Technical Advancements in Multi-Phase Extraction (MPE)

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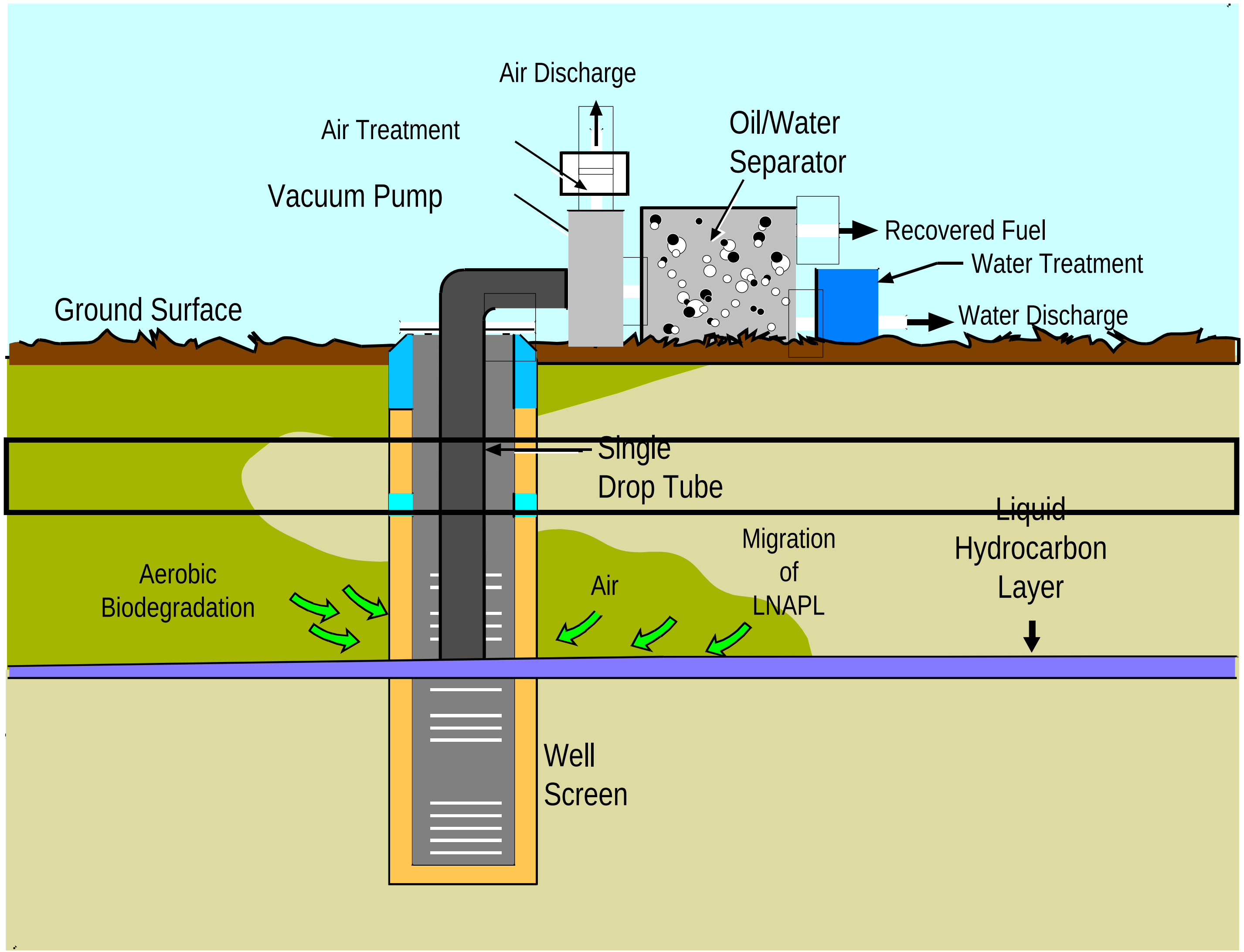
Technology Overview



Why Perform MPE?

- Enhance recovery of LNAPL
- Dewatering to enhance SVE and bioventing
- Enhance pump-and-treat (least common)

Benefits

- Greater LNAPL recovery rates compared to other pumping technologies
- A single aboveground pump necessary as opposed to a pump in each well
- Induces biodegradation of hydrocarbons in the vadose zone
- Air stripping of VOC from the vadose zone

Disadvantages

- Not possible to recover all LNAPL in subsurface
- Channeling in subsurface
- Creates secondary waste streams that can be cost-prohibitive to treat

Where is MPE reported to be technically feasible?

- Low transmissivity formations (<500 gpd/ft)
- Low hydraulic conductivities (10^{-3} to 10^{-5} cm/s)
- Apparent LNAPL thickness (>30 cm)
- LNAPL kinematic viscosity <10 centistokes
- Depth to groundwater >3 ft below ground surface

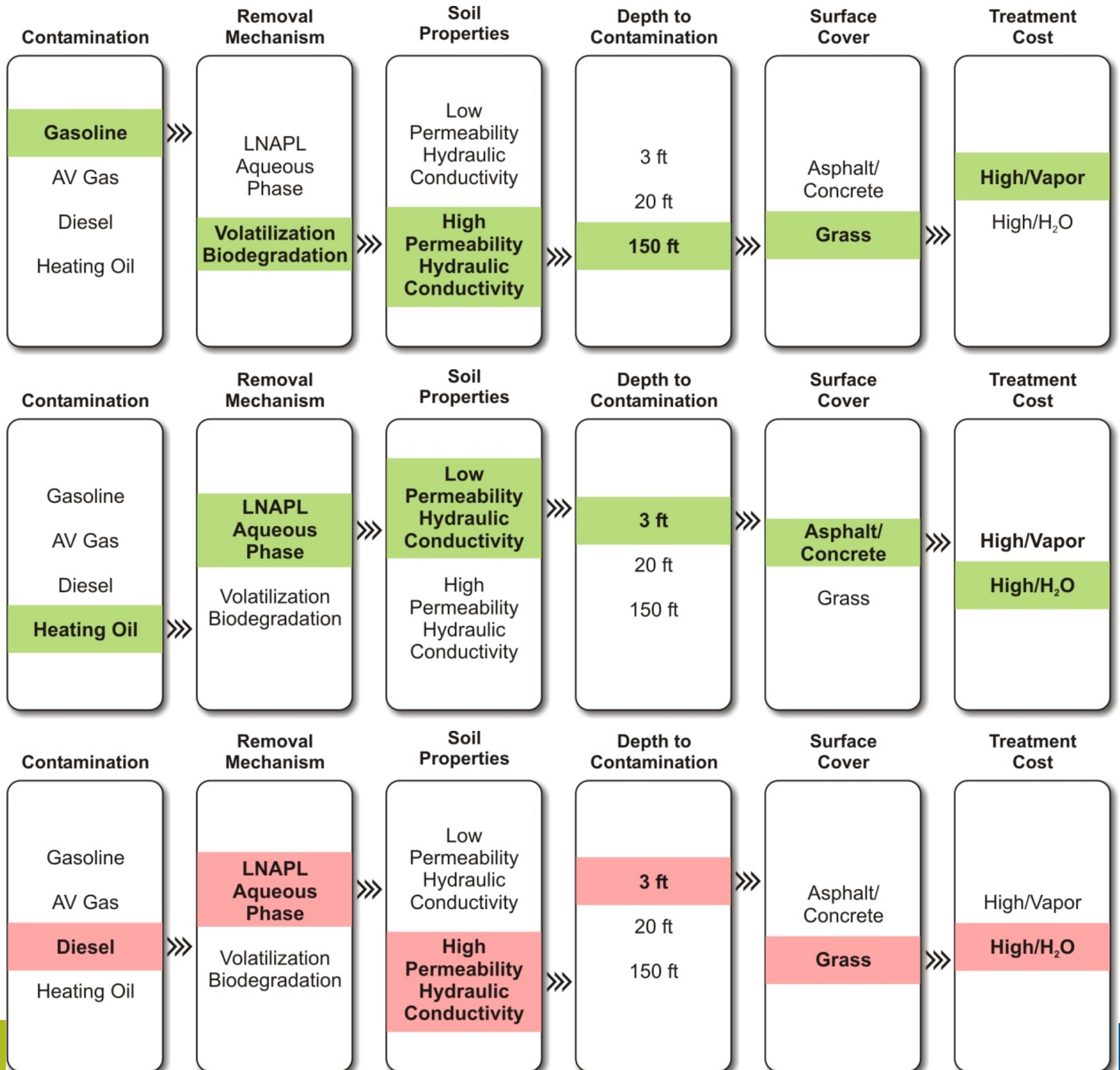
Easier!	→	*Harder!*
Gasoline		Heating Oil
Coarse Grain Soil		Fine Grain Soil
Homogeneous Formation		Heterogeneous Formation

