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Remedial Screening of Horizontal Injection Wells and Vertical Injection Wells for In-Situ Chemical Oxidation (ISCO) of Petroleum Hydrocarbons

IPEC Conference

San Antonio, TX

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Presentation Overview

- Chemical Oxidation
  - What is it?
  - What are reactions?
  - What type of equipment is needed?
- Performing Effective Injections
  - What are concerns?
  - How are concerns mitigated?
- Case Studies

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Experience with ISCO

California, Connecticut, Delaware, Georgia, Florida, Illinois, Louisiana, Maryland, Michigan, Mississippi, New York, New Jersey, Ohio, Pennsylvania, Texas, Virginia and West Virginia

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Example: Remedial Alternatives

- **Multi-Phase Extraction Events**
  – did not effectively remove contaminant mass
- **Natural Attenuation**
  – not feasible, concentrations too high
- **Excavate Soil**
  – limited space, proximity to buildings, potential soil exposure
- **In-Situ (or in place) Chemical Oxidation (ISCO)**
  – Pilot Test approved by regulatory agency

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In-Situ Chemical Oxidation

ISCO **is where oxidants are introduced into subsurface to chemically oxidize contaminants into harmless substances. Some oxidants include:**

- **Permanganate (MnO_4)**
- **Fenton's (hydrogen peroxide [H_2O_2] and Ferrous iron [Fe^{+2}]) or catalyzed hydrogen peroxide (CHP)**
- **Ozone (O_3)**
- **Persulfate ($S_2O_8^{2-}$)**

Oxidants + Petroleum Compounds (carbon) → CO_2 + H_2O

Note: Once oxidants are injected via injections wells, monitoring surrounding wells will gauge effectiveness

Will it work on my site?

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Chemical Oxidation Chemistry

1. Hydrogen peroxide will react with iron to form hydroxyl radicals:

$$H_2O_2 + C \rightarrow \bullet OH + OH^- + C^+$$

C = Iron or Metal Catalyst; OH = Hydroxyl Radicals

2. Hydrogen peroxide will react with persulfate to form sulfate radicals and hydroxyl radicals:

$$S_2O_8^{2-} + H_2O_2 \rightarrow 2SO_4\bullet + 2(\bullet OH)$$

3. Hydrogen peroxide will react with ozone to form hydroxyl radicals:

$$2\ O_3 + H_2O_2 \rightarrow 2(\bullet OH) + 3\ O_2$$

Note: Addition of persulfate can lower local pH, which will enhance first and second chemical reactions above.

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Oxidation Potential

Oxidizing Species	Oxidation Potential (Volts)	Relative Oxidation Power (Chlorine as reference)
Hydroxyl Radical	**2.80**	**2.05**
Activated Persulfate	**2.60**	**1.88**
Ozone	2.07	1.52
Persulfate	2.01	1.46
Hydrogen Peroxide	**1.77**	**1.30**
Perhydroxyl Radical	1.70	1.25
Permanganate	1.69	1.24
Chlorine	1.38	1.00
Oxygen	1.20	0.90

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Ref: Solvey Interox., Hydrogen Peroxide, Fenton's Reagent, 6/93

Example Site: Horizontal Wells

- Typical highway utility crossing
  - Traffic was not disrupted

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Example Site: Horizontal Wells

- Access inside this government facility was denied

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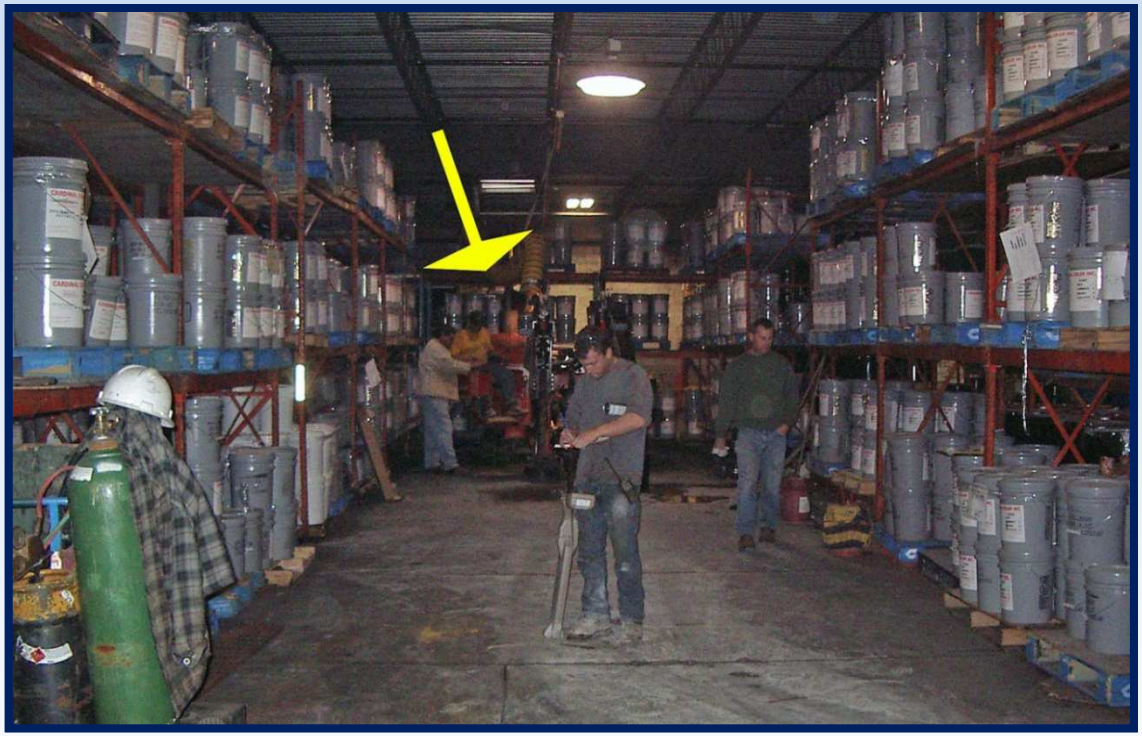
Example Site: Horizontal Wells

