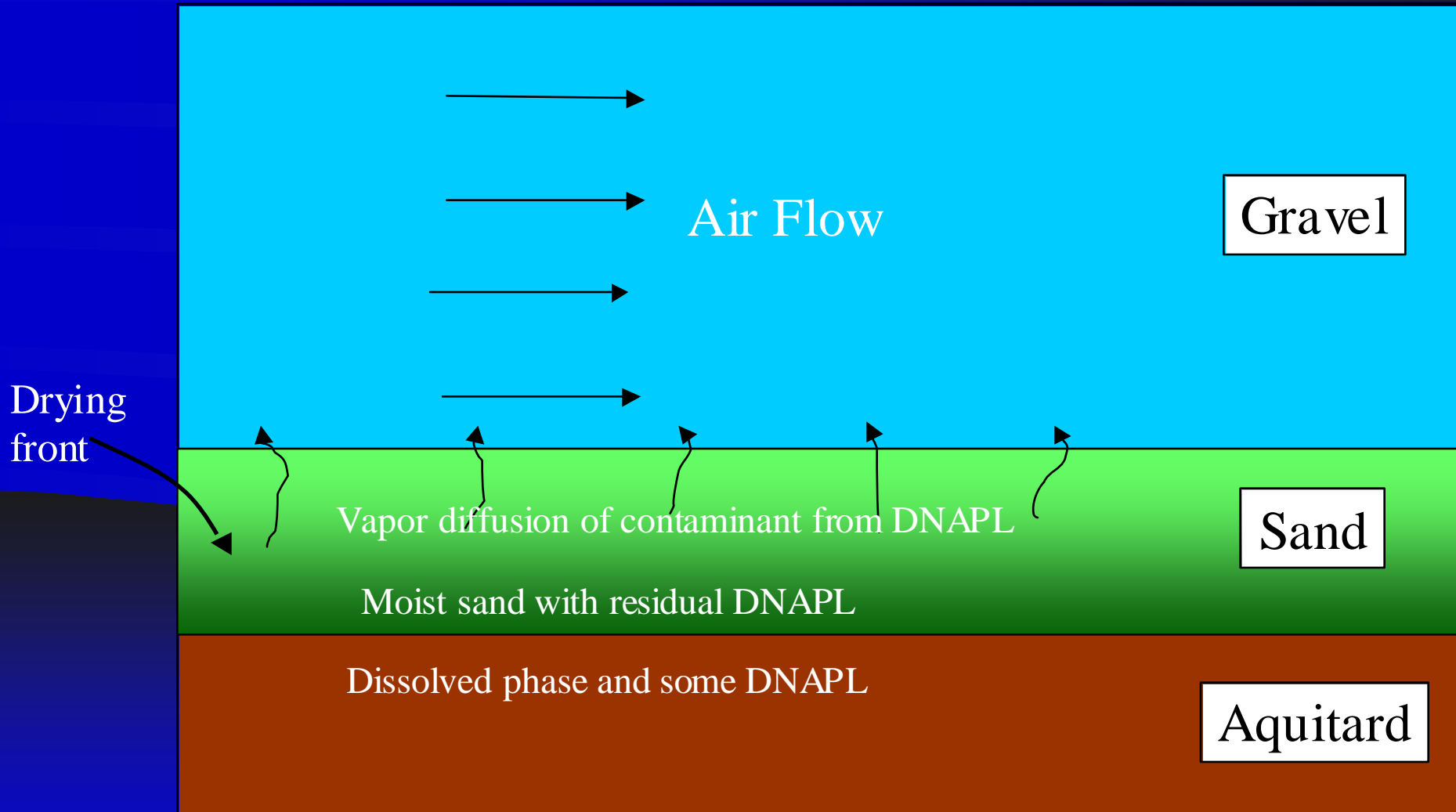
Example – Submerged DNAPL

Boring Locations



Example – Submerged DNAPL

Mass Transfer during Air Injection



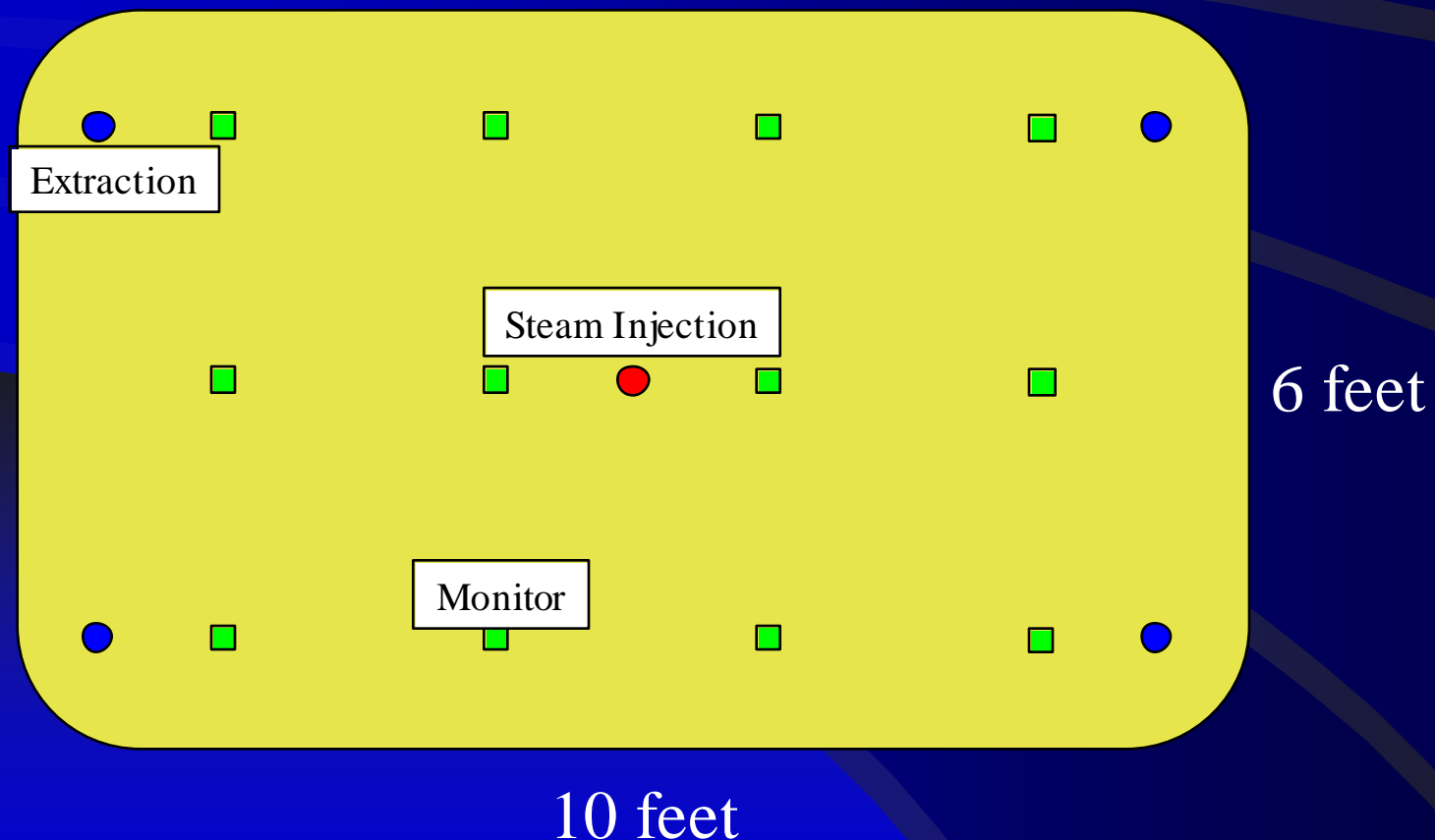
Example – Submerged DNAPL

- ~ 2,300 gallons of DNAPL Recovered
 - 1,400 during partial de-watering
 - 550 during steam injection (only 8 days)
 - 350 during air injection and SVE
- Excellent Control of Steam Zone Achieved
 - directed steam horizontally through DNAPL zone
 - steam zone contained within extraction wells
- Vapor Concentrations Reduced >90%
- Soil Concentrations Reduced
 - Gravel Channel ~96%
 - (initially) Saturated Zone ~97%
 - Aquitard >50%

Example – NAPL Pilot Test w/Steam

Hill AFB Operable Unit 1 (SERDP Funded):

- Heavy hydrocarbons with dissolved VOCs (e.g., benzene, TCE)
- Smear Zone of residual NAPL (no recovery from pumping)



