HEI Energy Collett Research Report 232

Measuring and Modeling Air Pollution and Noise Exposure Near Unconventional Oil and Gas Development in Colorado

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Appendix B. Supplementary Information for Chapter 3: Air Pollutant Levels Near UOGD Well Pads

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Appendix B. Supplementary Information for Chapter 3: Air Pollutant Levels Near UOGD Well Pads

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B.1. Detailed Results of Select Volatile Organic Compounds

Table B1. Median Values of Weekly Average and Plume-Triggered Canister (Wind Direction Filtered) Samples Concentrations (ppbv) of Select VOCs at Three Study Sites

		Weekly Average Canister Sample			Plume-triggered Canister Sample		Weekly Average Canister Sample			Plume-triggered Canister Sample		Weekly Average Canister Sample			Plume-triggered Canister Sample	
		Loc 1	Loc 2	Bkg	Loc 1	Loc 2	Loc 1	Loc 2	Bkg	Loc 1	Loc 2	Loc 1	Loc 2	Bkg	Loc 1	Loc 2
		Ethane					**Propane**					**Isobutane**				
Site 1	DL	11.96	8.53	6.90	188.29	NaN	7.89	5.61	4.62	157.88	NaN	1.08	0.82	0.63	25.24	NaN
	FR	10.87	9.21	7.07	363.61	495.78	6.74	5.65	4.13	551.69	490.63	0.97	0.80	0.54	141.70	76.63
	CT	8.42	20.52	6.58	30.66	4042.85	5.70	10.97	3.78	239.69	1358.30	0.91	1.18	0.49	153.68	101.75
	FB	5.32	6.46	4.49	49.13	2.49	3.93	4.60	2.83	54.64	1.18	0.63	0.73	0.39	42.55	0.17
	EP	12.51	12.66	7.19	389.66	1222.72	9.54	11.61	4.70	512.15	986.22	1.42	1.94	0.69	102.27	158.71
Site 2	DL	15.80	13.10	13.26	174.56	129.75	10.42	8.51	9.38	153.07	162.86	1.55	1.30	1.58	23.57	28.95
Site 3	FR	28.03	27.67	26.13	NaN	48.42	18.30	17.53	15.07	NaN	87.26	2.59	2.41	2.34	NaN	21.21
	FR & CT	12.83	13.59	10.27	512.80	2067.49	7.57	8.14	6.02	338.20	1198.09	1.03	1.09	0.88	46.90	174.33
	CT & EP	16.25	13.74	10.14	816.34	304.78	12.45	9.51	6.81	388.08	876.35	1.89	1.39	0.99	71.37	243.09
	EP	13.73	12.53	11.72	1067.29	219.47	10.85	9.07	8.17	973.38	1033.01	1.76	1.36	1.17	158.70	250.85
		n-Butane					**Isopentane**					**n-Pentane**				
Site 1	DL	3.18	2.26	1.58	79.38	NaN	0.84	0.61	0.49	25.18	NaN	0.96	0.68	0.52	38.21	NaN
	FR	2.45	2.56	1.38	367.37	190.72	0.65	0.65	0.37	116.52	47.88	0.74	0.71	0.41	147.83	60.76
	CT	2.57	3.30	1.25	589.63	216.60	1.83	1.17	0.39	429.15	19.59	1.12	1.05	0.41	427.81	18.82
	FB	1.72	2.63	1.00	193.30	0.49	0.55	0.70	0.36	51.43	0.18	0.61	0.82	0.38	61.75	0.21
	EP	4.30	4.19	1.89	2.82	195.37	1.11	1.16	0.53	0.84	63.70	1.34	1.45	0.59	1.14	109.51
Site 2	DL	4.41	3.75	4.65	86.36	96.84	1.44	1.29	1.53	26.36	24.42	1.58	1.31	1.55	40.67	31.75
Site 3	FR	6.28	5.74	5.97	NaN	28.58	1.60	1.48	1.53	NaN	8.18	1.81	1.67	1.69	NaN	9.86
	FR & CT	3.13	3.19	2.68	111.68	358.90	0.85	0.84	0.74	45.13	106.17	0.97	1.00	0.76	68.63	160.18
	CT & EP	6.56	3.49	2.72	158.77	688.76	1.99	1.02	0.85	14.77	199.39	2.81	1.25	0.88	20.32	268.22
	EP	4.63	4.34	3.47	520.70	652.99	1.30	1.22	1.13	126.50	195.40	1.47	1.44	1.19	174.53	260.96
		n-Hexane					**n-Octane**					**n-Nonane**				
Site 1	DL	0.38	0.24	0.16	23.49	NaN	0.15	0.06	0.03	13.12	NaN	0.13	0.06	0.03	14.22	NaN
	FR	0.20	0.20	0.12	31.75	11.16	0.03	0.03	0.02	0.17	0.30	0.02	0.03	0.02	0.02	0.04
	CT	0.26	0.22	0.15	85.02	1.50	0.04	0.02	0.03	0.24	0.04	0.02	0.02	0.02	0.08	0.02
	FB	0.19	0.33	0.11	21.18	0.08	0.04	0.09	0.03	10.49	0.04	0.02	0.07	0.02	6.24	0.02
	EP	0.42	0.47	0.18	0.44	61.24	0.06	0.08	0.03	0.14	6.17	0.03	0.05	0.02	0.08	1.05
Site 2	DL	0.66	0.53	0.55	21.03	10.47	0.27	0.18	0.08	12.27	3.43	0.41	0.22	0.06	17.40	4.57
Site 3	FR	0.40	0.43	0.37	NaN	1.70	0.08	0.08	0.07	NaN	0.28	0.05	0.06	0.04	NaN	0.18
	FR & CT	0.23	0.25	0.16	22.65	45.58	0.04	0.08	0.04	3.64	5.90	0.02	0.03	0.02	0.91	1.49
	CT & EP	0.67	0.38	0.20	13.92	57.58	0.32	0.19	0.05	1.98	3.81	0.29	0.10	0.02	0.76	0.69
	EP	0.33	0.31	0.25	36.96	45.56	0.09	0.06	0.05	4.01	4.23	0.04	0.05	0.03	1.09	0.94
		n-Decane					**Cyclopentane**					**Benzene**				
Site 1	DL	0.19	0.06	0.02	21.76	NaN	0.09	0.05	0.04	4.85	NaN	0.14	0.11	0.11	5.33	NaN
	FR	0.02	0.02	0.02	0.01	0.02	0.06	0.05	0.03	9.45	3.85	0.09	0.09	0.08	4.24	1.85
	CT	0.03	0.01	0.01	0.04	0.04	0.08	0.08	0.03	36.68	0.96	0.08	0.17	0.07	9.10	0.31

