LNAPL Technical Overview

New Jersey Department of Environmental Protection
Site Remediation Program
LNAPL Guidance Training
June 15, 2011

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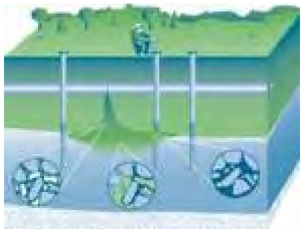
Presentation Outline

- Available LNAPL Training and the ITRC
- Brief Overview of Key LNAPL Concepts
  - LNAPL Basics
  - LNAPL Conceptual Site Model
  - Recoverability
  - Goals / Objectives / Endpoints
- Case Study 1 – Active Recovery
- Case Study 2 – Maintenance Recovery

Welcome – Thanks for joining us.
ITRC's Internet-based Training Program

LNAPL Training

An Improved Understanding of LNAPL Behavior in the Subsurface



State of Science vs. State of Practice

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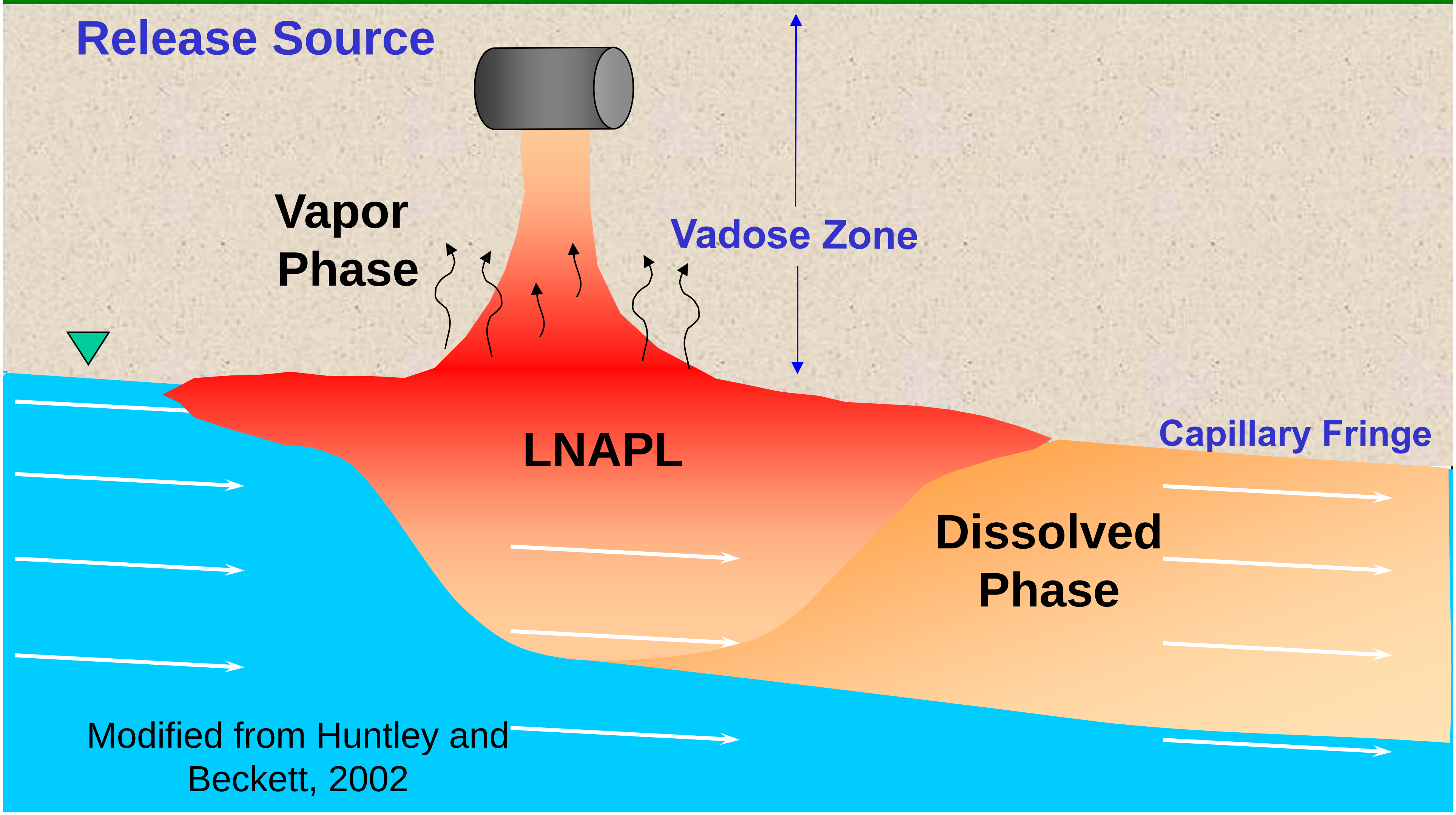
ITRC LNAPL Team Training

- Internet Based Training Part 1: Understanding LNAPL Behavior
- Internet Based Training Part 2: LNAPL Characterization and Recoverability
- Internet Based Training Part 3: ITRC Technical and Regulatory Guidance: Evaluating LNAPL Remedial Technologies for Achieving Project Goals
- 2-Day Classroom training: LNAPL Science, Management and Technology

Simplified Conceptual Model for LNAPL Release to the Subsurface and Migration

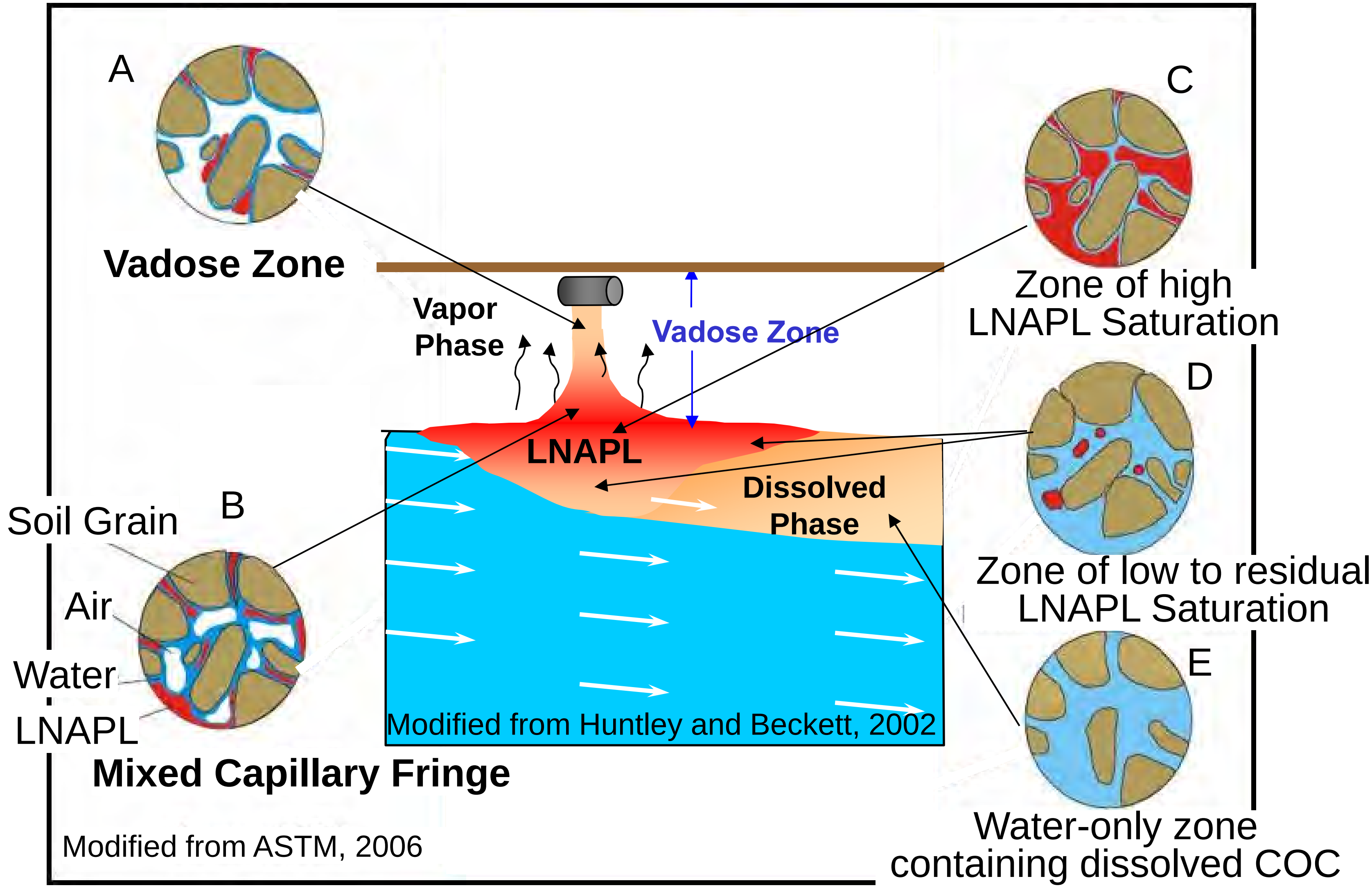


Modified from Huntley and Beckett, 2002

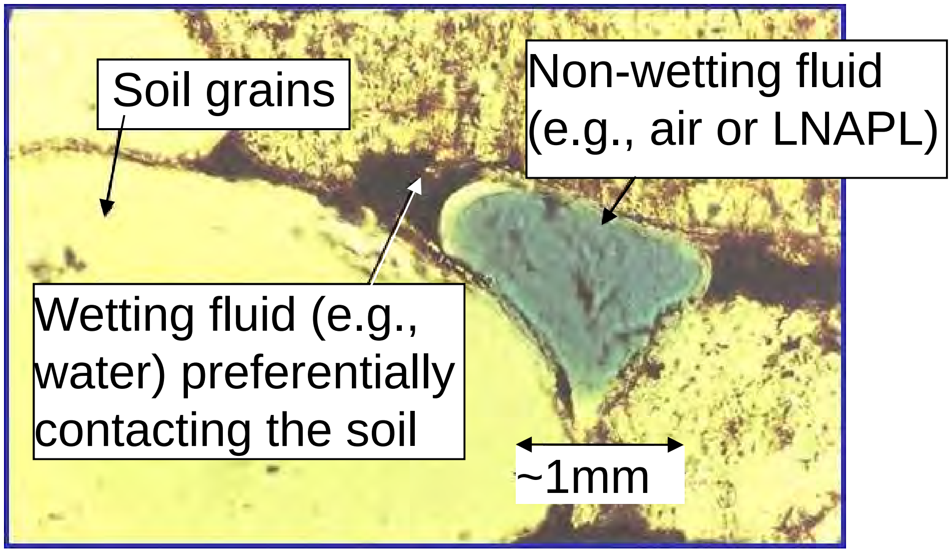
Common (mis) Perceptions about LNAPL

- LNAPL enters the pores just as easily as groundwater
- You can recover all LNAPL
- All the pores in an LNAPL plume are filled with LNAPL
- LNAPL floats on the water table or capillary fringe like a pancake and doesn’t penetrate below the water table
- Thickness in the well is exaggerated by a factor or 4, 10, 12, etc.
- LNAPL thickness in a well is always equal to the formation thickness
- If you see LNAPL in a well it is mobile and migrating
- LNAPL plumes spread due to groundwater flow
- LNAPL plumes continue to move over very long time scales

