



# Optimization Tools and Strategies Implemented at Sites with Long- Term Remediation Systems

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**Information in this presentation is current as of 9 May 2025.**

EXWC: Engineering and Expeditionary Warfare Center  
NAVFAC: Naval Facilities Engineering Systems Command

# Speaker Introduction



## Mike Perlmutter, PE Senior Environmental Engineer



- Bachelor of Science from Georgia Tech
- Master of Science from University of Texas at Austin
- Senior environmental engineer with more than 25 years of experience evaluating and designing a wide range of remediation systems to address contaminated soil and groundwater at numerous federal and commercial project sites
- Experience includes conducting feasibility and corrective measures studies; designing, implementing, and operating a wide range of cost-effective in situ and ex situ remedial systems for impacted soil and groundwater sites; and interpreting analytical and field data from environmental investigations and bench-, pilot-, and full-scale remedy applications

# Presentation Overview



- Introduction
- Optimization Basics
- Case Study #1: JBPHH Former Aiea Laundry Facility
- Case Study #2: Camp Lejeune Site 78
- Case Study #3: NAPR SWMUs 7 and 8
- Case Study #4: ABL Site 10
- Key Takeaways

ABL: Allegany Ballistics Laboratory

JBPHH: Joint Base Pearl Harbor-Hickam

NAPR: Naval Activity Puerto Rico

SWMU: solid waste management unit

# What is Optimization and its Objectives?



- Systematic review process with goal to achieve RC and ultimately SC in shortest amount of time and with least possible remedy footprint and expenditure (NAVFAC EXWC 2012)
- Specific objectives
  - Improve system performance
  - Reduce time to achieve response complete and site closeout
  - Reduce LCCs
  - Minimize impacts to mission and community
  - Maintain protectiveness of human health and the environment

LCCs: life-cycle costs

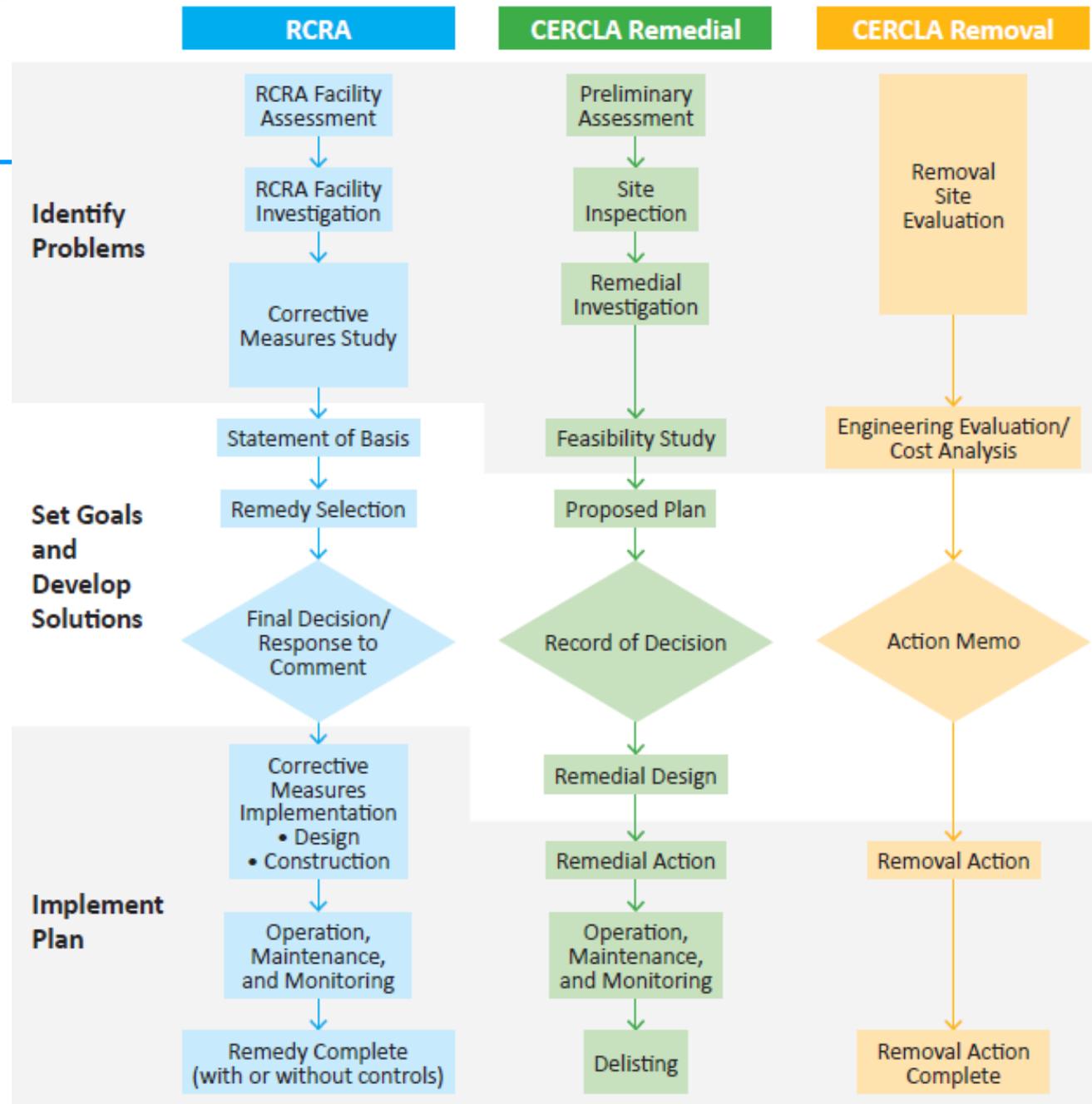
RC: response complete

SC: site closeout

# When is Optimization Applied?

- Applicable to range of regulatory programs (e.g., CERCLA, RCRA, state programs)
- Applicable throughout lifecycle of a site

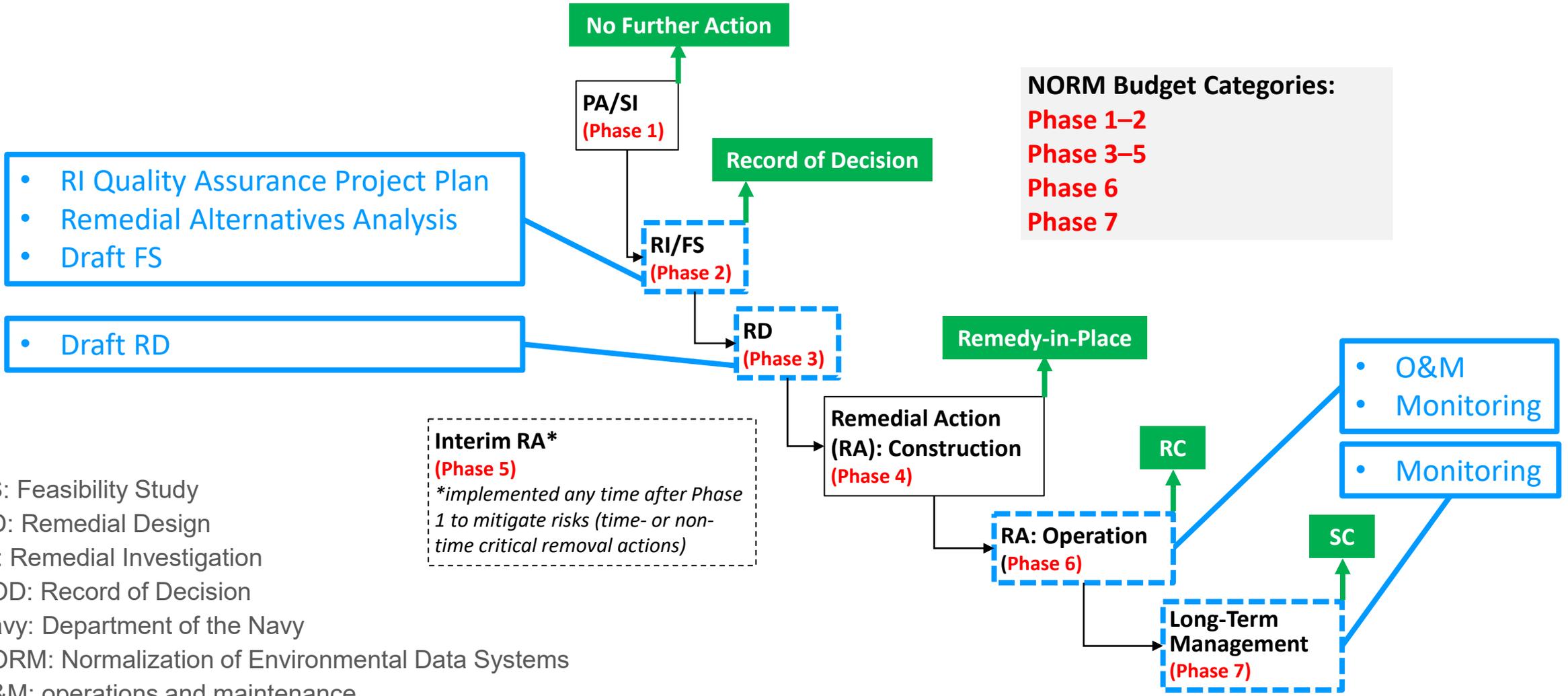
(NAVFAC n.d.)



CERCLA: Comprehensive Environmental Response, Compensation, and Liability Act

RCRA: Resource Conservation and Recovery Act

# When and How is Optimization Commonly Applied at Navy CERCLA Sites?



FS: Feasibility Study  
 RD: Remedial Design  
 RI: Remedial Investigation  
 ROD: Record of Decision  
 Navy: Department of the Navy  
 NORM: Normalization of Environmental Data Systems  
 O&M: operations and maintenance  
 PA/SI: Preliminary Assessment Site Inspection

# What are Common Triggers for Optimization?



- O&M and/or sampling data are consistent and predictable
- Contaminant mass recovery has become asymptotic
- Mechanical system repairs are required more frequently
- Costs per pound of contaminant removed are significantly increasing
- Contaminant concentrations in impacted site media are not decreasing according to the planned remediation timeframe
- Remedy not expected to meet RAOs

RAO: Remedial Action Objective

# Relevant Guidance Documents and Support



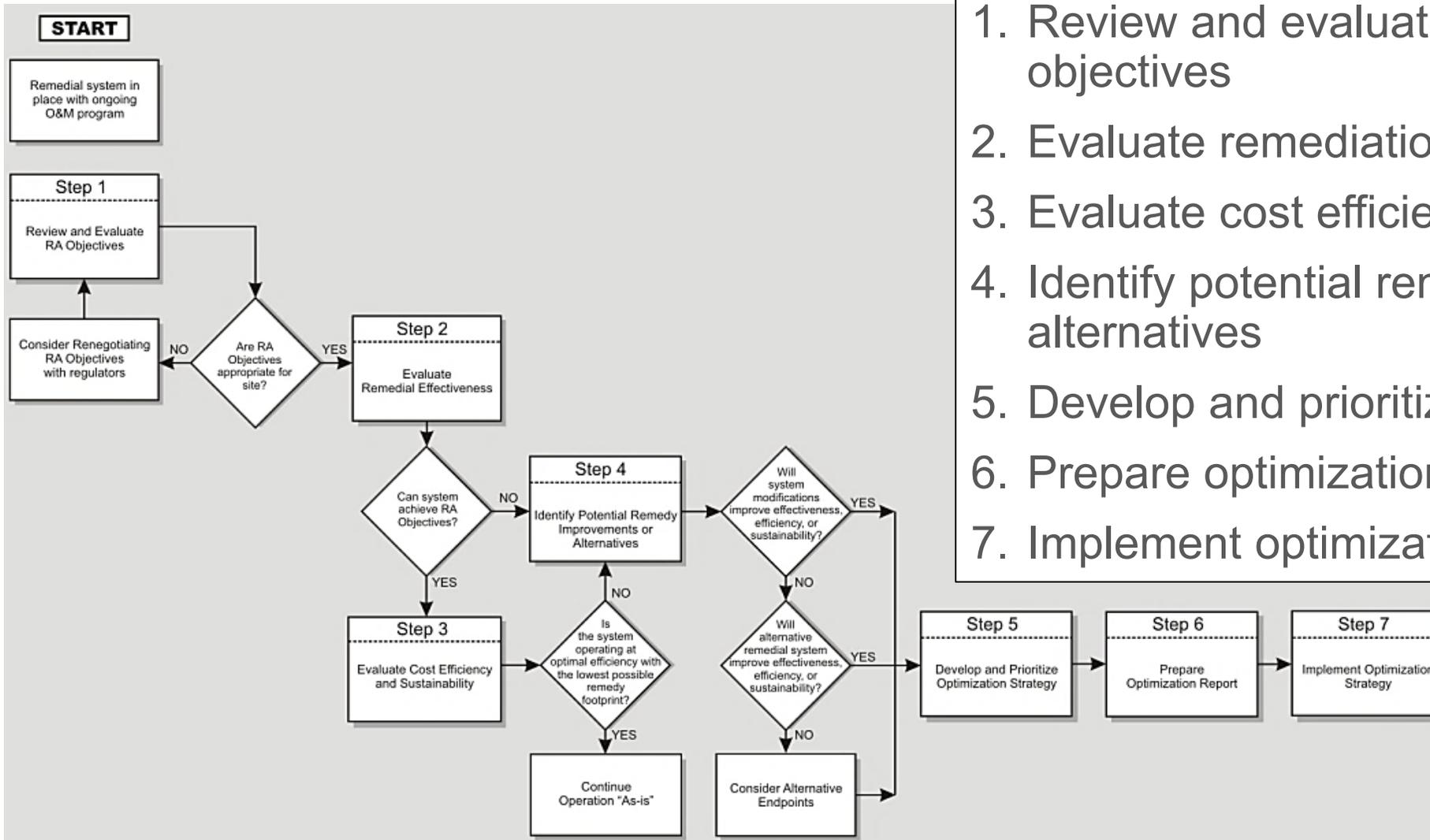
- [Optimizing Remedy Selection and the Site Closeout Process – Naval Civil Engineer Corps Officers School Environmental Training \(current\)](#)
  - Provides instruction on making technically sound and cost-effective remedial action decisions for Navy and Marine Corps ERP sites in a manner consistent with regulatory and Navy/Marine Corps policy requirements
- [NAVFAC Optimizing Remediation Technologies \(NAVFAC EXWC\) \(2022\)](#)
  - Provides technology-specific guidance for optimization of 15 commonly applied remediation technologies
- [Case Study Review of Optimization Practices and Navy Petroleum Sites \(NAVFAC EXWC\) \(2021\)](#)
  - Provides an overview of optimization concepts as applied to the cleanup of petroleum sites
- [Guidance for Optimizing Remedial Action Operation \(NAVFAC EXWC\) \(2012\)](#)
  - Focuses on ways to design and optimize remedial action operations to maximize cost efficiency and minimize the remedy footprint while maintaining effectiveness

# Relevant Guidance Documents and Support



- [Five Year Review Guidance \(NAVFAC EXWC n.d.\) \(2011 and later\)](#)
  - Clearinghouse of federal guidance documents for preparing Five-Year Reviews to assess whether the remedies selected for a site are functioning as intended and continue to be protective of human health and the environment
- [NAVFAC Tiered Approach for Developing Sampling and Analysis Plan \(Navy\) \(2011\)](#)
  - Provides guidance for the use and development of sampling and analysis plans using a tiered approach and employing a systematic planning process for ERP sites
- [Policy for Optimizing Remedial and Removal Actions under the ERPs \(Navy\) \(2004\)](#)
  - Establishes procedures for optimizing the screening, evaluation, selection, design, and implementation for long-term operation and management of response actions conducted under the ERP
- [Optimization checklists for 22 processes \(USACE n.d.\) \(1999 and later\)](#)
  - Provides process-specific checklists to guide optimization of 22 mechanical processes associated with commonly-applied remediation approaches

# Guidance for Optimizing Remedial Action Operation



1. Review and evaluate remedial action objectives
2. Evaluate remediation effectiveness
3. Evaluate cost efficiency and sustainability
4. Identify potential remedy improvements or alternatives
5. Develop and prioritize optimization strategy
6. Prepare optimization report
7. Implement optimizations recommendations

(NAVFAC EXWC 2012)

# Common Tools or Methods for Optimization



- Desktop tools
  - Statistical
  - Sustainability
  - Groundwater modeling
  - Value engineering
- MBTs + treatability testing
- Site characterization
  - High resolution
  - Conventional
- Other approaches
  - Risk assessment, regulatory/partnering, and system O&M

MBTs: molecular biological tools

# Desktop Tools



Example Tool	Description	Why use?	Typical Phase
<b>Statistical Tools</b>			
MAROS	Evaluates optimal number of sampling locations and frequency, and laboratory analytes; plume stability conditions and remedy performance	Optimize monitoring program to reduce LCCs	6,7
<b>Mann-Kendall and regression analyses</b> <i>(Case Studies 1 and 4)</i>	Nonparametric method used to identify whether there is a statistically significant trend over a period of monitoring and various methods to calculate slope of a series of concentration data	Estimate remediation timeframes at specific sampling locations and optimize monitoring program to reduce LCCs	6,7
Plume mass and center-of-mass analysis	Uses a consistent set of monitoring wells to calculate the total contaminant dissolved-phase mass and location of the center-of-mass over time	Provides a measure of overall plume behavior	6,7
<b>SERDP TA<sup>2</sup> tool</b> <i>(Case Study 4)</i>	Provides a sound framework to guide site management decisions about transitioning to MNA	Determine whether MNA can be used to meet site objectives within a reasonable timeframe	6,7

MAROS: Monitoring and Remediation Optimization System  
MNA: monitored natural attenuation

SERDP: Strategic Environmental Research and Development Program  
TA<sup>2</sup>: Transition Assessment Teaching Assistant

# Desktop Tools



Well	Parameter	Total Samples	Detect Results	Detect Freq. (%)	Min Non-Detect (µg/L)	Min Detect (µg/L)	Max Non-Detect (µg/L)	Max Detect (µg/L)	Mean (µg/L)	Median (µg/L)	Std Dev. (µg/L)	CV	Last Result (µg/L)	Last Sample Date	MK Test Value (\$)	MK p-value	Sen's Slope Estimator (µg/L/yr)	Mann-Kendall Result	Trend Analysis Result	Stability Based on CV	Minimum Sampling Spacing (days)
IW01	Trichloroethene	33	22	67	0.424	1.70	22.4	481	113	22.4	153	1.35	0.424 UJ	Dec-20	-153	0.008	-2.49	99.2% (sig -)	Decreasing	---	14
IW02	Trichloroethene	24	23	96	22.4	174	22.4	4,880	865	505	1,085	1.25	294	Dec-20	-32	0.221	---	77.9% (-)	No Trend	Not Stable	14
IW03	Trichloroethene	33	19	58	2.50	11.4	79.0	692	122	27.4	183	1.51	4.24 U	Dec-20	-207	0.000	-5.69	100% (sig -)	Decreasing	---	13
IW04	Trichloroethene	31	31	100	---	29.7	---	17,700	2,788	860	4,388	1.57	383	Dec-20	143	0.008	116	99.2% (sig +)	Increasing	---	14
IW05	Trichloroethene	8	8	100	---	22.4	---	3,620	1,160	872	1,127	0.971	3,620	Apr-20	10	0.138	---	86.2% (+)	No Trend	Stable	62
IW06	Trichloroethene	29	25	86	20.0	25.1	224	3,390	678	515	734	1.08	157	Dec-20	-116	0.015	-54.4	98.5% (sig -)	Decreasing	---	14
IW07	Trichloroethene	29	18	62	44.9	62.2	790	12,200	732	246	2,200	3.01	71.5	Dec-20	117	0.012	33.4	98.8% (sig +)	Increasing	---	14
IW08	Trichloroethene	23	20	87	7.90	3.81	100	3,630	978	234	1,259	1.29	3.81	Dec-20	-116	0.001	-139	99.9% (sig -)	Decreasing	---	65
IW09	Trichloroethene	30	28	93	4.24	1.09	15.8	1,150	250	111	343	1.38	4.24 U	Dec-20	-218	0.000	-25.1	100% (sig -)	Decreasing	---	15
IW10	Trichloroethene	25	24	96	44.9	36.0	44.9	4,280	588	308	847	1.44	273	Dec-20	-32	0.235	---	76.5% (-)	No Trend	Not Stable	62
IW11	Trichloroethene	29	26	90	10.0	6.15	79.0	3,270	468	212	706	1.51	6.15	Dec-20	-138	0.005	-32.4	99.5% (sig -)	Decreasing	---	14
IW12	Trichloroethene	29	26	90	200	67.0	1,000	6,940	953	689	1,251	1.31	893	Dec-20	-76	0.080	---	92% (-)	No Trend	Not Stable	14
IW13	Trichloroethene	29	23	79	4.00	4.17	89.7	3,100	372	122	678	1.82	4.59	Dec-20	17	0.381	---	61.9% (+)	No Trend	Not Stable	14
IW14	Trichloroethene	25	19	76	40.0	30.7	50.0	950	231	120	236	1.02	144 J	Sep-18	-23	0.302	---	69.8% (-)	No Trend	Not Stable	13
MW02	Trichloroethene	46	46	100	---	125	---	16,300	5,161	4,615	3,771	0.731	9320 J	Dec-20	-64	0.275	---	72.5% (-)	No Trend	Stable	7
MW09	Trichloroethene	45	26	58	112	234	4,500	7,300	1,333	910	1,673	1.25	1,660	Dec-20	625	0.000	214	100% (sig +)	Increasing	---	8
MW10	Trichloroethene	46	46	100	---	25.3	---	8,430	936	516	1,285	1.37	735	Dec-20	-14	0.451	---	54.9% (-)	No Trend	Not Stable	8
MW11	Trichloroethene	45	40	89	100	2.70	395	6,510	1,377	942	1,414	1.03	139	Dec-20	-345	0.000	-106	100% (sig -)	Decreasing	---	7
MW12	Trichloroethene	31	28	90	7.90	11.2	2,240	5,240	1,153	482	1,397	1.21	20.3	Dec-20	-254	0.000	-160	100% (sig -)	Decreasing	---	1
MW13	Trichloroethene	42	42	100	---	613	---	23,400	4,146	1,790	5,747	1.39	1,570	Dec-20	305	0.000	223	100% (sig +)	Increasing	---	7
MW14	Trichloroethene	41	40	98	7.90	1.43	7.90	475	193	193	132	0.688	6.66 J	Dec-20	-316	0.000	-18.3	100% (sig -)	Decreasing	---	2
MW15	Trichloroethene	39	38	97	158	171	158	5,530	2,136	1,440	1,688	0.790	186 J	Dec-20	42	0.310	---	69% (+)	No Trend	Stable	8
MW16	Trichloroethene	40	40	100	---	304	---	3,160	1,044	829	735	0.704	675	Dec-20	38	0.333	---	66.7% (+)	No Trend	Stable	7
MW17	Trichloroethene	40	40	100	---	4.21	---	10,200	3,392	2,920	2,263	0.667	2,180	Dec-20	-158	0.034	-186	96.6% (sig -)	Decreasing	---	7
MW18	Trichloroethene	38	38	100	---	770	---	7,010	3,027	2,595	1,697	0.561	2,070	Dec-20	-163	0.021	-145	97.9% (sig -)	Decreasing	---	3
MW19	Trichloroethene	39	38	97	395	3.61	395	5,110	766	223	1,153	1.51	1,230	Dec-20	232	0.003	71.2	99.7% (sig +)	Increasing	---	8

## KEY POINT

Mann-Kendall provides statistically defensible trend analysis results that can be used to predict remediation timeframes or optimize the monitoring program.

Typical Mann-Kendall tabular output (Jacobs 2021)

# Desktop Tools

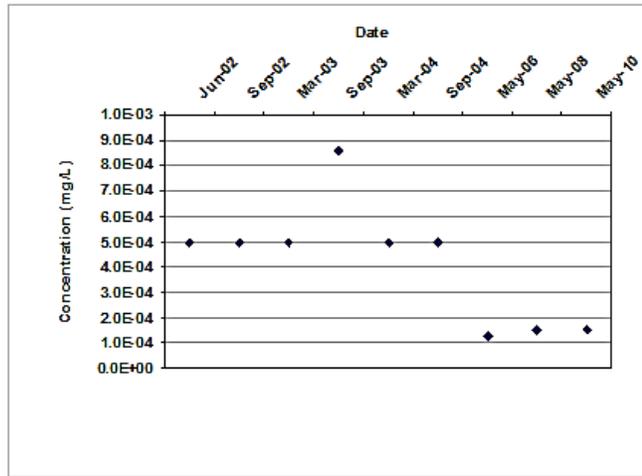


**KEY POINT** MAROS provides Statistics Summary Output for a well.

## MAROS Mann-Kendall Statistics Summary

Project: Bubbas Rent A Wreck User Name:  
 Location: Bubbas State: Texas

Well: MW-BB Time Period: 4/1/2000 to 5/6/2010  
 Well Type: T Consolidation Period: No Time Consolidation  
 COC: TETRACHLOROETHYLENE(PCE) Duplicate Consolidation: Median  
 Consolidation Type: Average  
 ND Values: 1/2 Detection Limit  
 J Flag Values : Actual Value



**Mann Kendall S Statistic:**  
-15  
**Confidence in Trend:**  
92.5%  
**Coefficient of Variation:**  
0.57  
**Mann Kendall Concentration Trend: (See Note)**

PD

Probably decreasing

### Data Table:

Well	Well Type	Effective Date	Constituent	Result (mg/L)	Flag	Number of Samples	Number of Detects
MW-BB	T	6/17/2002	TETRACHLOROETHY	5.0E-04	ND	1	0
MW-BB	T	9/1/2002	TETRACHLOROETHY	5.0E-04	ND	1	0
MW-BB	T	3/1/2003	TETRACHLOROETHY	5.0E-04	ND	1	0
MW-BB	T	9/1/2003	TETRACHLOROETHY	8.6E-04		1	1
MW-BB	T	3/1/2004	TETRACHLOROETHY	5.0E-04	ND	1	0
MW-BB	T	9/1/2004	TETRACHLOROETHY	5.0E-04	ND	1	0
MW-BB	T	5/1/2006	TETRACHLOROETHY	1.3E-04	ND	1	0
MW-BB	T	5/27/2008	TETRACHLOROETHY	1.5E-04	ND	1	0
MW-BB	T	5/6/2010	TETRACHLOROETHY	1.5E-04	ND	1	0

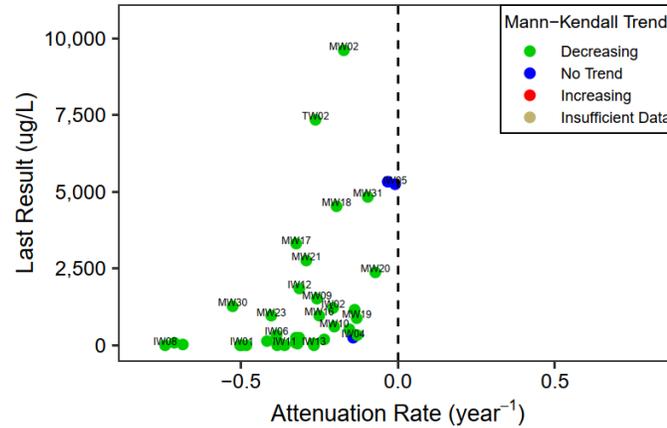
Typical MAROS Well Summary (GSI 2013)

# Desktop Tools

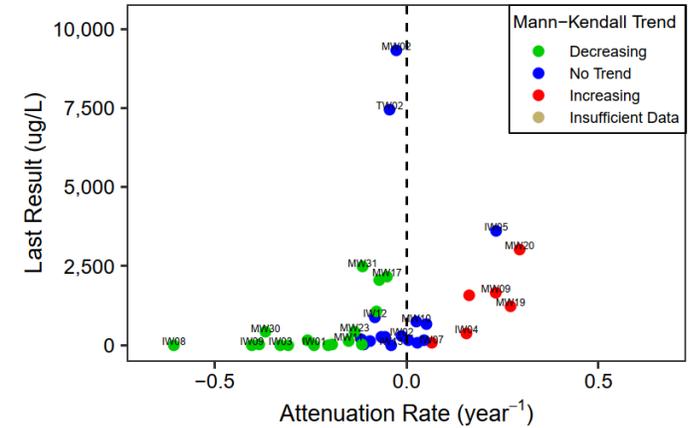


**KEY POINT** Combination plots consolidate trend data and attenuation rates from an entire monitoring network.

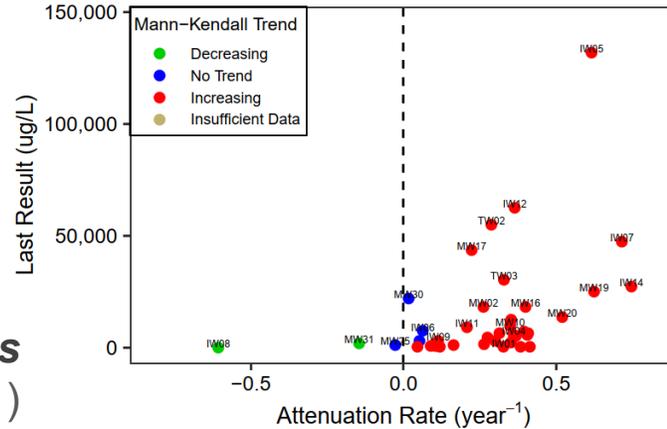
**Tetrachloroethene**  
 No. of decreasing trends = 36  
 No. of increasing trends = 0  
 Median attenuation rate = -0.28



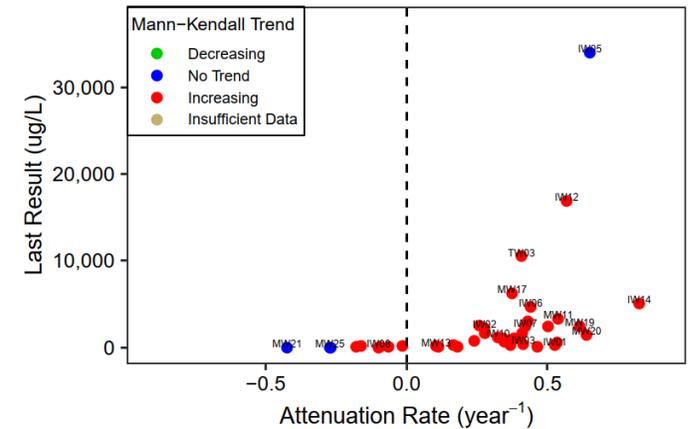
**Trichloroethene**  
 No. of decreasing trends = 17  
 No. of increasing trends = 6  
 Median attenuation rate = -0.068



**cis-1,2-Dichloroethene**  
 No. of decreasing trends = 2  
 No. of increasing trends = 34  
 Median attenuation rate = 0.307



**Vinyl Chloride**  
 No. of decreasing trends = 0  
 No. of increasing trends = 36  
 Median attenuation rate = 0.358



**Combination Plots**  
 (Jacobs 2021)

# Desktop Tools

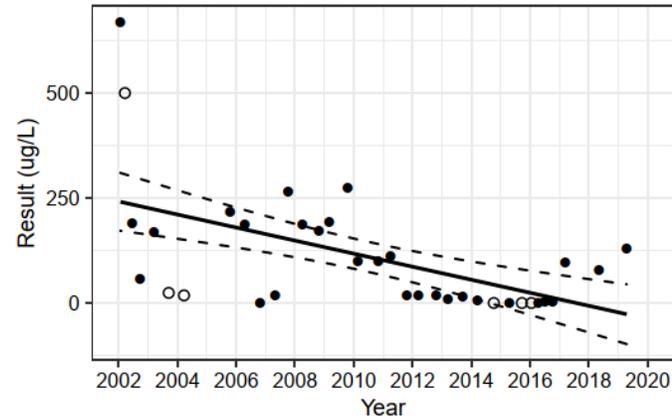


**KEY  
POINT**

Regression plots visualize concentration trends and their uncertainty.