	FB	0.02	0.05	0.01	4.89	0.04	0.05	0.09	0.03	4.79	0.01	0.09	0.13	0.07	5.58	0.24
	EP	0.02	0.03	0.01	0.05	0.31	0.12	0.13	0.05	0.11	14.54	0.18	0.21	0.10	0.20	9.02
Site 2	**DL**	0.68	0.39	0.08	29.79	8.86	0.14	0.12	0.15	4.54	2.83	0.21	0.17	0.21	3.82	1.81
Site 3	**FR**	0.03	0.03	0.02	NaN	0.12	0.13	0.14	0.13	NaN	0.68	0.20	0.21	0.20	NaN	0.57
	FR & CT	0.02	0.02	0.01	0.31	0.40	0.07	0.07	0.06	4.94	11.09	0.12	0.12	0.11	3.65	6.70
	CT & EP	0.11	0.06	0.02	0.43	0.20	0.23	0.12	0.07	3.01	17.42	0.18	0.15	0.11	2.81	8.10
	EP	0.05	0.05	0.03	0.43	0.24	0.11	0.11	0.09	12.01	16.94	0.15	0.16	0.13	6.04	7.98
		Toluene					**Ethylbenzene**					**m+p-Xylene**				
Site 1	**DL**	0.16	0.12	0.09	8.94	NaN	0.02	0.01	0.01	1.36	NaN	0.05	0.05	0.03	3.22	NaN
	FR	0.07	0.08	0.08	1.34	1.40	0.01	0.01	0.01	0.03	0.06	0.02	0.02	0.02	0.08	0.18
	CT	0.09	0.11	0.08	1.63	0.15	0.01	0.01	0.01	0.07	0.01	0.03	0.02	0.02	0.19	0.03
	FB	0.13	0.15	0.09	11.19	1.07	0.01	0.02	0.01	2.03	0.01	0.03	0.06	0.02	5.16	0.06
	EP	0.16	0.18	0.10	0.18	9.01	0.02	0.02	0.01	0.03	0.78	0.05	0.06	0.03	0.04	1.83
Site 2	**DL**	0.46	0.36	0.27	5.83	2.67	0.06	0.04	0.03	0.83	0.36	0.19	0.14	0.10	2.67	1.05
Site 3	**FR**	0.54	0.42	0.44	NaN	1.18	0.02	0.03	0.03	NaN	0.07	0.10	0.14	0.10	NaN	0.20
	FR & CT	0.28	0.31	0.21	7.42	7.26	0.02	0.02	0.01	0.32	0.67	0.06	0.08	0.05	1.74	2.64
	CT & EP	1.14	0.60	0.34	2.47	7.21	0.10	0.06	0.02	0.22	0.40	0.37	0.21	0.07	0.93	1.51
	EP	0.56	0.49	0.45	6.26	6.22	0.03	0.03	0.03	0.44	0.43	0.11	0.12	0.10	1.84	1.55
		o-Xylene					**4-Ethyltoluene**					**1,2,4-Trimethylbenzene**				
Site 1	**DL**	0.0265	0.0200	0.0100	1.9995	NaN	0.0043	0.0043	0.0043	0.3410	NaN	0.0150	0.0150	0.0080	1.1015	NaN
	FR	0.0100	0.0095	0.0050	0.0254	0.0700	0.0043	0.0043	0.0043	0.0043	0.0090	0.0039	0.0090	0.0060	0.0137	0.0260
	CT	0.0090	0.0150	0.0070	0.0830	0.0150	0.0043	0.0043	0.0043	0.0150	0.0043	0.0180	0.0160	0.0080	0.0380	0.0280
	FB	0.0140	0.0290	0.0090	3.0650	0.0170	0.0043	0.0043	0.0043	0.5870	0.0043	0.0140	0.0290	0.0120	1.9885	0.0150
	EP	0.0180	0.0210	0.0080	0.0300	0.8460	0.0043	0.0043	0.0043	0.0230	0.0740	0.0135	0.0150	0.0105	0.0510	0.1590
Site 2	**DL**	0.0690	0.0535	0.0340	1.5420	0.5885	0.0190	0.0170	0.0110	0.3185	0.0685	0.0660	0.0485	0.0290	2.1400	0.4290
Site 3	**FR**	0.0315	0.0430	0.0330	NaN	0.0730	0.0105	0.0125	0.0140	NaN	0.0180	0.0175	0.0240	0.0200	NaN	0.0390
	FR & CT	0.0175	0.0250	0.0175	0.5450	1.2260	0.0105	0.0155	0.0130	0.0600	0.1020	0.0185	0.0320	0.0160	0.1875	0.3400
	CT & EP	0.1250	0.0940	0.0240	0.4090	0.5530	0.0280	0.0260	0.0170	0.0460	0.0520	0.0490	0.0350	0.0330	0.1660	0.1320
	EP	0.0330	0.0430	0.0285	0.7790	0.7300	0.0265	0.0195	0.0200	0.0680	0.0450	0.0235	0.0245	0.0365	0.2560	0.1330
		1,4-Diethylbenzene					Isoprene									
Site 1	**DL**	0.0072	0.0072	0.0072	0.2582	NaN	0.0019	0.0019	0.0019	0.0045	NaN					
	FR	0.0072	0.0072	0.0072	0.0072	0.0072	0.0019	0.0019	0.0019	0.0019	0.0019					
	CT	0.0072	0.0072	0.0072	0.0072	0.0310	0.0150	0.0150	0.0270	0.0040	0.0190					
	FB	0.0072	0.0072	0.0072	0.5171	0.0150	0.0250	0.0330	0.0400	0.0245	0.0270					
	EP	0.0072	0.0072	0.0072	0.0072	0.0290	0.0019	0.0019	0.0019	0.0019	0.0019					
Site 2	**DL**	0.0180	0.0072	0.0072	0.4635	0.1056	0.0140	0.0235	0.0390	0.0210	0.0150					
Site 3	**FR**	0.0072	0.0072	0.0072	NaN	0.0072	0.0030	0.0030	0.0070	NaN	0.0040					
	FR & CT	0.0072	0.0111	0.0072	0.0505	0.0715	0.0019	0.0019	0.0030	0.0019	0.0030					
	CT & EP	0.0240	0.0170	0.0160	0.0560	0.0236	0.0400	0.0470	0.1650	0.0019	0.0155					
	EP	0.0072	0.0072	0.0072	0.0210	0.0320	0.0540	0.0760	0.1500	0.0140	0.0060					

NOTES:
1. Loc 1 and Loc 2 are:
   a) the eastern (E) and southwestern (SW) monitoring locations for Site 1 during drilling, and E and northeastern (NE) during other operations;
   b) the Northern (N) and SW monitoring locations for Site 2;
   c) the E and NE monitoring locations for Site 3.
2. Bkg is the background site.
3. DL, FR, CT, FB, and EP stand for drilling, fracking, coil-tubing, and early production, respectively.

Table B2. Median Values of Weekly Average and Plume-Triggered Canister Sample Concentrations (ppbv) of Select VOCs at Three Study Sites

		Ethane					Propane					Isobutane				
Site 1	DL	11.96	8.53	6.90	188.29	NaN	7.89	5.61	4.62	157.88	NaN	1.08	0.82	0.63	25.24	NaN
	FR	10.87	9.21	7.07	363.61	495.78	6.74	5.65	4.13	551.69	490.63	0.97	0.80	0.54	141.70	76.63
	CT	8.42	20.52	6.58	30.66	4042.85	5.70	10.97	3.78	239.69	1358.30	0.91	1.18	0.49	153.68	101.75
	FB	5.32	6.46	4.49	49.13	2.49	3.93	4.60	2.83	54.64	1.18	0.63	0.73	0.39	42.55	0.17
	EP	12.51	12.66	7.19	389.66	1222.72	9.54	11.61	4.70	512.15	986.22	1.42	1.94	0.69	102.27	158.71
Site 2	DL	15.80	13.10	13.26	174.56	129.75	10.42	8.51	9.38	153.07	162.86	1.55	1.30	1.58	23.57	28.95
Site 3	FR	28.03	27.67	26.13	NaN	48.42	18.30	17.53	15.07	NaN	87.26	2.59	2.41	2.34	NaN	21.21
	FR & CT	12.83	13.59	10.27	512.80	2067.49	7.57	8.14	6.02	338.20	1198.09	1.03	1.09	0.88	46.90	174.33
	CT & EP	16.25	13.74	10.14	816.34	304.78	12.45	9.51	6.81	388.08	876.35	1.89	1.39	0.99	71.37	243.09
	EP	13.73	12.53	11.72	1067.29	219.47	10.85	9.07	8.17	973.38	1033.01	1.76	1.36	1.17	158.70	250.85
		n-Butane					Isopentane					n-Pentane				
Site 1	DL	3.20	2.46	1.82	88.21	NaN	0.88	0.73	0.51	28.03	NaN	1.08	0.88	0.56	42.31	NaN
	FR	2.88	2.40	1.61	367.37	237.26	0.68	0.58	0.43	116.52	54.88	0.79	0.65	0.48	147.83	70.06
	CT	3.06	3.25	1.50	589.63	216.60	1.55	1.22	0.82	429.15	19.59	1.64	1.15	0.59	427.81	18.82
	FB	1.96	2.33	1.16	193.30	0.46	0.62	0.78	0.38	51.43	0.21	0.69	0.91	0.40	61.75	0.21
	EP	4.44	6.37	2.04	293.45	442.49	1.21	1.75	0.60	90.31	117.89	1.54	2.25	0.68	123.98	161.69
Site 2	DL	4.60	3.80	4.90	80.37	96.84	1.55	1.34	1.69	23.71	24.42	1.74	1.38	1.83	33.46	31.75
Site 3	FR	7.57	7.04	6.56	NaN	78.23	1.89	1.77	1.72	NaN	20.88	2.15	2.01	1.80	NaN	29.64
	FR & CT	3.15	3.26	2.58	149.50	539.29	0.85	0.85	0.72	42.73	146.11	1.01	1.04	0.77	62.77	184.76
	CT & EP	6.40	4.55	3.14	192.10	688.76	1.85	1.31	0.95	28.40	199.39	2.48	1.73	1.12	37.40	268.22
	EP	5.79	4.33	3.53	520.70	652.99	1.63	1.25	1.08	126.50	195.40	1.95	1.47	1.15	174.53	260.96
		n-Hexane					n-Octane					n-Nonane				
Site 1	DL	0.43	0.33	0.17	25.06	NaN	0.18	0.16	0.03	13.40	NaN	0.20	0.14	0.03	14.89	NaN
	FR	0.23	0.17	0.14	31.75	18.06	0.04	0.03	0.02	0.17	1.64	0.04	0.02	0.02	0.02	0.36
	CT	0.48	0.44	0.15	85.02	1.50	0.03	0.03	0.03	0.24	0.04	0.02	0.02	0.02	0.08	0.02
	FB	0.22	0.37	0.12	21.18	0.08	0.06	0.13	0.03	10.49	0.05	0.03	0.09	0.03	6.24	0.03
	EP	0.54	0.75	0.21	51.46	70.40	0.08	0.10	0.03	3.51	6.03	0.04	0.05	0.02	0.65	1.46
Site 2	DL	0.77	0.54	0.57	18.02	10.47	0.35	0.19	0.09	9.37	3.43	0.48	0.25	0.06	12.69	4.57
Site 3	FR	0.47	0.47	0.40	NaN	12.47	0.09	0.11	0.07	NaN	1.23	0.05	0.06	0.04	NaN	0.29
	FR & CT	0.24	0.27	0.17	23.57	56.60	0.06	0.09	0.04	5.09	8.89	0.03	0.04	0.02	1.87	2.98
	CT & EP	0.87	0.57	0.32	12.82	57.58	0.50	0.28	0.12	5.68	3.81	0.27	0.12	0.05	2.61	0.69
	EP	0.41	0.32	0.25	36.96	45.56	0.08	0.07	0.05	4.01	4.23	0.05	0.05	0.03	1.09	0.94
		n-Decane					Cyclopentane					Benzene				
Site 1	DL	0.28	0.22	0.02	23.32	NaN	0.10	0.08	0.05	4.77	NaN	0.14	0.16	0.12	5.45	NaN
	FR	0.02	0.02	0.02	0.01	0.11	0.06	0.05	0.04	9.45	5.04	0.10	0.09	0.08	4.24	2.76
	CT	0.02	0.02	0.01	0.04	0.04	0.13	0.10	0.04	36.68	0.96	0.12	0.14	0.08	9.10	0.31
	FB	0.03	0.05	0.04	4.89	0.03	0.06	0.09	0.03	4.79	0.01	0.07	0.12	0.09	5.58	0.21
	EP	0.02	0.03	0.02	0.18	0.67	0.14	0.21	0.06	10.63	15.70	0.21	0.26	0.09	8.32	14.78
Site 2	DL	0.90	0.45	0.08	23.97	8.86	0.17	0.12	0.16	3.77	2.83	0.22	0.17	0.21	3.49	1.81
Site 3	FR	0.03	0.03	0.02	NaN	0.16	0.16	0.15	0.14	NaN	2.75	0.22	0.22	0.21	NaN	2.35

