Kennedy/Jenks Consultants

Session 3 Presentation
F3. LNAPL Recovery/Remediation Technology Transitions

BATTELLE

Conference on Remediation of Chlorinated & Recalcitrant Compounds

Remedial Optimization:
Transitioning from Physical LNAPL Removal to Enhanced Biological Degradation to Natural Depletion

April 11, 2018 | Palm Springs, CA

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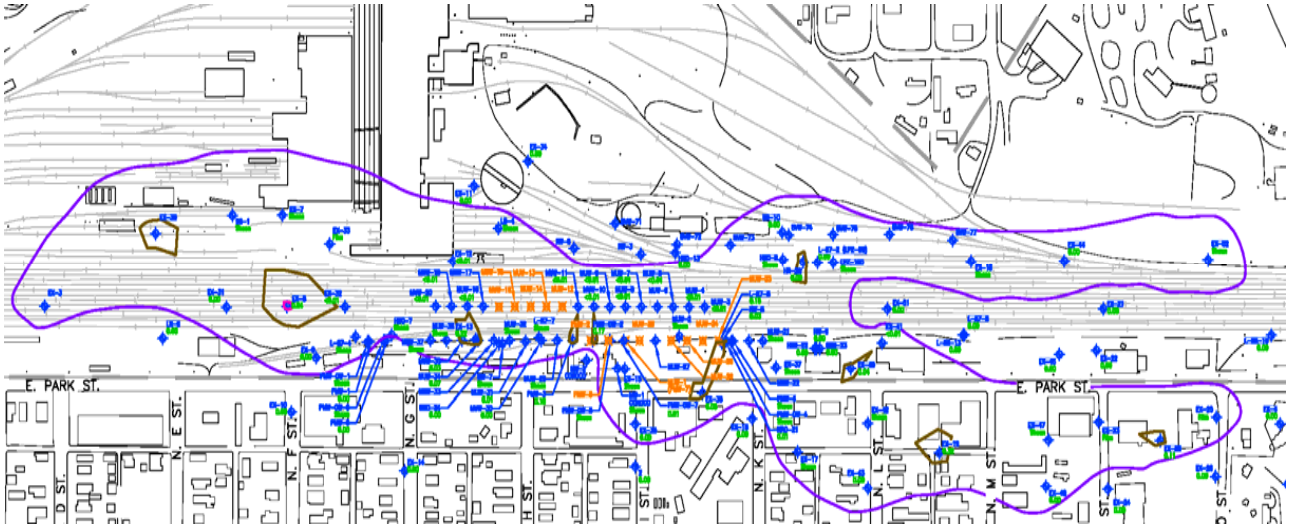
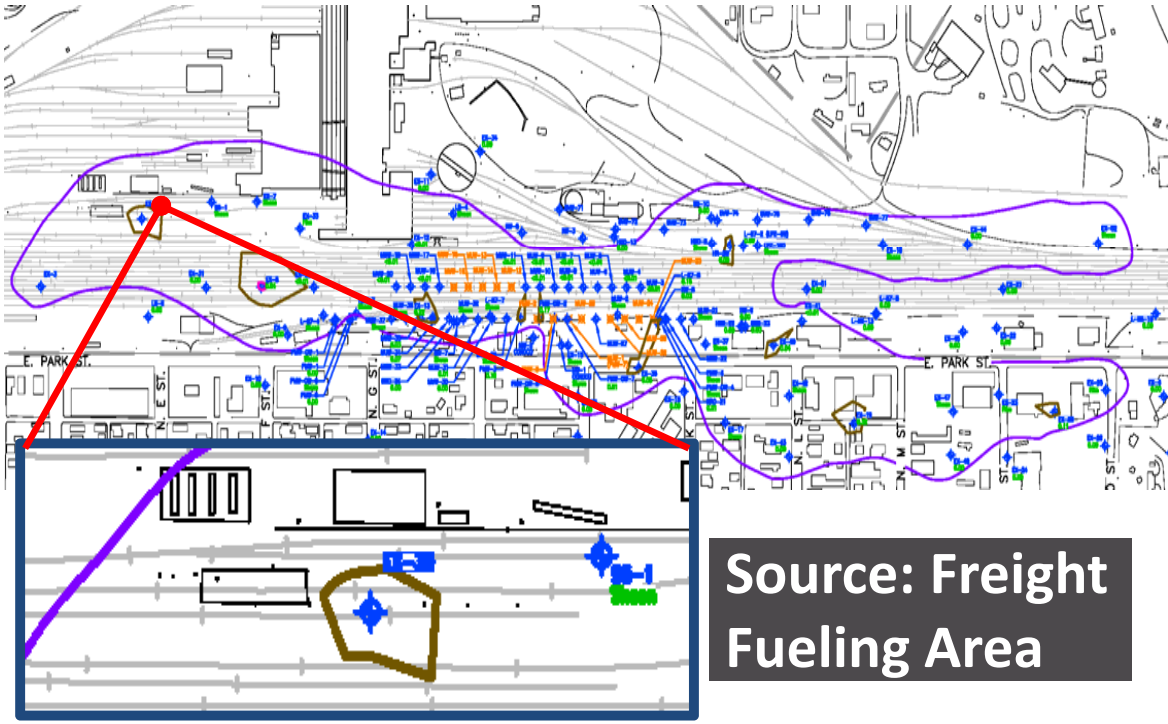
Agenda

- Background
- Hydrogeology
- LNAPL Remediation
- Bioventing System
  - Operational Details
  - Respirometry Testing
- Remediation Summary
- Path to Closure



