Optimization of a Large-Scale Biostimulation and Bioaugmentation Remedy

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Delivering Sustainable Solutions to Complex Local Challenges, Worldwide

Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies

Presentation Outline

- Site location and overview
- Initial optimization: from Record of Decision (ROD) to implemented remedy
- Optimization during remedy implementation
- Optimization during Long Term Response Action (LTRA)

Site Location

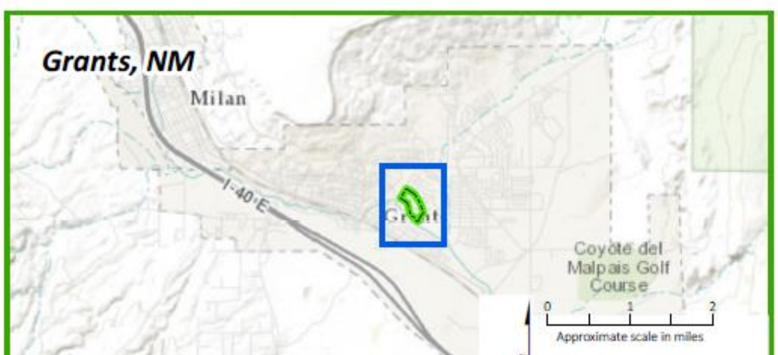
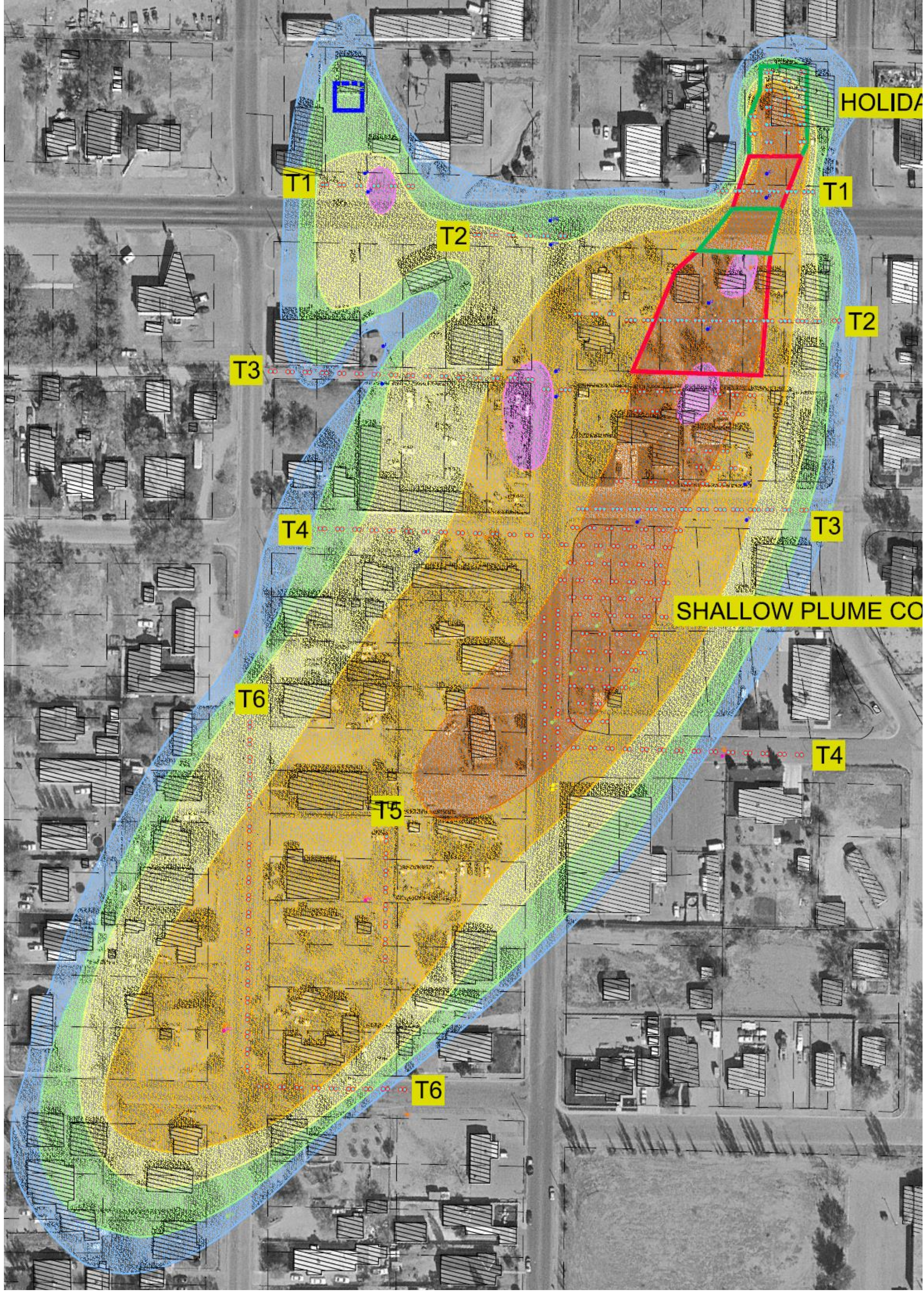


Figure 2-1
Area Map
2015 Annual Long-Term Response Action Report
Grants Chlorinated Solvents Plume Site
Grants, Cibola County, New Mexico

Site Overview

- Located in a mixed commercial and residential neighborhood
- 20 acre and 100-foot deep CVOC plume
  - Primarily PCE/TCE at concentrations greater than MCLs
- Associated with historical dry cleaning operations at the active Holiday Cleaners (since 1969)
- Comingles with petroleum hydrocarbon plume at gasoline station

