Department of the Environment

A Holistic View of Petroleum Recovery System Optimization

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MDE Oil Control Program

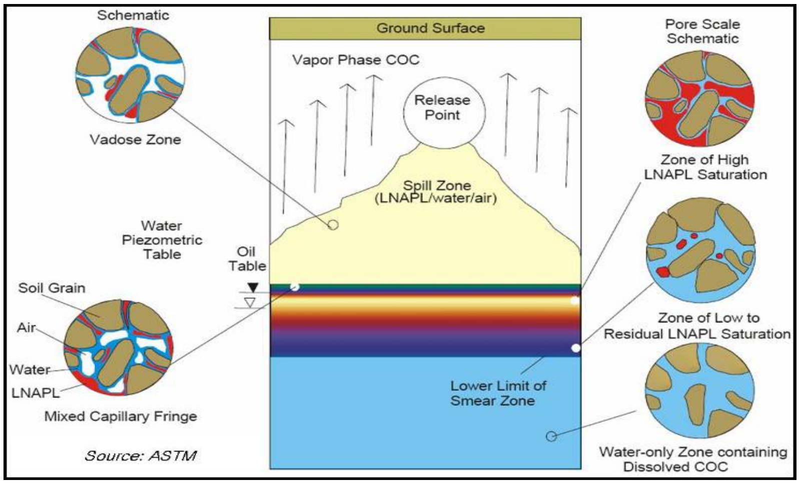
Introduction

- Historically, petroleum recovery systems have been long undertakings (operation for +10 years)
- Heavy reliance on pump and treat (P&T) / soil vapor extraction (SVE)
- Polishing technologies added haphazardly at the end to overcome remediation plateaus
- Does not adequately address the different phases of petroleum contamination (ITRC, 2010)

Introduction (cont.)

- Site characterization and conceptual model development is not an ongoing process to address:
  - Residual hot spots
  - Variable capture zones between recovery wells
  - Challenging zones in the formation
- Rebound of residual liquid phase hydrocarbons (LPH) and dissolved phase constituent levels often occurs, but historically was not explicitly addressed in the Corrective Action Plan

Four Phases of Petroleum Contamination



(ITRC 2010)

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Four Phases of Petroleum Contamination (cont.)

- **Mobile LPH** – LPH is mobile either as a migrating plume or locally mobile within a footprint. LPH moves readily with hydraulic control.
- **Residual LPH** – LPH plume is non-mobile or adsorbed to formation. May still have LPH levels from a few inches to a reoccurring sheen in wells
- **High Groundwater Concentrations** – Dissolved levels >1,000 ppb near source (mobile or residual LPH), causing down gradient impacts
- **Low Groundwater Concentrations** – Dissolved levels >100 ppb, down gradient receptors may drive the cleanup to lower endpoints

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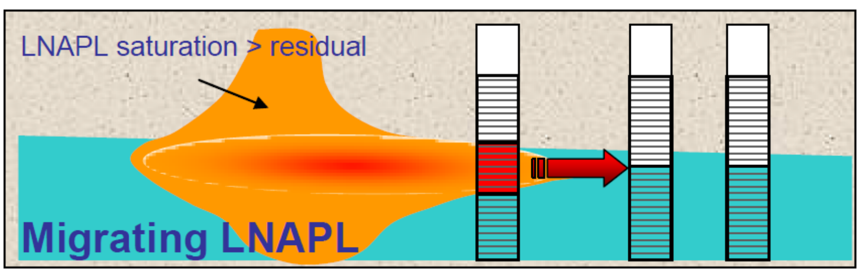
Four Phases of Petroleum Contamination (cont.)



(ITRC 2010)

- Migrating LPH is mobile due to high saturation of LPH in subsurface and a driving force (i.e. ongoing release)
- Typically ceases to migrate with 1 to 3 years of release ending

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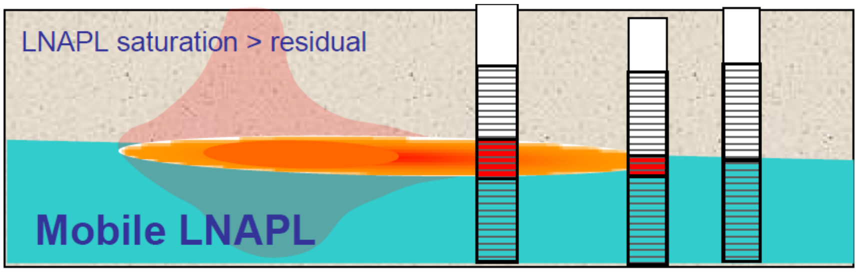
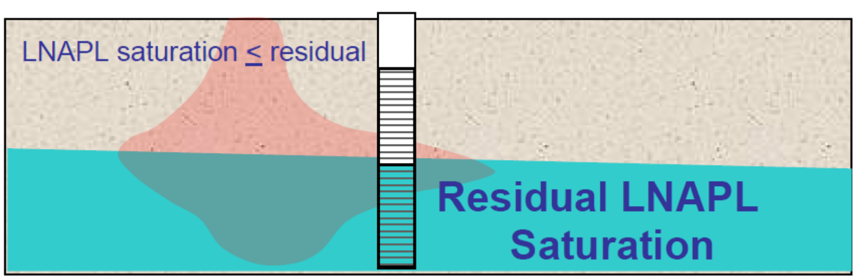
Four Phases of Petroleum Contamination (cont.)