Background

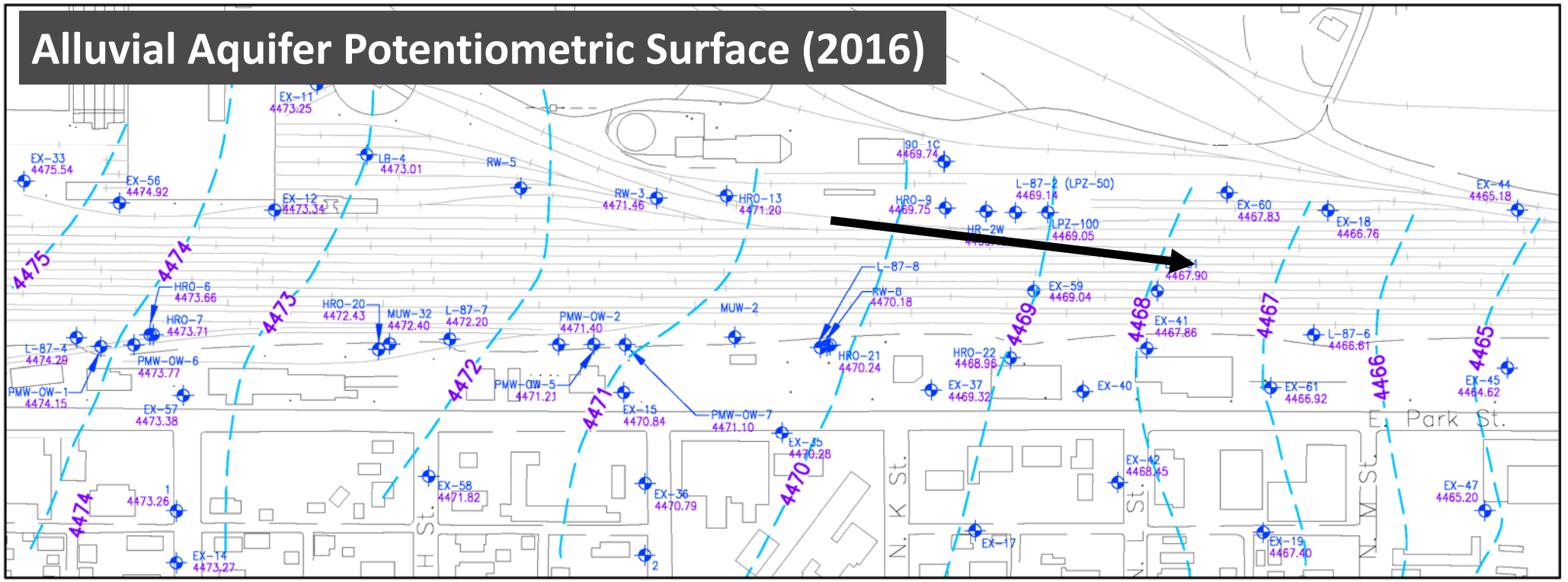
- Diesel fuel released from two separate source areas on-site
- LNAPL plume discovered in 1980s
- Remedial investigations conducted in 1990s & early 2000s
- LNAPL identified across a 16-acre area, up to 1.5 feet thick



Source: Freight Fueling Area

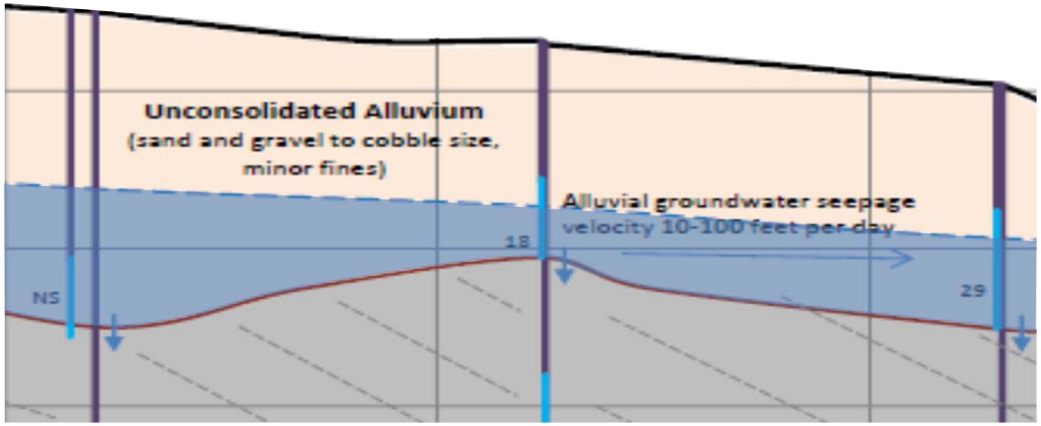
Hydrogeology

Alluvial Aquifer Potentiometric Surface (2016)



Hydrogeology

- Unconfined aquifer
- Sand & gravel matrix overlying bedrock
- General groundwater flow to the northeast
- Seepage velocity: 10 to 70 feet per day
- Saturated thickness ranges: ~ 2-35 feet
- Vadose zone thickness ranges: ~ 15-25 feet
- Annual groundwater surface fluctuations: 1-7 feet