Where has Battelle Implemented MPE?

Under a wide range of conditions including:

- Low-permeability silts and clays to highly permeable sands
- Apparent thickness of LNAPL from 0.3 foot to > 10 feet
- Groundwater from 3 to > 200 feet bgs
- LNAPL ranging from volatile AVGAS to viscous waste oils

Many Feasibility Factors to Consider



Technical and Economic Criteria

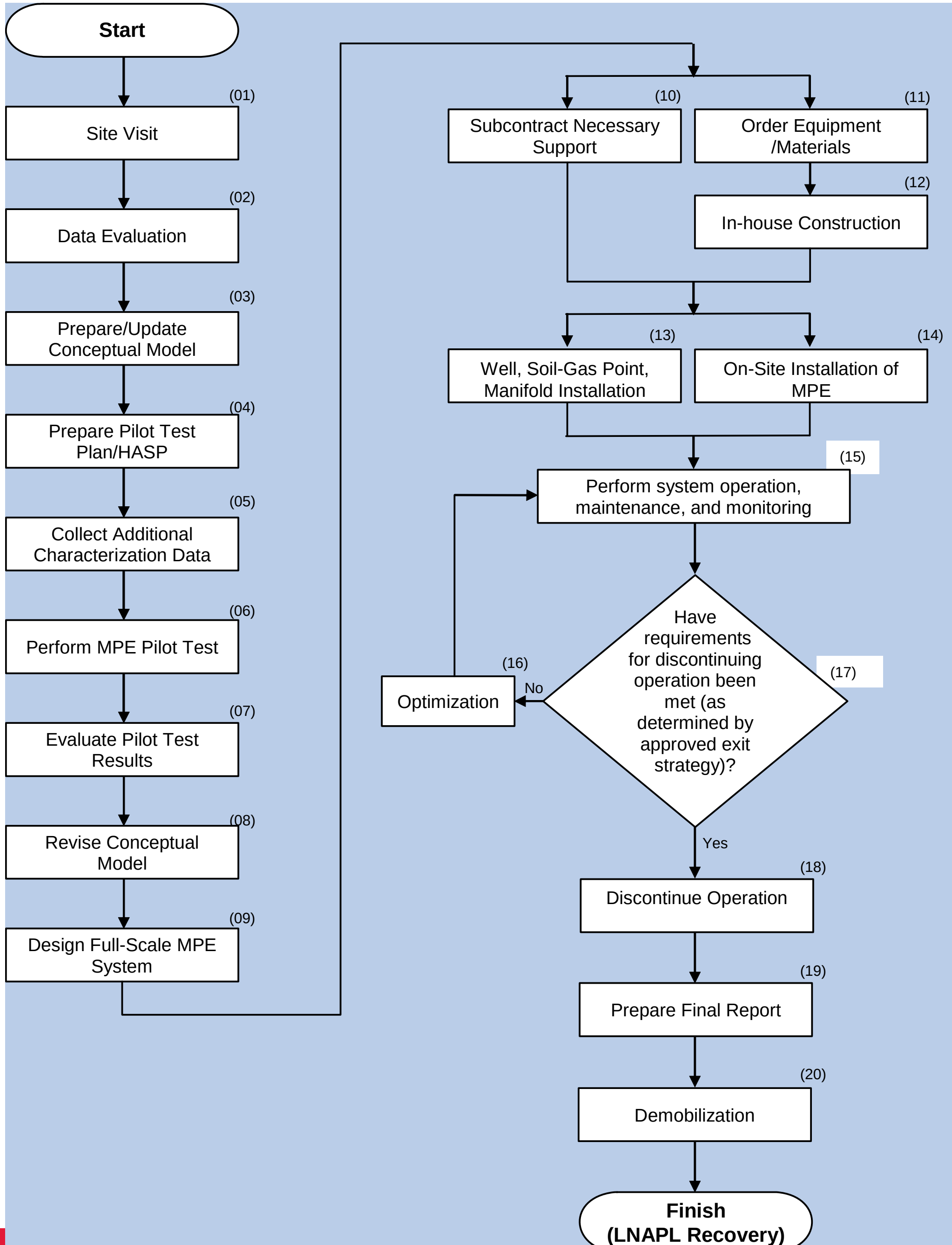
Technical Criteria	**Economic Impact**
Radius of Influence	Number of wells (More wells = higher cost)
Depth of Contamination	Depth of wells (Deeper wells = higher cost)
Plume size	Number of wells (More wells = higher cost)
Presence of preferential pathways	Not favorable unless substantial contaminant mass is present (More time to reach goals = higher cost)
Availability of utilities and sewers	Connection to power, water and sewer is needed (Limited or no access = higher cost)

Technical and Economic Criteria (cont)

Technical Criteria	**Economic Impact**
Regulatory requirements to treat process streams	Stringent water and off-gas treatment requirements = higher cost
Cleanup goals	Stringent cleanup goals = more time to reach goals = higher cost
Surficial topography- buildings, pavement, fields, etc	Subsurface manifold vs aboveground manifold (Subsurface manifold = higher cost)
Subsurface obstructions	Increase difficulty in well and manifold installation = higher cost
Location and availability of existing wells	More data = better design. Also saves on well installation costs

