MULTI-PHASE EXTRACTION AND PRODUCT RECOVERY

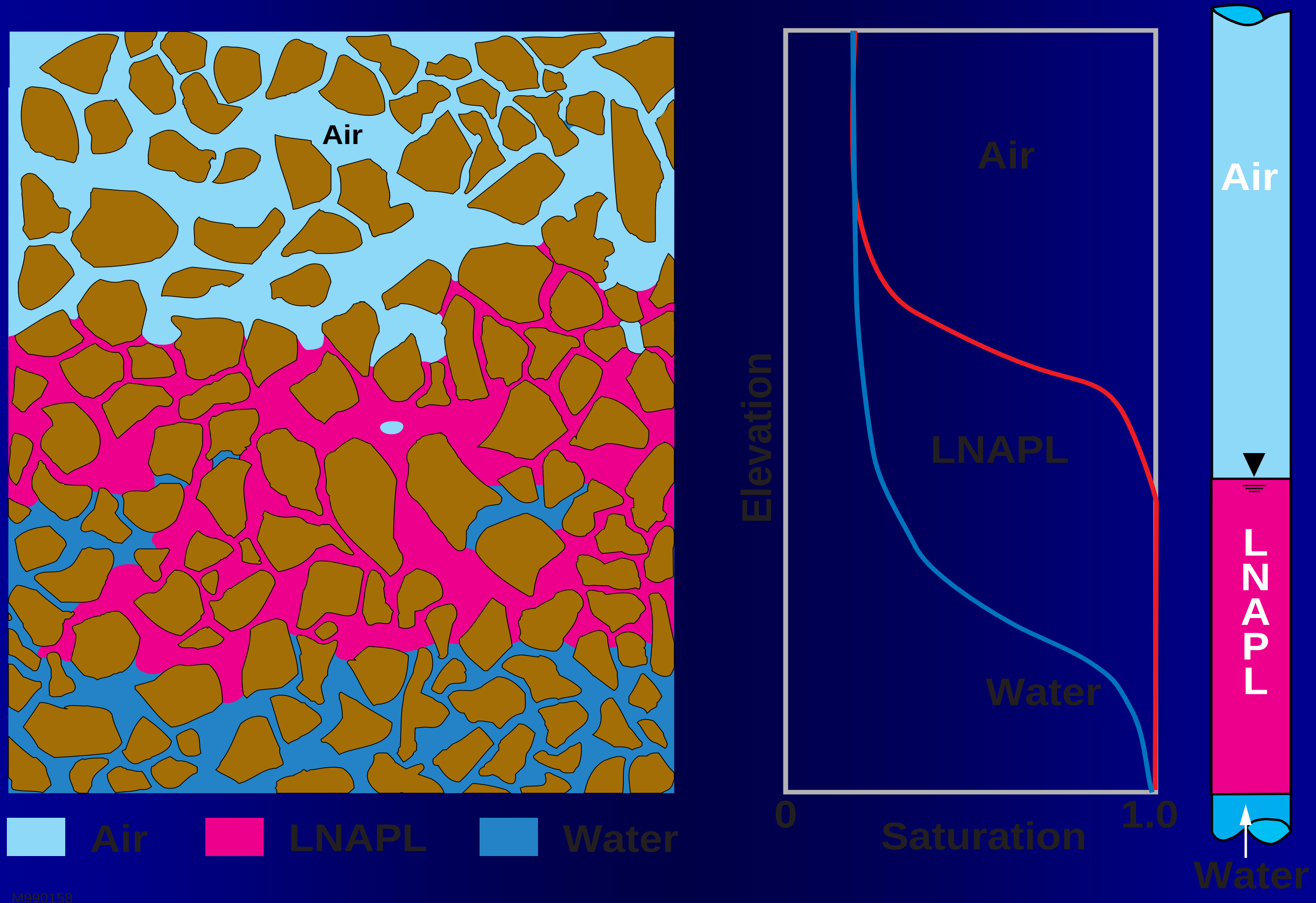
Presentation Objectives

- Discuss important processes affecting success
- Describe product recovery technologies and applicability
- Describe applicability of multi-phase technologies
- Identify data needs for technology selection/design
- Recommend pilot testing approaches
- Provide design guidance
- Discuss operational strategies
- Compare closure strategies and tools to determine progress toward close-out
- Identify contracting approaches and patent issues

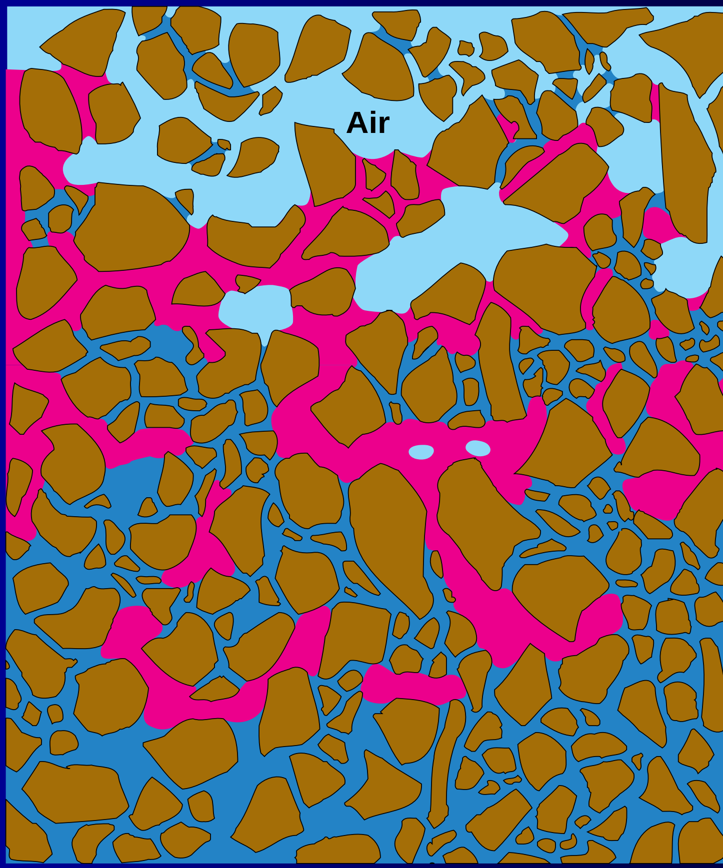
Important Processes: Product Recovery

- Floating product recovery options
- Oil/water mix
- Smearing over time
- Mobility
  - Product must be connected
  - Lower in fine material, at small apparent thickness
  - Affected by oil piezometric gradient
- Almost anything you do will strand product
  - Leave residual in soil, water
  - Waiting will also strand product

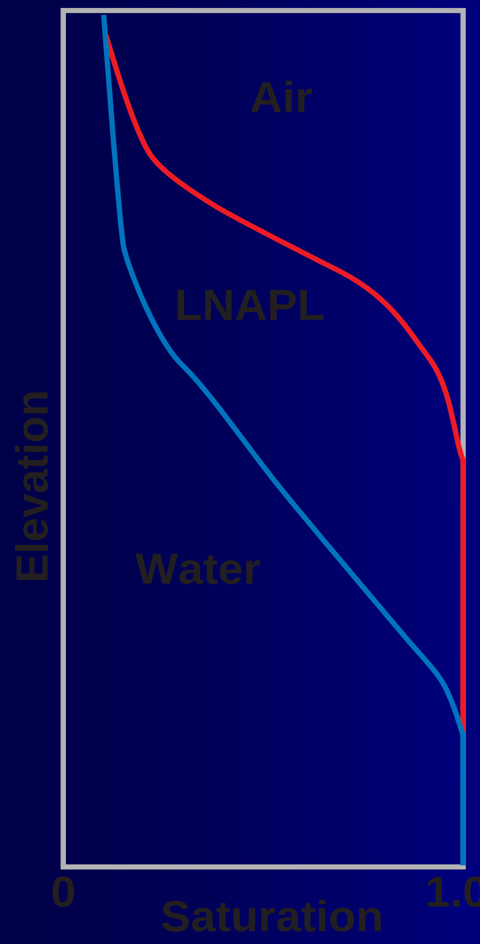
Light Non-Aqueous Phase Liquid (LNAPL) Distribution at the Pore Scale - Sand

