Enhanced *In Situ* Biodegradation of Chlorinated Ethenes in Low Permeability Groundwater

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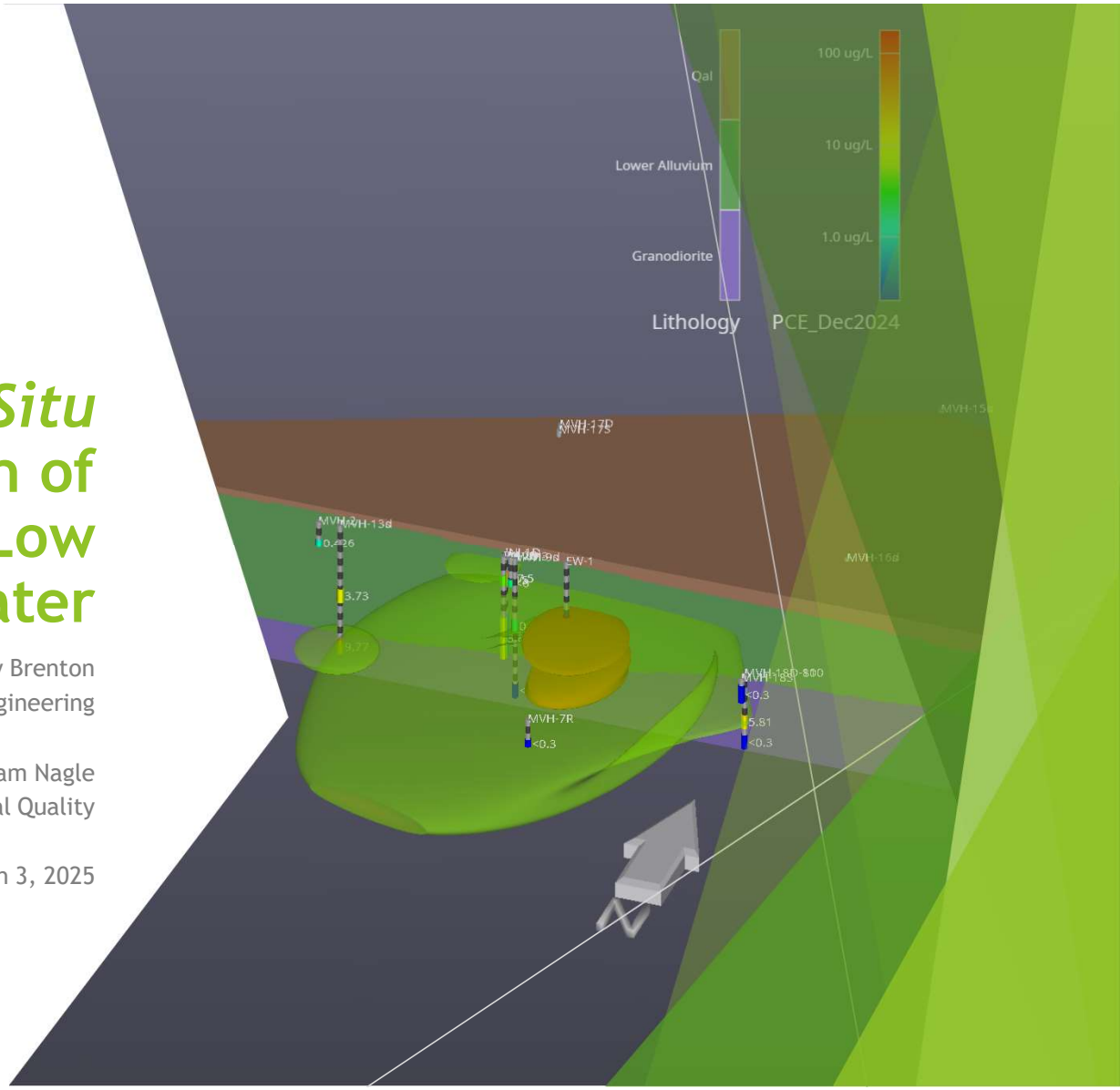

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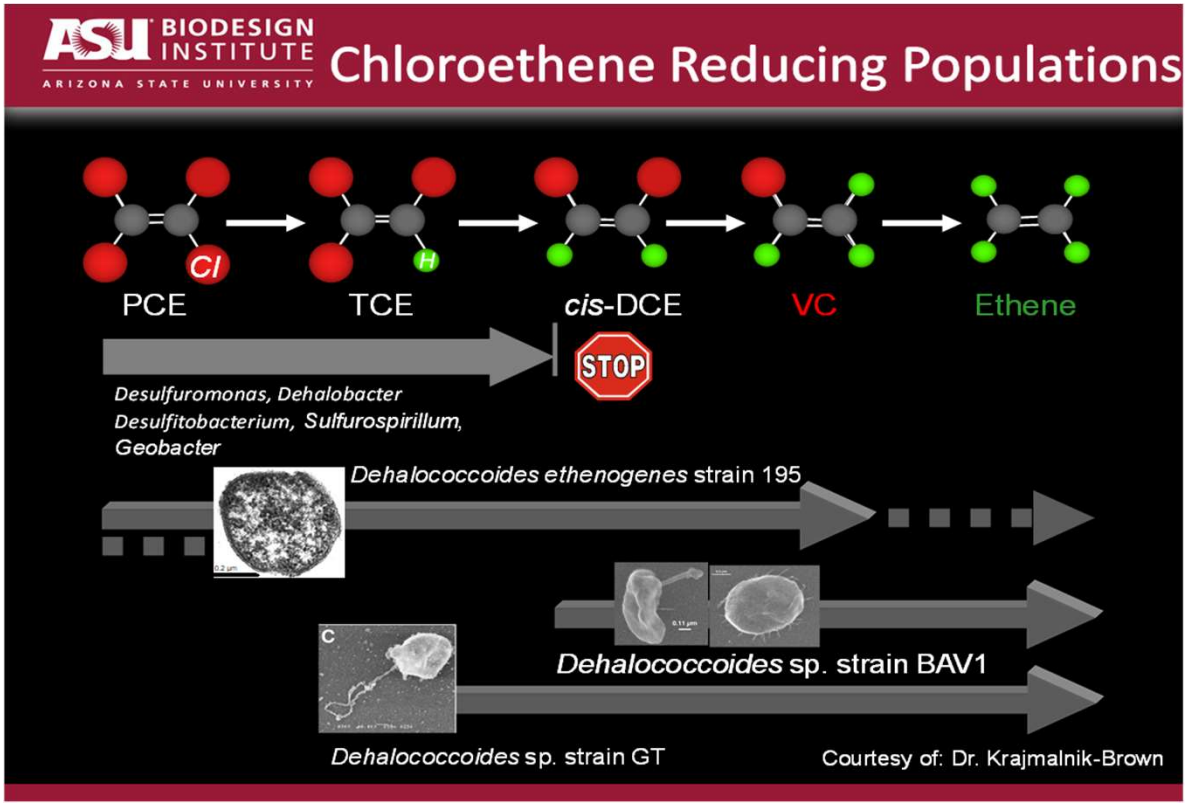
CVOC Degradation



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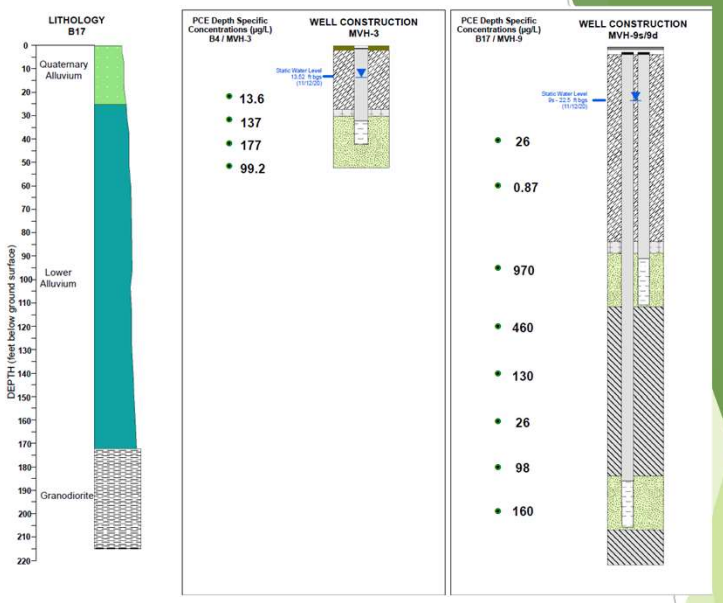
Site Background

