



Innovative Environmental Technologies, Inc.

**“Comparative Study for ZVI/Peroxide vs Ferric Iron Oxide Persulfate
Activation Followed by Intrinsic Facultative, Biologically Mediated Processes”**

Antonis Karachalios, PhD

Manager of Technology Assessment – Environmental Engineer

Innovative Environmental Technologies, Inc.

Pipersville, PA 18947

888-721-8283

www.iet-inc.net

- IET's Evolution
- In-Situ Approaches
- ISCO/Bio Attenuation
- Case Studies
- Questions

IET Evolution



1998 2000 2002 2004 2006 2008 2010 2012 2014 2016

IET Formed (1/2/1998) as first DPT based Injection Company in US.

IET Opens Midwest Office in Columbus OH

IET Establishes Environmental Drilling Division with offices in Ohio and NJ

IET Forms Provectus Environmental Products as Licensee of IET Patents

IET Expands Environmental Drilling Division with offices in NC and FL

IET Develops and Patents In-Situ Injection Processes – US 152' Patent

IET Pioneers and Implements In-Situ Aerobic Processes for BTEX Compounds

IET Designs and Implements First ISCR Projects in the US – Since 2001 over 700 Sites Remediated Since 2002

IET Files for 388' and 709' Patents for Organic Hydrogen Donor and ZVI for CVOCs - IET Establishes Itself as Leader in CVOC Remediation

IET Evaluates and Utilizes Various ZVI for In-Situ Applications. ZVIs from US, India, Russia and China Evaluated and Sourced

IET Develops Ferric Iron (ZVI + Peroxide) Oxidation-Biological Mechanisms for Petroleum Hydrocarbons and PAHs

IET Develops and Refines IN-Situ GeoChemical Stabilization Processes – 2015 Largest US Application (170,000 Gallons)

IET Develops Unique Organic Hydrogen Sources – Algae and Kelps, US patent 974'

IET Develops Unique Encapsulation Process for Organic Hydrogen Donors US Patent 244'

IET Develops Unique Methane Inhibition Process for Reductive Dechlorination US Patent 699'

Evolving Technology

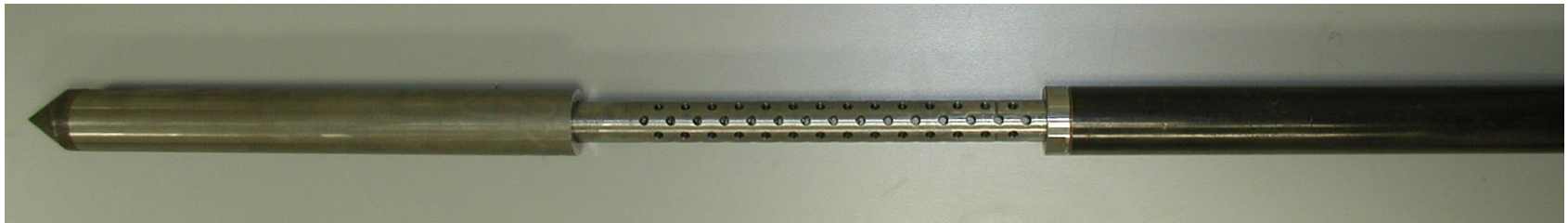


To introduce and discuss IET's capabilities for environmental drilling, in-situ delivery systems and remedial processes such that the mechanical, biological and chemical aspects of an in-situ remediation program are integrated

Design - Implementation - Data Evaluation

- Expendable Points
- Permanent and Temporary Wells
- Retractable Tooling
- Sealed Points (Open Under Pressure)
- Open Hole Bedrock Application

In-Situ Delivery Methods



Retractable Injection Zone
"Bottom-Up" Injections

Consistent Flow Velocity Across
Injection Zone

Varied Injection Screen Lengths



- Excavation and Soil Mixing
- Progressive Cavity Pump (Grout Pump)
- Pneumatic Fracture and Delivery
- Hydraulic Fracture and Delivery
- Low Pressure – High Flow
- High Pressure – Low Flow

In-Situ Delivery Methods

IET INJECTION SYSTEM
UNITED STATES PATENT 7,044,152



Injection Trailers Include: Multiple Liquid Feed Systems, Stainless Steel Piping, Isolated Compressed Gas Containment, Safety Shower, Eyewash Station, Onboard Generator, Chemical Resistant Construction, Mobile Office Space



In-Situ Delivery Methods



Overview of ISCO Technologies

- Introduction
- Oxidizing agents
- General chemistries of reactions

Use of Persulfate for ISCO Treatment

- Traditional Persulfate Activation Methods
- Limitations of convectional activation technologies

ISCO/Enhanced Bioremediation

- ZVI/Peroxide Persulfate Activation
- Ferric Iron Oxide Persulfate Activation
- Biological Attenuation Process

Cases Studies

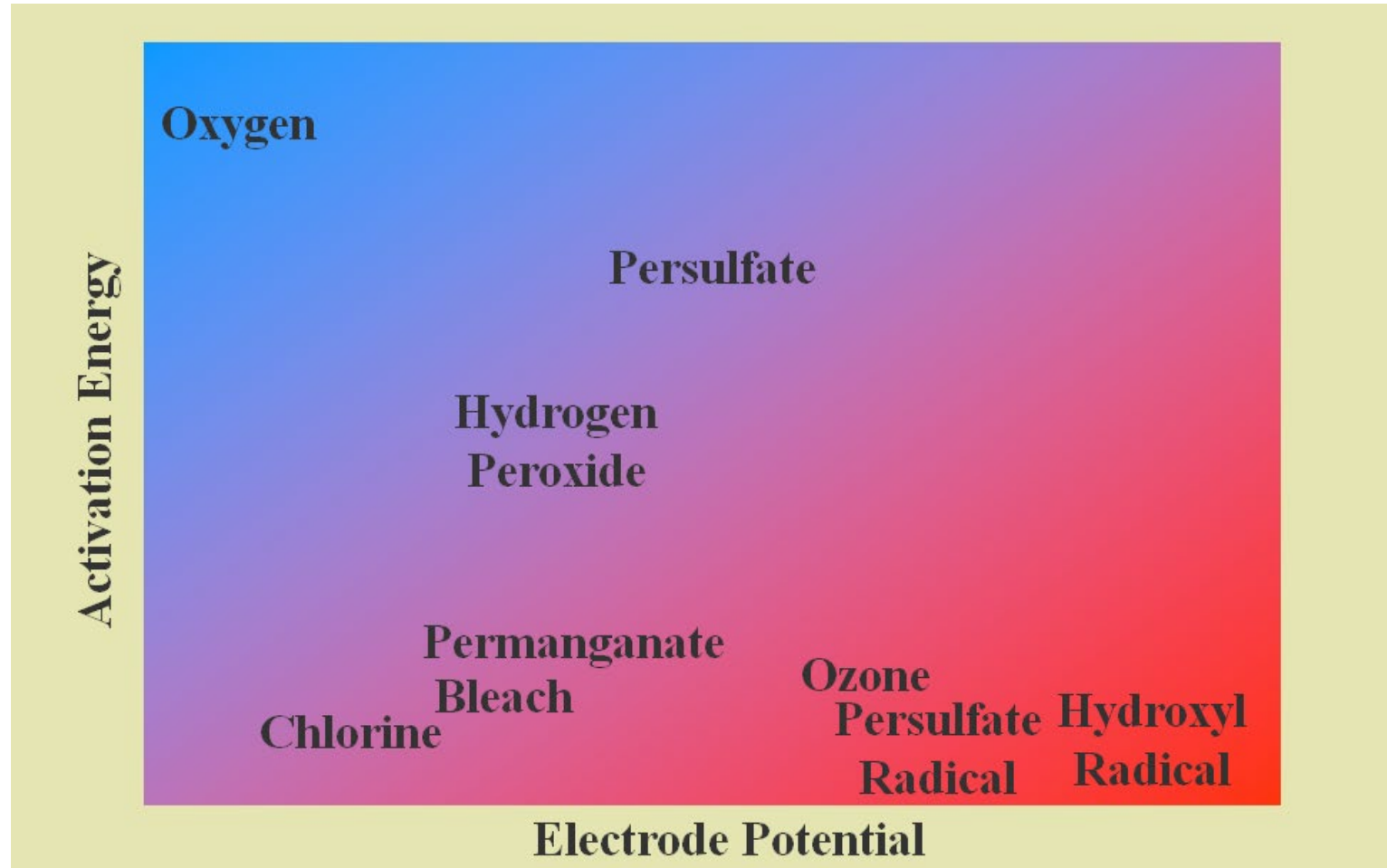
- ISCO involves:
 - ❖ Injection of an oxidizing agent into the subsurface to destroy organic compounds
 - ❖ The by-products for complete mineralization include carbon dioxide (CO₂), water (H₂O) and oxygen (O₂)

