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Bioslurping Implementation and Applications

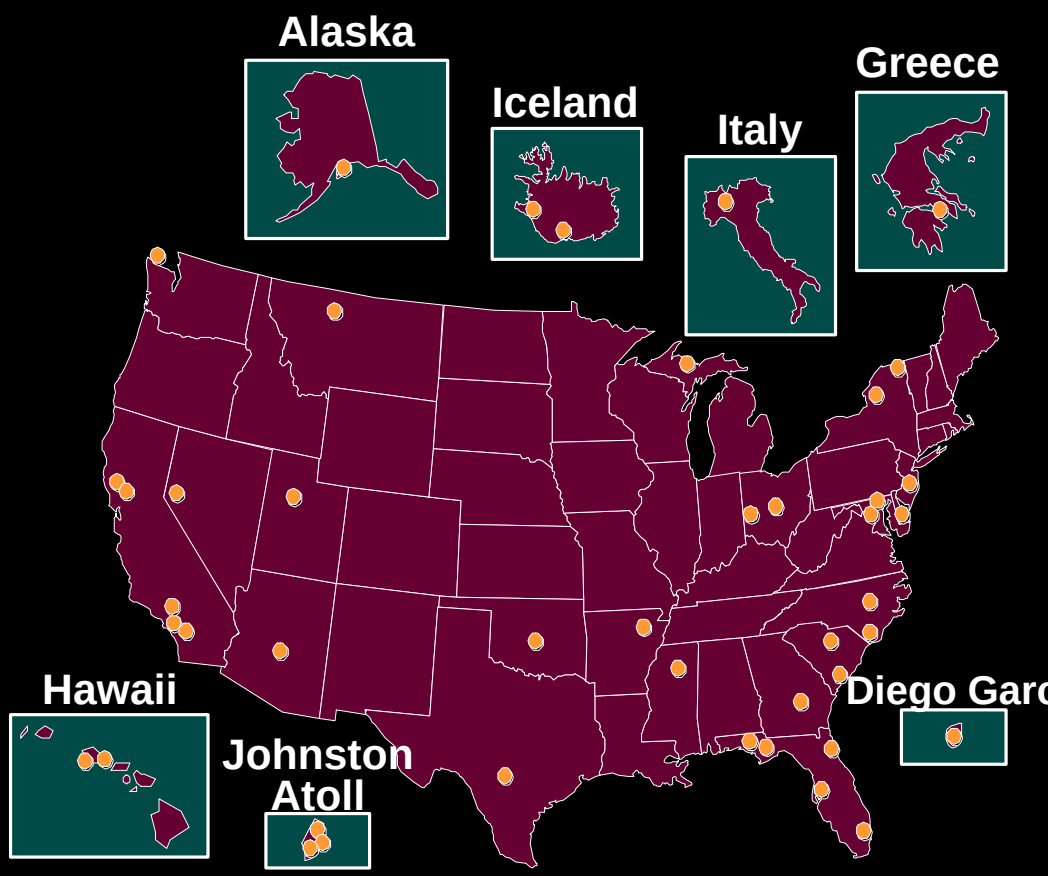
Battelle Memorial Institute

Overview of Presentation

- Pilot-scale testing
- Full-scale design
- Full-scale application
- Operation and maintenance
- Closure
- Questions and answers

Where is Bioslurping Effective?

- Low-permeability silts and clays to highly permeable sands
- Fluctuating water table, including tidal influence
- Apparent thickness of LNAPL from 0.1 foot to > 7 feet
- Groundwater from 3 to > 200 feet bgs
- LNAPL ranging from volatile AVGAS to viscous waste oils
- LNAPL plumes may be continuous or discrete pockets



Locations of Battelle Bioslurping Field Projects

Why Perform a Pilot Test?

- Determine cost-effectiveness of bioslurping at site
- Collect site-specific operational data for full-scale design and permitting
- Identify and overcome site-specific limitations

Pilot Test Trailer at Tyndall AFB, Florida

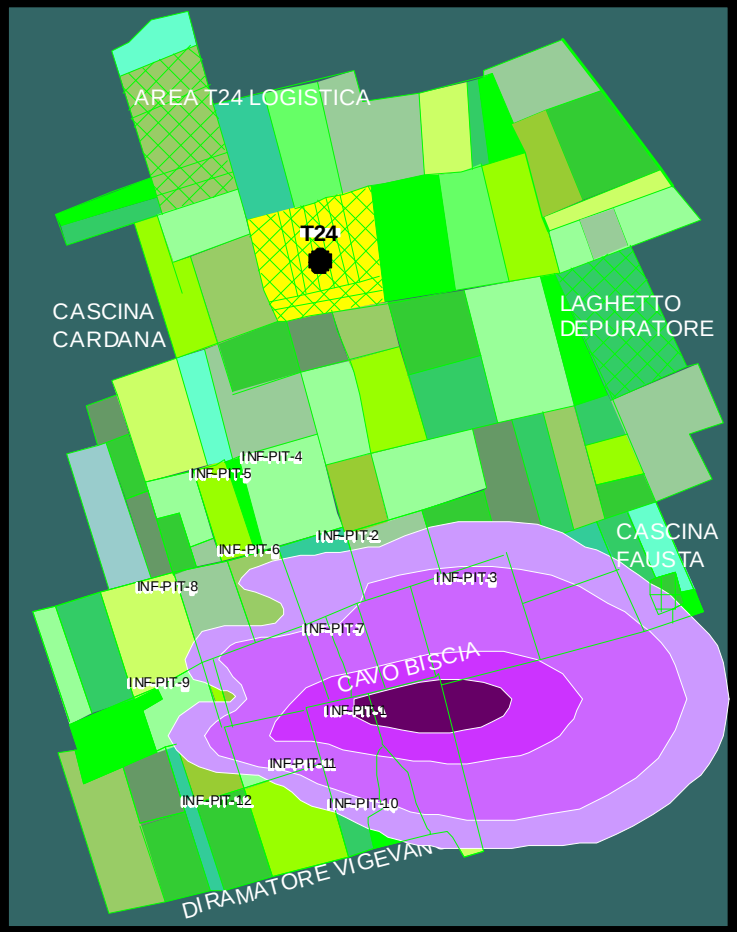
Limitations

- Difficult to apply at remote locations
- Water and off-gas treatment can be cost prohibitive

Oil/Water Separator at Travis AFB, California

Gathering Pilot Test Information

- Site evaluation
  - Soil composition
  - Soil-gas composition
  - Free-product thickness and groundwater table elevation
  - Passive free-product recovery
  - Hydraulic conductivity
- Bioslurping feasibility
- Well spacing
- Hydrocarbon degradation potential



Free-Product Plume Near Trecate, Italy

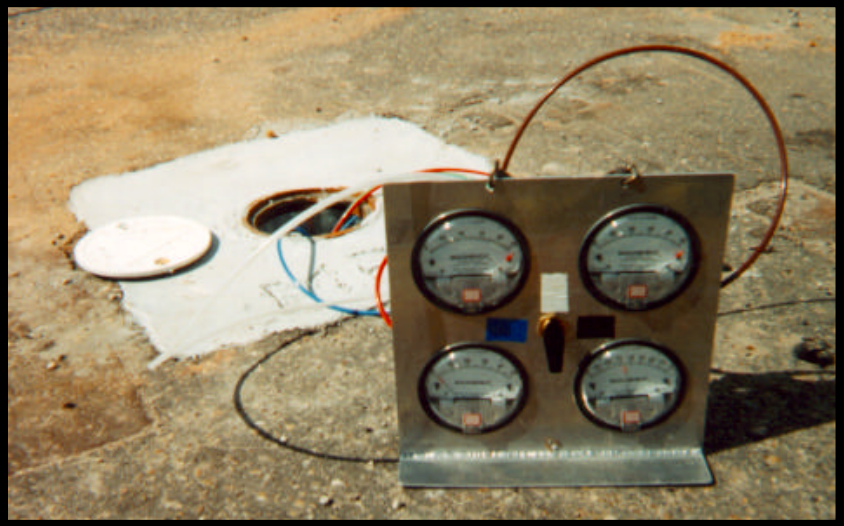
Gathering Pilot Test Information

- Site evaluation
- Bioslurping feasibility
  - Free-product recovery
  - Soil-gas composition and flowrate
  - Process-water composition and flowrate
  - Ability to aerate surrounding soils
- Well spacing
- Hydrocarbon degradation potential