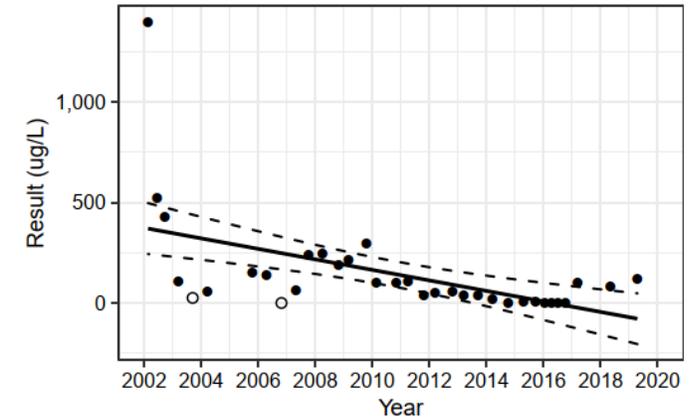
**MW-03: Tetrachloroethene**

Intercept = 0.3  
Slope = -15.5 ( $p < 0.001$ )  
 $r^2 = 0.3$



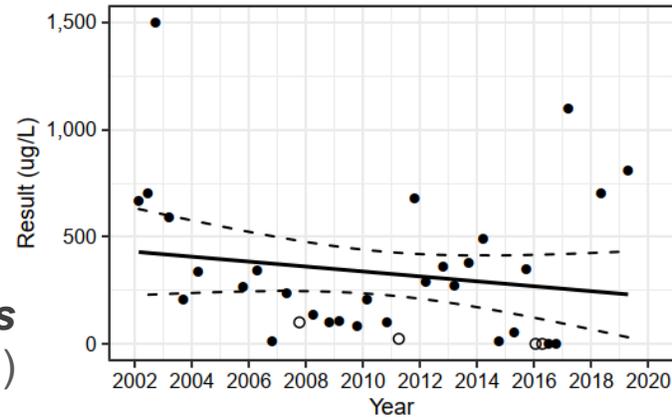
**MW-03: Trichloroethene**

Intercept = 0.274  
Slope = -26.2 ( $p = 0.001$ )  
 $r^2 = 0.274$



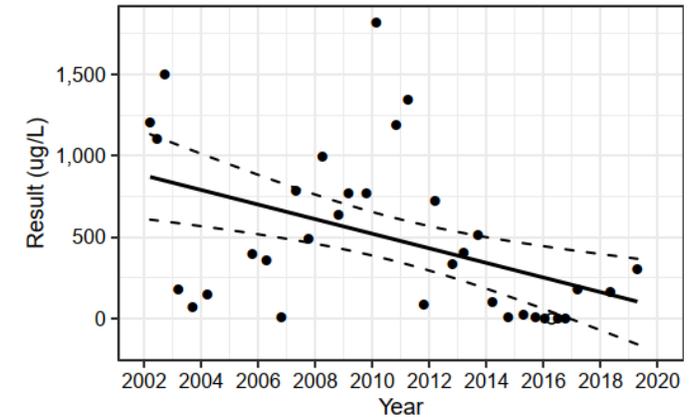
**MW-03: Vinyl Chloride**

Intercept = 0.0282  
Slope = -11.5 ( $p = 0.342$ )  
 $r^2 = 0.0282$



**MW-03: cis-1,2-Dichloroethene**

Intercept = 0.204  
Slope = -44.8 ( $p = 0.007$ )  
 $r^2 = 0.204$

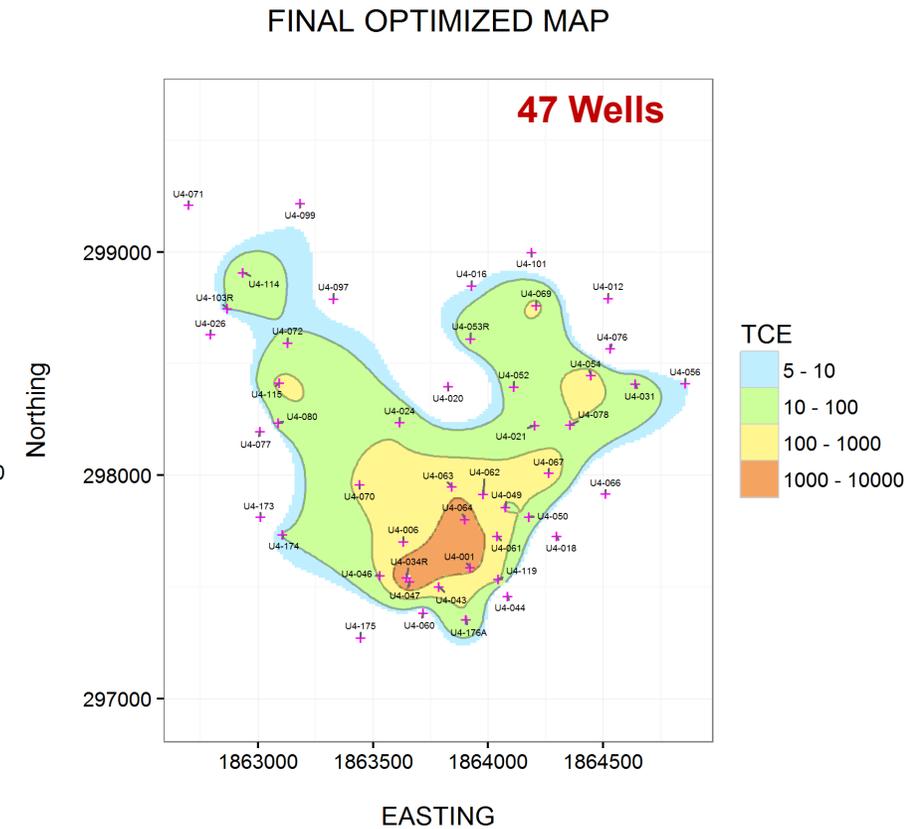
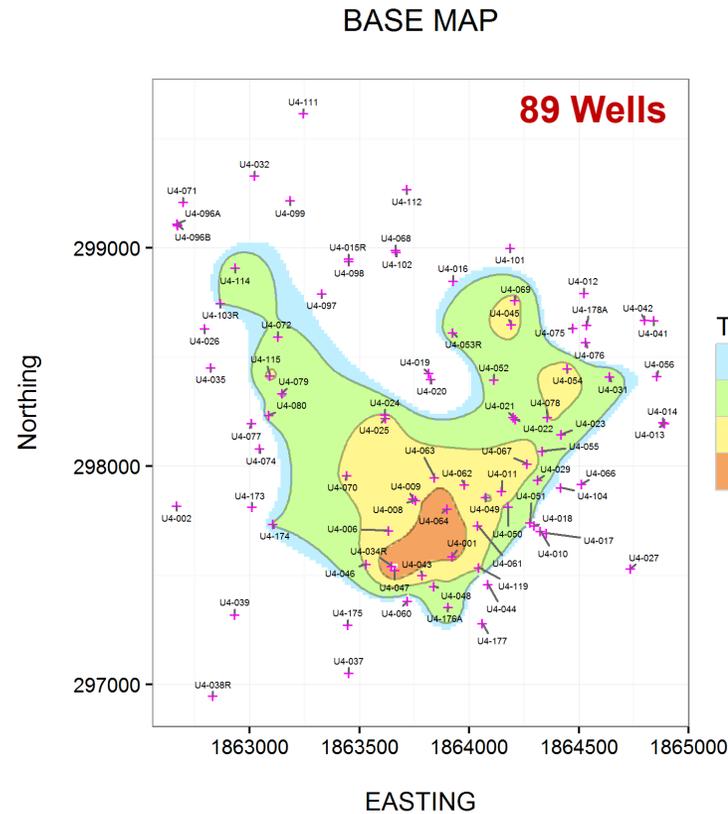


*Regression Plots*  
(Jacobs 2021)

# Desktop Tools



**KEY POINT** Visualizes how optimized network has minimal affect on plume geometry.



*Optimization Plume Map Output*  
(Jacobs 2021)

# Desktop Tools

## KEY POINT

Plume moment analysis indicates whether a plume is shrinking, stable, or expanding, which informs an MNA evaluation.

### Plume Moment Analysis (Jacobs 2021)

Select parameter

DCE12C

Average Porosity

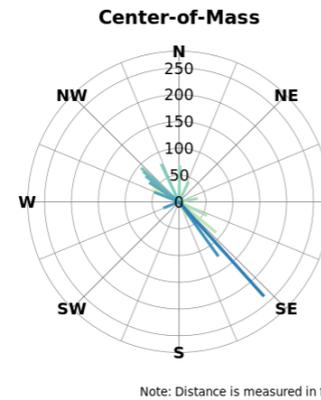
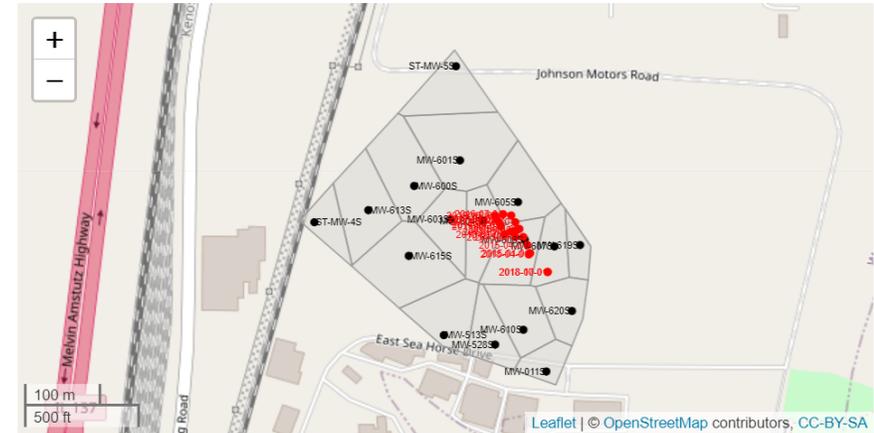
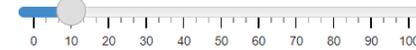
0.30

Aquifer Thickness

10

Polygon Buffer

10



- 2014-04-01
- 2014-07-01
- 2014-10-01
- 2015-01-01
- 2015-04-01
- 2015-07-01
- 2015-10-01
- 2016-01-01
- 2016-04-01
- 2016-07-01
- 2016-10-01
- 2017-01-01
- 2017-04-01
- 2017-07-01
- 2017-10-01
- 2018-01-01
- 2018-04-01
- 2018-07-01
- 2018-10-01



Analyte	Date	Xc	Yc	Bearing	Dist	DistUnits	Mass	MassUnits	Porosity	Thickness
DCE12C	2014-01-01	1,122,742	2,077,846	0	0.00	ft	62.22	kg	0.30	10
DCE12C	2014-04-01	1,122,692	2,077,873	298	56.07	ft	32.71	kg	0.30	10
DCE12C	2014-07-01	1,122,764	2,077,850	80	22.96	ft	24.37	kg	0.30	10
DCE12C	2014-10-01	1,122,757	2,077,818	152	31.91	ft	25.12	kg	0.30	10
DCE12C	2015-01-01	1,122,823	2,077,754	139	123.09	ft	29.06	kg	0.30	10

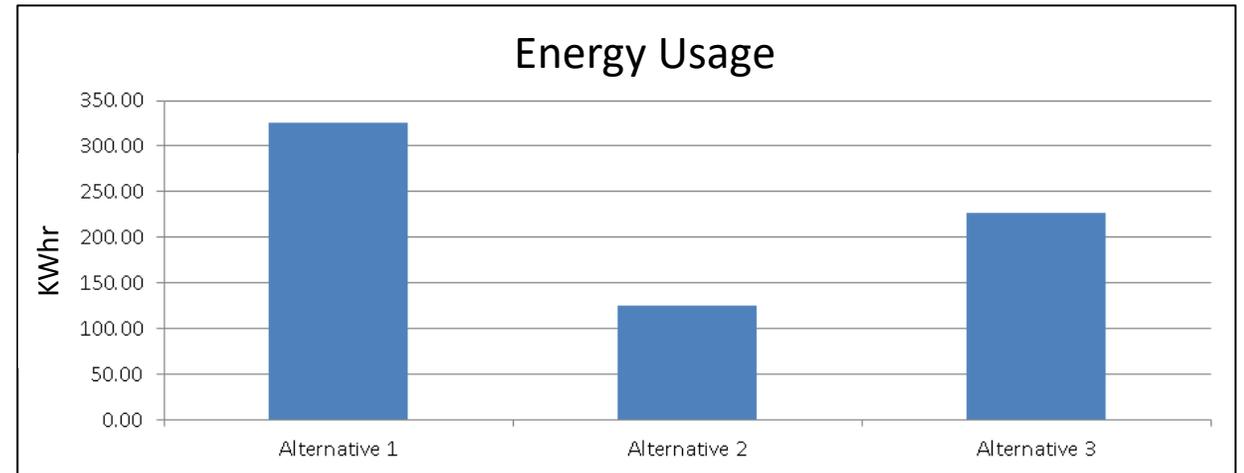
# Desktop Tools



Example Tool	Description	Why use?	Typical Phase
<b>Sustainability Tools</b>			
SiteWise or Sustainable Remediation Tool	Assesses the environmental impact of remedial alternatives and technologies	Optimize operation of existing remediation systems to reduce environmental impact and LCCs	2,3,5,6

**KEY POINT** Discuss with NAVFAC HQ prior to using SiteWise or other Sustainable Remediation Tool.

*Example Output* (Jacobs 2024)



# Desktop Tools



Example Tool	Description	Why use?	Typical Phase
<b>Groundwater Modeling Tools</b>			
BIOCHLOR, BIOPLUME, or BIOSCREEN	One-dimensional screening models that simulate remediation by natural attenuation of chlorinated solvents and petroleum hydrocarbons	Simple spreadsheet-based models to estimate decay rates and assess whether MNA can be used to meet site objectives within a reasonable timeframe	2,6
<b>REMChlor or REMChlor-Matrix Diffusion</b> <i>(Case Study 2)</i>	Two-dimensional analytical solution for simulating transient effects of groundwater source and plume remediation	Integrates site-specific characteristics to estimate influence of various remediation scenarios, including source and plume treatment, and MNA, on remediation timeframes	2,3,5,6
MODFLOW-MT3D	Three-dimensional modular finite-difference flow model used to simulate flow of groundwater through aquifers and fate and transport of contaminants	Same as above, but with greater site characterization granularity plus the ability to simulate the hydraulic influence of remedial alternatives	2,3,5,6
<b>Value Engineering</b>			
Value Engineering	Systematic problem-solving technique involving thorough analysis of project functions using team dynamics to creatively consider design options	Reduce LCCs while meeting intended functions, and/or to maximize functionality for roughly the same cost	3,5

# Desktop Tools



### BIOCHLOR Natural Attenuation Decision Support System

Version 2.2  
Excel 2000

Cape Canaveral  
Fire Training Area  
Run Name

**1. ADVECTION**  
 Seepage Velocity\* Vs: 111.7 (ft/yr)  
 Hydraulic Conductivity K: 1.8E-02 (cm/sec)  
 Hydraulic Gradient i: 0.0012 (ft/ft)  
 Effective Porosity n: 0.2 (-)

**2. DISPERSION**  
 Alpha x\*: 40 (ft)  
 (Alpha y) / (Alpha x)\*: 0.1 (-)  
 (Alpha z) / (Alpha x)\*: 1.E-99 (-)

**3. ADSORPTION**  
 Retardation Factor\* R: 2.87  
 Soil Bulk Density, rho: 1.6 (kg/L)  
 Fraction Organic Carbon, f<sub>oc</sub>: 1.8E-3 (-)  
 Partition Coefficient K<sub>oc</sub>:  
 PCE: 426 (L/kg) → 7.13 (-)  
 TCE: 130 (L/kg) → 2.87 (-)  
 DCE: 125 (L/kg) → 2.80 (-)  
 VC: 30 (L/kg) → 1.43 (-)  
 ETH: 302 (L/kg) → 5.35 (-)

**4. BIOTRANSFORMATION**  
 Zone 1:  
 PCE → TCE: λ = 2.000 (1/yr), half-life = 0.79 yrs  
 TCE → DCE: λ = 1.000 (1/yr), half-life = 0.74 yrs  
 DCE → VC: λ = 0.700 (1/yr), half-life = 0.64 yrs  
 VC → ETH: λ = 0.400 (1/yr), half-life = 0.45 yrs  
 Zone 2:  
 PCE → TCE: λ = 0.000 (1/yr), half-life = ∞ yrs  
 TCE → DCE: λ = 0.000 (1/yr), half-life = ∞ yrs  
 DCE → VC: λ = 0.000 (1/yr), half-life = ∞ yrs  
 VC → ETH: λ = 0.000 (1/yr), half-life = ∞ yrs

**5. GENERAL**  
 Simulation Time\*: 33 (yr)  
 Modeled Area Width\*: 700 (ft)  
 Modeled Area Length\*: 1085 (ft)  
 Zone 1 Length\*: 1085 (ft)  
 Zone 2 Length\*: 0 (ft)

**6. SOURCE DATA**  
 TYPE: Decaying Single Planar  
 Source Thickness in Sat. Zone\*: 56 (ft)  
 Width\* (ft): 105  
 Conc. (mg/L)\* C1:  
 PCE: 0.056  
 TCE: 15.8  
 DCE: 98.5  
 VC: 3.08  
 ETH: 0.03

**7. FIELD DATA FOR COMPARISON**

Conc. (mg/L)	0.056								
PCE Conc. (mg/L)	0.056								
TCE Conc. (mg/L)	15.8	.22	.017	.024	.019				
DCE Conc. (mg/L)	98.5	3.48	.776	1.2	.556				
VC Conc. (mg/L)	3.1	3.08	.797	2.52	5.024				
ETH Conc. (mg/L)	0.0	.188		.107	.15				

Distance from Source (ft): 0, 560, 650, 930, 1085

Date Data Collected: 1998

**8. CHOOSE TYPE OF OUTPUT TO SEE:**  
 RUN CENTERLINE | RUN ARRAY | Help | Restore | RESET | SEE OUTPUT | Paste | Unprotect

**Data Input Instructions:**  
 115 → 1. Enter value directly....or  
 or  
 0.02 → 2. Calculate by filling in gray cells. Press Enter, then  
 (To restore formulas, hit "Restore Formulas" button)  
 Variable\* → Data used directly in model.

Test if Biotransformation is Occurring → Natural Attenuation Screening Protocol

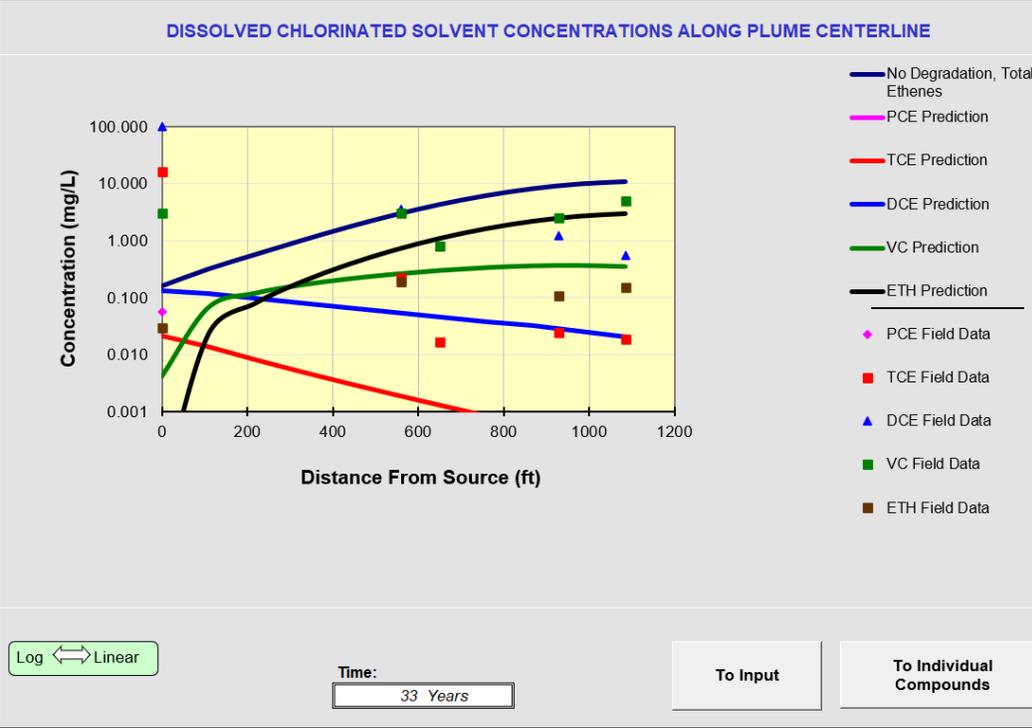
Vertical Plane Source: Determine Source Well Location and Input Solvent Concentrations

View of Plume Looking Down

Observed Centerline Conc. at Monitoring Wells

**KEY POINT**

BIOCHLOR is a simple desktop tool that can be used to quickly generate screening level remedial timeframe estimates



Example BIOCHLOR Data Entry (Aziz et al., 2012)

Example BIOCHLOR Output (Aziz et al. 2012)

# Desktop Tools



## REMChlor-MD Data Input Screen Version 1.0

Site Location and ID: REMChlor Tutorial 7

1. **STARTING INFORMATION**  SI Units  English Units  Unconsolidated  Fractured Rock/Media

2. **MODEL CONFIGURATION**

Cell Size	Model Size
X-Direction (in direction of groundwater flow): 20	2000 (m)
Y-Direction (transverse to groundwater flow): 10	200 (m)
Z-Direction (vertical) (all layers have same hydrogeology): 3	15 (m)

Observation Well Location: X-Value: 205.0 (m) Y-Value: 23.0 (m)  
 Obs. Well Z-Value Top of Screen (model bottom is at Z=0): 6.2 (m) Bottom of Screen: 0.8 (m)  
 Starting Year of Simulation (year the source started): 1970 (YYYY year)  
 Ending Year of Simulation: 2070 (YYYY year)

3. **MEDIA CHARACTERISTICS** (uniform for all cells)

Soil Type	Hydr. Cond. (m/yr)	Porosity (-)	Tortuosity (-)
Transmissive Zone (T-Zone): Sand	1.25E+04	0.33	0.70
Low Permeability Zone (Low-k): Clay	1.00E+00	0.4	0.70

T-Zone Hydraulic Gradient: 0.0020 (-)  
 T-Zone Groundwater Darcy Velocity: 2.50E+01 (m/yr)

4. **MATRIX DIFFUSION**

Average Darcy Velocity (including low-k units)	1.00E+01 (m/yr)
Transmissive Zone Volume Fraction	4.00E+01 (%)
Average Diffusion Length	5.00E-01 (m)
Surface Area of Low-k Interfaces	7.20E+02 (m <sup>2</sup> )

5. **CONTAMINANTS AND SOURCE TERM**

Parent	Deg. Prod. 1	Deg. Prod. 2	Deg. Prod. 3
Constituent (use dropdown menu): PCE	TCE	cis-DCE	Vinyl Chloride
Initial Source Concentration: 1.00E+02	0.00E+00	0.00E+00	0.00E+00 (mg/L)
Source Mass at Time of Release: 1.62E+03	0.00E+00	0.00E+00	0.00E+00 (kg)
Retardation Factor in T-Zone: 2	2	2	2 (-) Calc R
Retardation Factor in Low-k: 2	2	2	2 (-) Calc R'

Source Width (REMChlor-MD will round to nearest whole cell): 10 (m)  
 Z-Value for Top of Source (model bottom is at Z=0): 3 (m)  
 Z-Value for Bottom of Source: 0 (m)  
 General Molecular Diffusion Coefficient for all Constituents: 1.00E-09 (m<sup>2</sup>/sec)

6. **PLUME DEGRADATION** (Both T-Zone and Low-k Zone)

DATA INPUT INSTRUCTIONS:  
 Enter value directly.  Toolkit default value. OK to overwrite.  
 Value calculated by Toolkit. Cell cannot be edited.

Enter Custom Microbial Yield Terms

Time (yrs)	Distance From Source (m)	Degradation First Order Decay Rates			
		PCE	TCE	cis-DCE	Vinyl Chloride
Period 3	Zone 1	Decay Rate (1,3)	Decay Rate (2,3)	Decay Rate (3,3)	
		4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
	Zone 2	4.00E-01	4.00E-01	4.00E-01	Low-k (1/yr)
		Decay Rate (2,2)			
	Zone 3	4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
		Decay Rate (3,2)			
Period 2	Zone 1	Decay Rate (1,2)	Decay Rate (2,2)	Decay Rate (3,2)	
		4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
	Zone 2	4.00E-01	4.00E-01	4.00E-01	Low-k (1/yr)
		Decay Rate (2,2)			
	Zone 3	4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
		Decay Rate (3,2)			
Period 1	Zone 1	Decay Rate (1,1)	Decay Rate (2,1)	Decay Rate (3,1)	
		4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
	Zone 2	4.00E-01	4.00E-01	4.00E-01	Low-k (1/yr)
		Decay Rate (2,1)			
	Zone 3	4.00E-01	4.00E-01	4.00E-01	T-Zone (1/yr)
		Decay Rate (3,1)			

7. **PLUME TRANSPORT**

Dispersivity (m): Longitudinal: 0, Transverse: 0.5, Vertical: 0.1

8. **SOURCE ZONE REMEDIATION**

Percent Source Mass Removed by Remediation	90 (%)
Remediation Started in Year	30.00 (yrs)
Remediation Ended in Year	31.00 (yrs)
Mass-Flux/Remaining-Mass Term (Gamma, Γ)	1 (-)
Natural Source Decay Rate	0 (1/yr)

9. **MODELING PARAMETERS**

Timestep Size	1 (yr)
Maximum Number of Iterations	500 (-)
Convergence Tolerance	1.00E-05 (mg/L)
See Results Every	10 (yr)

Next Step: Show Graph | Show Previous Results | New Site/Clear Data | Paste Example | HELP | Return to Main Screen | Save/Export Data | Load Data

Typical REMChlor Data Entry (GSI n.d.)

# Desktop Tools



## REMChlor-MD Output

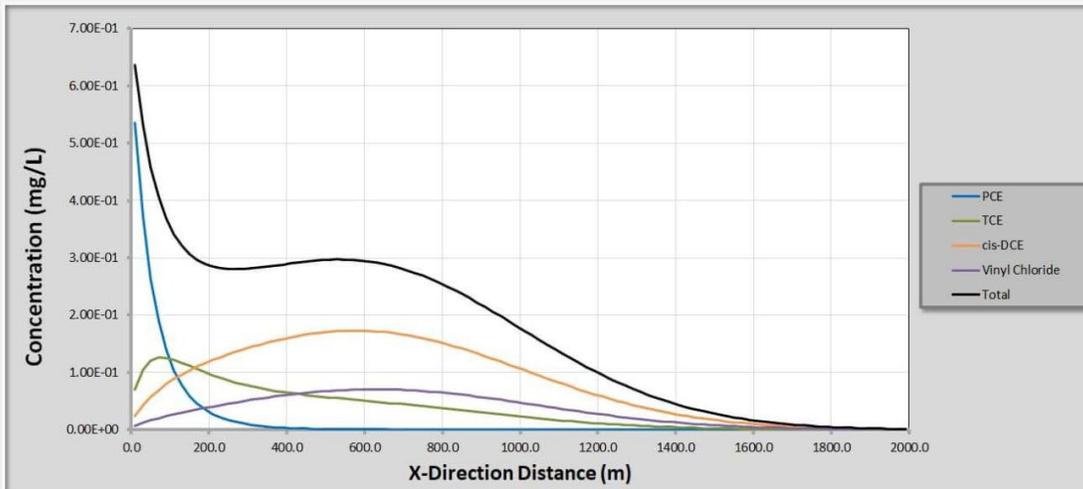
Version 1.0

Concentration vs. Distance in X-Direction (Time = 70 years; Y = 5 m; Z = 1.5 m)

Time	X	Y	Z
10	10	5	1.5
20	30	15	4.5
30	50	25	7.5
40	70	35	10.5
50	90	45	13.5
60	110	55	
70	130	65	
80	150	75	
90	170	85	
100	190	95	
	210		
	230		
	250		
	270		
	290		
	310		
	330		
	350		

- Select Component
- PCE
  - TCE
  - cis-DCE
  - Vinyl Chloride
  - Total

Log  Linear



- Concentration in T-Zone vs. Distance in X-Direction
- Concentration vs. Time in Observation Well
- Mass vs. Time in Low-k Zone
- Concentration in T-Zone vs. Distance From Bottom of Model
- Mass Discharge vs. Time in T-Zone
- Concentration in T-Zone vs. Time
- Mass vs. Time in T-Zone

Next Step: Save/Export Data

Return to Input Screen

Return to Main Screen

HELP

### Calculate T-Zone Mass Discharge at:

X  m ( $\geq 10$  and  $\leq 1990$  m for this model)  
 Time  yrs ( $\geq 1$  and  $\leq 100$  yrs for this model.)  
 (Rounds down to closest X and Timestep.)

	Mass Discharge (g/day)	Plume Magnitude
PCE		
TCE		
cis-DCE		
Vinyl Chloride		
Total		

### Calculate Mass (Kg) at:

Time  yrs ( $\geq 1$  and  $\leq 100$  yrs for this model.)  
 (Rounds down to closest Timestep.)

	Low-K Zone	T-Zone
PCE		
TCE		
cis-DCE		
Vinyl Chloride		
Total		

Typical  
REMChlor  
Output  
(GSI n.d.)

KEY POINT

REMChlor-MD can provide a more robust remediation timeframe estimate inclusive of active remediation.

