Site Assessment, Design Consideration, and Performance Results from an Innovative Barrier Application at Large Chlorinated Solvent Plume in Texas

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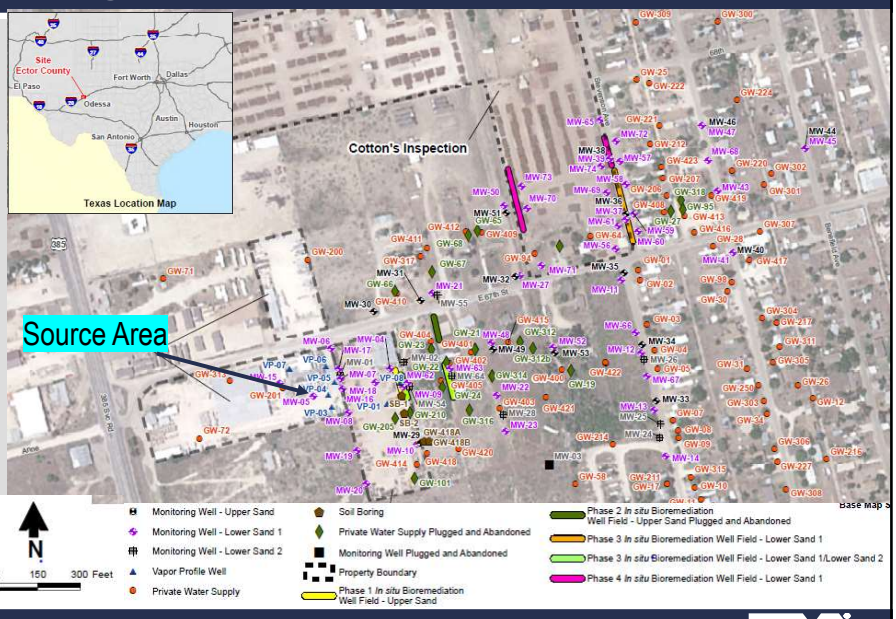
1

Background Information

- Located Outside Odessa, Texas
- PCE and Cis-1,2-DCE Groundwater Plumes Originating from a 1985 Release
- Multiple Zones in Aquifer
- Private Supply Wells Impacted
  - Sole Source of Drinking Water



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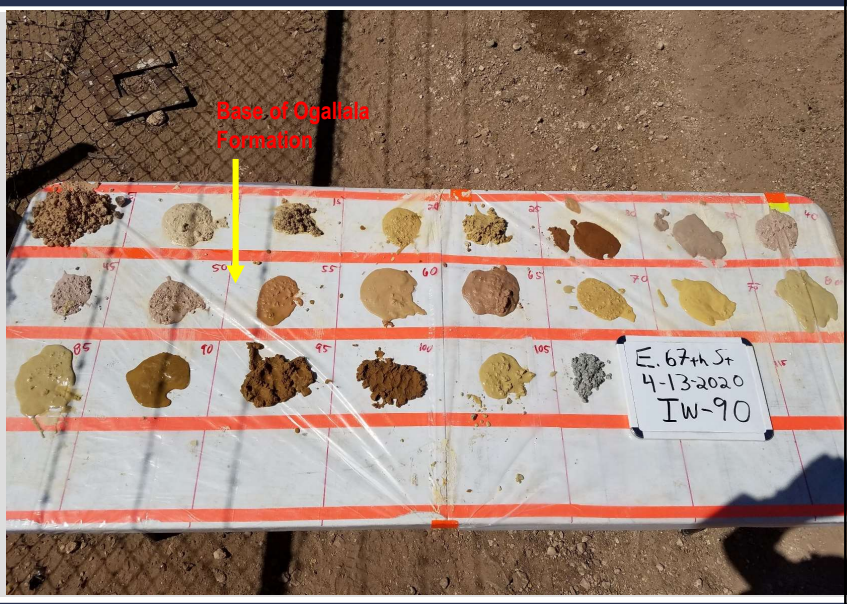
2

Conceptual Site Model – Subsurface Lithology

Subsurface Lithology

- Ogallala Formation – Caliche, Sand, Clay and Sandstone to 55 ft bgs
- Antler Formation (Trinity) – Sandstone & Claystone, to 140 -145 ft bgs
- Dockum Group – Triassic "Red Beds"



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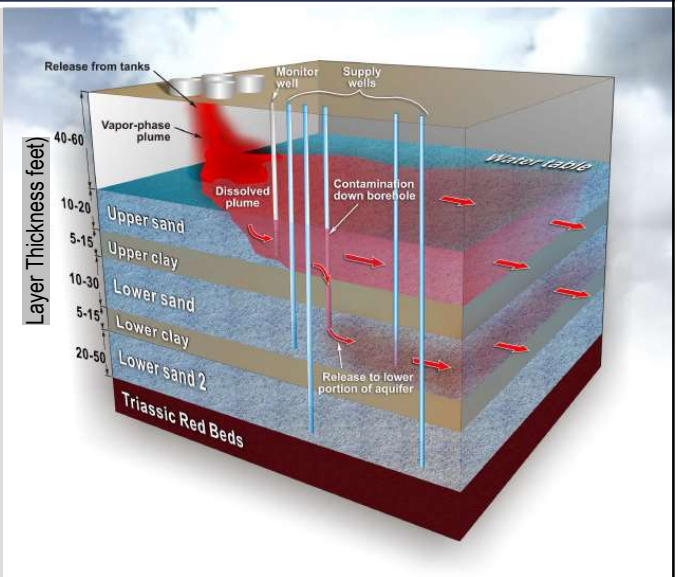
3

Conceptual Site Model – Multiple Water Bearing Zones

- Trinity Aquifer – Multiple Zones - Upper Sand, Lower Sand 1 and Lower Sand 2
- Depth to Groundwater 50 ft bgs
- Initial Release Impacted the Upper Sand Aquifer and migrated downgradient
- Supply wells pump from lower sands – downward head gradient
- Solute plume reached private supply wells completed with gravel packed annulus
- Contaminated groundwater migrated via borehole leakage into the Lower Sand 1 and Lower Sand 2
- Contamination is less extensive in the Lower Sand 2 Aquifer



