

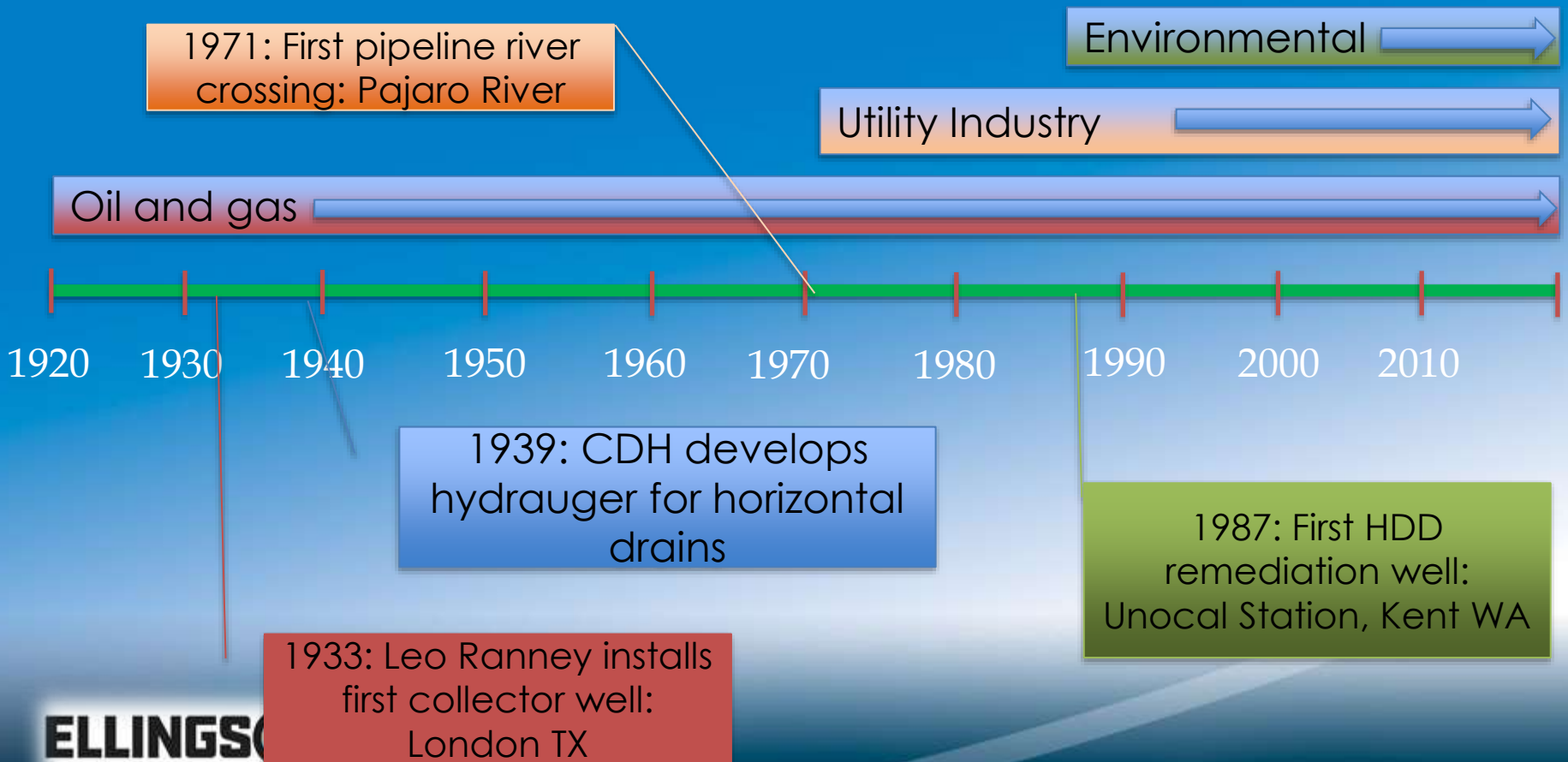
Optimization and Monitoring of Chlorinated and Related Compounds

April 2020

**Horizontal Directional Drilling and Well
Installation for Substrate Injection**



The History of Horizontal Wells, or: "How I learned to stop worrying and love drilling crooked on purpose."



Horizontal wells have since been used for most every environmental application since.



Horizontal wells offer three access technology benefits.

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

All three advantages at one site.