Value Engineering Process

Information Phase

Creative Phase

Analysis Phase

Development Phase

Presentation

# MBTs + Treatability Testing



Example Tool	Description	Why use?	Typical Phase
<b>Laboratory Molecular Biological Tools</b>			
Quantitative polymerase chain reaction	Nucleic acid-targeted quantitative tool to quantify specific microorganisms and functional genes responsible for biodegradation of contaminants	Identifies whether specific microorganisms that can biodegrade the site contaminants are present; and whether bioaugmentation might be productive	2, 6, and 7
Metagenomics and metabolomics	Study of the collection of all genomes and genes from all microorganisms present in a sample and their metabolic processes	Provides more comprehensive profile and health of microbial community so biodegradation processes may be optimized	2, 6, and 7
Compound specific isotope analysis	Analytical method that measures ratio of stable isotopes of a contaminant	Can provide direct evidence of degradation (rather than dilution) to support use of MNA as optimized remedial strategy	2, 6, and 7
Magnetic susceptibility	Provides an estimate of the quantity of magnetite present in environmental samples	Can provide support for abiotic degradation to support use of MNA as optimized remedial strategy	2, 6, and 7
Acid volatile sulfides	Estimates presence of iron sulfide minerals in sediment or soil samples	Can provide support for abiotic degradation to support use of MNA as optimized remedial strategy	2, 6, and 7

# MBTs + Treatability Testing



Example Tool	Description	Why use?	Typical Phase
<b>Field Molecular Biological Tools</b>			
BioTraps	Passive samplers that provide a substrate to facilitate microbial growth in a monitoring well for laboratory analysis	Identifies whether specific microorganisms that can biodegrade the site contaminants are present in situ, and whether bioaugmentation might be productive	2, 6, and 7
MinTraps	Passive samplers that collect mineralogic data in a monitoring well for laboratory analysis	Can provide support for abiotic degradation to support use of MNA as optimized remedial strategy	2, 6, and 7
<b>Laboratory or Field Treatability Testing</b>			
<b>Bench- or pilot-scale testing</b> <i>(Case Studies 2, 3, and 4)</i>	Laboratory or field-scale simulations of various remedial technologies to evaluate effectiveness and optimize designs	Cost-effective methods to evaluate technologies to replace existing approaches	2 and 6

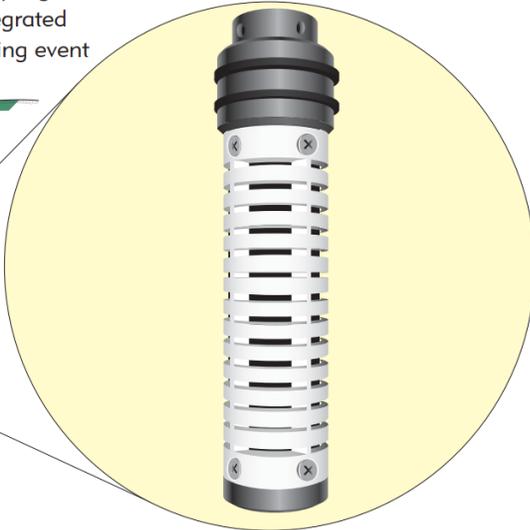
# MBTs + Treatability Testing



Bio-Trap samplers utilize a passive sampling approach allowing the results to be integrated over time rather than from a single sampling event

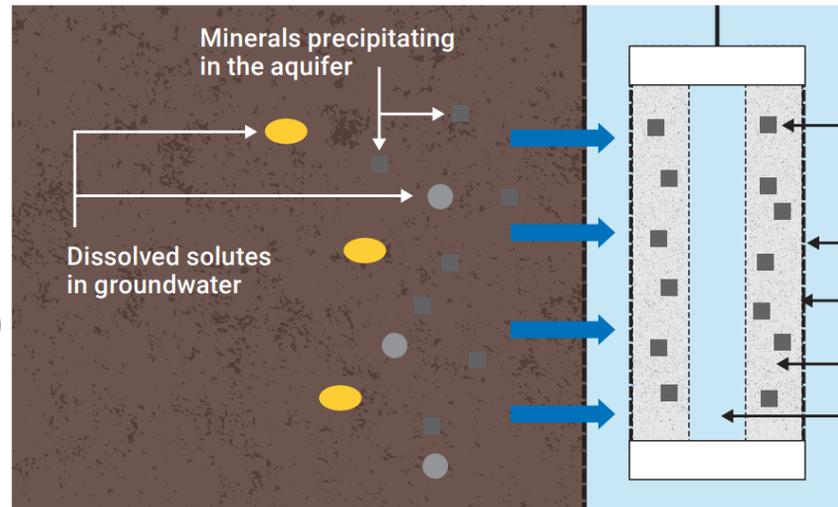
Multiple Bio-Trap samplers can be isolated from one another using a double seal cap assembly

Samplers are suspended in the screened interval for typically 30 days. \*study length can vary depending on objectives



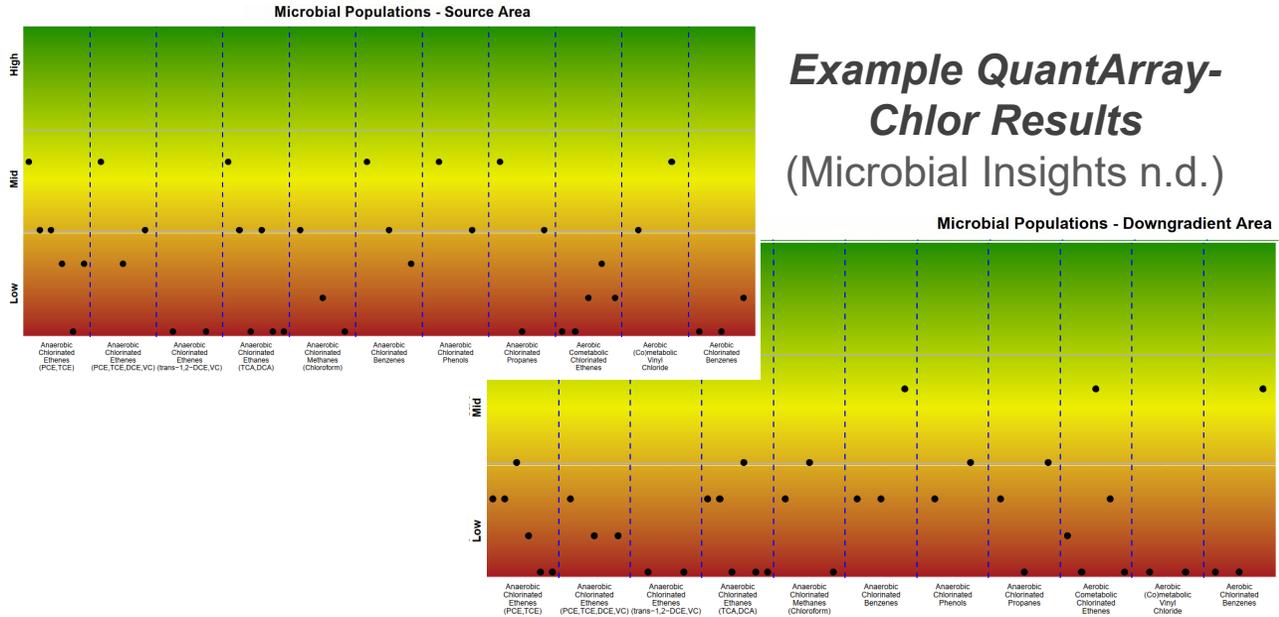
**Bio-Trap Sampler**  
(Microbial Insights n.d.)

**Min-Trap Sampler**  
(Microbial Insights n.d.)



- Mineral precipitates captured in Min-Trap™ matrix
- Monitoring Well Screened Interval
- Slotted PVC Housing
- Permeable mesh
- Non-reactive sand matrix (or reactive media, or site soil)
- Open interior facilitates groundwater flux through Min-Trap™

PVC: polyvinyl chloride



**Example QuantArray-Chlor Results**  
(Microbial Insights n.d.)

# Characterization



Example Tool	Description	Why use?	Typical Phase
<b>HRSC</b>			
Passive soil gas sampling	Use of adsorbent samplers emplaced just below ground surface to adsorb VOCs and semivolatile organic compounds in soil gas; often installed in a grid pattern	Cost-effective method to refine extent of soil and groundwater impacts in two dimensions and optimize more intrusive sampling approaches	2 and 6
MiHPT (membrane interface hydraulic profiling tool)	DPT-based logging tool that measures relative VOC concentrations in soil and groundwater, and provides lithology characterization	Cost-effective methods to identify residual source materials, refine the extent of soil and groundwater impacts in three dimensions, and optimize more intrusive sampling approaches	2 and 6
Discrete soil and groundwater grab sampling	Collection of a relatively high density of soil and groundwater samples typically using DPT	Verification of semi-quantitative characterization tools to refine extent of soil and groundwater impacts in three dimensions	2 and 6
Downhole geophysical testing	Use of temperature/conductivity, caliper, natural gamma, and optical/acoustic televiewer geophysical logging; and borehole dynamic flowmeter and nuclear magnetic resonance hydrophysical tools	Improves understanding of conceptual site model, especially with respect to preferential flow pathways that might be targeted during remedy optimization	2 and 6

DPT: direct-push technology

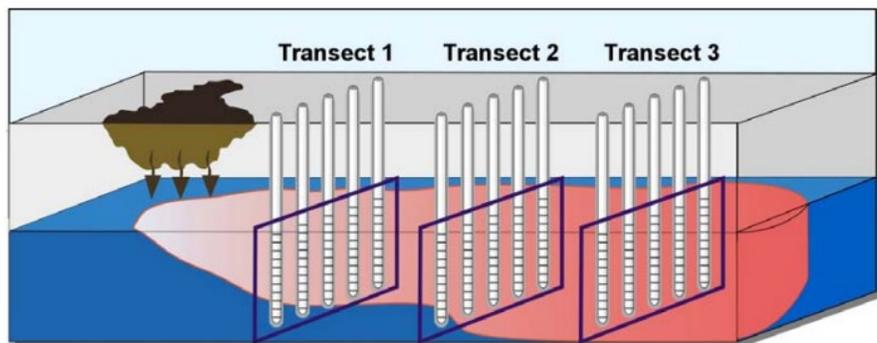
HRSC: high resolution site characterization

VOC: volatile organic compound

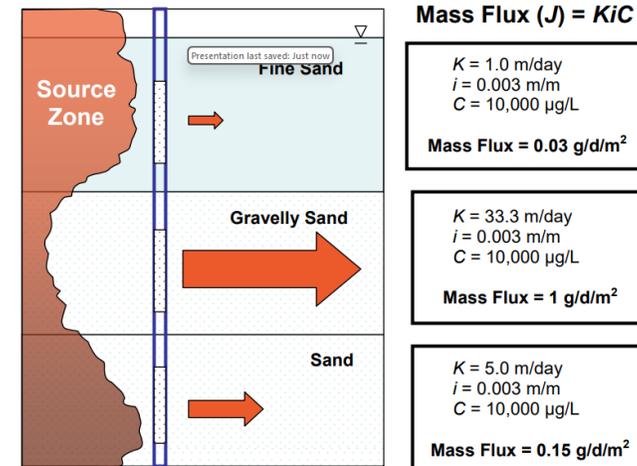
# Characterization



Example Tool	Description	Why use?	Typical Phase
<b>HRSC</b>			
<b>NSZD</b> <i>(Case Study 3)</i>	Collective naturally occurring processes of dissolution, volatilization, and biodegradation that result in mass losses of LNAPL petroleum hydrocarbon constituents from the subsurface (CRC CARE 2018)	Evaluates whether natural attenuation processes are removing more LNAPL mass than physical removal methods	2 and 6
Mass flux	Combines contaminant concentration data with groundwater velocity to estimate contaminant mass migration through a specific area	Can be used to identify cross-sectional areas of the site where most of the contaminant mass is migrating so that remediation strategies can be optimized to maximize contaminant removal	2 and 6



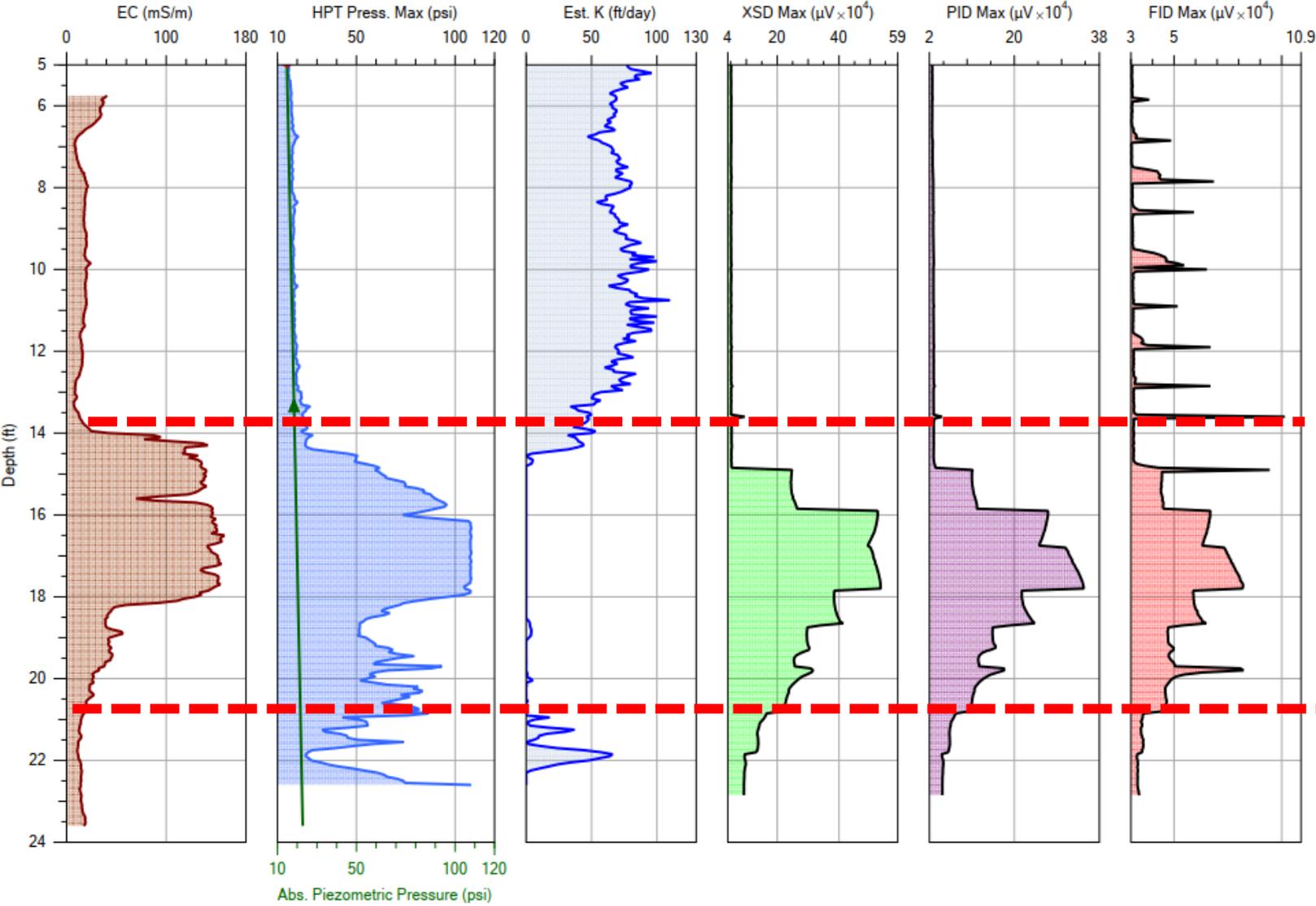
(ITRC 2010 [Adapted from Einarson and Mackay 2001])



(ITRC 2010)

LNAPL: light nonaqueous-phase liquid  
 NSZD: Natural Source Zone Depletion

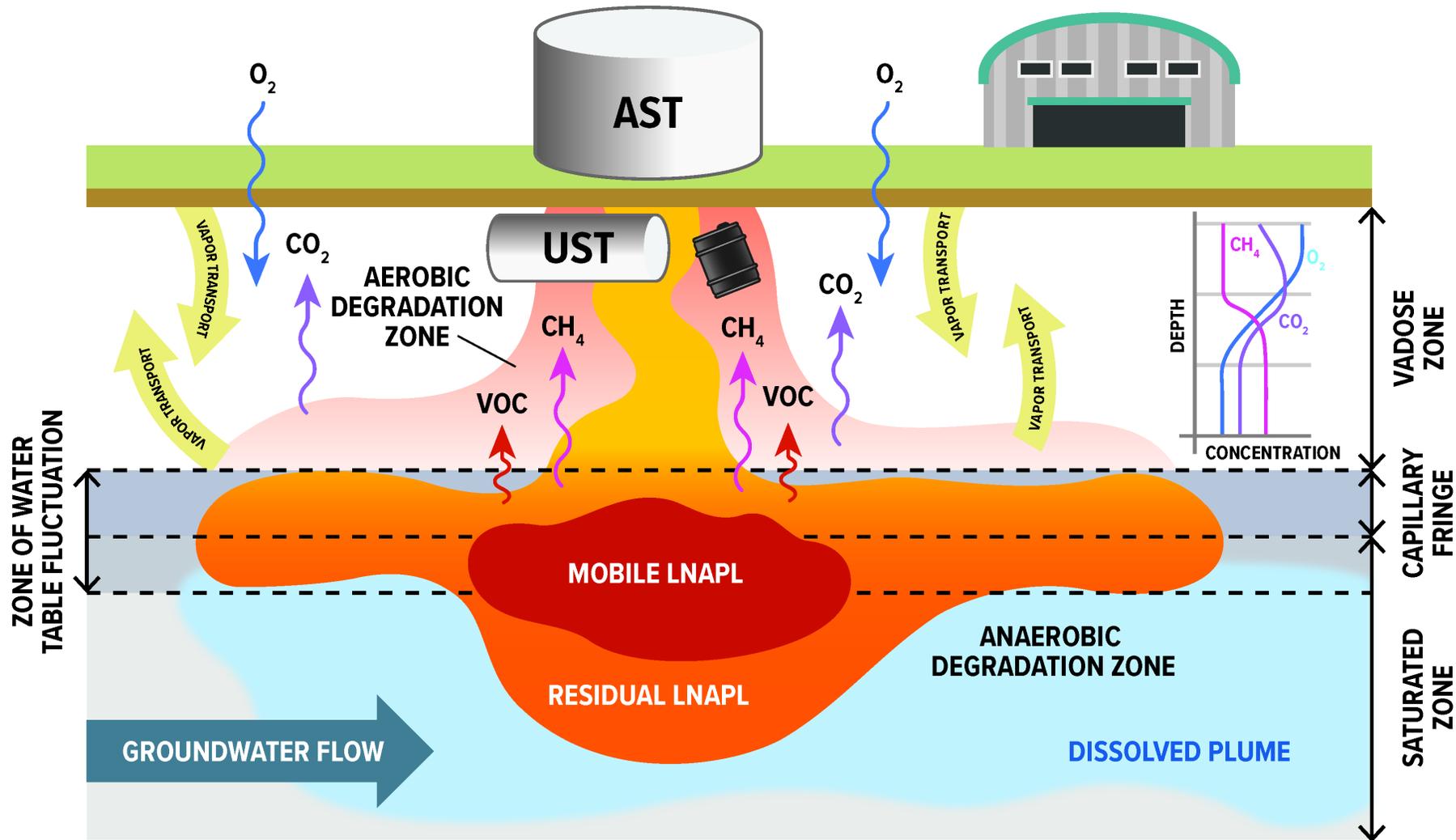
# Characterization



*Example MiHPT Output (CH2M 2023)*

*Low permeability with residual source mass that could be addressed with targeted remediation to optimize overall remedy*

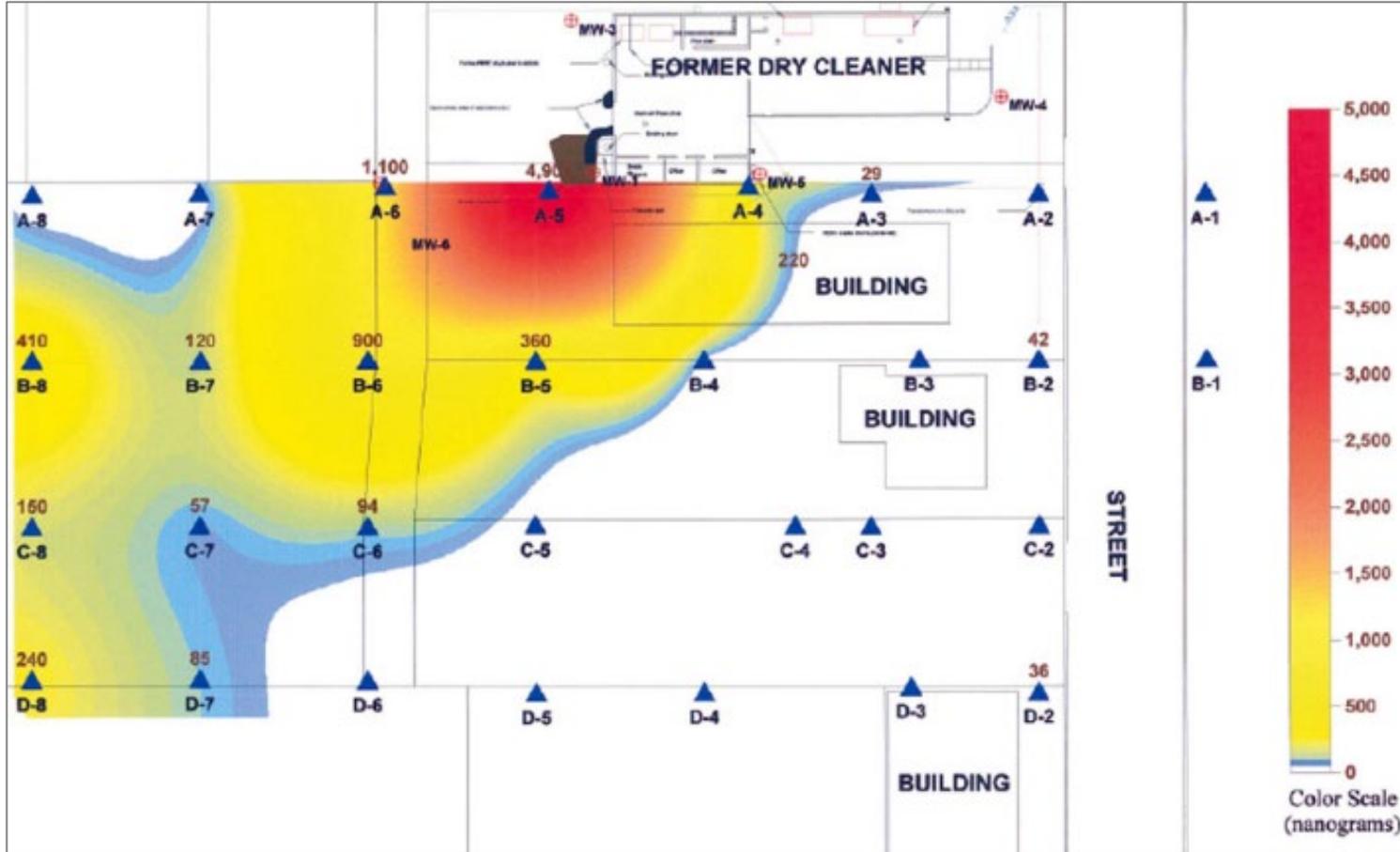
# Characterization



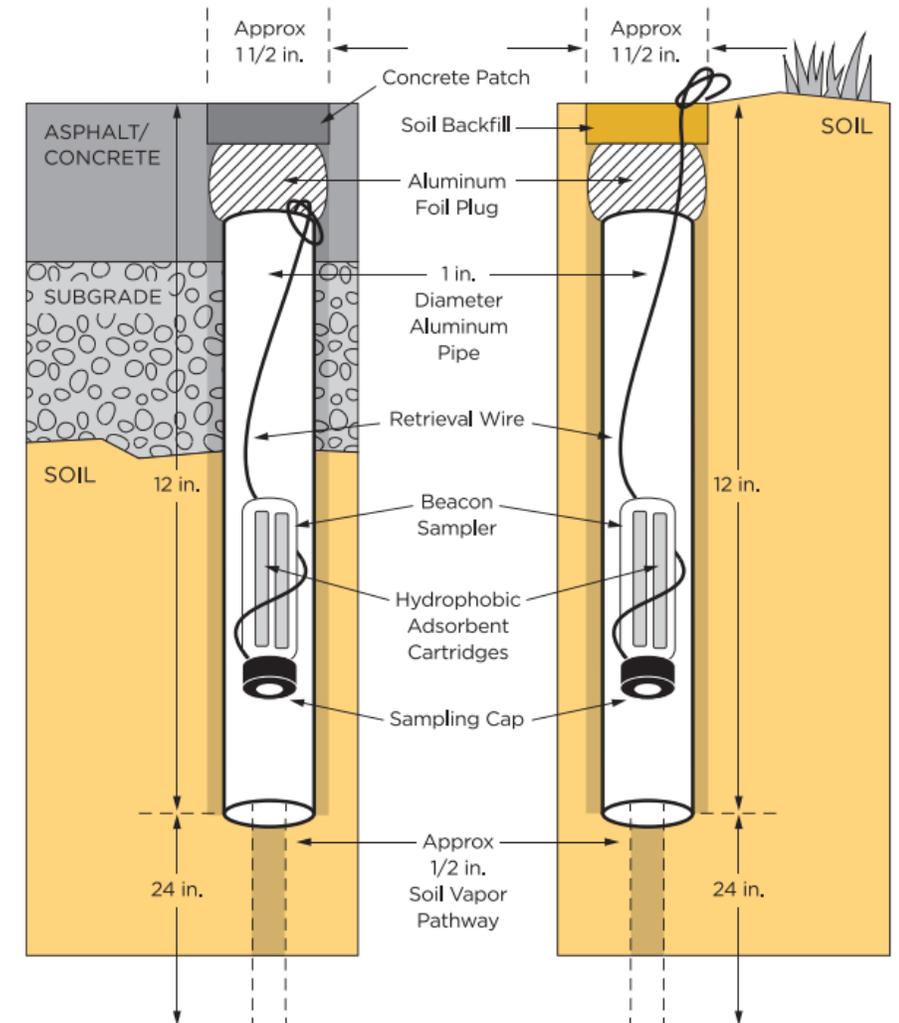
AST: above-ground storage tank  
 UST: underground storage tank

**NSZD Schematic**  
 (Jacobs 2025)

# Characterization



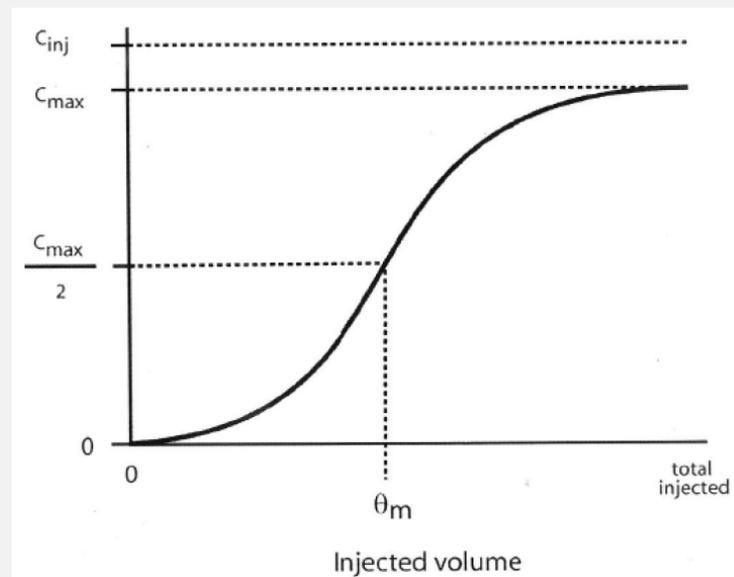
*Example Isopleth (l) and Sampler (r)*  
(Beacon 2024)



# Characterization



Example Tool	Description	Why use?	Typical Phase
<b>Conventional Characterization Tools</b>			
New monitoring wells	Installation of new monitoring wells via DPT or other drilling methods	Verification of grab groundwater sampling to refine extent of groundwater impacts in three dimensions	2 and 6
Tracer testing	Injection and monitoring of conservative compound (e.g., dye or bromide) to assess hydrogeologic properties of aquifer	Improves understanding of groundwater flow direction and velocity and improve in situ remedy design	2 and 6



## Tracer Test Process (USACE 2023)

**KEY POINT**

**Tracer studies can be used to evaluate radius of influence and pore volume to optimize injections.**

# Other Approaches



- Risk assessment
  - Updates to receptors, exposure pathways, contaminants of concern, and conceptual site model
- Regulatory/partnering
  - **Flexible decision documents with defined exit strategies (Case Study 2)**
  - **Defined exit strategies (Case Study 2)**
  - **Partnering process (Case Study 2)**
  - **Regulation and clean-up goal updates (Case Study 2)**
  - Five-Year Review process
  - State risk-based closure programs (especially useful for UST and RCRA sites)
- System O&M
  - Troubleshooting
  - Replace old equipment with updated technology

# Presentation Overview



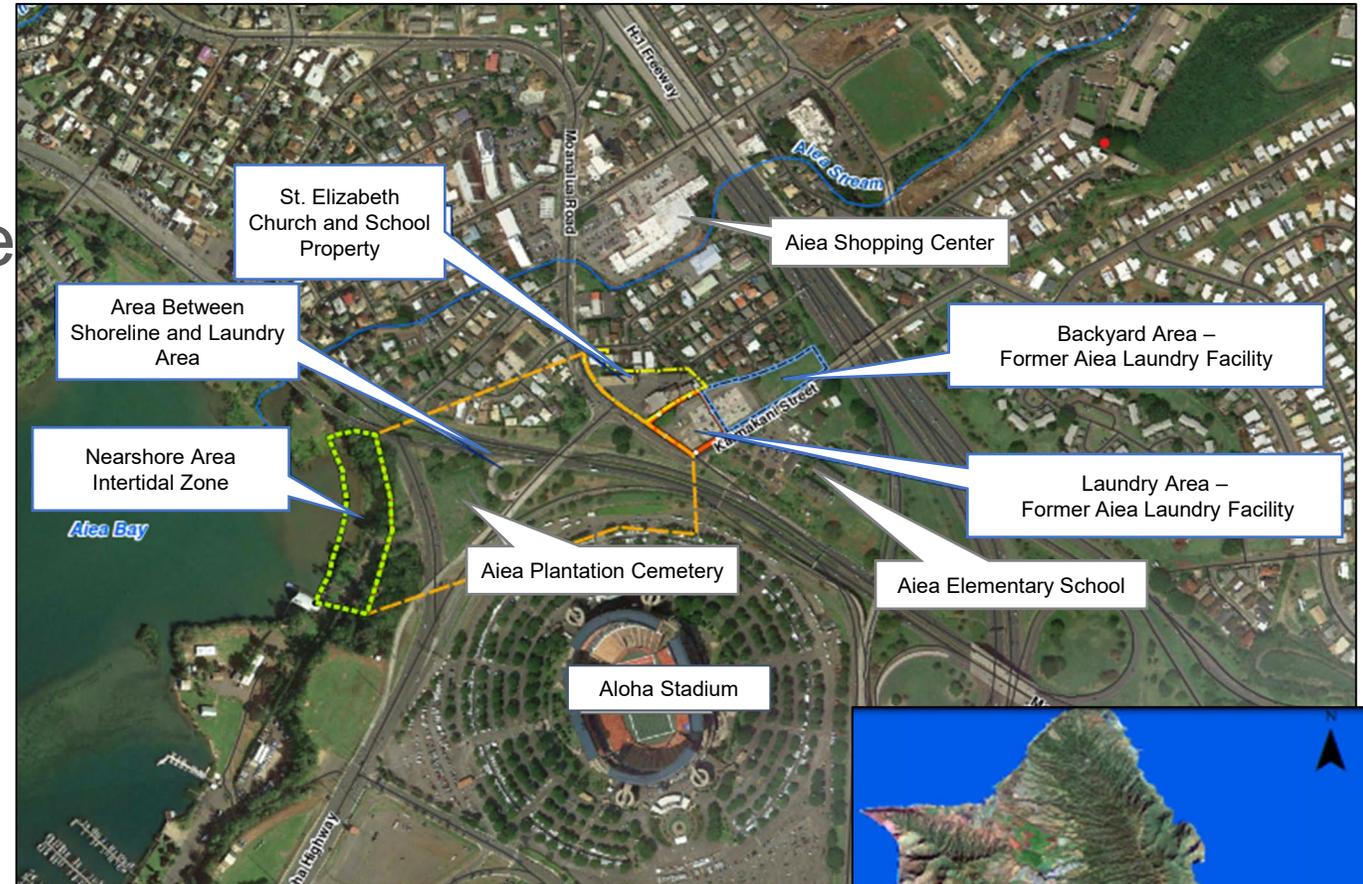
- Introduction
- Optimization Basics
- **Case Study #1: JBPHH Former Aiea Laundry Facility**
- Case Study #2: Camp Lejeune Site 78
- Case Study #3: NAPR SWMUs 7 and 8
- Case Study #4: ABL Site 10
- Key Takeaways

<b>NORM Phase(s)</b>	2 (but with elements of 6)
<b>Optimization trigger(s)</b>	Sampling data are consistent and predictable and contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Vapor concentration trend analysis</li><li>• Monitoring program optimization</li></ul>
<b>Key constraint(s)</b>	Sensitive receptors adjacent to site

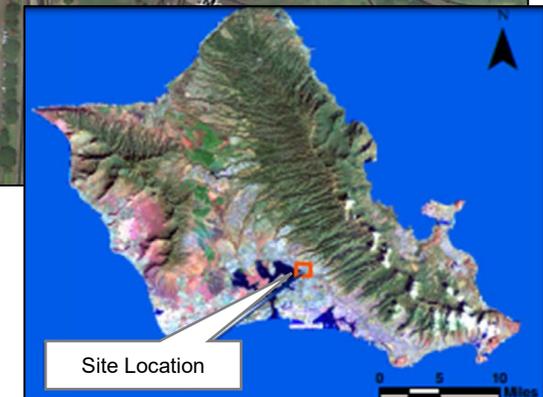
# Site Location



- 3.2-acre site
- Located approximately 0.3 mile east of the shoreline of Aiea Bay
- Bordered by
  - Saint Elizabeth Church
  - Residential housing
  - Aiea Elementary School and Kaimakani Street
  - Moanalua Road and Aloha Stadium



