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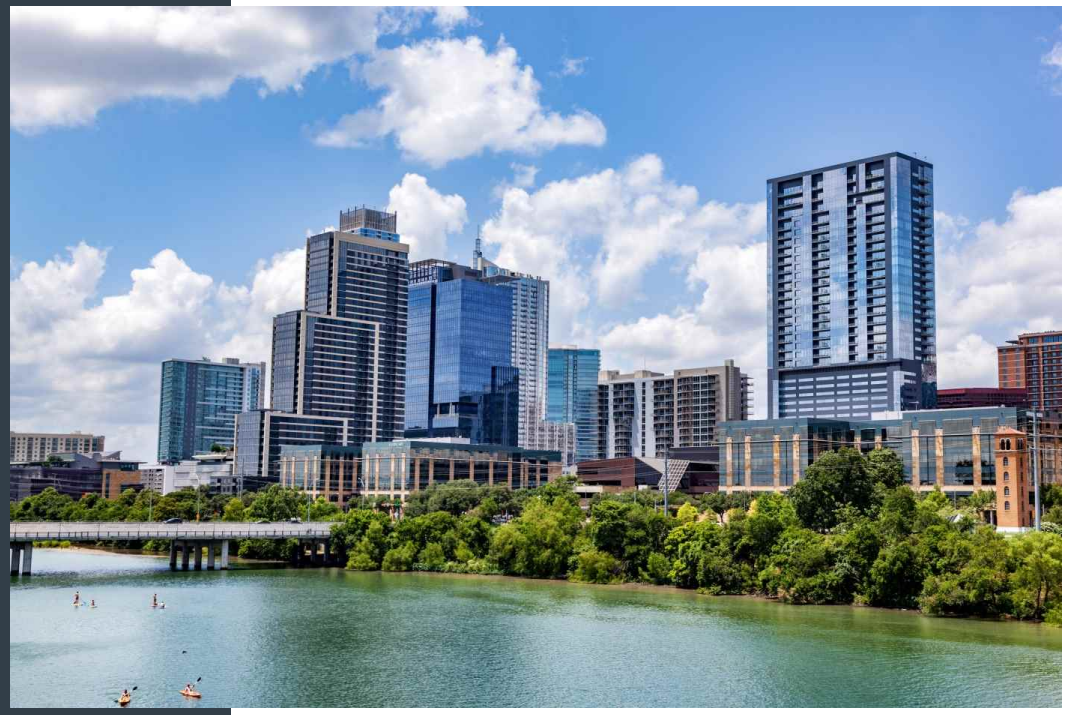
CREATIVE THINKING
EXCEPTIONAL SOLUTIONS



Development of an Adaptive Framework for Optimizing Bioremediation Implementation at a Fractured Bedrock Chlorinated Solvent DNAPL Site

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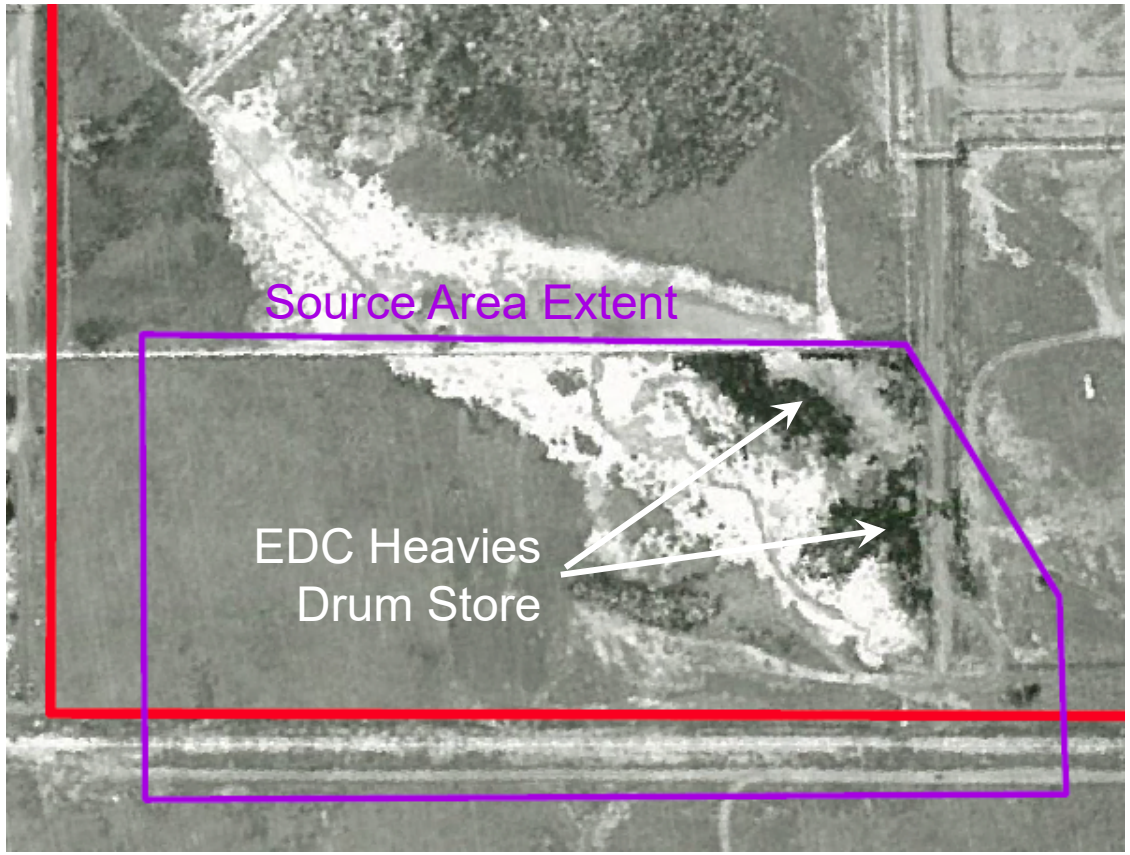
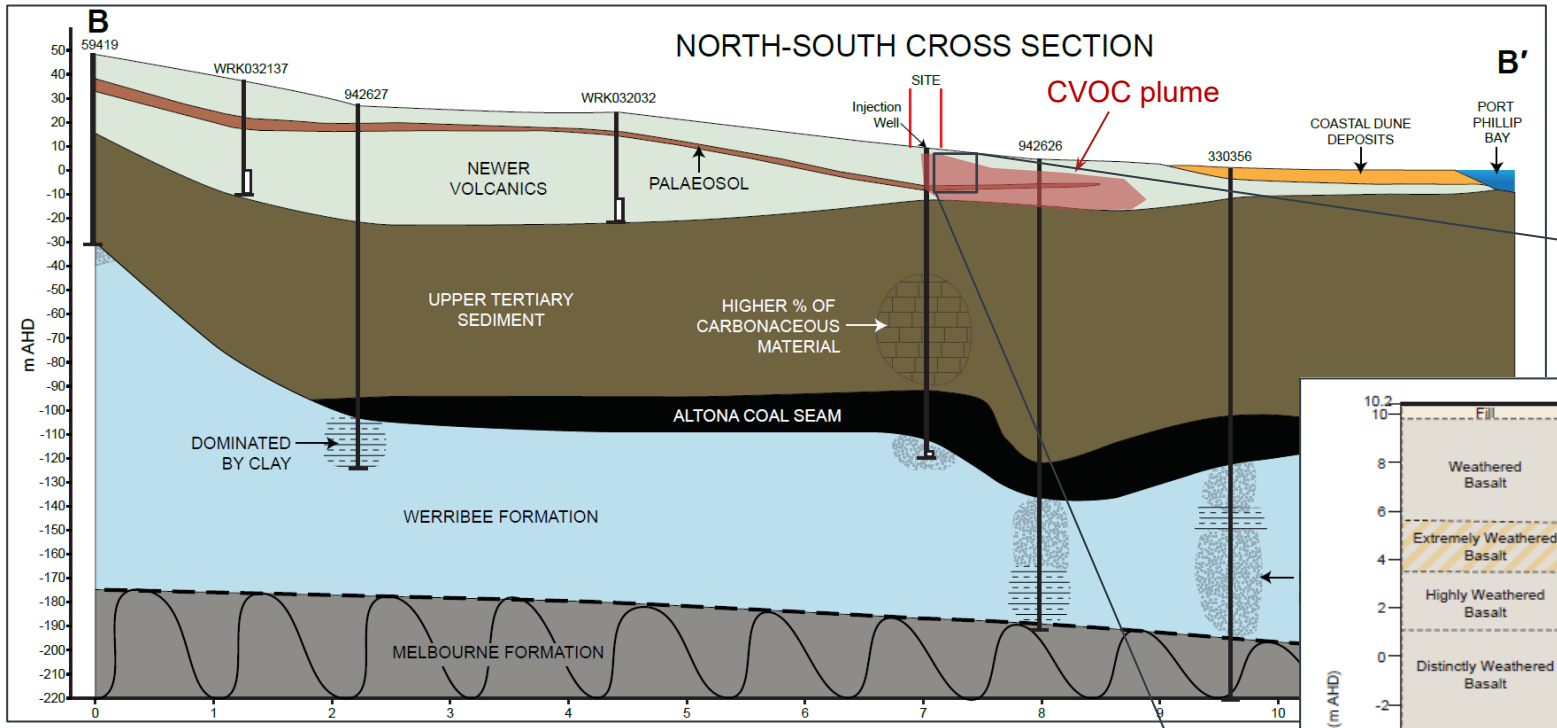
Release History