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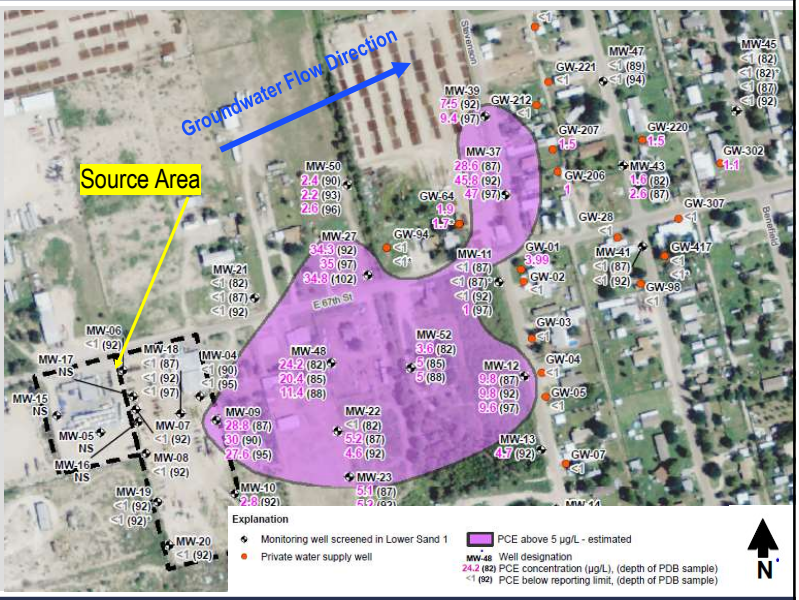
PCE Plume February – March 2016 Lower Sand 1

- Lower Sand 1 Aquifer
- PCE Plume Approximately 1,300 feet.
- Groundwater Flow Direction Northeast
- Private Wells Screened – Lower Sand 1 and Lower Sand 2
- Select Private Wells have had Pumps Removed and Wells Geophysically Logged



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Remedial Action

- Plugged Leaky Private Wells and Boreholes
- Replaced Private Supply Wells
- Horizontal SVE of Source Area
- In Situ Bioremediation (ISB) and Reductive Dechlorination (RDC)
  - Permeable Reactive Barriers

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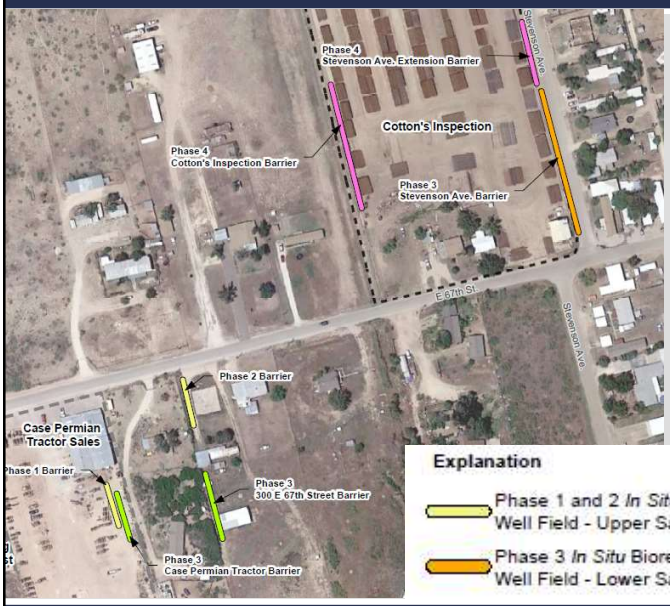
Remedial Action – ISB / RDC PRBs



- Installed in Phases
- Phase 1 and 2 - Upper Sand – EVO
- Phase 3 and 4 Lower Sand 1 and Lower Sand 2 – PlumeStop and Microscale ZVI (Green Barriers Only)

Explanation

- Phase 1 and 2 *In Situ* Bioremediation Well Field - Upper Sand
- Phase 3 *In Situ* Bioremediation Well Field - Lower Sand 1
- Phase 3 *In Situ* Bioremediation Well Field - Lower Sand 1/Lower Sand 2
- Phase 4 *In Situ* Bioremediation Well Field - Lower Sand 1

7

7

Challenges with Installation of Barriers

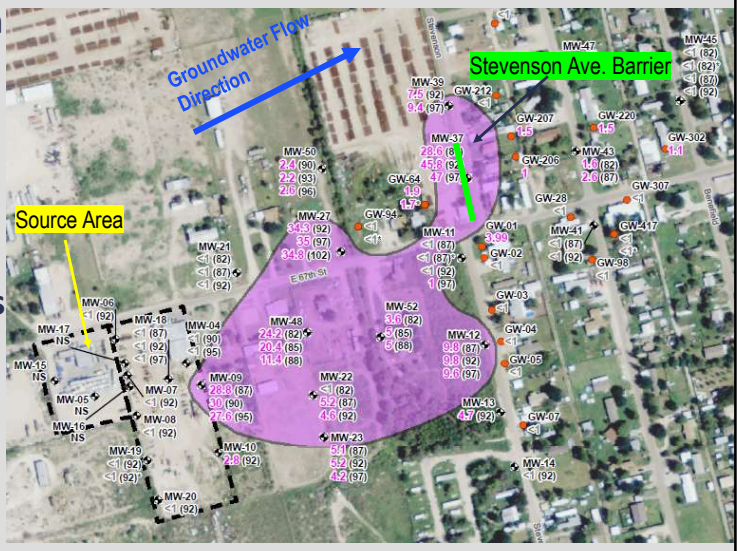
- Placement of Barrier/Injection Wells
- Well Screen Placement
- Vertical Profiling
- Cementation and Fractures
- Injection Issues
- Temporary Increase of Contaminate Levels Downgradient