Battelle
The Business of Innovation

MPE Implementation



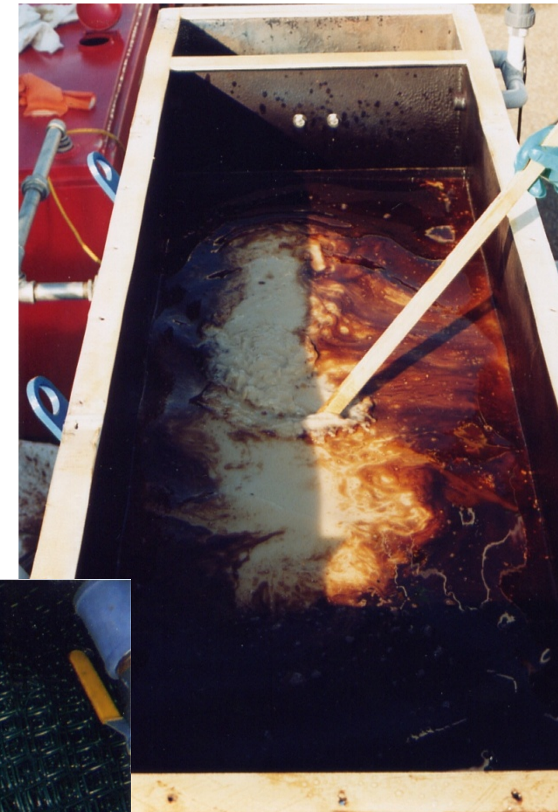
Pilot Test

Performed two weeks to several months to collect the data necessary to design the full-scale system

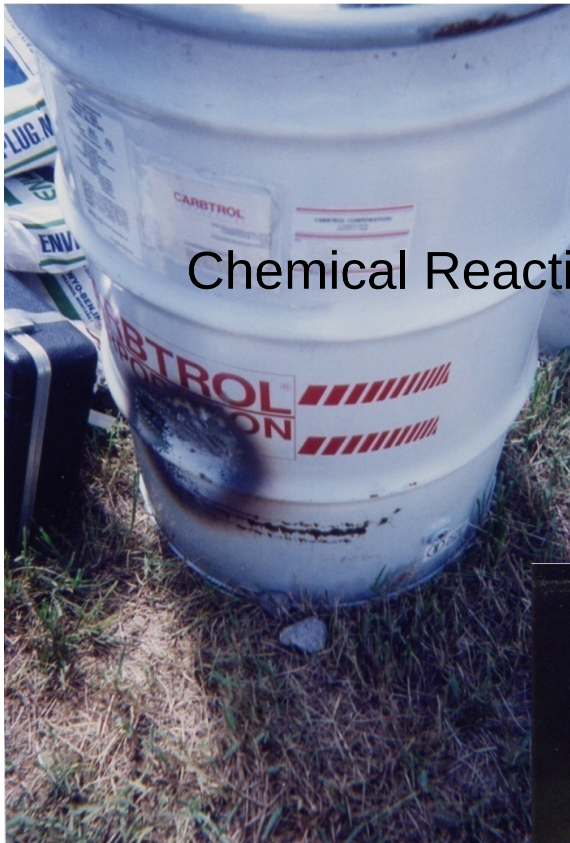
- Demonstrate and calculate mass removal
- Zone of influence
- Determine concentrations of contaminants in secondary streams
- Determine the impacts of any site specific limitations and how they can be overcome
- Develop cost-estimate for full-scale system
- Fill data gaps in conceptual model