- Shallow Aquifer
  - Bottom depth 29 to 50 ft bgs
  - Flow direction toward the east
    - DTW December 2024 5.81 to 12.17 ft btoc
  - Hydraulic gradient of 0.009 ft/ft
  - Hydraulic Conductivity – 0.0061 to 4.1 ft/day
  - Total porosity = 20%; Effective porosity = 10%
- Intermediate Aquifer
  - Bottom depth 80 to 115 ft bgs
  - Flow direction toward the east-southeast
    - DTW December 2024 5.81 to 14.80 ft btoc
  - Hydraulic gradient – 0.014 ft/ft
  - Hydraulic Conductivity – 0.12 ft/day
  - Total porosity = 20%; Effective porosity = 10%



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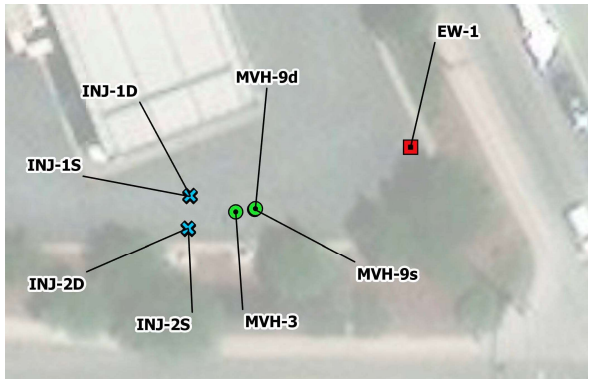
2020 Chlorinated Volatile Organic Compounds in Site Groundwater

- Main CVOC in site groundwater is tetrachloroethene (PCE)
- Low levels of trichloroethene (TCE) and cis-1,2-dichloroethene (cis-1,2-DCE) also observed



Well ID	Date Sampled	Depth Sampled (ft bgs)	PCE (µg/L)	TCE (µg/L)	*cis*-1,2-DCE (µg/L)	Vinyl Chloride (µg/L)
MVH-9s	8/26/20	100	**670**	<4.75	6.53	<5.85
MVH-3	8/26/20	40	**273**	**8.74**	5.09	<2.34
AWQS:			5	5	70	2

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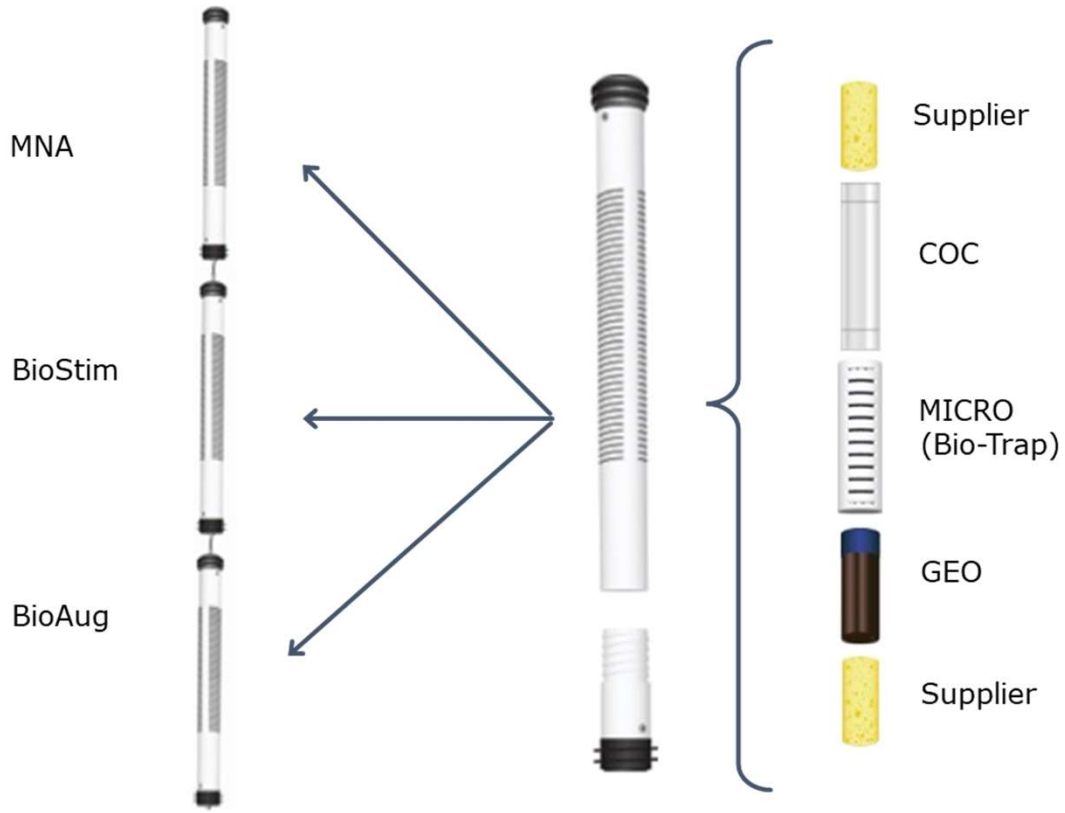
In Situ Microcosm Study



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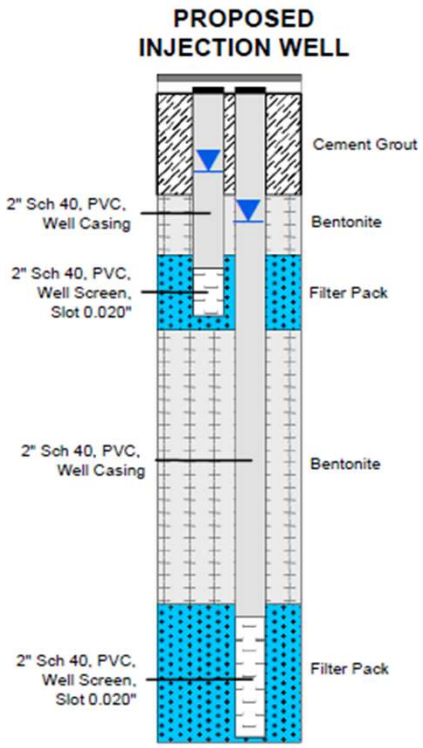
Review of *In Situ* Microcosm Results

Well ID	ISM Unit Type	Percent Reduction/Increase in Chemical of Concern			Relative Amount of VC and Ethene Produced (µg/L)	
		PCE	TCE	*cis*-1,2-DCE	VC	Ethene
MVH-9s	BioStim: EOS PRO	-99.76	-36.84*	+5,504	0.9J	< 1.3
	BioStim: EOS PRO + BioAug: SDC-9	-99.70	-74.74*	+2,962	44.3	12
	BioStim: EOS PRO + BioAug: KB-1	-99.25	-3.16*	+7,067	2.7	< 1.3
	BioStim: Wilclear Plus + BioAug SDC-9	-94.11	+729.47*	+2,932	14.1	6.2
MVH-3	BioStim: Wilclear Plus	-95.09	-85.12	-33.20	< 1.0	< 1.3
	BioStim: Wilclear Plus + BioAug: SDC-9	-73.66	+91.08	+2,926	< 1.0	< 1.3
	BioStim: Wilclear Plus + BioAug: KB-1	-99.99	-93.14	+3,693	7.80	2.4

Notes: J- The reported value is an estimate
* Percent reduction/increase and change in concentration determined using ½ the method detection limit.