8

8

Placement of the Barrier/Injection Wells

- Installed 1st PlumeStop Barrier in Lower Sand 1 in 2017 – Distal Plume to Protect Private Supply Wells
- Barrier length 300 feet
- 24 Injection Wells
- 6 Performance Assessment Wells
- Treatment Interval 85 to 105 ft bgs
- Performance Assessment Sampling: 30, 60, 90, 120, 180 and 365 days after injection



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9

Placement of the Barrier/Injection Wells

- PlumeStop® is a liquid activated carbon to adsorb and retard movement of contamination within the treatment area
- PlumeStop® Was Selected:
  - No mobilization of metals, that may impact downgradient private wells
  - Longevity – designed for 15 years
  - Lower Analytical Costs – VOCs Only and Passive Diffusion Bags

10

10

Continued Placement of Injection Wells

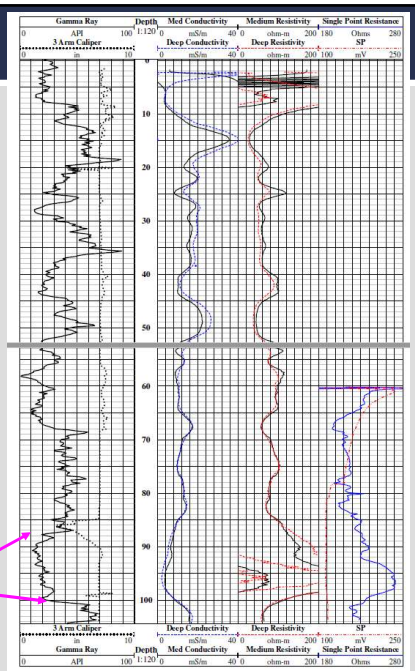
Stevenson Ave Barrier Design

- ROI Established based on EVO Pilot Test & Injections in Upper Sand Water Bearing Zone -
- EVO Injection Well Spacing 20 ft
- Reduced Well Spacing for PlumeStop Barrier to 12.5 ft
- Cost Savings Measure

11

Well Screen Placement

- Air-Rotary Drilling Method – Difficult to Establish Correct Placement of Screen Interval
- Geophysical Logging to Aid in Placement Of Well Screen and Provided Information Regarding Permeability
- Logged every 4th borehole.
  - Natural gamma
  - 16-inch normal resistivity
  - 64-inch normal resistivity
  - Single point resistance
  - Spontaneous potential
  - Medium and deep conductivity
  - Caliper in inches.



12

Vertical Profiling

- EON Products Inc. Passive Diffusion Bags Deployed at Various Depth Intervals
- First Sampling Event – Concentrations Lower than Expected – Resampled Middle Interval. Results confirmed.

PERCHLOROETHENE CONTAMINANT X-SECTION

Depth	IW-13	IW-14	IW-15	IW-16	IW-17	IW-18	IW-19	IW-20	IW-21	IW-22	IW-23	IW-24	IW-25	IW-26	IW-27	IW-28	IW-29	IW-30	IW-31	IW-32	IW-33	IW-34	IW-35	IW-36	Depth
79																									79
80																									80
81																							5X MCL		81
82																									82
83																							15.7	3.5	83
84																	9.27					8.2			84
85					4.27	6.25												13.2	40	33.5	21.9				85
86																									86
87								3.9	2.6	0.4	0.4	0.6													87
88							19.5						6.3	32.8	5.3	25							16.3	4.4	88
89	0.3	3.28	10.7	8.25													18.6					12.5			89
90					13.5													28.8	42.2	34.4	19.9				90
91																									91
92								6.3	2.3	0.8	0.5	0.6													92
93	1.2	2.9	11.9	12		29.9	27.1						22.4	34.2	23.1	24.4							15.1	5.5	93
94																	27.4					18.4			94
95					14.7													27.4	44.3	33.2	16.6				95
96																									96
97						28.2	27.2	1.6	1.3	0.5	0.5	0.6	21.4	35.3	29.3	24.5									97
98	2	2	12.5	9.6																					98
99																									99
100																									100
Screen (ft)	12	12	12	15	12	14	11	12	12	12	10	12	13	15	15	15	11	15	15	15	15	15	15	15	
Cumulative PCE	3.5	8.18	35.1	29.85	32.47	64.35	73.8	11.8	6.2	1.7	1.4	1.8	50.1	102.3	57.7	73.9	55.27	69.4	126.5	101.1	58.4	39.1	47.1	13.4	

1X MCL 5X MCL 1X MCL 5X MCL

300 ft

13.3 Average Screen (ft)
14.8 Average PCE (ppb)

Indentifies highest levels of contaminant mass

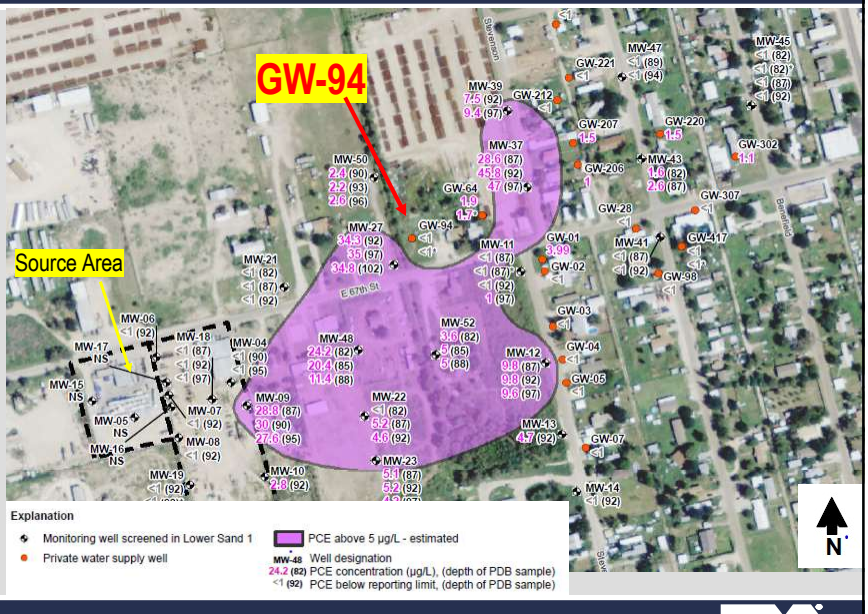
REGENESIS REMEDIATION SERVICES

13

PCE Plume February – March 2016

2016 Plume Configuration

- Pulled Pump and Logged Well GW-94
- Well Screened in Lower Sand 1
- Sampled via Bailer to Verify Tap Sample Results – Confirmed Well < 1 µg/L