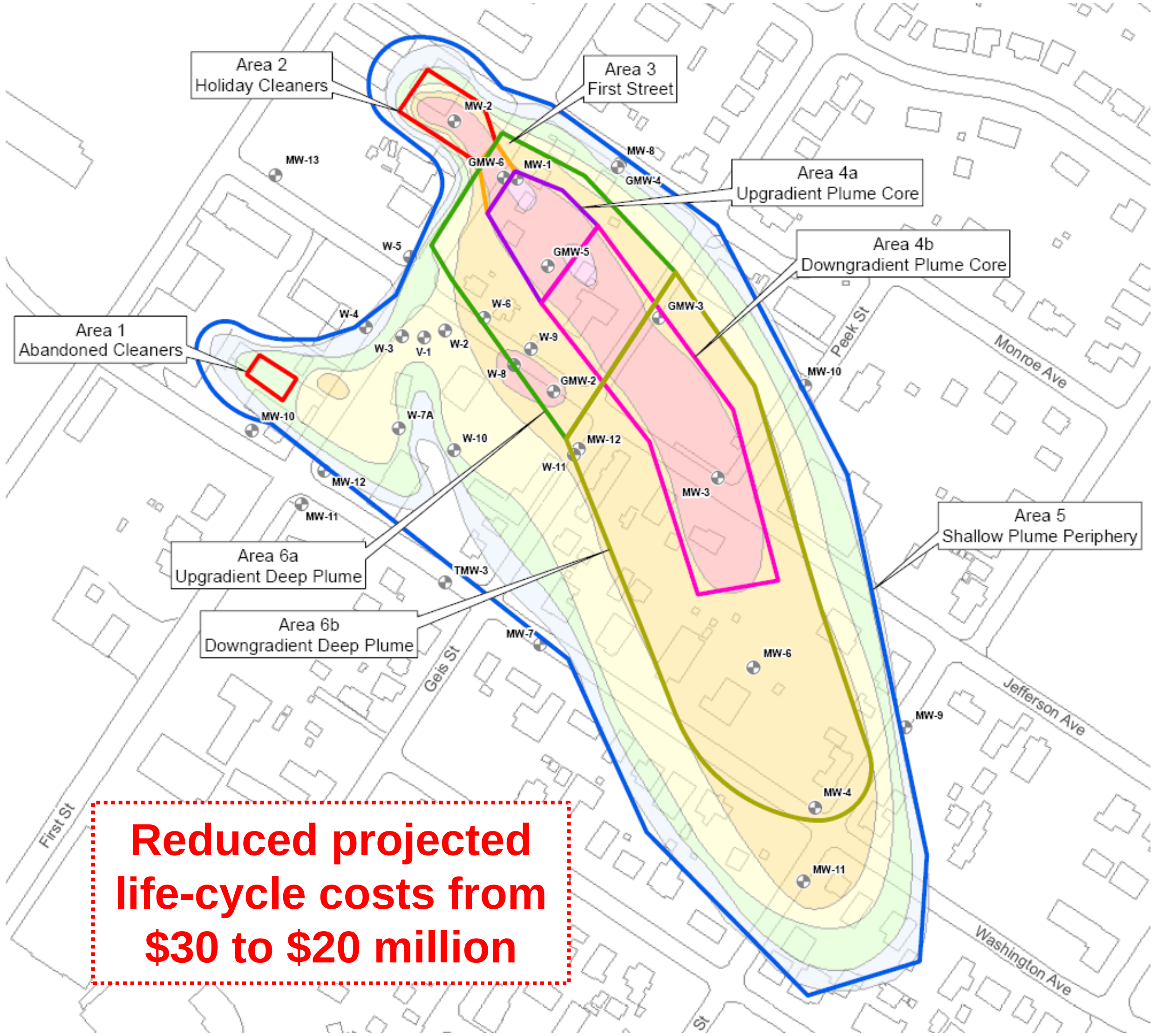


Initial Optimization: ROD Remedy

Area	Approach
1	In situ thermal treatment (ISTT)
2	ISTT
3	ISTT and in situ chemical oxidation (ISCO)
4a	ISCO
4b	ISCO with follow-on enhanced reductive dechlorination (ERD)
5	ERD
6a	ERD
6b	ERD
All	Vapor intrusion mitigation systems (VIMS) at residences within plume footprint

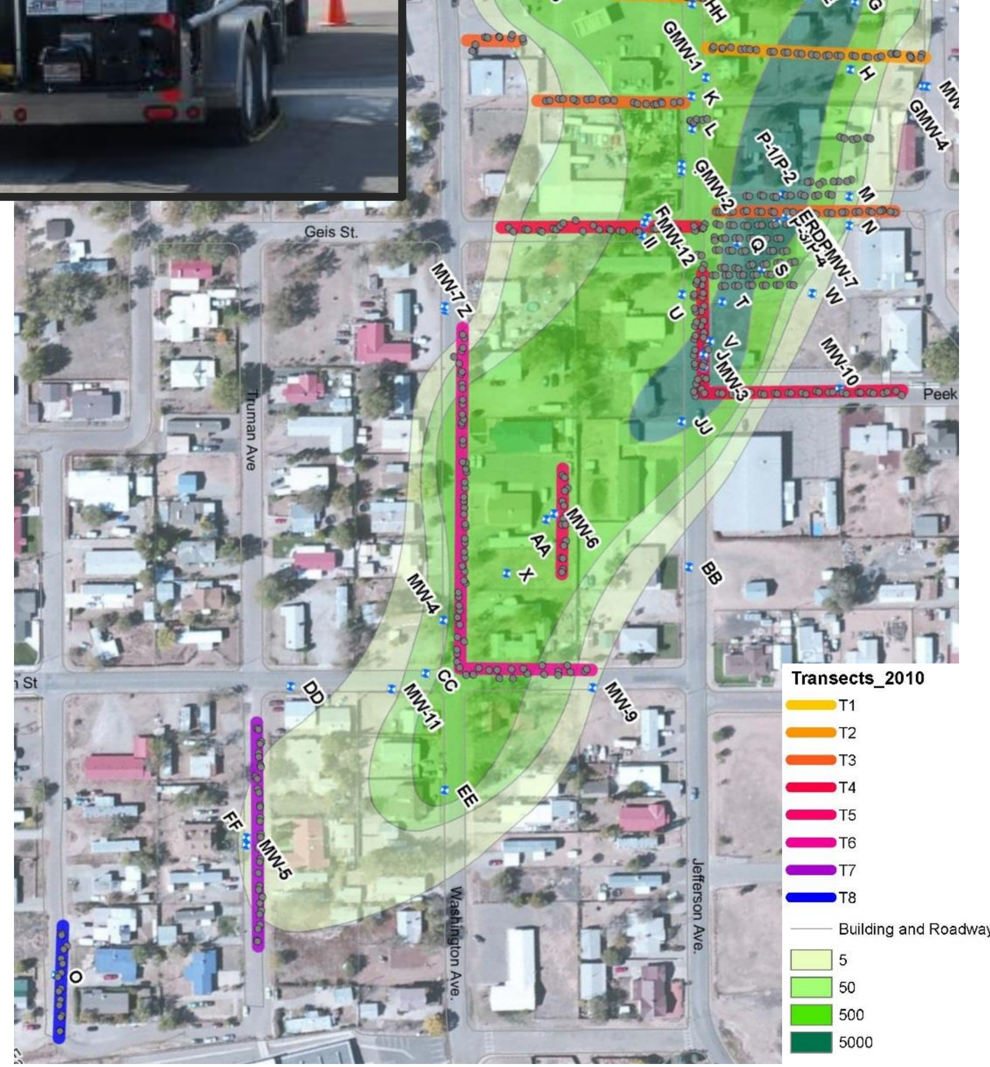
Initial Optimization: Remedy after Value Engineering

Area	Approach
1	Long-term monitoring (LTM)
2	ISTT and ERD
3	ISTT and ERD
4a	ISTT and ERD
4b	ERD
5	ERD
6a	ERD
6b	ERD and LTM
All	Vapor intrusion mitigation systems (VIMS) at residences within plume footprint



Reduced projected life-cycle costs from $30 to $20 million

ERD Summary



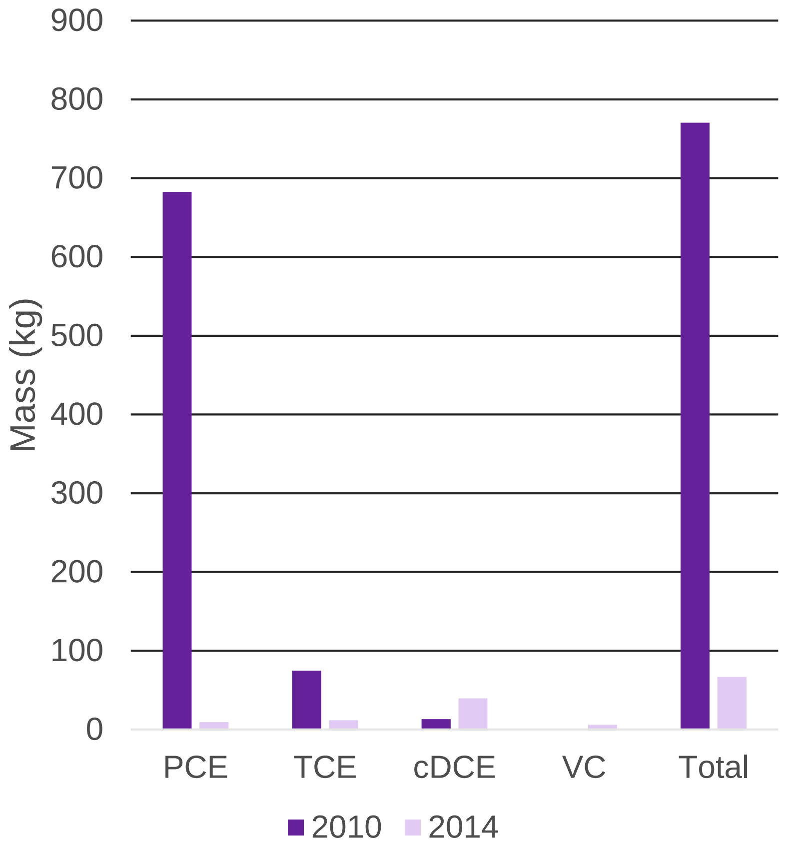
- ERD using EVO
- Over 700 injection wells
  - Eight biobarrier transects
  - Gridded area in plume core
- Up to 150 gallons of 3 to 5% EVO solution injected per foot of well screen (during each injection event) using mobile injection equipment
- For the entire 2- to 3-month long injection event:
  - Up to 750,000 gallons of injection solution
  - Up to 300,000 pounds of EVO
- Reinjection every 18 months
- Up to 20 years of treatment