- Traditional vertical equipment could not fit in tight spacing



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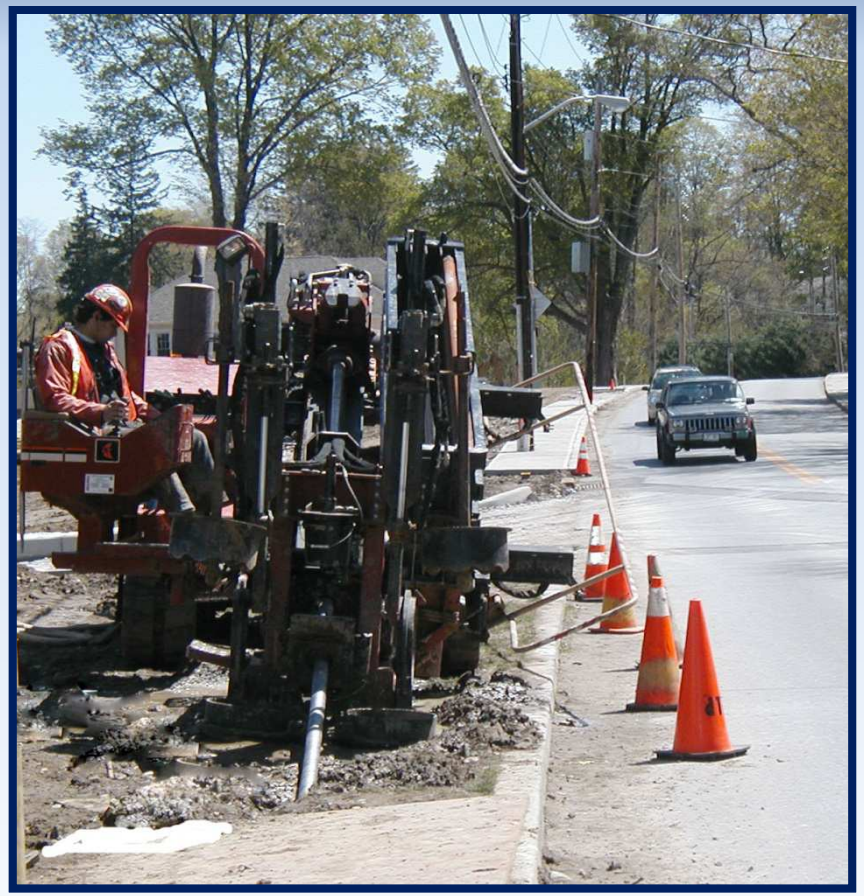
Example Site: Horizontal Wells

- Typical utility installation
  - Traffic was allowed to continue
  - Pristine urban revitalization was preserved



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Example Site: Horizontal Wells

Fast track environmental project required mandatory cleanup

$40 Billion project in South Korea

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Example Site: Horizontal Wells

Site constraints – wells had to terminate within property boundaries

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Example Site: Horizontal Wells

- Social Impacts
- Tight Set-Up Areas

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Horizontal *vs.* Vertical

- HRWs can run parallel or perpendicular to the plume
- HRWs can run through the plume, under the plume or over the plume
- HRW can curve to follow the plumes path
- HRWs can get right to the source
- Smear Zone
- HRWs can use a variety of well materials

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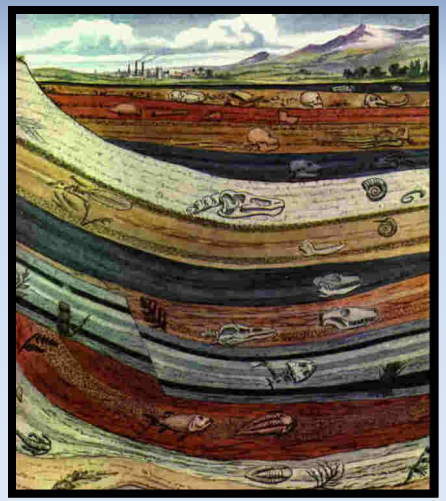
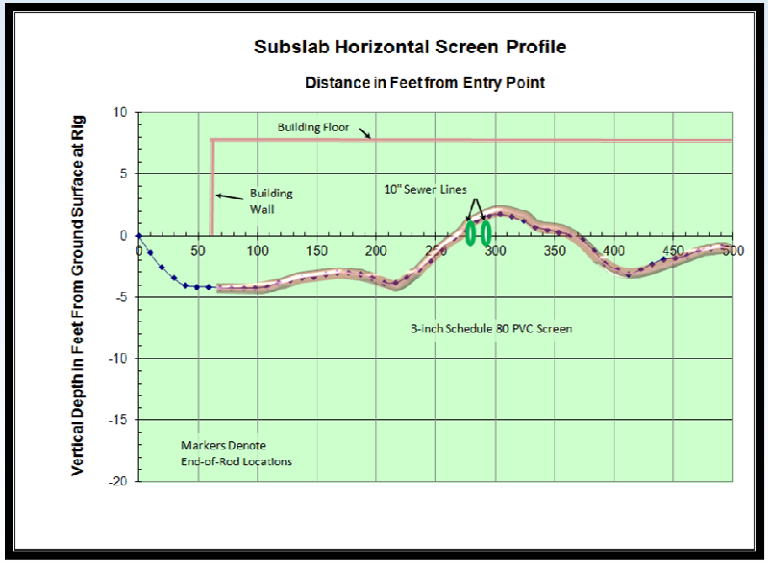
Ground Conditions

- Have to think linear – not point to point
- What can happen bgs over 450’ or 1,000’ of well screen
- Change in the geology
- Be prepared for a change in the geology with horizontal drilling and well placement
- Obstacles – left, right, up, down
- Change in the groundwater table





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Site Conditions/Restraints
HRW vs Vertical Wells

- Wire line locating technology can be used if access to the building is not possible
- Small compact directional drilling rigs can accommodate sites with low ceiling clearance
- HRWs can be installed from discrete locations so that commercial activities can continue
- Minimum site restoration is required
- Fewer if any conveyance lines are needed

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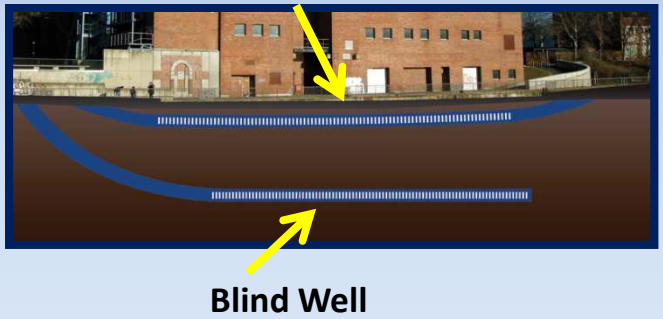
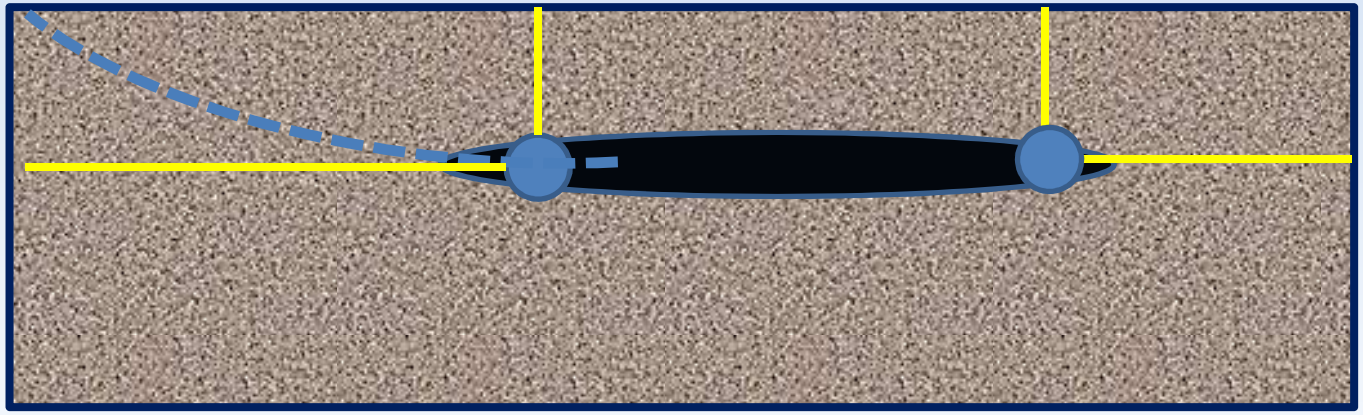
Site Conditions/Restraints
HRW *vs* Vertical Wells