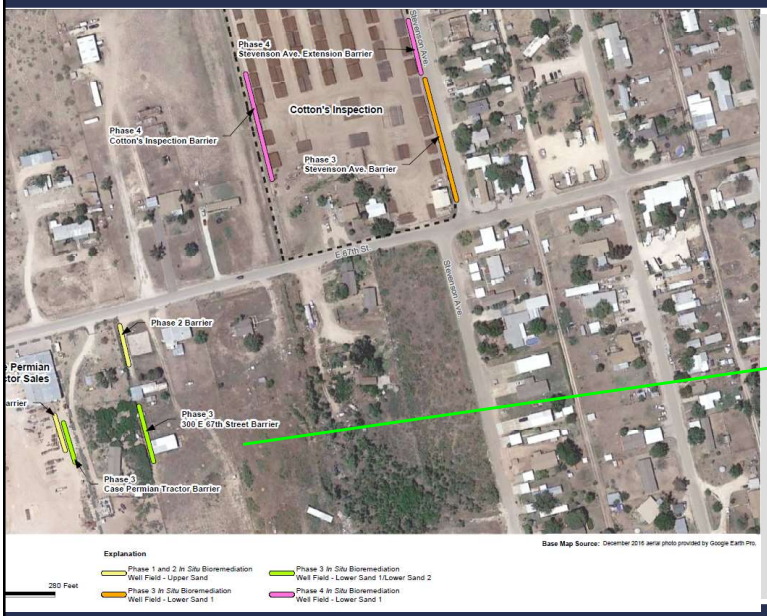
14

Cementation and Fractures – PCE Baseline Results 2017

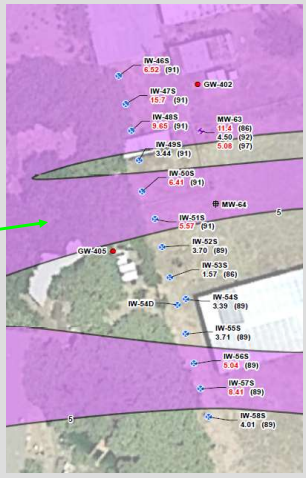
- Clean zones noted in baseline samples along barrier alignment
- Preferential migration of plume
- Differential Cementation Creates Permeability Contrast

15

Cementation and Secondary Fracture Permeability



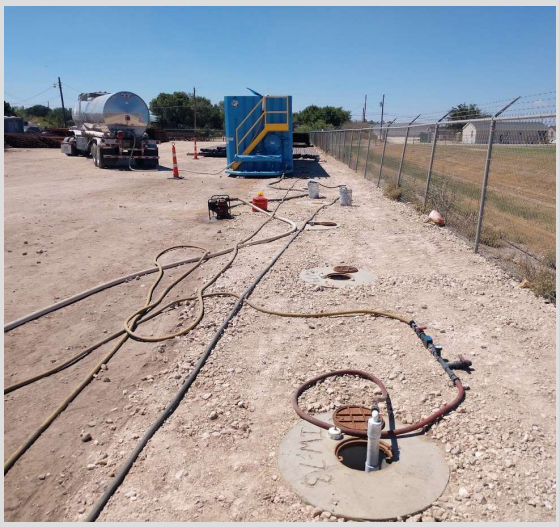
- Additional Barriers Installed in Lower Sand 1 and Other Sites



16

Injection Issues

- Injection Rates Varied Based on Permeability
  - High Injection Rates and Low Pressure - Poorly Cemented and/or Fracture Zones – Lowered Injection Rate to Obtain Better Coverage -
  - Well Cemented Areas – Low Permeability with Little to No Flow
  - As Injection Progressed, Pressure Rose and Injection Rate Decreased
  - In Response, Subsequent Injection Rates were Held To 5 gpm and Pressure 100 psi or less.



17

17

Injection Issues

Stevenson Ave Barrier

- Injection rate 5 to 16 gpm and injection pressures 4 to 77 psi for Stevenson Barrier – Full Volume Injected

Stevenson Ave. Extension Barrier

- Stevenson Extension Barrier injection rate 1 to10 gpm and pressure 10 to 120 psi – Several Wells Did not Accept Full Dose
- Overdosed Permeable Wells That Could Accept Amendment to Compensate for Wells that Could Not Accept Design Volume

