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Initial SVE Well Testing for the A-Area Miscellaneous Rubble Pile (ARP) Trenches Area

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Background

Site Description

The A-Area Miscellaneous Rubble Pile (ARP) is a 5.9-acre unit located at the southern end of A/M Area at the Savannah River Site (SRS). The ARP is bounded by a gravel road to the north and two drainage ditches to the east and southwest. Disposal activities at ARP (731-6A) began in the early 1950s. The exact dates of operation and material disposed in the unit remain unknown.

Within the ARP exists a smaller, approximately 2-acre, subunit identified as the Trenches Area. The Trenches Area is dominated by a T-shaped trench (approximately 50 feet wide) containing 8 to 12 feet of ash material. This T-shaped trench will be referred to as the ARP Trench. Vegetation has been removed from the Trenches Area and a lower permeability earthen cover now covers the ARP Trench.

The ARP active soil vapor extraction (ASVE) remediation system consists of seven extraction wells and twelve monitoring wells that were pushed into the vadose zone of the ARP Trench. The remediation system was designed based on the pre-design study conducted in 2002.

Purpose and Goals

The purpose of the initial soil vapor extraction (SVE) well testing was to verify the integrity and functionality of the nineteen wells installed in the ARP Trench. The well integrity was evaluated based on the flow rate, vacuum, and indication that soil gas and not surface air was pulled from the well. Soil gas was defined as gas with levels of carbon dioxide (CO_2) above ambient concentrations (400-700 ppmv). Volatile organic compound (VOC) concentrations were measured at each well to determine the initial distribution of the contamination. In addition, the subsurface vacuum distribution was measured around each extraction well as a relative measure of the influence of each well.

Methods

A portable SVE unit (SRO 2856) was used for vapor extraction and testing of each well. The unit is a high vacuum liquid ring extraction system instrumented for testing and research and is permitted by the South Carolina Department of Health and Environmental Control (SCDHEC) Bureau of Air Quality (BAQ) to be operated on any well or piezometer within the boundaries of the SRS. The permit number is 0080-0041-G-CQ-R1, which limits the total combined emissions of the three Savannah River National Laboratory (SRNL) units to 6.96 tons per year. Operation of the unit followed SRNL work instruction WI-ERTS-0008.

Trichloroethylene (TCE), perchloroethylene (PCE), carbon dioxide (CO_2) and water vapor were measured at the outlet of the SVE unit using an infra-red photo-acoustic spectrometer (IRPAS). Gas chromatography (GC) analysis was completed on Tedlar bag samples following SRNL work instruction WI-ERTS-0013 for sample collection and procedure L14.1 ESSOP 2-106 for gas analysis. Contour plots of concentration and pressure were generated using the computer program Surfer™ (version 7.0, Golden Software, Inc.).

Results and Discussion

Well Integrity

Results from the well integrity testing are presented in Table 1 along with the initial VOC concentration distribution. The high levels of CO_2 (orders of magnitude higher than ambient concentrations) and high flow rates reveal all the wells passed the integrity testing. Contour plots of the initial VOC and CO_2 concentrations are shown in Figure 1. Lower CO_2 concentration at wells EW-1 and EW-7 probably indicate some surface air inflow around the edge of the low permeability soil cover. The well coordinates are provided in Table 2.

Table 1 – Well Integrity Testing Results and Initial VOC Concentration

Well	ID Alias	PCE, Ppmv	TCE, Ppmv	Maximum Flow, scfm	Vacuum at Wellhead, inches of water	CO_2, ppmv
AMP001VEW	EW-1	4.20	1.41	112.0	34.6	10,400
AMP002VEW	EW-2	2.31	3.32	118.1	19.3	17,000
AMP003VEW	EW-3	3.88	3.74	130.9	7.3	32,000
AMP004VEW	EW-4	4.96	2.11	116.8	17.4	61,600
AMP005VEW	EW-5	0.67	0.49	111.2	16.8	36,400
AMP006VEW	EW-6	1.77	0.23	85.7	41.5	18,300
AMP007VEW	EW-7	0.48	0.00	89.3	50.1	8,100
AMP001VMW	W-1	1.84	2.54	103.2	26.6	10,200
AMP002VMW	W-2	2.53	3.22	105.1	33.0	32,700
AMP003VMW	W-3	2.28	2.39	97.5	37.7	51,600
AMP004VMW	W-4	1.37	0.97	93.0	50.9	52,100
AMP005VMW	W-5	0.26	0.00	81.5	*	23,700
AMP006VMW	W-6	0.51	0.00	80.8	*	8,120
AMP007VMW	W-7	2.26	0.51	80.3	*	12,700
AMP008VMW	W-8	2.62	1.81	90.3	46.8	26,800
AMP009VMW	W-9	2.05	1.92	97.2	40.7	40,500
AMP0010VMW	W-10	2.51	3.18	124.6	25.8	36,200
AMP0011VMW	W-11	2.53	3.25	120.9	29.6	29,000
AMP0012VMW	W-12	0.73	0.89	116.9	41.5	5,130

PCE and TCE were collected in Tedlar bags and measured by GC
CO_2 was measured by IRPAS
* indicates the vacuum at the wellhead was beyond the range of the meter

