Optimization and Monitoring of Chlorinated and Related Compounds

November 2019

Horizontal Directional Drilling and Well Installation for Substrate Injection

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Horizontaldrill.com

History of Horizontal Environmental Wells

- **Horizontal/Directional Oil Wells in the 1930s – Present**
- **Directional "River Crossings" in the 1970s**
- **Environmental Applications**
  - **Unocal Station – Kent Washington 1987**
  - **DOE – Savanah River Plant 1988**
- **Utilized for Most Remediation Applications by 2019**

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Environmental Applications

Sampling under obstructions

Extraction techniques

Injection techniques

Recirculating wells

Thermal treatment

Dewatering

Slope stability

CCR impoundments

Mine tailings

Groundwater production

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Access/Delivery Technology

Three Major Advantages

- **Geometry**
- **Access areas unreachable to vertical wells**
- **Minimal site impact**

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Access Technology

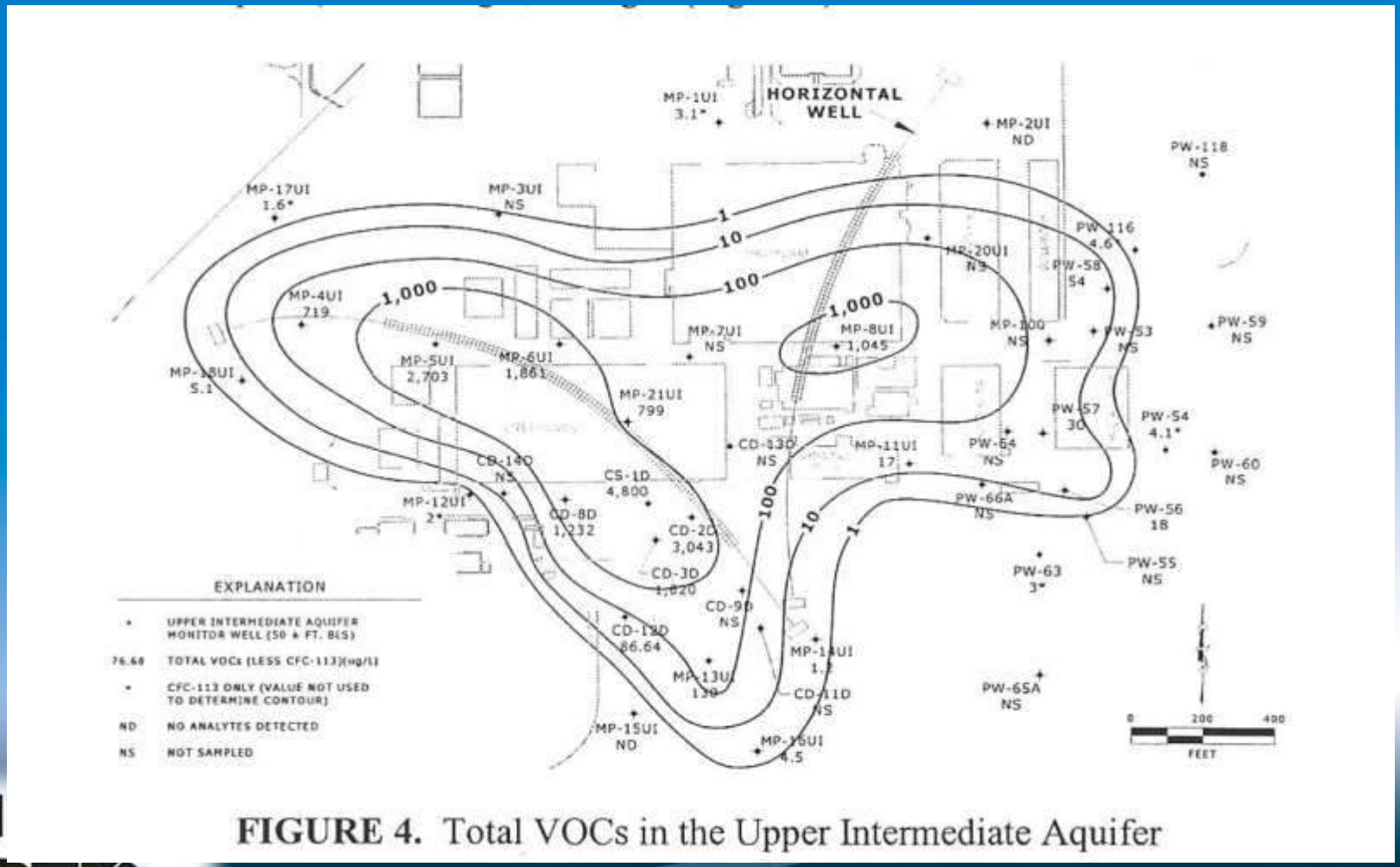

FIGURE 4. Total VOCs in the Upper Intermediate Aquifer

Directional Control

- **The bit is navigated along a prescribed path**
- **The well need not be horizontal**
- **Bore path design is based on**
  - **Treatment objective**
  - **Allowable bending radius of drill pipe and well materials**
  - **Geology**
  - **Surface constraints**

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Directional Control/Steering

- **The drill string is steered by pushing the drill pipe against an asymmetric bit with a hydraulic jet; "duck bill" or bent sub**

Directional Control/Steering

Walkover Navigation Systems

- **Walkover navigation systems**
  - **Low cost**
  - **Ease of use**
  - **Battery or wireline powered**
  - **Requires access to surface over the bore path**
  - **Depth limited to about 80’**

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Drilling Fluids

- Maintain hole stability
- Remove cuttings
- Limit drilling fluid loss to the formation
- Cool bit and steering tools
- Two types commonly utilized
  - Bentonite
  - Biodegradable polymer

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Roll Off Containers Required

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Well Construction

- **Well screen and casing**
- **No gravel pack installed**
- **Proper screen design**
- **Grouting/surface seals are critical**