18

18

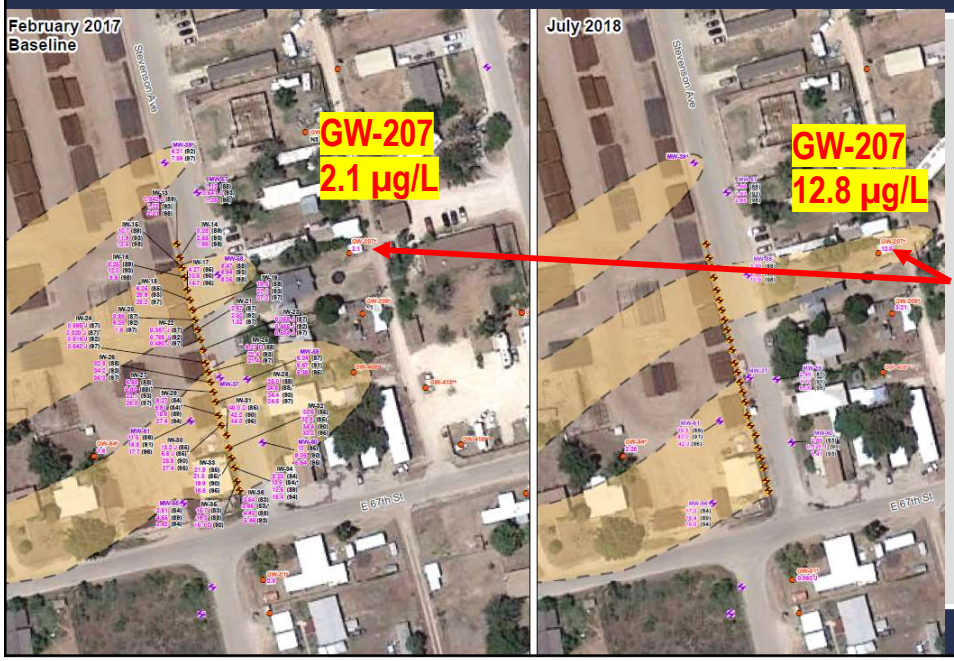
Injection Issues

- Surfacing
  - Rarely occurred during initial injection -
  - More frequent during second injection.
  - Keep pressure below 100 psi
- PlumeStop in upgradient wells
  - MW-69 Upgradient Performance Assessment Well - Well ND due to PlumeStop present

19

19

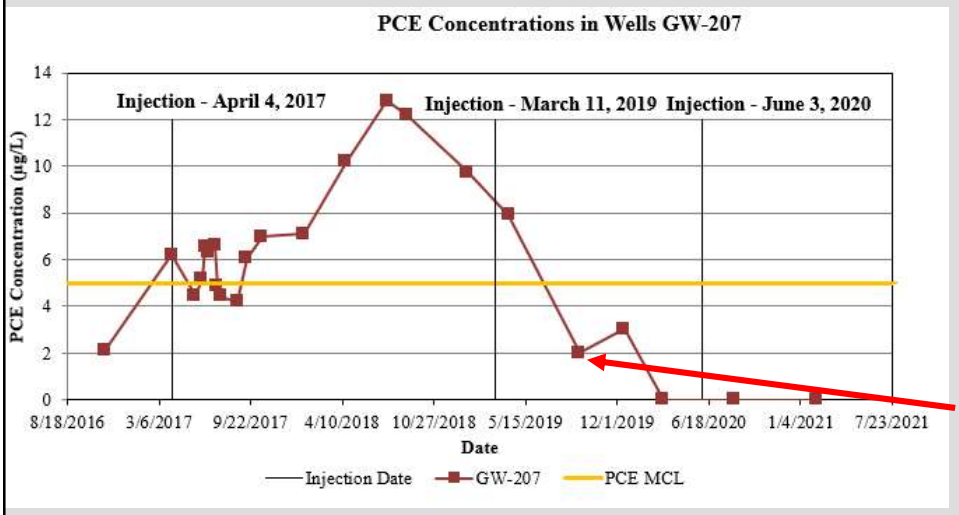
Temporary Increase of Contaminate Levels Downgradient



- Injection of 34,247 gallons of PlumeStop /Water Mix Appears to Have Displaced Plume
- Private Supply Well GW-207 Affected
- Filtration System Installed
- Partial Second Injection

20

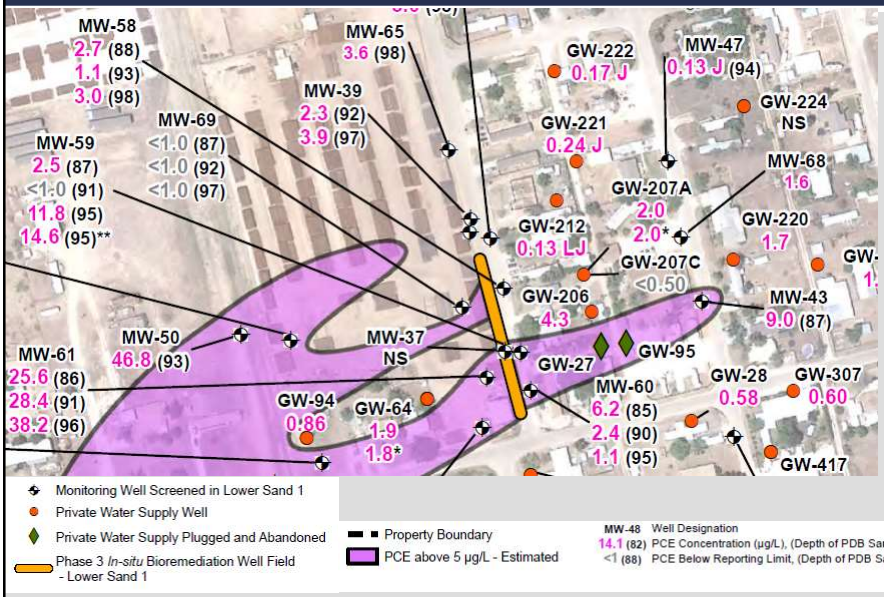
Increased Contaminate Levels DG – Reapplication #1



- Second Application
  - 2019 - 3 Injection Wells Installed Immediately Upgradient of PRB
  - Reapplied PlumeStop to Address GW-207
  - September 2019 below MCL