- Horizontal Remediation Well requirements
  - 5:1 ratio to achieve depth
    - Can overcome this with design modifications
  - Entry/Exit well or blind well
  - No room for exit point will require blind well





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Case Study

- Release history – multiple UST releases
- Remediation history – mass excavation, but significant impacted material left
- Recontamination of site from residuals

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Selecting the Remedy

Feasibility Study Assessed:

- Excavation
  - Cost prohibitive – business interruption losses alone would exceed $10K per day
  - No guarantee of achieving NFA

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Selecting the Remedy

- Feasibility Study Assessed:
  - Proven technology
  - Suitable for site's subsurface conditions
  - Business interruptions reduced to loss of one dispenser island during vertical system installation
- – Decision: select AS/SVE

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Vertical AS/SVE System Conceptual Layout

- 10 vertical wells with sufficient ZOI overlap to cover the entire impacted area
- Projected time to NFA: 3-5 years

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Vertical AS/SVE System Costs

- Well installation: $300K – approximately half ($150K) for soft-dig trenching for interconnecting piping
- Treatment system: $100K
- 5 years O & M @ $40K/yr.: $200K
- Total estimated project life cycle costs: $600K
- Estimated lost business revenue due to dispenser island shut-down: $7.5K/day X 15 days = $112.5K

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Cost Assessment

- Client's lost business revenue due to dispenser island shut-down of approximately $112.5K was intolerable
- Cannot justify a $150K expenditure for soft-dig trenching for interconnecting piping

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Technology Reassessment

- How to implement a remedy without shutting down the business?
- Solution: Horizontal Remediation Wells

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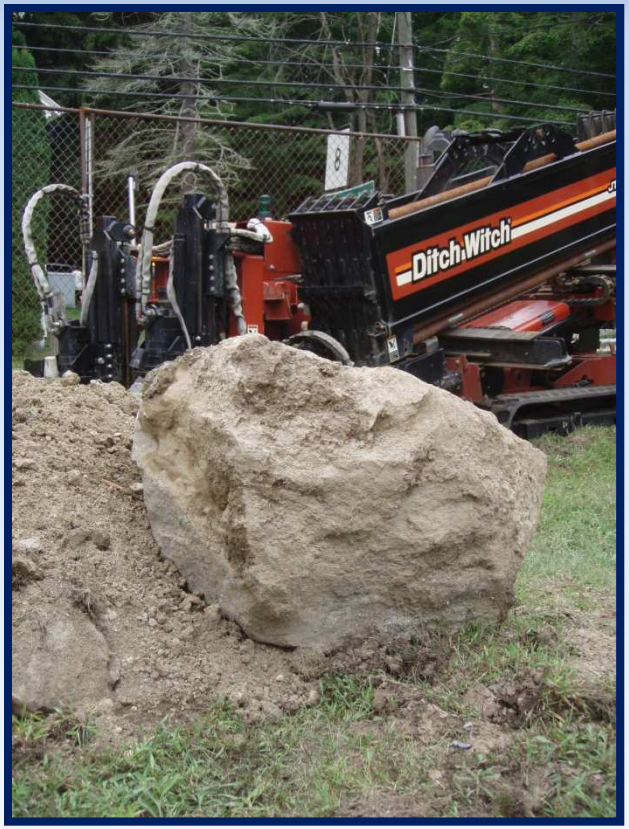
Horizontal Remediation Well Conceptual Design

3 Horizontal Remediation Wells

- 2 HRWs along north and south flanks of plume – overall length 175 ft.; screen length 135 ft.
- 1 HRW well between the 2 HRWs wells along plume centerline – overall length 175 ft.; screen length 135 ft.
- 3” diameter Sch. 40 PVC
- Blind completions



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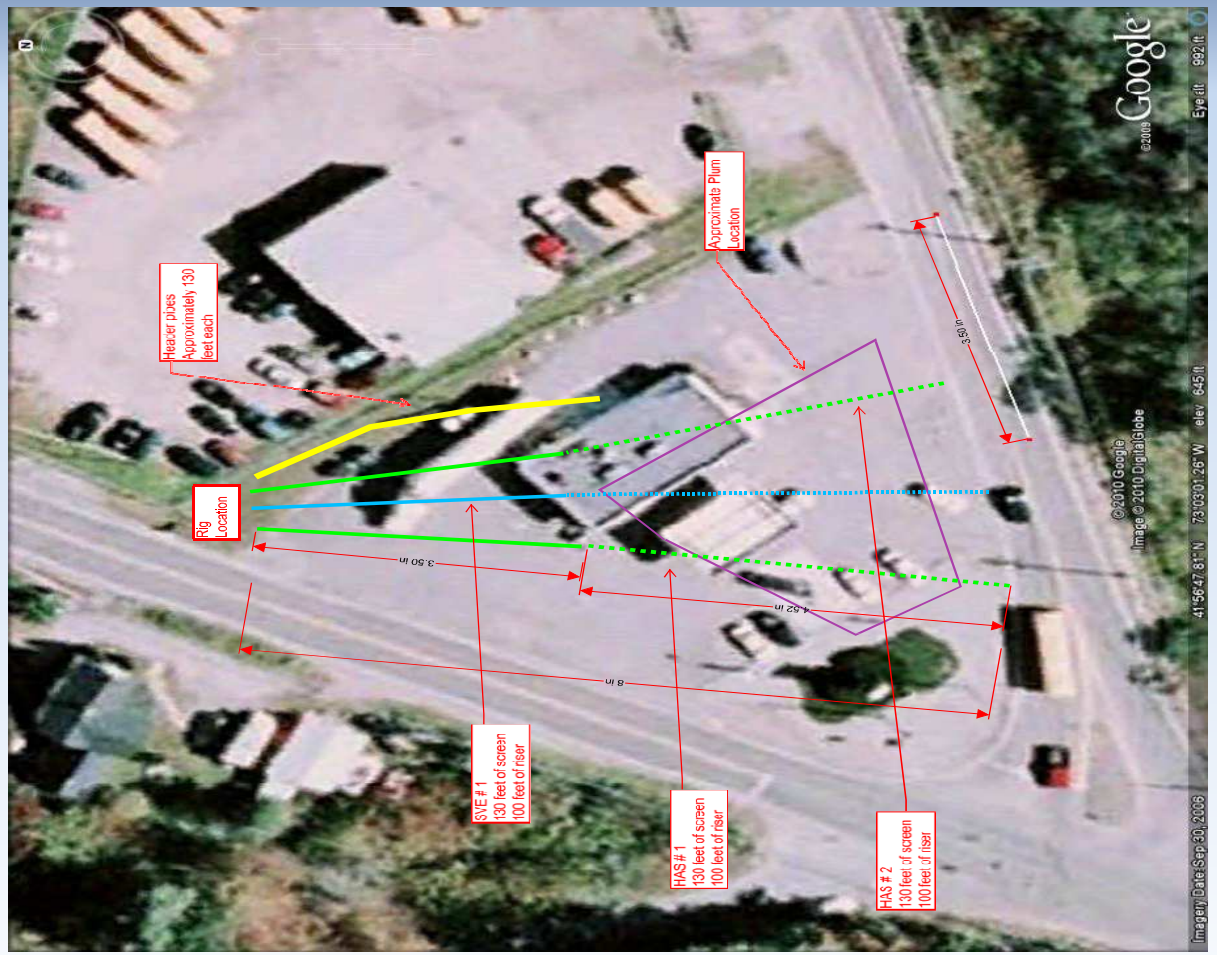
Site Design



