Innovative LNAPL Recovery Techniques

RTDF
NON-AQUEOUS PHASE LIQUID (NAPL)
CLEANUP ALLIANCE

San Antonio, Texas

February 7-8, 2006

Presented by:
Patrick E. Haas
P. E. Haas & Associates, LLC
http://www.phaas.net


Problem:
LNAPL on Soil

Problem: LNAPL in Soil and in a well

LNAPL Characteristics

- **LNAPLs**
  - Gasoline; jet fuels; diesels contain 200+ individual components
  - Composition varies with source
- **LNAPLs can contain DNAPLs**
- **DNAPLS can contain LNAPLs**
- **Always characterize NAPL composition; viscosity; density**
  - Composition over time

Vertical NAPL Migration

- Zones of higher relative soil moisture or water saturation tend to inhibit downward migration of NAPL and cause spreading and pooling
- Examples:
  - Clay layers: Lower porosity and more perfectly wetted
    - Higher displacement pressures

NAPL Phases

- Mobile - flows into wells - 30 - 80% saturation (pore space)
- Residual - small discontinuous globules or ganglia trapped in pore spaces
  - Can accumulate in wells
- Dissolved - solubilized in water in accordance with Rauolt's law
- Vapor - volatilized into soil gas

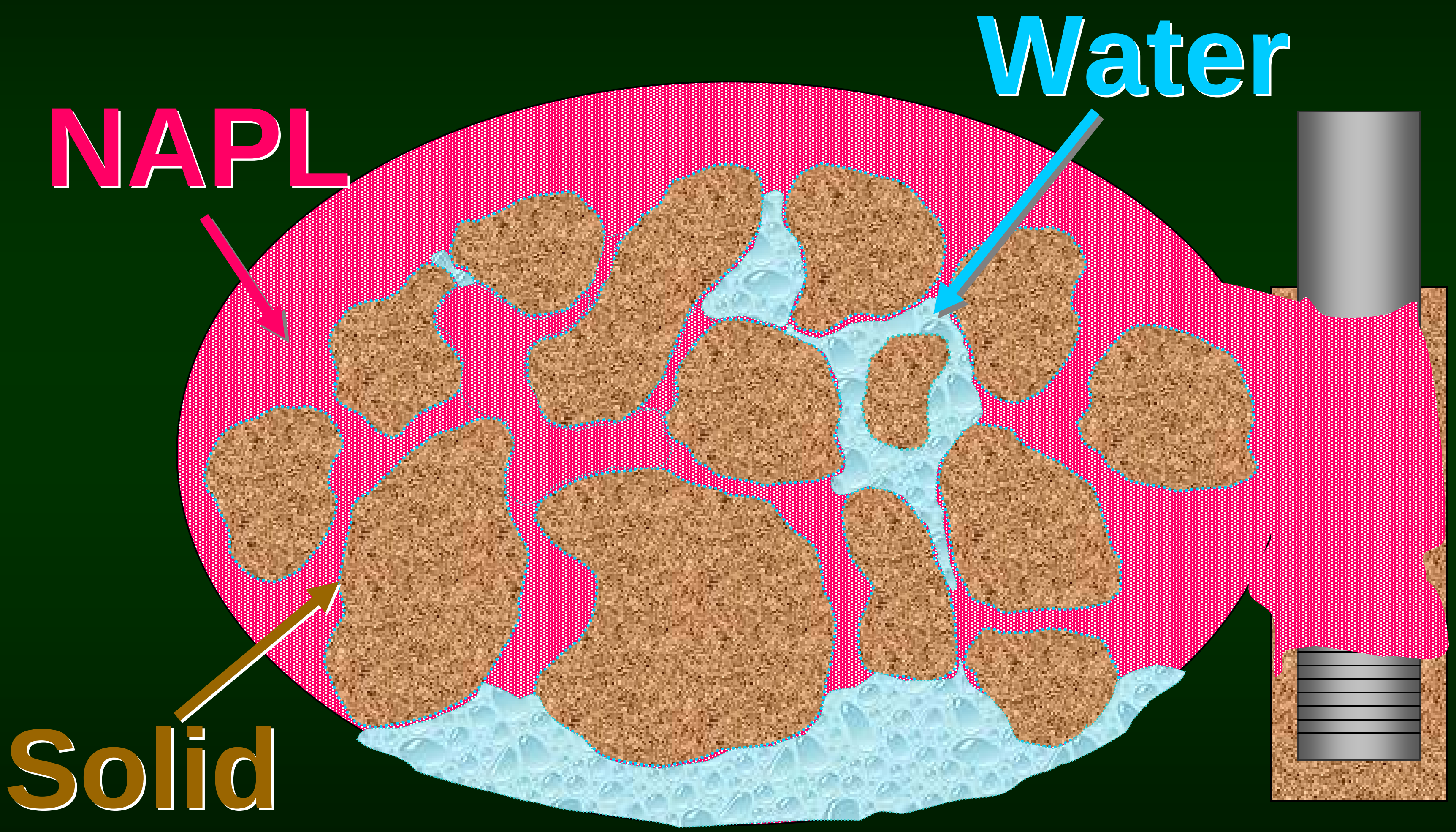
Influence of Site Conditions on Maximum Plume Length

Free Product?	Number of sites	25th Quartile	50th Quartile (median)	75th Quartile	Maximum
Yes	115	170	210	330	7,600
No	78	160	200	290	1,700