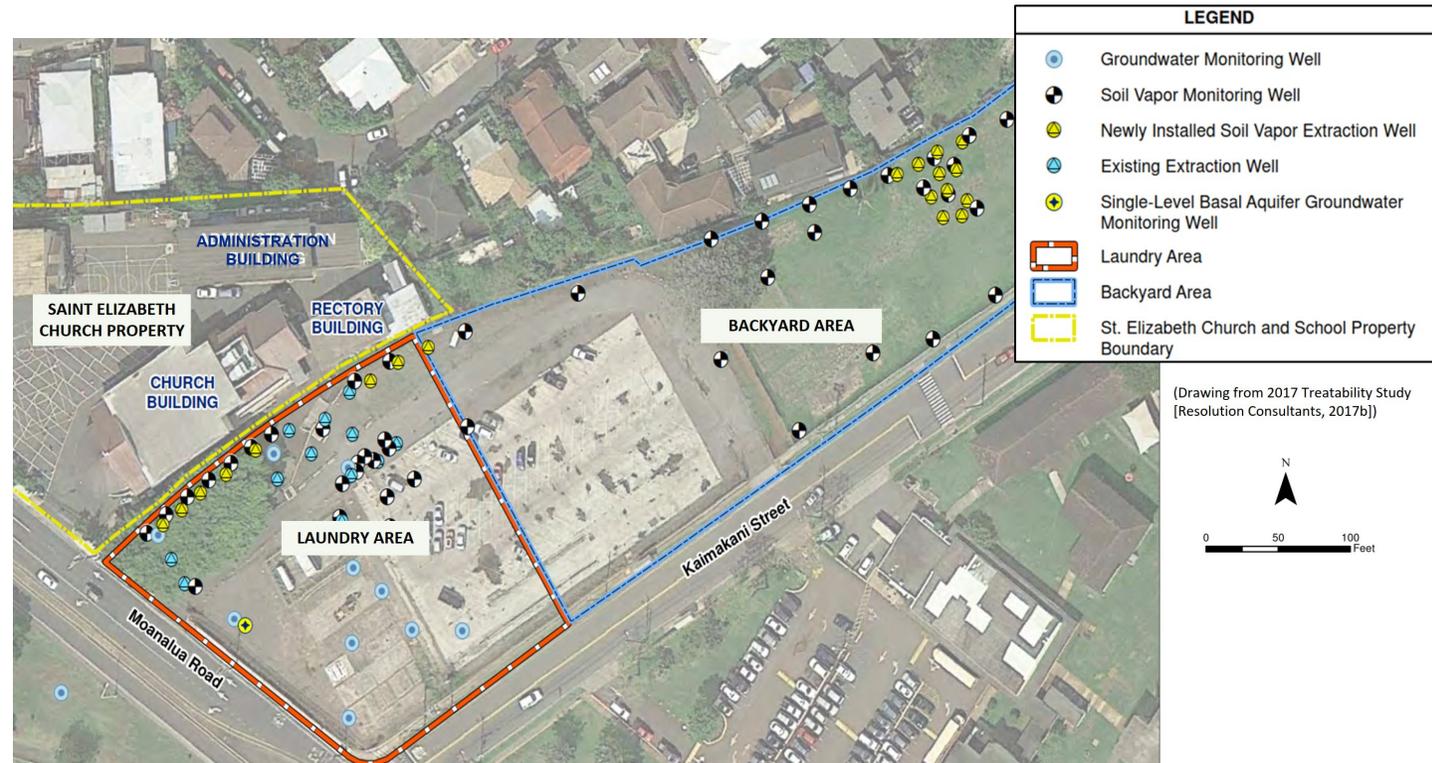
(AECOM 2023a)



# Site Background



- Divided into two areas based on historical use and sources
  - **Laundry Area**
    - Currently used as a parking lot by Saint Elizabeth Church and School
    - Saint Elizabeth Church property consists of Church Building, Rectory Building, and Administration Building
  - **Backyard Area**
    - Currently an unused grassy area

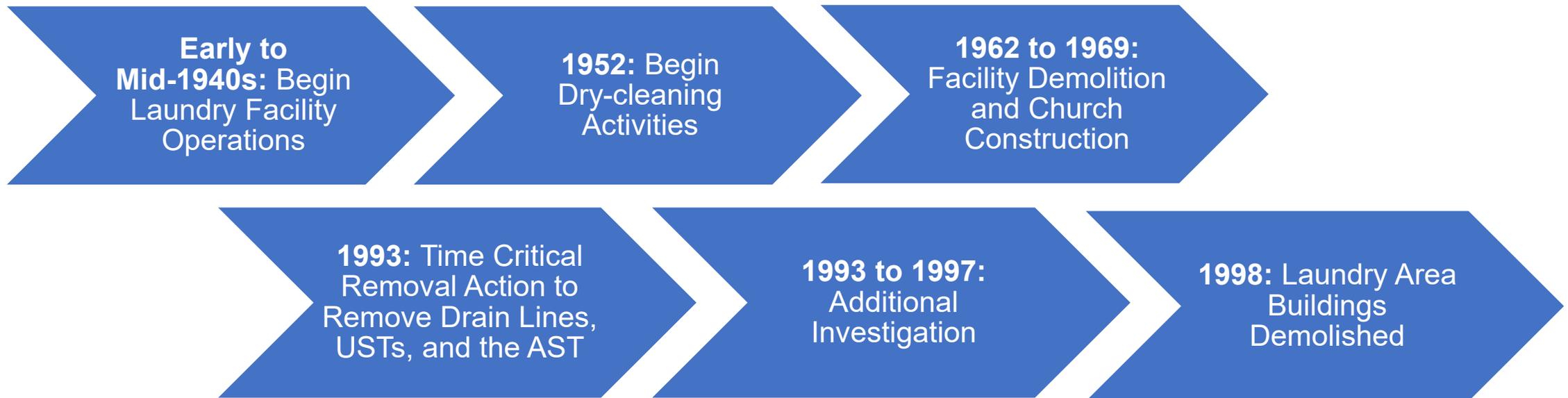


(Resolution Consultants 2017b)

# Site Background



- Operated as a laundry and dry-cleaning facility
  - PCE was stored in four USTs (considered the primary CVOC source)
  - One AST stored diesel fuel; a potential source of LNAPL
- Investigations conducted from 1993 to 1997 indicated CVOCs in soil, soil vapor, and groundwater at the Laundry Area and Saint Elizabeth Church



CVOC: chlorinated volatile organic compound

PCE: tetrachloroethene

# Site Background



- Additional investigations included human health and ecological risk assessments
  - **Human health risk:** Potential to future receptors due to migration of dissolved caprock-aquifer contaminants to the basal aquifer
    - COCs: PCE, TCE, cis-1,2-DCE, trans-1,2-DCE, and VC
  - **Ecological:** None from impacted soil or groundwater
- SVE system installed in 1996 to remediate and prevent potential offsite migration of COCs in soil and soil vapor and operated intermittently
  - Deactivated in 2007 based on reductions of CVOC concentrations
- Field monitoring activities conducted in support of the RI and FS in 2011 and 2012, respectively
  - PCE concentrations in soil gas exceeded the PSLs in both Laundry and Backyard areas

COC: chemicals of concern

DCE: dichloroethane

EPA: United States Environmental Protection Agency

PSL: project screening levels

RI: Remedial Investigation

TCE: trichloroethene

VC: vinyl chloride

SVE: soil vapor extraction

**Note:** PSLs are based on lowest screening residential criteria from EPA and the Hawaii State Department of Health.

# Site Background

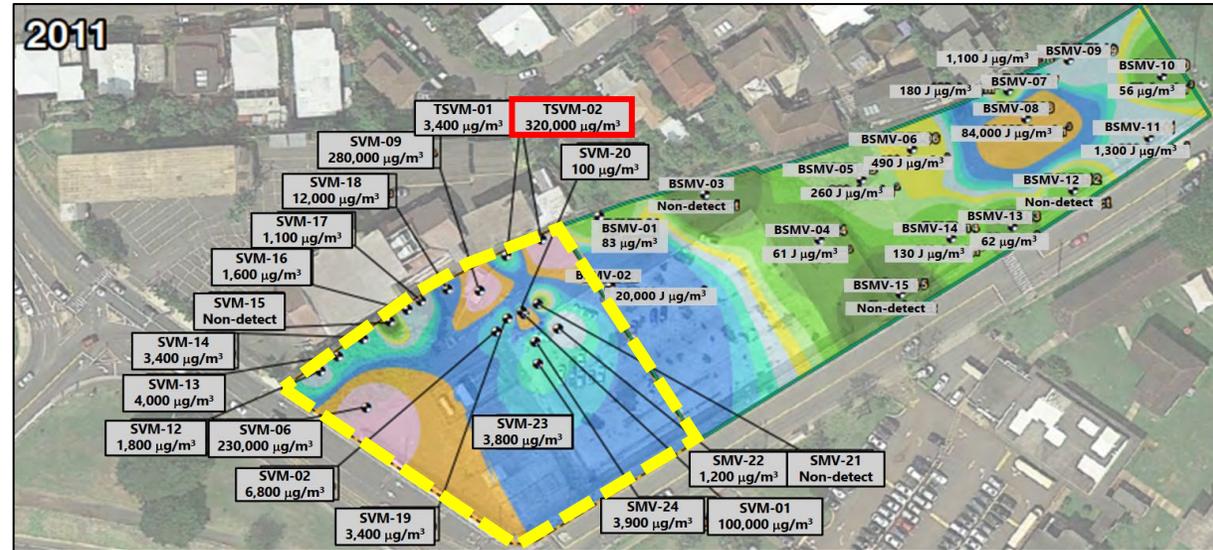
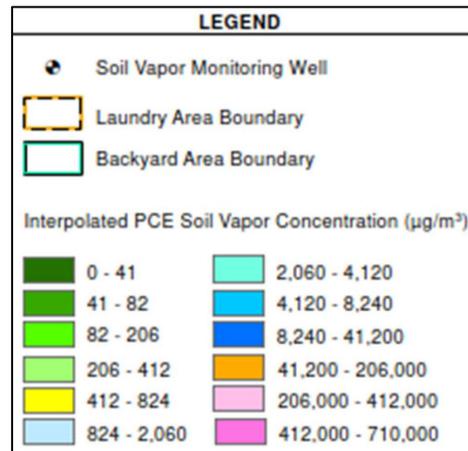


- Laundry Area soil vapor concentrations before optimization
  - **Shallow:** up to 320,000  $\mu\text{g}/\text{m}^3$  (TSVM-02)
  - **Deep:** up to 150,000  $\mu\text{g}/\text{m}^3$  (SVM-18)

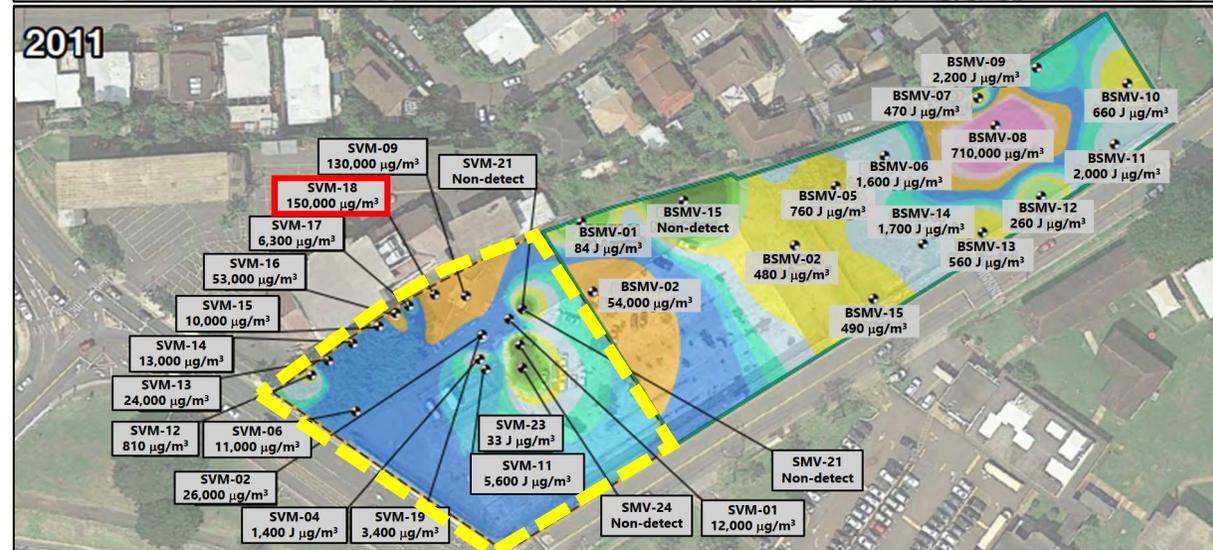
$\mu\text{g}/\text{m}^3$ : microgram(s) per cubic meter

SVM: soil vapor monitoring probe

TSVM: temporary soil vapor monitoring probe



Laundry Area Shallow Soil Vapor Results (2011)



Laundry Area Deep Soil Vapor Results (2011)

(Resolution Consultants 2017b)



# Site Background



- Second SVE/SVMC system was installed and began operation in October 2013 to:
  - Mitigate potential migration of soil vapors from site to neighboring receptors including the Priest residence and preschool in Saint Elizabeth Church
  - Reduce soil vapor mass around hotspot area near BSVM-08
- Second SVE/SVMC system operations are ongoing
  - Soil vapor and indoor air monitoring performed as part of SVE/SVMC system operation, maintenance, and monitoring program



Naval Facilities Engineering Command Hawaii  
JBPHH HI

Final  
**Treatability Study for Soil Vapor Extraction/Soil Vapor Migration Control**  
**Site 31 Aiea Laundry Building 436**  
JOINT BASE PEARL HARBOR-HICKAM OAHU HI

PHNC National Priorities List Site

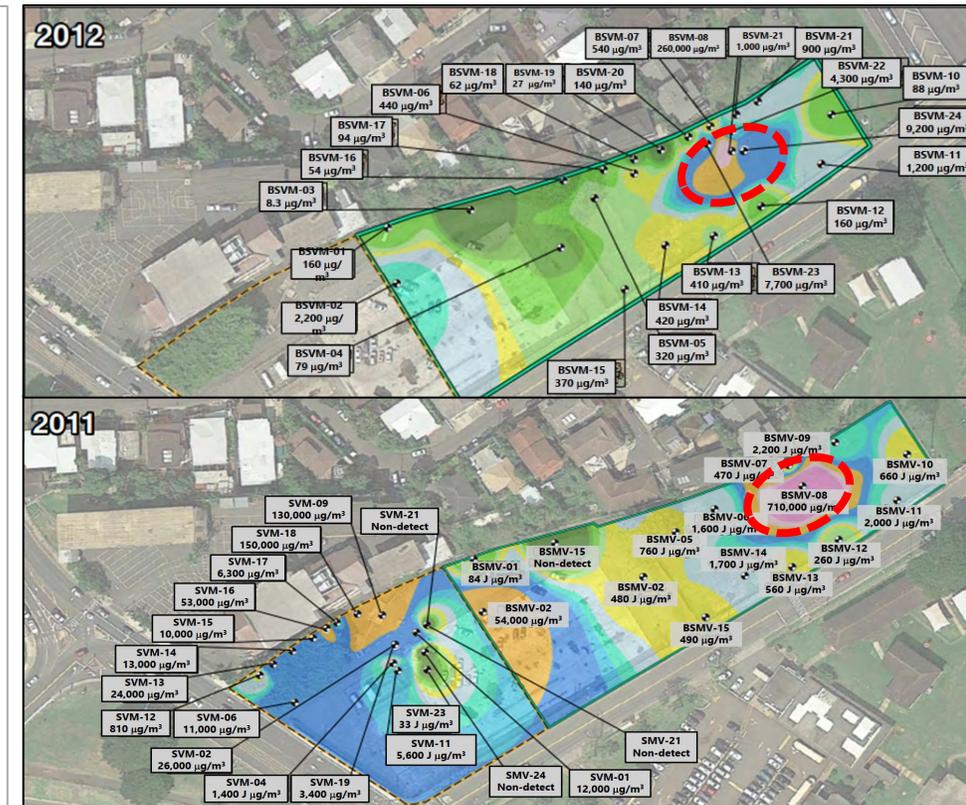
September 2017

Prepared for NAVFAC Hawaii by:  
**Resolution Consultants**  
A Joint Venture of AECOM & EnSafe  
1001 Bishop Street, Suite 1600  
Honolulu, HI 96813-3698

N62470-11-D-8013  
CTO KB14

(NAVFAC 2017)

## Targeted Hot Spots



(Resolution Consultants 2017b)

SVMC: soil vapor migration control

# Optimization Study: Objectives



- Second SVE/SVMC operations optimization study conducted in 2024
- Objectives
  - Evaluate second SVE/SVMC system performance based on main objectives to mitigate migration and decrease source mass
  - **Assess the potential for current VI impacts** to neighboring property (Saint Elizabeth Church)
  - **Optimize the current monitoring program**
  - Determine next steps for second SVE/SVMC system operation
  - Identify exit strategies to be included in Proposed Plan/ROD

VI: vapor intrusion

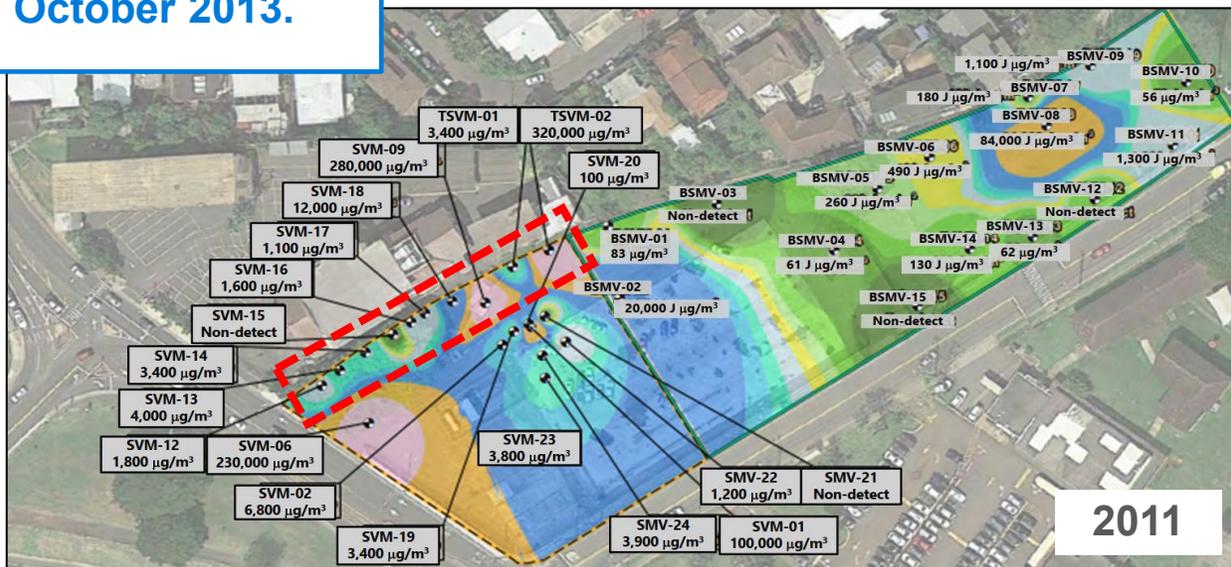
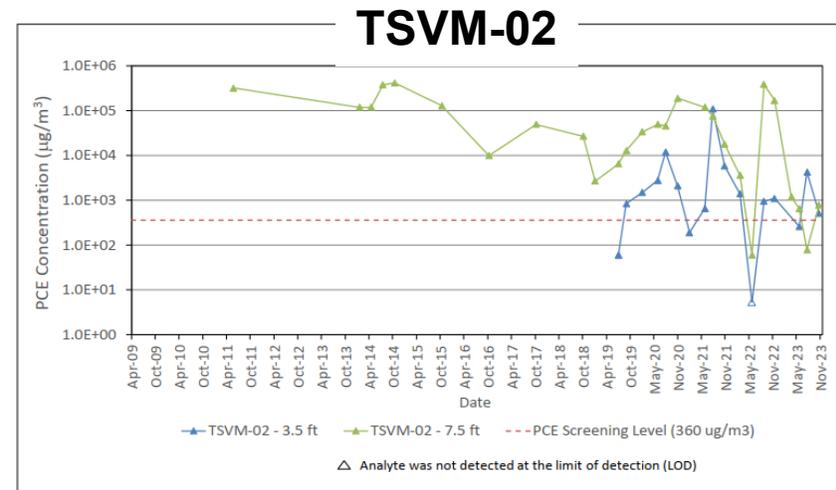
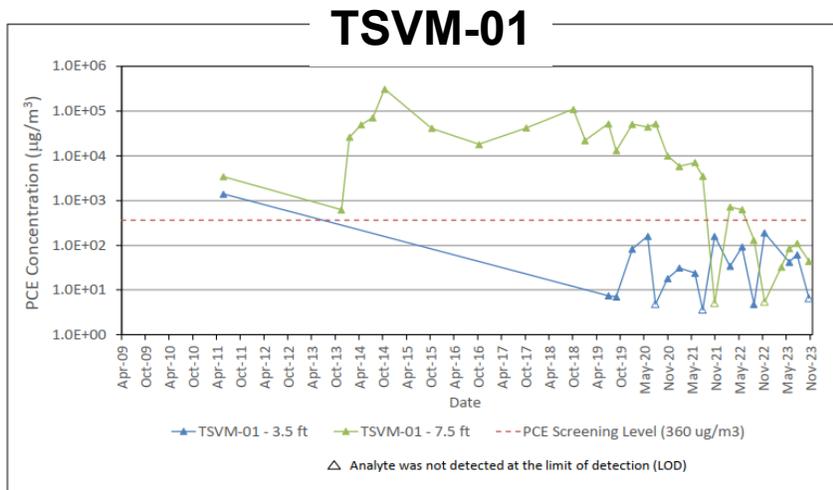
# Optimization Study: Data Summary



## KEY POINTS

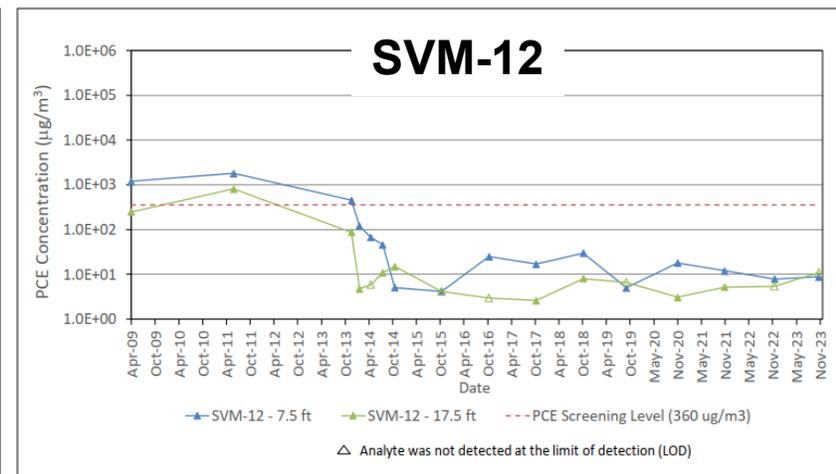
Second SVE/SVMC system effectively mitigated lateral migration from Laundry Area into Saint Elizabeth Church buildings.

CVOC concentrations have reduced by 1 to 3 OOM since SVE/SVMC system startup in October 2013.



2011

(NAVFAC 2017)



Select Laundry Area Soil Vapor Analytical Results

OOM: order(s) of magnitude

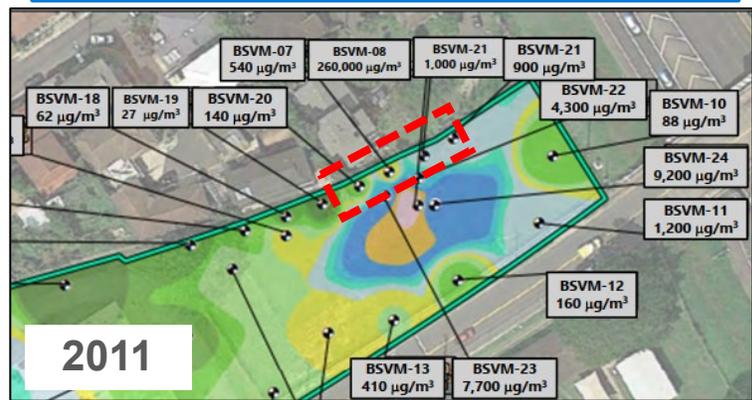
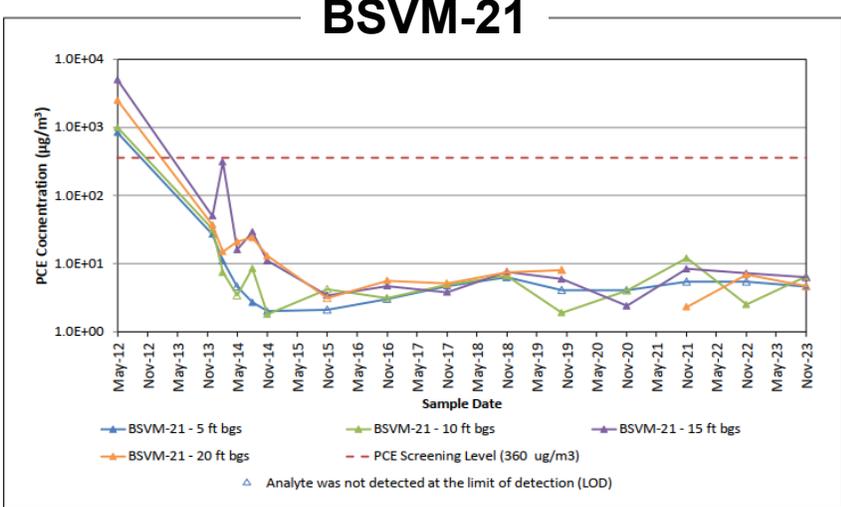
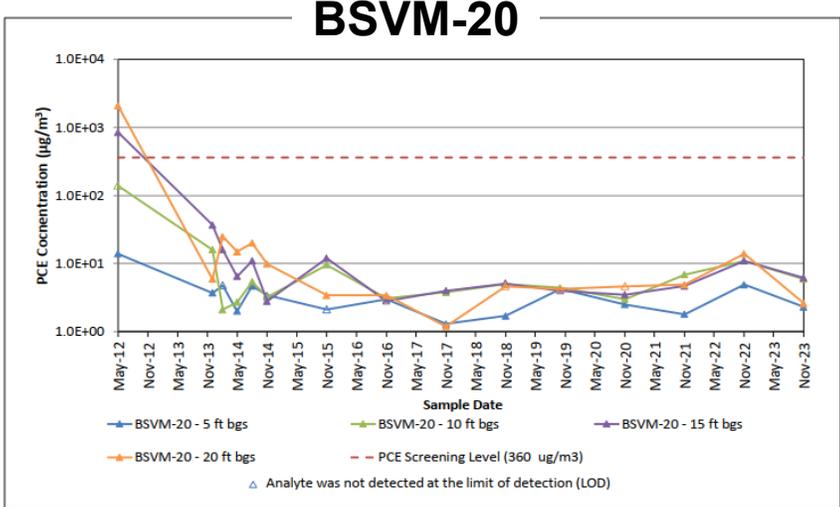
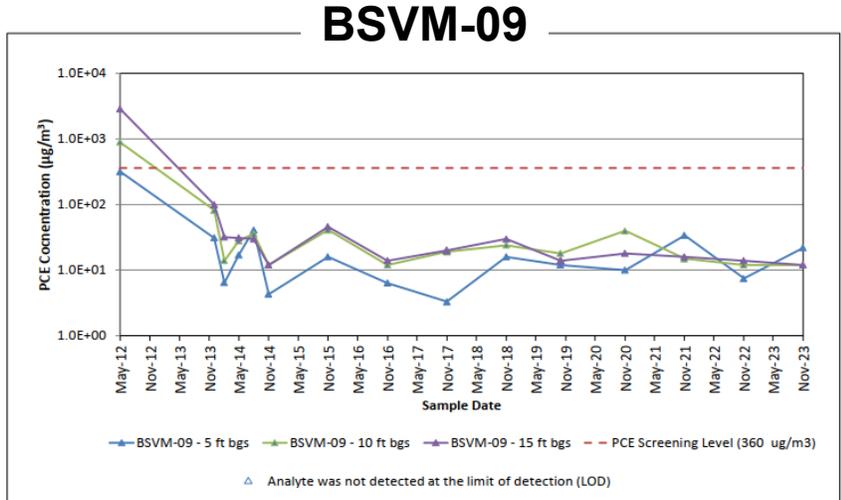
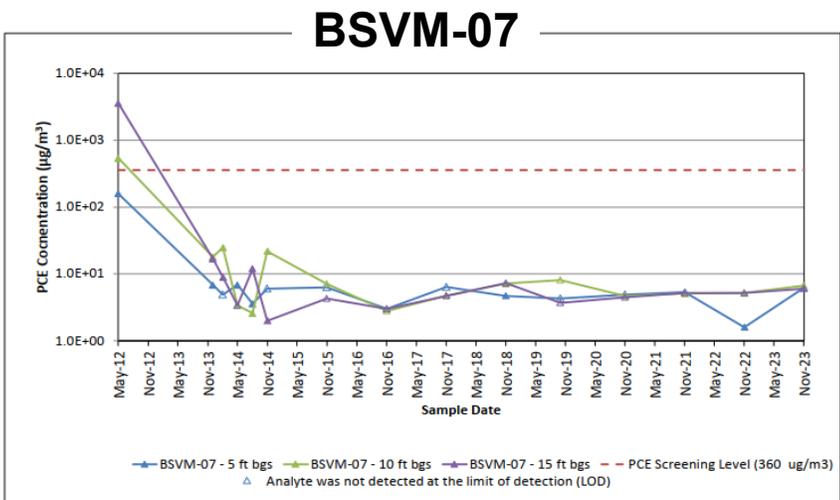
# Optimization Study: Data Summary



## KEY POINTS

Second SVE/SVMC system effectively mitigated lateral migration from Backyard Area into Saint Elizabeth Church buildings

CVOC concentrations have reduced by 1 to 3 OOM since SVE/SVMC system startup in October 2013



(NAVFAC 2017)

## Backyard Area Fenceline Soil Vapor Results

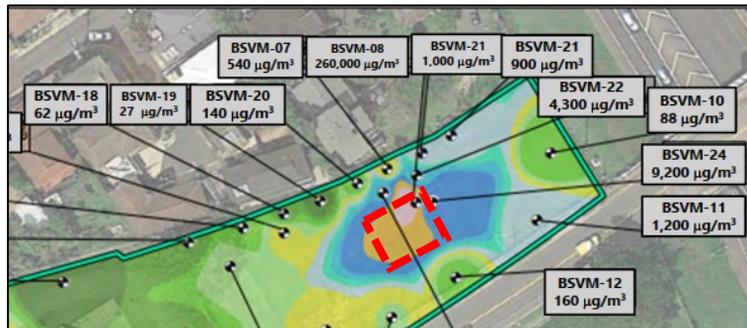
# Optimization Study: Data Summary



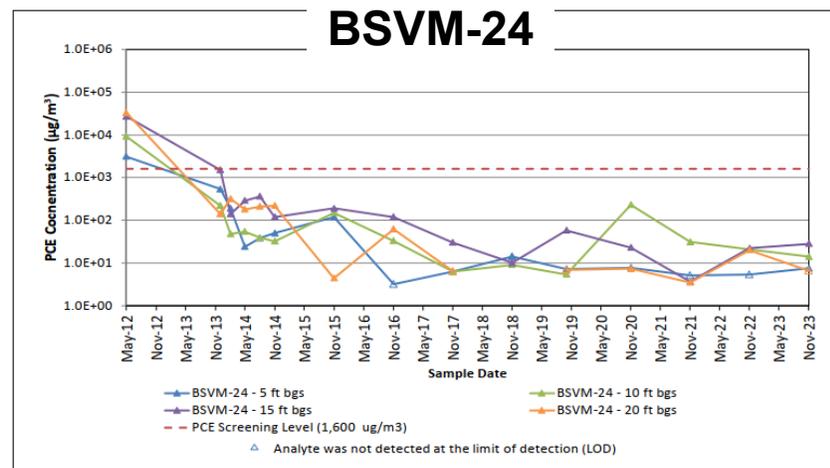
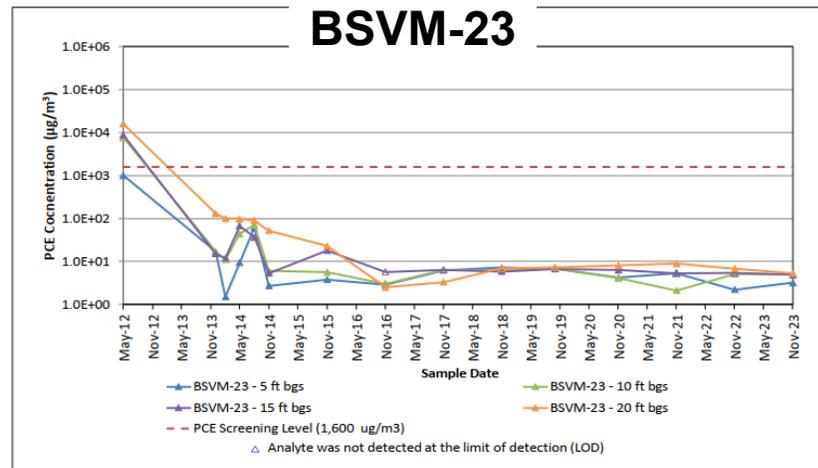
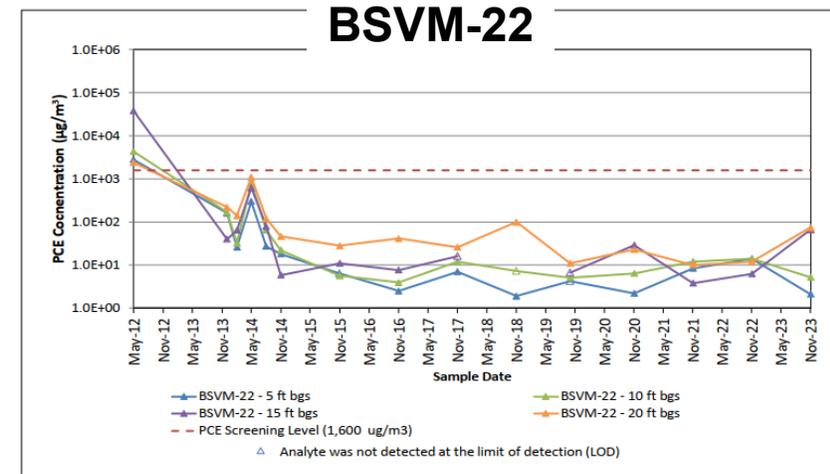
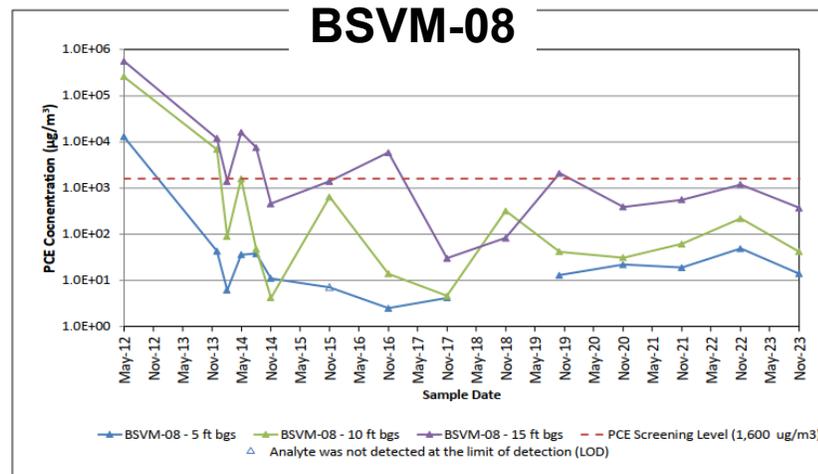
## KEY POINTS

