Headquarters U.S. Air Force

I n t e g r i t y - S e r v i c e - E x c e l l e n c e

Bioventing/ Bioslurping – “Work Horses” for Fuel Remediation

Presented By

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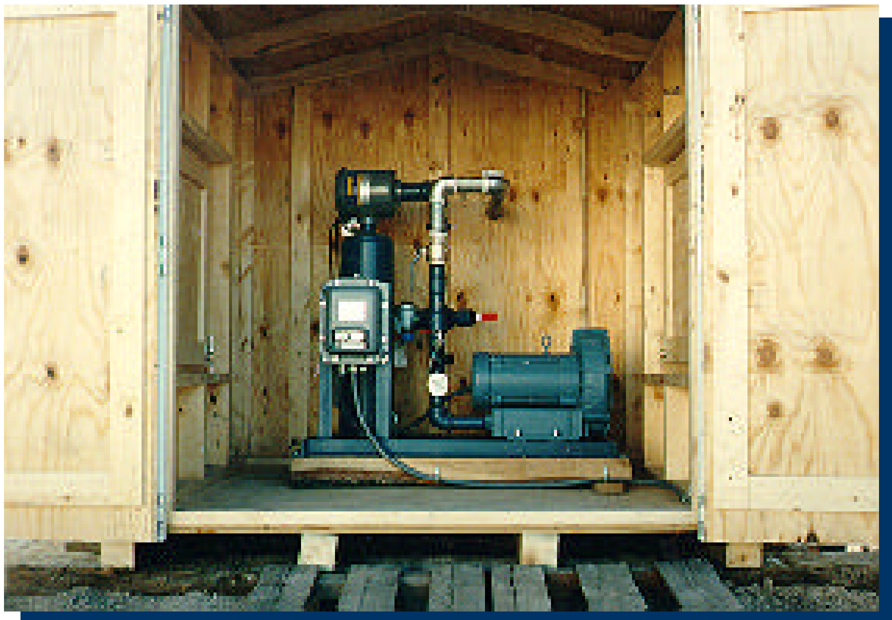
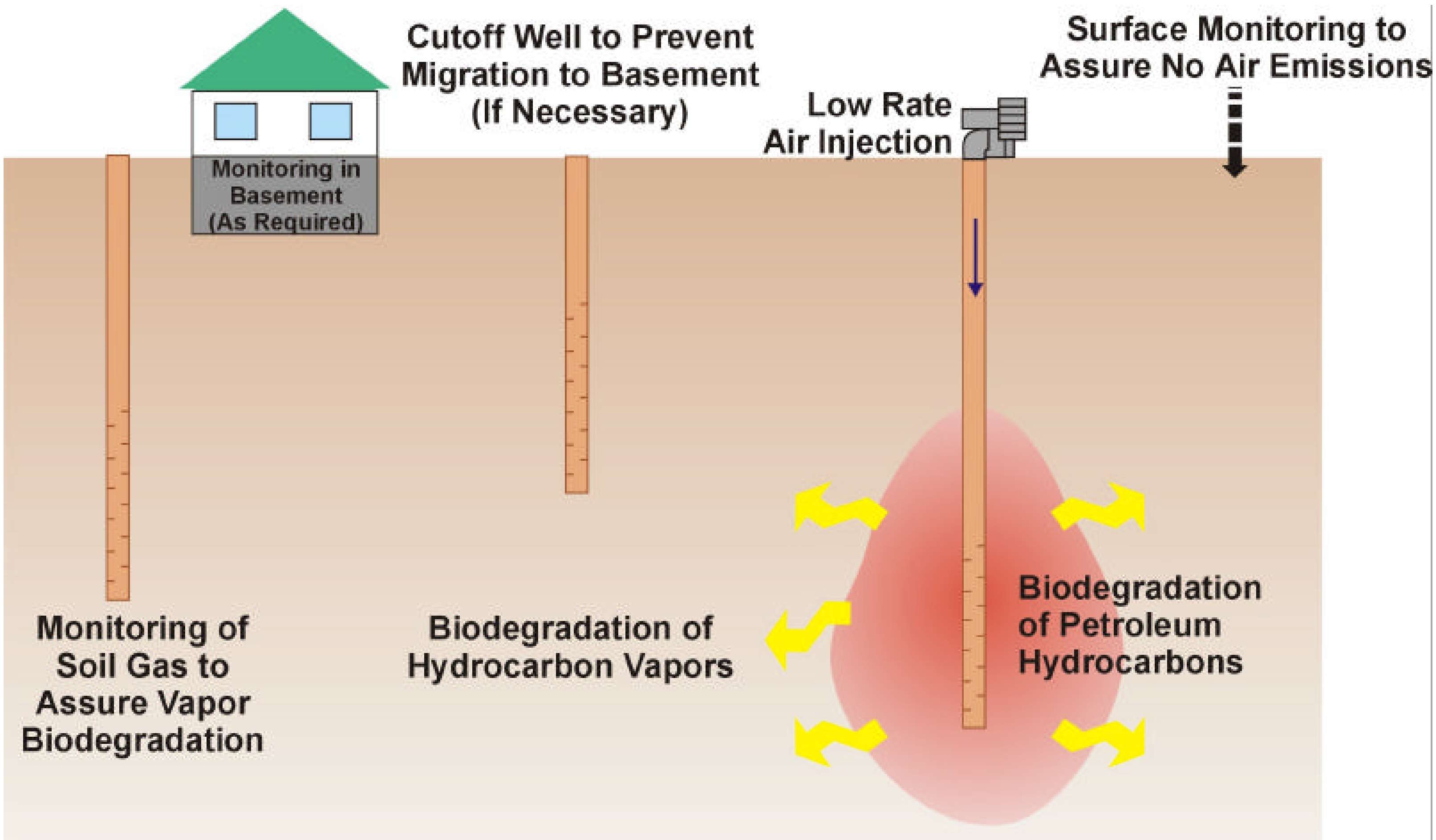
Overview

- Bioventing Effectiveness
- Best Applications for Bioventing
- Worst Applications for Bioventing
- Cost of Bioventing
- Bioslurping Operations
- Effectiveness
- Lessons Learned from Bioslurping Initiative
- Cost of Bioslurping vs Other Methods

Bioventing vs Complex SVE Systems



Simple Bioventing System



Bioventing Effectiveness

- Effective for all petroleum products that are biodegraded aerobically
- Average TPH reductions of 20-25 percent per year
- BTEX reductions of 90-95 percent in first year
- Excellent for benzene risk reduction in soil vapor
- Positive impact on groundwater depends upon seasonal lowering of the water table to expose smear zone