Site-Specific Limitations

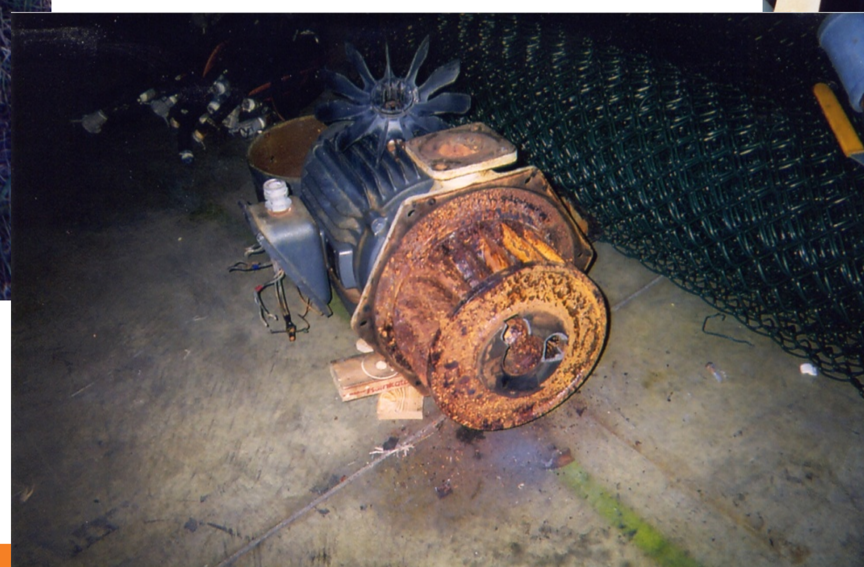
Severe Emulsion



Chemical Reaction and Fire



Severe Scaling



General Design Considerations

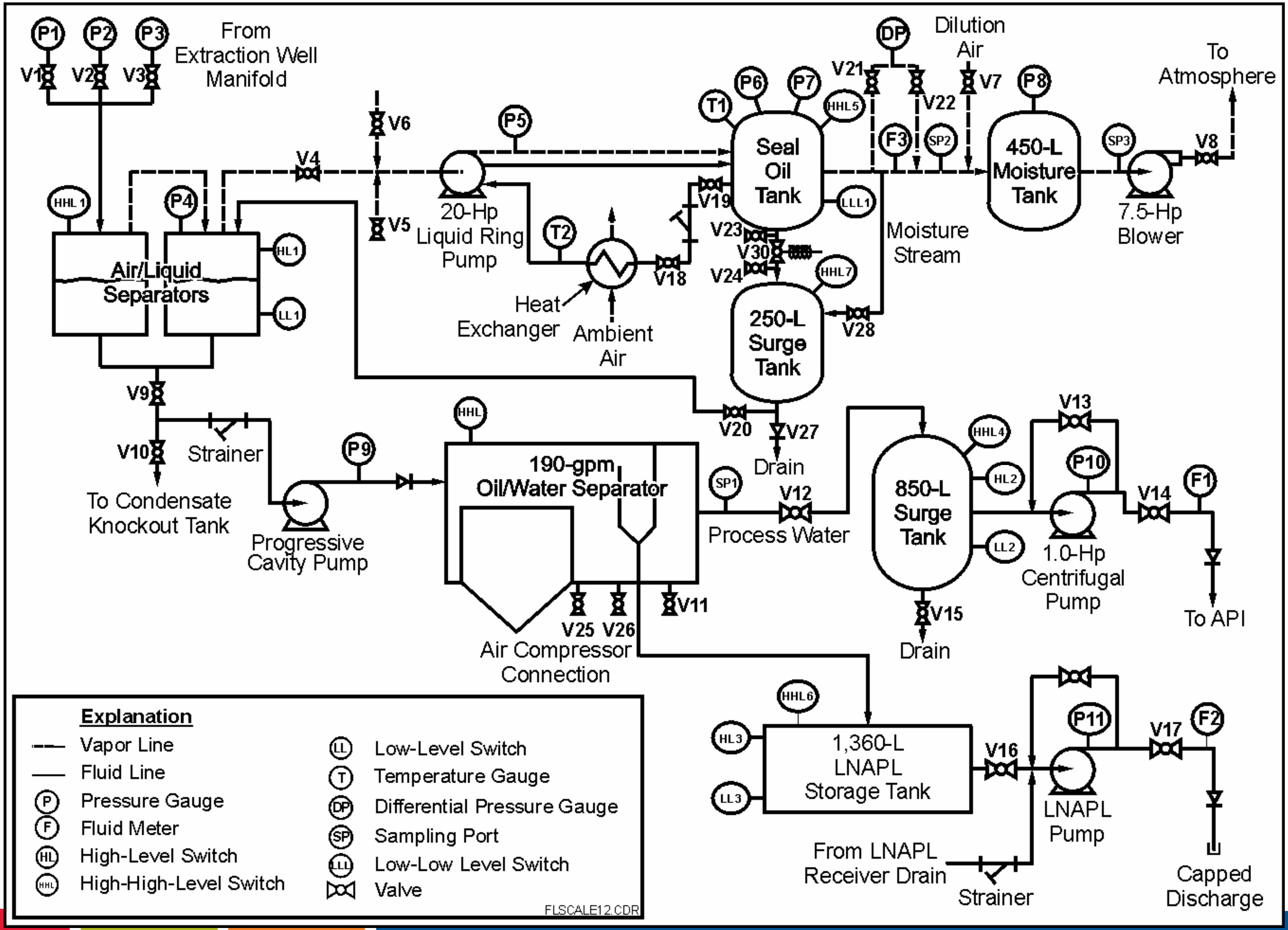
- Remedial Objectives
  - MPE with (or without) drawdown to recovery LNAPL
  - MPE with drawdown to enhance SVE and/or bioventing
  - Vacuum-enhanced groundwater extraction
- Urban vs. industrial and rural settings
  - Availability of utilities
  - Pedestrian and vehicular traffic
  - Site access and control
- Subsurface manifold vs. aboveground manifold

Other Considerations

- Cold weather applications
- Severe tidal fluctuations
- Remote control and monitoring
- Scale buildup in process equipment
- Availability of utilities
- Explosion-proof vs. non explosion-proof

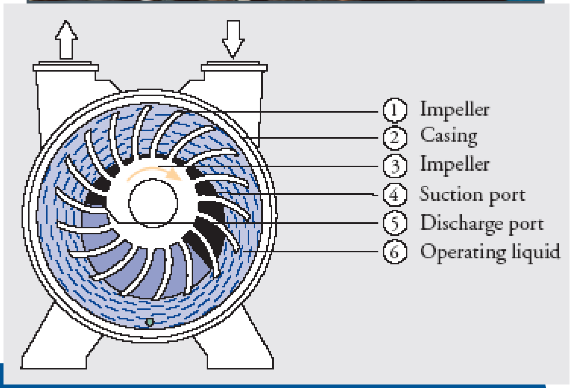
Scale Buildup in Liquid Ring Pump

Full-Scale Design



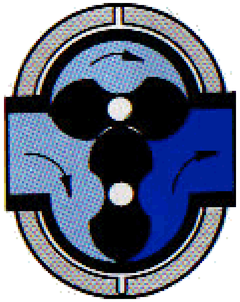
Liquid Ring Vacuum Pumps

- Vacuum from 20 CFM to 23,000 CFM
- Vacuum up to 29+" Hg
- Designed to operate safely, cleanly and continuously in wet environments
- Require minimal care - low maintenance
- Provide years of dependable service
- Higher capacities with less energy/power
- Needs an operating liquid to create vacuum, oil is the most convenient and commonly used
- Water vs. oil seal



Twin-Lobe Rotary Blower

- Alternative to LRP
- Dry pumping prevents mixing of LNAPL and water
- Entirely mechanical, light weight & compact design
- Simple to maintain
- However, will not tolerate any water
- Not as efficient as LRP’s



Internal Combustion Engine

- Generates vacuum of ~20 in Hg
- 99+% destruction of hydrocarbons in vapor stream
- Equipped with generator
- Uses propane or natural gas for supplemental fuel source
- Trailer-mounted

Aqueous Treatment

- Usually is one of the two most expensive part of process
- Many technologies to choose from
  - Hydrophobic clay
  - Air stripping
  - Chemical treatment/DAF
  - Settling tanks
- Reinjection or discharge to surface water also should be considered