In the center of the Backyard Area, PCE concentrations decreased to less than the PSL following startup, except for BSMV-08

After 1 year, PCE concentrations were 1 to 2 OOM less than the PSL and 2 to 3 OOM less than baseline



(NAVFAC 2017)



Center of Backyard Area Soil Vapor Results

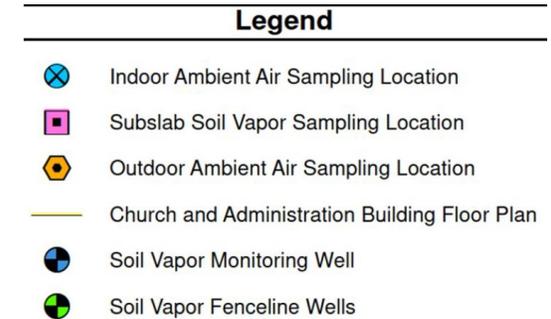
# Optimization Study: Data Summary



- Sub-slab soil vapor data indicate detected PCE concentrations decreased 2 to 3 OOM once second SVE/SVMC system began operations
- Indoor air concentrations have been less than project screening levels except when background sources are present
- Overall, second SVE/SVMC system effectively mitigated lateral migration of contamination from Laundry Area into buildings



(AECOM 2023a)



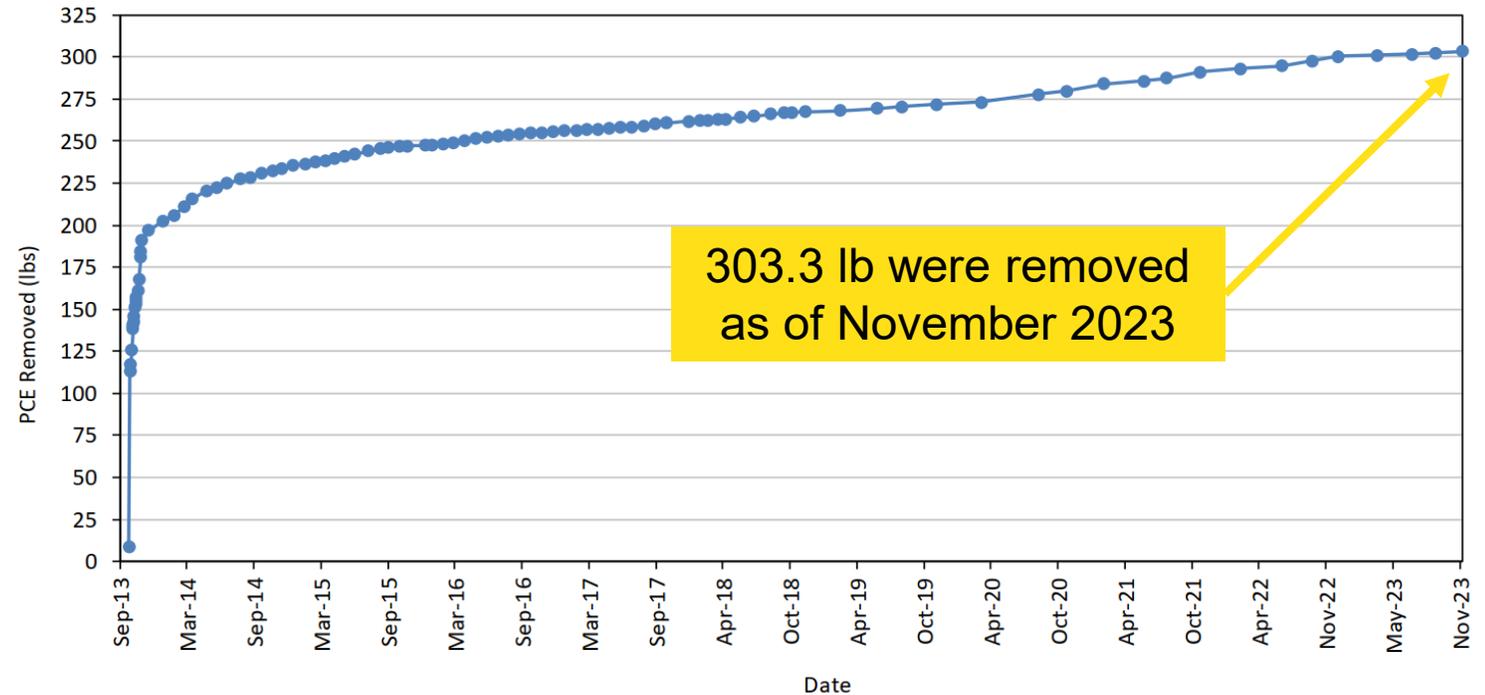
**KEY POINT** Potential for VI concerns in church and rectory buildings is low.

# Optimization Study: Data Summary



- Second SVE/SVMC system reduced PCE mass in source areas
- PCE removal rate has been asymptotic since 2022
  - About 0.01 lb per day

*PCE Cumulative Mass Removed; Laundry Area and Backyard Area*



(AECOM 2023b)

lb: pound(s)

# Optimization Study: Recommendations



Observation	Recommendation
<p>PCE concentrations along western portion of fenceline decreased after second SVE/SVMC system startup in October 2013 and have been less than PSLs since 2014</p>	<ul style="list-style-type: none"> <li>• Shut down second SVE/SVMC wells</li> <li>• Perform a rebound study (with quarterly monitoring) to evaluate whether further operation of second SVE/SVMC along fenceline is necessary</li> </ul>
<p>PCE concentrations have fluctuated at TSVM-02 and SVM-24; subsurface lithology in these areas includes fat and high-plasticity clays that appear to be limiting mass removal</p>	<ul style="list-style-type: none"> <li>• Intermittently operate (e.g., 2 weeks on, 2 weeks off) second SVE/SVMC wells near TSVM-02 and SVM-24 to reduce energy cost and equipment wear</li> <li>• Reduce second SVE system inspections to semiannual</li> <li>• Perform HRSC in these areas and conduct an evaluation of additional remediation technologies (including soil removal options)</li> </ul>



(Resolution Consultants 2017a)

# Optimization Study: Recommendations



Observation	Recommendation
<p>PCE concentrations decreased to less than PSL in center of Backyard Area</p>	<ul style="list-style-type: none"><li>• Shut down second SVE/SVMC wells in Backyard Area</li><li>• Conduct rebound study (with quarterly monitoring) to evaluate whether further operation is necessary</li></ul>
<p>Nearly 10 years of data indicate second SVE/SVMC system has reduced source mass and prevented soil vapor migration onto Saint Elizabeth Church property, and there is a low potential for VI because subslab soil gas concentrations have remained below PSLs since 2014</p>	<ul style="list-style-type: none"><li>• Continue second SVE/SVMC operation around TSVM-02 (per previous recommendation)</li><li>• Discontinue quarterly monitoring activities in buildings on church property</li><li>• Monitor potential soil vapor migration at multiple soil vapor probes along property border as part of rebound study</li></ul>

## KEY POINT

**Pending rebound monitoring results, the optimized monitoring program will reduce annual costs by \$100,000 to \$200,000.**

# Knowledge Check



- **Question:** What path forward or next steps would most likely allow for accelerated site closure?
- **Answers:**
  - a. Shutdown of second SVE/SVMC system
  - b. Targeted removal of source material bound in subsurface clay
  - c. Reduced monitoring frequency of second SVE/SVMC system
  - d. Rebound testing of second SVE/SVMC system

# Knowledge Check



- **Question:** What path forward or next steps would most likely allow for accelerated site closure?
- **Answers:**
  - a. Shutdown of second SVE/SVMC system
  - b. **Targeted removal of source material bound in subsurface clay**
  - c. Reduced monitoring frequency of second SVE/SVMC system
  - d. Rebound testing of second SVE/SVMC system

Why  
Answer b?

**Concentration trends showing asymptotic removal indicate system is likely nearing maximum mass removal that can be achieved.**

# Summary



<b>NORM Phase(s)</b>	2 (but with elements of 6)
<b>Optimization trigger(s)</b>	Sampling data are consistent and predictable, and contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Vapor concentration trend analysis</li><li>• Monitoring program optimization</li></ul>
<b>Key constraint(s)</b>	Sensitive receptors adjacent to site
<b>Outcome</b>	<ul style="list-style-type: none"><li>• Reduced second SVE/SVMC operation</li><li>• Optimized vapor monitoring program</li></ul>
<b>Path forward</b>	<ul style="list-style-type: none"><li>• Consider HRSC to identify residual source mass</li><li>• Operate second SVE/SVMC as needed and implement optimized vapor monitoring program</li></ul>
<b>Potential financial impact</b>	Annual cost reduction of \$100,000 to \$200,000

# Presentation Overview



- Introduction
- Optimization Basics
- Case Study #1: JBPHH Former Aiea Laundry Facility
- **Case Study #2: Camp Lejeune Site 78**
- Case Study #3: NAPR SWMUs 7 and 8
- Case Study #4: ABL Site 10
- Key Takeaways

<b>NORM Phase(s)</b>	6 and then 2 (3 and 4 pending)
<b>Optimization trigger(s)</b>	Remedy not projected to meet RAOs
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Bench and pilot studies</li><li>• REMChlor modeling and development of active remediation goals</li><li>• Partnering process</li></ul>
<b>Key constraint(s)</b>	<ul style="list-style-type: none"><li>• No defined exit strategy in decision document</li><li>• Different state and federal cleanup levels</li></ul>

# Site Background

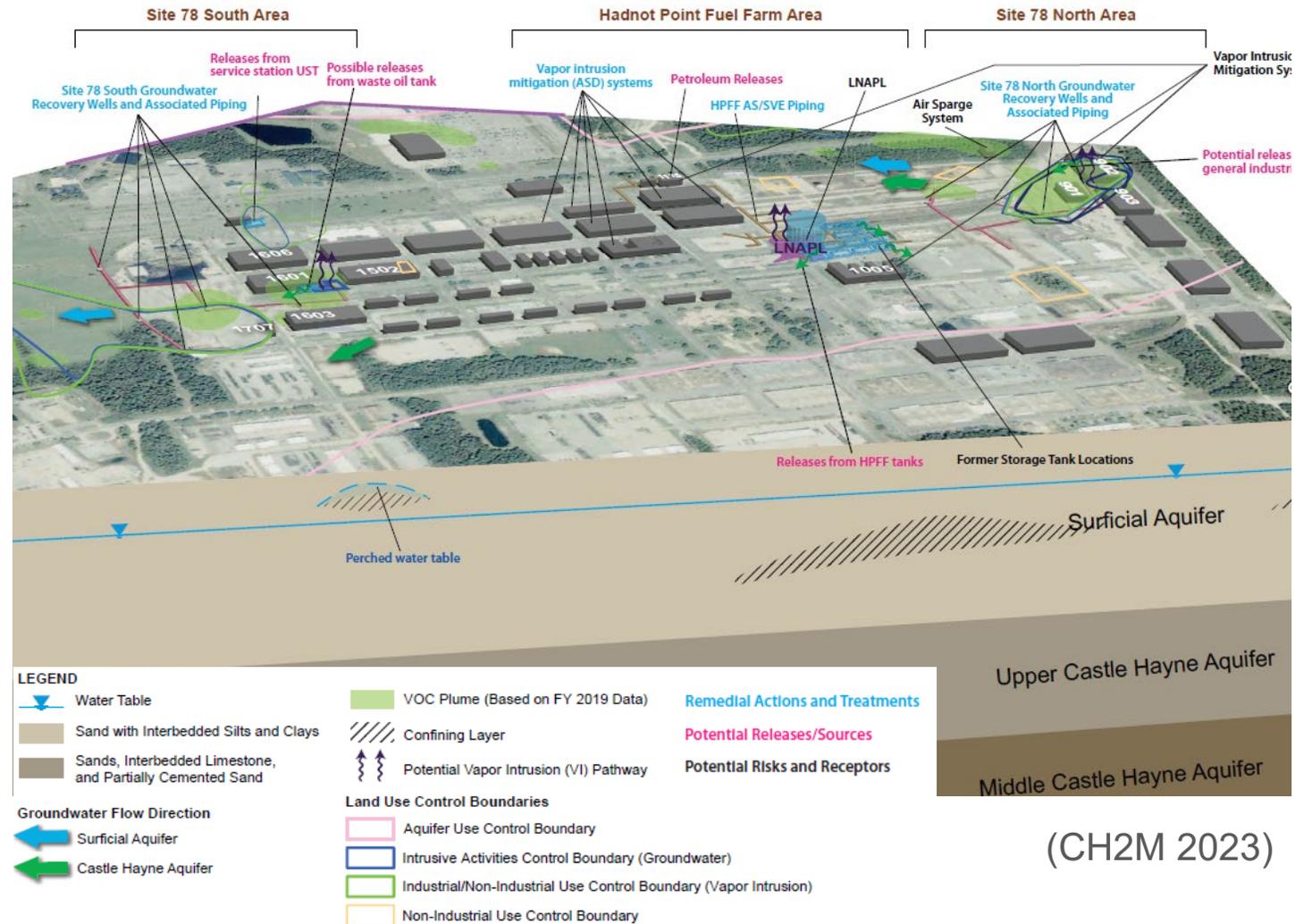


- Site background

- 590 acres of industrial land developed in late 1930s
- Maintenance shops, warehouses, painting shops, printing shops, auto body shops
- Numerous spills and leaks of petroleum-related products and chlorinated solvents

- Potential risks

- Human health risks from VOCs in groundwater
  - Potable water source for future residents
  - Construction



(CH2M 2023)

# Long-term Remedy



- Two P&T systems (Sites 78 North and Site 78 South) began operation in 1994, along with LTM and LUCs
  - Originally, 15 recovery wells screened from 25 to 35 feet bgs
  - Currently, 9 recovery wells operational
  - Treatment via air strippers and carbon
  - Discharged to sanitary sewer
- No exit strategy defined in ROD
  - Operation to continue until NCGWQS achieved (more stringent than MCLs)

bgs: below ground surface

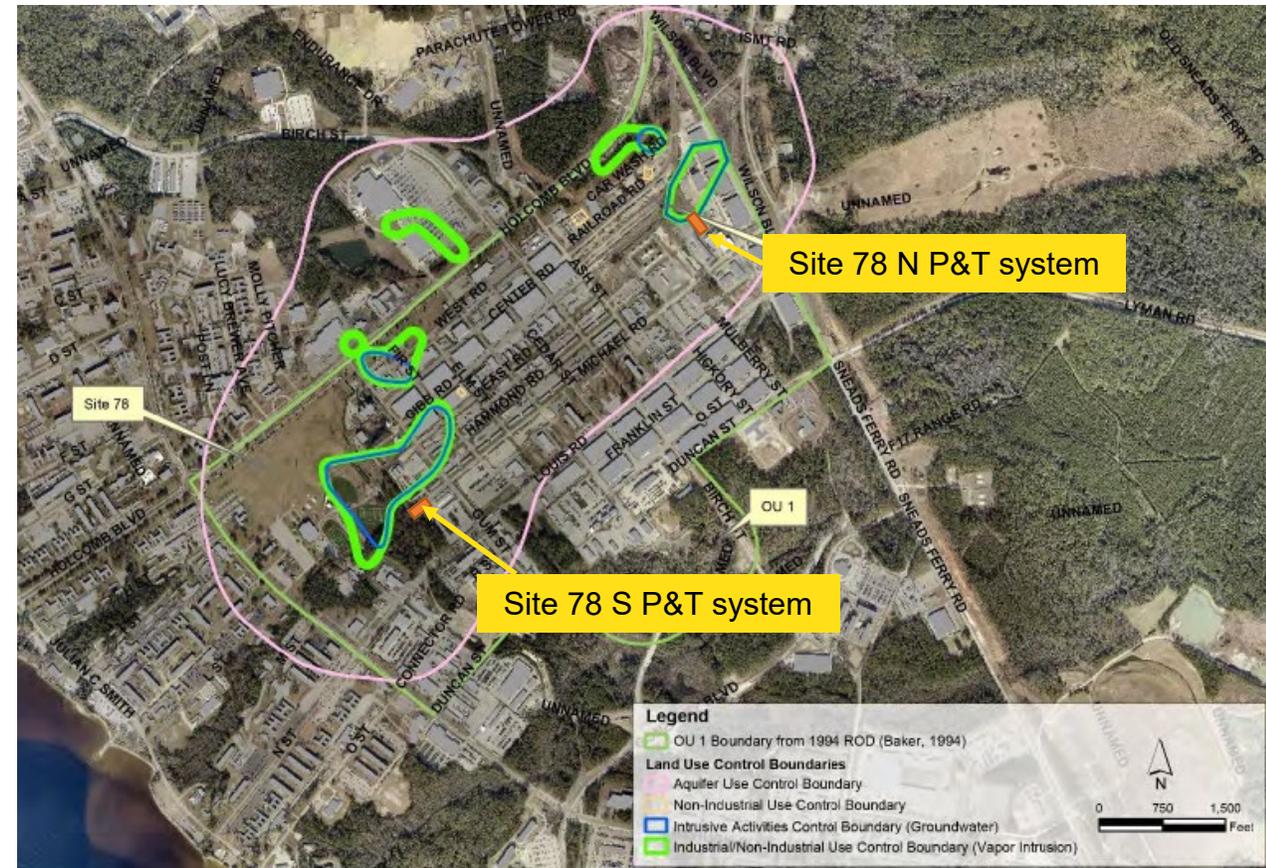
LTM: long-term monitoring

LUC: land use control

MCL: maximum contaminant level

NCGWQS: North Carolina Groundwater Quality Standards

P&T: (groundwater) pump and treat



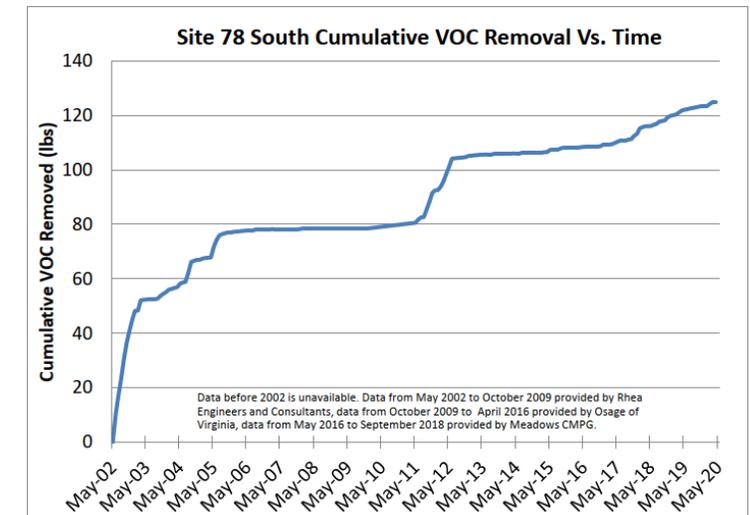
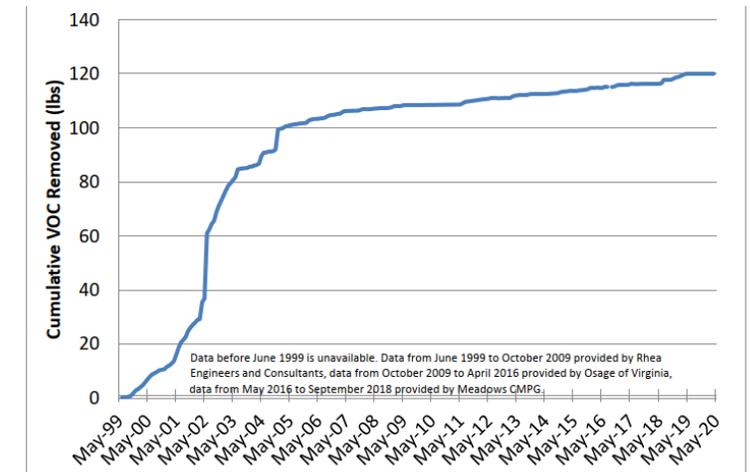
(CH2M 2023)

# Optimization Rationale



- Remedy is **not functioning** as designed and RAOs will not be met
  - Contaminant mass removal is asymptotic
    - Approximately 0.32 lb of VOCs removed per month
    - >400 years of pumping required to achieve NCGWQS
  - Impacted groundwater **extends beyond influence** of extraction well network
    - Plume identified to northwest of site
    - Impacts observed up to 125 feet bgs; recovery wells screened to 35 feet bgs

*Total of approximately 245 lb of VOCs removed*



(CH2M 2022)

# Technology Evaluation (2003 to 2017): Site 78 North



Technologies Piloted	General Approach	Outcome
Aerobic bioremediation (2003–2005)	Focused Oxygen Release Compound injections to address elevated VC concentrations	Little change to dissolved oxygen concentrations and oxidation reduction potential, and no apparent contaminant concentration reductions
ISCO (2012)	Persulfate bench-scale study using site soil and groundwater	Not effective in lab; not recommended for field implementation
ISCR + ERD (2012–2013)	Bench-scale study testing using a buffered, micro-emulsion of slow-release, EHC <sup>®</sup> Liquid and bioaugmentation to target lower VOC concentrations	Not effective in lab; not recommended for field implementation
AS (2017-2018)	Air injection via stacked injection wells in Northwest Woods to target elevated VOC concentrations down to 125 feet bgs	Highly effective at mass reduction, influence observed 40 feet from injection wells, VOC accumulation not observed in shallower zones
Enhanced P&T (2018–2019)	Pumping test to evaluate groundwater extraction in deeper intervals	Determined extraction well radius of influence

AS: air sparging

ERD: enhanced reductive dechlorination

ISCO: in situ chemical oxidation

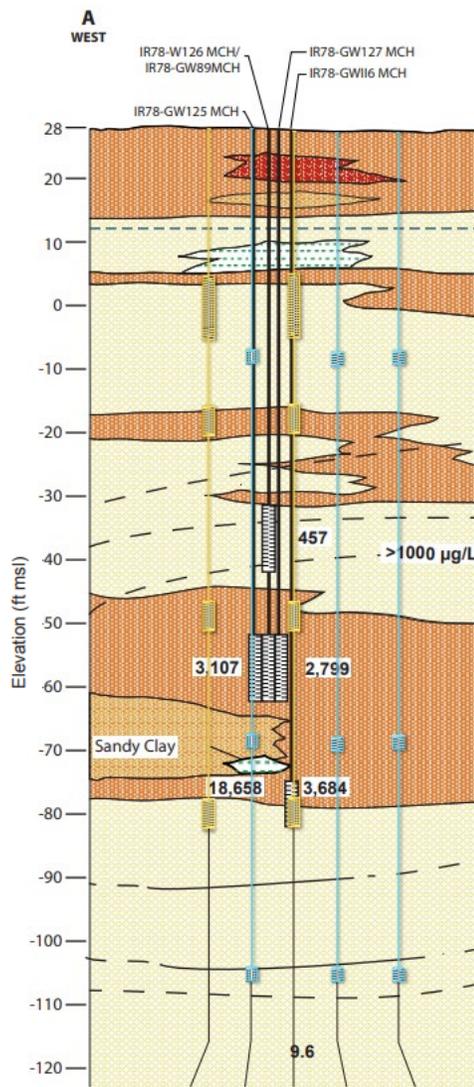
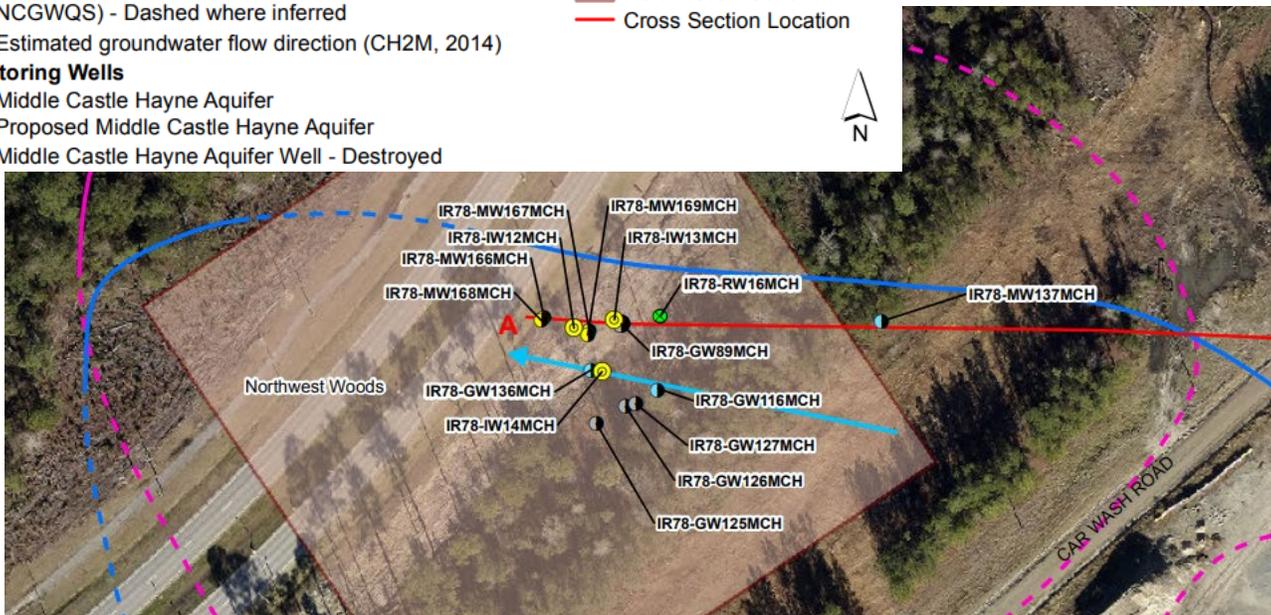
ISCR: in situ chemical reduction

# Technology Evaluation (2003 to 2017): Site 78 North

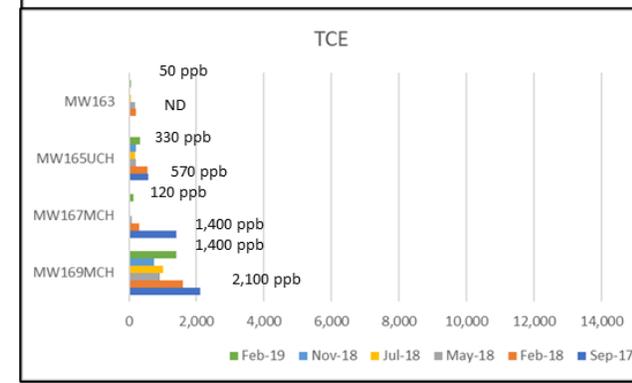
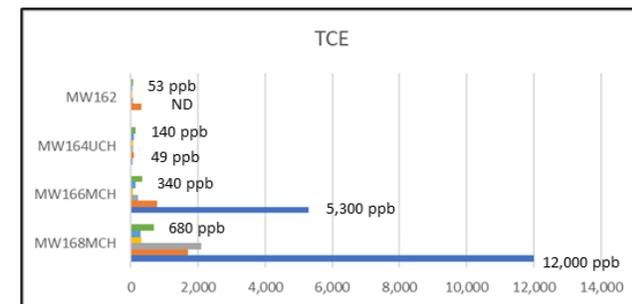


- Legend**
- Blue line: Benzene, Toluene, Ethylbenzene, and Xylene Plume (exceeds NCGWQS) - Dashed where inferred
  - Pink line: Chlorinated Volatile Organic Compounds Plume (exceeds NCGWQS) - Dashed where inferred
  - Blue arrow: Estimated groundwater flow direction (CH2M, 2014)
  - Green circle: Recovery Well
  - Yellow circle: Proposed Air Sparging Well (CH2M 2017, 2023)
  - Red line: Northwest Woods
  - Red line: Cross Section Location

- Monitoring Wells**
- Blue circle: Middle Castle Hayne Aquifer
  - Yellow circle: Proposed Middle Castle Hayne Aquifer
  - Black circle: Middle Castle Hayne Aquifer Well - Destroyed



- LEGEND**
- Sand
  - Silty Sand
  - Sandy Silt
  - Sandy Clay/Silty Sandy Clay
  - Clayey Sand
  - Well bore with screened interval
  - Approximate Water Table
  - Groundwater Flow
  - Isoconcentration contour, dashed where inferred
  - Monitoring Wells
  - Injection Wells



**KEY POINT**

AS pilot study confirmed the effectiveness of a stacked wells system to overcome challenges of removing VOC mass from a stratified lithology.