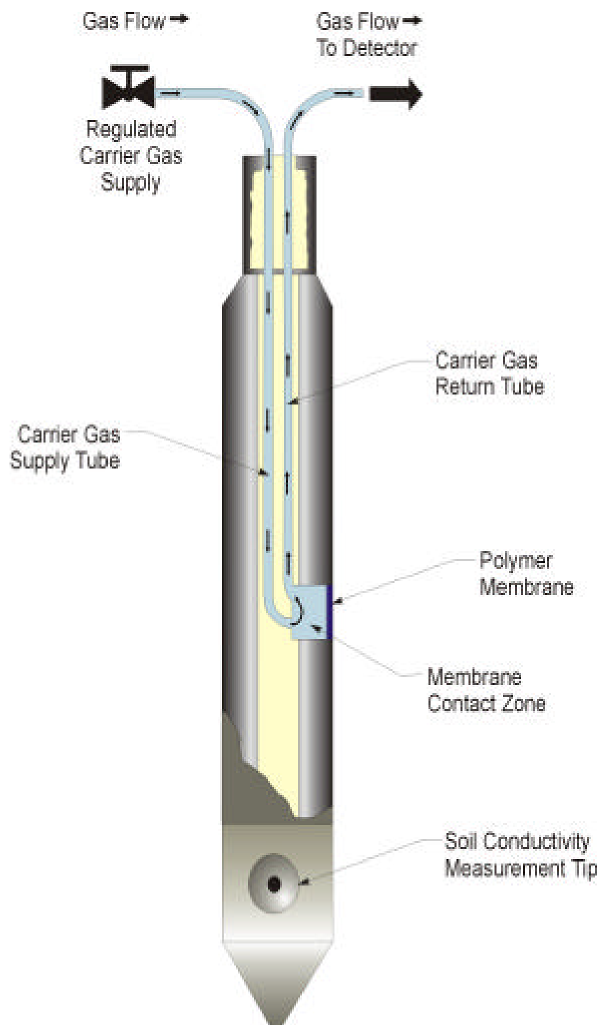
Best Applications for Bioventing

- Soils with moisture at less than 75 % field capacity
- Sands, silts and drier clays can all be bioventing
- Low to moderate volatility hydrocarbons (Jet Fuel)
- Deep vadose zone contamination
- Shallow vadose zones with seasonal groundwater levels
- >100 yards from basements or utility corridors if gasoline present
- Remediation time of 2-3 years is acceptable

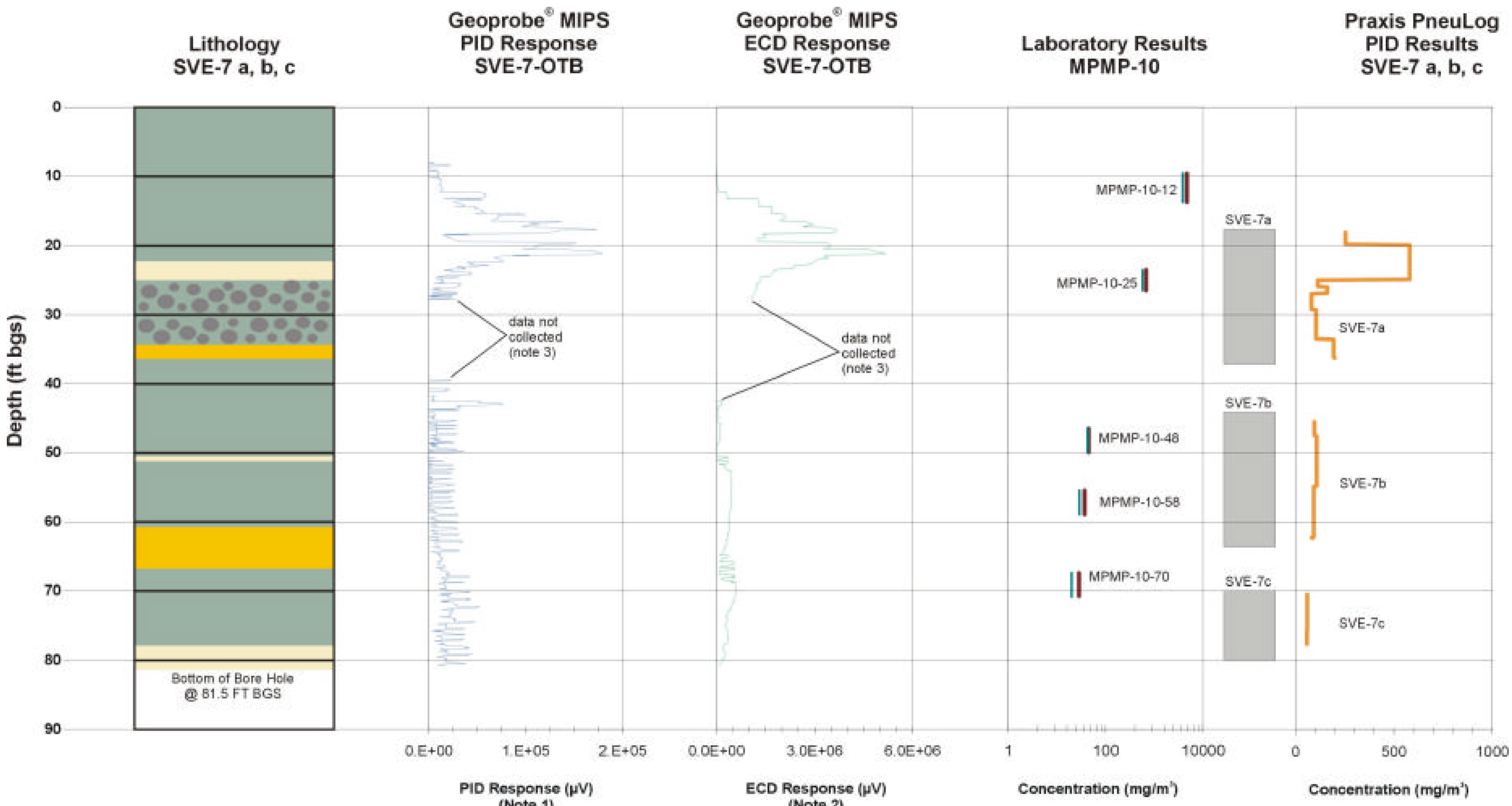
Worst Applications for Bioventing

- **Soils with moisture greater than 75 % field capacity**
- **Chlorinated hydrocarbon sites**
- **Groundwater within 4 feet of surface (biosparge instead)**
- **Sites with gasoline next to basements/utilities**
- **Sites with rising water tables**

Geoprobe™ Membrane Interface Probe MIPS™ System Diagram



SVE-7, SVE-7-OTA and MPMP-10 Concentration Comparison Charts



MIPS, Field and PneuLog Permeability Comparison Charts

Bioventing Cost Study

- Bioventing Has Been Widely Applied Since 1992
- AFCEE Has Produced an Extensive Performance Database
- A Large Cost Database is also Available and is the Subject of this Presentation

Basis of Cost

- 36 Full-Scale Bioventing Projects
- DOD and Industrial Sites Located in 23 States
- Treated Volumes of up to 100,000 Cubic Yards
- Small Systems: Single Vent Well and 1 HP Blower
- Largest 27 Vent Wells and 20 HP Blower
- Standardization of Design, Construction and OM&M

Basis of Cost (Cont.)

Capital Costs:

- Work Plan
- Regulatory Approval
- Pilot Test
- Pilot Test Report
- Full-Scale Design
- Full-Scale Construction
- System Optimization
- All Labor, Equipment, Materials, and Profit

Basis of Cost (Cont.)

