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Adaptive Injection Strategies for Zero Valent Iron and In-Situ Bioremediation in a Complex Geologic Setting

Lessons Learned and New Techniques

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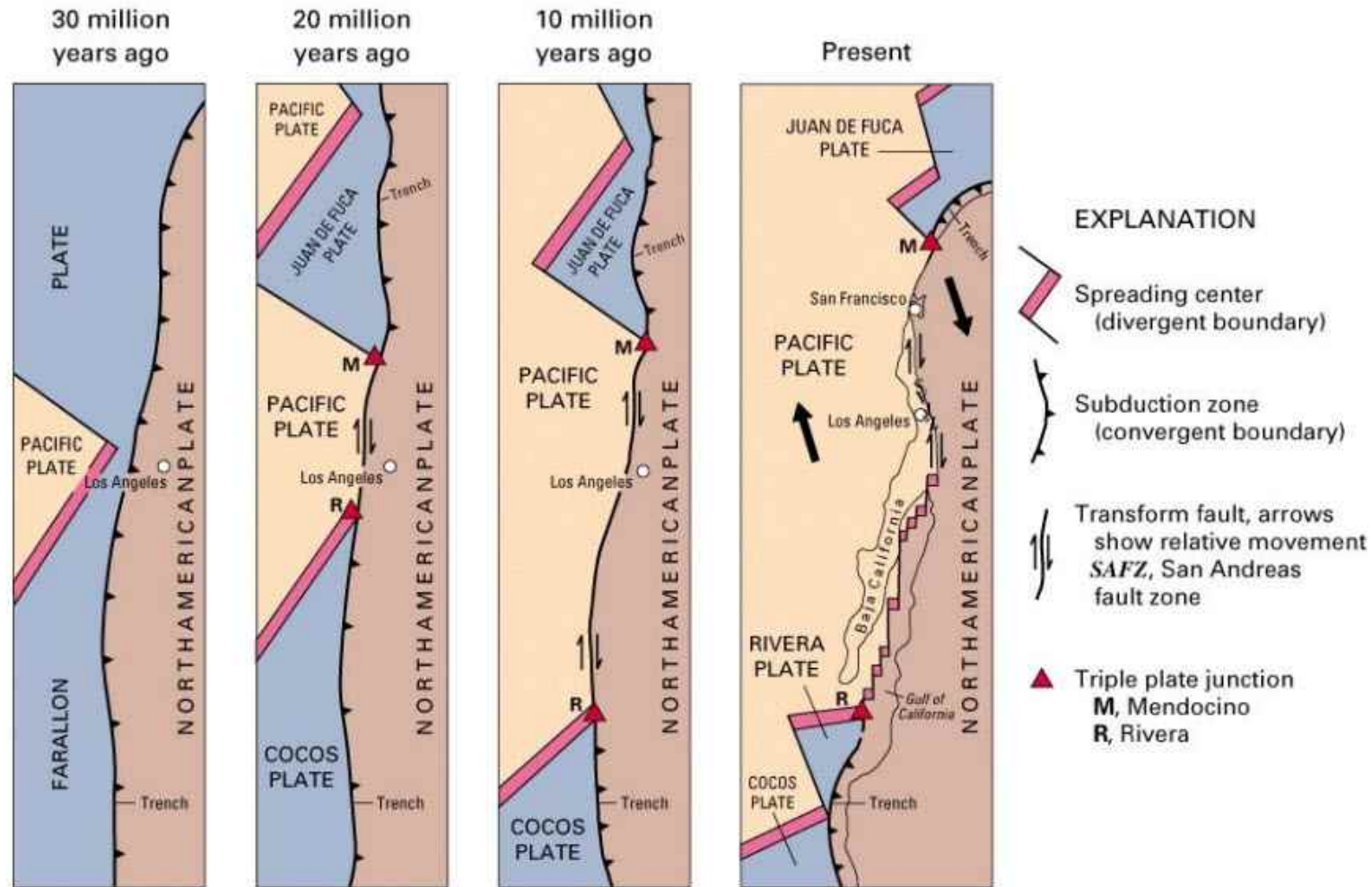
The Remediation Site

A developed industrial site once used for ship building and maintenance

What are the Challenges of Remediation at the Site?