- Goal is to mineralize or transform contaminants of concern (COCs)

Common Oxidizing Agents

Oxidant	Potential (V)	Form
Fenton's Reagent (OH^\cdot)	2.80	Liquid
Activated Persulfate ($\text{SO}_4^{\cdot-}$)	2.60	Salt/Liquid
Ferrate (Fe^{6+})	2.20	
Ozone (O_3)	2.07	Gas
Persulfate ($\text{S}_2\text{O}_8^{2-}$)	2.01	Salt/Liquid
Hydrogen Peroxide (H_2O_2)	1.78	Liquid
Permanganate (MnO_4^-)	1.68	Salt (KMnO_4) Liquid (NaMnO_4)

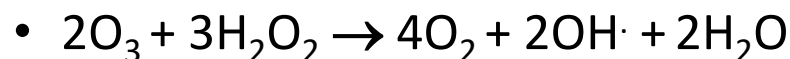
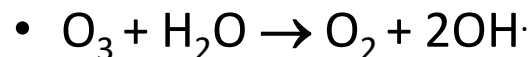
Reactivity of Oxidizing Agents



Ozone (No Activator)



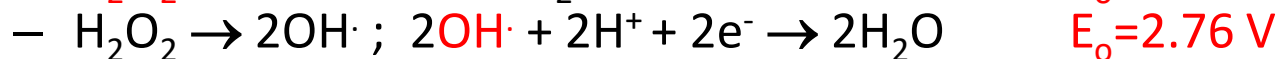
– Hydroxyl Radical



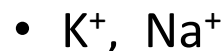
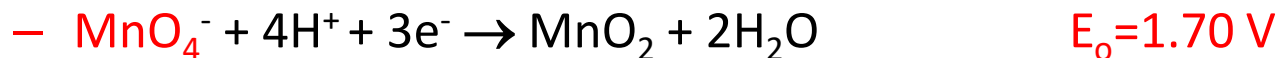
Persulfate (Requires Activation)



Hydrogen Peroxide (Requires Activation)



Permanganate (No Activator)



Accepted Oxidizing Techniques for Specific COCs

Oxidant	Amenable VOC's	Reluctant VOCs	Recalcitrant VOCs	Limitations
Peroxide, Old Fenton's	PCE, TCE, DCE, VC, CB, BTEX, PAHs, MTBE, TBA	DCA, CH ₂ Cl ₂	TCA, CT, CHCl ₃	Stability (25-95% decomp/hr), low pH
Peroxide, New Fenton's	PCE, TCE, DCE, VC, CB, BTEX, PAHs, MTBE, TBA	DCA, CH ₂ Cl ₂ , TCA, CT, CHCl ₃		Stability (10-50% decomp/hr)
Potassium Permanganate	PCE, TCE, DCE, VC, TEX, PAH	MTBE, TBA	TCA, CT, B, CHCl ₃ , DCA, CB, CH ₂ Cl ₂	Soil oxidant demand
Sodium Permanganate	PCE, TCE, DCE, VC, TEX, PAH	MTBE, TBA	TCA, CT, B, CHCl ₃ , DCA, CB, CH ₂ Cl ₂	Soil oxidant demand
Sodium Persulfate, Fe	PCE, TCE, DCE, VC, CB, BTEX, PAHs, MTBE, TBA	DCA, CH ₂ Cl ₂ , CHCl ₃	TCA, CT	Stability (10-25% decomp/wk), low pH
Sodium Persulfate, Base	All VOCs			Stability (10-25% decomp/wk), NaOH costs
Sodium Persulfate, Heat	All VOCs			Stability (10-50% decomp/day), low pH, heating costs
Ozone	PCE, TCE, DCE, VC, CB, BTEX, PAHs, MTBE, TBA		DCA, CH ₂ Cl ₂ , CHCl ₃ , TCA, CT	Mass Delivery, Volatilization

➤ Divalent Metal Activation

- ❖ Oxidant consumption during conversion of ferrous iron to ferric iron
- ❖ Inhibition of biological utilization of the generated ferric species (EDTA)
- ❖ High oxidant consumption due to overdosing of the ferrous chelated iron

➤ Caustic Activation

- ❖ Significant health and safety issues
- ❖ Unsuitably high (extreme) pH environment for biological attenuation
- ❖ Self-limiting biological attenuation process due to hydrogen sulfide generation

➤ Heat Activation

- ❖ Difficult Implementation
- ❖ High Cost
- ❖ Elevated hydrogen sulfide production

➤ Hydrogen Peroxide Activation

- ❖ Limited efficacy on many targeted compounds
- ❖ Elevated hydrogen sulfide production
- ❖ Produces heat and (excessive) gassing which can lead to surfacing issues

The ISCO reactions are short lived

- ❖ Ozone (minutes to hours) Fenton's (hours to days) Persulfate (days to weeks) Permanganate (months).
- ❖ The ISCO process can enhance COC desorption
- ❖ Lack of secondary treatment mechanism mandates subsequent treatments

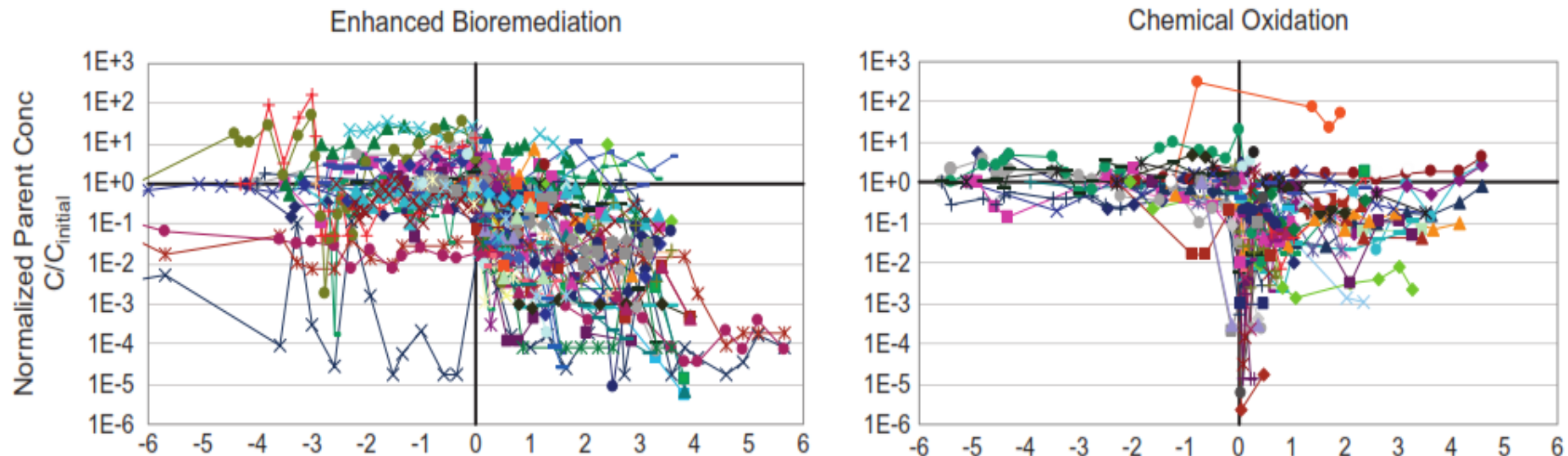


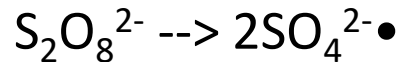
Figure 1. Temporal concentration records for wells at source depletion sites. Concentration is normalized by the initial measured concentration. Sampling time is normalized by the time of the initial source depletion treatment.