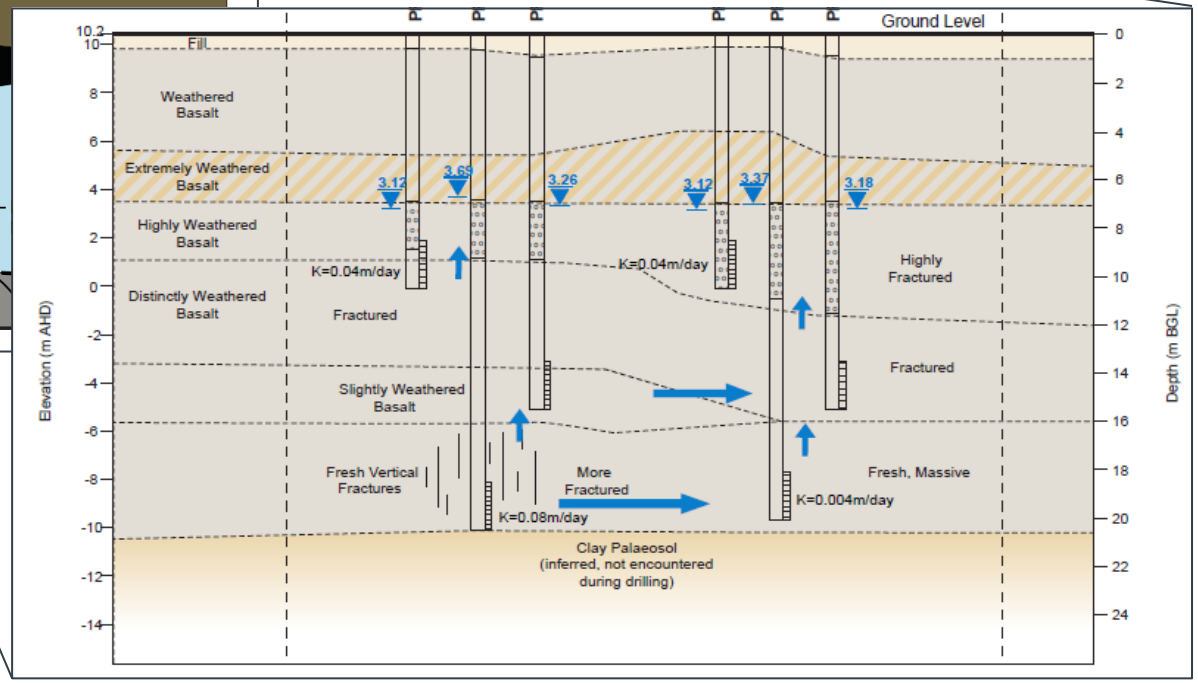


1962 and 1976: Ethylene dichloride (EDC or 1,2-dichloroethane) manufacturing on site produced a by-product called “EDC Heavies”.

1969: A grass fire engulfed the EDC Heavies drum store leading to a loss of containment and release of chlorinated hydrocarbons comprised of mainly 1,1,2-TCA, EDC, and some PCE and 1,1,2,2-TeCA.

Geological Environment





Contamination primarily migrates through basalt bedrock. Basalt environment is complex, with potential for storage of mass in the matrix and capture of DNAPL in low permeability zones.

Flow is dominated by the bedrock characteristics (fracturing, massive intervals) and generally follow dominant fracture pathways.