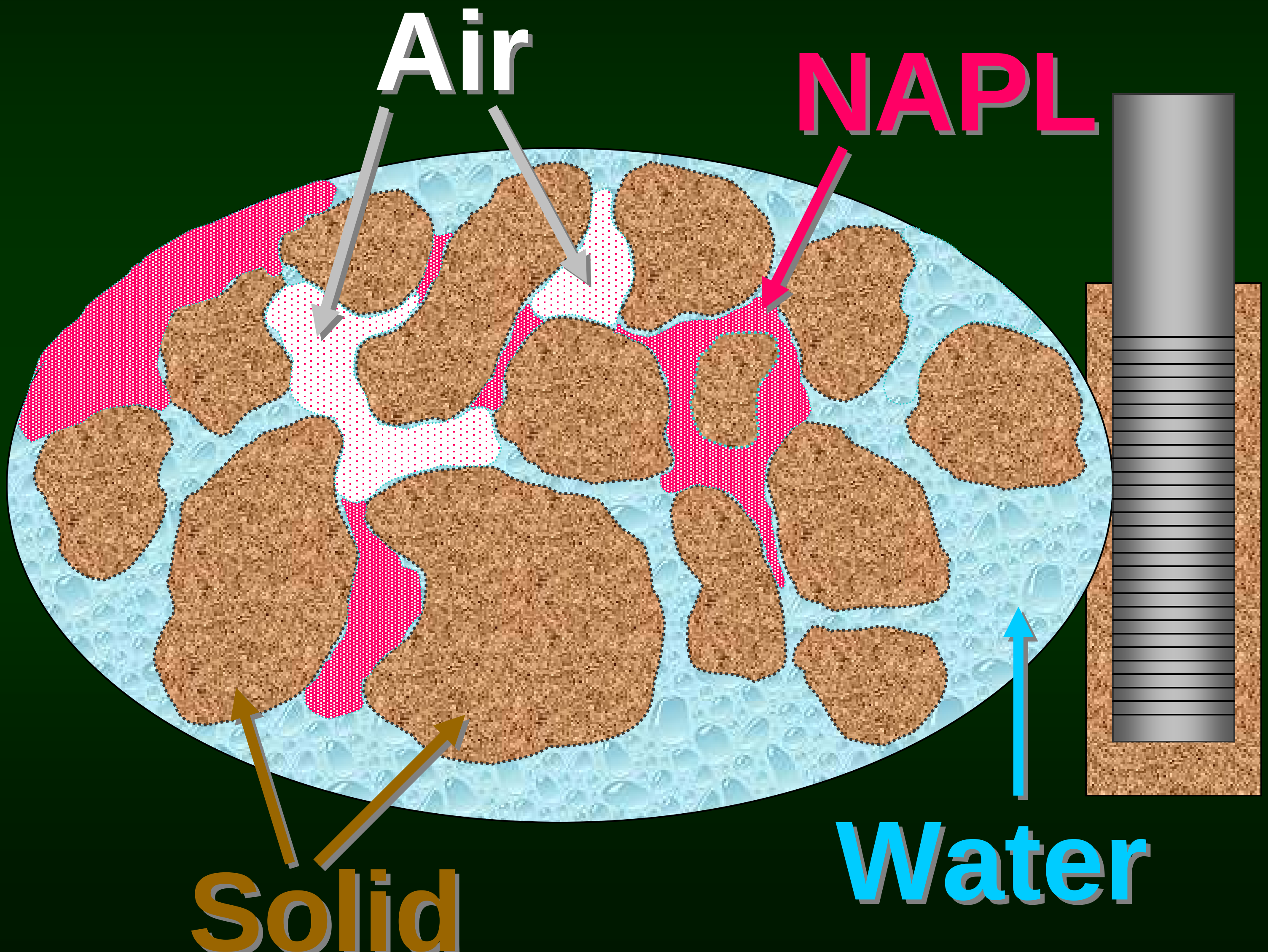
Units: feet

Reference: University of Texas at Austin Bureau of Economic Geology, 1997

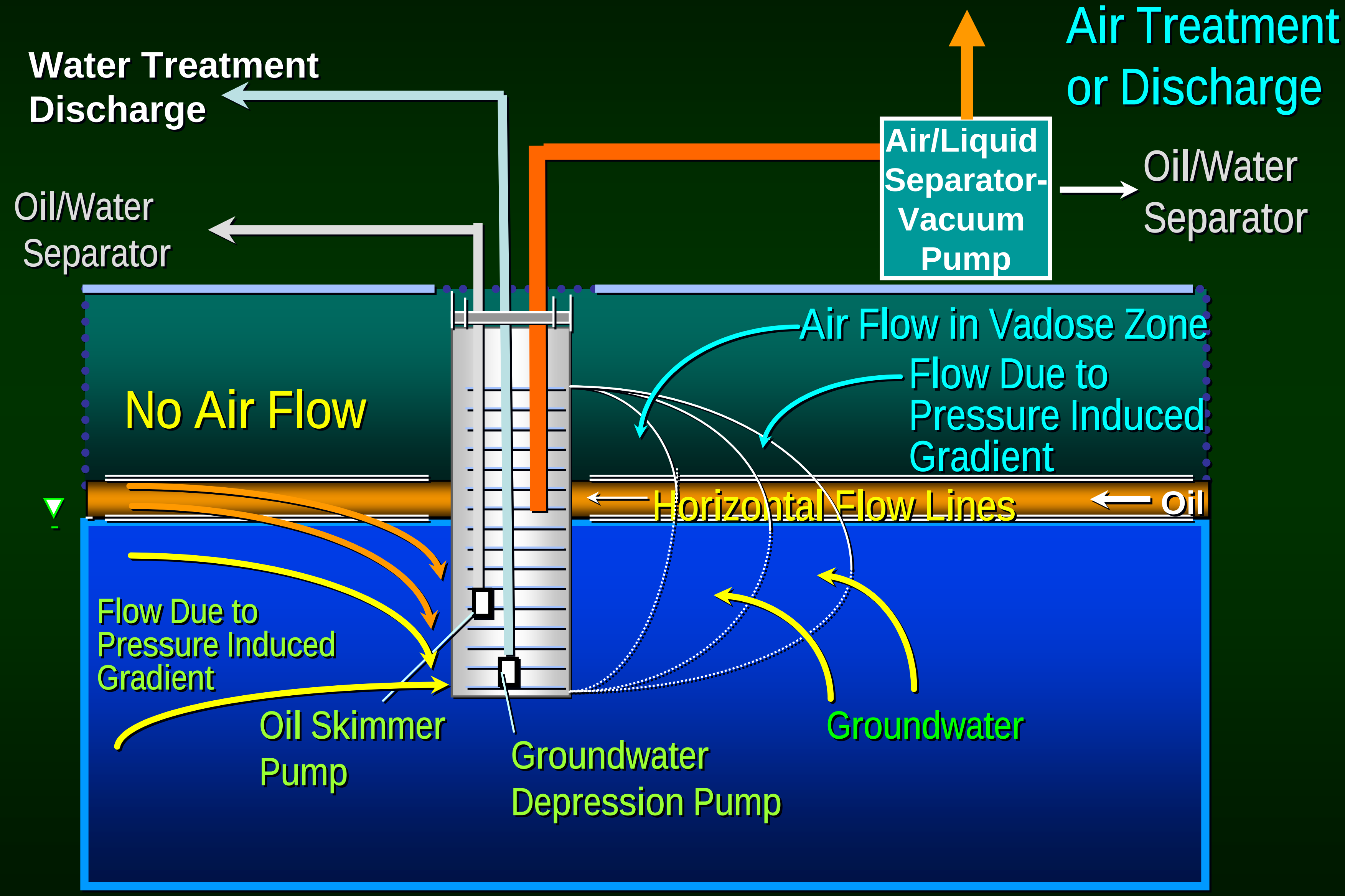
Smearing: Before Water Table Fluctuation



Smearing: After Water Table Fluctuation



Conventional   Vacuum-enhanced



Schedule of Activities: Free Product Recovery Pilot Test

Pilot Test Activity	Schedule
Site-specific Test Plan	Day 14
Test Plan Approval	TBD
Mobilization	Day 1-2
Site Characterization	Day 2-3

- Baildown Tests
- Soil Gas Survey (Focused)
- Vapor Monitoring Point Installation
- Soil Sampling
- Slug Test

Schedule of Activities: Free Product Recovery Pilot Test

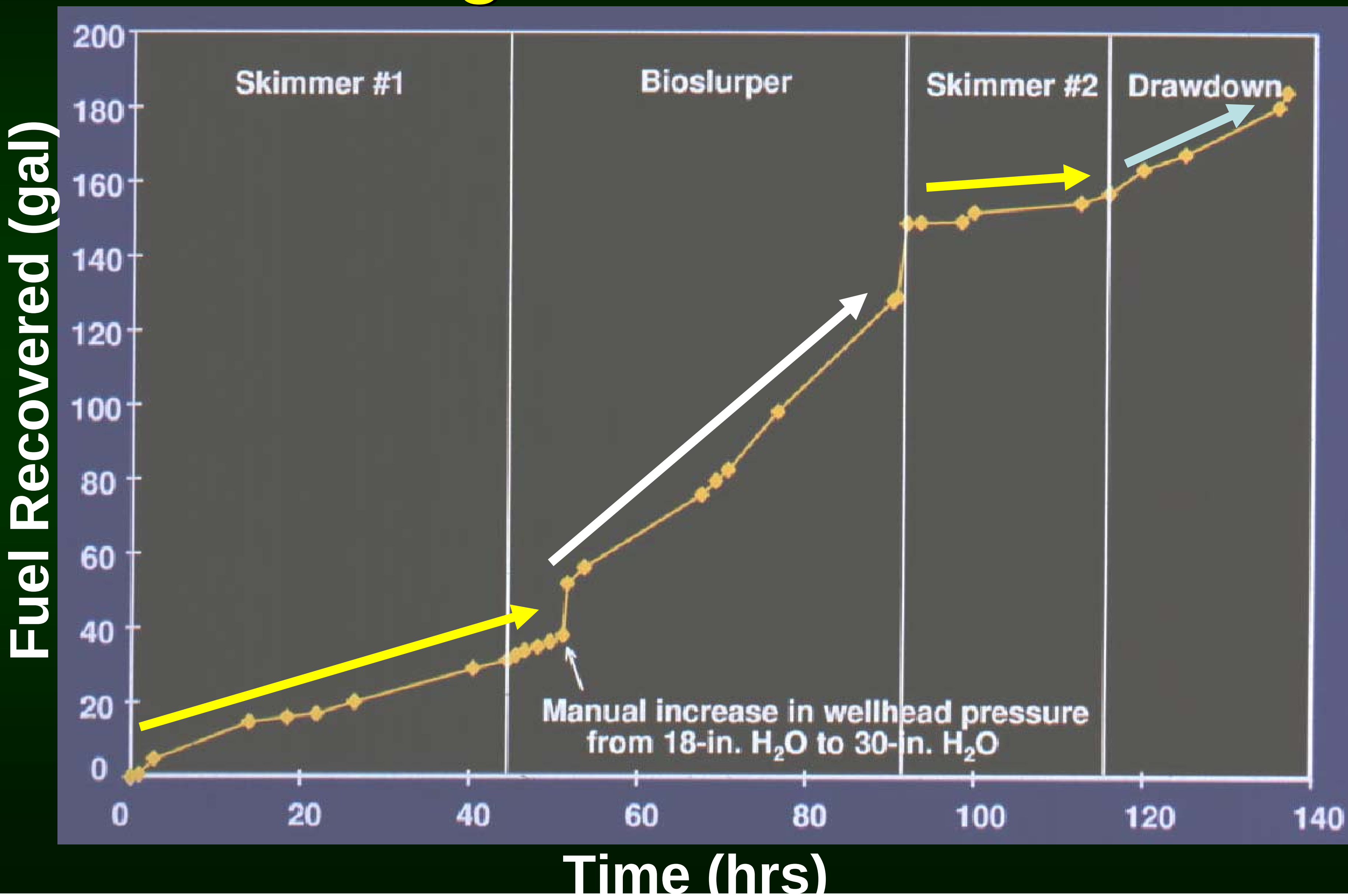
(cont)

Pilot Test Activity	Schedule
System Installation	Day 2-3
Test Start-up	Day 4
• Skimmer Test (2 days)	Day 4-5
• Bioslurper Test (4 days)	Day 6-9
• Air Permeability Test	Day 6
• Skimmer and/or SVE Test (1 day)	Day 10
• Drawdown Test (2 days)	Day 11-12
• In Situ Respiration Test	Day 11
• In Situ Respiration Test	Day 12-14
Demobilization	Day 14-15

