

Implementation of Solar -Powered Bedrock Vapor Extraction (BVE)

Removing Trichloroethylene (TCE) in Deep Fractured Sandstone

Santa Susana Field Laboratory (SSFL)

National Aeronautics and Space Administration (NASA)



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Agenda



Facility History and Operations

Environmental Cleanup Requirements

Remedy Selection

Remedy Implementation

Results

Wrap Up

SSFL Facility History and Operations

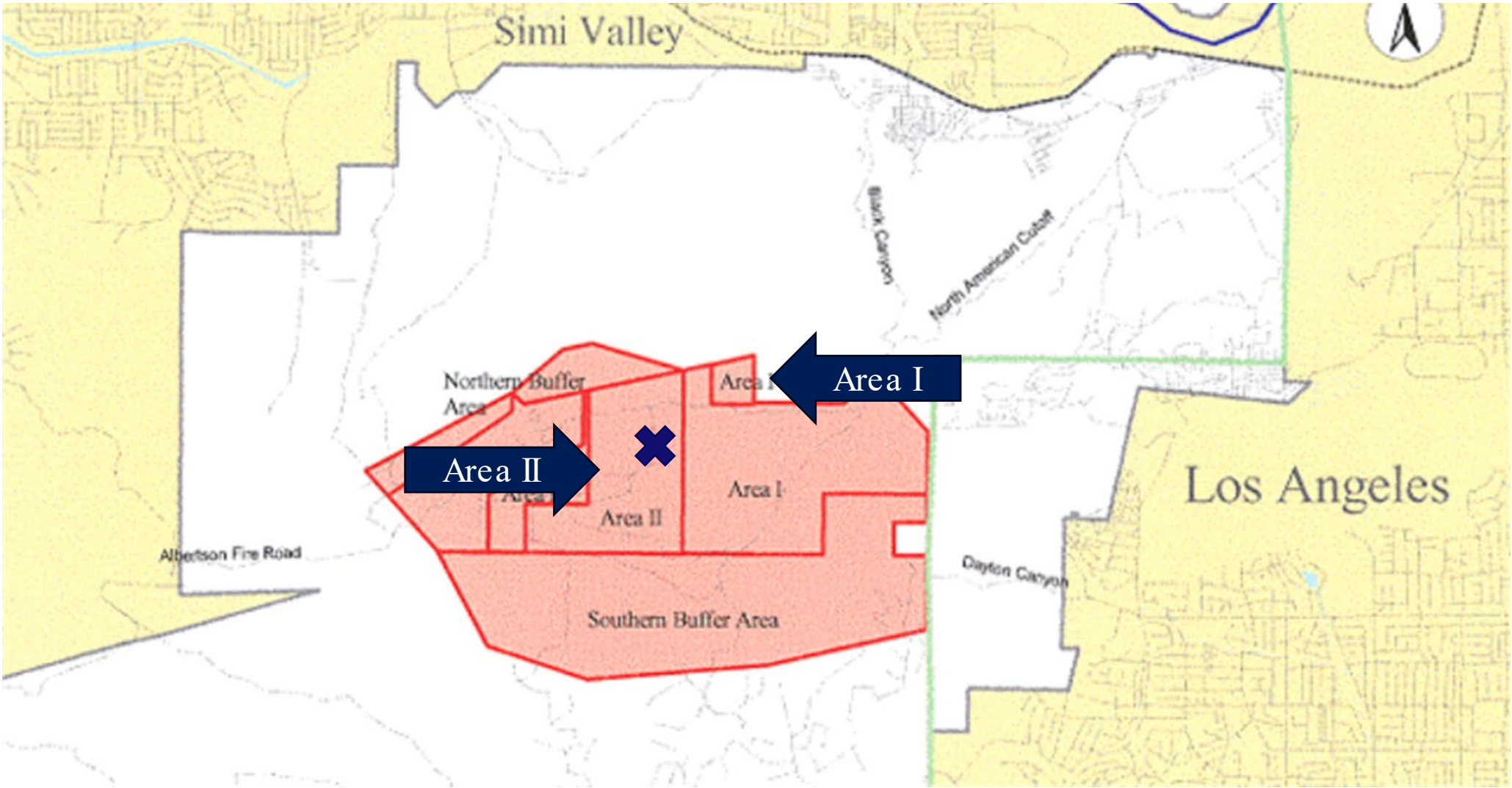
- Location
- Facility administrative areas
- Historic operations



Test Stand 1



Regional Map



SSFL Environmental Cleanup Requirements

- Comprehensive regulatory framework
- Status

Below: Enhanced In Situ Bioremediation (EISB) Injection Well



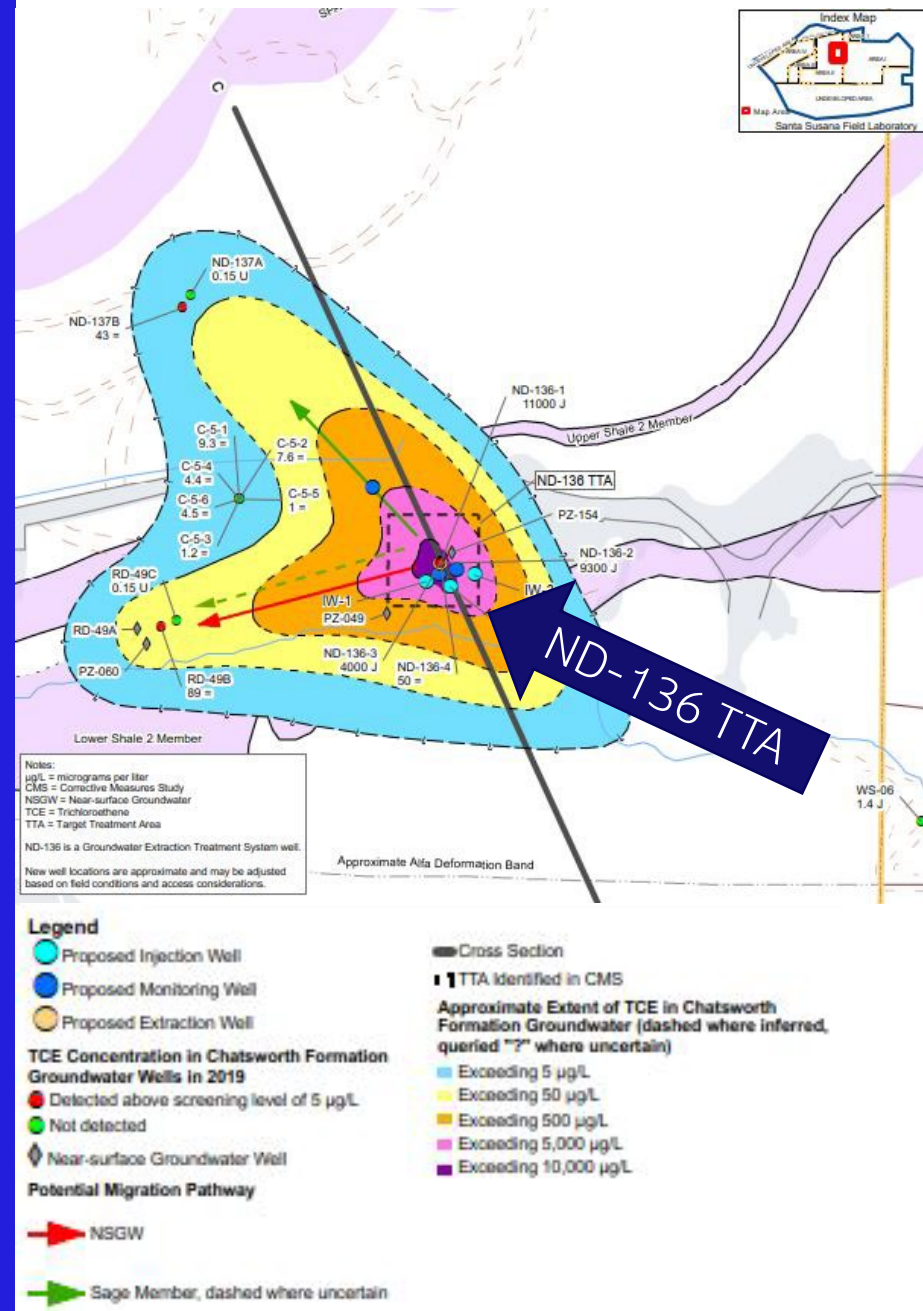
Above: Drilling of Groundwater Remediation Well