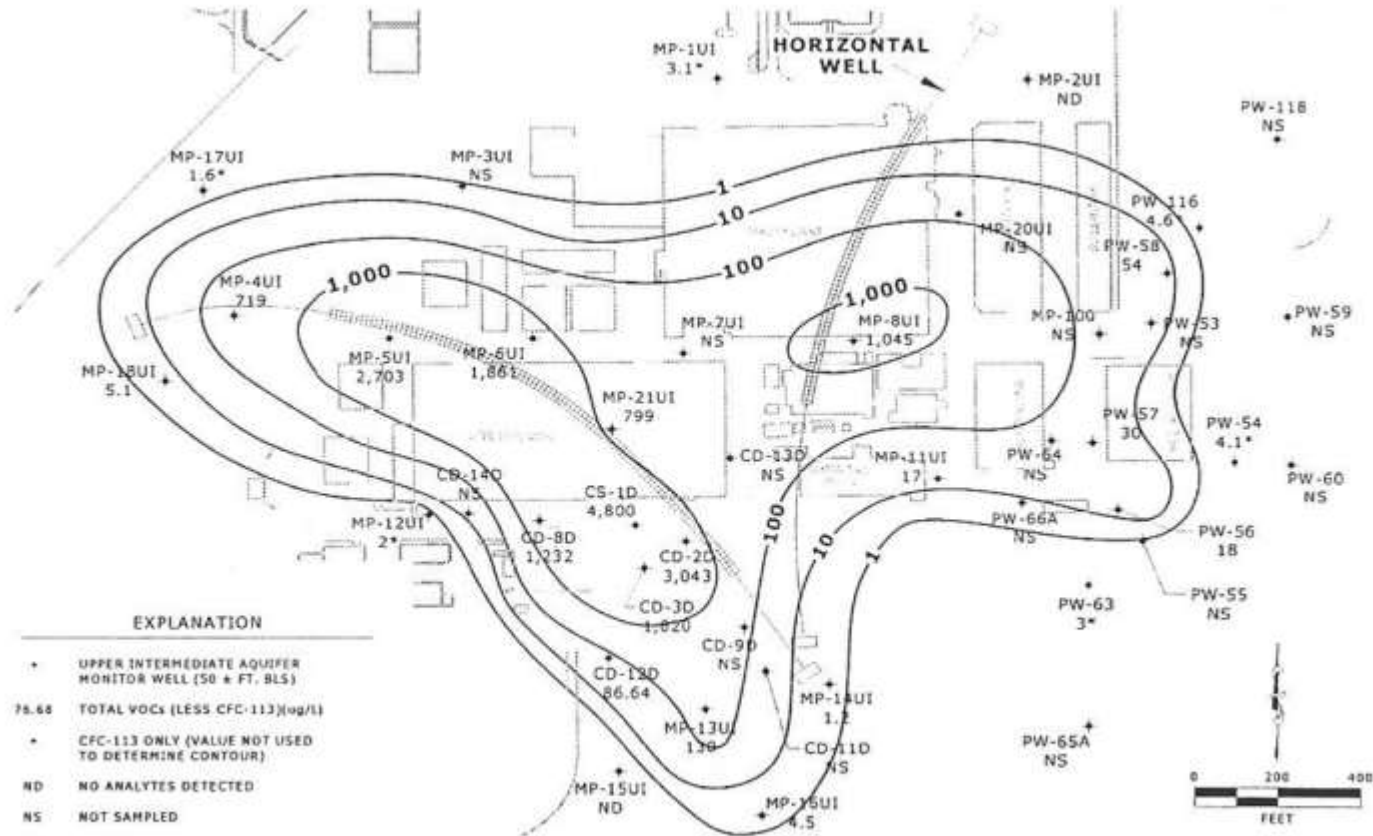
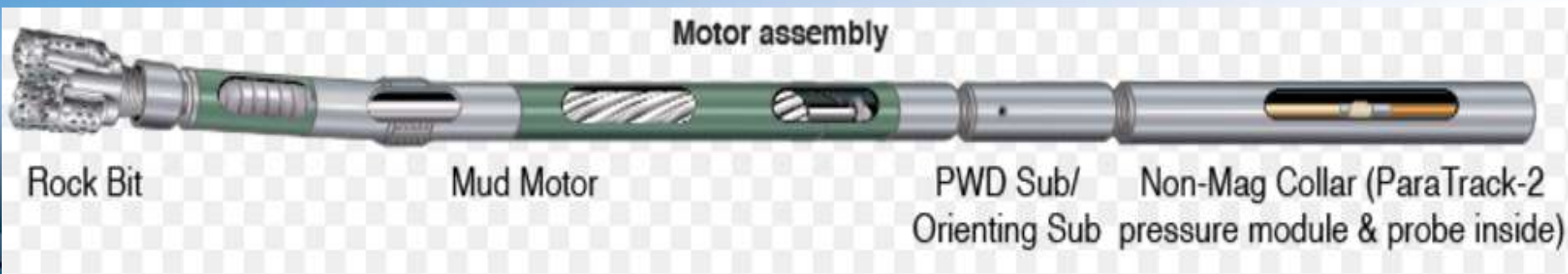


FIGURE 4. Total VOCs in the Upper Intermediate Aquifer

Asymmetry in the bit allows steering in three dimensions.