The Complex Geology of Coastal California

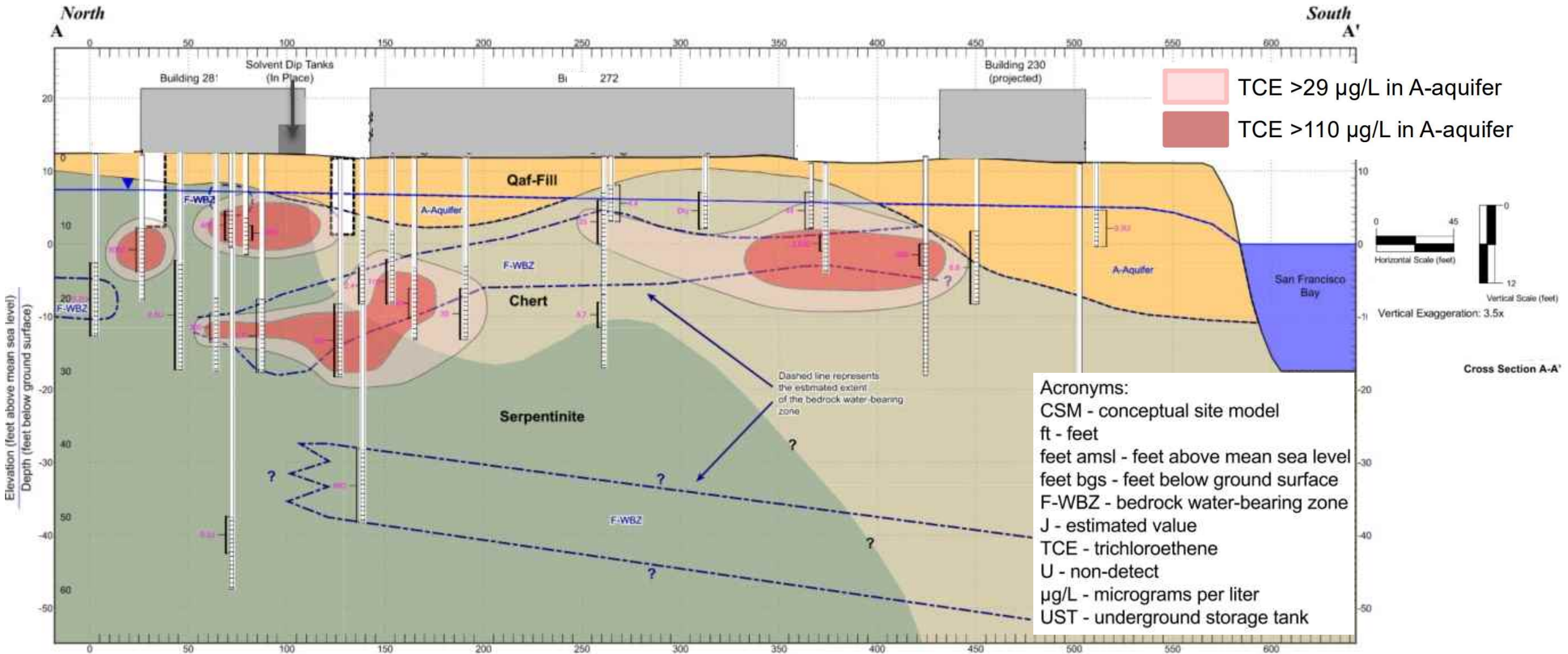
- Accretionary landforms create a mosaic of formations
- Formations contain mafic and felsic rocks of both marine and terrestrial origin
- Human factors further complicate the subsurface as developers filled harbors and shorelines with artificial fill



Formation of the San Andreas Fault system through time (from "This Dynamic Earth" (<http://pubs.usgs.gov/pdf/planet.html>) modified from USGS Professional Paper 1515).

What Site-specific Factors Influence the Remedial Design?

Chemical of concern is trichloroethene (TCE) and related volatile organic compounds