Early Response Action



- *In Situ* Bioremediation Injection Well Design
- Two nested injection wells (1S, 2S, 1D, 2D)
- Drilled using Sonic methodologies
- Depth specific hydropunch samples to determine vertical contaminant profiles
- Target screen intervals within shallow and intermediate aquifers
- 2-inch diameter wells
- SCH 40 PVC well casing and screen
- 0.060”mill slots with 6-9 filter pack

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Clean Water Injection Test

- Hydrogeology of this area was a very tight formation
- INJ-1S
  - Thin clay layers and silty sand
  - Screened 27 to 47 ft bgs
  - <1.67 gpm
  - Drawdown 0.47 ft/min
- INJ-2S
  - Gravel and poorly graded sand with silt
  - Screened 27 to 42 ft bgs
  - <1.67 gpm
  - Drawdown 0.84 ft/min
- INJ-1D
  - Sandy silt
  - Screened 90 to 150 ft bgs
  - 1 gpm for 15 min then 0.33 gpm
  - Drawdown 3.74 ft/min
- INJ-2D
  - Silty sand with clay
  - Screened 90 to 150 ft bgs
  - 1 gpm for 15 min then 0.45 to 0.2 gpm
  - Drawdown 3.88 ft/min

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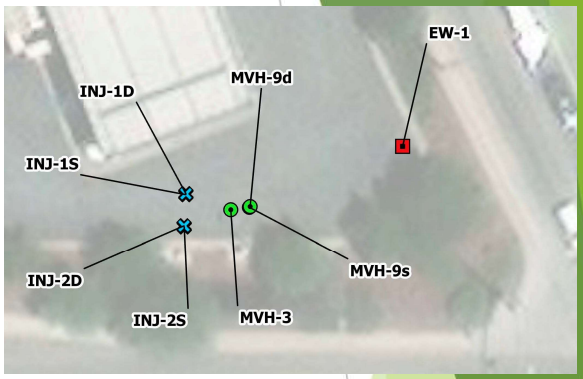
Injection Well Design Parameters

Aquifer / Well Parameter	Value
Radius of Influence	~7.5 feet
Screen Length Impact	20 feet
Porosity (n_e)	10%
Pore Volume per Injection Well	2,644 gallons
Target Pore Volume 30% of Total Pore Volume per Injection Well*	793 gallons
Amendments Per Injection Well	**Quantity**
EOS QR	280 pounds (27 gallons)
Estimated Total Organic Carbon (TOC) Post-Injection**	4,950 mg/L
BAC-9 also referred to as SDC-9 Dose	2 liters
Sodium Bicarbonate	14 pounds
Sodium Ascorbate	6 pounds
Sodium or Potassium Bromide	5 pounds
Dilution Water and Chase Water per Injection Well	**Quantity**
EOS QR (27 gallons) and Dilution Water (270 gallons)	297 gallons
Anaerobic Chase Water	497 gallons
Anaerobic Chase Water post BAC-9/SDC-9 Injection	25 gallons
Total Volume of Injected Material per Well:	819 gallons
Total Volume EISB Amendments and Water (4 Wells):	**3,276 gallons**



Notes: * = Total volume recommended is 30% of total pore volume and this percent is based on more than 20 years of experience of injecting this type of carbon substrate into the groundwater in similar lithologic conditions.
** = TOC calculated by mass of EOS QR (in mg) times 0.39 mg carbon content by weight divided by pore volume in liters.

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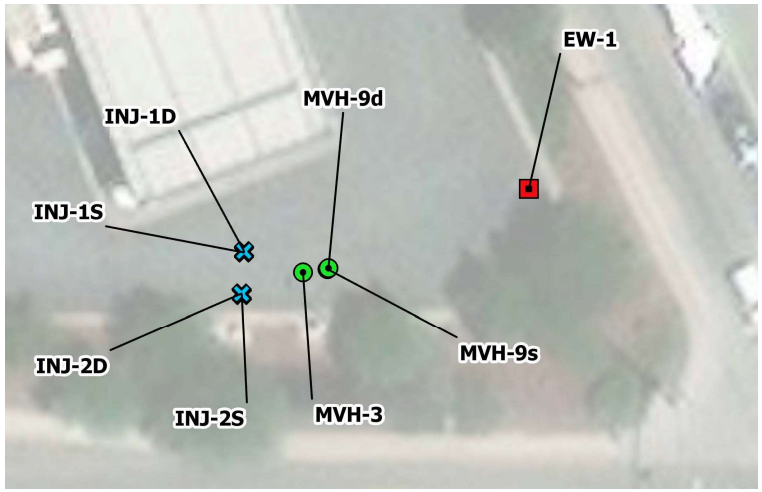
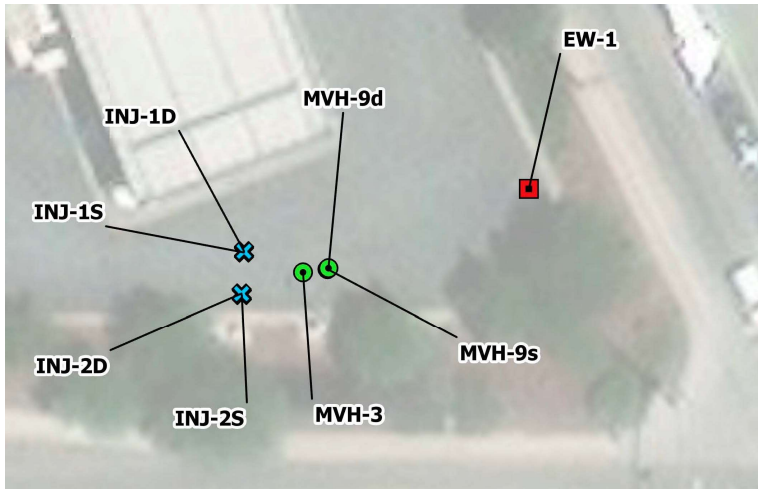
Groundwater Field Parameters in ISB Wells



Sample ID	Sample Date	Ferrous Iron (mg/L)	Temp. (°C)	ORP (mV)	DO (mg/L)	pH (SU)	Specific Conductance (µS/cm)
MVH-3	02/07/24	0.50	15.96	76.8	5.36	6.37	362
MVH-3	03/20/24	0.00	15.17	3.2	4.07	7.94	1,169
MVH-3	04/18/24	+++	19.6	28.2	1.00	5.18	1,680
MVH-3	12/11/24	2.54	17.50	-67.3	1.34	5.17	1,680
MVH-9S	02/08/24	0.31	15.16	-26.2	6.25	7.04	392
MVH-9S	03/20/24	---	16.24	62.9	1.53	8.07	390
MVH-9S	04/18/24	+++	15.9	-152.8	1.32	5.66	1,166
MVH-9S	12/12/24	2.13	15.10	-221.9	0.70	6.58	966
INJ-1D	02/06/24	0.32	16.2	-162.4	3.51	9.75	308
INJ-1D	04/18/24	NM	18.9	-171.3	0.61	6.56	4,050
INJ-1D	12/11/24	0.66	13.10	-106.4	1.55	6.49	3,771
INJ-1S	02/06/24	0.36	14.84	-152.8	3.20	9.57	481
INJ-1S	04/18/24	+++	19.00	-163.7	1.16	6.17	3,978
INJ-1S	12/11/24	3.14	17.40	-116.0	0.77	6.43	4,463
INJ-2S	02/06/24	0.26	15.72	-145.0	4.20	9.57	232
INJ-2S	04/18/24	0.96	19.0	-210.1	0.93	7.57	1,312
INJ-2S	12/10/24	2.17	15.50	-140.8	0.79	6.94	3,006
INJ-2D	02/06/24	0.18	14.51	-152.1	4.19	9.73	230
INJ-2D	04/18/24	+++	19.9	-188.3	0.73	6.44	5,729
INJ-2D	12/10/24	0.00	15.60	-166.3	0.51	6.19	10,713
EW-1	12/12/24	0.19	18.70	-105.4	1.35	7.54	347