Timeline of Historical Remedial Activities

1969
Grassfire and release of DNAPL

1994
Commenced Characterization

1994-1996
Groundwater pump-and-treat trials

1998
On-site risk assessment completed and Groundwater Management Plan implemented

2007-2014
On-site AS/SVE system operating

2012-Present
Enhanced in-situ bioremediation (EISB) system commenced operation

2016
2016 Clean Up Plan approved adopting sustainable remediation principles

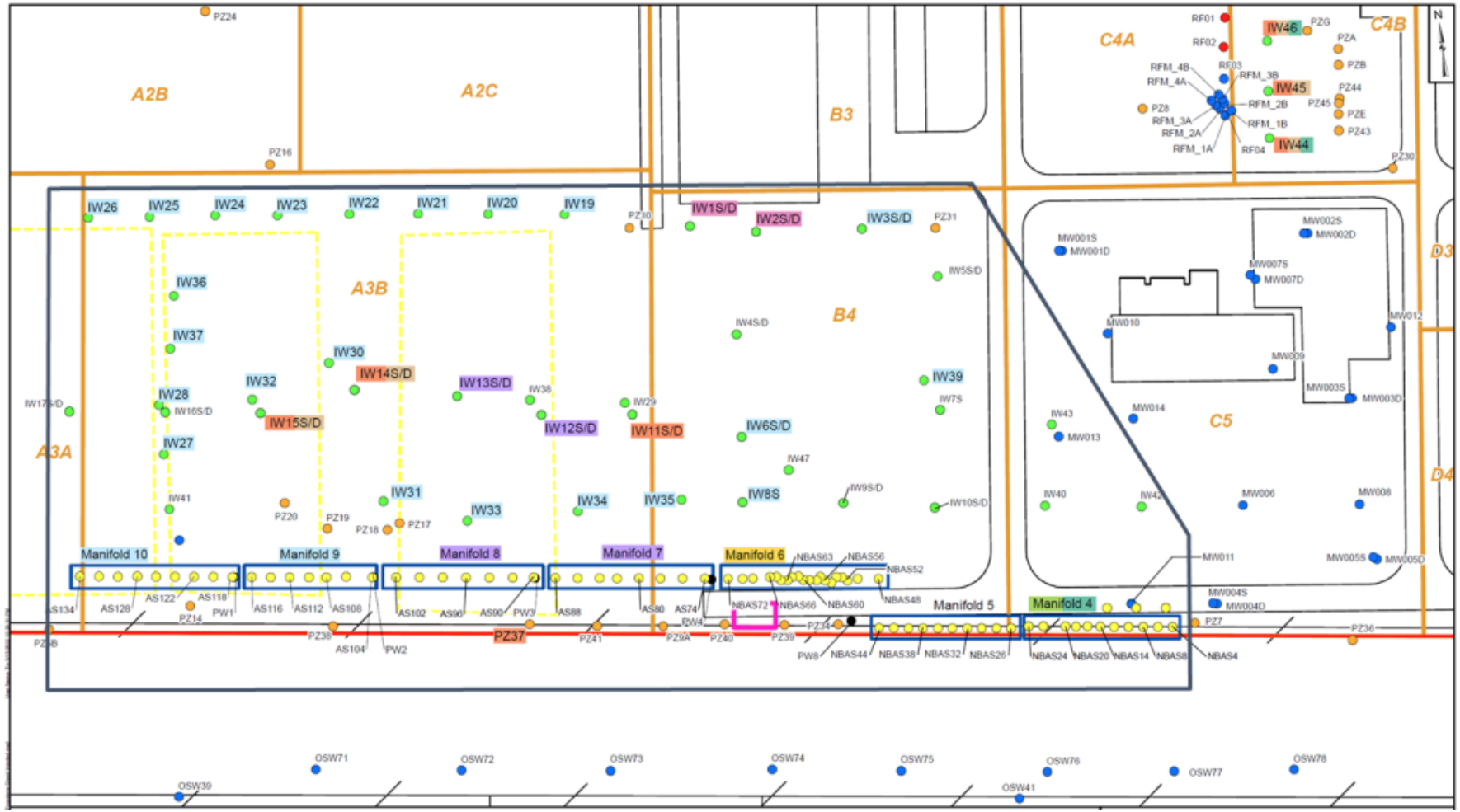
2016-2022
Implementation of the 2016 Clean Up Plan

2017-2020
Zero-valent iron permeable reactive barrier (PRB) pilot trial implemented

2017-Present
Full-scale soil vapor extraction (SVE) operating

2022-Present
Implementation of the 2022 Clean Up Plan

Bioremediation Program 2012 to 2021



Injection Locations and Timings

- IW30 PG injected between December 2011 and September 2015
- IW1S PG injected between July 2012 and September 2016
- IW11S PG injected between October 2015 and September 2016
- IW12S PG injected between October 2016 and September 2017
- NBAS4 PG injected between October 2017 and December 2018
- IW44 PG injected between January 2019 and December 2019
- IW45 PG* injected between January 2020 and December 2020
- NBAS72 PG* injected between January 2021 and December 2021

Timeframe	Total Electron Donor Mass Injected (tonnes)
2011-2017	302.4 (97.5%)
2018-2021	7.7 (2.5%)
Total	310.1

Impact of Remediation on COI Concentrations

COI	Maximum Concentrations in Period (mg/L)		
	Natural Attenuation 2000-2006	AS/SVE Operation 2006-2011	EISB Operation 2011-2021 (Max 2021)
1,1,2,2-TeCA	44	210	270 (111)
1,1,2-TCA	1,030	3,500	2,000 (874)
EDC	710	3,000	1,400 (263)
PCE	12	16	67 (3.0)
TCE	78	130	88 (25)
cis-1,2-DCE	6.2	41	45 (10)
VCM	73	2,400	910 (62)
CTC	0.04	ND	0.09 (ND)
CF	14	33	38 (4.2)
DCM	2.1	11	3.2 (0.83)

COI	Reduction in Average Concentrations (%)[1]		
	Natural Attenuation 2000-2006	AS/SVE Operation 2006-2011	EISB Operation 2011-2021
1,1,2,2-TeCA	-112%	87%	99.8%
1,1,2-TCA	-12%	89%	99.9%
EDC	4%	97%	98.6%
PCE	46%	75%	99.6%
TCE	36%	89%	99.2%
cis-1,2-DCE	-5%	63%	96%
VCM	-216%	71%	97.7%
CTC	N/A	N/A	N/A
CF	45%	72%	99.8%
DCM	25%	91%	82%

[1] Reduction in average concentrations compares the geomean concentration at the beginning of the time period to the end of the specified time period in each remedial period.

Status as of end of 2021:

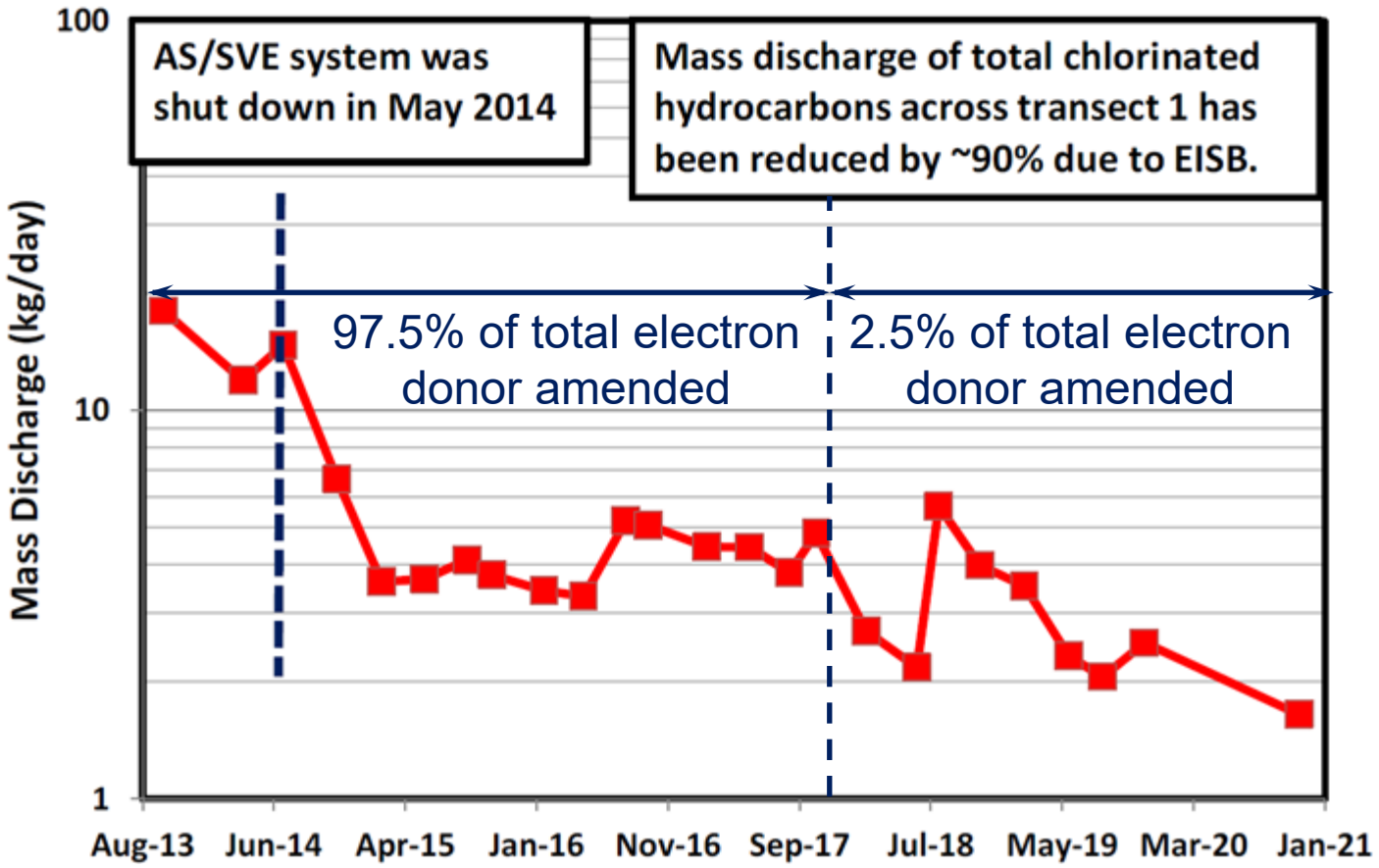
- Concentrations indicative of residual DNAPL in isolated areas only
- On average, >96% reduction in concentrations achieved
- Decreasing trends or lack of detections in the majority of wells
- Remedial goals achieved in the majority of wells
- Vinyl chloride most persistent COI
- Inhibitory levels of CF persist at 7% of locations sampled
- Minor rebound observed in some areas