Remedial Design Approach

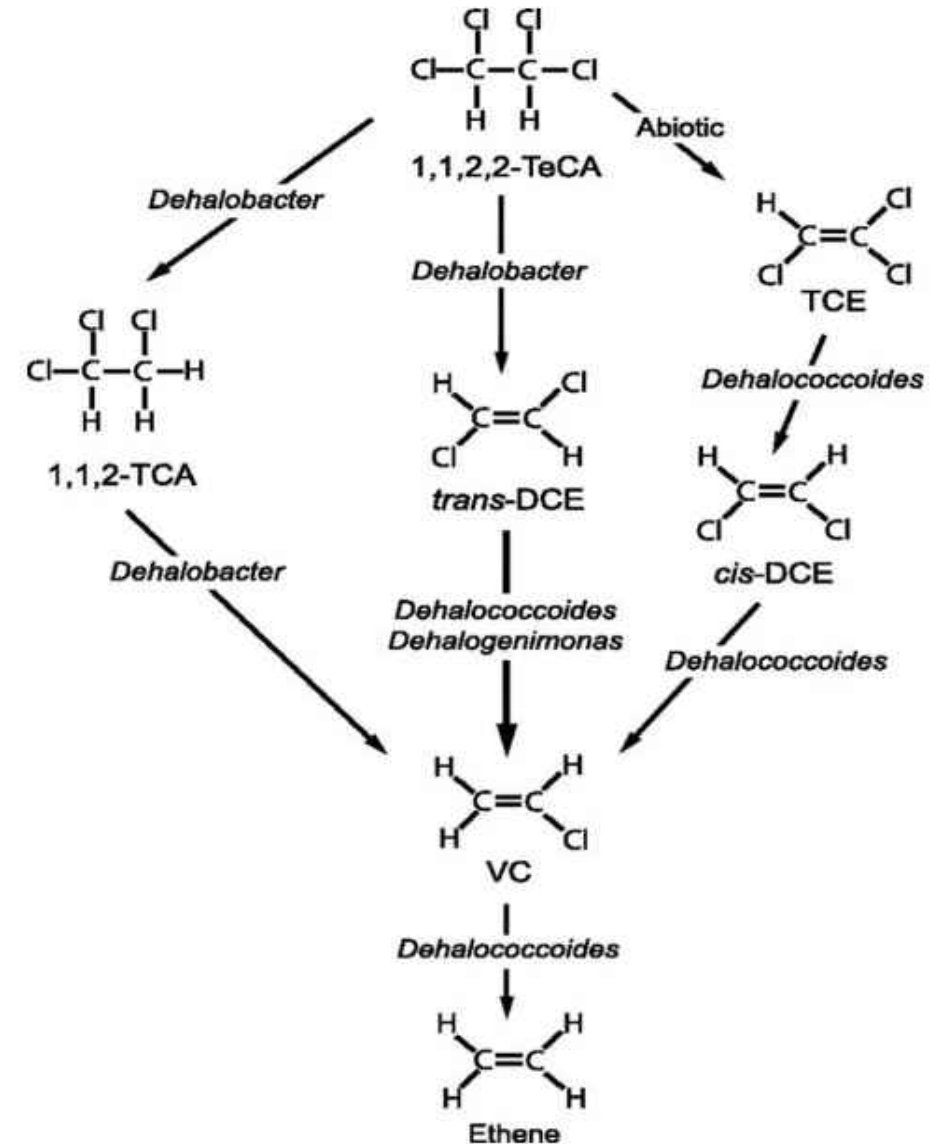
Zero-Valent Iron (ZVI) suspended in bean guar

In-Situ Bioremediation (ISB) using Dehalococcoides (DHC) suspended in anoxic water

Multi-faceted Approach to Injection Strategy

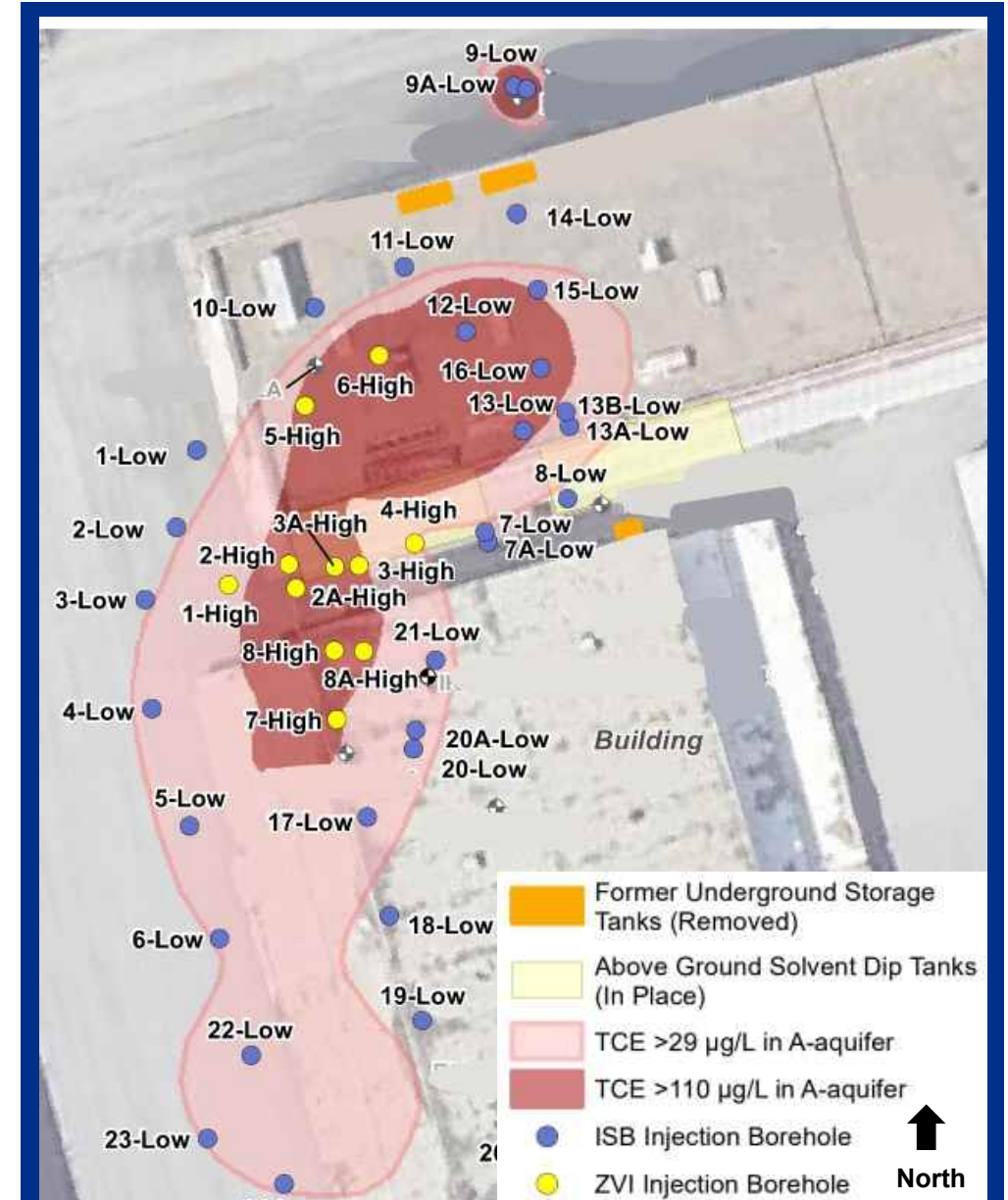
Low-dose ZVI locations were augmented with in-situ bioremediation injection, *Dehalococcoides* (DHC) suspended in anoxic water

