IMPORTANCE OF ADAPTIVE TECHNICAL APPROACHES

Case Studies from a 10-Year Performance-Based Remediation Contract

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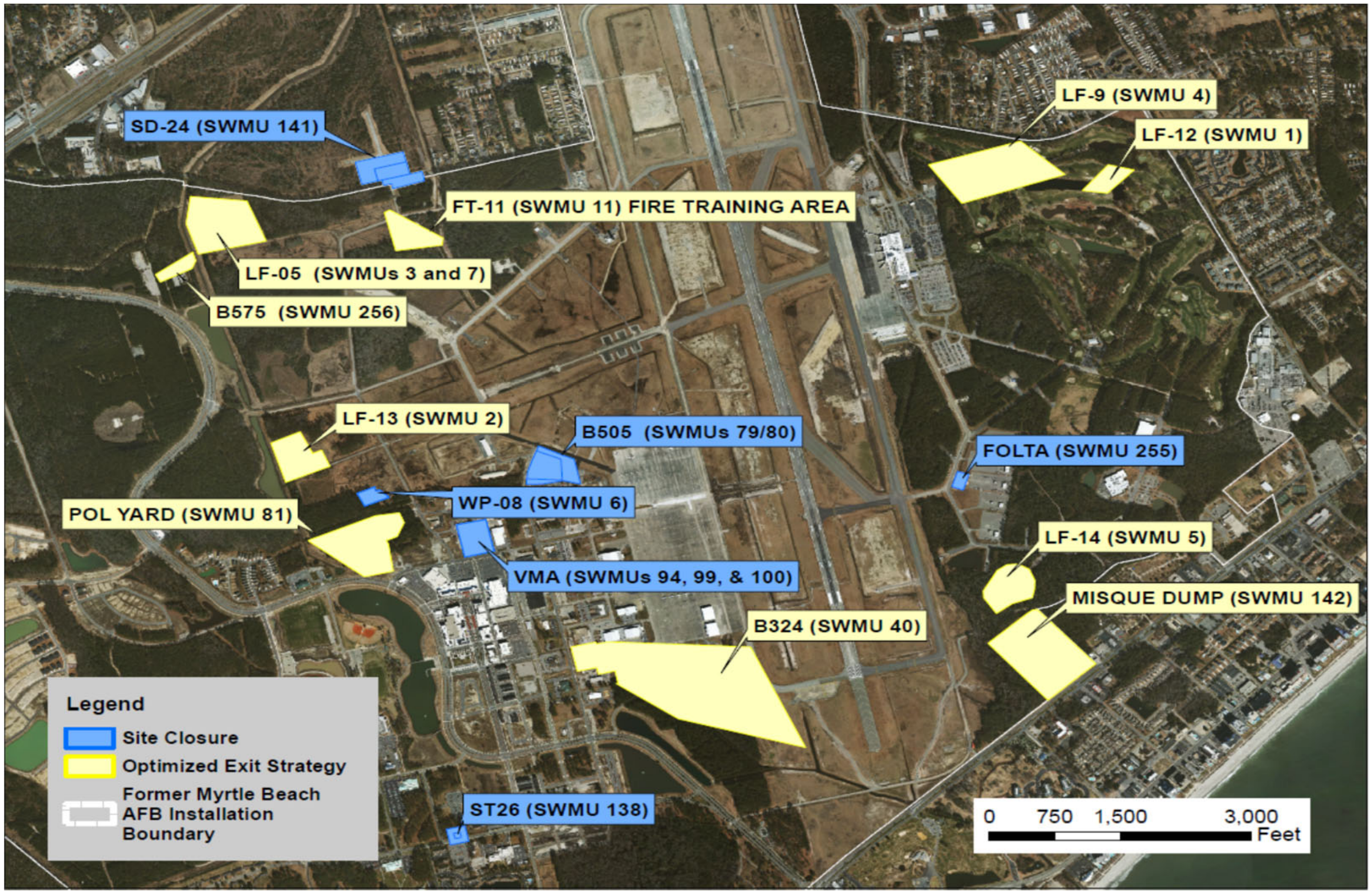
AGENDA

- Background – Former Myrtle Beach AFB, South Carolina
- Case Study #1 – Chlorinated solvent site; Building 505
- Case Study #2 – Petroleum contaminated site; FOLTA
- Case Study #3 – Landfills with metals in groundwater
- Case Studies Summary

BACKGROUND

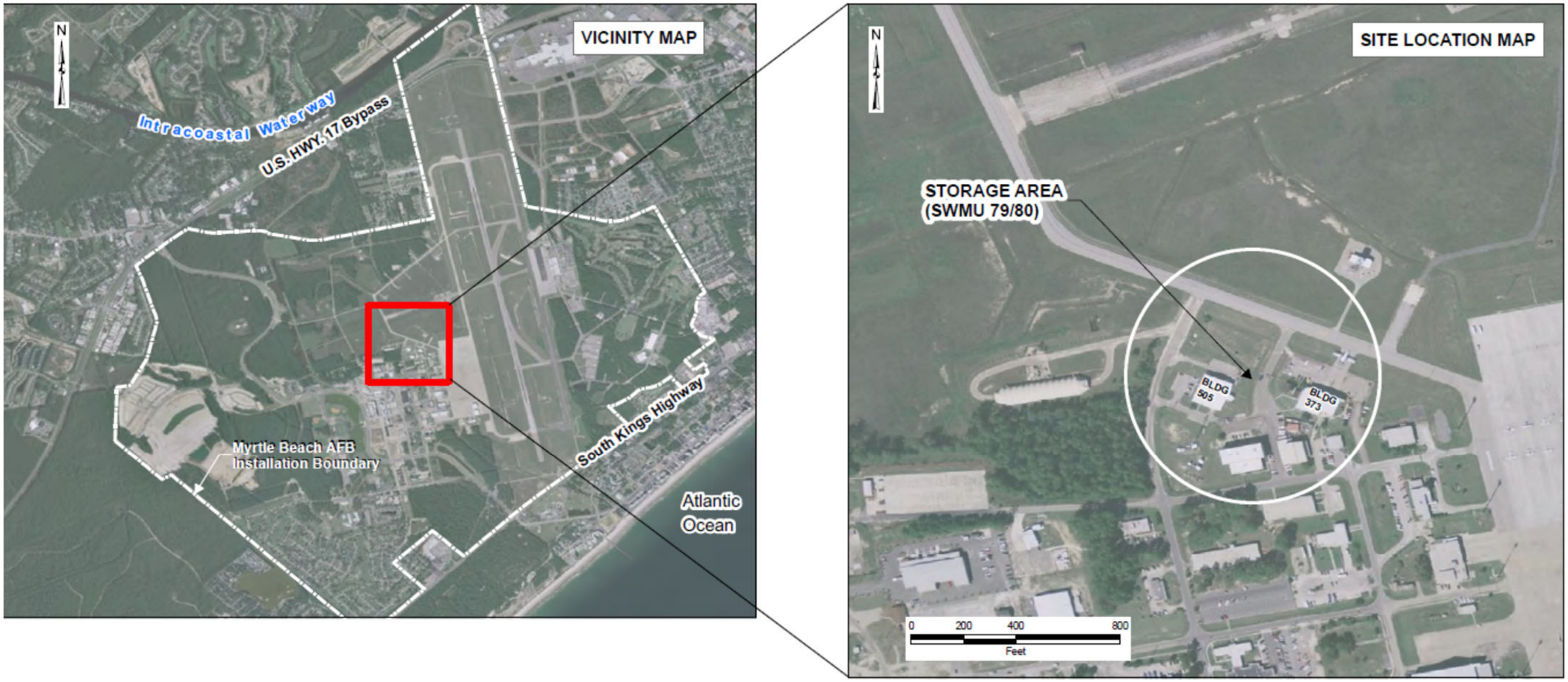
- The former Myrtle Beach AFB was closed in 1991
- Environmental remediation conducted under RCRA Administrative Order
- APTIM, including legacy companies CB&I, Shaw Environmental, and IT Corporation, have performed environmental investigation and remediation activities at the former Myrtle Beach AFB since the mid 1990s
- APTIM was awarded a 10-year Performance Based Remediation contract by AFCEC in March 2008 covering 16 sites. Performance Objectives are as follows:
  - 6 Site Closure sites; defined as unrestricted use/unlimited exposure (MCLs for groundwater)
  - 10 Optimized Exit Strategy sites
- The period of performance was extended by 2-years to enable achievement of Site Closure for 2 sites