- Iron catalyzed peroxide oxidation (Fenton reactions) utilize iron to catalyze the decomposition of hydrogen peroxide, producing OH radicals

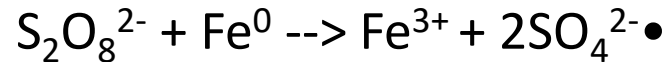


- Advantage of the evolution of free radicals
 - ❖ Offer higher oxidation capabilities
 - ❖ Broader spectrum of applicable targeted compounds
- In addition to the reactions occurring between the oxidant and the organics present, radical-propagating reactions also occur involving the excess H_2O_2
- More radicals are available to react with the contaminants

- The persulfate anion ($S_2O_8^{2-}$) has a high redox potential and can be chemically activated to form the sulfate radical ($SO_4^{2-\bullet}$)



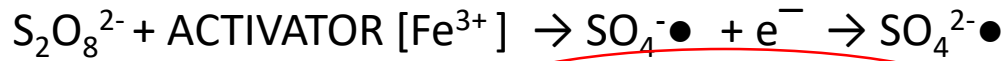
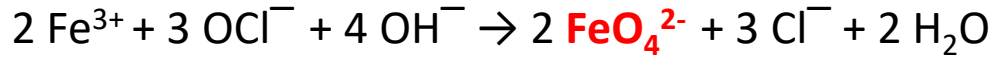
- Persulfate oxidation commonly uses sodium persulfate, to produce sulfate radicals that attack most petroleum hydrocarbons



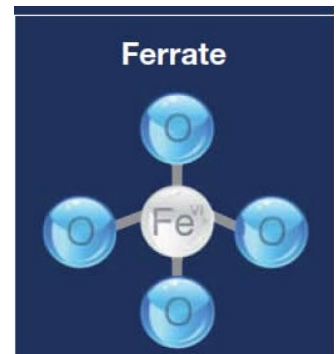
- Persulfate activation with iron requires a lower activation energy than thermal activation, making iron activated persulfate a more efficient and rapid way of degrading contaminants
- The generated sulfate ion from the decomposition of the persulfate acts as a terminal electron acceptor for sulfate reducers

Sodium Persulfate + Ferric Oxide (Fe₂O₃)

- Chemical Oxidation via Sulfate (SO₄•) Radical
- Chemical Oxidation via Ferrate (Fe⁶⁺•) Radical

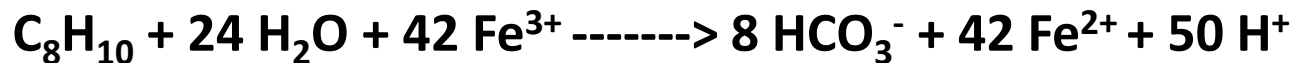


Oxidation Potentials	Volts
Fluorine (F ₂)	2.87
Hydroxyl radical (OH•)	2.80
Persulfate radical (SO ₄ •)	2.60
Ferrate (Fe ⁺⁶)	2.20
Ozone (O ₃)	2.08
Persulfate (S ₂ O ₈ ⁻²)	2.01
Hydrogen peroxide (H ₂ O ₂)	1.78
Permanganate (MnO ₄ ⁻)	1.68
Chlorine (Cl ₂)	1.49



- Persulfate is activated by Fe(III) requiring lower activation energy than alternative mechanisms
- No consumption of persulfate oxidant
- Elevation of iron oxidation state to a supercharged iron ion, ferrate species (Fe^{6+}) which can itself acts as an oxidant
- The supercharged iron cation consumption results into ferric species that act as a terminal electron acceptor for biological attenuation

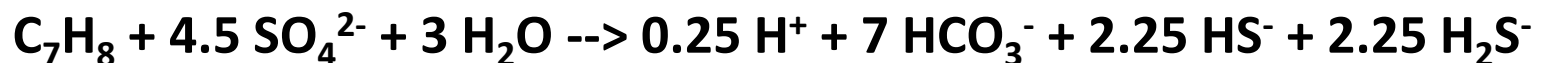
- Ferric iron used as electron acceptor during anaerobic biodegradation of contaminants
- Stoichiometrically, the degradation of 1.0 mg/L of BTEX results in the average consumption of approximately 22 mg/L of ferric iron



- Ferric iron is reduced to Ferrous iron, which is soluble in water
- Ferrous iron is oxidized to Ferric iron and the iron cycling provides sustained secondary bioremediation via one electron transfer reactions (Weber *et al*, 2006)

Sulfate Reduction

- After dissolved oxygen depletion sulfate is used as an electron acceptor for anaerobic biodegradation by indigenous microbes (sulfidogenesis)
- Stoichiometrically, 1.0 mg/L of sulfate consumed by microbes results in the destruction of approximately 0.21 mg/L of BTEX compounds
- Sulfate acts as an electron acceptor in co-metabolic processes during bioremediation of petroleum products
- Basic reactions for the mineralization of benzene and toluene under sulfate reducing conditions:



Pyrite Formation

- Sulfate residual is utilized as terminal electron acceptor by facultative organisms thereby generating sulfide
- The ferrous iron and the sulfide promote the formation of pyrite as a remedial byproduct
- This reaction combats the toxic effects of sulfide and hydrogen sulfide accumulation on the facultative bacteria
- Provides a means of removing targeted organic and inorganic COIs via precipitation reactions
- Pyrite possesses a high number of reactive sites that are directly proportional to both its reductive capacity and the rate of decay for the target organics

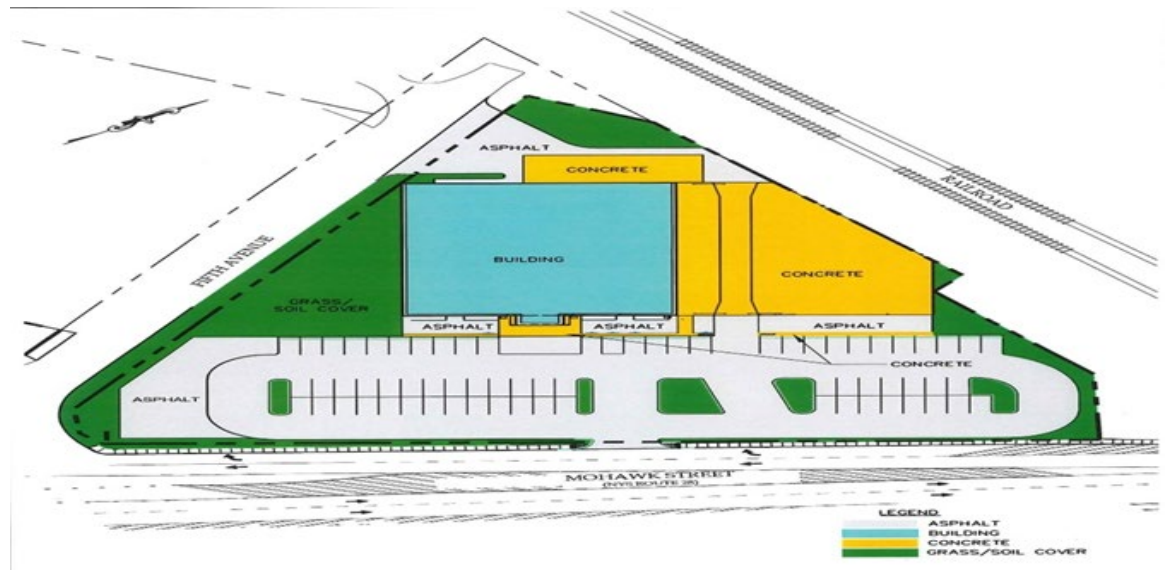
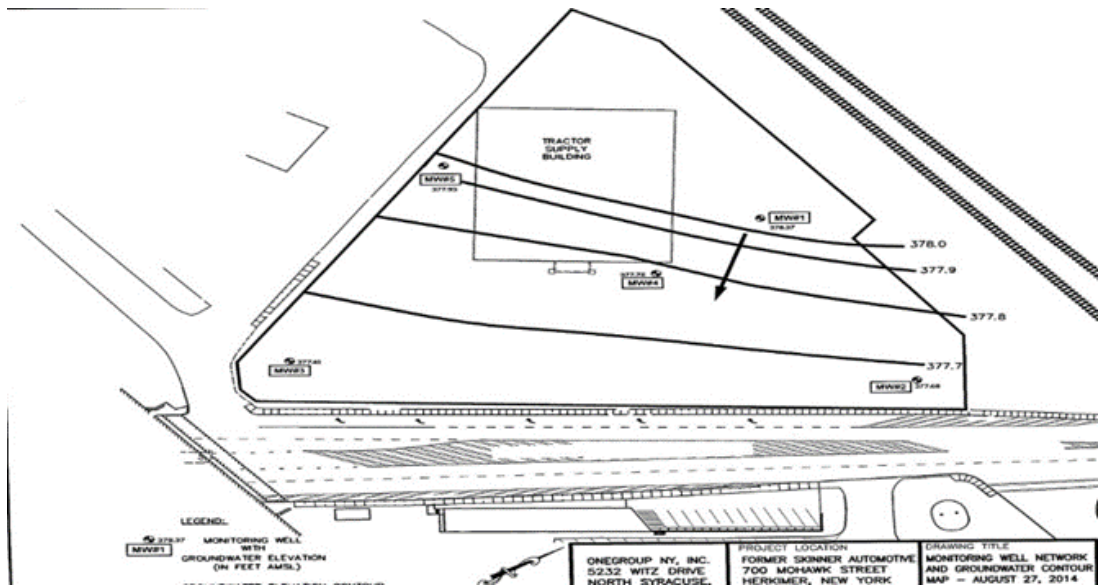


In situ chemical oxidation remedial event at a former gas station in Herkimer County, NY, from August 2012 to August 2013

- The Site is 2.531-acre commercial property
- The site was operated as a car dealership, repair facility and body shop
- It was classified as a Brownfield Cleanup Program (BCP)
- The site was remediated in accordance with Brownfield Cleanup Agreement
- Targeted VOCs were treated through the introduction of chemical oxidants
- Total of 3,545 tons of contaminated soil was removed and treated using soil mixing

Contaminants of Concern:

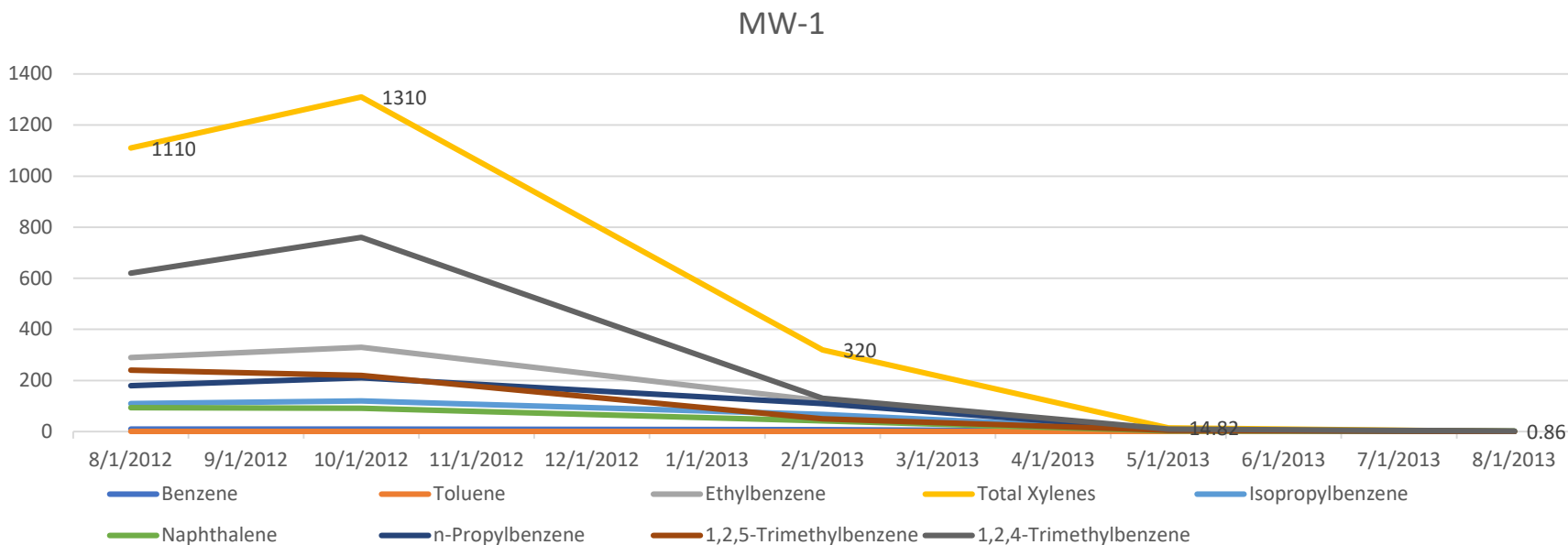
- Benzene
- Toluene
- Ethylbenzene
- Xylene
- Isopropyl benzene
- Naphthalene
- N-Propylbenzene
- 1,3,5-Trimethylbenzene
- 1,2,4-Trimethylbenzene





ZVI/Peroxide Persulfate Activation - Case Study 1

MW-1					
Sampling Date	08/15/2012	10/18/2012	02/21/2013	05/30/2013	08/06/2013
Benzene	9.9	9.3	7.0	0.25J	ND
Toluene	2.1J	1.6J	ND	ND	ND
Ethylbenzene	290	330	120	7.1	ND
Total Xylenes	1,110	1,310	320J	14.8J	0.86J
Isopropylbenzene	110	120	67.0	4.3	0.73J
Naphthalene	93.0	91.0	42.0	2.4J	1.7J
n-Propylbenzene	180	210	110	6.6	1.0J
1,2,5-Trimethylbenzene	240	220	50.0	5.5	ND
1,2,4-Trimethylbenzene	620	760	130	9.9	2.1J



- Single injection event implemented at a former gas station in Herkimer, New York in April 2017 to remediate soils and groundwater impacted by the historical release of BTEX compounds.
- Total treatment area of approximately 19,515 square feet, treating between 10 and 18 feet below ground surface.

