Optimized Air Sparging Coupled with Soil Vapor Extraction Groundwater Remediation

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ABSTRACT

Air sparging coupled with soil vapor extraction (AS/SVE) has obvious benefits for groundwater contamination consisting of volatile organic compounds, particularly benzene, ethylbenzene, toluene, and xylenes (BTEX). Although AS/SVE is easily employed given suitable site conditions, optimized AS/SVE system operation and monitoring (O/M) are often overlooked once treatment is initiated. Site O/M typically is conducted with on-site field staff, or as an alternative, by remotely connecting to the site via modem and programmable logic controller (PLC). Two AS/SVE sites located in Wisconsin have used either traditional on-site O/M or the remote modem/PLC option to evaluate and optimize system operation. System on-time efficiency using remote telemetry was improved compared to traditional O/M and system operations.

INTRODUCTION

Available subsurface remedial technologies, particularly for petroleum hydrocarbons, have increased over the past two decades. Soil vapor extraction (SVE) was first demonstrated to be effective for subsurface removal of the volatile fractions of hydrocarbon contamination in the vadose zone. Within the past 10 years, air sparging (AS) applications have been added to potential technologies available for groundwater and vadose-zone subsurface remediation.

Volatilization, or in-situ air-stripping, is the major process by which the volatile fraction of total petroleum hydrocarbon (TPH) removal is accomplished (Loden, 1992). A secondary, but as important, remediation process for SVE is aerobic biodegradation that uses the increased oxygen provided during SVE operation (Dupont 1991; Hinchee 1990; Loden 1992). Multiple air exchanges are induced by high

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SVE airflow rates in the unsaturated subsurface. Aerobic biodegradation for both nonvolatile and volatile TPH is enhanced by soil oxygen levels that can easily exceed 3 to 5% concentrations, and in lower airflow venting applications (i.e., bioventing), aerobic biodegradation can become the dominant remediation process (Hinchee 1993; Miller 1991; Newman 1993).

Likewise, volatilization can be the major process accomplishing volatile TPH removal from groundwater during AS (Loden 1992). Variations in AS operation can result in minimal air-stripping action of volatile TPH fractions from groundwater and greatly increased rates for in-situ aerobic biodegradation of dissolved-phase contamination (Brown 1993).

Typically, either on-site visits by field staff or remote telemetry provides the means by which to evaluate and modify AS/SVE system operation. Site operation and monitoring (O/M) methods can be accomplished by mobilizing field staff to the site or by remotely connecting to the site via modem/PLC. Functionally, a PLC examines the status of input interfaces, and, in response, controls various switches, valves, or monitoring equipment through output interfaces. During the remote scan of the PLC program, all inputs are examined, the control plan can be evaluated/altered, and output records are updated. Two sites (Figures 1 and 3) used AS/SVE remediation designs and offer comparisons of system operation for data evaluation/system operation options. By continually evaluating the performance of combined AS/SVE treatment systems, and correspondingly, modifying the mode of system operation for the desired removal mechanisms, system efficiency is enhanced and regulatory closure can be achieved in the shortest possible time frame.

BACKGROUND SITE INFORMATION

Site #1

During a tank closure operation in 1988, residual impacted soil was noted surrounding a former tank basin (Figure 1). Subsurface soil consists of medium to fine sand with thin silt lenses (SP in Unified Classification System). Original remediation efforts at the site focused on a prior release from the former tank basin. In 1985, a pump-and-treat (P&T) system was installed, primarily for free-product recovery. The operation of the P&T system continued into 1987, and during that period approximately 1,230 liters of free product were recovered.

From 1988 through 1991, SVE was employed seasonally to provide vadose zone remediation efforts and to achieve soil cleanup objectives in the area surrounding the former tank basin. While cleanup of unsaturated soils progressed during 1988-1991, changes in groundwater elevations periodically flushed additional TPH contamination into site groundwater as noted by increased dissolved-phase concentrations (Table 1). To accelerate remediation progress in 1992, particularly toward groundwater cleanup goals, AS was added to the system remediation design (Figure 2).

The primary goals for AS/SVE operation at this site were to flush remaining capillary fringe TPH and maximize volatilization/biodegradation processes for removal of contaminants. In particular, aerobic biodegradation environmental conditions were closely evaluated, and AS operation was continually modified to promote more efficient dissolved-phase remediation.