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Horizontal Remediation Well Estimated Installation Cost

- $150K, including well screen design, materials, mob/demob, well installation, well development

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Horizontal AS/SVE System Costs

- Well installation: $150K
- Treatment system: $100K
- 1 year O & M @ $40K/yr.: $40K
- Total project life cycle costs: approx. $290K
- Avoided costs:
  - $150K soft–dig trenching
  - $160K O & M (4 years)
- Total savings: approx. $210K
- Avoided business loss: $112.5K

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Cost Summary

	Horizontal Wells	Vertical Wells
Well Installation	150,000	300,000 includes trenching
Treatment	100,000	100,000
O & M : 1st year	40,000	40,000
2nd year	0	40,000
3rd year	0	40,000
4th year	0	40,000
5th year	0	40,000
Total estimated life cycle project costs	$290,000	$600,000
Interruption of business	0	$112,500

Summary

- Avoided approximately $290K in program costs
- Avoided at least $100K in lost revenue for client by allowing business to continue during remedial construction
- Avoided street closures and police details
- Cleaned up site in 1 year vs. 5 years

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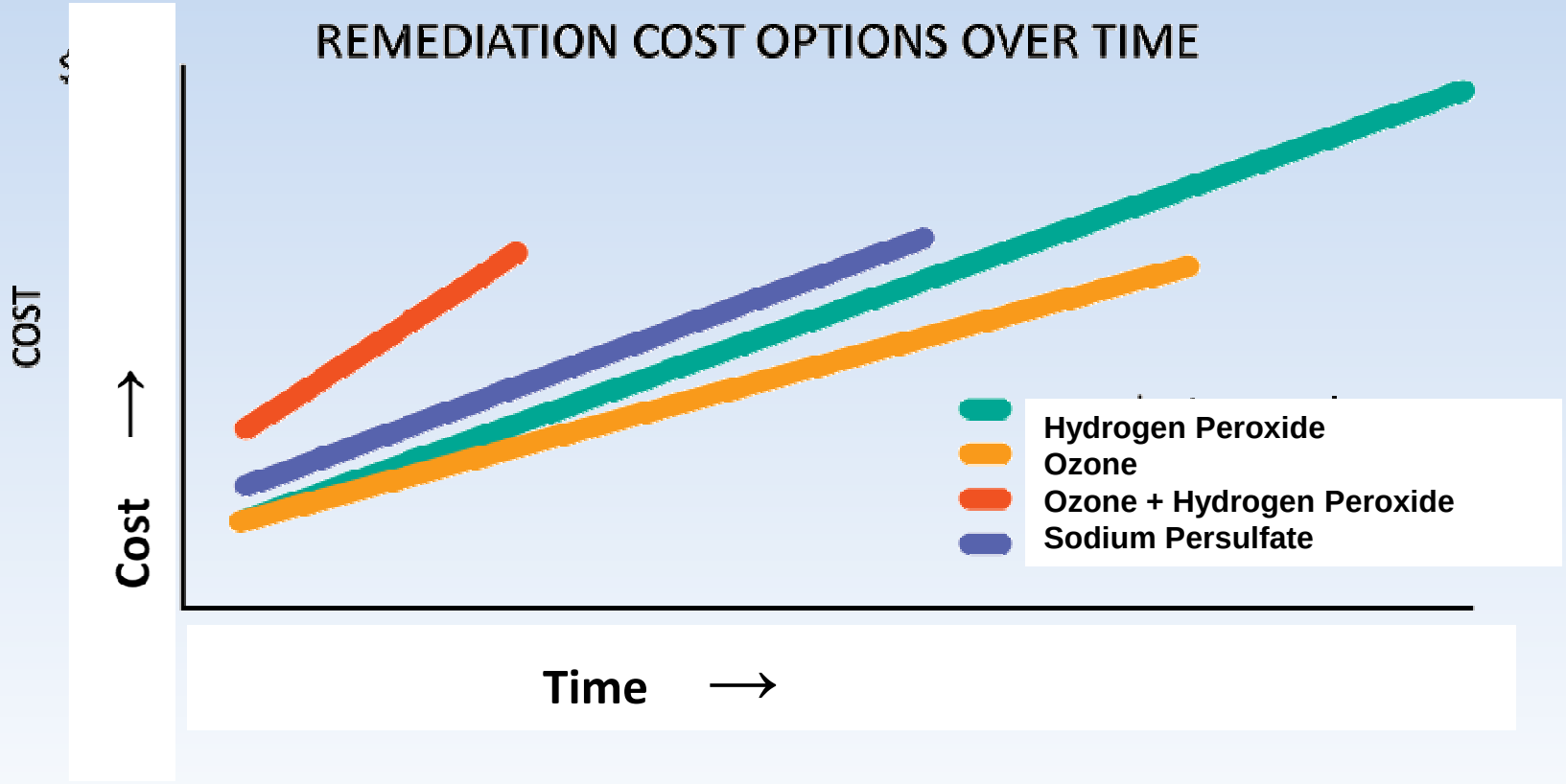
ISCO Evaluation



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Planning

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Planning

Chemical Management Persulfate

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Planning

Chemical Management Tankers

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Perform and Assess

SUBSURFACE REACTIONS

Constantly monitor injection process

- Volume, flow and pressure of oxidants

Constantly monitor subsurface effects

- Groundwater levels, pH, temperature, ORP, DO and oxidant concentrations
- PID, % LEL and % O_2

During injections, vacuum applied to well closest to injection point

- Recovers any potential vapors, if any
- Vapors treated via carbon, as necessary