Anoxic conditions in the soil support natural attenuation while ISB cultures amplify the chemical breakdown



Multi-faceted Approach to Injection Strategy

- High and low-dose zero-valent iron (ZVI) in suspension with bean guar gel supporting loading of up to 7.2 pounds of ZVI per gallon of slurry
- Dosage dependent on TCE concentrations
- Dual injection methods – top-down shallow injections with direct-push technology and bottom-up deep injections using packer assembly and hoist truck in boreholes pre-drilled by a sonic drill rig



Adaptive Approach

- Anticipated surfacing amendment due to shallow target depth
- Remediation goals based on total ZVI emplaced in formation, total KB-1 emplacement, and total LactOil emplacement
- Injections of ZVI slurry were measured by weight and limited by the mixing tank size. Many targeted volumes were split into two batches.
- Christmas tree method

Missed target values get added to nearest neighbor





■ Daylighting

- Borehole out wash
- Seeping
- Preferential pathways

■ Teams working in parallel

■ Formation back pressure

■ Weighing ZVI

■ Broken equipment

■ Buried packers and collapsed boreholes

Problems Faced

Daylighting – Borehole Out Wash

When Your Slurry Does Not Reach the Intended Target

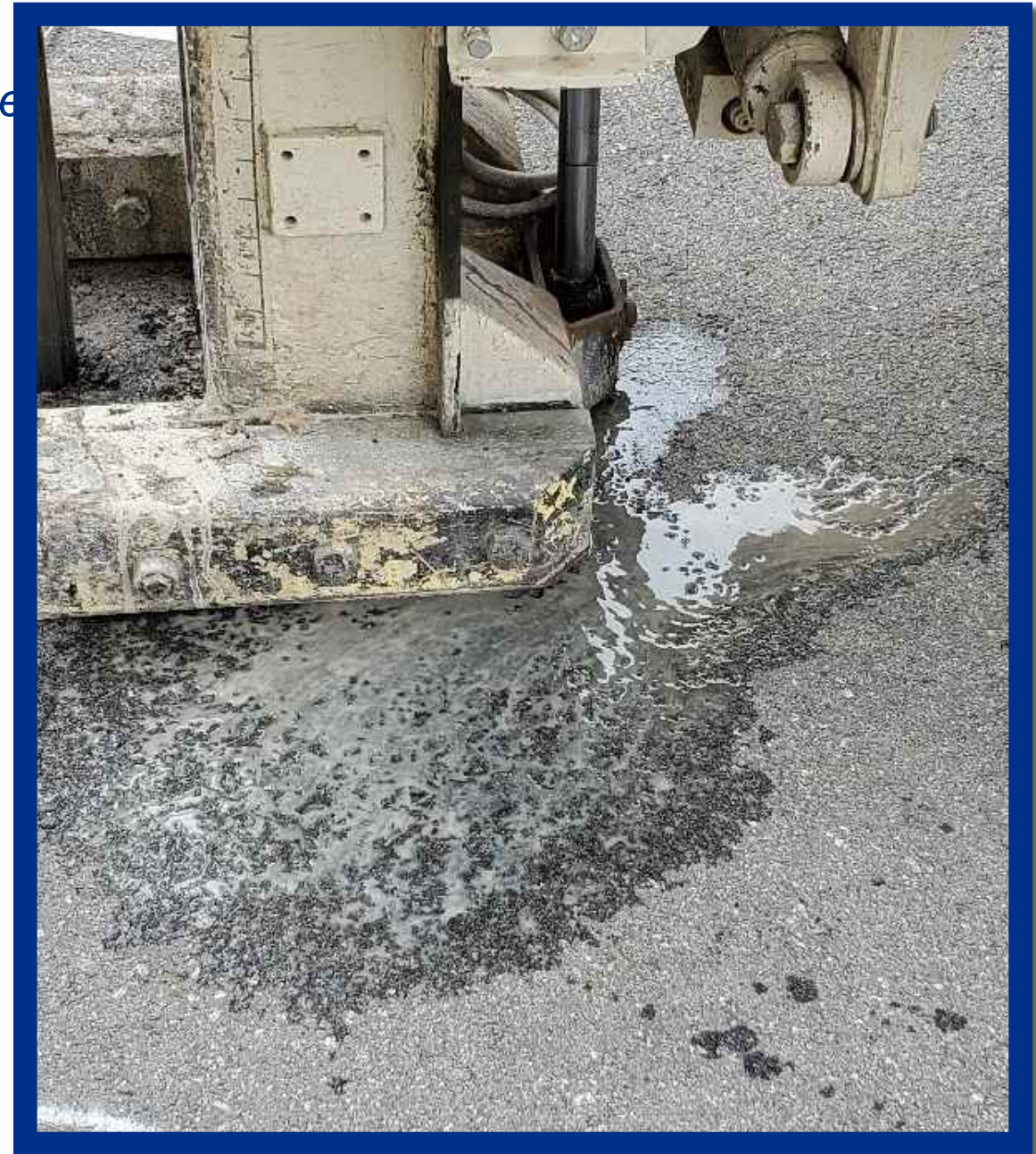
- ZVI slurry washes around unconsolidated borehole walls.
- Slurry connects with open borehole above the packer assembly, allowing free pathway to the surface.
- Results in ZVI missing the target, leaving hole in borehole walls that destabilizes borehole integrity.
- Creates an interval off-limits for packer assembly to work in, reducing the functional target depth.