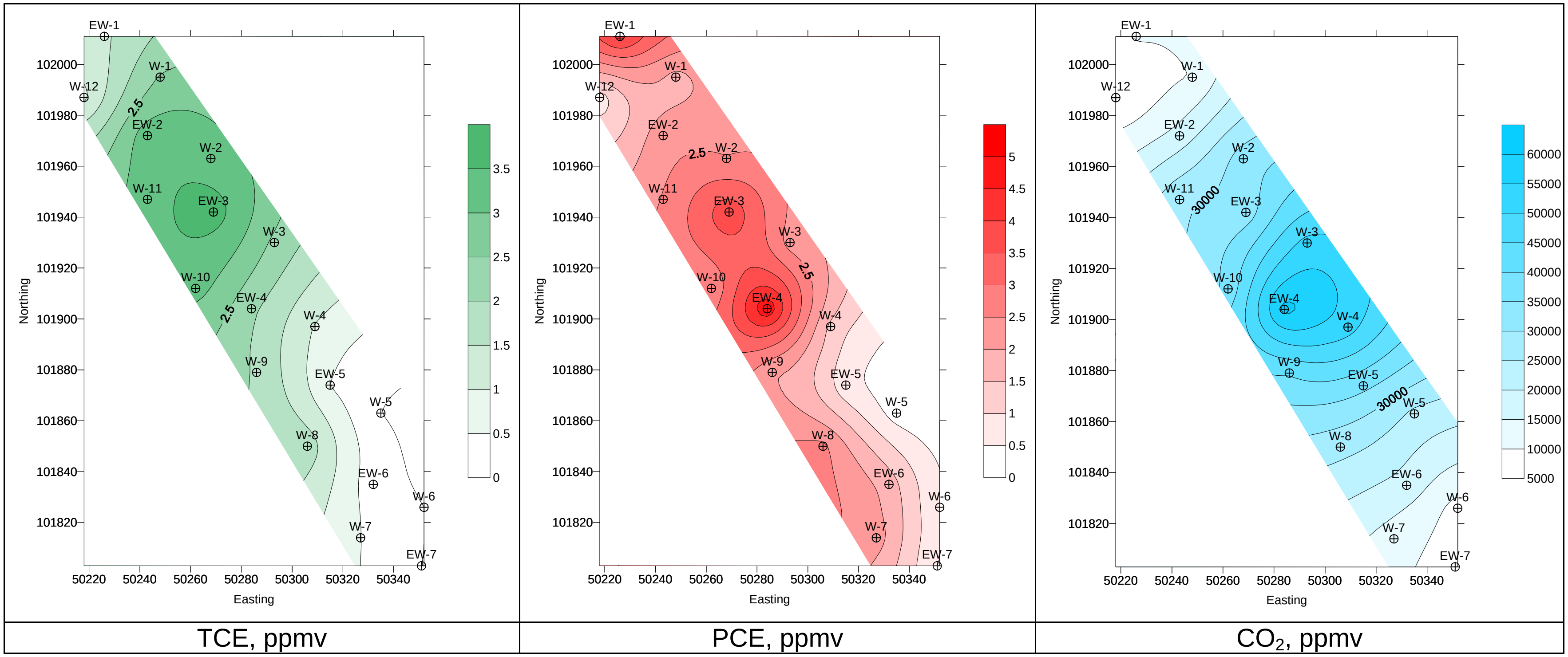


Figure 1 – Initial VOC and CO_2 Concentrations during Well Integrity Testing

Table 2 – Well Coordinates

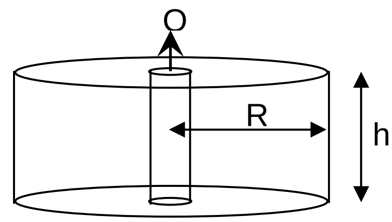
Well	ID Alias	Easting	Northing
AMP001VEW	EW-1	50226	102011
AMP002VEW	EW-2	50243	101972
AMP003VEW	EW-3	50269	101942
AMP004VEW	EW-4	50284	101904
AMP005VEW	EW-5	50315	101874
AMP006VEW	EW-6	50332	101835
AMP007VEW	EW-7	50351	101802
AMP001VMW	W-1	50248	101995
AMP002VMW	W-2	50268	101962
AMP003VMW	W-3	50293	101930
AMP004VMW	W-4	50310	101897
AMP005VMW	W-5	50335	101863
AMP006VMW	W-6	50352	101826
AMP007VMW	W-7	50327	101814
AMP008VMW	W-8	50307	101849
AMP009VMW	W-9	50285	101879
AMP010VMW	W-10	50262	101912
AMP011VMW	W-11	50242	101947
AMP012VMW	W-12	50218	101987

Zone of Capture

The Zone of Capture (ZOC) is based on pore-gas velocity calculations that include the volume that has a pore-gas velocity greater than a previously established value. The critical pore-gas velocity is selected based on mass transfer kinetics and the desired clean-up time. The critical pore-gas velocity can be defined as the minimum pore-gas velocity necessary to produce timely remediation (DiGiulio and Varadhan 2001). Using this method, the ZOC is defined as the maximum radial distance from the well where the critical pore-gas velocity is maintained. A ZOC based on pore-gas velocity helps to ensure that extraction well spacing is sufficient to cause meaningful airflow towards the well. It may also reduce the likelihood of dead zones (zones of little or no air movement) between extraction wells. The ZOC based upon pore-gas velocity will typically be less than the Zone of Influence (ZOI) based on pressure distribution, depending on the cutoff values chosen for each method. If vapor containment is the objective, a ZOI based approach may be sufficient; however, if vapor collection is the objective, a ZOC approach may be more appropriate. In either case, the cutoff value chosen to define the limits of the ZOC or ZOI must be chosen carefully.

A cylindrical model was used to predict the ASVE flow profiles. The cylindrical model is an appropriate choice to model this system since the permeability of the ash is several orders of magnitude higher than the surrounding sediment and low permeability soil cover. The following equation provides the relationship between pore-gas flow velocity (or volumetric flow rate per unit area) and zone of capture (radius) for a given flow rate:

$$V = \frac{Q}{n 2 \pi R h},$$



where V is the gas flow velocity (L/t) , Q is the volumetric flow rate (L^3/t), n is the porosity (L^3/L^3), R is the radial distance from the extraction well (L) and h is height of the soil column (L). The porosity of the ash was estimated at n = 0.25 and the average height of the soil column was estimated at h = 10 ft. A typical porosity value for SRS sediments is n=0.40 due to the fine grain material in the natural formation as compared to the coarser nature of the ash. At flow rates of 25 and 50 cfm, the pore gas velocity is 0.1 ft/min at radiuses of approximately 16 and 32 ft respectively.