Optimization during Remedy Implementation

	Element	Benefit
1	18-month pilot study in 2007 and 2008	Verify ERD effectiveness and identify design parameters
2	Use of membrane interface probe (MIP) during pre-design investigation	Refine target treatment areas
3	Injection test	Evaluate various screen lengths, radius of influence, and reduce number of injection wells
4	Sampling of injection wells during full-scale installation	Refine biobarrier layout
5	Tracer test during full-scale injection	Confirm radius of injection influence
6	Use of multiple substrates during full-scale injection	Concurrent evaluation to identify best long-term substrate for site
7	Partial bioaugmentation during full-scale injection	Assess need for bioaugmentation

Results through 2014

- Total CVOC mass reduced by more than 90%
  - ISTT influence
    - 80% of the decrease
  - ERD influence
    - Dissolved-phase mass outside of the ISTT treatment area decreased from about 200 to 66 kg after two injection events
    - 70% of remaining CVOC mass was cis-1,2-DCE or VC
    - Though center of COC mass has shifted the plume footprint remained relatively consistent



Optimization during LTRA

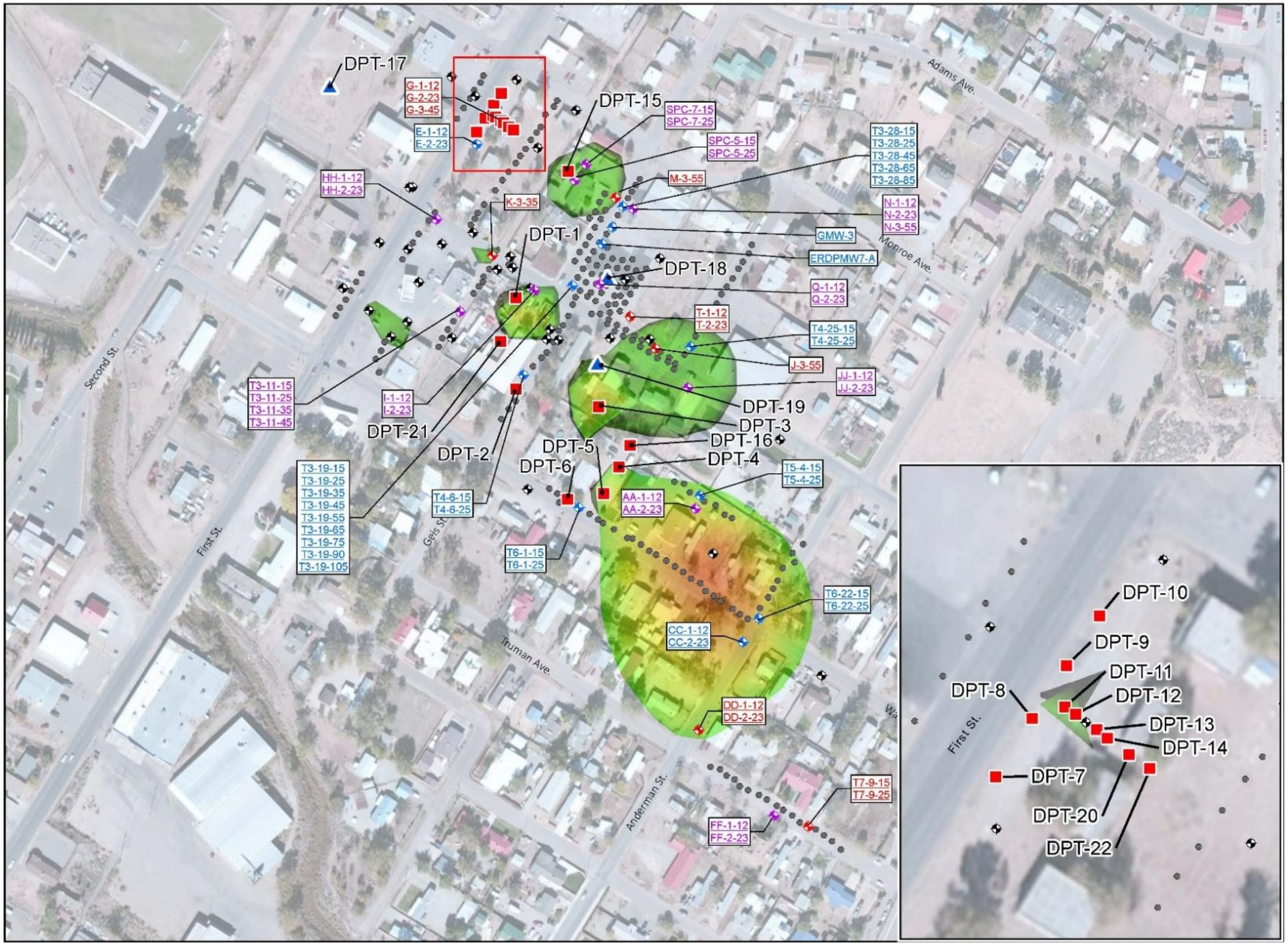
1. Comprehensive total organic carbon (TOC) sampling event
   - Confirm biobarrier longevity assumptions and optimize injection frequency
2. Supplemented monitoring well network with direct push technology (DPT) sampling
   - Assess plume geometry data gaps
   - Adjust substrate quantities based on VOC results
   - Evaluate contribution of abiotic degradation to VOC reductions
3. Evaluate use of methane inhibitor
   - Potential to reduce methane generation from ERD process and optimize substrate use
4. Evaluate long-term VOC data trends
   - Reduce sampling frequency at select site monitoring wells
5. Rehabilitate and redevelop injection wells and add new monitoring wells

1. TOC Assessment (2016)

Injection Year	Time Since Injection	TOC Geometric Mean (mg/L)	Number of IWs Sampled in July 2016
2015	7 months	570	22
2014	26 months	40	8
2013	36+ months	740	3 (all deep)

- Findings
  - Comparison of 2014 and 2015 injection grouping indicate injection frequency should not exceed 24 months – 18 months is probably still optimal for sustaining peak reduction
  - The persistence of TOC within the deepest portion of injection transect T3 suggests less frequent injections
- 30 monitoring wells also sampled
  - Range = 3 to 130 mg/L; average = 15 mg/L
  - TOC concentrations in monitoring wells generally adequate for sustaining reducing conditions downgradient of the biobarrier transects

2. Supplemental Grab Sampling (2016)



LEGEND

- Grab groundwater locations
- Abiotic Soil Boring Locations

Monitoring Well Samples

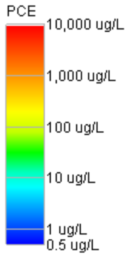
- TOC only
- VOC only
- VOC and TOC
- Monitoring wells
- Injection wells

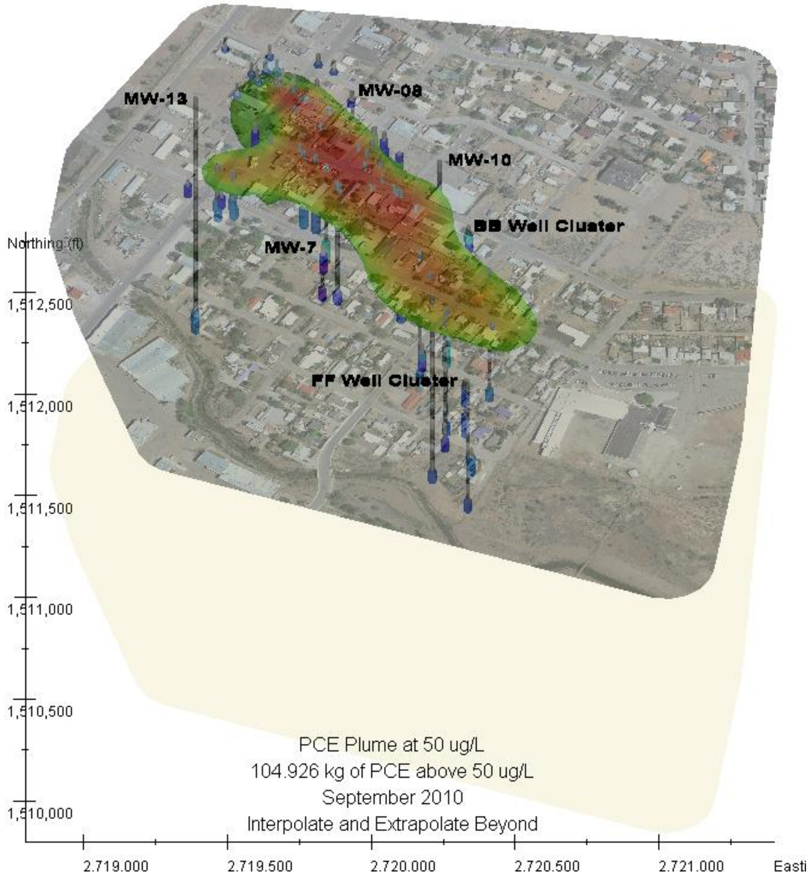
2016 Estimated PCE at Water Table (in μg/L)