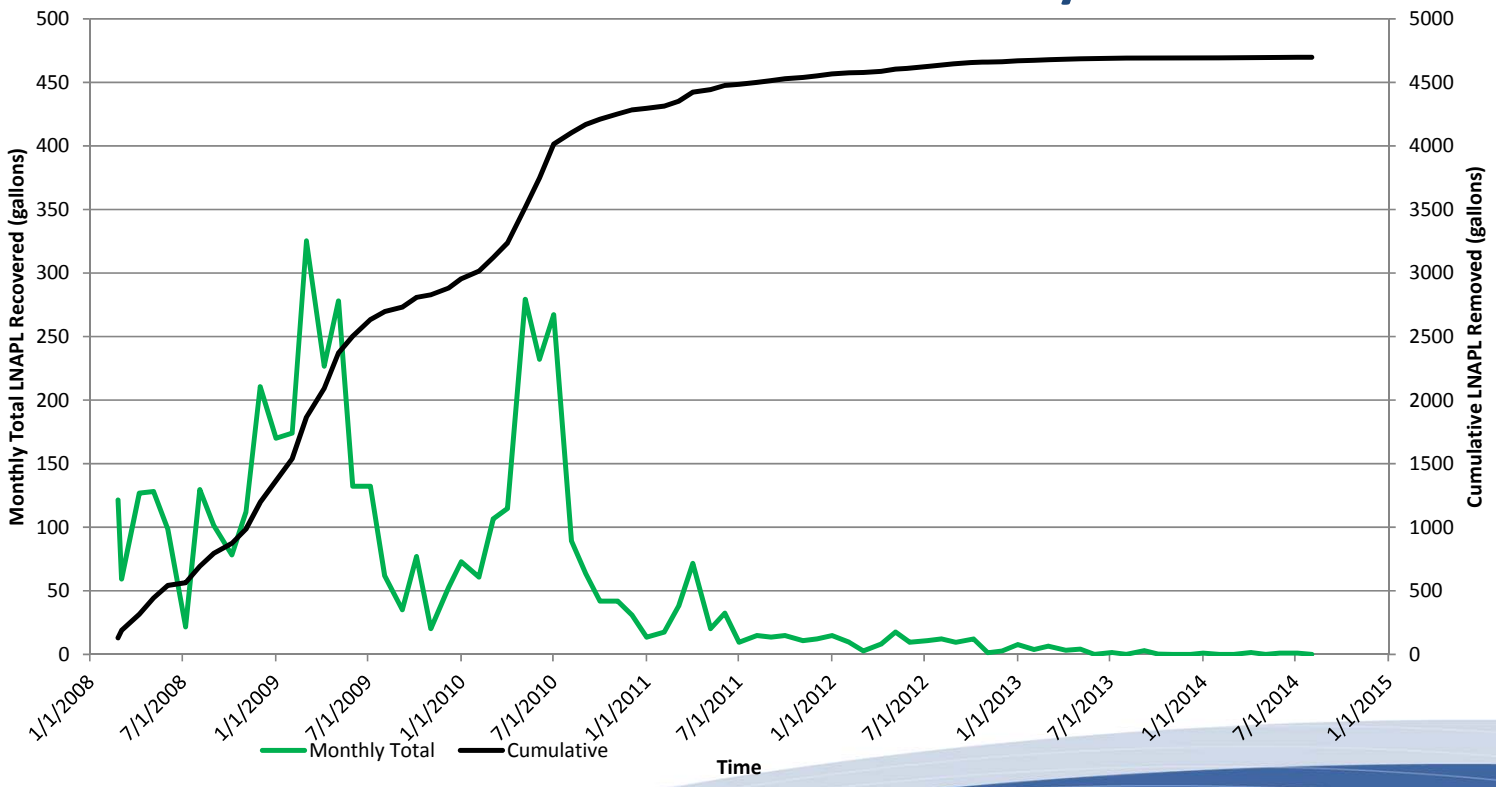
LNAPL Remediation

- Dual-Level Pumping System[1] (DLPS)
  - Constructed in 2007 & operated from 2008-2014
  - 39 extraction wells over 6 acres
  - Average extraction rate - 270 GPM (total)
  - Groundwater pumps extracted groundwater to depress water table
  - Fluid pumps removed LNAPL from extraction wells
  - Centralized separation & treatment plant
  - Effluent discharged to nearby river
- Bioventing System[2]
  - Constructed in 2007 & started operating in 2008
  - System expanded in 2012
  - 41 injection/extraction wells in 3 zones
  - Closed-loop system
  - Injecting beneath railroad tracks & in open areas
  - Extracting near building

ITRC LNAPL-3 *LNAPL Site Management: LCSM Evolution, Decision Process and Remedial Technologies,* Appendix A-4[1] and A-14[2]