Remedy Selection – Bedrock Vapor Extraction

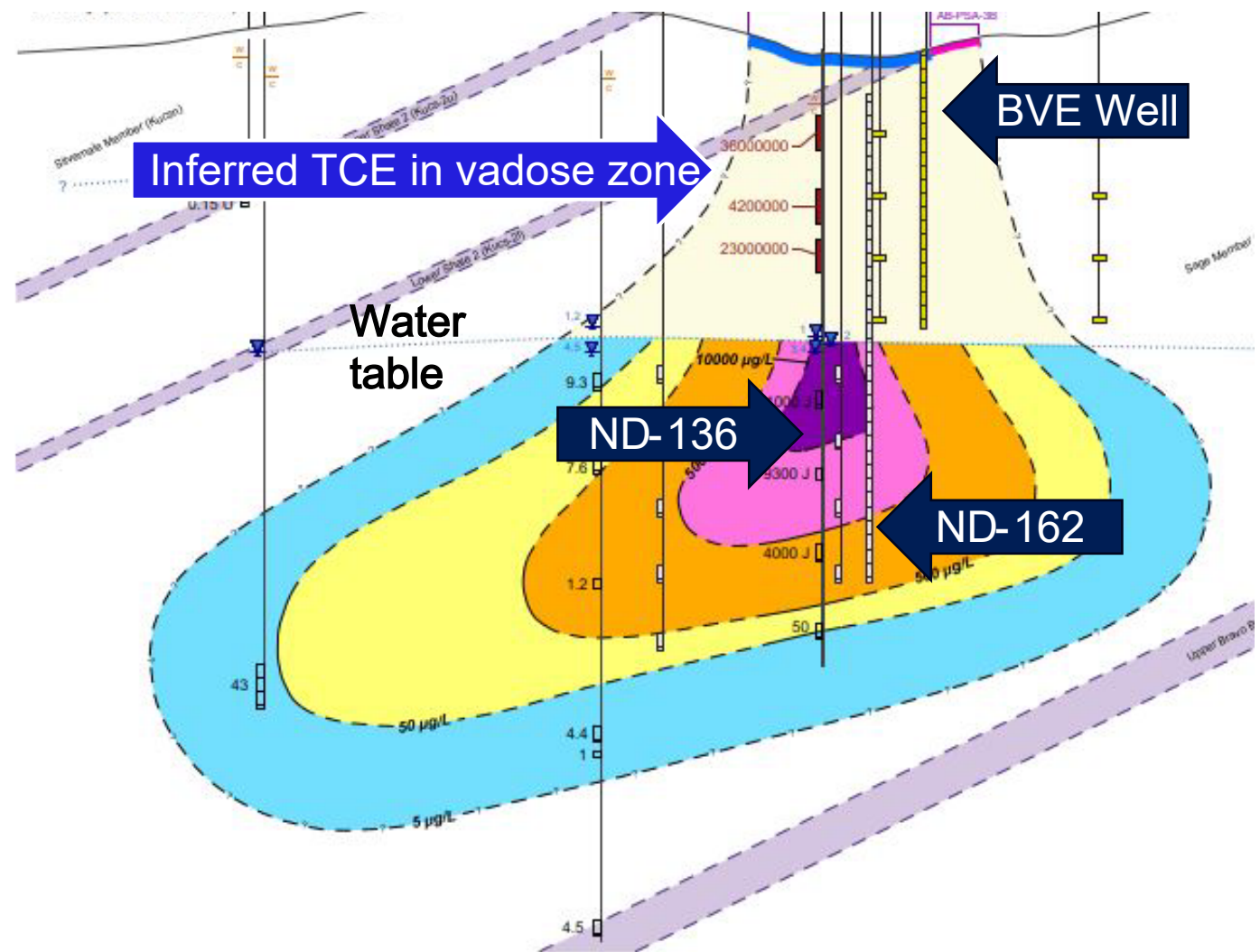
- Technology selection for groundwater restoration
- Treatment opportunity for the source of groundwater TCE
- Target Treatment Area (TTA) selected for measured fracture density and high TCE concentrations

Location	Depth Interval (feet bgs)	Bedrock Vapor Concentrations (µg/m³)			
		TCE	cis-1,2-DCE	trans-1,2-DCE	VC
ND-136	60 - 90	36,000,000	200,000	7,300 J	71,000
	126 - 156	4,200,000	93,000	5,200 J	6,700
	170 - 200	23,000,000	430,000	19,000	32,000