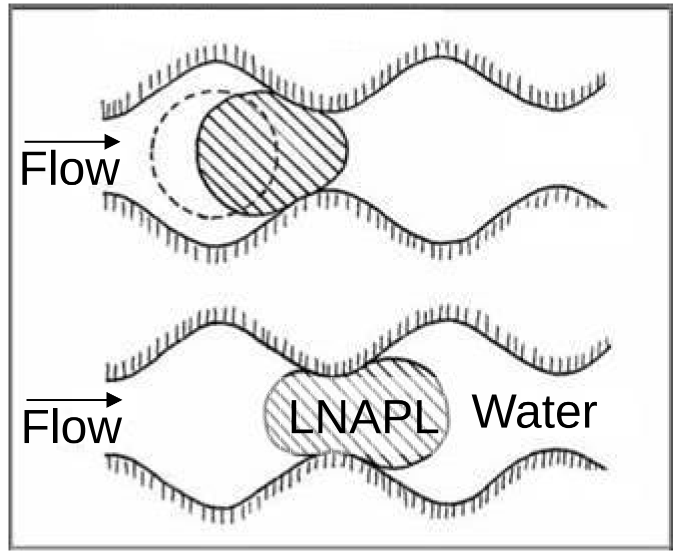
Pore Scale LNAPL Distribution



"Resistance" to Movement of LNAPL into and Out of Water-saturated Soil Pores



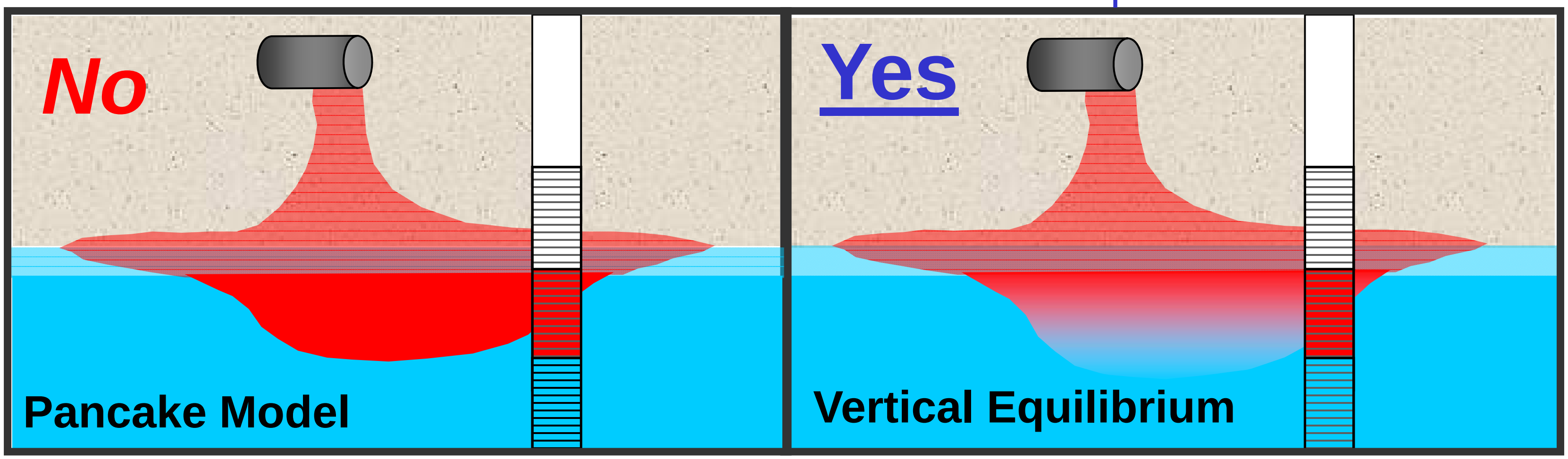
For water wet media



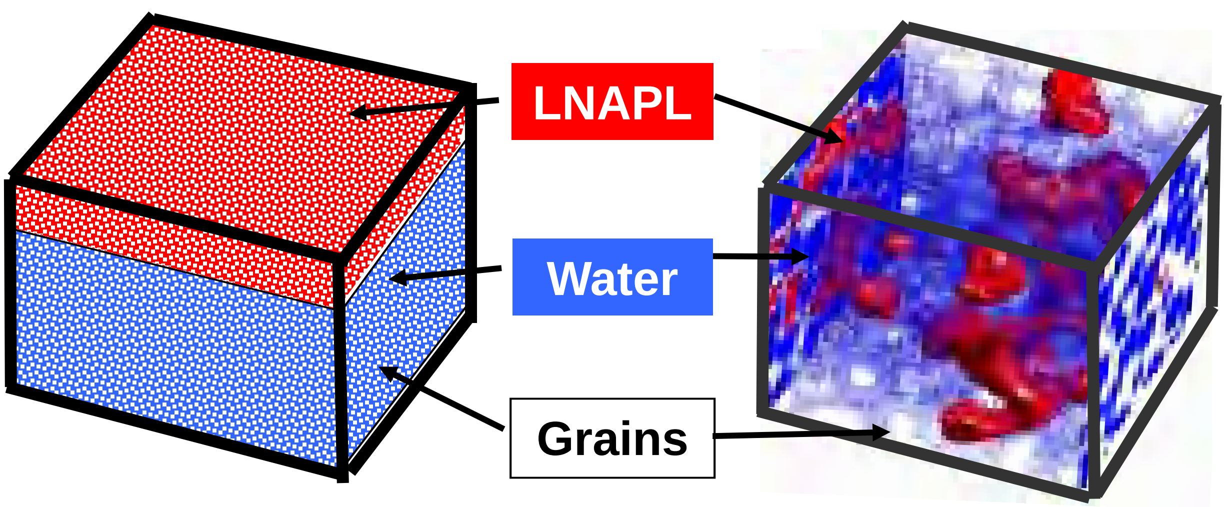
- LNAPL will only move into water-wet pores when entry pressure (resistance) is overcome
  - To distribute vertically and to migrate laterally

Vertical LNAPL Distribution

Pancake Model vs. Vertical Equilibrium Model

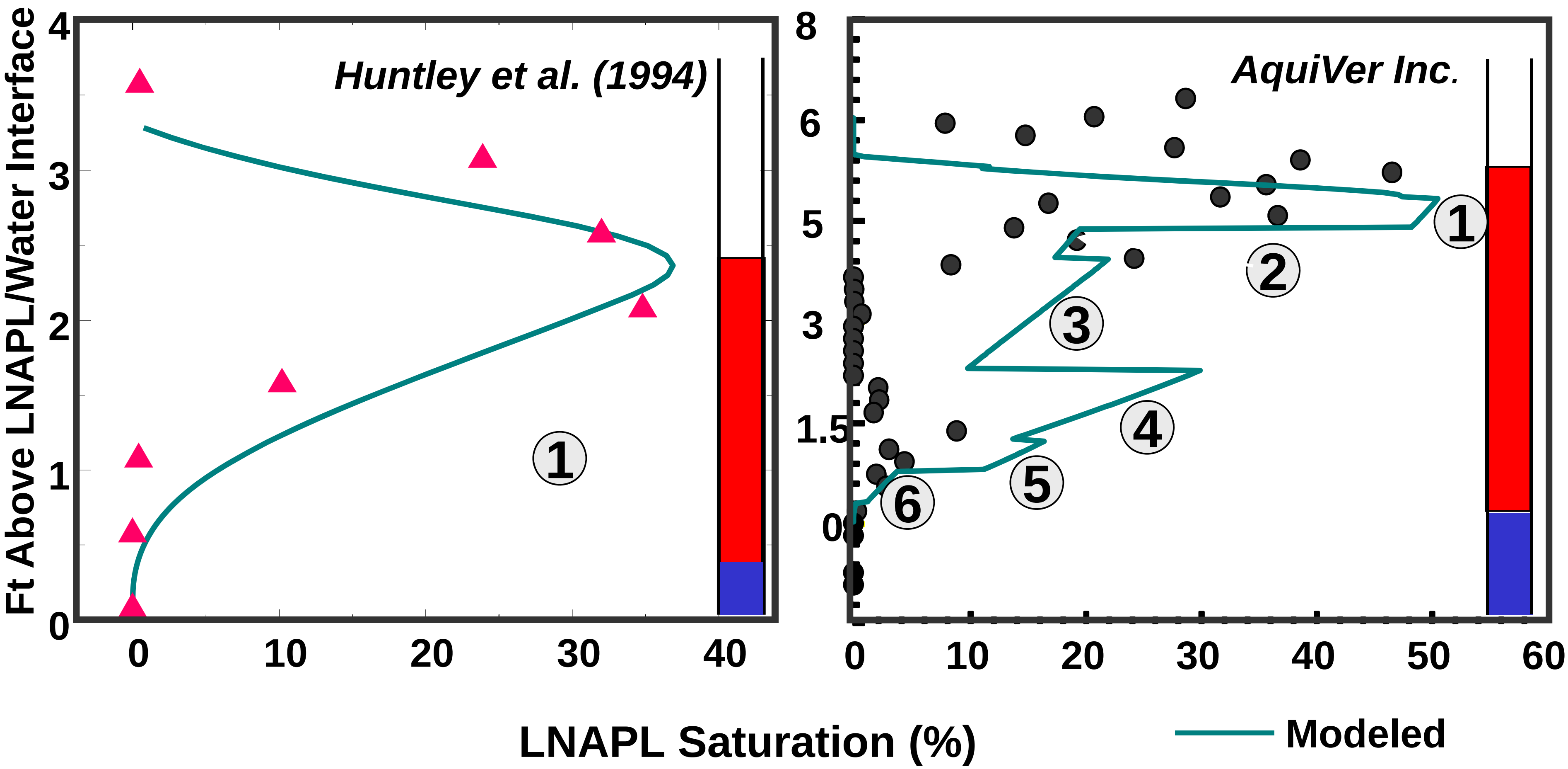


- Assumes LNAPL floats on water table
- Uniform LNAPL saturation



- LNAPL penetrates below water table
- LNAPL and water coexist in pores

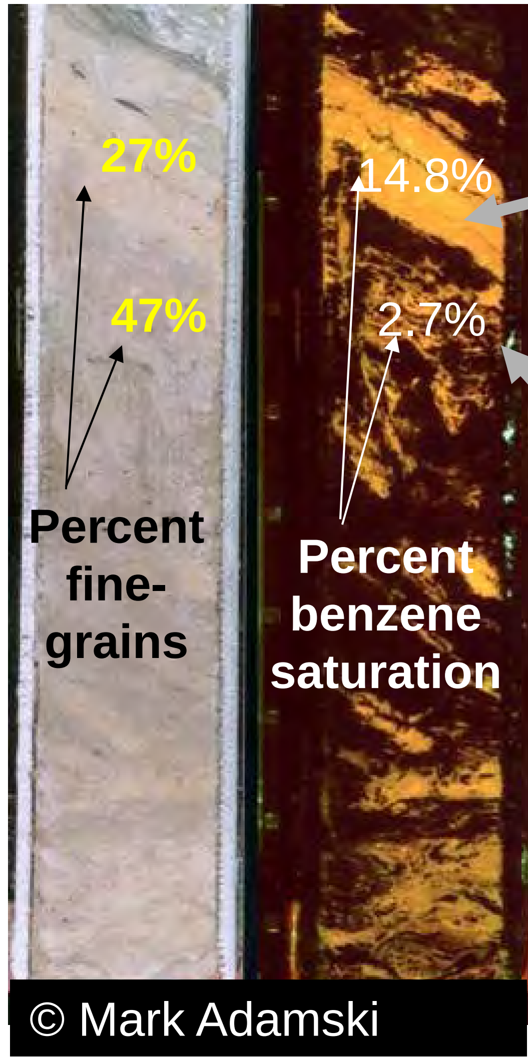
Measured and Modeled Equilibrium LNAPL Saturations



- Soil Type

LNAPL Saturations Are Not Uniform

- LNAPL preferentially enters larger pores (easier to move water out of the pore)
- Maximum LNAPL saturations typically low (5-30%) in sands (can be higher at new release or constant release)
- Saturations even lower for finer-grained sediments



Plain light

UV light

Higher LNAPL saturation in coarser-grained soil

Lower LNAPL saturation in finer-grained soil

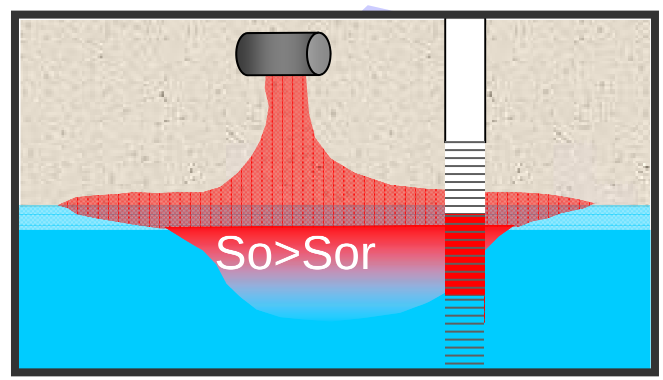
Fluoresced benzene in soil core

Saturation versus Residual Saturation

When LNAPL *Saturation* in the ground exceeds LNAPL *Residual Saturation*

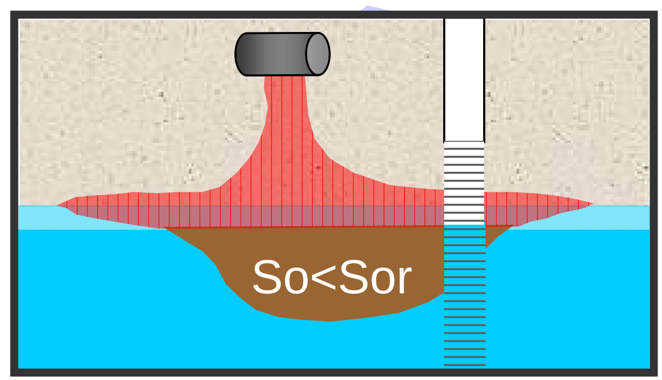
LNAPL Saturation (So)