FORMER MYRTLE BEACH AFB



CASE STUDY #1
BUILDING 505

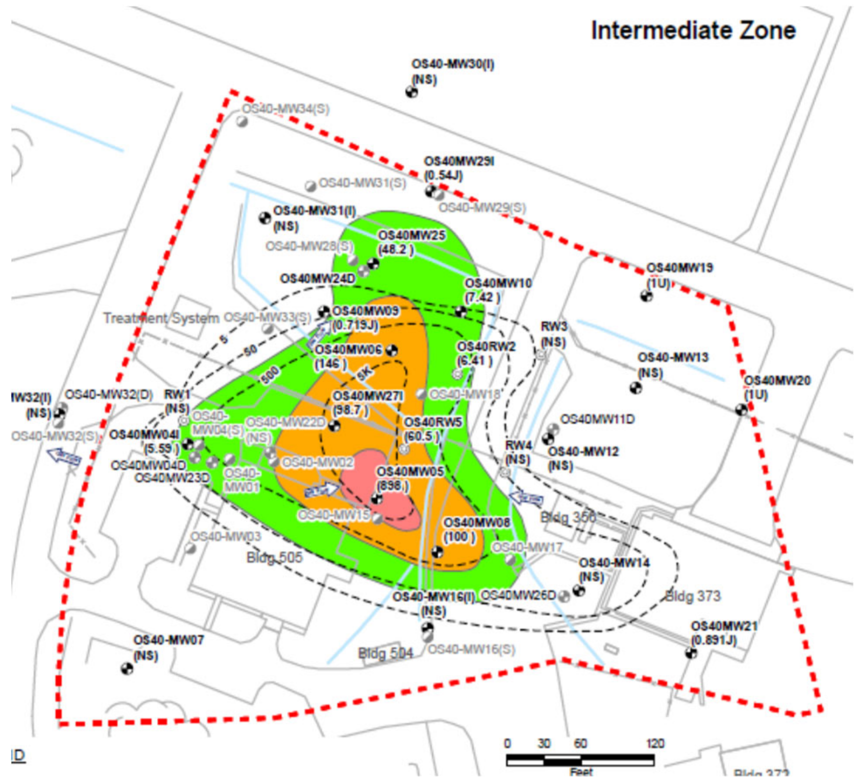
CASE STUDY #1: BUILDING 505



CASE STUDY #1: BUILDING 505

Baseline (2008) Conditions

- TCE/cis-DCE/VC in shallow, intermediate, and deep groundwater
- Selected remedy – P&T and MNA
- ~9-years of groundwater extraction and treatment prior to PBR award
  - ~50 kg of solvents removed
- Partial dechlorination to cis-DCE
- Total chlorinated VOCs ~1,400 ug/L (898 ug/L max TCE; 296 ug/L max cis-DCE)
- 14 wells impacted > MCLs