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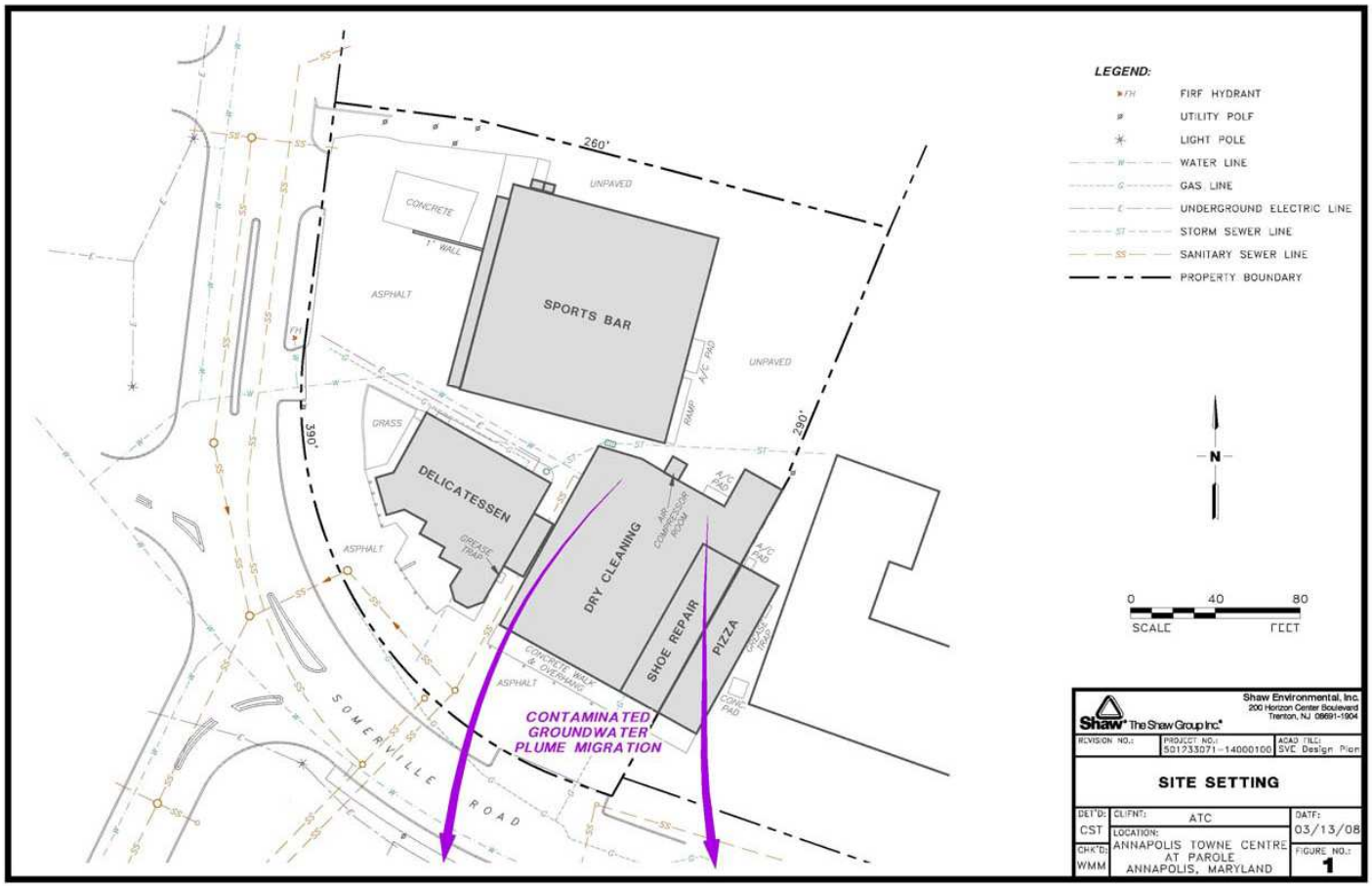
Case Study: HRW Injection



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Conceptual Model

- Site Soils: Silty Sand to 65 feet
- Groundwater Flow Rate: 0.2 to 0.4 fpd
- Low Soil Oxidant Demand: 1.5 to 2.0 g/kg
- Contaminated Groundwater Zone: ≈25 to 55 feet bgs

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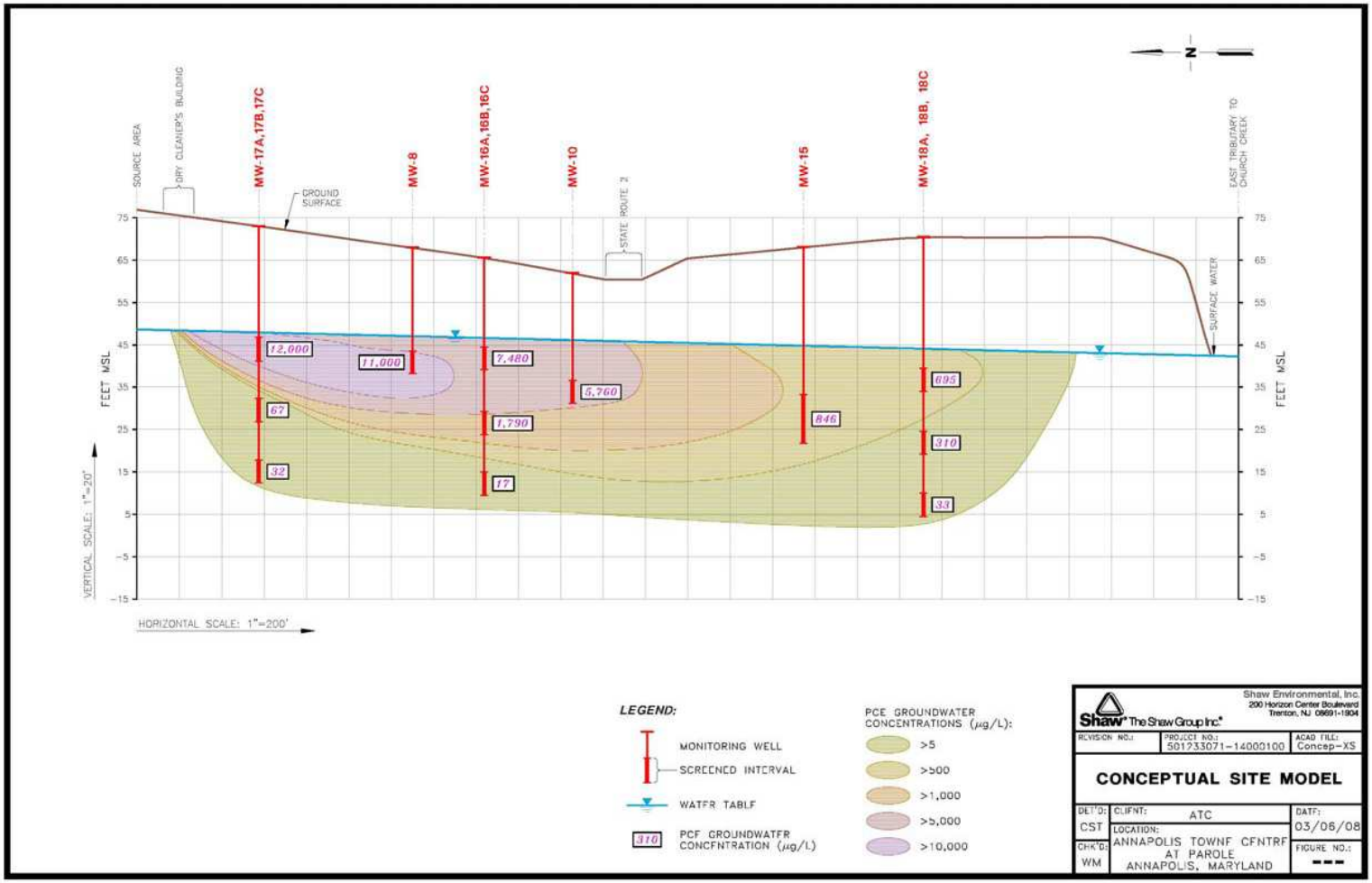
Plume Cross-Section