A graphical depiction of the calculated zone of capture for pore-gas velocity at 0.1 ft/min (0.05 cm/s) and well flow rates of 25 and 50 scfm is shown in Figure 2. The pore-gas velocity was arbitrarily chosen based on ranges in the EPA SVE design document (DiGiulio and Varadhan 2001) and may be re-evaluated based on concentration trends during startup. Since the mass transfer kinetics are difficult to measure and interpret, a simplification will be made to decrease the required pore-gas velocity if the VOC vapor concentration decreases significantly.

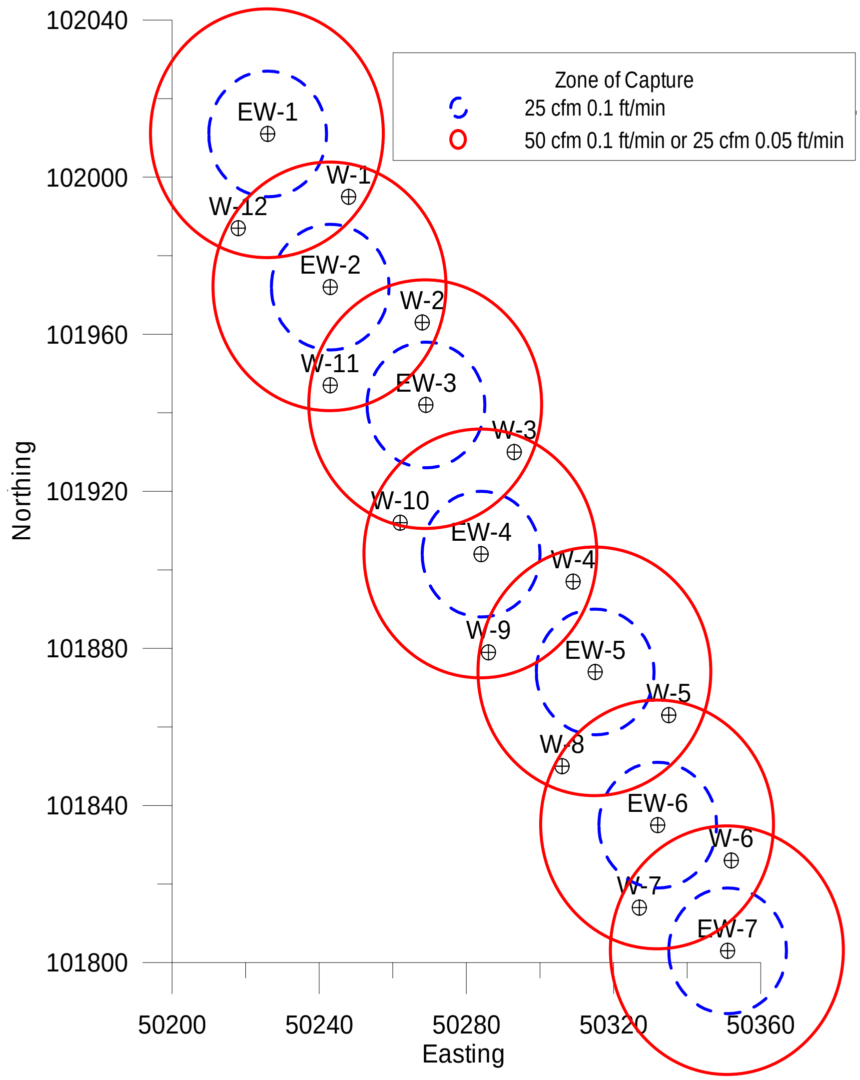


Figure 2 – Calculated Zone of Capture for Pore Gas Velocities at 0.1 ft/min

Zone of Influence

The most common approach for SVE well field design is to use vacuum as a criteria for well spacing. In this approach a critical or cut-off vacuum is established based on the natural variation in subsurface gas pressure that results from atmospheric waves that are transmitted through connected pores in the unsaturated zone. Calculations are then performed using pilot test data and the appropriate analytical model to determine the distance from the well where the critical vacuum is achieved. The volume contained within this radius is referred to as the Zone of Influence (ZOI). The value selected for the cutoff vacuum can significantly affect the predicted ZOI. Hence, it is necessary to be cautious in selecting the cutoff value.

Several passive SVE tests have been conducted at SRS. The results of these tests show that the short term natural diurnal variation in subsurface gas pressure that results from atmospheric waves that are transmitted through connected pores in the unsaturated zone ranges from 0.1 to 0.5 inches of water. In order to ensure a vacuum that is greater than the typical variation in gas pressure, a critical vacuum of 1 inch of water is typically selected to define the boundary of the ZOI. The ZOI can be viewed as a cylinder containing the volume of gas that is influenced by the SVE well. Soil vapor near the outer edge of the ZOI is only marginally influenced by the SVE well and will have a long travel time before extraction.

The ZOI was evaluated at the ARP ASVE system by pumping on each extraction well individually and measuring the vacuum at surrounding wells. At the initiation of the testing, air flow at the ARP wells was observed as a result of the influence of the operating 782-3M SVE Unit. The unit has a significant influence on the ARP Trench due to the low permeability soil cover. The 782-3M SVE Unit was turned off during the well integrity and ZOI testing.

The vacuum influence of the 782-3M SVE Unit on the ARP Trench is illustrated in Figure 3 where the initial differential pressure profile is caused by natural barometric pressure fluctuations and the later profile shows a significant increase in the vacuum when the 782-3M SVE Unit was turned on. The variation in the vacuum of the later profile is cause by barometric pressure fluctuations. The pressure variations caused by barometric pressure indicate the low permeability soil cover provides a significant pressure barrier and that passive SVE can be initiated as a polishing step towards the end of remediation if the 782-3M SVE Unit is shut down.