Pre and Post Geochemical Data in ISB Wells



Sample ID	Sample Date	Bromide	Chloride	Nitrate	Sulfate	Total Organic Carbon	Methane	Ethane	Ethene
		(milligrams per liter)					(micrograms per liter)		
MVH-3	02/06/24	**0.857 J**	**20.9**	**2.45 J**	**22.5**	**2.14**	**24.0**	<4.07	<4.26
MVH-3	03/20/24	**146**	**19.6**	**0.949 J**	**15.7 J**	**2,520**	**57.8**	<4.07	<4.26
MVH-3	04/18/24	**162**	**12.6**	<0.048	**94.8**	**2,750**	**67.3**	<4.07	**5.70 J**
MVH-3	12/11/24	**71.4 J**	**<54.7**	<8.84	**<63.7**	**929**	**8,610**	<3.40	**77.7**
MVH-9S	02/07/24	**1.1**	**40.2**	**8.04 J**	**17.4**	**0.943 J**	<2.91	<4.07	<4.26
MVH-9S	03/20/24	**0.818 J**	**38.0**	**7.25**	**16.0**	**0.882 J**	<2.91	<4.07	<4.26
MVH-9S	04/18/24	**23.4**	**33.0**	**0.0619 J**	**14.6 J**	**626**	**3,330**	<4.07	<4.26
MVH-9S	12/12/24	**6.64**	**43.3**	<0.0884	<0.637	**44.3**	**48,000**	**32.4**	**12.2 J**
INJ-1S	04/18/24	**142**	**13.9**	<0.048	**86.7**	**1,800**	**12,500**	<4.07	**75.7**
INJ-1S	12/11/24	**111**	**9.63 J**	<0.884	<6.37	**1,280**	**18,100**	<3.40	**6.29 J**
INJ-1D	04/18/24	**117**	**19.7**	<0.048	**57.3**	**491**	**6,420**	<4.07	<4.26
INJ-1D	12/11/24	**166**	**10.8**	<0.884	<6.37	**1,120**	**34,800**	<3.40	<3.40
INJ-2S	04/18/24	**35.9**	**18.4**	**0.228 J**	**23.1**	**232**	**9,230**	<4.07	**23.3**
INJ-2S	12/10/24	**50.2**	**30.9**	<0.0884	<0.637	**35.8**	**22,500**	<3.40	<3.40
INJ-2D	04/18/24	**439**	**35.4**	<0.48	**236**	**3,950**	**8,420**	<4.07	**8.68 J**
INJ-2D	12/10/24	**332**	**9.87**	<0.0884	<0.637	**5,980**	**41,000 M3**	<3.40	**30.0**
EW-1	09/17/24	**1.62**	**13.1**	**0.871**	**6.12**	**0.877 J**	<5.10	<3.40	<3.40
EW-1	12/12/24	<0.68	**13.3**	**0.984**	**6.31**	<0.495	**690**	<3.40	<3.40

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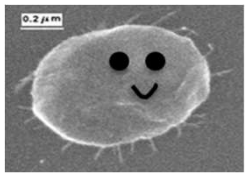
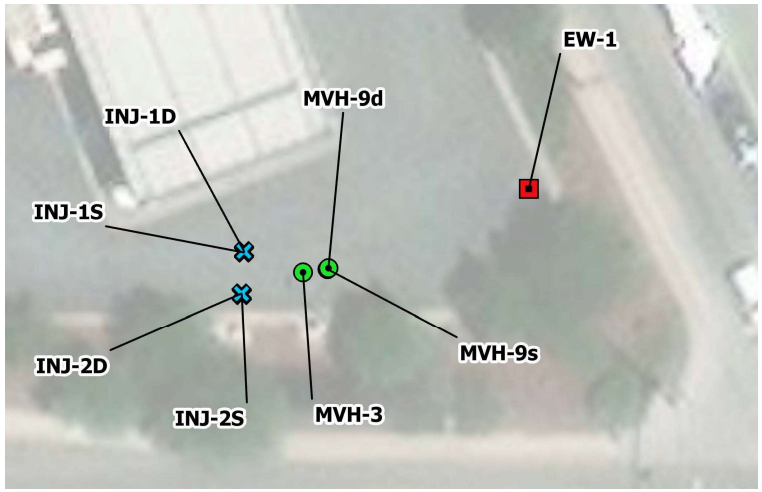
Pre and Post Microbial Data in ISB Wells





Sample ID	Sample Date	*Dehalococcoides* (DHC)	tceA Reductase (TCE)	BAV1 Vinyl Chloride Reductase (BVC)	Vinyl Chloride Reductase (VCR)
MVH-3	02/06/24	**5.50E+00**	**0.20 J**	**5.00E-01**	**2.50E+00**
MVH-3	03/20/24	**6.60E+01**	**2.30E+01**	**5.80E-01**	**1.40E+01**
MVH-3	04/18/24	**1.60E+01**	**2.10E+00**	<0.13	**3.70E-01**
MVH-3	12/11/24	**7.10E+01**	**2.30E+01**	**1.20E+01**	**2.30E+01**
MVH-9S	02/07/24	**4.80E+00**	<0.66	<0.66	**1.70E+00**
MVH-9S	03/20/24	**1.10E+01**	**2.30E+00**	<0.25	**2.70E+00**
MVH-9S	04/18/24	**3.20E+01**	**1.10E+00**	**7.80E-01**	**6.70E+00**
MVH-9S	12/12/24	**1.10E+04**	**3.20E+03**	**3.10E+02**	**3.10E+03**
INJ-1S	04/18/24	**2.00E+03**	**3.00E+02**	<0.13	**5.10E+02**
INJ-1S	12/11/24	**2.20E+03**	**6.90E+02**	<5.00E-01	**7.50E+02**
INJ-1D	04/18/24	**2.00E+03**	**2.70E+02**	<0.13	**4.60E+02**
INJ-1D	12/11/24	**2.20E+02**	**9.60E+01**	<5.00E-01	**9.50E+01**
INJ-2S	04/18/24	**1.60E+04**	**2.40E+03**	<0.13	**4.50E+03**
INJ-2S	12/10/24	**1.30E+04**	**4.20E+03**	<2.50E-01	**4.10E+03**
INJ-2D	04/18/24	**3.10E+04**	**4.70E+03**	<0.13	**7.20E+03**
INJ-2D	12/10/24	**7.10E+03**	**1.10E+03**	<5.00E-01	**9.30E+02**
EW-1	09/17/24	**1.10E+00**	<0.25	<0.25	<0.25
EW-1	12/12/24	**9.10E+00**	**3.00E+00**	<5.00E-01	**3.40E+00**

All results reported in cells per milliliter (cells/mL).