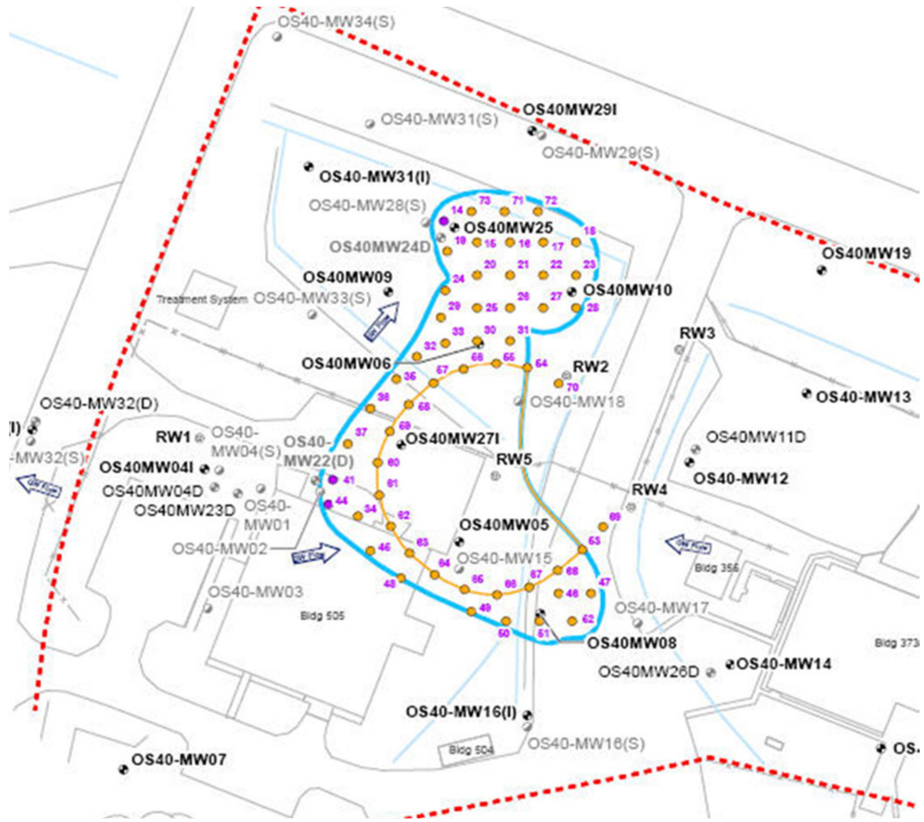


TCE Plume in Intermediate Zone - 2008

CASE STUDY #1: BUILDING 505

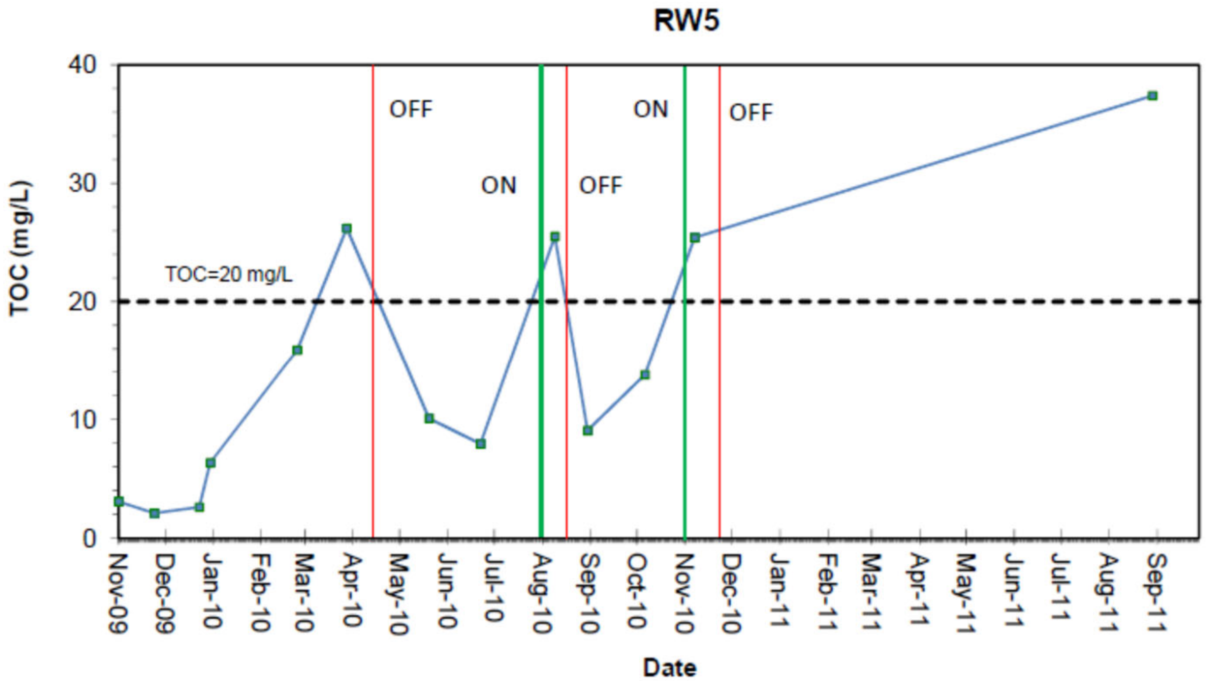
Initial Technical Approach under PBR

- In situ enhanced biodegradation to target the bulk of the contaminant mass; implemented in 2009 and 2012
  - LactOil® ~5,500 lbs (500 mg/L target)
  - Lactate ~6,500 lbs (500 mg/L target)
  - SDC-9 ~850-L targeting $1x10^7$ cells/L
- Continued groundwater extraction from plume center (RW05) for mass removal, hydraulic control, and to facilitate distribution of amendments
  - Injection points were placed based on 120-day capture zone



CASE STUDY #1: BUILDING 505

- Suspended groundwater extraction from RW05 upon TOC breakthrough defined as TOC > 20 mg/L



CASE STUDY #1: BUILDING 505

Results Following Initial Approach

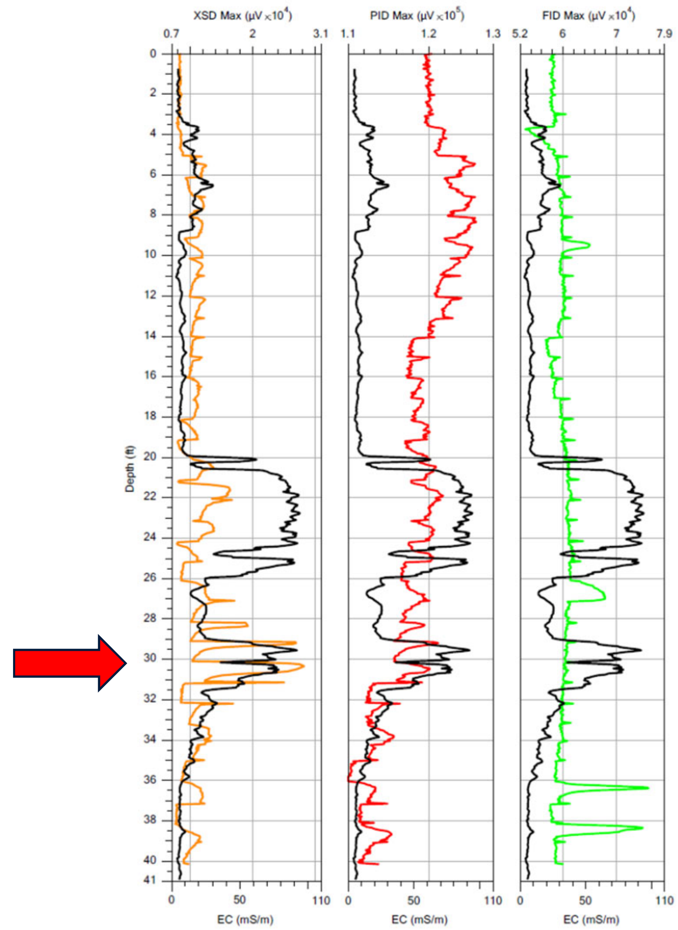
- Achieved >95% reductions in TCE
  - Maximum TCE 26 ug/L (one well RW05)
  - Maximum cis-DCE 65 ug/L (below MCL)
  - Maximum VC 15 ug/L
  - Maximum ethene/ethane 25/53 ug/L
- Significant reduction in plume magnitude and extent including completion of shallow zone remediation
- Plume primarily converted to VC in intermediate zone with the exception of TCE in RW05

VC Plume in Intermediate Zone - 2012

CASE STUDY #1: BUILDING 505

Phase I Remedy Optimization

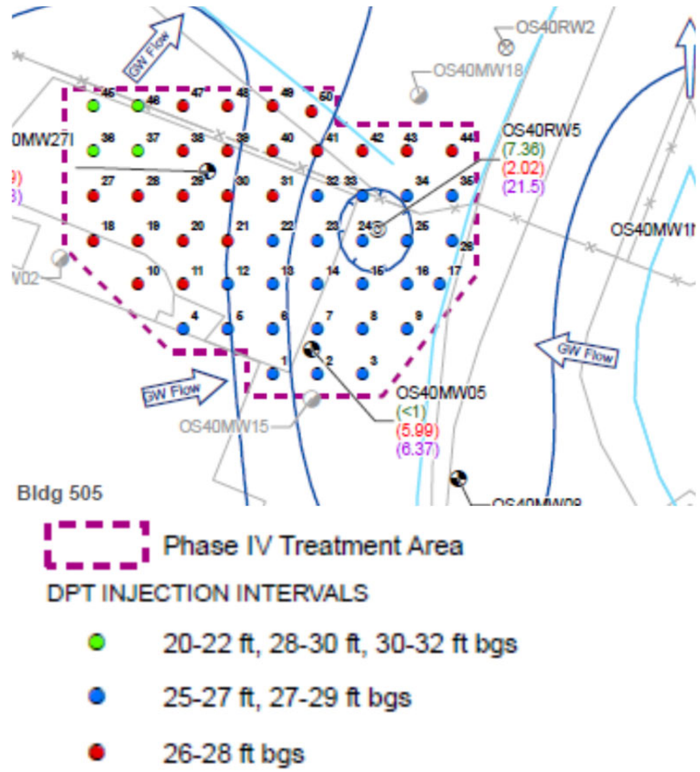
- Conducted HRSC in 2014 utilizing low-level MIP and HPT to identify secondary source of residual TCE
- Identified clay stringers at the bottom of the intermediate zone (~20-32 ft bgs) with residual CVOCs contributing to prolonged remediation due to matrix diffusion
- Targeted follow-on remediation to address impacted zones in 2015/16
  - ~1,380 lbs of emulsified lecithin substrate (ELS®) to target 2,000 mg/L in situ; and
  - ~6,000 lbs of ZVI (0.2% of aquifer mass)