# Technology Evaluation (2003 to 2017): Site 78 South



Technologies Piloted	General Approach	Outcome
Enhanced bioremediation (2003–2005)	Focused Hydrogen Release Compound injections	Reductive dechlorination increased significantly following study, but was not complete and appeared to stall at cis-1,2-DCE
ISCO (2012)	Persulfate bench-scale study using site soil and groundwater	Not effective in lab; not recommended for field implementation
Enhanced bioremediation (2012–2013)	Sulfate bench-scale study using site soil and groundwater	No reduction in benzene, toluene, ethylbenzene, and xylene or CVOC concentrations; not recommended for field implementation
ISCR + ERD (2015)	Focused injections of EHC-L and bioaugmentation	TCE concentrations decreased by 94% and total CVOC concentrations decreased by 75%; treatment observed up to 18 feet from injections wells

# Technology Evaluation (2003 to 2017): Outcome

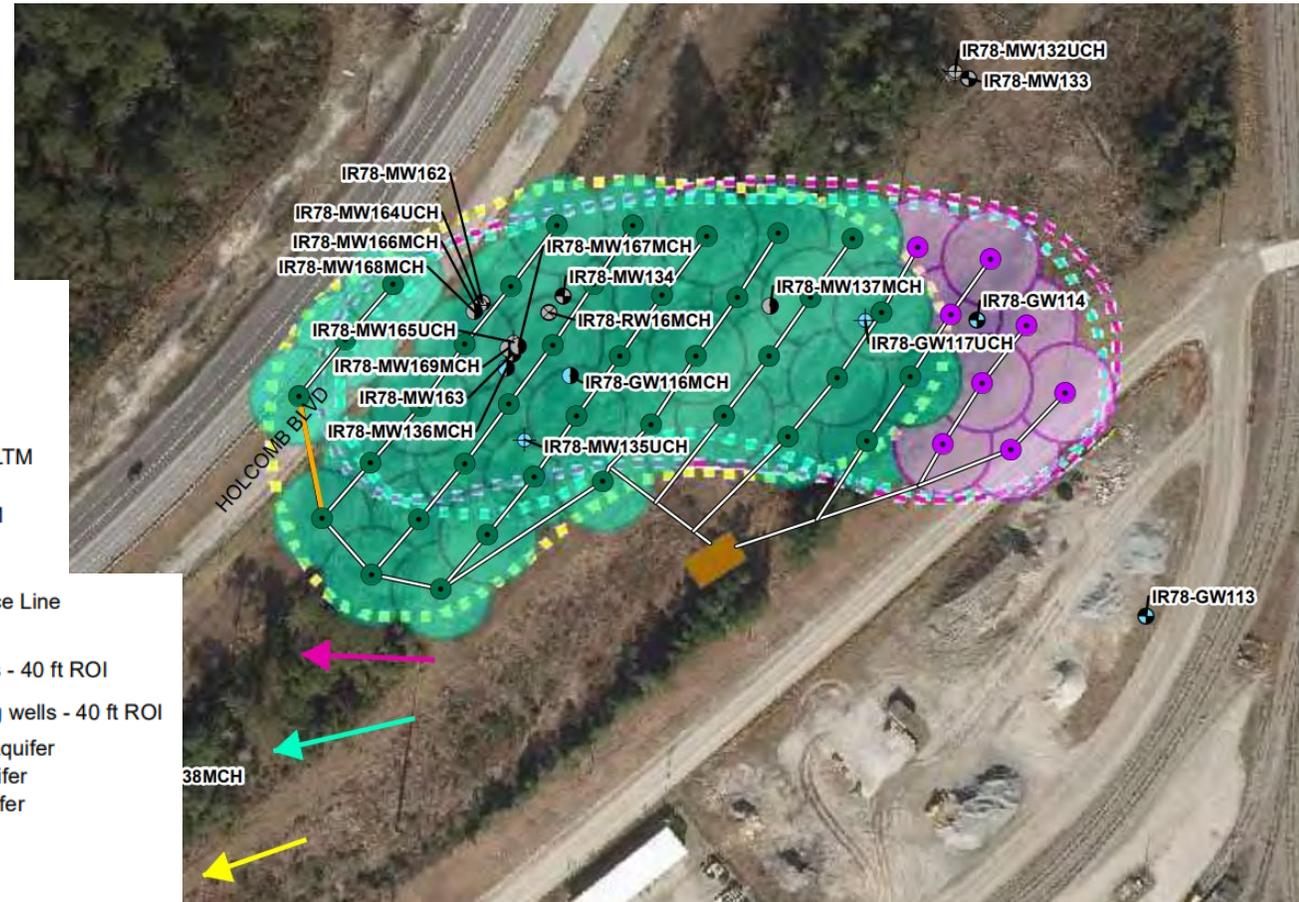


- Technologies retained for FS Amendment
  - Enhanced P&T
  - ERD
  - AS
  - MNA

AS Alternative Layout for Site 78 North  
(CH2M 2023)

### Legend

- Surficial Aquifer Monitoring Well
- LCH Aquifer Monitoring Well
- MCH Aquifer Monitoring Well
- ⊕ UCH Aquifer Monitoring Well
- Surficial Aquifer Monitoring Well - not in LTM
- MCH Aquifer Monitoring Well - not in LTM
- ⊕ UCH Aquifer Monitoring Well - not in LTM
- ⊗ Recovery Well - Not Operational
- Proposed Conveyance Line
- Proposed Horizontally Drilled Conveyance Line
- Proposed Air Sparging System
- ⊕ Proposed UCH vertical air sparging wells - 40 ft ROI
- ⊕ Proposed UCH/MCH vertical air sparging wells - 40 ft ROI
- ⋯ Extent of COCs > MCLs in the Surficial Aquifer
- ⋯ Extent of COCs > MCLs in the MCH Aquifer
- ⋯ Extent of COCs > MCLs in the UCH Aquifer
- MCH Aquifer GW Flow Direction
- Surficial Aquifer GW Flow Direction
- UCH Aquifer GW Flow Direction



# Remediation Timeframe Quandary



- For this site, EPA determined reasonable timeframe is 100 years
- Focused treatment will reduce remediation timeframe by achieving MCLs (EPA's priority) within 100 years
- However, **REMChlor modeling** suggests timeframe to reduce COCs from MCLs to NCGWQS (applicable or relevant and appropriate requirement in ROD) via MNA >400 years
- Extensive active treatment would be required to achieve NCGWQS within 100 years, with no change to risk profile

COC	MCL (µg/L)	NCGWQS (µg/L)
PCE	5	0.7
TCE	5	3
Cis-1,2-DCE	70	70
VC	2	0.03

µg/L: microgram(s) per liter

# Remediation Timeframe Quandary



- Selection of preferred alternative stagnated for several years
  - Conflicting stakeholder opinions on remediation timeframe
  - Concern about projected cost of active treatment to achieve NCGWQS
    - \$28 million to \$50 million sitewide
- EPA and NCDEQ managers and attorneys met to discuss conflict between cleanup levels and remediation timeframe, and reached agreement
  - Based on site-specific conditions, EPA and NCDEQ concurred that remedy will be optimized to meet MCLs within 100 years
  - Once active groundwater treatment is no longer necessary, LUCs will remain, and long-term monitoring will be conducted until NCGWQS achieved
- NAVFAC agreed to focused treatment and defined short-term operation period to optimize mass removal

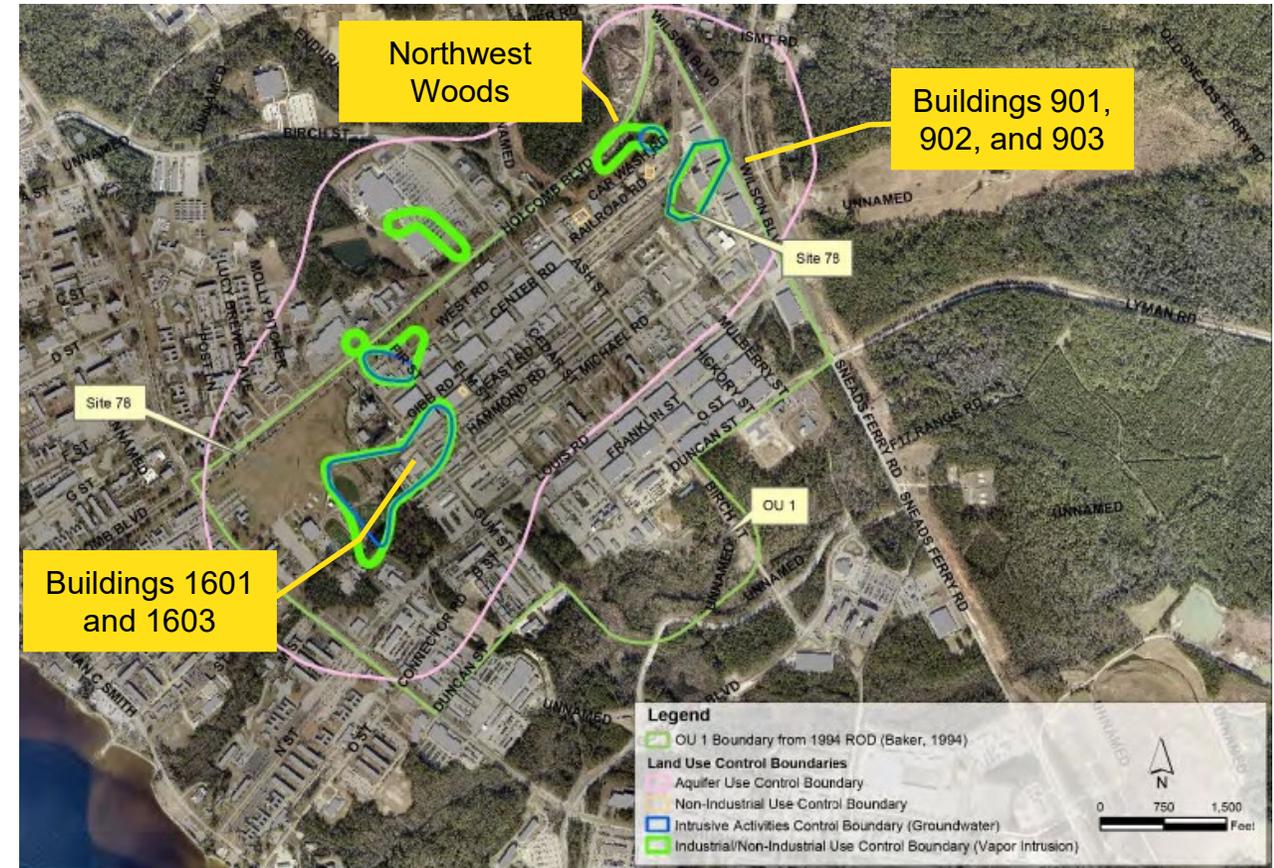
## KEY POINT

**Regulatory stakeholder collaboration facilitated an alternate interpretation of reasonable timeframe and active remediation goals.**

NCDEQ: North Carolina Department of Environmental Quality

# Revised Optimization Approach

- Three target treatment areas
  - Buildings 901, 902, and 903
  - Northwest Woods
  - Buildings 1601 and 1603
- Model ARGs within each area
  - COC concentrations that will attenuate to MCLs within 100 years
  - Determined by
    - Using REMChlor to back into ARG
    - Reviewing trend analysis using empirical data
- Develop alternatives in FS Amendment



(CH2M 2023)

ARG: active remediation goal

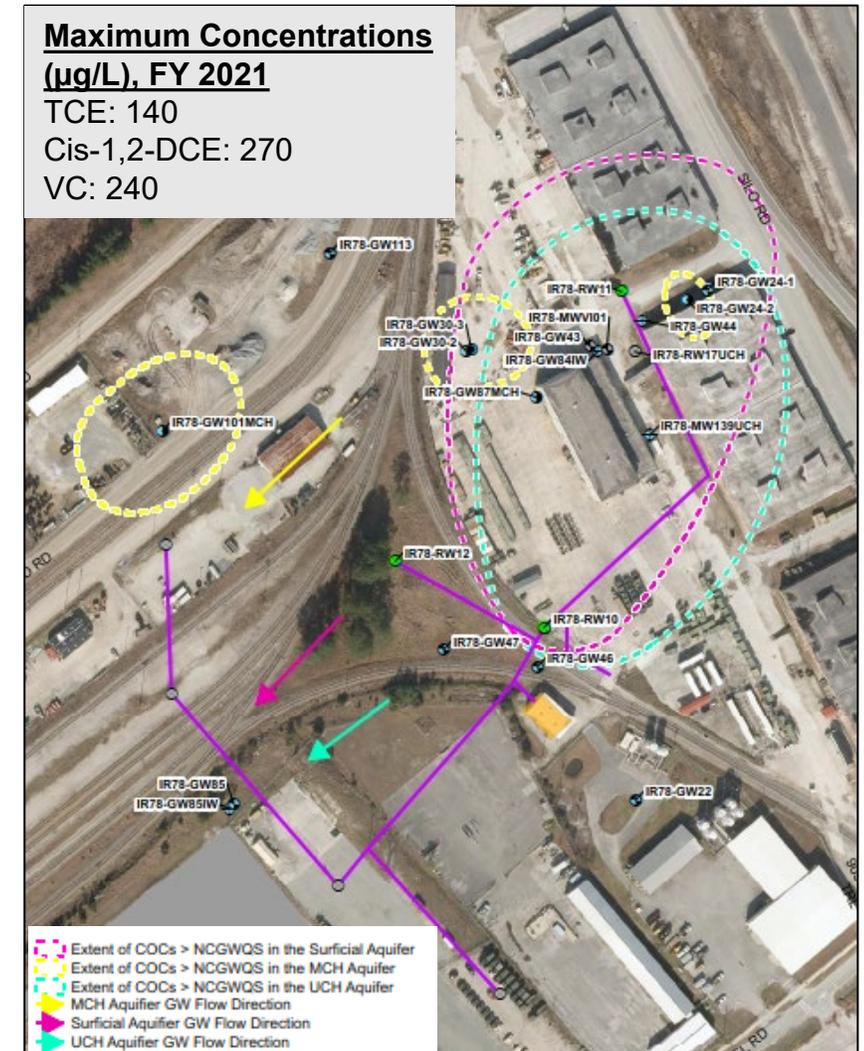
# Optimized Remedies



- Buildings 901, 902, and 903: MNA
  - REMChlor modeling and empirical data trend analysis indicates COC concentrations will be less than MCLs within 100 years via MNA
  - Additional active treatment not required

Key Element	Current Remedy (P&T)	Optimized Remedy (MNA)
Description	Continued operation of pump and treat system, LTM, and LUCs	MNA using existing well network, LTM, and LUCs
Remediation timeframe	>400 years (to NCGWQS)	Approximately 60 years (to MCL) >400 years (to NCGWQS)
Sampling program	Annual monitoring	Monitoring every 5 years
Capital costs	\$0	\$0
Annual costs	\$100,000	\$50,000
Total costs	\$6,500,000	\$600,000

FY: fiscal year



(CH2M 2023)

# Optimized Remedies



- Northwest Woods: AS
  - ARG
    - TCE = 15 µg/L

### Legend

- Surficial Aquifer Monitoring Well
- Middle Castle Hayne Aquifer Monitoring Well
- Upper Castle Hayne Aquifer Monitoring Well
- Recovery Well
- Proposed Air Sparging System
- Proposed Conveyance Line
- Existing air sparging well - 40 foot radius of influence (ft ROI)
- Proposed MCH air sparging well - 40 foot radius of influence (ft ROI)
- Proposed UCH air sparging well - 40 foot radius of influence (ft ROI)
- Active Remediation Goals (ARGs) Exceedance

Key Element	Current Remedy (MNA)	Optimized Remedy (AS)
Description	LTM and LUCs	AS via 24 wells, followed by MNA, LTM, and LUCs
Remediation timeframe	>400 years	Active operation: 2 years (to ARGs)
Sampling program	Annual monitoring	Annual performance monitoring, followed by MNA monitoring every 5 years
Capital costs	\$0	\$1,770,000
Total annual costs	\$30,000	\$200,00 AS   \$40,000 MNA
Total costs	\$2,000,000	\$2,230,000



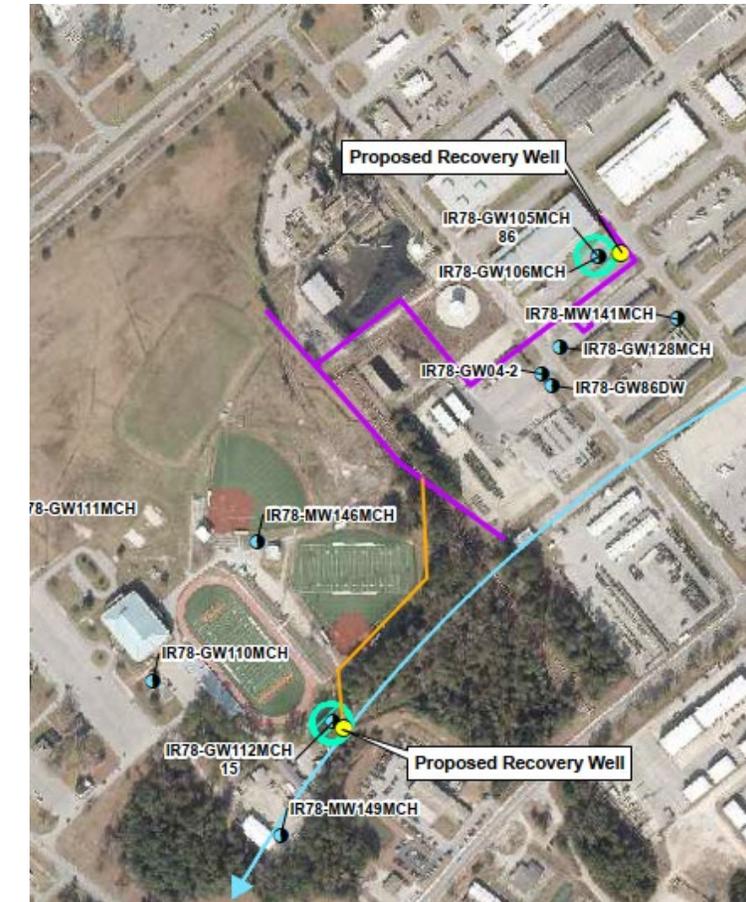
(CH2M 2024)

# Optimized Remedies



- Buildings 1601 and 1603: Enhanced P&T
  - ARGs
    - TCE = 13 µg/L
    - VC = 23 µg/L

Key Element	Current Remedy (P&T)	Optimized Remedy (Enhanced P&T)
Description	Continued operation of pump and treat system, LTM, and LUCs	Operate three existing recovery wells and two new recovery wells
Remediation timeframe	>400 years	Active operation to achieve ARGs or maximum of 5 years
Sampling program	Annual monitoring	Annual performance monitoring, followed by MNA monitoring every 5 years
Capital costs	\$0	\$184,000
Total annual costs	\$108,000	\$104,000   \$55,000 MNA
Total costs	\$7,200,000	\$683,000



(CH2M 2024)

# Next Steps



- Proposed Plan and ROD Amendment: 2025
  - Will memorialize the following key attributes of the new remedy
    - ARGs (to facilitate transition to MNA)
    - Limit of 5 years of additional operation of the expanded P&T system
- Pre-design investigation: 2026
  - To finalize the layout of the new remedies
- Remedial design: 2027
- Remedial action: 2028

## KEY POINT

**Optimized remedies will save \$12.4M (LCC) and define active remediation exit strategy.**

# Knowledge Check



- **Question:** Which of the following was **not** a critical component of the optimization effort?
- **Answers:**
  - a. Use of REMChlor modeling to determine active remediation goals for focused remediation
  - b. Collaboration among stakeholders
  - c. Continued active treatment until goals in ROD are achieved
  - d. Clearly defined exit strategy

# Knowledge Check



- **Question:** Which of the following was **not** a critical component of the optimization effort?
- **Answers:**
  - a. Use of REMChlor modeling to determine active remediation goals for focused remediation
  - b. Collaboration among stakeholders
  - c. **Continued active treatment until goals in ROD are achieved**
  - d. Clearly defined exit strategy

**Why  
Answer c?**

**The optimized remedy prioritized stakeholder positions and focused on clearly defined treatment end points based on modeling to save LCCs.**

# Summary



<b>NORM Phase(s)</b>	6 and then 2 (3 and 4 pending)
<b>Optimization trigger(s)</b>	Remedy not projected to meet RAOs
<b>Key tools or concepts</b>	<ul style="list-style-type: none"> <li>• Bench and pilot studies</li> <li>• REMChlor modeling and development of active remediation goals</li> <li>• Partnering process</li> </ul>
<b>Key constraint(s)</b>	<ul style="list-style-type: none"> <li>• No defined exit strategy in decision document</li> <li>• Different state and federal cleanup levels</li> </ul>
<b>Outcome</b>	<ul style="list-style-type: none"> <li>• Stakeholder agreement on updated remediation alternative that includes multiple technologies, and a defined active remediation exit strategy</li> </ul>
<b>Path forward</b>	<ul style="list-style-type: none"> <li>• Prepare Proposed Plan and ROD Amendment</li> <li>• Conduct predesign investigation to refine remaining treatment areas</li> <li>• Design and implement updated remedy</li> <li>• Transition to MNA within 5 years of active remedy implementation</li> </ul>
<b>Potential financial impact</b>	\$12.4 million reduction in LCC

# Presentation Overview



- Introduction
- Optimization Basics
- Case Study #1: JBPHH Former Aiea Laundry Facility
- Case Study #2: Camp Lejeune Site 78
- **Case Study #3: NAPR SWMUs 7 and 8**
- Case Study #4: ABL Site 10
- Key Takeaways

<b>NORM Phase(s)</b>	6 and 7
<b>Optimization trigger(s)</b>	Contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Lines of evidence approach outlined in <i>Case Study Review of Optimization Practices and Navy Petroleum Sites</i> (NAVFAC EXWC 2021)</li><li>• NSZD</li><li>• Pilot study</li></ul>
<b>Key constraint(s)</b>	Insufficient data to transition to NSZD and MNA

# Site History

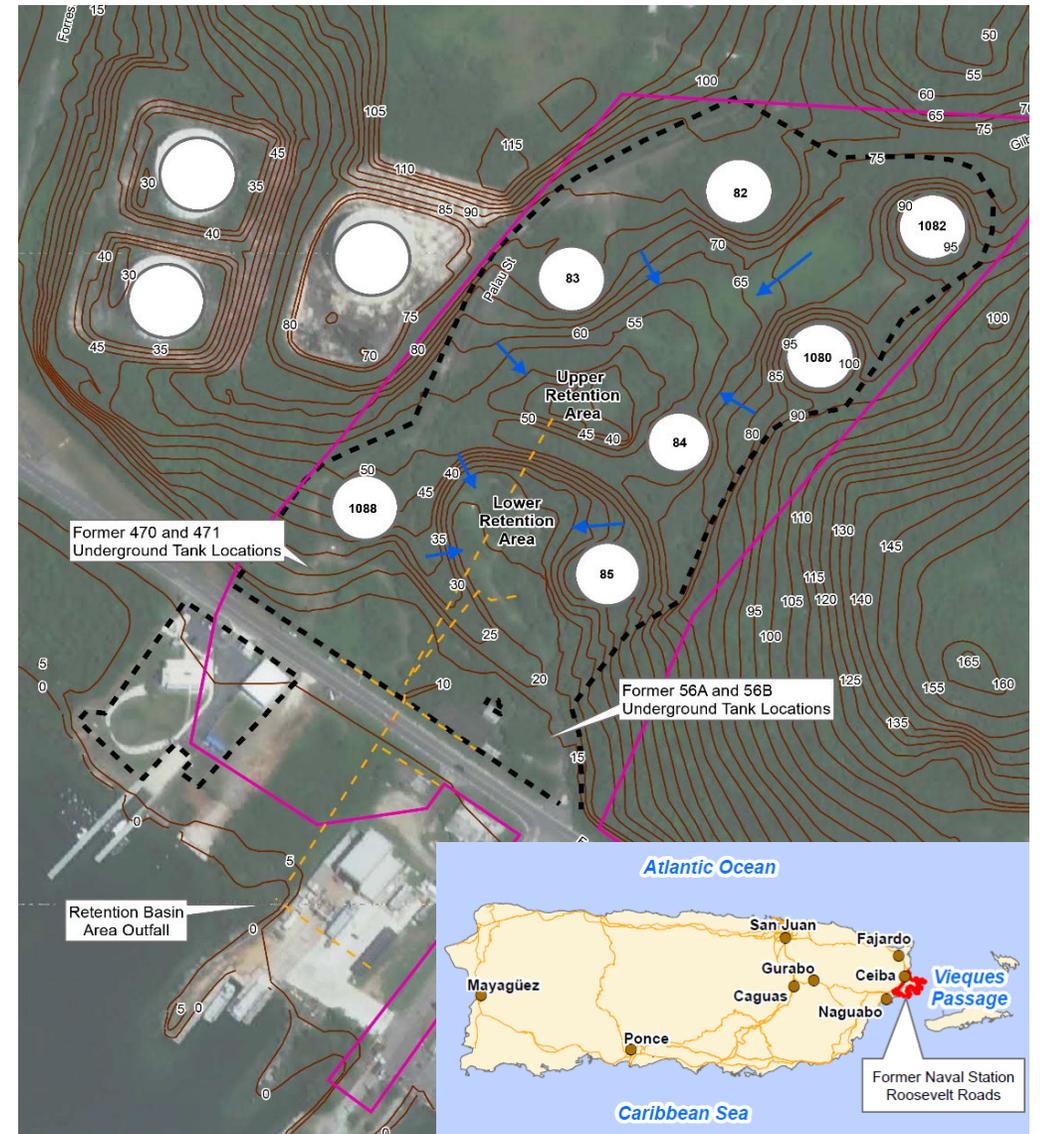


- Former TWFF constructed in 1957 on a hillside along Forrestal Drive north of Ensenada Honda
- Nine bombproof and two additional USTs
  - Marine diesel fuel, JP-5, Bunker C fuel, and leaded and high-octane aviation gasoline
- Two 10,000-gallon bombproof USTs and associated soil, and the two additional USTs were removed in 1996
- Fueling operations ceased in 2004

JP-5: jet fuel

TWFF: Tow Way Field Farm

(CH2M 2025)



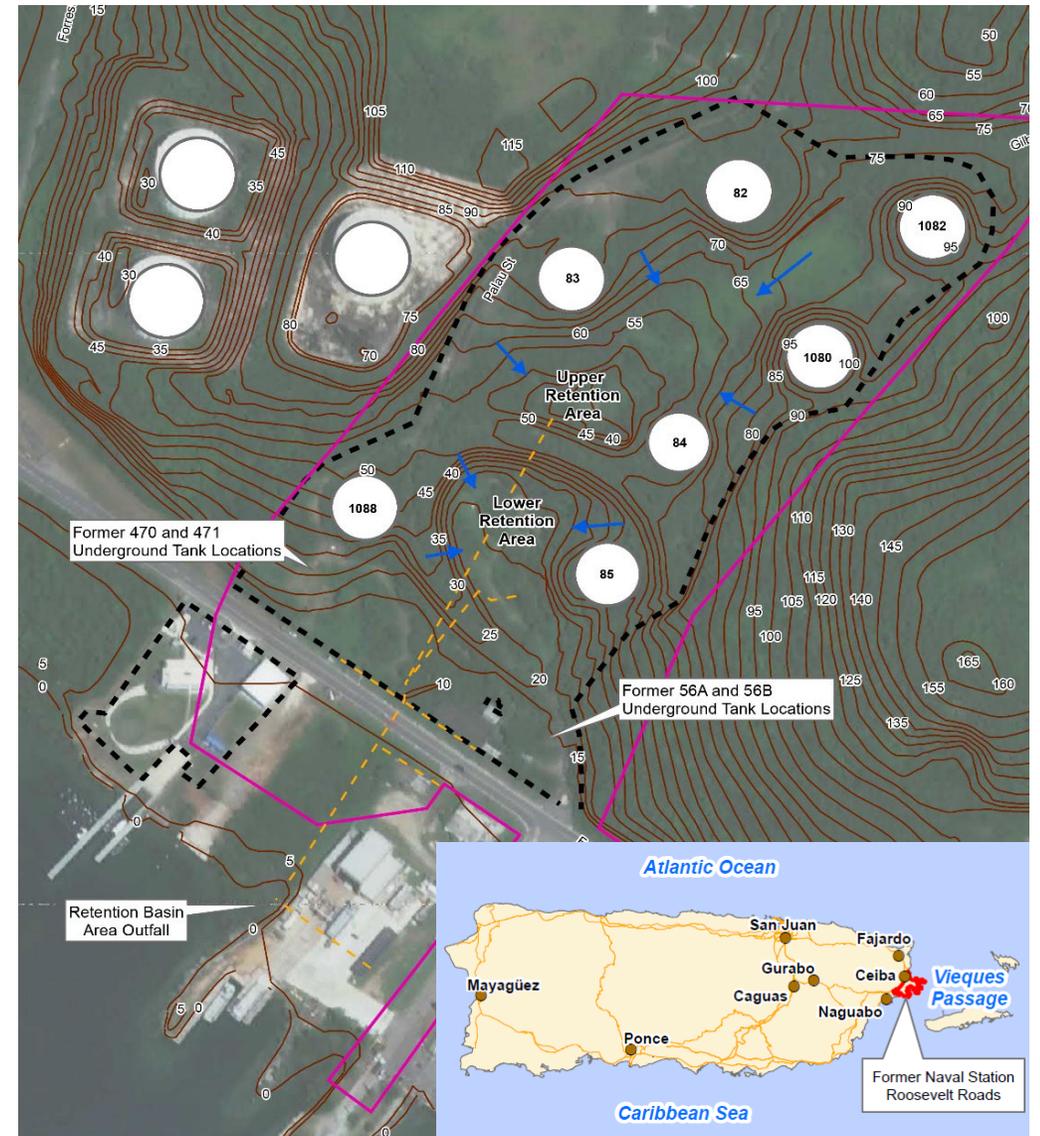
# Site History



- Remaining USTs were drained and cleaned, and conveyance piping was purged and grouted in place in 2012 and 2013
- SWMU 7 is result of environmental impacts from the USTs
- SWMU 8 is TWFF sludge disposal
- CAOs
  - LNAPL goal is 0.01 foot or less
  - Benzene goal is 160  $\mu\text{g}/\text{L}$ 
    - Based industrial worker inhalation of benzene from groundwater vapors in an industrial building

CAO: Corrective Action Objective

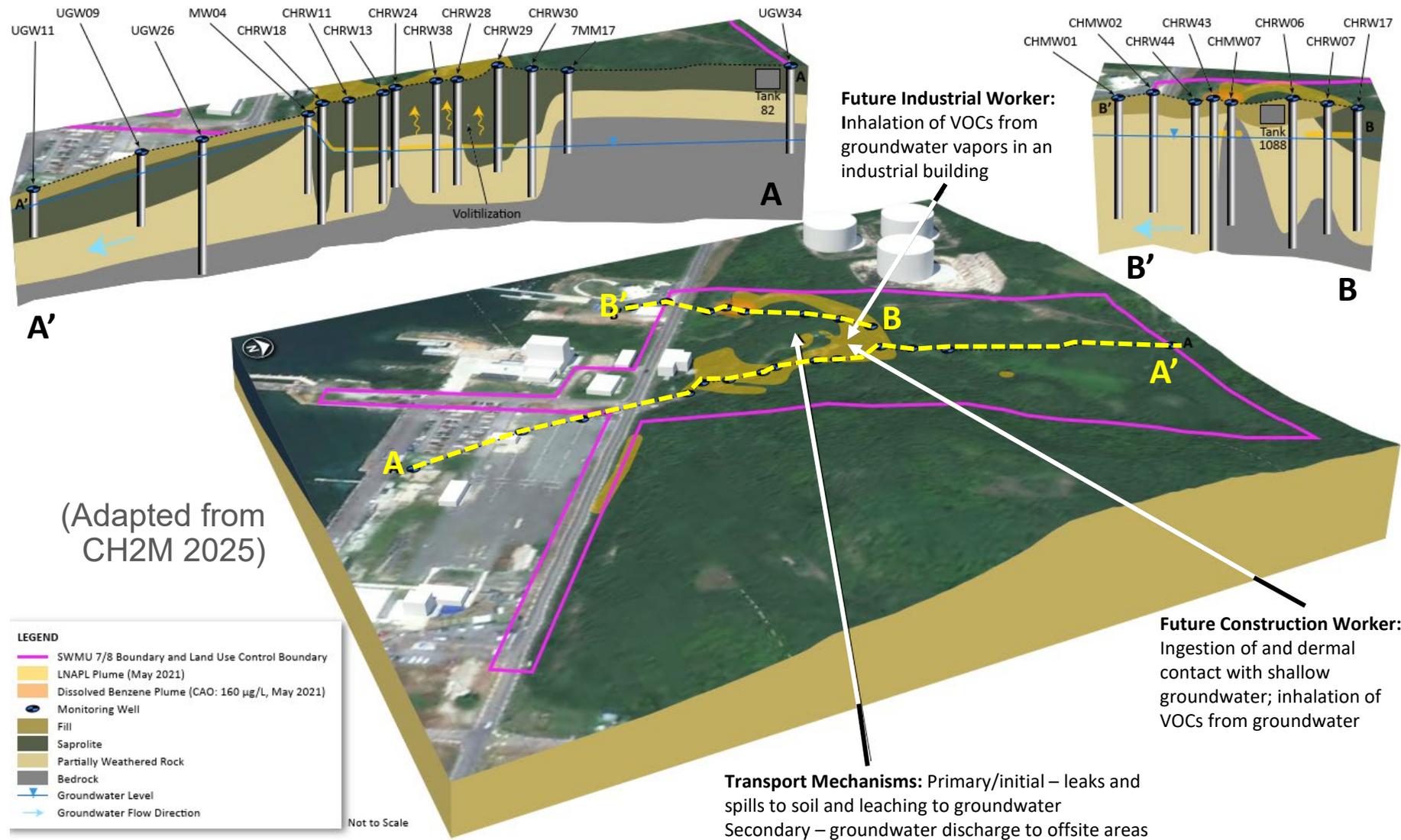
(CH2M 2025)