Daylighting - Seeping

When Your Slurry Does Not Reach the Intended Target

- ZVI Slurry connects directly to surface and pools under protective asphalt cover.
- Pools of slurry under protective cover “sweat” through the asphalt and become visible.
- Often gets mistaken for water spot or spill until the bean guar becomes visible.



Daylighting - Preferential Pathways

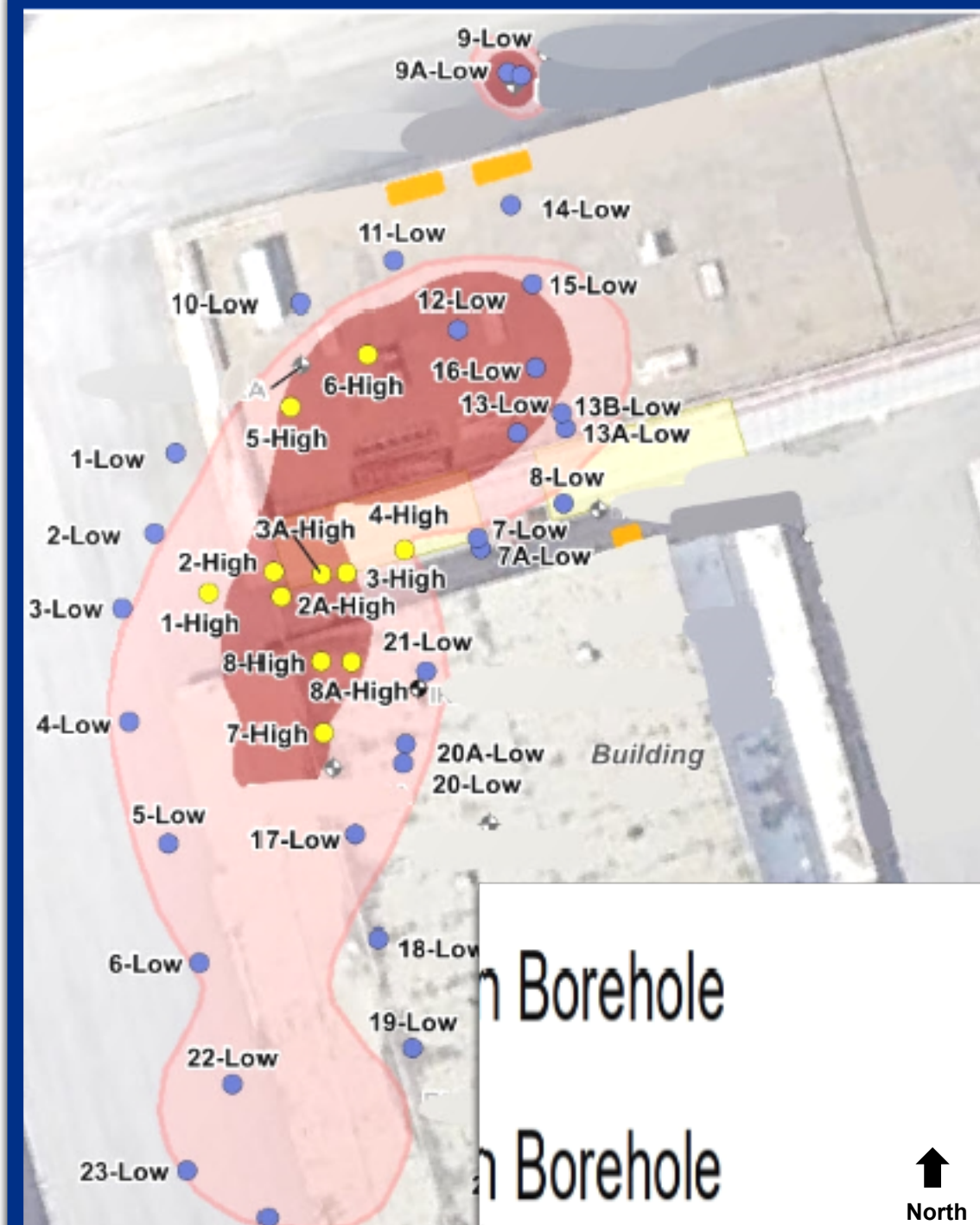
When Your Slurry Does Not Reach the Intended Target