Air Stripper with Vapor Phase Carbon

CRF/DAF System

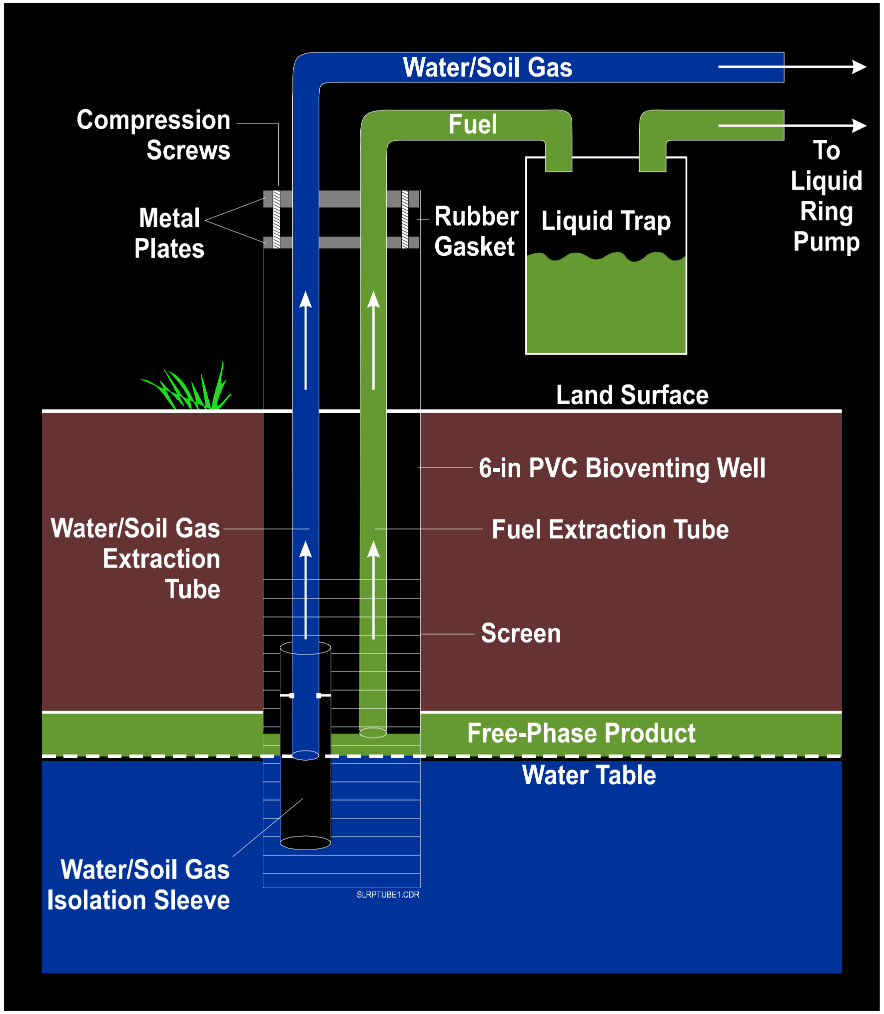
In-Well Oil/Water Separation

Advantages

- Reduces degree of oil/water emulsion
- May reduce hydrocarbon concentrations in off-gas
- Low capital cost (inexpensive to implement)

Disadvantages

- Tricky to operate
- Increases on-site labor requirement
- More efficient using fewer wells

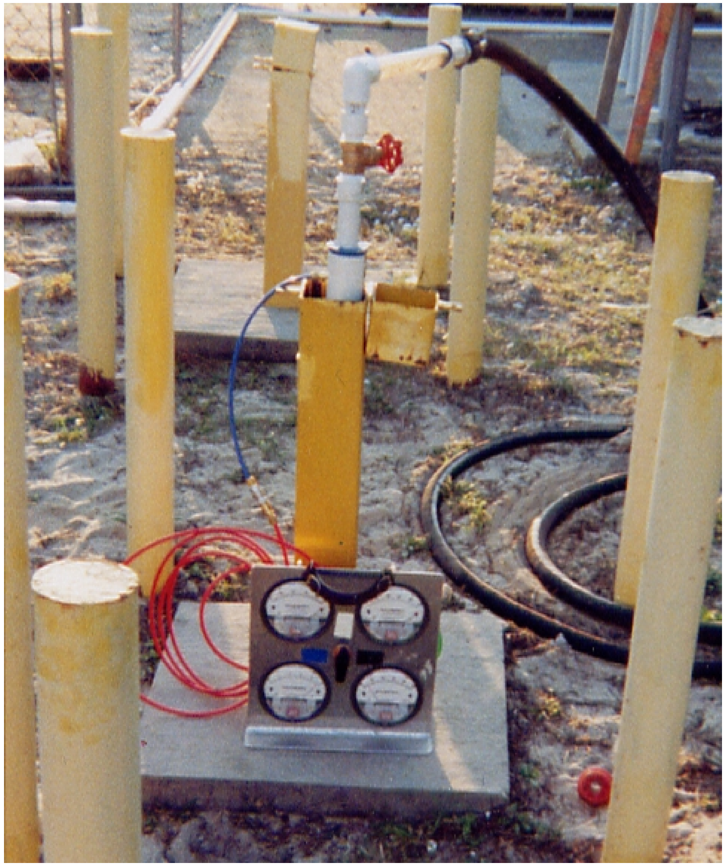


Vapor Treatment

- Thermal Oxidation
  - Low capital
  - High supplemental fuel when loading decreases
- Recuperative Oxidation
  - Capital cost for heat exchanger
  - Lower supplemental fuel
- Catalytic Oxidation
  - Capital cost adder for catalyst
  - Catalyst and heat exchanger combine results in low fuel requirement even at low loading
- Granular Activated Carbon

MPE Monitoring

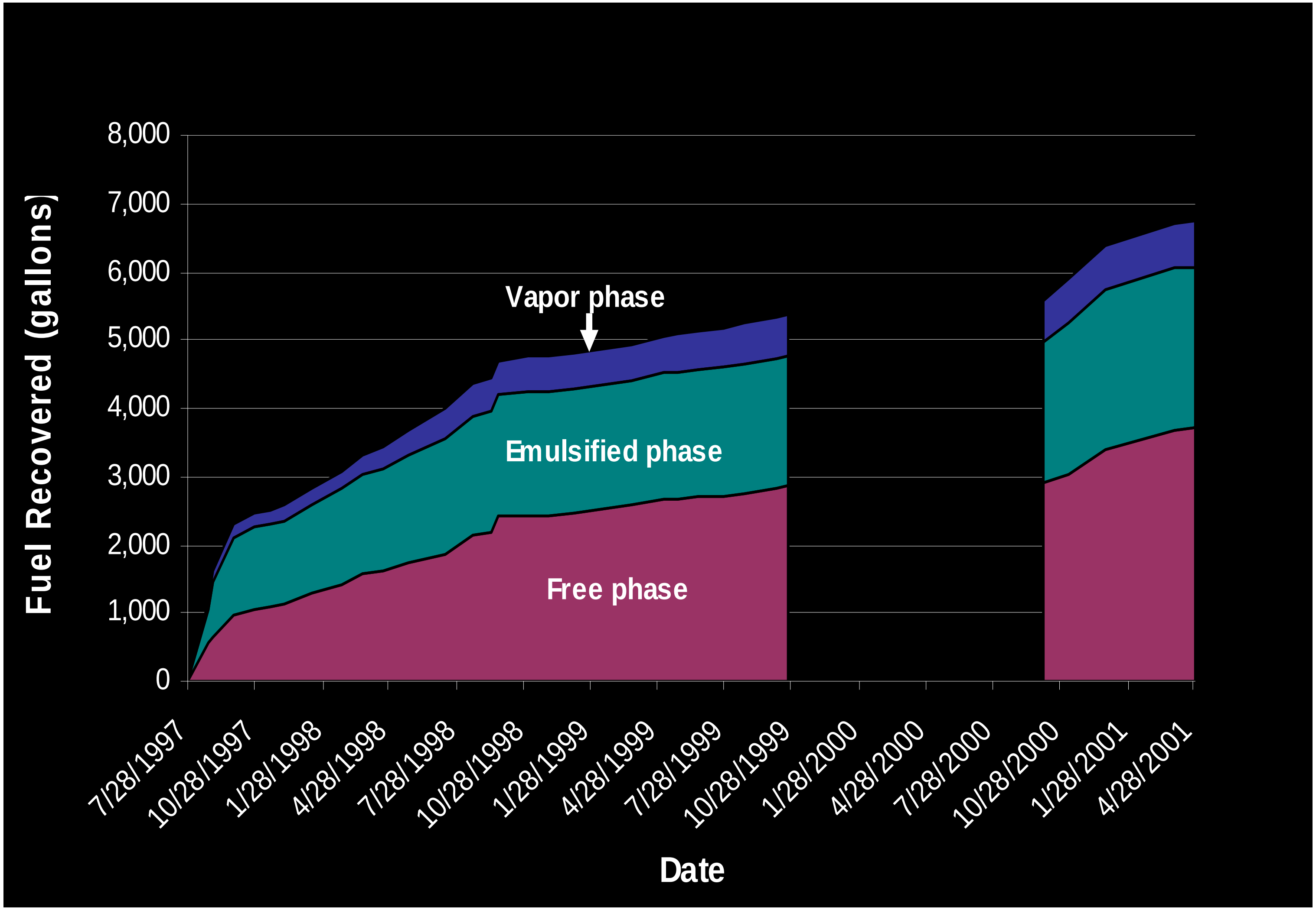
- Key to successful implementation
- Ensure data is collected to demonstrate compliance with remedial action objectives
- Process monitoring
  - Mass recovery rates as LNAPL, in vapor and in water
  - System and well vacuums and pressures
  - Biodegradation rates
  - Radius of influence
- Performance monitoring
  - Rebound of LNAPL
  - COCs in dissolved phase



