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

Horizontal Directional Drilling and Horizontal Wells to Enhance Remediation at Complex Sites

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Speaker Introduction

Kyle Carlton

- Specialties
  - HDD planning and oversight
  - HW design, installation, and operation
  - Contamination assessment and in situ remediation
- Experience
  - 17 years in environmental industry (including 2 years working directly for a nationwide HDD company)
  - Project management/HDD support for 25+ HDD projects across country, including three DOD sites (Joint Base Charleston, Eglin AFB, and Robins AFB)
- Education: BS, Geology 2005 University of Alabama, Tuscaloosa
- Certifications: PG: MS, FL
- Location: Pensacola, FL

US Navy Blue Angels over Pensacola Beach, FL
(North Escambia 2022)

AFB: Air Force Base
DOD: Department of Defense
HDD: horizontal direction drilling
HW: horizontal well
PG: Professional Geologist

Presentation Objectives

Two-Part Technology: Horizontal Directional Drilling (HDD) and Horizontal Wells (HWs)

Objective 1: Understand **HDD** basic processes, capabilities, and limitations

Objective 2: Understand **HW** applications, designs, and operations and maintenance

Objective 3: Understand the **best practices** of HDD and HW for successfully managing and implementing a project

Presentation Overview

- Introduction to HDD and HWs
- HDD technology overview
- HW design, construction, and installation
- HW O&M and refurbishment
- Cost considerations
- Case studies
- Conclusions and references

O&M: operations and maintenance

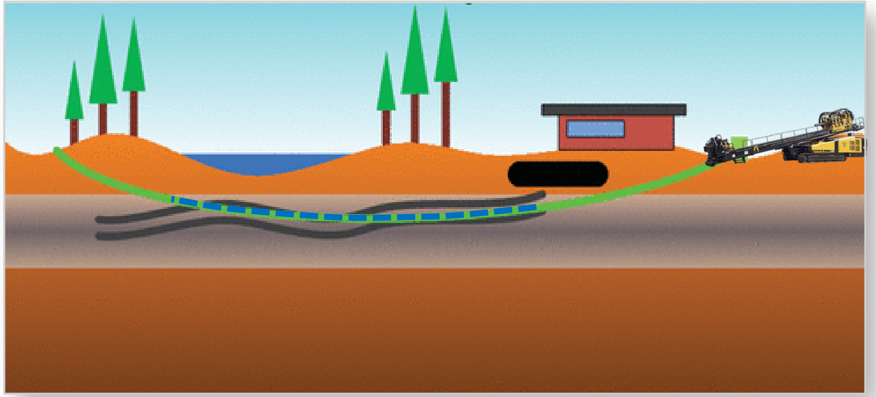
What Is HDD? What Is a HW?

What is HDD?

- Also called directional boring, horizontal drilling
- Rigs advance a shallow entry angle borehole with planned curvature to achieve a horizontal (near zero) pitch/orientation
- Not angled drilling or jack and bore
- Mud rotary
- Purposes:
  - Installing utilities and pipelines
  - ***Installing HWs (most of our discussion)***
  - Informing site assessments (less common)

What is an HW?

- Also called an HDD well, collection pipe, French drain, or perforated pipe
- Horizontally placed pipe with slots/perforations
- Installed via HDD boring and trenching



Conceptual HDD boring
(Environmental Science and Technology 2012)

DOD facilities where HDD/HWs have been implemented for site remediation
(NAVFAC EXWC 2020)

EDTD: Ellingson-DTD

When, Where, and Why? HDD and HWs

Access: Allows access to areas beneath surface obstacles/infrastructure, such as buildings, roads, runways/taxiways, railways, wetlands, water bodies, landfills, mine tailings, containment basins, and ash ponds. ***Access is primary reason for using HDD for remediation.***

Coverage: HWs can cover large areas and be installed to lengths > 2,000 ft.

Targets: Targets horizontal features, such as thin geologic units, aquifers, LNAPL plumes, smear zones, and DNAPL plume.

HDD for installation of horizontal air-sparge well installation at Eglin AFB
(EDTD 2023)

Horizontal air-sparge wellhead at Eglin AFB
(EDTD 2023)

HDD installation of a biosparge well at Joint Base Charleston
(DTI 2019)

DTI: Directional Technologies, Inc.
DNAPL: dense nonaqueous-phase liquid
ft: feet
LNAPL: light nonaqueous-phase liquid

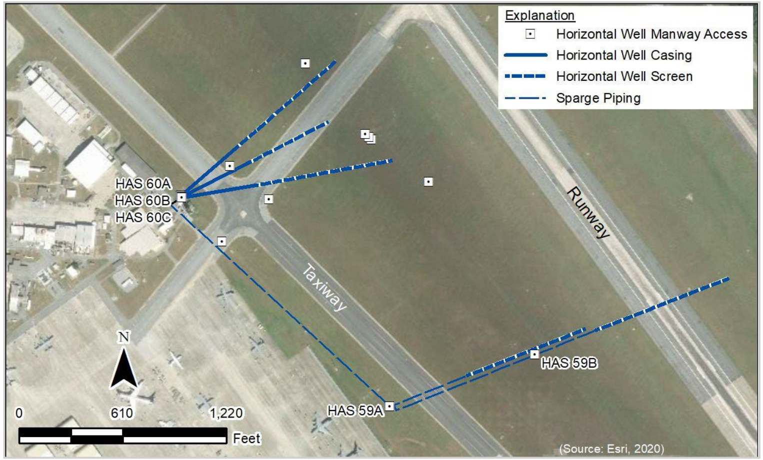
Remedial Applications

Remedial technologies using HWs

- Air and ozone sparge/biosparge/sparge curtains
- SVE and dual-phase extraction
- Injection
- GW extraction
- Subslab vapor extraction and VI mitigation (active or passive)
- Thermal: ERH
- Permeable reactive barrier

Investigation techniques using HDD

- Soil sampling
- GW sampling
- High-resolution site characterization and direct imaging



Horizontal air-sparge wells beneath Taxiway B at Robins AFB (NAVFAC EXWC 2020)

Water being pumped through horizontal air-sparge well demonstrating uniform flow through well screen (DTI 2011)

ERH: electrical resistance heating
GW: groundwater
SVE: soil vapor extraction
VI: vapor intrusion

When Not to Use HDD?

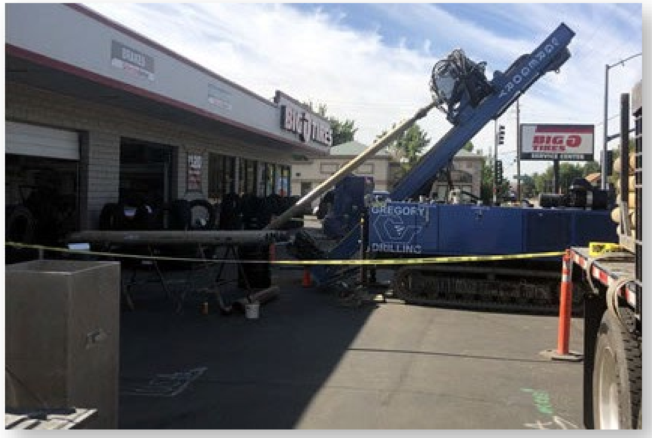
Trenching

- Lack of surface infrastructure/utilities
- Unconsolidated soils
- Filter media around collection pipe

Angled drilling

- Area beneath surface infrastructure accessible at predefined angle
- Wells can be installed through drill rods with filter packs

50-foot one-pass trenching (Geosyntec 2020)



Angled sonic drilling (Gregory Drilling 2023)

Intro to HDD and HWs

$200

Answer:

This is the primary reason for implementing HDD for site remediation.

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HDD Rig Sizes and Uses

Rig Size	Thrust/Pullback	Length of Bore	Max Depth	Well Diameters	Subsurface Material
Small	24,000–40,000 lb	50–500 ft	50 ft	2–4 in	Unconsolidated soils
Medium	60,000–80,000 lb	100–1,000 ft	100 ft	3–6 in	Unconsolidated soils, cobble, and soft rock
Large	90,000–200,000 lb	300–2,500 ft	200 ft	4–8 in	Unconsolidated soils and rock

Vermeer 23x30
(Trenchless Technology Magazine 2023)

Ditch Witch JT60
(Ditch Witch 2023)

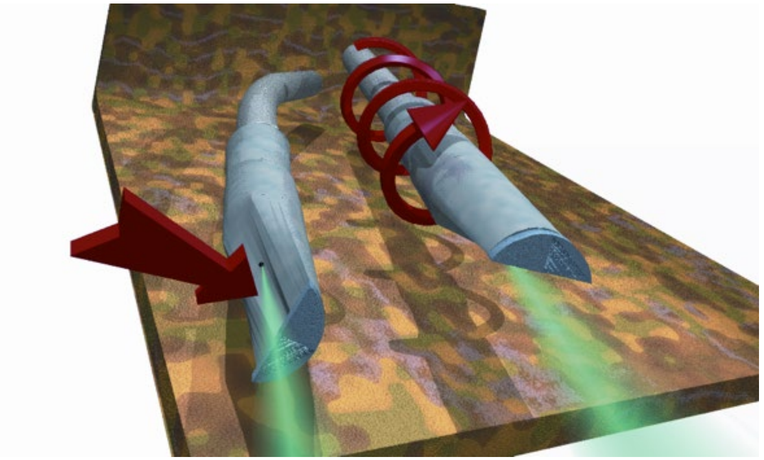
American Auger 440
(American Auger 2023)

in: inches
lb: pound(s)

Steering Controls

- Steerable drill bits
  - Angled face to enable turns
  - Forward advancement = rotation
  - Steering adjustment
    - Tool face of bit rotated into desired position
    - Forward thrust applied from rig on drill rods
    - 10%–20% steering capabilities

Assorted unconsolidated HDD bits for sand, clay, loose rock, granular rock, cobble/gravel
(Radiushdd.com 2023)



A 3-dimensional conceptual HDD steering graphic
(DTI 2023)

HDD rod joint
(Trenchless Technology Magazine 2023)

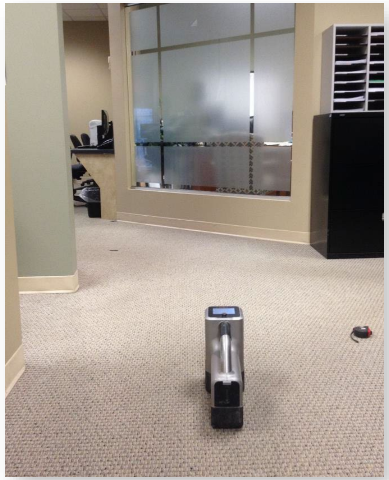
KEY POINT

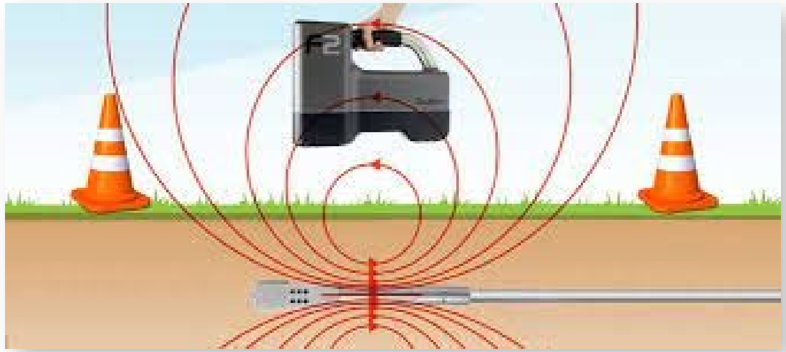
Bend radius is the distance required for the drill string to perform a 90-degree turn.

Drill Bit Tracking Systems: Walk-Over Location

- Walk-over location
  - Is the most common type of locating system
  - Has shallower target depths (50 ft or less)
  - Must have walk-over access over target areas
  - Is subject to interferences from utilities, rebar

Sonde/Beacon housing
(Vermeer 2023)

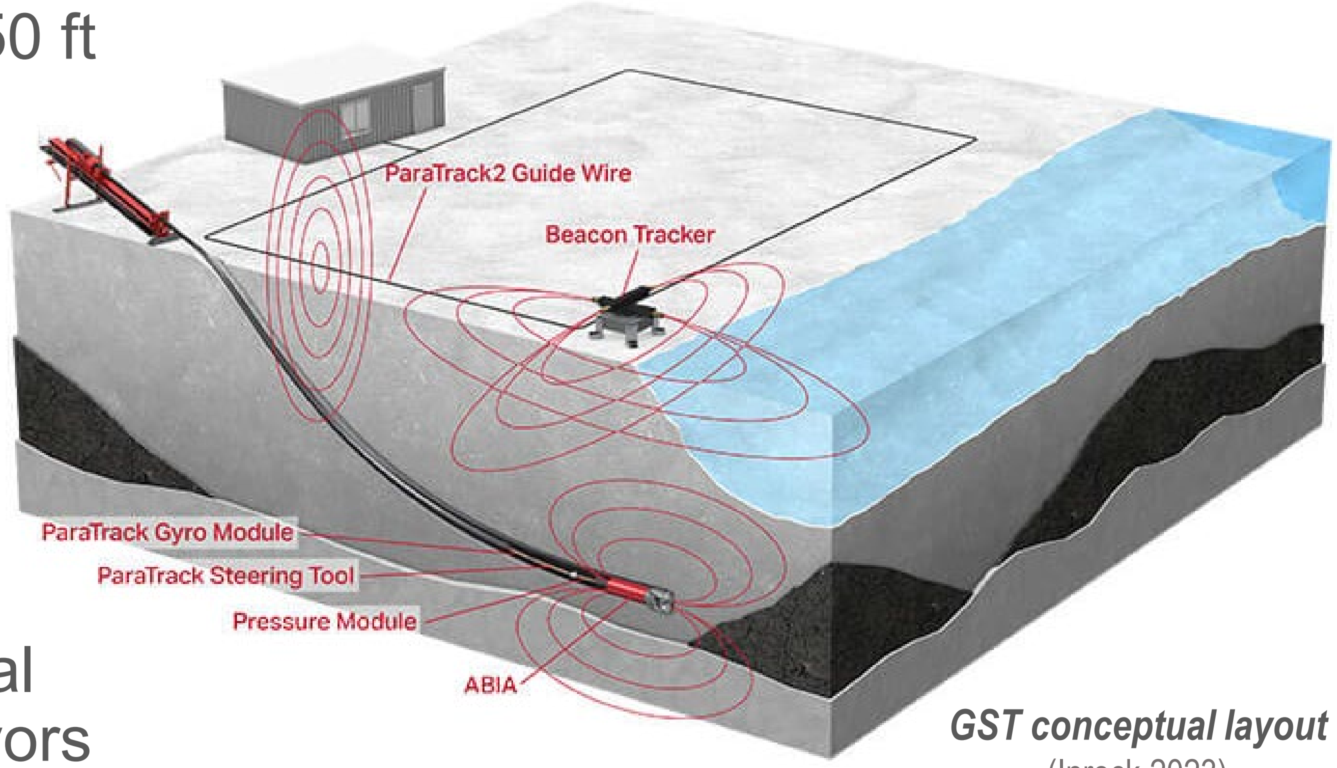




Walk-over locating technology, Falcon F2 system
(EDTD and Underground Construction 2023)

Drill Bit Tracking Systems: Wire-Line and GST

- Wire-line and GST
  - Deeper target depths below 50 ft
  - Wire-line requires a wire-grid at surface for first several hundred feet
  - GST provides X, Y, Z coordinates compared to planned bore path
  - More costly and time consuming, requires additional crew, and may require surveyors to lay out bore path and grid



GST conceptual layout
(Inrock 2023)

GST: gyroscopic steering tool

Drilling Fluids

- HDD is mud rotary! It must be, and here's why:
  - Transportation of soil/rock cuttings
  - Cleaning and cooling of cutters on bits and reamers
  - Borehole stabilization
  - Reduction of friction
  - Transmission of hydraulic power
  - Hydraulic excavation
- Drilling fluids must be properly managed
- Roll-offs, vac boxes, vac trucks, tanker trucks are required
- Recycling/recirculating mud can be beneficial (larger projects)

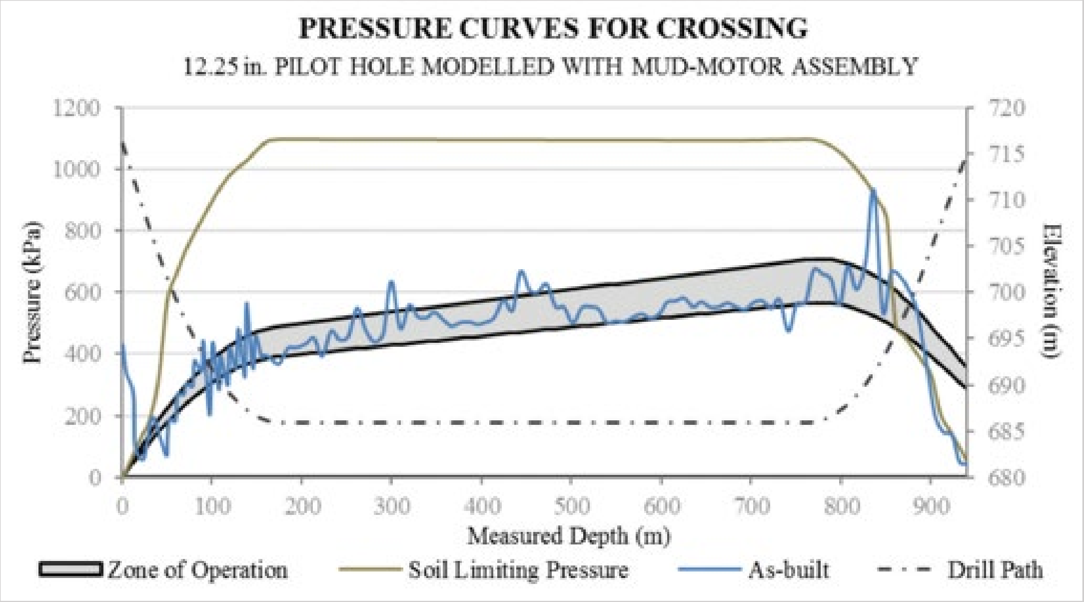
Mud recycler
(EDTD 2023)

- Bentonite or biodegradable mud?
  - Bentonite-based mud
    - Mostly used for utility installations
    - Risk of formation porosity damage (mud cake)
    - Less expensive
    - Can be developed out of well if done properly
  - Biodegradable mud (biopolymers)
    - Generally considered better for HW installations
    - Less risk of formation porosity damage

Inadvertent Returns/Frac-outs

- Inadvertent returns
  - Frac-outs or hydrofracturing
  - When drilling fluids return to surface above boring (not back to entry pit)
  - Causes include utilities/structures, low drill angle, insufficient cover, soft soils, wrong equipment, wrong drilling fluid
- Mitigation
  - Understand subsurface geology
  - Prepare bore plan with sufficient cover/overburden
  - Prepare mud program, including correct mud type, viscosity, planned pressures
  - Complete hydrofracture analyses and inadvertent return analysis

Inadvertent returns (Utility Magazine 2016)