- Daylighting occurred in former boreholes that had long since been grouted.
- Preferential pathways allowed daylighting at boreholes that had been deemed a safe distance away.
- Consistently found foundation walls to act as preferential pathway to the surface, making narrow alleys challenging for ZVI placement.



Teams Working in Parallel

- Sonic crew to drill boreholes with geologist logging drill cuttings
- Injection crew to pump amendment using packer assembly and hoist truck
- Injection crew catches up to sonic crew when drilling is slow.
- Grouting crew to close off completed boreholes to prevent preferential pathways.
- Grouting was under sonic crew scope of work.



The Teams Working in Parallel

Lesson Learned

- Minimize crews working in parallel whenever possible
 - If formation allows for DPT injections (unconsolidated), it is more streamlined and less expensive than bottom-up injections.
 - Smaller remedial designs with greater spacing between boreholes could allow for all drilling to be completed ahead of injections.
- Need to strike a balance between order of boreholes (laterally distant or close together)
- When working in and out of buildings with narrow corridors, having multiple decontamination pads helps reduce mobilization time between boreholes.



Formation Back Pressure

Unexpected Wait Time

- Back pressure in the formation due to hydrostatic groundwater or from the amendment added time to the schedule.
- Wait times up to 45 minutes between ZVI and ISB injections
- Consider if the remedial design can accommodate KB-1 in the mix tank injecting the ZVI slurry.



Weighing the ZVI – An Added Step

ZVI supersack is loaded into scale and dispensed by weight into hopper below before being mixed into the slurry.

Adaptive approach results in different amounts of ZVI in each batch.



Weighing the ZVI – A Design Solution



- Subsequent remedial action incorporated ZVI supersacks into design in whole integers.
- Eliminated extra iron weighing, resulting in less tracking and oversite.
- Reduces potential for error.

Saves time and reduces potential for generating dust

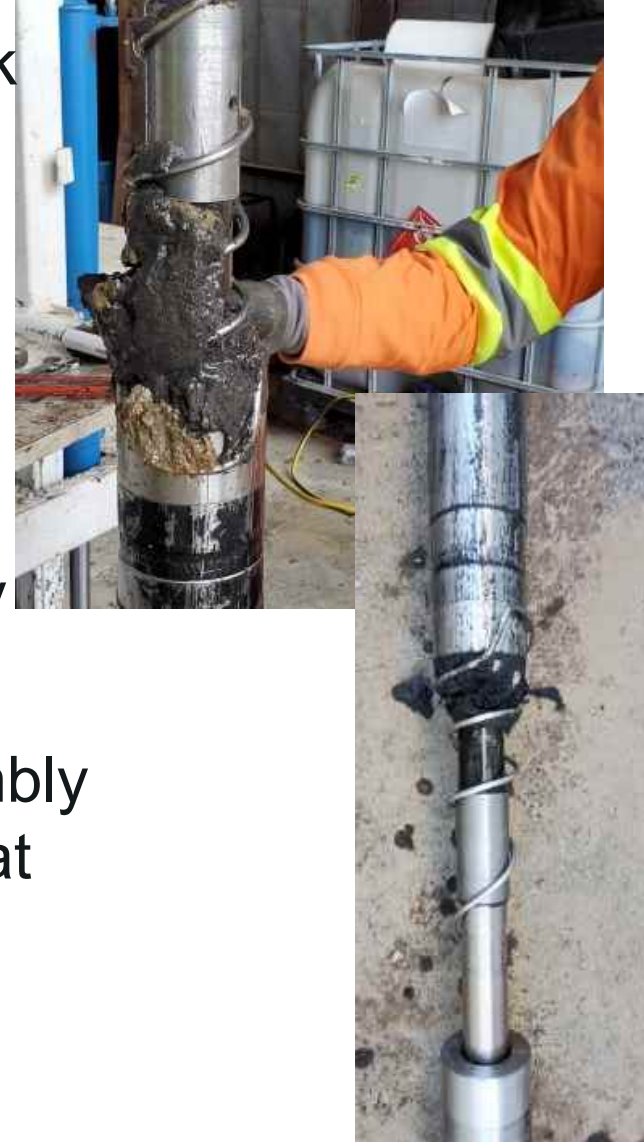
Broken Equipment





Buried Packers and Collapsing Boreholes

- Packer assembly can get stuck by not properly deflating
 - ZVI clogging packer interval
 - Wipers missing
- Inflate/deflate to loosen
- Use more force to pull (can damage packer assembly or borehole walls)
- Overdrill around packer assembly (will destroy further injections at the borehole)