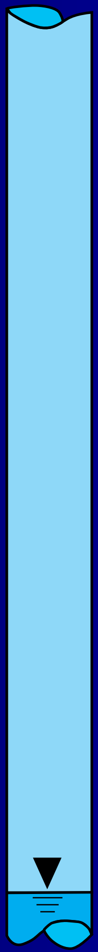


LNAPL Distribution At The Pore Scale - Sandy Loam



Air LNAPL Water





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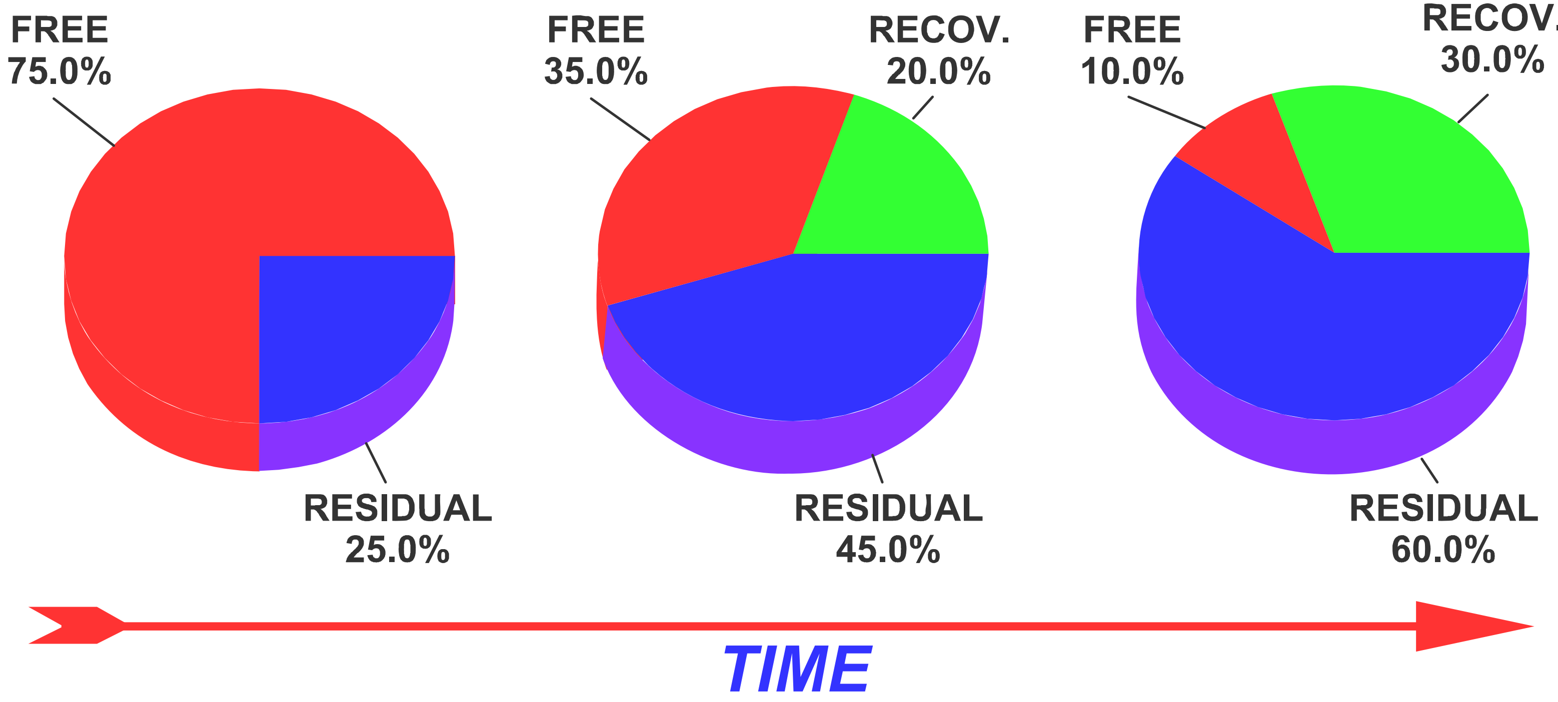
Distribution of Product Over Time



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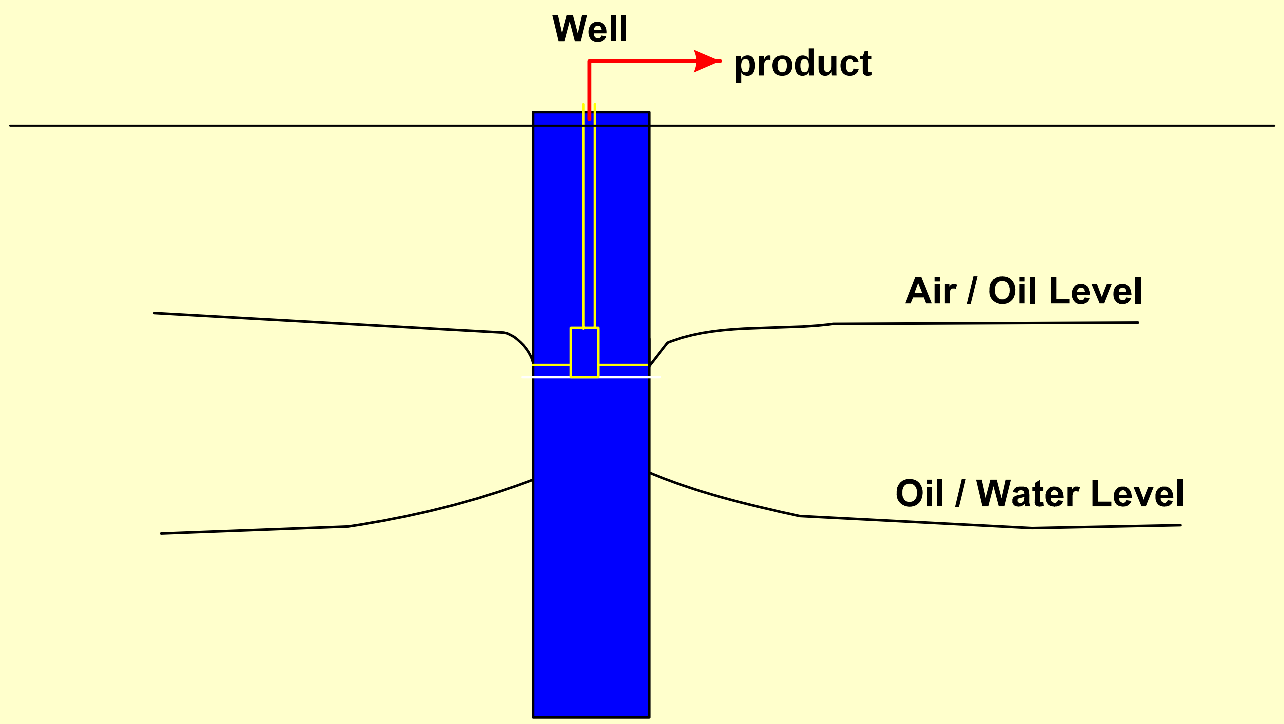
Estimating Oil Volume

- Baildown test - coarse material only
  - Remove oil
  - Monitor oil/air, oil/water contacts
  - Oil thickness in well when oil/water level begins to drop is free-oil thickness
- Summation of fuel saturation over area

Product Recovery - Skimming

- Concept: recover product only
  - Floating pumps
  - Hydrophobic membrane
- Advantages: low cost
- Disadvantages: poor recovery

Skimmer Systems



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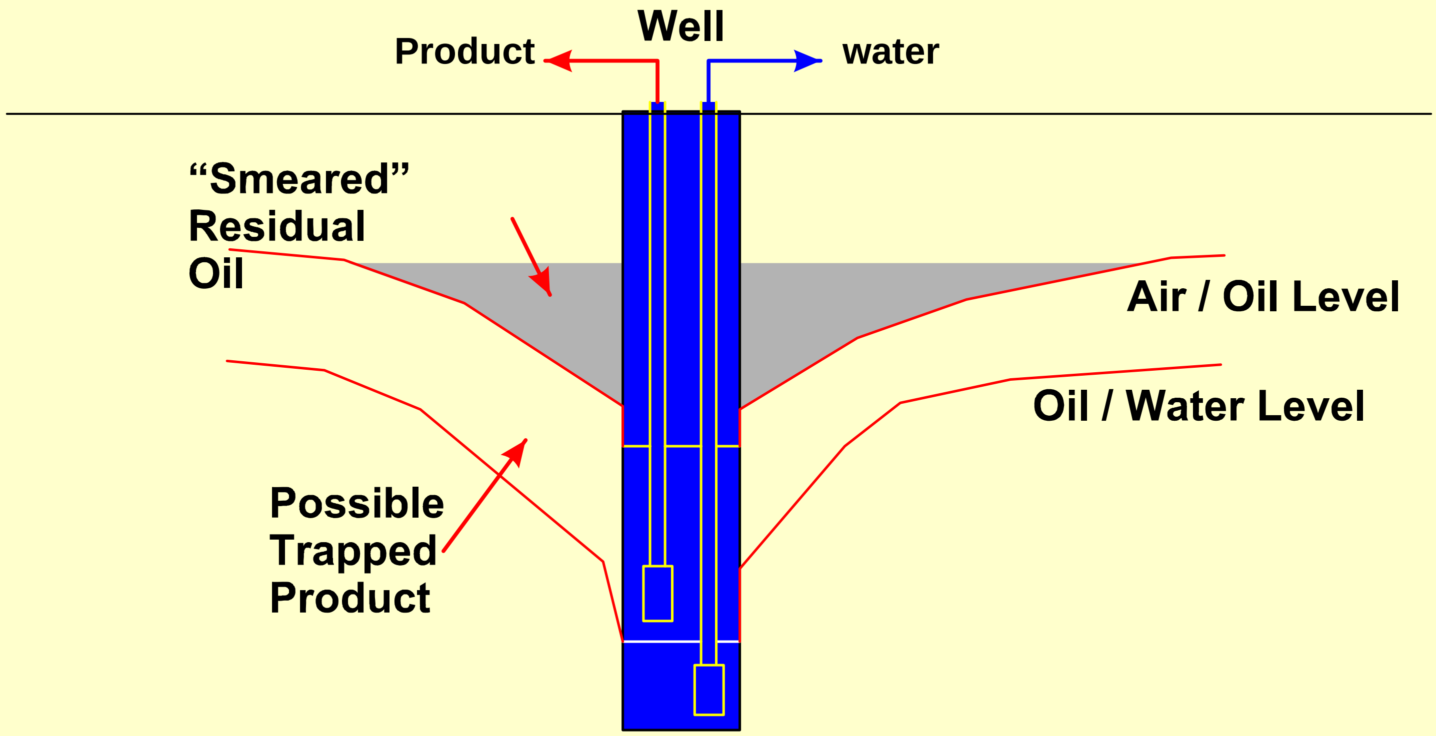
Dual Extraction & Total Fluids Extraction

- Dual extraction
  - Concept: pump water and product separately from same well
  - Advantage: improved recovery, separation
  - Disadvantages:
    - Cost to treat water
    - Larger wells required
    - More stranding of product in cone of depression
- Single pump (total fluids) extraction
  - Simultaneously remove both water, oil w/single pump
  - Lower water table, ease of operation
  - Emulsification of product and water