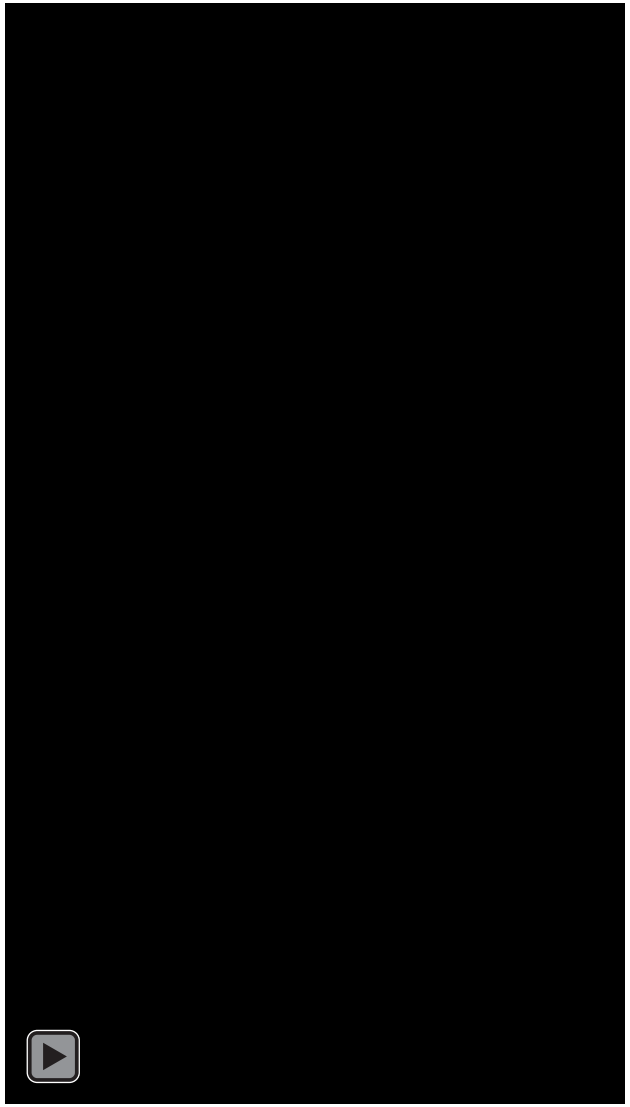


Pressure model with as-built pressures overlain (CCI Inc. 2020)

HDD Video

- Boring advancement
  - Mud jetted
    - Provides hydraulic excavation
    - Cools drill bit and beacon housing
    - Mobilizes cuttings to entry
  - Steering adjustments
    - Stop rotation
    - Apply forward thrust to drill bit

HDD Video
(Geosyntec 2021)

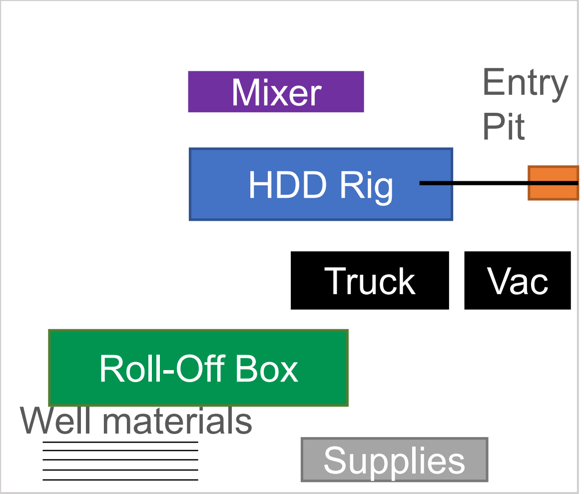


HDD Equipment Footprint

Small HDD project equipment

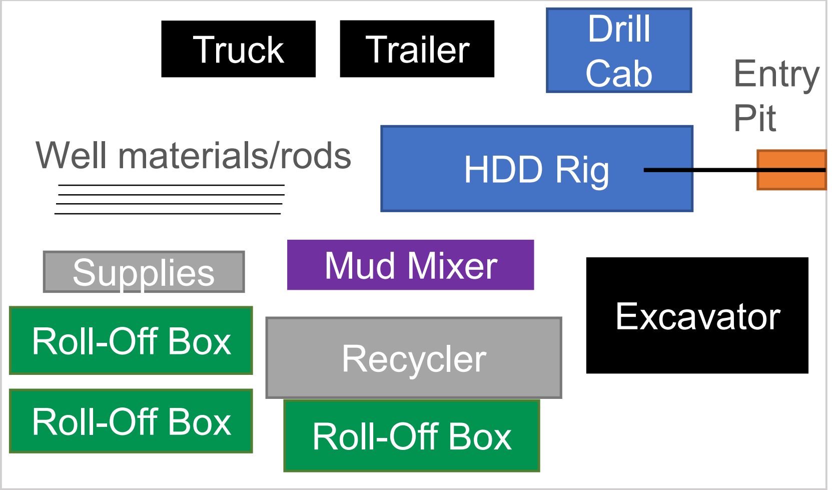
Large HDD project equipment

Conceptual footprint layout (not to scale)



50 ft

50 feet



150 ft

200 feet

Equipment footprint photographs (EDTD 2023)

Don't forget a water source!

HDD Technology

$400

Answer:

The distance required for the drill string to perform a 90-degree turn.

Presentation Overview

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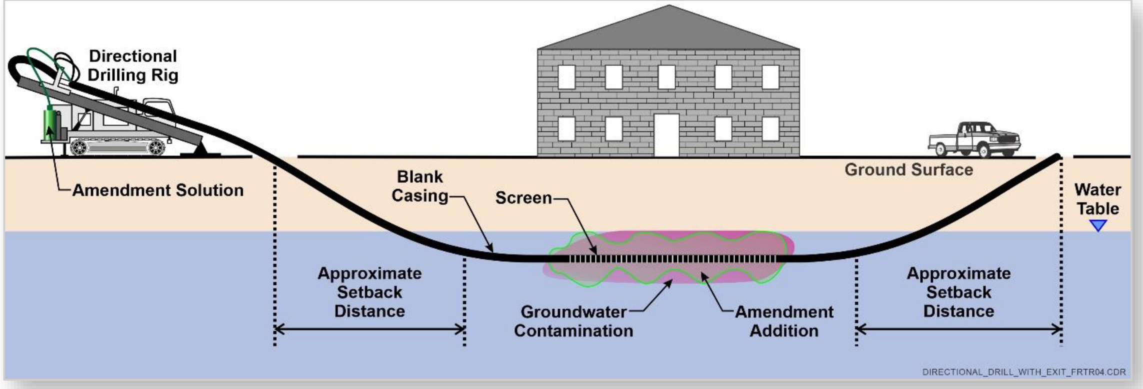
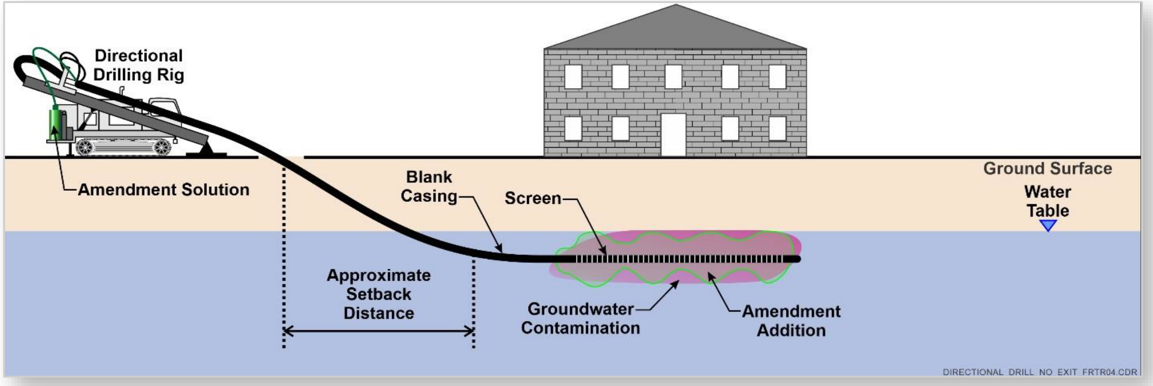
HW Well Types

- Entry-exit wells
  - Double-ended wells or surface to surface
  - HW pulled into borehole from exit
  - Two access points
  - Larger diameter wells: up to 8 inches in diameter
  - Easier maintenance
- Blind wells (do not daylight)
  - Single-ended wells, dead-ended wells
  - HW pushed into place from entry
  - More layout options
  - Reduced total linear feet (cost effective)
  - Limited to 2-, 3-, and 4-inch-diameter wells

KEY POINT *Use a 5:1 horizontal to vertical ratio to determine approximate setback distance.*



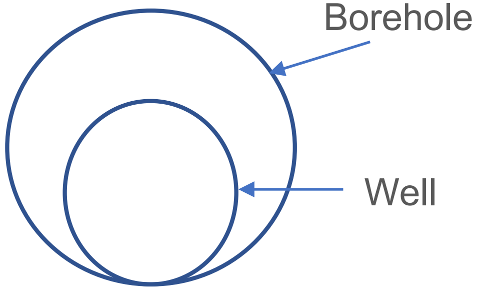
Entry-exit well installation (NAVFAC-EXWC 2020)

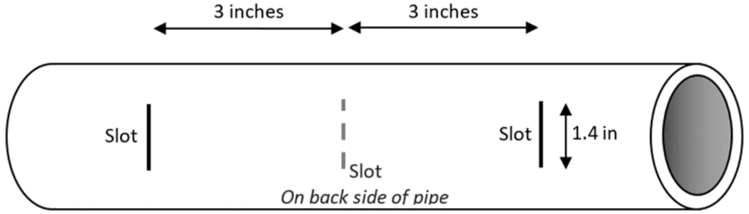


Blind well installation (NAVFAC-EXWC 2020)

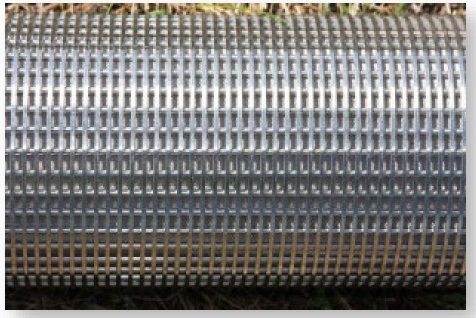
HW Materials and Screen Design

- Well materials: PVC (typically Sch 80), HDPE, SS, fiberglass
- Multiple types of stresses on well materials
- Custom slotted for remedial application
- Can be zoned to control fluid exit from screen
- Grain size analysis helps design!
    - Typically, no filter sand installed





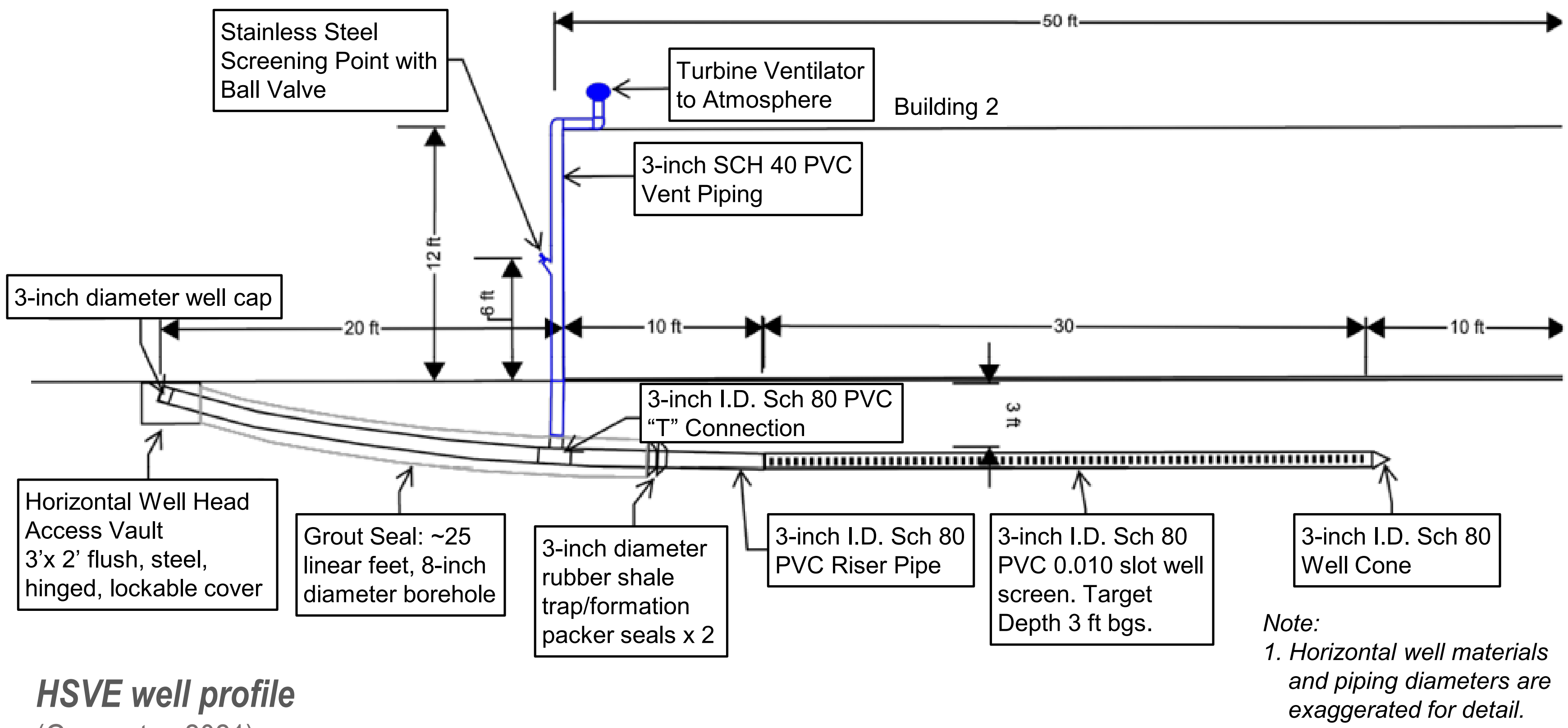
Horizontal freshwater injection well screen design and PVC screen
(Geosyntec 2021)



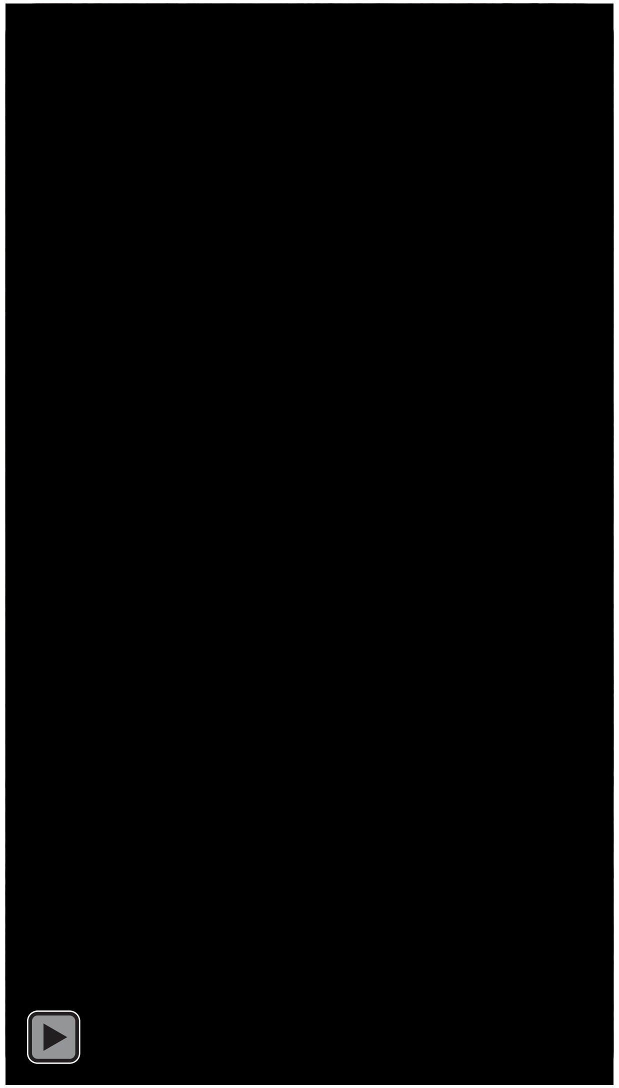
Varying well materials and custom slotting: SS (GW extraction), HDPE (injection), PVC (SVE and injection)
(EDTD and DTI 2023)

HDPE: high-density polyethylene
PVC: polyvinyl chloride
SS: Stainless Steel

HW Installation Well Video



HSVE well profile
(Geosyntec 2021)



Well materials installation
(Geosyntec 2021)

HSVE: horizontal soil vapor extraction

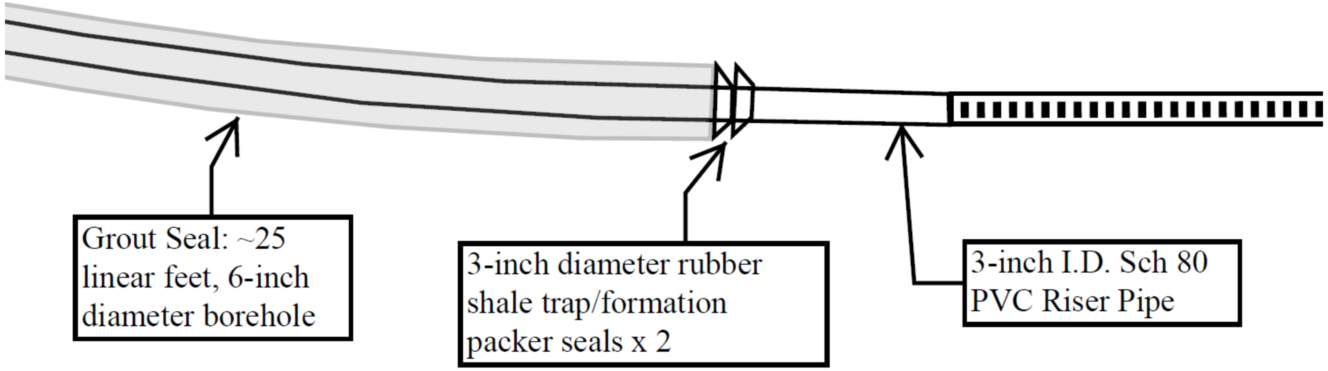
Grouting an HW

Grouting

- Can be challenging with HDD, but important
- Cannot rely on gravity feed
- Install tremie pipe/grout line entry and exit side
- Use shale traps/formation packers prior to screen

Horizontal well head with grout tremie pipe (FPM Remediations 2018)

HW profile with grout seal design (Geosyntec 2021)

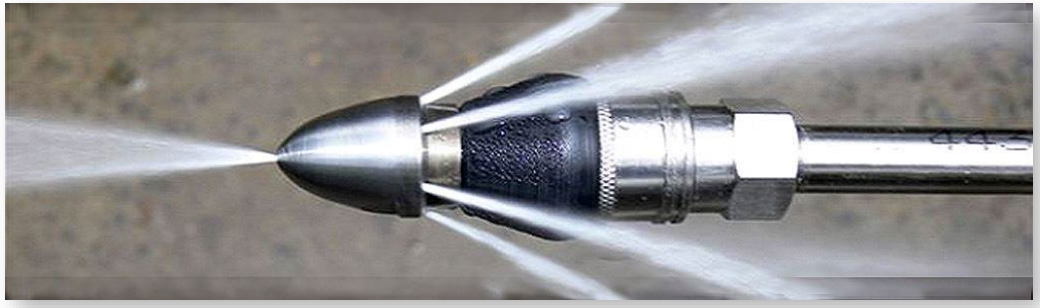


Formation packer/shale trap (Geosyntec 2021)

HW Development

Very important multistep process:

1. Remove drilling mud
2. Break down residual mud
   - Bentonite mud: clay dispersants
   - Biodegradable mud: enzyme breakers
3. Flush/jet/pump (repeat)
4. Manage fluid



Screen jetting tool
(EDTD 2023)

Vac box and frac tank for fluid containment (Geosyntec 2021)

HW head flushing connection
(Geosyntec 2021)

Horizontal submersible pump
(EPG Companies 2023)

HW Design

$600

Answer:

This is the horizontal to vertical ratio to determine setback distance.