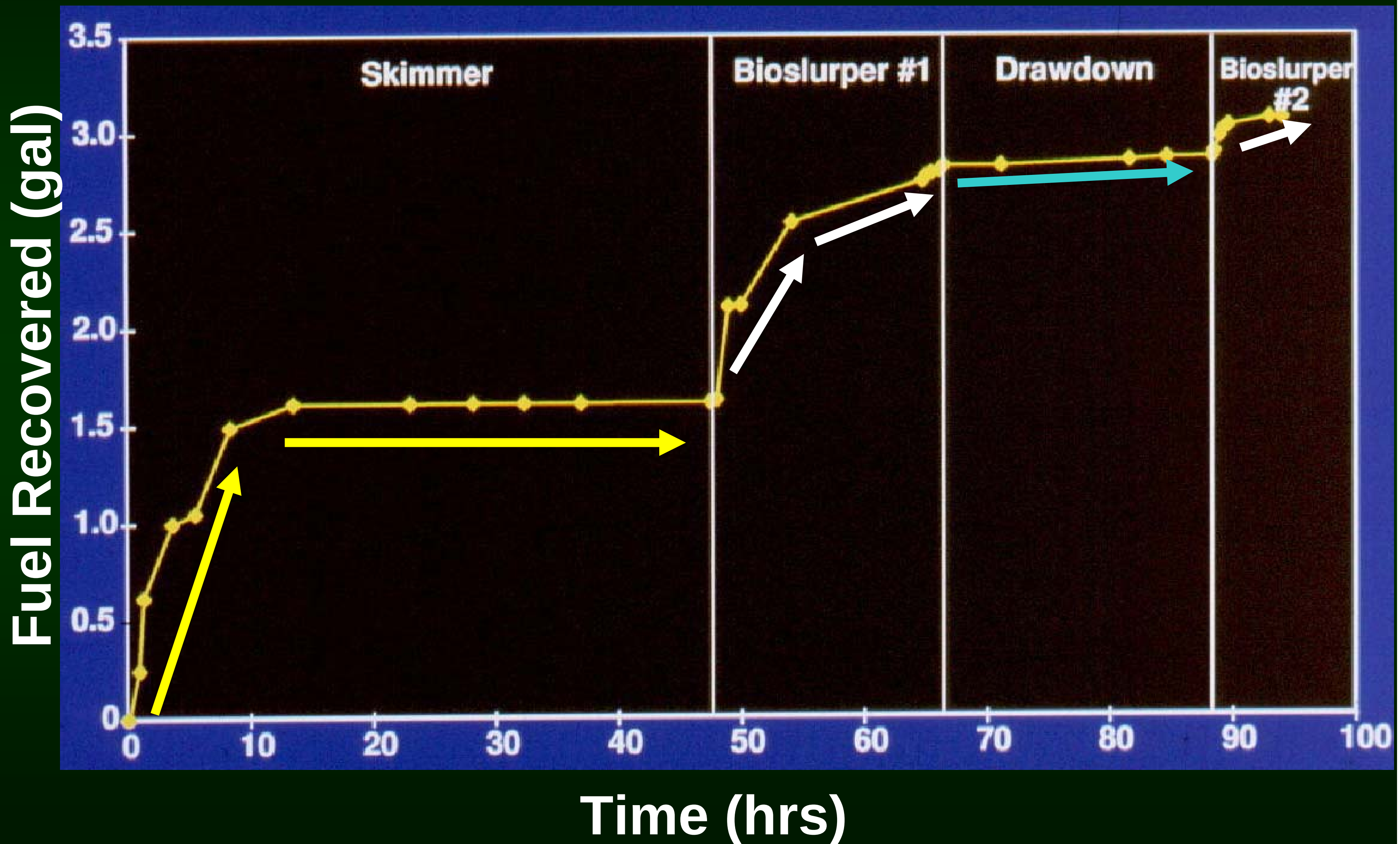
Baildown and Recovery Data

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

Fuel Recovery vs. Time
Building 18 – Well # HP-3



Fuel Recovery vs. Time
Building 41 – MW-3



Comparative Recovery Data

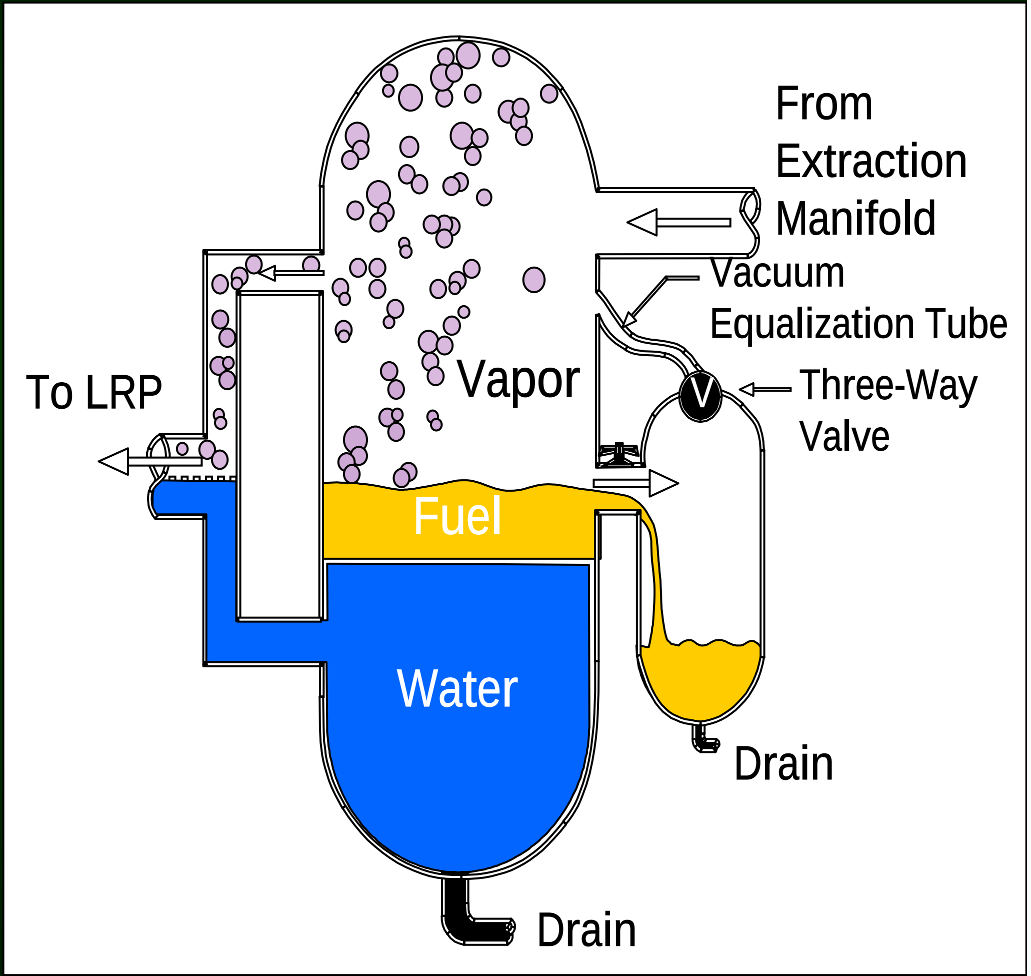
Base Location	Site ID	Final Daily Fuel Recovery Rates (gal/day) 2-Day Skimmer Test	4-Day Bioslurper Test	1-Day Skimmer Test	2-Day Drawdown Test	Bioslurper Vapor (lb/day TPH)
Andrews AFB, MD	B. 1845	6.6	64.5	0.71	(a)	6.5
Bolling AFB, D.C.	B. 18	15.25	59.9	8.2	31.2	0.009
Bolling AFB, D.C.	B. 41	0	0.48	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

Soil Vapor Extraction via Internal Combustion Engine

Monitoring Well Converted to a SVE Well

Abovegound Knockout Tank Separator

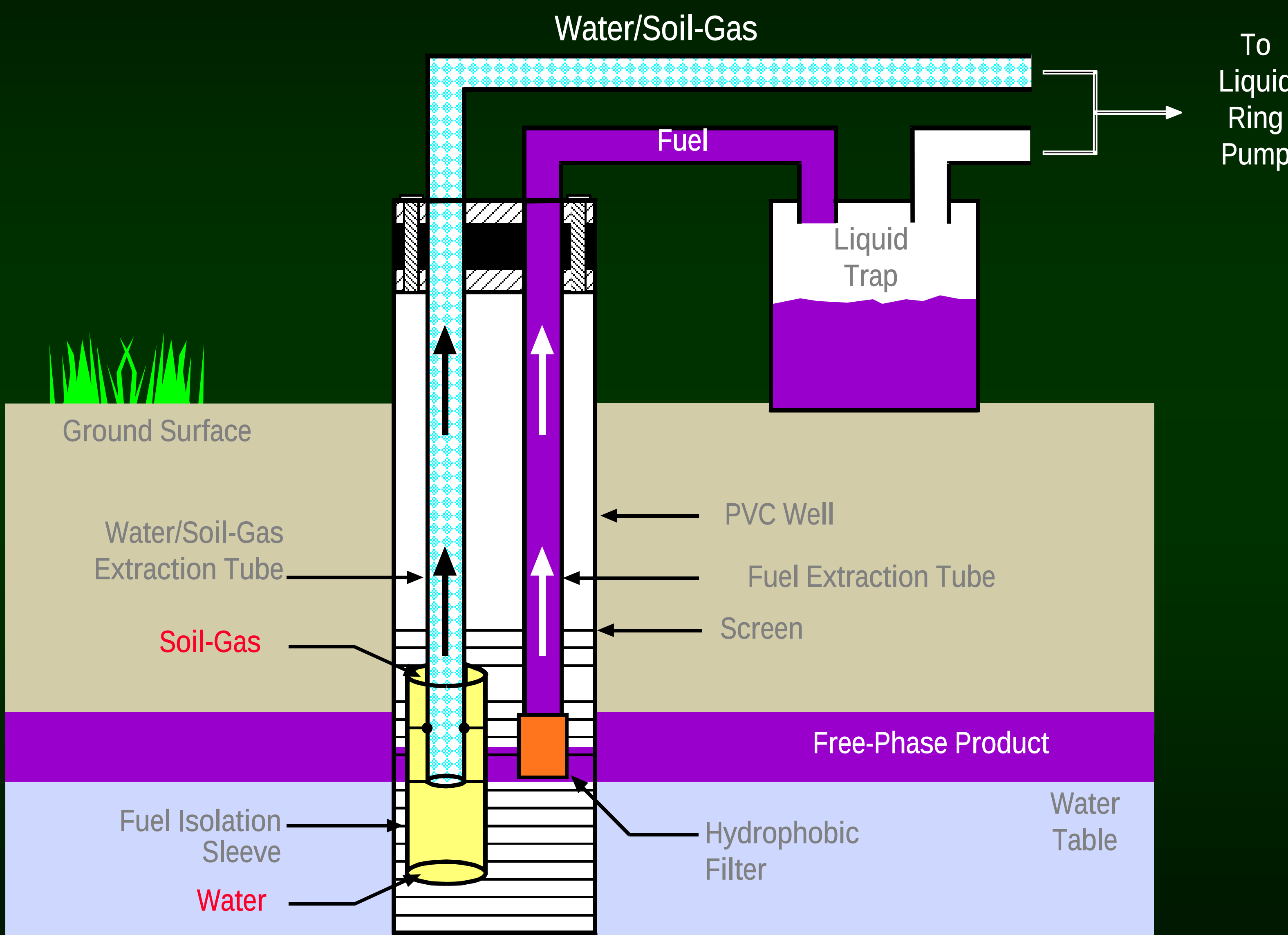
- Separator is modified vacuum tank that separates LNAPL from ground water/soil gas
- LNAPL accumulates in tank to a pre-set level and then drains to fuel storage tank under gravity



Knockout Tank Separator

Liquid ring pump

Dual Drop Tube Design



In-Well Separator: Dual Drop Tube

- Shield prevents LNAPL from entering into drop tube while allowing groundwater to enter from below and soil vapor to enter from above
- LNAPL is extracted by a small-diameter tube located outside the shield