- 50-100 μg/L
- 100 - 1000 μg/L
- >1000 μg/L

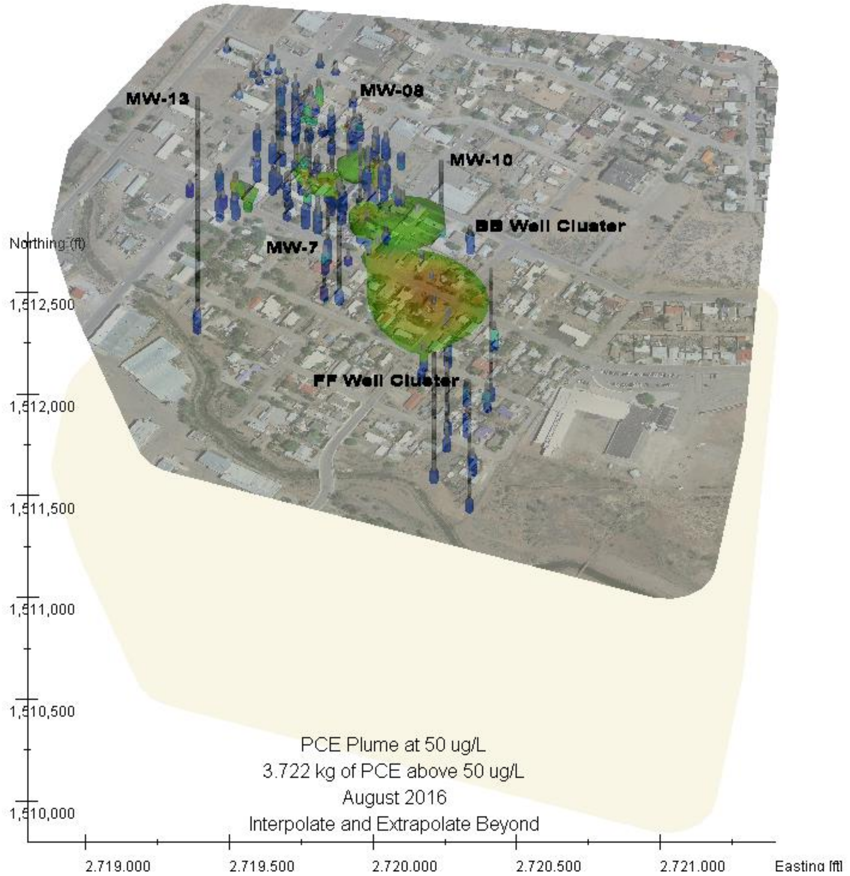
Figure 3-2.
Remedial Optimization Groundwater Sampling Locations
2016 Annual Long-Term Response Action Report
Grants Chlorinated Solvents Plume Site
Grants, Cibola County, New Mexico

2. Supplemental Grab Sampling – Plume Updates





September 2010



August 2016

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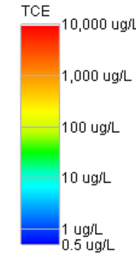

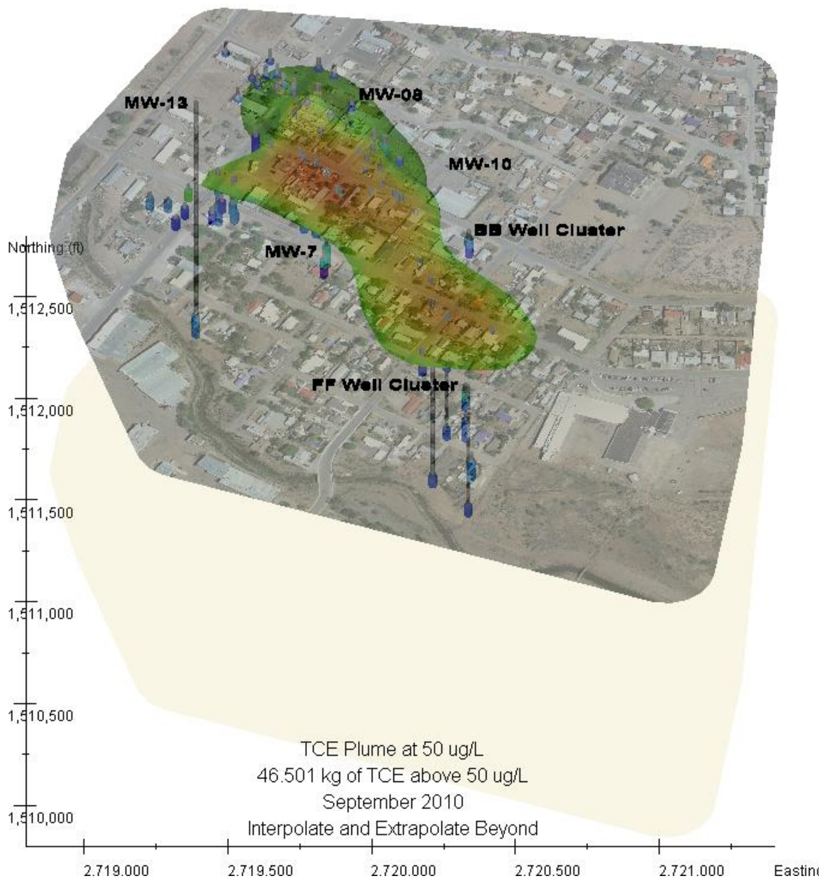

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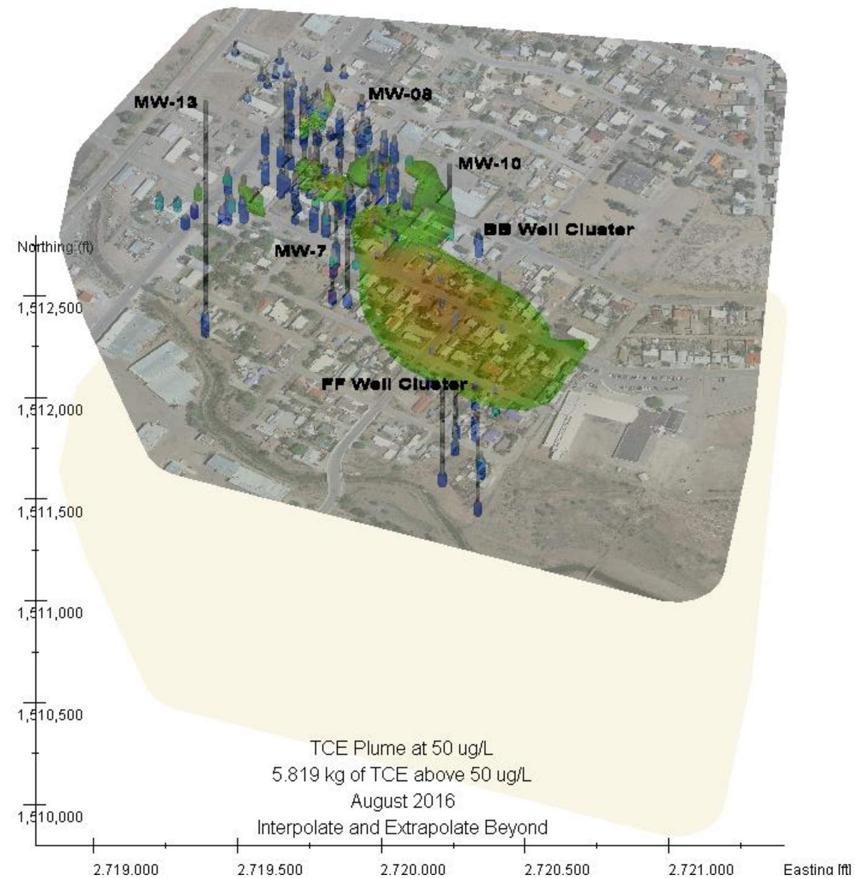