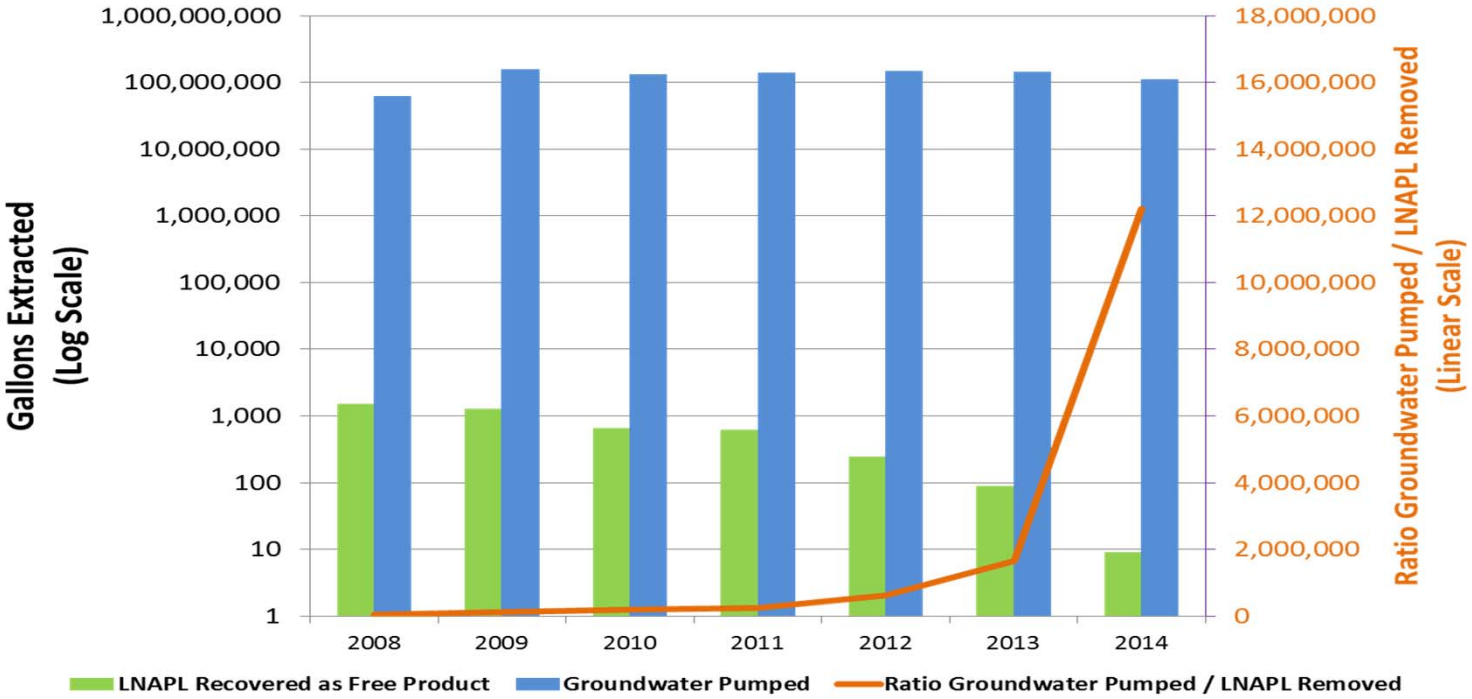
LNAPL Remediation - DLPS

Cumulative LNAPL Recovery



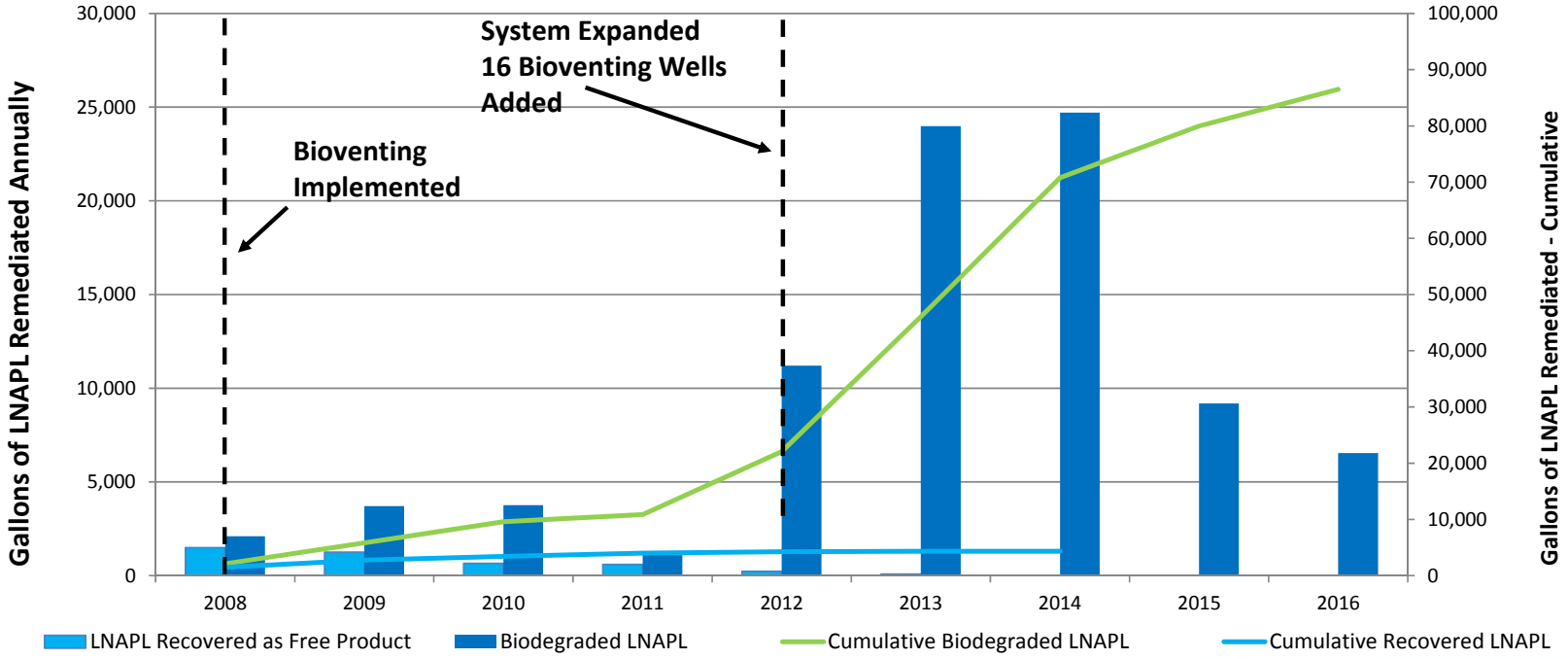
LNAPL Remediation - DLPS

Annual Liquid Recovery Comparison



LNAPL Remediation - Bioventing

Cumulative LNAPL Degradation

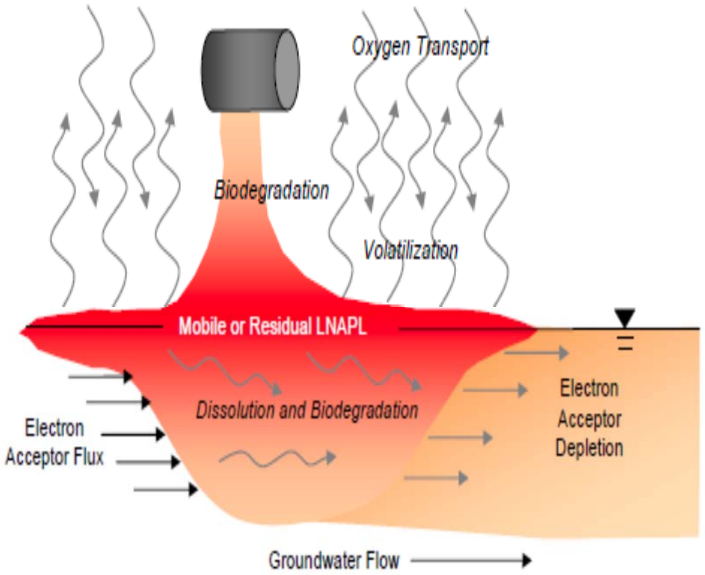


LNAPL Remediation – Natural Source Zone Depletion

Biodegradation	
Electron Acceptor or Electron Acceptor Product	**Hydrocarbon Biodegraded (kg/yr)**
O_2	248
NO_3^-	15
$Fe(OH)_{3(s)}$	0.1
$MnO_{2(S)}$	8
SO_4^{2-}	0.0
CH_4	0.2
Total	**272**

Dissolution	
Compound	**Mass Flux Under Natural Gradient Conditions (kg/yr)**
TPH	252

Depletion Mechanism	kg/yr	gal/yr
Biodegradation	272	177
Dissolution	252	162
Total	**524**	**341**