Dual Extraction



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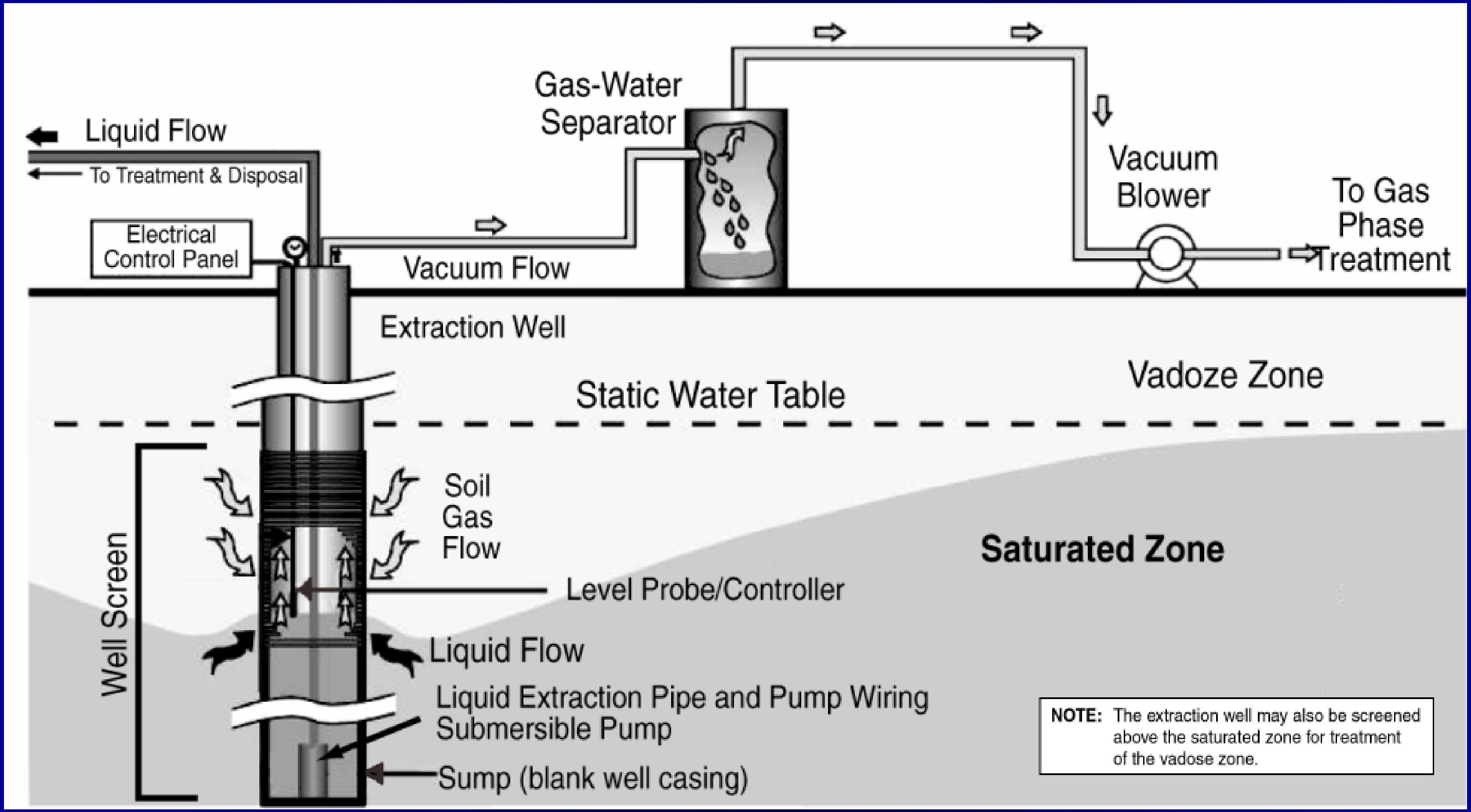
Multi-Phase Extraction (MPE)

MPE is the combined extraction of gas and liquid from the subsurface, in one of two forms:

- Dual-phase extraction (DPE): separate conduits/pumps convey gas and liquid from the extraction well
- Two-phase extraction (TPE): same conduit/pump conveys gas and liquid from the extraction well. Also known as “slurping”

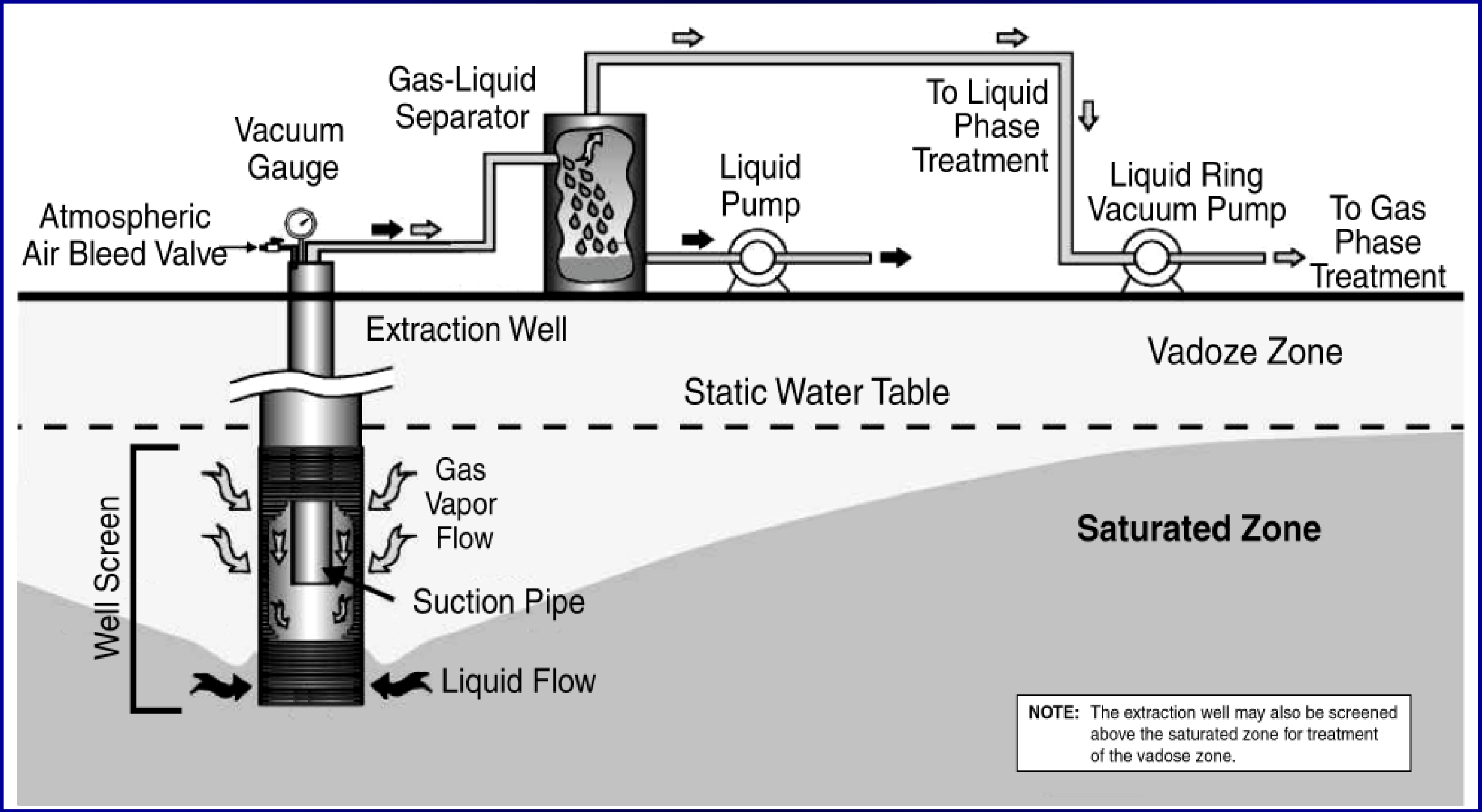
Schematic of DPE System (Low or High Vacuum)

(After EPA 1997)



Schematic of TPE System

(After EPA 1997)



MPE Applicability

- Vocs and biodegradable semi-volatile organic compounds (SVOCs) in the unsaturated zone and/or zones that can be dewatered
- Sites with recoverable non-aqueous phase liquid (NAPL)
- Medium-permeability soil (10^{-3} to 10^{-5} cm/sec)
- Groundwater yield < 20 L per minute per well