	FR & CT	0.02	0.03	0.01	0.76	1.08	0.08	0.08	0.06	5.03	13.13	0.12	0.13	0.12	4.15	8.51
	CT & EP	0.13	0.06	0.03	1.31	0.20	0.23	0.16	0.10	3.17	17.42	0.26	0.19	0.15	2.75	8.10
	EP	0.05	0.06	0.04	0.43	0.24	0.14	0.11	0.09	12.01	16.94	0.16	0.16	0.14	6.04	7.98
		Toluene					**Ethylbenzene**					**m+p-Xylene**				
Site 1	**DL**	0.18	0.17	0.10	8.24	NaN	0.02	0.02	0.01	1.49	NaN	0.06	0.07	0.03	3.42	NaN
	FR	0.08	0.08	0.07	1.34	2.18	0.01	0.01	0.01	0.03	0.17	0.02	0.02	0.02	0.08	0.43
	CT	0.12	0.12	0.08	1.63	0.15	0.01	0.01	0.01	0.07	0.01	0.03	0.03	0.02	0.19	0.03
	FB	0.12	0.20	0.09	11.19	0.87	0.01	0.03	0.01	2.03	0.03	0.03	0.08	0.03	5.16	0.05
	EP	0.19	0.21	0.10	5.69	10.52	0.02	0.02	0.01	0.38	0.74	0.06	0.06	0.03	0.98	2.02
Site 2	**DL**	0.50	0.35	0.26	5.55	2.67	0.06	0.04	0.03	0.77	0.36	0.19	0.15	0.10	2.24	1.05
Site 3	**FR**	0.58	0.46	0.52	NaN	2.80	0.03	0.04	0.04	NaN	0.21	0.12	0.15	0.13	NaN	0.73
	FR & CT	0.32	0.31	0.21	7.40	10.10	0.01	0.02	0.01	0.61	1.09	0.06	0.08	0.05	2.54	4.16
	CT & EP	2.00	0.75	0.47	5.26	7.21	0.09	0.06	0.03	0.78	0.40	0.34	0.24	0.11	2.77	1.51
	EP	0.52	0.52	0.46	6.26	6.22	0.02	0.03	0.03	0.44	0.43	0.10	0.12	0.10	1.84	1.55
		o-Xylene					**4-Ethyltoluene**					**1,2,4-Trimethylbenzene**				
Site 1	**DL**	0.032	0.030	0.011	2.053	NaN	0.008	0.016	0.004	0.354	NaN	0.019	0.044	0.010	1.145	NaN
	FR	0.009	0.009	0.007	0.025	0.218	0.005	0.004	0.004	0.004	0.027	0.007	0.008	0.010	0.014	0.068
	CT	0.010	0.012	0.006	0.083	0.015	0.004	0.004	0.004	0.015	0.004	0.017	0.016	0.007	0.038	0.028
	FB	0.014	0.035	0.012	3.065	0.020	0.009	0.010	0.007	0.587	0.011	0.017	0.029	0.021	1.989	0.019
	EP	0.021	0.022	0.010	0.434	0.904	0.007	0.007	0.006	0.043	0.085	0.015	0.015	0.011	0.120	0.231
Site 2	**DL**	0.080	0.056	0.034	1.291	0.589	0.019	0.018	0.010	0.272	0.069	0.069	0.051	0.032	1.583	0.429
Site 3	**FR**	0.037	0.046	0.042	NaN	0.252	0.012	0.012	0.015	NaN	0.026	0.024	0.029	0.030	NaN	0.078
	FR & CT	0.021	0.026	0.018	1.053	1.918	0.011	0.013	0.012	0.110	0.216	0.021	0.034	0.017	0.447	0.786
	CT & EP	0.147	0.086	0.043	1.488	0.553	0.029	0.030	0.019	0.187	0.052	0.078	0.075	0.039	0.710	0.132
	EP	0.029	0.042	0.028	0.779	0.730	0.032	0.020	0.021	0.068	0.045	0.029	0.029	0.032	0.256	0.133
		1,4-Diethylbenzene					**Isoprene**									
Site 1	**DL**	0.008	0.009	0.007	0.271	NaN	0.003	0.003	0.006	0.007	NaN					
	FR	0.007	0.007	0.007	0.007	0.015	0.002	0.002	0.005	0.002	0.002					
	CT	0.007	0.007	0.007	0.007	0.031	0.017	0.015	0.020	0.004	0.019					
	FB	0.007	0.010	0.009	0.517	0.013	0.032	0.049	0.051	0.024	0.037					
	EP	0.008	0.008	0.008	0.018	0.040	0.009	0.008	0.012	0.005	0.011					
Site 2	**DL**	0.017	0.012	0.008	0.409	0.106	0.032	0.032	0.036	0.026	0.015					
Site 3	**FR**	0.007	0.008	0.010	NaN	0.017	0.004	0.004	0.007	NaN	0.048					
	FR & CT	0.011	0.019	0.009	0.082	0.130	0.002	0.003	0.004	0.003	0.006					
	CT & EP	0.025	0.020	0.015	0.159	0.024	0.043	0.052	0.153	0.006	0.016					
	EP	0.011	0.012	0.013	0.021	0.032	0.046	0.073	0.123	0.014	0.006					

NOTES:
1. Loc 1 and Loc 2 are:
   a) the eastern (E) and southwestern (SW) monitoring locations for Site 1 during drilling, and E and northeastern (NE) during other operations;
   b) the Northern (N) and SW monitoring locations for Site 2;
   c) the E and NE monitoring locations for Site 3.
2. Bkg is the background site.
3. DL, FR, CT, FB, and EP stand for drilling, fracking, coil-tubing, and early production, respectively.