21

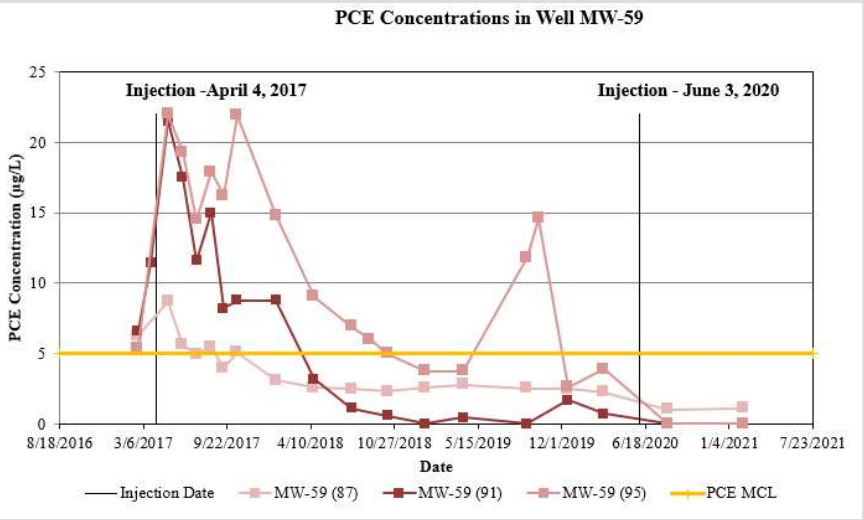
Reapplication #2



- PCE Groundwater Plume Lower Sand 1 September – October 2019

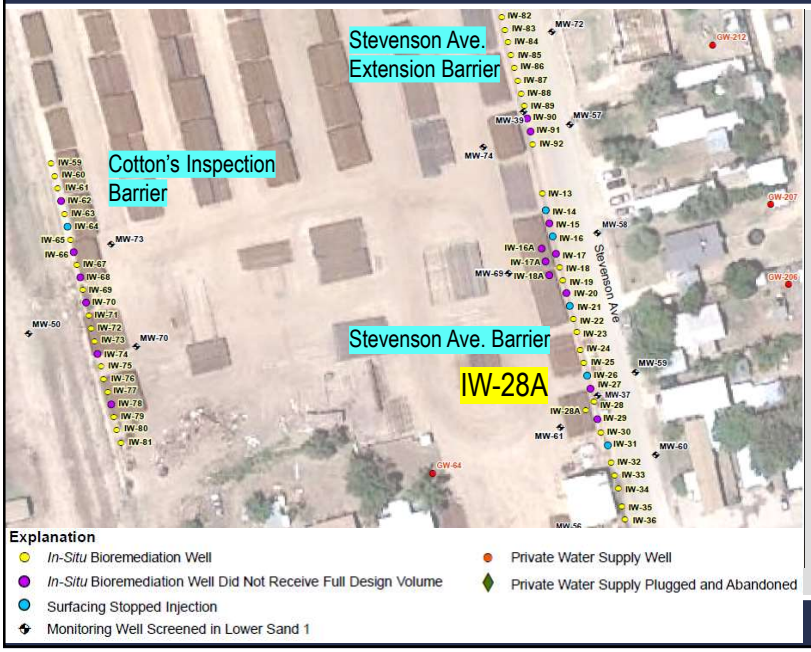
22

Reapplication #2



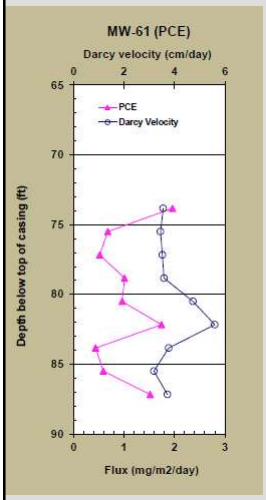
- Exceedances Of PCE at MW-59 at Only One Depth Interval in Each Well
- Possible Cause May Be Back Diffusion from Primary Porosity
- This is Area Where Surfacing Occurred

Injection June 2020



- Reapplication of PlumeStop for Stevenson Ave. Barrier – Installed MW-28A
- First Injection of PlumeStop for other Two Barriers – Wells Spaced 11 ft Apart

Reapplication #2

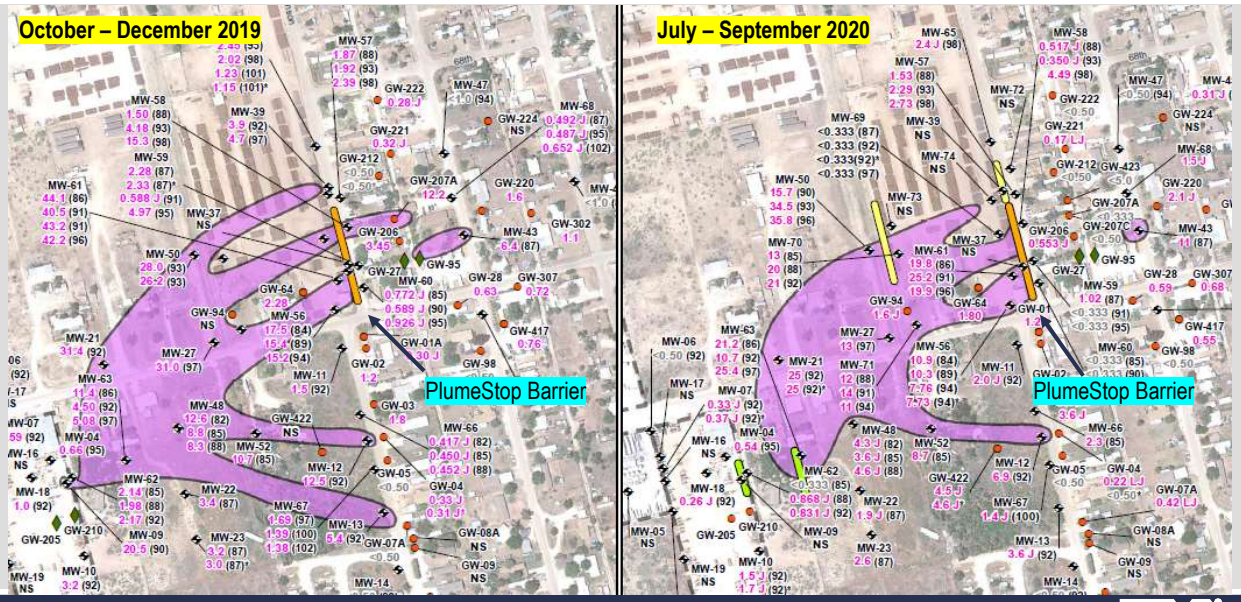


- EnviroFlux Passive Flux Meters Measured Time Average Cumulative Contaminant Mass Fluxes and Groundwater Flux
- Darcy Velocity – 3.3 to 7.7 cm/day – This was 2X faster than anticipated
- PCE Mass Flux – 0.09 to 2.47 mg/m^2/day