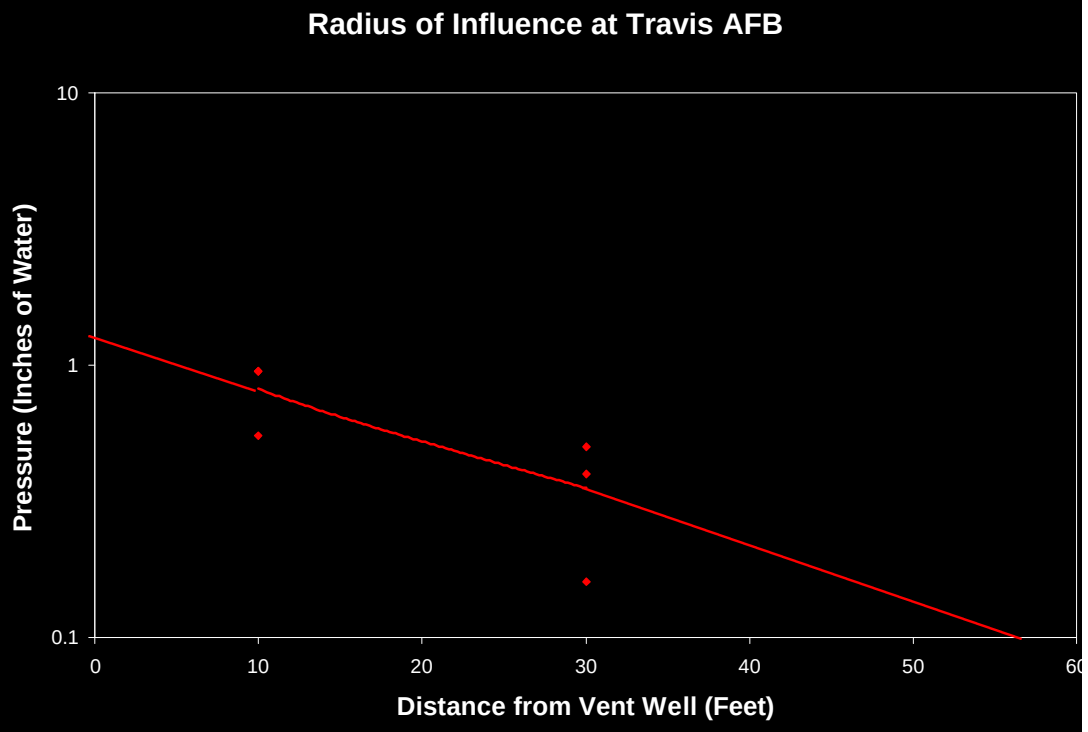
Bioslurper Pump Test

Gathering Pilot Test Information

- Site evaluation
- Bioslurping feasibility
- Well spacing
- Hydrocarbon degradation potential

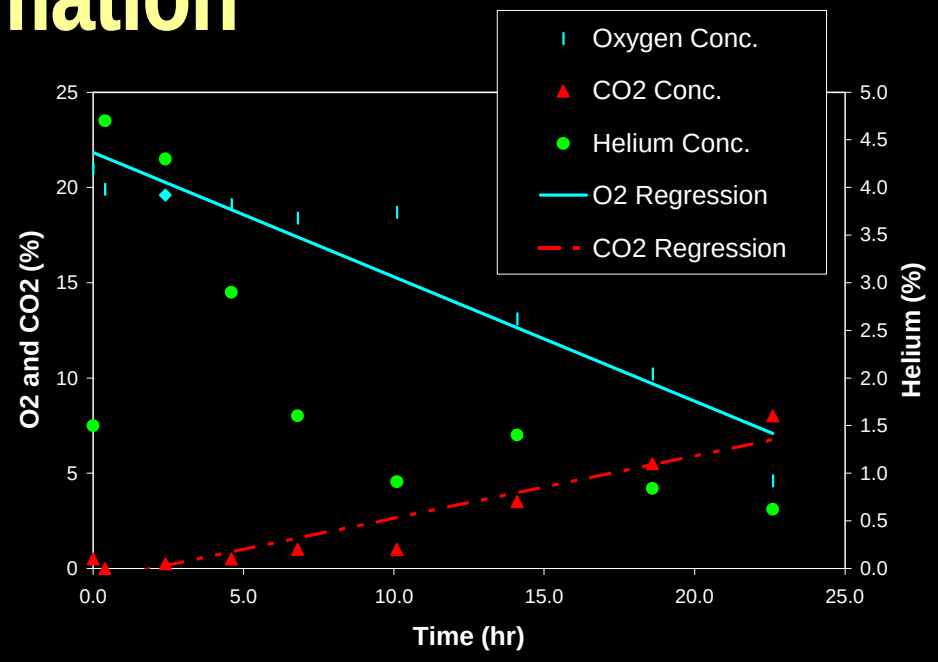


Soil Permeability Test Equipment



Gathering Pilot Test Information

- Site evaluation
- Bioslurping feasibility
- Well spacing
- Hydrocarbon degradation potential



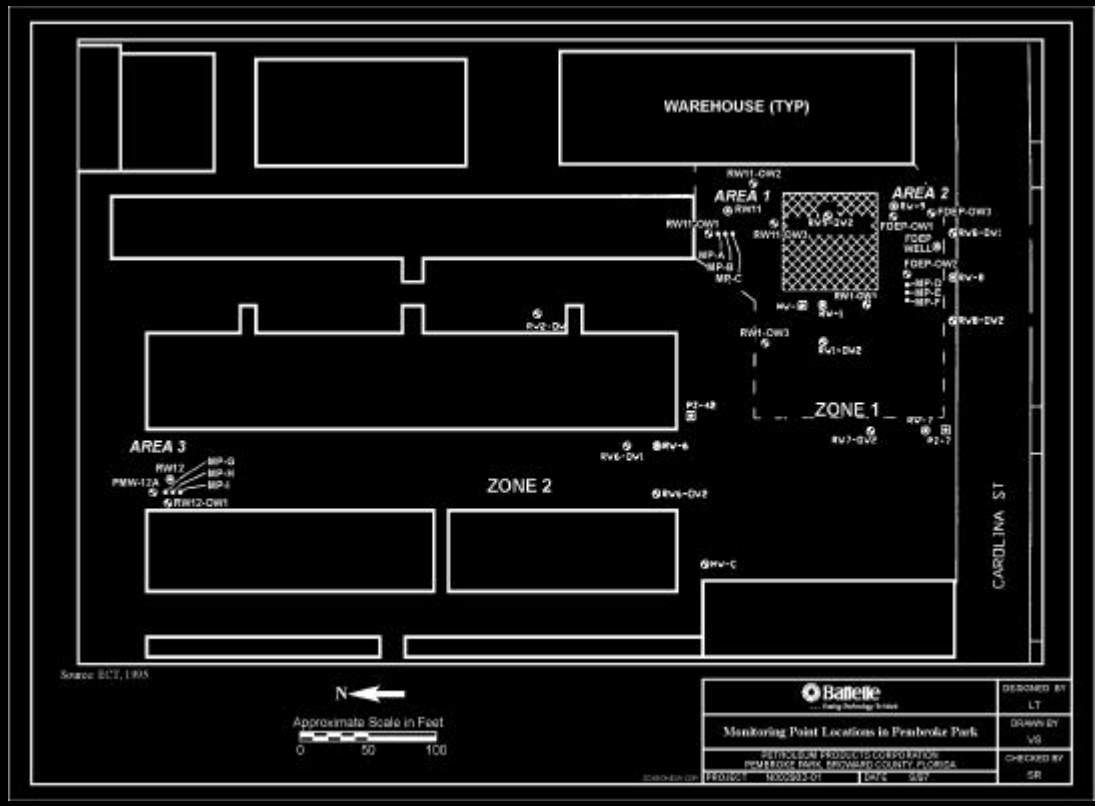
Respiration Test Data fro
Plattsburgh AFB, New Yo

Respiration Test in Progress

Pilot Test Implementation
PPC Superfund Site, Pembroke Park, Florida

Step 1 - Define Remedial Objectives

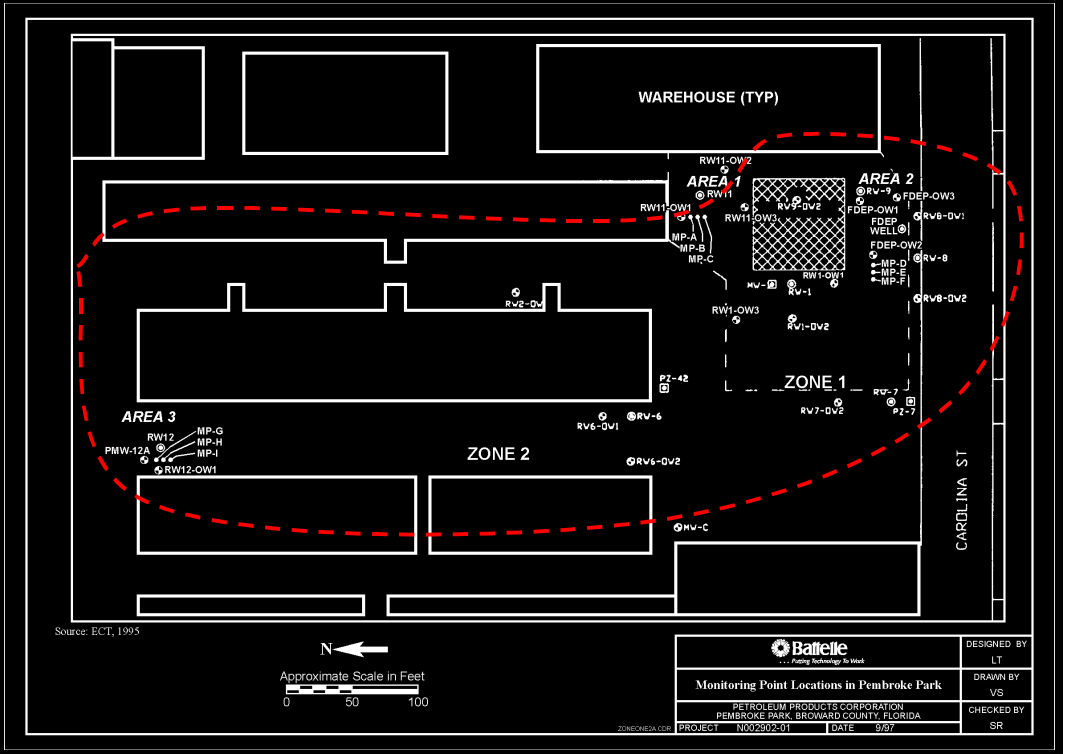
- Demonstrate recovery of high-viscosity LNAPL
- Demonstrate enhanced biodegradation
- Demonstrate that bioslurping can recover more LNAPL than existing treatment system