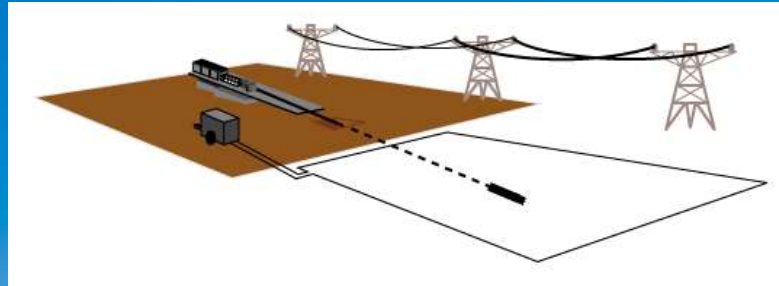
ELLINGSON
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Horizontaldrill.com

There are three basic locating technologies available.



Walkover



Wireline



Gyroscope

Walkover is adequate for most environmental projects.



Drilling fluids are required and serve several key functions.

Borehole Stability

Remove Cuttings

Prevent Fluid Loss

Cool/Lubricate

There are two commonly used types of drilling fluid:

Bentonite

Biopolymer



Roll Off Containers Required



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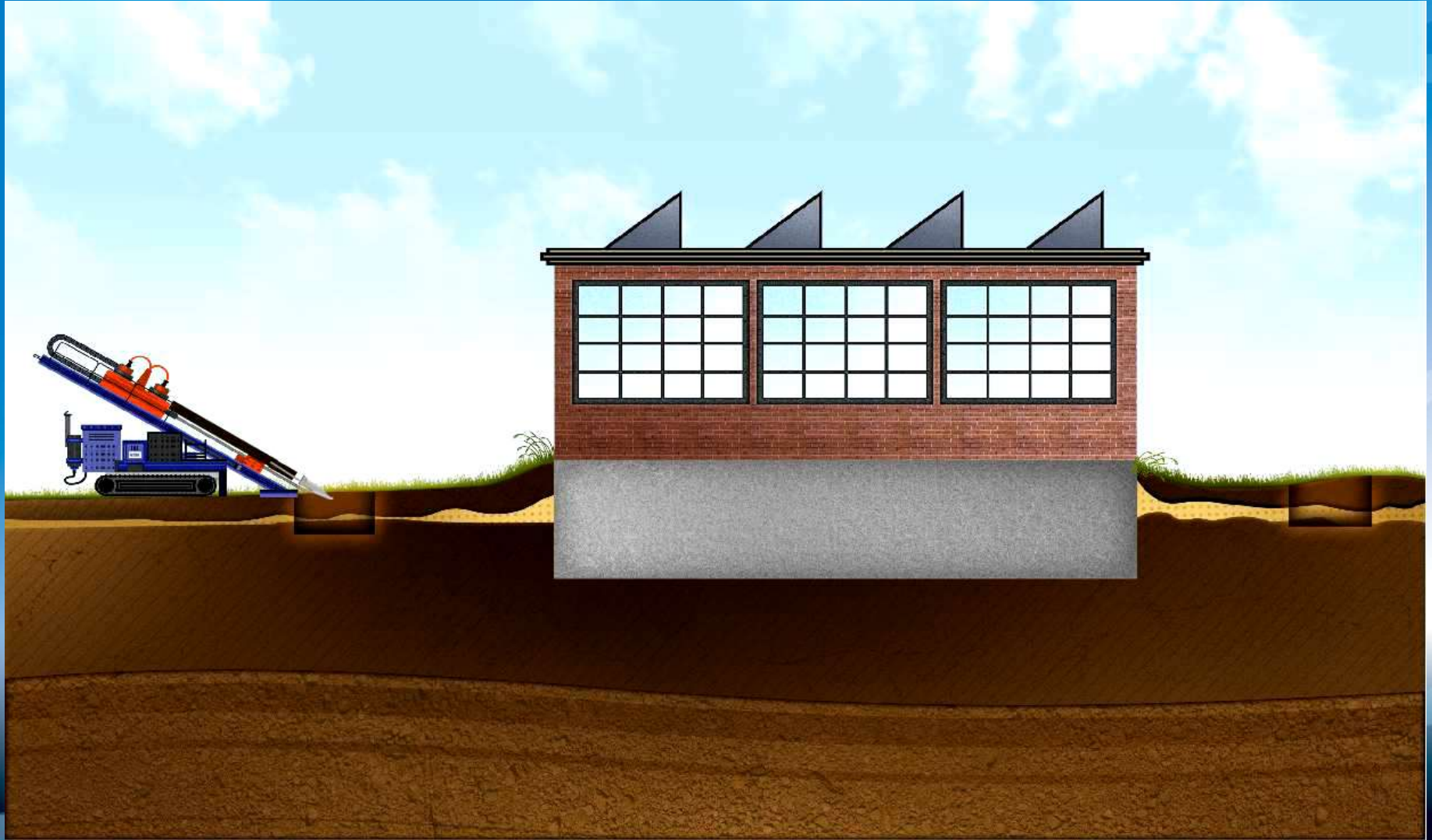
HDD wells are (mostly) made of the same materials as traditional vertical wells.