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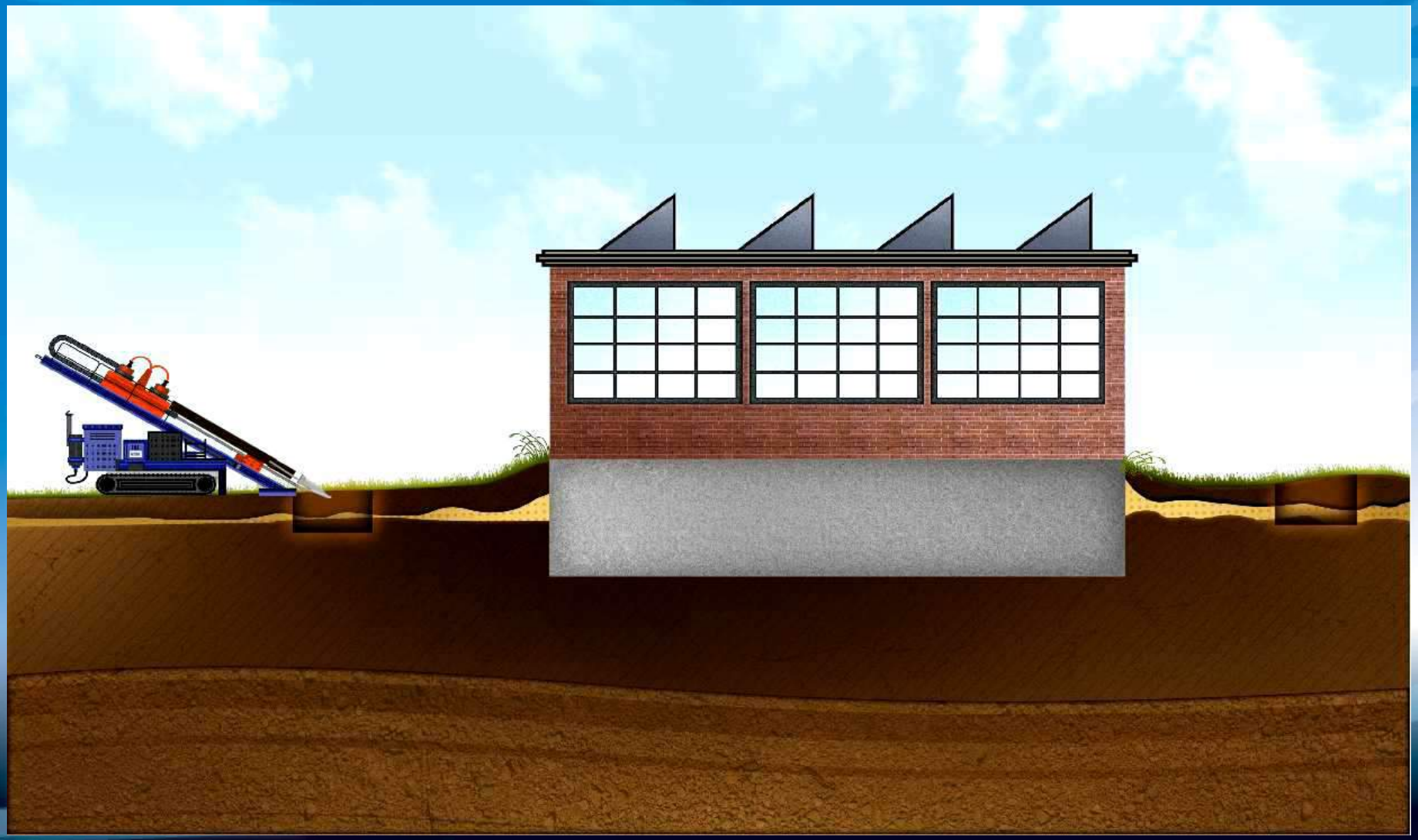
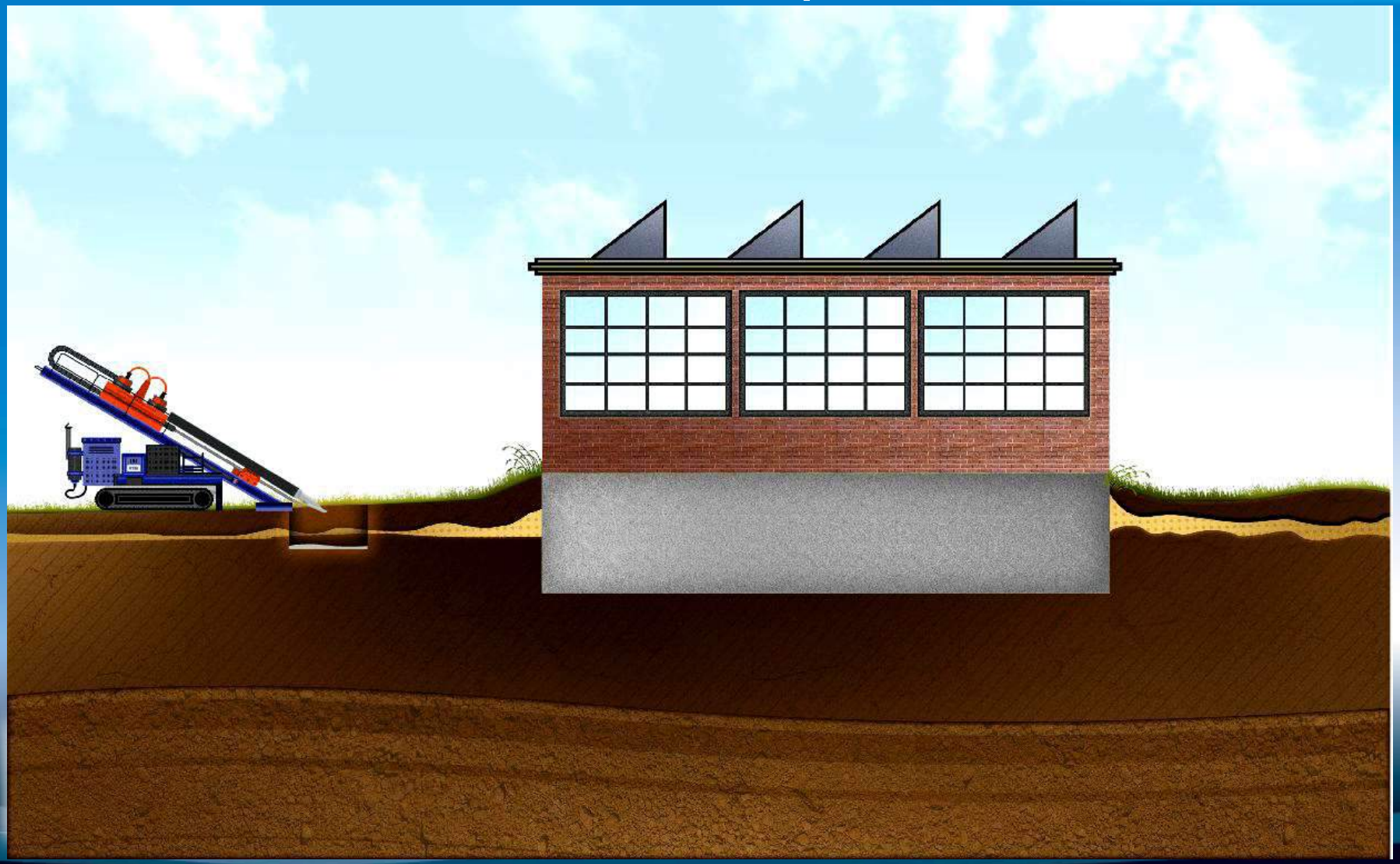
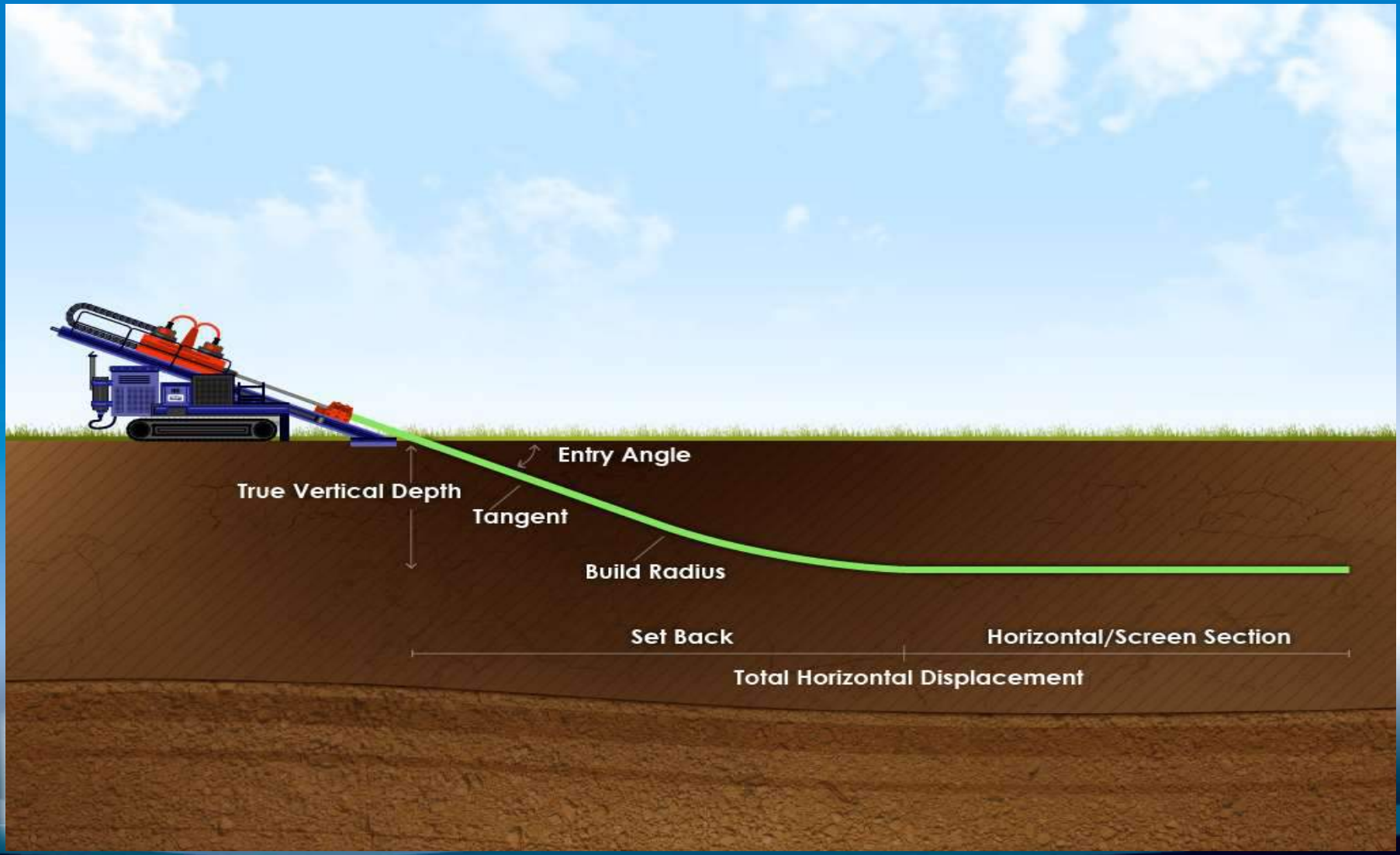
Continuous Well Installation