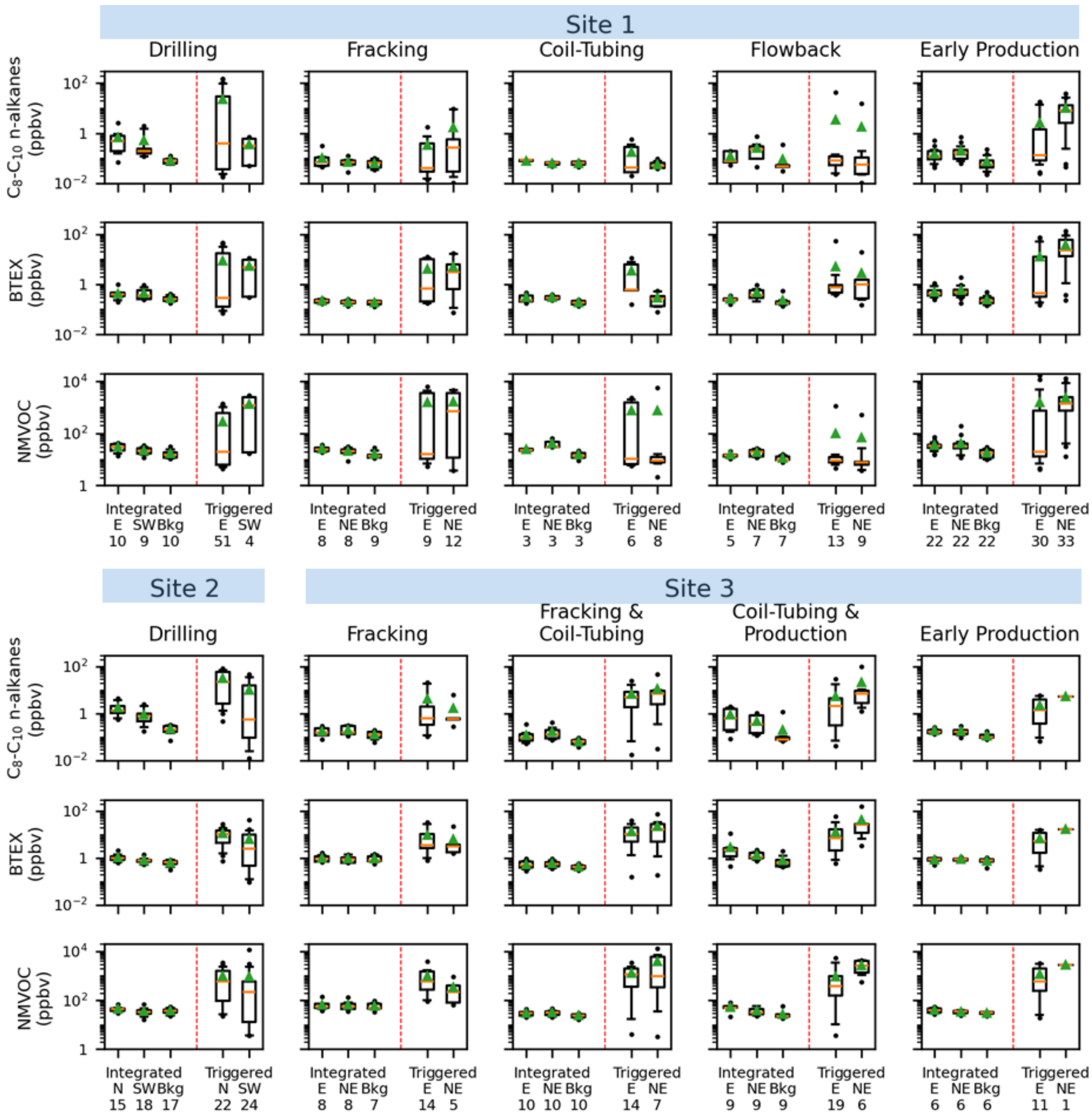

Figure B1. Weekly average and plume-triggered canister sample concentration distributions of select VOCs at the three study sites. All triggered canister samples are included. Results are presented by the UOGD operation for the background and two near-pad monitoring locations at each study site. The box and whisker plots depict the median (line), 25th and 75th (box), 5th and 95th (whiskers) percentiles of the measured concentrations along with individual points that fall outside these values.

B.2. One-Hour Concentration Extrapolation Method for Plume-Triggered Canister Samples

The SPOD system collects one canister sample in approximately one minute when triggered by a high signal. To compare these results with hourly AERMOD simulations and health guideline values for one-hour exposure, VOC concentrations in the triggered samples were extrapolated to 1-hour average concentrations based on the PID reading and the VOC concentrations in the triggered canister samples. This method assumes that the plume's composition remains consistent during each triggered event. Therefore, changes in PID readings during a triggered event are presumed to be proportional to changes in the concentrations of all plume species.

Minute-by-minute concentration of VOC X during the event is calculated for periods from 60 minutes before to 60 minutes after the triggered canister was collected as follows:

$$X_{\text{minute}} = X_{\text{weekly}} + k_{ambient/event} \cdot \text{PID}_{\text{minute}} \tag{B1}$$

where X_{weekly} is the concentration of X in the weekly integrated canister sample. If the PID reading increased to 1.2 times the weekly average PID signal, the $\text{PID}_{\text{minute}}$ is the PID reading at the moment minus the weekly average PID reading, otherwise $\text{PID}_{\text{minute}}$ is equal to the PID reading at the moment. The ambient and event conversion factors, $k_{ambient}$ and k_{event}, are calculated as follows:

$$k_{ambent} = \frac{X_{\text{weekly}}}{\text{PID}_{\text{weekly}}} \tag{B2}$$

$$k_{event} = \frac{X_{\text{minute}} - X_{\text{weekly}}}{\text{PID}_{\text{minute}} - \text{PID}_{\text{weekly}}}, \tag{B3}$$

where X_{minute} is the concentration of X in the plume-triggered canister sample and $\text{PID}_{\text{weekly}}$ is the weekly averaged PID reading. k_{event} is used when the PID reading ≥1.2 times the weekly average PID signal. To avoid sporadic negative enhancements, negative k values were set to zero, and the corresponding hourly concentrations were taken to be the same as the weekly averages. Figure B2 shows an example of the method.

Finally, the 60-minute moving averages were calculated for the estimating window, and the maximum 1-hour average VOC_x mixing ratio was reported.

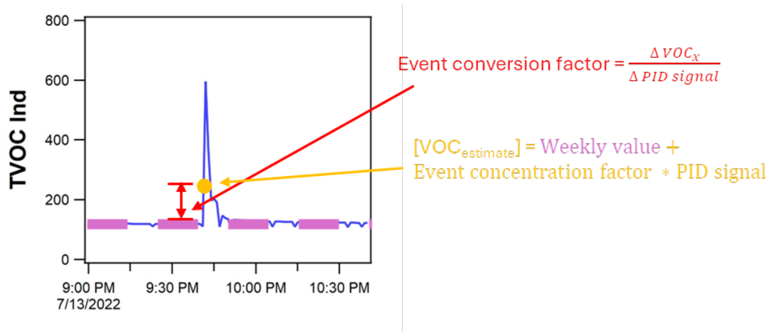

Figure B2. Example of the 1-hour extrapolation method for plume-triggered canister samples.

B.3. Mobile Sampling Results

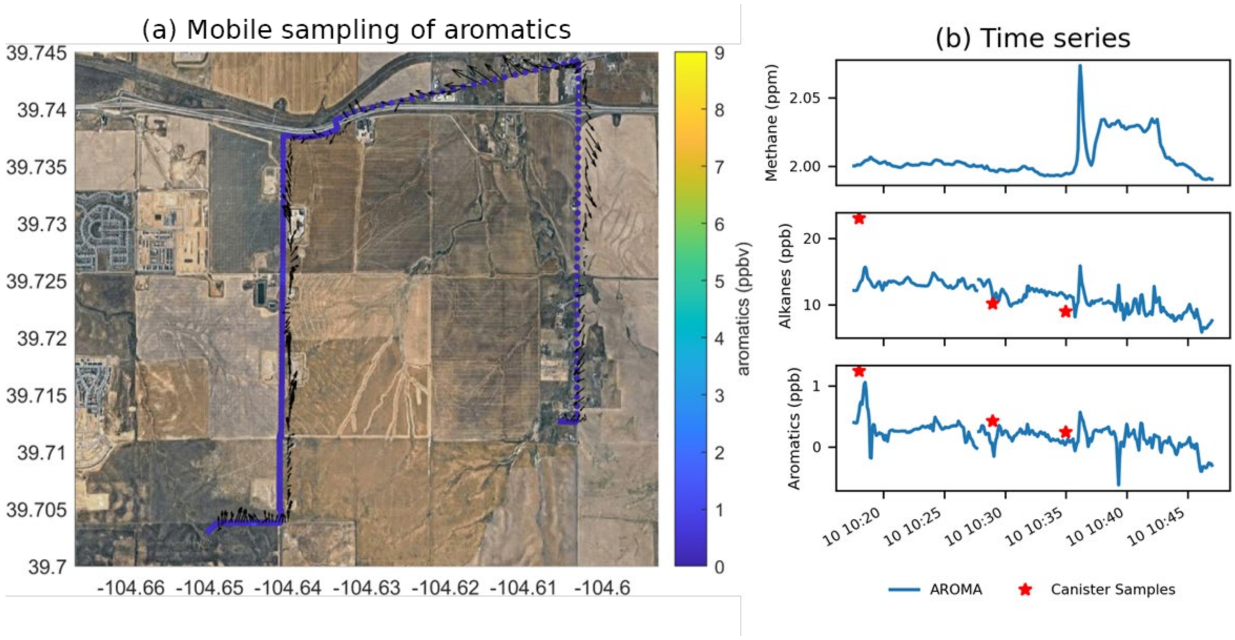

Figure B3. Mobile sampling results of 2022/10/10.

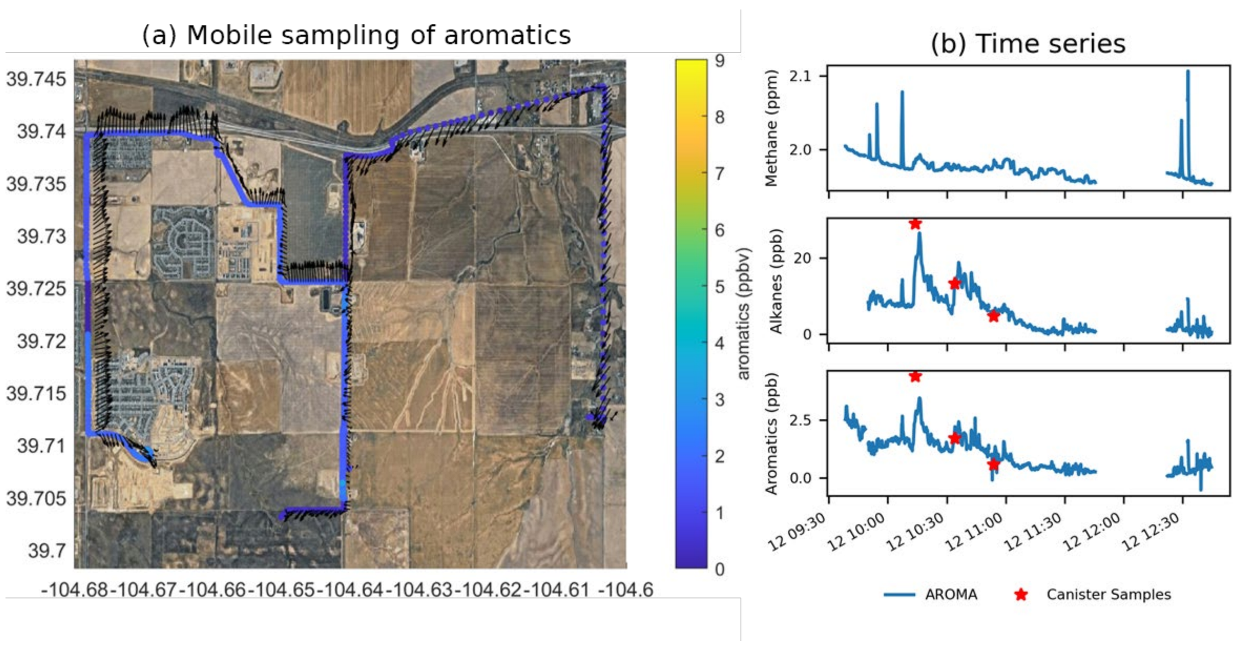

Figure B4. Mobile sampling results of 2022/10/12.