(ITRC 2010)

- Mobile LPH is typically mobile only within a stable footprint
- Footprint stable because LPH saturation is too low at edges of plume and driving force not present (i.e. release controlled)
- Major source of high dissolved phase plumes

Four Phases of Petroleum Contamination (cont.)



(ITRC 2010)

- Residual phase LPH is completely entrained in the subsurface
- Can result in occasional LPH in wells and sheens with water table drops, particularly in core of plume
- Major source of high and low dissolved phase plumes

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Cautions to the Historical Approaches to Recovery System Design

- Preliminary Site Conceptual Model based upon:
  - Emergency recovery well installation
    - Location and screened intervals may not be ideal
  - Source zone wells converted to recovery wells
    - Few wells remain to monitor system performance
  - Limited gauging and sampling data
    - Don't have the full picture
  - PID readings from well logs
    - Not ideal

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Cautions to the Historical Approaches to Recovery System Design (cont.)

- Short term pilot test using existing monitoring wells as observation wells to save $
  - Installing appropriately designed and spaced observation wells will provide better data
- Generic slotted screens, gravel pack, and screened intervals
  - More efficient recovery wells using PVC wrapped wire screens with formation specific slots and gravel pack

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Appropriate Technologies for The Four Phases of Product

- **Mobile LPH** – Hydraulic Recovery / Control
  - Single / multi-well enhanced fluid recovery (EFR) with vacuum trucks
  - Emergency / portable systems
  - P&T
    - Expensive/high maintenance
    - Period of mobile LPH recovery is relatively short (months)
    - Move to appropriate technology for next phase, when point of diminishing returns is reached

Appropriate Technologies for The Four Phases of Product (cont.)

- **Mobile LPH** – Vapor Recovery
  - SVE
  - EFR
  - Emergency / portable vapor recovery units
  - P&T used to lower water levels and expose smear zone to remove residual LPH with SVE

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Appropriate Technologies for The Four Phases of Product (cont.)

- Traditional P&T / SVE
  - Can treat all phases, but may be other more effective solutions
  - Hydraulic control
  - Vapor control
  - Dissolved capture
  - Dewater smear zone

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Appropriate Technologies for The Four Phases of Product (cont.)

- **Residual LPH**
  - P&T dewatering of smear zone with SVE
  - Sparge wells with SVE
  - Surfactant soak with hydraulic recovery
  - Chemical oxidation
    - Best for low amounts of LPH
    - Existing SVE can be used to capture vapors
  - Steam, heat, radio frequency
    - Used in conjunction with SVE
  - Co-solvents
    - Good for heavy oils
  - Move to appropriate technology for the next phase, when the point of diminishing returns is reached

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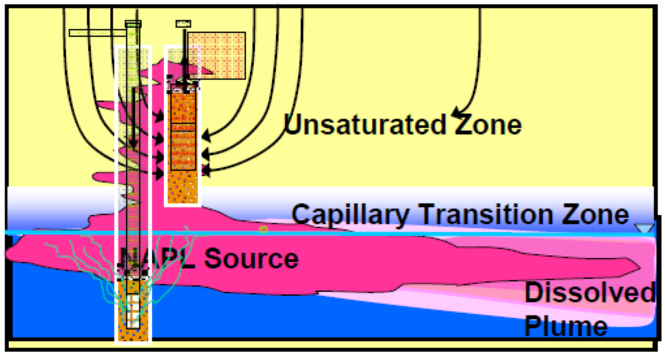
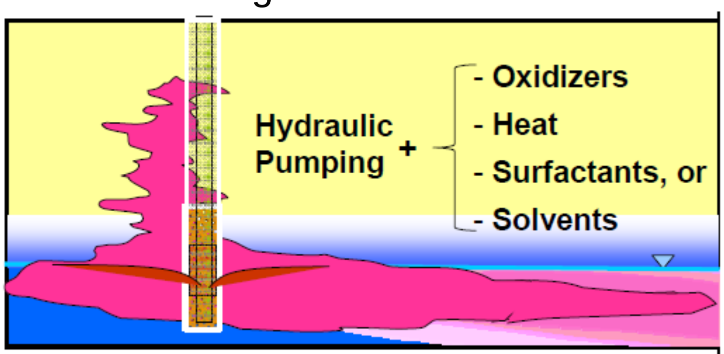
Appropriate Technologies for The Four Phases of Product (cont.)