- 56 injection points
- Spaced 20 ft apart



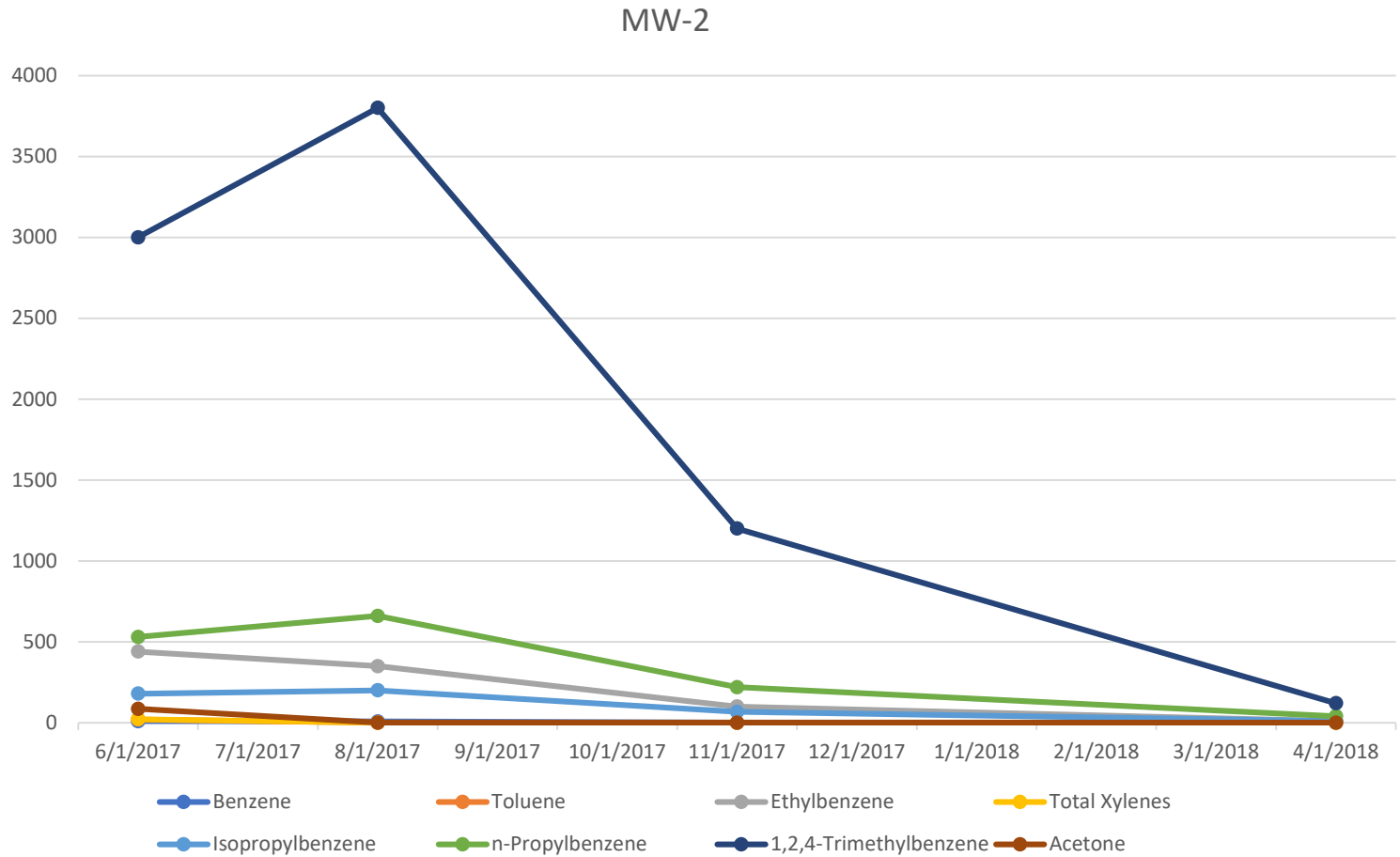


ZVI/Peroxide Persulfate Activation - Case Study 2

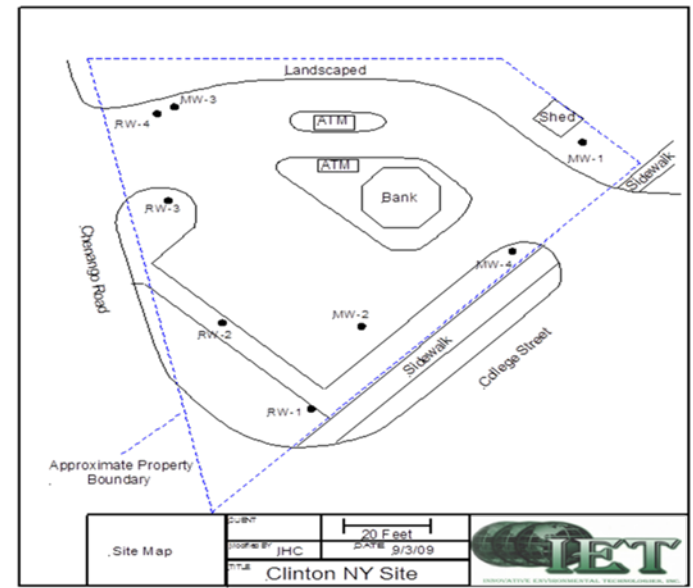
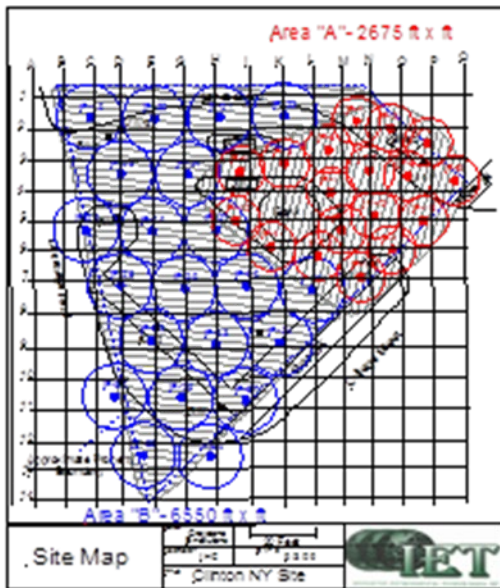
MW2017-2				
Sampling Date	06/29/2017	08/30/2017	11/09/2017	04/24/2018
Water Level (ft)	9.66	16.89	9.39	8.70
pH	6.62	6.02	7.22	6.81
ORP (mV)	-28.7	-68.0	-35.7	-32.7
D.O. (mg/L)	0.26	7.54	4.16	4.76
Conductivity (mS/cm)	4.574	3.330	2.260	1.098
Turbidity (NTU)	799	NA	370	53.4
Temperature (oC)	15.92	20.97	16.50	9.96
Total Iron (µg/L)	NA	84,600	51,400	57,700
Dissolved Iron (µg/L)	NA	2,500	347 J	200
Sulfate (µg/L)	NA	1,600,000	740,000	270,000

MW2017-2				
Sampling Date	06/29/2017	08/30/2017	11/09/2017	04/24/2018
Benzene	10 J	8.0 J	ND	0.32 J
Toluene	20 J	ND	ND	ND
Ethylbenzene	440	350	100	9.2
Total Xylenes	22 J	ND	ND	ND
Isopropylbenzene	180	200	67.0	11.0
n-Propylbenzene	530	660	220	40.0
1,2,4-Trimethylbenzene	3,000	3,800	1,200	120
Acetone	86 J	ND	ND	ND

ZVI/Peroxide Persulfate Activation - Case Study 2



- In situ chemical oxidation remedial event at a former gas station in Clinton, NY, from October 27 to October 29, 2009
- Targeted BTEX compounds while promoting biological mineralization.
- Total treatment area of 9,225 square foot area, treating between 9 and 15 feet below ground surface.



MW-1						
Field Parameter	10/26/2009	12/28/2009	02/24/2010	06/23/2010	10/07/2010	03/31/2011
pH	6.70	5.28	7.57	6.92	6.81	6.86
ORP (mV)	-67	+339	-142	-151	-100	-88
DO (mg/L)	0	0.24	0	0	0	0

MW-2						
Field Parameter	10/26/2009	12/28/2009	02/24/2010	06/23/2010	10/07/2010	03/31/2011
pH	6.92	5.44	7.58	6.75	6.62	6.77
ORP (mV)	-140	+286	-127	-153	-91	-81
DO (mg/L)	0	0.12	0	0	0	0

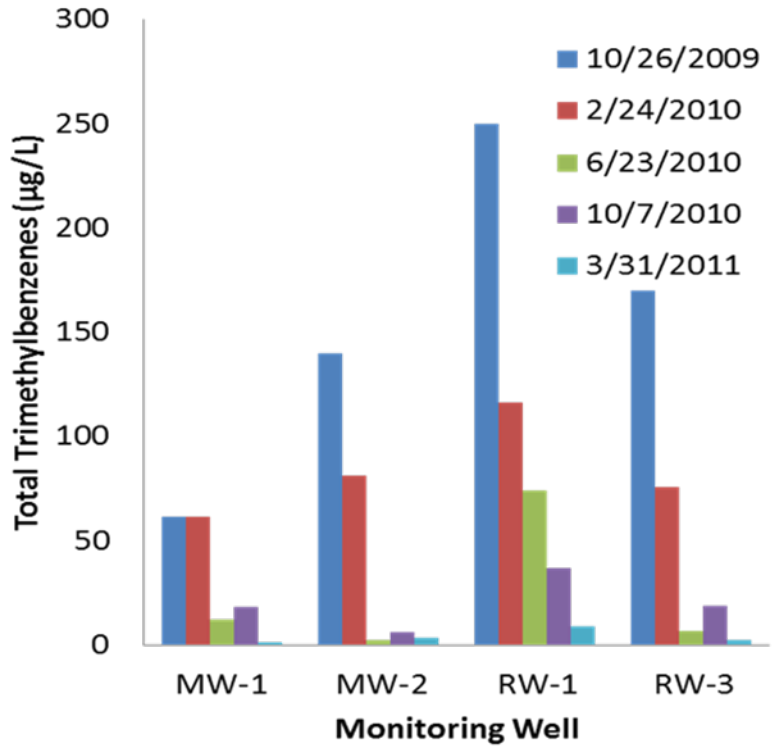
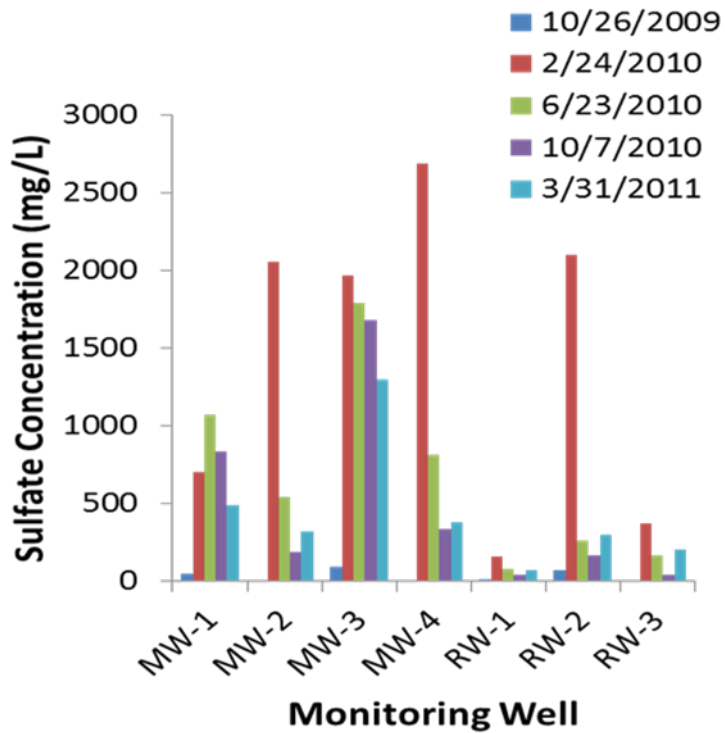
MW-4						
Field Parameter	10/26/2009	12/28/2009	02/24/2010	06/23/2010	10/07/2010	03/31/2011
pH	7.05	5.56	7.54	6.85	6.67	6.94
ORP (mV)	-143	+277	-122	-145	-106	-102
DO (mg/L)	1.54	3.36	1.79	1.84	0.11	0