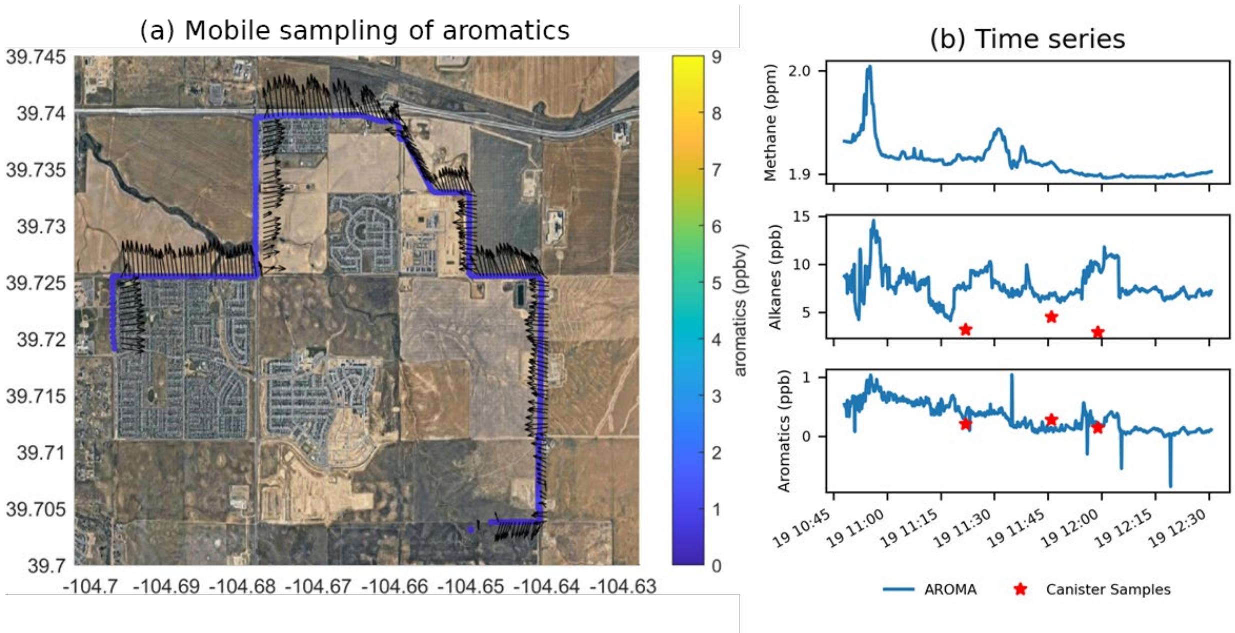

Figure B5. Mobile sampling results of 2022/10/19.

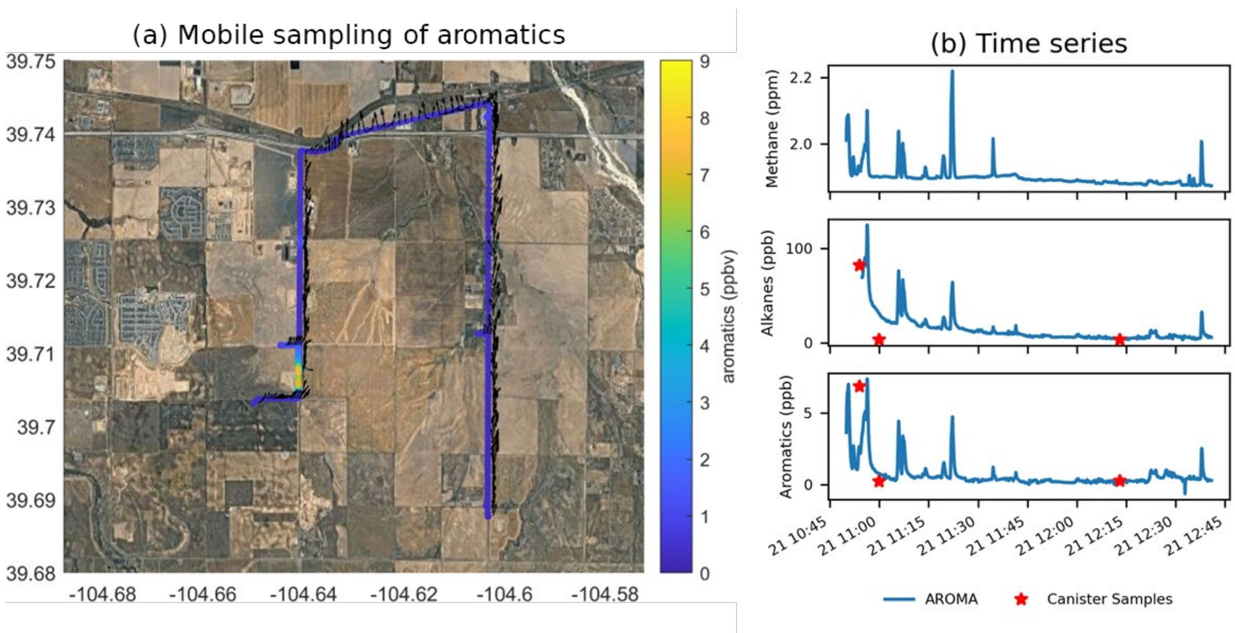

Figure B6. Mobile sampling results of 2022/10/21.

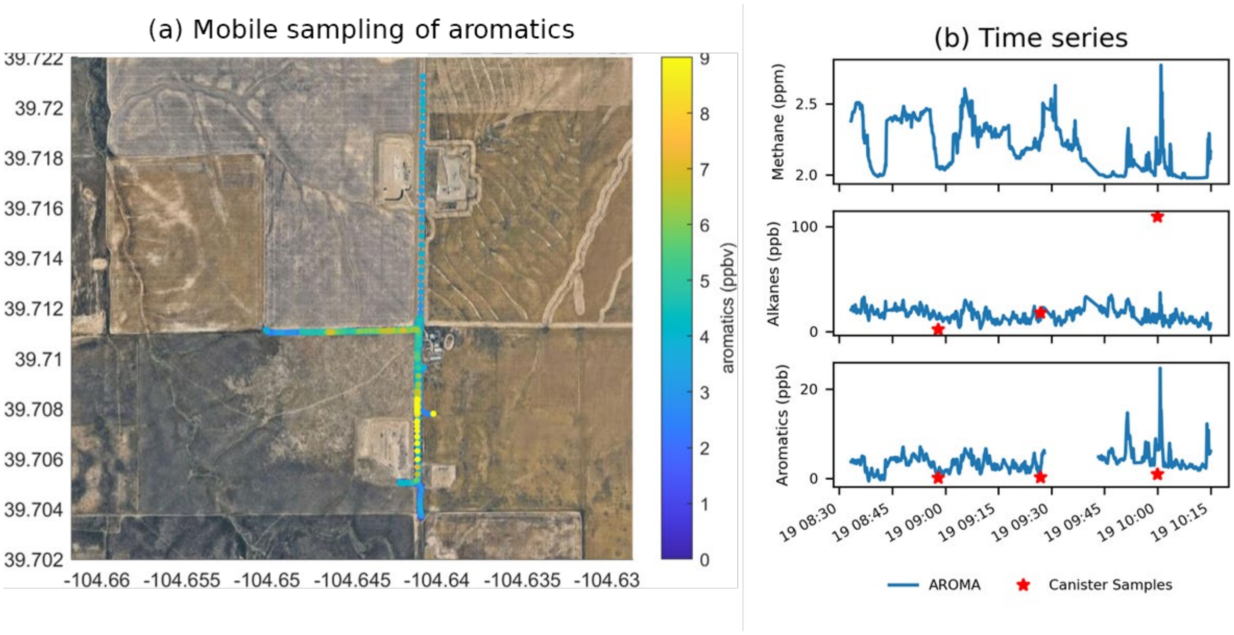

Figure B7. Mobile sampling results of 2023/06/19.