Pilot Test Implementation
PPC Superfund Site, Pembroke Park, Florida

Step 2 - Review Site-Specific Characterization Data

- Heavy viscous waste oil
- LNAPL plume about 6 acres
- Soil consists of dense, mixed-grain sand
- Groundwater table ranges from 4 to 10 feet bgs
- Acidic soils in some areas



Pilot Test Implementation
PPC Superfund Site, Pembroke Park, Florida

Step 3 - Identify and Perform Test Activities

- Short-term bioslurper pump test in 3 areas
- Oil/water interface and drawdown pump tests (vacuum-enhanced)
- LNAPL viscosity and density measurements
- Radius-of-influence test
- In situ respiration test
- Moisture content, pH, and total number of heterotrophs in soil

Bioslurper Extraction Well at
PPC Superfund Site, Pembroke Park, Florida

Pilot Test Implementation
PPC Superfund Site, Pembroke Park, Florida

Step 4 - Compile and Evaluate Results

	Average LNAPL Recovery Rate gal/day		Kinematic Viscosity cPs	Density g/cm^3	Biodegradation Rate mg/kg-day
	Oil/Water Interface	Drawdown			
Area 1	1.9	4.4	780	0.95	14.5 - 46.6
Area 2	7.3	4.9	51.3	0.89	6.23 - 12.4
Area 3	---	9.8	127	0.89	---

Pilot Test Implementation
PPC Superfund Site, Pembroke Park, Florida

Step 5 - Determine Applicability for Full-Scale Remediation

Conclusions

- Bioslurping effectively recovered free product in all three areas
- Bioslurping effectively removed VOCs and enhanced biodegradation of organic contaminants

Recommendations

- Delineate leading edges of plume
- Collect additional soil pH and heterotroph data
- Design and install a full-scale bioslurper system

Data Variability

Fuel Type	Gasoline, JP-4, JP-5, AVGAS, Diesel, Waste Oil, Heating Oil
Depth to Groundwater (ft)	5.7 to 210
Fuel Recovery Rate (gal/day)	0 to 91
Process Water Flowrate (gal/day)	40 to 5,000
TPH Loading in Process Water (lb/day)	0 to 48
Off-Gas Flowrate (scfm)	3.2 to 78
TPH Loading in Off-Gas (lb/day)	0 to 980
Biodegradation Rate (mg/kg-day)	0.021 to 122
Radius of Influence (ft)	12 to 130

Design

- Flexible
- Site-specific
- Cost-effective

Full-Scale Bioslurper System
at MCBH Kaneohe Bay, Hawaii

Full-Scale Bioslurper System at NS Mayport, Florida

Caution

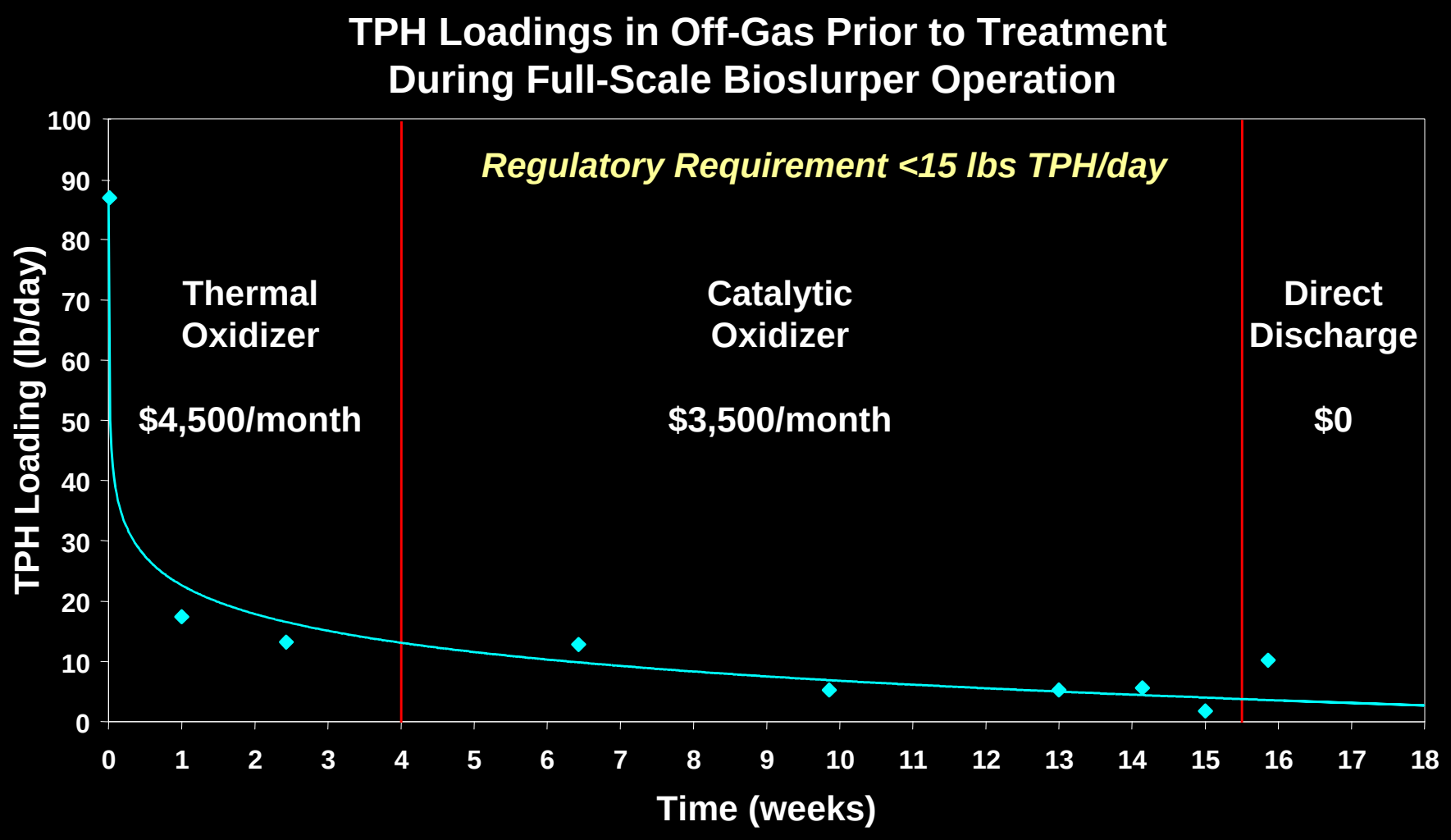
Don’t over-design!!

Life Cycle Design

- Investigate leasing vs. purchasing equipment
- Design for expected duration of LNAPL recovery
- Design for average — not maximum — fluid recoveries/contaminant loadings
- Use inexpensive construction materials

Note: The design is not finalized at system installation and startup; it continuously evolves throughout remediation