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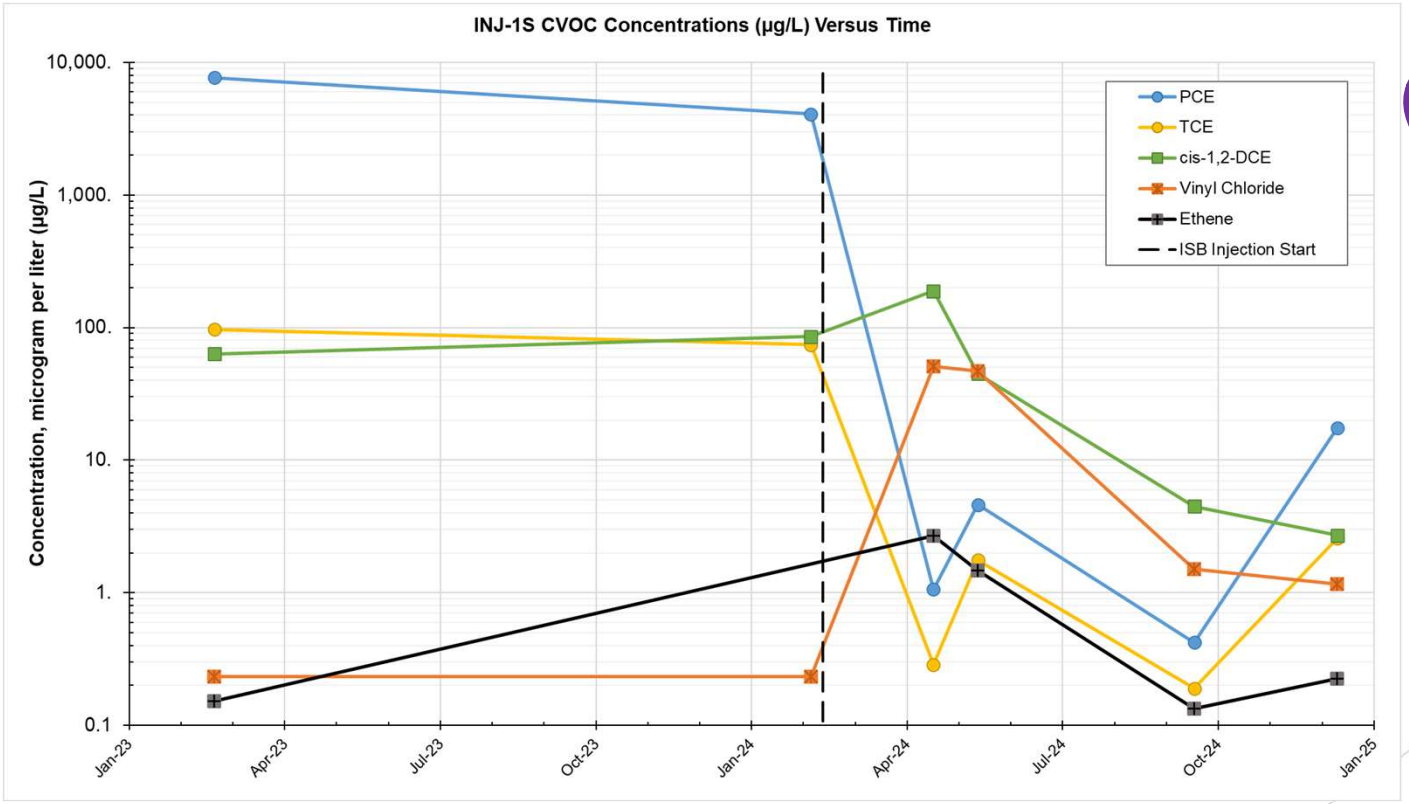
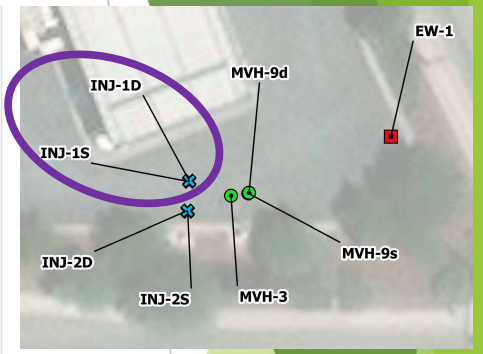
INJ-1S CVOC Concentrations





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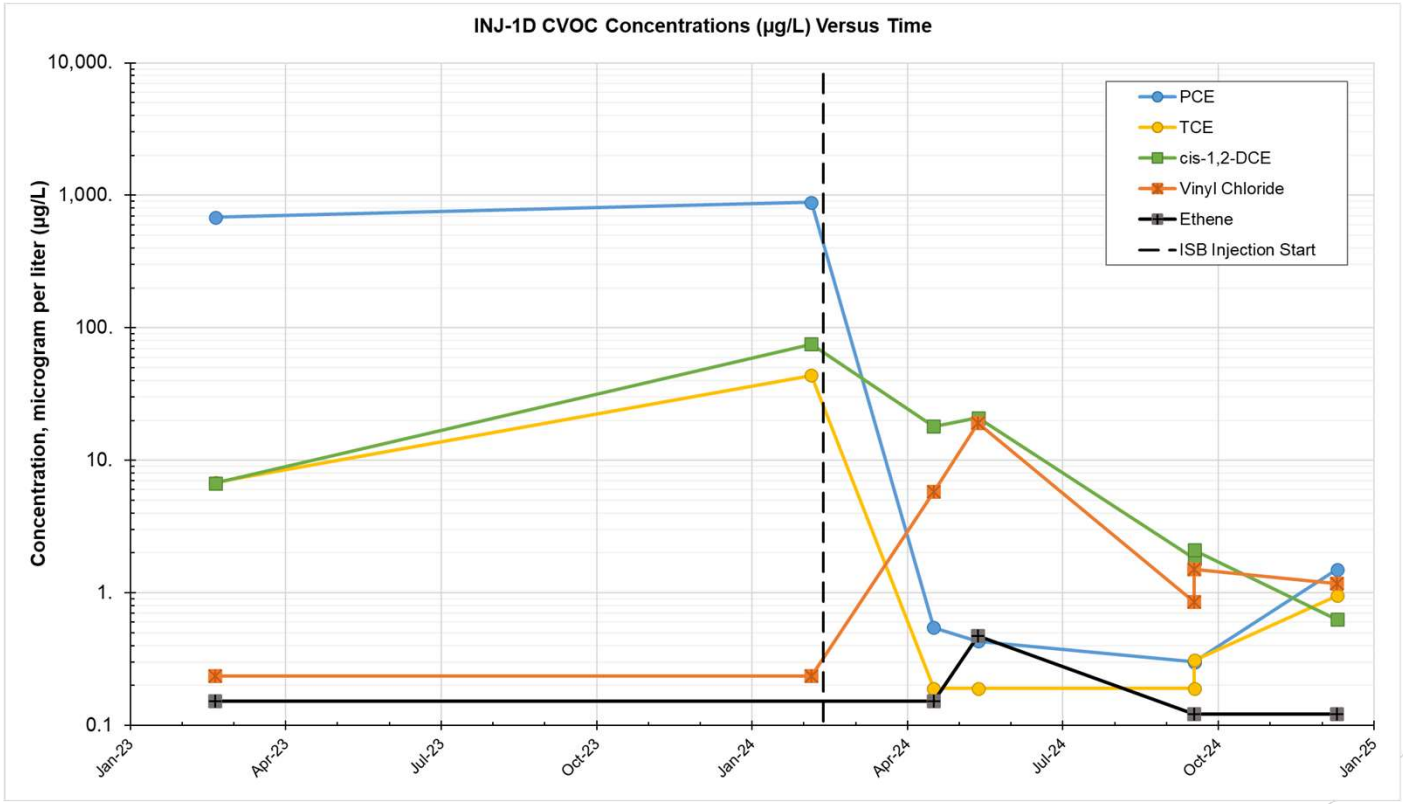
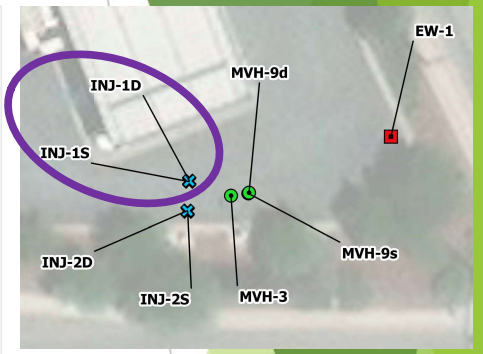
INJ-1D CVOC Concentrations