Dual Drop Tube Test: CSS Panama City

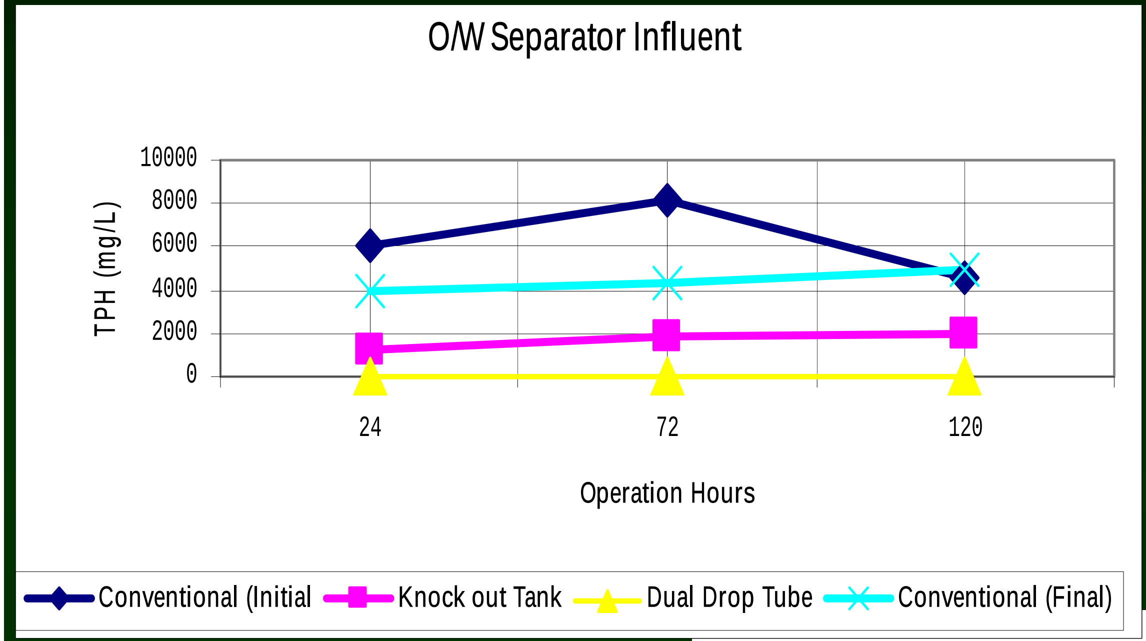
Results: Vacuum Pump Effluent Water

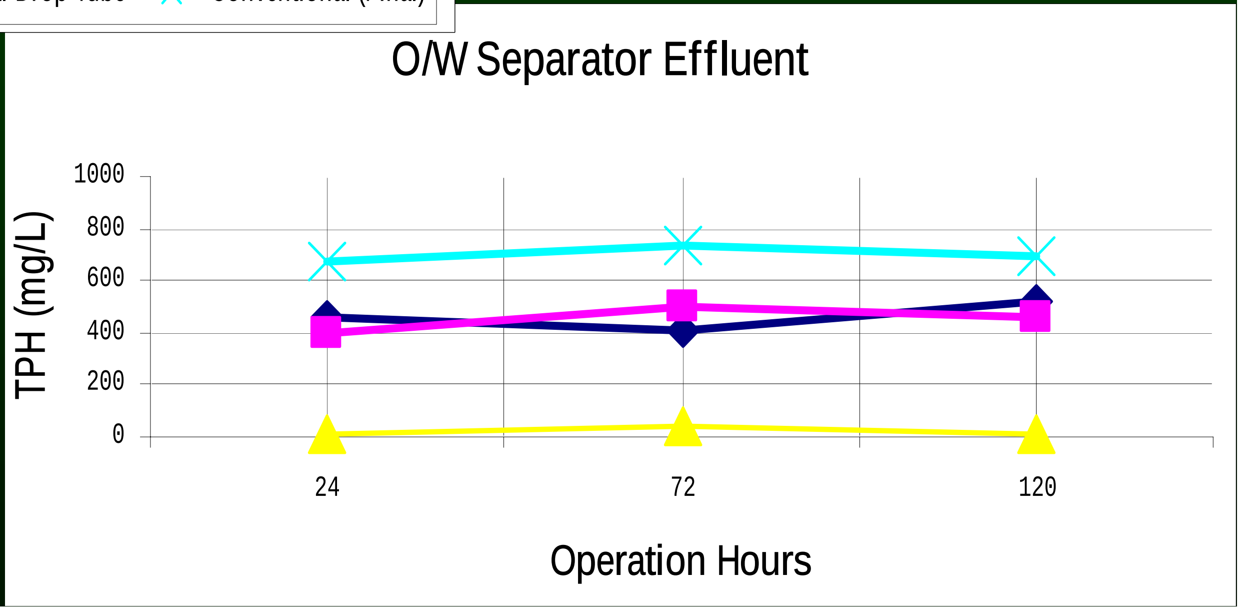
Site Location	TPH Concentration (mg/L) (Percent Reduction from Conventional Configuration)		
	Conventional	Dual Drop Tube	Knockout Tank
Short-Term Test Sites (1—2 day)			
NAS Fallon	1,800	7.5 (99%)	500 (72%)
NCBC Davisville (EW-3)	1,040	450 (57%)	NA
NCBC Davisville (EW-4)	3,050	16 (99%)	NA
MCBH Kaneohe	1,715	60 (96%)	230 (86%)
CSS Panama City	220	22 (90%)	NA
ESTCP Short-Term Demonstrations (Preliminary)			
NAS Fallon	4,944	32.5 (99%)	1,600 (67%)
Bolling AFB	588	1.2 (99%)	633 (0%)
NAWS China Lake			

Results: Vacuum Pump Effluent Water

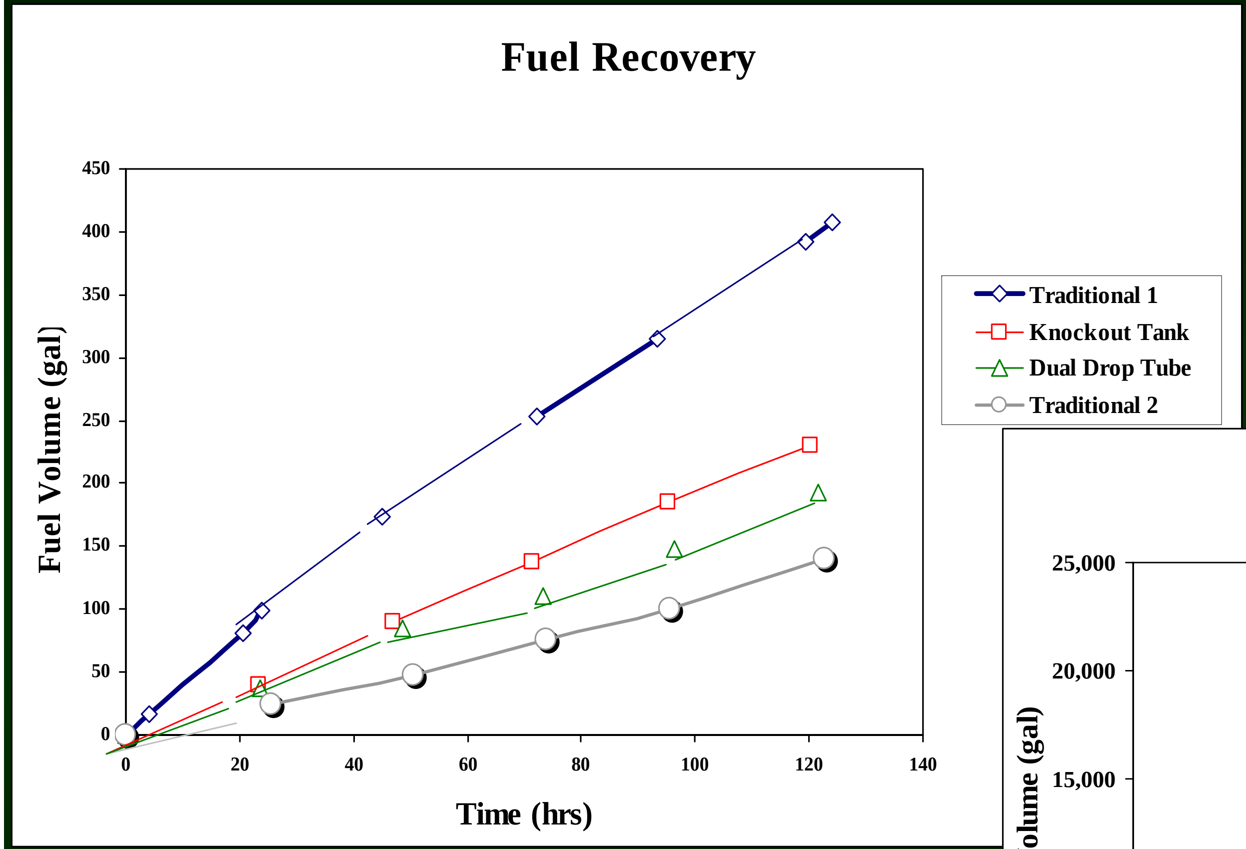
- NCBC Davisville Samples

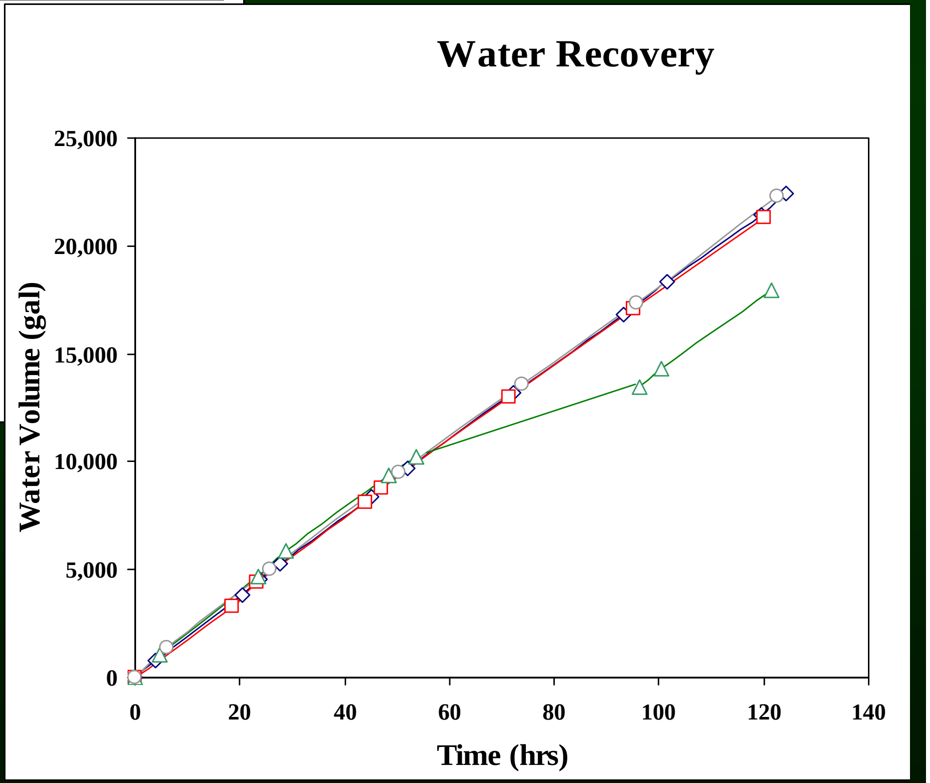
NAS Fallon - Short Term Test Influent and Effluent TPH