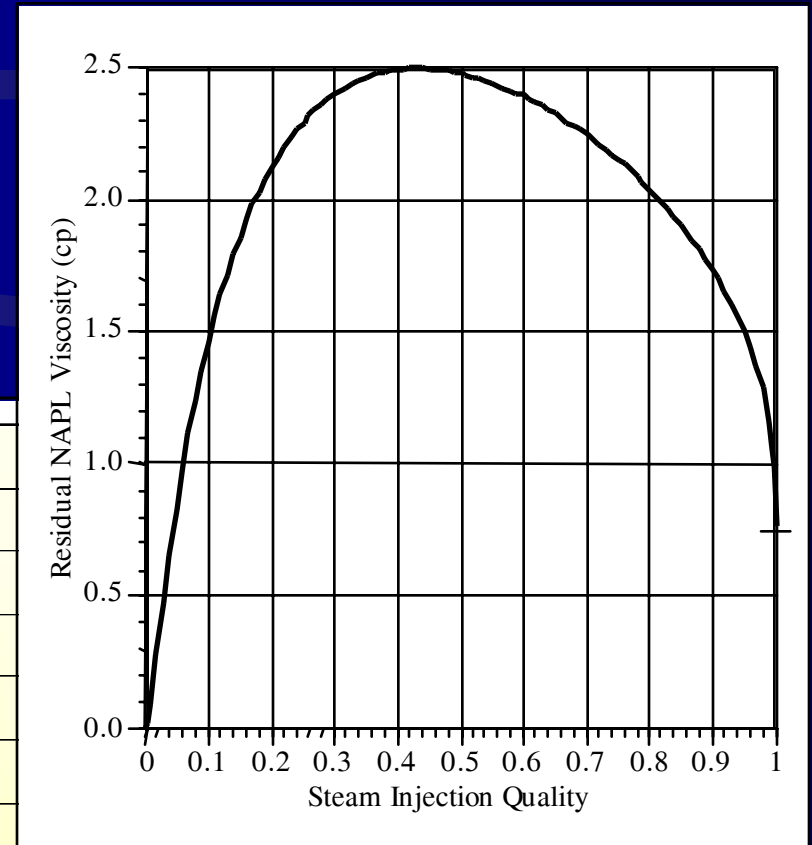
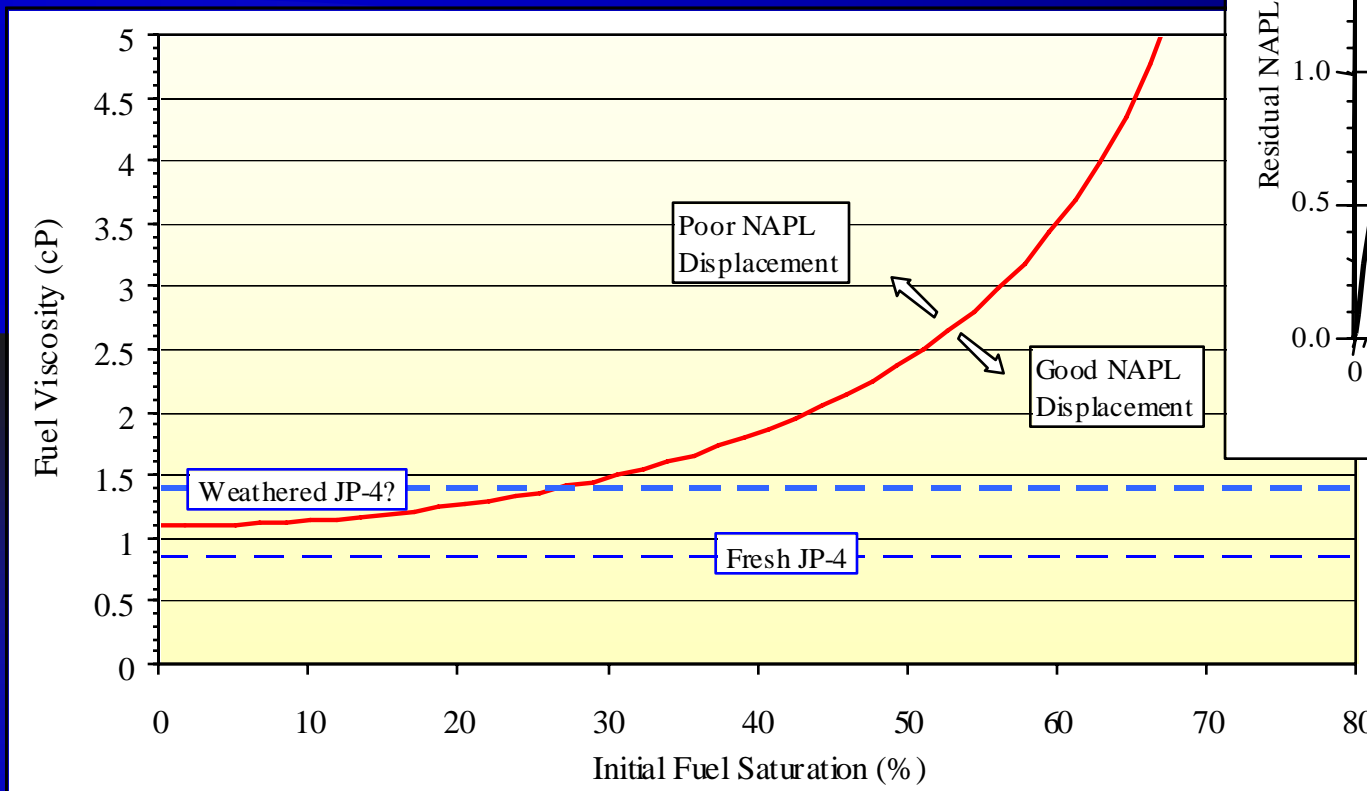
Example – NAPL Pilot Test w/Steam

- Target Compounds Effectively Reduced in Soil
 - Volatiles > 90%
 - Moderate Volatiles 80% to 90%
 - Semi-Volatiles 70% to 80%
- Groundwater Concentrations Reduced ~90%
- Distillation was Primary Recovery Mechanism
- Residual NAPL was not mobilized

Example – NAPL Pilot Test w/Steam

Stable NAPL displacement only if:

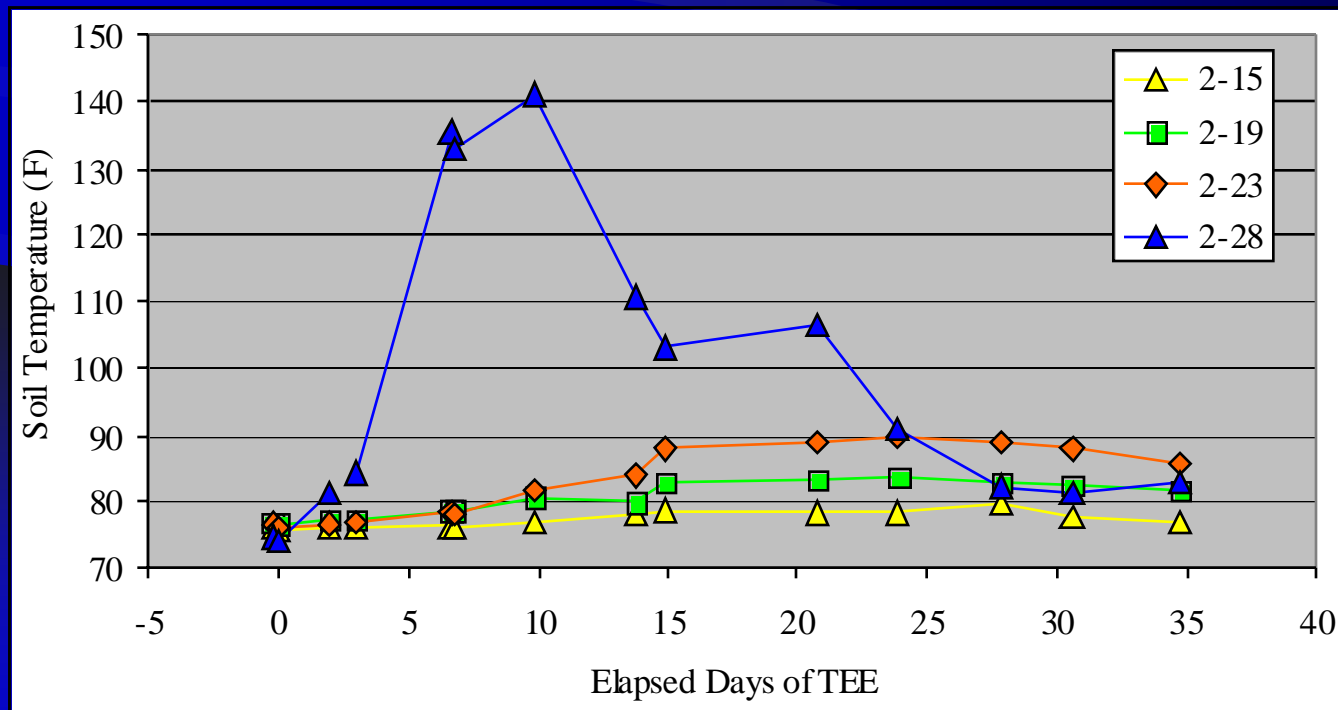
$$-\frac{dP_v}{dx} \geq -\frac{dP_o}{dx}$$



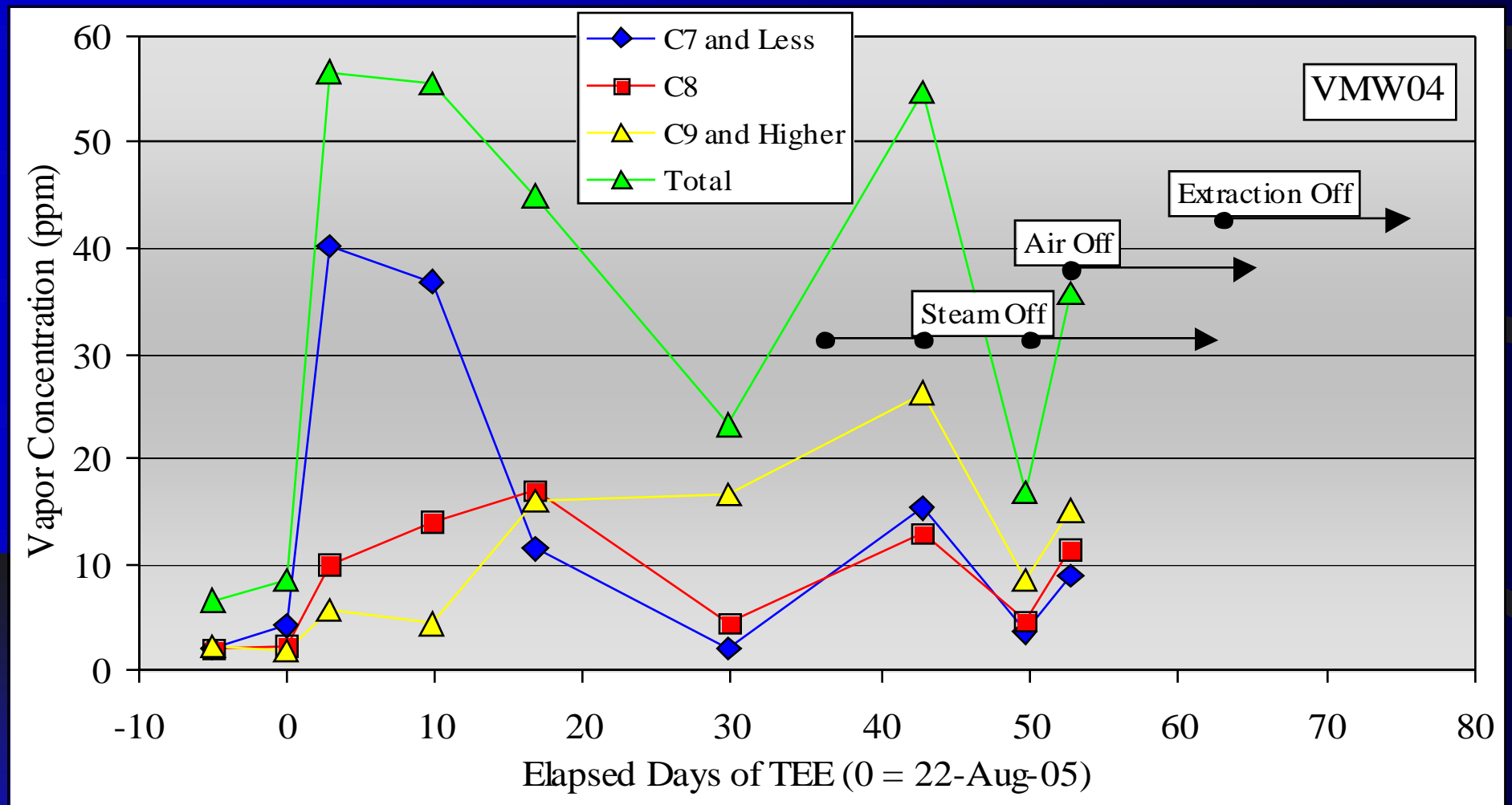
Example – Accelerated SVE & Bio

Castle AFB:

- Residual NAPL in vadose zone including VOCs (e.g., benzene)
- Ongoing SVE for several years
- Added injection of steam/air mixture at ~150 F

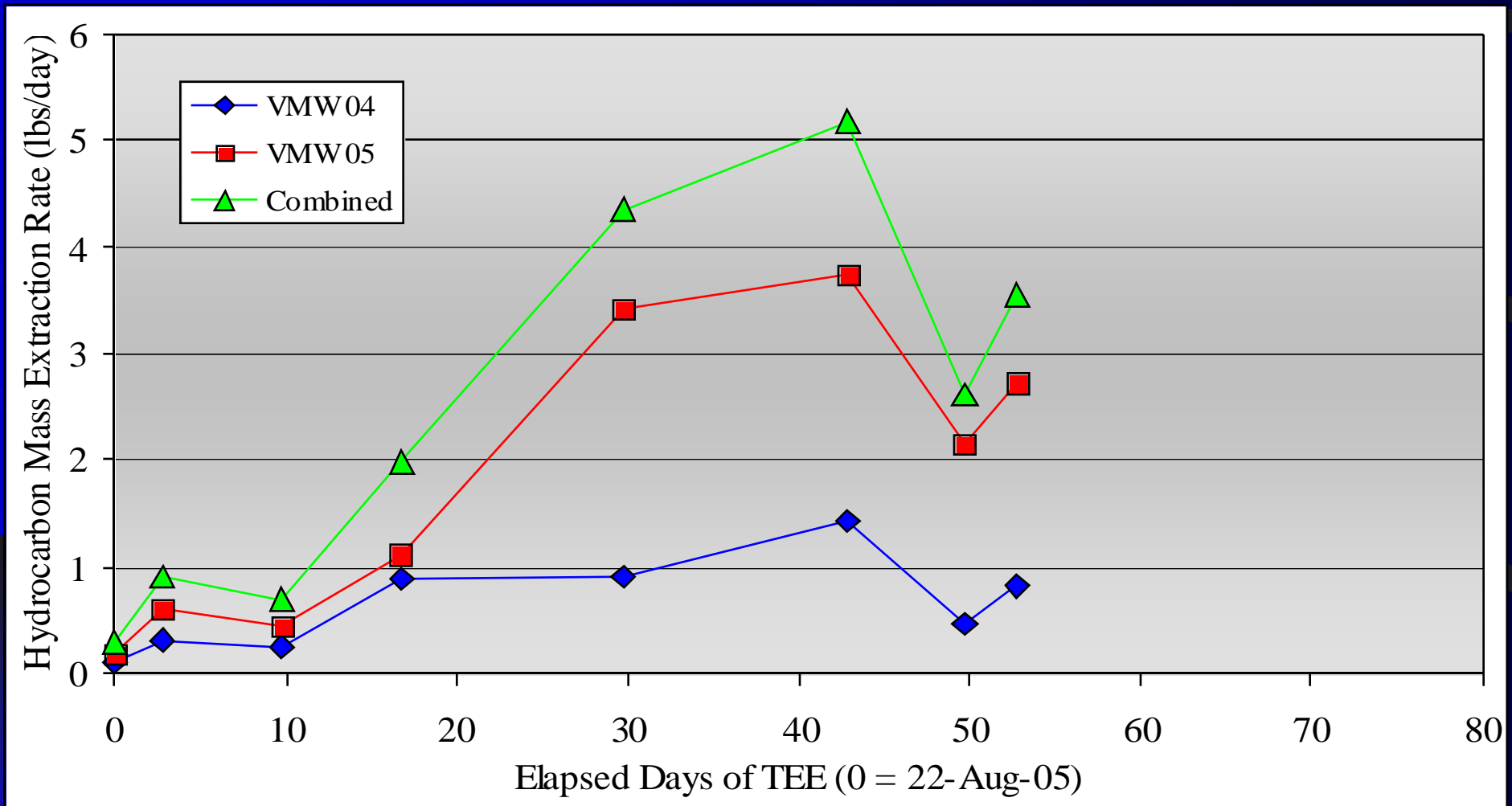


Example – Accelerated SVE & Bio



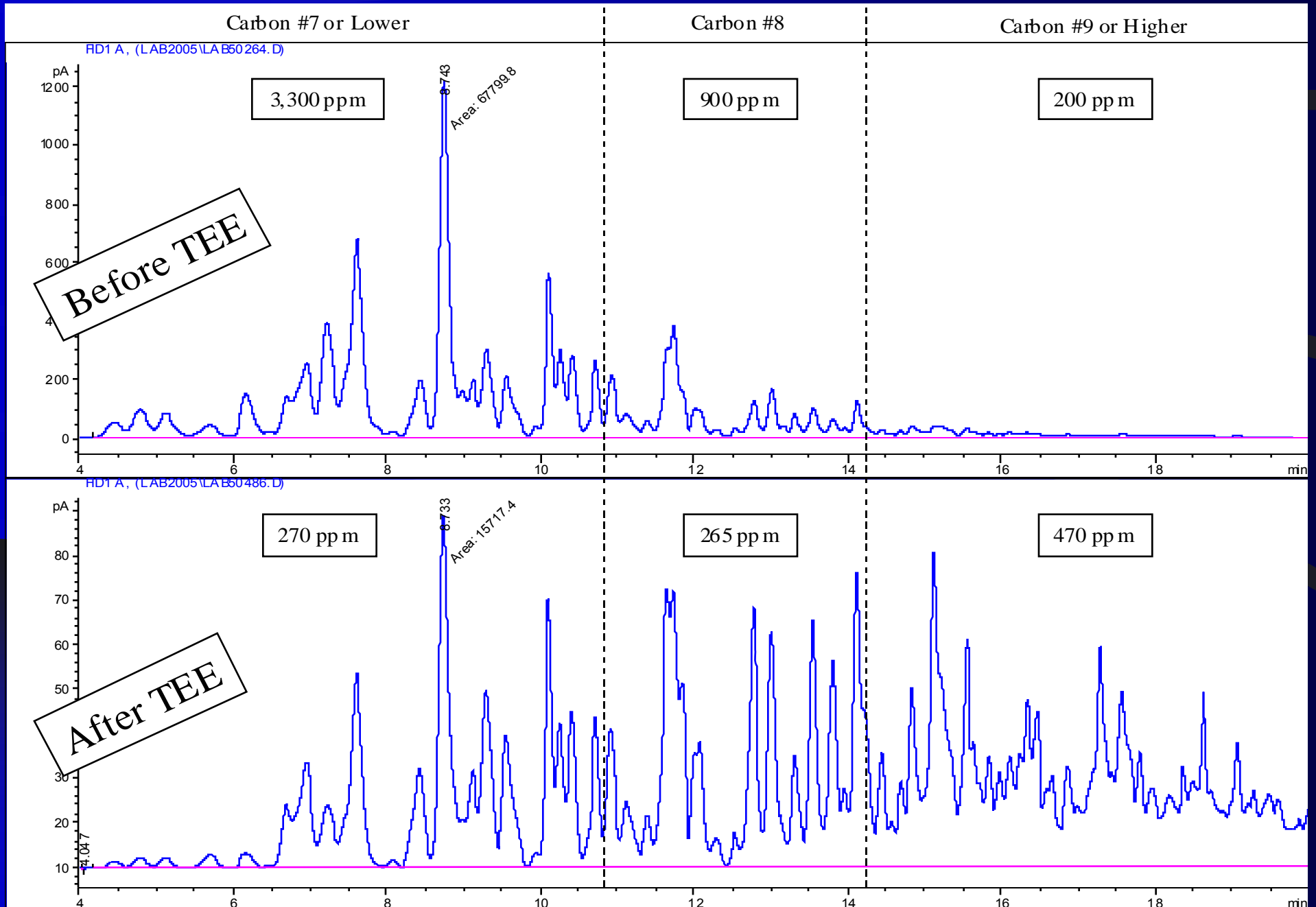