Hydrocarbon Loading in Off-Gas at CSS Panama City, Florida



Full-Scale Design Steps

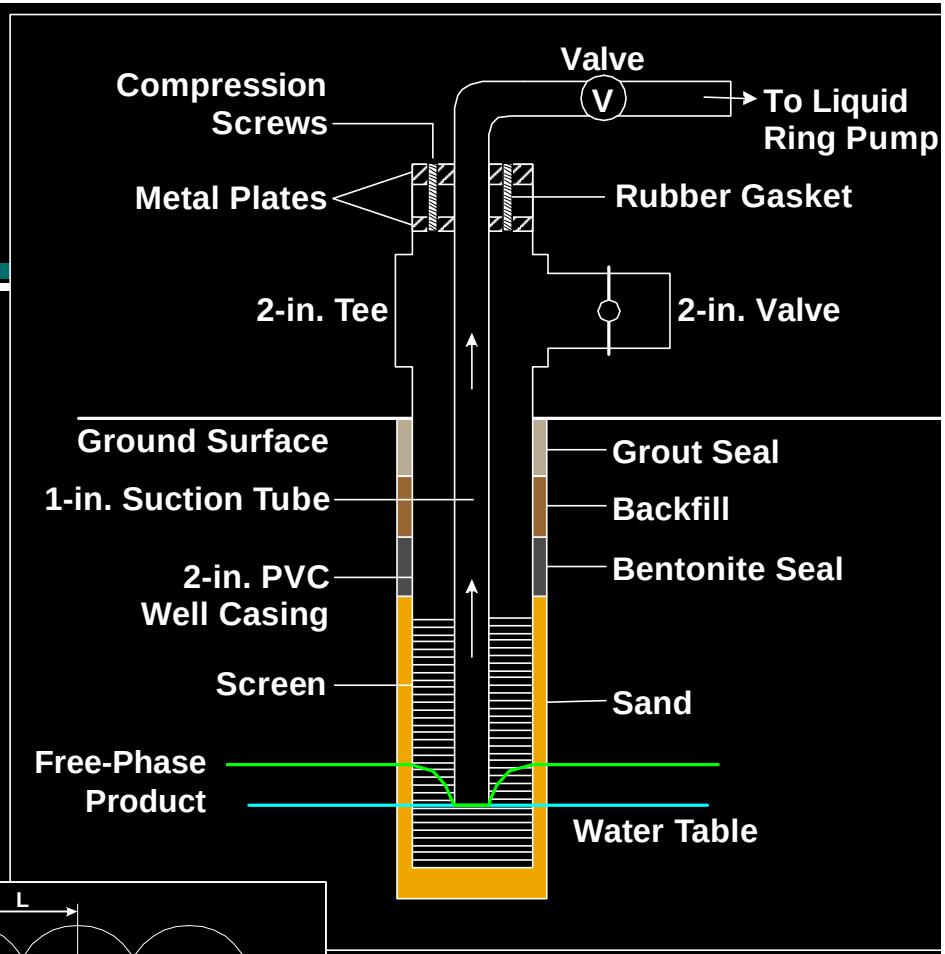
- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment

SCAPS System

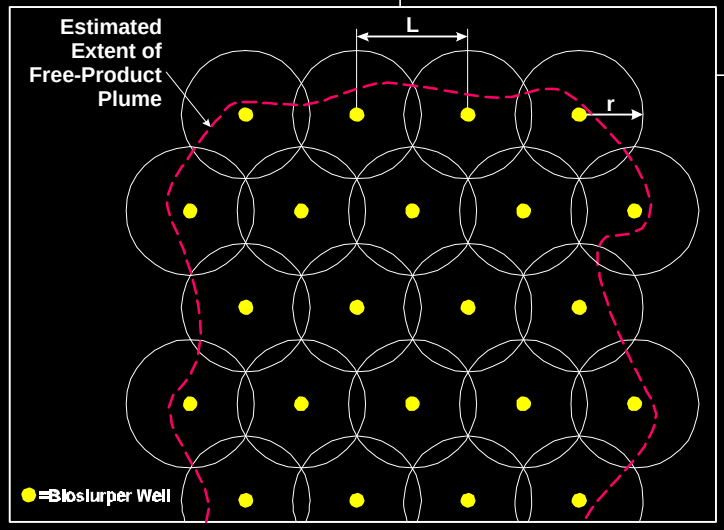
LNAPL Plume at NS Mayport

Full-Scale Design Steps

- Define LNAPL plume
- Design extraction wells
  - Spacing
  - Construction
  - Aboveground/subsurface completion
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment



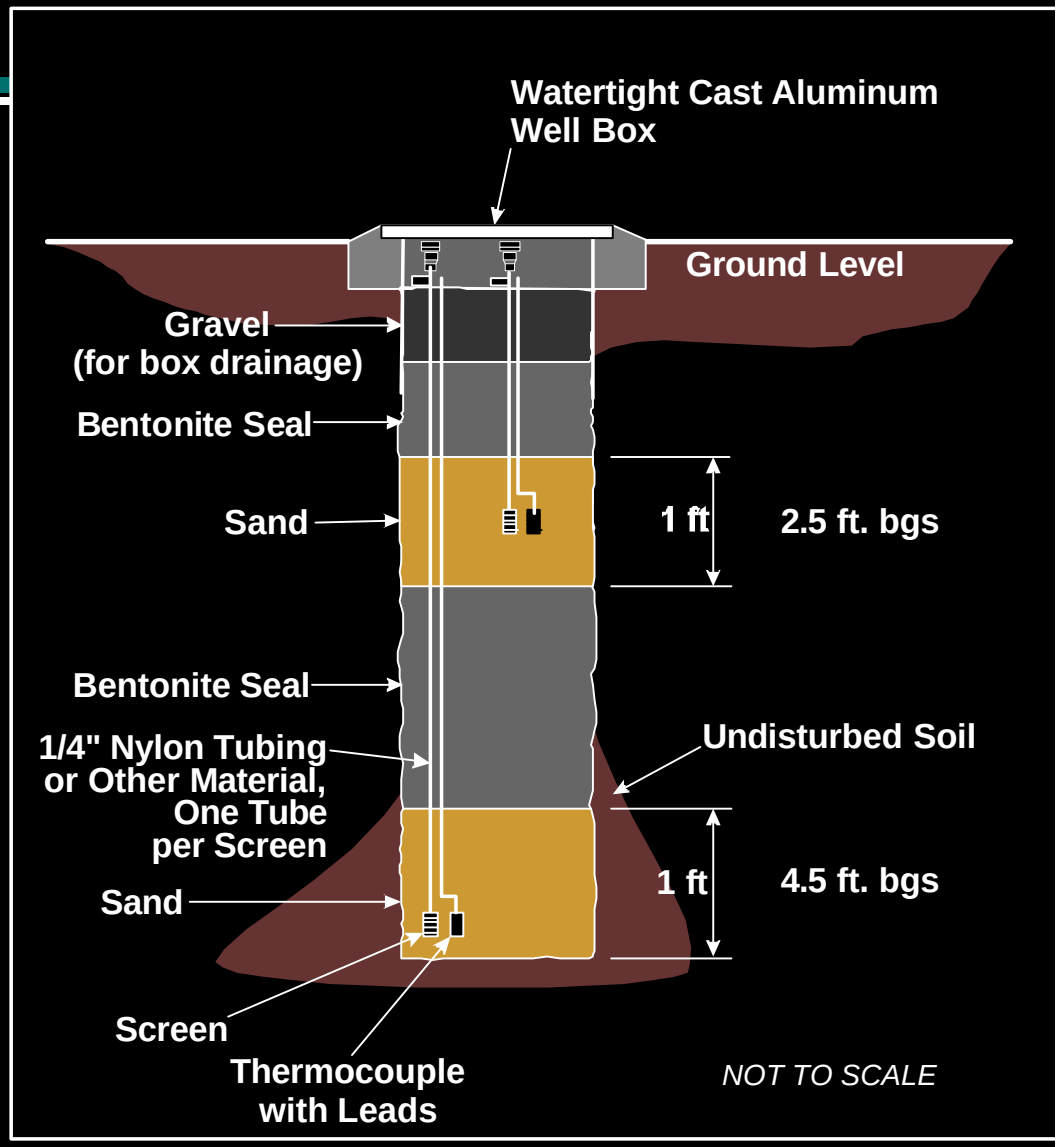
Typical Extraction Well



Well Spacing Concept

Full-Scale Design Steps

- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment



Typical Soil-Gas Monitoring Point

Full-Scale Design Steps

- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment

Manifold Header and Valves at NS Mayport

- 5-acre site
- 2 bioslurper systems
- 54 wells
- Subsurface manifold

Extraction Manifold at Höfn, Iceland

- 0.25-acre site
- 10 wells
- Aboveground manifo

Full-Scale Design Steps

Rule of Thumb:
♋ to ♌ hp per extraction well

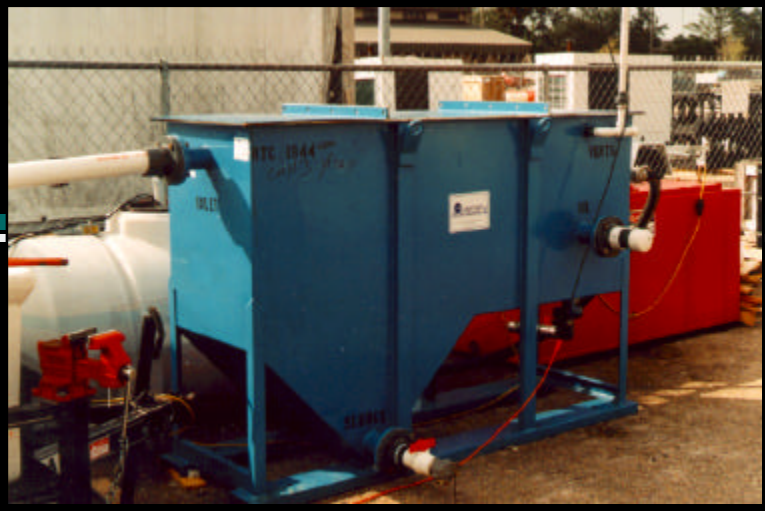
- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
  - Estimate fluid flowrates
  - Use pump performance curves
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment

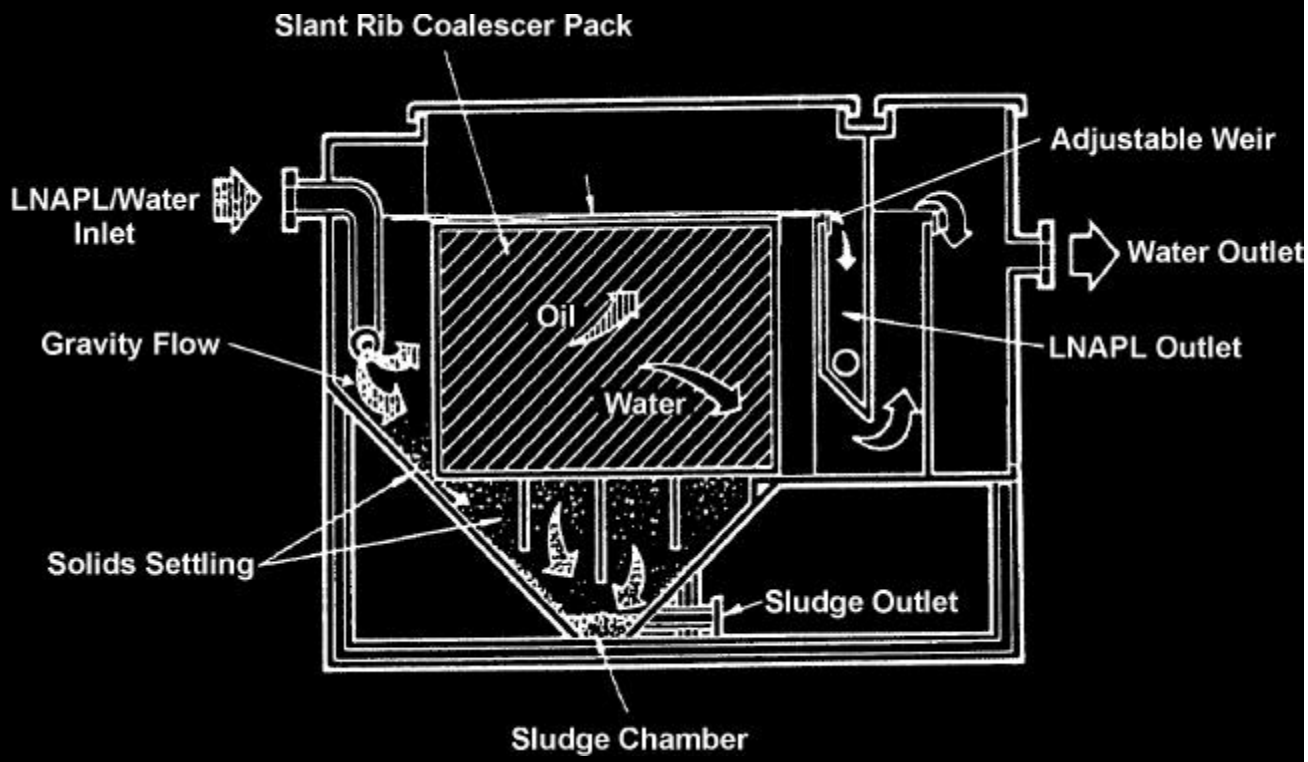
15-hp Liquid Ring Pump

Full-Scale Design Steps

- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment

Oil/Water Separator Used at CSS Panama City, Florida





Slant Rib Coalescing Separator

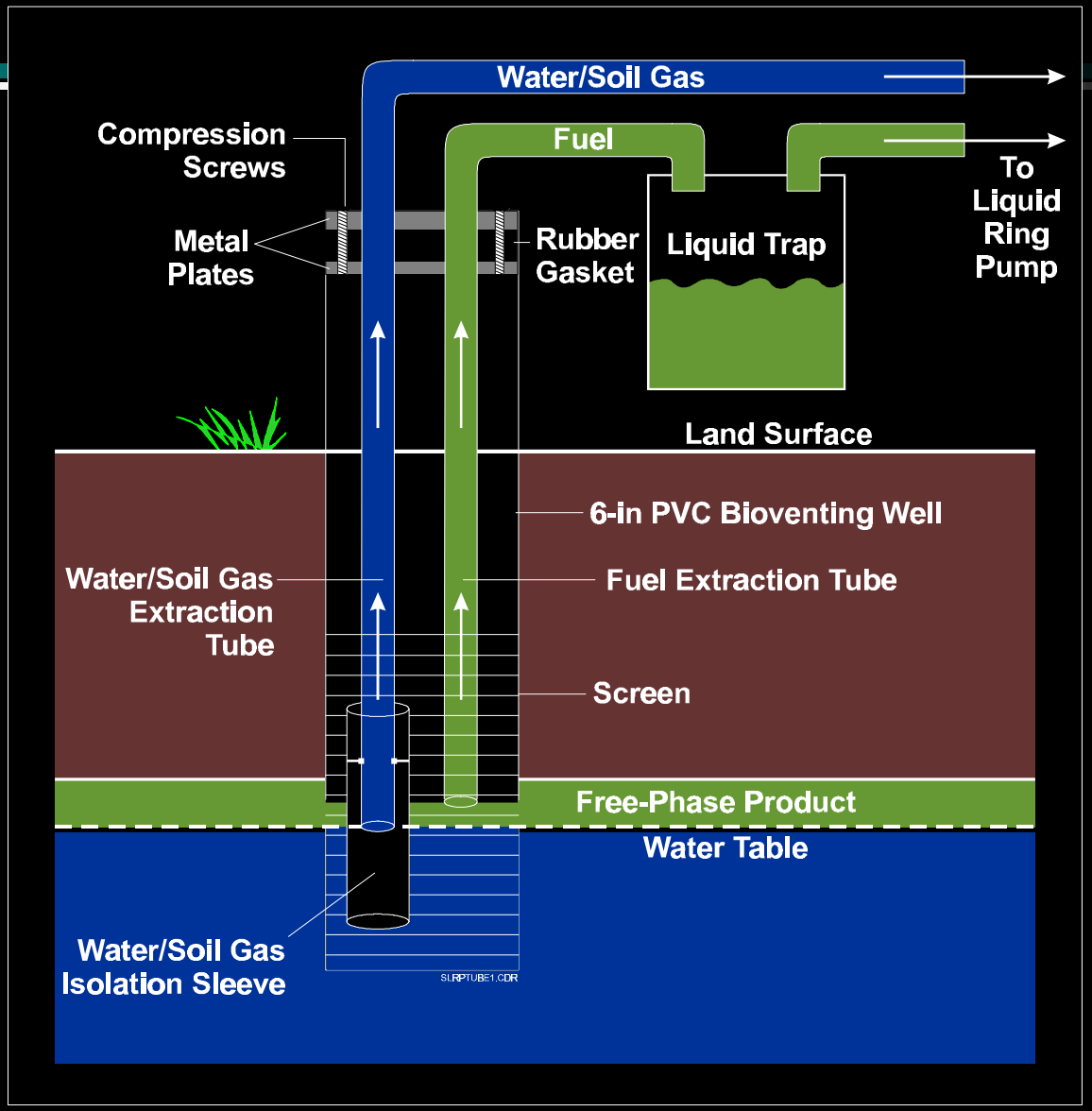
Full-Scale Design Steps

- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
  - Chemical treatment combined with DAF
  - Hydrophobic clay
  - Separation tanks
  - Air stripping
  - Carbon adsorption
- Select off-gas treatment equipment

CRF/DAF System at CSS Panama City, Florida

In-Well Oil/Water Separation

- Reduces degree of oil/water emulsion
- May reduce hydrocarbon concentrations in off-gas
- Inexpensive to implement