MPE Application Strategies

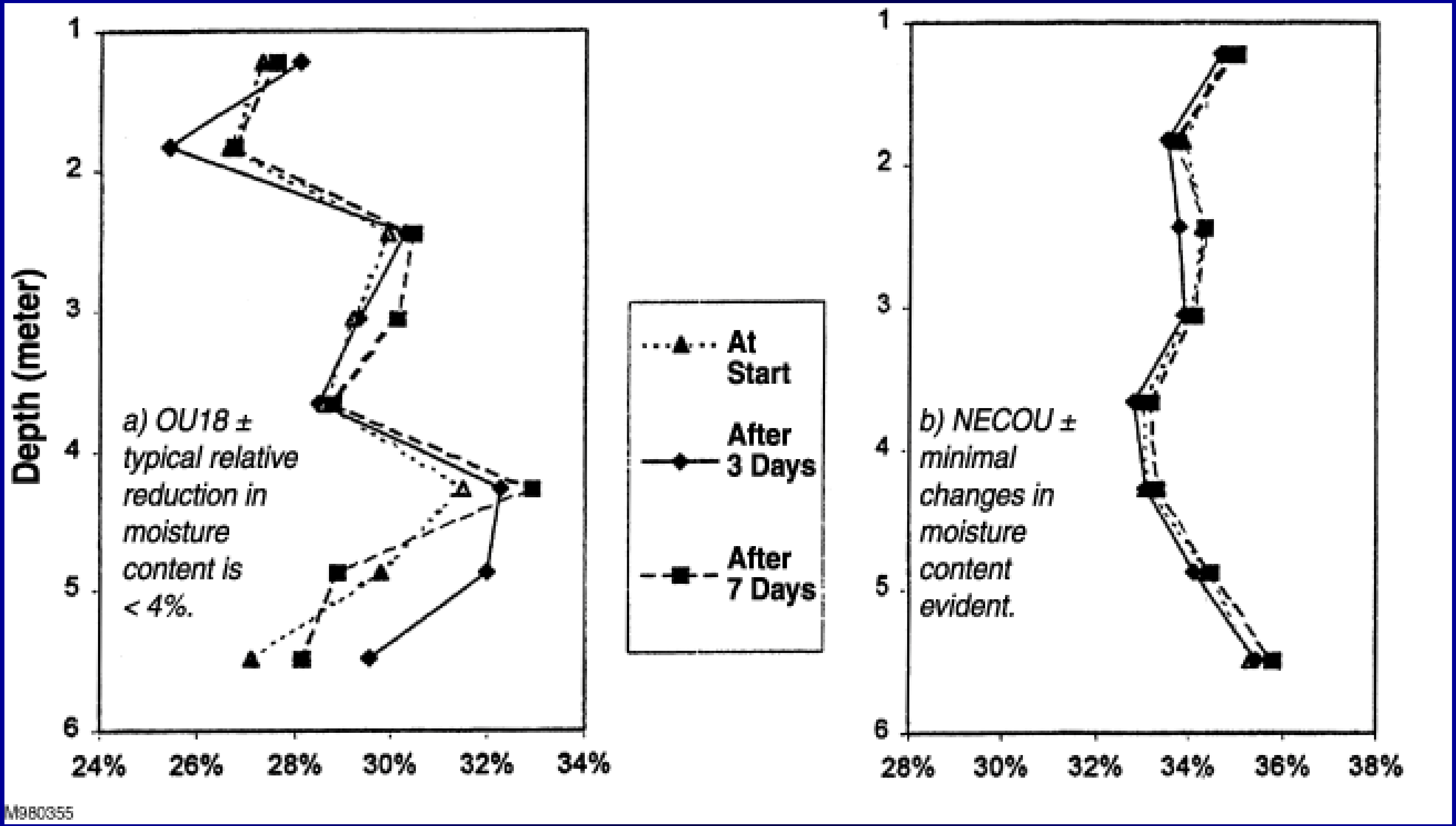
MPE generally chosen for following reasons:

- To enhance the extraction of soil gas to accomplish SVE or bioventing;
- To enhance the recovery of NAPL (i.e., accomplish free product recovery), also known as bioslurping; and/or
- To increase production of ground water from a low-yield aquifer (vacuum dewatering)

Common Limitations Of MPE

- Non-uniform and/or narrow zone of influence
- Inadequate air-contaminant contact
- Causes
  - Subsurface heterogeneity
  - Mass transfer limitation
- Excessive recovery of groundwater (driving up treatment costs)
- Emulsions

Moisture Profiles, Clay-Rich Soils
(Radian International 1997; Baker and Groher 1998)



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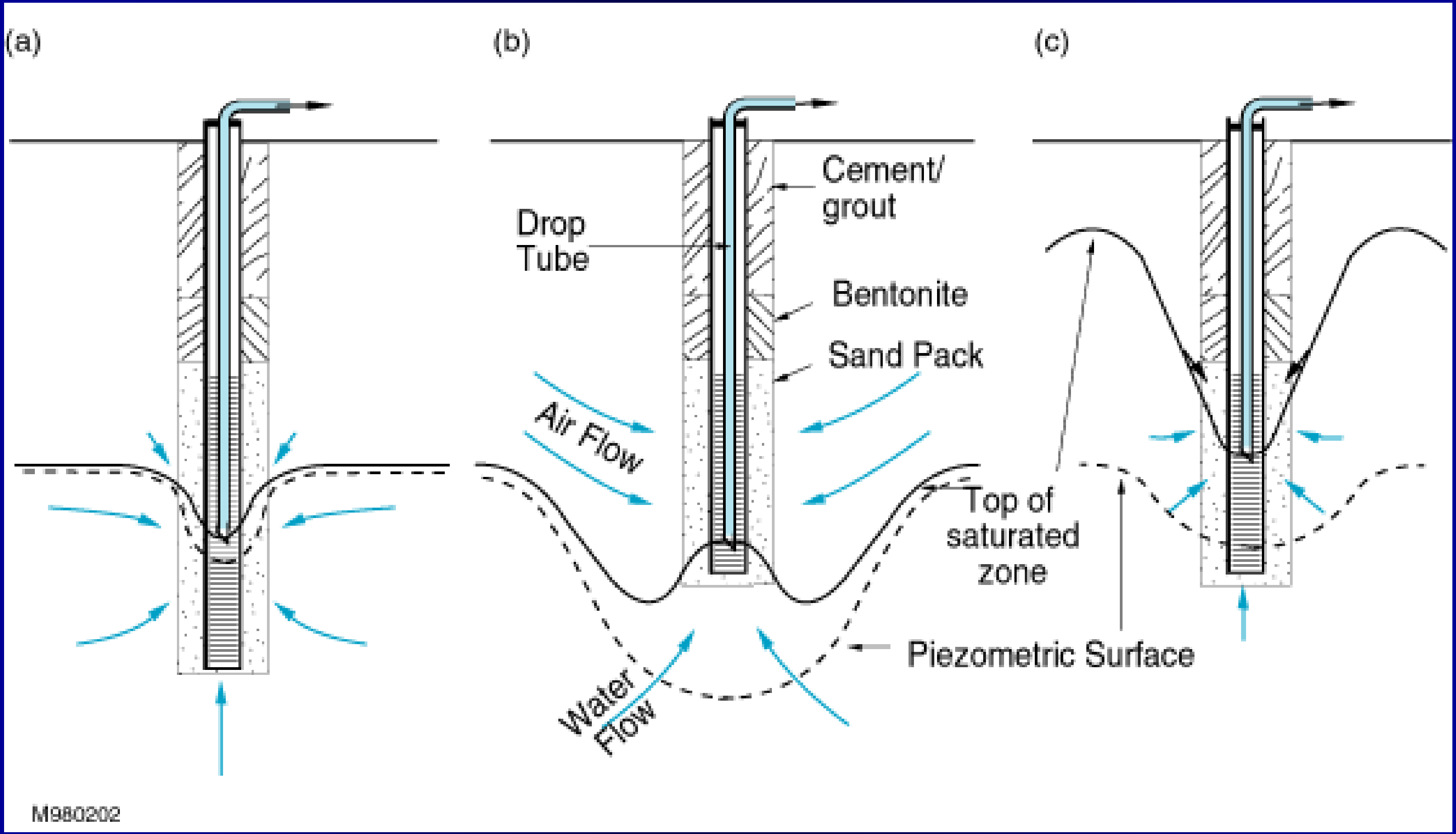
Implications For Technology Effectiveness

- At sites with high permeability soil ($>10^{-3}$ cm/s), TPE wells will tend to be flooded with water, with very little or intermittent airflow, resulting in limited effectiveness
- At low permeability sites ($<10^{-5}$ cm/s), high emergence pressure will limit MPE effectiveness, except within preferential pathways
- MPE is best suited for moderate permeability sites

Hypothetical Scenarios That Can Prevail During MPE. (After Baker and Groher 1998)

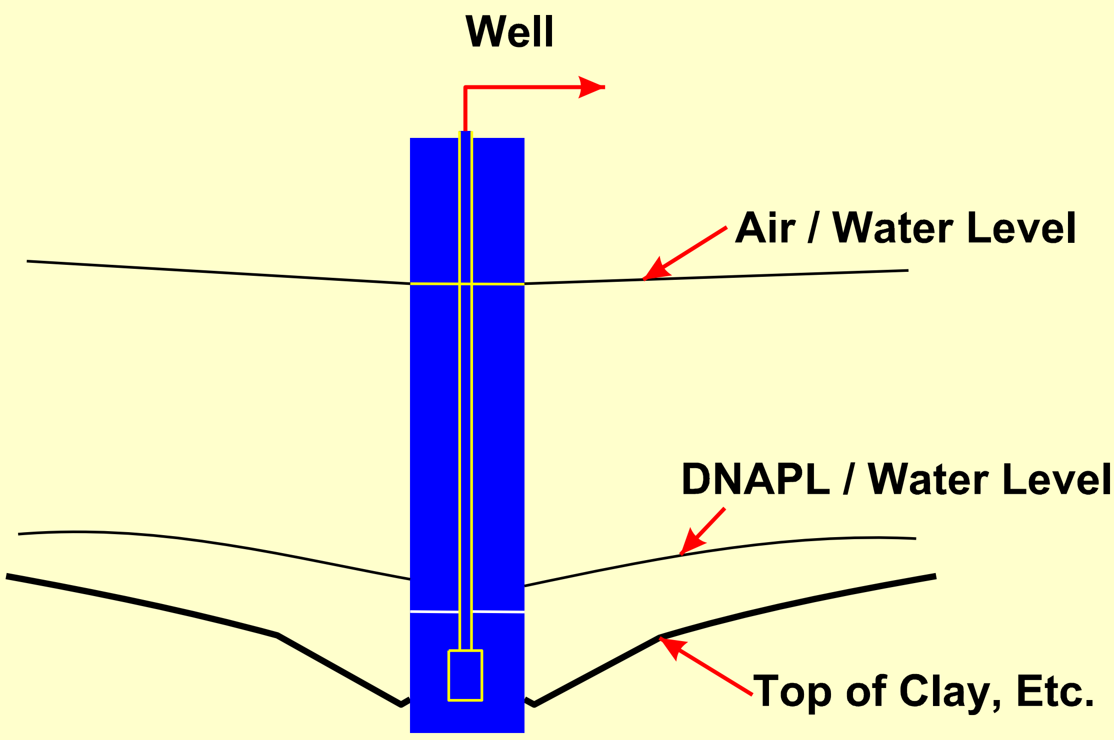


Dense Non-Aqueous Phase Liquid (DNAPL) Recovery

Concepts

- Understand stratigraphy, look for low spots
- Construct well appropriately
  - Screen low
  - Sump
- Pumps - single, dual phase
- Limitations - similar to floating product