Annual Operation, Maintenance and Monitoring Costs:

- Annual Respiration Test
- Power Cost for Blower
- Allowance for Blower Repair
- Annual Status Report
- All Labor, Equipment, Materials and Profit

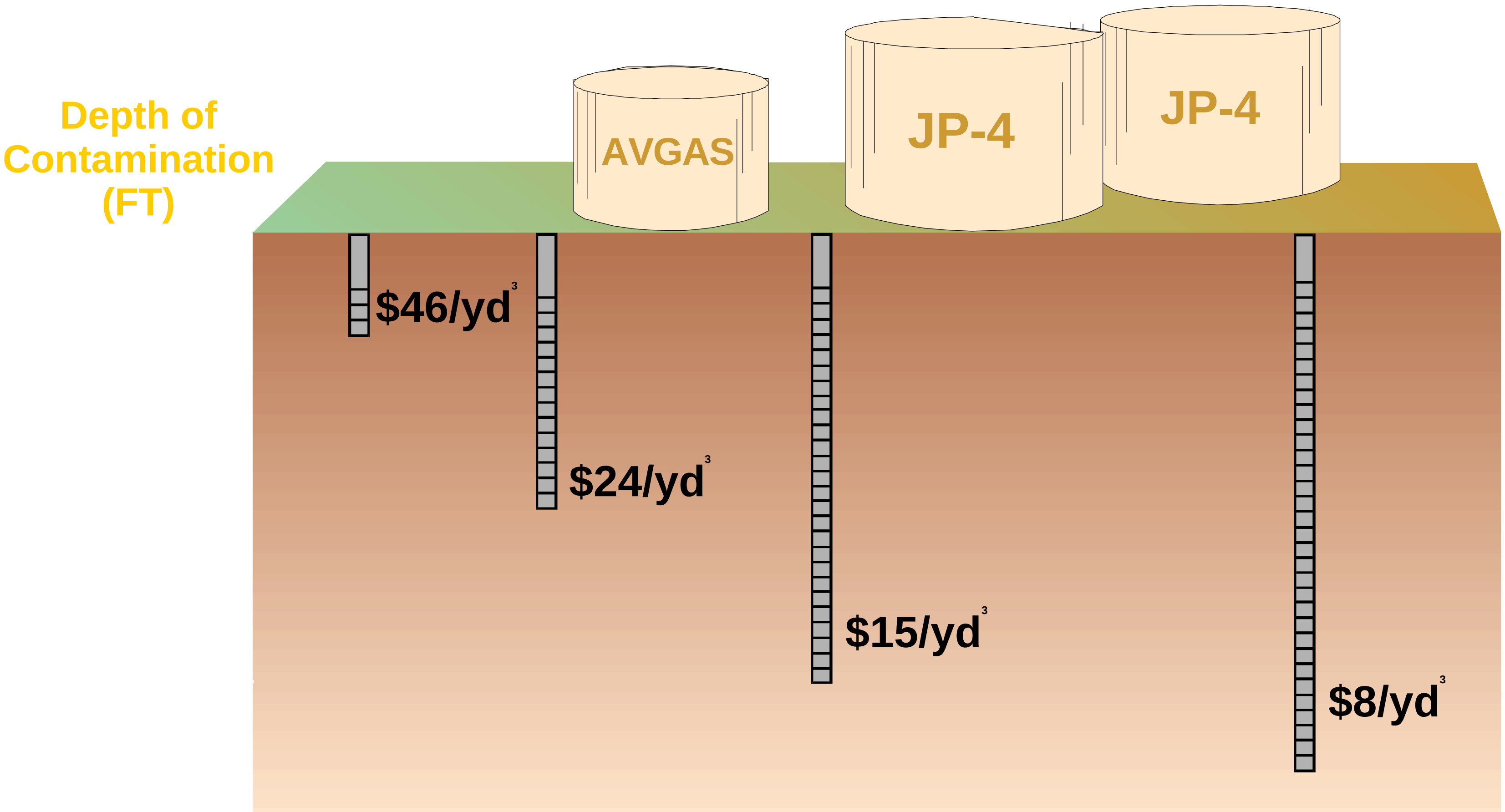
Factors Influencing Bioventing Costs

- Site Geometry
  - Shallow Soils Require more Vent Wells or Horizontal Wells
  - Deep Contamination Optimizes Treatment Volume
- Surface Features such as Reinforced Concrete can add 20% to Construction Costs
- Treatment Time
  - OM&M Cost $8K - $20K Per Year
  - Greatest Impact on Small Sites

Conclusions

- Bioventing Proven Effective for TPH/BTEX Reduction
- Significant Economy of Scale
- Total Costs of $4/yd3 to $80/yd3
- Cost Decreases as Depth Increases
- Greatest Cost “Risk” is Extended OM&M on Small Sites

Bioventing Cost vs. Depth



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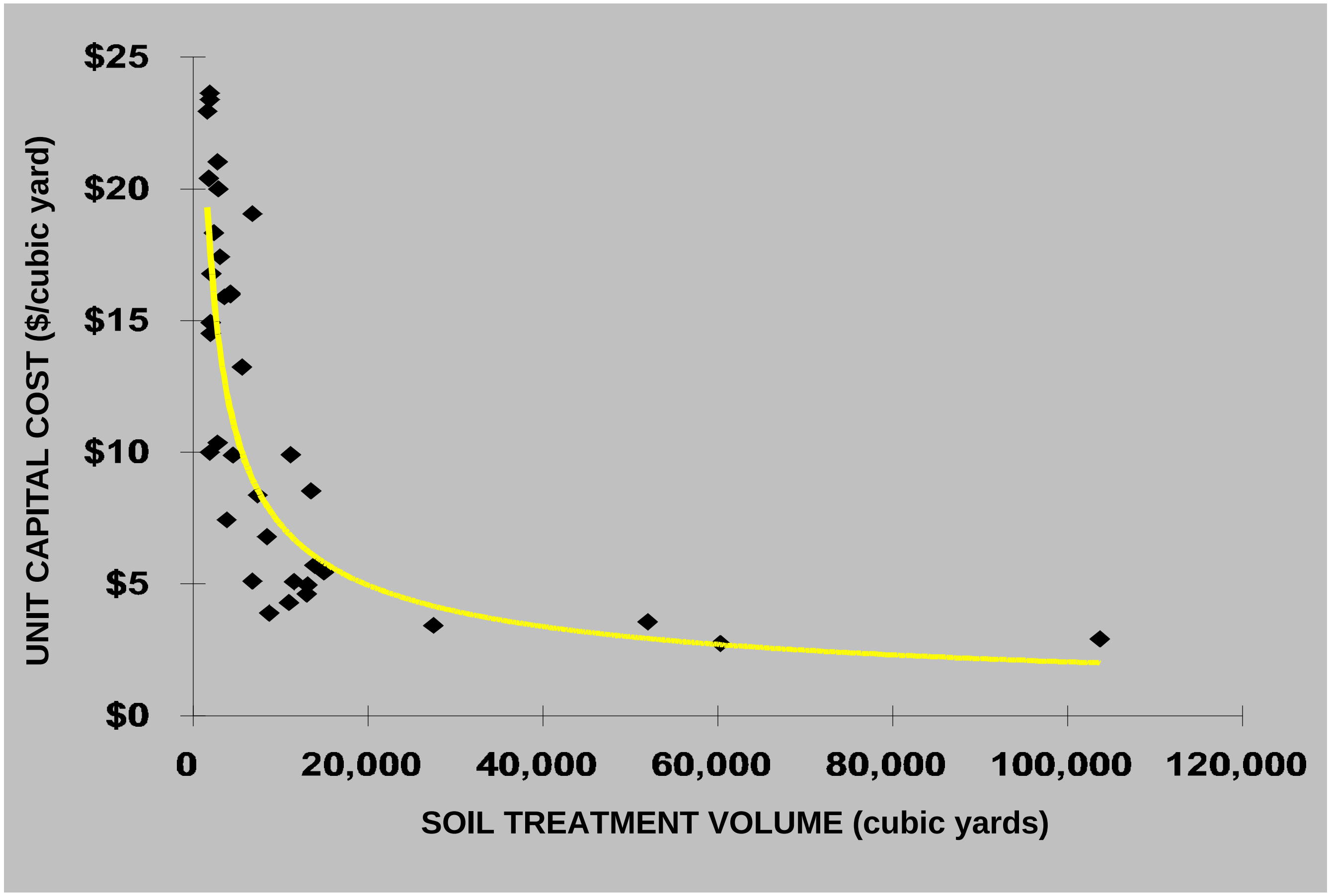
Unit Capital Costs