Blind Well Open Hole



Borepath/Well Geometry



Well Development

- **Jet/flush with fresh water**
  - **Bentonite fluids**
    - **Jet and flush with low pH/surfactant solution**
    - **Requires aggressive physical development**
    - **High pressure jetting and surging**
  - **Polymer fluids**
    - **Flush and/or jet with enzyme breaker**
- **Overpump to remove solids and clean near well formation**

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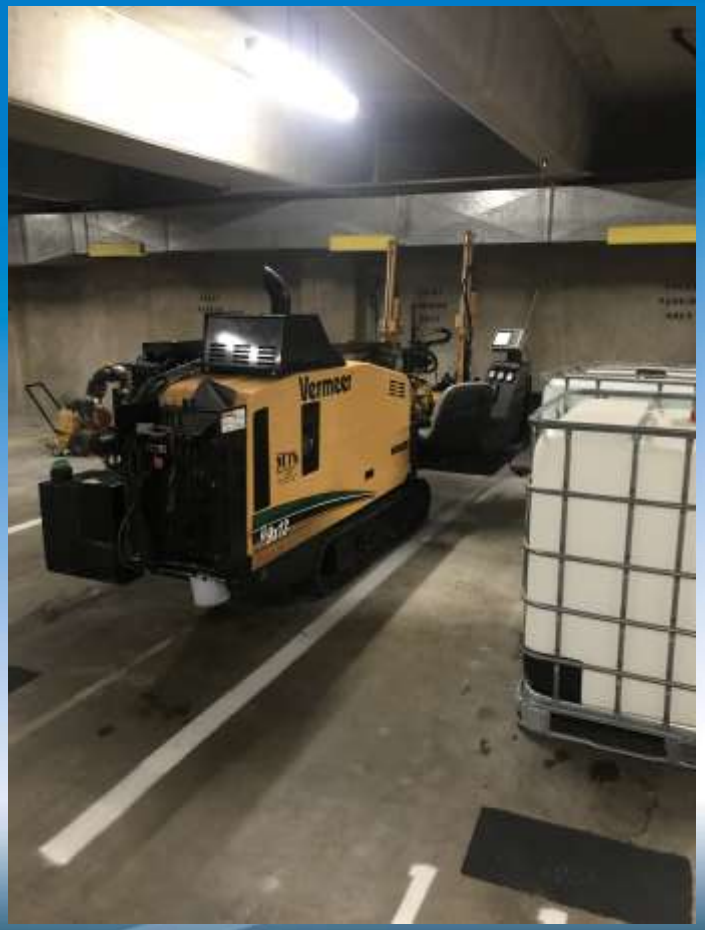
Rig Size Large