DNAPL "Skimmer" Systems



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Design Data Needs

Multi-Phase Extraction

- Water table depth, fluctuations, gradient
- Stratigraphy
- Distribution and nature of contaminants
  - Product saturation
  - Solubility / vapor pressure
  - Location relative to flow
  - Biodegradability
- Hydraulic conductivity
- Ground water geochemistry
- SVE properties, bacteriological nature

Pilot Testing for MPE

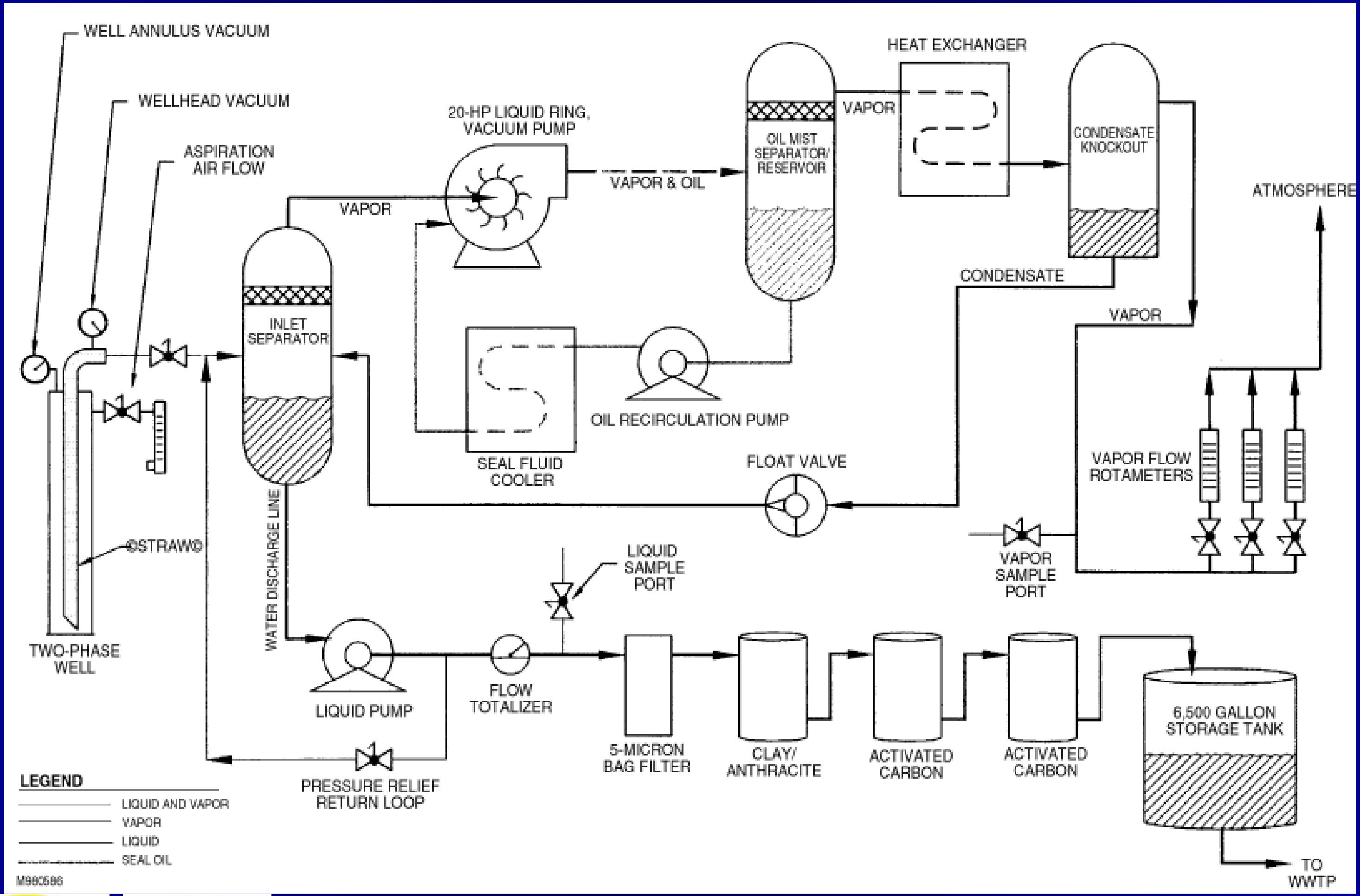
- Purpose:
  - Verify enhanced recovery of immiscible product is possible
  - Verify can aerate soil above new water table
  - Determine vacuum propagation
  - Determine hydraulic properties of saturated zone
- Approach
  - Single well typical, construct as expected for full-scale
  - Temporary air/liquid recovery and treatment equipment
  - Monitoring points around the extraction well

Pilot Test Monitoring

- Above-ground vacuum and fluid flow
- VOC removal, NAPL recovery
- Vacuum influence (unsaturated zone)
- Drawdown and upwelling, hydraulic conductivity
- Monitoring saturation (e.G., Neutron probes)
- Comparisons with air-emergence pressures

Process Flow Diagram Of TPE Pilot Study Equipment

(Radian International 1997)



Air-Based Remediation Technologies

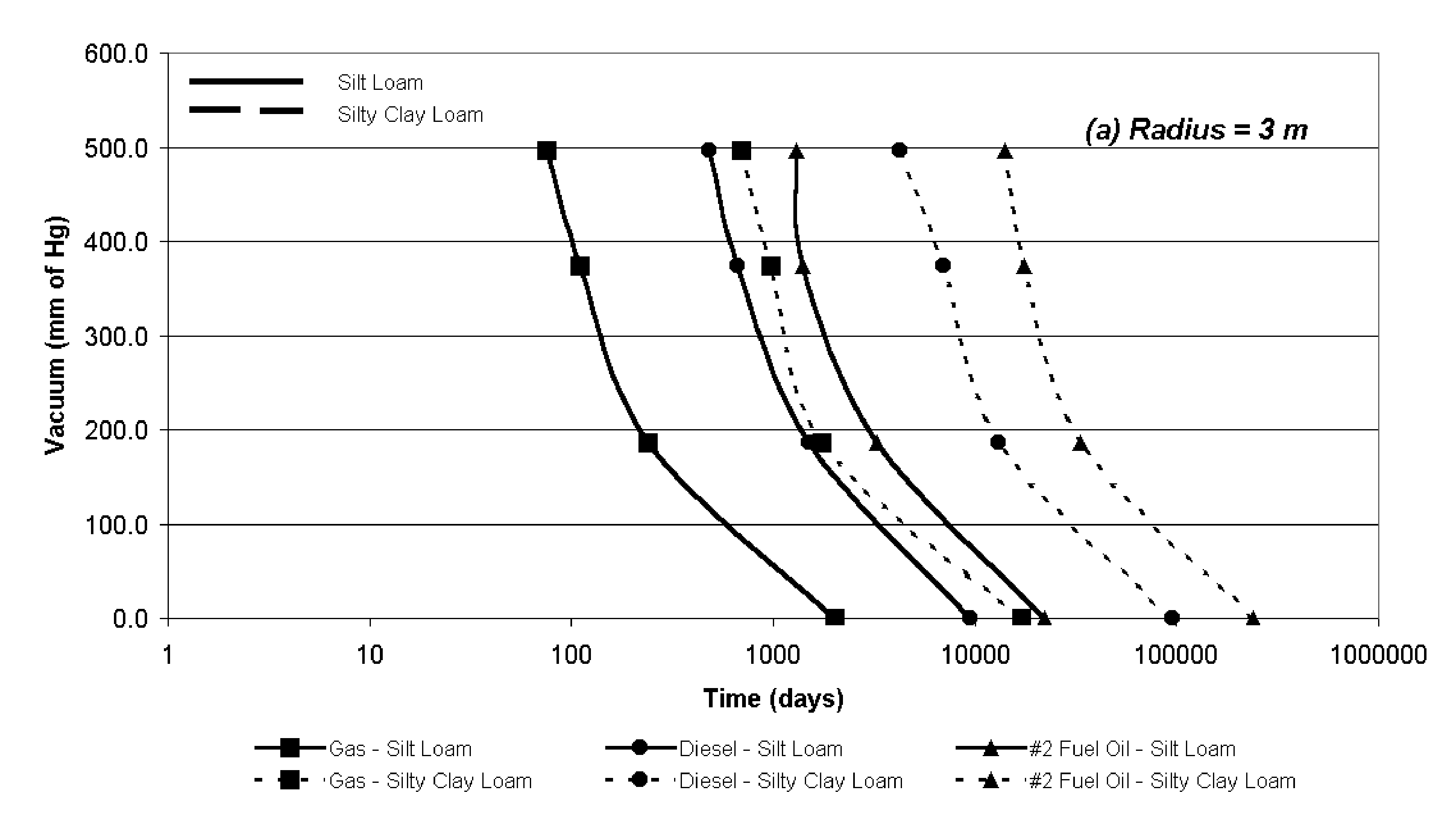
Subsurface Design

- Well placement
  - Cover **<u>3-D</u>** extent with adequate capture in saturated and unsaturated zones
  - Criteria:
    - Achieve adequate gradient to cause modest movement of product toward wells, if product recovery is goal
    - Apply adequate vacuum to aerate cone of depression or improve water recovery
    - Consider lateral variation in permeabilities
  - Modeling very helpful, some useful nomographs in USACE engineer manual on MPE