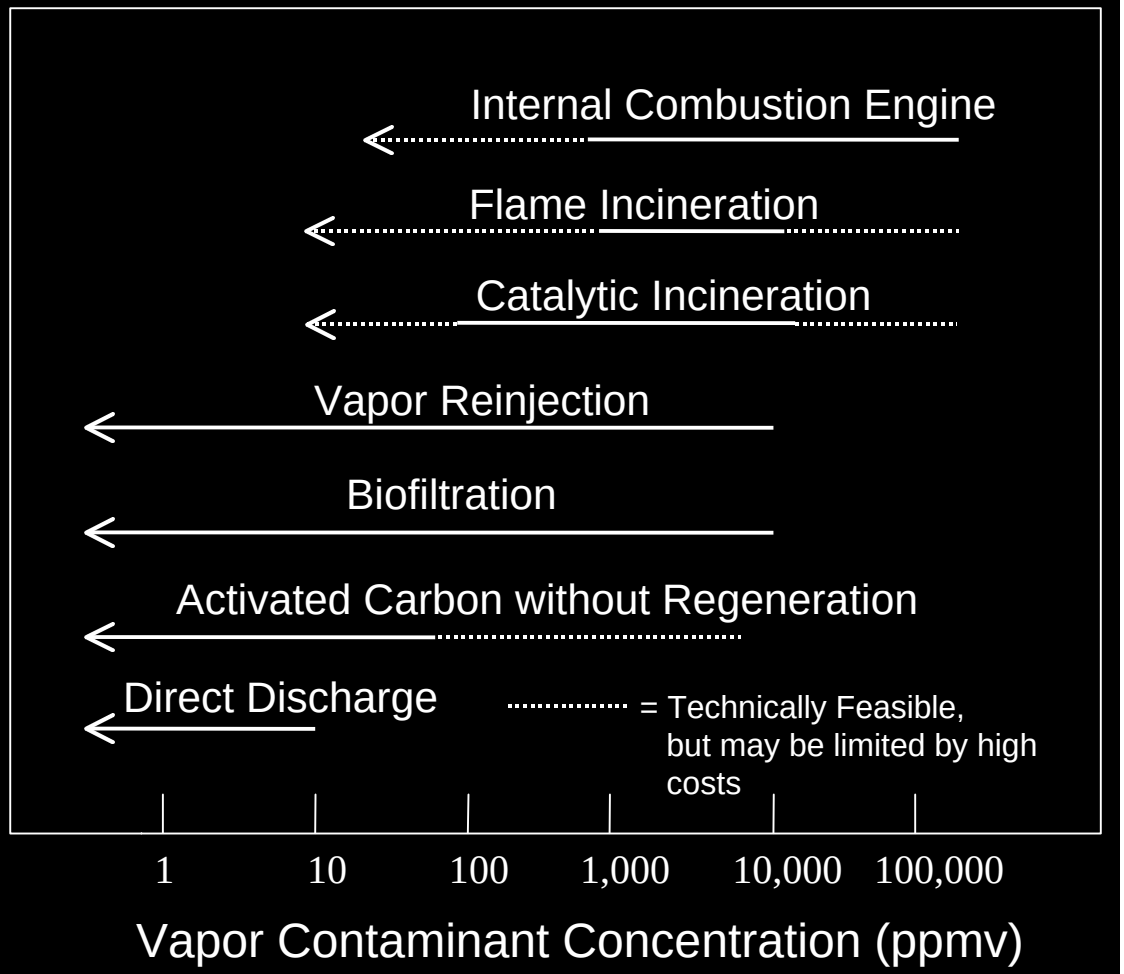
In-Well Oil/Water Separation — Results

Site		Hydrocarbon Concentrations (ppm)	
	Bioslurper Mode of Operation	OWS Discharge Water	Stack Gas
CSS Panama City, FL	Normal	220	NA
	In-Well Separation	22	NA
NAS Fallon, NV	Normal	1,800	3,200
	In-Well Separation	7.5	900

NA - Not available

Off-Gas Treatment Choices

- Define LNAPL plume
- Design extraction wells
- Design monitoring points
- Design extraction manifold
- Select quantity and size of liquid ring pump(s)
- Select oil/water separator
- Select aqueous treatment equipment
- Select off-gas treatment equipment



Other Design Considerations

- Cold weather applications
- Severe tidal fluctuations
- Remote monitoring
- Scale buildup in process equipment

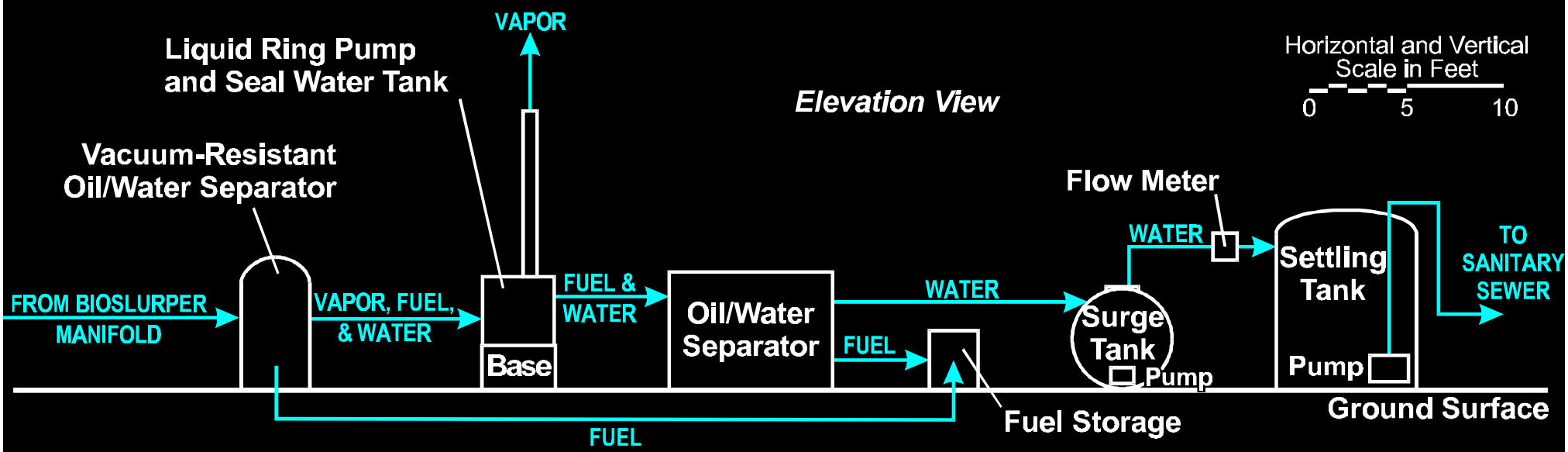
Scale Buildup in Liquid Ring Pump

Full-Scale Implementation
Naval Air Station Fallon, Nevada

- 1-acre site
- JP-5 jet fuel contamination from aboveground storage tanks
- Loose sand to approximately 5 ft bgs, then alternating layers of clay and sandy/silty soil
- Groundwater table approximately 9 ft bgs
- LNAPL present with apparent thickness up to 2 ft

Full-Scale Application
Site 2, NAS Fallon, Nevada

- 48 extraction wells installed with a 30' by 30' grid spacing
- Process water discharged to sanitary sewer
- Off-gas discharged to atmosphere



Full-Scale Application
Site 2, NAS Fallon, Nevada

Recovery Results:

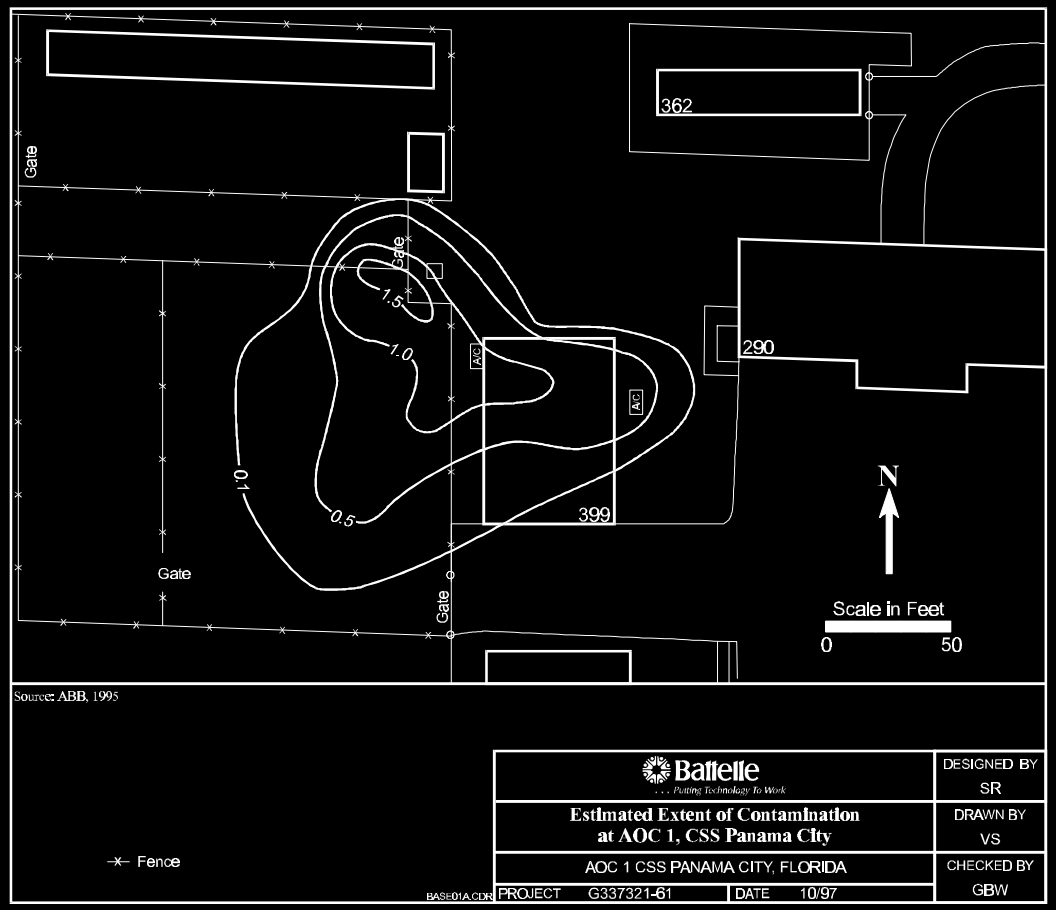
- 1,000 operating days
- 15,600 gallons of LNAPL recovered
- 1,090,000 gallons of water extracted