# Site Characteristics



- Lithology consists of fill material and weathered rock overlying bedrock
- Groundwater depths can range between 10 and 57 feet bgs
- Groundwater flow is controlled by topography and presence and competency of the bedrock



# How Has LNAPL Been Removed?



- **Since 1994:** Biodegradation
  - Estimated 23,000 to 30,000 gallons removed based on sulfate utilization and CO<sub>2</sub> production
- **1994 to 1996:** Multi-stage product recovery
  - 13,700 gallons recovered; asymptotic recovery reached in 2 years
- **1996 to 2010:** Clean Ox injections, pneumatic fracturing, aggressive fluids vacuum recovery, SVE, and total fluids recovery
  - Estimated 3,900 gallons were removed using all five technologies
  - 2012 Corrective Measures Implementation Plan included LNAPL-only recovery skimmer pumps, MNA, and LUCs (AGVIQ-CH2M 2012)
    - All other implemented technologies were rejected due to limited radius of influence, rapidly declining rates of LNAPL recovery, or production of contaminated water containing emulsified oil

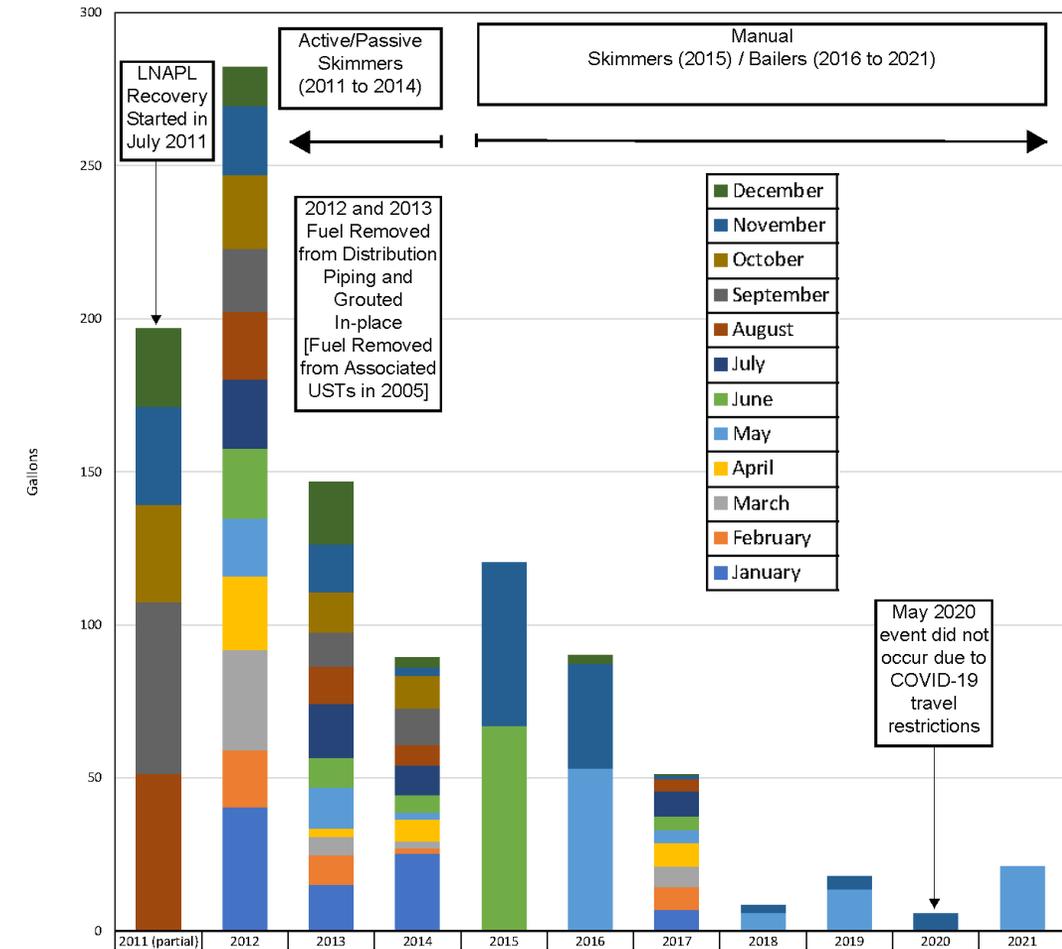
CO<sub>2</sub>: carbon dioxide

TFR: total fluids recovery

# How Has LNAPL Been Removed?

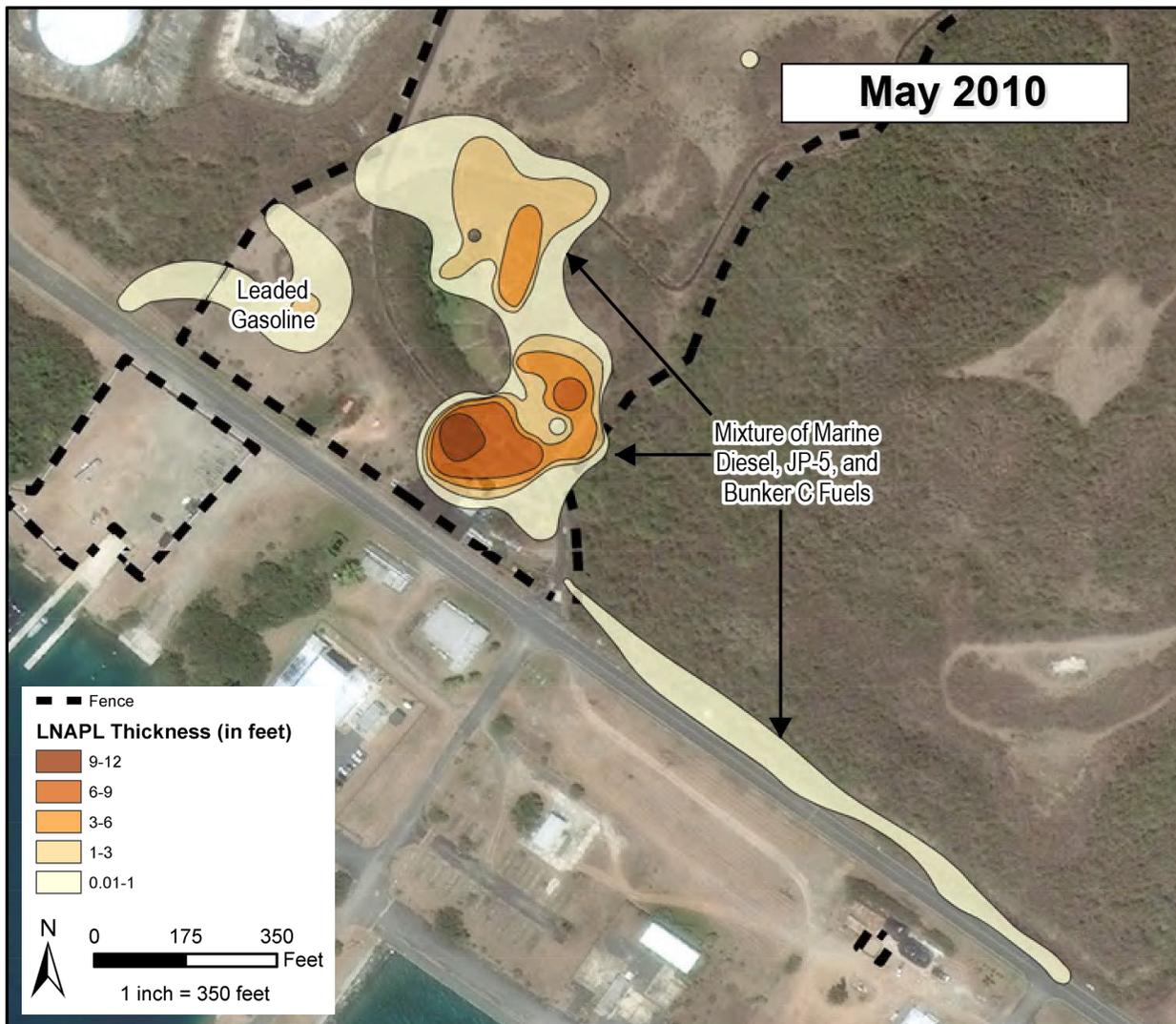


- **2011 to 2014:** Full-time active and passive and skimming
  - 715 gallons recovered, but decreased each year
- **Since 2015:** Manual product recovery
  - 315 gallons recovered
  - Last 4 years averaged 13 gallons per year compared to at least 900 gallons a year via biodegradation
- Demonstrations from 11 years of LNAPL monitoring at up to 60 wells
  - Average LNAPL thickness in site wells decreased by more than 75%
  - Remaining LNAPL is not moving downgradient
  - Thicknesses of remaining LNAPL are being reduced by natural attenuation processes



(CH2M 2023)

# Significant LNAPL Thickness Reductions Observed



(AGVIQ-CH2M 2015)



(CH2M 2023)

# Optimization Approach



- Follows **lines of evidence approach** outlined in *Case Study Review of Optimization Practices and Navy Petroleum Sites* (NAVFAC EXWC 2021)
  1. No lateral LNAPL migration: *Is LNAPL at risk of migrating?*
  2. Restricted LNAPL exposure: *Are there any potential risk exposure scenarios if LNAPL remains?*
  3. Limited LNAPL recoverability: *How much LNAPL is recoverable?*
  4. Effective natural attenuation: *Will naturally occurring processes serve to attenuate remaining LNAPL and dissolved contaminants in a reasonable timeframe?*

# LNAPL Migration?

- LNAPL mobility was evaluated using intact soil coring from the smear zone within LNAPL plume and laboratory analysis
  - Collected two intact soil cores
  - Core photography under natural and ultraviolet light
  - Pore fluids saturation via Dean Stark method
  - Gravity drain and water drive testing of samples with peak LNAPL saturation based on other observations

(CH2M 2023)

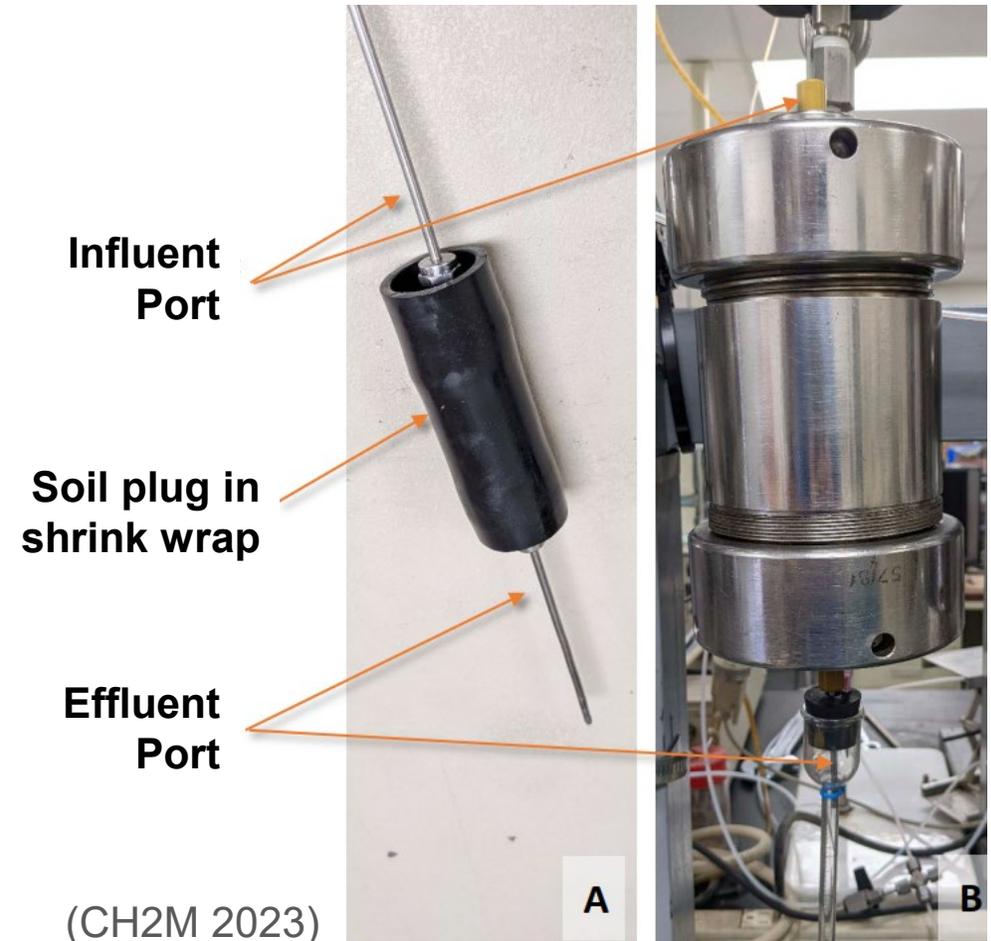


# LNAPL Migration?

- Findings
  - LNAPL detections and thickness monitoring over past 11 years demonstrate plume stability
  - LNAPL saturations were less than 5% of total pore volume in soil, indicative of residual levels
  - LNAPL at sample depths with highest recorded LNAPL pore fluid saturation was not mobilized during gravity and water drive test

**KEY  
POINT**

**No lateral LNAPL  
migration is occurring.**



*Photograph of soil plug in shrink wrap and fitted with influent and effluent ports (A) before loading into cell for gravity drain and water drive testing (B); note graduated effluent catchment below test device*

# Risk Exposure?



- Findings
  - LUCs prevent unintended receptor exposure to groundwater and prevent unrestricted use of property and groundwater
  - No Further Action was approved for SWMUs 7 and 8 soil under an industrial land use scenario
  - Remaining LNAPL plume is located at depths greater than 10 feet bgs, with LNAPL core deeper than 20 feet bgs

**KEY  
POINT**

**Potential for  
human exposure  
is very low.**

# LNAPL Recoverability?

- Baidown tests were performed at seven locations to determine hydrocarbon transmissivity associated with in-well LNAPL
  - Using a pump or bailer, LNAPL is removed from test well and surrounding borehole sand and then recovery rate is measured
  - 11-day recovery period
- Transmissivity is calculated using in-well LNAPL thickness, recharge data, and Bouwer and Rice (1976) method for variable discharge, variable drawdown conditions

(CH2M 2023)



# LNAPL Recoverability?

- Findings
  - Results of baildown tests were primarily below Interstate Technology and Regulatory Council transmissivity threshold metric of 0.1 to 0.8 square foot per day (ITRC 2018)
    - Metric established as benchmark for remedial decision making or technology transitions

**KEY  
POINT**

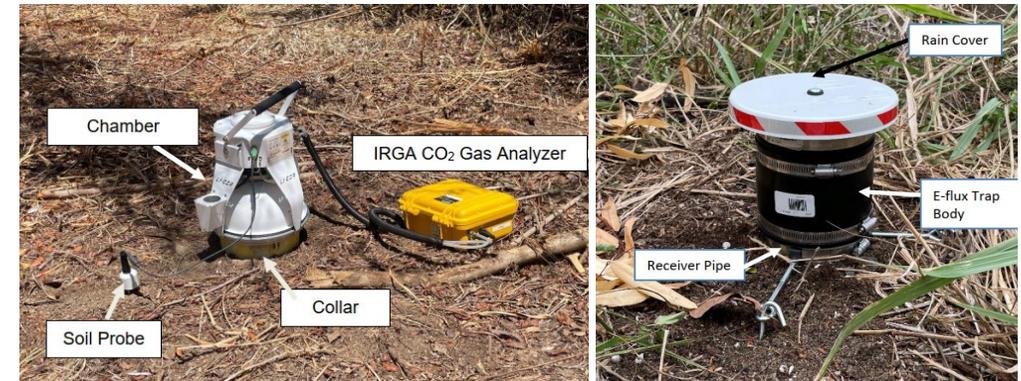
**Negligible amount  
of LNAPL remains  
for recovery.**

(CH2M 2023)

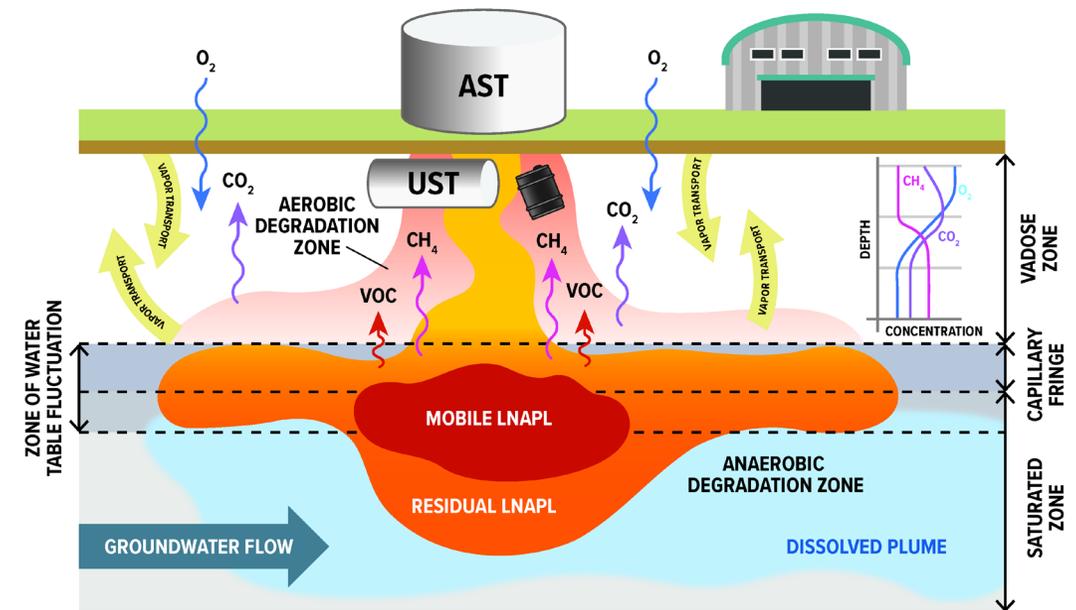


# Natural Attenuation via NSZD?

- CO<sub>2</sub> generated from NSZD processes can be measured at ground surface and stoichiometrically converted to LNAPL degradation and loss rates
- Two methods used to measure CO<sub>2</sub> efflux at ground surface
  - LI-COR dynamic closed chamber and infrared gas analyzer
    - 27 locations, including 6 background
    - Two 1-day sampling events
  - CO<sub>2</sub> passive flux trap (E-flux trap)
    - 11 locations, including 1 background
    - One 10-day sampling event



(CH2M 2023)



(Jacobs 2025)

# Natural Attenuation?

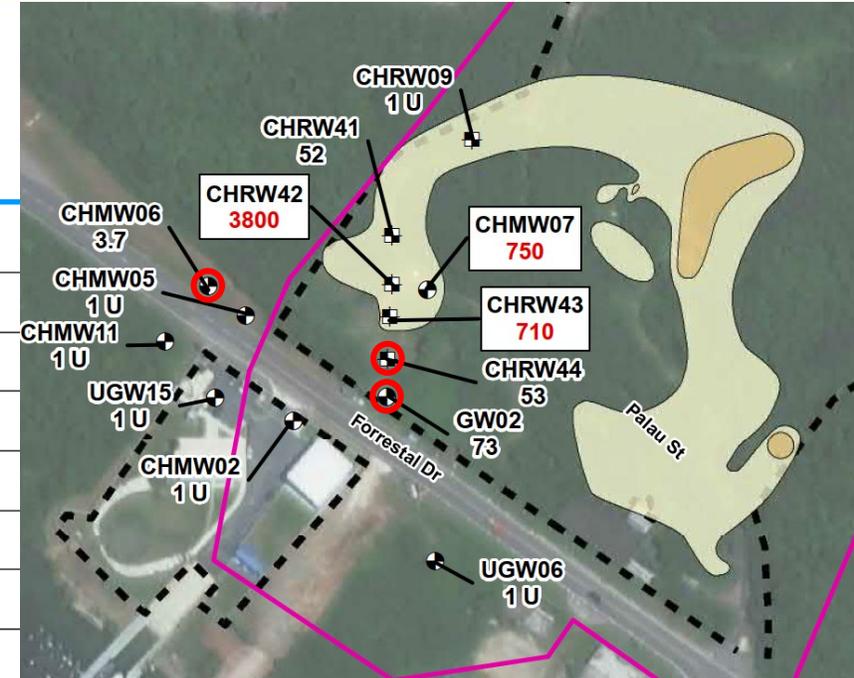
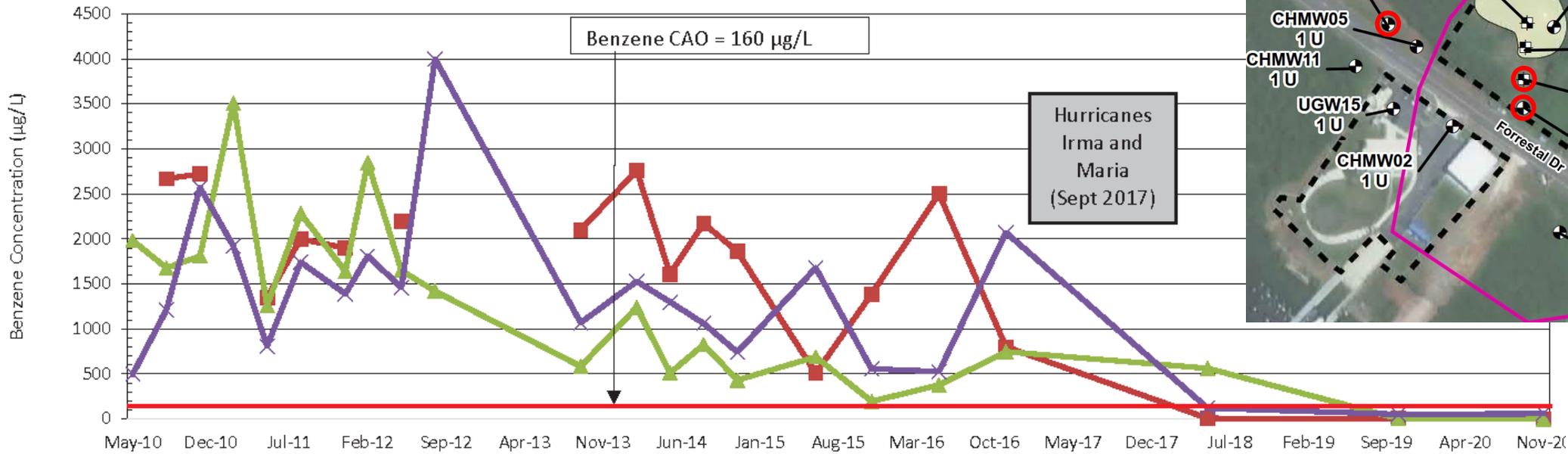


- Findings
  - LI-COR results were used to estimate sitewide annual NSZD rate because its survey network had a more complete coverage than E-Flux traps
  - Sitewide NSZD rates ranged from 300 to 800 gallons per acre per year, consistent with literature values
  - LNAPL mass removal rates by NSZD far surpass removals using mechanical and manual removal methods over past 11 years

## KEY POINT

**NSZD is estimated at 900 to 3,600 gallons removed per year, while manual recovery from all wells has yielded only 13 gallons per year from 2018 to 2021.**

# Natural Attenuation?



**May 2021 Benzene Concentrations and LNAPL Extent (CH2M 2022)**

	May-10	Aug-10	Nov-10	Feb-11	May-11	Aug-11	Dec-11	Feb-12	May-12	Aug-12	Sep-13	Feb-14	May-14	Aug-14	Nov-14	Jun-15	Nov-15	May-16	Nov-16	May-18	Oct-19	Nov-20
CHMW06	LNAPL	2670	2720	LNAPL	1350	2000	1900	LNAPL	2200	LNAPL	2100	2760	1610	2170	1860	508	1390	2500	802	7.76	5.5	0
CHRW44	1980	1680	1810	3510	1260	2280	1640	2850	1650	1420	584	1240	512	828	433	692	196	378	749	563	4.4	0
GW02	498	1210	2570	1920	810	1740	1390	1810	1460	4000	1070	1530	1300	1060	743	1680	558	528	2070	123	53	59

(CH2M 2024)

- In addition to LNAPL, natural attenuation reduced benzene concentrations downgradient of LNAPL by more than 96% from 2010 to 2021
- Recent analytical data indicate benzene concentrations were not detected above laboratory detection limit of 1 µg/L in downgradient sentry well samples

# Natural Attenuation?



- Conclusions
  - Naturally occurring processes will attenuate remaining LNAPL and dissolved contaminants in reasonable timeframe
  - Dissolved benzene plume continues to be stable and does not extend south of Forrestal Drive
  - LNAPL recovery at site has been completed to maximum extent practical

## KEY POINT

**Continued product recovery is not needed to maintain LNAPL and dissolved-phase plume stability.\***

\*Consistent with UST Technical Compendium: Release Investigation, Confirmation, and Corrective Action (EPA), which indicates that EPA's intention is to *mitigate the risk of free product spreading to uncontaminated areas of a site*, and not necessarily to achieve a specific LNAPL thickness as only end goal.

# Proposed Revised CAOs



- Reduce groundwater concentrations to approved risk-based CAOs for dissolved petroleum-related constituents in groundwater (for example, benzene to below 160 µg/L)
- Provide groundwater monitoring to demonstrate continued benzene and LNAPL plume stability by monitoring 10 downgradient wells\*
- Enforce existing industrial LUCs restricting contact with subsurface LNAPL, groundwater use, and excavations deeper than 10 feet

*\*No more LNAPL recovery*

# Additional Optimization



- Benzene is being biodegraded anaerobically through sulfate reduction
  - Average upgradient sulfate concentration is 394 mg/L
  - Average plume sulfate concentration is 3.9 mg/L
- Addition of sulfate solution was selected as a **pilot study** to enhance benzene natural attenuation
- In August 2023, three injection wells received
  - 81,397 gallons of injectant
  - 1,450 lb of Nutrisulfate-LT Granular Sulfate Salts (magnesium sulfate heptahydrate)
  - 150 lb of TersOx Nutrients QR blend (nitrogen, phosphorus, and microbial growth enhancers)

**Note:** Hydraulic tests were conducted at three recovery wells to see if they could supply water for injection. Because of low recovery rates, hydrant water was used for injection.

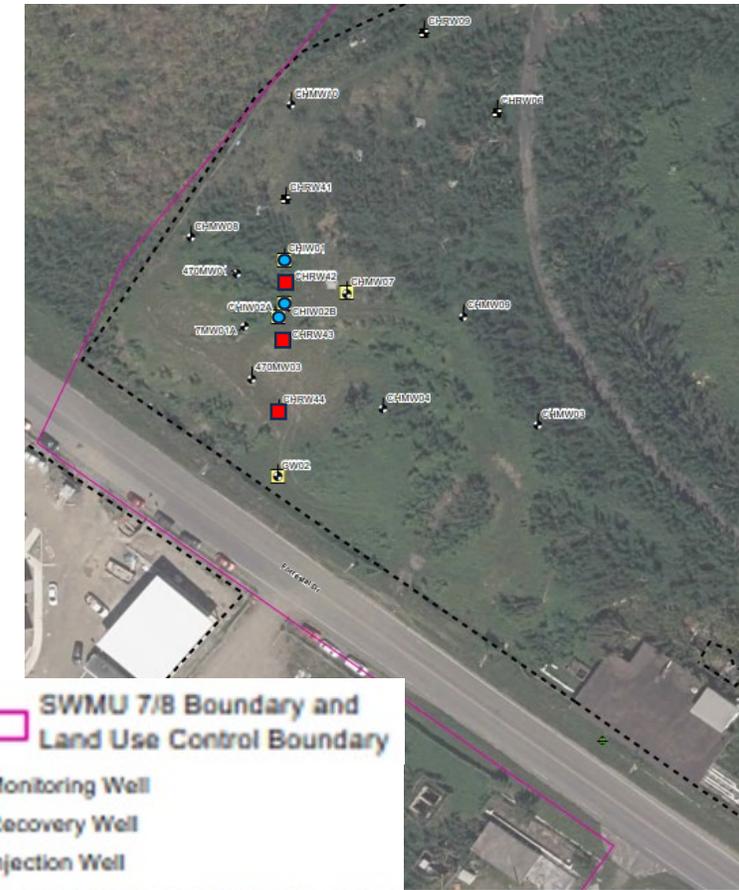


Figure 4-1  
Pilot Test Area Layout  
SWMUs 7/8  
Naval Activity Puerto Rico  
Cabo, Puerto Rico

Legend:  
SWMU 7/8 Boundary and Land Use Control Boundary  
Monitoring Well  
Recovery Well  
Injection Well  
Baseline/Performance Monitoring Wells  
Fire Hydrant  
Fence

mg/L: milligram(s) per liter

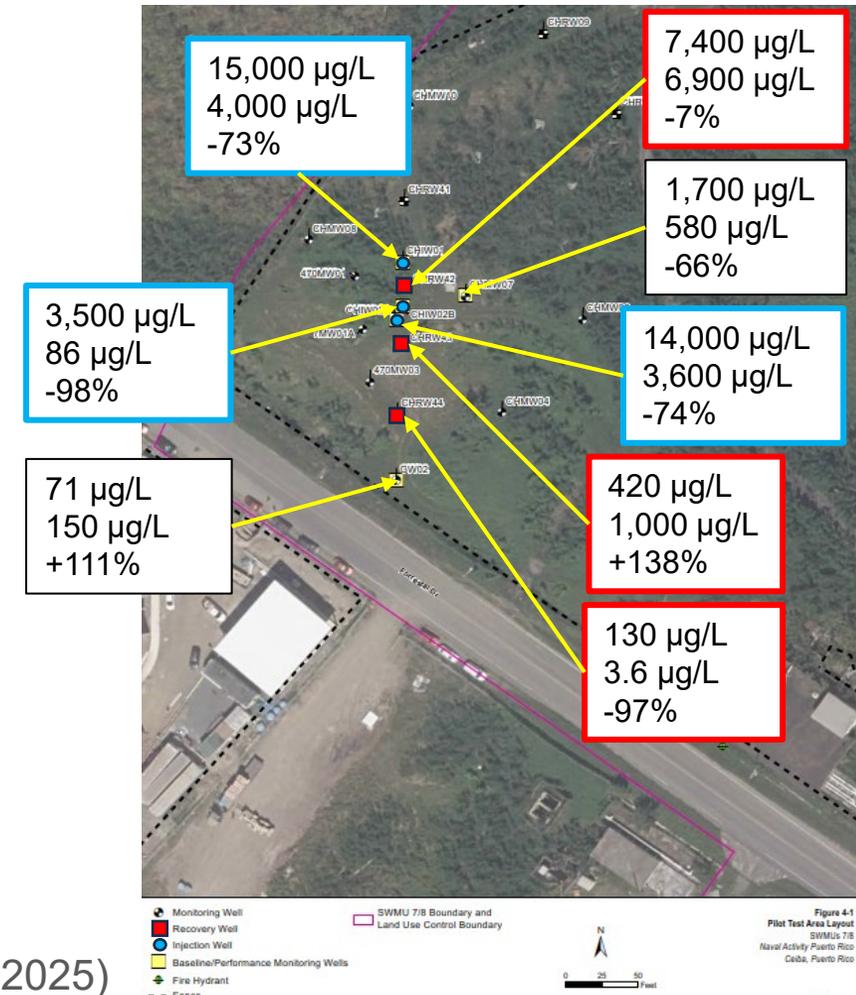
(CH2M 2025)

# Additional Optimization



- Findings after 14 months
  - Benzene concentrations decreased at injection wells by 73% to 98%
  - Benzene concentration changes at recovery and monitoring wells ranged from a 66% decrease to a 138% increase
  - Sulfate distribution and persistence was inconsistent
- Conclusions
  - Additional monitoring required to assess feasibility for full-scale implementation
  - Consider other technologies for benzene remediation (e.g., AS)
  - Consider revising risk assessment to increase benzene concentration goal from 160 µg/L

**Note:** Hydraulic tests were conducted at three recovery wells to see if they could supply water for injection. Because of low recovery rates, hydrant water was used for injection.