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Bioslurping Review

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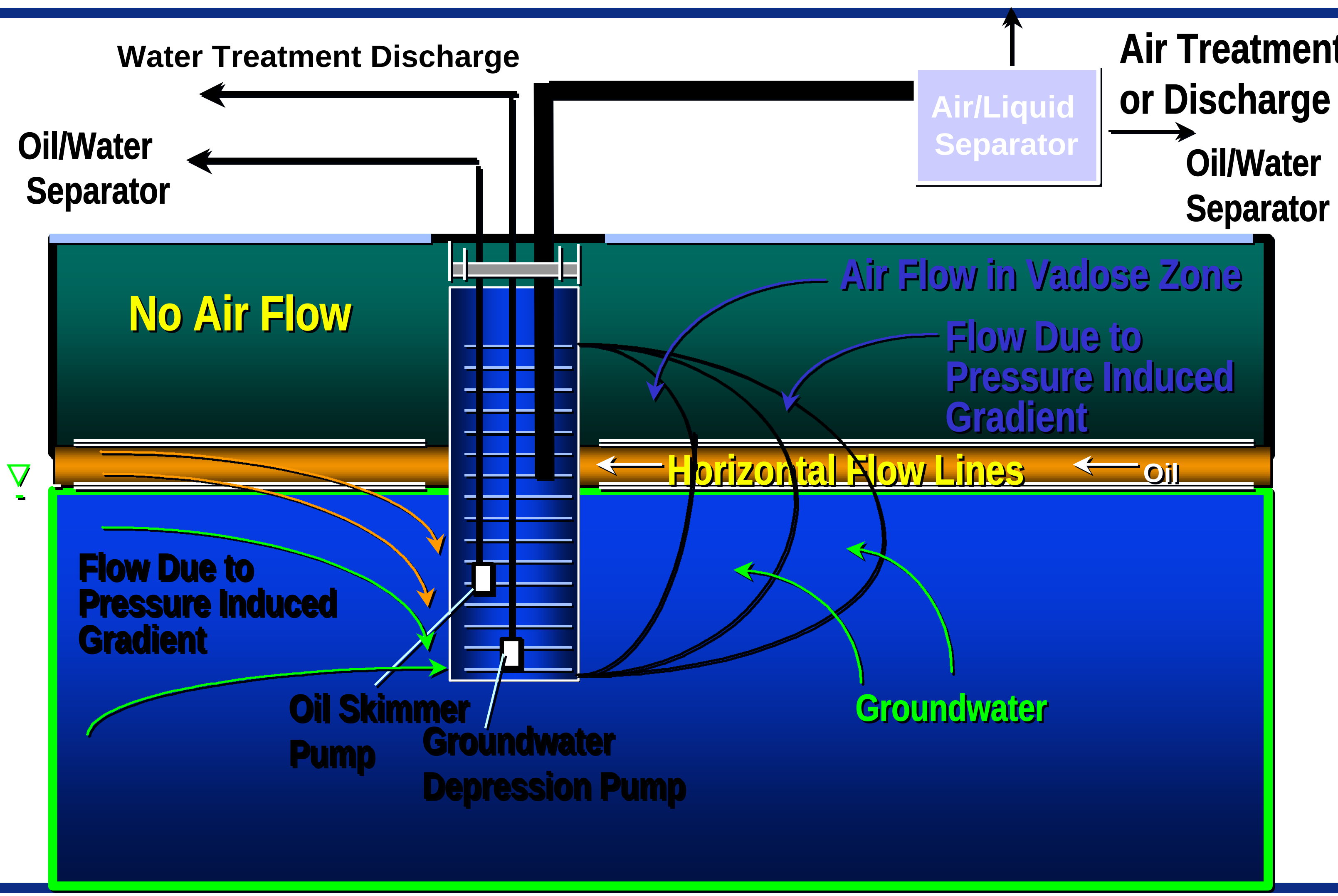
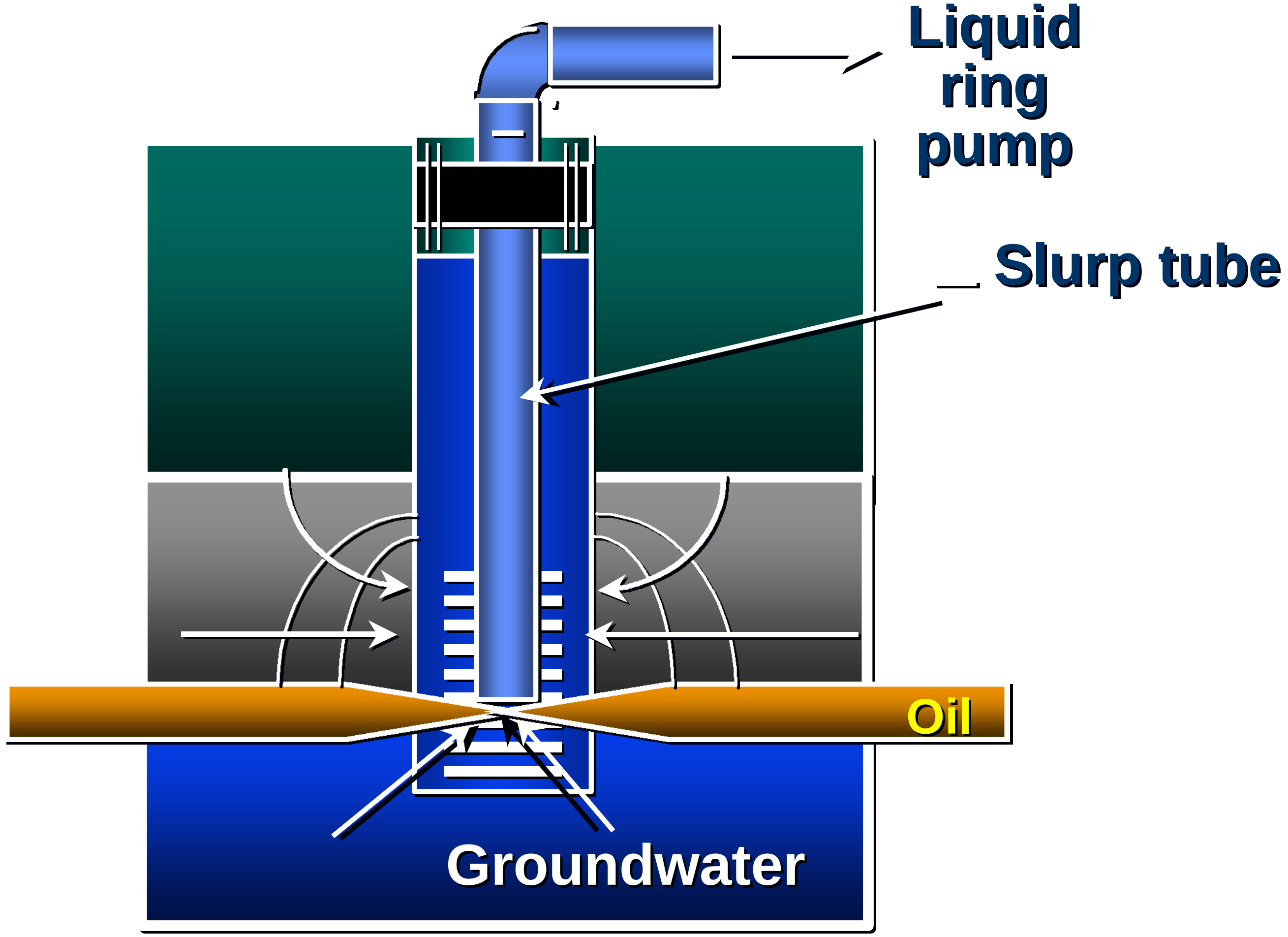
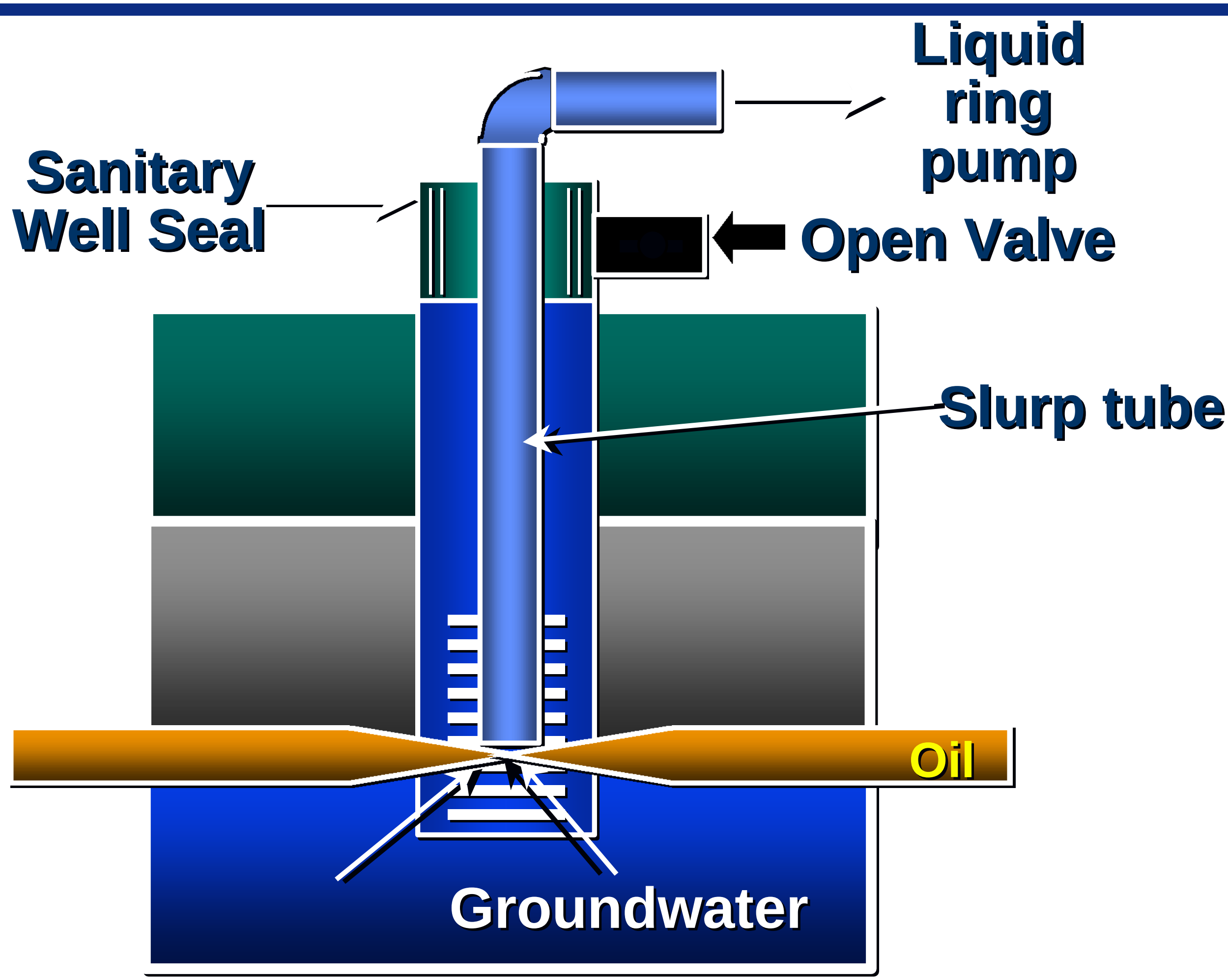
Conventional Bioslurper