Rig Size Small

Rig Size Small



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Method Challenges

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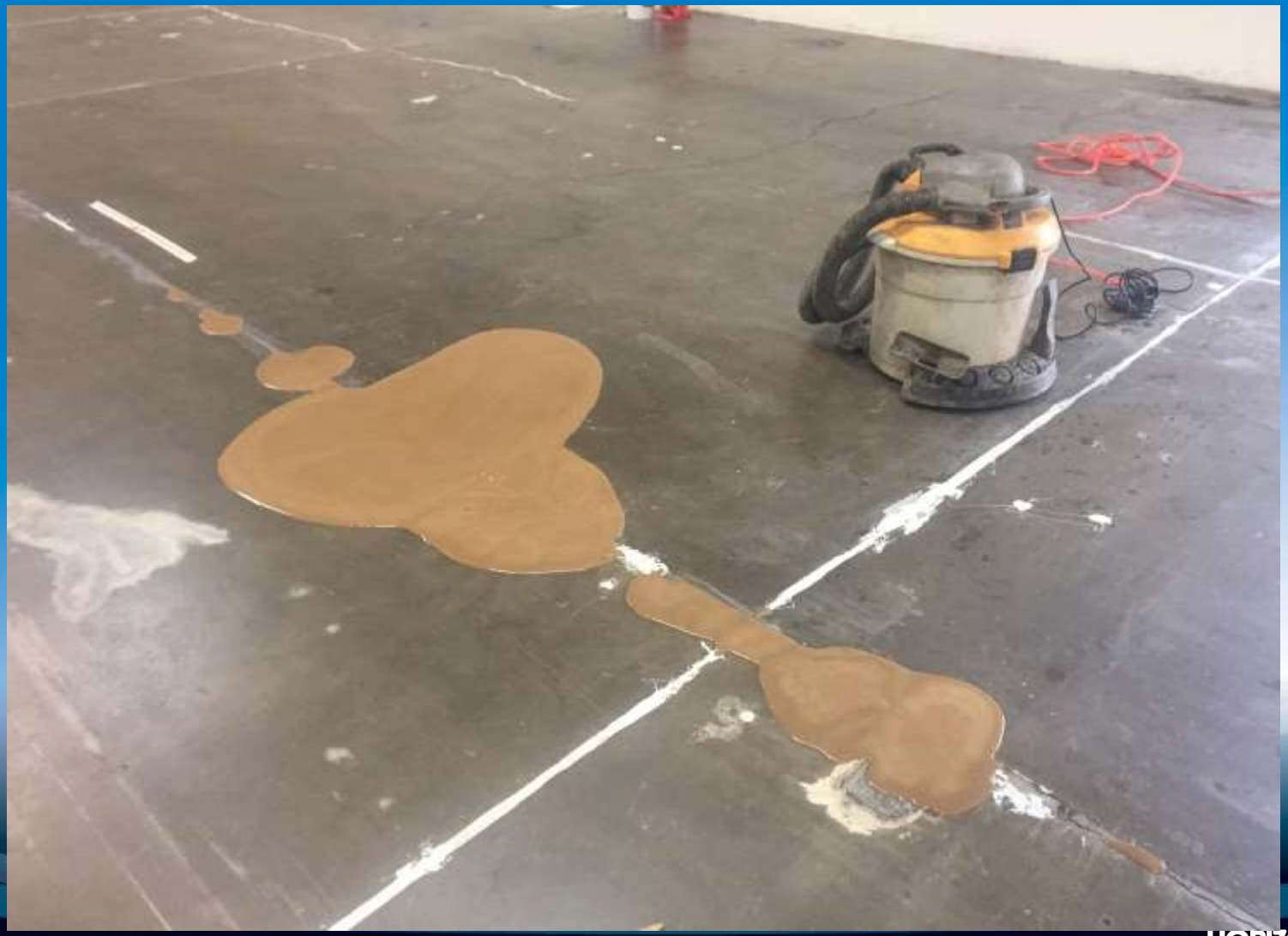
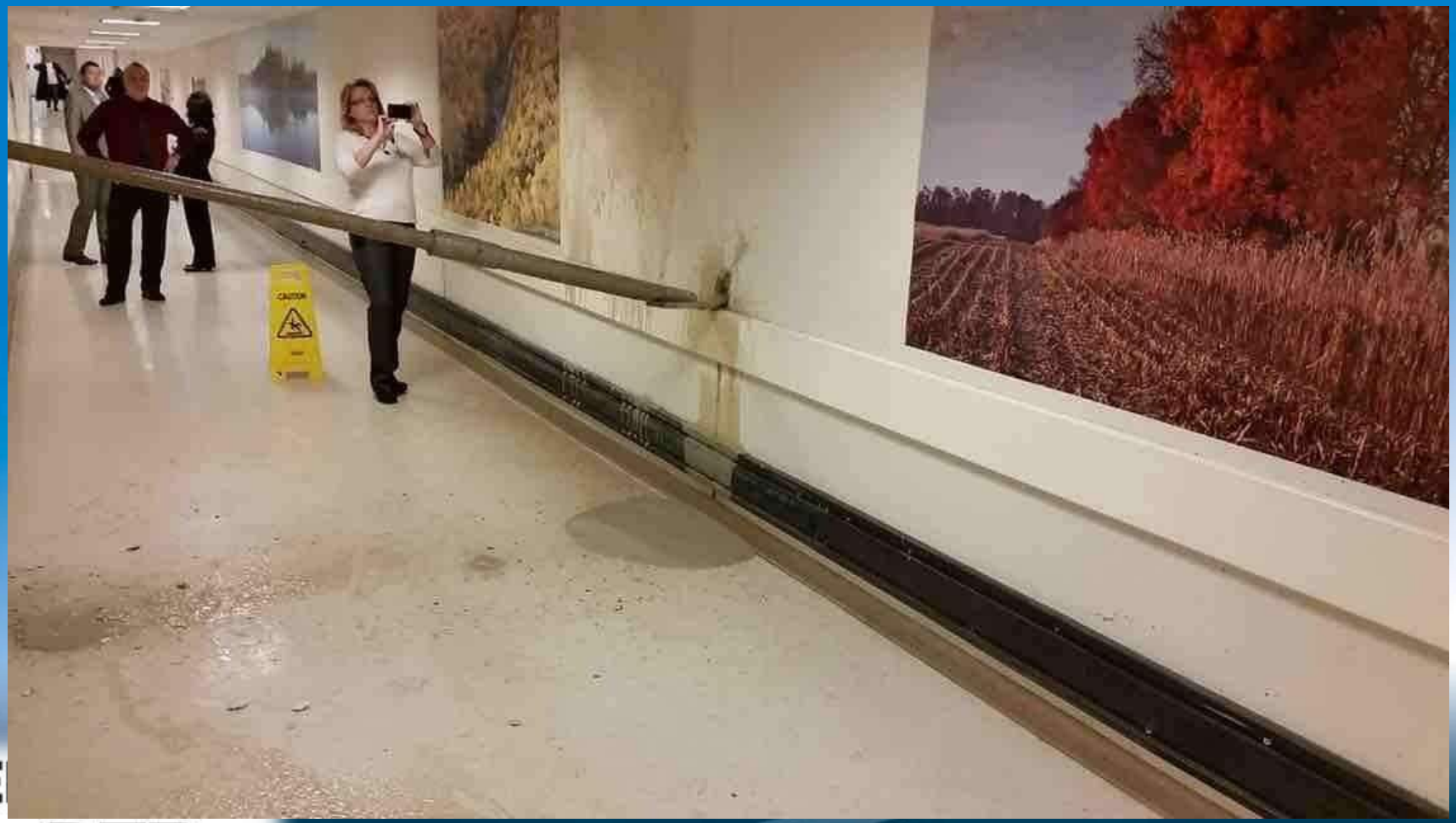
Method Challenges



Pay Attention To Utilities

My Favorite



Horizontal Injection Well Screens

- **DTD 2014 – 2019**
  - **115 Injection wells**
    - **Air**
    - **EVO**
    - **Sodium/potassium Permanganate**
    - **Sodium lactate**
    - **Sodium bicarbonate**
    - **Treated water**
    - **Oxygen enriched water**
    - **B-vitamin and nutrient-amended carbohydrate**
  - **Longest Screen 1,102' – WHAT, IT'S IMPOSSIBLE TO GET THE INJECTATE TO THE END OF A SCREEN THAT LONG; IT WILL ALL COME OUT AT THE BEGINNING!!!!!**

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Horizontal Injection Well Screen Design

- **Each screen individually designed based primarily on fluid dynamics**
- **Iterative approach comparing flow rates and pressure drop values to match design rates**
- **Fundamentals**
  - **Darcy Weisbach Equation – pipe friction**
  - **Conservation of mass – what goes in must come out**
  - **Orifice Equation**

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Horizontal Injection Well Screen Design

- **Important Data**
  - **Fluid density**
  - **Fluid viscosity**
  - **Design flow rate**
  - **Well casing and screen material**
  - **Well casing and screen diameter**
  - **Hydrostatic head**
  - **Potential biofouling**
  - **Formation back pressure – maybe…**

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Injection Screen Design?