(CH2M 2025)

# Knowledge Check



- **Question:** What was most robust indicator that LNAPL attenuation was occurring?
- **Answers:**
  - a. LNAPL thickness measurements over time
  - b. Dissolved phase benzene concentration trends
  - c. Elevated carbon dioxide flux rates at ground surface
  - d. Diminishing LNAPL recovery rates

# Knowledge Check



- **Question:** What was most robust indicator that LNAPL attenuation was occurring?
- **Answers:**
  - a. LNAPL thickness measurements over time
  - b. Dissolved phase benzene concentration trends
  - c. **Elevated carbon dioxide flux rates at ground surface**
  - d. Diminishing LNAPL recovery rates

**Why  
Answer c?**

**CO<sub>2</sub> generated from NSZD processes can be measured at ground surface and stoichiometrically converted to LNAPL degradation/loss rates.**

# Summary



<b>NORM Phase(s)</b>	6 and 7
<b>Optimization trigger(s)</b>	Contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Lines of evidence approach outlined in <i>Case Study Review of Optimization Practices and Navy Petroleum Sites</i> (NAVFAC 2021)</li><li>• NSZD</li><li>• Pilot study</li></ul>
<b>Key constraint(s)</b>	Insufficient data to transition to NSZD and MNA
<b>Outcome</b>	<ul style="list-style-type: none"><li>• Active LNAPL recovery no longer required</li><li>• Sulfate injection shown to enhance benzene MNA</li></ul>
<b>Path forward</b>	<ul style="list-style-type: none"><li>• Shift to LTM for LNAPL</li><li>• Consider additional remediation for benzene to reduce time to achieve response complete or negotiate new clean-up standard</li></ul>
<b>Potential financial impact</b>	Not estimated

# Presentation Overview



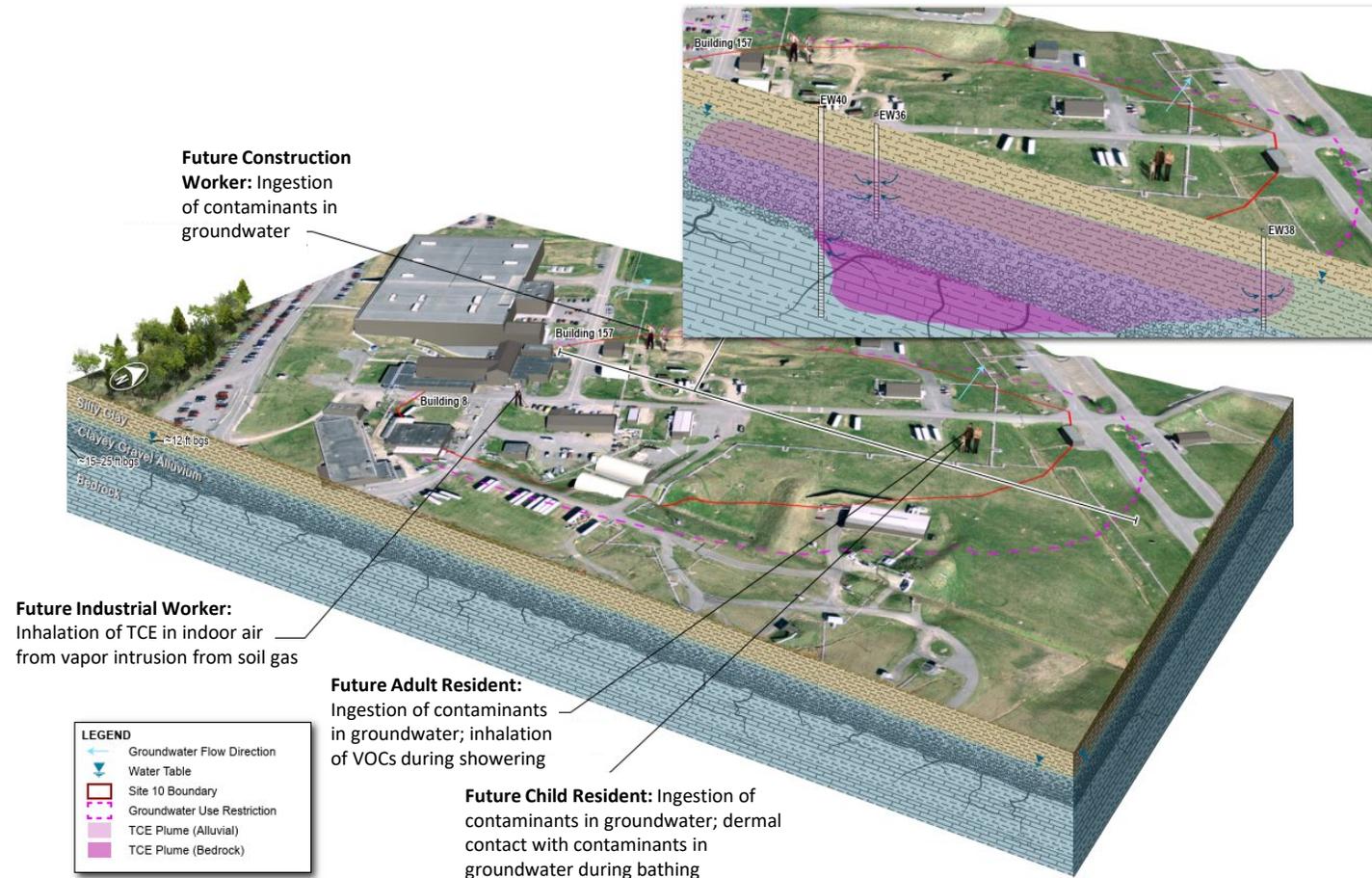
- Introduction
- Optimization Basics
- Case Study #1: JBPHH Former Aiea Laundry Facility
- Case Study #2: Camp Lejeune Site 78
- Case Study #3: NAPR SWMUs 7 and 8
- **Case Study #4: ABL Site 10**
- Key Takeaways

<b>NORM Phase(s)</b>	6 and 7
<b>Optimization trigger(s)</b>	Contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Pilot study rebound monitoring with Mann-Kendall trend analysis</li><li>• SERDP TA<sup>2</sup> tool</li></ul>
<b>Key constraint(s)</b>	Potential discharge to surface water without active remedy and insufficient data to transition to MNA

# Site Background



- Former TCE still
  - Operated in early 1960s
  - TCE recovered by distilling, then used and stored onsite
- VOC plumes (<math><100 \mu\text{g/L}</math>)
  - PCE, TCE, and VC
  - Alluvial and bedrock aquifers affected
  - Human health risks from VOCs in groundwater
    - Potable water source for future residents
    - Construction



(Adapted from CH2M 2014)

# Long-Term Remedy



- Selected remedy in ROD is P&T to meet the following RAOs
  - Prevent or minimize exposure of potential future onsite residents and construction workers to contaminated groundwater
  - Achieve chemical-specific MCLs, where practical
- P&T began operation in 1999
  - Four alluvial and four bedrock extraction wells
  - Treatment via air stripping
  - Discharge to North Branch Potomac River
- LUCs in place
- Groundwater LTM every 5 years

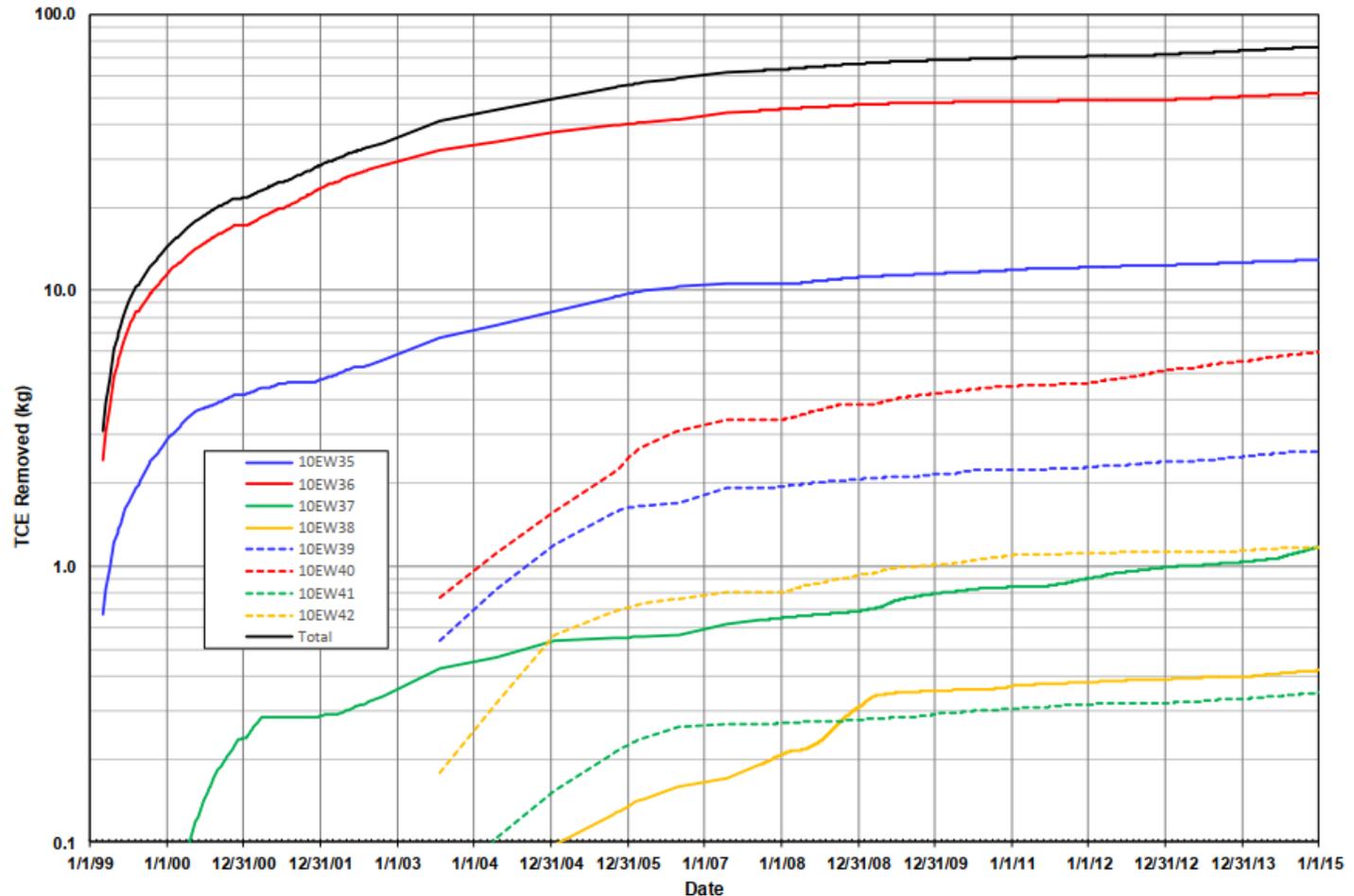


(NAVFAC 2024)

# Optimization Rationale



- Mass removal with P&T is asymptotic
- 2018 Five-Year Review indicated uncertainty associated with timeframe to achieve MCL-based RAO
- Optimization of existing groundwater remediation system recommended in an Optimization Technical Memorandum



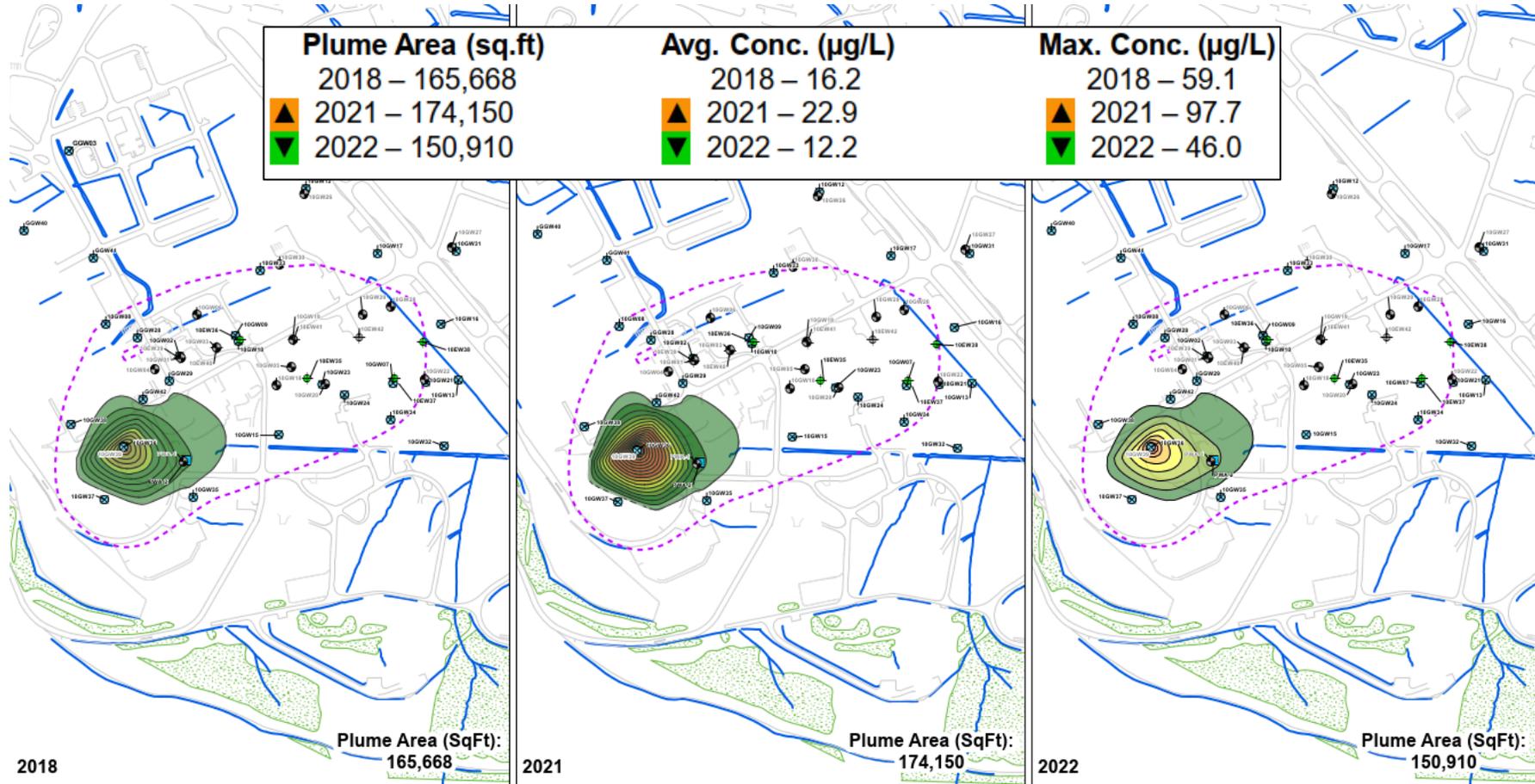
(CH2M 2023)

# Shutdown Pilot Study: Approach



- 2-year **shutdown (rebound) pilot study** began Summer 2020
  - Baseline sampling June/July 2020
  - Site 10 pumping ceased July 2, 2020
  - Semi-annual post-shutdown sampling from January 2021 through July 2022
    - Four total sampling events including baseline

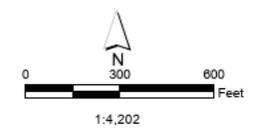
# Shutdown Pilot Study: Monitoring Results



**Legend**

- Monitoring Well - Bedrock
- Monitoring Well - Alluvial
- Extraction Well - Bedrock
- Extraction Well - Alluvial
- Former Production Well
- Vegetation
- Area of Restricted Groundwater Use
- Alluvial PCE Concentrations

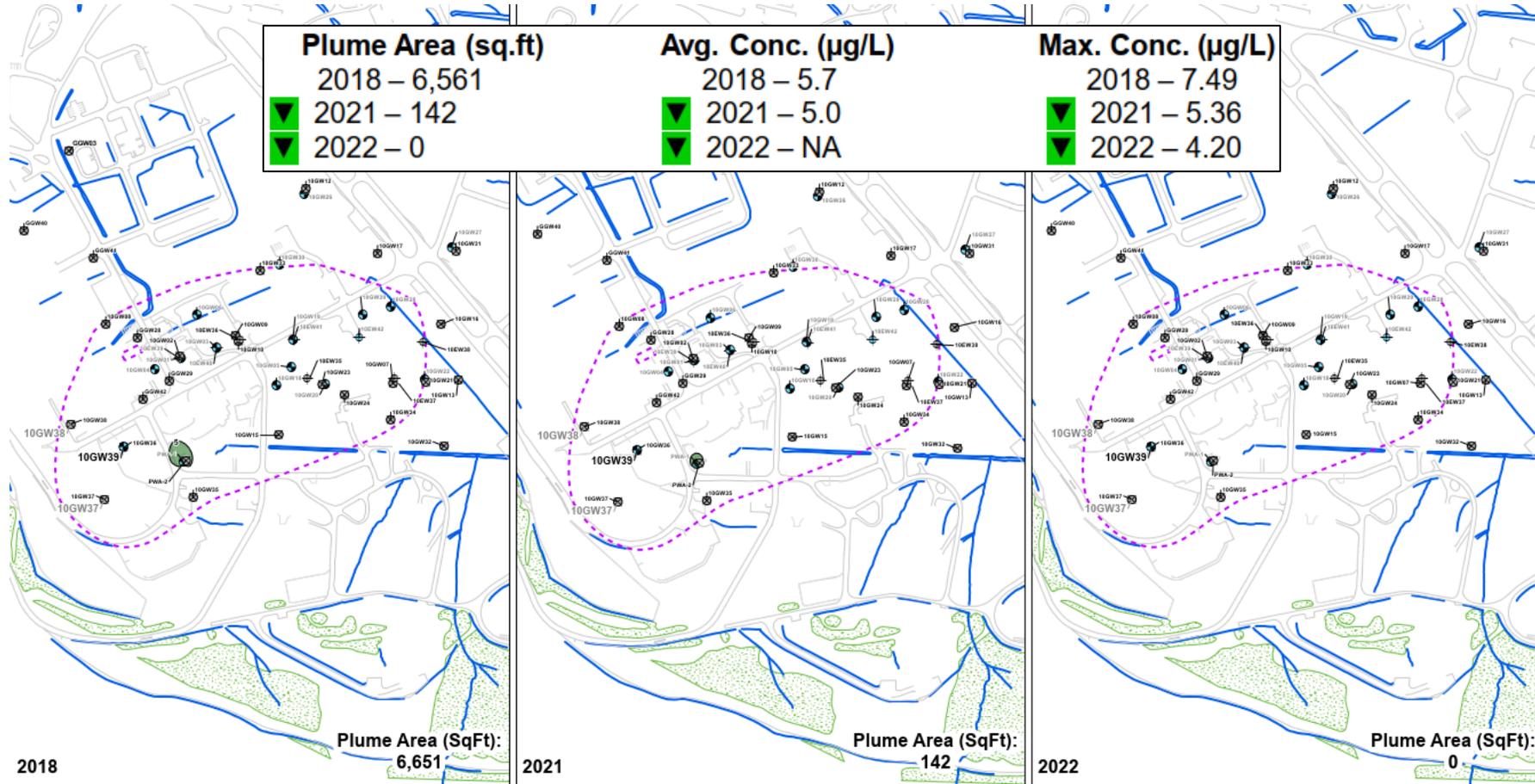
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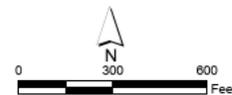
**PCE Plume in Alluvial Aquifer**

(CH2M 2023)

# Shutdown Pilot Study: Monitoring Results



- Legend**
- Monitoring Well - Bedrock
  - ⊕ Extraction Well - Bedrock
  - ⊗ Monitoring Well - Alluvial
  - ⊕ Extraction Well - Alluvial
  - Roads
  - Surface Water
  - Vegetation
  - ⋄ Area of Restricted Groundwater Use

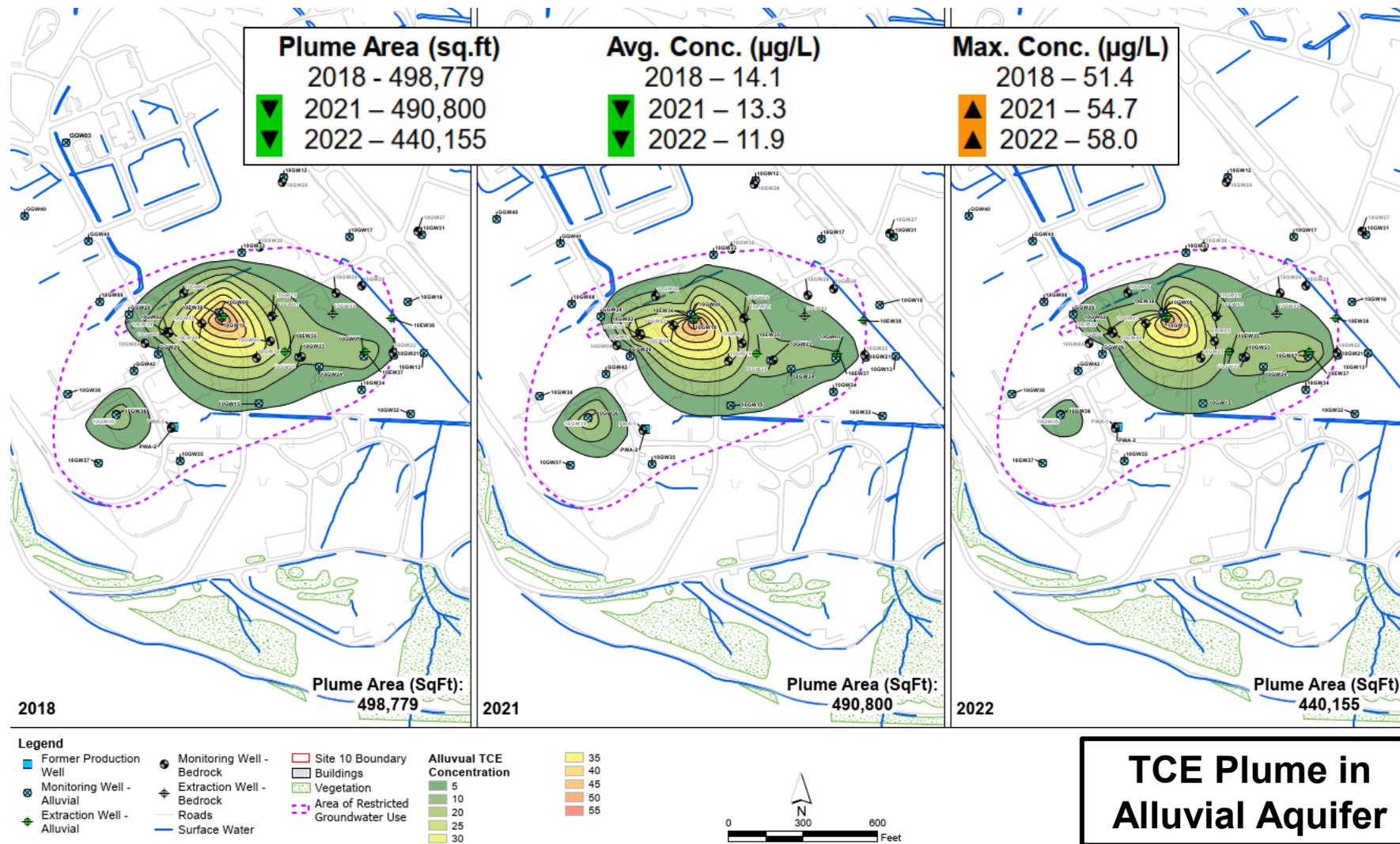


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**PCE Plume in Bedrock Aquifer**

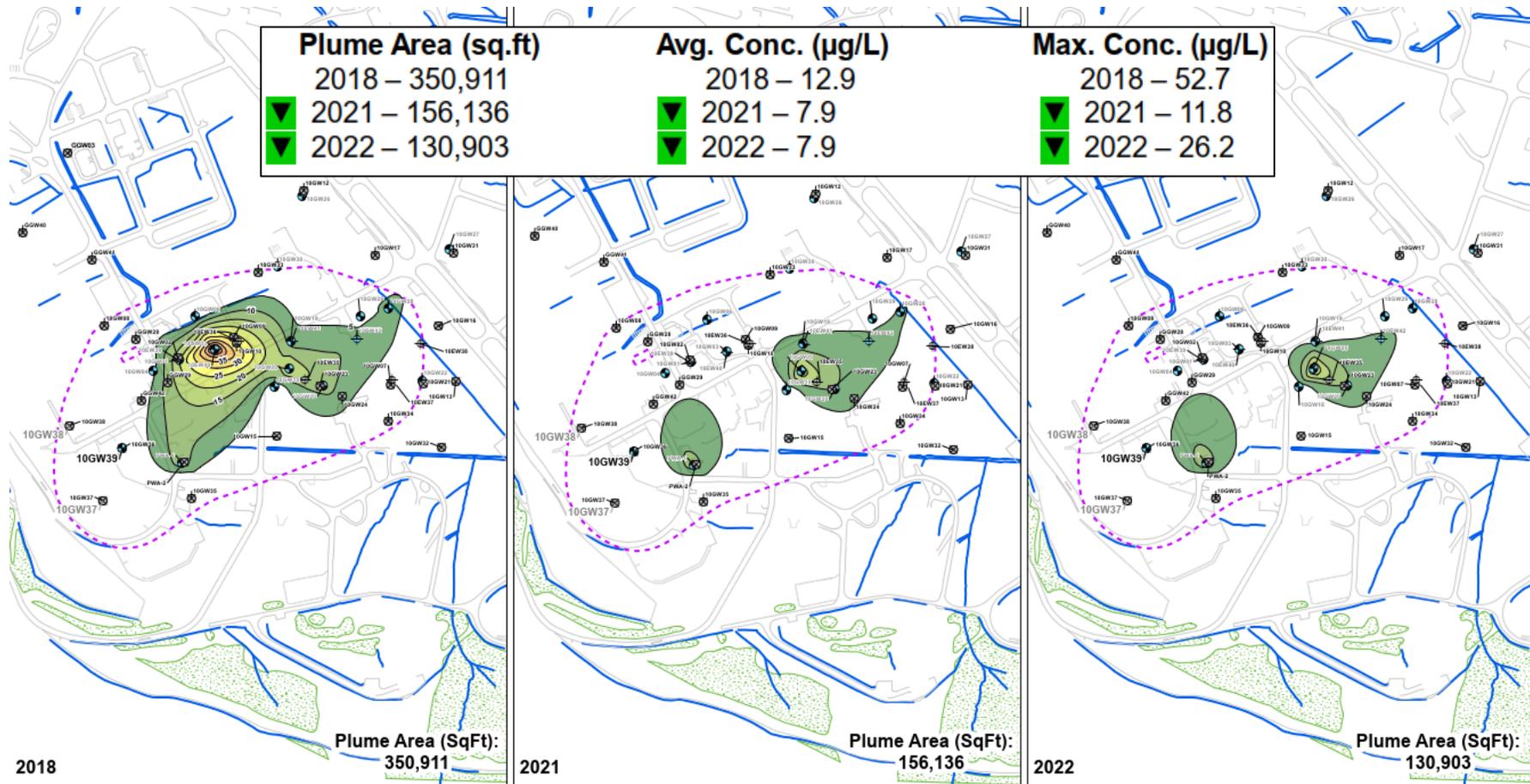
(CH2M 2023)

# Shutdown Pilot Study: Monitoring Results



(CH2M 2023)

# Shutdown Pilot Study: Monitoring Results



- Legend**
- Monitoring Well - Alluvial
  - Extraction Well - Alluvial
  - Monitoring Well - Bedrock
  - Extraction Well - Bedrock
  - Roads
  - Surface Water
  - Site 10 Boundary
  - Buildings
  - Vegetation
  - Area of Restricted Groundwater Use
- Bedrock TCE Concentrations**
- 5
  - 10
  - 15
  - 20
  - 25
  - 30
  - 35
  - 40
  - 45



**TCE Plume in Bedrock Aquifer**

(CH2M 2023)

# Shutdown Pilot Study: Findings



- COCs
  - Generally decreasing PCE and TCE concentrations
  - Plumes stable or decreasing via Mann-Kendall analysis
  - No sentinel well concentrations exceeded remedial goals
  - Remediation timeframe estimates remain uncertain because of small post-shutdown sample size and effects of matrix back diffusion
    - Evaluation method: well-by-well evaluation of concentration trends
    - Non-pumping scenario anticipated to slightly lengthen remediation timeframe
- Lines of evidence for MNA
  - Presence of PCE/TCE daughter products
  - Favorable microbial populations
  - Reducing geochemical conditions
  - Evidence of abiotic dechlorination

# Shutdown Pilot Study: Recommendations



- Recommendations
  - P&T system should remain off while additional data are gathered to support MNA
  - Continue semi-annual monitoring
- Benefits of remaining shut down
  - Energy and resource savings
  - Reduced operation and maintenance cost (estimated at \$50K per year), despite similar remediation timeframe
- Challenges of remaining shut down
  - ROD does not specify MNA after P&T; ROD Amendment or Explanation of Significant Differences may be required
  - Additional data needed to support potential remedy transition to MNA with LUCs
    - Evaluate the prevalence of biotic and abiotic natural attenuation processes
    - Analyze statistical trends

## KEY POINT

**The rebound data indicated a transition to MNA was feasible but additional monitoring was required to finalize the optimization.**

# Path Forward



- Use SERDP TA<sup>2</sup> tool to support transition to MNA
  - Step-by-step guide
  - Remediation transition assessment index (lines of evidence)
  - Checklists

(Adapted from Adamson 2024)

## Instructions:

- (1) Use Tools #1 – 9 to evaluate specific issues that are important for Transition Assessments.
- (2) Use Summary Tools #10 to see how to integrate this information into a full Transition Assessment.

### *I want to do calculations to answer the question...*

- 1. Has a concentration vs time asymptote been reached at my site?
- 2. Is my plume still expanding?
- 3. How long will it take to reach cleanup goals after source remediation at my site?
- 4. What level of performance can I expect from an in-situ source remediation projects?
- 5. Can I meet my cleanup goal at a downgradient point of compliance after stopping active treatment?

### *I would like to learn more about how to...*

- 6. Model a groundwater plume and account for matrix diffusion.
- 7. Enhance Monitored Natural Attenuation processes.
- 8. Understand how much geologic heterogeneity there is at a site.
- 9. Incorporate new insights from other recent SERDP Transition Assessment Projects.

## Summary

10a. Step-by-Step Guide for an MNA Transition Assessment

10b. Remediation Transition Assessment Index (RTAI)

10c. Transition Assessment Checklists

# Knowledge Check



- **Question:** What challenge resulted from the shutdown pilot study?
- **Answers:**
  - a. Statistically significant concentration increases were observed following shutdown
  - b. Limited number of post-shutdown samples
  - c. SERDP TA<sup>2</sup> Tool indicated that transition to MNA is not recommended
  - d. Increased operation and maintenance costs

# Knowledge Check



- **Question:** What challenge resulted from the shutdown pilot study?
- **Answers:**
  - a. Statistically significant concentration increases were observed following shutdown
  - b. **Limited number of post-shutdown samples**
  - c. SERDP TA<sup>2</sup> Tool indicated that transition to MNA is not recommended
  - d. Increased operation and maintenance costs

**Why  
Answer b?**

**Multiple lines of evidence are required to evaluate whether a transition to MNA is appropriate.**

# Summary



<b>NORM Phase(s)</b>	6 and 7
<b>Optimization trigger(s)</b>	Contaminant mass recovery has become asymptotic
<b>Key tools or concepts</b>	<ul style="list-style-type: none"><li>• Rebound monitoring with Mann-Kendall trend analysis</li><li>• SERDP TA<sup>2</sup> tool</li></ul>
<b>Key constraint(s)</b>	Potential discharge to surface water without active remedy and lack of data to transition to MNA
<b>Outcome</b>	Shutdown of P&T with minimal impact to remediation timeframe is feasible
<b>Path forward</b>	Extend rebound monitoring another two years and use SERDP TA <sup>2</sup> tool to support decision to transition to MNA
<b>Potential financial impact</b>	\$50K reduction in annual costs

# Presentation Overview



- Introduction
- Optimization Basics
- Case Study #1: JBPHH Former Aiea Laundry Facility
- Case Study #2: Camp Lejeune Site 78
- Case Study #3: NAPR SWMUs 7 and 8
- Case Study #4: ABL Site 10
- Key Takeaways

# Key Takeaways



- Optimization can occur throughout lifespan of a remediation project, not just to address diminishing performance
- Optimization may include reducing remediation timeframes and/or LCCs
- Asymptotic remedy performance can be addressed with a range of optimization tools including desktop, laboratory, and field methods
- Collaboration with partnering teams to revise objectives or updating risk assessment may be as effective of an optimization strategy as technical modifications
- Use technical resources within the Navy to support optimization

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# Questions