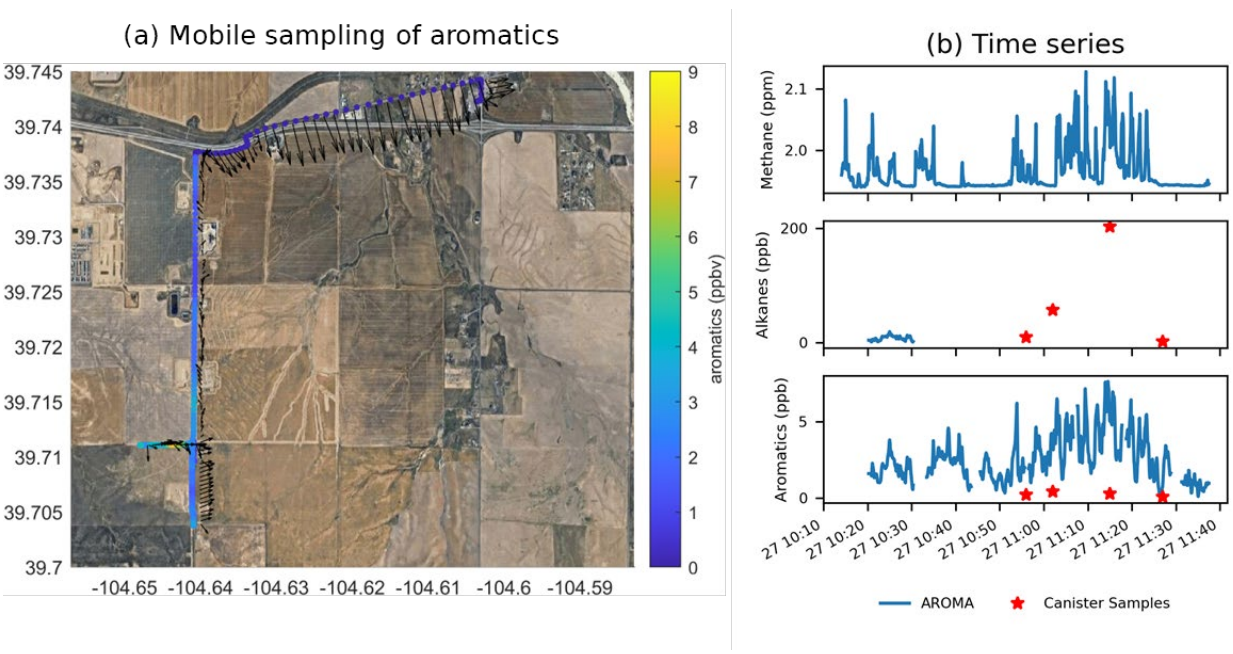

Figure B8. Mobile sampling results of 2023/06/27.

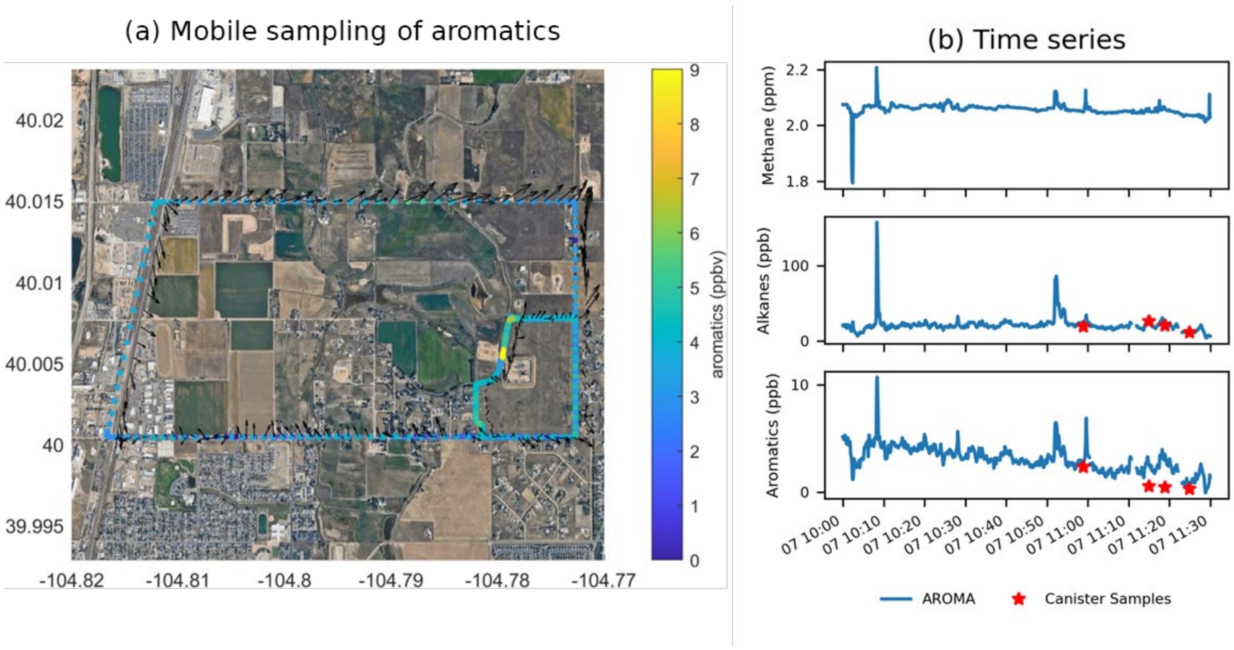

Figure B9. Mobile sampling results of 2023/08/07.

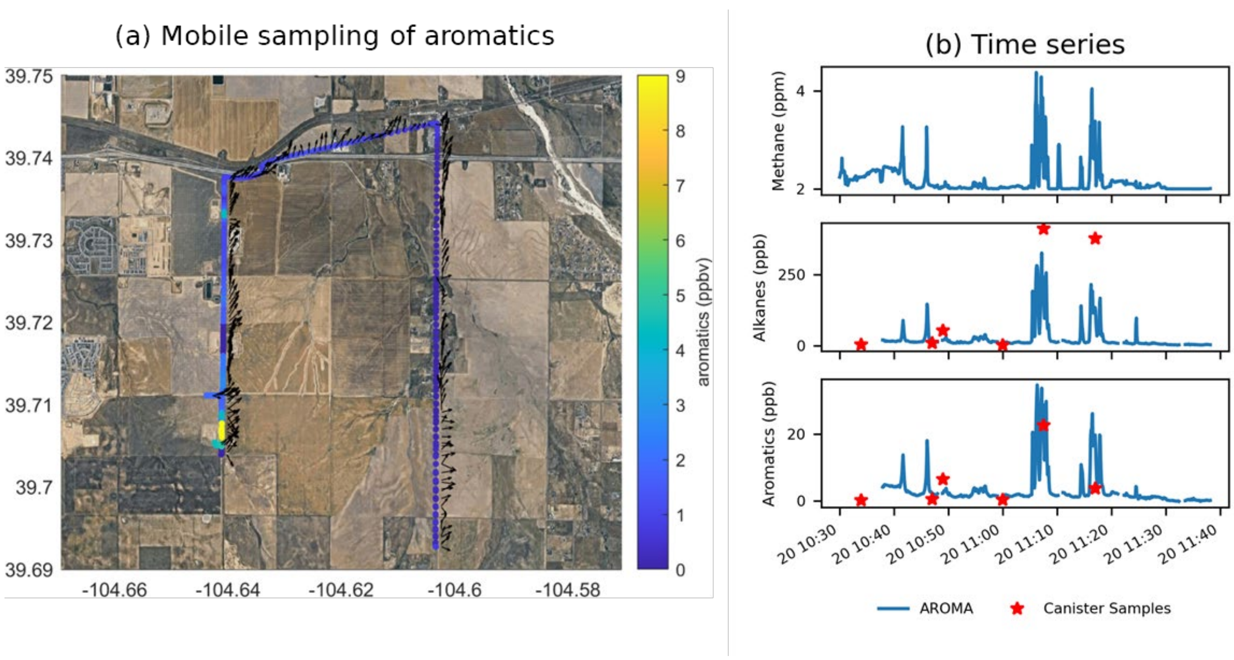

Figure B10. Mobile sampling results of 2023/10/20.

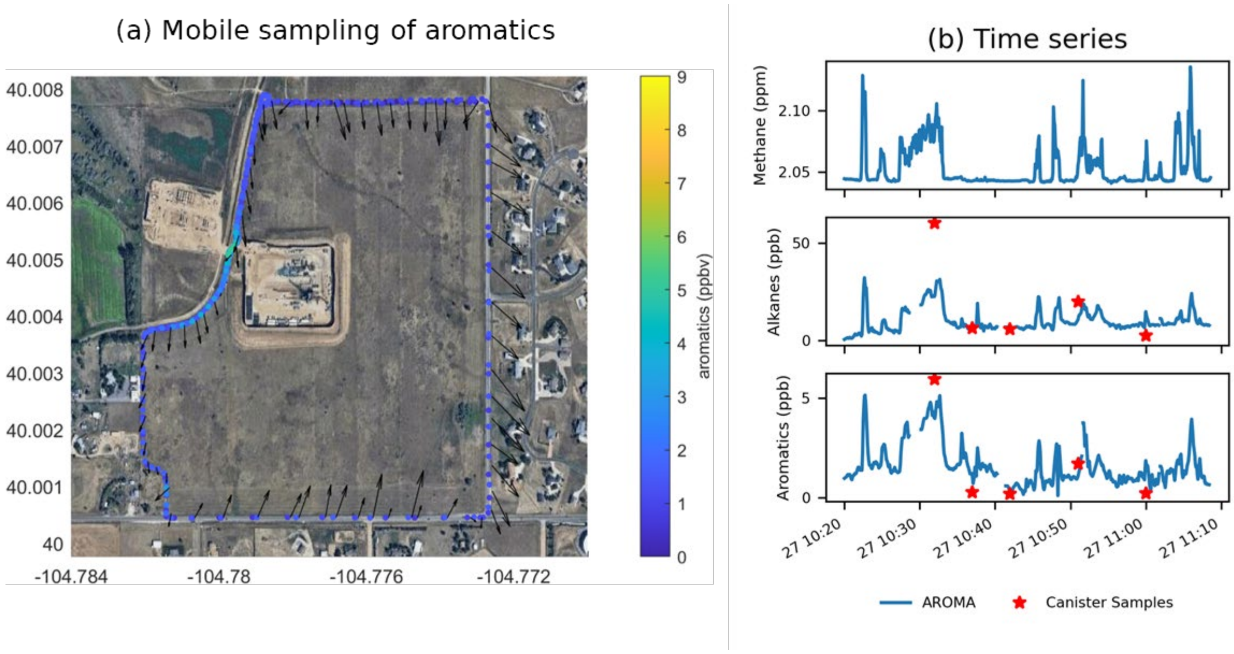

Figure B11. Mobile sampling results of 2023/10/27.