Fraction of pore space occupied by LNAPL



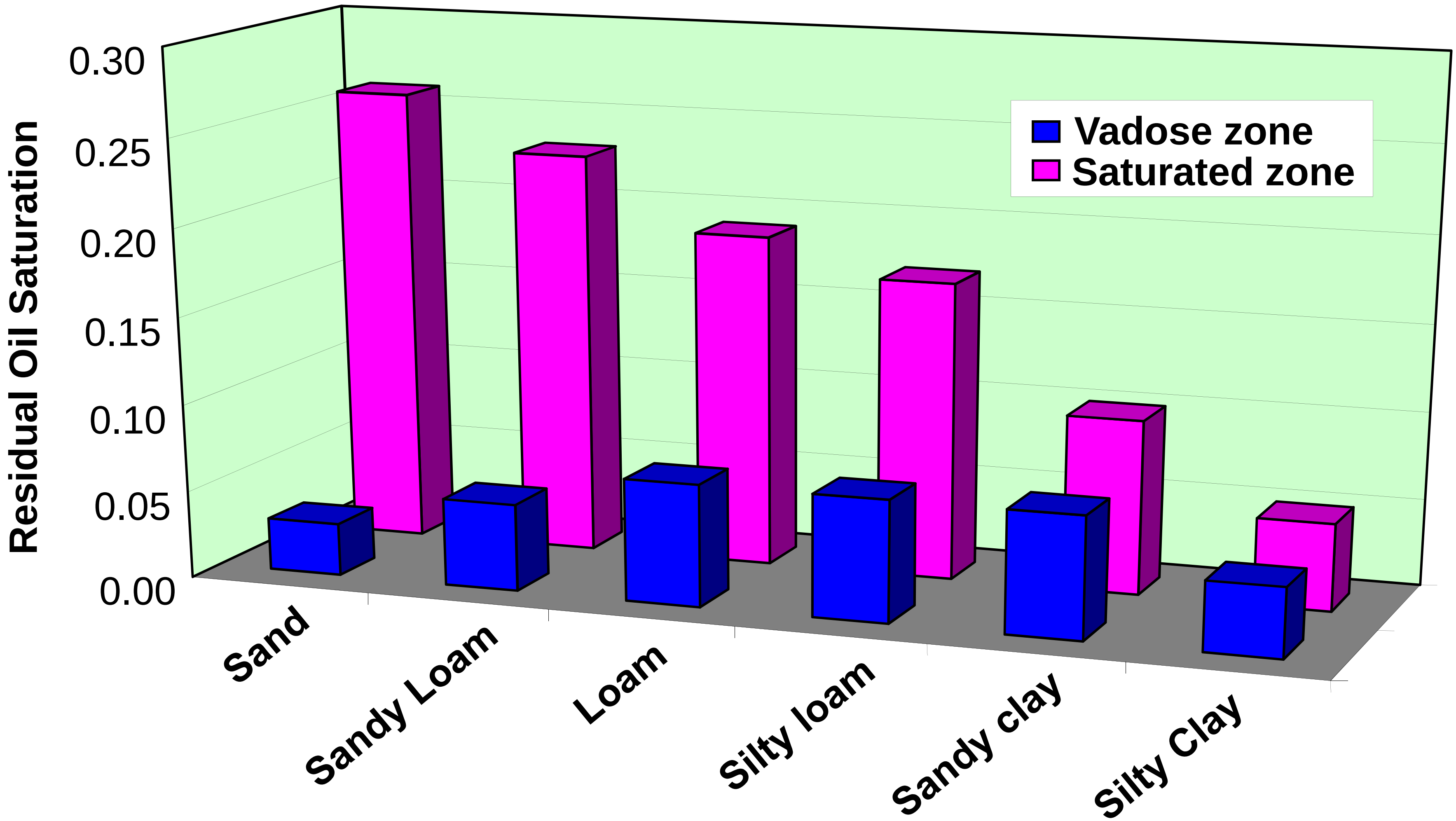
Residual LNAPL Saturation (Sor)

Fraction of pore space occupied by LNAPL that cannot be mobilized under an applied gradient



When So < Sor, non-multiphase flow fate-and-transport decision frameworks (dissolved phase or vapor phase) work well (e.g., RBCA)

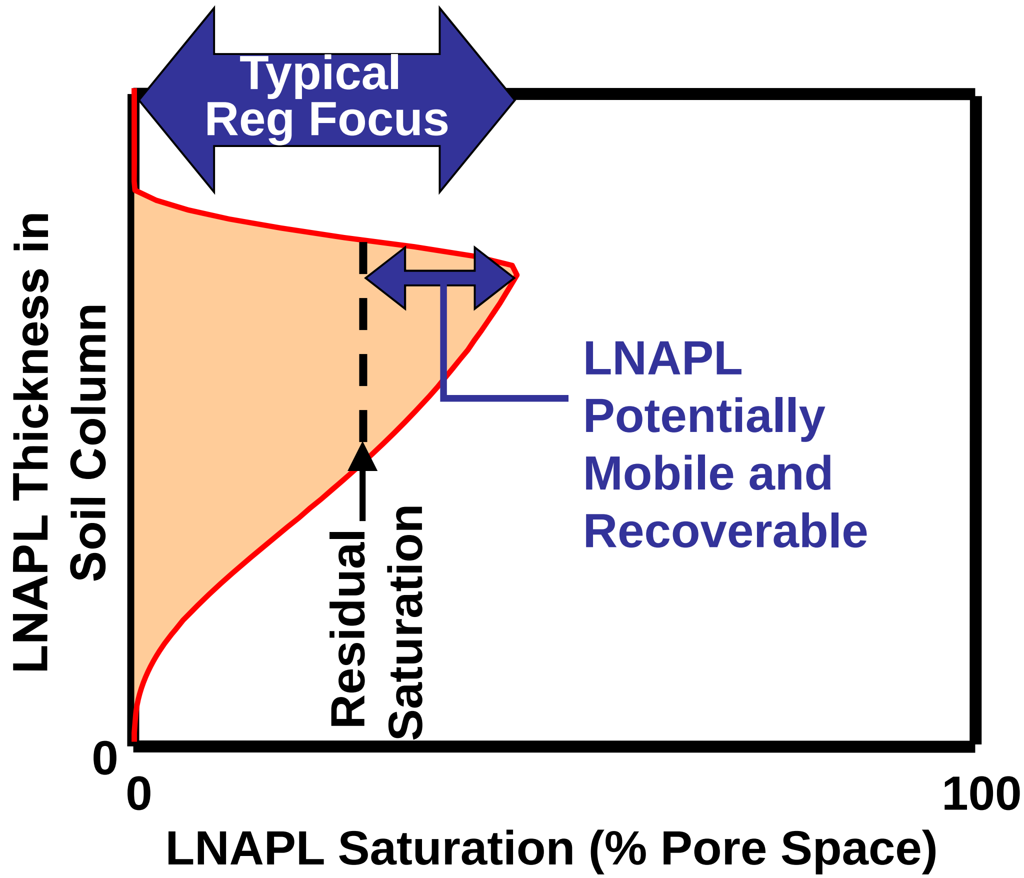
Residual LNAPL Saturation – Higher in Saturated Zone than in Vadose Zone



Example ranges from Parker et al., 1989

Potentially Mobile Fraction of the LNAPL Distribution

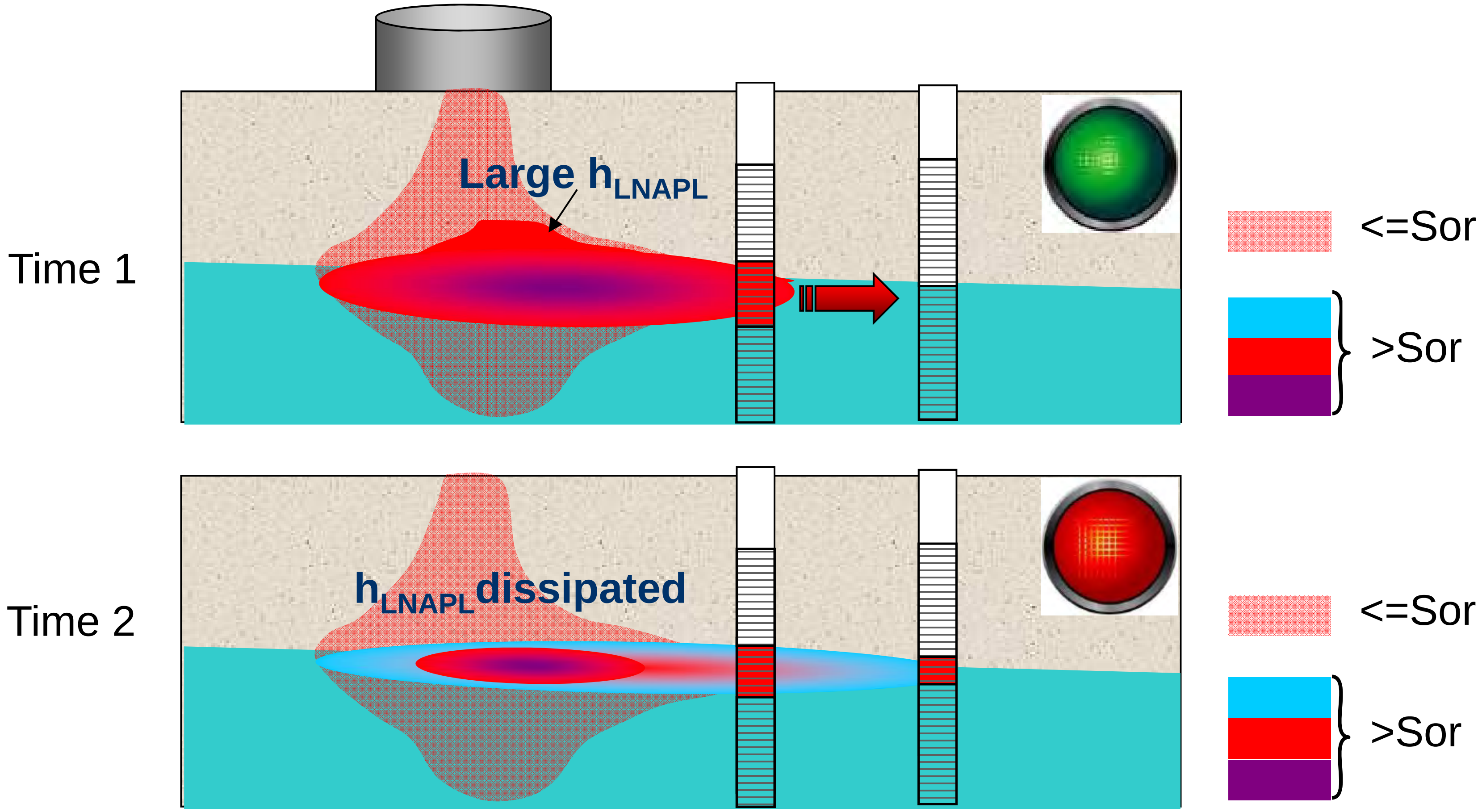
Source: Garg



LNAPL mobility is the additional consideration due to exceeding residual saturation

Key Point: LNAPL potentially mobile only if the saturation exceeds residual saturation