Horizontal Injection Well Screen Design

- **Ellingson – DTD "Screenerator 2020"**
  - **Slots act differently from orifices - empirical testing**
  - **Some slots on "bottom" of screen will become blocked due to sediments**
  - **Well development varies in SVE vs. Sparge wells**
  - **Grout seal important**
  - **Soil pneumatic conductivity is constant**
  - **Iterative approach to slot design**

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Or You Can Cheat

Case Study - NJ

- New Jersey site
- Commercial metal plating facility discharged waste containing hexavalent chromium (Cr6+) onto sandy soil
- Contamination moved vertically and laterally to a municipal well field, impacting potable wells
- Well field closed
- Industrial and residential area

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Case Study - NJ

- **Phase II pilot study**
- **Utilize a blind horizontal well for sodium lactate injection**
- **Pilot study challenges**
  - **Screen depth approximately 90' bgs**
  - **850' long blind well**
  - **Sand and gravel target zone**
  - **Equal lactate distribution across 450' screen**

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Case Study - NJ

- **Well screen – 450' long, Sch. 80, 4" dia. PVC**
- **Constant slot configuration along entire screen length**
- **0.03% Open area**

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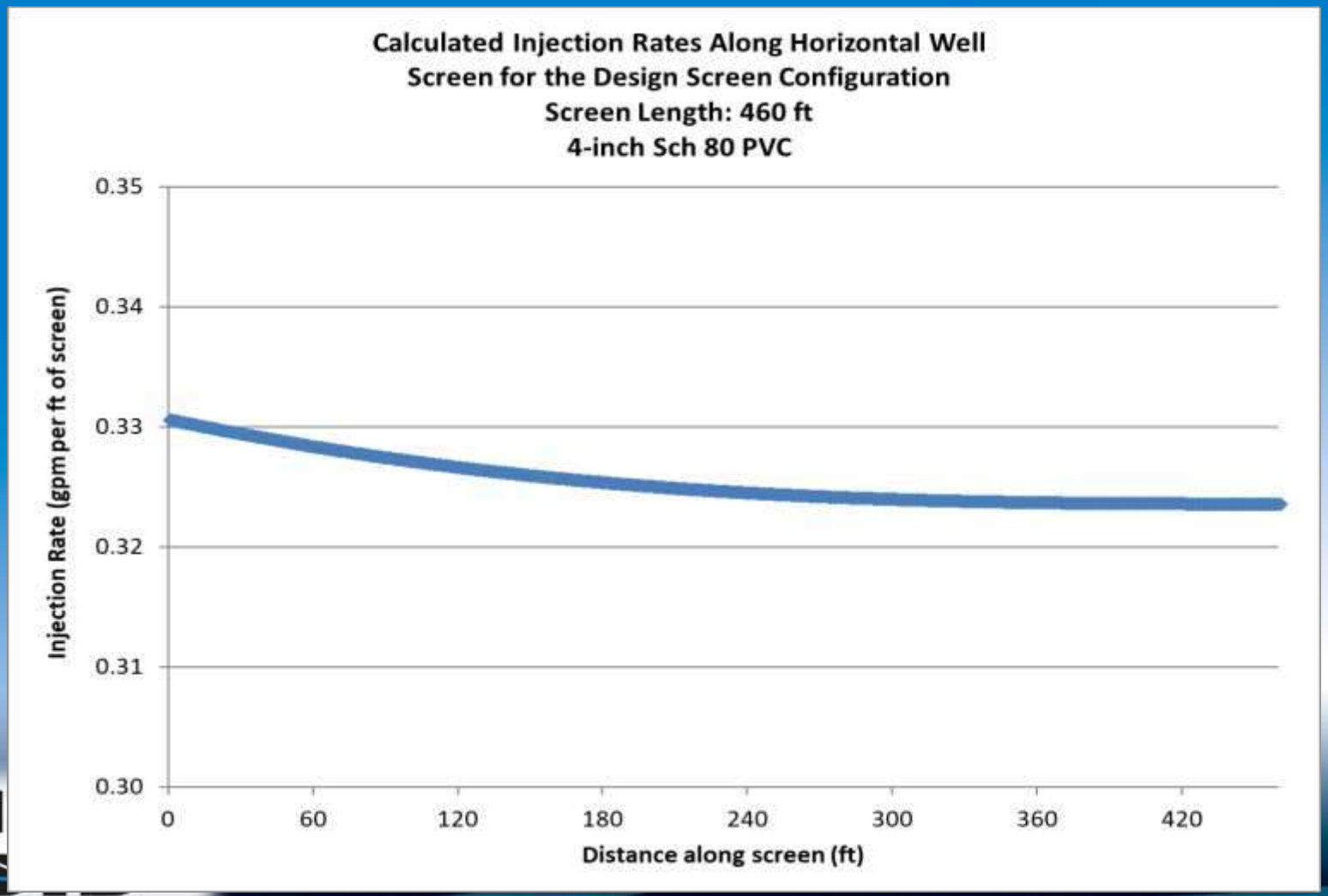
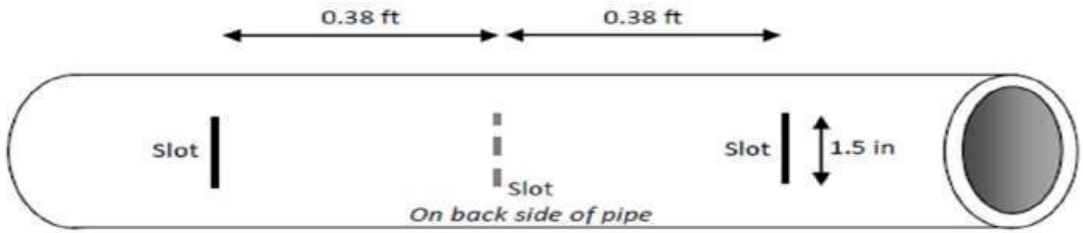
Case Study - NJ



Well Screen
Isometric View



NOTES

1) Each slot 0.01" wide x 1.5" long (typical)
2) Slots are oriented across the pipe
3) Two rows of slots
4) Each row has slots spaced on 0.76 ft centers
5) Rows spaced 180 degrees apart in cross-section, with slots in opposite rows offset by 0.38 ft