CASE STUDY #1: BUILDING 505

Phase I Remedy Optimization Results – 2017

- Achieved further reductions in plume extent
  - Two additional wells below MCLs
- Only two wells remained with MCL exceedances
  - TCE from max 898 to <1 ug/L
  - cis-1,2-DCE from max of 491 to 4 ug/L
  - VC from max of 63 to 15 ug/L
- VC concentrations slightly above MCL

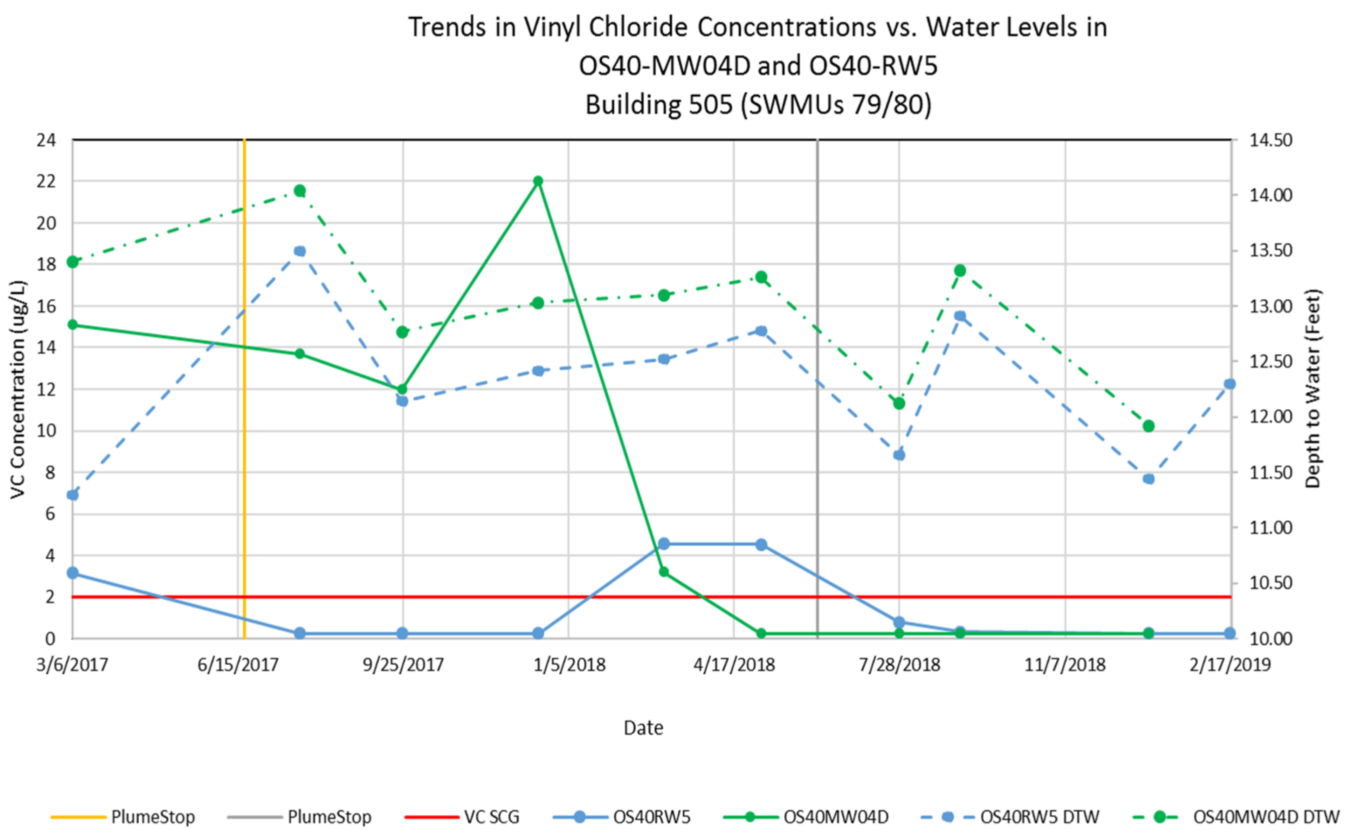


CASE STUDY #1: BUILDING 505

Phase II Remedy Optimization

- Injected PlumeStop®, HRC®, and SDC-9 in 2017 to remediate low-levels of VC around two remaining wells
  - PlumeStop® 8,200 lbs
  - HRC® 1,380 lbs
  - SDC-9 ~20 liters
- The Regenesis product PlumeStop® was selected to distribute activated carbon in situ for adsorption of the VC, followed by biodegradation via enhanced reductive dechlorination
- Limited follow-up injection in 2018

CASE STUDY #1: BUILDING 505



CASE STUDY #1: BUILDING 505

Site Closure achieved

- Achieved 4 consecutive sampling events of all CVOCs below MCLs as of February 2019
- Abandoned 33 monitoring/recovery wells
- Abandoned P&T system and groundwater extraction infrastructure
- Obtained SCDHEC approval of NFA in April 2019

P&T System

System and well abandonment

CASE STUDY #2
FORWARD OPERATING LOCATION TRAINING AREA (FOLTA)

CASE STUDY #2: FOLTA

Baseline (2008) Conditions

- Petroleum hydrocarbon contamination in shallow groundwater
  - Benzene ~300 ug/L
  - Naphthalene ~250 ug/L
  - 1,2,4-trimethylbenzene ~400 ug/L
  - 1,3,5-trimethylbenzene ~200 ug/L
- Selected remedy: Aerobic ISEB
- Aerobic ISEB implemented in 2004, prior to PBR, was not successful due to presence of continuing source

CASE STUDY #2: FOLTA

Initial Technical Approach

- Completed excavation of ~2,500 tons of contaminated soil to remove the bulk of the contaminant mass in 2008/09
  - Phased excavation to address discovery of free product and an unexpected culvert with fuel contamination
  - Lateral limitations due to site infrastructure
- Injected dilute hydrogen peroxide in 2010 to facilitate chemical oxidation and aerobic bioremediation of area not addressed by excavation
  - ~33,000 gal via 18 injection wells