COI	Maximum Concentrations (mg/L)	Reduction in Average Concentrations (%)	% Wells with Concentrations < Remedial Goals
1,1,2,2-TeCA	111	99.8%	98%
1,1,2-TCA	874	99.9%	85%
EDC	263	98.6%	85%
PCE	3.0	99.6%	98%
TCE	25	99.2%	83%
cis-1,2-DCE	10	96%	85%
VCM	62	97.7%	53%
CTC	ND	N/A	100%
CF	4.2	99.8%	100%
DCM	0.83	82%	100%

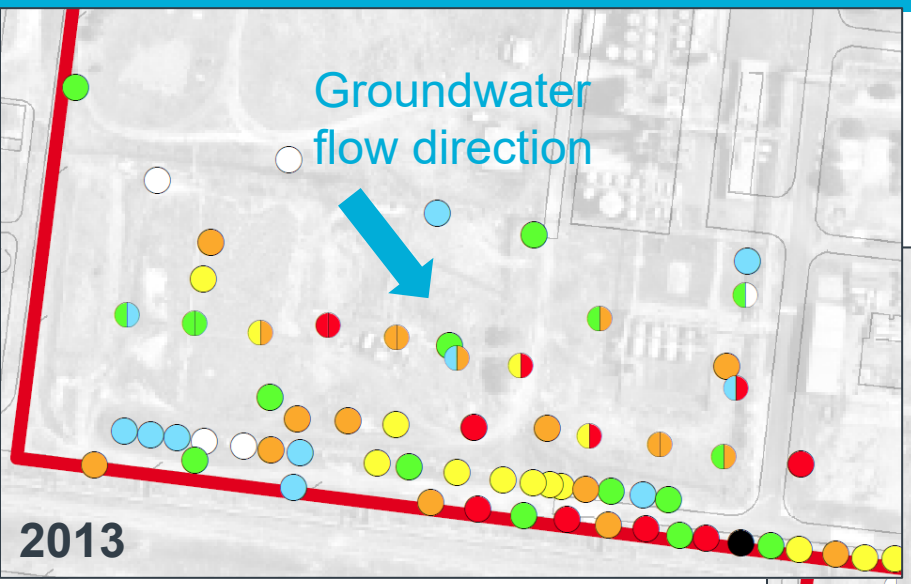
Analyte	Increasing	Decreasing	Stable	No Trend	Not Detected
1,1,2,2-TeCA	0%	38%	2%	16%	44%
1,1,2-TCA	3%	51%	5%	19%	22%
EDC	7%	49%	11%	27%	5%
PCE	1%	42%	10%	14%	33%
TCE	4%	54%	10%	17%	17%
cis-1,2-DCE	7%	27%	9%	38%	19%
VCM	4%	37%	13%	27%	18%
CTC	0%	1%	0%	0%	99%
CF	2%	47%	6%	15%	30%
DCM	5%	18%	7%	19%	52%

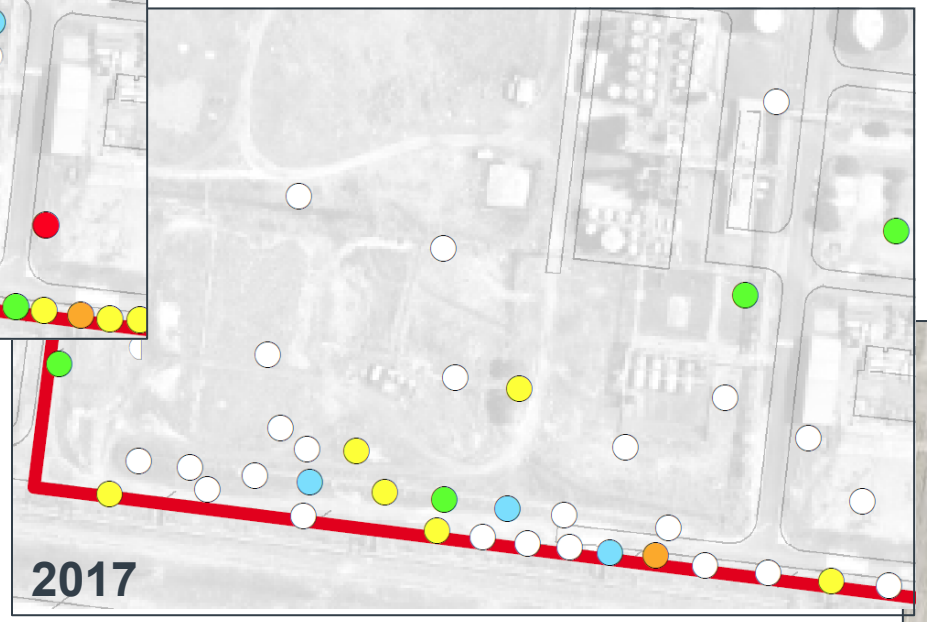
Status as of end of 2021:

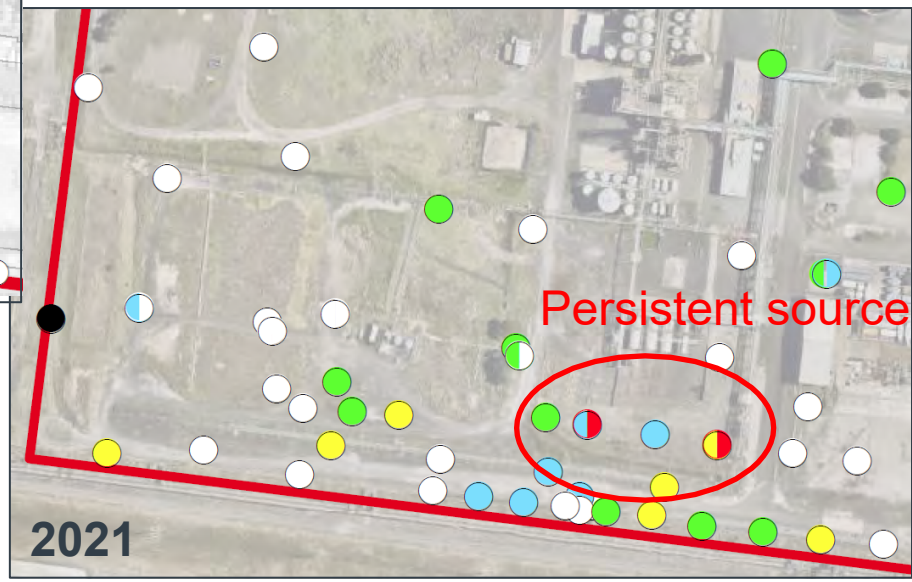
- Mass discharge across site boundary reduced by 90% reduction compared to baseline
- 50% reduction achieved within first few years, but then stable for years while DNAPL being treated