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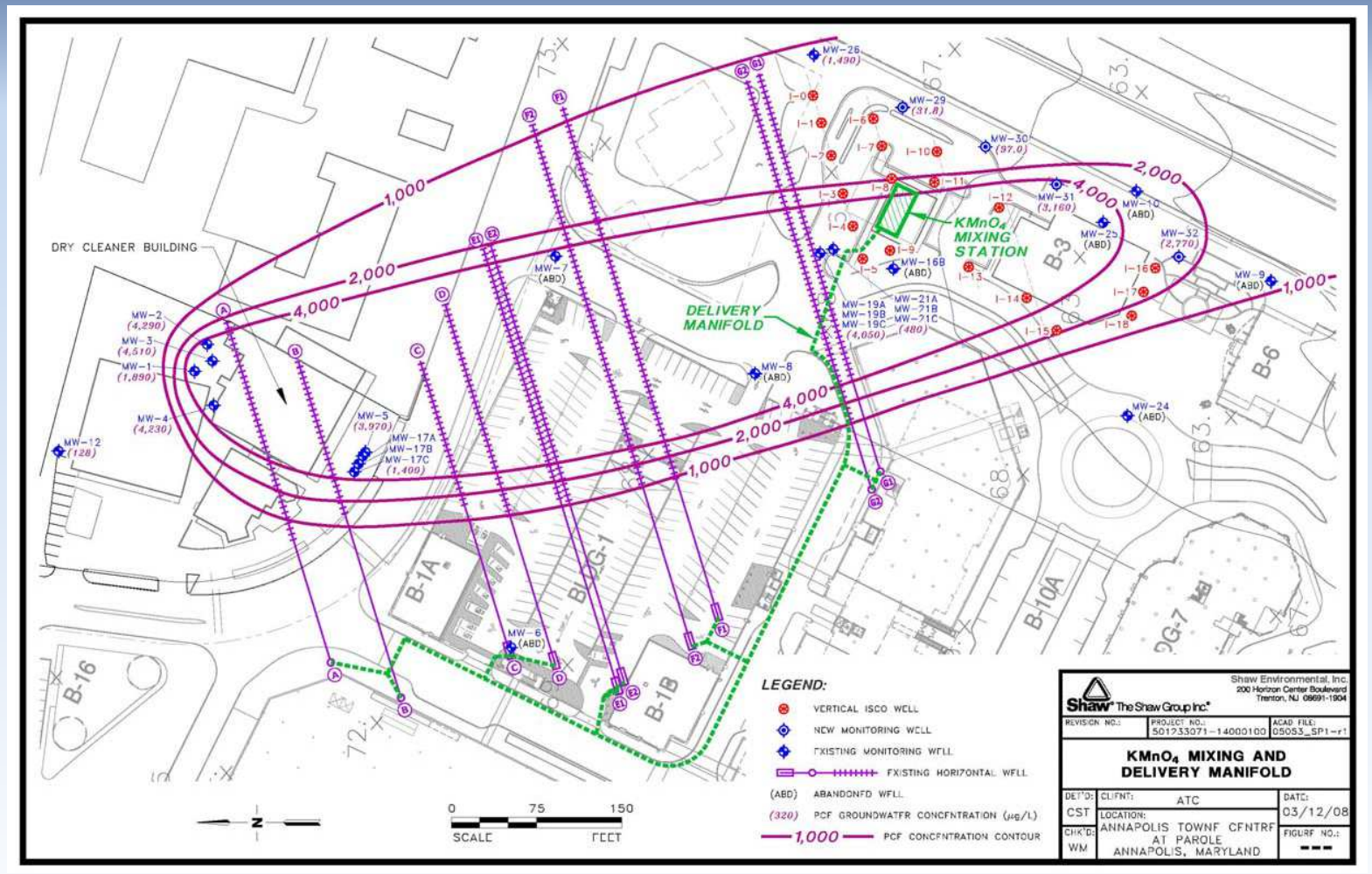
Horizontal Well Design Layout



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Horizontal Screen Design

- Modeling to achieve uniform distribution of oxidant through length of well screen
- 3D finite difference flow and transport model to design screen pattern
- MODFLOW
- Design specifies percent open area of well screen to generate uniform distribution

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Horizontal Screen Design

- Model simulates injection fluid moving down the well, through screen slots, and into and through formation
- Open area requirements for well screens ranged from 0.0357 to 0.0429 percent open area
- Required number of slots were calculated for each length of screen at slot width of 0.02-inch