Buried Packers and Collapsing Boreholes

Lesson Learned: Using Cased Boreholes

- Installation of PVC needs extra pressure/weight while grouting or PVC will float up and out of borehole.
 - Water pressure (fill PVC with water)
 - AWJ tooling or narrow downhole casing to depth while grout cures.
- PVC slot can fail to cut
 - Adjustment depth and retry
 - PVC can have a snagged edge (causes wear)

Considerations for cased boreholes

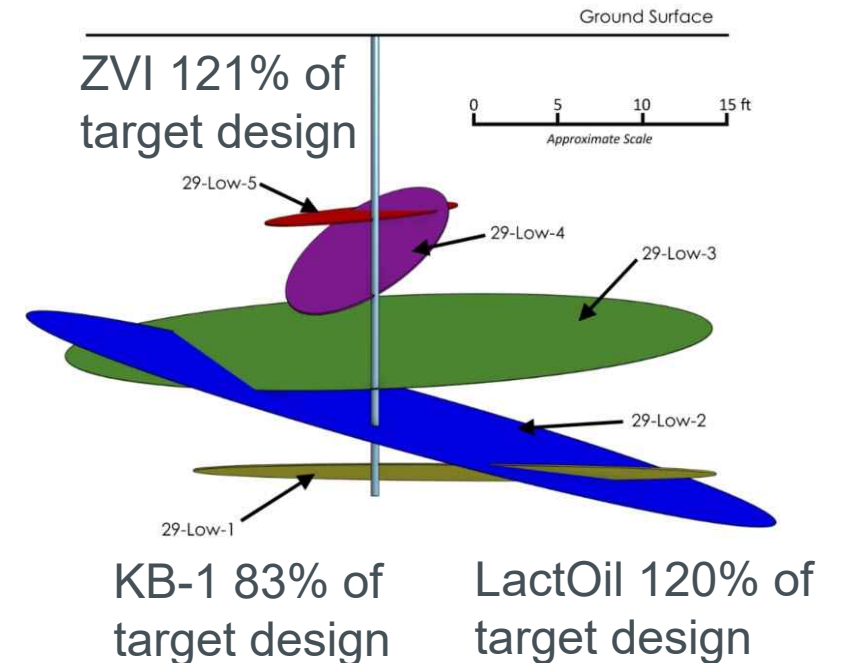
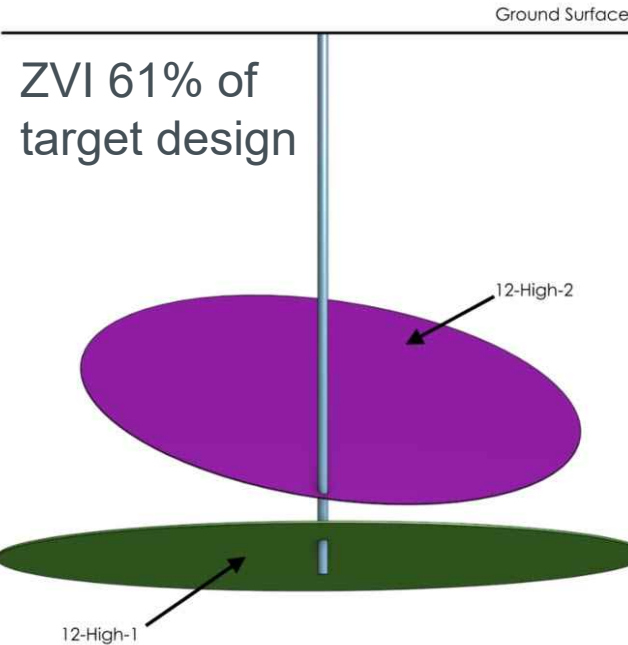
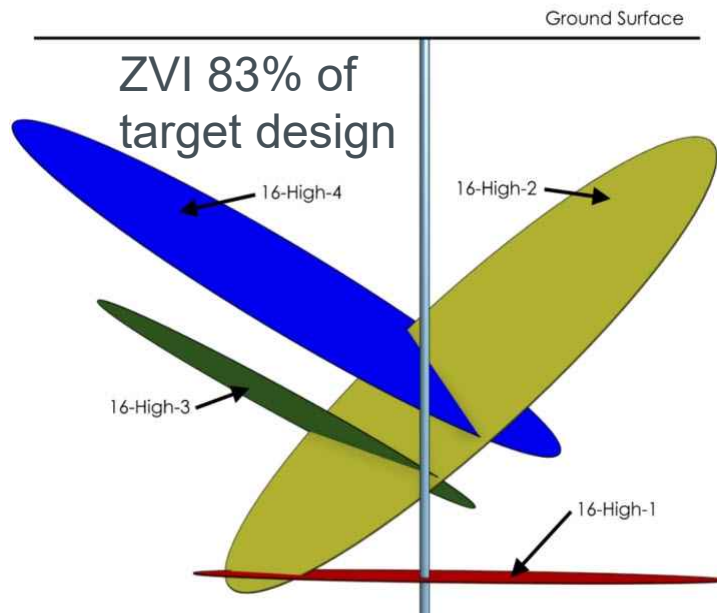
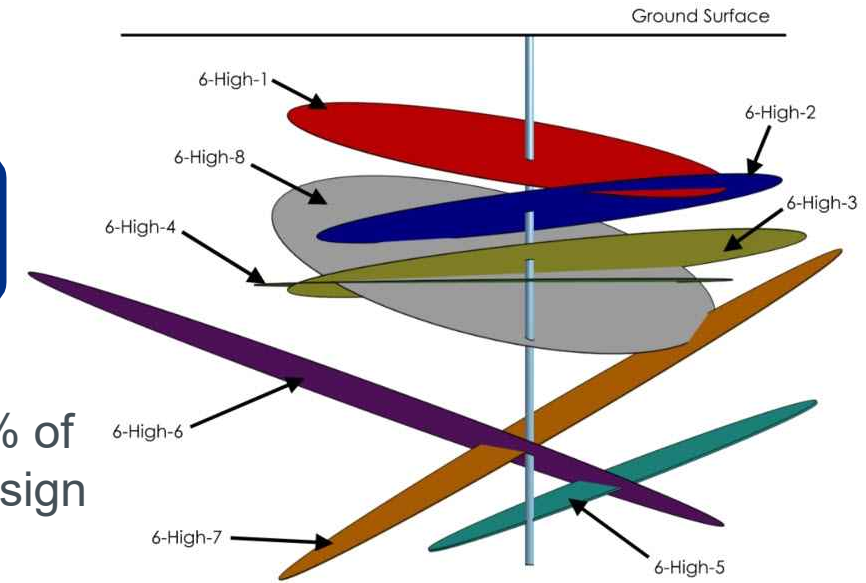