Improvements in Contaminant Concentrations Through 10 Years of EISB – 1,1,2-Trichloroethane

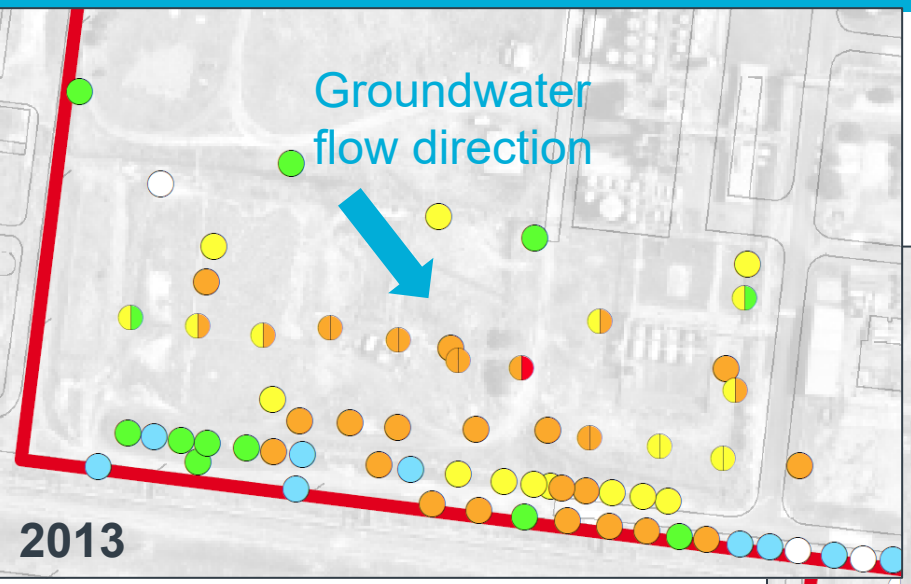


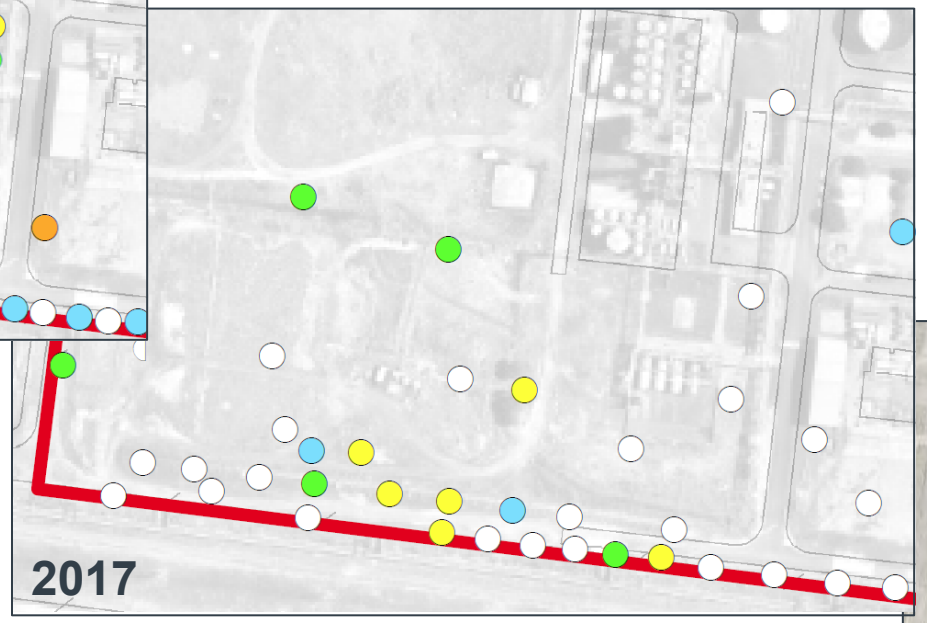


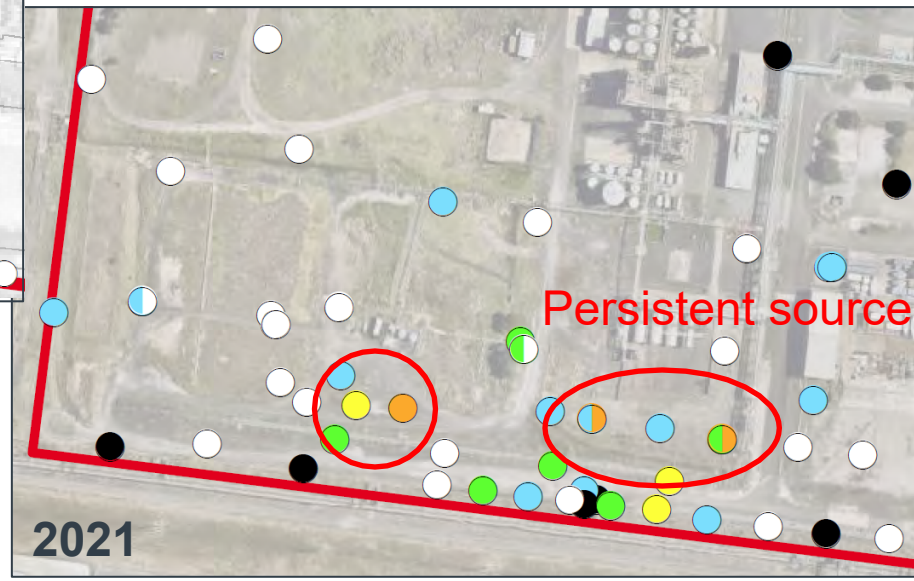


Concentration (mg/L)
- ND
- ND (LOR ≥ PCR)
- ≤ 0.02
- > 0.02 - ≤ 0.2
- > 0.2 - ≤ 2.0
- > 2.0 - ≤ 20
- > 20 - ≤ 200
- > 200 - ≤ 2,000
- > 2,000

Improvements in Contaminant Concentrations Through 10 Years of EISB – Ethylene Dichloride (1,2-DCA)