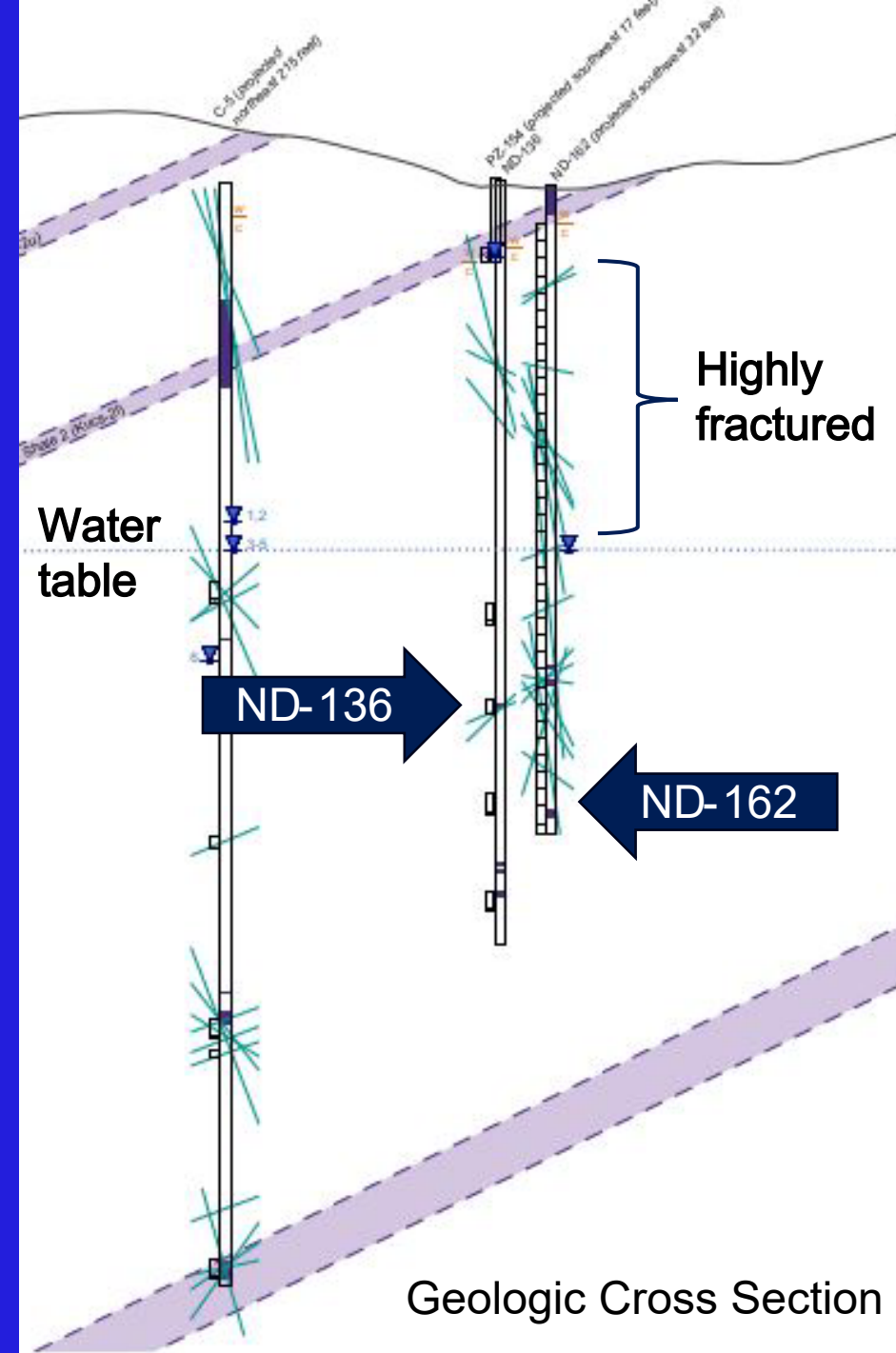
bgs: below ground surface
ug/m³: micrograms per cubic meters



TTA Geologic and TCE Cross Sections



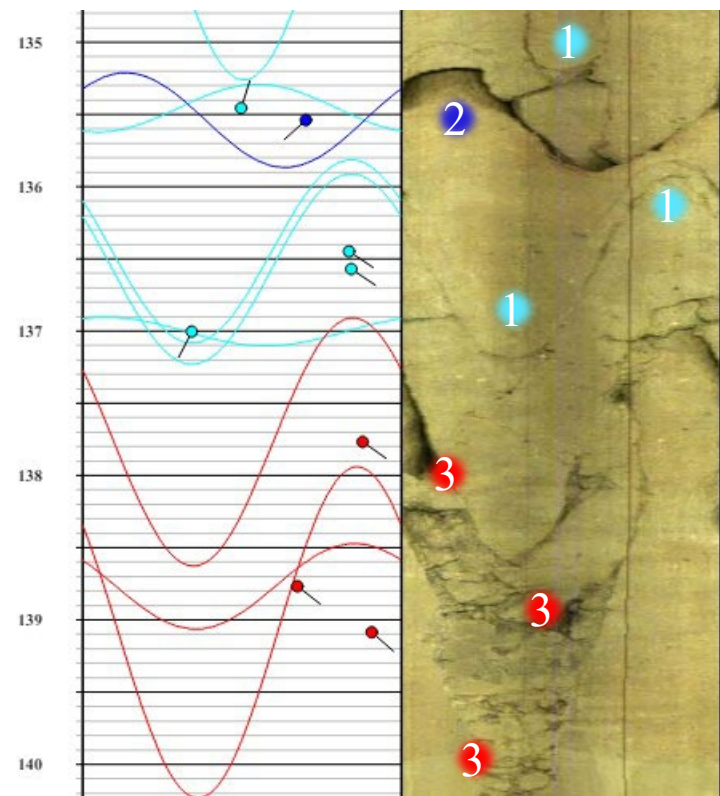
TCE Cross Section



Geologic Cross Section

ND-136 and ND-162 Fracture Comparison

ND-136 Optical Televiewer

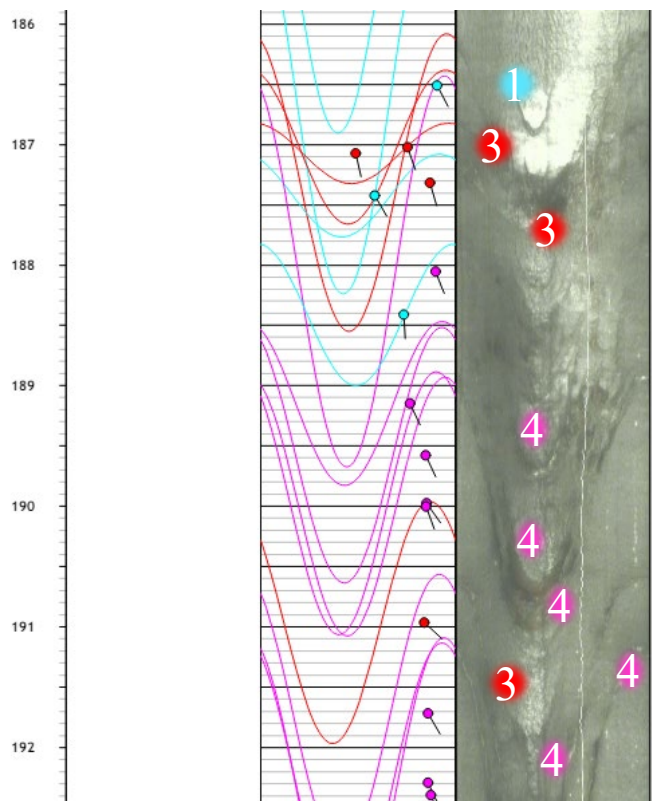


ND-136 Fracture Orientation Summary Table

Depth (ft)	Dip Direction (deg)	Dip Angle (deg)	Feature Rank (0-5)
135.5	229	63	2
136.5	123	75	1
136.6	123	76	1
137.0	207	31	1
137.8	125	79	3
138.8	128	61	3
139.1	130	82	3
141.2	101	60	1