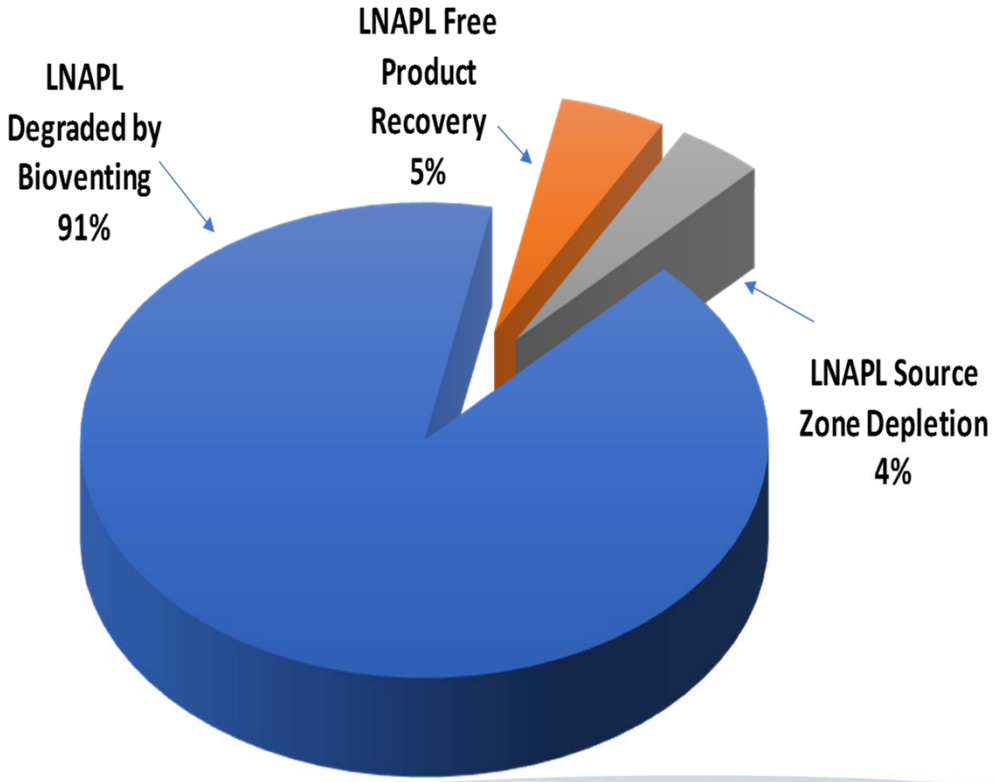


NSZD will be used as a polishing step

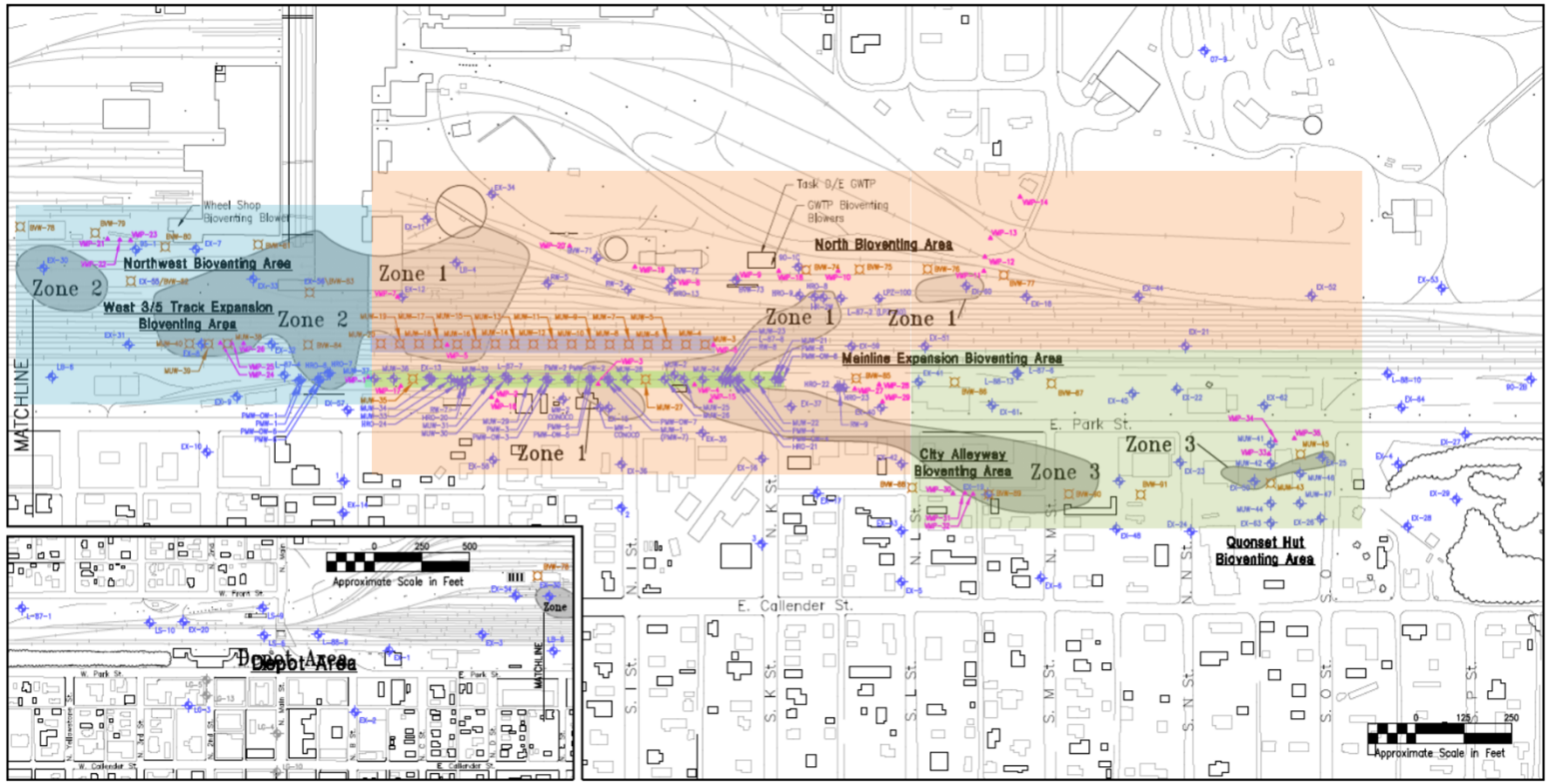
LNAPL Remediation – Results

- DLPS: 7 years/4,600 gallons of LNAPL removed
- Bioventing: 10 years/96,750 gallons of LNAPL biodegraded