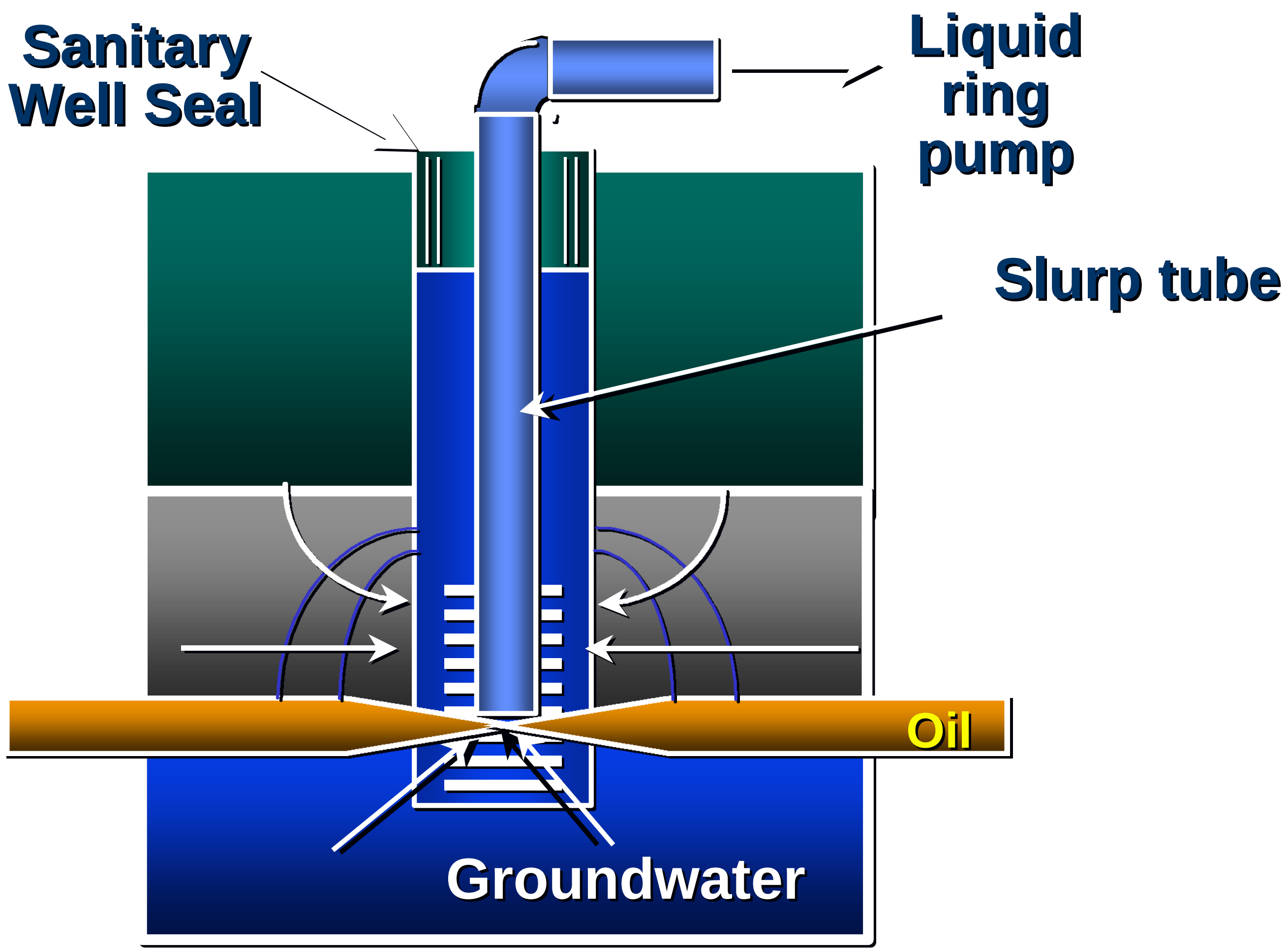
Bioslurper Well



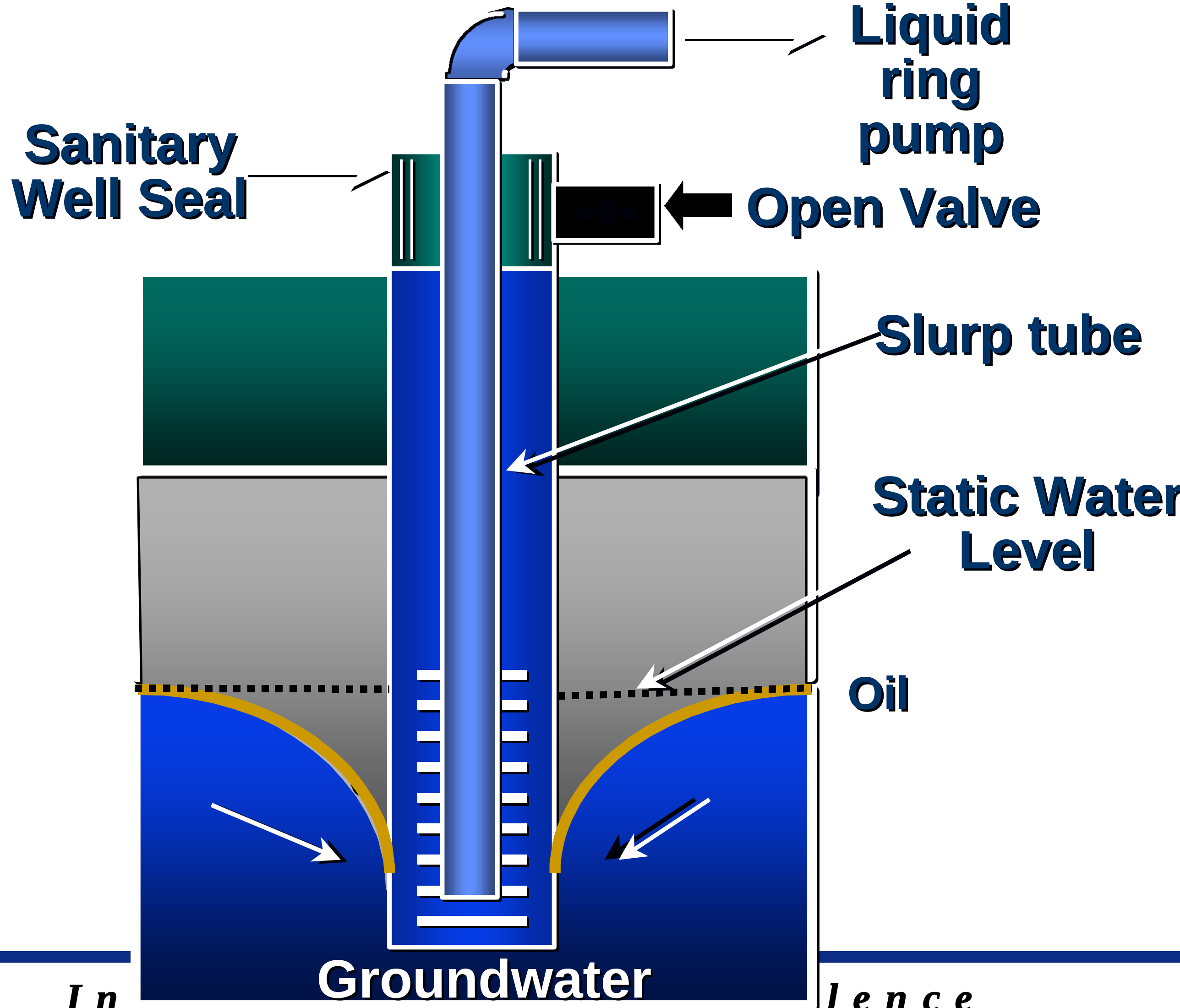
Skimming Configuration



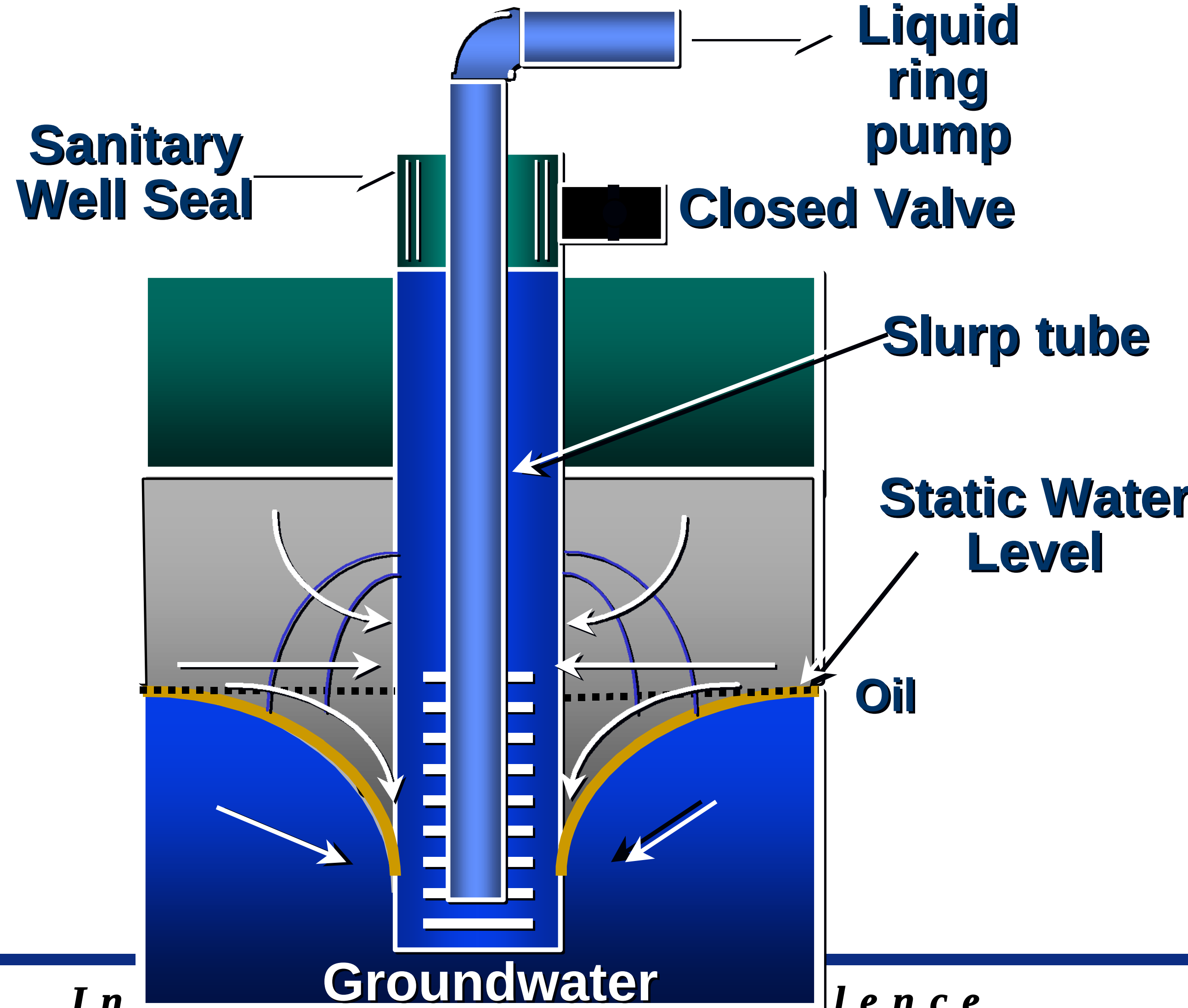
Bioslurper Configuration



Drawdown Configuration



Vacuum Dewatering Configuration



Program: Key Features

- Development of rapid, low-cost pilot test procedures for routine application
- Development of procedures for correlating free product thickness measurements with:
  - Actual thickness and distribution
  - Feasibility of recovery
- Application at the pilot scale at ~40 sites
  - Hands-on technology transfer
  - Real-world field experience
- Development of scale-up procedures
  - Built-in flexibility up or down

Baildown and Recovery Data

Site	Fuel Type	Baildown Test			Recovery Rates		
		Original Product Thickness (ft)	Final Product Thickness (ft)	Recovery (%)	Fuel (gal/day)	Water (gal/day)	TPH Vapor (lb/day) *
Andrews AFB, MD	No. 2 Fuel Oil	2.32	2.01	87	78.5	1,820	6.5
Bolling AFB, D.C. (B. 18)	No. 2 Fuel Oil	4.44	3.52	79	59.85	2,751	0.009
Bolling AFB, D.C. (B.41)	Gasoline	0.34	0.32	94	1.55 0.81	1,286 1,052	470.1/---
Dover AFB, DE	JP-4	3.73	3.77	101	43.2	2,844	---/4.4
Edwards AFB, CA	JP-4	5.05	3.02	60	289.7	2,447	
Havre AFS, MT (MW-7)	No.2 Fuel Oil	0.36	0.28	78	0.14	76	0.89
Havre AFS, MT (MW-F)	No.2 Fuel Oil	1.50	0.25	17	1.2	210	---
Hickam AFB, HI	Aviation Gasoline	3.98	3.95	99	90.9	2,313	132/ 0.030
Hill AFB, UT	Fuel Oil	0.60	0.56	93	3.2	1,500	92

Comparative Recovery Data

Base Location	Site ID	Final Daily Fuel Recovery Rates (gal/day) 2-Day Skimmer Test	4-Day Bioslurper Test	1-Day Skimmer Test	2-Day Drawdown Test	Bioslurper Vapor (lb/day TPH)
Andrews AFB, MD	B. 1845	6.6	64.5	0.71	(a)	6.5
Bolling AFB, D.C.	B. 18	15.25	59.9	8.2	31.2	0.009
Bolling AFB, D.C.	B. 41	0	0.48	NA	0.126	470.1
Dover AFB, DE	SS-27	27.9	43.2	9.4	(a)	612
Edwards AFB, CA	Site 24	13	55.8/ 73	(b)	NA	54