Shown: 4 of 10 complete fractures with flow potential

ND-162 Optical Televiewer



ND-162 Fracture Orientation Summary Table

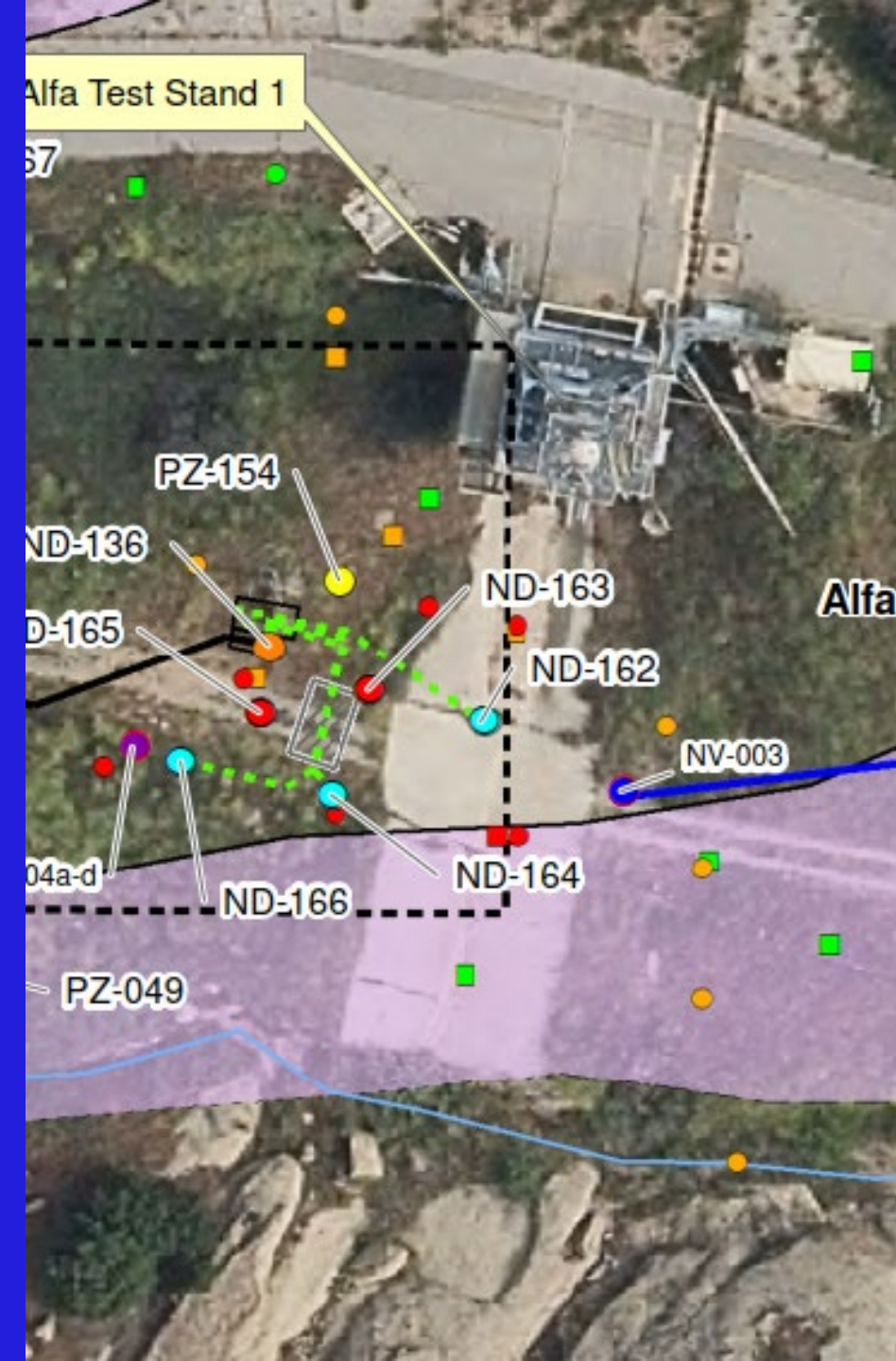
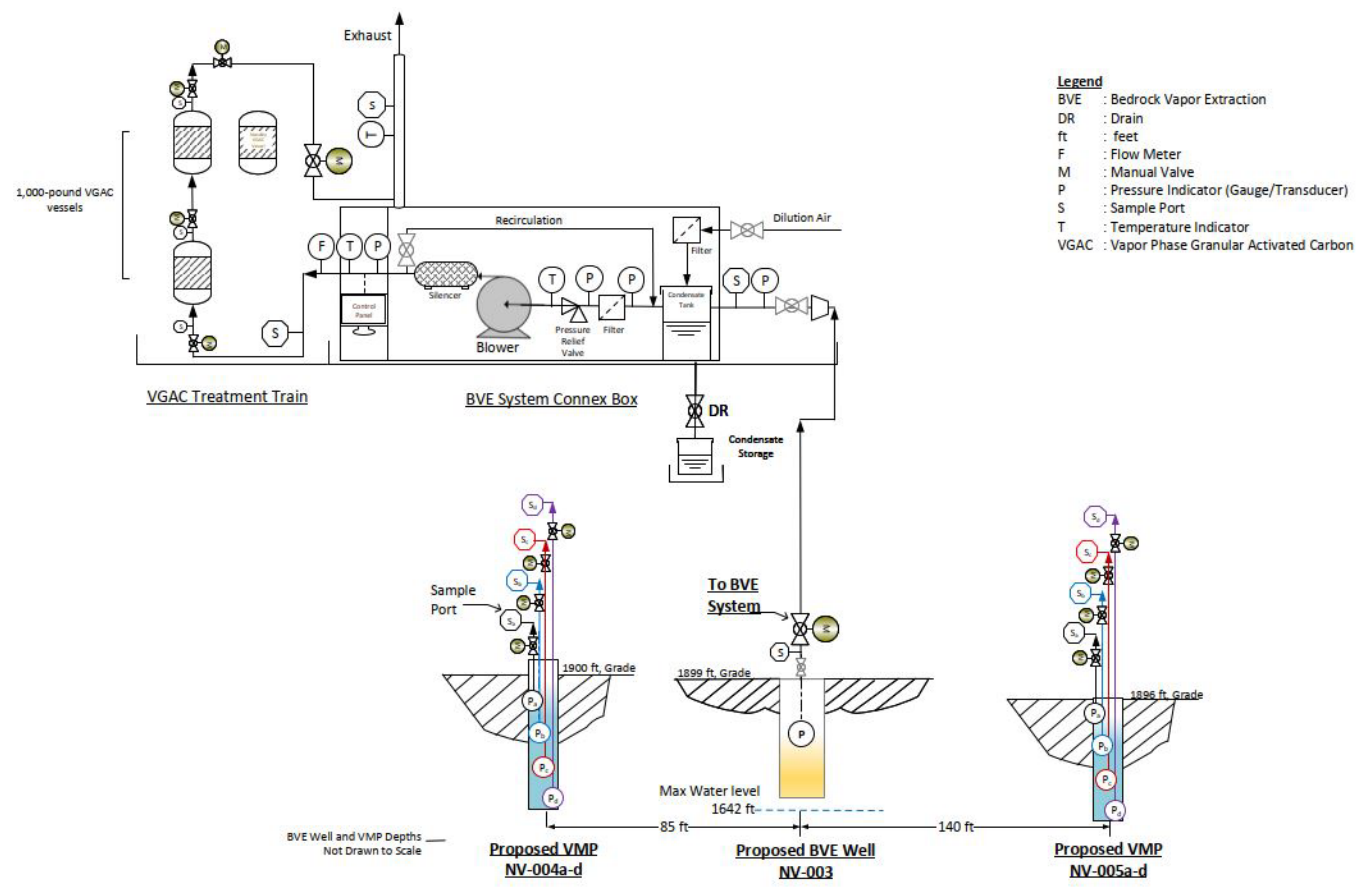
Depth (ft)	Dip Direction (deg)	Dip Angle (deg)	Feature Rank (0-5)
187.1	168	44	3
187.3	163	78	3
187.4	150	53	1
188.1	159	81	4
188.4	176	66	1
189.2	155	69	4
189.6	155	76	4
190.0	144	77	4
190.0	160	76	4
191.0	133	75	3
191.7	150	77	4
192.3	155	77	4
192.4	158	79	4