The results from the ZOI testing is shown in Table 3 where the columns contain the results for each well tested (extraction well vacuum is in bold italics). From these results, vacuum contours for each extraction well were plotted for a nominal 50 cfm flow rate (Figure 4 through Figure 10). Wells EW-1 through EW-4 have a significant ZOI while EW-5 through EW-7 have diminishing ZOI towards the south end of the trench. The contours further away from the extraction well are likely artifacts of the contouring method since vacuum was only measured at the surrounding wells. The most representative contour plot is for well EW-4 (Figure 7) where the vacuum was measured at all the extraction wells. As a conservation measure, a ZOI cutoff value of 2 inches of water was selected and is the lowest contour on the plots.

The last column in Table 3 contains vacuum measurements from the influence of the 782-3M SVE Unit while no active testing was being performed on the ARP Trench wells. The vacuum from the 19 wells only varied by 1 inch of water, emphasizing the high permeability of ash material and the integrity of the low permeability soil cover. A contour plot of the steady state vacuum measurements is provided in Figure 11.

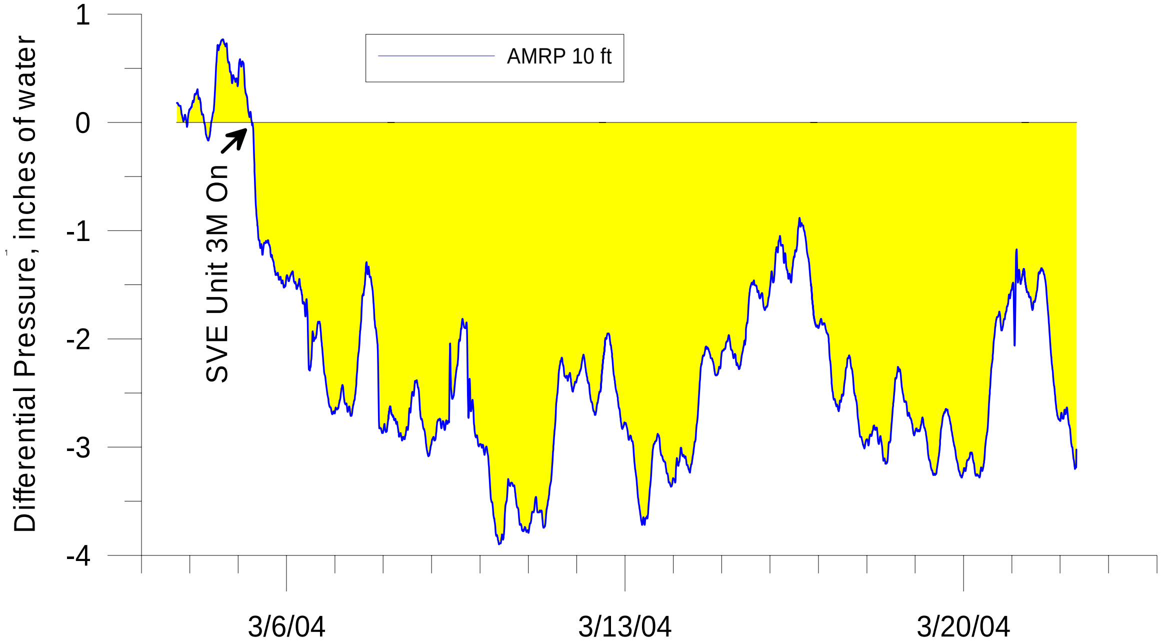


Figure 3 – Subsurface Differential Pressure Measured at Well EW-3

Table 3 – Measured Vacuum for ZOI Evaluation

Well	ID Alias	Average Flow cfm	EW1 Vacuum Inches of water	EW2 Vacuum Inches of water	EW3 Vacuum Inches of water	EW4 Vacuum Inches of water	EW5 Vacuum Inches of water	EW6 Vacuum Inches of water	EW7 Vacuum Inches of water	Steady State Vacuum[a] Inches of water
AMP001VEW	EW-1	51.1	***19.48***	4.47		3.79				3.21
AMP002VEW	EW-2	50.6	4.99	***19.31***	4.39	4.14				3.34
AMP003VEW	EW-3	50.2		4.31	***7.32***	4.46				3.30
AMP004VEW	EW-4	49.6			4.39	***17.36***	2.49			3.26
AMP005VEW	EW-5	50.7				3.28	***16.80***	3.05		3.06
AMP006VEW	EW-6	41.2				2.17	2.77	***41.45***	3.20	3.41
AMP007VEW	EW-7[b]	47.9				1.21		3.40	***50.7***	2.66
AMP001VMW	W-1		5.76	4.66						3.34
AMP002VMW	W-2		4.52	4.35	4.73					3.37
AMP003VMW	W-3				4.67	4.56				3.35
AMP004VMW	W-4					4.07	3.22			3.29
AMP005VMW	W-5						3.63	3.56	1.69	2.90
AMP006VMW	W-6							3.50	4.84	2.33
AMP007VMW	W-7							5.22	4.89	2.57
AMP008VMW	W-8						3.64	4.03	1.76	3.08
AMP009VMW	W-9					4.39	3.13			3.29
AMP010VMW	W-10				4.58	4.54				3.34
AMP011VMW	W-11		4.48	4.37	4.59					3.33
AMP012VMW	W-12		4.91	4.19						2.98

a: measured influence while the 782-3M SVE Unit was operating (all ARP Trench wells were sealed)
b: 2.5 ft well screen