Reapplication

- June 2020 Stevenson Ave. Barrier
  - 47,634 gallons PlumeStop/Water Mixture Injected
  - Injected in Wells that were Above MCL – Baseline Concentrations
  - Injections Averaged 3.48 gpm and 26 psi, Not to Exceed 50 psi
  - Surfacing More Extensive During Reapplication
  - Several Wells Would Not Take Any Volume
    - Well loss of capacity
  - Was able to Inject in Most Wells

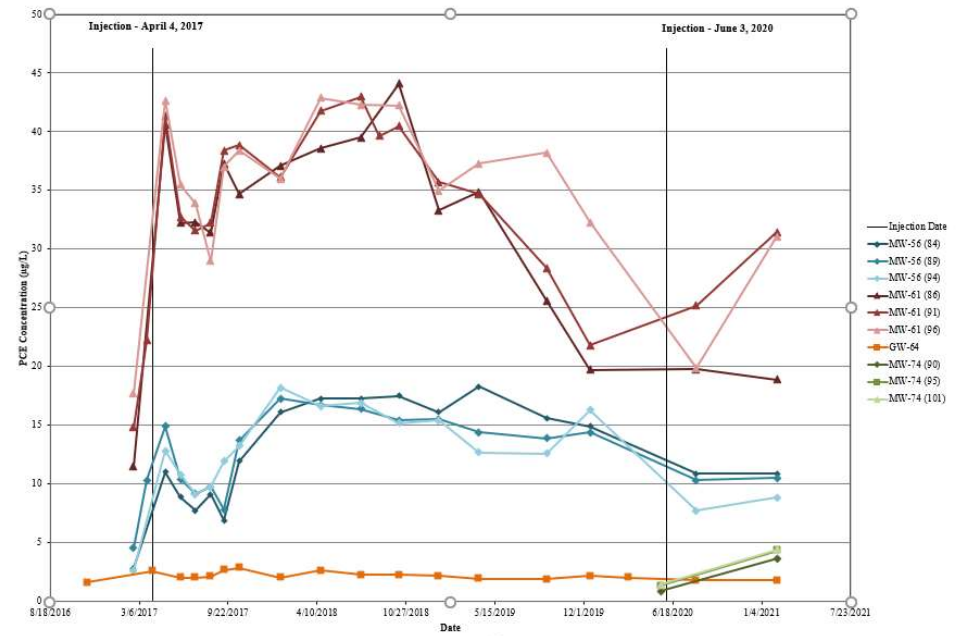
PCE Lower Sand 1



27

27

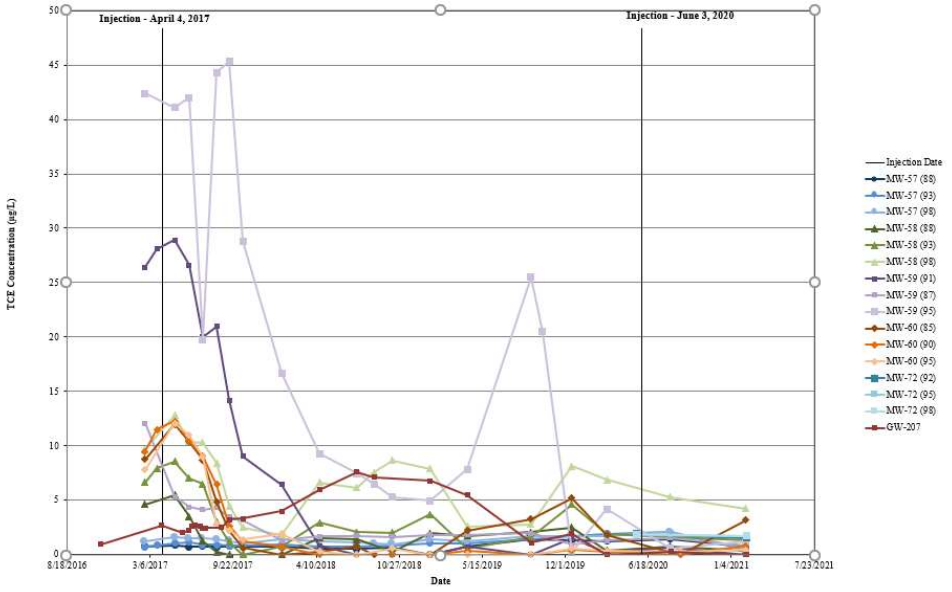
Feb 2021 PCE Concentrations Upgradient of PRB



28

28

Feb 2021 PCE Concentrations Downgradient of PRB

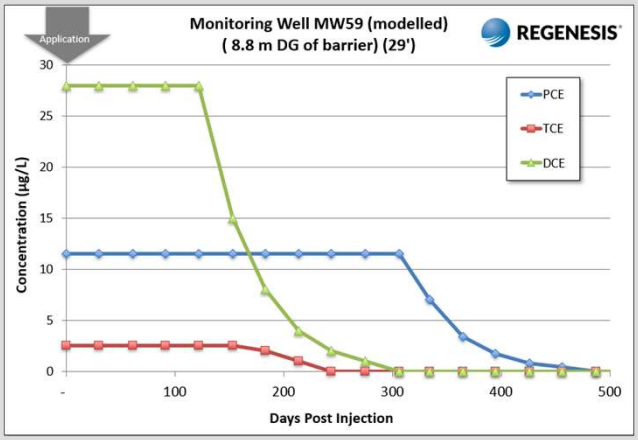


29

29

Modeling

- PlumeStop PlumeForce™ Model
- Competitive and dynamic sorption model of multiple contaminants
- Predicts back-diffusion and contaminant breakthrough
- Considers the following design parameters:
  - Groundwater velocity
  - Contaminant Mass-Flux
  - Current estimated degradation rates and kinetics for multiple contaminants
  - Daughter product formation
  - Sorption dynamics
  - Retardation factors