Shown: 11 of numerous complete fractures with flow potential

Qualitative Ranking of Fractures

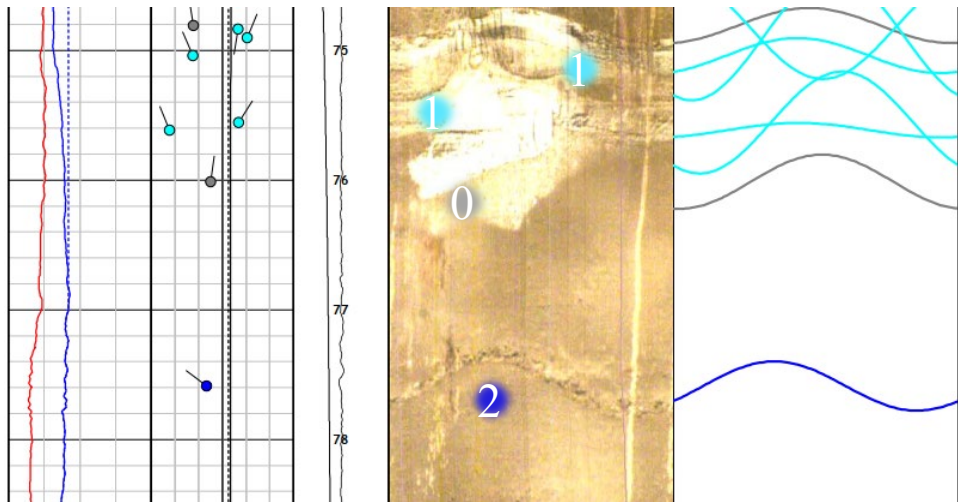
- 0/ Gray: Non-Flow Feature
- 1/ Cyan: Partial Fracture
- 2/ Blue: Clean, Distinct Fracture
- 3/ Red: Distinct Fracture with Notable Aperture
- 4/ Magenta: Distinct Fracture, Wide Aperture or Multiple Connected Fractures

Original BVE Well (NV-003) Selection



ND-136, ND-162, NV-003 Fracture Comparison

NV-003 Optical Televiewer

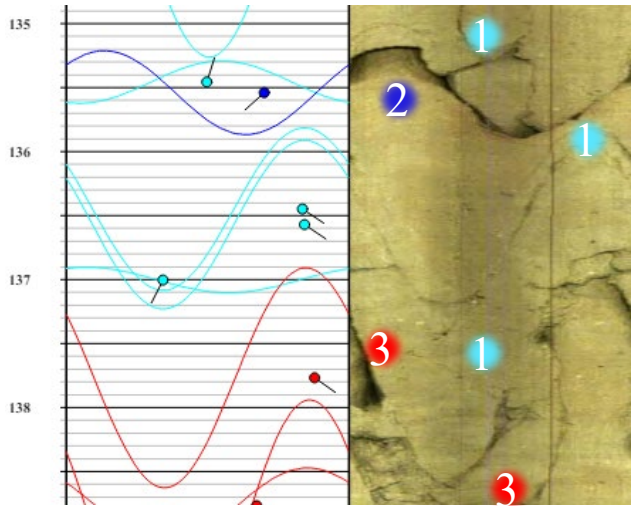


NV-003 Fracture Orientation Summary Table

Depth (ft)	Dip Direction (deg)	Dip Angle (deg)	Feature Rank (0-5)
74.8	189	55	1
74.9	23	61	1
75.0	337	27	1
75.6	33	55	1
75.6	338	12	1
76.0	8	38	0
77.6	307	35	2
79.1	331	31	0

- Only Complete Fracture
- Minimal Aperture

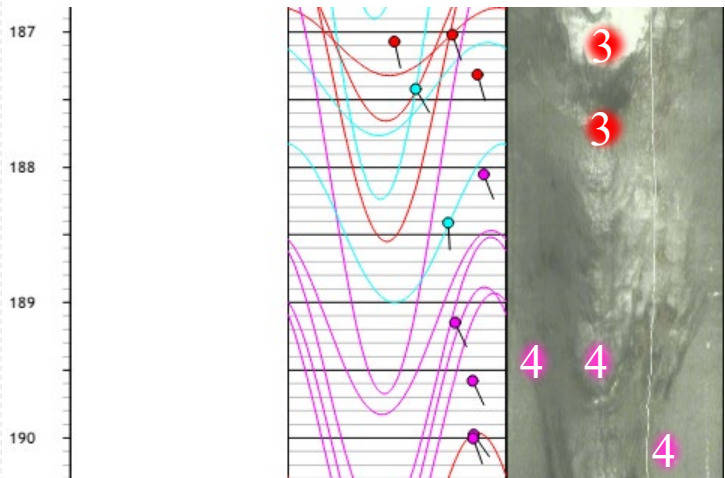
ND-136 Optical Televiewer



ND-136 Fracture Orientation Summary Table

Depth (ft)	Dip Direction (deg)	Dip Angle (deg)	Feature Rank (0-5)
135.5	229	63	2
136.5	123	75	1
136.6	123	76	1
137.0	207	31	1
137.8	125	79	3
138.8	128	61	3
139.1	130	82	3
141.2	101	60	1