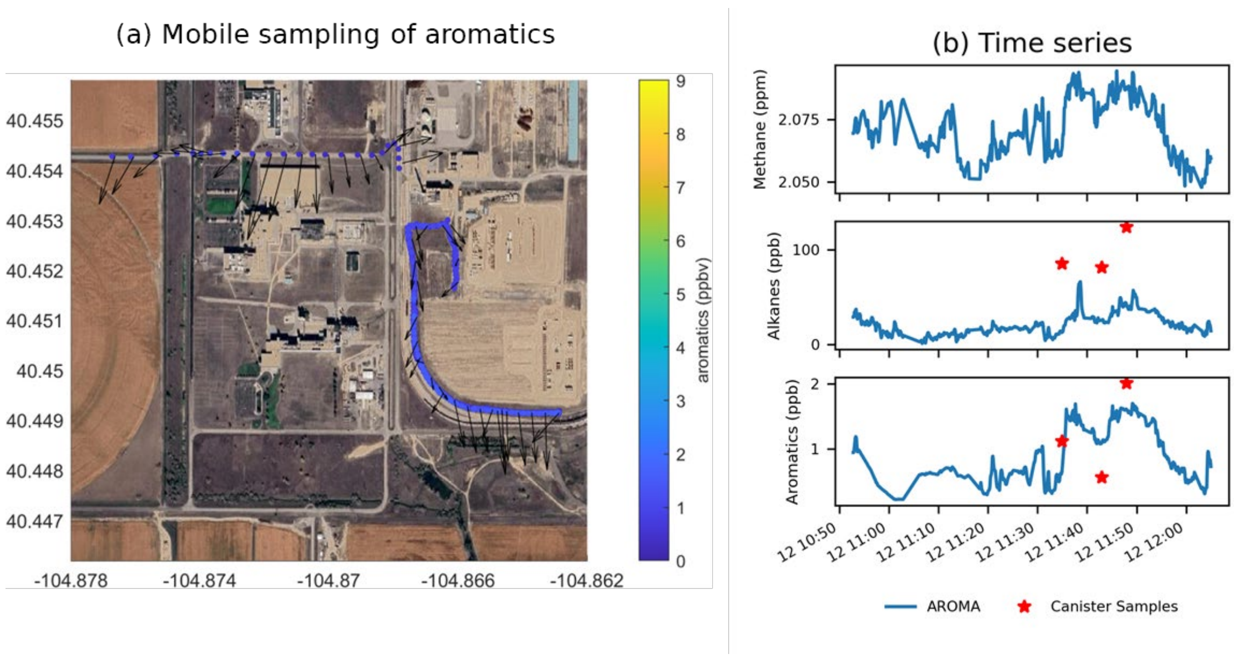

Figure B12. Mobile sampling results of 2024/03/12.

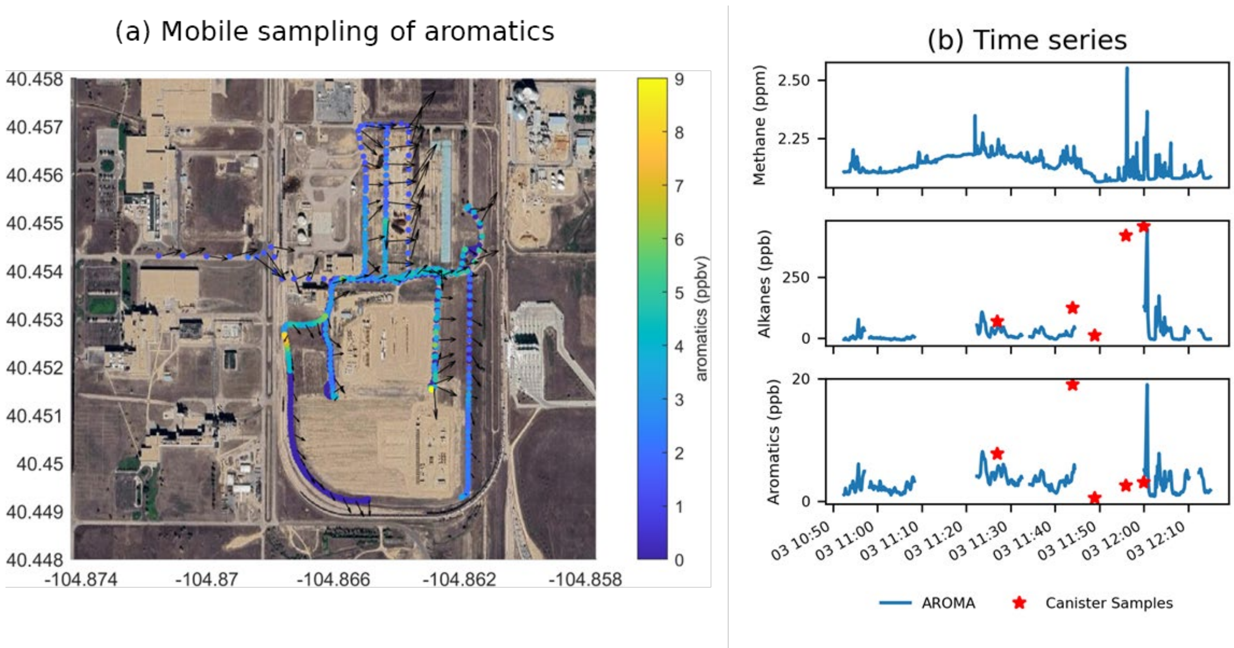

Figure B13. Mobile sampling results of 2024/06/03.

B.4. Headspace Analyses of Neoflo-Based Drilling Mud Samples

Four samples of Neoflo-based drilling mud and drilling cuttings were provided by the operator at site 2 (**Figure B14a**). One bottle contained pure Neoflo-based drilling mud that had not been used, while two other samples were recycled drilling muds. The final sample consisted of drilling cuttings collected at the drilling mud shaker, which separates drilling mud from cuttings.

Headspace analyses were conducted to characterize the VOC composition of emissions from Neoflo synthetic-based drilling mud (**Figure B14c–d**). Ten milliliters of the drilling mud fluid were pipetted into 20 mL enclosed amber sterile glass vials, sealed with PTFE-faced silicone septa caps for storage. The pure Neoflo sample was divided into seven sub-samples, and the two recycled Neoflo mixture samples were separated into three sub-samples each. Two sub-samples of drilling cuttings with different weights (8 g and 25 g) were also analyzed. Before analysis, the samples were equilibrated at room temperature for at least 1 hour. For heat testing experiments, the vials were placed in a water bath and heated to the target temperature (30°C, 50°C, and 80°C), allowing them to equilibrate for 30 minutes.

A gas-tight syringe was used to extract 1 mL of headspace gas above the drilling mud fluid, which was subsequently injected through a zero-air generator to create a gas mixture with a mixing time of 20 seconds. This mixture was transferred to an evacuated 1.4 L Silonite-coated stainless steel canister. The canister samples were analyzed using the CSU GC system to quantify 49 NMHC species.

Figure B15 compares the headspace VOC compositions of pure Neoflo and Neoflo mixture samples. The mixing ratios of light alkanes and C9 aromatics were significantly higher in recycled Neoflo mixture samples, reflecting the impacts of hydrocarbon residuals in the recycled drilling muds. However, the mixing ratios of the 14 VOCs strongly associated with drilling mud itself are relatively consistent, especially within recycled drilling mud samples. The headspace VOC compositions of drilling cuttings are similar to those of the recycled samples (**Figure B16**). Finally, the mixing ratios of the 14 primary ingredients slightly increased as the temperature increased, but the relative contributions remained relatively stable (**Figure B17**).

Figure B14. The procedure of headspace analysis to characterize drilling mud fluid outgassing. A series of headspace VOC analyses of both pure Neoflo drilling fluid and of a recycled drilling mud sample were conducted in the CSU lab.