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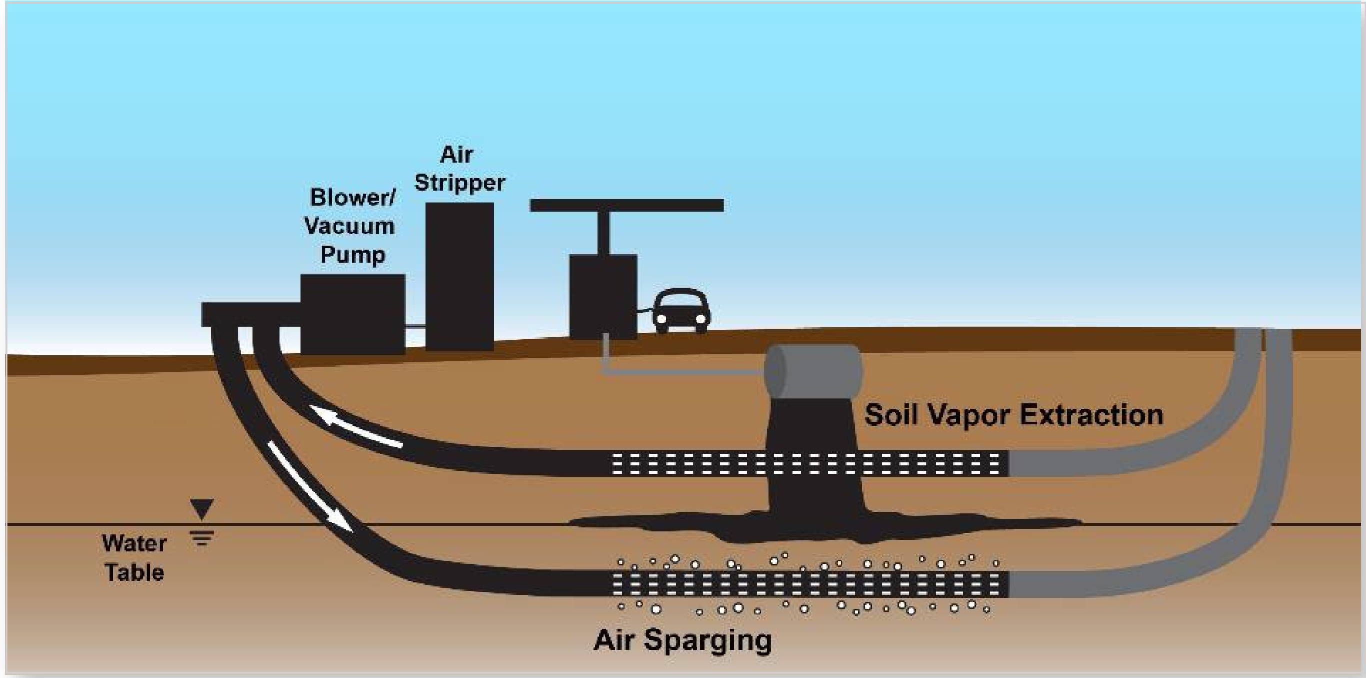
Horizontal Air Sparge

- HW operations: air sparge
  - Larger compressors needed for HWs
  - Continuous or pulsating
  - Often combined SVE wells in vadose zone
  - Use HDD for conveyance conduits

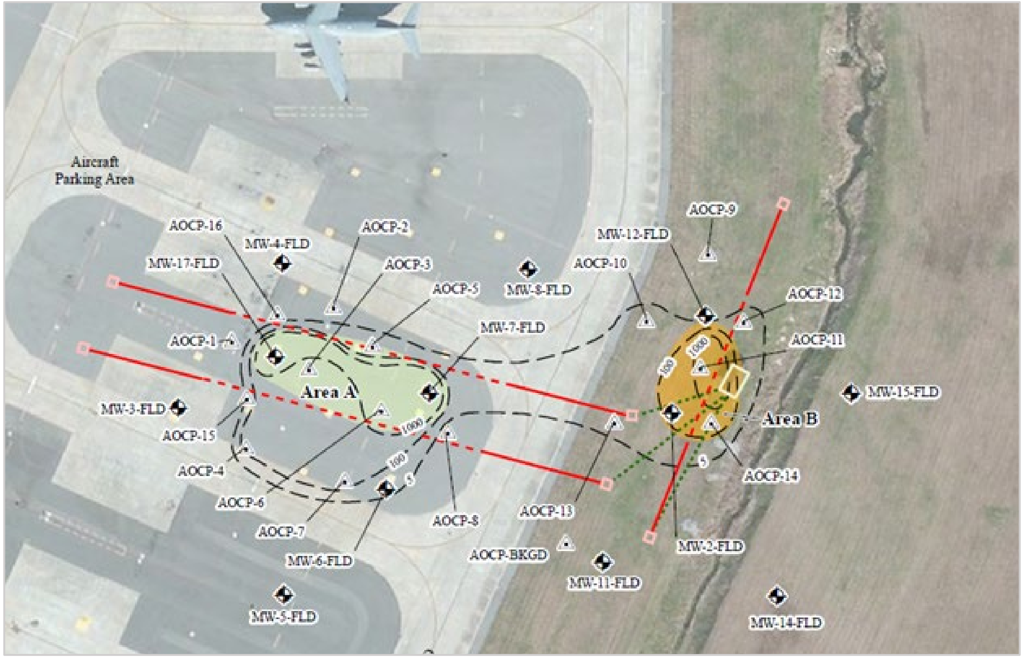


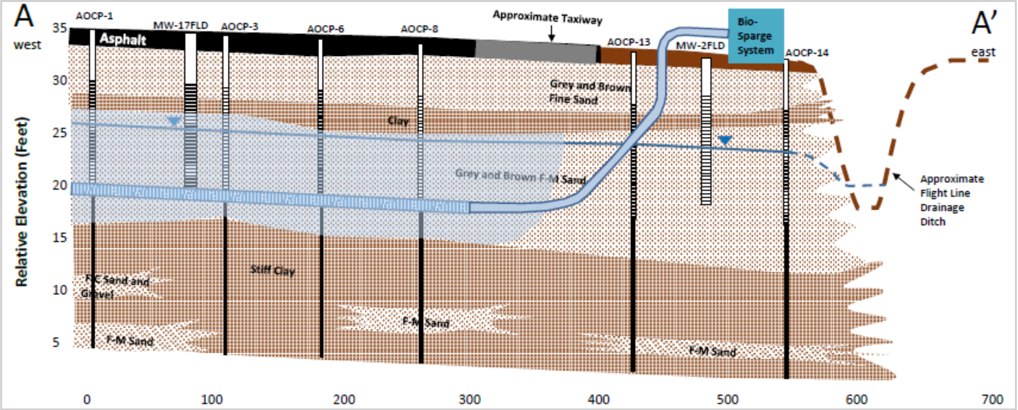
Horizontal air sparge/SVE conceptual graphic
(US EPA 2017)

US EPA: United States Environmental Protection Agency

Horizontal Biosparge

- Oxygen is introduced in GW to augment biodegradation of contaminates.
- Typically, low flow compared to air sparging.
  - 0.1 to 0.2 cfm per foot of wells screen
  - 0.010-inch-diameter slots
- Cycling/pulsing operation can be beneficial.
- Layouts commonly include sparge curtains to mitigate further migration of contaminates.





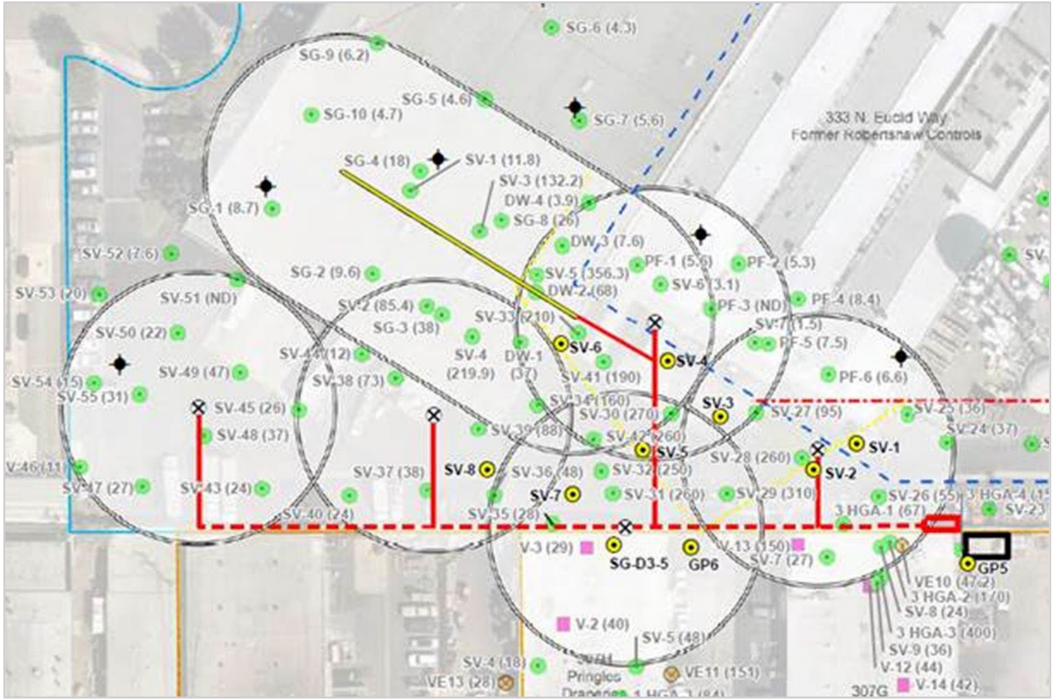
Horizontal biosparge well layouts and profile at Joint Base Charleston, flightline drainage ditch
(DTI & FPM Remediations 2018, 2019)

cfm: cubic feet per minute

HSVE and VI

- Varied blower sizes based on well diameters and lengths
- Passive ventilation or active
- One of the most common HW remedial application

HSVE well installation
(Geosyntec and EDTD 2021)



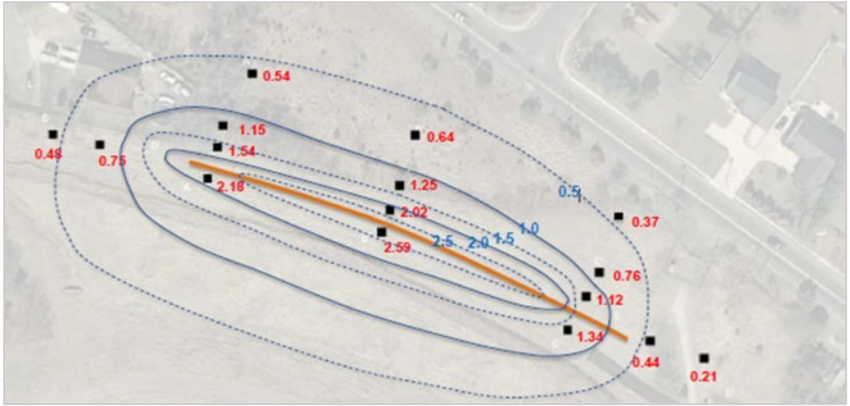
HSVE radius of influence achieved 80 ft
(Geosyntec and EDTD 2021)

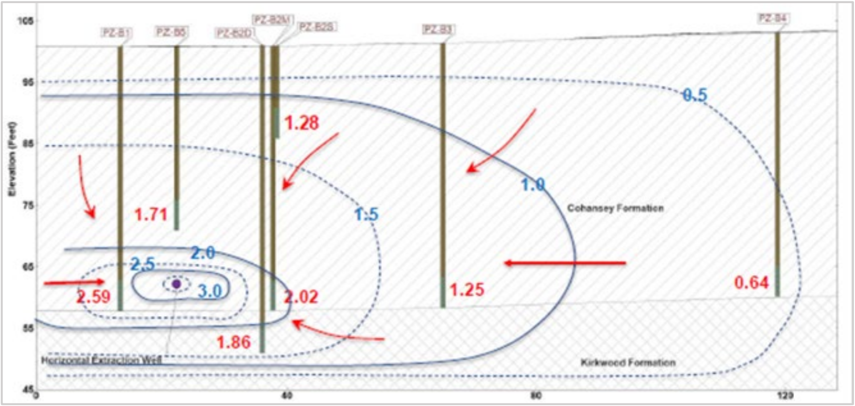
Hydraulic Control/GW Extraction

- A trough of depression
- Double-ended well (two pumping locations)
- Grain size analysis
- Horizontal pumps
  - Maintenance
  - Risks

Horizontal GW extraction: aerial drone view

(DTI 2016)



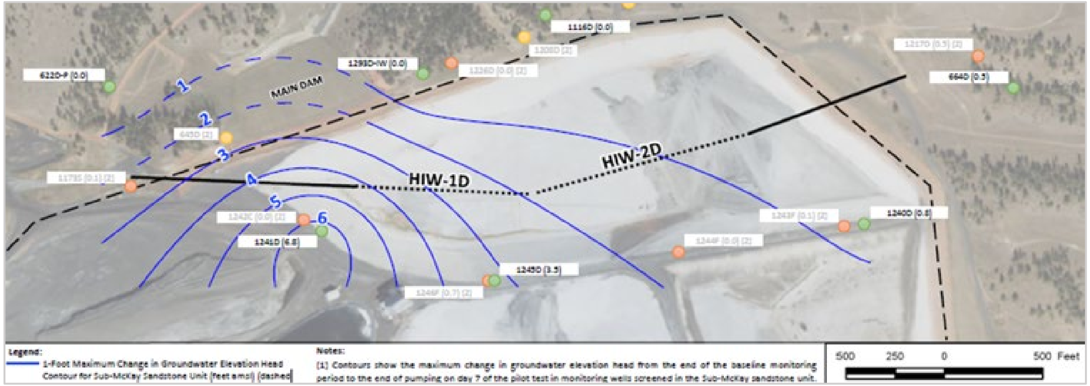


Horizontal GW extraction: plan view and profile view

(DTI 2016)

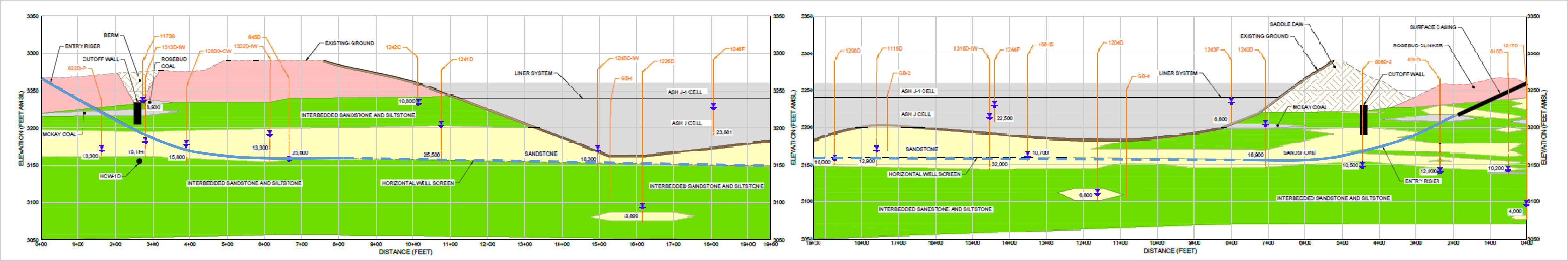
Horizontal Injection

- Permanent infrastructure for injections
- Screen design for flow
- Up-front costs higher but lessen for repeated injection amendments and application
- Injection packers isolate screen
- Daylighting/inadvertent returns



Horizontal freshwater injection pilot test GW head rise results

(Geosyntec 2021)



Horizontal freshwater injection wells profile view (two blind wells), Montana Coal Ash Site

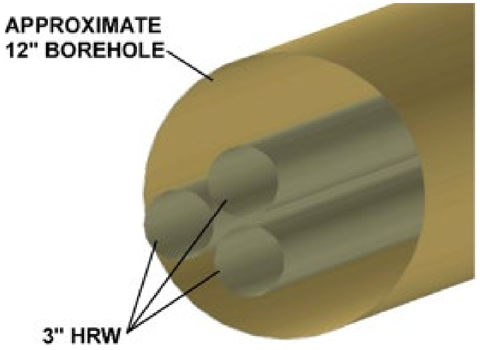
(Geosyntec 2021)

Segmented HWs

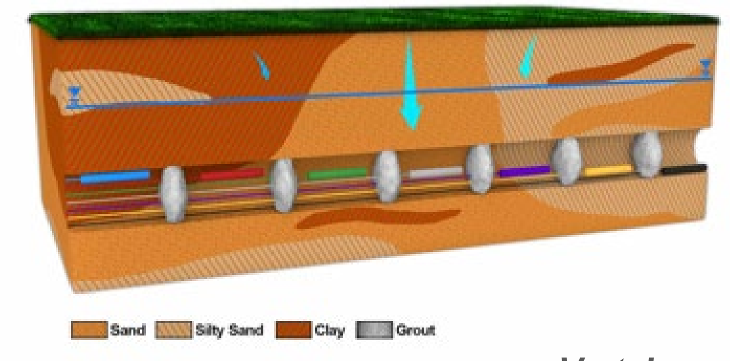
Segmented/Nested HW Systems

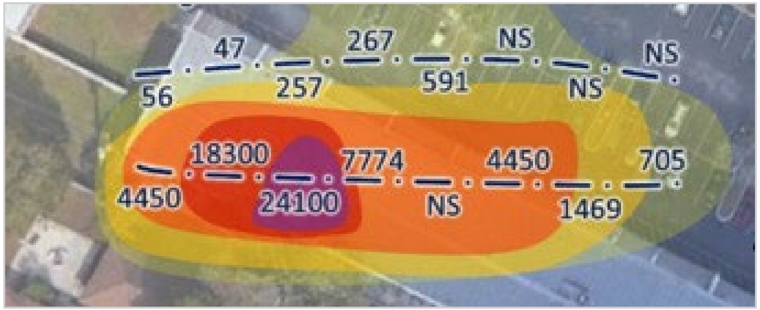
- Multiple well screens within one horizontal boring
- Discrete remedial approaches
  - Injection
  - SVE
  - Air sparge/biosparge

- Discrete groundwater and soil gas sampling beneath surface infrastructure
- Vertebrae© HW system installed at DOD site
  - Fleet Logistics Center, Jacksonville-Navy Fuel Depot, NFD Site #8, Jacksonville, FL



Segmented HSVE well
(DTI 2022)



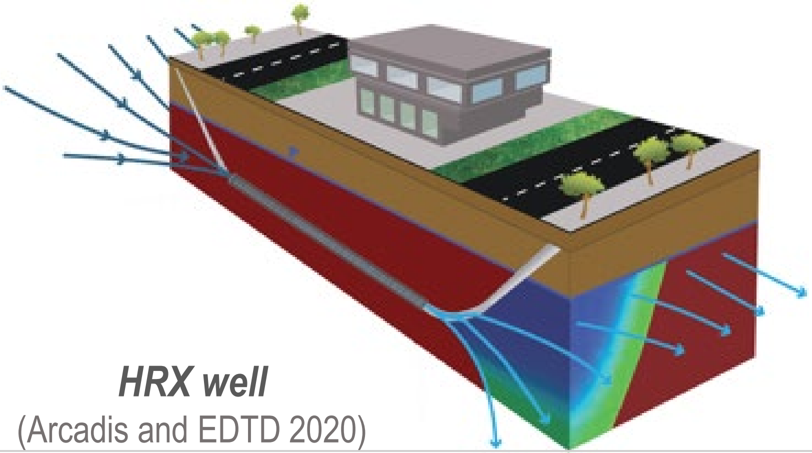


Vertebrae well system
(Vertebrae 2023)