Excavation with shoring

Culvert with fuel contamination

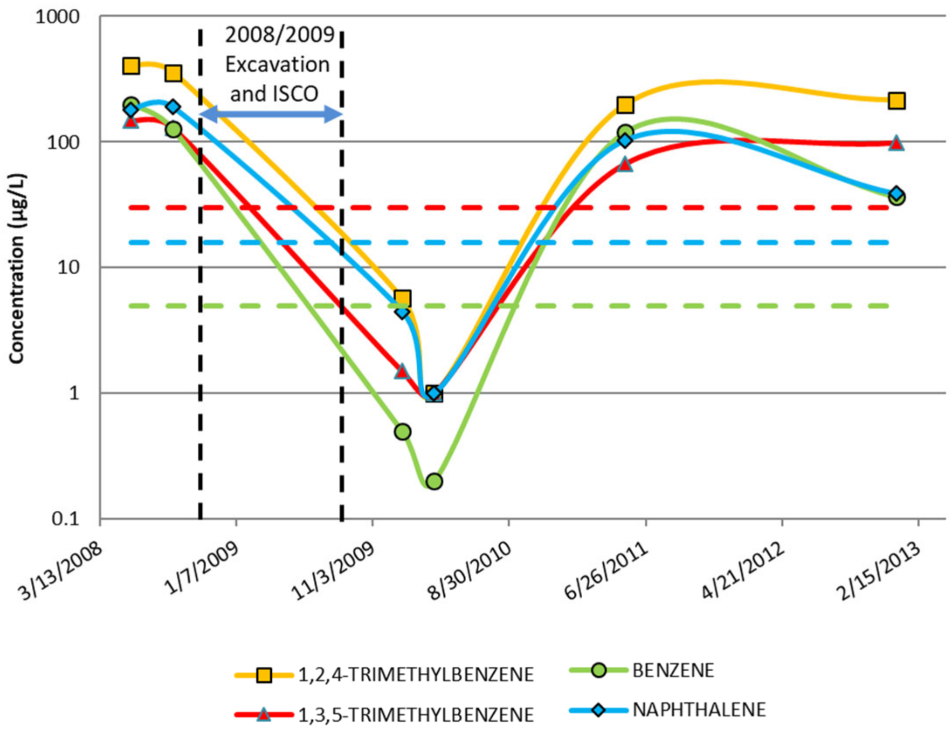
CASE STUDY #2: FOLTA

Results Following Initial Approach

- Achieved cleanup goals of all site contaminants in first post excavation and injection monitoring event in March 2010

BUT…

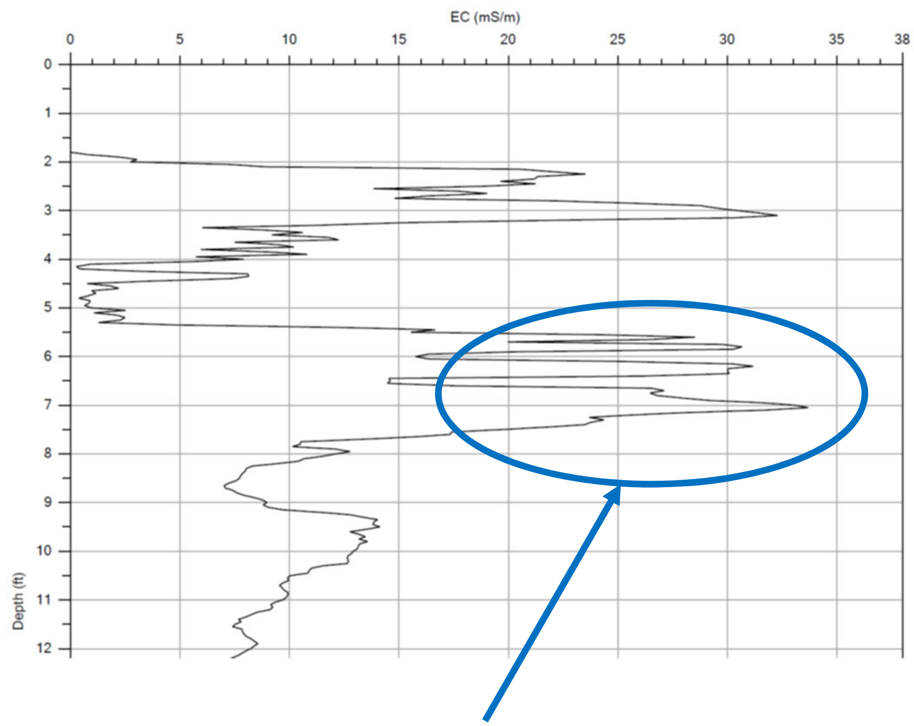
- Significant rebound observed by May 2010
  - Benzene 120 ug/L
  - Naphthalene 103 ug/L
  - 1,2,4-trimethylbenzene 198 ug/L
  - 1,3,5-trimethylbenzene 67 ug/L
- Concentrations ultimately rebounded to levels close to pre-excavation and ISCO



CASE STUDY #2: FOLTA

Remedy Optimization Phase I

- Conducted HRSC in 2011 utilizing soil conductivity logging and discrete interval groundwater sampling
- Identified clay stringers at the bottom of the shallow zone with residual contaminants contributing to prolonged remediation due to matrix diffusion
- Targeted follow-on remediation to address impacted zones in 2012/13 using catalyzed hydrogen peroxide – ~20,000 gal injected over two events



Clay stringers identified beyond lateral extent of excavation

CASE STUDY #2: FOLTA

Phase I Remedy Optimization Results – 2013

- Contaminant concentrations decreased as a result of the two rounds of ISCO, but remained above cleanup goals
- Factors contributing to insufficient treatment
  - Matrix diffusion from clay layers in saturated zone
  - Inadequate distribution and contact between ISCO amendments and low conductivity contaminated zones
  - Limited half-life of hydroxyl radicals

ISCO Injections

Back to the drawing board…

CASE STUDY #2: FOLTA

Phase II Remedy Optimization

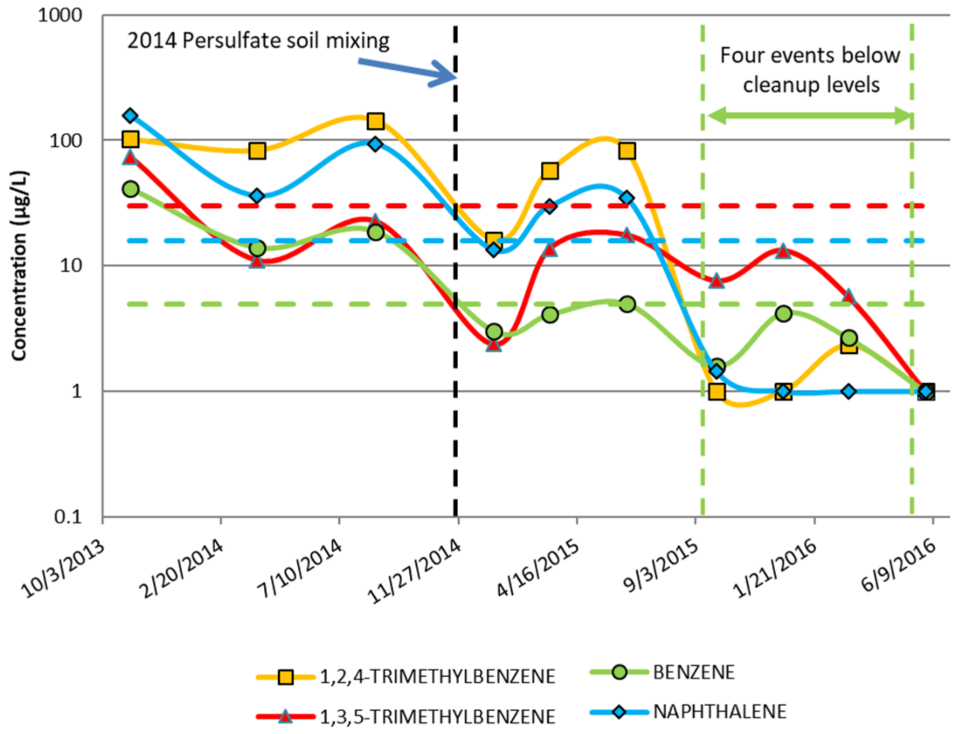
- Direct-injection not likely to be successful in remediating the site regardless of amendment being delivered.
- Revised approach in 2014:
  - In situ soil mixing with activated persulfate to target residual source ~3,745 lbs of persulfate mixed to depth of 15-ft by ERFS
  - Sulfate enhanced anaerobic bioremediation as polishing step; injected ~8,000 gal of diluted EAS®