Subsurface Design, Continued

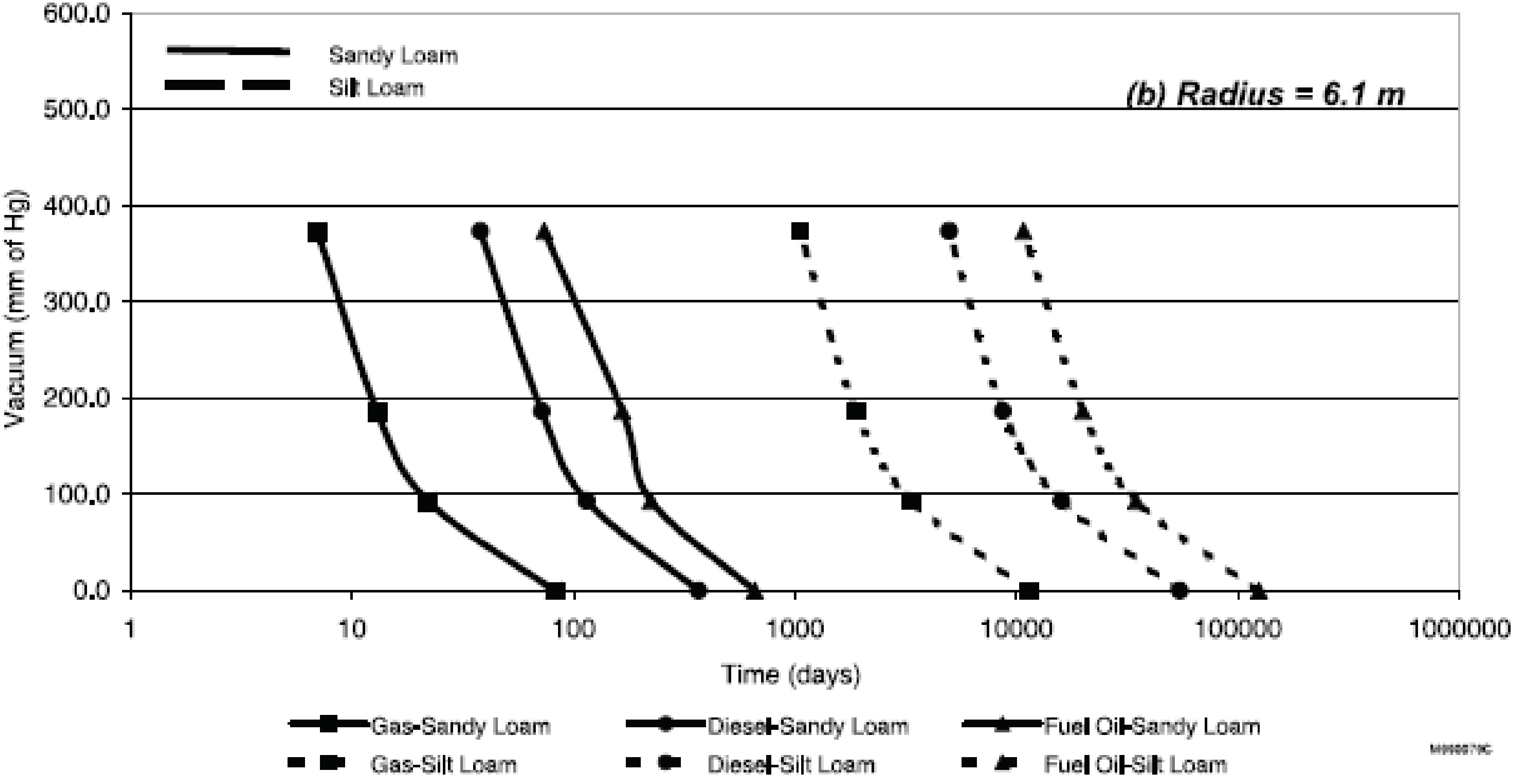
- Airflow design
  - Similar to SVE if goal is to aerate newly dewatered soil
  - Flow generated at adequate vacuum to dewater pores or enhance liquid movement
- Water recovery design
  - Flow at desired drawdown, accounting for applied vacuum (pilot data critical)
- Product recovery
  - Depends on specific location, pilot testing, baildown testing important

Time to 80% Reduction in Product Thickness for Different Soils, 3 m Well Spacing



Air-Based Remediation Technologies

Time to 80% Reduction in Product Thickness for Different Soils, 6.1 m Well Spacing



Subsurface Design

- Well design
  - Drill method: do not use drilling mud if possible, difficult to develop near water table
  - Take careful logs of materials encountered, take samples
  - Diameter: typical 10-cm or larger (at high flows)
  - Materials: typically PVC, need stainless if aggressive NAPL, need special wellhead for applying vacuum
  - Screen: continuous wrap, size slot based on formation,
  - Filter pack: design as for water wells
  - Development important, but take care to preserve product saturation at water table

Subsurface Design, Continued

- Monitoring systems
  - Parameters: pressure/air flow, ground water and soil gas concentrations
  - Permanent probes
    - Both saturated/unsaturated zones
    - Choose representative locations based on geology, contaminants
    - Neutron probe/TDR access holes
  - Flow control valves, pressure gauge at each well
  - Flow measurement device for each wellhead
    - Difficulty in measuring combined flow

Component Design, Continued

- Piping:
  - Similar to SVE, water lines. May need dual wall pipe
  - Can use flexible tubing
  - Need to handle product if applicable
  - Calculate balanced flow for individual piping legs
  - Increased piping losses due to moving liquids and vapor

Component Design

- Blowers/pumps/separators
  - Blower type: often high vacuum, liquid ring, rotary vane or rotary lobe
  - Identify necessary vacuum, have flexibility
  - Liquid pumps: consider cavitation due to vacuum
  - Separation of liquids from vapors, emulsification
  - Safety issues, especially with fuel recovery

MPE System Construction, Start-Up

- Install and test wells to verify conditions before treatment system finished, to allow modification
- Collect baseline data
- Verify construction adequacy (wells, piping, above-ground equipment)
  - Start-up Checklist in EM 1110-1-4010 on MPE
- Start ground water extraction, verify liquid pump controls, if separate liquid pumps
- Start vapor extraction equipment with dilution valves open, gradually close dilution valves
- Verify treatment equipment meeting emission requirements
- Collect subsurface response

Air-Based Remediation Technologies


BIOSLURPER


V3 S/N 141


EX-CELL

Operations

- Balancing system (fluid flows)
- Adjust to changes in water table
  - Change pump depth (skimming, dual extraction, DPE)
  - Adjust drop tube depth (TPE)
  - Adjust applied vacuum and air flow (DPE, TPE)
- Maximize mass recovery (NAPL, vapor, dissolved, bio)
- Additional wells may be needed
  - Extraction wells
  - Passive or active air injection wells
- Well Maintenance (biofouling, solids in well)

Operations, Continued

- Maintain equipment
  - Blowers, pumps, thermal oxidizers
  - Safety, particularly with jet fuel, rotating equipment, hot piping at thermal oxidizer
- Dispose of recovered product
  - Reuse options, energy recovery
- Emulsion issues
- See EM 1110-1-4010 checklists and tables, including:
  - Suggested operational performance checklist
  - Field troubleshooting guide
  - Operational strategy guide