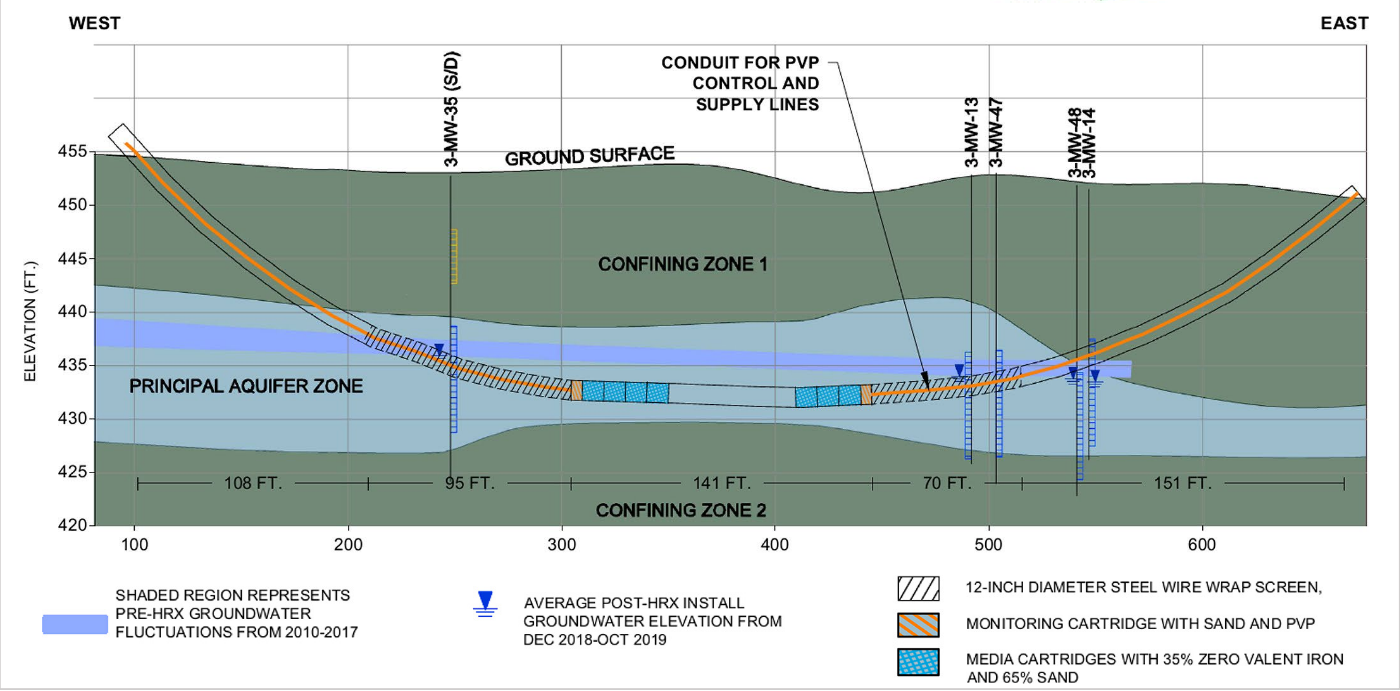
Permeable Reactive Barrier

Permeable Reactive Barrier/Horizontal Treatment Well (HRX)©

- Passive GW flow pathway
- Cartridges within HW
- Installed at three DOD sites:
  - Vandenberg AFB: CVOC treatment
  - Antigo Air Station: CVOC treatment
  - Peterson AFB: PFAS treatment



HRX well
(Arcadis and EDTD 2020)



CVOC: chlorinated volatile organic compound
PFAS: per- and polyfluoroalkyl substances

HW Refurbishment Process

Step 1: Camera/scope

Step 2: Flush and pump

May include mixing clay dispersants or additional enzyme breakers solutions

Step 3: Jet (multiple passes)

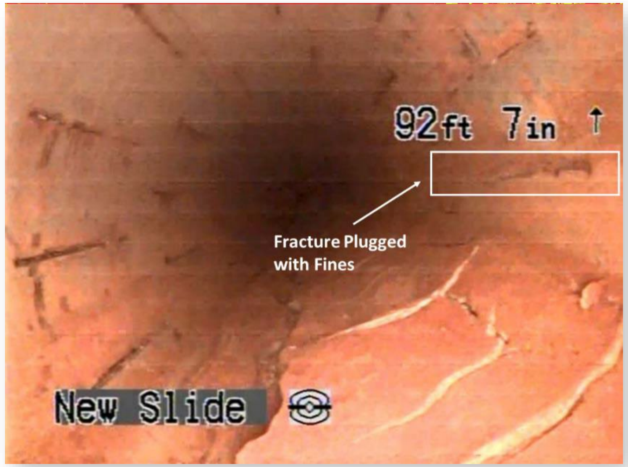
Step 4: Chemical treatment

Step 5: Abandon and reinstall

HWs cannot be over-drilled	Grouting with tremie, or pressure grouting

KEY POINT

Don't forget about fluid management!



HW camera footage
(NAVFAC EXWC 2020)

HW jetting tool
(EDTD 2023)

HW O&M and Refurbish

$800

Answer:

An 80-foot radius of influence was observed from this type of well at a site in Southern California.

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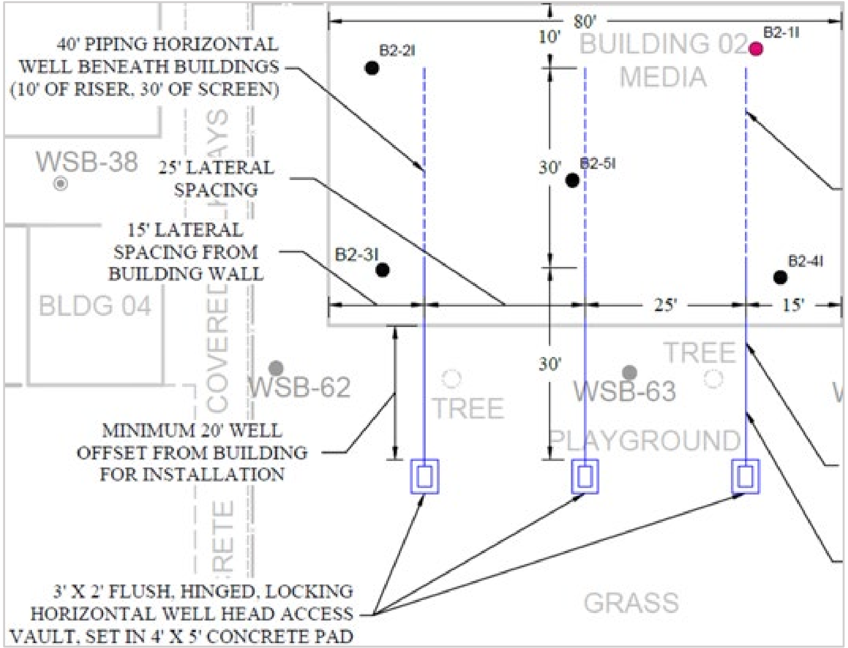
HDD/HW Costs: Small Project



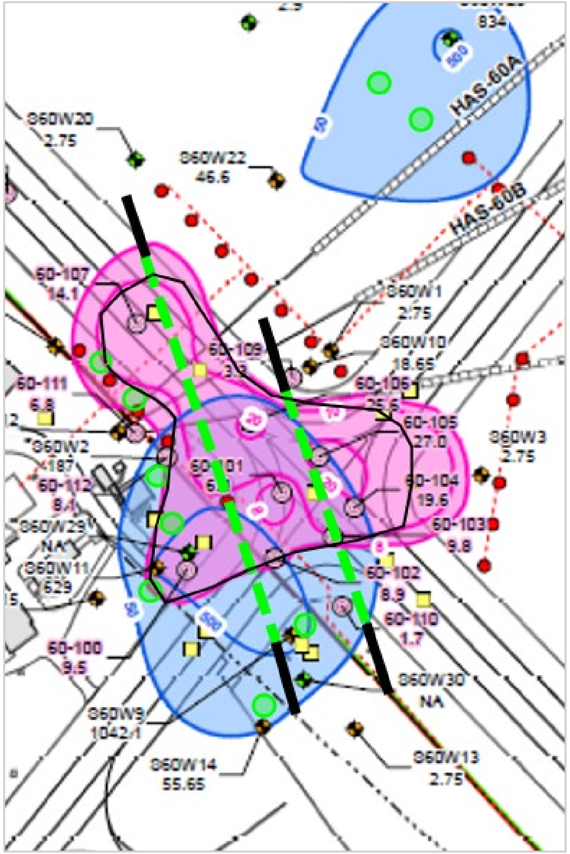
Small HDD project example: three HSVE wells beneath school library. Left: walk-over locating/tracking bit
(Geosyntec 2021)

Estimated ranges of costs: three HSVE wells ~200 total linear ft

Line Item	Rate Range	Units	Example Project Totals	Approx. Cost Totals
Mobilization*	$8,000–$15,000	Lump sum	1	$12,500
HDD (small rig)	$100–$140	Per foot	200	$26,000
Well Materials (3-inch-diameter PVC)	$20–$40	Per foot	200	$6,000
Drilling Mud	$150	Per bag	10	$1,500
Grouting	$250 - 500	Per well	3	$1,500
Development	$50–$100	Per hour	6	$3,000
	Estimated project total		**± 25%**	**$50,000**
	Estimated total price per foot		**± 25%**	**$250**
Other costs (outside of HDD drilling costs)				
Waste Management and Disposal	$0.50–$5	Per gallon	5,000	$5,000
Well Completions	$250–$500	Per well	2	$1,000
Screen Design	$2,500 - $5,000	Lump sum	1	$3,000
Site Restoration	$1,000–$3,000	Lump sum	3	$4,500

* Mobilization cost if using a nationwide environmental HDD firm

HDD/HW Costs: Midsize Project



Midsized HDD project example: two horizontal biosparge wells, active taxiway
(Geosyntec 2020)

Estimated ranges of costs: two horizontal biosparge wells ~1,500 total linear ft

Line Item	Rate Range	Units	Example Project Totals	Approx. Cost Totals
Mobilization*	$15,000–$25,000	Lump sum	1	$20,000
HDD (midsize rig)	$110–$160	Per foot	1,500	$180,000
Well Materials (3-inch-diameter PVC)	$20–$40	Per foot	1,500	$45,000
Drilling Mud	$150	Per bag	40	$6,000
Grouting	$1,000–$4,000	Per well	2	$4,000
Development	$400–$800	Per hour	8	$4,000
		Estimated project total	**± 25%**	**$260,000**
		Estimated total price per foot	**± 25%**	**$175**
Other costs (outside of HDD drilling costs)				
Waste Management and Disposal	$0.5–$5	Per gallon	15,000	$10,000
Screen Design	$5,000 - $10,0000	Lump Sum	1	$10,000
Well Completions	$250–$500	Per well	2	$1,000
Site Restorations	$1,000–$3,000	Lump sum	1	$2,000

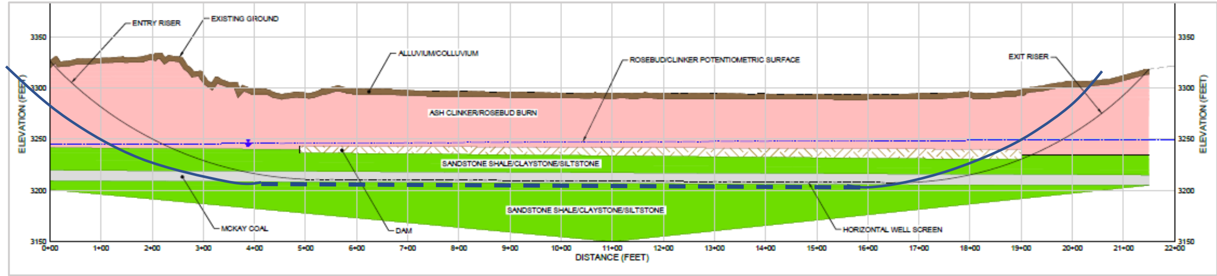
* Mobilization cost if using a nationwide environmental HDD firm

HDD/HW Costs: Large Project

Estimated ranges of costs: two horizontal GW extraction wells ~4000 linear ft

Line Item	Rate Range	Units	Example Project Totals	Approx. Cost Totals
Mobilization*	$50,000–$80,000	Lump sum	1	$60,000
HDD (large rig, wire-line, rock drilling)	$200–$300	Per foot	4,000	$1,000,000
Well Materials (6-inch-diameter HDPE)**	$30–$60	Per foot	4,000	$200,000
Drilling Mud	$150	Per bag	200	$30,000
Grouting	$3,000–$6,000	Per well	2	$10,000
Development	$500–$1,000	Per hour	24	$20,000
	Estimated project total		**± 25%**	**$1,330,000**
	Estimated total price per foot		**± 25%**	**$333**
Other costs (outside of HDD drilling costs)				
Waste Management and Disposal	$0.5–$5	Per gallon	15,000	$10,000
Screen Design	$5,000 - $10,000	Lump sum	1	$10,000
Well Completions/Site Restoration	$1,000–$3,000	Per well	2	$4,000

Large HDD project example: Two horizontal GW extraction wells in bedrock, each ~2,000 ft long
(Geosyntec 2021)



* Mobilization cost if using a nationwide environmental HDD firm
**Prices of materials subject to fluctuations

HDD/HW: Driller Selection

- Regional HDD contractors vs nationwide HDD contractors
- Licensure requirements
- Vet subcontractor experience
- **Utility installation experience ≠ HW installation experience**
- Utility installations do not include
  - Screen design
  - Blind/single-ended installations
  - Well development
  - Grouting
  - Waste management/hazardous IDW

KEY POINT

Subcontractor experience is key!

IDW: investigation-derived waste

Change Orders

Change Order	Legitimate	Poor Planning/Driller Error
Boring Offset/Redrill	Unforeseen obstructions • Building footer • Unknown utility • Cobble/boulder • Loss of fluids/void space	Poor planning • Wrong entry angle • Wrong drill bit • Insufficient setback • Missed target
Additional Drilling Fluid	Loss of returns due to unforeseen void space	• Wrong viscosity or additives • Poor fluid management (should have been recycled)
Mobilization of Larger Drill Rig or Recycler	Legitimate if discussed during planning/proposal/contracting to try smaller rig, may need to mobilize larger rig	Driller says rig isn't big enough during project
Failed HW Installation	• Borehole collapse • Obstruction shift into bore (cobble/debris)	• Installation pressures too high for materials • Bend radius too steep, materials buckle • Poorly fused HDPE
Necessity to Exit (blind installation)	Legitimate if discussed during planning/proposal/contracting for collapsing formations	Driller says they need to exit and was not discussed during project planning/proposal/contracting
Switch to Mud-Motor	• Legitimate if discussed during planning/proposal/contracting • Anticipate ground conditions	Driller says they need to switch to mud-motor and it was not discussed during project planning/proposal/contracting
Material Cost Increases	• Legitimate if discussed during planning/proposal/contracting • Anticipate ground conditions	If driller's quote is firm without stipulation for adjustment in market prices of materials

Cost Considerations

$1,000

Answer:

This portion of the HW installation project is charged as an hourly rate.

Naval Facilities Engineering Systems Command

EXWC Engineering and Expeditionary Warfare Center

Break

Presentation Overview

- Introduction to HDD and HWs
- HDD technology overview
- HW design, construction, and installation
- HW O&M and refurbishment
- Cost considerations
- Case studies
- Conclusions and references

Case Studies

Joint Base Charleston, South Carolina

- Case Study 1A: SWMU 145, Building 575 JP-4 Tank Leak
- Case Study 1B: AOC I, Base Gasoline Station Leak

Marine Corps Base Camp Lejeune, North Carolina

- Case Study 2: Site 88, Horizontal ISCO Injection and Recirculation

Naval Air Station North Island, California

- Case Study 3: Building 379, Combined Remedy Horizontal Well Approach for Vapor Mitigation, SVE, and NAPL Recovery

AOC: area of concern
ISCO: in situ chemical oxidation
SWMU: solid waste management unit

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

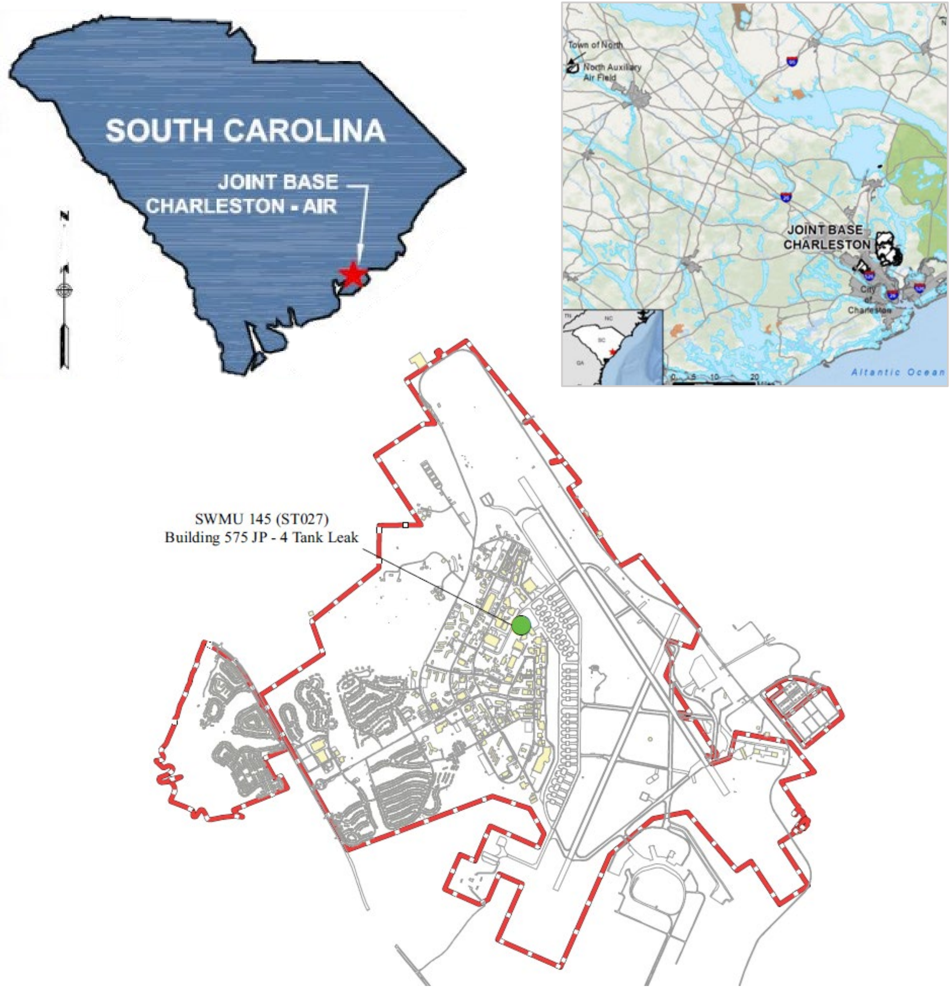
Case Study #1
Enhanced Hydrocarbon Degradation Using Horizontal Biosparge Wells at Joint Base Charleston, South Carolina

Contributors: Laura Powers, Remedial Project Manager, Joint Base Charleston, AFCEC/CZOE
Katherine Pezzillo, Restoration Support Contractor, Joint Base Charleston Air/Weapons
Dave Forse, CPG, FPM Remediations, Inc.
Kyle Carlton, PG, Geosyntec, Inc.