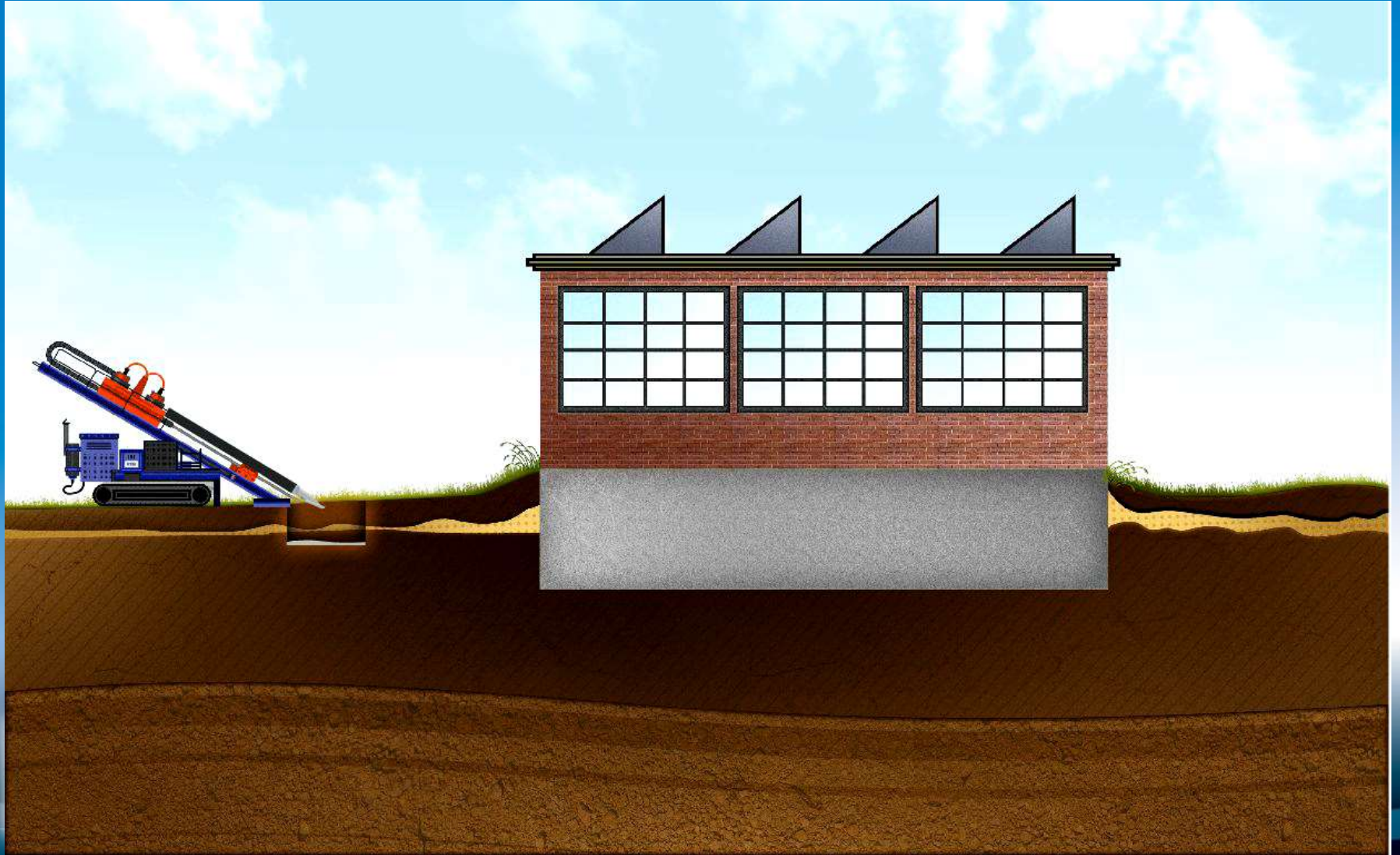
HDD wells do not use artificial filter packs.