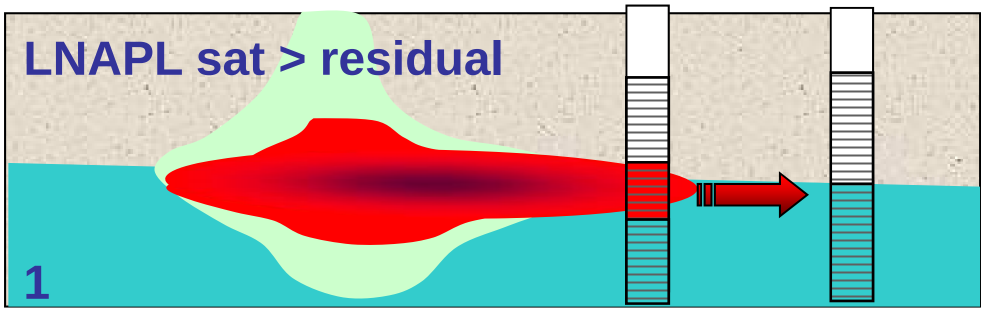
LNAPL Mobility and Plume Spreading



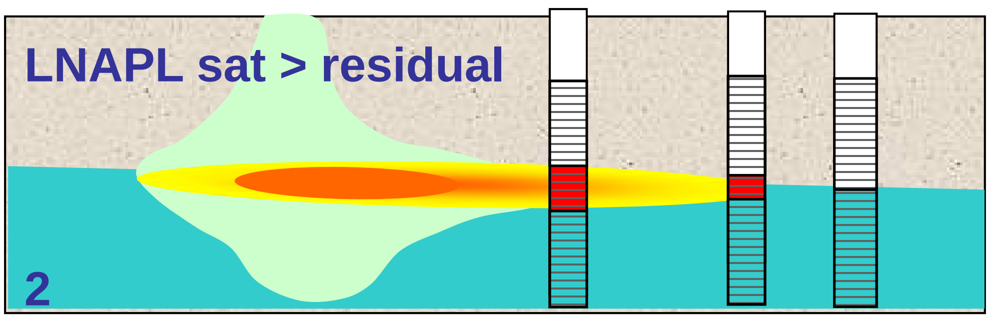
Key Point: Once the LNAPL head dissipates, it is no longer sufficient to overcome LNAPL entry pressure and LNAPL movement ceases

The Three Basic LNAPL Site Scenarios

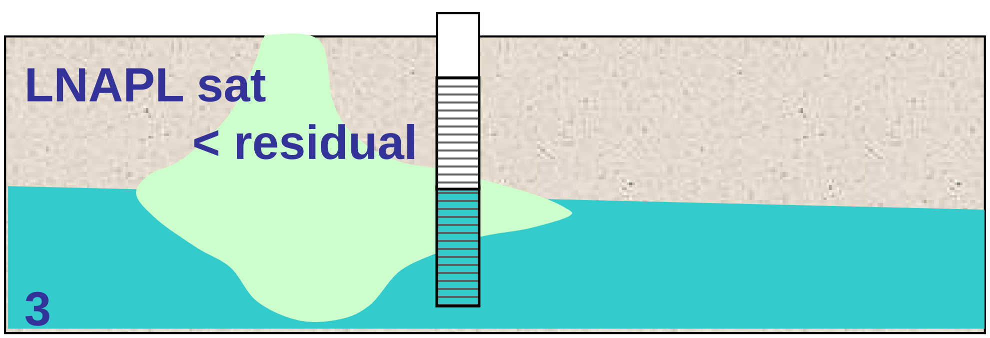
Covered in this training



Condition: LNAPL in wells, mobile
Driver: LNAPL saturation



Condition: LNAPL in wells, mobile, not migrating
Driver: LNAPL composition, saturation

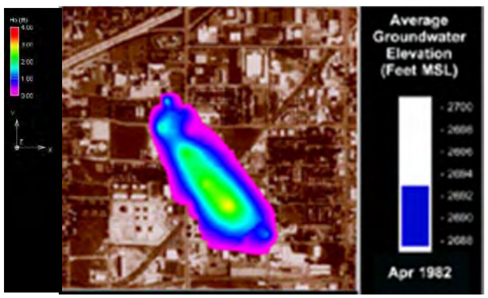


Condition: No LNAPL in wells
Driver: LNAPL composition

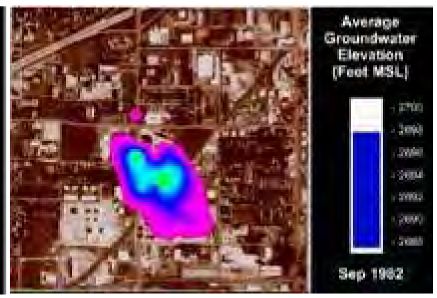
Example Seasonal LNAPL Redistribution

LNAPL Monitoring Over Time Refinery

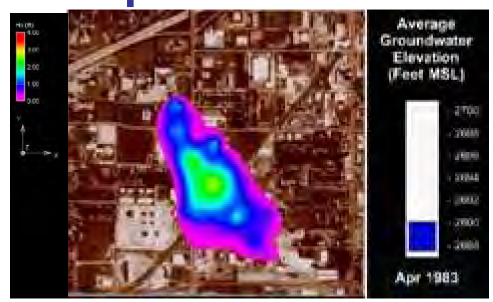
Low Water April 1982



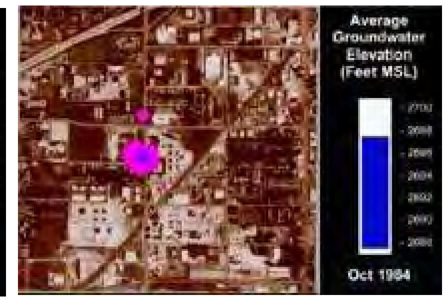
High Water Sept 1982



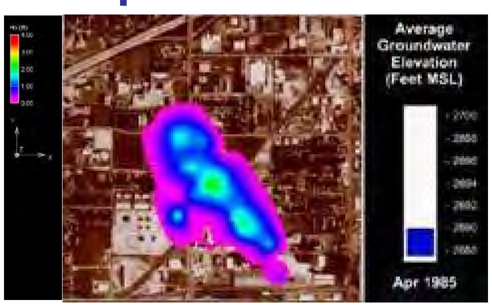
Low Water April 1983



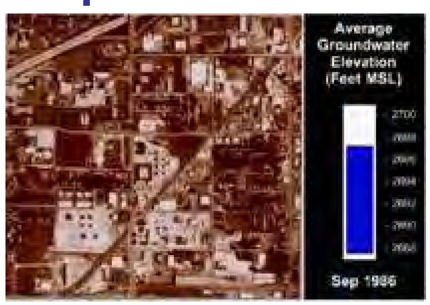
High Water Oct 1984



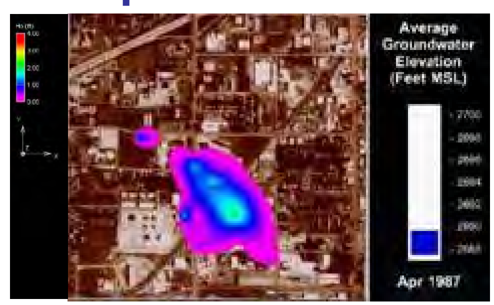
Low Water April 1985



High Water Sept 1986



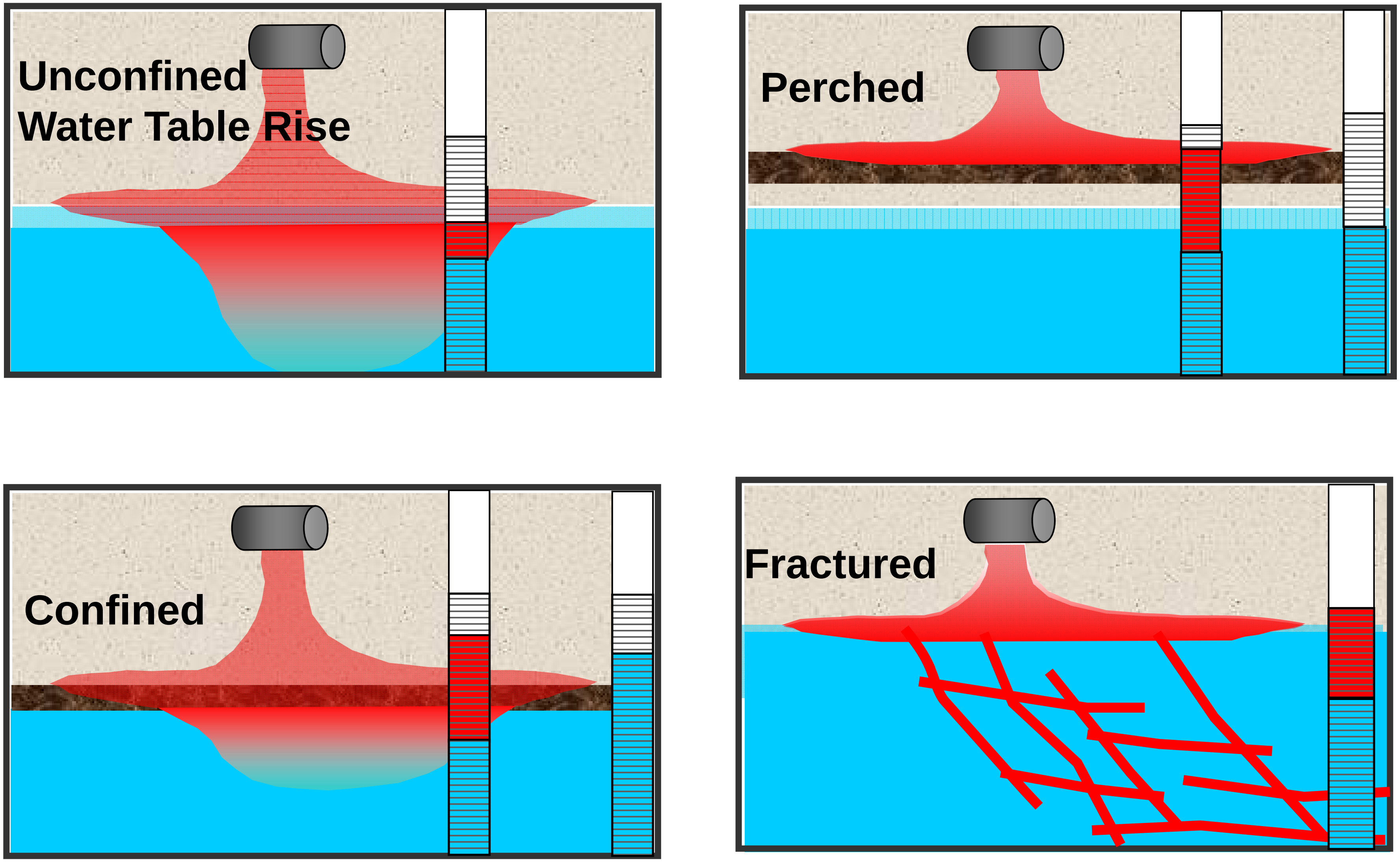
Low Water April 1987



From API Interactive NAPL Guide, 2004

- **Measured LNAPL Depth in Monitoring Wells : 0 to 3 feet**
- **Seasonal Water Table Variation : 8 foot range**

Well Thickness versus Formation Thickness



Summary of LNAPL Basics

- LNAPLs are not distributed vertically in a "pancake" fashion, but are distributed according to vertical equilibrium as a multiphase (saturations vary vertically- always less than 100%)
- LNAPL saturations are not uniform, but depend on soil type, capillary pressure and soil heterogeneity
- The specific volume of LNAPL within soil will be greater in coarse than fine grained soil for a given LNAPL thickness
- As the LNAPL saturation increases, the relative permeability and potential LNAPL velocity also increases

Summary of LNAPL Basics (continued)

- The pressure exerted by LNAPL must exceed the displacement pore entry pressure for LNAPL to enter a water-filled pore
- Measurable LNAPL thickness in a well does not necessarily indicate mobility, LNAPL plumes generally come to stable configurations over relatively short periods of time
- Once the LNAPL release stops, LNAPL near the water table will eventually cease to spread as the resistive forces in soil balance the driving forces (LNAPL head) in the LNAPL pool
  - Smaller releases will stop migrating sooner
  - Continuing releases will result in a growing plume
- LNAPL plume may be stable at the LNAPL fringe, but there may be local re-distribution within the LNAPL core

LNAPL Concerns and Drivers

LNAPL Concerns:

LNAPL driver:

- Explosive hazards
- Dissolved-phase concentration
- Vapor-phase concentration
- Direct contact or ingestion

→ **LNAPL Composition**

- Mobility (spreads and creates new or increased risk)
- Visible aesthetics

→ **LNAPL Saturation**

Regulatory driver: "recover to maximum extent practicable" – State's interpretation?