Well Screen
End View

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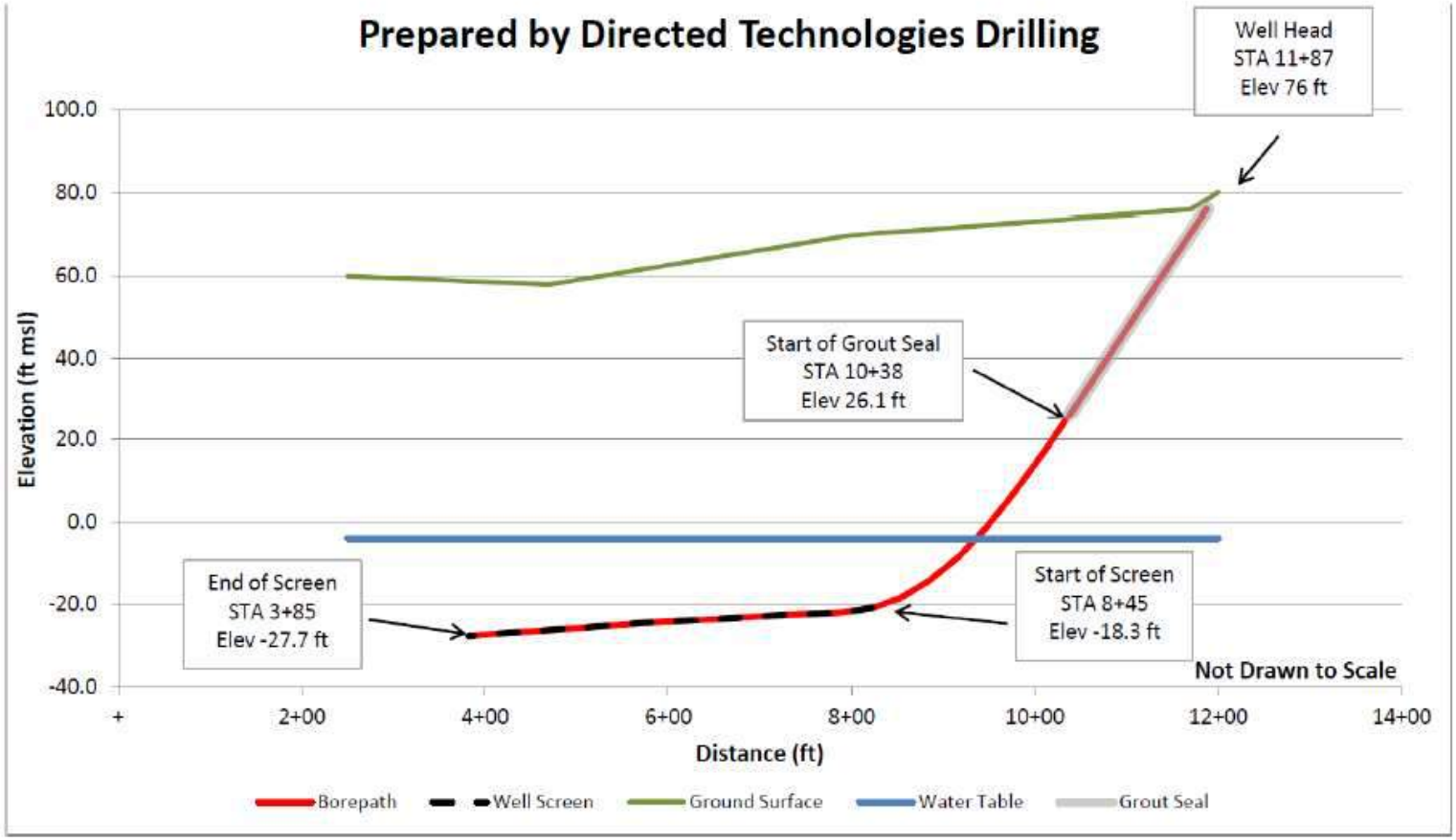
Case Study - NJ

Phase II Pilot Study – As-Built



Case Study – NJ Results

- **Lactate injection**
- **6% Sodium lactate**
  - **Density 11.13 ppg**
- **July 15, 2015 – August 5, 2015**
- **22,132 gallons**
- **245,329 pounds**

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Case Study Results - NJ

- **Lessons learned**
  - **Well performed as designed**
    - **Gravity flow**
    - **Anticipated backpressure**
    - **No biofouling**
  - **Lactate was distributed along the entire length of the well**
  - **Formation permeability drives injectate distribution in the formation**

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Case Study - FL

- Former DOE weapons program facility
- Tampa Florida area
- Building 100, approximately 11 acres
- Solvent release from drains and drum storage area
- Commercial use with restricted areas within building.

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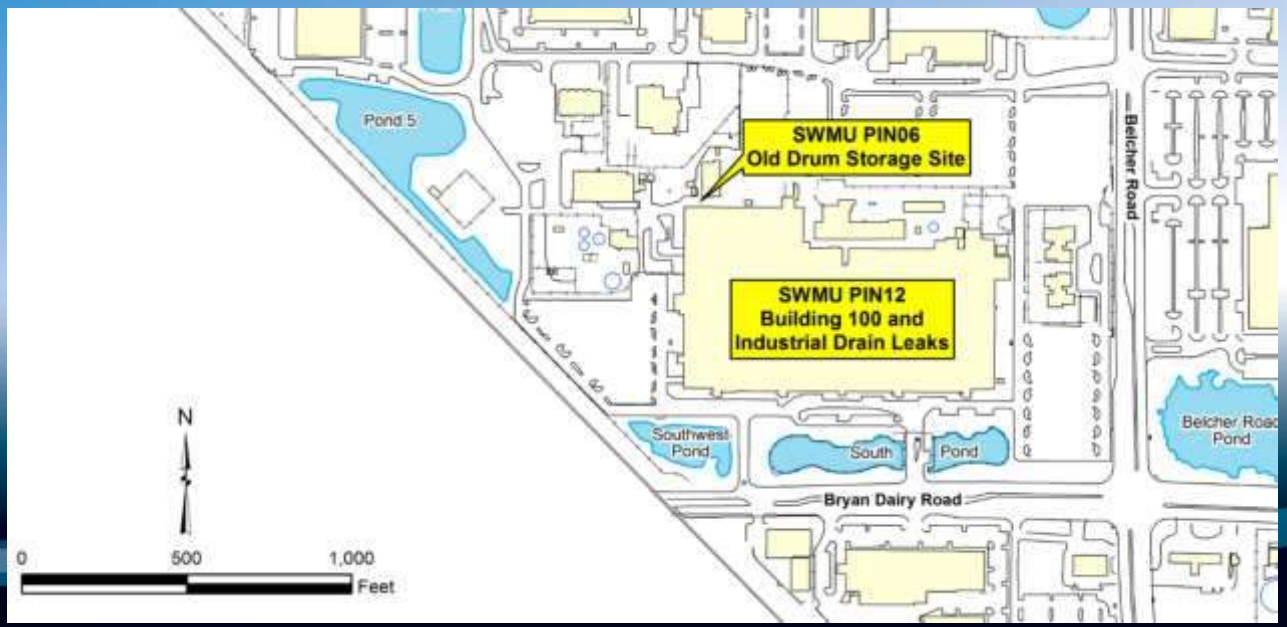