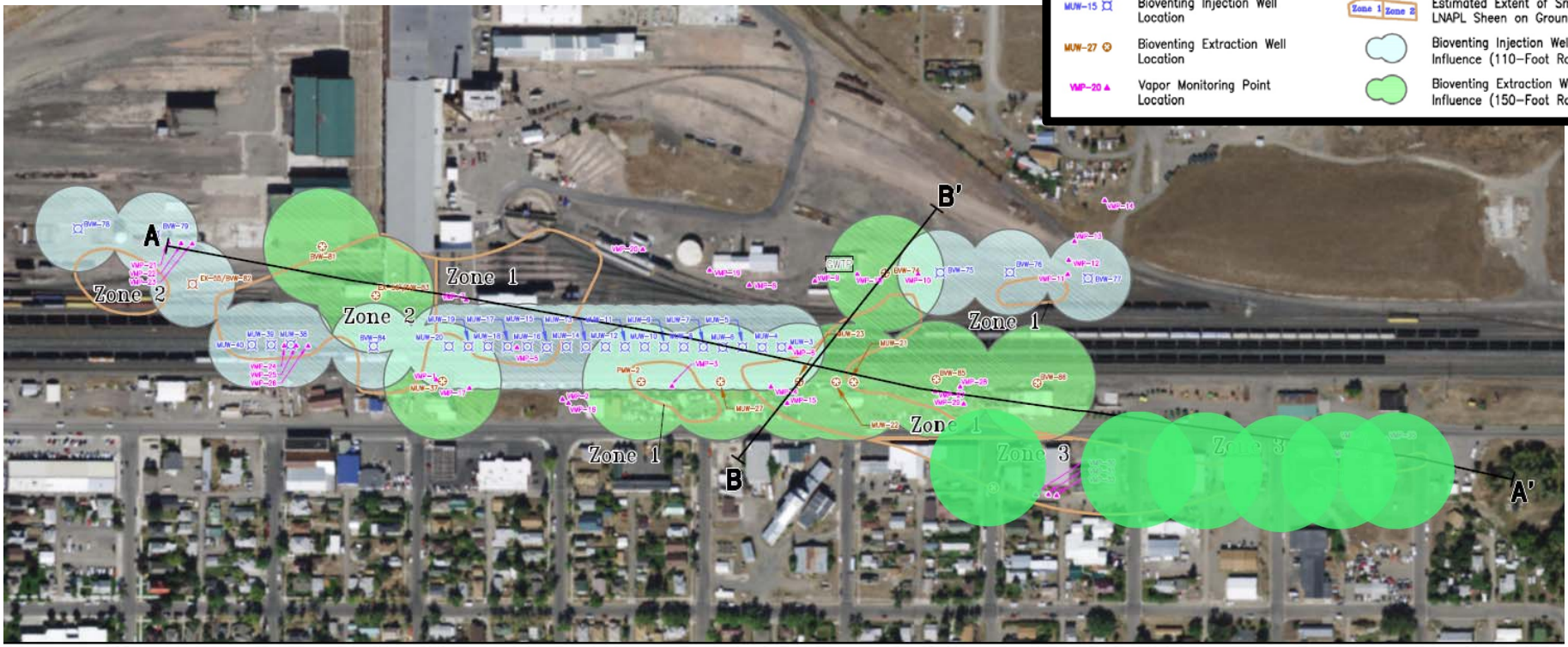
Criteria	2008	2017
No. of Wells with LNAPL	84	11
Maximum LNAPL Thickness (ft)	1.35	1.02
Average LNAPL Thickness (ft)	0.21	0.13
Aerial Extent of LNAPL (acres)	16	<0.1