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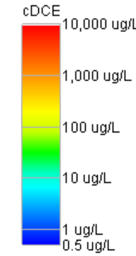

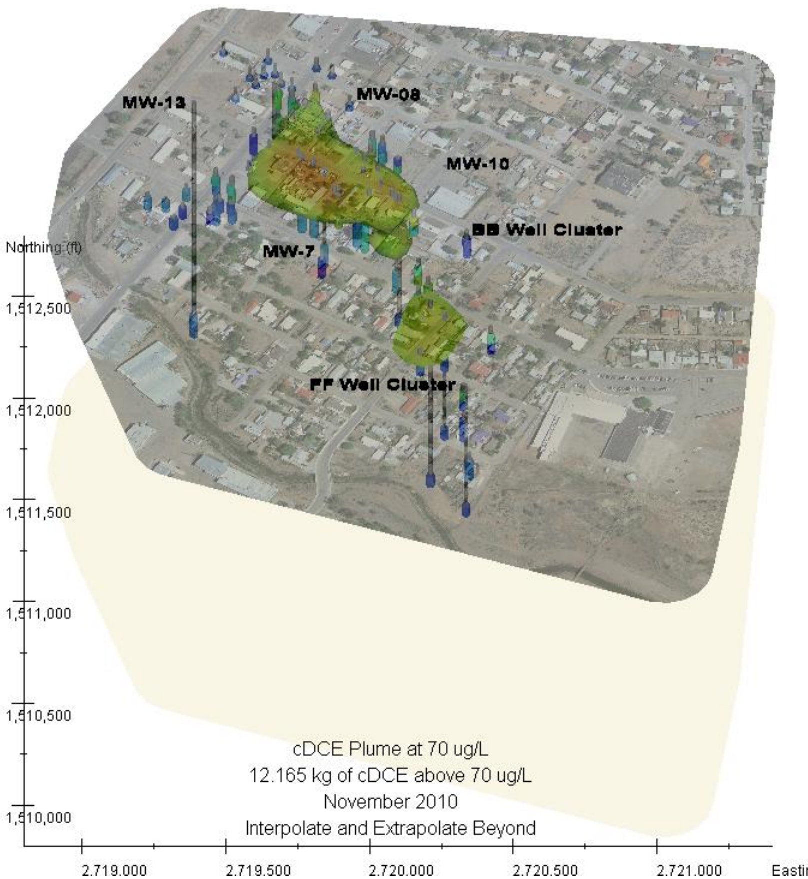

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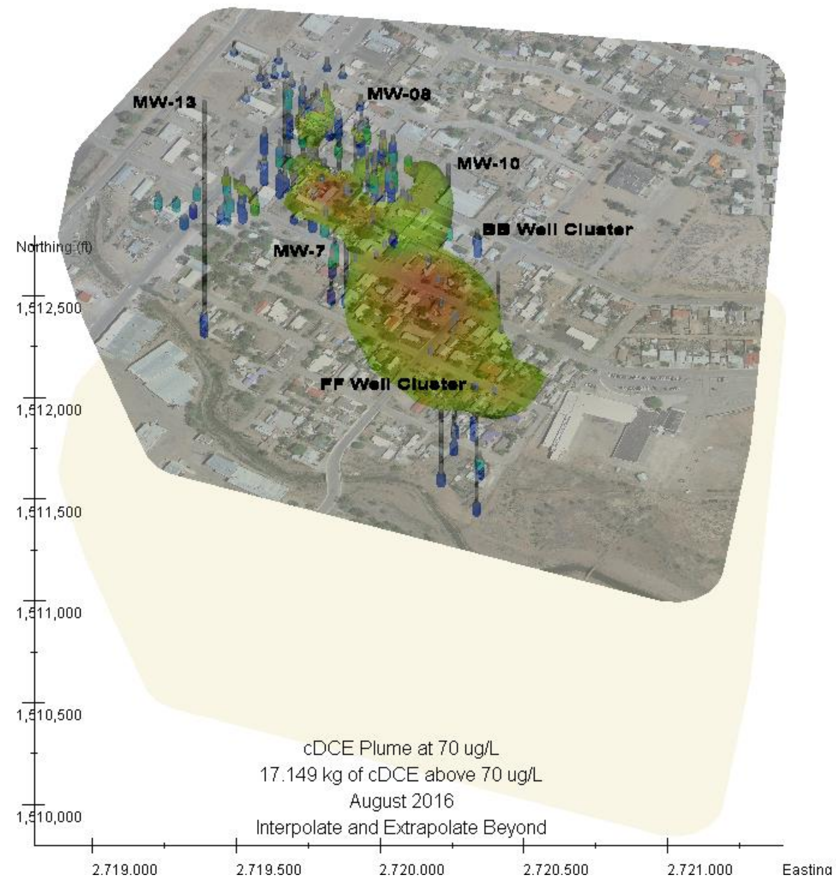

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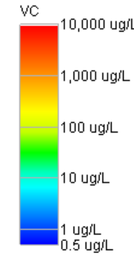