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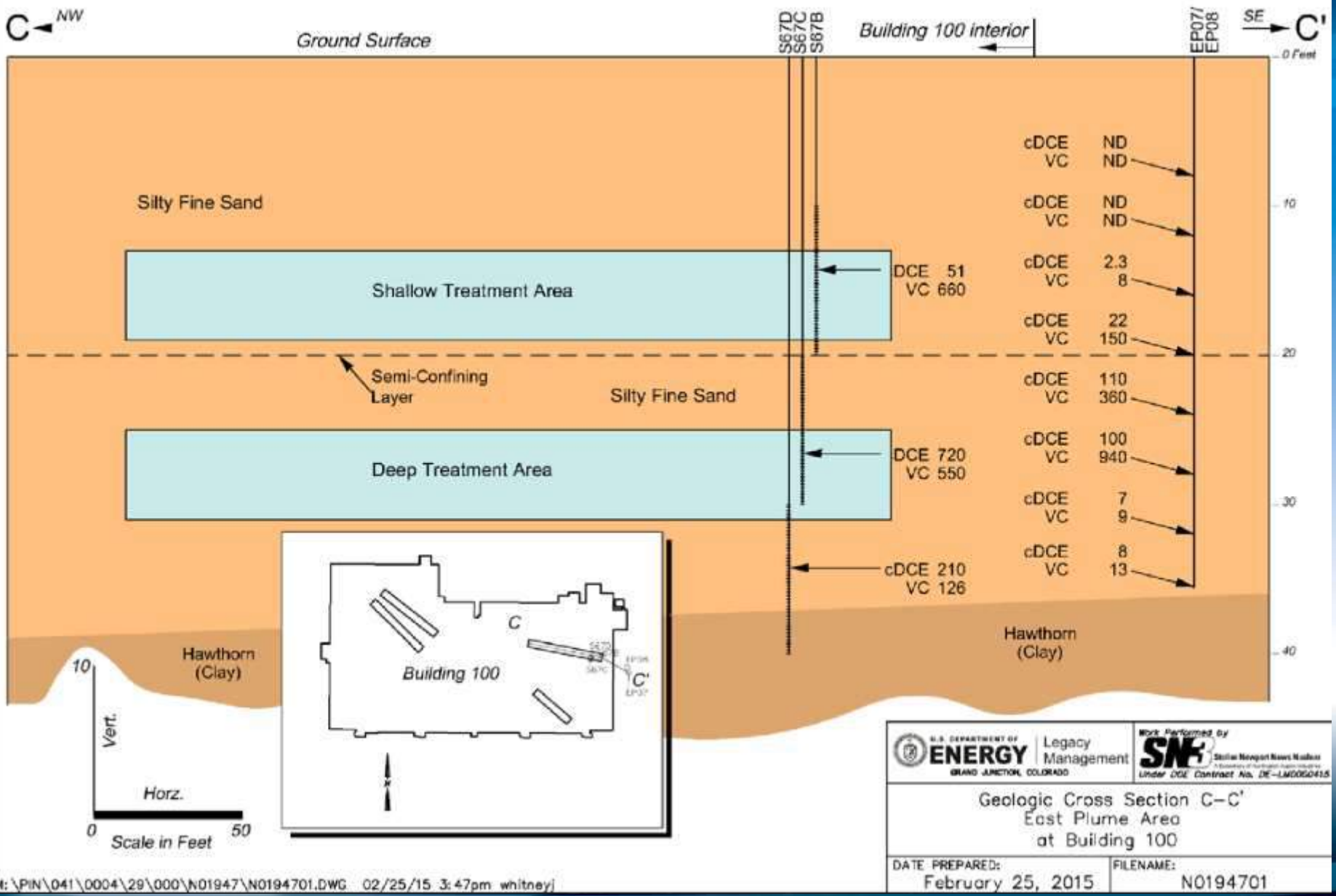
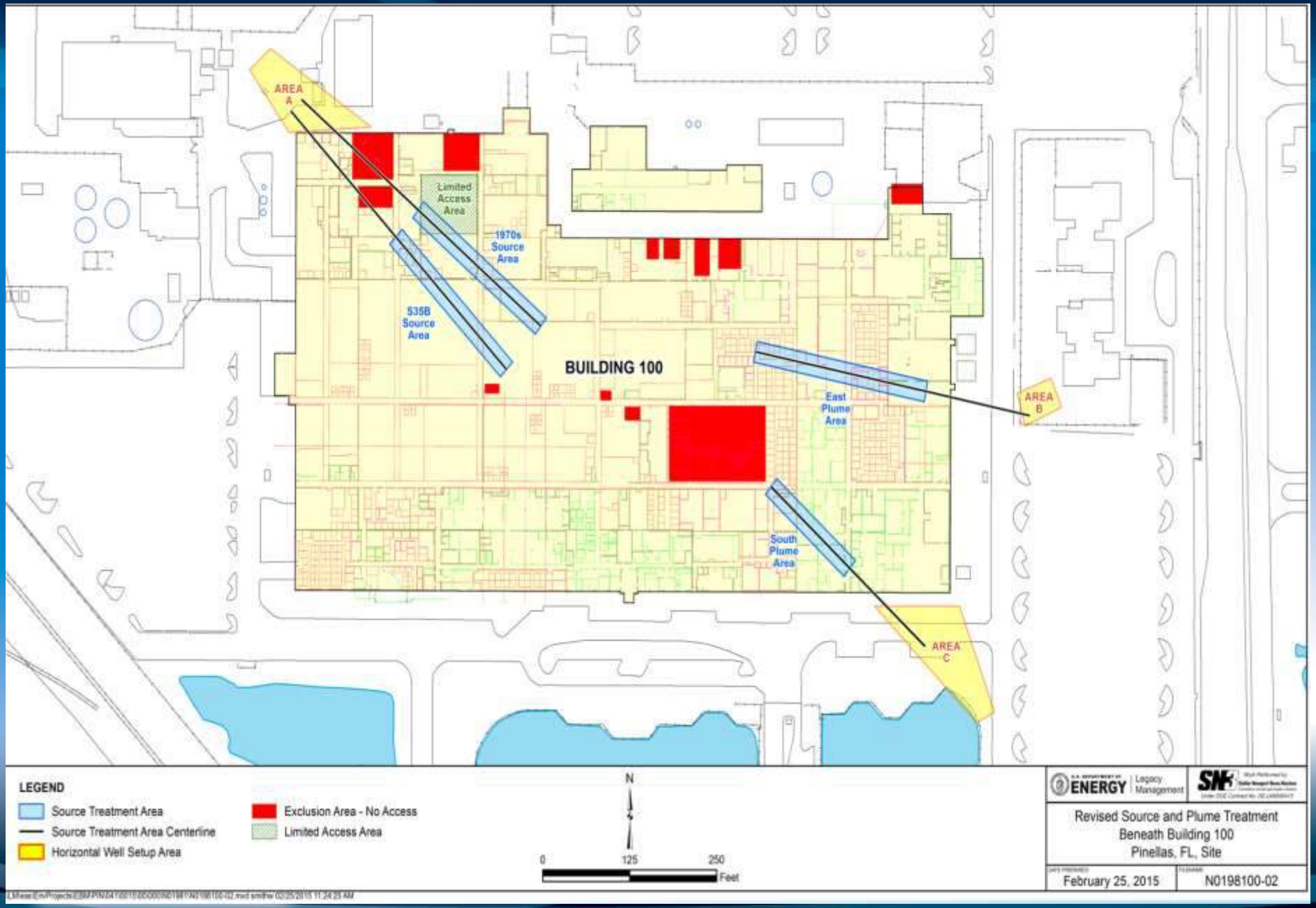
Case Study - FL