Outcomes

Design Delivery Was Met

- 95% of targeted ZVI was emplaced
- 109% of the lactoil was emplaced
- 93% of the KB-1 was emplaced

ZVI 101% of target design



KB-1 83% of target design

LactOil 120% of target design

Thank you!



To learn more, contact:

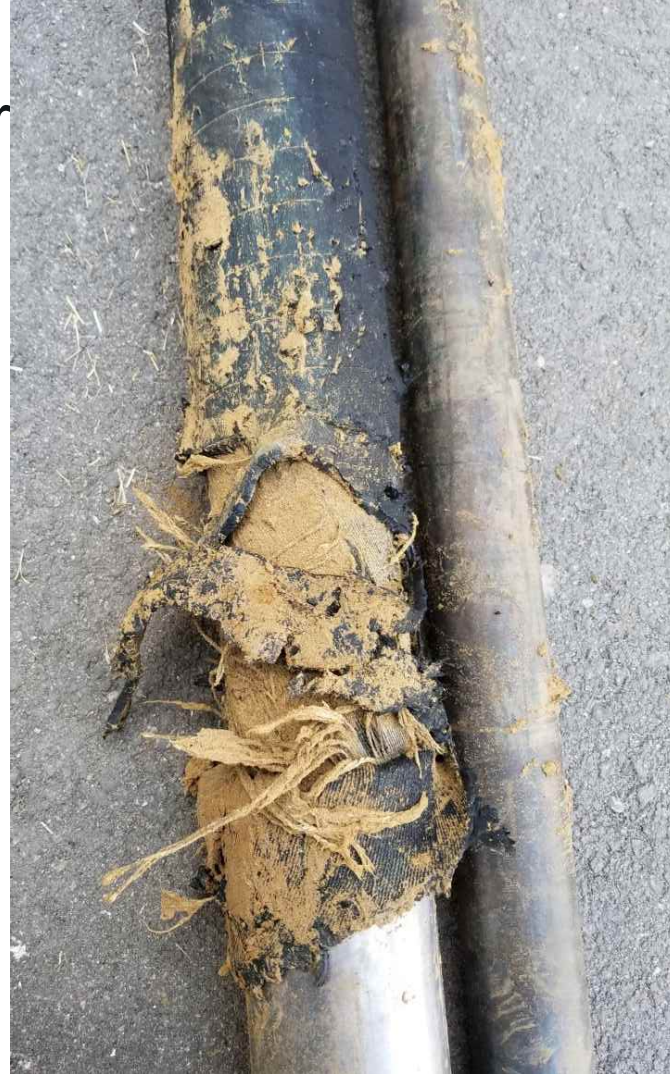
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Background slides: blown packers



Background Slides: Packer Assembly