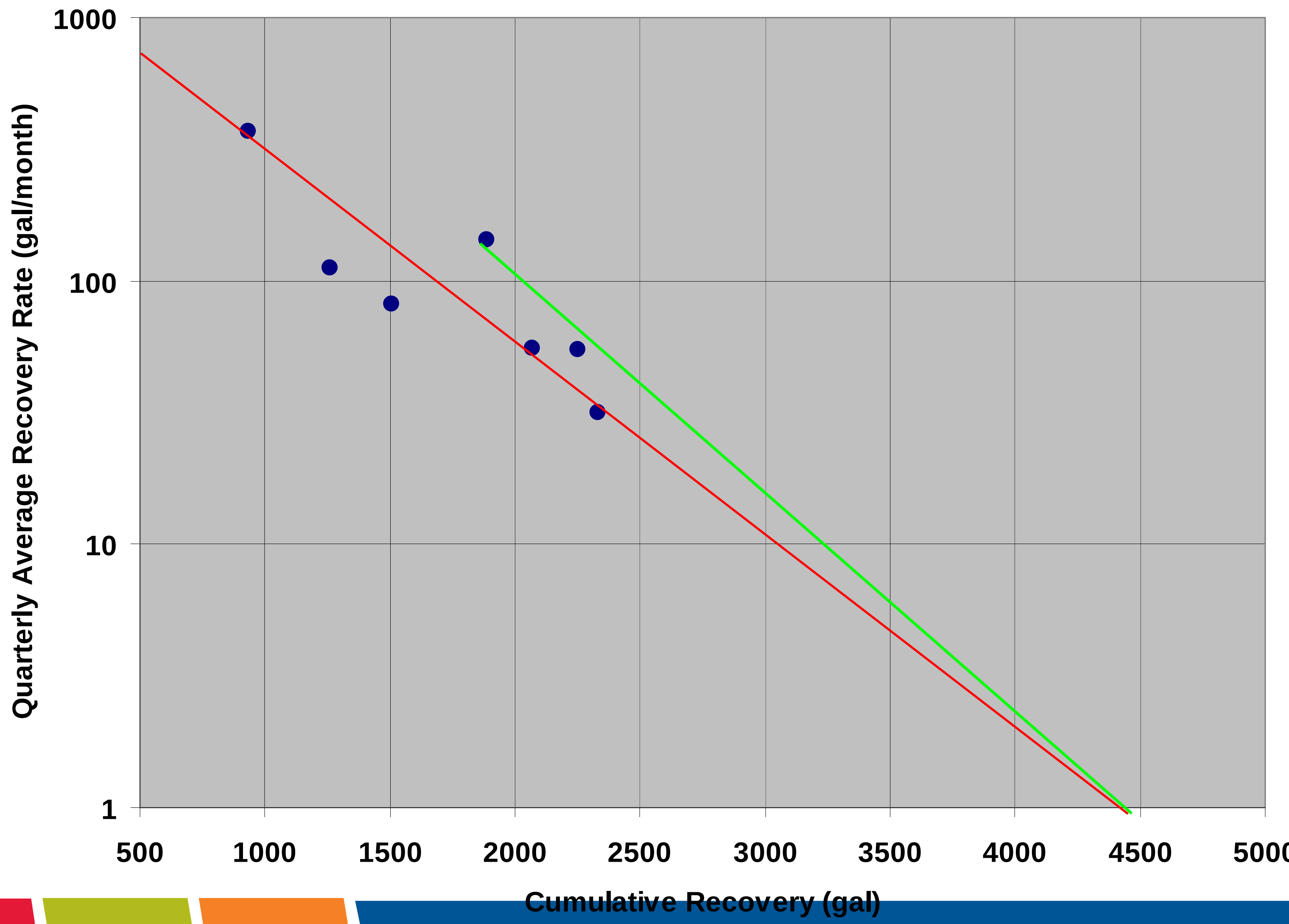
Recommended Monitoring Frequency

Activity	Frequency
Baseline oil/water level data	Prior to startup
Routine system monitoring and site inspection (i.e., process vacuums, flowrates, and temperatures)	A minimum of 5 times a week during the first month of operation; two or three times a week thereafter
LNAPL thickness and water levels in wells	Prior to rotating extraction wells
Extraction well vacuums	Before and after rotating extraction wells
Aeration monitoring	
Respiration test	Quarterly for first year, semi-annual after
Field monitoring of TPH, carbon dioxide, and oxygen in the vapor stream from each well	Monthly
Field monitoring of TPH in the vapor stream (influent and effluent of thermal oxidizer)	A minimum of 5 times a week during the first month of operation; two or three times a week thereafter
Aqueous and vapor sampling and analysis	Weekly at startup, at least monthly after
LNAPL recovery	Determined based on rate of recovery

Cumulative Volume of Hydrocarbons Recovered



Recoverability



The Problem

It is not technically practicable to measure the recovery rate of LNAPL from individual wells

(Devices have been developed but typically are expensive to construct, require significant O&M, and interfere with system operation)