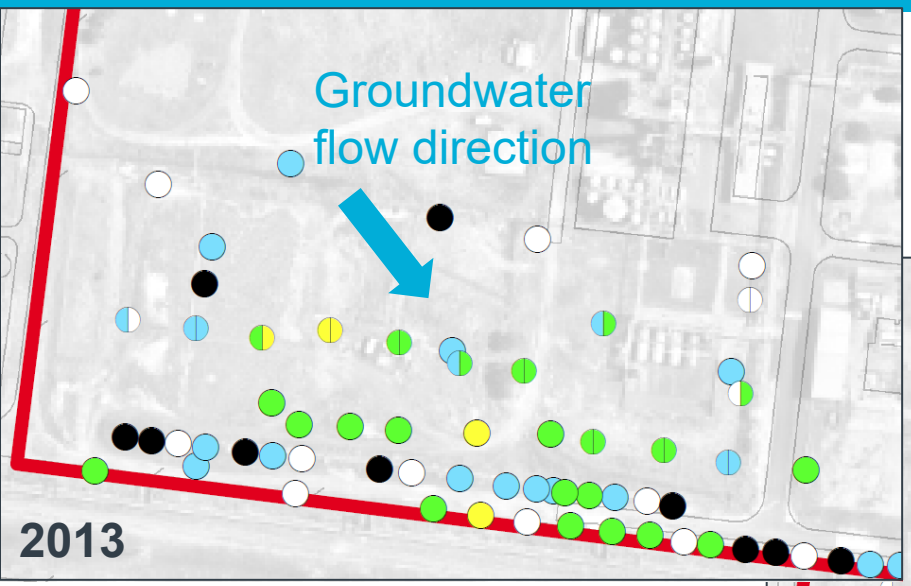


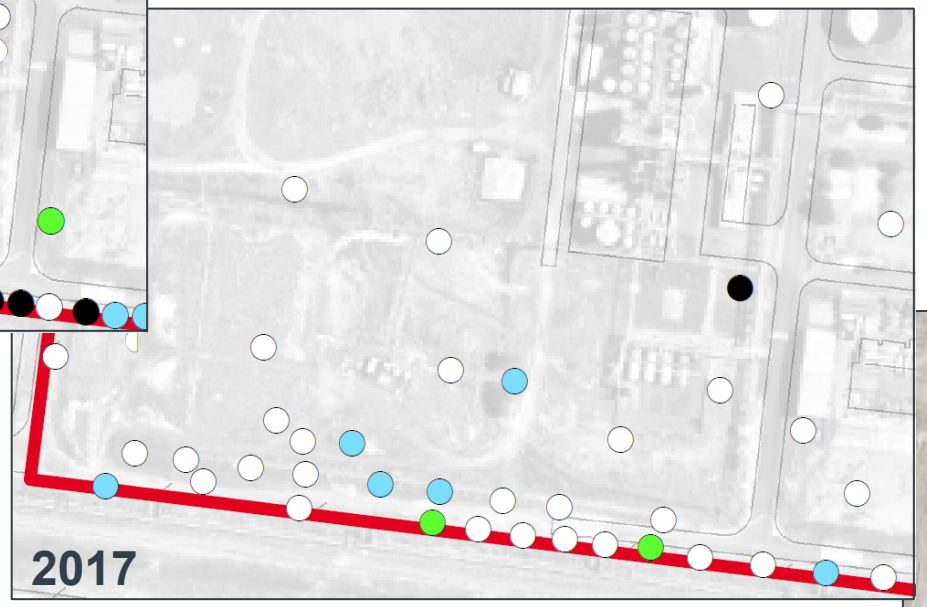


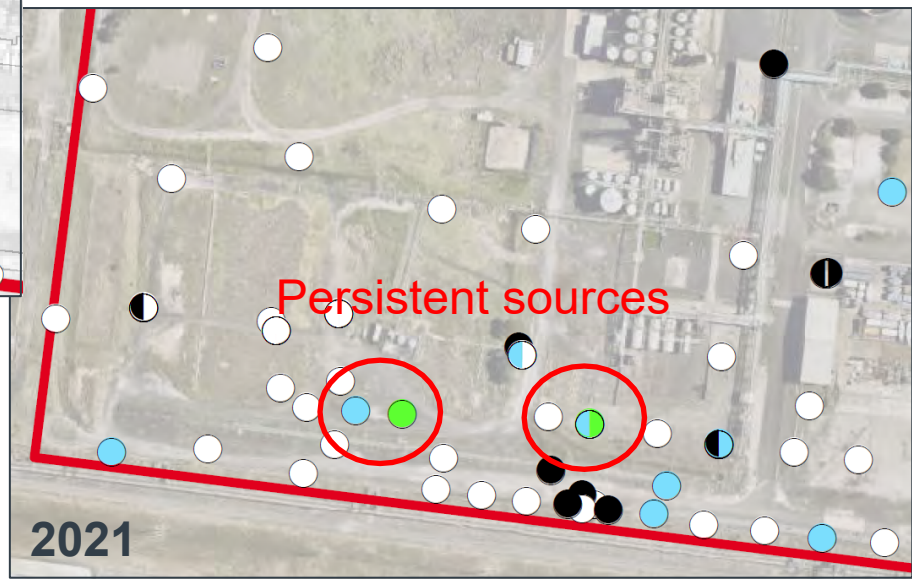


Concentration (mg/L)
- ND
- ND (LOR ≥ PCR)
- ≤ 0.03
- > 0.03 - ≤ 0.3
- > 0.3 - ≤ 3.0
- > 3.0 - ≤ 30
- > 30 - ≤ 300
- > 300 - ≤ 3,000
- > 3,000

Improvements in Contaminant Concentrations Through 10 Years of EISB - Tetrachloroethene