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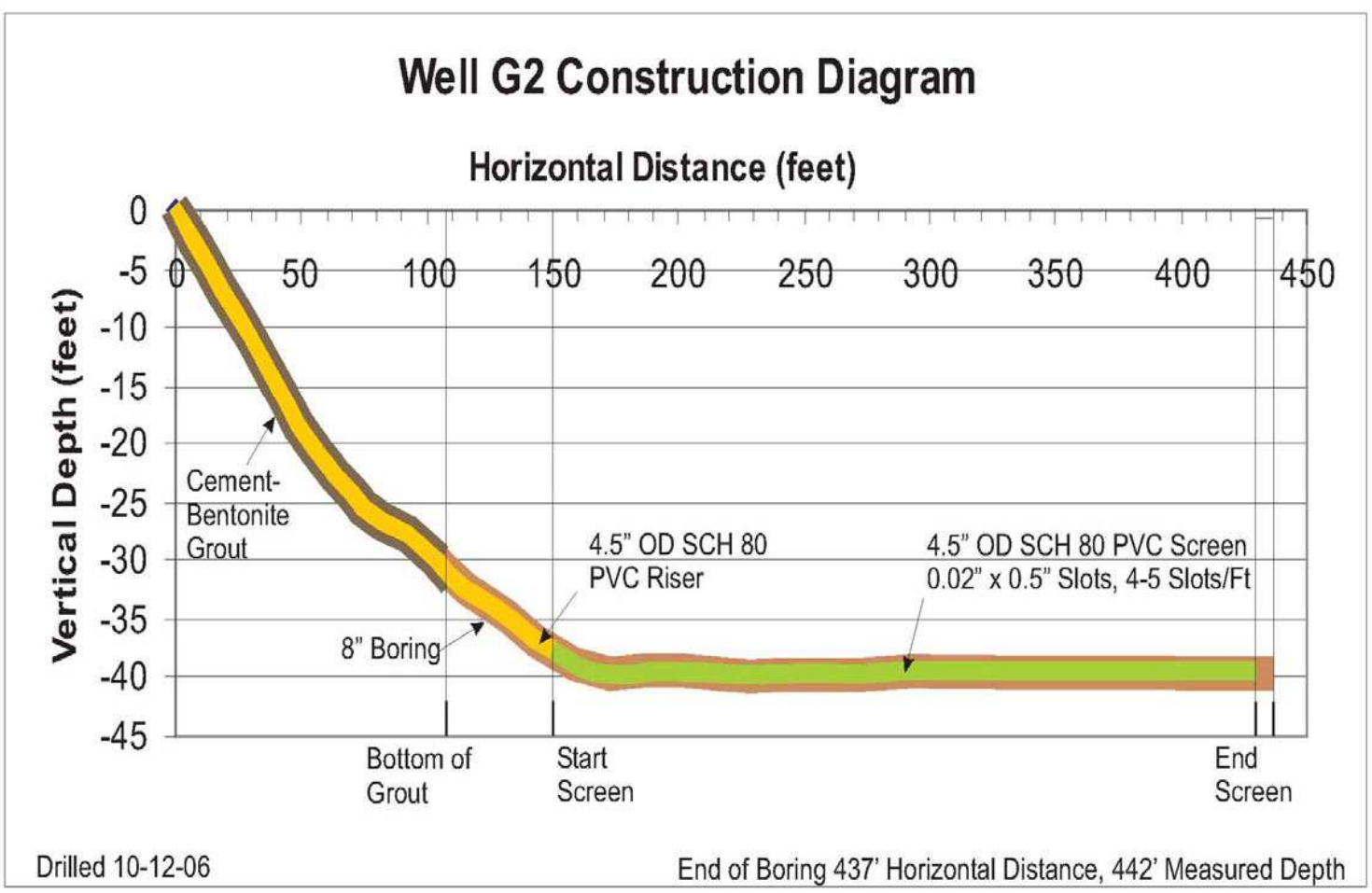
Horizontal Screen Design



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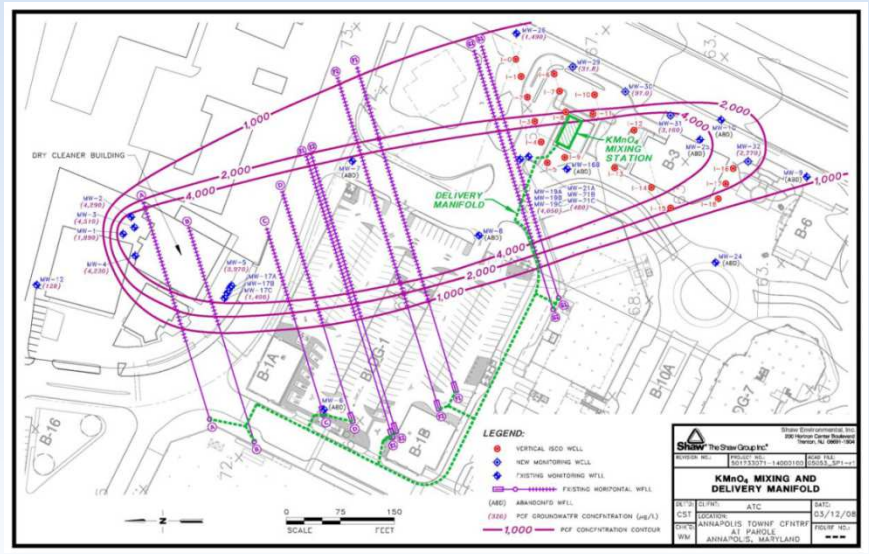
Horizontal Well Installation

- Design: 7 rows of Horizontal Remediation Wells
- Some rows used two wells at various depths (≈30 and 40 feet bgs)
- Installation completed in 35 days (3,870 feet of drilling)



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Horizontal Well Installation

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ISCO 1st Injection Event

- Injection into 10 Horizontal Wells
  (total of 2,330 feet of screen)
- Flow Rate: 11.7 GPM per well (average)
- Batch Process: 10,000 Gallons per Batch
- Injection Time: 85 Minutes per Batch
- ISCO 1st Injection Event: 340,000 gallons

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Oxidant Mixing Station

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ISCO 2nd Injection Event

- ISCO 2nd Injection Event: 1,032,333 gallons
- Average Injection Rate: 38,235 gallons per 10-Hour Shift
- Maximum Injection Rate: 55,000 gallons in 10-Hour Shift
- 81 Tons of Oxidant Chemicals Injected in 26 Days

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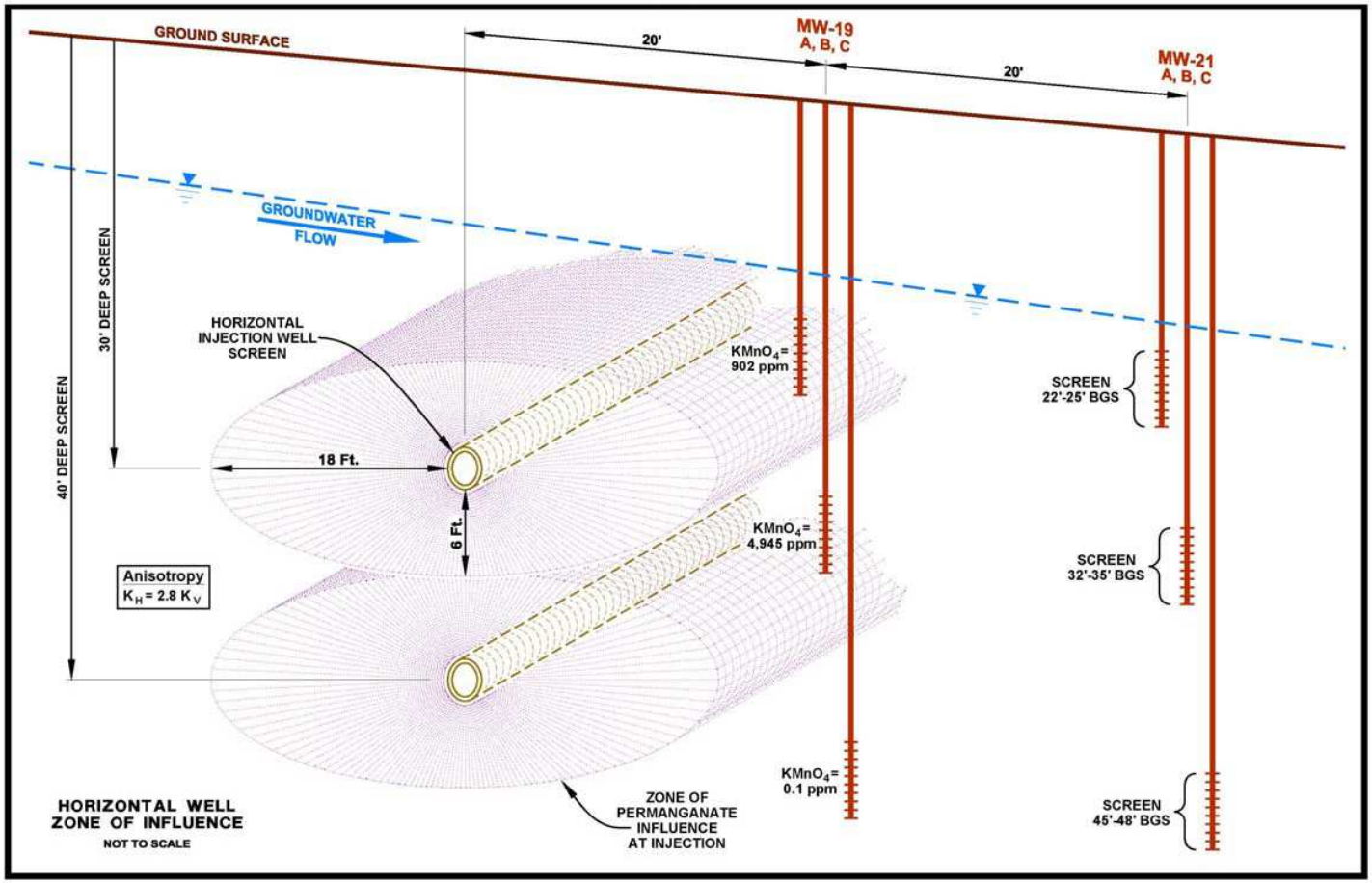
Oxidant Distribution at Initiation of Injection