AFCEC/CZOE: Air Force Civil Engineer Center / Environmental Directive
CPG: Certified Professional Geologist
Photograph Source: USAF, 2006

Case Study 1A Building 575: Background

- HWs for biosparge remediation of residual hydrocarbons (multiple AOCs)
- SWMU 145 (ST027) Building 575
  - Three USTs
    - 10,000-gallon UST (JP-8)
    - 3,000-gallon UST (JP-4)
    - 1,000-gallon UST (JP-4)
  - USTs operated 30 years before removal in 1988
  - Soil impacts discovered during UST removal



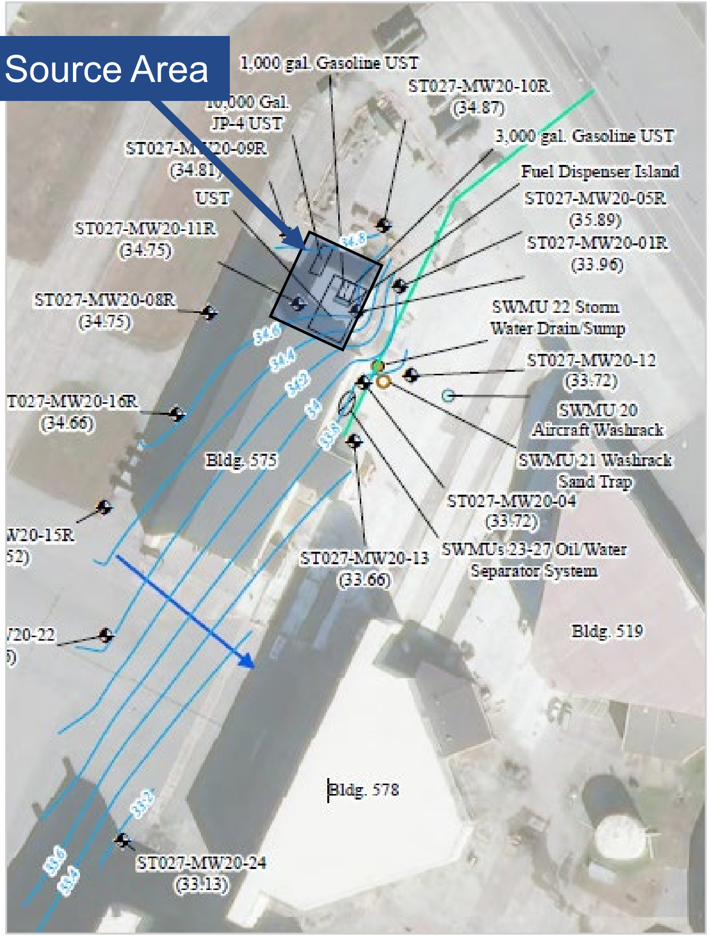
Joint Base Charleston-Air location and SWMU 145 site location map
(FPM Remediations and DOD REPI 2022)

JP: jet propellant
UST: underground storage tank

Case Study 1A Building 575: Background

- Two new USTs installed in 1988:
  - 4,000-gallon UST for motor gasoline
  - 3,000-gallon UST for diesel
- Leak testing in 1996 discovered both USTs were leaking.
- Source is combined jet fuel, diesel, and motor gasoline.
- Site geology is as follows:
  - Sands and silty to clayey fine sands
  - GW within silty/clayey sands, flow to southeast

UST Source Area



Building 575 GW flow map, March 2022
(FPM Remediations 2022)

Case Study 1A: HWs

HDD Driver

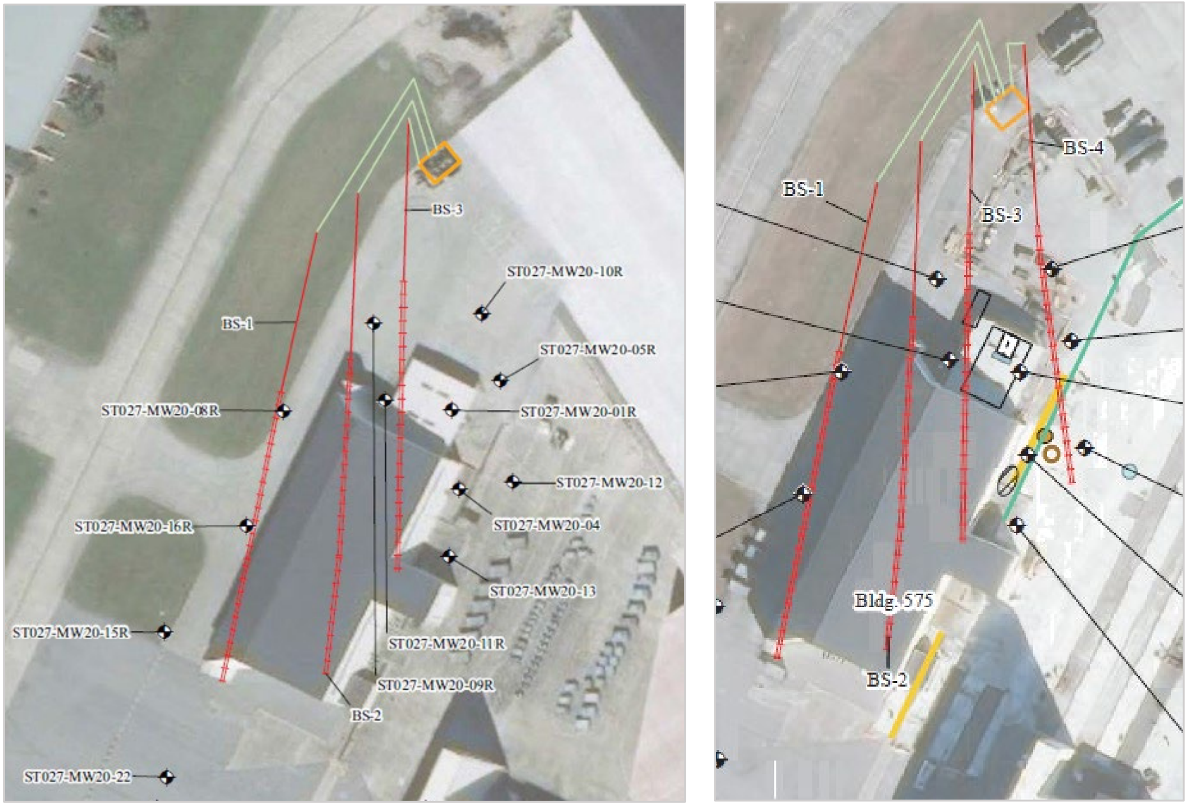
Access beneath source area (USTs) and downgradient beneath building

Horizontal biosparge wells

- Three wells installed in 2017
  - Target depth 25 ft bgs
  - 0.010-inch slot diameter
  - 0.1–0.2 cfm per foot of screen
  - 3-inch-diameter HDPE
- Fourth well added in 2018 (to address naphthalene east of UST source area)

Horizontal biosparge well network

(FPM Remediations 2022)



bgs: below ground surface

Case Study 1A: Installation Photographs

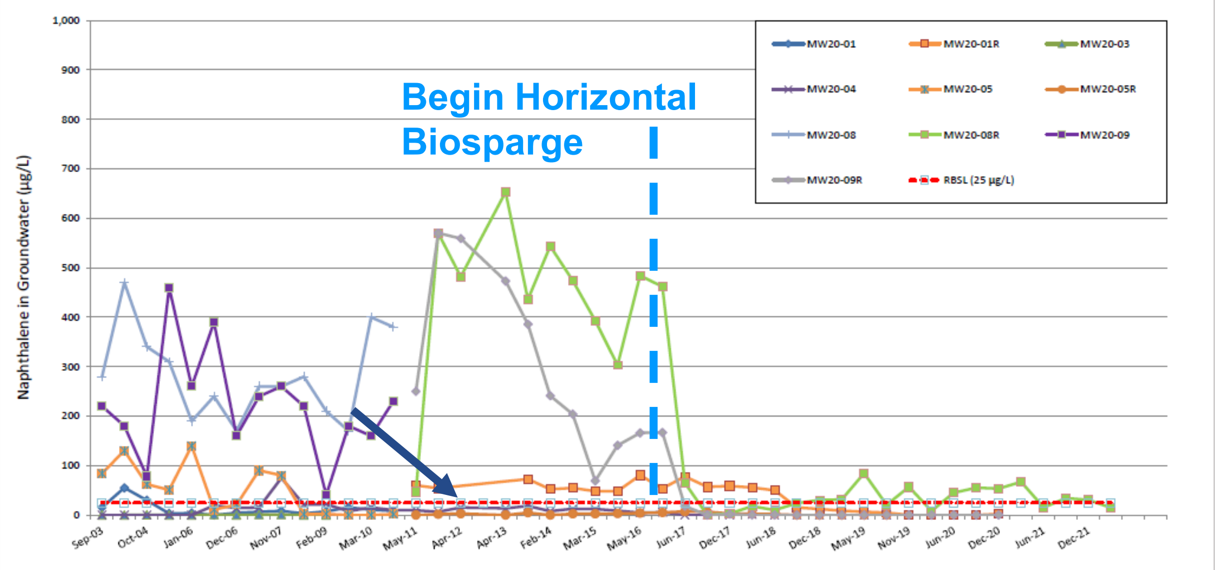
Horizontal biosparge well installation (FPM Remediations 2018)

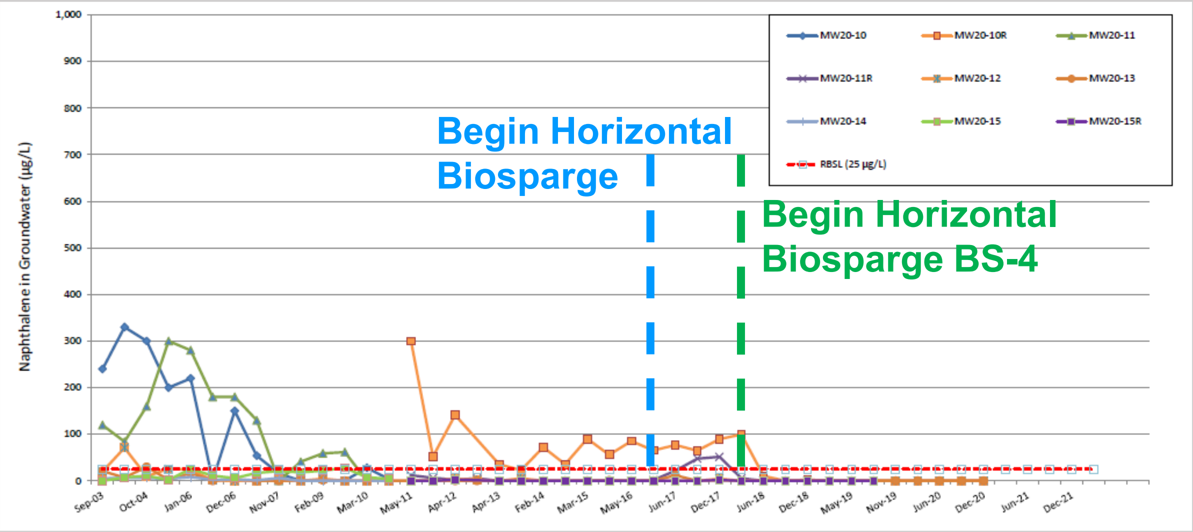
Case Study 1A: Operations and Results

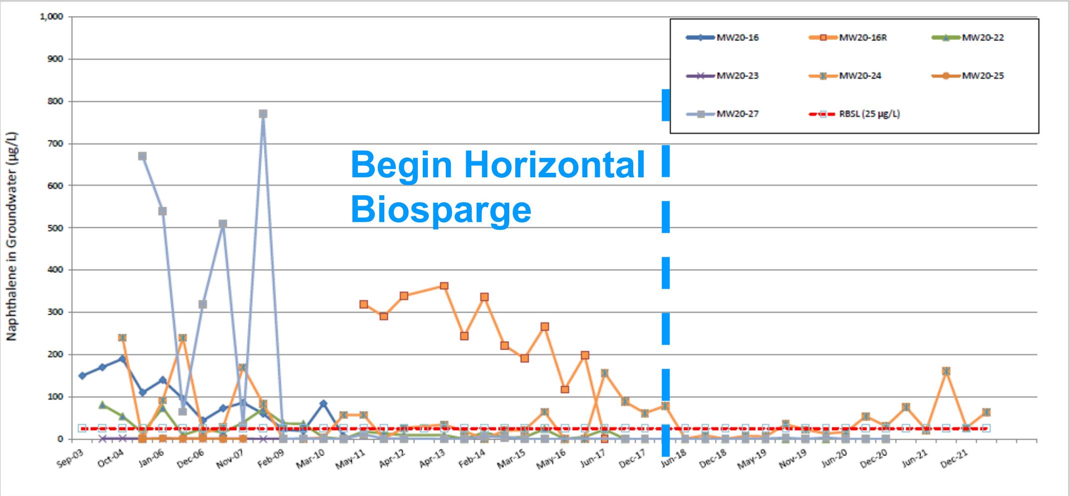
Horizontal biosparge well operations

- 30-horsepower air compressor with 160 scfm air flow
- Began spring 2017
  - After one year of operation, only naphthalene remained above site specific target level
  - Horizontal biosparge well BS-4 installed to address naphthalene in MW-20-10R
- Periodic cycling began in 2019

Naphthalene concentrations vs time graphs (FPM Remediations 2022)







scfm: standard cubic feet per minute

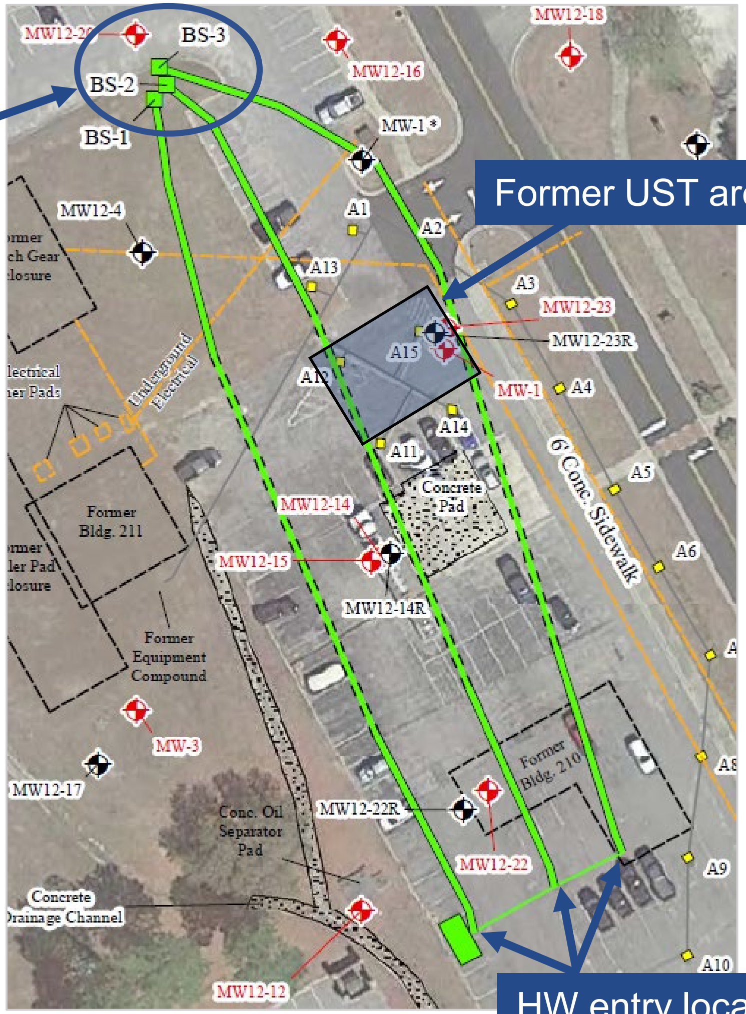
Case Study 1A Building 575: Key Takeaways

Lessons Learned	Successes
• Initial coverage required expansion with fourth biosparge well • Original compressor was oversized and replaced with smaller one (260 scfm to 160 scfm) • Polishing biosparge events were required to address elevated concentrations outside radius of influence of horizontal biosparge wells	• Horizontal biosparge wells provided access to source area beneath USTs • Horizontal biosparge wells provided access to downgradient impacted areas beneath building • After one year of biosparging, naphthalene concentrations were above site-specific target levels in only three monitoring wells

Case Study 1B AOC I: HWs

- Horizontal biosparge wells
  - Three horizontal biosparge wells to address residual petroleum constituents in groundwater
  - Target depth of 15–16 ft bgs
    - 9–10 ft below water table
    - 1–2 ft above confining clay
  - Entry-exit design (exit locations congregated)
  - 2-inch-diameter, HDPE, custom-slotted screen
  - 375 ft total lengths per well
  - 150–200 ft of biosparge screen per well
  - Designed for 0.1 scfm per foot of wells screen

Horizontal biosparge well network (FPM Remediations 2018)



HDD Drivers

Coverage: large area to treat residual petroleum COCs in GW after excavation

Cost savings: less costly than vertical grid of sparge points and supporting trenching and piping

COC: contaminant of concern

Case Study 1B AOC I: Installation Photos

Horizontal biosparge well installation (FPM Remediations 2018)

HDD rig

Walk-over location of bore path

HDD bit exiting ground surface

Reamer and swivel head attached to HDPE well material prior to pullback

Vacuum truck removing liquid IDW from roll-off

Exit-side well head with pressure release valve

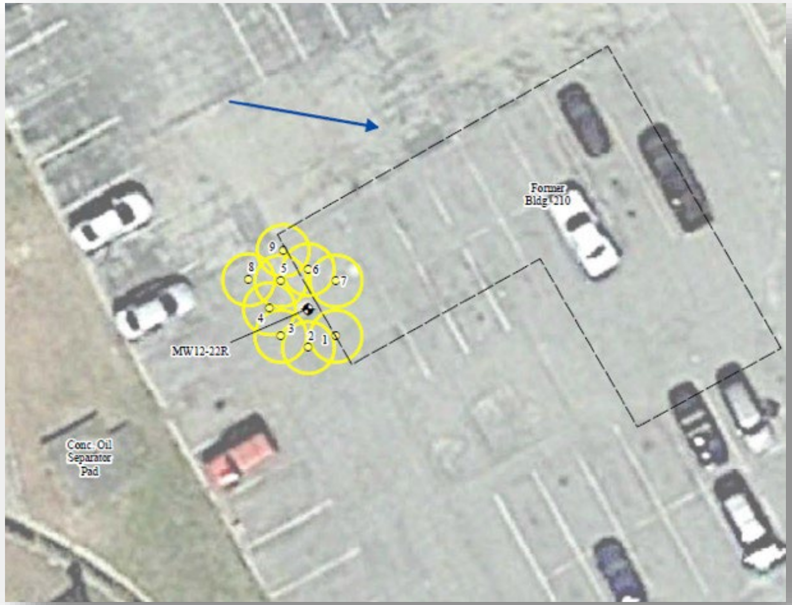
Case Study 1B AOC I: Key Takeaways

Lessons Learned

- Shallow GW resulted in surface bubbling
  - Base facility management was concerned
  - Communication is key
- Remediation system electrical compatibility issues
  - Caused delay in full-time operations

Successes

- Large area covered
- Costs, site disturbance, and materials reduced compared to vertical grid
- Combined remedy approach for local exceedances of naphthalene
- NFA pending well abandonment spring 2023



Oxidant injection locations for local exceedance MW 12-22R
(FPM Remediations 2018)

NFA: No Further Action

Case Studies

$1,200

Answer:

During horizontal biosparge well installation at AOC-I, the bend radius was used to successfully consolidate the locations of these.