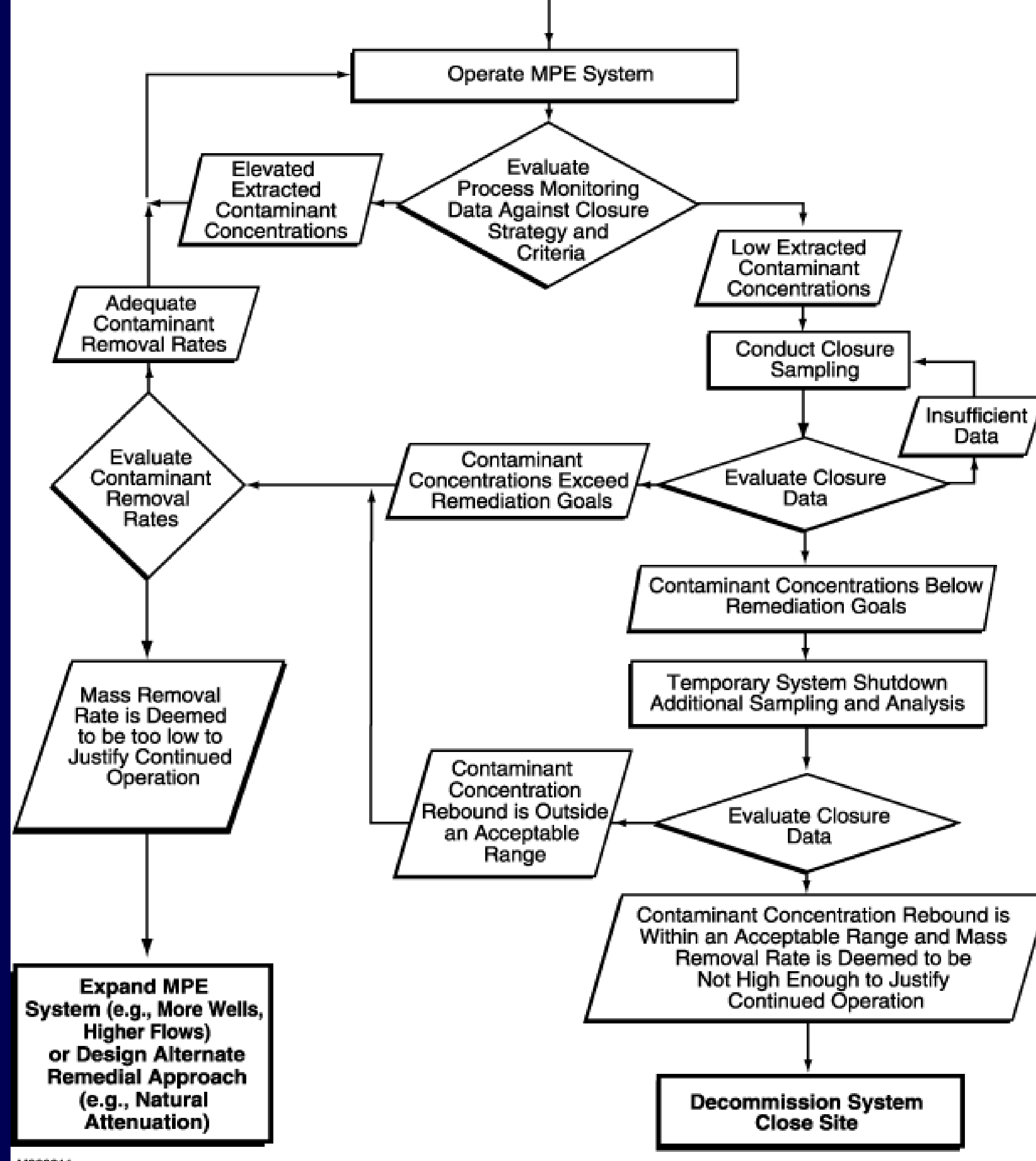
MPE SYSTEM O&M MONITORING

- System monitoring
  - Pressure (P), temperature (T), flow (Q) at various points
  - Extraction wells (P), monitoring wells (P), blower (P, T, Q), flow measurement points (P, T), effluent (T, Q)
- Contaminant monitoring
  - Contaminant concentrations in ground water and effluents, at blower inlet / outlet, each MPE extraction well, and vadose zone monitoring point
  - Thickness and composition change of NAPL
  - Carbon adsorption units
    - Measure concentrations between carbon contactors,
    - Measure humidity

MPE System O&M Monitoring, Continued

- Biological parameters monitoring
  - Respiratory parameters – O_2, CO_2, CH_4
  - Nutrients, pH, ORP, microbial plate counts
- Soil moisture change, ground water elevation, blower amperage, noise level

Optimization Data Evaluation Decision Matrix



Evaluation Process available in EM1110-1-4010

Patent Issues

- Xerox US patent for TPE
  - May be expired
- Other patents? Should verify

MPE Site Closure

- Verification sampling
  - Soil sampling
  - Soil gas sampling
    - Monitoring points (especially in areas of stagnation)
    - Extraction wells
    - Influent monitoring (inadequate basis if sole means of monitoring progress)
    - Require adequate purging
    - Offgassing from ground water
  - Rebound test

Multi-phase & Product Recovery References

- EM 1110-1-4010 Multi-Phase Extraction http://www.environmental.usace.army.mil/sve.htm
- EPA/600/R-96/031 Engineering Design of Free Product Recovery Systems
- EPA/600/R-96/042 In-Situ SVE-Based Systems for Free Product Recovery & Residual Hydrocarbon Removal
- EPA Clu-in Web Site on Multi-Phase Extraction http://www.clu-in.org/techfocus/default.focus/sec/Multi-Phase_Extraction/cat/Guidance/
- DPE and TPE are both Presumptive Remedies for VOCs in soil and groundwater (4/97): See: http://www.epa.gov/oerrpage/superfund/health/conmedia/gwdocs/voc/index.htm or http://www.clu-in.org/download/toolkit/finalapr.pdf
- US Air Force Bioslurping Page (many references) http://www.afcee.af.mil/resources/technologytransfer/programsandinitiatives/bioslurping/index.asp

Multi-Phase Extraction Case Study
Holloman AFB, New Mexico USA

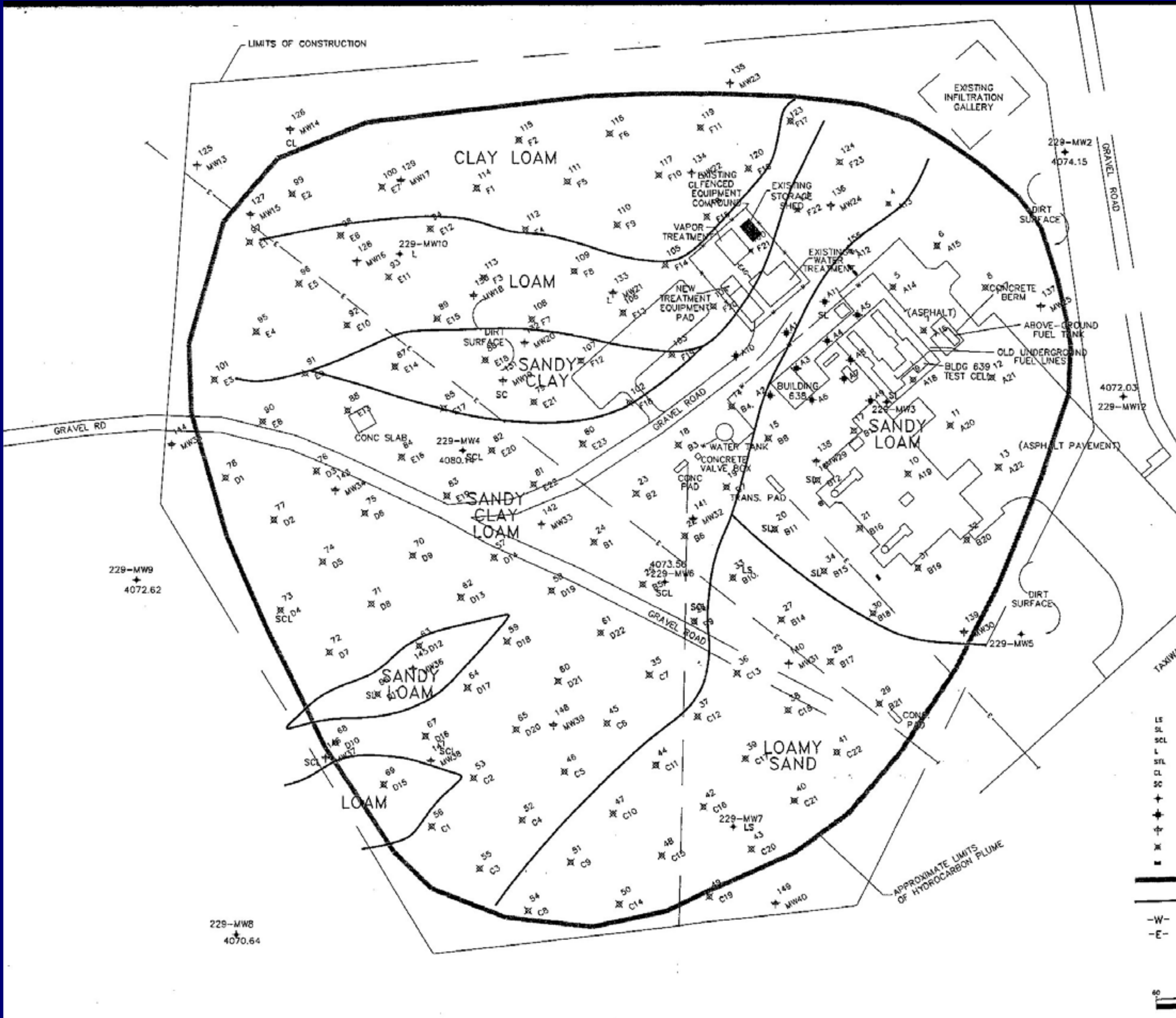
- Engine Testing Facility, leaking piping from storage tank
- Contaminant: Jet Fuel, up to 2 m floating product in wells, estimated 3,800,000 L fuel
- Hydrogeology:
  - Unsaturated, homogeneous silty sand (hydraulic conductivity [K] 0.002 cm/sec)
  - Water table 2-6 m depth
  - Soils near water table layers of sand, silt, clay (K = $3.5x10^{-5}$ cm/sec
  - Deeper soils: sandy silt, silty sand (K = 0.0003 cm/sec)
- Goal – remove immiscible product only

MPE Case Study - Holloman AFB, New Mexico USA, Continued

- Technology applied (full scale remediation)
  - Multi-phase extraction (TPE, 1995-1998), followed by vacuum-enhanced skimming
  - 133 extraction wells, 40-60 wells operated at once
  - Bail-down testing of wells
  - Liquid-ring vacuum pumps
  - Air-liquid, oil-water separation
  - Thermal oxidation for vapors
    - High energy content of extracted vapors
    - Supplemented by burning recovered product
  - Groundwater treatment – original limitation