ND-162 Optical Televiewer

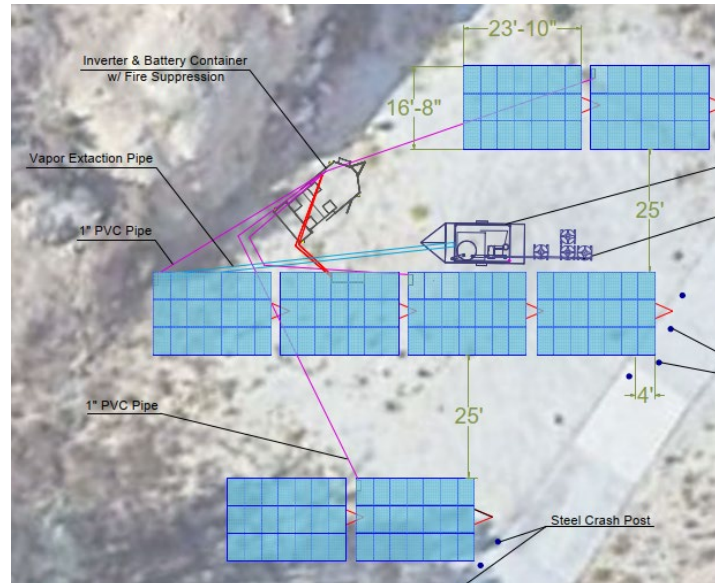


ND-162 Fracture Orientation Summary Table

Depth (ft)	Dip Direction (deg)	Dip Angle (deg)	Feature Rank (0-5)
187.1	168	44	3
187.3	163	78	3
187.4	150	53	1
188.1	159	81	4
188.4	176	66	1
189.2	155	69	4
189.6	155	76	4
190.0	144	77	4
190.0	160	76	4

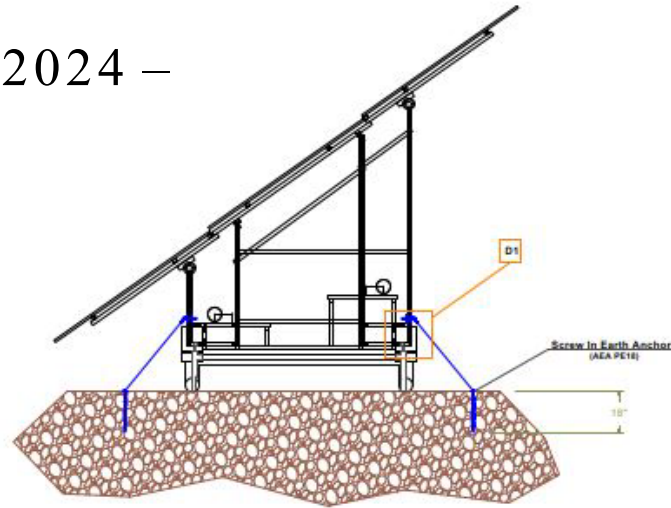
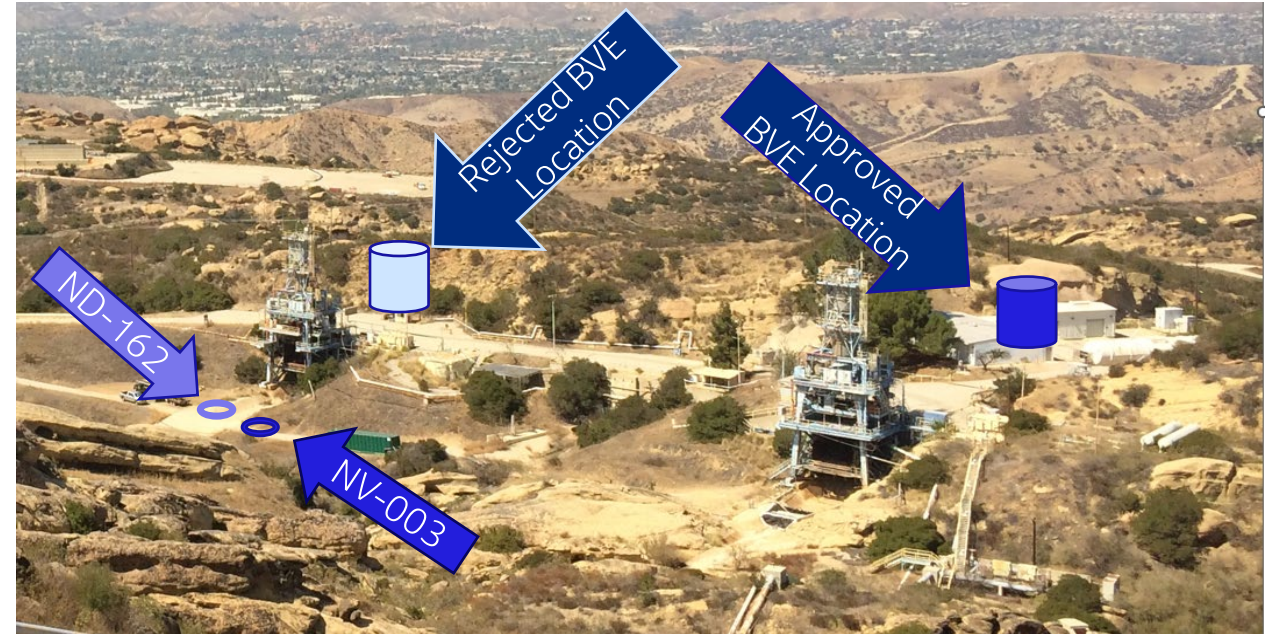
BVE System Construction

- Monitoring network for capture zone assessment
- Lack of pilot testing opportunities
- Sizing of vapor extraction system
- Power supply decision



Challenges Implementing BVE

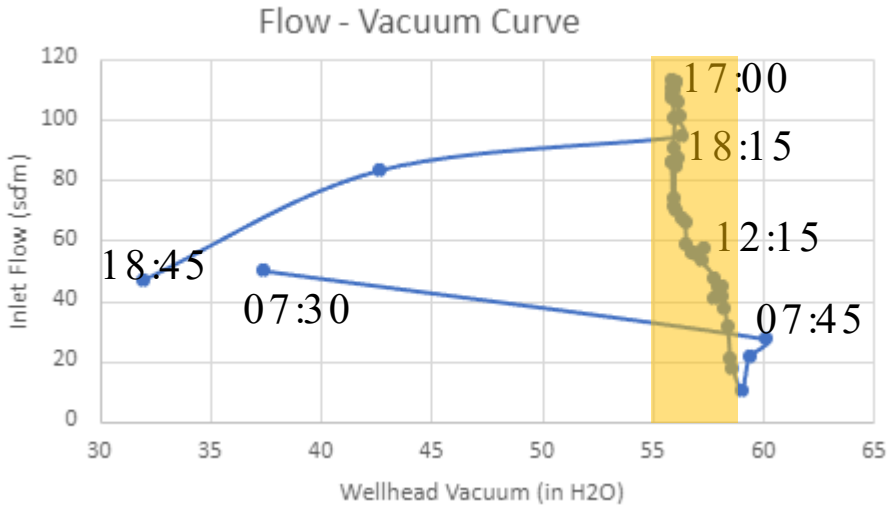
- Site-specific design constraints
 - cultural resource management
 - sustainable power & electrical infrastructure
 - mobility and modularity
- Implementation challenges
 - solar equipment availability (spring 2021 – 2023)
 - battery & inverter troubleshooting (2024 – to date)
- Operational challenges
 - direct solar operations
 - well flow limitations & total flow requirements