LNAPL Understanding is an Iterative Process

LNAPL Characterization

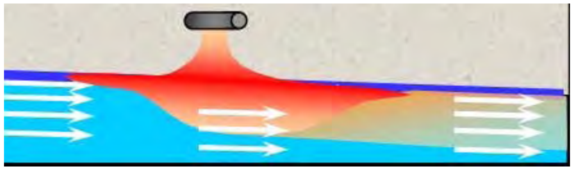
- LNAPL composition
- LNAPL saturation
- LNAPL location

LNAPL Conceptual Site Model

LNAPL Management

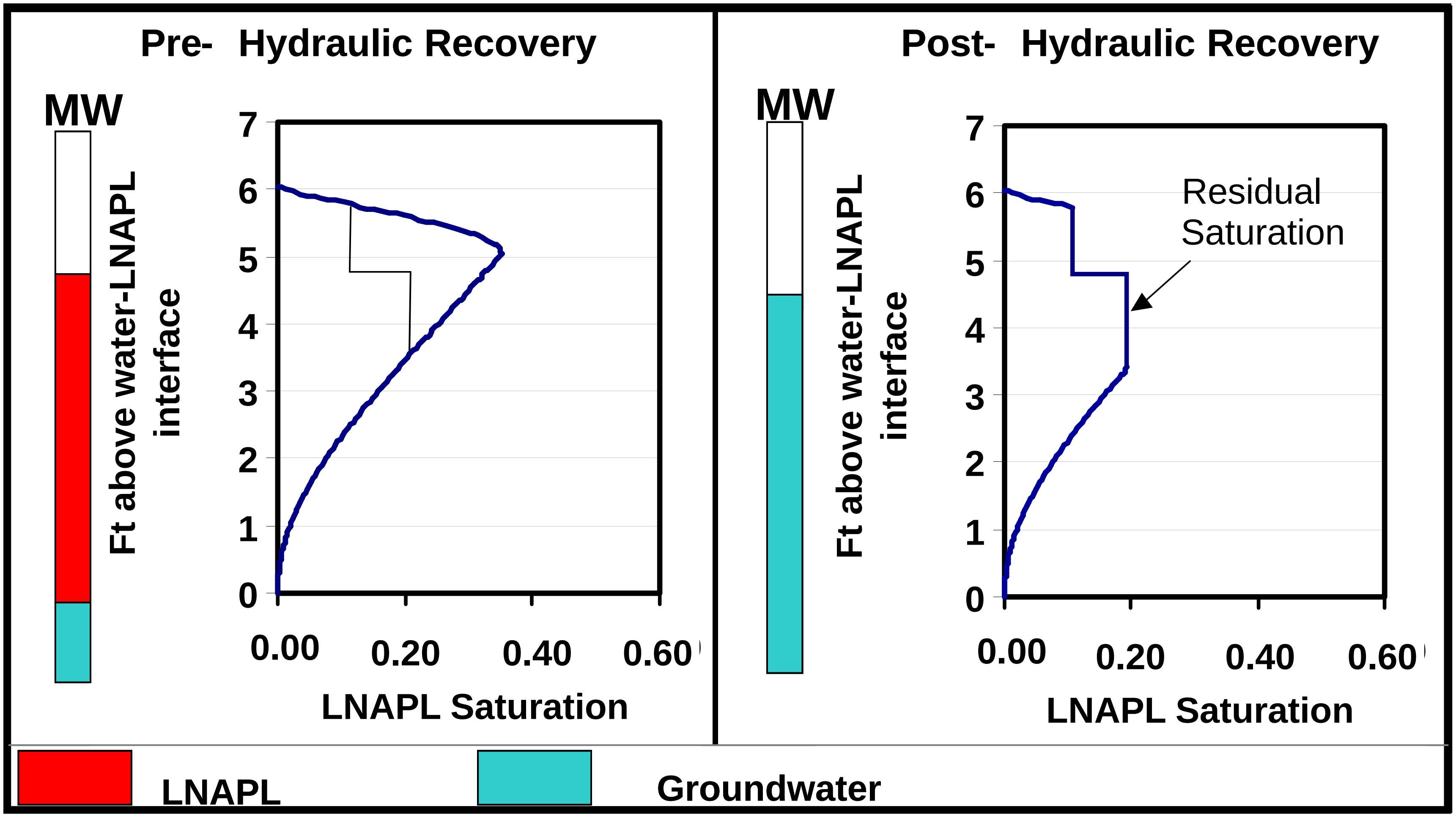
- Maximum extent practicable?
- Drivers: mobility and future risk
- Remedial objectives and end points
- Remedial action selection

LNAPL Conceptual Site Model (LCSM)



- Site characterization and management link
- Description and interpretation of physical and chemical state of the LNAPL body
- Facilitates understanding of the LNAPL conditions, site risks, and how best to remediate
- Scaled to the LNAPL impacts and associated issues that require management
- Iterative process to increase the understanding of the LNAPL body and site risks
- Sufficient when additional information likely would not lead to a different decision

Hydraulic Recovery (recoverability)



Objectives, Goals and Performance Metrics

- LNAPL Remedial Objectives – Established to mitigate the LNAPL concerns
- LNAPL Remediation Goals – the Remedial Objectives stated in the context of a remedial technology
- Performance Metrics – measurements that demonstrate achievement or progress to achievement of the Remediation Goal

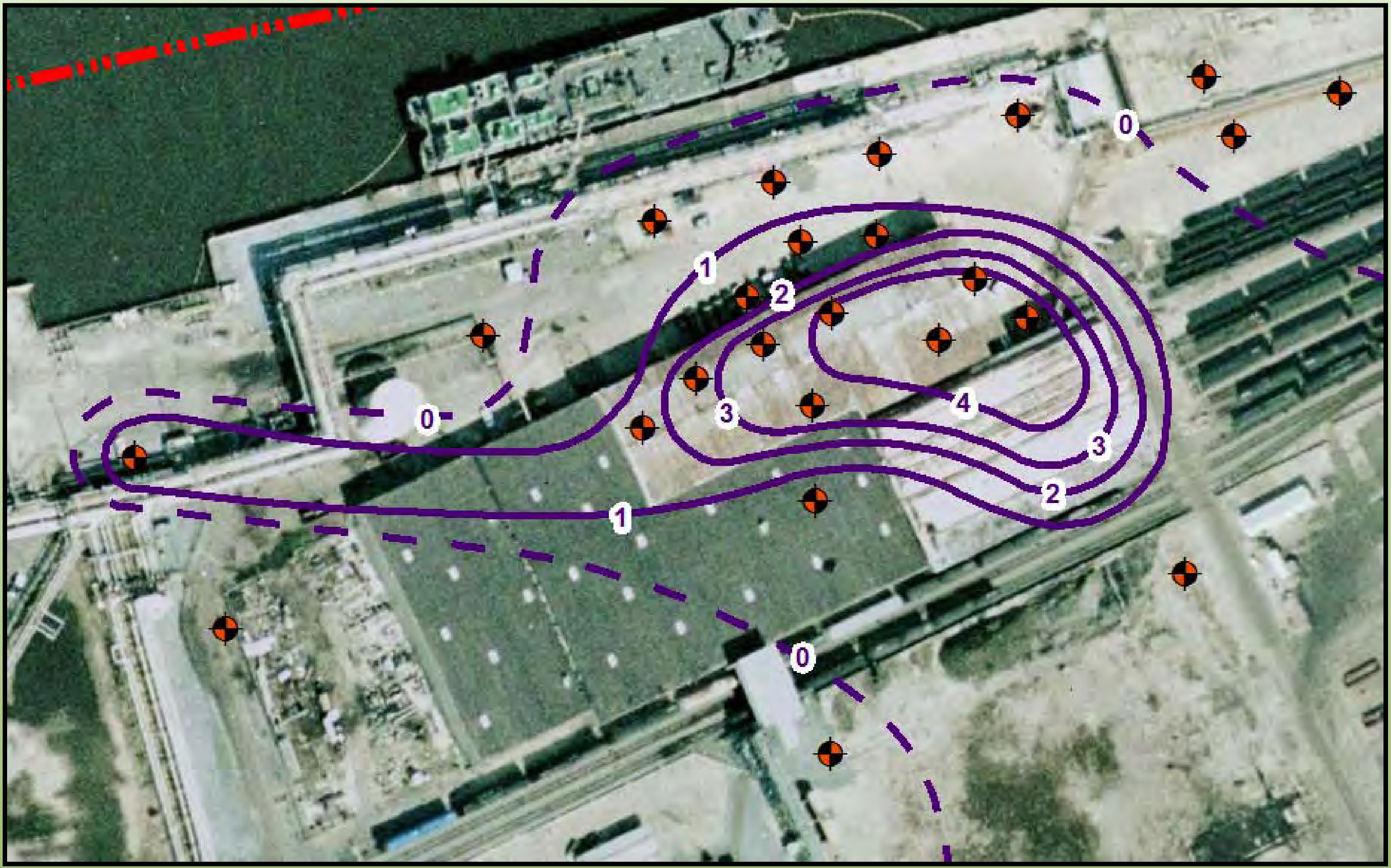
Examples	Scenario 1	Scenario 2
Objective	Stop LNAPL migration off site. (Saturation Objective)	Stop dissolved BTEX plume in groundwater from migrating off site. (Composition Objective)
Goal	Remove LNAPL by skimming to reduce LNAPL head and stop LNAPL migration.	Remove BTEX components in the LNAPL using air sparging & vapor extraction.
Metric	No LNAPL appearing in monitor wells on property line.	BTEX less than MCLs in monitor wells at downgradient property line.

Case Study #1 – Active Recovery

Objectives

- Walk through process – (although older site, generally consistent with current LNAPL Guidance)
- Provide example of LCSM
- Illustrate key points leading to final remedy decision

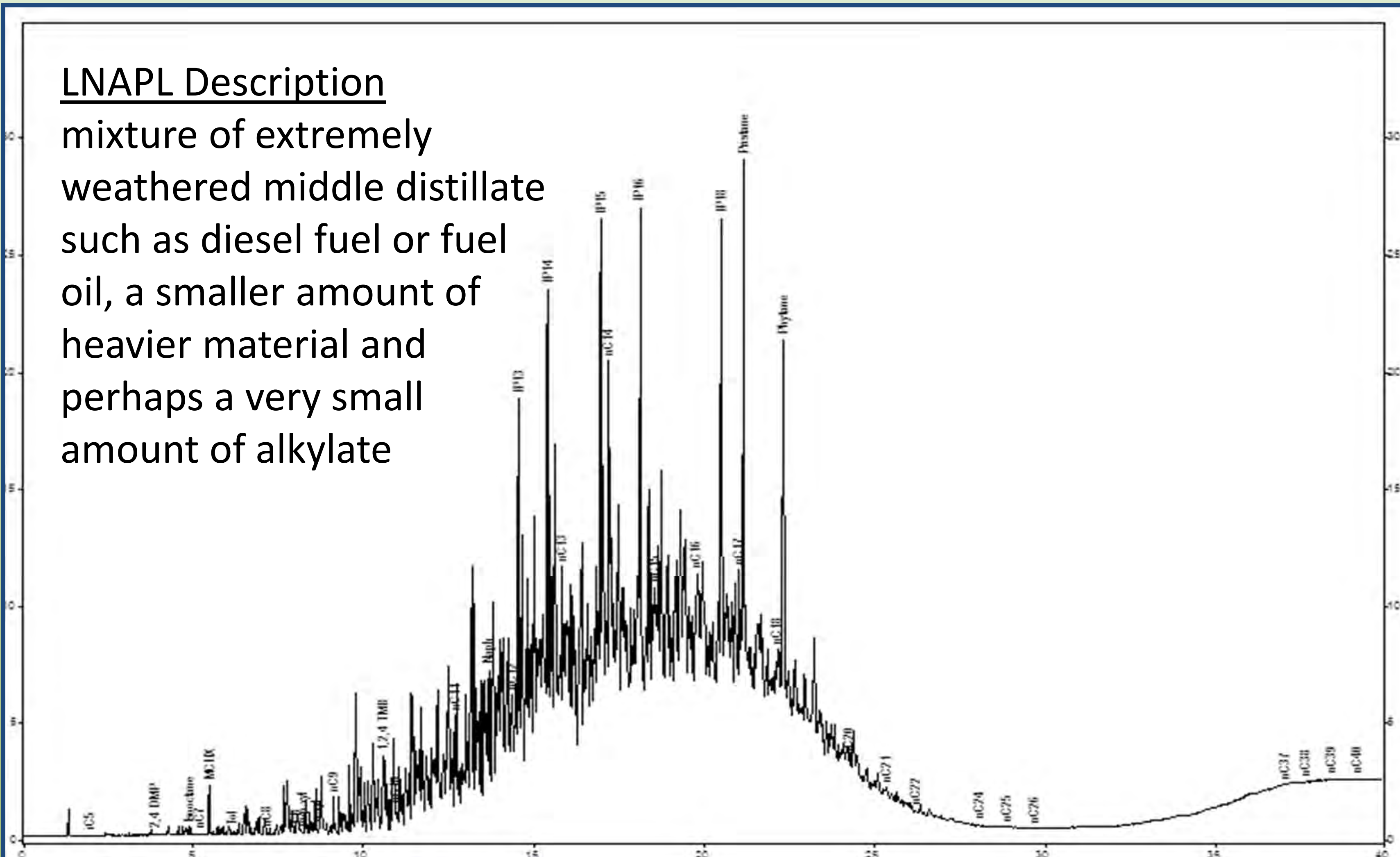
Site Plan



Overview of Process Steps

- Focused remedial investigation (RI)
  - 13 additional monitoring wells
  - Tidal study
  - Product sampling/fingerprint analysis
  - Soil core physical property analysis and UV photos
- Recoverability Assessment
  - Baildown testing
  - API Mobility Modeling
- Initial Recovery and IRM
- Operational Monitoring
- LNAPL Skimming and MPE Pilot Testing
- Final Remedy Selection and Design