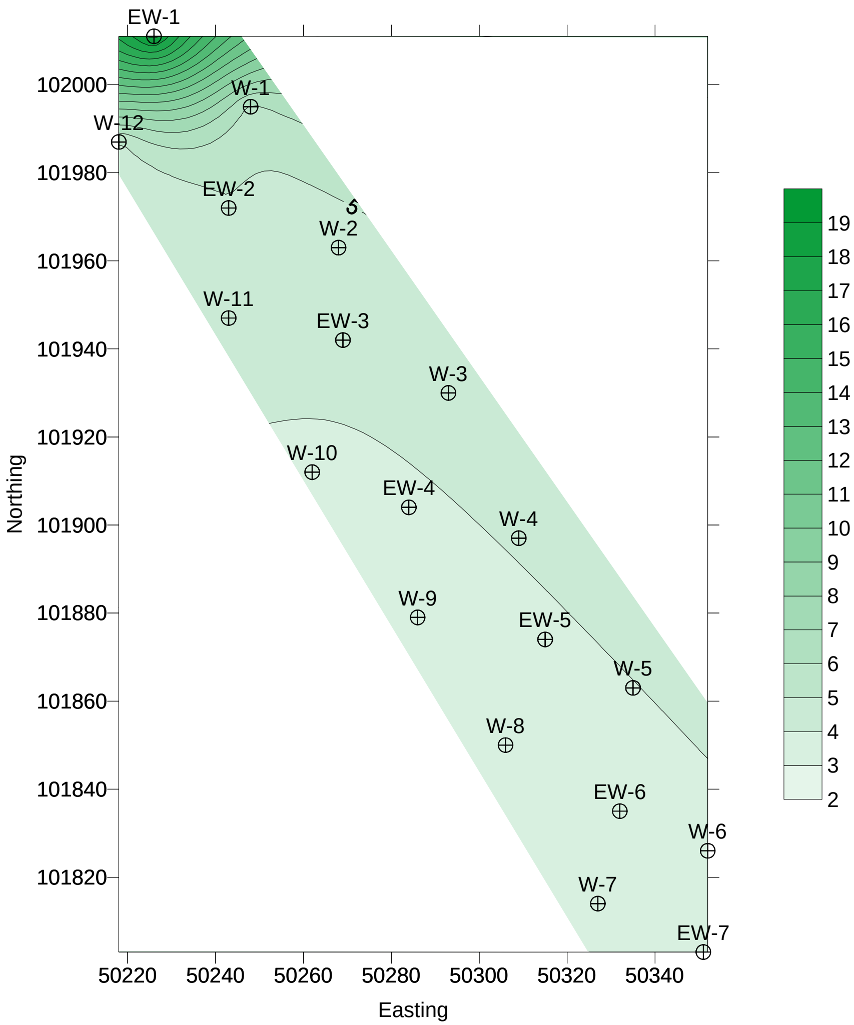


Figure 4 – ZOI (inches of water) for EW-1 at 51.1 cfm

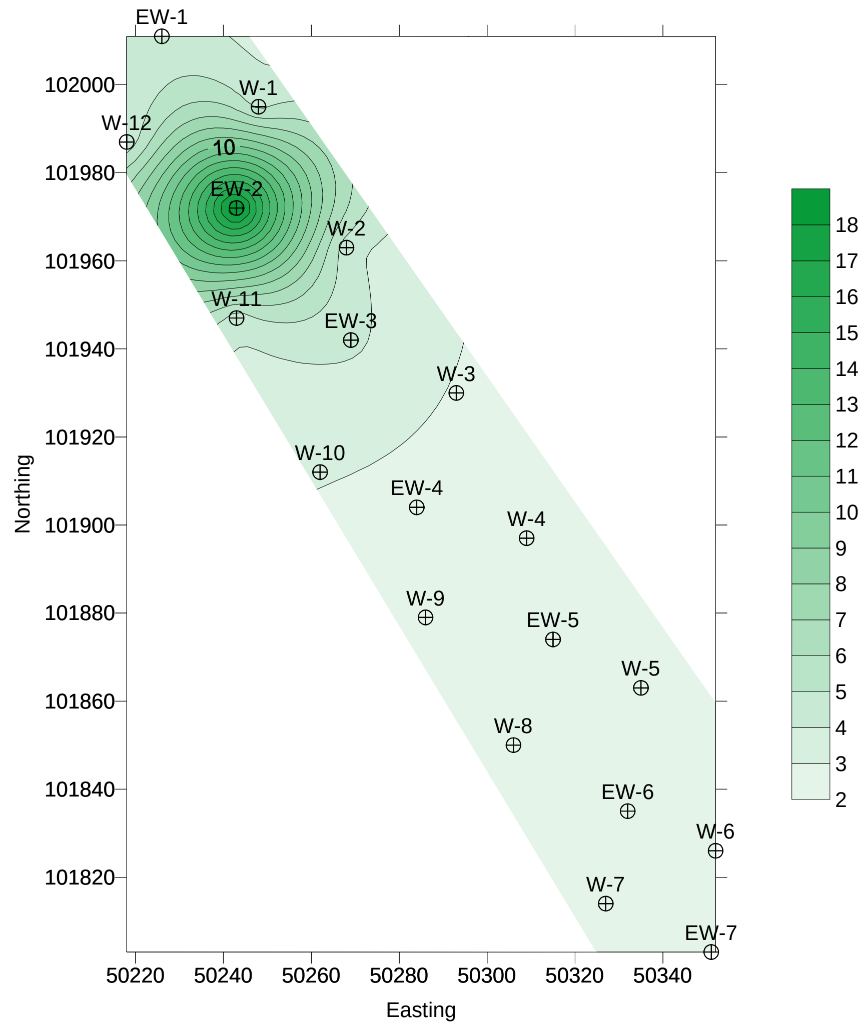


Figure 5 – ZOI (inches of water) for EW-2 at 50.6 cfm

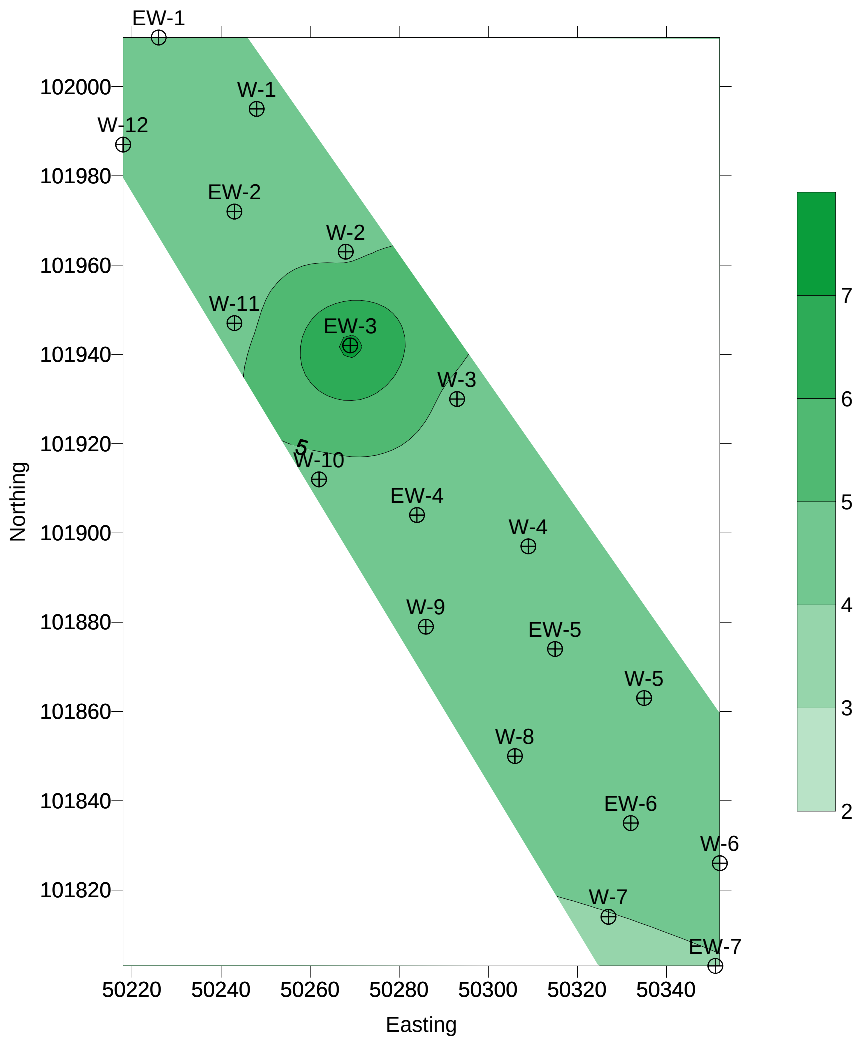


Figure 6 – ZOI (inches of water) for EW-3 at 50.2 cfm

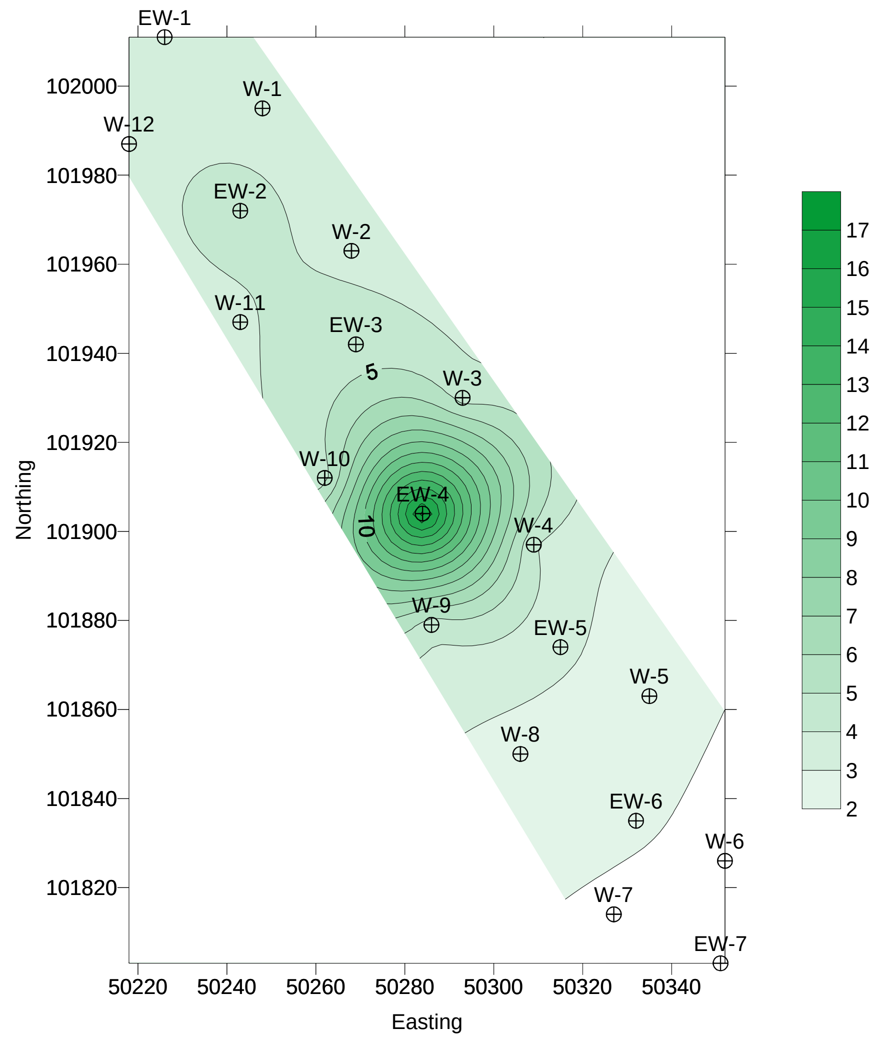


Figure 7 – ZOI (inches of water) for EW-4 at 49.6 cfm

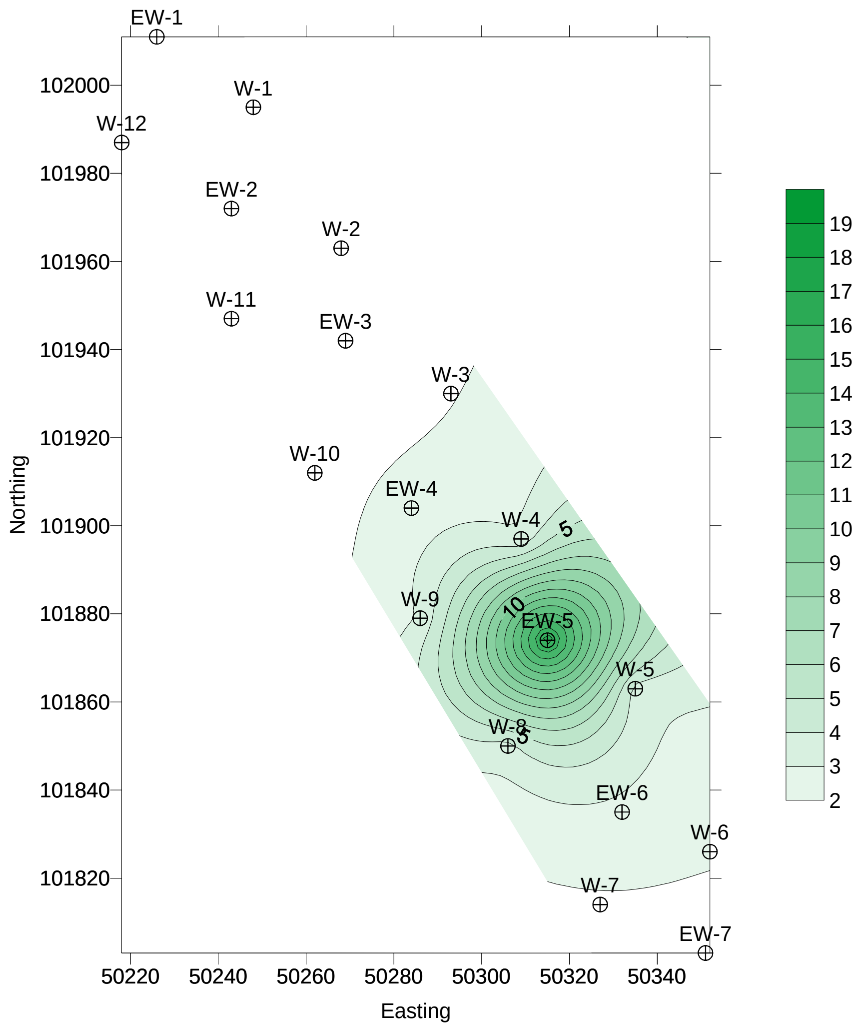