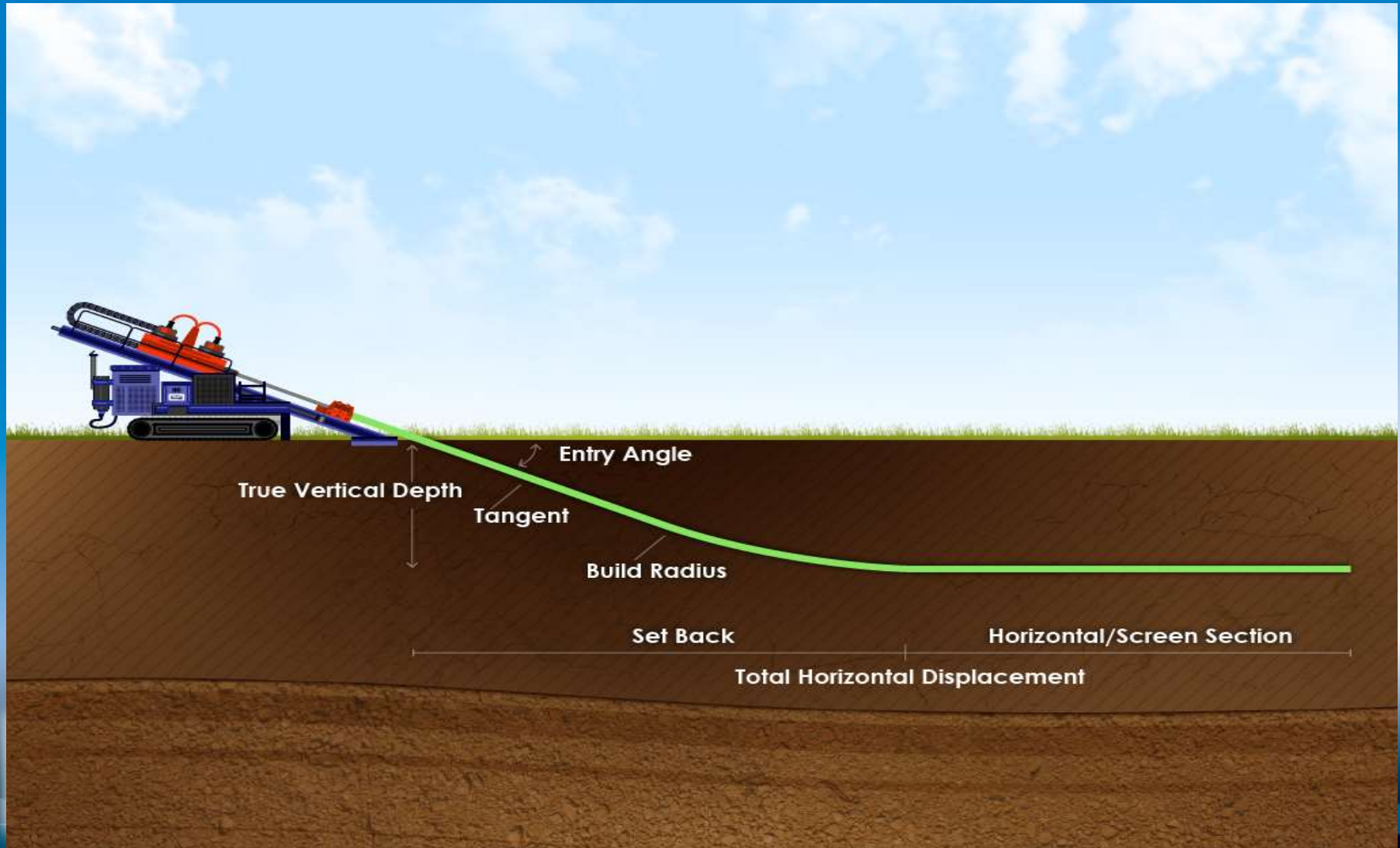
Continuous Well Installation



Blind Well Open Hole



Borepath/Well Geometry



Flushing/jetting and overpumping are the primary well development methods.



Rig size determines well length/diameter limitations.