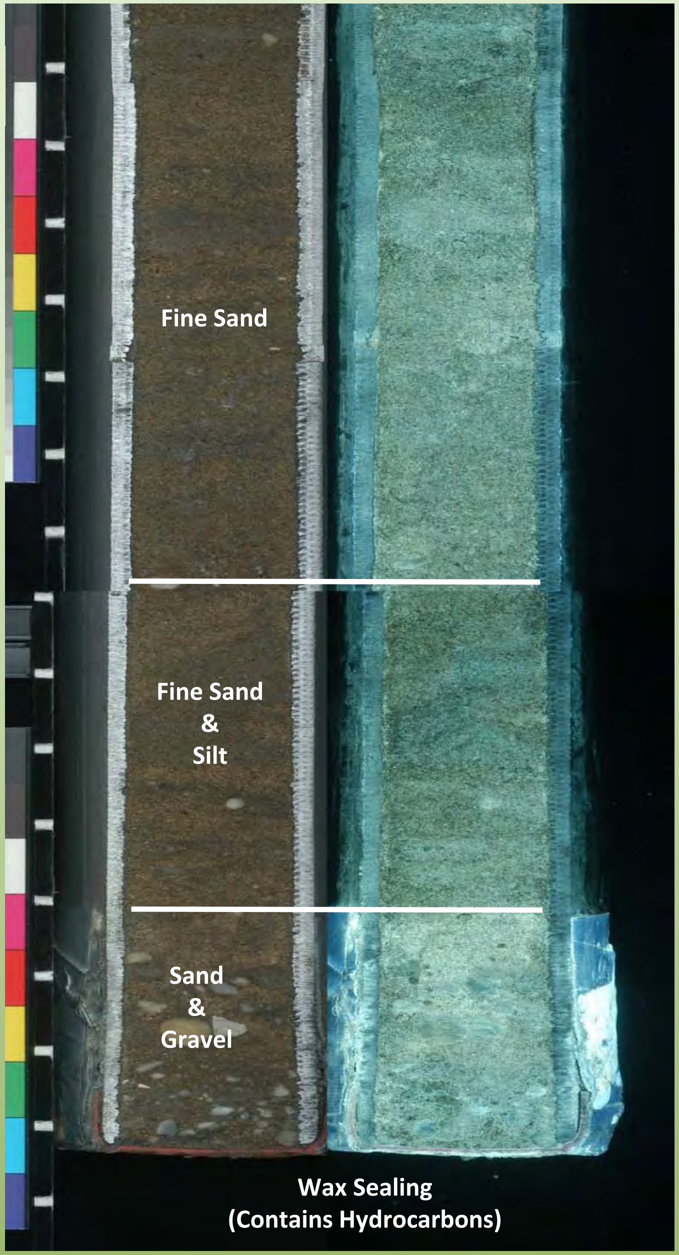
Investigation and Characterization

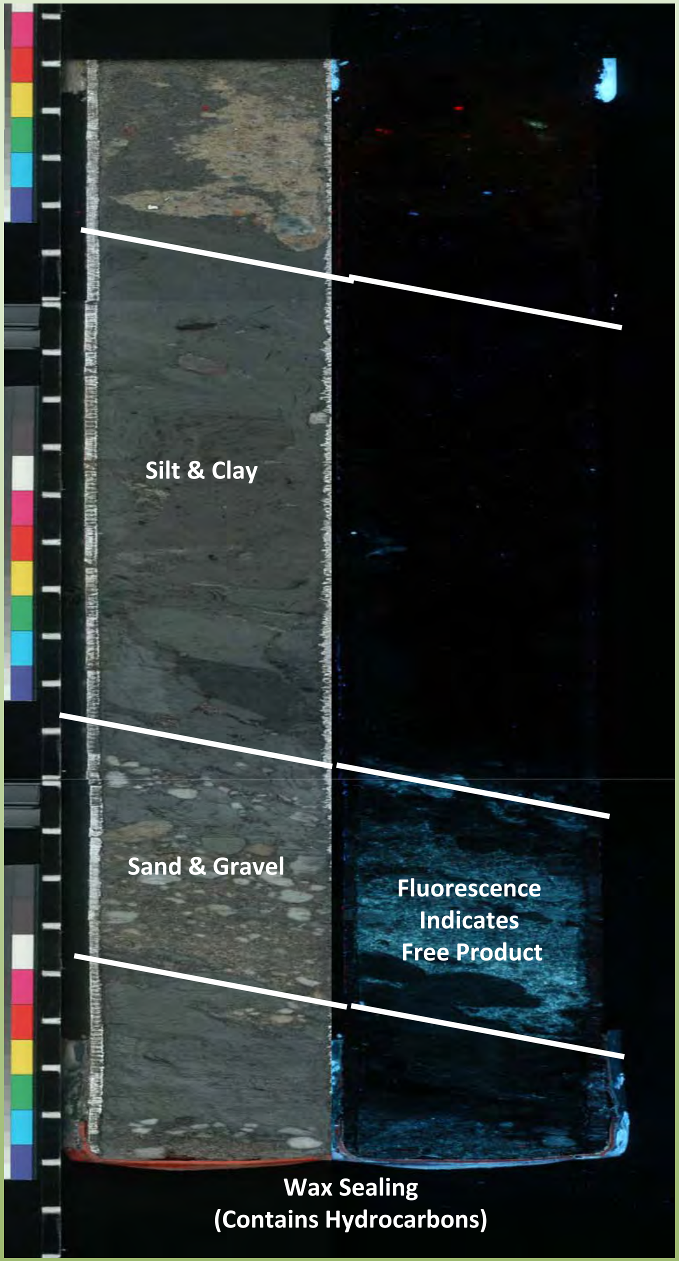


<u>LNAPL Description</u>

mixture of extremely weathered middle distillate such as diesel fuel or fuel oil, a smaller amount of heavier material and perhaps a very small amount of alkylate

Investigation and Characterization





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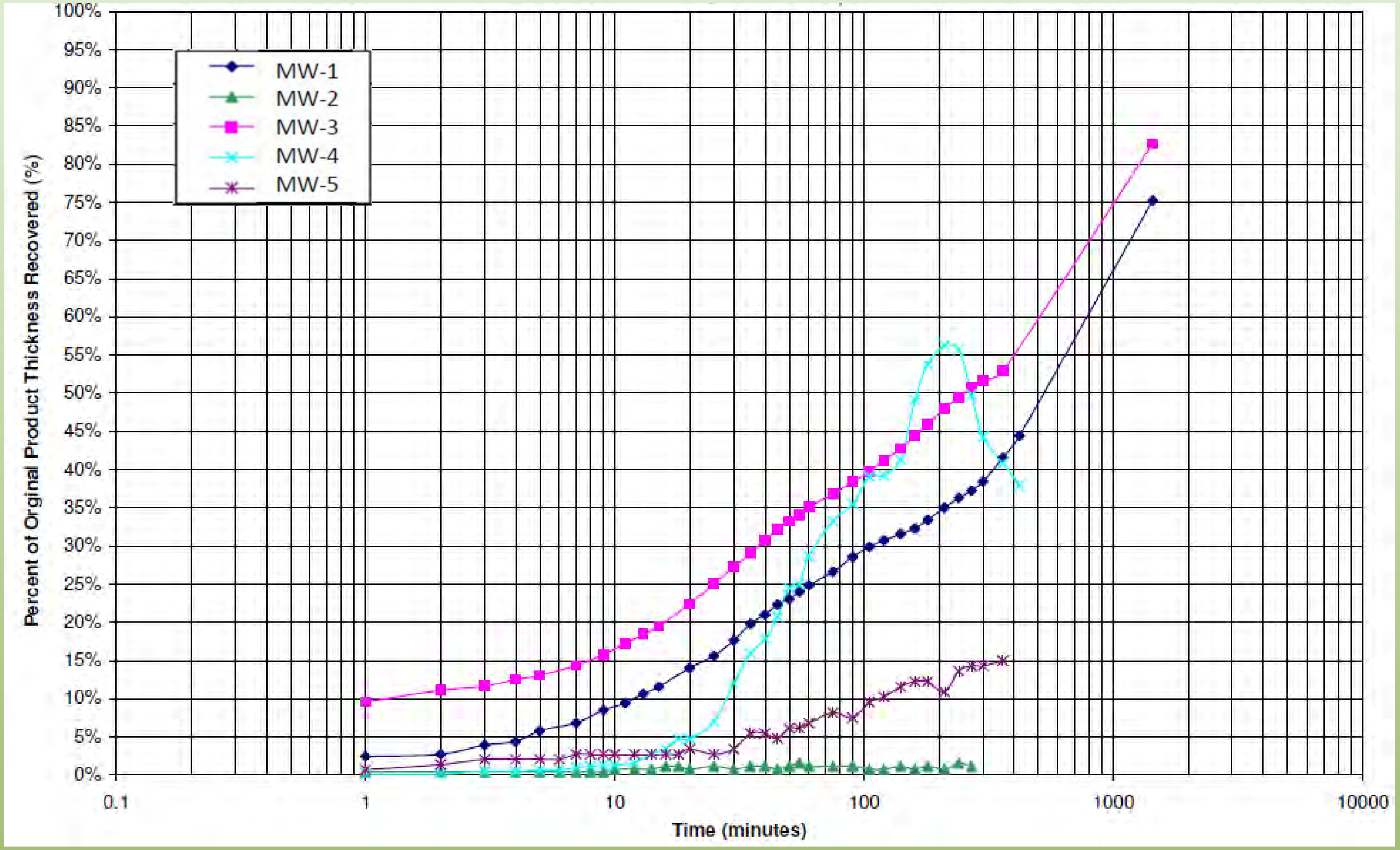
Baildown Testing Results