Extraction Well

Example – Accelerated SVE & Bio

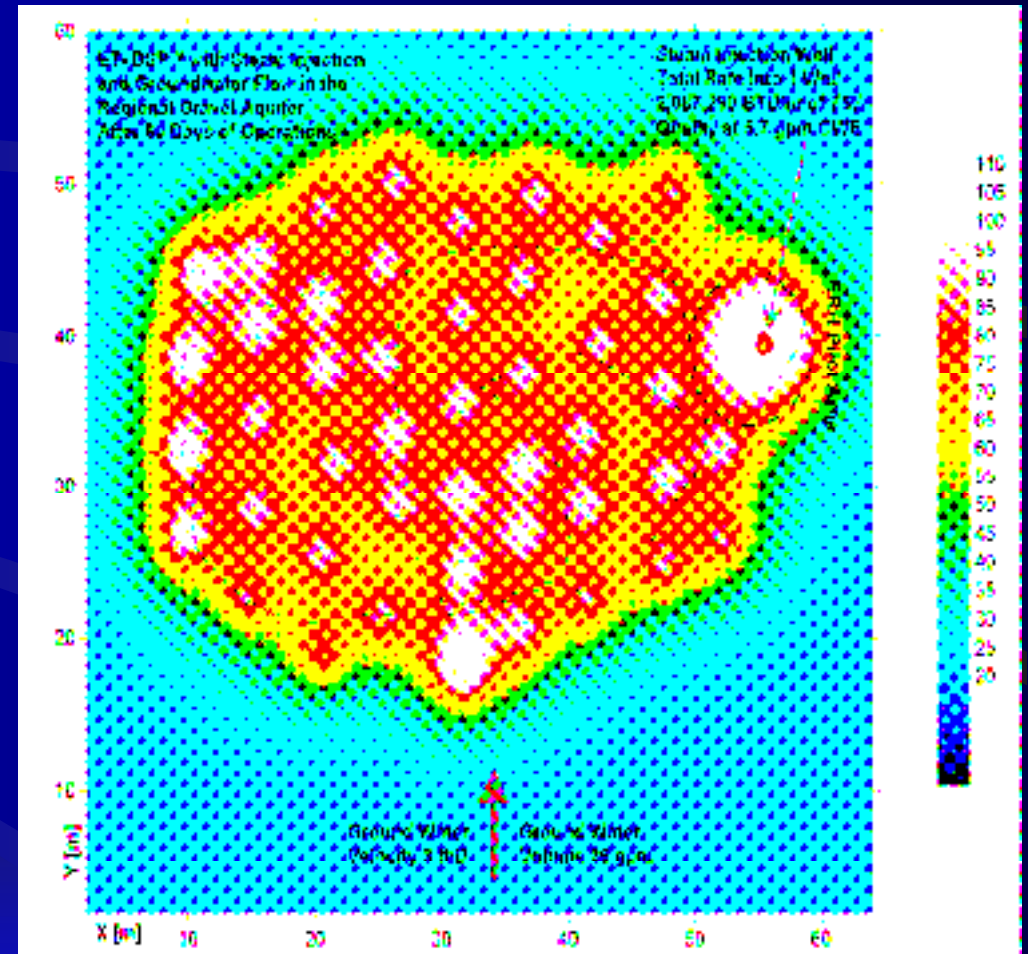
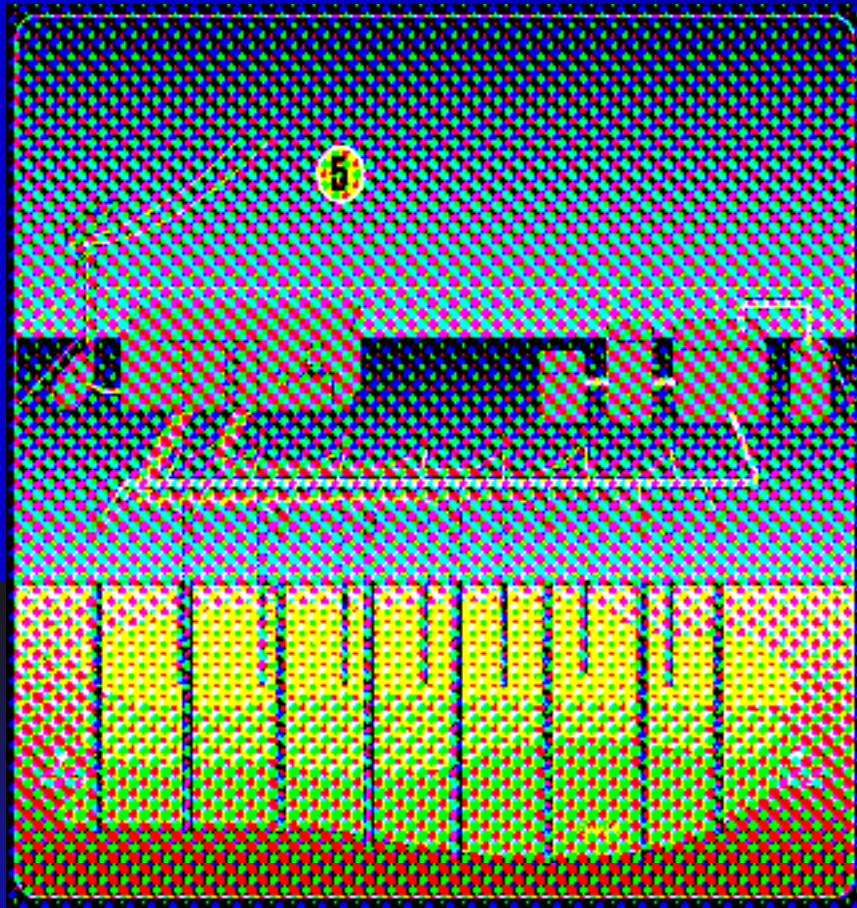