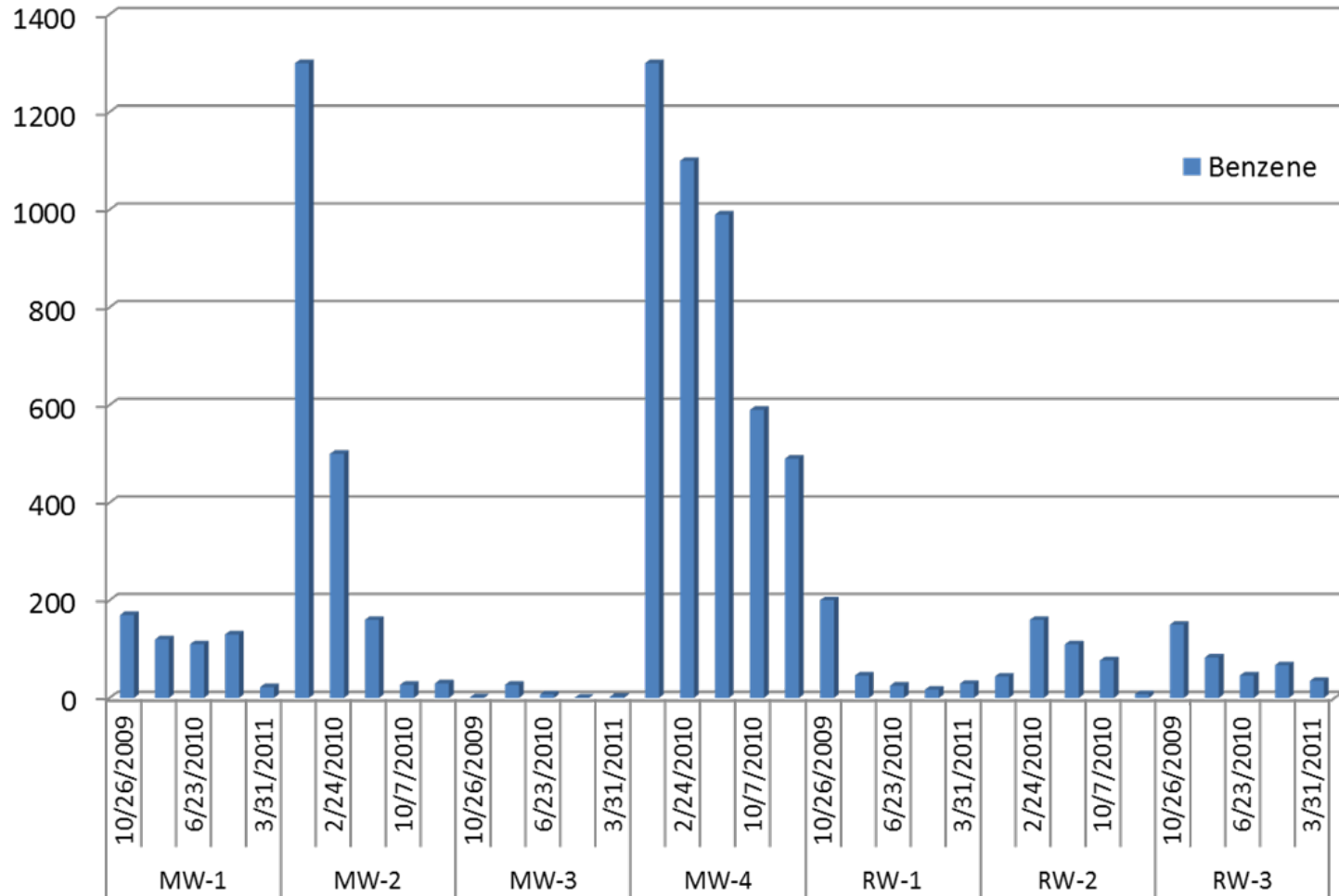
RW-1						
Field Parameter	10/26/2009	12/28/2009	02/24/2010	06/23/2010	10/07/2010	03/31/2011
pH	7.13	5.69	7.75	6.96	6.81	7.01
ORP (mV)	-160	+253	-139	-147	-104	-92
DO (mg/L)	0	0.09	0	0	0	0

➤ Four monitoring wells are located in the vicinity of the injection area:

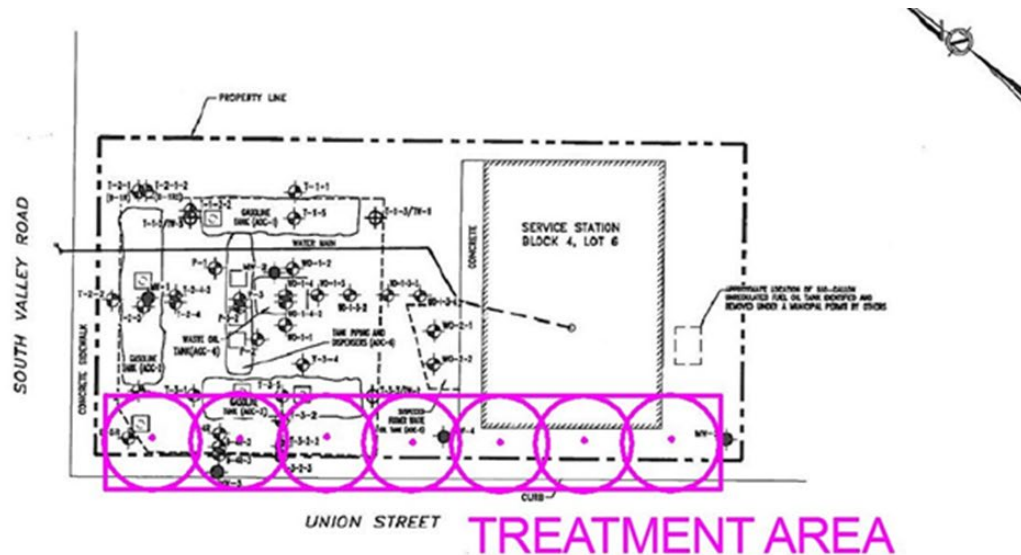
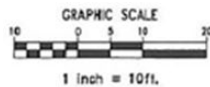
❖ **MW-1 & MW-2 & MW-4 & PW-1**

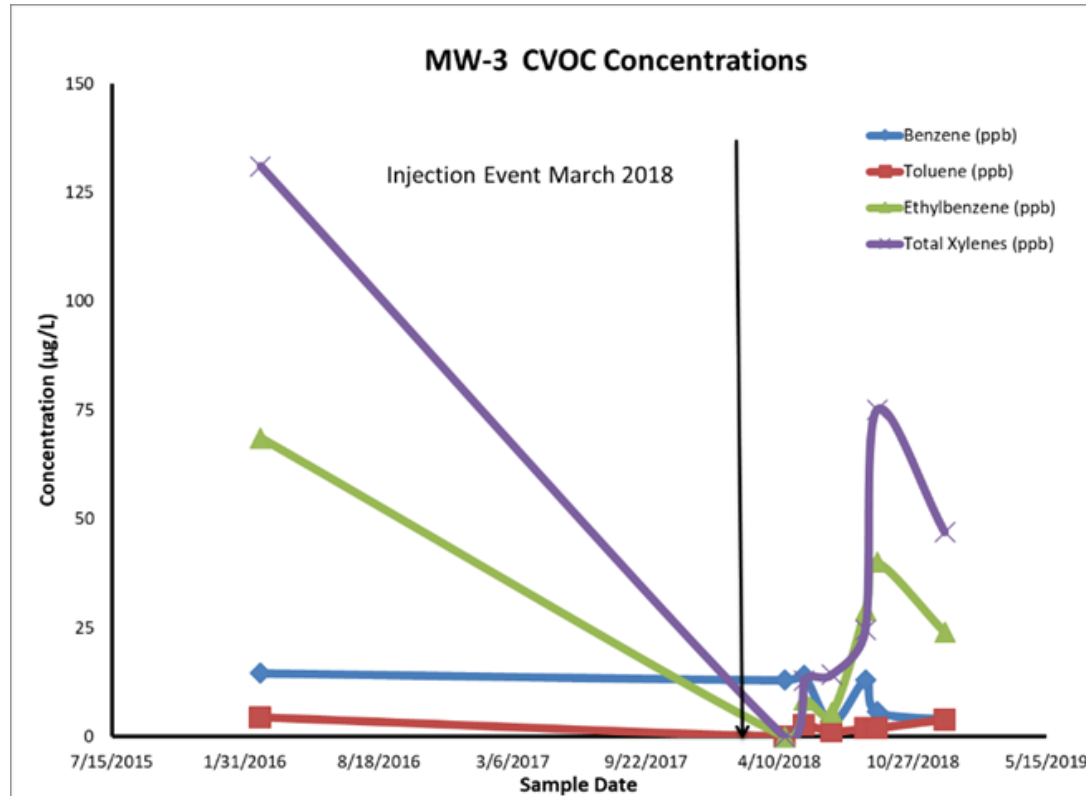
- ✓ Geochemical parameters ideal for biological attenuation
- ✓ Iron present in the ferrous state
- ✓ Sulfate concentrations elevated
- ✓ pH remains neutral
- ✓ Redox Potential is negative





- Single injection event implemented at a former auto service station in West Orange, New Jersey in December 2018 to remediate soils and groundwater impacted by the historical release of petroleum compounds.
- Total treatment area of approximately 1,500 square feet, treating between 15 and 21 feet below ground surface.
- 7 injection points
- 2,500 pounds of Sodium Persulfate and 600 pounds of Ferric Iron Oxide