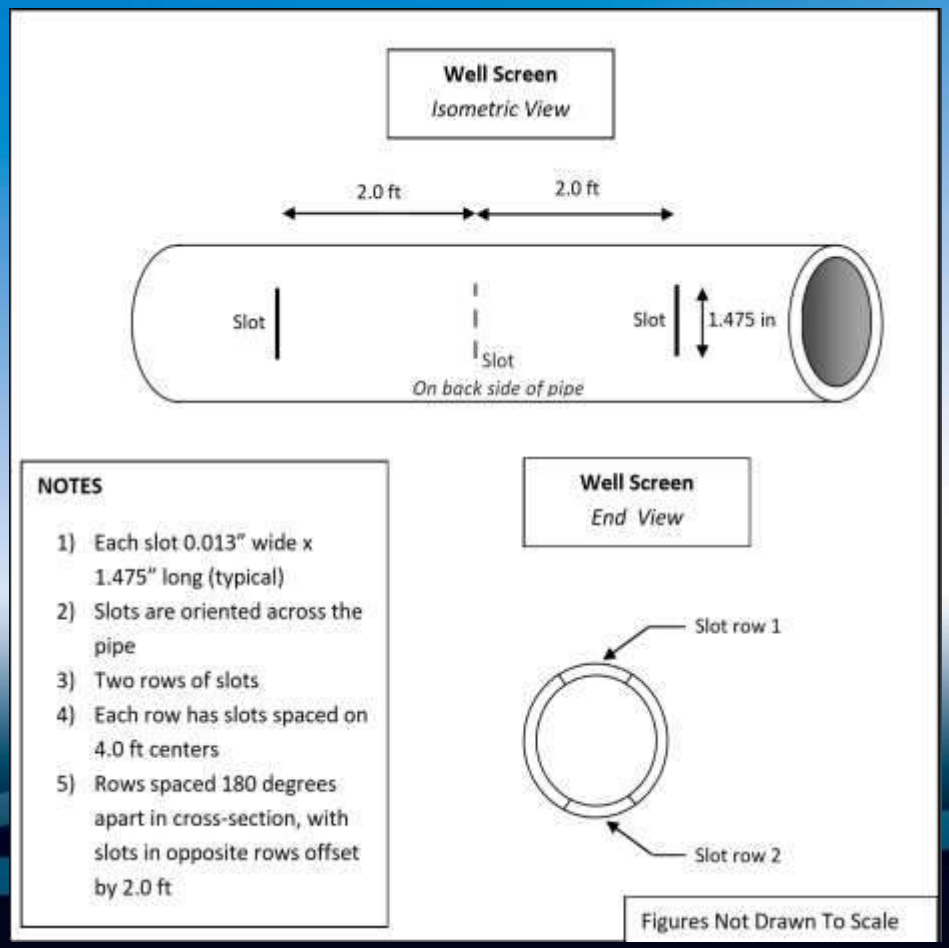
- Chlorinated solvent plume
- Horizontal injection wells under building
- Substrate
  - Emulsified vegetable oil (EVO)
  - Dehalococcoides mccartyi (DHM; formerly known as Dehalococcoides ethenogenes)



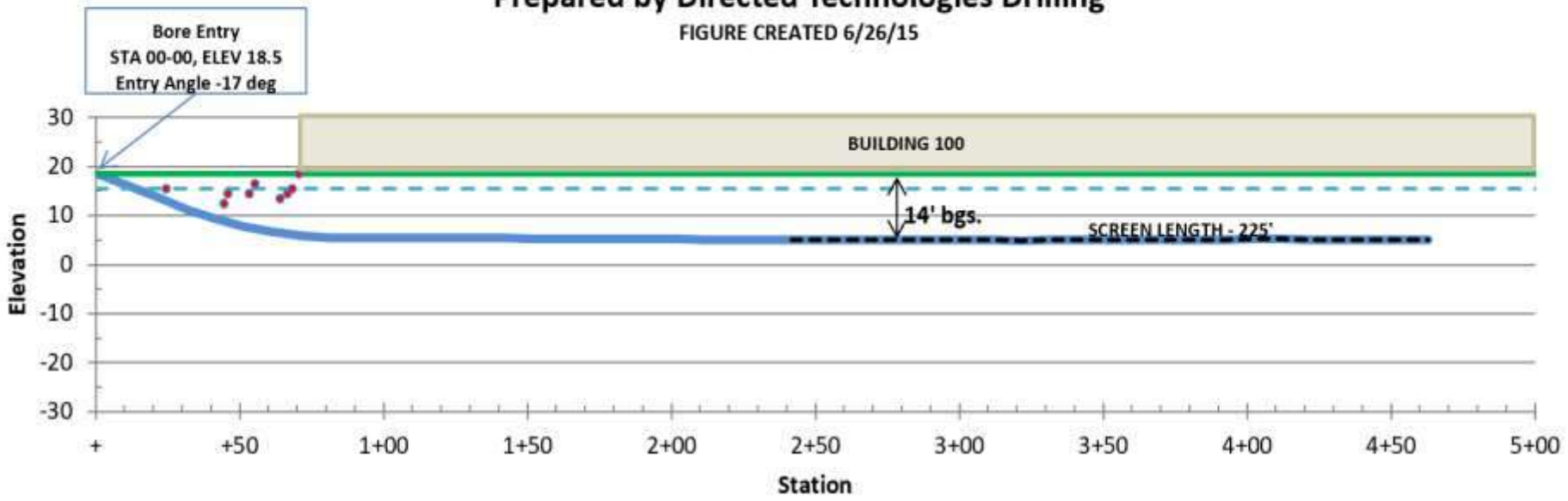


Case Study - FL

- Screen design
- 3” Diameter fiberglass screen
- 75 gpm design flow rate
- ~ 16 psi operating pressure
- 0.136% open area



3-inch Diameter FRE Well
Prepared by Directed Technologies Drilling
FIGURE CREATED 6/26/15



BORE NOTES:
Well Length - 452'
Horizontal Length - 450'
Screen Length - 225'
Start of Screen - STA 2+25, 14' bgs
End of Screen - STA 4+50, 14' bgs

Bore Plan Screen Approx Ground Surface Utilities Water Table

Case Study - FL

- **Injection 30 Oct – 18 Nov 2015**
- **9:1 Water to EVO**
- **23 gpm injection rate**
- **Pressure 0 – 15 psi**
- **3 Casing volumes of fresh water**

Well	Depth (ft below floor surface)	Slotted Interval Length (ft)	Total Well Length (ft)	Total Injected Volume (gallons)
PIN12-HW01	13.3	225	463	6,746
PIN12-HW02	29.2	225	468	6,750
PIN12-HW03	13.4	225	448	6,735
PIN12-HW04	31.9	225	456	6,782
PIN12-HW05	15.8	250	415	7,550
PIN12-HW06	26.9	250	417	7,550
PIN12-HW07	20.9	150	344	4,450
PIN12-HW08	29.0	150	348	4,450
			Total:	51,013

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Case Study - FL

- **Florida Case Study Data From US Department of Energy – Legacy Management**
  - **Bioinjection Performance Review for the Building 100 Area and 4.5 Acre Site at the Pinellas County, Florida, Site**
  - **Pinellas County, Florida, Site Environmental Restoration Project Sitewide Environmental Monitoring Semiannual Progress Report for the Young - Rainey STAR Center June Through November 2016**

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In Summary

- **The technology is innovative - not experimental**
- **Horizontal injection wells are a proven, cost effective installation method**
- **Screen design is science**
- **Hundreds of wells have been successfully completed in the US**
- **The technology is innovative – not experimental**

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Contact Information

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