Site #2

The geology of Site #2 consists of 2.4 meters of silty sand underlain by approximately 1.8 meters of clay which locally confines the underlying fine- to medium-grained sand. At this site (Figure 3) a P&T system, operating from October 1987 to the present, had recovered over 3,580 liters of free product. During this period, only modest decreases were noted in dissolved-phase hydrocarbon concentrations (Table 2). A site bioassessment and laboratory bench-scale microcosm testing were completed in 1992 to provide design criteria for options to upgrade site remediation. Oxygen and nutrient additions to the site groundwater were found to be beneficial in optimizing aerobic biodegradation of TPH. A pilot test for AS/SVE was completed in January 1993 to gain additional design criteria for an upgrade for site remediation. Results of these tests indicated that AS/SVE combined with in-situ inorganic nutrient delivery would provide an effective remedial technology for the site. In 1993, AS/SVE was implemented to gain faster site closure.

METHODS

Groundwater monitoring parameters included dissolved oxygen (DO), pH, temperature, conductivity, and water levels using calibrated field instruments and colorimetric test kits. Following purging of four well bore volumes of groundwater, the concentrations of DO, soluble iron, and total iron in bailed groundwater were measured using colorimetric test kits. Temperature, conductivity, and pH meter measurements were also collected from bailed water samples. Samples were collected for analysis of petroleum hydrocarbon concentrations including BTEX by U.S. Environmental Protection Agency (EPA) Method 8020. The AS/SVE was turned off for at least one hour prior to collected groundwater measurements and samples.

RESULTS

Standard site visits for Site #1 were employed from 1992 until AS/SVE system operation was discontinued in July 1994. System data evaluation, operation modifications, and data collection were accomplished by field staff visits to the site on a monthly basis. Collected data were used to evaluate and provide guidance for optimization of system operation. Site monitoring data are summarized in Tables 1 and 3. The log of the system operation is reviewed in Table 4.

Modifications to the Site #2 treatment system, AS/SVE added to complement a P&T system that incorporated inorganic nutrient infiltration, were completed in October 1993. At Site #2, telemetry control using modem/PLC equipment was built into the treatment system upgrade (Figure 4) to allow remote monitoring/adjustments of system performance, troubleshooting of system problems, and correction of problems without physically visiting the site. By having up-to-date monitoring information available on the operation of the treatment system prior to site visits, field staff were better able to anticipate the need for on-site work or repairs. If system problems were noted during remote monitoring, the appropriate on-site response and urgency to schedule could be determined. Site monitoring data are summarized in Tables 2 and 5. The system operation log is reviewed in Table 6.

CONCLUSIONS

While AS/SVE remediation was relatively easy to employ at each of these locations given the site conditions of geology, hydrogeology, and contaminants, the two sites had differences in design complexities that required varying needs for system operation and monitoring. These two sites used either on-site field staff visits or modem/PLC "visits" prior to actual field staff mobilization to the site. Given the different complexities for each site's remediation design, each O/M method was appropriate for site-specific design considerations.

For Site #1, monthly site visits by field staff proved sufficient to maintain reasonable system operation, approximately 90% reliability, after minor equipment problems were solved. Monitoring of groundwater quality parameters was important to optimize system performance. Site #2 used a more complex treatment design to correct deficient site conditions and to provide more biologically optimized remediation treatment, therefore remote telemetry monitoring was warranted. Groundwater quality parameters illustrate even better levels for key system performance indicators, such as DO, compared to Site #1.

While the less complex site (Site #1) may have benefitted from the modem/PLC option for site O/M, the less complex, more standard site O/M was adequate to reach target remediation goals in a reasonable time frame given the budgetary constraints of the project. In contrast, the more difficult and complex site conditions presented at Site #2 greatly benefitted from the ability to remotely monitor and adjust system performance during project remediation. Site #2's remote telemetry system has provided more efficient O/M, greater than a 95% operating system efficiency, compared to Site #1's non-telemetry O/M program.

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LIST OF FIGURE AND TABLE CAPTIONS

Key Word List

air sparging
air injection
petroleum hydrocarbons
soil vapor extraction

TABLE 1. Site #1: Groundwater analytical summary.