Figure 8 – ZOI (inches of water) for EW-5 at 50.7 cfm

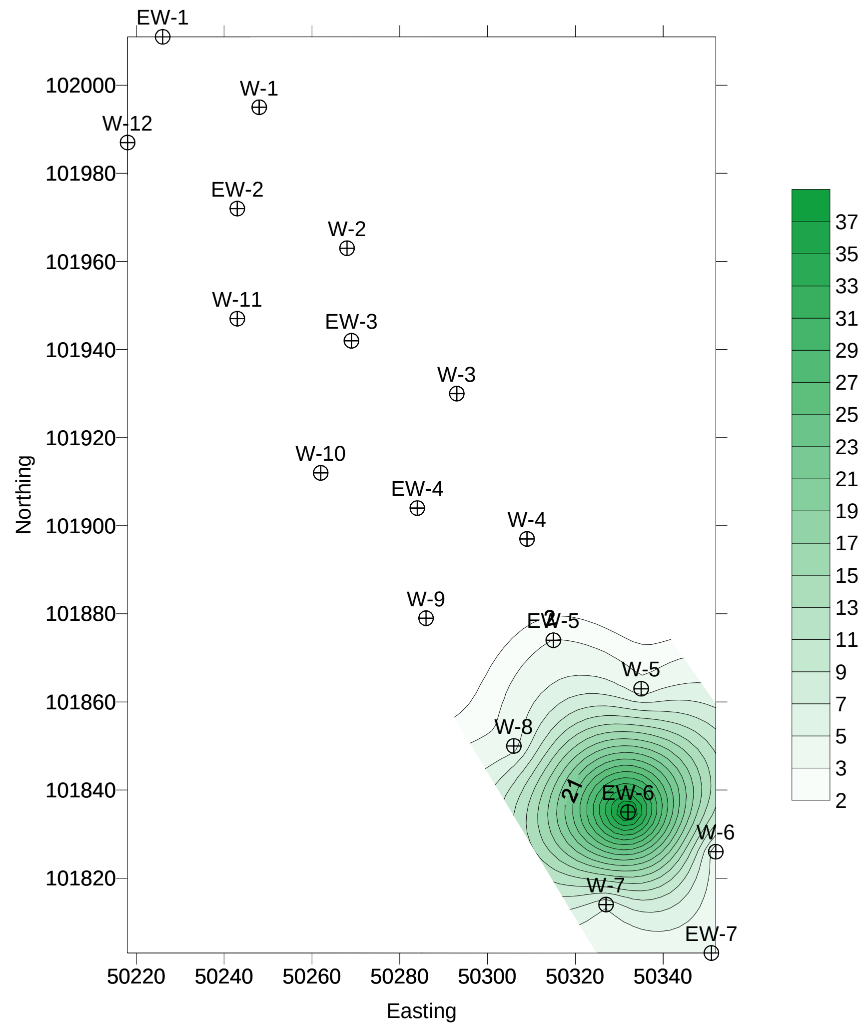


Figure 9 – ZOI (inches of water) for EW-6 at 41.2 cfm

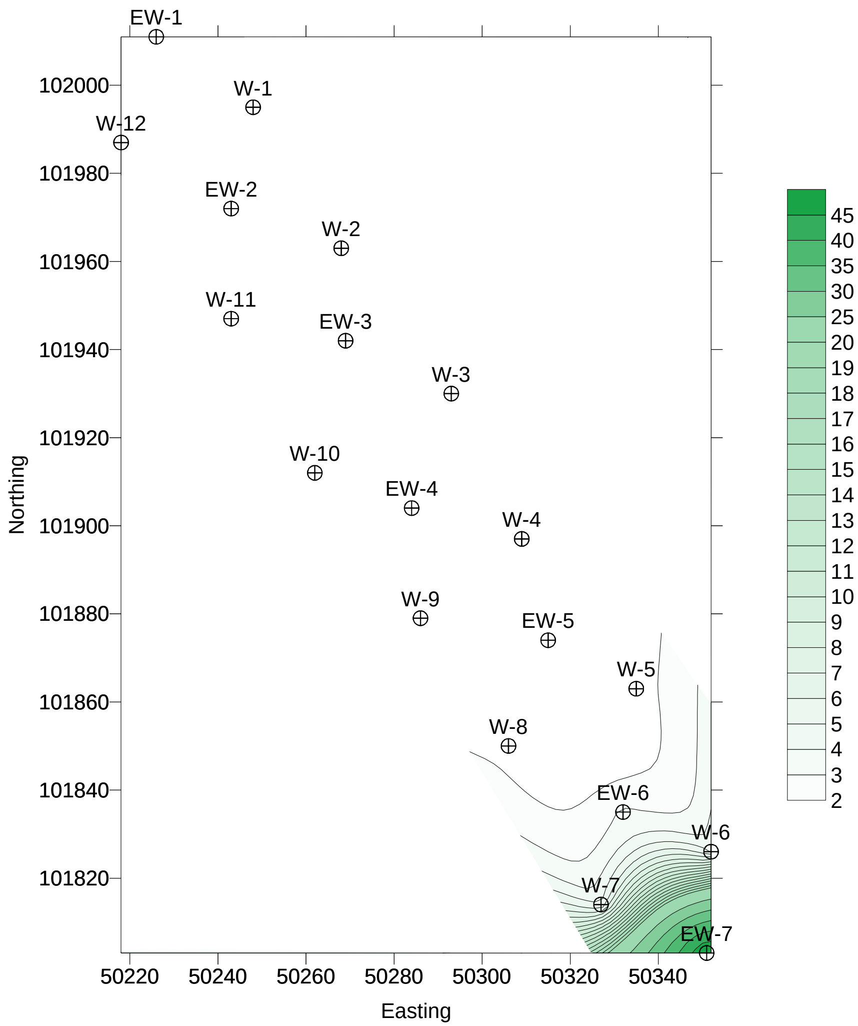


Figure 10 – ZOI (inches of water) for EW-7 at 47.9 cfm

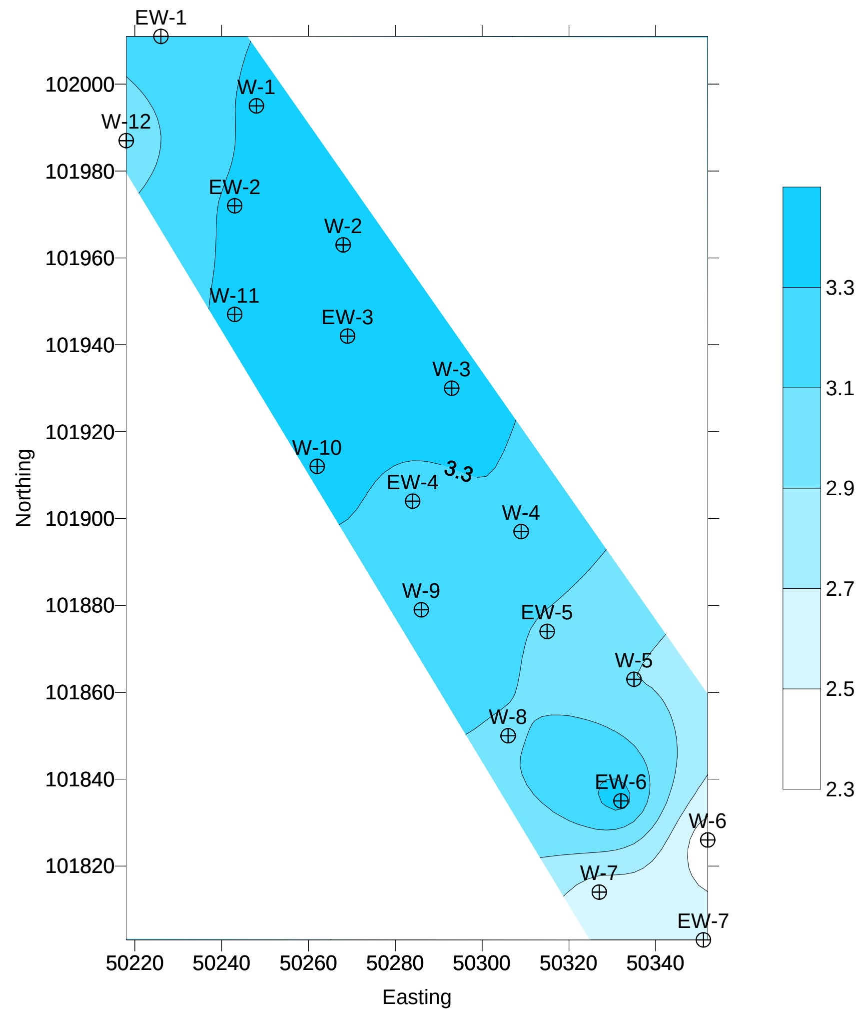


Figure 11 – Steady State Influence from 782-3M SVE Unit

Summary

All 19 wells passed the integrity testing and will provide VOC vapor transport through the contaminated ash material. The ZOC and ZOI analysis supports adequate design and areal coverage for the SVE system for efficient remediation at the ARP Trench. The observation of pressure fluctuations caused by barometric pressure fluctuations and the significant pressure draw down throughout the trench during testing and from the 782-3M SVE Unit indicate the low permeability soil cover provides a significant pressure and flow barrier for the system. The pore gas velocity and extraction flow may need to be reevaluated as the vapor concentrations decrease.

References

DiGiulio, D. C. and R. Varadhan. 2001. Development of Recommendations and Methods to Support Assessment of Soil Venting Performance and Closure. National Risk Management Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency. Cincinnati, OH. EPA/600/R-01/070.