Bioventing


Northwest Bioventing Area
West 3/5 Track Expansion Bioventing Area
North Bioventing Area
Meinline Expansion Bioventing Area
City Alleyway Bioventing Area
Quonset Hut Bioventing Area
Depot Area
Zone 1
Zone 2
Zone 3
MATCHLINE
E. Park St.
E. Callender St.
Approximate Scale in Feet

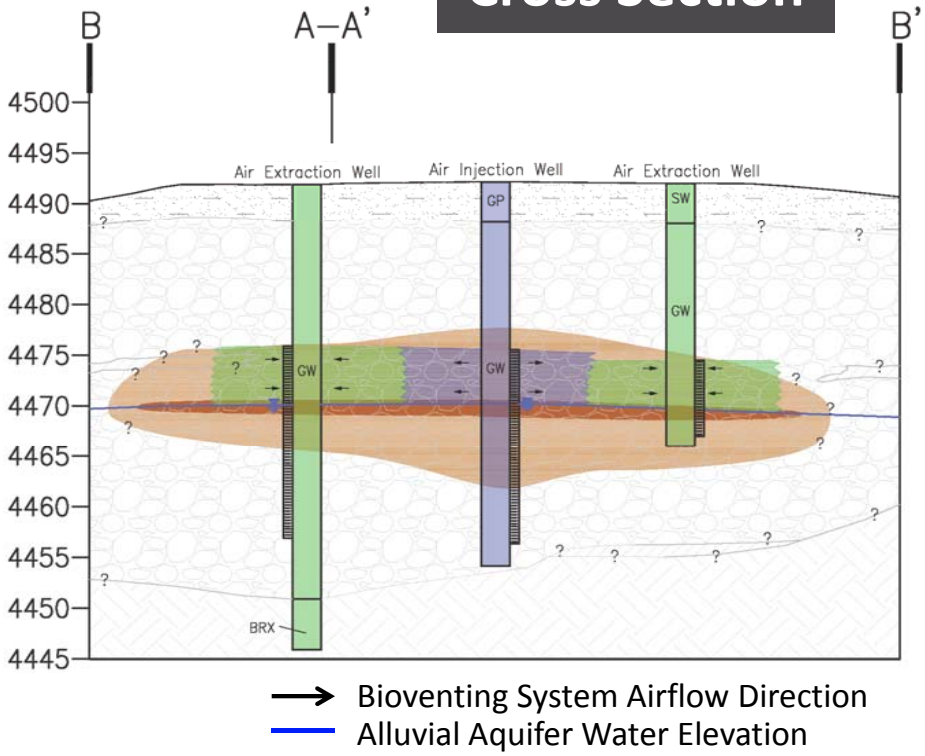
Bioventing


Legend
MW-15
Bioventing Injection Well Location
MW-27
Bioventing Extraction Well Location
VMP-20
Vapor Monitoring Point Location
Zone 1
Zone 2
Estimated Extent of Smear Zone/ LNAPL Sheen on Groundwater
Bioventing Injection Well Area of Influence (110-Foot Radius)
Bioventing Extraction Well Area of Influence (150-Foot Radius)
A
A'
B
B'
Zone 1
Zone 2
Zone 1
Zone 1
Zone 1
Zone 3
Zone 3
N

Bioventing

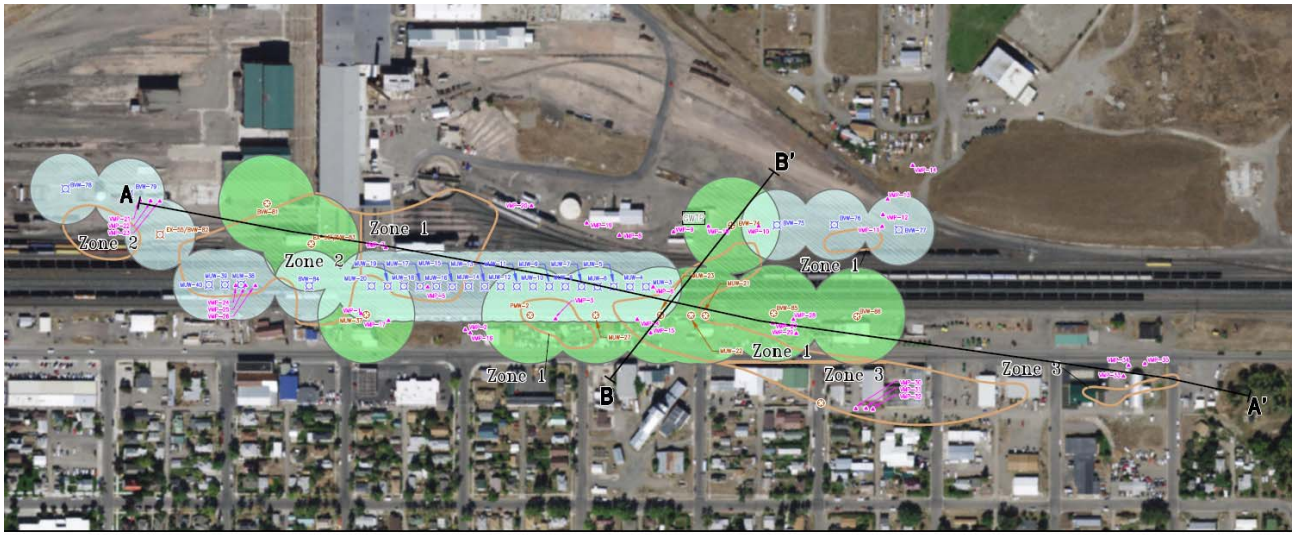
- Provides air/oxygen (O_2) to existing microorganisms in soil to stimulate/ sustain natural in situ biodegradation
- Microbial population uses the petroleum hydrocarbon compounds as a food source & respires carbon dioxide (CO_2)
- Biodegradation evaluated by monitoring O_2 reduction & CO_2 production (respirometry testing)