Capital Cost: $54,000

Operating Cost: $1,400/month

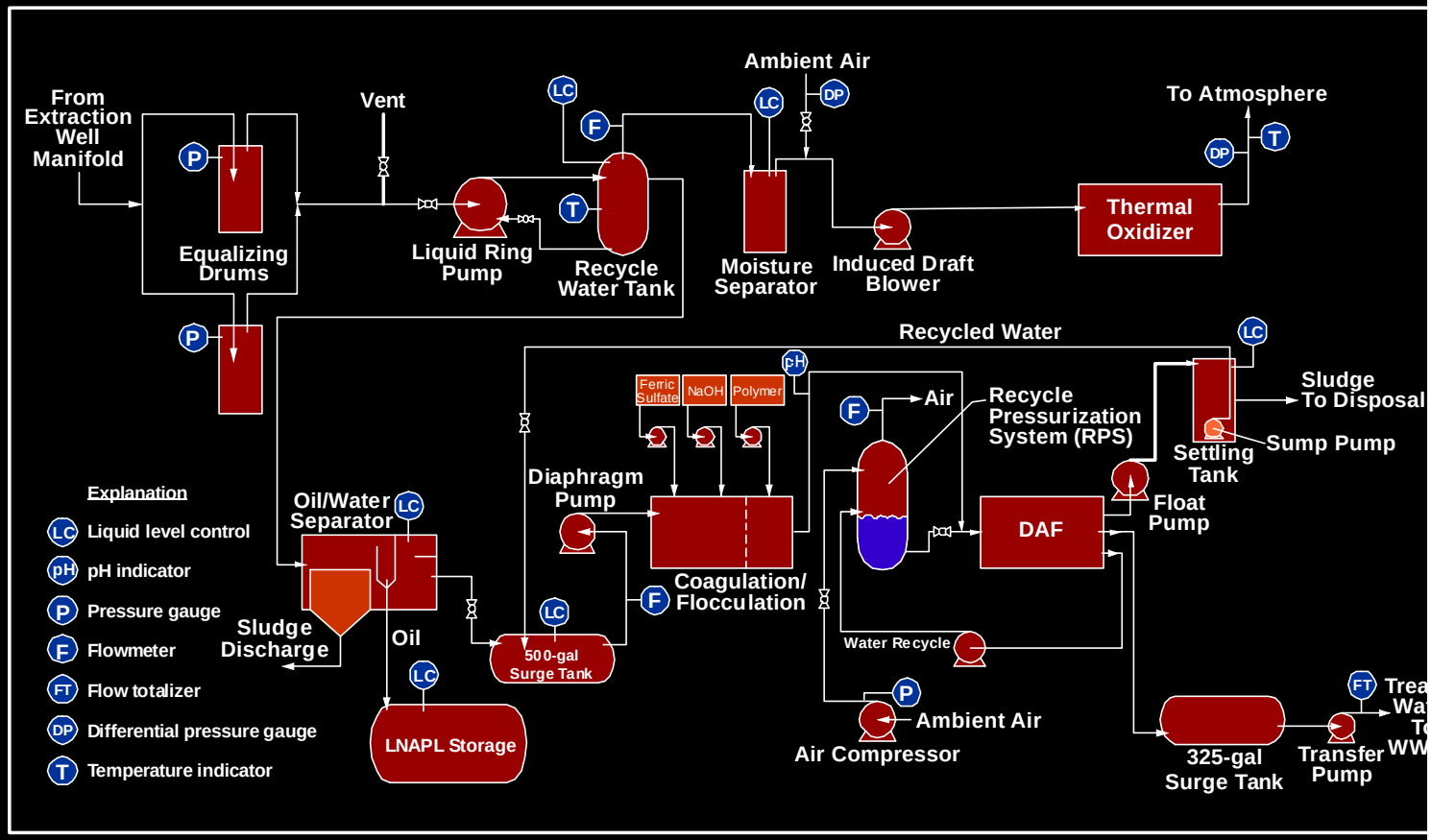
Full-Scale Application
AOC1, Naval Coastal Systems Station Panama City, Florida

- Former fire training area
- Over 63,000 gallons of hydrocarbons were spilled and ignited
- ½-acre plume
- Recoverable LNAPL estimates range between 500 to 5,000 gallons
- Groundwater table ranges 3.5 to 7.5 ft bgs
- Fine- to medium-grained sands



Full-Scale Application
AOC1, Naval Coastal Systems Station Panama City, Florida

- 17 extraction wells
- 12 groundwater monitoring wells
- Extraction wells spaced about 43 feet apart
- Off-gas treated by thermal oxidizer
- Process water treated using chemical treatment and DAF



Full-Scale System at CSS Panama City, Florida

Full-Scale Application
AOC1, Naval Coastal Systems Station Panama City, Florida

Recovery Results:

- 104 operating days
- 1,250 gallons of free-phase LNAPL
- 1,260 gallons of emulsified LNAPL recovered in process water
- 744,000 gallons of water extracted

Capital Cost: $110,000

Operating Cost:

$14,000/month with treatment

$2,500/month w/o treatment

Full-Scale System at CSS Panama City, Florida

Operation and Maintenance

- Ensure system is operating within design specifications
- Track remedial progress
- Continually evaluate need for aqueous and off-gas treatment
- Minimize system downtime

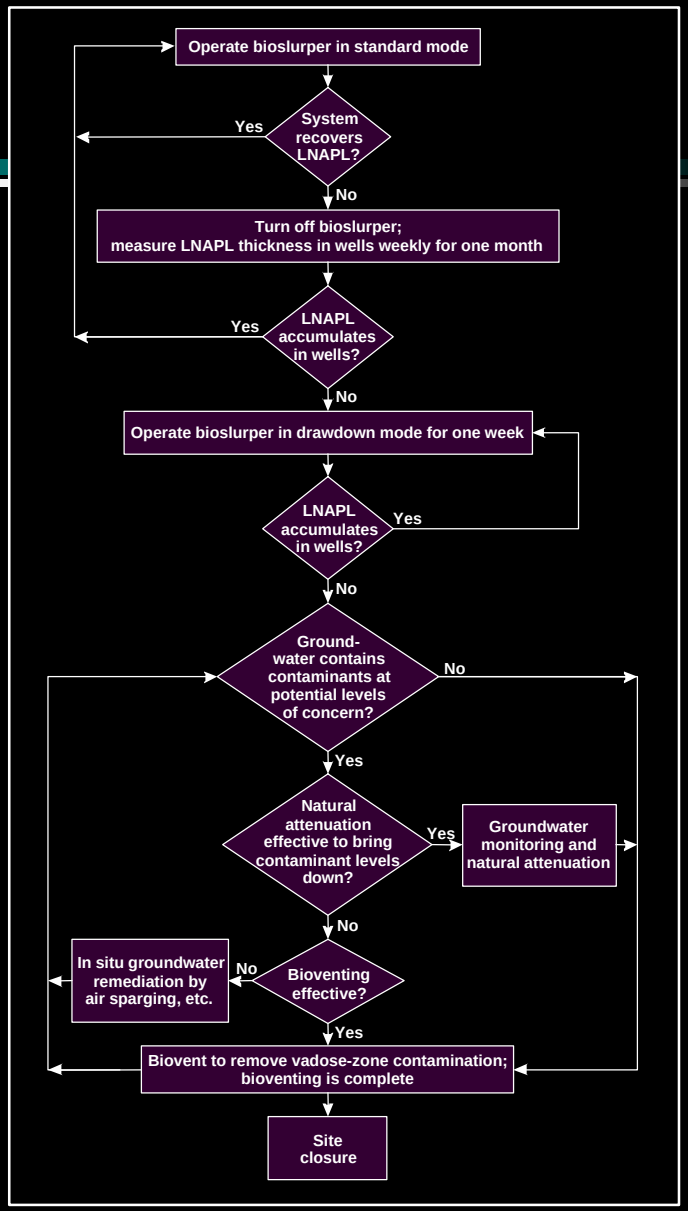
Develop an Exit Strategy

- Understand applicable regulations and cleanup criteria
- Propose risk-based approach
- Determine endpoint for bioslurping
- Establish monitoring program

	Regulatory Requirement for LNAPL Thickness in Clean Wells
Florida	0.1 inches
California	LNAPL must be removed "to the extent practicable"
Nevada	< 0.5 inches
Washington	"all practicable methods" must have been used to remove LNAPL
42 states are considering or have adopted RBCA Cleanup Requirements	