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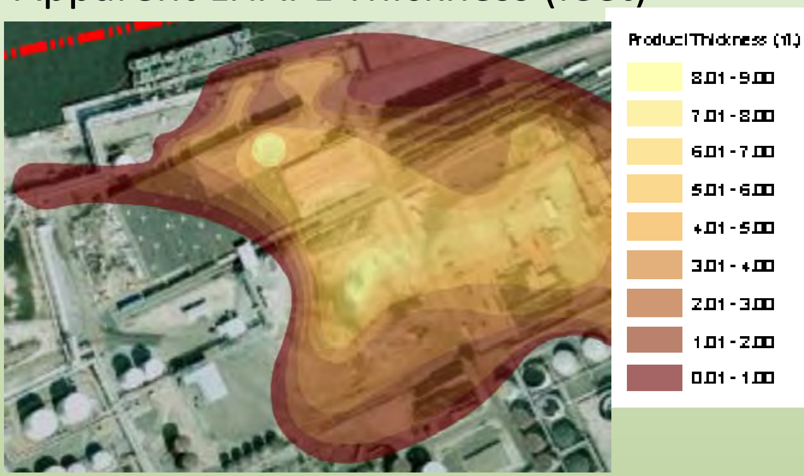
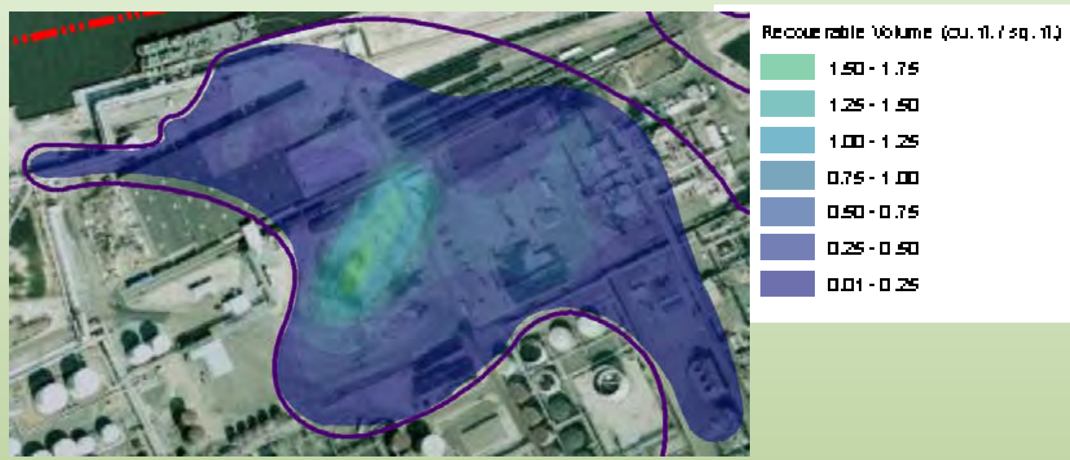
API Modeling Results

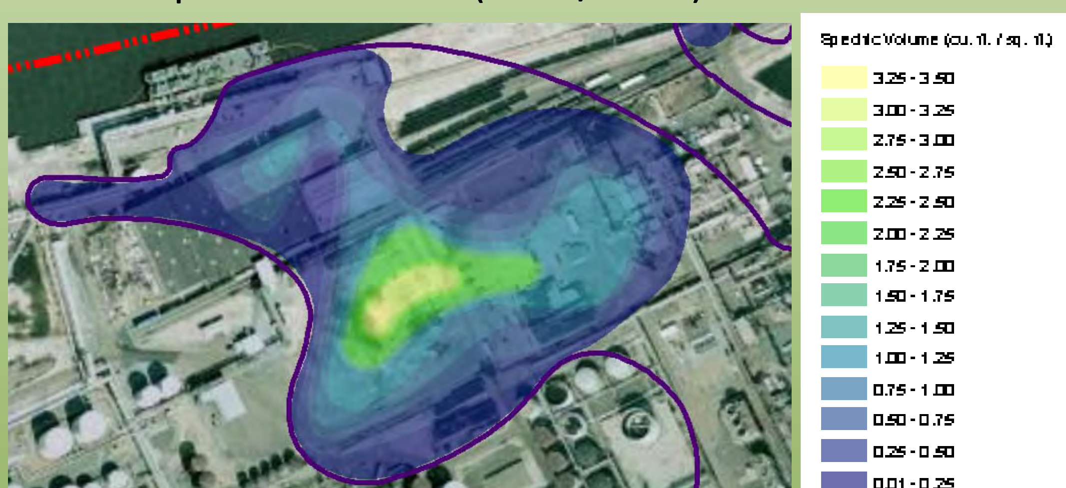
Apparent LNAPL Thickness (feet)



Recoverable Volume (feet^3/feet^2)



Specific Volume (feet^3/feet^2)



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LNAPL Conceptual Site Model

- LNAPL plume in proximity to, but not migrating toward the river - GW flow is away from river (losing stream)
- Large LNAPL smear zone – elevations influenced by tidal fluctuations (avg. 1.5 feet)
- LNAPL is a mixture of petroleum middle distillates with varying degree of weathering
- LNAPL trapped in distinct soil zones due to heterogeneities
- Baildown tests indicate LNAPL is recoverable in central core area of plume
- API model results show variable recoverability based on LNAPL type, saturation and soil conditions

Initial Recovery and IRM Selection

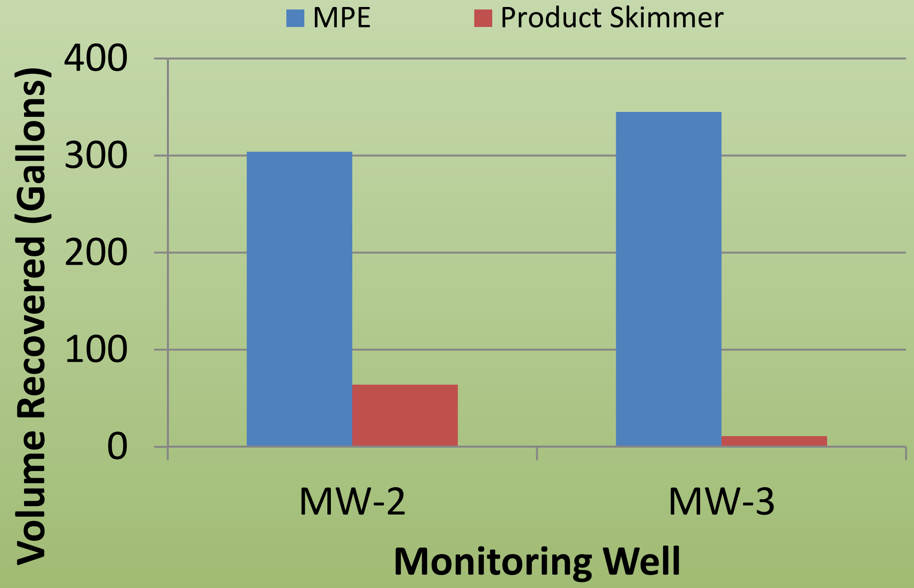
- Vacuum truck extraction initially used to address areas of newly detected LNAPL
- Wells and extraction frequency selected and “prioritized”
- IRM implemented as 3 events / week
- Well head assembly utilized to achieve multi-phase vacuum extraction

Operational Monitoring Program

- Quarterly gauging events (DTW, DTP, LNAPL thickness)
- On-going evaluation of LNAPL volume recovered from each recovery point and total groundwater and LNAPL recovery volumes from IRM activities
- Ongoing system adjustments based on LNAPL recovery observations, drop tube depths and total applied vacuum measurements

Product Skimming and Multi-Phase Extraction Pilot Testing

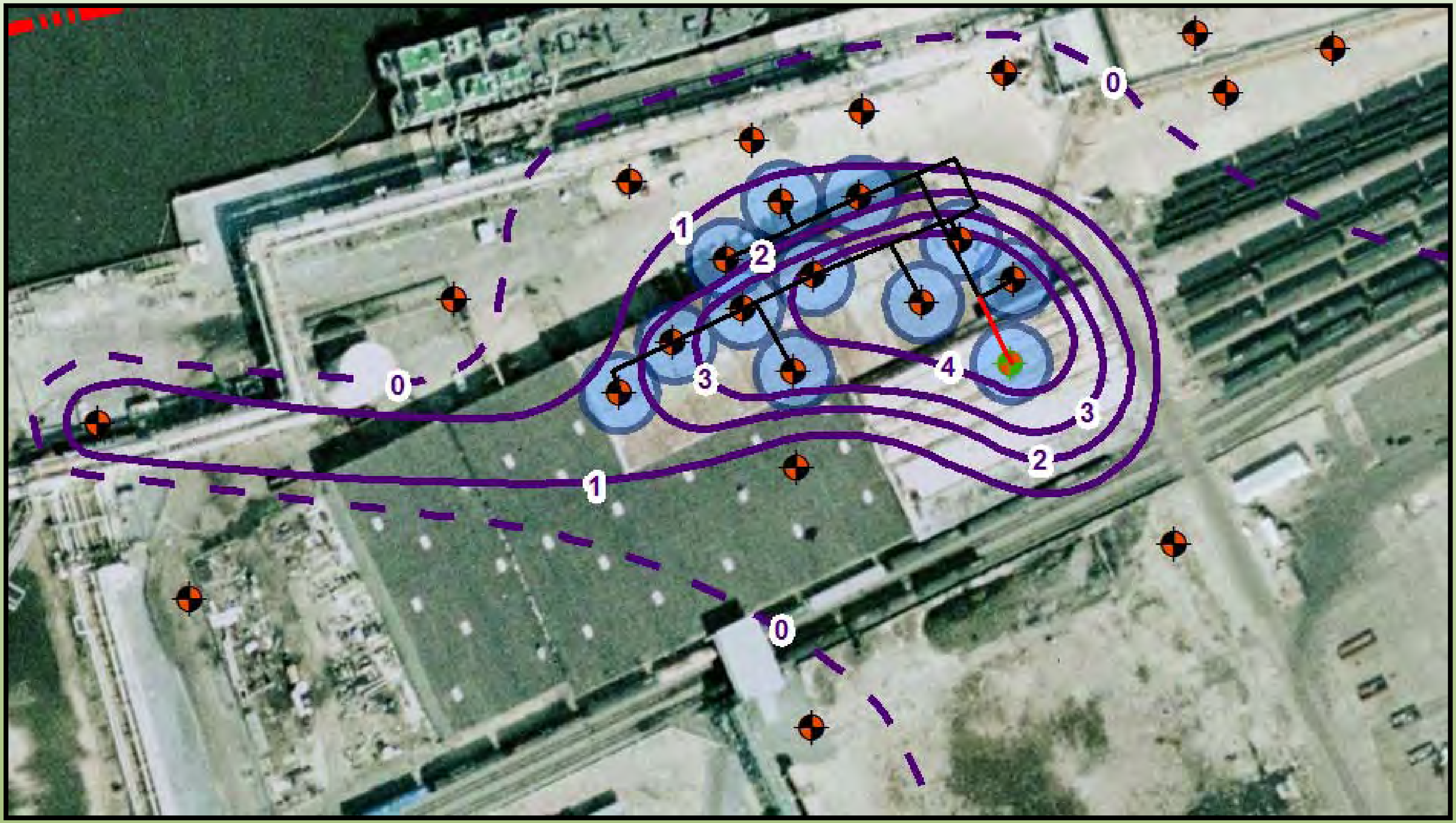
- Assess the feasibility and performance of skimming vs MPE
- Skimming showed poor recovery affected by tidal fluctuations
- MPE showed very good results
  - 345 gpd of LNAPL
  - up to 60 foot vacuum radius of influence



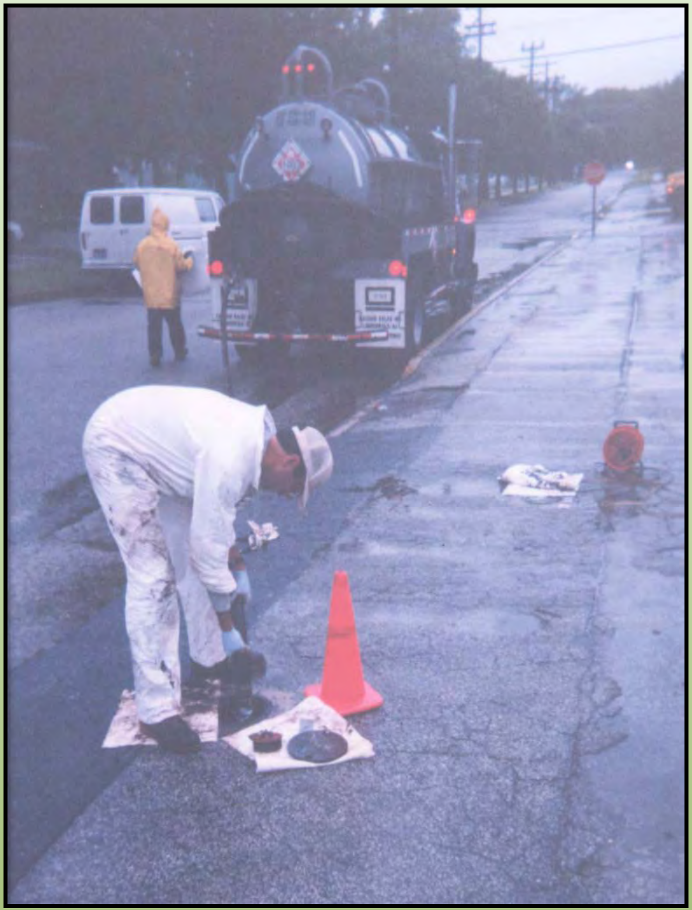
Full-Scale LNAPL Recovery System Design

- MPE selected for full scale system
- Site construction and piping installation has been completed.
- Fabrication of mobile MPE system currently on-going. System startup anticipated in the 2nd half of 2011.
- Ultimate goal is to recover free-phase LNAPL to extent practicable.