- Residual / High Dissolved Phase
  - SVE / Sparge



Appropriate Technologies for The Four Phases of Product (cont.)

- Residual / High Dissolved Phase



Appropriate Technologies for The Four Phases of Product (cont.)

- **<u>High Dissolved Phase Concentrations</u>**
  - SVE / Sparge
  - Chemical oxidation (chemox)
  - Oxygen addition technologies – ORC, oxygen / ozone diffusers
  - Nutrient / microbial treatments
  - Combined – chemox / ORC (Regenox™)
  - If low dissolved phase level cleanup is required, move to next technology when point of diminishing returns is reached

Appropriate Technologies for The Four Phases of Product (cont.)

- **<u>Low Dissolved Phase Concentrations</u>**
  - Sparge - in favorable formations
  - ORC, oxygen addition methods
  - Nutrient / microbial amendments
  - Regenox (chemox with time release ORC)

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Hydraulic Control

- Full time pumping vs. pulsed vs. treatment pumping
- Hydraulic control is part of the treatment train for the four different phases
  - Pulsed pumping allows time for adsorbed material to move into the dissolved phase, less $ (mobile, residual phases)
  - Surfactants / chemox – cause residual LPH to move out of adsorbed phase and move down gradient as high dissolved levels – need short term treatment pumping to capture

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Hydraulic Control (cont.)

- P&T system can be used to expose the smear zone for treatments of dissolved phase constituents and later recovery
  - Formation capture zones, groundwater velocity will determine time interval of pulsing
  - Surfactant solution or other treatments – design to prevent fouling of the water treatment system

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Hydraulic Control (cont.)

- Long term capture zones may differ from initial pilot test design
- May not need to run all of the recovery wells as the plume shrinks in size
- Dead zones – where capture is inefficient due to formation characteristics
- Hot spots – source strength is variable, some areas easier to clean up
  - Source material at the bottom of smear zone may be inaccessible

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Vapor Control

- Separate monitoring of mass recovery of hydraulic vs. vapor influent provides clues for which aspect of the system needs a change in strategy
- SVE often run beyond the point of diminishing returns in hopes of decreasing dissolved phase concentrations
  - May be ineffective in addressing deeper smear zone contamination

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Improving the Site Conceptual Model (SCM) – Initial Steps

- Instrument multi-well EFRs to get initial pilot test data to augment / design later formal pilot test
- Conduct bail-down tests to determine LPH hydraulic conductivity and LPH recharge rates for different wells within the plume
- Instrument surrounding wells during system operation to determine equilibrium capture zones
- Pulse system and test individual wells for capture, water and LPH hydraulic conductivity, LPH recharge rates

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Improving the SCM – Treatment Train Strategy (cont.)

- Define the horizontal and vertical extent of smear zone, dead zones and hot spots with targeted direct push investigations at different decision points
  - Laser Induced Fluorescence (LIF) – residual LPH
  - Membrane Interface Probe (MIP) – residual LPH and high dissolved
  - Electrical Conductivity – fine tune knowledge of lithology
  - Hydraulic profiler – fine tune understanding of preferential zones of water flow, injection rates, etc.

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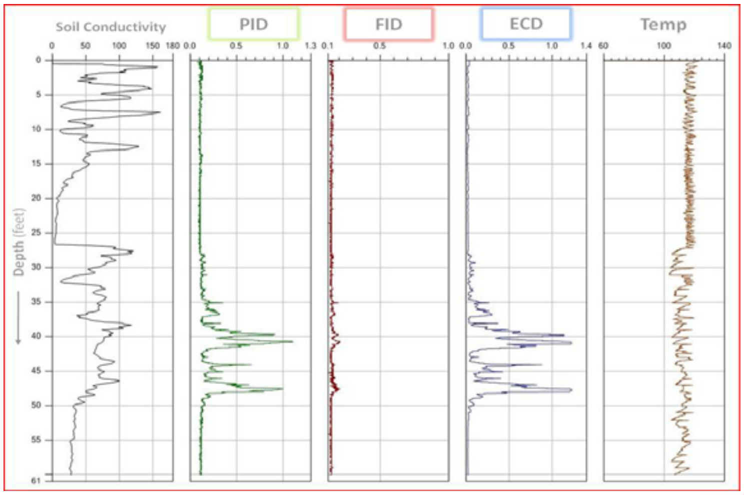
Targeted Assessment - Direct Push Tools