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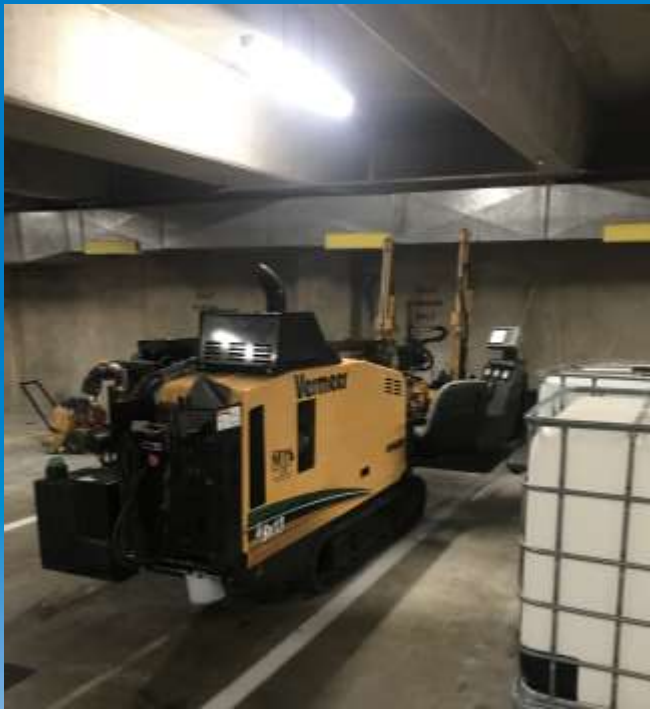
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Big rigs have a big footprint!



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There are limited access rigs too for tighter sites.



Horizontal wells are used for a variety of injection applications.

- **DTD 2014 – 2020**

- 127 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!!!!**



“Off the shelf” well screen has too much open area.



Fluid dynamics is the basis for 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

It's "basic" fluid dynamics...and a practical solution can be found iteratively.

B7 0.00166

Input Data in Green Cells			
Flow rate, Q	150	gpm (total)	
Injection fluid density, ρ	1.95	slugs/ft ³	
Depth of screen below water table	50	ft	
Hydraulic conductivity, K	1.66E-03	ft/sec	
Bore hole diameter	12	in	
Screen slot length	2	in	
Screen slot width	0.01	in	
Screen diameter	3.786	in	
Orifice coefficient for slot discharge eqn.	0.6		
Length of screen	450	ft	
Length of casing	400	ft	
Equivalent pipe roughness, ϵ	5.00E-06	ft	
dynamic viscosity of fluid, μ	2.34E-05	lb s/ft ²	
Desired injection pump operating pressure	300	psig	
Calculations			
Flow rate, Q	0.334225	cfs total	
Pipe pressure at start of screen	100	psi	
Cross-Sectional area of pipe	0.078179	ft ²	
flow rate	0.000743	cfs per foot	
area	3.14	ft ²	
K	150	ft/day	
K	0.001736	ft/sec	

Orifice flow per foot (gpm)	Flow down pipe (cfs)	pipe velocity (ft)	Re	e/d	friction factor	Head loss thru section	Pipe pressure at end of section
0.3383006	0.3335	4.2955	1.12E+05	0.0000	0.0175	0.0156	144.6584
0.3382435	0.3327	4.2558	1.12E+05	0.0000	0.0175	0.0156	144.6829
0.3383104	0.3330	4.2462	1.12E+05	0.0000	0.0175	0.0155	144.6673
0.3382754	0.3312	4.2366	1.11E+05	0.0000	0.0175	0.0155	144.6519
0.3382404	0.3305	4.2269	1.11E+05	0.0000	0.0175	0.0154	144.6365
0.3382056	0.3297	4.2173	1.11E+05	0.0000	0.0175	0.0153	144.6212
0.3381708	0.3289	4.2076	1.11E+05	0.0000	0.0175	0.0153	144.6059
0.3381361	0.3282	4.1980	1.10E+05	0.0000	0.0175	0.0152	144.5907
0.3381015	0.3274	4.1884	1.10E+05	0.0000	0.0175	0.0151	144.5756
0.3380670	0.3267	4.1787	1.10E+05	0.0000	0.0175	0.0151	144.5605
0.3380325	0.3259	4.1691	1.10E+05	0.0000	0.0176	0.0150	144.5455
0.3379981	0.3252	4.1595	1.09E+05	0.0000	0.0176	0.0150	144.5305