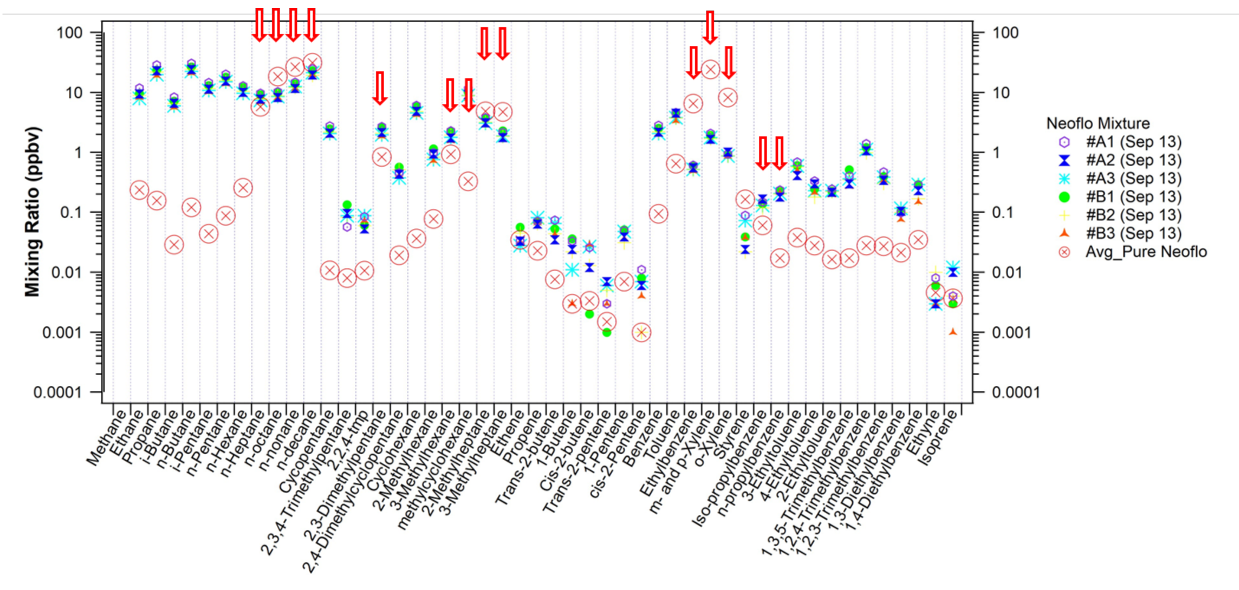

Figure B15. Comparison of VOC compositions for pure Neoflo and recycled Neoflo mixture samples from the headspace analyses.

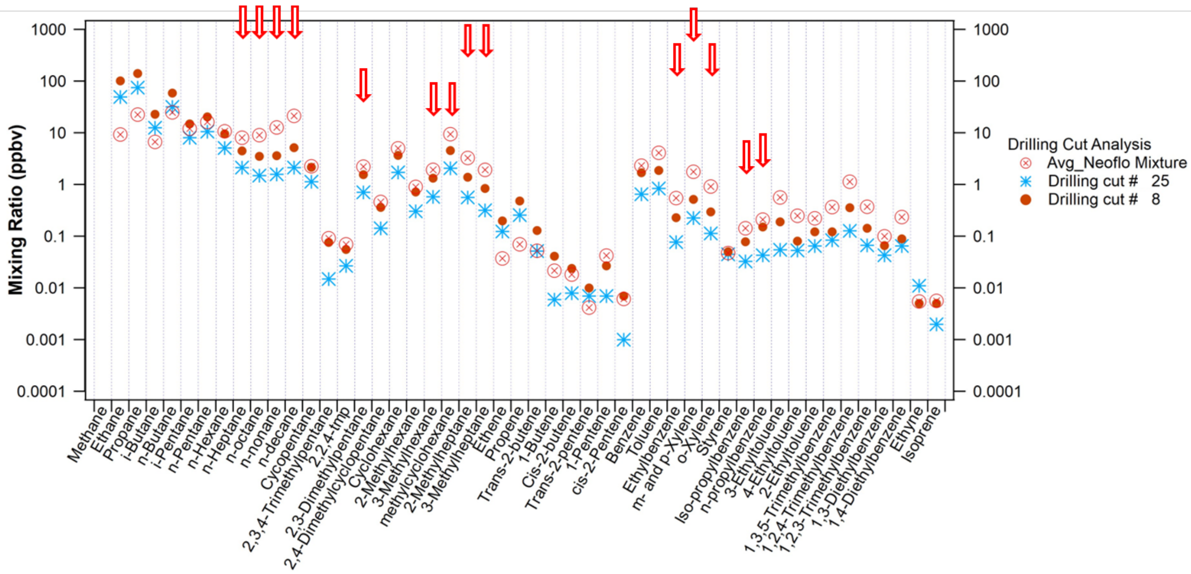

Figure B16. Comparison of VOC compositions for recycled Neoflo mixture samples and drilling cuttings from the headspace analyses.

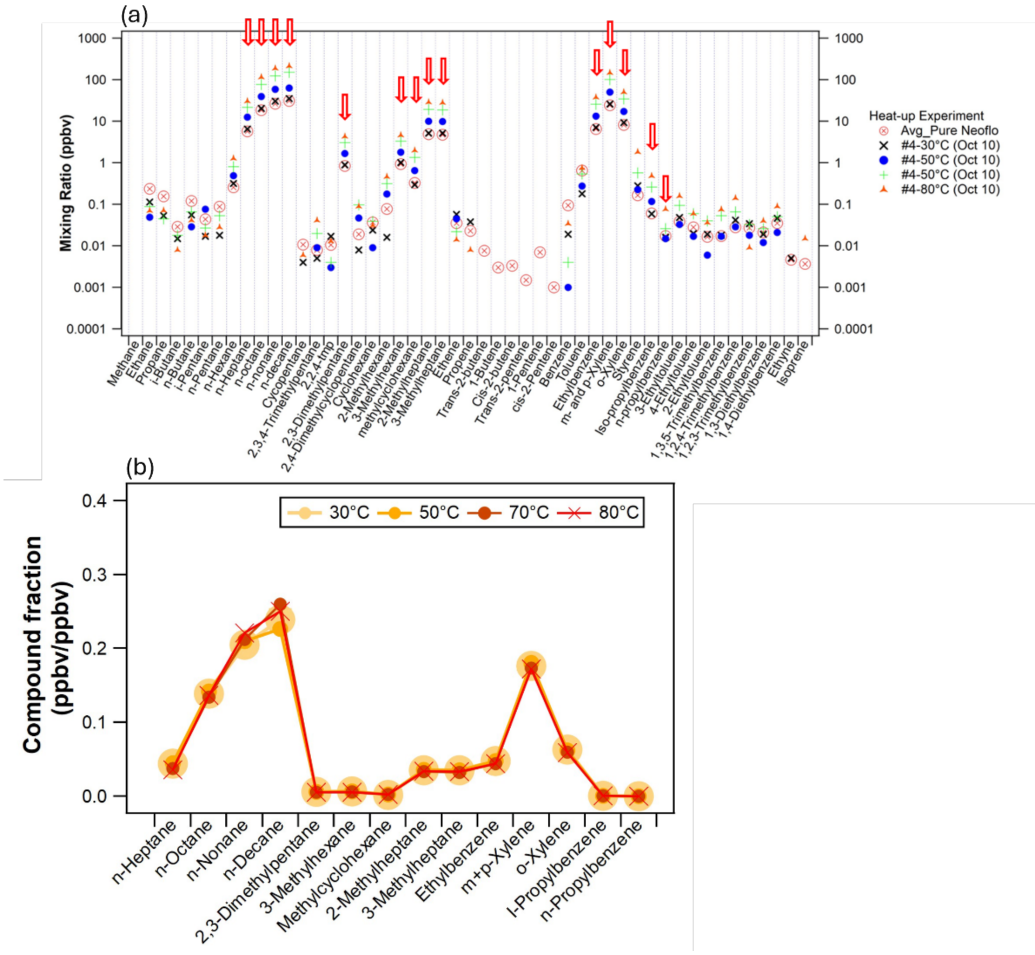

Figure B17. (a) VOC compositions for pure Neoflo sample at different temperatures from the headspace analyses, and (b) comparing the fractional composition fingerprint of 14 key VOCs at different mud temperatures during headspace testing.

B.5. Events with Benzene HQ Values Above 1.0 for Acute Exposure

Table B3. Information on Samples Showing Benzene HQ Values Above 1.0 for Acute Exposure During the Entire Study Periods

No.	Site	Date	Distance from the Pad	Operation Type	Site Location	HQ Value	Sample Type
1	Site 1	Jun 23, 2023; 20:58	0.28 km	Flowback	E	2.076	Triggered canister
2	Site 3	Jul 16, 2024; 23:42	0.31 km	Coil+Pro	E	2.534	Triggered canister
22	Site 1	Nov 20, 2022; 09:00	0.39 km	Drilling		1.054	CAMML
23	Site 3	Jul 24, 2024; 15:00	0.10/0.30 km	Production		4.129	CAMML
24	Site 3	Jul 12, 2024; 18:00	0.10/0.30 km	Coil+Pro		2.974	CAMML
25	Site 3	Aug 2, 2024; 08:00	0.10/0.30 km	Production		2.664	CAMML
26	Site 3	Jul 26, 2024; 08:00	0.10/0.30 km	Production		2.536	CAMML
27	Site 3	Jul 13, 2024; 21:00	0.10/0.30 km	Coil+Pro		2.126	CAMML
28	Site 3	Jul 13, 2024; 20:00	0.10/0.30 km	Coil+Pro		1.788	CAMML
29	Site 3	May 31, 2024; 23:00	0.10/0.30 km	Coil+Pro		1.775	CAMML
30	Site 3	Jun 26, 2024; 23:00	0.10/0.30 km	Coil+Pro		1.689	CAMML
31	Site 3	May 31, 2024; 21:00	0.10/0.30 km	Coil+Pro		1.360	CAMML
32	Site 3	Jul 20, 2024; 11:00	0.10/0.30 km	Production		1.176	CAMML
33	Site 3	Jun 20, 2024; 21:00	0.10/0.30 km	Coil+Pro		1.151	CAMML
34	Site 3	Jun 8, 2024; 10:00	0.10/0.30 km	Coil+Pro		1.027	CAMML

Notes:
1. There are two well pads at Site 3, which are 0.20 and 0.31 km away from the eastern (E) monitoring location and 0.10 and 0.30 km away from the CAMML.
2. “Coil+Pro” stands for Coil-Tubing and Production.