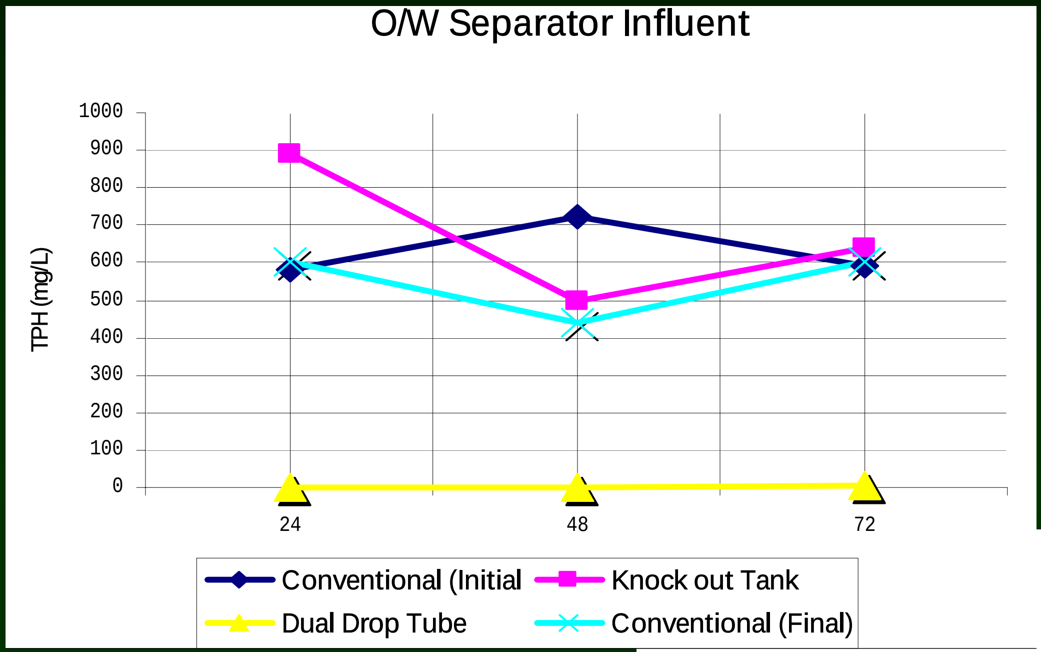


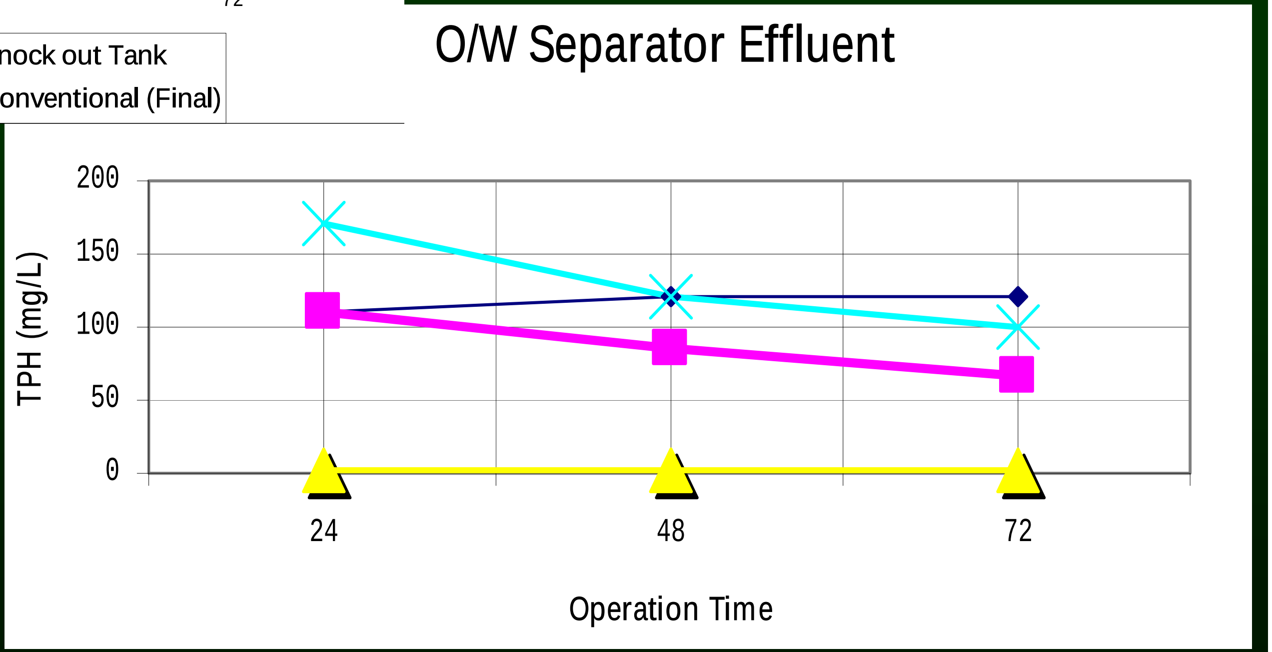
NAS Fallon - Short Term Test
Fuel and Groundwater Recovery



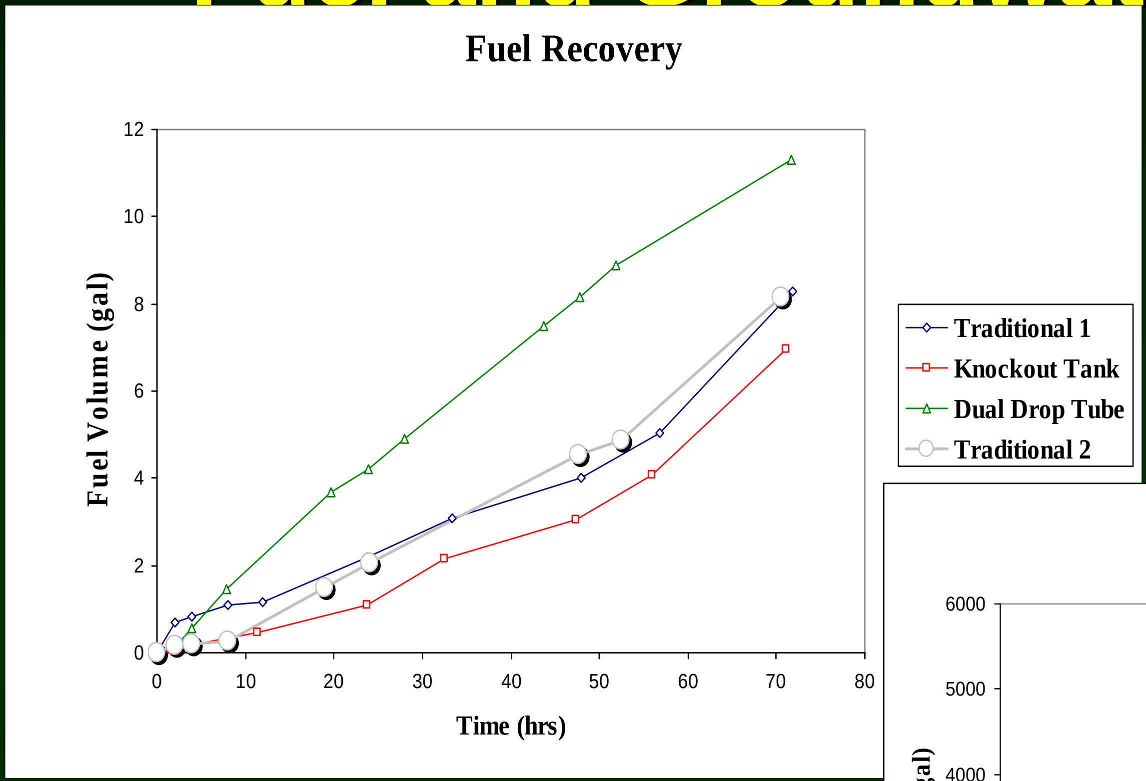


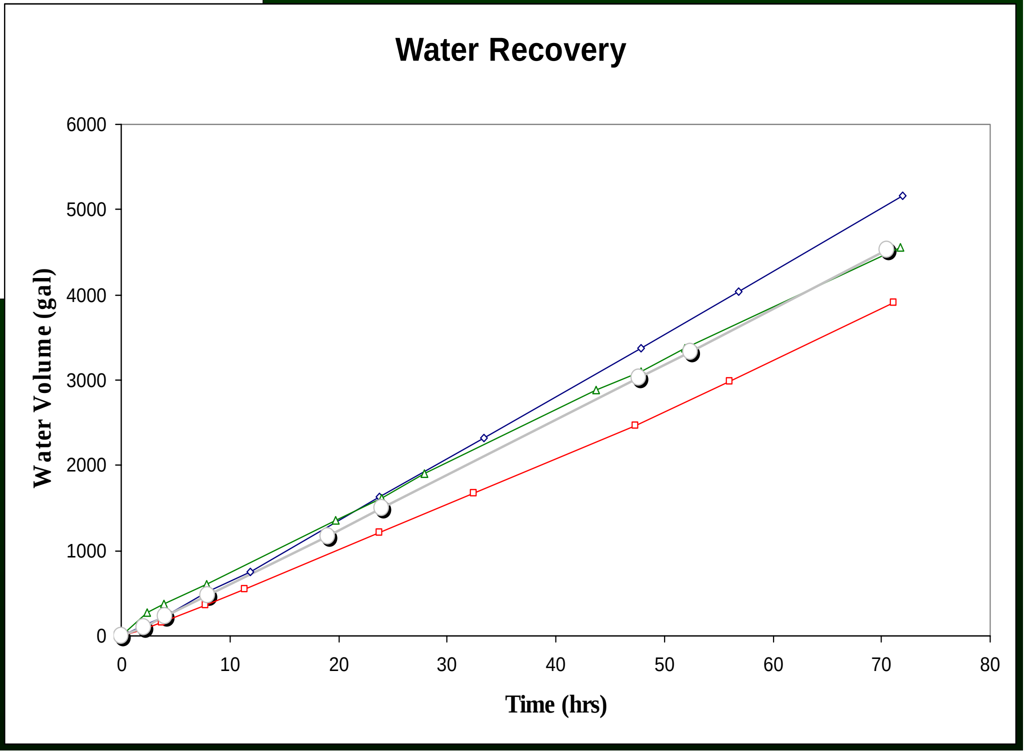
Bolling AFB - Short Term Test Influent and Effluent TPH



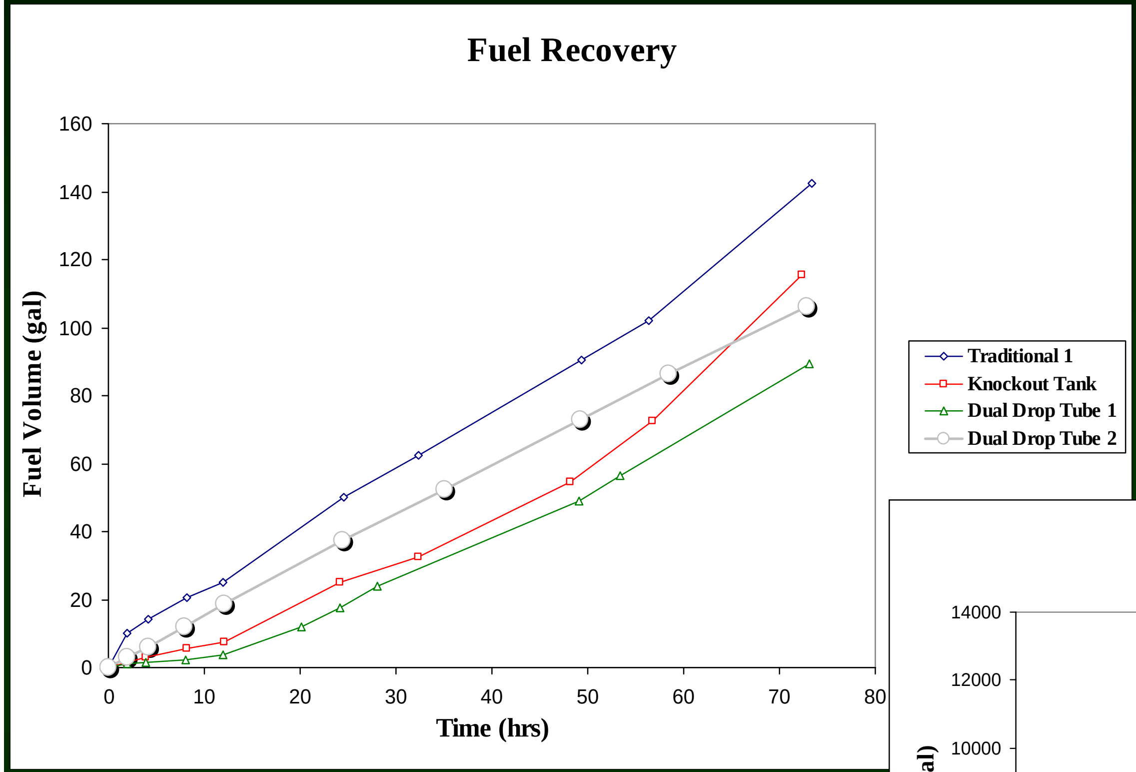


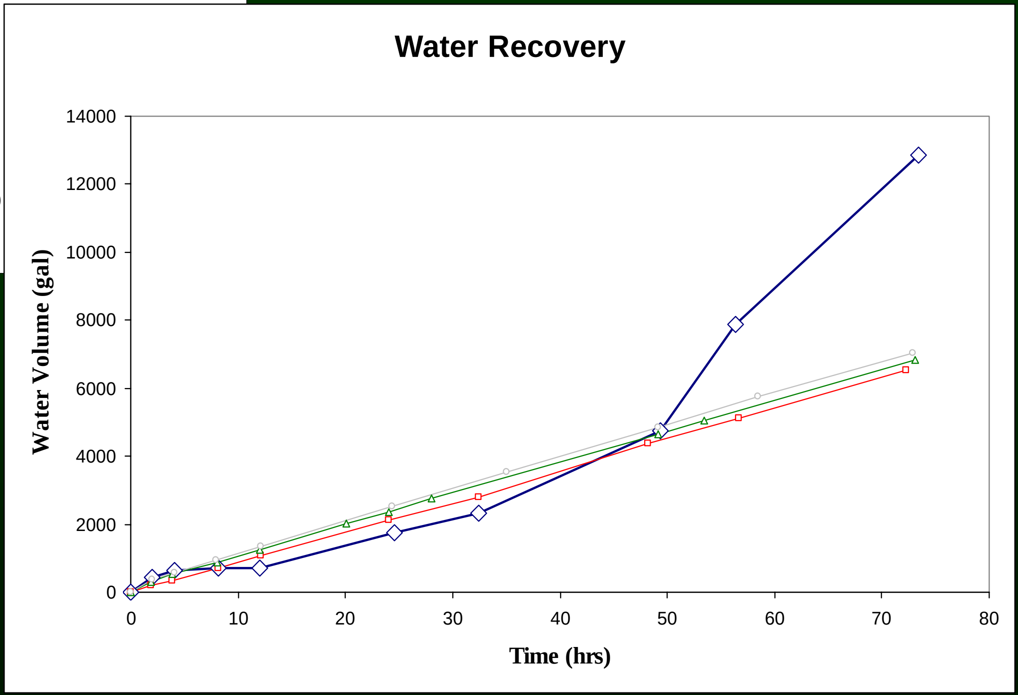
Bolling AFB - Short Term Test
Fuel and Groundwater Recovery