a	0.000015		
a-total	0.00675	area	1.178097

e/d	friction factor	Head loss thru section	Pipe pressure at end of section	Outside screen pressure	Orifice area	slot length (in)	Pipe Pressure (psi)	slot open area (in ²)
0.0000	0.0175	0.0156	144.6584	16.0	0.000108	1.551	63.1	0.0155
0.0000	0.0175	0.0156	144.6829	18.0	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0155	144.6673	18.0	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0155	144.6519	18.0	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0154	144.6365	18.0	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0153	144.6212	16.1	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0153	144.6059	16.1	0.000108	1.552	63.1	0.0155
0.0000	0.0175	0.0152	144.5907	16.1	0.000108	1.553	63.1	0.0155
0.0000	0.0175	0.0151	144.5755	16.1	0.000108	1.553	63.0	0.0155
0.0000	0.0175	0.0151	144.5604	16.1	0.000108	1.553	63.0	0.0155
0.0000	0.0175	0.0150	144.5454	16.1	0.000108	1.553	63.0	0.0155
0.0000	0.0176	0.0150	144.5305	16.1	0.000108	1.553	63.0	0.0155

Sheet1 Sheet2 Sheet3 Sheet2 (2) Chart1 Ch

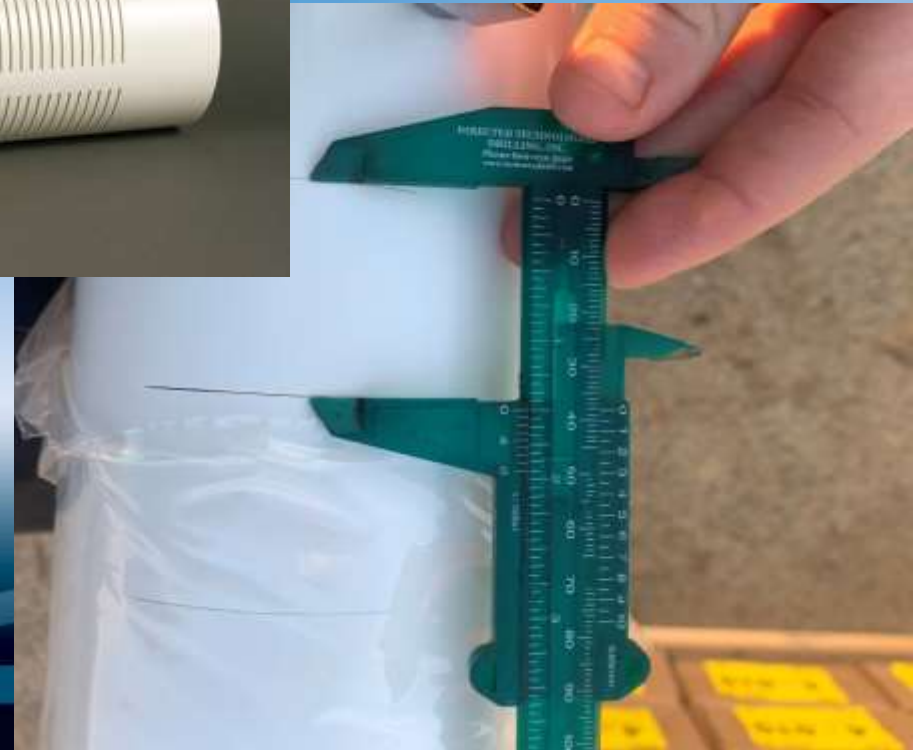
Farmers can do it.



Or You Can Cheat



Custom slotted screen limits open area to reduce pressure loss along length of screen.



Site background: chrome plating facility impacted neighboring well field.



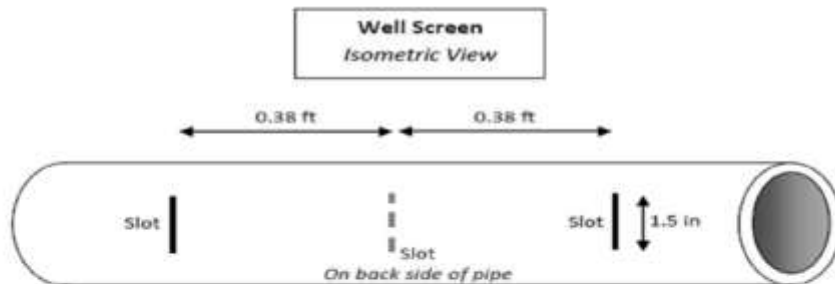
Pilot study objective: blind horizontal injection well to deliver sodium lactate (gravity feed).