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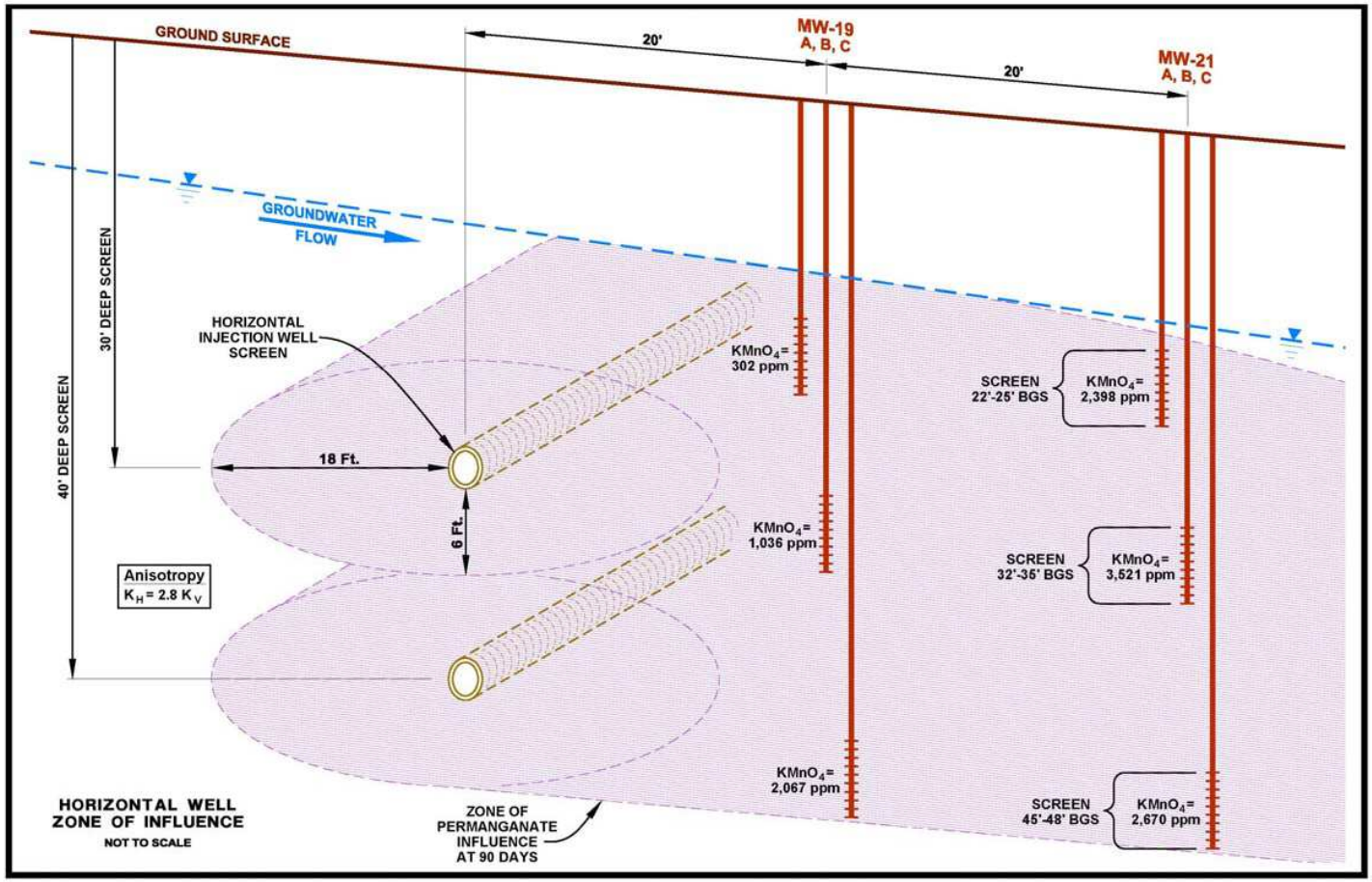
Oxidant Distribution at 90 Days After Injection



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Concentration Reductions

- Source Area MWs
  Pre-Treatment Concentrations: as high as 13,000 ppb
  Post-Treatment Concentrations: from ND to 400 ppb

- Downgradient MWs
  Pre-Treatment Concentrations: as high as 8,000 ppb
  Post-Treatment Concentrations: from ND to 1,840 ppb

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Summary of Advantages: Horizontal Remediation Wells

- Length of screen allows for higher volume injections – faster, less costly injection process
- Reduces effect of oxidant clogging
- Allow injections in areas where streets, utilities and buildings interfere with vertical wells
- HRWs are typically more effective than vertical wells
- HRWs are flexible technology that allows for many possible designs, applications and combinations
- Traditional vertical remedies can be transferred to HRWs

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Horizontal Remediation Wells

Horizontal Remediation Technologies • Installation • Design • Engineered Well Screens • Services

Questions?

Founded in 1992, Directional Technologies, Inc. has installed over 1,000 horizontal remediation wells thru out the world.

Corporate Headquarters in Wallingford, CT
Branches offices in Philadelphia, PA; Ashby, MA; Tallahassee, FL

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