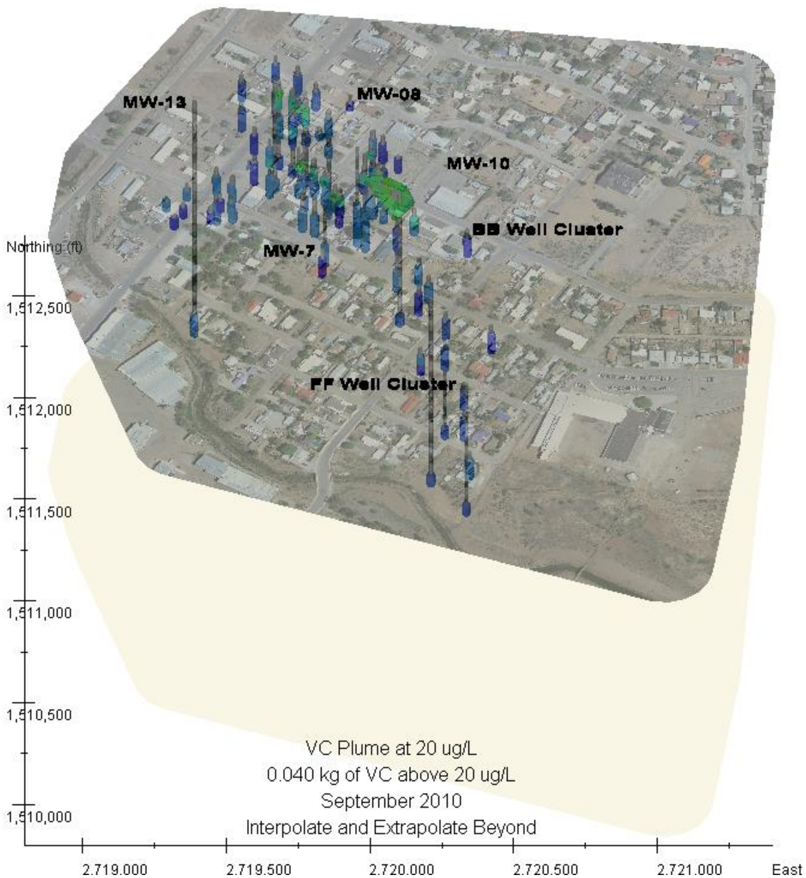

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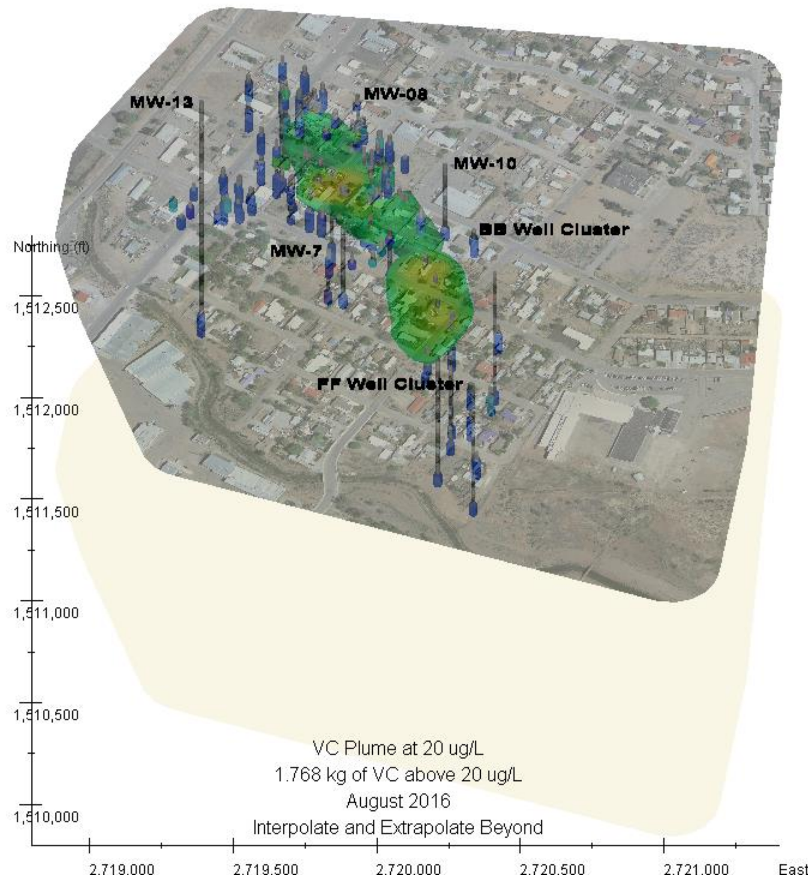
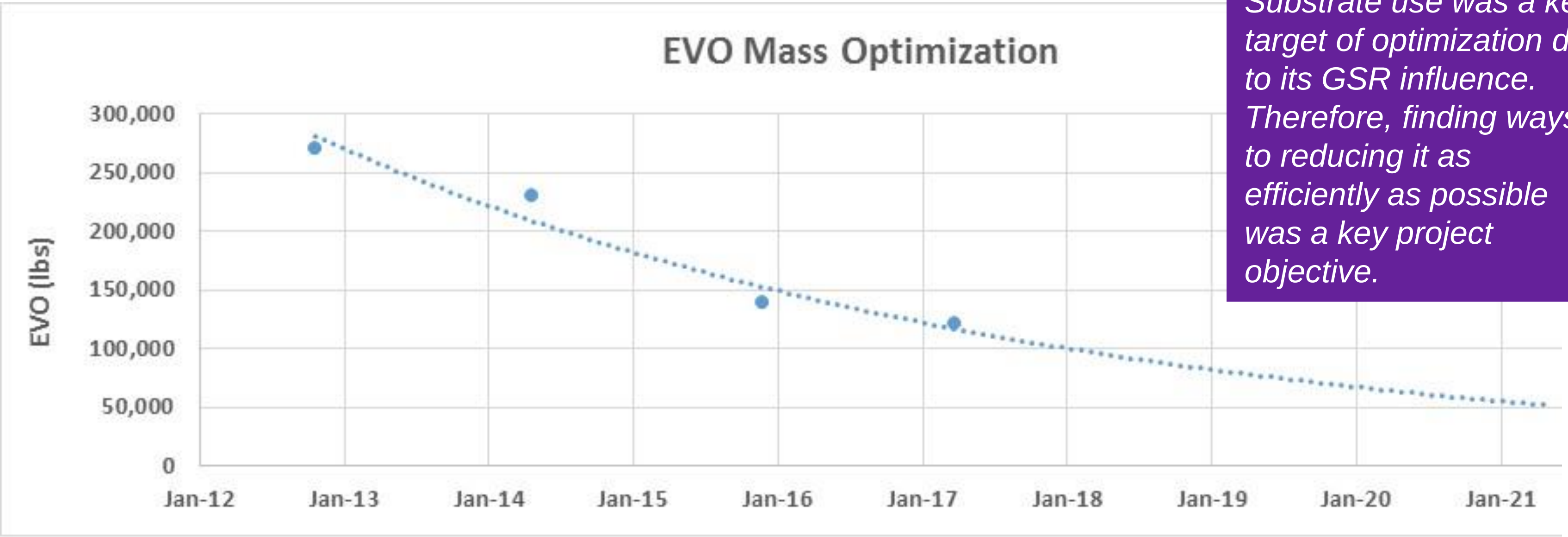


August 2016

2. Supplemental Grab Sampling – Injection Optimization

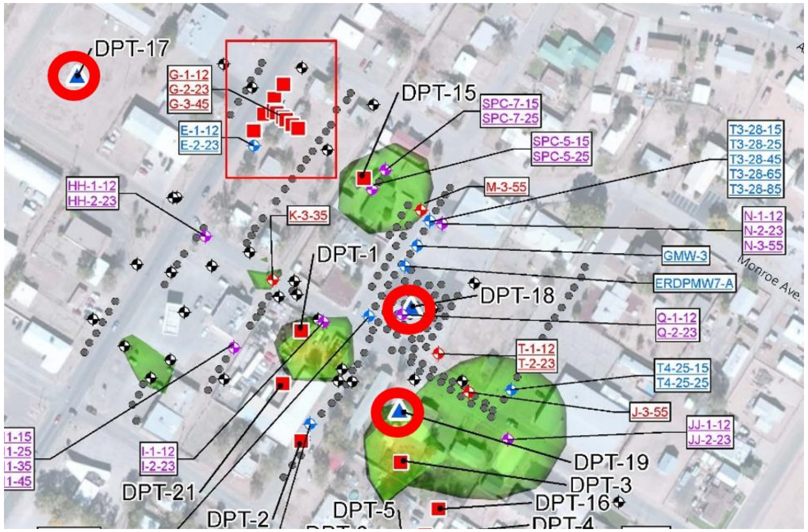
- Complemented permanent injection well network with DPT injections to address recalcitrant areas between transects and where the target substrate volume could not be delivered via injection wells due to well ineffectiveness and/or the local lithology
- Outcome
  - Reduced injections in deeper intervals and on plume periphery
  - Reduced injections in shallow plume core where relatively aggressive approach has resulted in plume collapse



Substrate use was a key target of optimization due to its GSR influence. Therefore, finding ways to reducing it as efficiently as possible was a key project objective.