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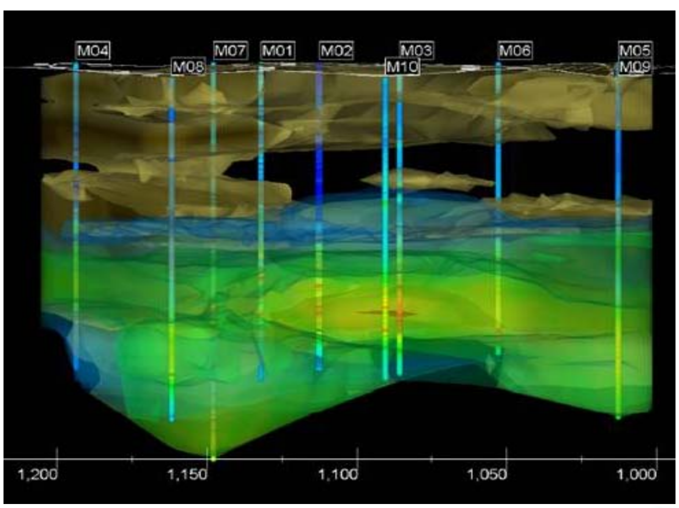
Analysis of Targeted Assessment - 3-D Rendering



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Fine Tuning the Well Network

- Based upon improvements to the SCM from additional targeted delineation
  - Add additional recovery well locations
  - Fine tune the next round of injections – amounts and intervals (surfactants, chemox, ORC, etc.)
  - Add monitoring well locations to improve understanding of the remaining extent of plume
  - Abandon locations that are no longer providing useful data to attain a representative and cost effective monitoring well network
  - Design monitoring well network for post-remediation monitoring, to address rebound, and achieve case closure

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Well Maintenance and Redevelopment

- Wells are developed after installation to remove fines and ensure an efficient well
- Over time wells become silted in and well screens get clogged with fines and microbial growth – redevelop with mechanical surging, pH, and temperature treatments
- Recovery wells that once removed LPH need regular redevelopment due to higher microbial growth rates and surfactant redevelopment after LPH is absent
- Post remediation monitoring should be done with a clean well network
- Surface seals get compromised and need maintenance – monitoring well data should not reflect the effects of surface runoff

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Rebound of LPH and Dissolved Phase Concentrations

- Site specific and can lengthen project and $
- Rebound depends upon:
  - Formation complexity
  - Appropriate technology for each phase of petroleum contamination
  - Strength of SCM
  - Mass of petroleum remaining after each treatment
  - Approach to dead zones and hot spots
  - Well maintenance
  - Representativeness of monitoring well network

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Improved Time Frames for Different Phases of Cleanup

- Mobile LPH (migrating) – 6 months to 1 year
- Mobile LPH (locally mobile, but not migrating) – 6 months to 2 years
- Residual – 6 months to 2 years
- Dissolved – depends upon risk scenario and cleanup goals – 1 to 2 years
- Post-remediation monitoring 1 to 2 years
- Average time to closure with Holistic Approach – 6 ¼ years instead of +10 years

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Cost Offsets

- Shorter time of remediation offsets costs for:
  - SCM updates
  - Targeted direct push investigations
  - Monitoring well network improvements
  - Well maintenance
  - Additional work plans/bench and pilot testing for different technologies, reporting to regulators

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Costs of Remediation Plateaus / Failure to Close Case

- If closure not achieved, Responsible Party (RP) often switches consultants
  - Loss of project memory
  - Down time during consultant switch
  - Loss of property value/revenue
  - RP is concerned about throwing good money after bad - which limits options for the next consultant
    - May lead to overselling a technology, e.g. chemox with too much residual LPH present

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Regulatory Perspective

- Pressure from EPA and upper management to close cases for the last 5 years
  - "Low hanging fruit" has already been picked
  - Remaining cases are in difficult formations/complex source issues (dead zones, hot spots, etc.)
  - Economic downturn
  - Major oil companies getting out of retail
  - Will need to work more cost effectively in the future

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Conclusions

- The remedial treatment train should recognize the limitations of different technologies for different phases of petroleum contamination
- Hydraulic control is expensive, use judiciously
- Don't run SVE too long
- Collect the right pilot test and operational data to understand what your system is capturing and missing
- Continual evolution of the SCM
- Gather targeted source data using the latest direct push tools to focus remediation efforts and improve monitoring well network
- Maintain the monitoring well network

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