NAWS China Lake - Short Term Test Fuel and Groundwater Recovery



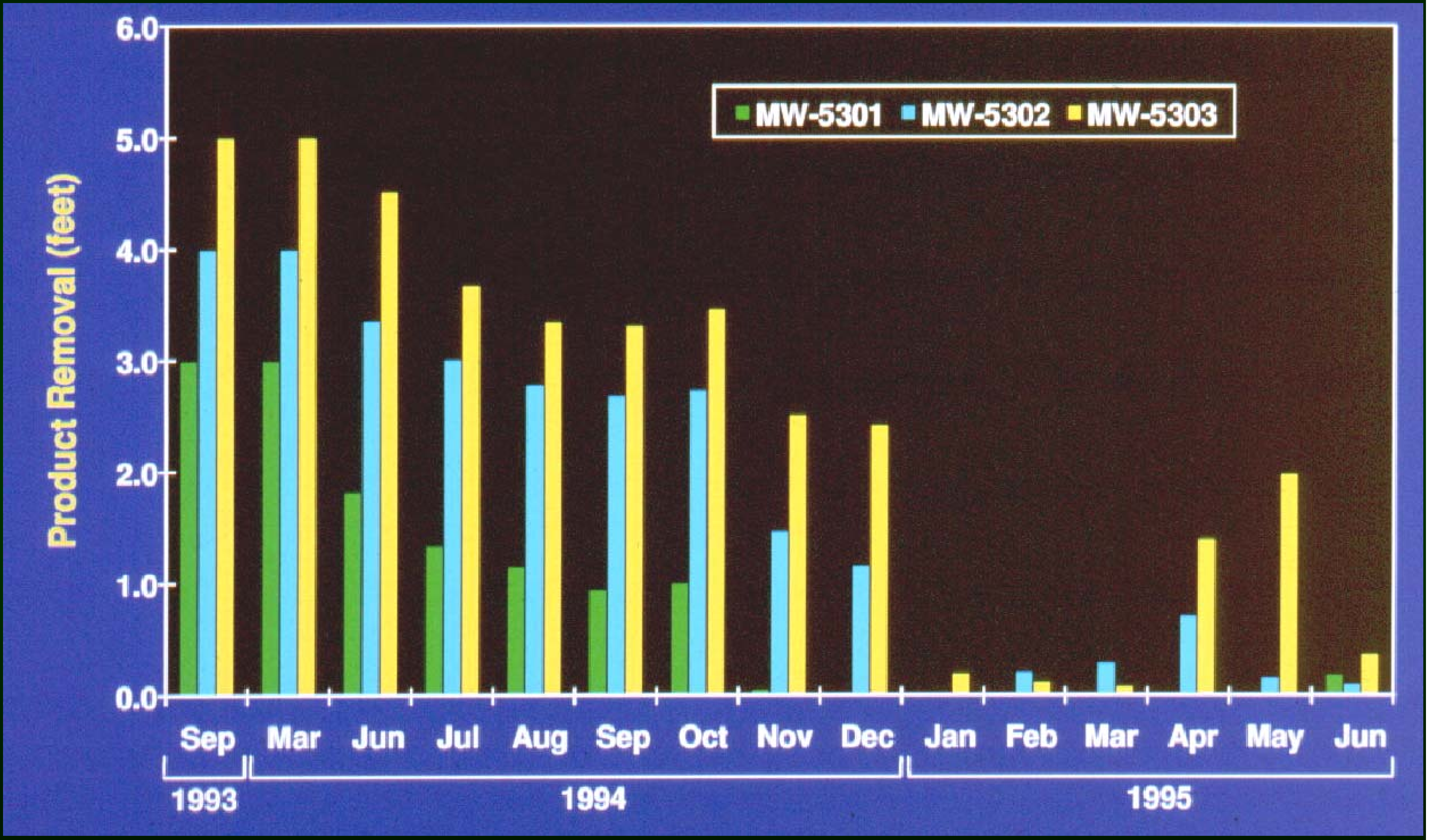


Results: Off-Gas

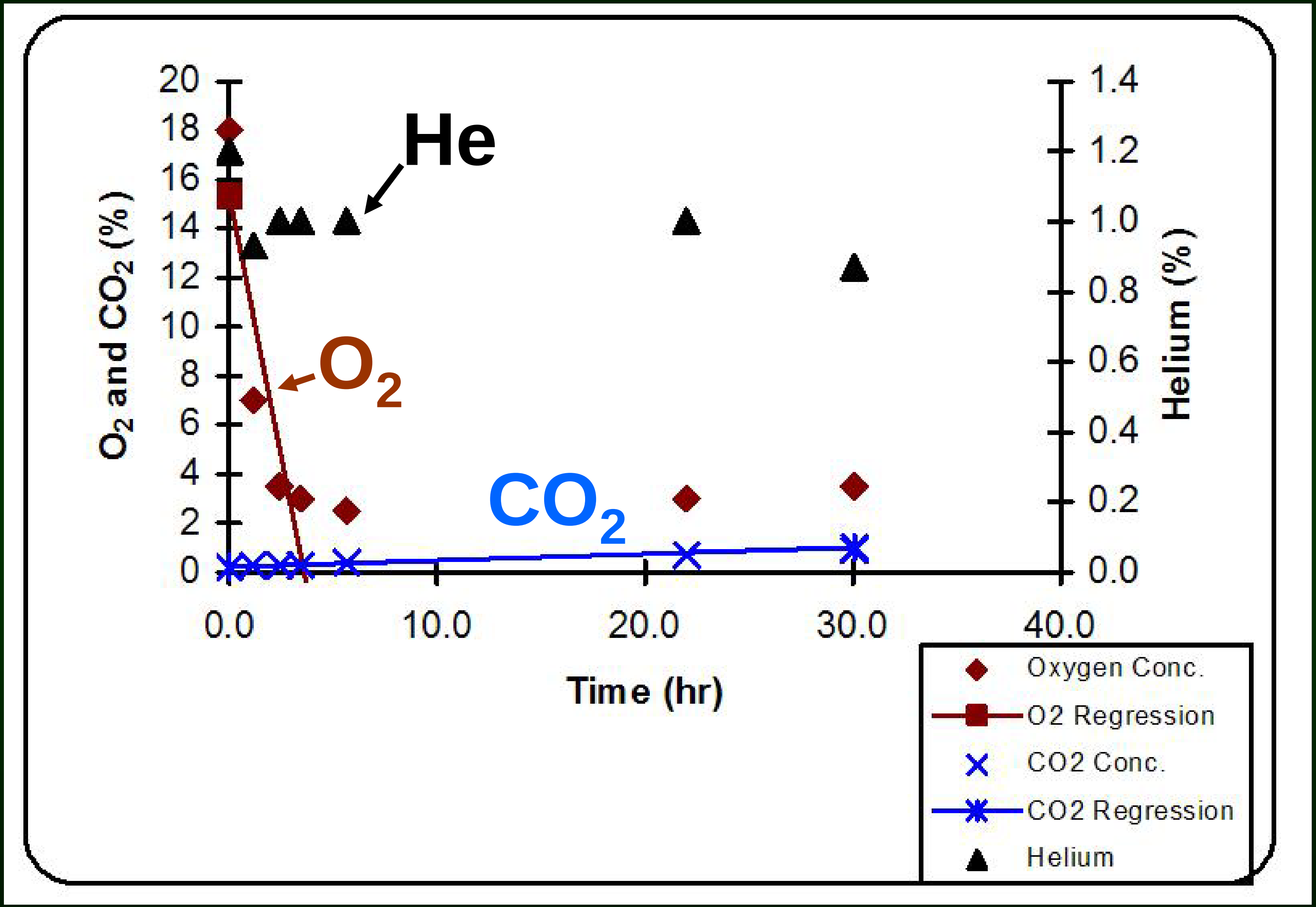
Site Location	TPH Concentration in the Off-Gas (ppmv), (Percent Reduction from Conventional Configuration)		
	Conventional	Dual Drop Tube	Knockout Tank
NAS Fallon	3,210	900 (72%)	1,950 (39%)
NCBC Davisville (EW-3)	675	620 (8%)	NA
NCBC Davisville (EW-4)	870	145 (83%)	NA
ESTCP Short-Term Demonstrations (Preliminary)			
NAS Fallon	2,940	2,350 (20%)	3,960 (0%)
Bolling AFB	160	100 (37%)	150 (6%)
NAWS China Lake			

Source: Hoeppel et. al.