Case Study #2
Horizontal Injection Wells at MCB Camp Lejeune, North Carolina

Contributors: Monica Fulkerson, PE, Project Manager, Jacobs
Jessica Persons, PE, Project Engineer, Jacobs
Mike Perlmutter, PE, Senior Technical Consultant, Jacobs
David Cleland, PG, Remedial Project Manager, NAVFAC

MCB: Marine Corps Base
PE: Professional Engineer
Photograph Source: USMC, 2023

Background

- Site 88
  - Former dry-cleaning facility
  - GW plume approximately 51 acres
  - Since 1996, PCE and daughter products in GW
  - Past remedial actions, pilot studies, and feasibility study refined remedial strategies
    - ISCO
    - Air sparging
    - Enhanced reductive dichlorination
    - Monitored natural attenuation

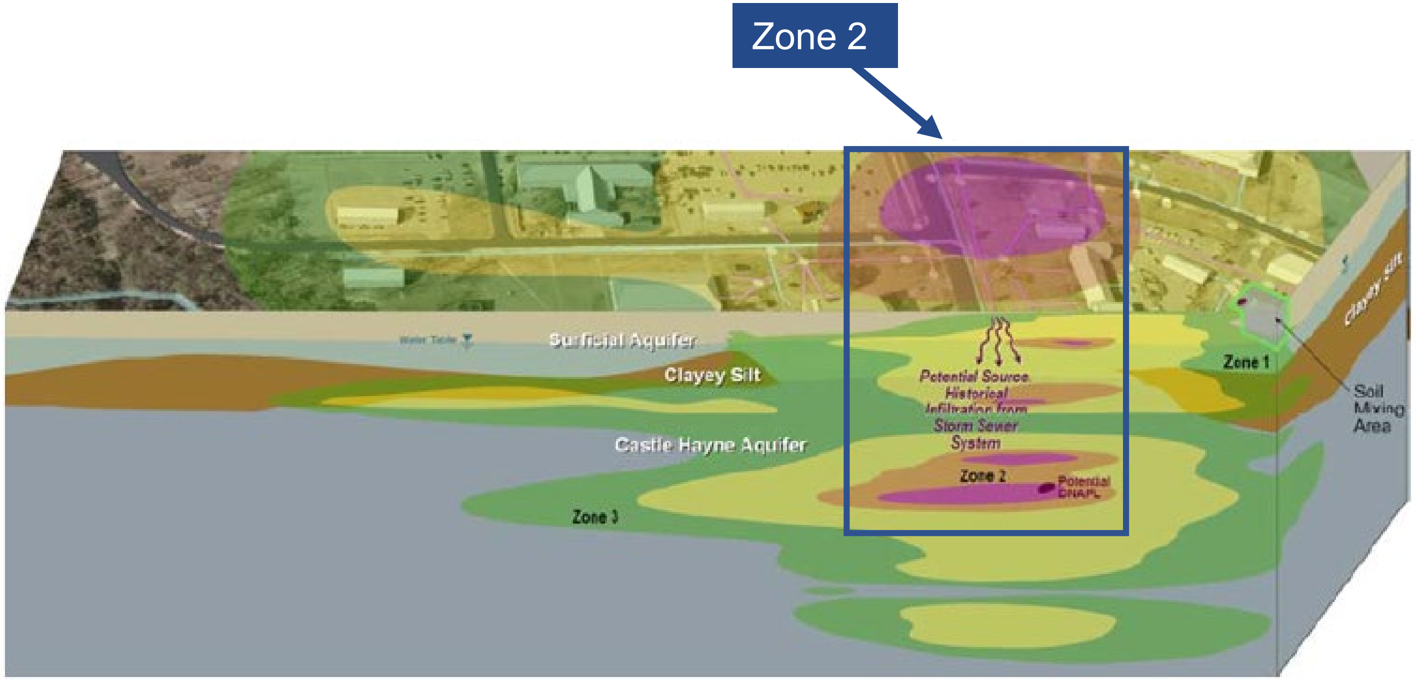
Camp Lejeune/Site 88 Location
(Paragon 2022)

Past site remedial actions: UST removal (five USTs total)
(Jacobs 2018)

PCE: tetrachloroethene

Conceptual Site Model

- **Zone 1** (clayey silt, surficial aquifer): PCE from dry-cleaning building
- **Zone 2** (sand aquifer): migrated downward vertical gradient to underlying clay unit
- **Zone 3:** transported horizontally and vertically downgradient to west
  - Highest concentrations at ~100 ft bgs
  - Impacts up to 180 ft bgs
  - Concentrations indicative of DNAPL in Zones 1 and 2



Conceptual site model, plan view and 3D cross section
(Jacobs 2018)

Zone 2 Study

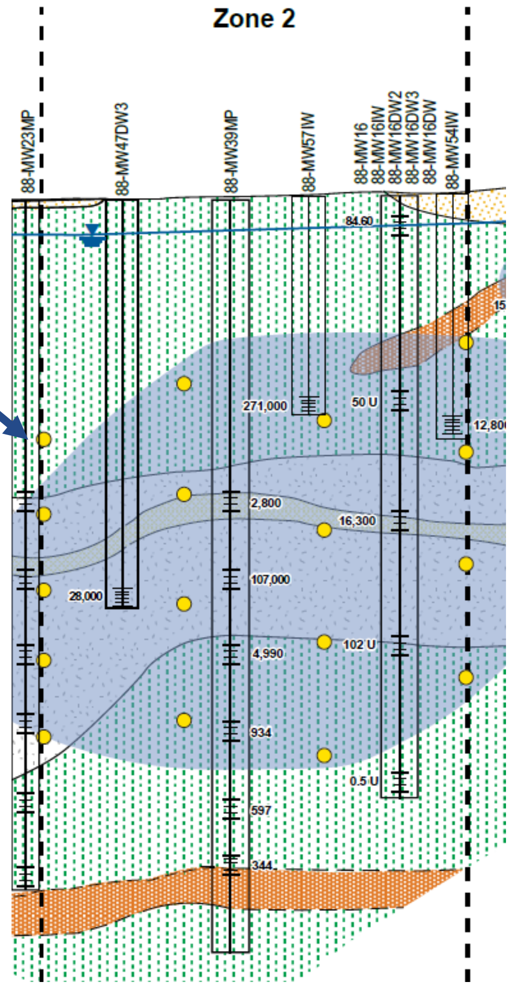
- Zone 2 remedy selection
  - ISCO
  - Conceptual design
    - 17 horizontal injection wells installed with HDD
    - Injection of permanganate
    - Supplemented by recirculation
  - Pilot study recommended

HDD Drivers

Coverage: large target area at significant target depths (50 to 115 ft bgs)
Cost savings: vertical wells would have required more infrastructure (vaults, piping, and trenching)

Horizontal injection well cconceptual design targets (Jacobs 2018)

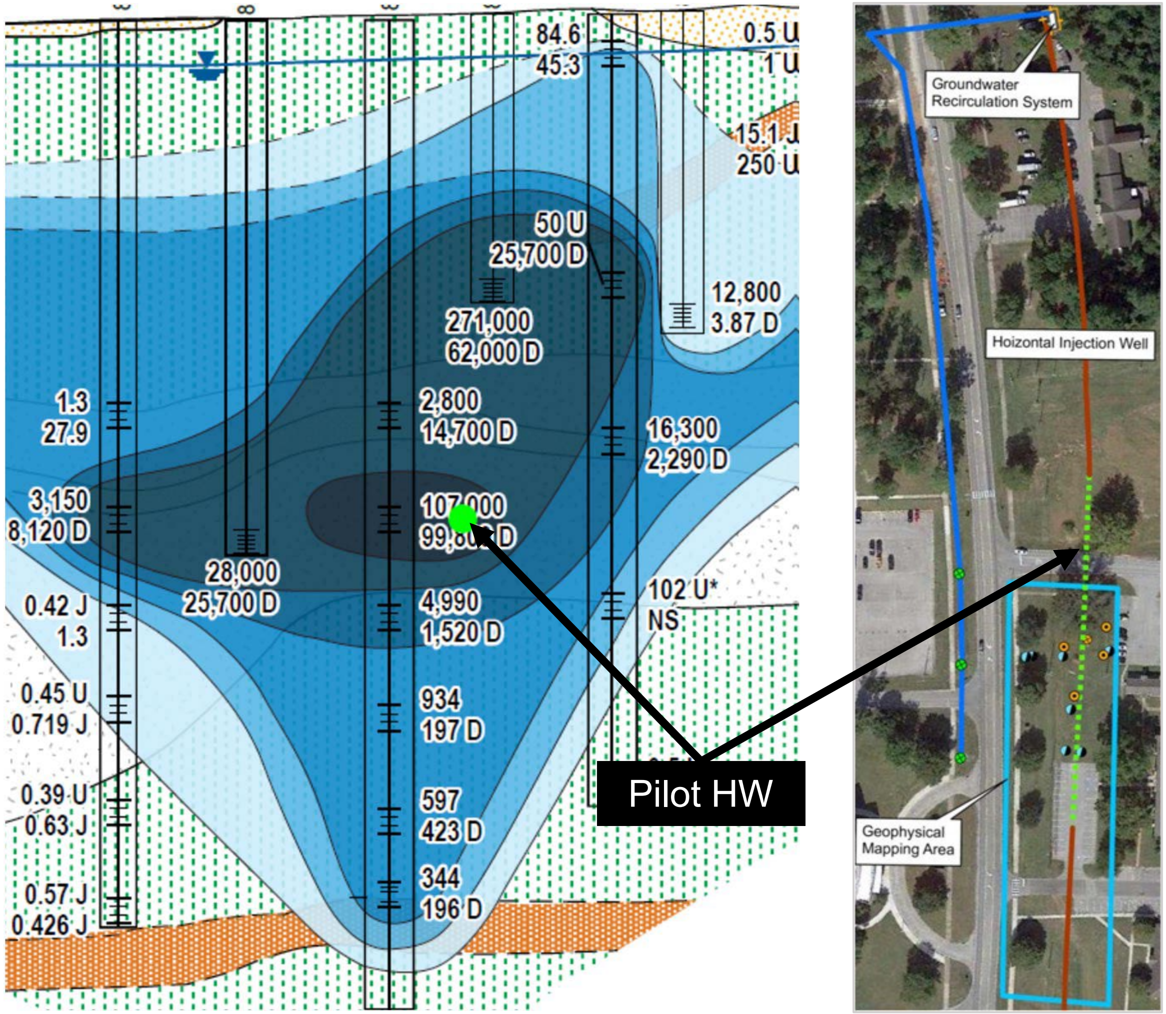
Proposed horizontal injection well



Zone 2 Study Objectives

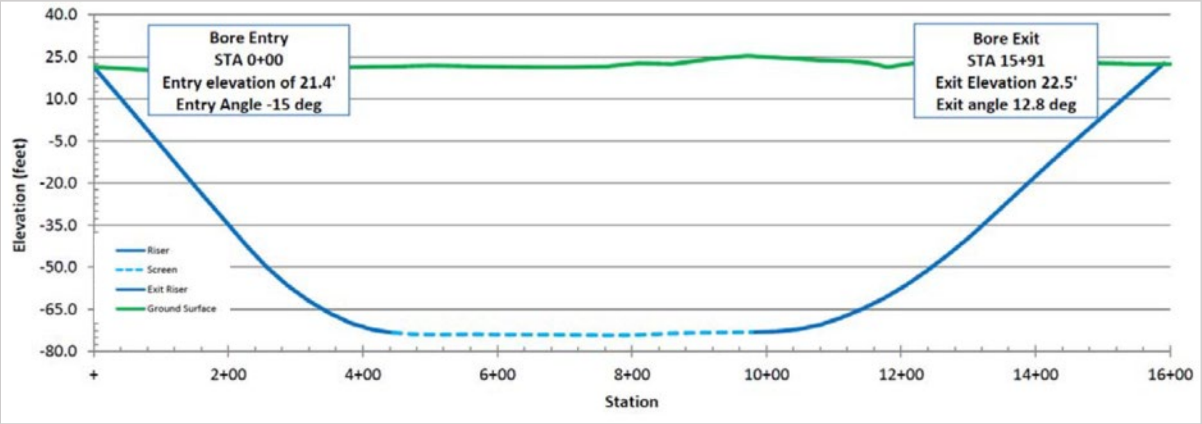
- Zone 2 permanganate tracer study objective
  - Evaluate feasibility and effectiveness:
    - ISCO using permanganate
    - HDD injection as effective delivery
    - Extraction and recirculation to improve distribution

Pilot test horizontal injection well target and layout (Jacobs 2018)



Zone 2 Study HDD Installation

- Pilot horizontal injection well
  - 1,560 ft long, double ended
  - 500-foot screen
  - 100 ft bgs
  - 4-inch-diameter HDPE SDR 11, custom-slotted screen
  - AA DD210 HDD drill rig



Pilot test horizontal injection well as built (Jacobs 2018)

Pilot test horizontal injection well HDD installation and bit exit (Jacobs 2018)

Zone 2 Study Injection

- Phase 1 permanganate injections, May/June 2016
  - 98,000 gallons (42,000 lb) of 2% sodium permanganate
  - 800 mg/L sodium chloride tracer
  - Average flow rate of 65 gpm at 10 to 15 psi
  - Post-injection geophysical mapping and performance monitoring, June 2016

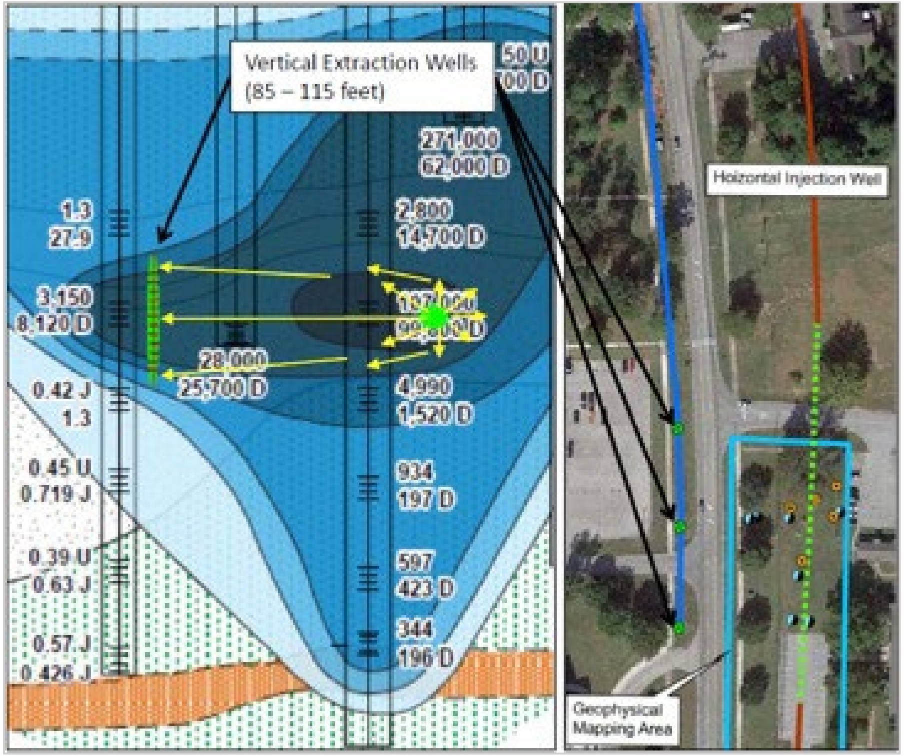
Pilot-test injections (Jacobs 2018)

gpm: gallons per minute
mg/L: milligrams per liter
psi: pounds per square inch

Zone 2 Study Recirculation

- Phase 2 recirculation system operation, September 2016
  - Three vertical extraction wells
  - Spaced 125 ft apart, 160 ft from HDD pilot injection well
  - Installed to 100 ft bgs
  - 30 ft of well screen
  - Extracted water pumped back into HDD pilot injection well, approximately 60 gpm

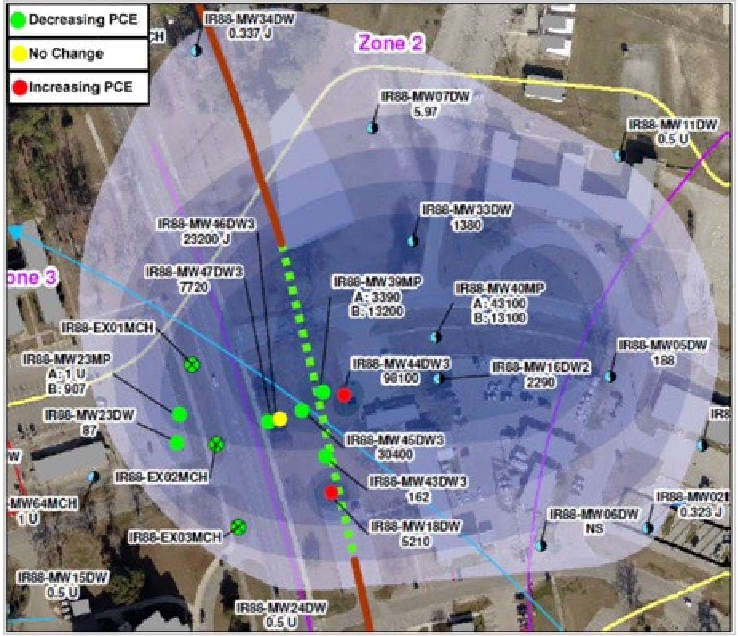
Pilot test recirculation (Jacobs 2018)



Zone 2 Study Results

- Study results
  - Post-injection results (prior to recirculation)
    - No initial signs of breakthrough in wells 7, 10, and 12 ft from injection well
  - Post-recirculation results
    - Observed tracer responses
      - 10 ft away after first day of operation
      - 25 ft away after 20 days of operation
      - Not observed 45 or 60 ft away after 30 days of operation
    - Geophysical mapping showed vertical and horizontal migration of GW: 15 to 25 ft vertical and 35 ft horizontal

- Analytical results
  - PCE reduced up to 97%
  - Total VOCs reduced up to 82%
  - Increased PCE observed 35 feet upgradient of HDD well
  - Impacted GW pulled into treatment zone

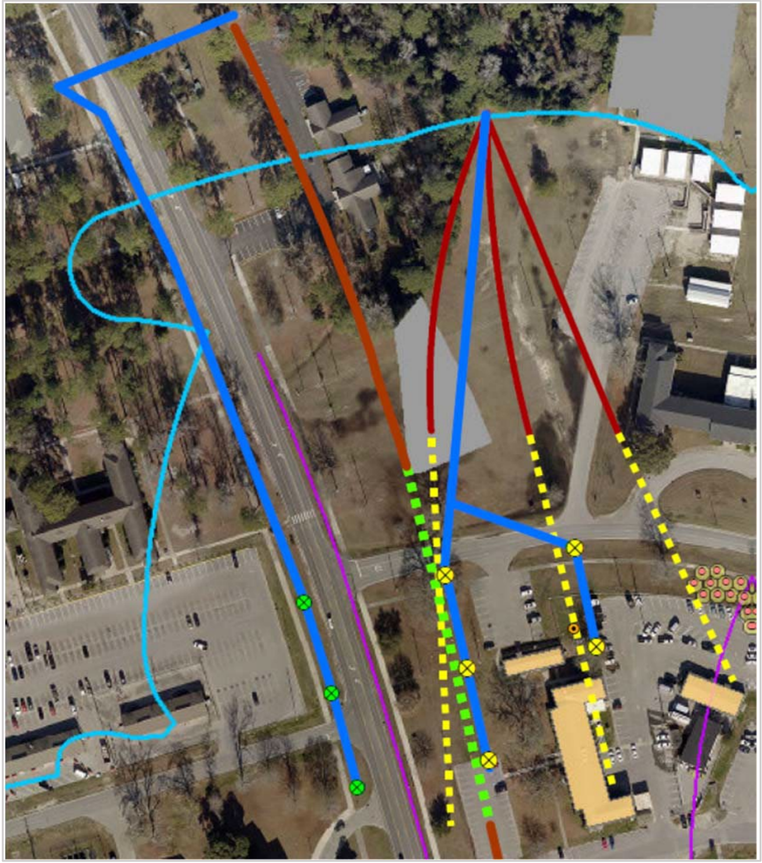


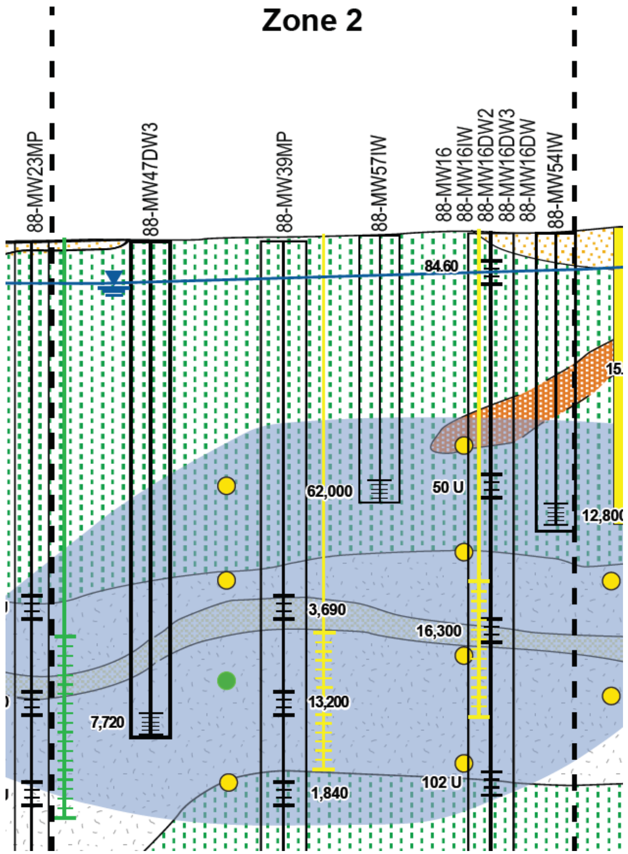
Post-pilot analytical results
(Jacobs 2018)

VOC: volatile organic compound

Full-Scale Design

- Refined design
  - 10 total horizontal injection wells (blind/single ended)
  - 8 vertical extraction wells
  - Operation of recirculation for 1 year subsequent of injections
  - 2 injection events





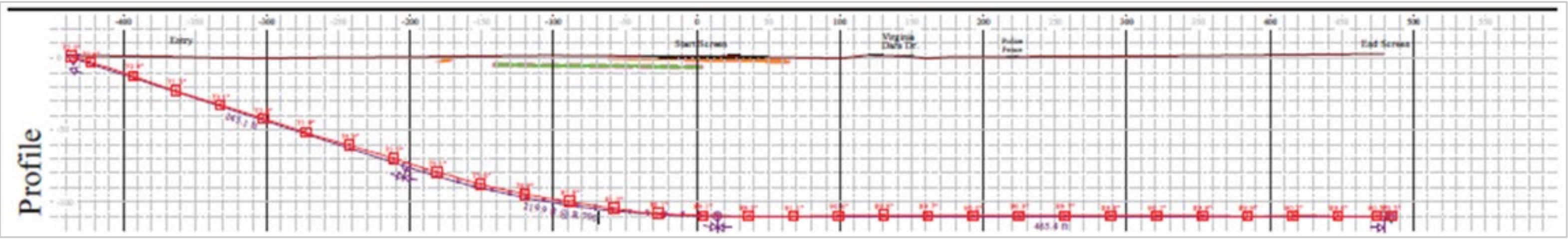
Redefined full-scale design
(Jacobs 2018)