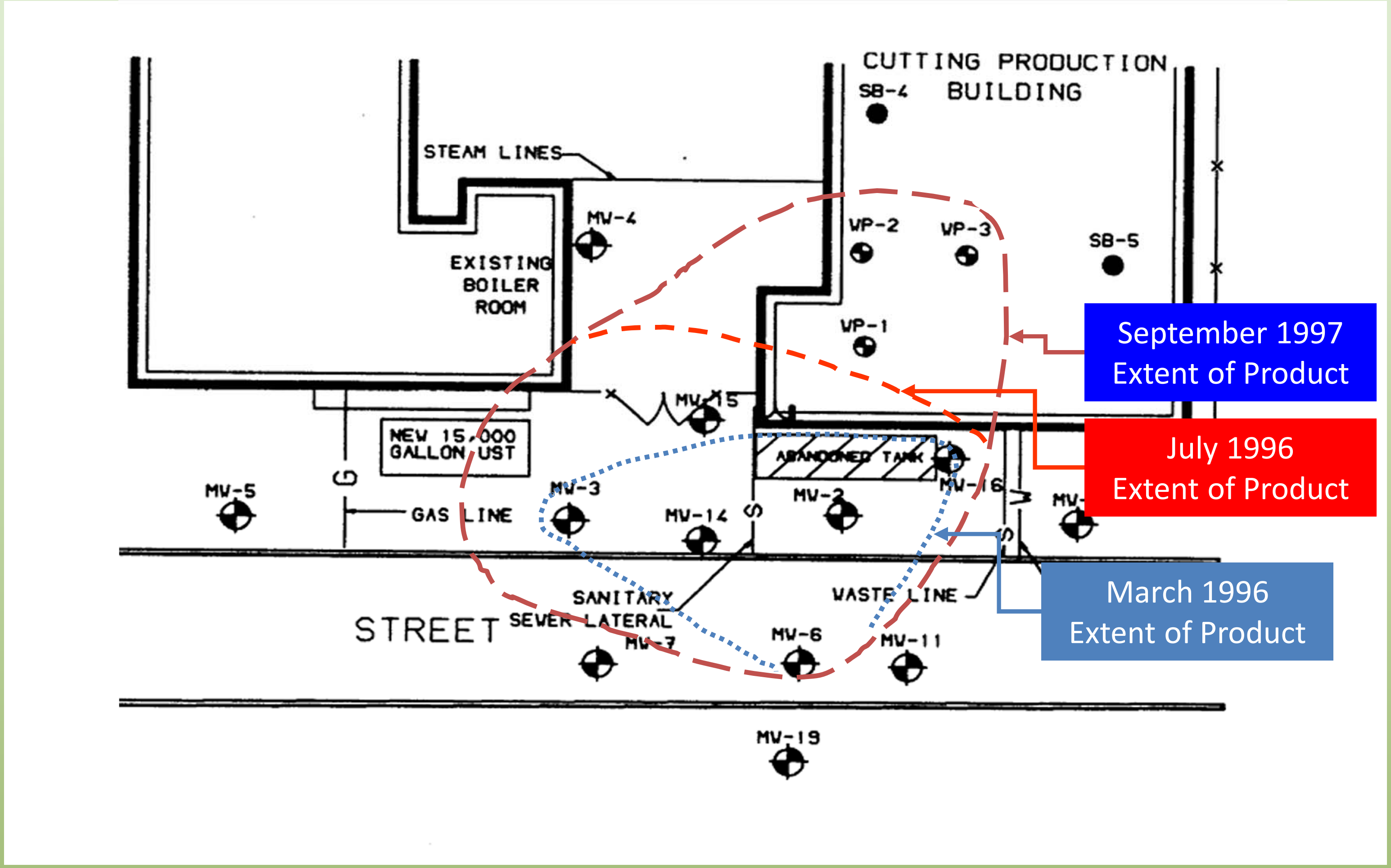
LNAPL Recovery Approach



Case Study #2 – Maintenance Recovery



Detailed Remedial Investigations



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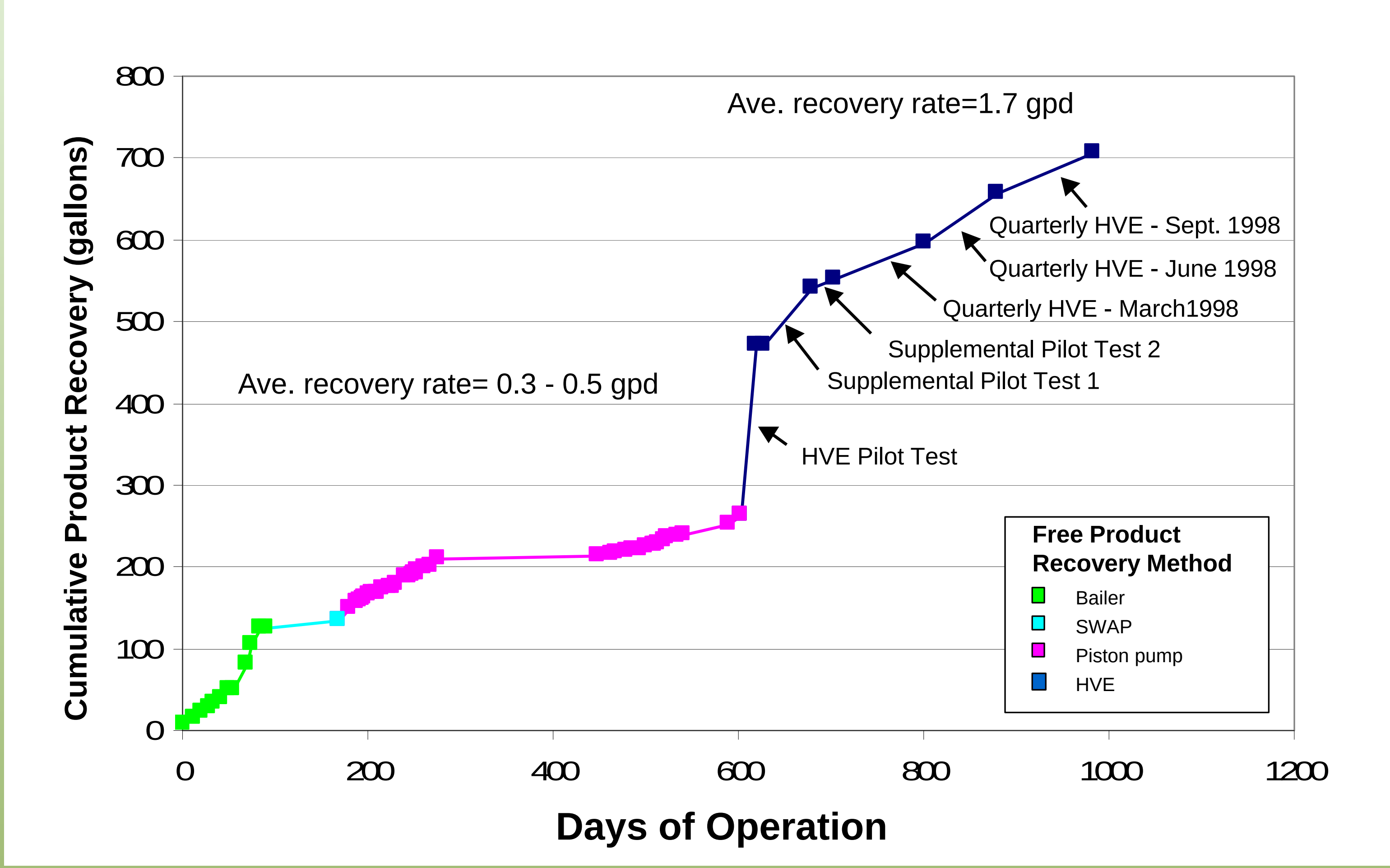
Initial Product Recovery and Interim Remedial Measures



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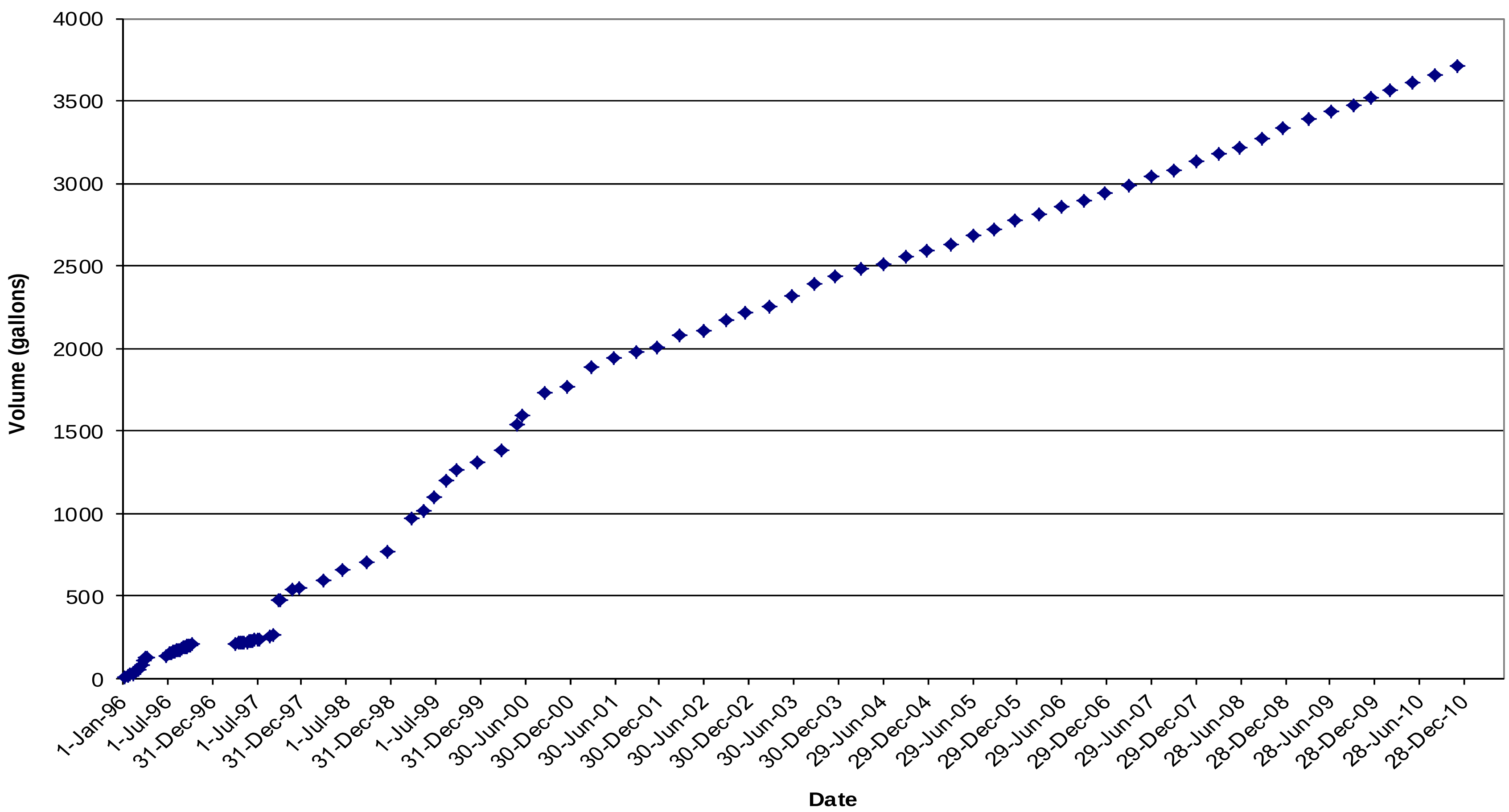
Cumulative Product Recovery Through Time



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