72-hour Baildown Recovery Test Data



In Situ Respiration



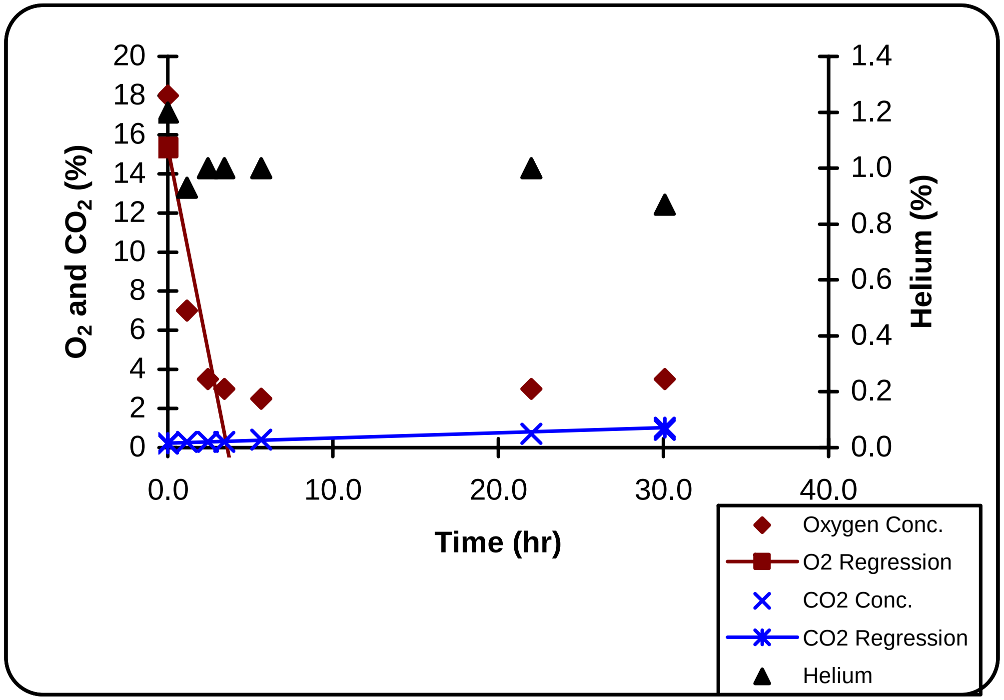
In Situ Respiration

In Situ Respiration Test: Data Analysis

Date: 1/23/95 **Site Name:** Travis Air Force Base

Monitoring Point: MPC **Depth of MP (ft):** 5.5

Date/Time (mm/dd/yr hr:min)	Time (hr)	Oxygen (%)	Carbon Dioxide (%)	Helium (%)
1/23/95 11:05	0.0	18.00	0.20	1.20
1/23/95 12:15	1.2	7.00	0.30	0.93
1/23/95 13:30	2.4	3.50	0.30	1.00
1/23/95 14:30	3.4	3.00	0.30	1.00
1/23/95 16:45	5.7	2.50	0.40	1.00
1/24/95 9:05	22.0	3.00	0.70	1.00
1/24/95 17:10	30.1	3.50	0.90	0.87



Regression Lines	O_2	CO_2
Slope	-4.2642	0.0264
Intercept	15.3373	0.2288
Determination Coef.	0.8240	0.6164
No. of Data Points	4	4

BiodegradationRate (mg/kg-day)

82.895

O_2 Utilization Rate

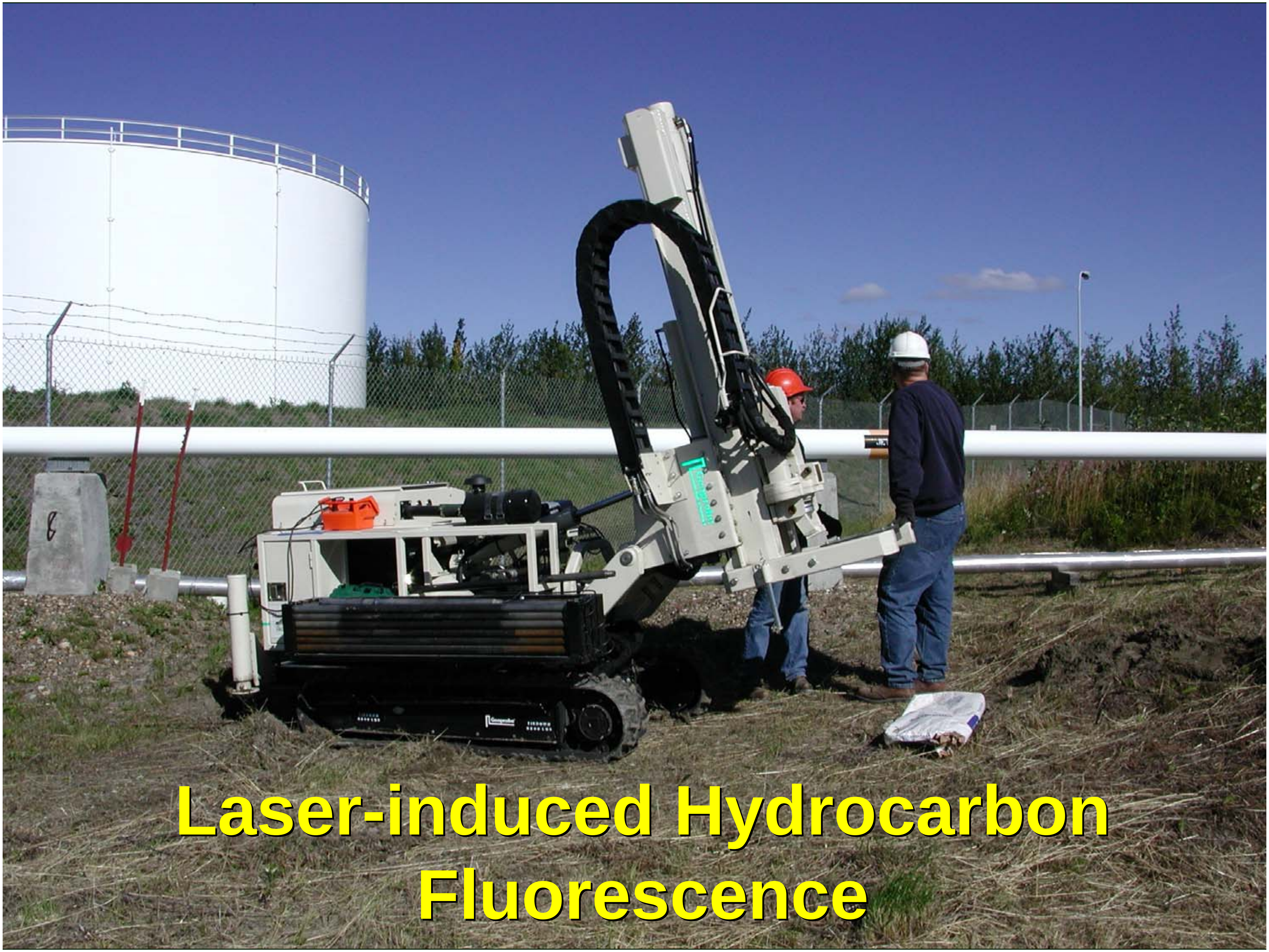
ko		
	0.071	%/min
	4.264	%/hr
	102.340	%/day

Bioventing Potential

- Fuel Storage Area G
  - Average biodegradation rate = 67.6 mg/kg-day
  - Assume:
    - Area of contamination = 750 m^2
    - Contaminated soil is 2m thick
    - 1m^3 of soil weighs 1440kg

$67.6 mg/kg\text{-}day \times 1440 kg/m^3 \times 750 m^2 \times 2 m = 146 kg/day$