2. Supplemental Grab Sampling – Abiotic Degradation Assessment

- Abiotic degradation can occur in reducing environments where sulfate concentrations are naturally high leading to the formation of reactive iron and sulfur minerals
  - If occurring, could reduce substrate demand to sustain treatment
- Assessment approach
  - Soil samples collected via DPT upgradient of the site to establish background conditions and from two locations within the plume: 1) downgradient of an injection area and 2) within an injection area
  - Samples collected from 8-13, 18-23, and 40-45 feet bgs
  - Parameters
    - Magnetic susceptibility to estimate magnetite concentration in the soil
    - Acid volatile sulfides (AVS) to estimate iron sulfide in sediment
    - Total iron to verify the magnetic susceptibility results

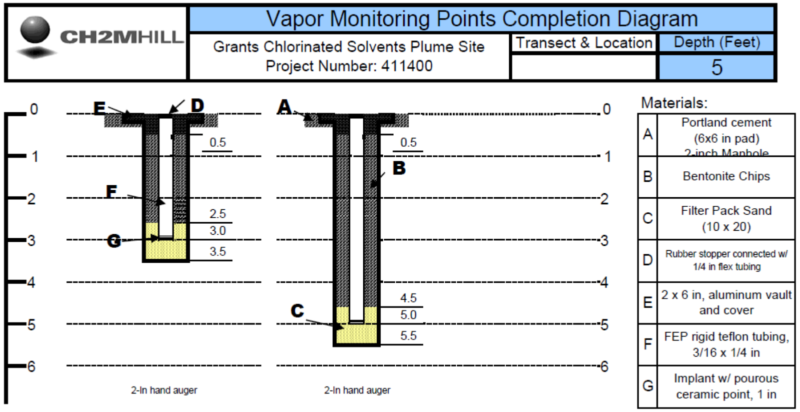


2. Supplemental Grab Sampling – Abiotic Degradation Assessment

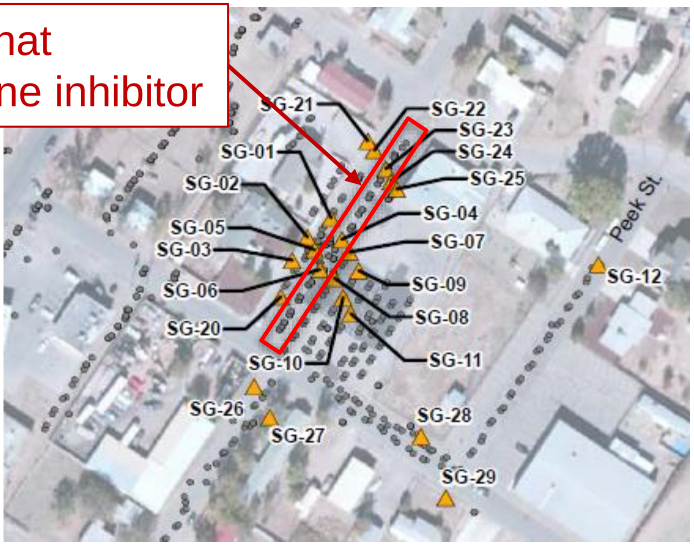
- Magnetic susceptibility
  - No significant difference among sample locations and depth intervals
  - Based on relationship between the magnetic susceptibility results and nearby degradation rates, it appears that biotic degradation is the dominant mechanism (PCE decay rate ranges from 2.2 to 2.7 yr^{-1})
  - Downgradient and outside of active treatment zones, the data show more of a combination of abiotic and biotic degradation
- Acid volatile sulfides
  - Seven of eight samples were below detection limits
  - Only detection was 0.84 micromoles per gram in the 18-23 feet bgs interval upgradient of the plume
  - Little evidence of an abiotic component
- Overall conclusion – no obvious evidence that abiotic processes are contributing to the VOC concentration reductions at the site

3. Methane Inhibitor

- A commercially-available methane inhibitor was added in a pilot test area at wells T3-19 through T3-32
  - Objective is to reduce methane generation and optimize substrate use
- Sampling program
  - Vapor monitoring point pairs (SG) screened from 2.5 to 3.5 and 4.5 to 5.5 feet below ground surface
  - Monitoring and injection wells and water meter vaults manholes



Injection wells that received methane inhibitor



3. Methane Inhibitor: Results

VMP		Methane Inhibitor	Cover	Δ Month 1	Δ Month 4	Δ From 2015 Baseline
SG-01D	T3	yes	Soil	-34.4	--	-68.4
SG-02D	T3	yes	Soil	28.2	-29.3	-55.0
SG-03D	T3	yes	Asphalt	37.4	no change	1.2
SG-05D	T3	yes	Asphalt	-29.5	60.0	41.6
SG-06D	T3	yes	Asphalt	-58.3	-9.2	no change
SG-20D	T3	yes	Asphalt	--	0.0	-69.3
SG-21D	T3	yes	Soil	3.9	19.8	18.6
SG-22D	T3	yes	Asphalt	81.1	0.4	-17.9
SG-23D	T3	yes	Asphalt	43.4	-0.1	-5.6
SG-24D	T3	yes	Asphalt	--	no change	--
SG-25D	T3	yes	Asphalt	34.2	0.7	0.7
SG-26D	T4	no	Soil	--	16.0	16
SG-27D	T4	no	Soil	0.0	17.1	3.7
SG-28D	T4	no	Asphalt	--	8.1	8.1
SG-29D	T4	no	Soil	--	--	no change
SG-13D	T5	no	Soil	28.9	5.3	6.6
SG-30D	T6	no	Soil	--	30.5	-17.9
SG-31D	T6	no	Asphalt	--	--	--
SG-32D	T6	no	Soil	--	8.7	8.7
SG-33D	T6	no	Soil	0.0	0.1	0.1
SG-34D	T6	no	Soil	0.0	no change	no change
SG-35D	T7	no	Soil	0.0	-0.1	-0.1
SG-36D	T7	no	Soil	--	--	no change
SG-15D	T8	no	Soil	4.3	-0.3	-7.4
SG-16D	T8	no	Soil	no change	-0.2	no change
SG-17D	T8	no	Soil	no change	-0.1	no change
SG-18D	T8	no	Soil	no change	-0.1	-0.9

AVERAGES

	Δ Month 1	Δ Month 4	Δ From 2015 Baseline
Soil	-0.8	-4.8	-34.9
Asphalt	18.1	8.6	-8.2
Total	11.8	5.3	-17.1
Soil	5.5	7.0	1.0
Asphalt	--	8.1	8.1
Total	5.5	7.1	1.7

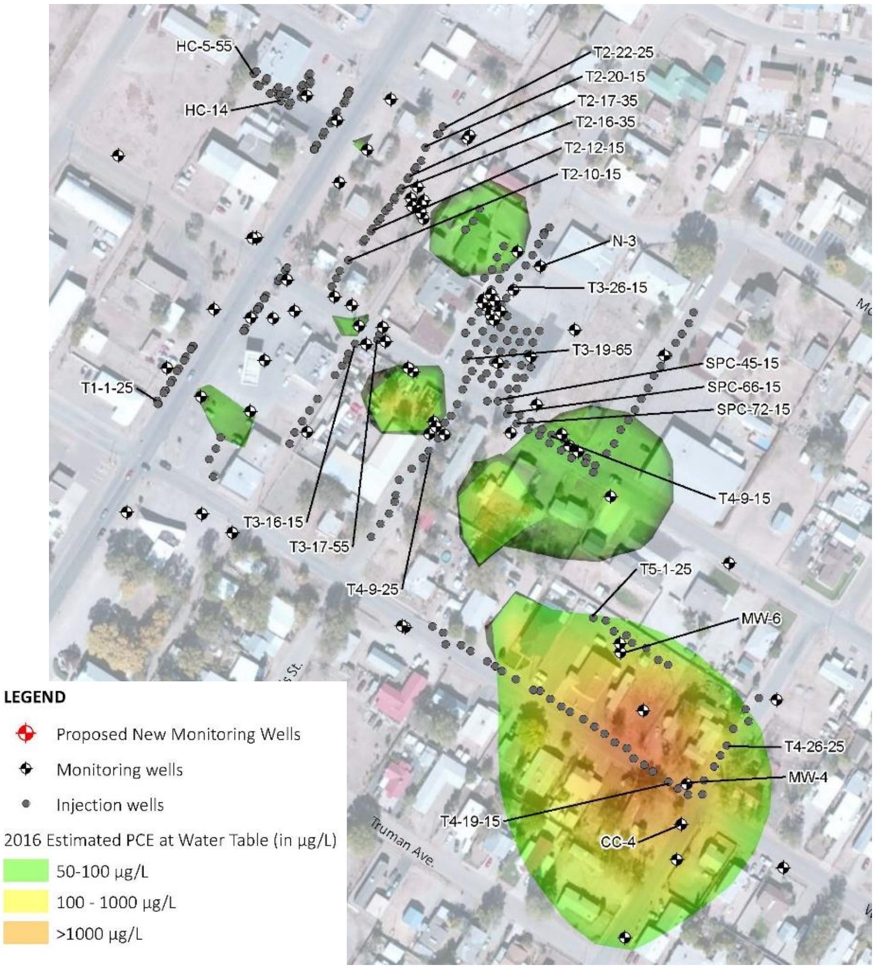
- Comparisons to previous substrate injections
  - Baseline
  - One month after injection
  - Four months after injection
- **Result is no significant influence from methane inhibitor**