Cross Section



Bioventing – 2017 Operations

- Air Recirculation – No Discharge to Atmosphere
- Estimated ROIs (per well)
  - 150-200 feet (extraction)
  - 50-100 feet (injection)
- Zone 1
  - Extraction: 515 CFM (4 to 5 in. H_2O per well)
  - Ambient Air Dilution 300 CFM
  - Injection: 800 CFM



- Zone 2
  - Extraction: 200 CFM (10 to 20 in. H_2O per well)
  - Injection: 200 CFM (3 to 10 in. H_2O per well)

Bioventing – Respirometry Testing

- Semiannual measurements
- 25 multiscreened (shallow/deep) monitoring points
- Measure O_2 & CO_2 2x/daily for 7-10 days
- Evaluate O_2 utilization/CO_2 generation
- Biodegradation rates (Hinchee, R.E. 1996):
  - $K_b = (-k_O/100) * (\theta_a * \rho_{O2} * C/\rho_k)$
  - $K_b = (k_{CO2}/100) * (\theta_a * \rho_{CO2} * C/\rho_k)$

Term	Definition
k_B	Biodegradation rate
k_O	Oxygen utilization rate
k_{CO2}	Carbon dioxide generation rate
θ_a	Gas-filled porosity
ρ_{O2}	Oxygen density
C	Hydrocarbon to oxygen ratio
ρ_k	Soil bulk density

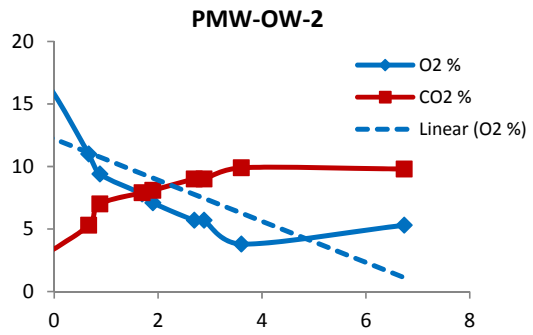
Bioventing – Respirometry Testing Results

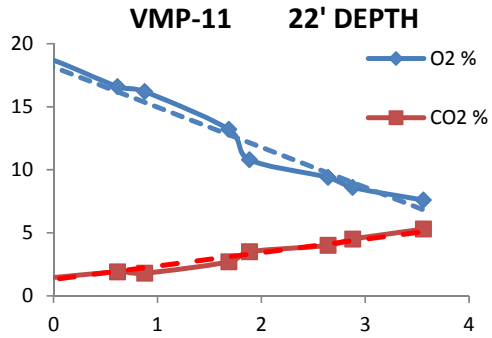
- Oxygen Utilization
  - K_o = 4.70%/day
  - K_b = 0.96 mg/kg/day*
- Carbon Dioxide Generation
  - K_{co2} = 2.03%/day
  - K_b = 0.65 mg/kg/day*

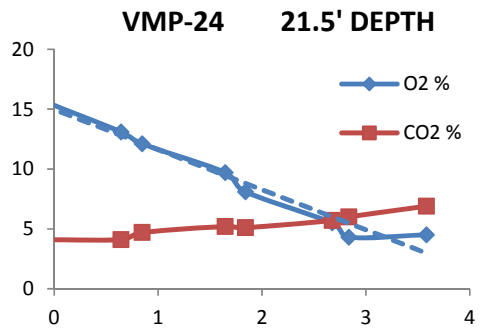
$K_b = (-k_O/100) * (\theta_a * \rho_{O2} * C/\rho_k)$

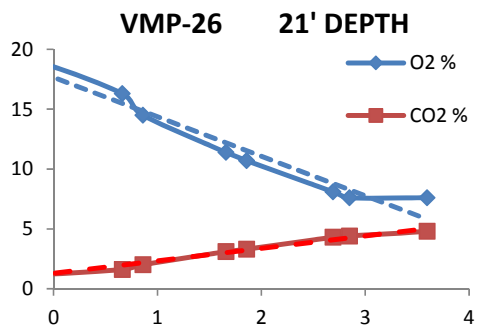
$K_b = (k_{CO2}/100) * (\theta_a * \rho_{CO2} * C/\rho_k)$

*mg hexadecane equivalent/kg/day









Remediation Summary

Remediation Systems	
Dual Phase Extraction System	**Bioventing**
Operated 7 years	Operated 10 years
39 Dual Phase Extraction Wells	42 Injection/Extraction wells
970,000,000M gal water 4,600 gal LNAPL	96,750 gal LNAPL
5% of LNAPL	91% of NAPL

LNAPL Reduction	
2008	**2017**
84 Wells	11 Wells
16 Acres	<0.1 Acre
1.35 ft / 0.21 ft LNAPL	1.02 ft / 0.13 ft LNAPL

Path Forward to Closure

- Zones 1&2 shut down on 5 March 2018 for long-term respirometry test
  - Respirometry testing weekly in March 2018
  - Respirometry testing monthly through 2018 or until subsurface oxygen concentrations drop below 7% for three consecutive months
- Additional focus on hot spots
  - Look for options for hot-spot removal of LNAPL from individual wells, if needed
  - Monitor dissolved plume changes over time
- Groundwater monitoring program
  - Monitor natural source zone depletion
  - Demonstrate remedial goals achieved

Introduction

- 31 Years of Experience
- Professional Geologist, CA/OR
- Certified Hydrogeologist, CA
- BA, Geology, 1987
- BS, Oceanography, 1989

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