Well Construction Details

Construction material:	4" dia SCH80 PVC
Total measured length:	850ft
Total vertical depth:	90ft BGS
Length of screen:	450ft
Slot dimensions:	0.010" slots, 1.5" long
Slot pattern:	2 rows, 0.76ft centers
Open area:	0.03%

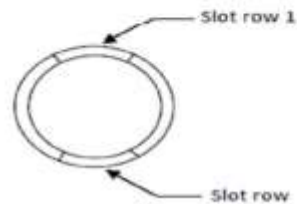
Open area of a slot is calculated based on the INSIDE dimensions.



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

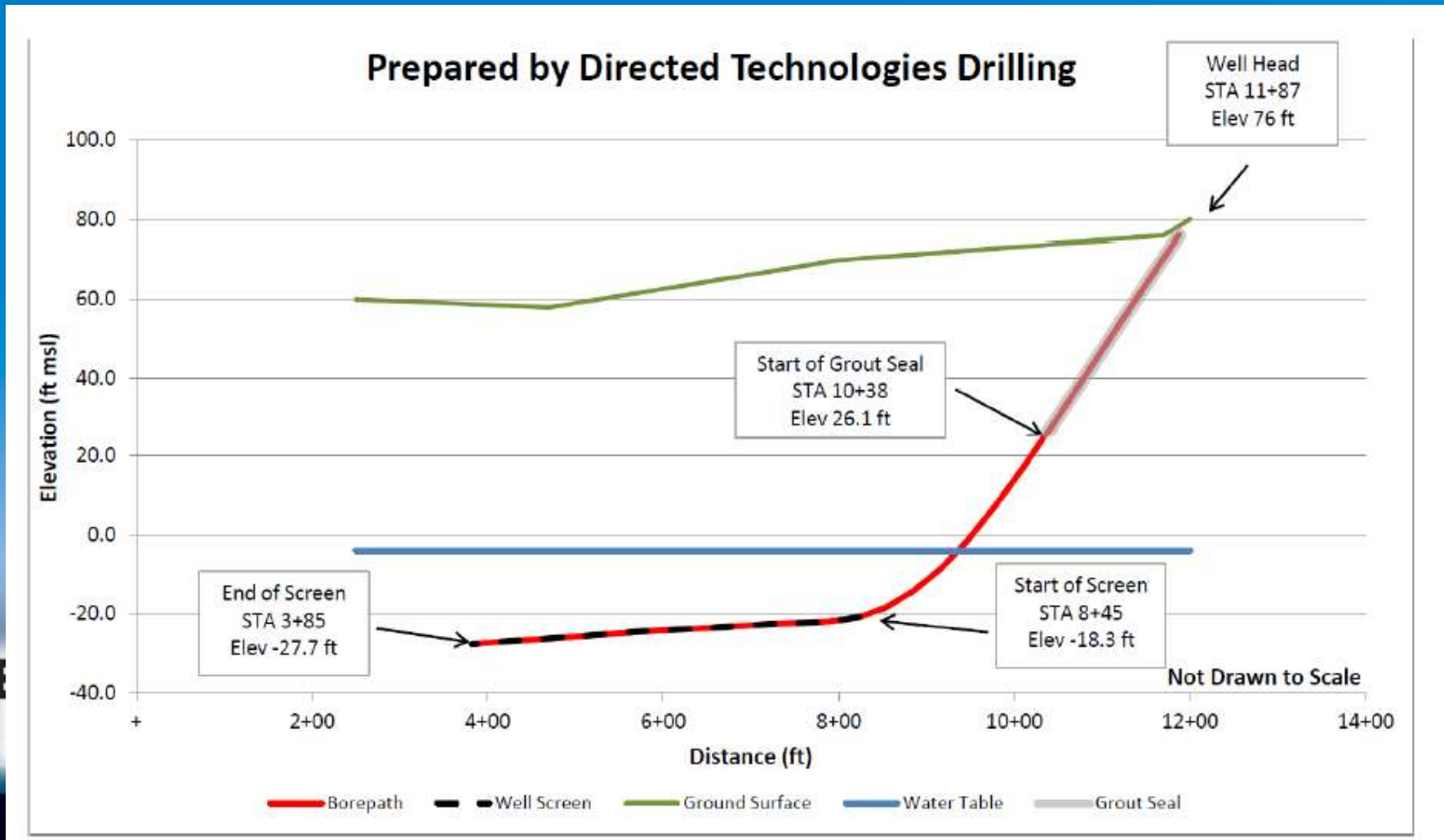
Well Screen End View



Figures Not Drawn To Scale



Well screen was slightly dipping to follow geology.



Injection Summary

Amendment:	6% Sodium Lactate
Volume:	22,132gal (245,329lbs)
Pressure/flow:	Gravity feed
Event duration:	July 15 – Aug 5, 2015
Distribution along entire screen?	Confirmed by DO data in MWs

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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