Approximately 146 kg of hydrocarbons are biodegraded per day

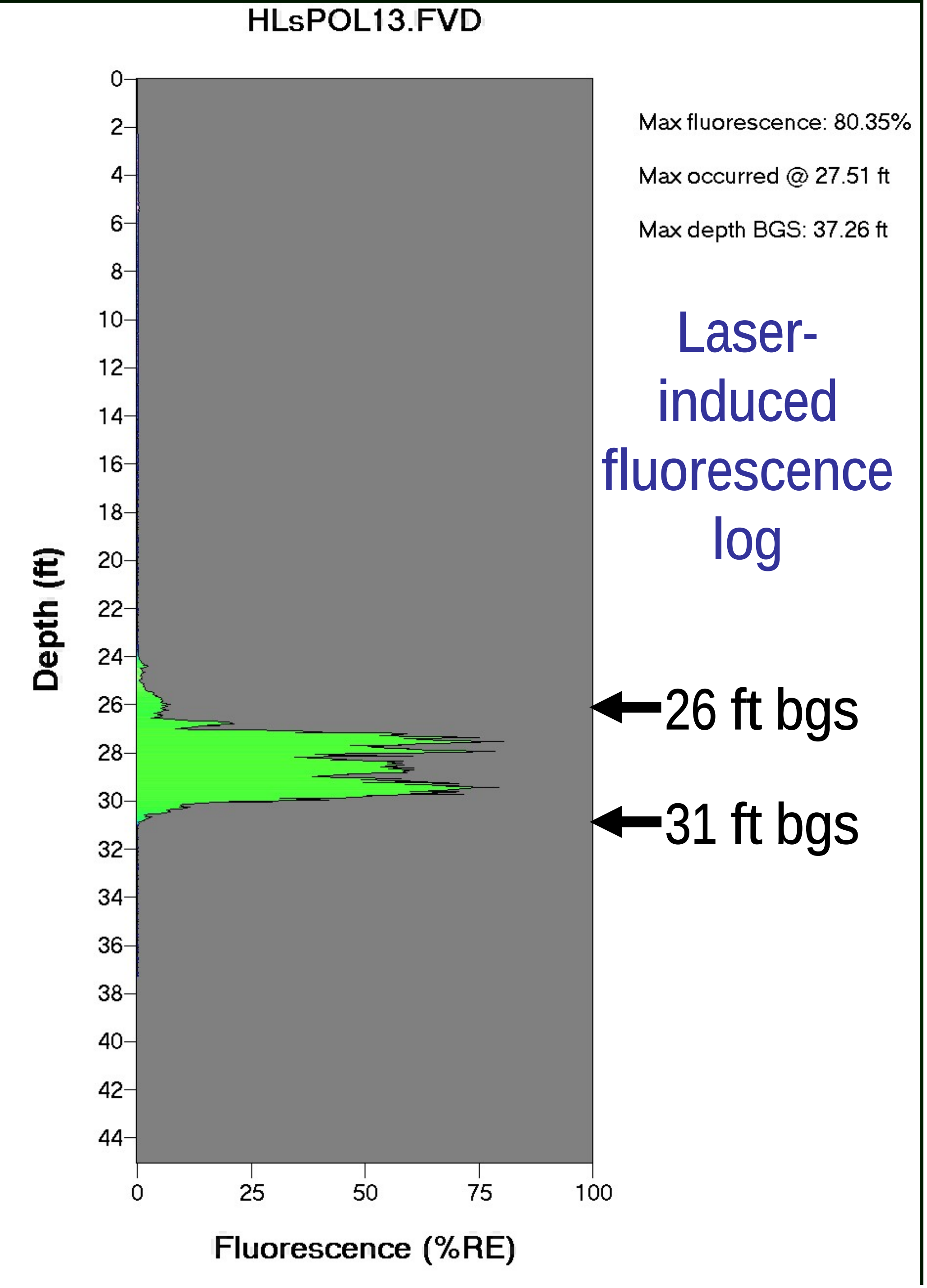


Laser-induced Hydrocarbon Fluorescence

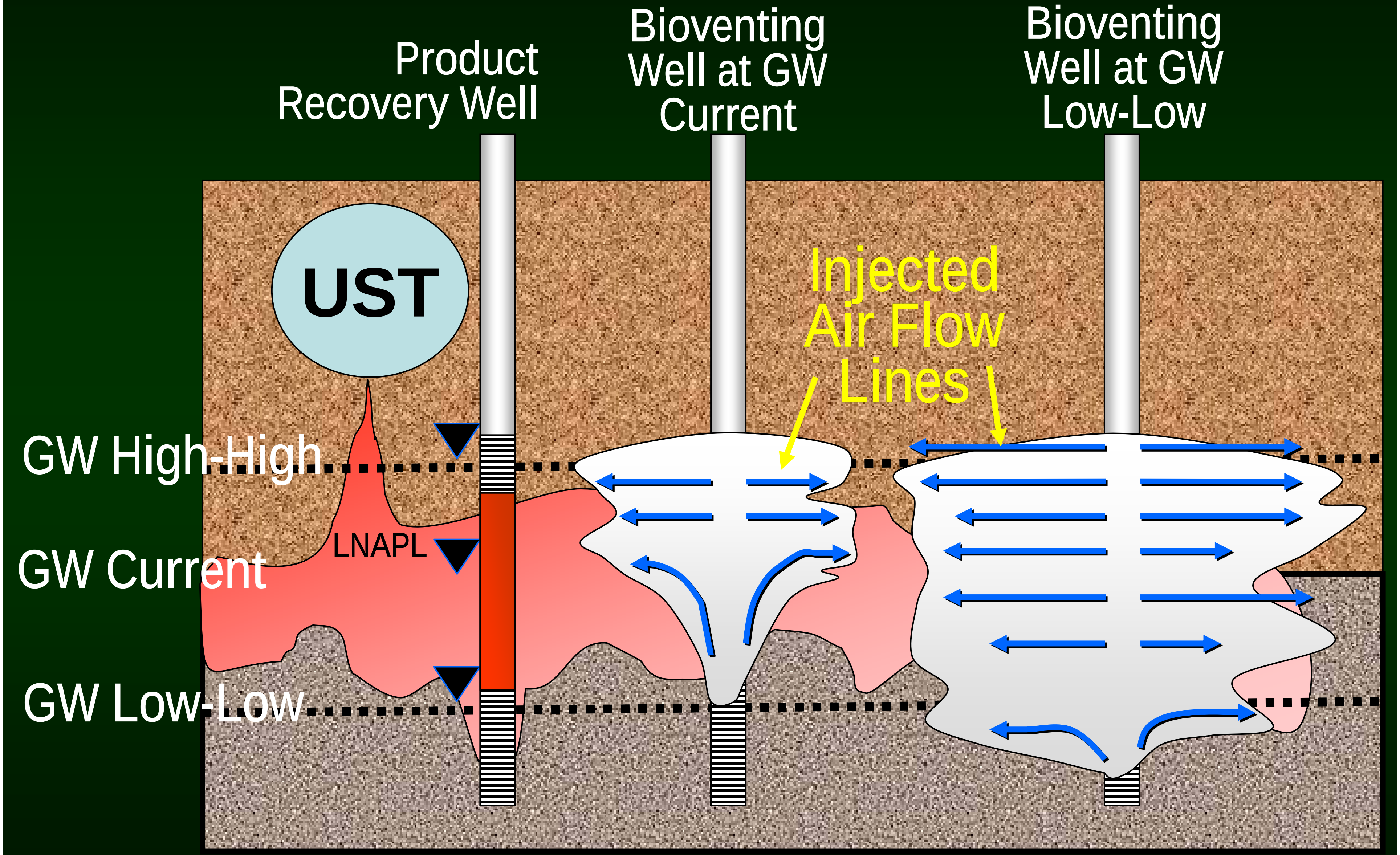
Fuel hydrocarbons at 26-31 ft bgs

Water table fluctuates from 6-26 ft bgs

Historic low at 32 ft bgs

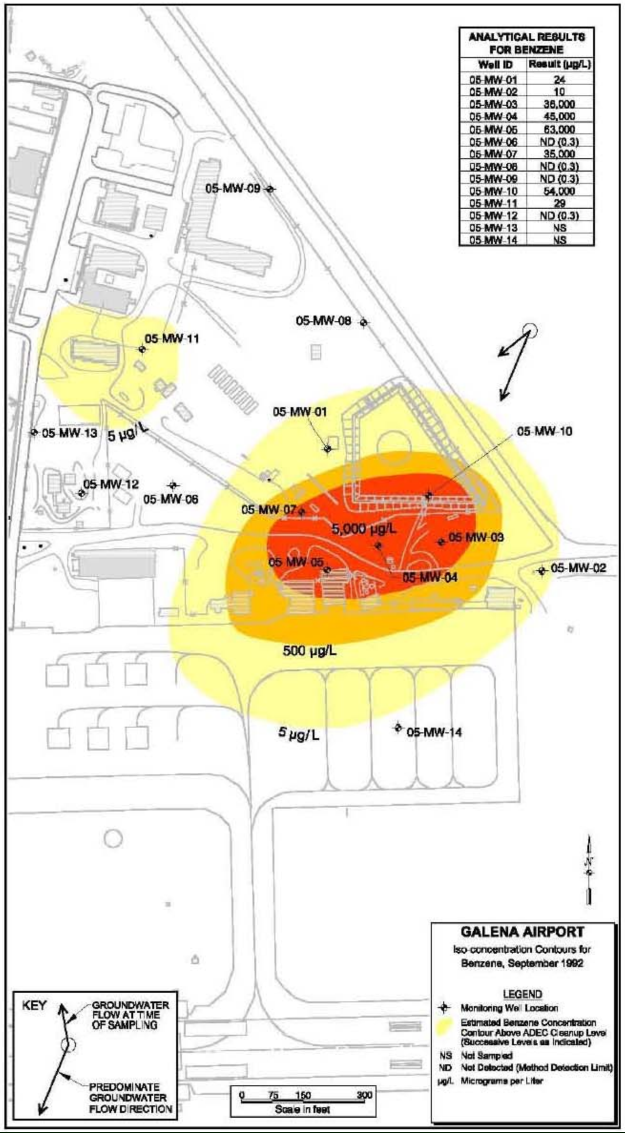


Smear Zone Treatment

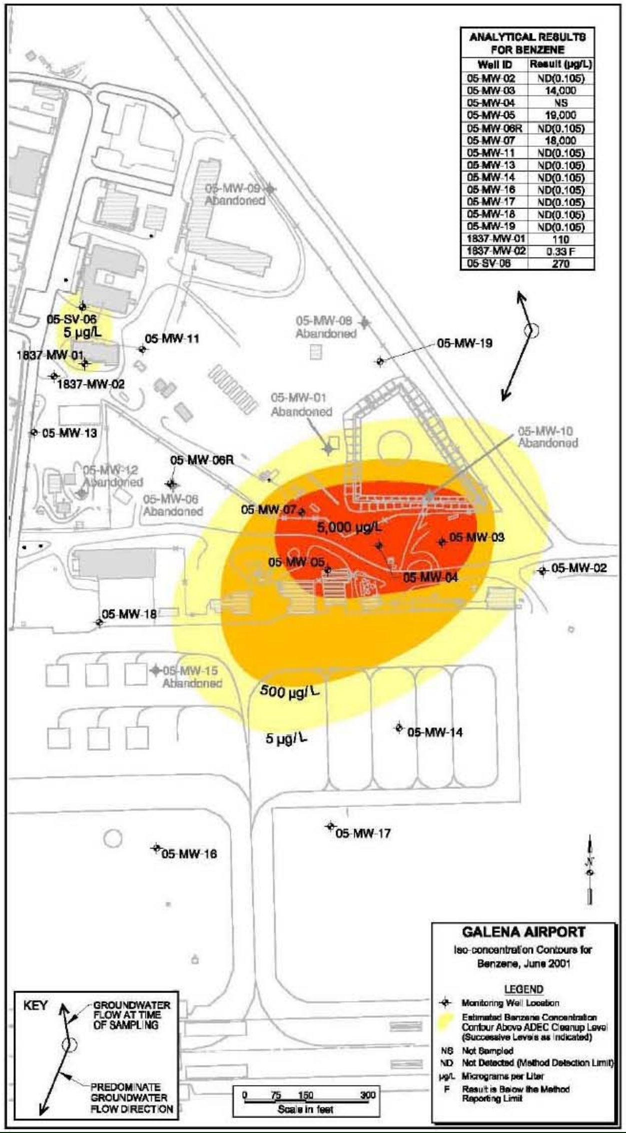


Stable Benzene Plume

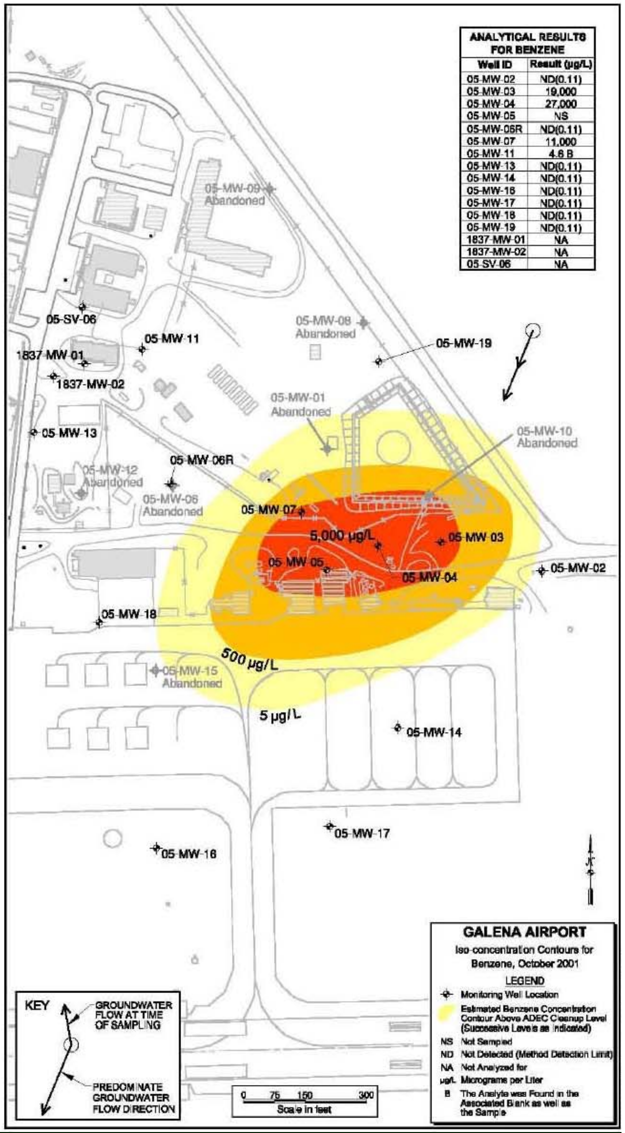
June 1992



June 2001



October 2001



Natural Removal Rates

Stable Plume

- **Assuming ground water seepage velocities of 1 to 11 feet/day, a 450-foot plume width and an average dissolved benzene concentration of 15 mg/L across a 20-foot vertical thickness, the mass removal rate of natural attenuation ranges from <u>940 – 10,400 lbs/year (140- 1,600 gallons/year)</u>**

Strategy

- Site characterization
  - Where is LNAPL in soil/aquifer matrix?
  - Is LNAPL mobile?
    - Consecutive baildown recovery to assess mobility
    - Short-term low tech removal
- Recovery Potential
  - Baildown, baildown, baildown?
- What's the risk?
  - Composition – Kerosene or Benzene?
  - NAPL and dissolved plume mobility – Stable, decreasing?

Strategy (cont)

- Remediation
  - During low ground water levels
  - If mobile, consider liquid phase recover
    - Vacuum-enhanced?
  - If volatile, consider SVE
  - Always consider biodegradation – Natural and bioventing
- Closure
  - Risk-based
  - Develop criteria for free product recovery to the maximum extent practical

Questions?