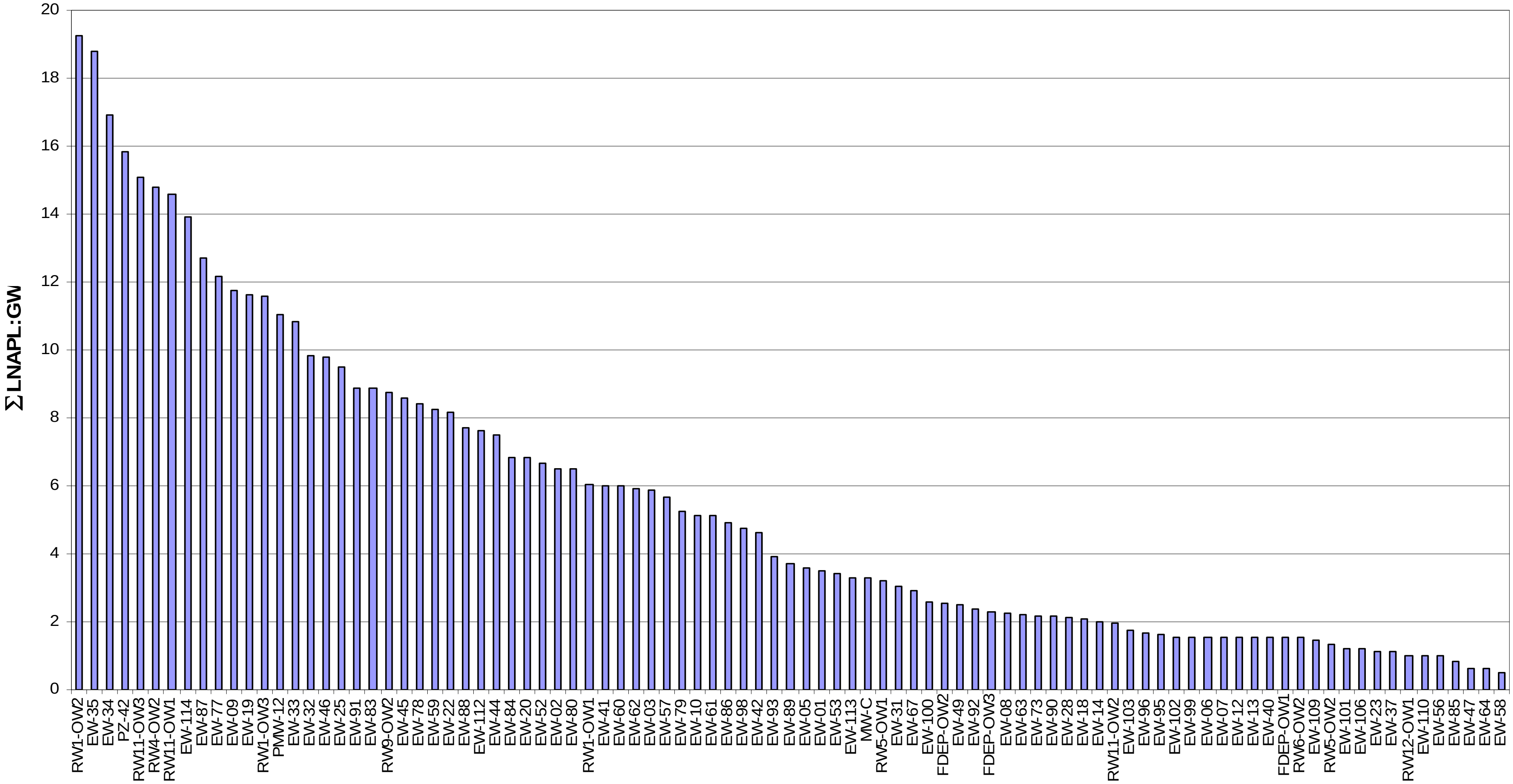
The Solution - Well Rotation with Proper Data Collection and Evaluation

What data is required to evaluate the recovery performance of individual extraction wells?

- Extraction well activity
  - Well IDs
  - Dates of operation
- Total LNAPL (not from individual wells) recovered during specific periods
- Total groundwater extracted during specific periods
- The number of hours that the MPE system extracted fluids from each well

System Modifications and Optimization

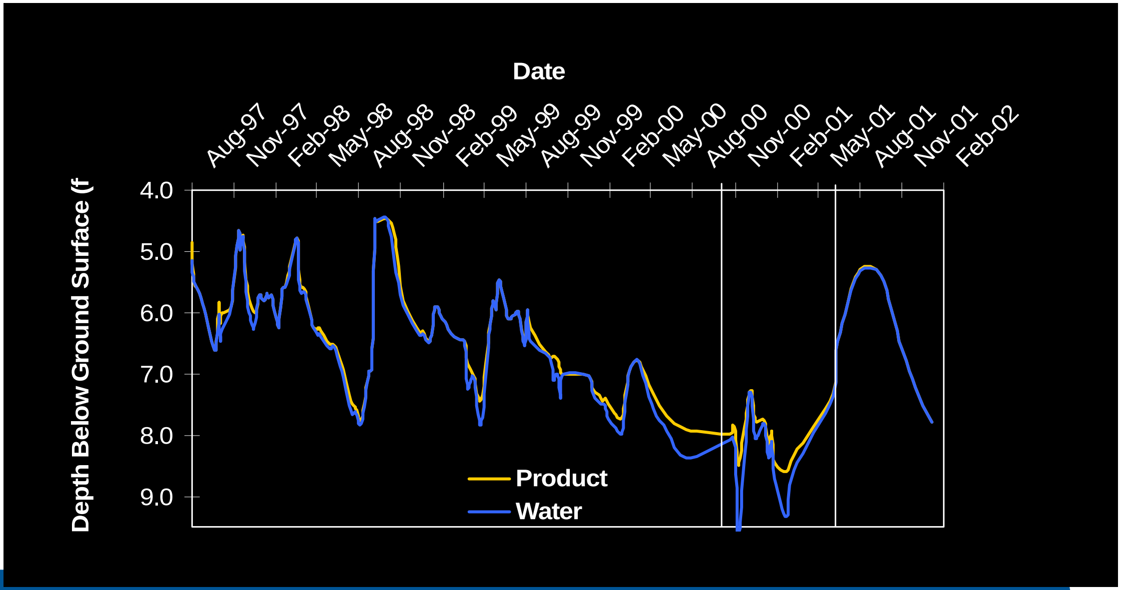
Example of Extraction Well Performance Evaluation



Understand Relationship between LNAPL Thickness and Groundwater Elevation

LNAPL thicknesses increase when the groundwater table elevation decreases and vice versa because of a redistribution of LNAPL.

- Changes in distribution of LNAPL in the porous media as the water table moves up or down, leaves different volumes of residual LNAPL in both the vadose and saturated zones
- LNAPL (and/or water) migrates to/from the soil surrounding the well as the water table elevation changes
- Redistribution can take a long time to reach equilibrium