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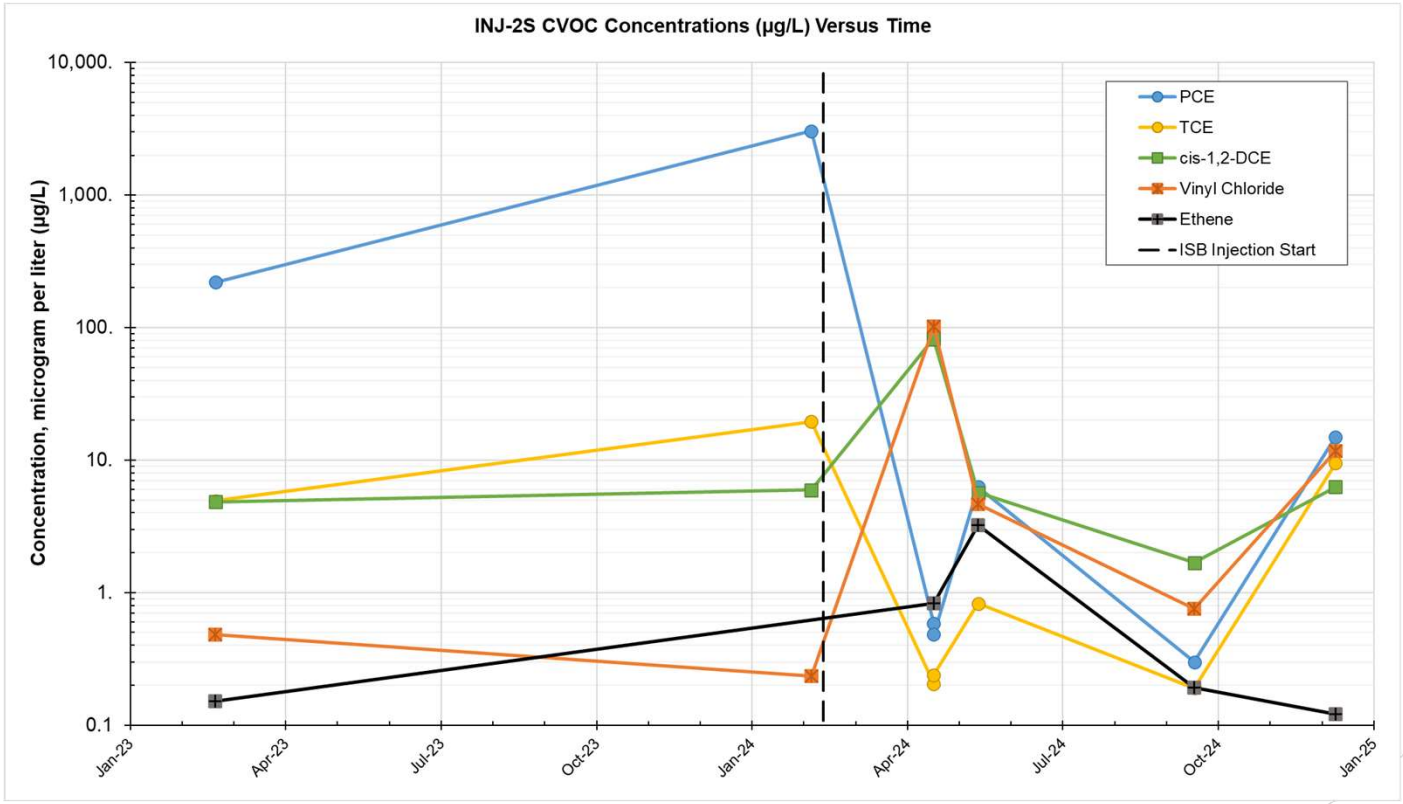
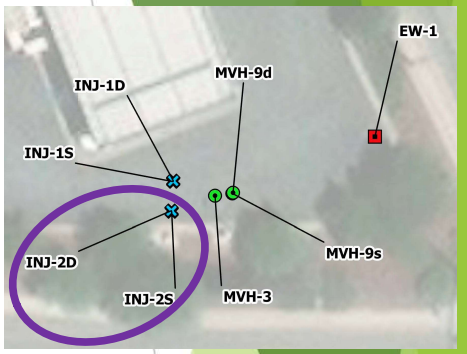
INJ-2S CVOC Concentrations





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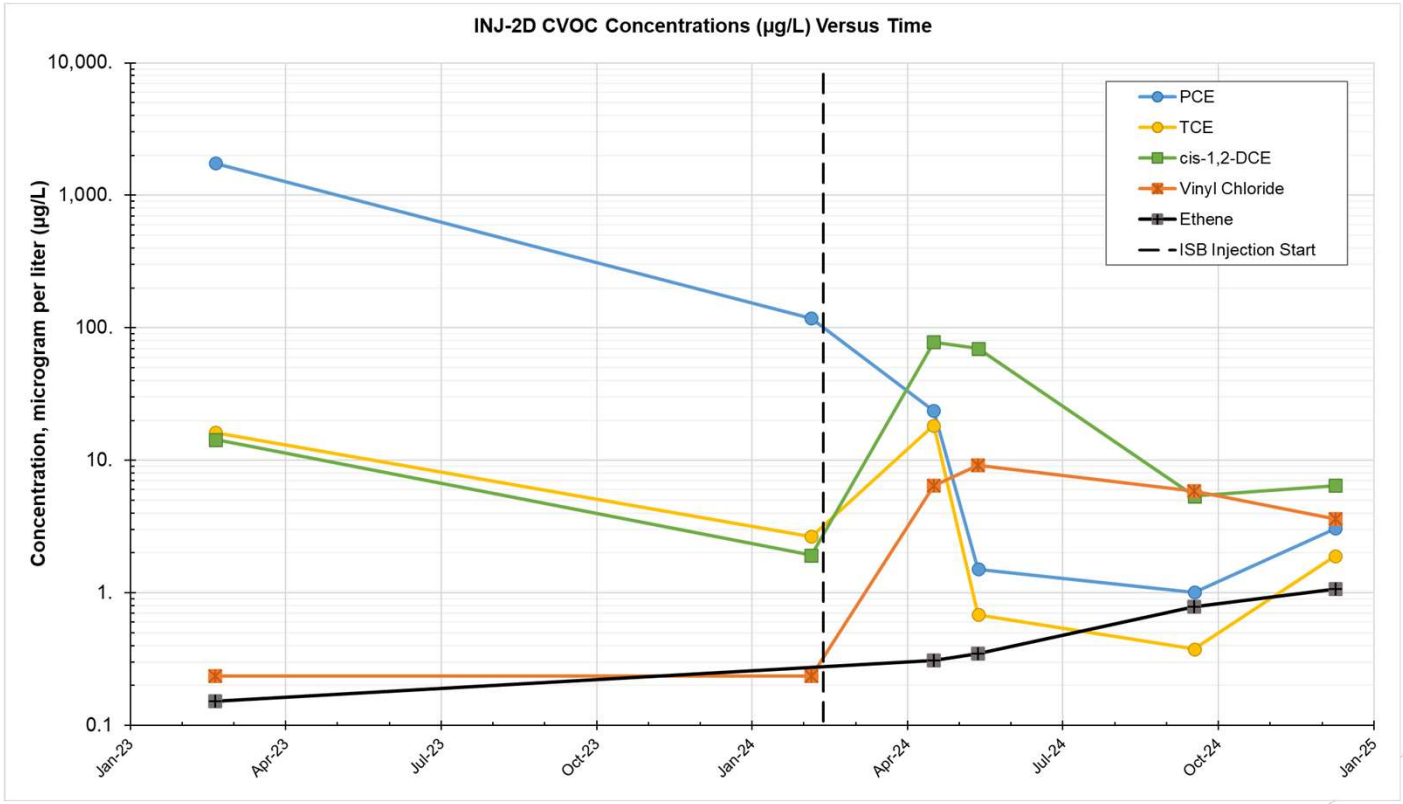
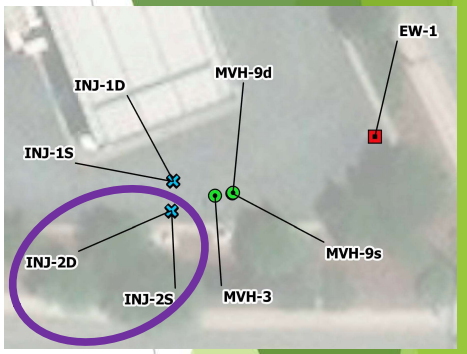
INJ-2D CVOC Concentrations