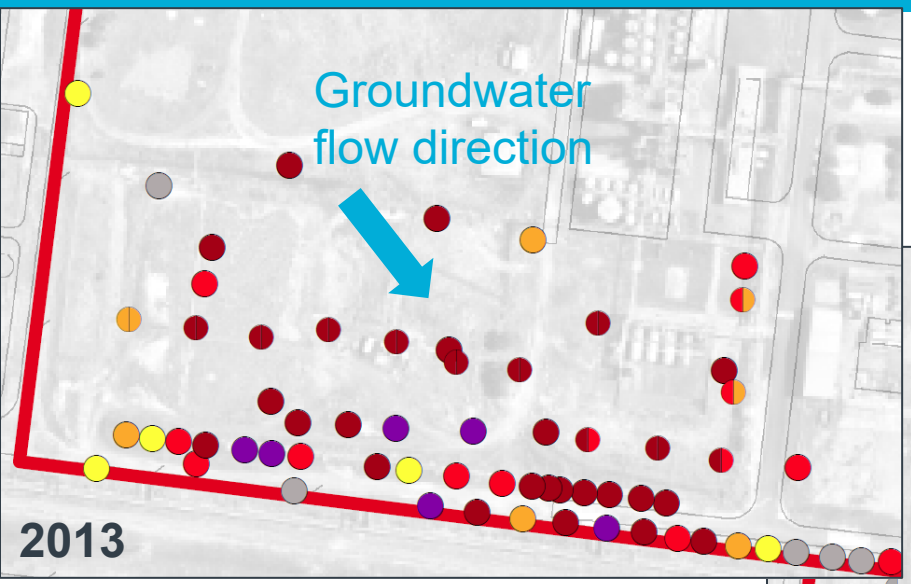


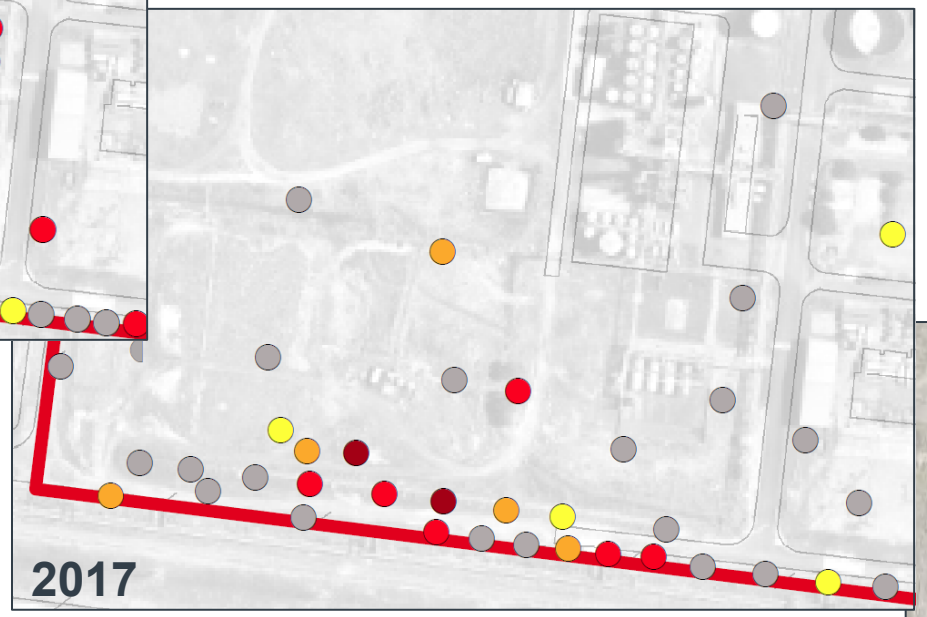


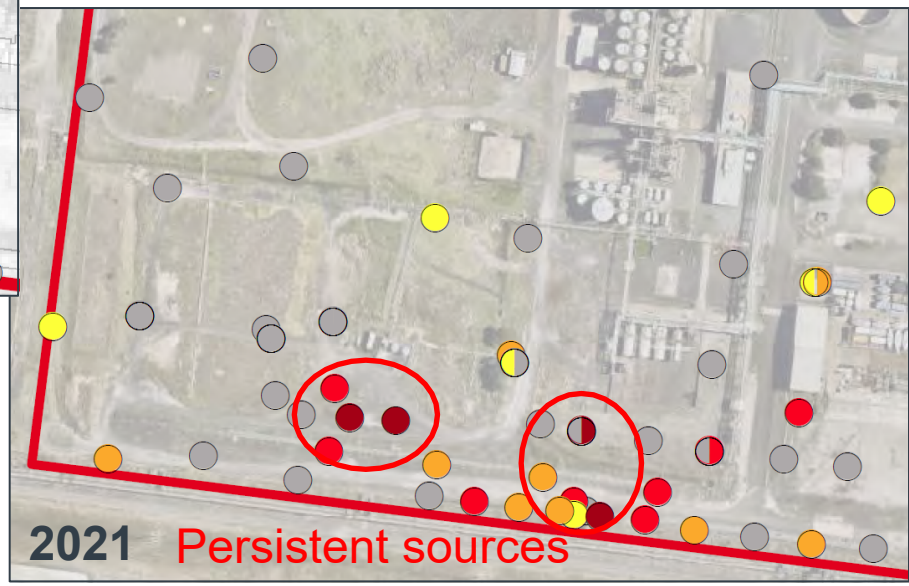


Concentration (mg/L)
- ND
- ND (LOR ≥ PCR)
- ≤ 0.09
- > 0.09 - ≤ 0.9
- > 0.9 - ≤ 9.0
- > 9.0 - ≤ 90
- > 90

Improvements in Contaminant Concentrations Through 10 Years of EISB – Vinyl Chloride