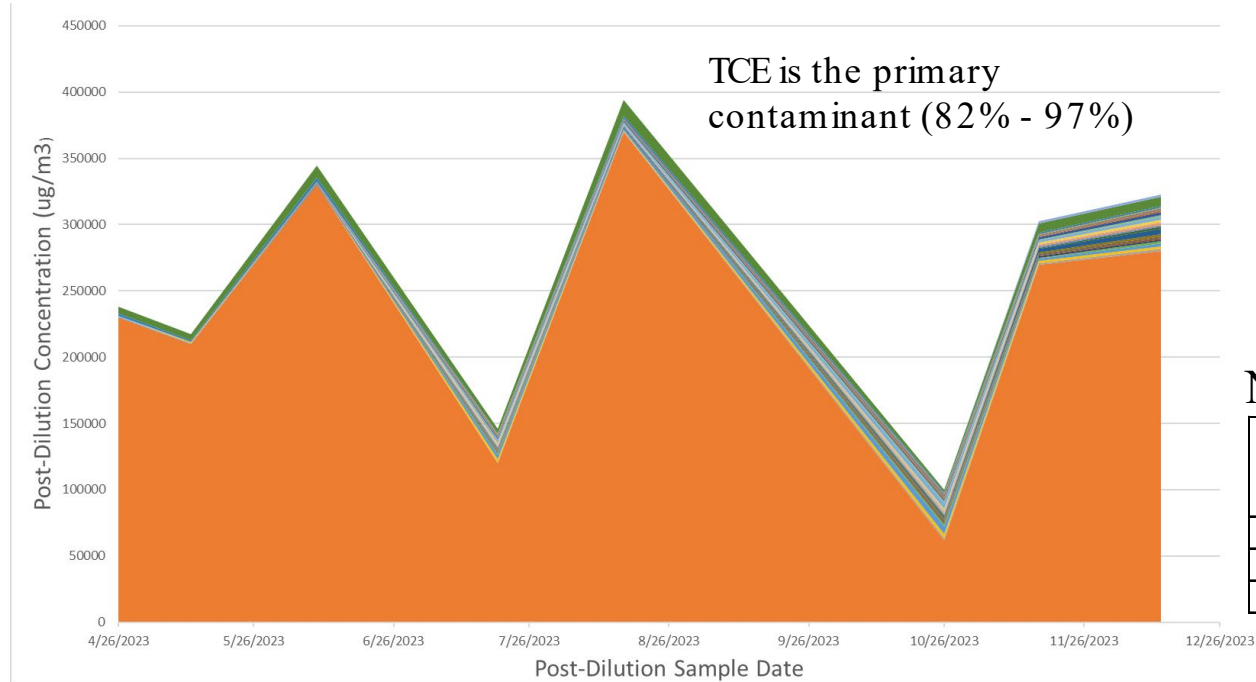
NV-003 Operational Results (Feb 2023 – Dec 2023)

NV-003	Hours Run	Average Influent Flow Rate (scfm)	Average Post-Dilution Flow Rate (scfm)	Average Dilution Flow Rate (scfm)	Average Influent Vacuum (inWC)	Cumulative Mass Extracted (pounds TCE)
1Q 2023	361	54	230	176	-23	142
2Q 2023	883	67	187	119	-51	423
3Q 2023	1172	88	172	84	-87	792
4Q 2023	945	74	198	124	-76	1211

+281 lbs
+369 lbs
+419 lbs



Post-Dilution Sample Compositions (ug/m³)



Results:

- 1,211 pounds of TCE extracted from 1 Q23 – 4 Q23
- Dilution flow typically equals or exceeds influent flow by 1.5x - 3x
- Applied vacuum is limited by solar availability when operating without solar batteries

NV-003 Wellhead & Influent Sample Data

Sample Location	Sample Date	Operating Well	Total VOCs (ug/m ³)	TCE Percent Composition (%)	TCE (ug/m ³)	Change in Total VOCs Between Measurements (ug/m ³)
Wellhead	9/30/2022	NV-003	2,094,880	95.47%	2,000,000	--
Influent	4/26/2023	NV-003	21,470,098	97.81%	21,000,000	19,375,218
Influent	9/8/2023	NV-003	3,571,000	72.81%	2,600,000	-17,899,098

scfm: standard cubic feet per minute
in H₂O / inWC: inches of water column

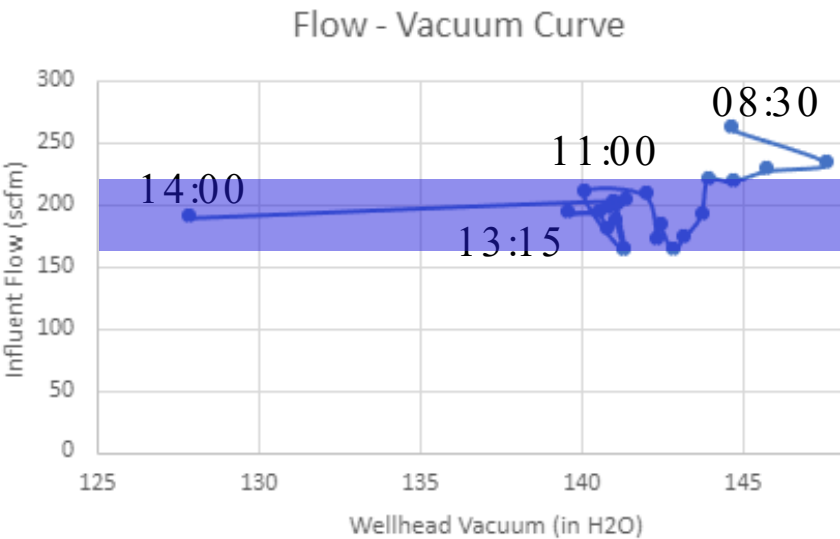
NV-003 & ND-162 Operational Results (Feb 2023 – Apr 2024)