Full-Scale Horizontal Injection Wells

- Construction: August–December 2020
- Injection and recirculation through 2022
- 10 horizontal injection wells
- Vertically nested or stacked
- Blind installation with sacrificial bit system (knock-off technology)
- GST locating device
- 4-inch-diameter PVC, custom-slotted for flow of 0.1 to 0.2 gpm per foot of screen
- Perpendicular to GW flow

Horizontal injection well installation details (Agviq 2022)

Horizontal Injection Well ID	Nominal Depth (ft bgs)	Total Installed Length (ft)	PVC Blank Length (ft)	PVC Screen Length (ft)	Screen Slot Design
UPGRADIENT					
HIW-2	75	750	370	380	0.016-inch, 3x10
HIW-3	100	840	460		
CENTRAL					
HIW-4	50	792	312	480	0.016-inch, 3x10
HIW-5	70	851	371		
HIW-6	90	889	409		
HIW-7	110	937	457		
DOWNGRADIENT					
HIW-8	55	877	337	540	0.016-inch, 3x10
HIW-9	75	918	378		
HIW-10	115	976	436		
HIW-1	95	NA	NA	500	NA



Horizontal injection well as-built profile (Agviq 2022)

HDD Installation Photographs

Full-scale HDD construction photographs (Aptim 2022)

Installation of horizontal injection wells

Horizontal injection well development

Sacrificial drill bit knock-off bit

Solidification of drilling mud IDW

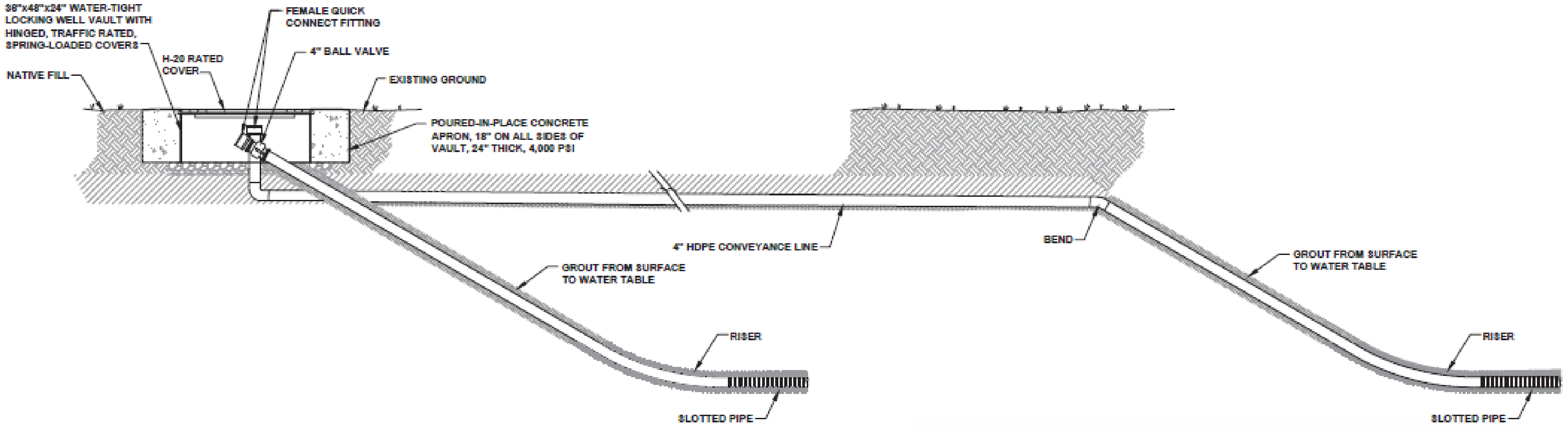
Vertical extraction well installation

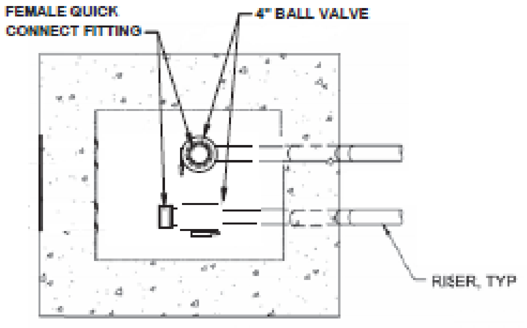
IDW management and disposal

Horizontal Injection Well Head Design

Horizontal injection well head design

(Agviq 2022)





VAULT PLAN

(TWO WELL HEADS PER FAULT

SCALE: N.T.S.

Vertical Extraction Wells

- Five new vertical extraction wells
- Purpose
  - Induce a gradient
  - Amplify circulation with the three existing extraction wells downgradient of HIW-1
  - Circulate GW augmented with sodium permanganate
- 20 to 30 ft of screen
- Installed with rotosonic drilling methods
- Conveyance lines installed with HDD (utility driller) and conventional trenching

Vertical extraction well installation details (Agviz 2022)

Vertical Extraction Well ID	Nominal Depth (ft bgs)	Screen Interval (ft bgs)	Screen Slot Design	Well Diameter (in)	Status
UPGRADIENT					
IR88-EX07MCH	101	80-100	0.01-inch, continuous wrap PVC	4	New
IR88-EX08MCH					
CENTRAL					
IR88-EX04MCH	111	90-110	0.01-inch, continuous wrap PVC	4	New
IR88-EX05MCH					
IR88-EX06MCH					
DOWNGRADIENT					
IR88-EX01MCH	NA	85-115	NA	NA	Existing
IR88-EX02MCH					
IR88-EX03MCH					

HDD installation of conveyance lines (Jacobs 2022)

Full-Scale ISCO Injections

- Total weight and volume ~1,871,400 lb and ~4,404,000 gallons of 2% sodium permanganate
- Overall molar mass of COCs reduced
- PCE reductions of 1 or 2 orders of magnitude

ISCO dosing summary for full scale though 2022
(Jacobs 2022)

Table 4. Permanganate Dosing Summary

Well ID	Target Depth of Screen Measured from Ground Surface (feet bgs)	Screen Length (feet)	Target Flowrate (gpm)	Pore Volume (gallons)	Mass of Sodium Permanganate (40% by weight solution) (lb)	Target Sodium Permanganate Volume (40% by weight solution) (gallons)	Total Dilution Water Volume (gallons)	Total Target Sodium Permanganate Solution Volume (2% by weight solution) (gallons)
Upgradient Area (HIW-2, HIW-3)								
	Area Total:			3,949,714	311,895	27,181	710,127	734,016
Central Area (HIW-4, HIW-5, HIW-6, HIW-7)								
	Area Total:			9,874,288	779,738	67,952	1,775,317	1,835,041
Downgradient Area (HIW-8, HIW-9, HIW-10, HIW-1)								
	Area Total:			9,874,288	779,738	67,952	1,775,317	1,835,041
	INJECTION EVENT TOTAL			**23,698,290**	**1,871,371**	**163,084**	**4,260,760**	**4,404,097**

ISCO injection manifold and circulation equipment
(Agviq 2022)

Conclusions and Lessons Learned

1. **HDD/horizontal injection wells**
   - Effective method of delivering injectate in deeper subsurface
   - One of largest horizontal injection projects to date
2. **Blind (single-ended) vs entry-exit (pilot horizontal injection well)**
   - Sacrificial bit system (knock-off)
   - Eliminated exit side site disturbance
   - Better installation method in flowing sands collapsible formation
   - Reduced total footage drilled, reducing cost
3. **Recirculation with vertical extraction wells**
   - Improved injectate distribution
   - Provided cost savings through optimized infrastructure needed to create contact with impacted zones of treatment area
4. **Additional injections will be required to achieve active remediation goals**

Case Studies

$1,400

Answer:

During the Zone 2 study, three of these were installed downgradient of the horizontal injection well.

Case Study #3
Enhanced Contaminant Recovery, Vapor Mitigation, and Heat Transfer Using Horizontal Wells at Building 379, Naval Air Station North Island, California

Contributors: Michael Pound, Base Realignment and Closure, BRAC

Pamela Chang, Battelle Memorial Institute

Vitthal Hosangadi, PE Civil, Vice President/Sr. Consulting Engineer NOREAS, Inc.

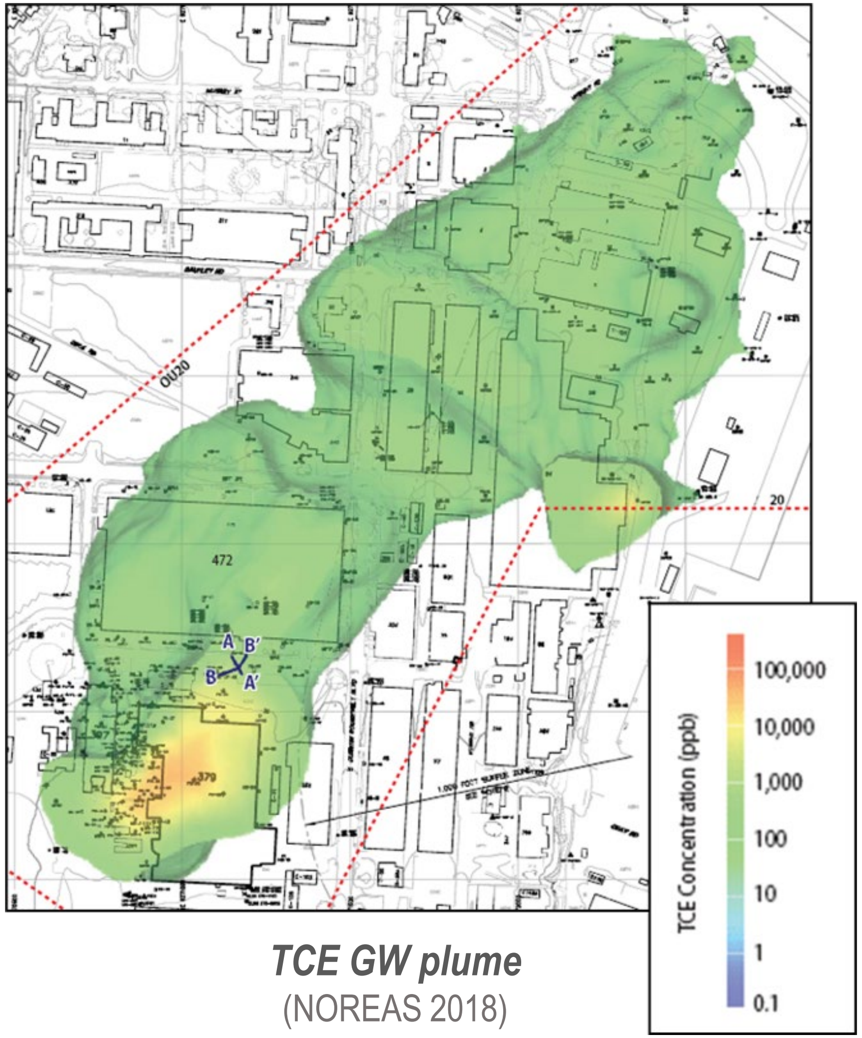
Lisa Goode, PhD, PE, Senior Engineer, Geosyntec Consultants, Inc.

Photograph Source: Getty Images

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

Building 379: Background

- Overlies 0.5-mile-long GW plume migrating toward San Diego Bay
- CVOCs from day-to-day operations
- Sources
  - Several USTs containing jet fuels and Stoddard solvent
  - AST leaked TCE, which migrated downward
- LNAPL present at ~23 to 25 ft bgs
  - Jet fuel and Stoddard solvent released first
  - High levels of TCE and other CVOCs (dissolved) became entrained with LNAPL while migrating downward

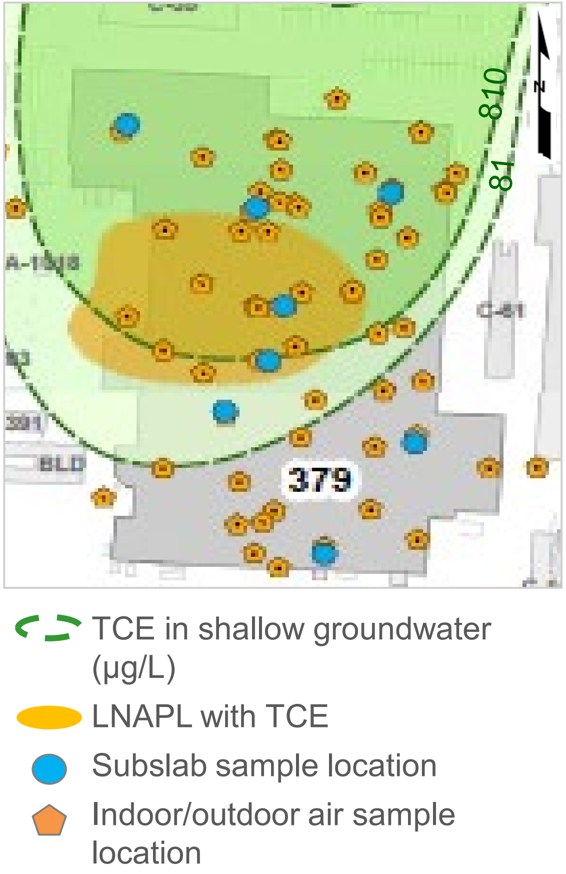


TCE GW plume
(NOREAS 2018)

AST: aboveground storage tank
NASNI: Naval Air Station, North Island
TCE: trichloroethylene

Building 379: Background

- VI of CVOCs was a significant concern
- TCE in subslab soil gas up to 6,000,000 µg/m^3 (June 2014)
- Indoor air concentrations of TCE measured at **53 µg/m^3** (June 2015)
- US EPA Region 9 Indoor Air Response Action Levels
  - **Accelerated 8 µg/m^3**
  - **Urgent 24 µg/m^3**
- TCRA implemented
- Steam lines raised temperatures of LNAPL, exacerbating subslab gas concentrations
- Measured as high as 140 ºF (compared to 70 ºF ambient)



Baseline impacts Building 379
(NOREAS 2018)

TCRA: time-critical removal action
µg/m^3: micrograms per cubic meter

Mitigation and Remedial Approach

Phase 1

- Consisted of sealing >15,000 ft of cracks and joints of the concrete foundation of the building

Phase 2

- TCRA specified subslab SVE installation of HSVE wells
- Vertical wells were not feasible. Interior of building not conducive to additional piping
- Radius of influence from one HSVE can be much greater than one SVE (Phase 1 sealing resulted in better radius of influence)

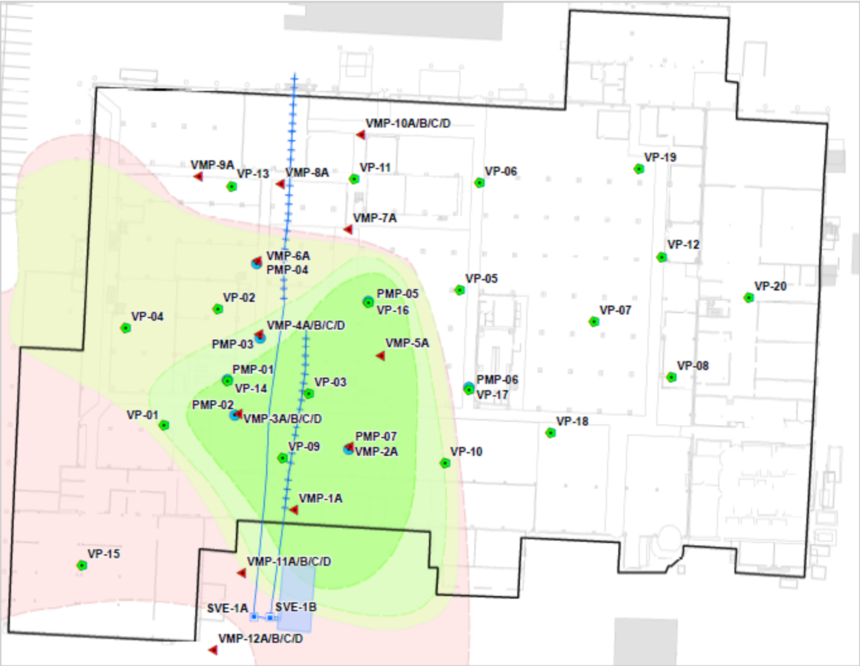
Joint sealing with flexible self-leveling silicone joint sealant (NOREAS 2018)

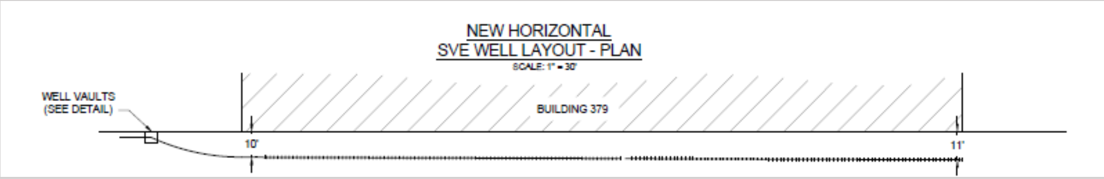
Phase 3

- Use steam to assist with VOC mobilization from NAPL
- Install three additional HSVE wells
- Install two horizontal NAPL recovery wells
- Install three horizontal steam injection wells

Phase 2 HSVE Wells

- HSVE-1A and HSVE-2A (blind wells)
  - Spaced 8 ft apart, east-west orientation
  - Targeted highest soil gas concentrations
  - 140 ft of 0.010-slot SS 304
  - Approximate 50-foot setback distances
  - 10–11 ft bgs installed depth
  - Walk-over location





HSVE pilot test layout and design profile
(NOREAS, 2018)

HDD Drivers

HSVE wells **access** impacted vadose zone beneath building and achieve **coverage of a large area without interior disruption.**