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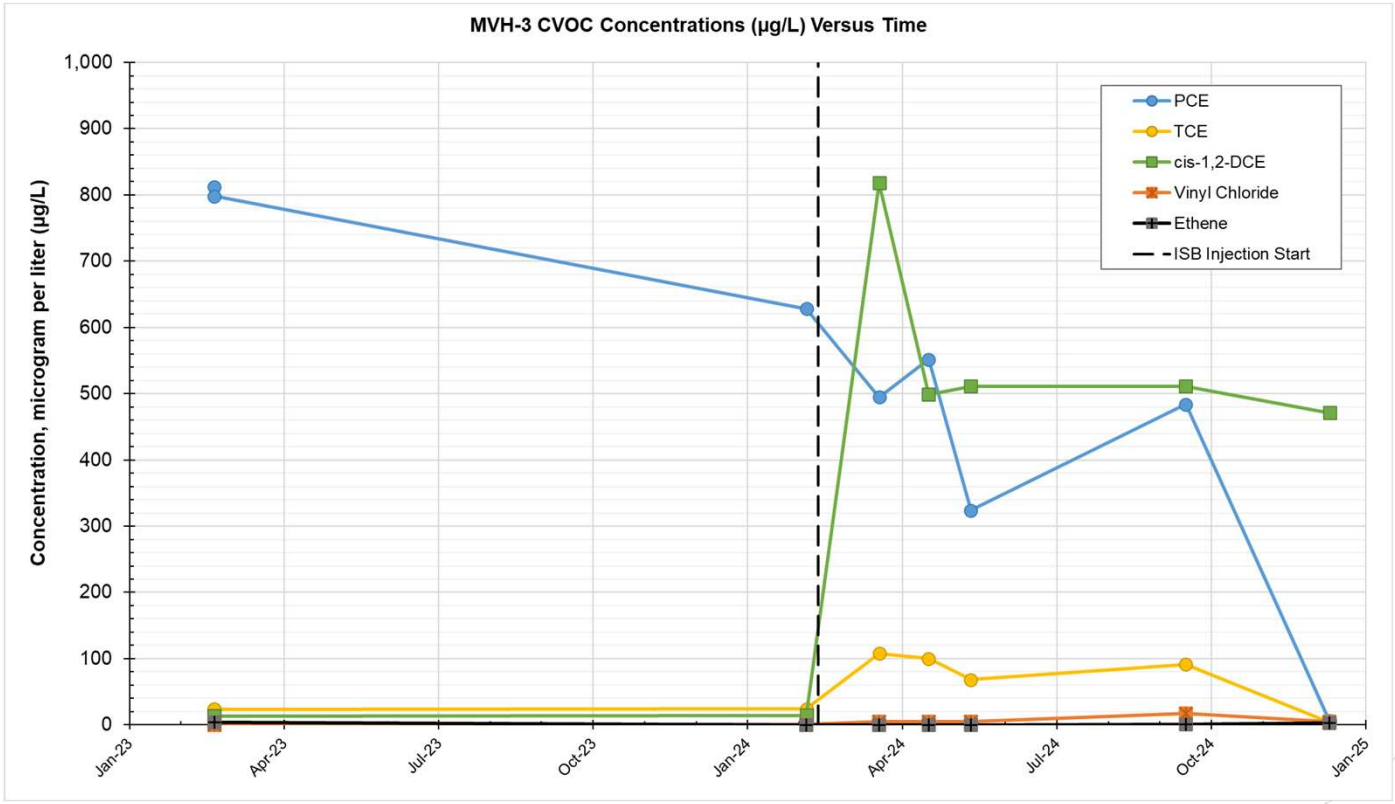
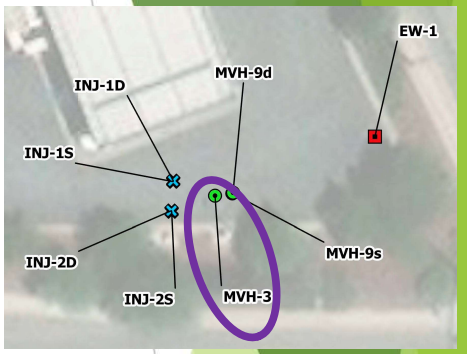
MVH-3 CVOC Concentrations





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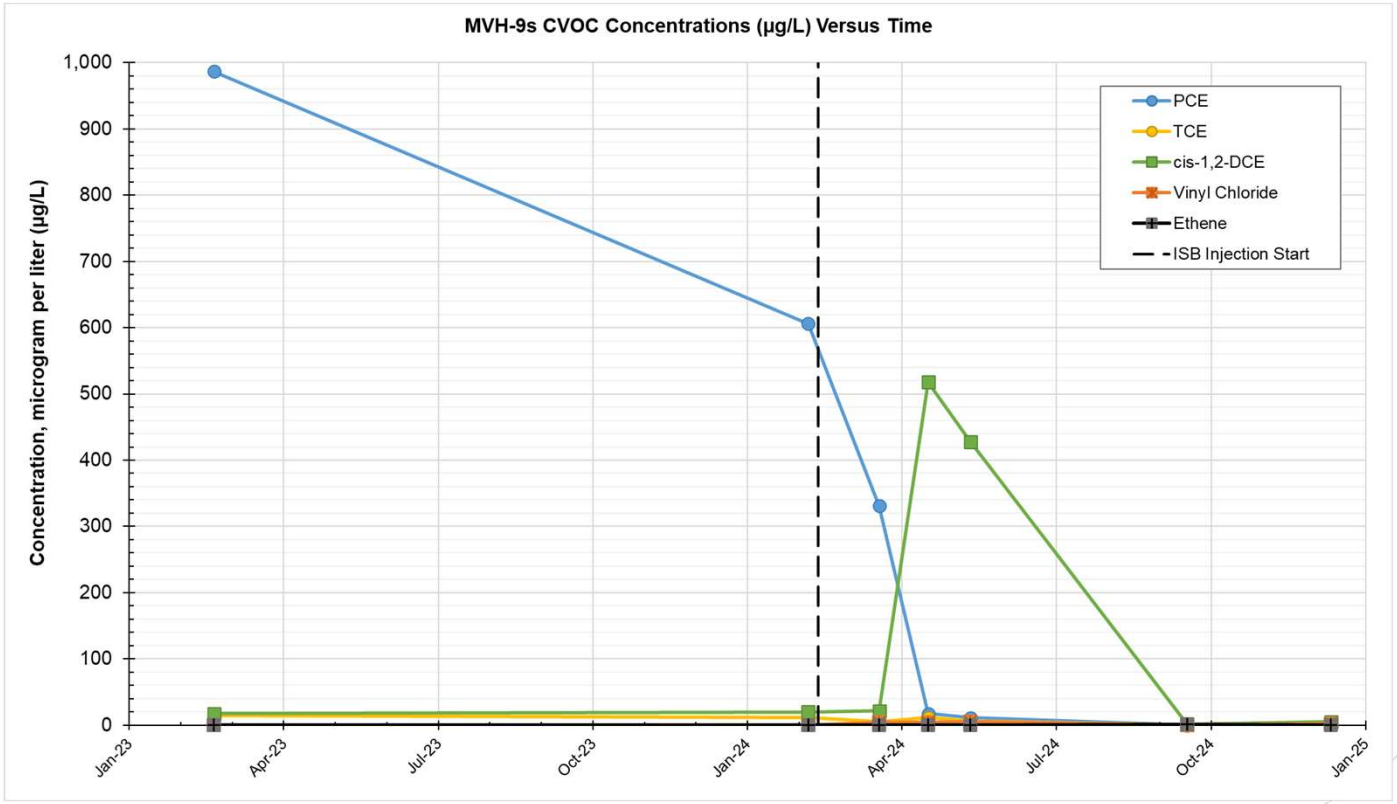
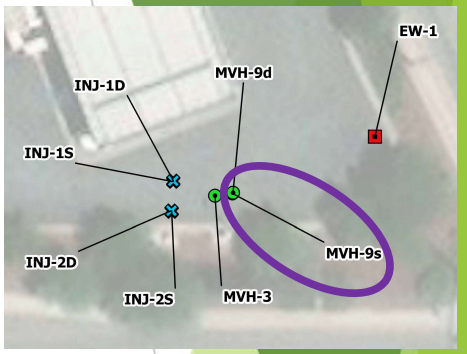
MVH-9s CVOC Concentrations