Develop an Exit Strategy

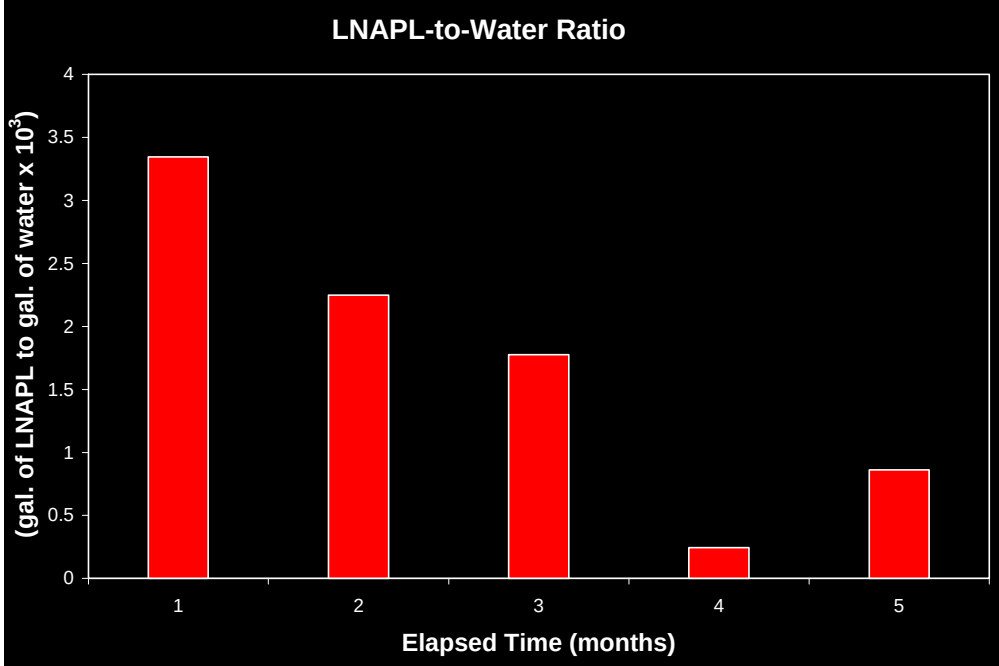
- Understand applicable regulations and cleanup criteria
- Propose risk-based approach
- Determine endpoint for bioslurping
- Establish monitoring program

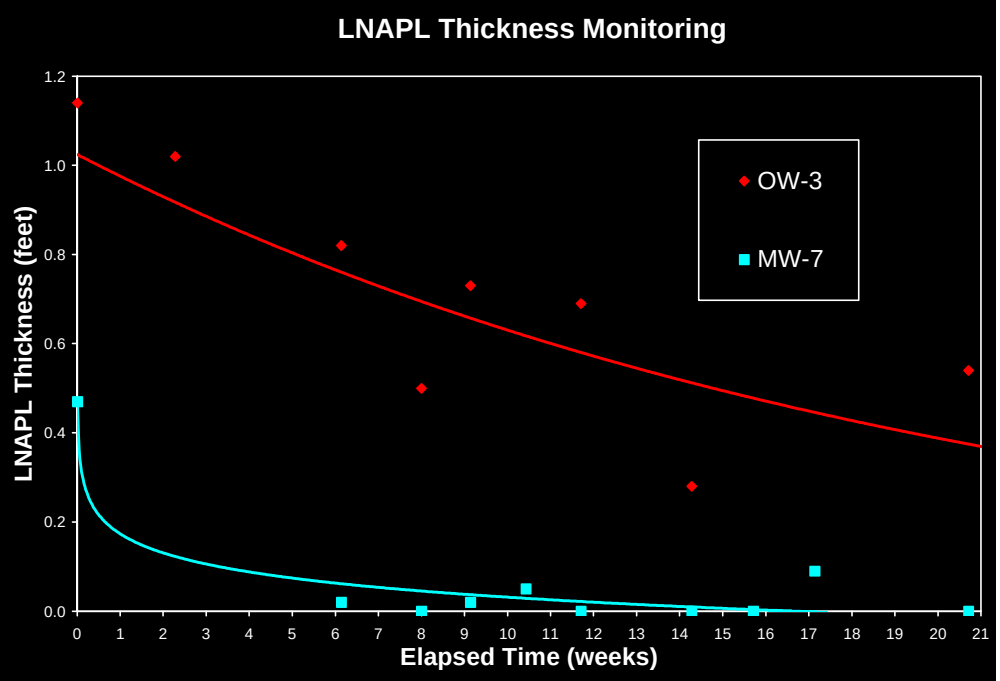


Site Closure Decision Tree

Develop an Exit Strategy

- Understand applicable regulations and cleanup criteria
- Propose risk-based approach
- Determine endpoint for bioslurping
- Establish monitoring program





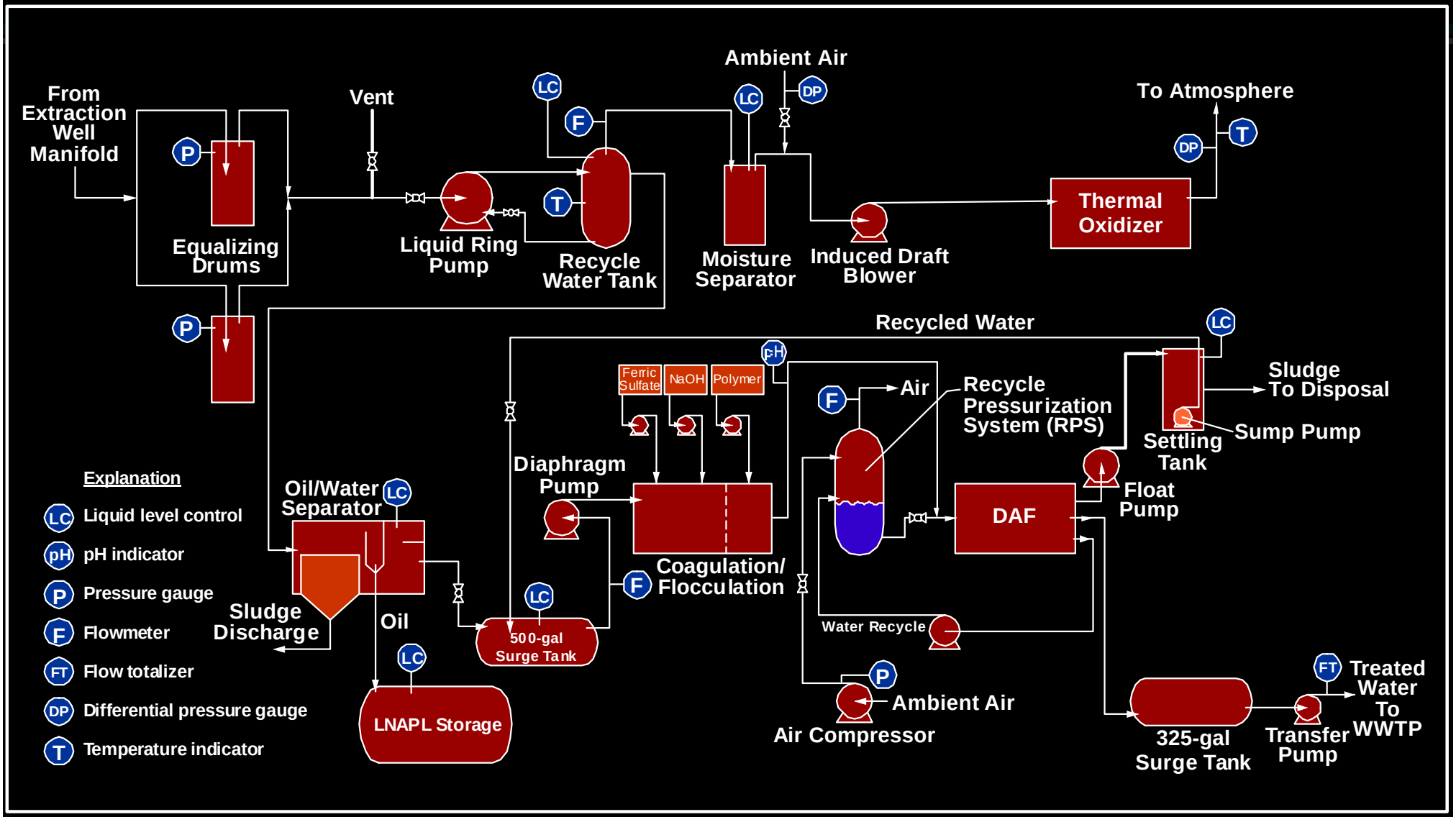
Develop an Exit Strategy

- Understand applicable regulations and cleanup criteria
- Propose risk-based approach
- Determine endpoint for bioslurping
- Establish Monitoring Program
  - Oil/water measurements
  - Groundwater monitoring
  - Demonstrate natural attenuation

Groundwater Monitoring

Questions and Answers

Full-Scale System at CSS Panama City, Florida



Site Characterization

- Plume delineation
- Oil/water measurements
- Baildown test
- Soil-gas survey
- Soil/site geology analyses
- Hydrogeology

Oil/Water Interface Testing at a Bioslurper Extraction Well, CSS Panama City, Florida