Griffiss AFB, NY	PH-5	0	0.6	NA	0	91
Havre AFS, MT	Unit 70, (MW-7)	0.19	0.073	0.012	0.01	0.89
Havre AFS, MT	Unit 63, (MW-F)	NA	0.62	NA	NA	NA
Hickam AFB, HI	Area H	16.5	(b)	(b)	470	132
Hill AFB, UT	OU-1	0.8	1.5	0.6	0.5	92

Design Considerations

- Baildown Recovery Tests
  - Inexpensive method to better evaluate recovery potential
  - Use to select subset of wells that will be "producers"
  - Recommend 3 - 4 consecutive baildown tests over a 24 - 48 hour period
- Product/water ratios and number of "producing" wells change significantly over time

Bioslurper Pump Sizing

- Approaches
  - Minimum Entrainment Velocity (e.g. 100 ft/sec)
    - Extraction Tube - Up-hole Velocity
    - Throughout Extraction Network
  - Scale-up from Pilot Tests
    - (Pilot Test Flow Rate/Vacuum) x (# of Wells) x (Fudge Factor)
  - Observational
    - Make Best Professional Estimate and Adjust Operation to Focus on “producing” Wells

Pump Size, Well, and GW Depth

- Example Pump to Well Ratios (GW Depth)
  - Fallon NAS, NV: 10 HP/48 well system (9 ft bgs)
  - Travis AFB, CA 3 HP/8 well system (9 ft bgs)
  - Robins AFB, GA: 5 HP/5 well system (7 ft bgs)
  - Andrews AFB, MD: 3 HP/3 well system (15 ft bgs)
  - Kaneohe Bay MCAS, HI: 10 HP/30 well system (17 ft bgs)
  - Hickam AFB, HI: 10 HP/12 well system (19 ft bgs)
  - Johnston Atoll: 15 HP/30 well system (8 ft bgs)

Liquid Ring Pump Sizing

Capacity (CFM) at Vacuum (in Hg.)

Model	HP	5"	10"	15"	20"	25"	27"	28"	Weight (lb.) approx
					1725 RPM				
A75	**5**	72	72	74	74	72	65	45	180
A100	**7-1/2**	100	102	102	102	100	86	60	195
A130	**10**	125	125	125	125	118	95	65	250
					1160 RPM				
A200	**15**	230	230	230	230	220	190	135	560
A300	**20**	280	280	280	280	245	200	160	600

Dry air performance data based on service liquid water at 60 degrees F, Barometric Pressure-Sea Level-29.92 degrees Hg.