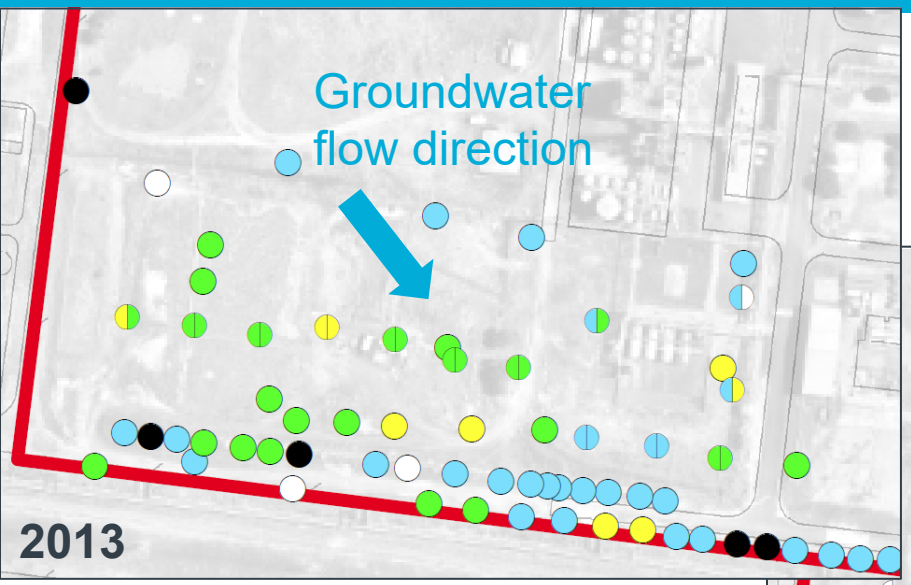


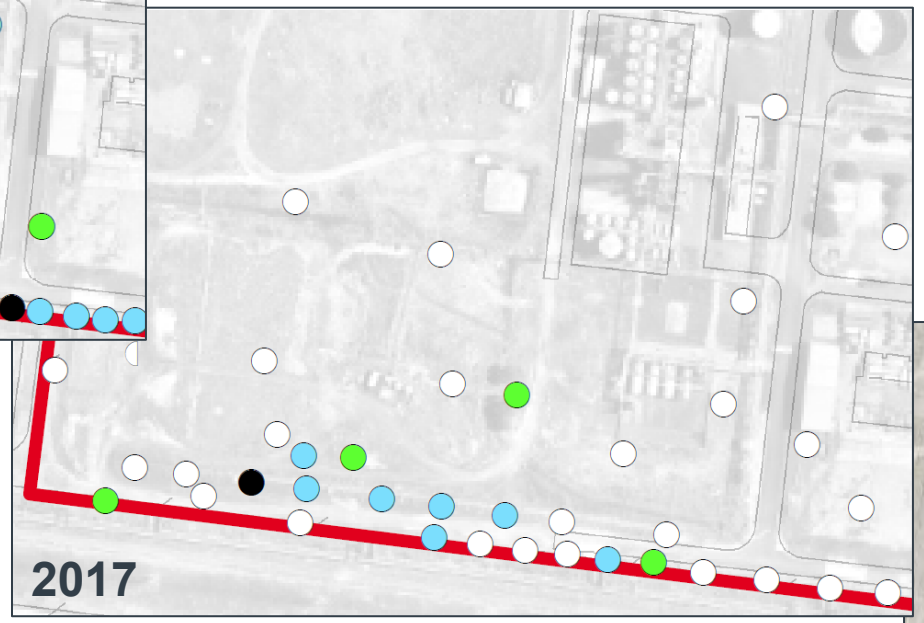


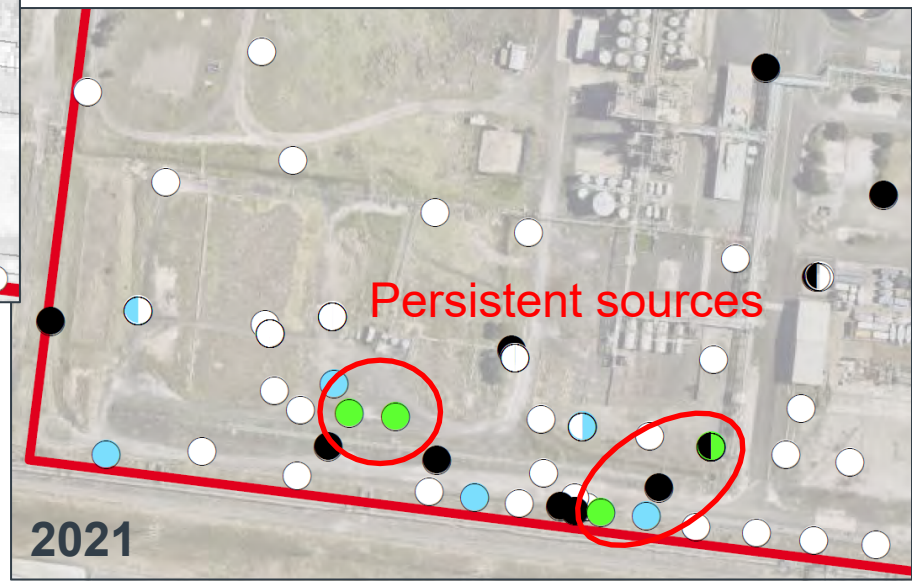


Concentration (mg/L)
- ND
- ND (LOR ≥ PCR)
- {not applicable}
- ≤ 0.002
- > 0.002 - ≤ 0.02
- > 0.02 - ≤ 0.2
- > 0.2 - ≤ 2.0
- > 2.0 - ≤ 20
- > 20 - ≤ 200
- > 200

Improvements in Contaminant Concentrations Through 10 Years of EISB - Chloroform







Concentration (mg/L)
- ND
- ND (LOR ≥ PCR)
- ≤ 0.08
- > 0.08 - ≤ 0.8
- > 0.8 - ≤ 8.0
- > 8.0 - ≤ 80
- > 80 - ≤ 800
- > 800

Potentially inhibitory concentrations

Summary of EISB Progress to Date

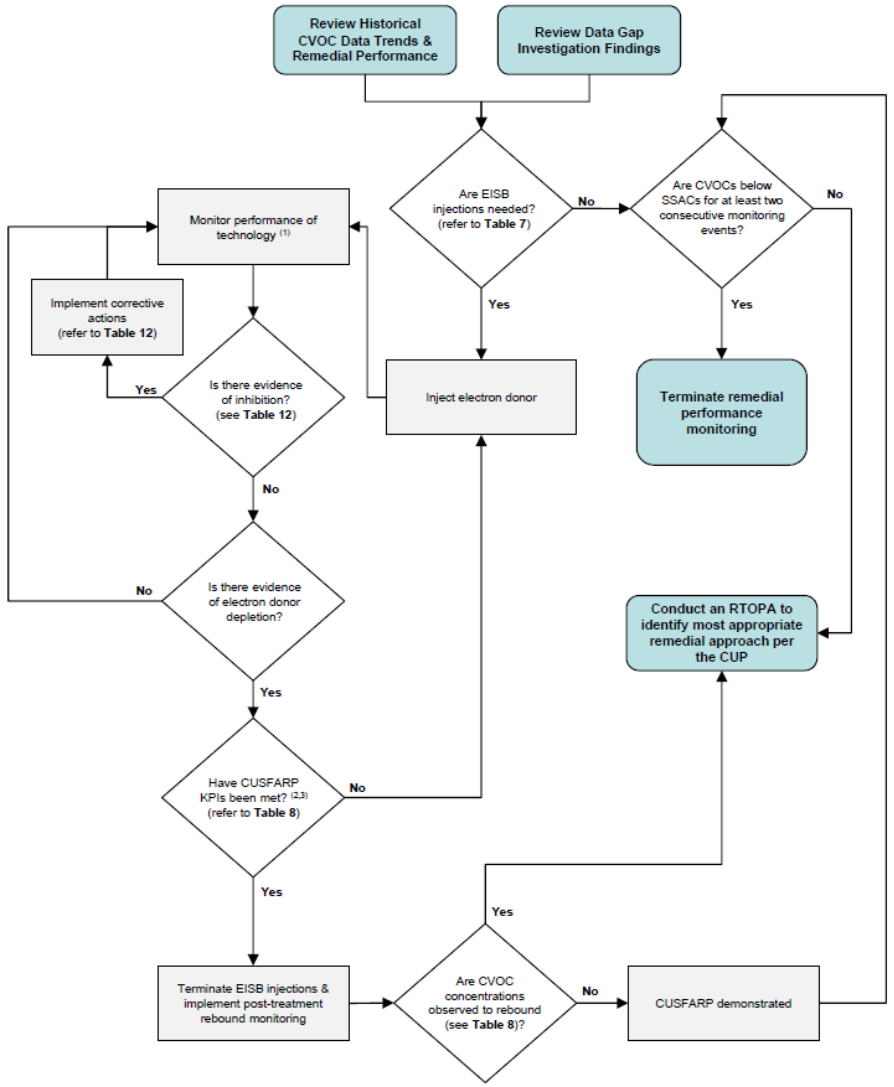
Achievements to date include:

- Signs of substantial reductions in DNAPL mass / concentrations
- Substantial reductions in off-site mass discharge achieved, allowing off-site plumes to attenuate

Residual concerns / optimization opportunities:

- Methane generation has been significant in the past → GHG issue as SVE system emits methane to atmosphere
- Pockets of residual DNAPL remain in 2 to 3 isolated areas
- Elevated concentrations, particularly VC and DNAPL constituents, persist in some areas
- Electron donor no longer manufactured on site
- Tailoring of dosing frequency/locations

Adaptive Framework for EISB Program



Features include:

- Ongoing focused injections in areas of:
  - mass persistence
  - rebound post-treatment
  - CF concentrations > 1 mg/L
- Injections near site boundary to enhance treatment of mass migrating off-site
- Bioaugmentation to address CF inhibition where needed
- Treatability studies to evaluate potential to use waste product as electron donor
- Modified performance monitoring to better identify donor-limited conditions

Key Performance Indicators (KPIs) for Transition to MNA

CUSFARP Target	Specific CUSFARP KPIs
DNAPL depletion	1,1,2,2-TeCA < 29 mg/L 1,1,2-TCA < 45 mg/L EDC < 86 mg/L PCE < 2 mg/L
	Total molar COIs < 1.2X pre-EISB baseline
Risk mitigation	[COI] ≤ 10X risk-based criteria
Achievement of stable, long-term reductions in COI concentrations after active treatment terminated	In wells where active treatment is not ongoing: • [COI] ≤ 10X risk-based criteria • Mann-Kendall trend assessment does not indicate increasing trends • Parent COI concentrations remain < 1% of single-component solubilities
Treatment of inhibitory CF	[CF] < 1 mg/L
Stable mass discharge	Mass discharge (M) ≤ 0.1 M_{2013}

CUSFARP = “clean up so far as reasonably practicable” (i.e. cleanup goals)

KPIs developed to achieve:

- Treatment of DNAPL mass
- Stable, long-term reductions in COI concentrations after treatment is terminated (no rebound)
- Stable, low rates of mass discharge across the southern site boundary to allow off-site plumes to attenuate
- Treatment of CF to below inhibitory levels to achieve optimal conditions for long-term natural attenuation

Thank you for your attention

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