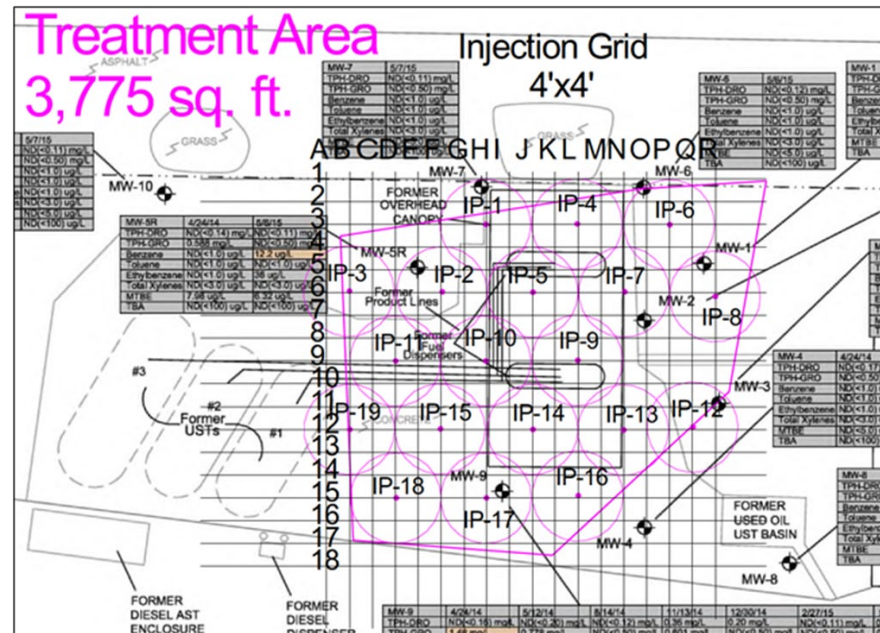




Conclusions

- In MW-3 total BTEX concentrations decreased by 64%.
- Benzene concentration decreased by 73%.

- Single injection event implemented at a gas station in St. Albans, West Virginia in February 2016 to remediate soils and groundwater impacted by the historical release of petroleum compounds.
- Total treatment area of approximately 3,775 square feet, treating between 6 and 12 feet below ground surface.
- 19 injection points
- 7,200 pounds of Provect-Ox





Ferric Iron Oxide Persulfate Activation - Case Study 2

MW-5R											
Sampling Date	05/15	03/16	06/16	09/16	12/16	03/17	06/17	09/17	12/17	03/18	06/18
Depth to Groundwater (ft)	6.26	5.68	6.05	7.58	7.04	5.75	6.05	6.83	7.45	6.80	6.25
pH	6.48	8.97	8.96	7.62	5.92	6.13	6.26	6.18	6.12	6.24	6.49
ORP (mV)	NM	+171.7	-124.5	-186.0	+22.0	-170.2	-60.3	-55.8	+4.4	-2.3	-32.7
D.O. (mg/L)	0.16	1.23	0.40	0.47	0.27	0.75	0.43	0.41	0.43	1.49	0.19
Conductivity (mS/cm)	804	3,534	2,593	2,960	4,455	3,097	2,989	3,332	2,296	1,752	2,099
Temperature (°C)	16.12	13.93	18.75	21.46	15.49	12.04	19.76	22.35	12.90	9.37	20.25
Sulfate (mg/L)	NM	1,260	1,230	1,480	2,390	2,200	1,350	1,830	1,500	1,470	1,490
Iron (mg/L)	NM	1.12	8.23	26.9	47.6	42.9	38.1	41.0	37.2	32.8	34.3

MW-9											
Sampling Date	05/15	03/16	06/16	09/16	12/16	03/17	06/17	09/17	12/17	03/18	06/18
Depth to Groundwater (ft)	11.33	7.14	5.54	8.63	9.67	8.50	8.76	9.90	10.46	9.02	8.69
pH	6.28	NM	9.47	2.05	6.30	6.01	6.58	6.06	6.17	6.16	6.25
ORP (mV)	NM	NM	-147.6	-36.9	+72.6	-84.7	+36.9	+13.5	+70.9	+49.9	+51.1
D.O. (mg/L)	0.21	NM	6.04	2.88	6.41	10.32	2.46	0.40	1.19	1.10	0.32
Conductivity (mS/cm)	657	NM	1,974	1,842	1,217	794	1,329	2,220	1,298	1,539	1,865
Temperature (°C)	17.07	NM	19.04	21.96	16.10	12.39	19.83	22.90	12.24	9.78	19.79
Sulfate (mg/L)	NM	2,000	600	762	453	328	550	961	588	651	729
Iron (mg/L)	NM	174	0.425	0.042	0.892	0.038	0.122	4.69	37.4	1.76	0.69



Ferric Iron Oxide Persulfate Activation - Case Study 2

MW-5R											
Sampling Date	05/15	03/16	06/16	09/16	12/16	03/17	06/17	09/17	12/17	03/18	06/18
Benzene (ppb)	12.2	4.24	7.48	4.55	5.08	5.23	2.01	1.50	5.10	ND	ND
Toluene (ppb)	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ethylbenzene (ppb)	36.0	9.61	25.3	0.83	0.78	1.64	ND	ND	ND	ND	ND

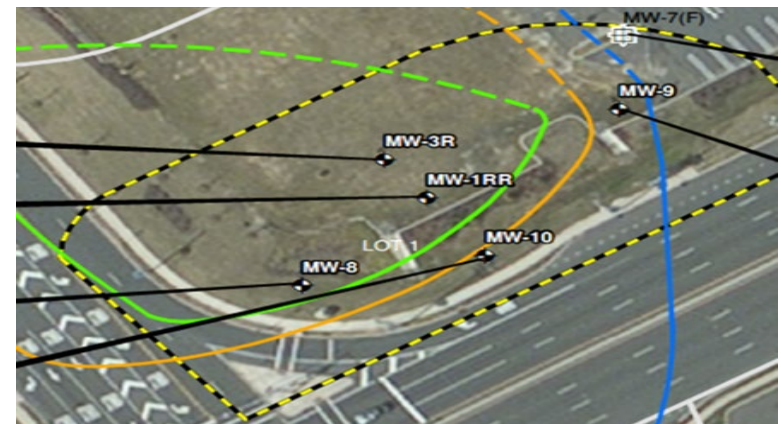
MW-9											
Sampling Date	05/15	03/16	06/16	09/16	12/16	03/17	06/17	09/17	12/17	03/18	06/18
Benzene (ppb)	77.0	2.02	ND	4.35	11.3	2.20	5.23	4.57	5.73	7.52	5.95
Toluene (ppb)	2.89	ND	ND	ND	ND	ND	ND	ND	1.25	ND	ND
Ethylbenzene (ppb)	66.5	ND	ND	0.86	11.7	1.91	1.63	ND	1.94	2.45	ND

Conclusions

- In MW-5R all BTEX concentrations decreased below the laboratory detection limits.
- In MW-9 total BTEX concentrations decreased by 96%.

Combined ZVI/Peroxide and Ferric Iron Oxide Persulfate Activation - Case Study

- Single injection event implemented at a former Jiffy Lube in Cinnaminson, New Jersey in April and May 2016 to remediate soils and groundwater impacted by the historical release of petroleum compounds.
- Total treatment area of approximately 14,850 square feet, treating between 32 and 47 feet below ground surface.
- 30 injection points
- 22,464 pounds of Sodium Persulfate and 6,432 gallons of 5% hydrogen peroxide





Combined ZVI/Peroxide and Ferric Iron Oxide Persulfate Activation - Case Study

MW-1RR								
Sampling Date	03/2016	08/2016	11/2016	02/2017	05/2017	08/2017	02/2018	05/2018
Water Level (ft)	36.20	36.11	36.55	37.23	36.50	35.95	36.91	35.14
pH	6.70	1.65	3.11	13.09	6.81	5.35	6.29	5.87
ORP (mV)	-115	+598	+394	+27.6	+167.1	+183.8	-114.6	-42.0
D.O. (mg/L)	7.40	9.99	0.38	1.74	0.88	3.00	0.23	4.81
Conductivity (ms/cm)	0.962	7.683	2.310	3.216	66.59	0.066	4.714	0.368
Temperature (°C)	11.7	22.9	16.3	11.95	17.26	24.33	16.80	21.67
Sulfate (mg/L)	12.2	4,250	775	61.0	38.4	NA	NA	NA
Iron (mg/L)	77.4	313	63.1	0.834	0.809	NA	NA	NA

MW-3R								
Sampling Date	03/2016	08/2016	11/2016	02/2017	05/2017	08/2017	02/2018	05/2018
Water Level (ft)	36.61	36.32	36.75	37.01	36.70	36.40	37.21	35.77
pH	6.68	3.28	6.26	6.53	5.65	6.20	5.90	7.46
ORP (mV)	-72.8	+245.1	+53.7	-143	-38.8	-12.3	-15.4	+0.3
D.O. (mg/L)	13.48	999.99	0.34	0.84	0.11	0.95	0.67	3.98
Conductivity (ms/cm)	0.920	2.198	1.353	2.113	168.8	2.297	2.218	1.069
Temperature (°C)	11.5	23.4	15.5	14.24	17.97	18.05	17.56	19.04
Sulfate (mg/L)	25.1	341	74.0	12.4	27.4	NA	NA	NA
Iron (mg/L)	49.1	62.9	25.2	26.5	48.0	NA	NA	NA