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Vapor Treatment Considerations

- Low Volatility LNAPLs
  - JP-5; JP-8; Heating Oil; Hydraulic Fluids; etc.
  - Typically Yield Low Vapor Discharge Rates
- Discharge and Treatment Options
  - Direct Discharge
  - Reinjection
  - Thermal (e.g. Internal Combustion, Thermox, etc.)
  - Other
- Design Goal
  - Maximize LNAPL Product to Water Ratio, Minimize Vapor Discharge

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Vapor Treatment Considerations

- **Internal Combustion Engine Can Serve as Vacuum Source and Vapor Treatment System**
- **Vapor Discharge Rates Typically Remain Constant as Long as LNAPL Recovery Rate Remain Constant - Volatilization during extraction**
- **Beware of Limited Recovery Potential and Falling Concentrations**

Process Water Treatment Considerations

- Emulsions
  - Floating Sludge
    - Maybe Oil-based Emulsion
    - Maybe Sludge (e.g. biomass, sediment, precipitates,(e.g. iron), etc)
  - “Milky” or Suspended Microemulsions
- “Solutions” are Often “Worse” Than the Problem

Process Water Treatment Considerations

- Common Solutions
  - Anti-emulsion Additives
  - Acids (Anti-scale additives)
  - High Performance Oil/Water Separators
  - Other
- Recommendations
  - Maximize Product/Water Ratios - Focused Extraction
  - Provide for Maximum Physical Removal and Ease of Maintenance (e.g. emulsion tanks)
  - Maximize Process Water Retention Time
    - Tanks are cheaper than most treatment options

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Bioslurper System Costs

Item	Cost
Site Preparation:	
1,000 ft buried 4-inch conduit ($5/ft)	$5,000
1,500 ft2 subgrade and pad ($6/ft2)	$9,000
9 wells, 2-inch PVC, 30 ft deep ($67/ft)	$18,100
Equipment:	
10 hp Liquid Ring Vacuum Pump	$8,500
1,000 ft PVC Pipe (0.5 - 2-inch, installed) ($10/ft)	$10,000
100 ft PVC Water Transfer Pipe (2-inch) ($14/ft)	$1,400
50 ft 4-inch PCV Vapor Stack Piping ($19/ft)	$950
Instrumentation (pressure gauges, flow meters)	$2,000

Bioslurper System Costs (cont)

Item	Cost
50 gpm Oil/Water Separator	$10,000
LNAPL Holding Tank (1000 gal double-walled)	$2,000
LNAPL Transfer Pump (5 gpm)	$700
Water Holding Tanks (2) (1,100 gal Poly)	$2,200
Water Transfer Pump (25 gpm)	$700
Mobilization	$5,000
Engineering (10% of other direct costs)	$7,800
Total:	$85,350

Bioslurper O&M Costs

Item	Monthly Cost
Electricity (15kW, $0.08kW-hr)	$780
Testing and Monitoring (2 stack, 2 water)	$1,600
Wastewater Disposal (3gpm, $3/1000 gal)	$400
Operating Labor (20 hrs/month, $50/hr)	$1,000
Reporting (Monthly Report and Final (prorated))	$1,000
Total Monthly Operating Cost:	$4,780

Total Capital and 6 months Operation: $114,000

Cost Comparison

- Total Capital and 6 months Operation
  - Skimmer System - $130,700
  - Bioslurper System - $114,000
  - Dual-pump Drawdown System - $195,800
- Total Capital and 12 months Operation
  - Skimmer System - $150,600
  - Bioslurper System - $140,700
  - Dual-pump Drawdown System - $234,400
- Balance Against Performance

Observations:

- **If total ground water production rates are above 10 gpm, it's a pump and treat**
  - **Optimize for higher product to water ratio over time**
    - **Focus extraction on higher producing wells (minority)**
- **Bioslurping is "easy" to make expensive**
  - **Typical "Conservative" Design**
    - **Pilot test flow rates X number of wells + 50% safety factor**
    - **Water and vapor treatment via carbon adsorption**
    - **Entrained/annular flow throughout extraction system**
    - **Exclude sanitary sewer discharge, direct vapor discharge or reinjection, and more liberal limits in favor of non-detect limits**
    - **30-year design for a 1-month to 24 month system**

Conclusions:

- Free product recovery is unpredictable!
  - The feasibility of free product recovery must be determined in the field with focused testing
- The avoidance of one free product recovery system ($250K) pays for over five pilot tests ($35 - 56K/test)
- Free product recover approach should be opportunistic
- Use mobile equipment where possible. Free product recovery is a risky, short-term undertaking
- 5 - 10% (Realistic); 30% (Maximum) of free product is recoverable via liquid phase recovery

References

- Results of a Multi-site Field Treatability Test for Bioslurping: A Comparison of LNAPL Recovery Rates using Vacuum-enhanced Recovery (Bioslurping), Passive Skimming, and Pump Drawdown Recovery Techniques. NTIS # AD-324119, Contact 703-487-4600
- AFCEE/ERT, January 1995, Draft Test Plan and Technical Protocol for a Field Treatability Test For POL Free Product Recovery - Evaluating the Feasibility of Traditional and Bioslurping Technologies.
- AFCEE/ERT, March 1997, Engineering Evaluation and Cost Analysis for POL Free Product Recovery.

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Thank You

Skimmer System Costs

Item	Cost
Site Preparation:	
1,000 ft buried 4-inch conduit ($5/ft)	$5,000
1,500 ft2 subgrade and pad ($6/ft2)	$9,000
9 wells, 4-inch PVC, 35 ft deep ($74/ft)	$23,310
Equipment:	
Skimmer Pumps/Compressor (9, $4,000/pump)	$36,000
1,000 ft Air/Fuel Pipe (0.5-inch, installed) ($8/ft)	$8,000
Instrumentation (pressure gauges, flow meters)	$500

Skimmer System Costs (cont)

Item	Cost
Oil/Water Separator (2 gpm)	$1,500
LNAPL Holding Tank (1000 gal double-walled)	$2,000
LNAPL Transfer Pump (5 gpm)	$700
Water Holding Tanks (1) (500 gal Poly)	$760
Water Transfer Pump (5 gpm)	$600
Mobilization	$5,000
Engineering (10% of other direct costs)	$10,000
Total:	$110,800

Skimmer O&M Costs

Item	Monthly Cost
Electricity (10kW, $0.08kW-hr)	$520
Testing and Monitoring (2 water)	$800
Wastewater Disposal (minimal)	NA
Operating Labor (20 hrs/month, $50/hr)	$1,000
Reporting (Monthly Report and Final (prorated))	$1,000
Total Monthly Operating Cost:	$3,320

Total Capital and 6 months Operation: $130,700

Dual-Pump Drawdown System Costs

Item	Cost
Site Preparation:	
1,000 ft buried 4-inch conduit ($5/ft)	$5,000
1,500 ft2 subgrade and pad ($6/ft2)	$9,000
9 wells, 6-inch PVC, 45 ft deep ($84/ft)	$34,020
Equipment:	
LNAPL Pumps (1 gpm pneumatic, $3000ea)	$27,000
Ground Water Pumps (1 gpm, $3000ea)	$27,000
Air Compressor (20scfm, 15 HP)	$1,800
LNAPL Transfer Pipe (1,000 ft 1-inch, installed) ($10/ft)	$10,000
Water Transfer Pipe (1,000 ft 2-inch, installed) ($14/ft)	$14,000
Instrumentation (pressure gauges, flow meters)	$3,000

Dual-Pump Drawdown System Costs

Item	Cost
Oil/Water Separator (2 gpm)	$1,500
LNAPL Holding Tank (1000 gal double-walled)	$2,000
LNAPL Transfer Pump (5 gpm)	$700
Water Holding Tanks (2) (1,100 gal Poly)	$2,200
Water Transfer Pump (25 gpm)	$ 700
Mobilization	$5,000
Engineering (10% of other direct costs)	$14,300
Total:	$157,200

Dual-Pump Drawdown O&M Costs

Item	Monthly Cost
Electricity (20kW, $0.08kW-hr)	$1,040
Testing and Monitoring (2 water)	$800
Wastewater Disposal (20 gpm, $3/1000 gal)	$2,600
Operating Labor (20 hrs/month, $50/hr)	$1,000
Reporting (Monthly Report and Final (prorated))	$1,000
Total Monthly Operating Cost:	$6,440

- **Capital and 6 months Operation: $195,800**