HDD HW Install Photos, Phase 2


Well pit construction


HDD


HSVE well screen


Well materials installation


Well head completion

GEO C3 vapor treatment system

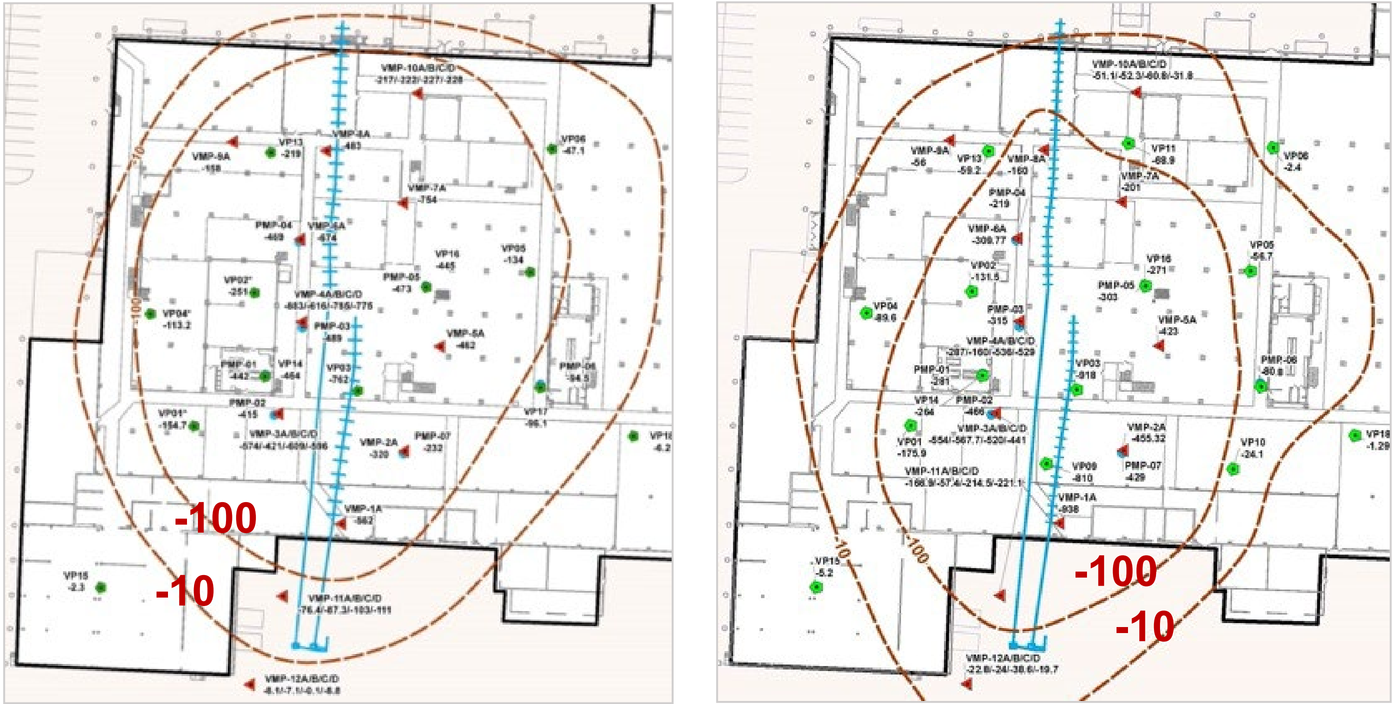
C3: cooling, compression, condensation

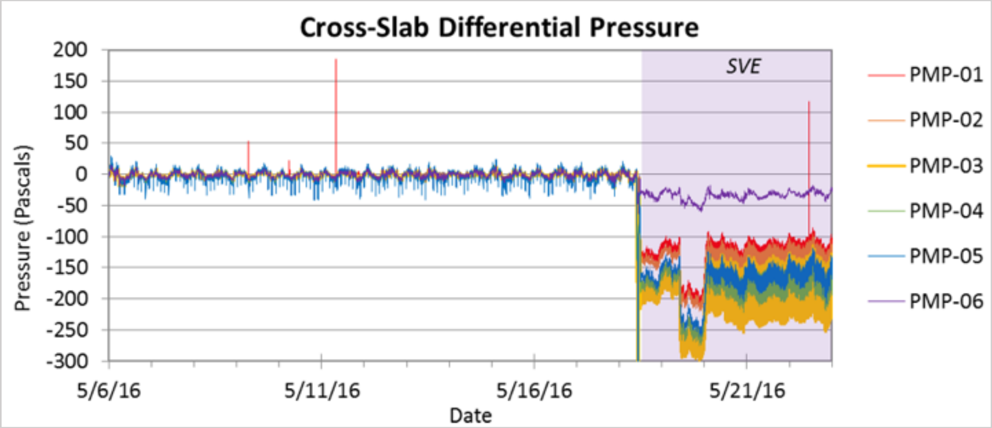
HW installation photographs (NOREAS 2018)

HSVE Operations, Phase 2

- Phase 2 operation
  - Operated for 20 months before expanding system for LNAPL recovery
  - Approximately 6,000 lb of VOCs recovered
  - GEO C3 vapor treatment

HSVE-1A and HSVE-1A layouts with observed SVE influence
(NOREAS 2018)





Negative differential pressure measurements after SVE startup
(NOREAS 2018)

HSVE Expansion, Phase 3

Three additional SVE wells installed in 2017 (as part of Phase 3)

Before start of SVE (April 2016)

3 months after start of SVE (August 2016)

15 months after start of SVE (July 2017)

HSVE operation 2016–2017
(NOREAS 2018)

Phase 3 HW Design

- HW design, Phase 3
  - Three additional HSVE wells
    - Target depths 10 and 20 ft bgs
  - Three horizontal steam injection wells
    - Target ~3 ft below LNAPL zone
    - Connected to base steam supply line
  - Two horizontal LNAPL recovery wells
    - Entry-exit installation
    - Historical GW levels reviewed for target depths immediately below LNAPL zone

HDD Driver

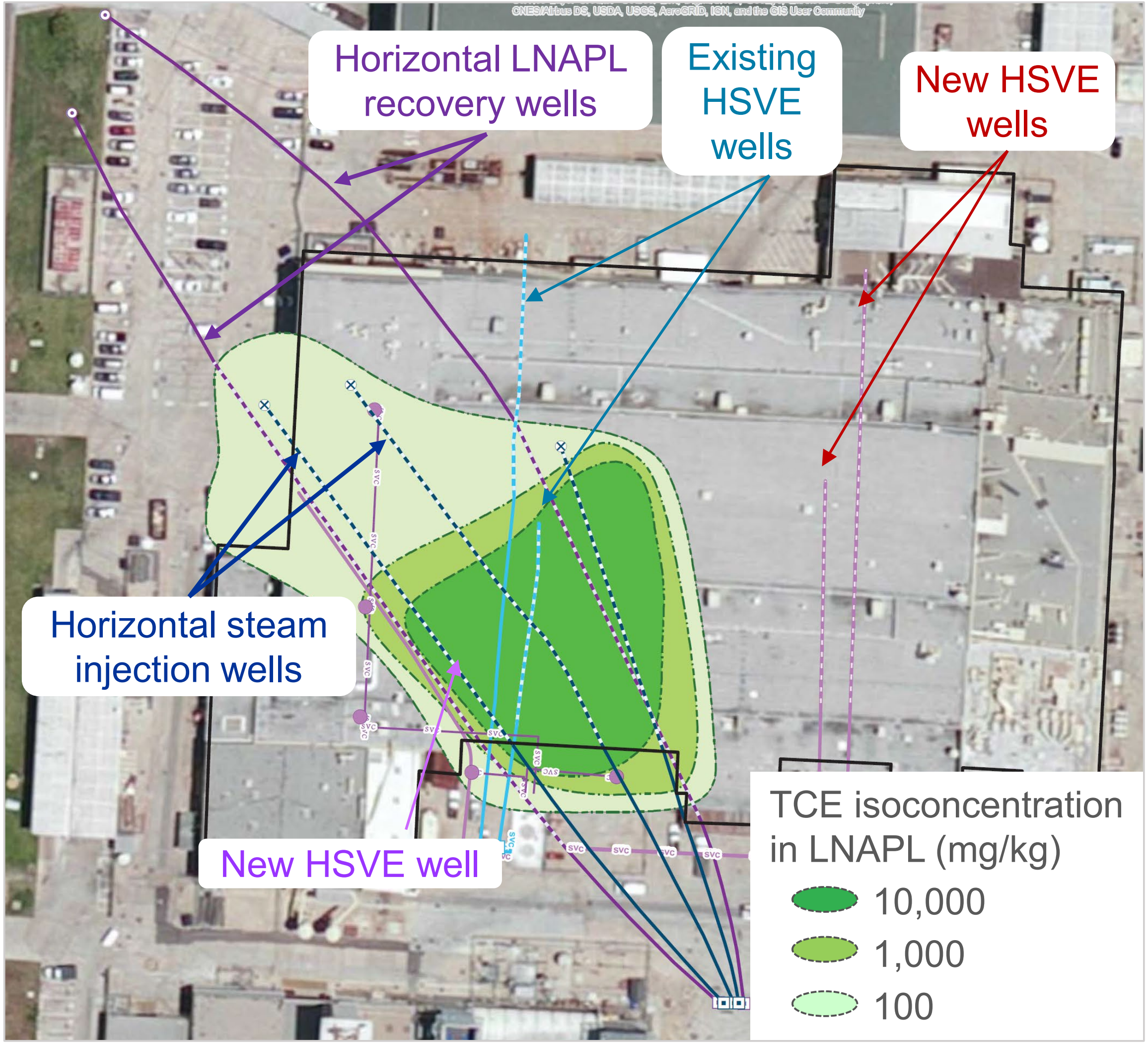
Horizontal steam injection wells and horizontal LNAPL recovery wells **access LNAPL beneath the building.**

HW construction details (NOREAS 2018)

Well Type	Well ID	Screen Depth (ft bgs)	Diameter (inch)	Riser Length (ft)	Screen Length (ft)
SVE	HSVE-2A	10	3	90	130
	HSVE-2B	10	3	210	140
	HSVE-3	20	3	50	190
Steam	HSIW-1A	15	3	200	240
	HSIW-1B	15	3	170	250
	HSIW-1C	15	3	160	180
LNAPL Recovery	NAPLRW-A	25	6	470	260
	NAPLRW-B	25	6	380	350

Phase 3 HW Layout

Horizontal well network (NOREAS and Geosyntec 2018)



mg/kg: milligrams per kilogram

Horizontal LNAPL Installation Video

HDD drill bit exiting prior to pullback of horizontal LNAPL recovery well materials
(NOREAS 2018)

Remediation System

- Vapors recovered and treated by GEO C3 system
- Routed through vapor liquid separator
- Condenses vapors into liquids
  - Condensate filtration
  - Coil coalescing filtration
  - Two heat exchangers
  - Two, 1,000-pound activated carbon vessels
- Periodic measurement of temperatures in product

Remediation system compound
(NOREAS 2018)

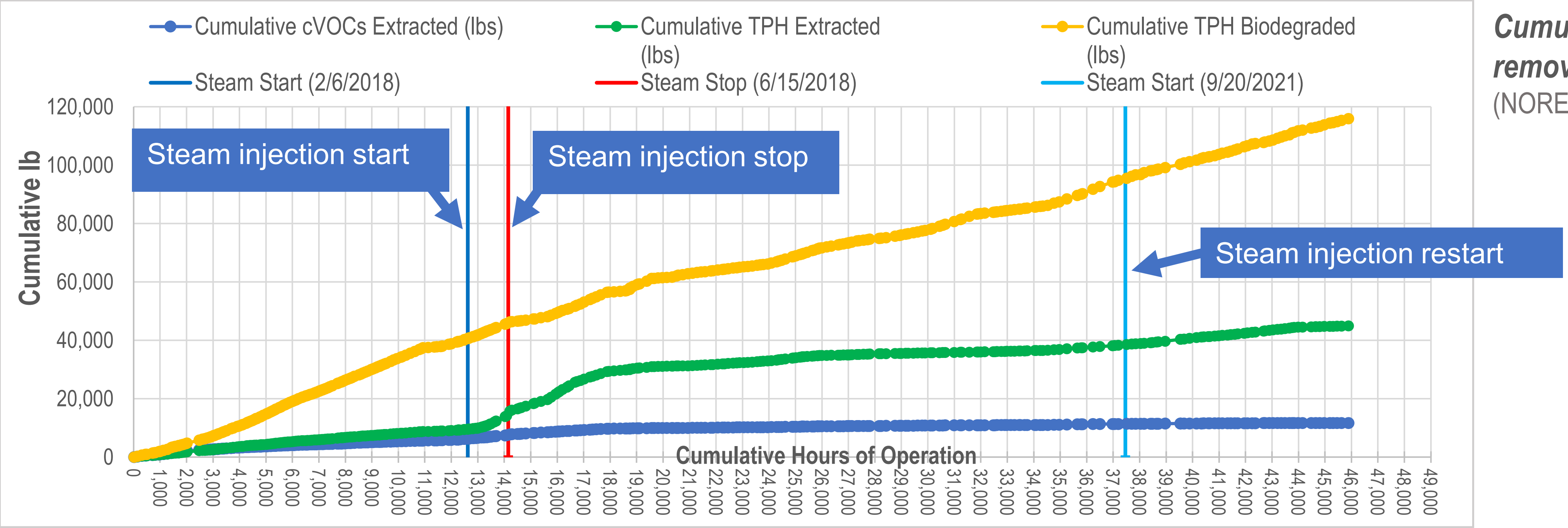
Operations and Results

- Indoor air TCE concentrations decreased below action levels within days of operation (and remain below)
- Concentrations remained low, so tenants returned to building
- Steam injections commenced 1,360 days after SVE, resulting in sharp increase of TPH recovery
- LNAPL temperature rose from ~ 70 ºF to 110 ºF
- Steam injection ceased due to base steam system shutdown in June 2018
- Steam injection resumed in September 2021

TPH: total petroleum hydrocarbons

Cumulative Mass Removed

- Operations and results (cumulative since May 2016)
  - CVOCs extracted: 12,000 lb
  - TPH extracted: 45,000 lb
  - TPH biodegraded: 120,000 lb
  - Total removed: 177,000 lb

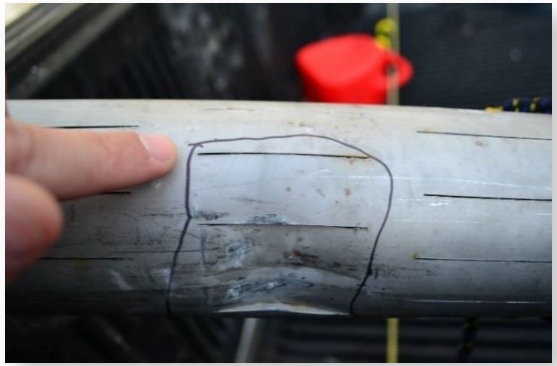


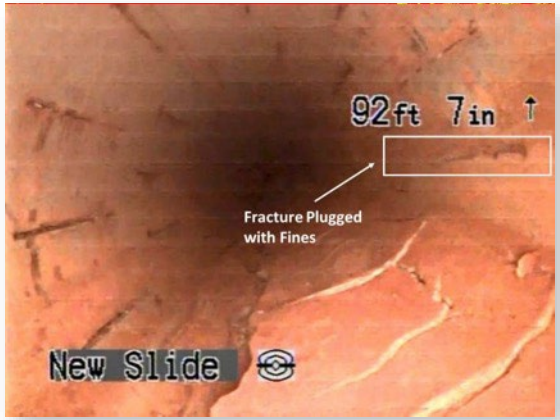
Cumulative mass removed
(NOREAS 2022)

Conclusions and Key Takeaways

	HSVE	Horizontal Steam Injection	Horizontal LNAPL Recovery
Advantages	• Provided access to impacts below building • Abated need for interior piping for SVE	• Used available steam to volatilize	• HWs allow for increased well screen contact with NAPL zone
Challenges and Lessons Learned	• Locating interferences • HDD footprint • IDW • SS well materials still subject to buckling	• Steam delivery ceased shortly after startup • Independent boiler for system • Slot diameter to grain size	• Greater target depth posed installation challenges, entry exit requirement • Maintenance
Key Takeaways	• HSVE highly effective for inducing vacuum over large area • Provided vapor mitigation to satisfy TCRA and improve indoor air	• Innovative use of available heat source • First horizontal steam injection wells	• Successful combined remedy approach for significant mass removal

Well materials buckling and downhole camera showing damage
(NOREAS 2018)





What's Next?

Next Steps for Building 379

1. Levels of TPH and CVOCs in extracted vapor are decreasing: evaluate less-expensive treatment methods
2. Cyclical operations: 1 month per quarter will likely still meet the original VITCRA objective of indoor air protection
3. Additional HSVE: install additional HSVE between HSVE-1 and HSVE-2 to address residual elevated TCE in soil gas at depth

VITCRA: vapor intrusion time critical removal action

Case Studies

$1,600

Answer:

HWs were constructed of this durable material for Building 379.

Presentation Overview

- Introduction to HDD and HWs
- HDD technology overview
- HW design, construction, and installation
- HW O&M and refurbishment
- Cost considerations
- Case studies
- Conclusions and references

Conclusions

- HDD allows for creative placement of borings/wells for three primary remedial objectives:
  - **Access beneath surface obstructions and infrastructure**
  - **Coverage of large areas**
  - **Targeting horizontal subsurface features (aquifers, smear zones, top of confining layers)**
- Multiple applications for remediation and assessment
- Not a silver bullet (typically a combined remedy)
- Four key factors in successful HWs:
  - **Design**
  - **Installation**
  - **Development**
  - **Maintenance**
- ***HDD and HWs are used throughout the environmental industry and innovative DOD site remediation using HDD has pushed envelope and will continue to do so***

Final Jeopardy

Category: Horizontal Injection Wells

Answer:

At 1,976 ft and 1,973 ft, the longest blind horizontal injection wells ever installed to date[1] were installed beneath a coal ash basin located in this state known for its world class fly fishing.

References

Agviq, LLC. 2022. *Final Construction Completion Report. Remedial Action for Zone 2 at Site 88,* Marine Corps Base Camp Lejeune, Jacksonville, North Carolina.

Chang, Pamela, N. Durant, V. Hosangadi, M. Pound. 2018. *Successful Rapid Response Mitigation of High Strength Vapor Plume Underneath a Large, Active Navy Building.* Presented at the Conference on Remediation of Chlorinated and Recalcitrant Compounds, April 8-12, 2018, Palm Springs, CA.

Cleland, Charity, C. Delaney, M. Fulkerson, J. High, M. Perlmutter. 2018. *Distribution of Permanganate via 100-Foot Deep Horizontal Well*. Presented at the Conference on Remediation of Chlorinated and Recalcitrant Compounds, April 8-12, 2018, Palm Springs, CA.

Directional Technologies, Inc. 2023. “Case Studies.” Available at: https://www.directionaltech.com/category/horizontal-well-case-studies/.

Divine, C.E., J. Wright, M. Crimi, J.F. Devlin, M. Lubrecht, J. Wang, J. McDonough, M. Kladias, J. Hinkle, Al. Cormican, T. Osorno, B.N. Nzeribe, F. Laramay, D. Ombalski, K. Gerber, and H. Anderson. 2020. *Field Demonstration of the Horizontal Treatment Well (HRX ® Well) for Passive In Situ Remediation*. July 26. Available at: https://ngwa.onlinelibrary.wiley.com/doi/full/10.1111/gwmr.12407.

Ellingson-DTD. 2023. “Case Studies” Available at: https://www.directionaltech.com/category/horizontal-well-case-studies/

ENRx/Vertebrae. 2023. “Case Studies.” Available at: https://enrxinc.com/vertebrae/

References

FPM Remediations, Inc. & URS Group, Inc. 2018. *Corrective Action Implementation Report (Construction Completion Report)* AOC I (ST013) – Base Gasoline Station Leak GWPD Site #A-10-AA-16344, Joint Base Charleston-Air, North Charleston, South Carolina, Facility ID SC3570024460.

FPM Remediations, Inc. 2022. *2021 Annual Groundwater Monitoring Report / Corrective Action System Evaluation Report March and June 2021 Events*, AOC-I (ST013) - Base Gasoline Station Leak GWPD Site #A-10-AA-16344, Joint Base Charleston-Air, North Charleston, South Carolina, Facility ID SC3570024460.

FPM Remediations, Inc. 2022. *Performance Monitoring Progress Report, December 2021 and March 2022.* AOC-P (DD540) – Flight Line Drainage Ditch, Joint Base Charleston, South Carolina, Facility ID SC3570024460.

FPM Remediations, Inc. 2022. *2022 Semi-Annual Groundwater Monitoring Report (Corrective Action System Evaluation (CASE) Report – December 2021 and March 2022).* SWMU 145 (ST027) Building 575 JP-4 Tank Leak GWPD Site # A-10-AA-01829.

References

FPM Remediations, Inc. 2022. *Construction Completion Report, Corrective Action Progress Report, And 1st and 3rd Quarter 2017 Groundwater Monitoring Report.* SWMU 145 (ST027) Building 575 JP-4 Tank Leak GWPD Site # A-10-AA-01829.

NAVFAC EXWC. 2020. *Application of Horizontal Wells to Enhance Site Remediation.* Technical Report TR-NAVFAC-EXWC-EV-2103. Available at: https://clu-in.org/download/techfocus/horizontal-wells/Horizontal-Well-Case-Studies-11_13_20_Final.pdf.

NOREAS, Inc, Geosyntec Consultants, Inc., and Battelle Memorial Institute. 2018. *Soil Vapor Extraction Interim Removal Action Completion Report,* Building 349, Operable Unit 19/20.

Paragon Professional Services, LLC. 2022. *Final Construction Completion Report. Remedial Action for Zone 2 at Site 88,* Marine Corps Based Camp Lejeune, Jacksonville, North Carolina.

US EPA. 2017. *How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites, A Guide for Corrective Action Plan Reviewers.* Appendix A, Horizontal Wells. Available at: https://www.epa.gov/sites/default/files/2017-10/documents/tums-app-a-oct2017.pdf

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Questions and Discussion