TER yielded 40 pounds; preceding 7 months of SVE only 24 pounds

Example – Accelerated SVE & Bio



Electrical Resistance Heating



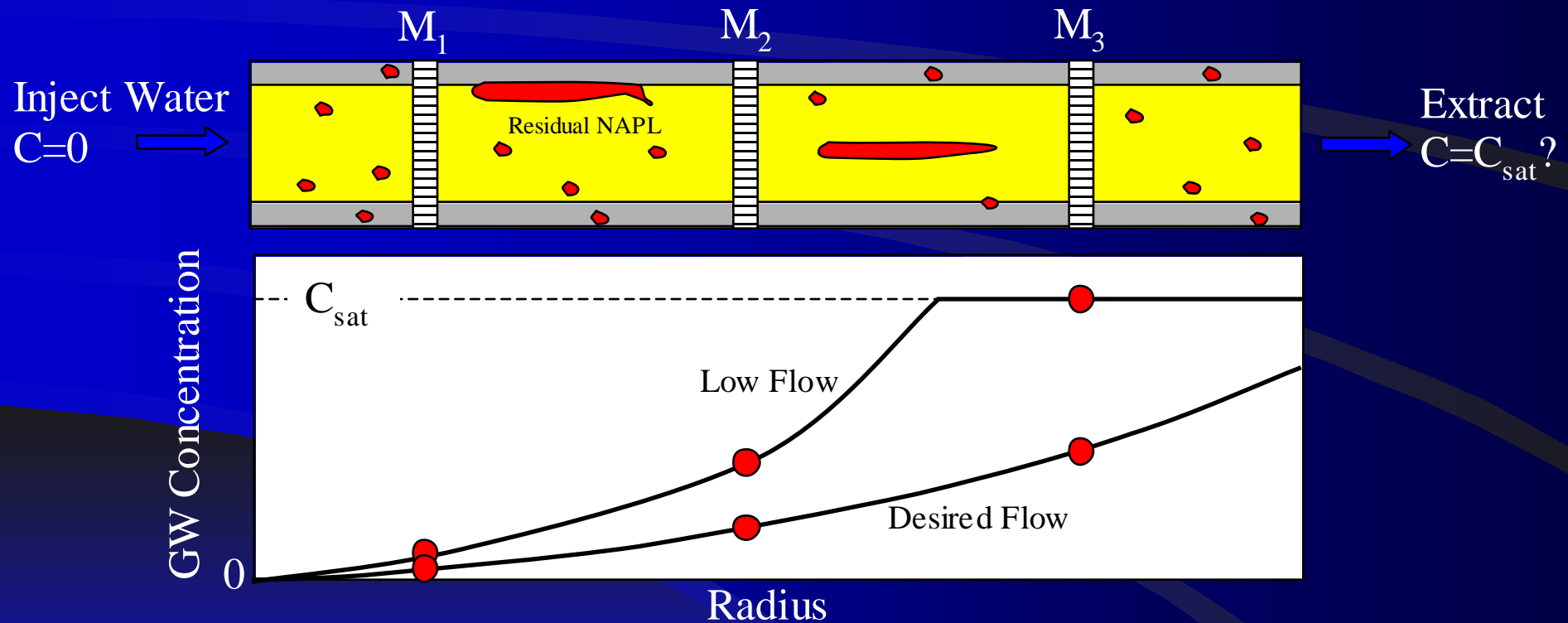
Thermally Enhanced ISCO

Current Hot Topic is Combined Remedies, eg:

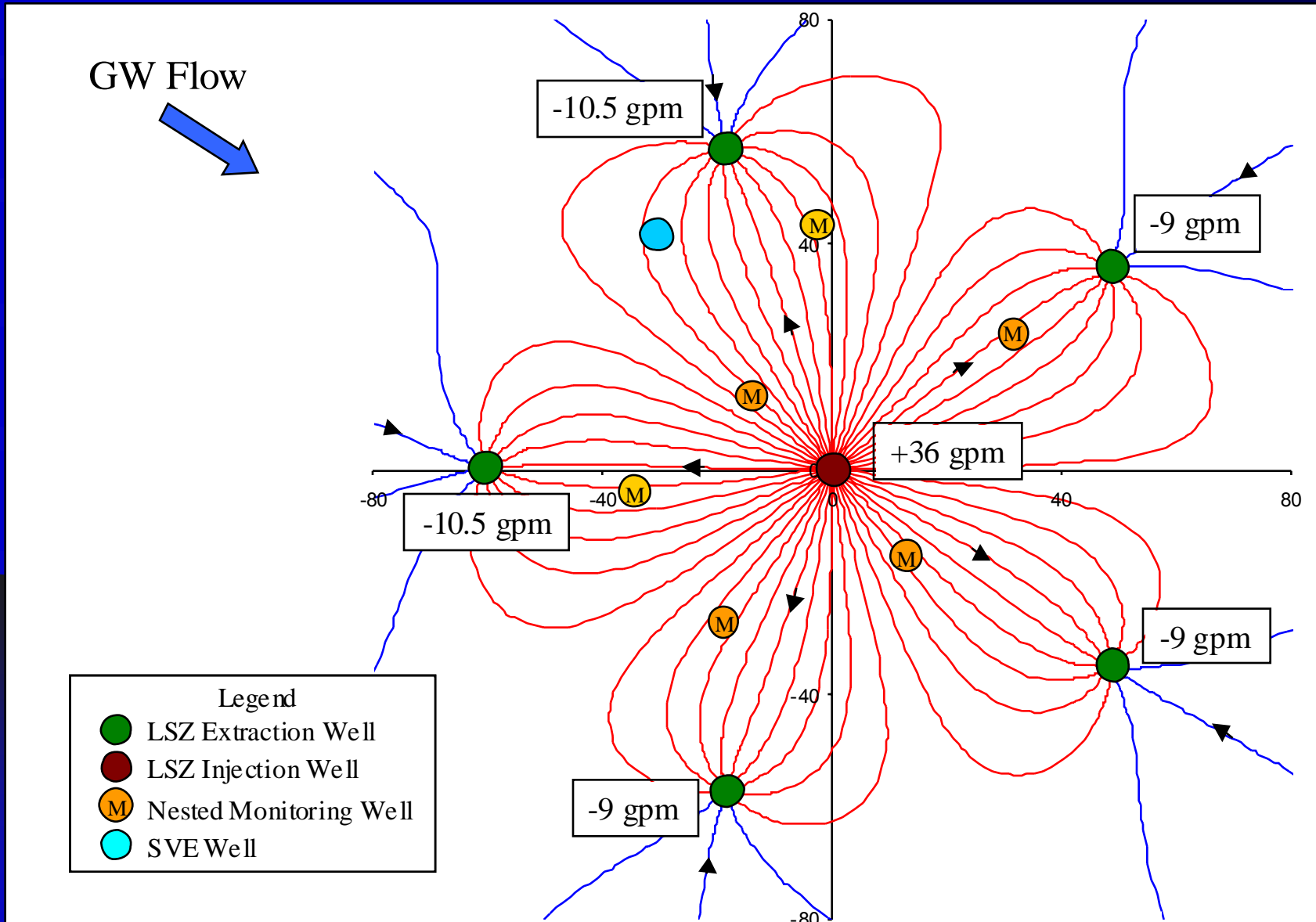
- NAPL displacement by steam
- ERH for volatilization
- ISCO utilizing residual heat for activation
- Hopefully a well documented case study will be available soon

Mass Transfer Assessment

Is mass transfer of COC quantifiable?



Mass Transfer Assessment



Final Thoughts

- Thermal enhancements are used in conjunction with conventional technologies – not really separate technologies
- Recipes are needed for broader use
- Risk reduction is realistic
- ???