MW-8								
Sampling Date	03/2016	08/2016	11/2016	02/2017	05/2017	08/2017	02/2018	05/2018
Water Level (ft)	32.87	32.94	33.10	33.20	33.00	32.75	33.73	32.17
pH	6.48	4.46	5.81	5.90	4.65	5.73	5.94	5.68
ORP (mV)	-85.9	+635	+373	+5.7	+469.7	+305.4	+5.60	+104.4
D.O. (mg/L)	5.68	999.99	0.12	0.03	0.39	1.81	0.33	1.63
Conductivity (ms/cm)	0.607	3.398	1.279	2.405	158.5	0.965	1.890	0.975
Temperature (°C)	11.7	24.4	16.8	15.47	19.25	16.87	16.52	15.34
Sulfate (mg/L)	15.9	322	340	89.3	53.0	NA	NA	NA
Iron (mg/L)	22.4	5.91	22.6	80.6	22.0	NA	NA	NA



Combined ZVI/Peroxide and Ferric Iron Oxide Persulfate Activation - Case Study

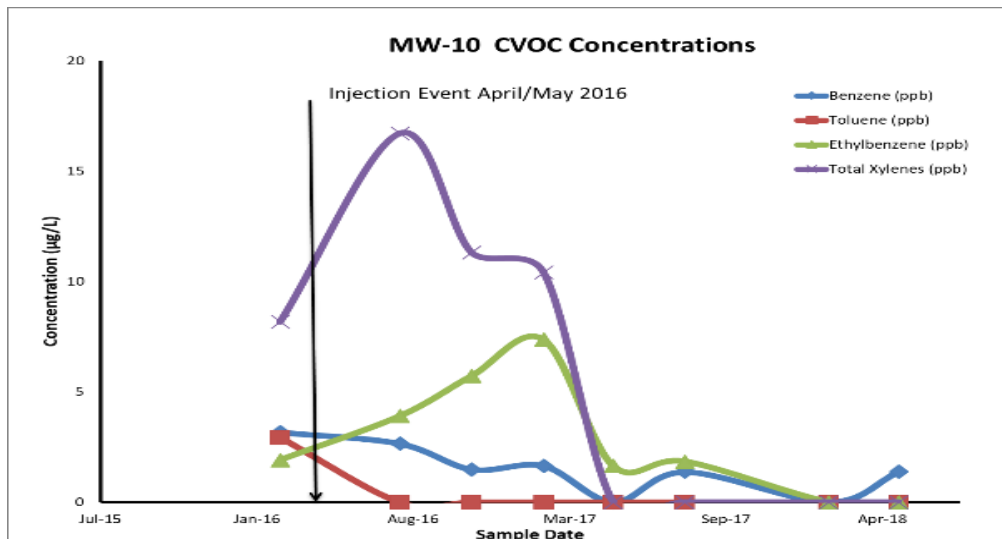
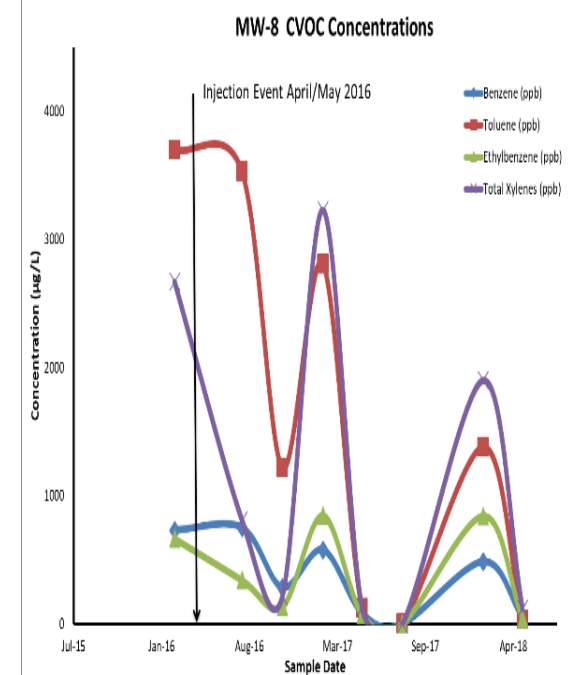
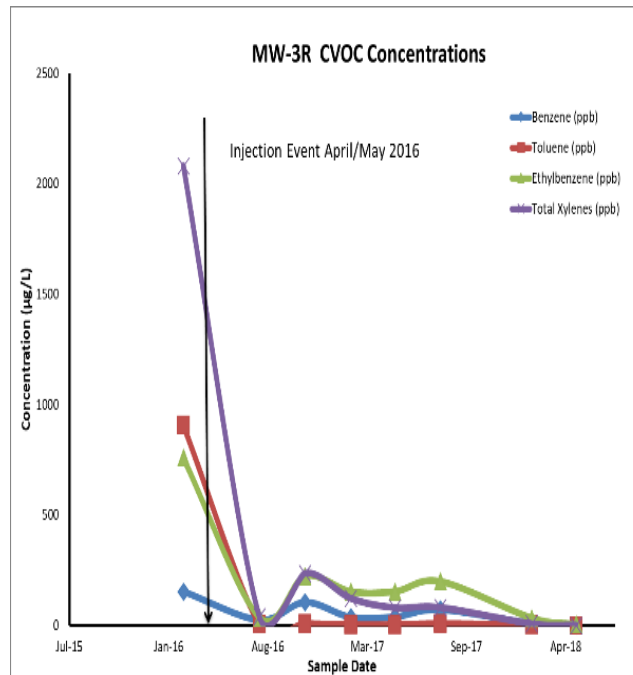
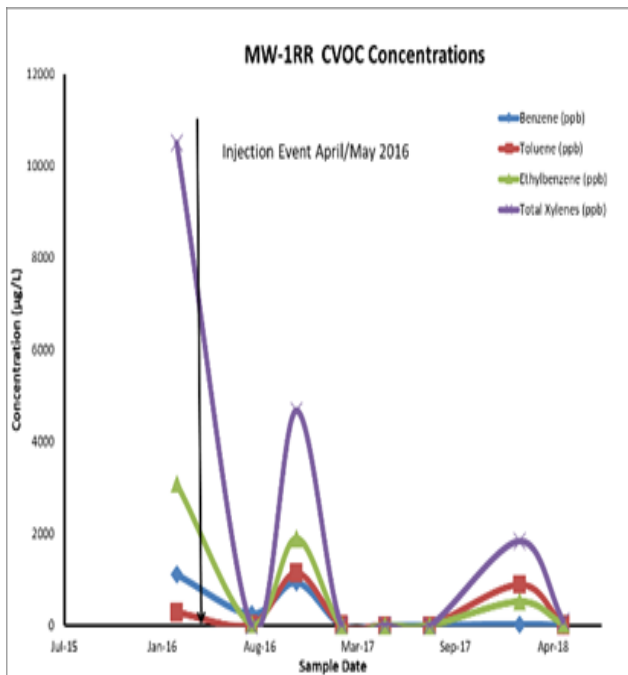
MW-10								
Sampling Date	03/2016	08/2016	11/2016	02/2017	05/2017	08/2017	02/2018	05/2018
Water Level (ft)	32.43	32.71	32.60	32.79	32.65	32.20	32.99	31.64
pH	6.12	5.69	6.04	6.27	6.02	6.25	6.01	5.80
ORP (mV)	+17.0	+314.0	+3.9	-20.3	+12.1	-8.1	+25.4	+14.6
D.O. (mg/L)	0.11	0.00	0.08	0.31	1.59	0.58	0.41	1.27
Conductivity (ms/cm)	0.648	0.915	0.976	0.958	1.350	1.175	1.063	1.356
Temperature (°C)	12.4	17.4	17.0	15.1	16.8	16.95	16.30	15.91
Sulfate (mg/L)	66.8	55.4	59.6	52.2	61.8	NA	NA	NA
Iron (mg/L)	1.33	1.78	1.81	4.03	19.0	NA	NA	NA

Four monitoring wells are located in the vicinity of the injection area:

MW-1RR, MW-3R, MW-8 and MW-10

- ✓ Geochemical parameters ideal for biological attenuation
- ✓ Iron present in the ferrous state
- ✓ Sulfate concentrations elevated
- ✓ pH remains neutral
- ✓ Redox Potential is negative

Combined ZVI/Peroxide and Ferric Iron Oxide Persulfate Activation - Case Study



Conclusions

- In MW-1RR total BTEX concentrations decreased by 99.1%.
- In MW-3R total BTEX concentrations decreased by 99.9%.
- In MW-8 total BTEX concentrations decreased by 97%.
- In MW-10 total BTEX concentrations decreased by 92%

**“Comparative Study for ZVI/Peroxide vs Ferric Iron Oxide Persulfate Activation Followed
by Intrinsic Facultative, Biologically Mediated Processes”**



Questions