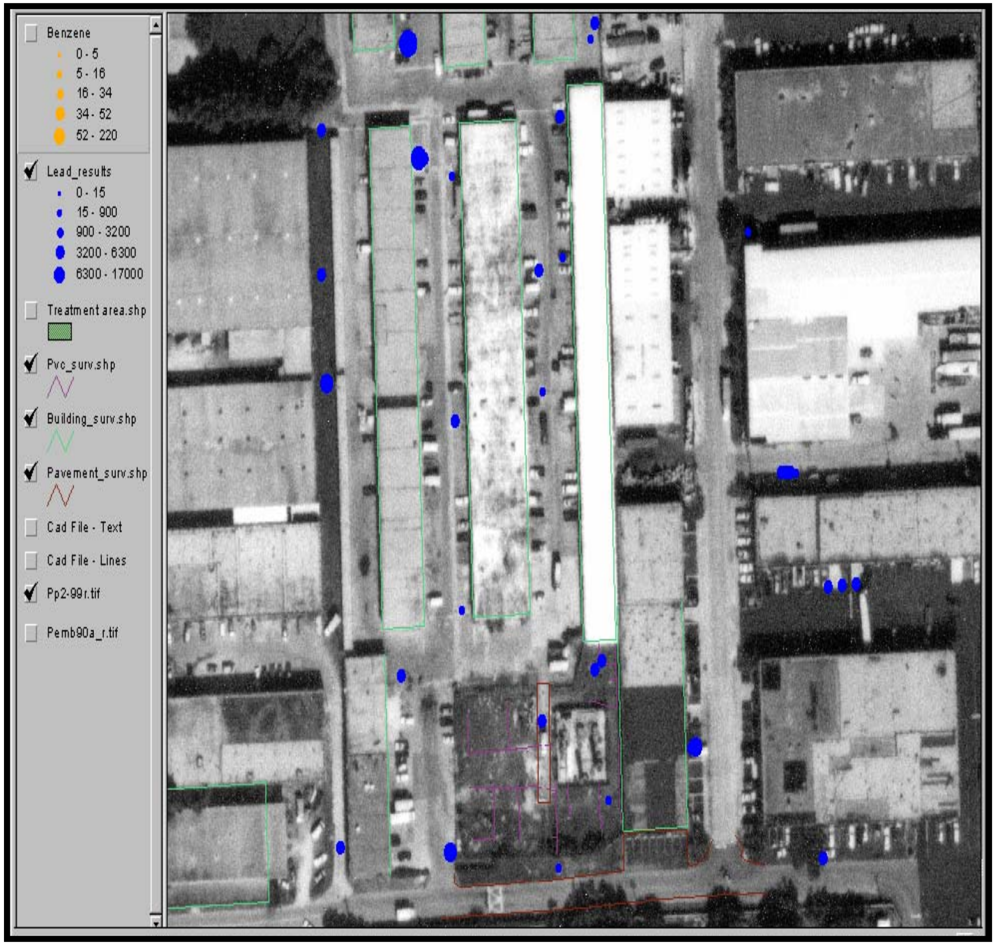
Health and Safety Considerations

- High vacuums and or pressures
- Water hammer
- Fire/Explosion
- Vapor hazards

Example
Bioslurping for LNAPL Recovery

Petroleum Products Corporation Superfund Site, FL

- Former re-refinery contaminated with viscous oils
- Lead contamination in groundwater
- Approximately 11 acres
- Commercial area occupied by active warehouses



GIS was used to Demonstrate Lead Contamination is not Migrating

Original Remedy

- Pump-and-treat to remove LNAPL
- Close portion of warehouses
- Perform in situ stabilization
- Estimate of $20M to $30M to implement

32

Project Activities

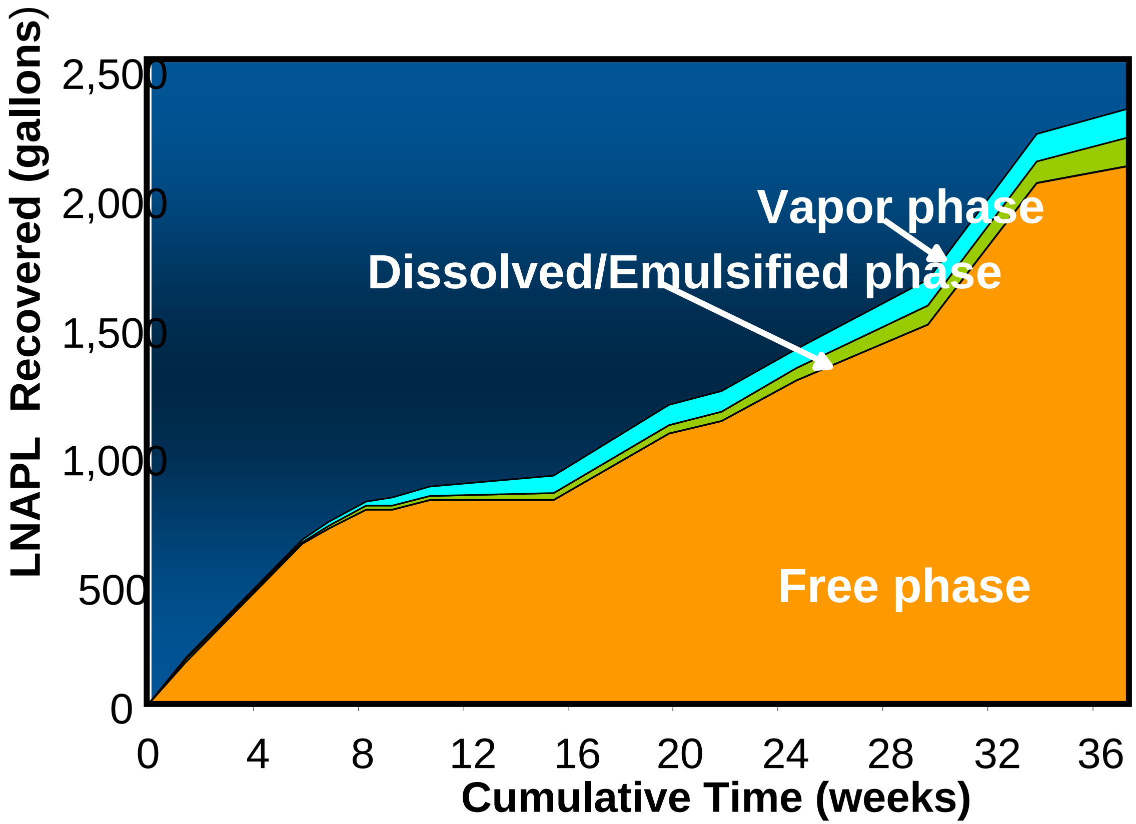
- Performed a pilot test to demonstrate efficacy of technology
- Delineated boundary of LNAPL contamination
- Installed and operated full-scale bioslurper system
- Designed and installed a full-scale system to treat the southern portion of the site
- Designed and installed a 2nd system to treat the northern portion of the site

Pilot-Scale System


Full-Scale System

Accomplishments

- Achieved cost savings by convincing EPA to modify ROD to implement bioslurping opposed to S/S
- Recovered about 10,000 gal of waste oil in <2 years of operation
- Used GIS to demonstrate lead is not migrating offsite
- Estimated costs savings >$15M
- Successful transfer of technology to a local contractor



Useful Resources

- Hazardous Waste Information Cleanup System (CLU-IN) http://clu-in.org
- EPA Remediation and Charicterization Innovative Technologies (REACH-IT) http://eapreachit.com
- Remediation Technologies Screening Matrix and Reference Guide (FRTR) http://www.frtr.gov
- Remediation Technologies Development Forum (RTDF) http://www.rtdf.org
- American Petroleum Institute (API) http://api-ep.api.org/environment