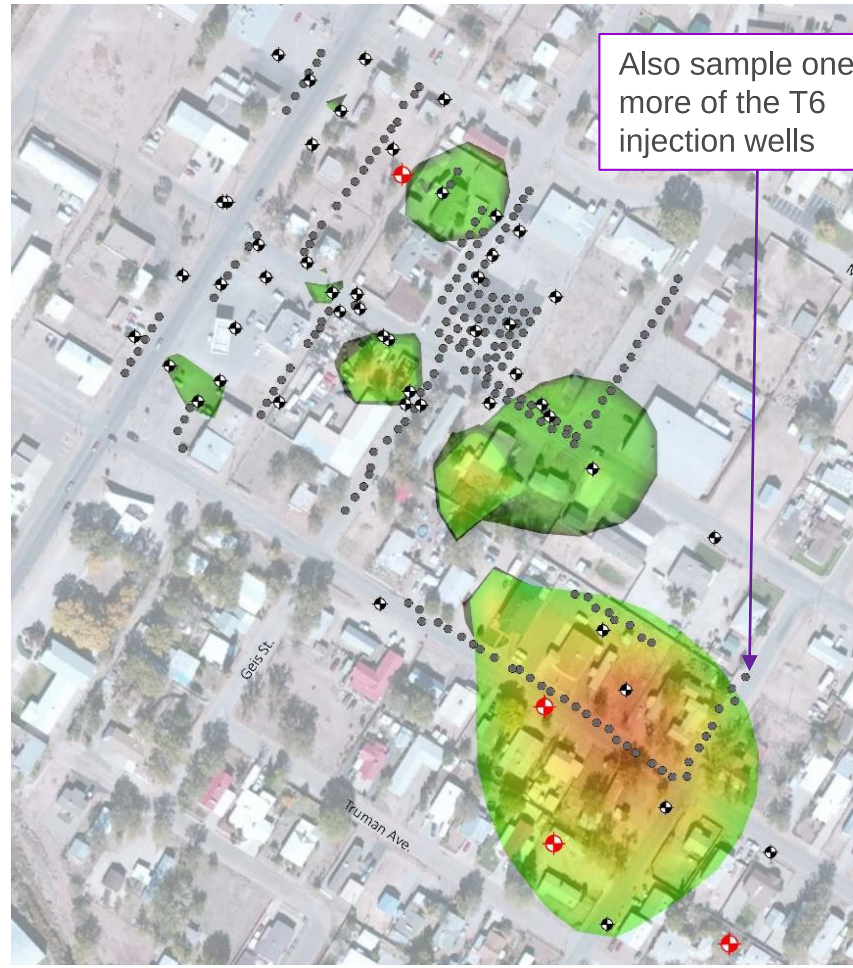
4. Monitoring Program

By reducing site visits and staff level of effort, this achieved another sustainability benefit

- 120 monitoring wells sampled annually
- VOC concentrations in 18 monitoring wells have been below detection limits since 2013
- VOC concentrations in 37 monitoring wells have been below MCLs since 2013
- Recommended to convert the 37 monitoring wells to a biennial sampling frequency

5. Injection Well Redevelopment and New Monitoring Well Installation

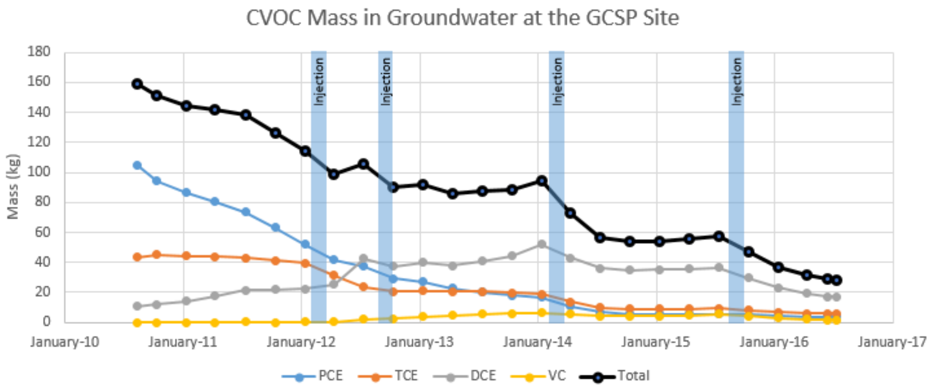


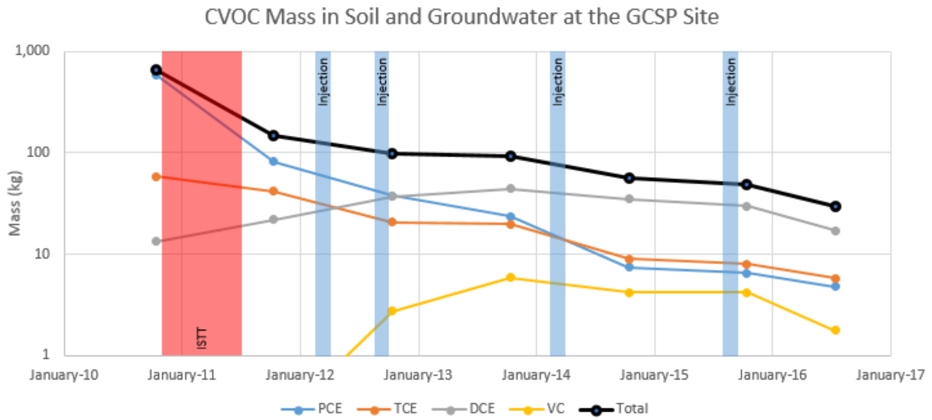


Also sample one or more of the T6 injection wells

Results through 2016

- Total CVOC mass reduced by more than 95%
  - ISTT influence
    - 80% of the decrease
  - ERD influence
    - Dissolved-phase mass outside of the ISTT treatment area decreased >80% after three injection events
    - 70% of remaining CVOC mass is cis-1,2-DCE or VC
    - Though center of COC mass has shifted the plume footprint remained relatively consistent





Summary/Conclusions

- Optimization process continuously implemented since Preliminary Remedial Design
- Monitoring optimization
  - Up to 30% of monitoring wells shifted to biennial sampling
  - Remainder sampled annually
- Substrate quantity optimization
  - Fourth injection event used 60% less than first
    - Includes 365 injection wells; down from nearly 700
  - Fifth injection event expected to be 80% less than first
- Performance maximized: VOC mass reduction
  - From ERD = >80%
  - From total system implementation: >95%
- Well ahead of schedule presented in Final Remedial Design
  - Optimization efforts completely paid for with realized cost savings
  - Additional life cycle cost reductions expected with shorter remediation timeframe as compared to design estimate

Thank you!

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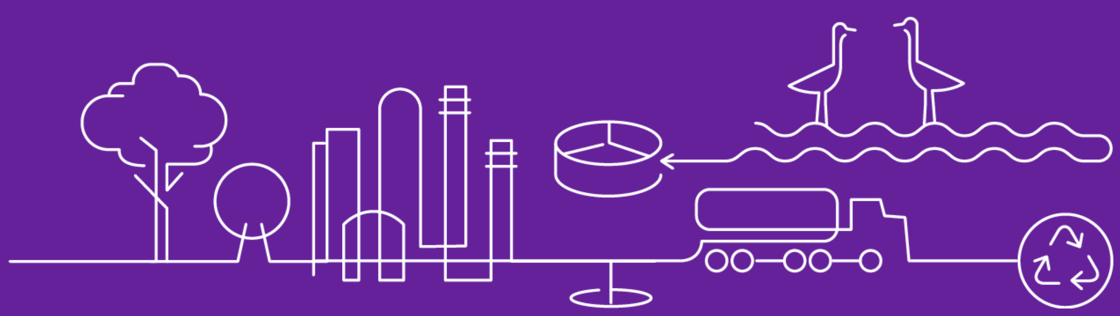

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