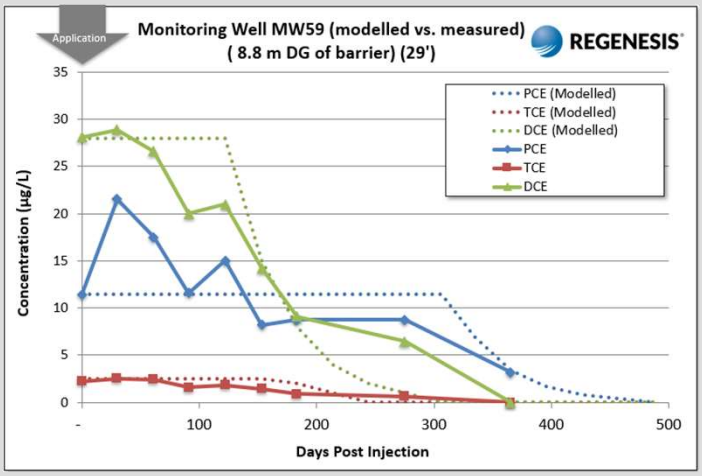
*Modelled performance for MW-59 (91' interval) located approximately 30 ft downgradient from the barrier.

30

30

Modeling

- PlumeStop PlumeForce™ Model
  - It will take time to observed treatment influence on downgradient performance well
  - Observed concentration reductions will be gradual due to distance, back-diffusion mass contribution, and retardation
  - TCE and DCE influences observed before PCE influence due to retardation factors



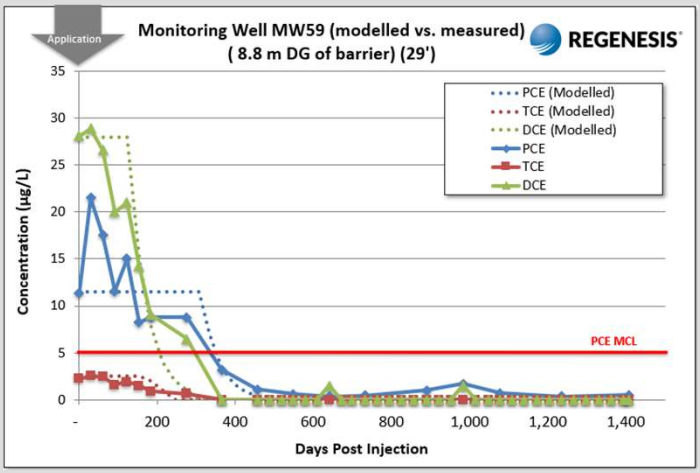
*Modelled performance for MW-59 (91' interval) at 12 months

31

31

Modeling

- PlumeStop PlumeForce™ Model
  - Model is a descriptive/predictive tool
  - Model allows to anticipate data trends.
  - Qualitative and semi-quantitative prediction/communication
  - Performance monitoring should allow for data noise.
  - Data noise should be validated through multiple events



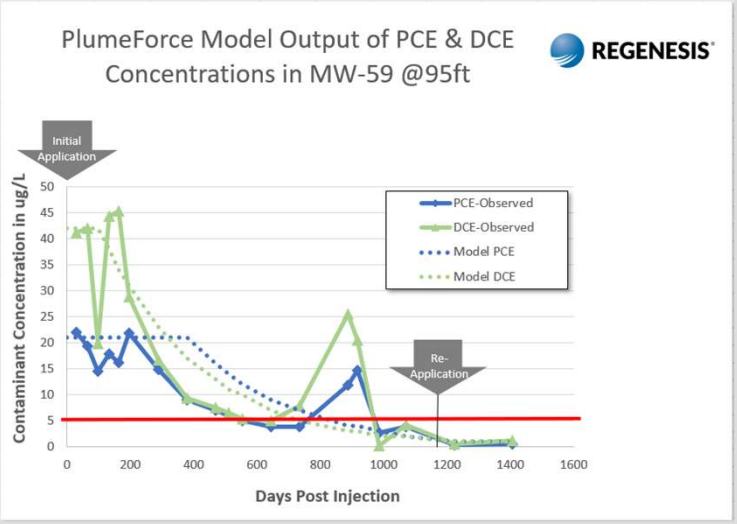
*Modelled performance for MW-59 (91' interval) at 42 months

32

32

Modeling

- **PlumeStop PlumeForce™ Model**
  - **Modelled performance for MW-59 (95') interval**
  - **Information used in conjunction with Passive Flux Meters, Geophysical Logs review, etc., to optimize re-application design**
  - **Performance data meeting compliance with MCLs**
  - **Data representative of all Performance wells**



33

Lessons Learned

- **Wells Spaced Close Together Provide Excellent Plume Detail**
  - **If High Resolution Site Characterization Direct Push Tools Cannot Negotiate Cemented Sands, this Level of Characterization is Costly to complete during Remedial Investigation**
- **Pilot Testing –**
  - **Complete in Different Portions of Plume to See Different Cementation and**
  - **Provides better injection well spacing**
- **Geophysical Logging Provided Useful Information: refine screen intervals, focused treatment, and reduced costs**

34

Lessons Learned

- Over Pressuring During Injection Does Not Work -
  - Slows injection
  - Back Pressure
  - Surfacing
- Plume Displacement following injection results in temporary concentrations increases in receptor wells
  - Need to be Prepared Especially if there are Private Supply Wells

Lessons Learned from this First PRB were used for Subsequent Injections for Additional Barriers at this Site and Other Sites with Similar Lithology

35

35

Questions

36

36