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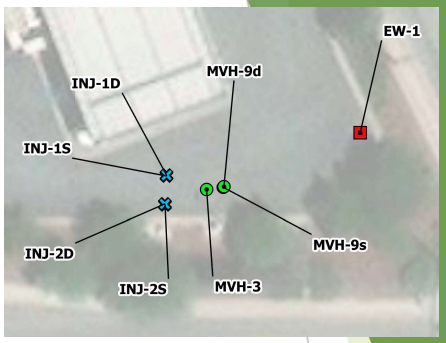
Percent Change



Sample ID	Sample Date	PCE		TCE		cis-1,2-DCE		Vinyl Chloride		Ethene	
		Concentration	% Change	Concentration	% Change	Concentration	% Change	Concentration	% Change	Concentration	% Change
	AWQS	**5.0**		**5.0**		**70**		**2.0**		**NE**	
MVH-3	02/06/24	**628**	-99.0%	**24.3**	-84.4%	**14.7**	3104%	**0.687 J**	581%	<4.26	1724%
MVH-3	12/11/24	<6.00		<3.80		**471**		<4.68		**77.7**	
MVH-9s	02/07/24	**606**	-99. 9%	**12.0**	-96.3%	**20.2**	-74.9%	<0.234	806%	<4.26	186%
MVH-9s	12/12/24	**0.652 J**		**0.443 J**		**5.08**		**2.12**		**12.2 J**	
INJ-1S	02/06/24	**4,080**	-99.6%	**74.1 J**	-96.5%	**85.8**	-96.8%	<0.234	--	<4.26*	47.7%
INJ-1S	12/11/24	**17.5**		**2.57 J**		**2.72 J**		<1.17		**6.29 J**	
INJ-1D	02/06/24	**883**	-99.8%	**43.7 J**	-97.8%	**75.5**	-99.2%	<0.234	--	<4.26*	--
INJ-1D	12/11/24	<1.50		<0.950		<0.630		<1.17		<3.40	
INJ-2S	02/06/24	**3,050**	-99.5%	**19.5 J**	-51.3%	**5.96**	5.70%	<0.234	--	<4.26*	--
INJ-2S	12/10/24	<15.0		<9.50		<6.30		<11.7		<3.40	
INJ-2D	02/06/24	**118**	-97.4%	**2.66 J**	-28.6%	**1.92**	236%	<0.234	1434%	<4.26*	604%
INJ-2D	12/10/24	**3.07 J**		<1.90		**6.46 J**		**3.59 J**		**30**	

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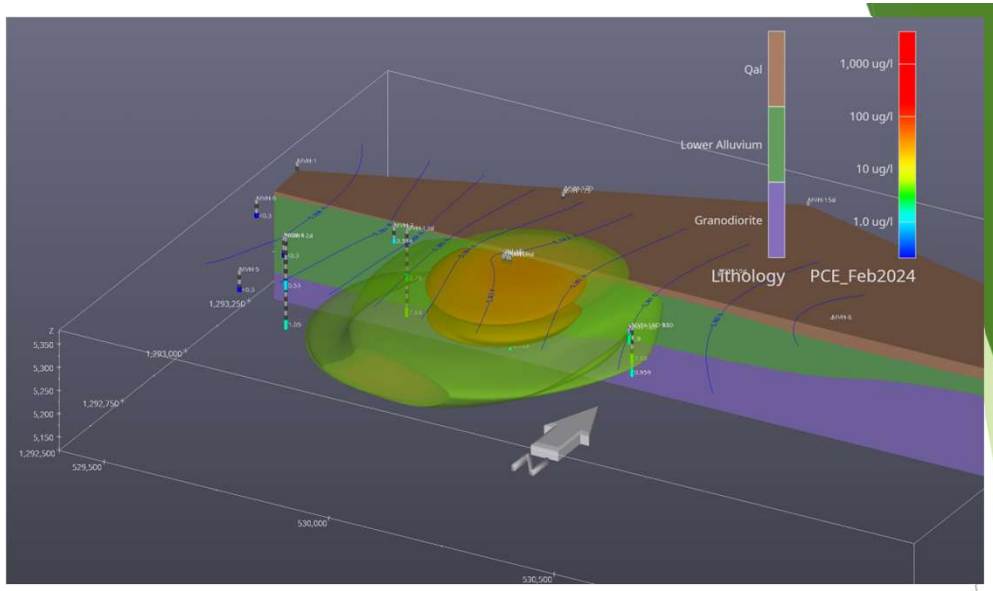
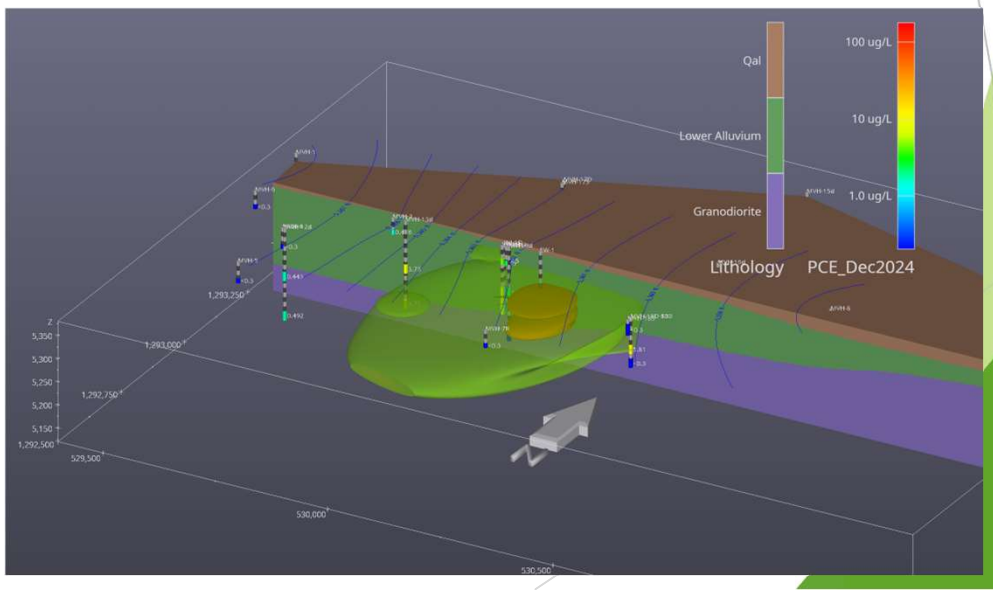
PCE Plume February 2024 and December 2024





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Summary

- ISM study: enhanced anaerobic bioremediation is an appropriate remedial approach
- Clean water test: aquifers displayed low permeability.
  - Changed from slow-release carbon substrate to quick-release soluble substrate
- Bromide and TOC results: injected carbon substrate impacted downgradient monitor wells.
- Increase in *Dehalococcoides* observed in all wells
- PCE reduction more than 97%, two to three orders of magnitude.
- Significant increases in TCE and cis-1,2-DCE observed as parent compounds were biodegraded.
- Continue to monitor and evaluate need for additional amendments
- Further evaluation of ISB using EVS

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Questions?

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