Extraction Well(s)	Operational Period	Hours Run	Average Influent Flow Rate (scfm)	Average Post-Dilution Flow Rate (scfm)	Average Dilution Flow Rate (scfm)	Average Influent Vacuum (inWC)	Cumulative Mass Extracted (pounds TCE)
NV-003	1Q 2023	361	54	230	176	-23	142
NV-003	2Q 2023	883	67	187	119	-51	423
NV-003	3Q 2023	1172	88	172	84	-87	792
NV-003	4Q 2023	945	74	198	124	-76	1211
NV-003 & ND-162	1Q 2024	161	161	173	11	-100	2494

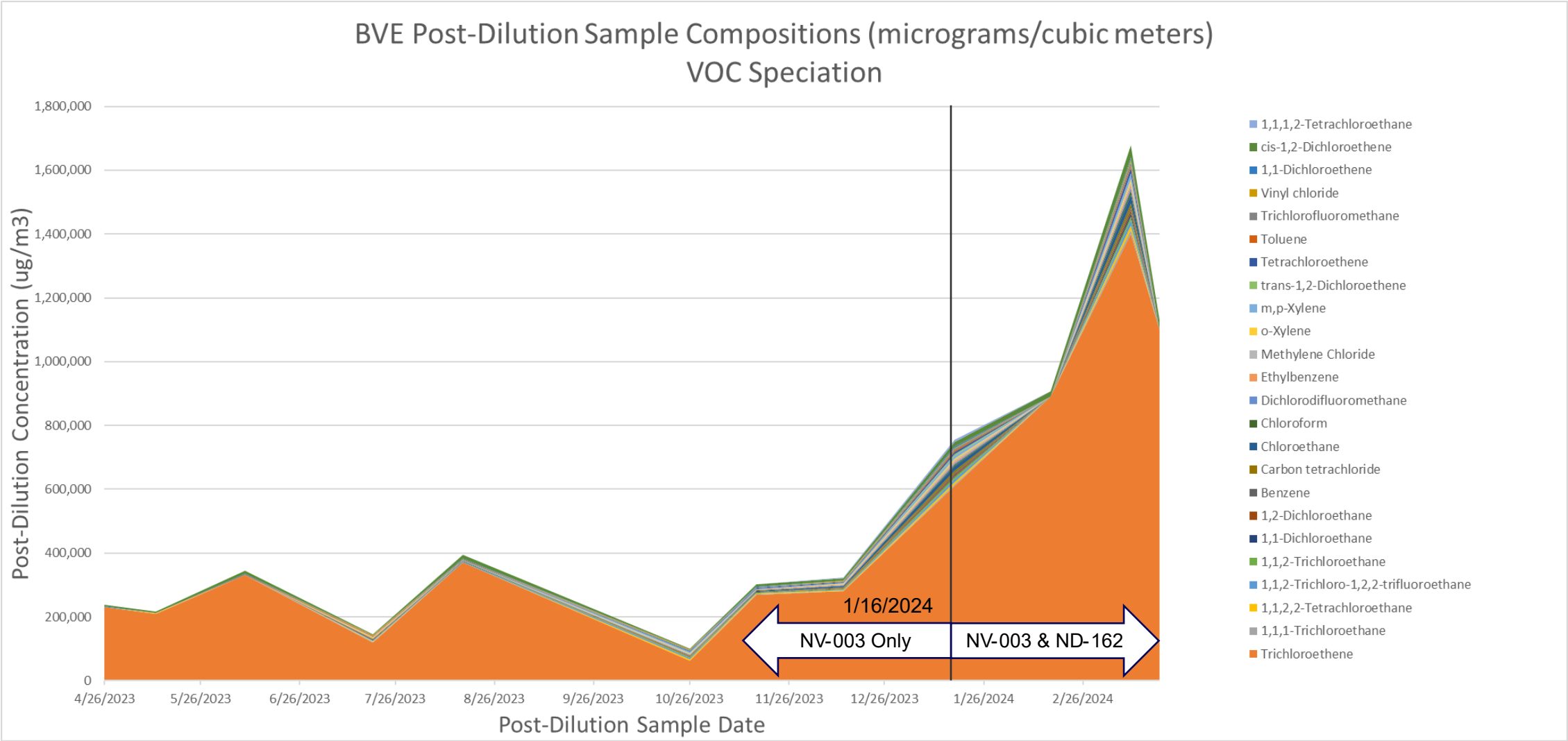
- Results:
- Influent flow increased 2x
 - Cumulative mass removed in 1Q24 > 1Q23 – 4Q23
 - Well flow contributions in line with degree of fracturing
 - Solar batteries allowed well flows to develop at a higher rate, daily

NV-003 & ND-162 Wellhead & Influent Sample Data

Sample Location	Sample Date	Operating Well	Total VOCs (ug/m3)	TCE Percent Composition (%)	TCE (ug/m ³)	Change in Total VOCs Between Measurements (ug/m ³)
Wellhead	9/30/2022	NV-003	2,094,880	95.47%	2,000,000	--
Influent	4/26/2023	NV-003	21,470,098	97.81%	21,000,000	19,375,218
Influent	9/8/2023	NV-003	3,571,000	72.81%	2,600,000	-17,899,098
Wellhead	1/10/2024	ND-162	254,700	78.52%	200,000	--
Wellhead	1/17/2024	NV-003	13,897,000	79.15%	11,000,000	10,326,000
Wellhead	1/17/2024	ND-162	1,582,300	82.16%	1,300,000	1,327,600
Influent	1/17/2024	NV-003 & ND-162	3,895,000	84.72%	3,300,000	--
Wellhead	3/22/2024	NV-003	9,340,000	97.43%	9,100,000	-4,557,000
Wellhead	3/22/2024	ND-162	3,630,000	96.42%	3,500,000	2,047,700
Influent	3/22/2024	NV-003 & ND-162	4,650,000	96.77%	4,500,000	755,000



BVE PostDilution Data



Wrap Up

■ Design Constraints

- Cultural & historic districts
- Sustainable power
- Future Uses & Mobility
- Cost Constraints
 - Complex geography
 - Variable Fracturing

■ Operational Challenges

- Daytime-only operations
- Well flow limitations

■ Design Outcomes

- System installed in remote location
- Mobile and modular remediation system
 - Rotational pilot testing
 - Quick & cost-effective mobilization
- Upsized BVE: vacuum propagation up to 150-ft away from NV-003; up to 99% VOC reduction in VMPs and piezometers

■ Operational Outcomes

- 2,650 pounds of TCE removed (Feb 2023 – April 2024)
- Operating two BVE wells (NV-003, ND-162)
- System remains in daytime-only mode
- BVE well concentrations are not asymptotic

Acknowledgements

- Peter Zorba, NASA SSFL Program Director
- Jacobs BVE Pilot Study Team
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 - Steve Demus, BVE Pilot Study Project Manager
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 - Randy Dean, Site Operations Project Manager
 - Danny Hill, Project Engineer
- Solar System Subcontractor
 - Ernesto Montenero, Owner, Sustainable Technologies
- BVE System Subcontractor
 - Colin Kreller, Project Manager, Northstar Environmental Remediation

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