Soil mixing with Persulfate at FOLTA

CASE STUDY #2: FOLTA

Phase II Remedy Optimization Results – 2015/2016

- Concentrations of site contaminants decreased below their cleanup goals and did not rebound (4 consecutive events)
  - Benzene < 5 ug/L
  - Naphthalene < 16 ug/L
  - 1,2,4-trimethylbenzene < 30 ug/L
  - 1,3,5-trimethylbenzene < 30 ug/L
- Completed well abandonment activities and site closure documentation in September 2016 with approval of NFA by SCDHEC



CASE STUDY #3
GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER

GEOCHEMICAL MECHANISMS CONTROLLING TRACE ELEMENT CONCENTRATIONS IN GROUNDWATER

- Many natural processes can cause elevated trace element concentrations (e.g., suspended particulates, pH effects, redox effects, TDS and complexation effects).
- Contamination may be the source of trace elements if natural processes cannot explain the observations.
- Geochemical signatures of each natural and anthropogenic process can be identified.

EFFECTS OF SUSPENDED PARTICULATES

- Most common suspended particulates in groundwater are clay minerals, hydrous aluminum oxides, aluminum hydroxides; and iron oxides, iron hydroxides, iron oxyhydroxides
- In circumneutral-pH water, Al concentrations > 1 mg/L indicate suspended Al-bearing minerals (clays)

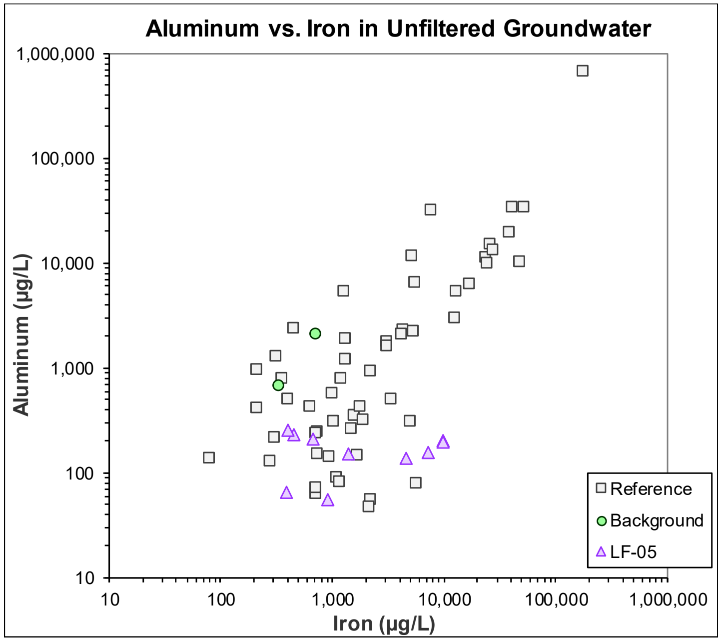
  (–) surface charge

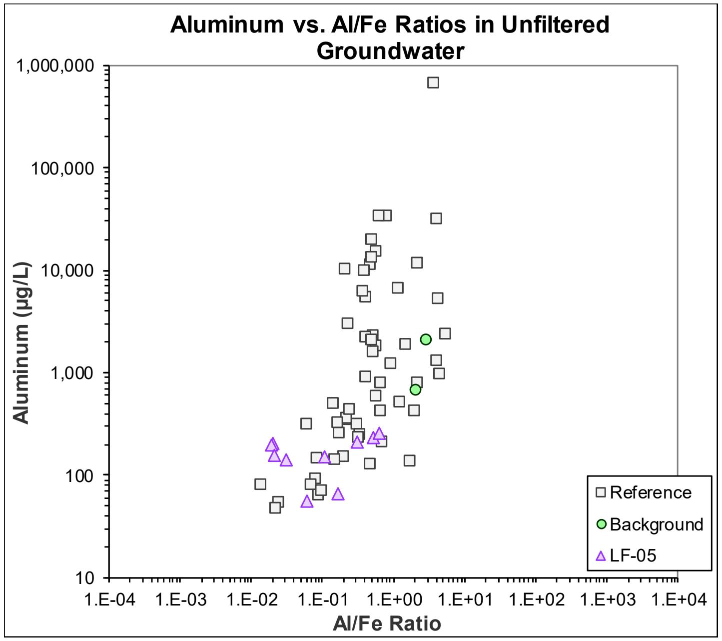
  Strong affinity to adsorb cations (e.g., Ba^{2+}, Pb^{2+})
- In circumneutral-pH, moderate to oxidizing redox conditions, Fe concentrations > 1 mg/L indicate suspended iron oxides

  (+) surface charge

  Strong affinity to adsorb oxyanions (e.g., $HAsO_4^{2-}$, $H_2AsO_4^{-}$)

CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF05





LF05 Samples:

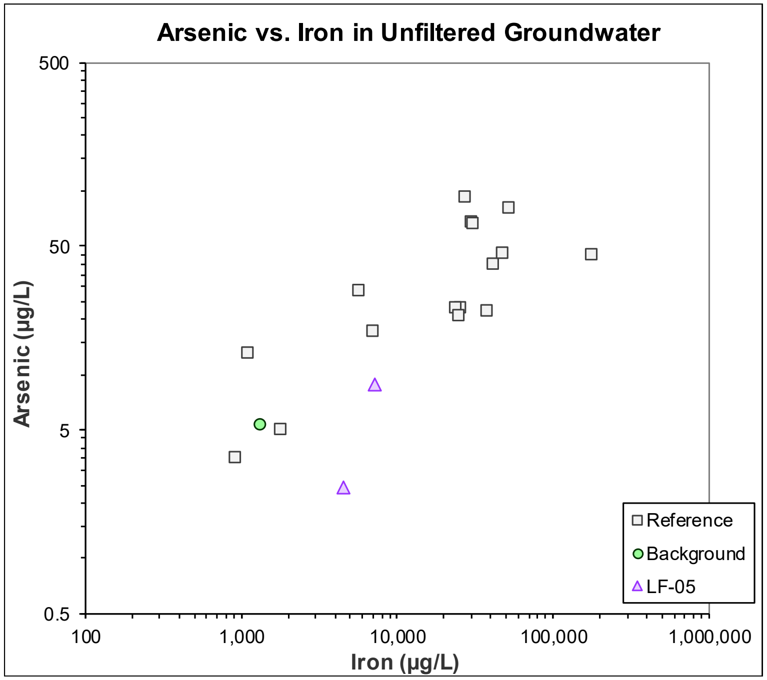
pH: 5.80 to 7.14
median = 6.39

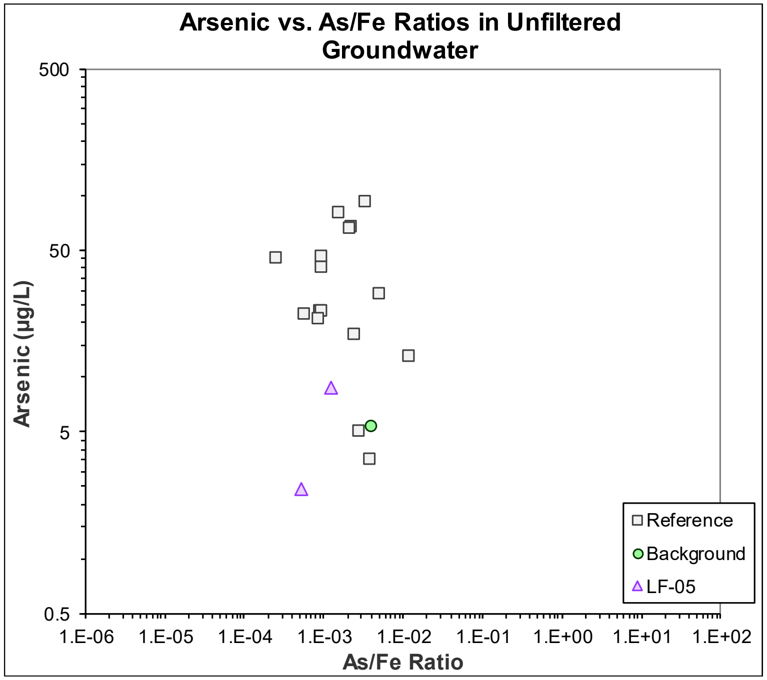
DO: 0.32 to 1.77 mg/L
median = 0.75 mg/L

ORP: -97.2 to +140 mV
median = -14.5 mV

Turbidity: 0 to 8.8 NTU
median = 0 NTU

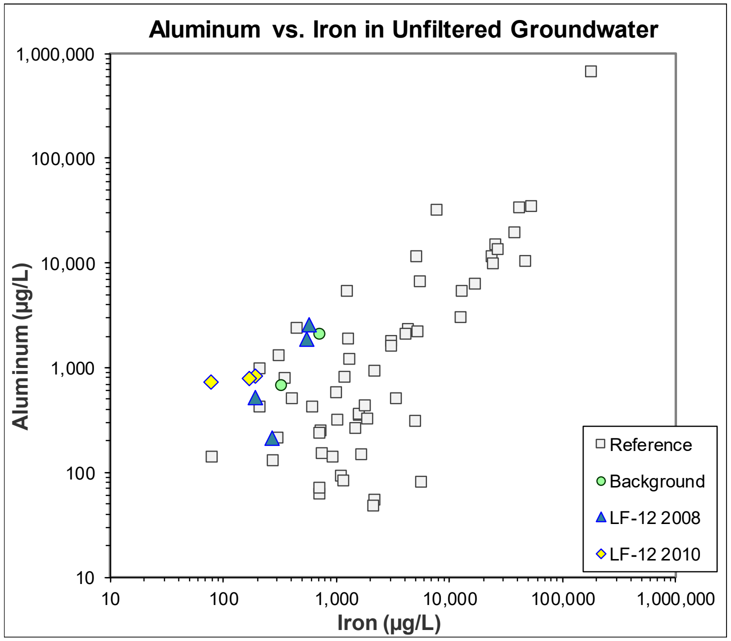
CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF05

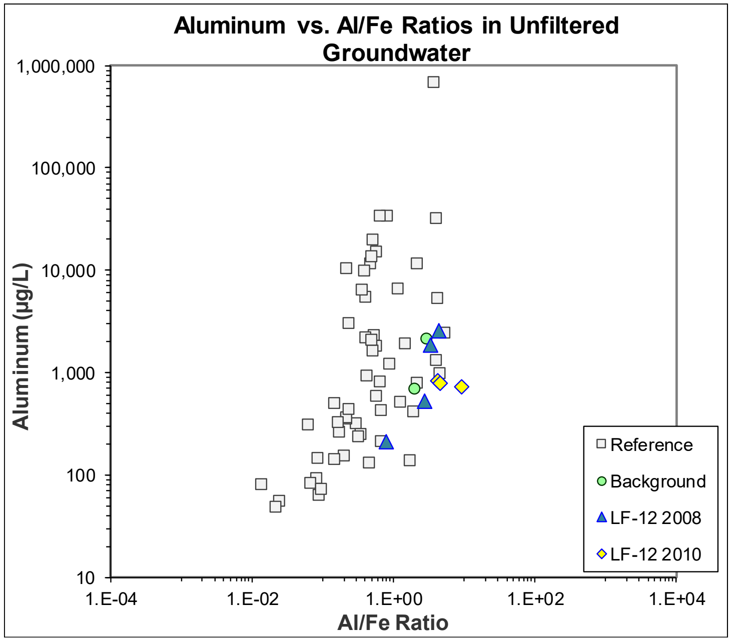




Site samples have low arsenic concentrations and As/Fe ratios that are consistent with the background and reference samples' As/Fe ratios, indicating no arsenic impacts from anthropogenic sources.

CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF12





LF12 Samples:

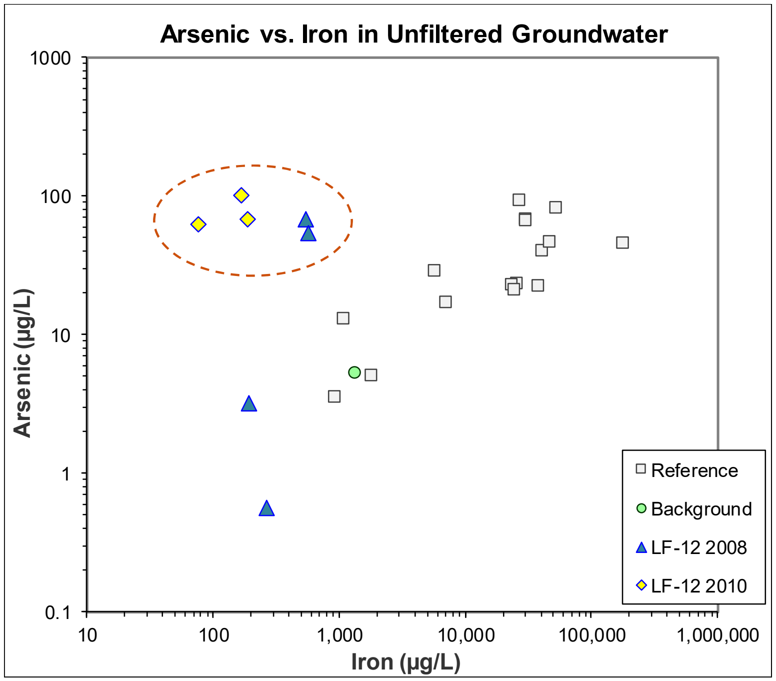
pH: 5.01 to 5.62
median = 5.33

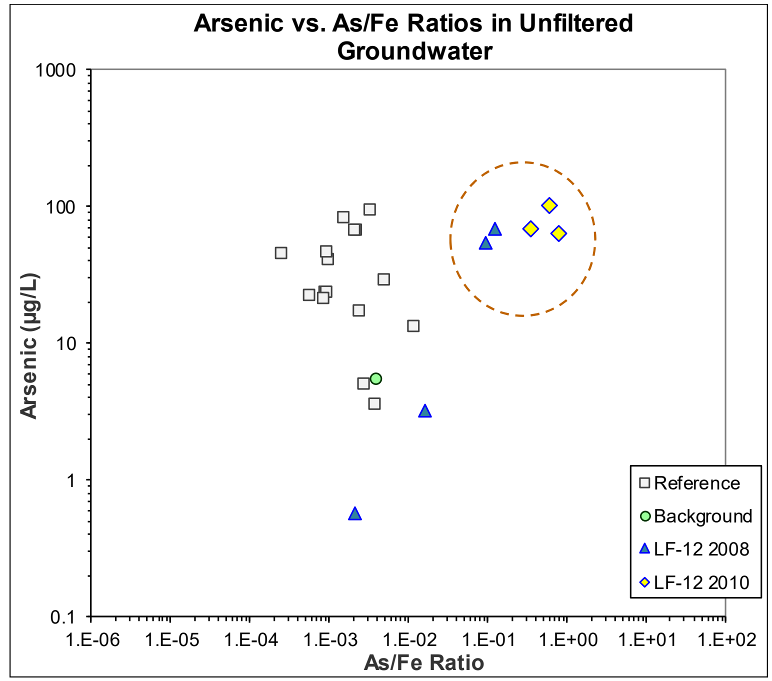
DO: 0.54 to 6.14 mg/L
median = 4.34 mg/L

ORP: -83.4 to +129 mV
median = +26.6 mV

Turbidity: 1.9 to 43.4 NTU
median = 24.0 NTU

CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF12





Five LF12 site samples have As/Fe ratios that exceed the range of background and reference samples' As/Fe ratios. Groundwater at these locations contains excess arsenic from an anthropogenic source.

CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF12

- LF12 is within the boundary of the Whispering Pines Golf Course
- Confirmed prior usage of arsenical herbicides by maintenance crew including:
  - Monosodium methanearsonate (MSMA): CH_4AsNaO_3

    No Fe in compound
- Anomalously high As/Fe ratios provide signature for arsenical-herbicide impact.

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J Agric Food Chem. 2005 May 4; 53(9): 3556–3562. doi:10.1021/jf047908j.

Arsenic Transport and Transformation Associated with MSMA Application on a Golf Course Green

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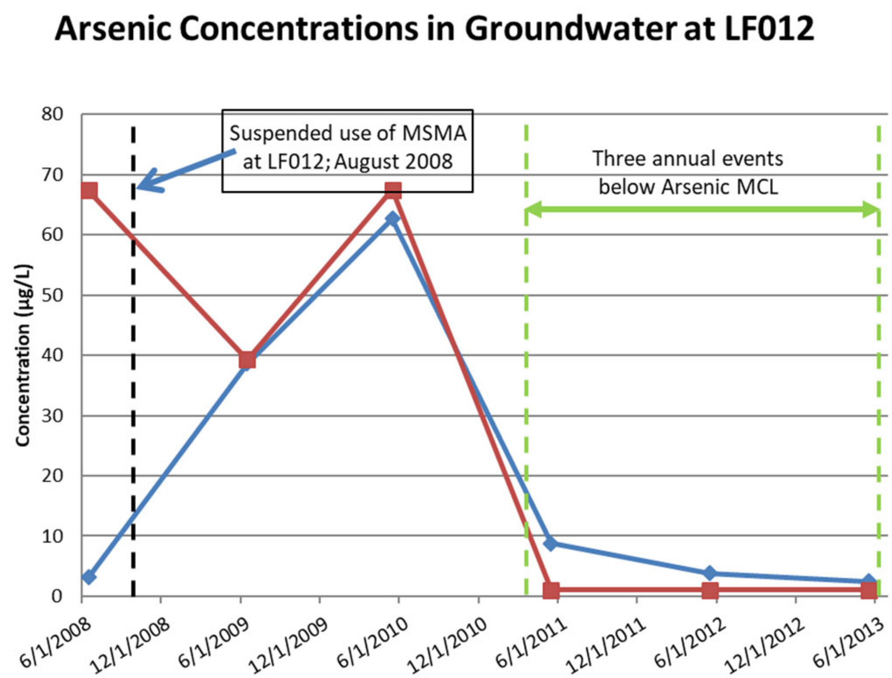
CASE STUDY 3: GEOCHEMICAL EVALUATIONS OF ARSENIC IN LANDFILL GROUNDWATER – LF12

- Golf Course maintenance crew agreed to suspend further usage of arsenical herbicide MSMA
- Monitoring was continued on annual basis
- Arsenic concentrations decreased below the MCL of 10 ug/L ~2-years following suspension of MSMA usage
- Concentrations remained below MCL for 3 consecutive annual events
- SCDHEC approved request for No Further Monitoring and well abandonment in 2013



CASE STUDIES SUMMARY

- Multiple approaches were required to achieve low ug/L cleanup levels. Remedial design selection/optimization corresponded with continuous updates to CSMs over the life of the project.
- Supplemental investigations using HRSC, implemented following removal of the bulk of the contaminant mass, played a critical role in identifying zones with residual contamination.
- Maintaining flexibility regarding selection of investigation and remediation technologies was critical for project success. Several technologies implemented over the 12-year project duration had not been developed or were not commercially available when the project was started.

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- **Remediation Amendments** – Regenesis, JRW Bioremediation, PeroxyChem, and EOS Remediation
- **Injection Services** – Cascade, RedoxTech, ERFS, and Regenesis

Groundwater Geochemical Evaluations Explained:

- Thorbjornsen, K. and J. Myers, 2008, “Geochemical Evaluation of Metals in Groundwater at Long-Term Monitoring Sites and Active Remediation Sites,” ***Remediation***, Vol. 18, No. 2, pp. 99-114.

- Thorbjornsen, K. and J. Myers, 2007, “Identifying Metals Contamination in Groundwater Using Geochemical Correlation Evaluation,” ***Environmental Forensics***, Vol. 8, No. 1, pp. 25-35.

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QUESTIONS

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