MPE Case Study, Continued

Wells and Geology



MPE Case Study, Continued

Mass Removal

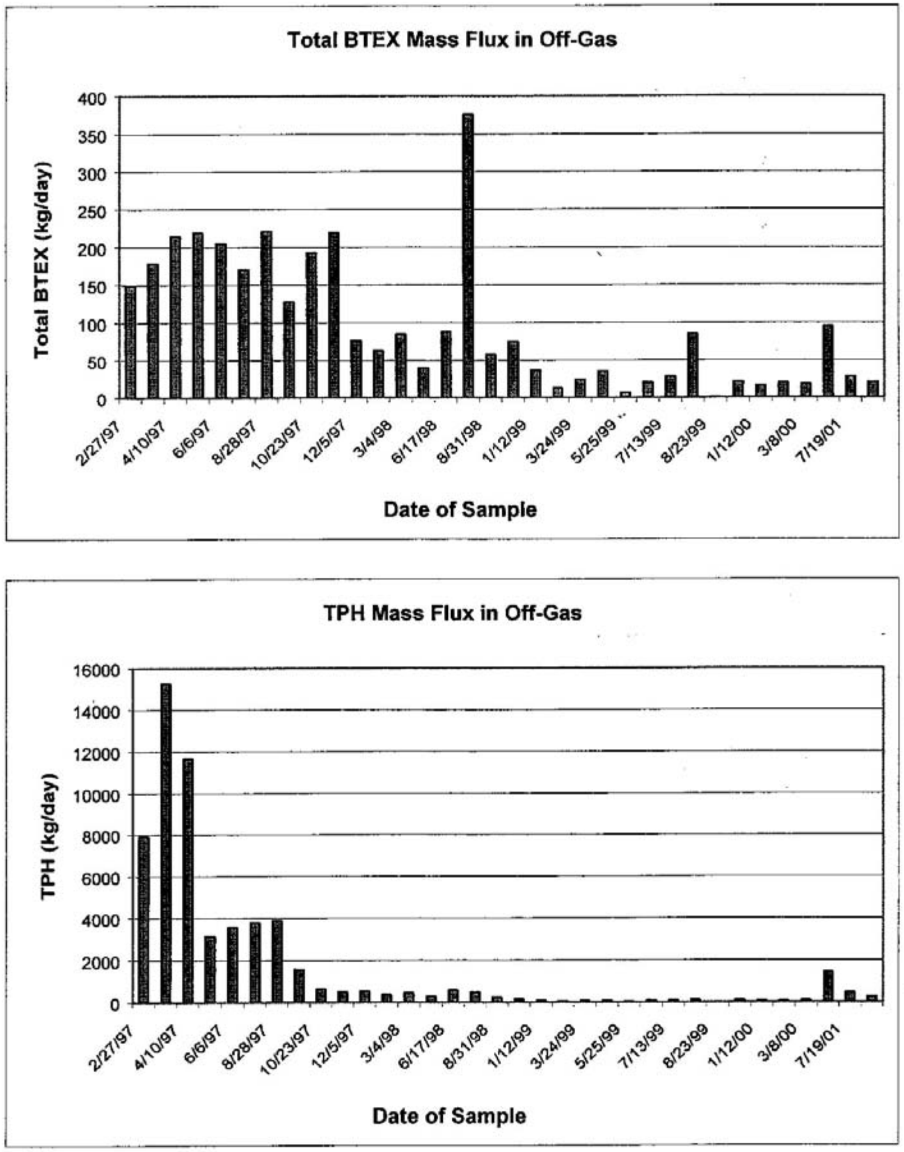


Figure 2-18. Plots of Vapor Mass Fluxes for BTEX and TPH, 1997–2001

MPE Case Study, Product Recovery

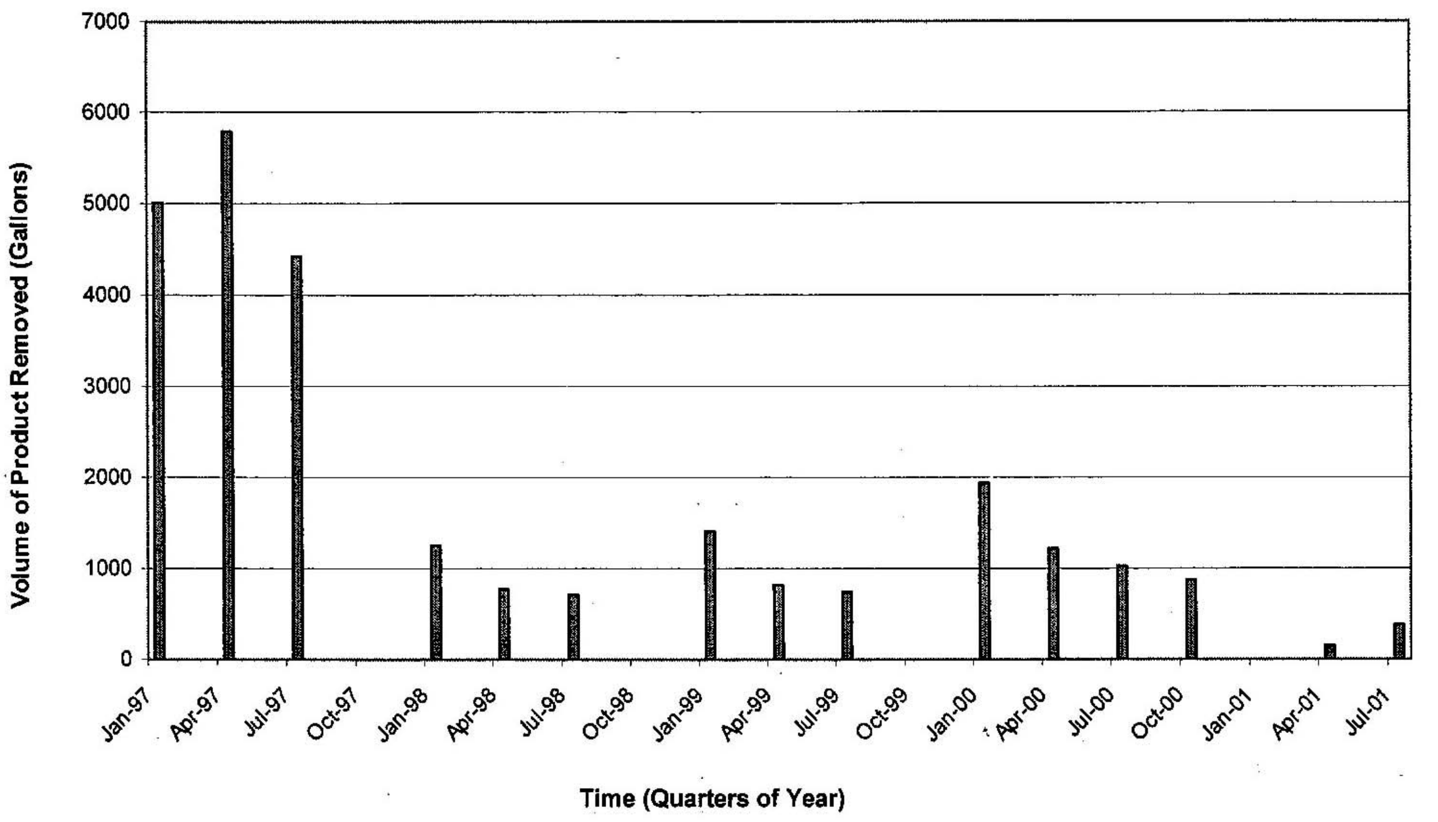


Figure 2-20. Plot of Free Product Yield by Quarters, January 1997 to July 2001

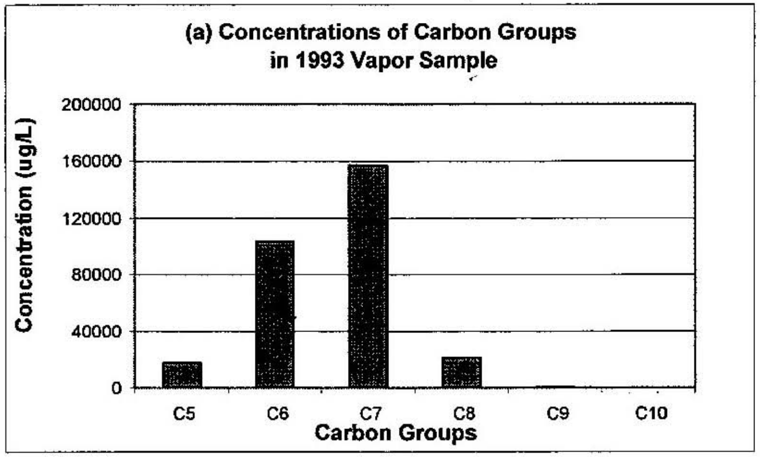
Air-Based Remediation Technologies

MPE Case Study, Continued

Change in Composition Over Time

Observed Concentrations in 1993

Carbon Group	Concentration (ug/L)	Relative Concentration (percent)
C5	17851	8.26
C6	103801	39.52
C7	156952	47.90
C8	21390	4.31
C9	128.90	0.00
C10	0	0.00
Totals	300123	100.00



Observed Concentrations in 2001

Carbon Group	Concentration (ug/L)	Relative Concentration (percent)
C5	226	0.95
C6	1320	5.52
C7	8527	35.67
C8	7827	32.74
C9	3257	13.63
C10	2224	9.31
C11	521	2.18
Totals	23902	100.00

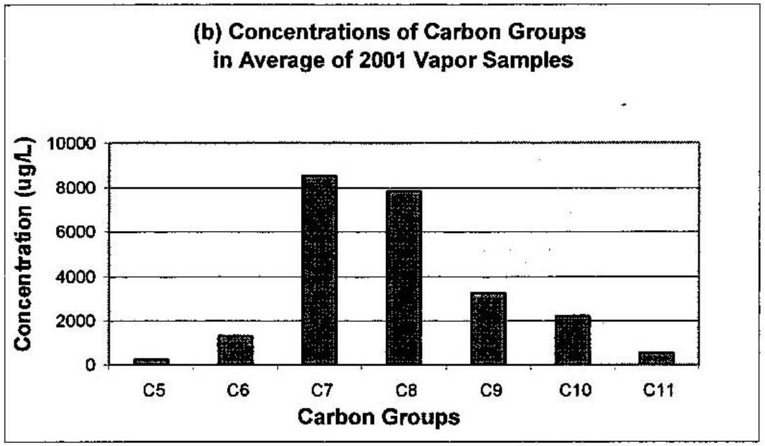


Figure 2-9. Plots of Carbon Group Concentrations in Vapor-Phase Samples of 1993 and 2001

MPE Case Study - Holloman AFB, New Mexico USA, Continued

- Results
  - Over 6 years, recovered only approximately 15% of the product
  - Modeled future recovery
    - Possible to get 70% and achieve goal
    - Long time to attain goal, though
    - MPE necessary to attain goal, skimming not adequate
  - Remediation continues

Summary

- Need to understand distribution of contaminant and moisture
- Product recovery/MPE has specific applicability based on project goals and aquifer properties
- Limitations include:
  - Inadequate contaminant recovery or contact
  - Excessive ground water recovery or emulsions
- MPE EM provides concepts and tools for MPE application