	Total BTEX concentration (micrograms/liter)			
Location:	MW-3	MW-7	MW-8	SV-10
Date:				
7/89	770	FP(a)	NS(b)	NS
1/90	7	FP	NS	NS
7/90	34	FP	NS	NS
2/91	ND(c)	2,334	NS	NS
10/91	20	164	15,870	28
2/92	3	ND	1,009	62
4/92	AS/SVE	Initiated	---------	--------->
5/92	28	1,664	2,730	ND
7/92	6	5,740	509	3
5/93	2	723	8	4
11/93	1	128	ND	ND
2/94	ND	9	ND	ND
5/94	7	ND	ND	ND
8/94	23	ND	12	ND
11/94	12	ND	4	ND

(a) FP - Free product
(b) NS - Not sampled/installed
(c) ND - Not detected at EPA Method 8020 detection limits

Note: Wisconsin Administrative Code NR 140 limits (ug/L):

		Enforcement	Preventative Action
Benzene	-	5	0.5
Toluene	-	343	68.6
Ethylbenzene	-	700	140
Xylenes	-	620	124

TABLE 2. Site #2: Groundwater analytical summary.

	Total BTEX concentration (micrograms/liter)				
Location:	MW-3	MW-4	MW-8	MW-9	MW-15
Date:					
1/89	108,500	43,440	NS(a)	NS	NS
10/90	64,700	NS	56,000	NS	NS
8/91	30,200	25,500	81,300	NS	NS
8/92	13,900	23,200	53,200	73,600	NS
2/93	13,450	25,000	16,990	88,400	NS
8/93	4,650	103,400	21,560	82,600	72,500
10/93	AS/SVE	Initiated	---------	---------	--------->
12/93	260	41	1,820	58,300	26,570
5/94	ND(b)	14,620	132	5,637	452
8/94	ND	66	4	320	98
11/94	24	ND	ND	412	ND
2/95	4	ND	ND	ND	ND

(a) NS - Not sampled/installed
(b) ND - Not detected at EPA Method 8020 detection limits

Note: Wisconsin Administrative Code NR 140 limits (ug/L):

	Enforcement	Preventative Action
Benzene -	5	0.5
Toluene -	343	68.6
Ethylbenzene -	700	140
Xylenes -	620	124

TABLE 3. Site #1: Groundwater quality summary.

	Groundwater quality parameters (milligrams/liter)				
	Location:	MW-3	MW-7	MW-8	SV-10
Date:					
10/91	DO(a)	2.0	2.0	6.0	2.0
	Fe^{3+}(b)	>10.0	2.0	5.0	>10.0
	Fe^{2+}(c)	6.0	0.3	2.0	8.0
4/92		AS/SVE	Initiated	---------	--------->
5/92	DO	1.0	1.0	1.0	3.0
	Fe^{3+}	10.0	2.0	5.0	1.0
	Fe^{2+}	5.0	1.0	2.0	0.2
11/92	DO	1.0	1.0	1.0	5.0
	Fe^{3+}	10.0	10.0	10.0	0.8
	Fe^{2+}	10.0	10.0	10.0	0.3
5/93	DO	2.0	4.0	6.0	6.0
	Fe^{3+}	6.0	6.0	4.0	2.0
	Fe^{2+}	4.0	5.0	2.0	2.0
11/93	DO	2.0	6.0	6.0	6.0
	Fe^{3+}	10.0	10.0	5.0	NM(d)
	Fe^{2+}	7.0	1.0	0.4	1.0
5/94	DO	1.0	4.0	5.0	3.0
	Fe^{3+}	6.0	0.1	0.6	1.0
	Fe^{2+}	6.0	0.1	0.6	1.0
11/94	DO	2.0	2.0	4.0	2.0
	Fe^{3+}	7.0	7.0	0.3	0.6
	Fe^{2+}	7.0	7.0	0.2	0.4

(a) DO - Dissolved oxygen
(b) Fe^{3+} - Total iron
(c) Fe^{2+} - Dissolved iron
(d) NM - Not measured

TABLE 4. Site #1: System operating log.

Date	AS(a) points	Pressure (psi)	Pressure (kPa)	Air flow (cfm)	Air flow (m^3/min)	AS cycles (min)	Notes
4/92	1,2,3	8.0	55.2	9.0(b)	0.255(b)	10 on/10 off	System startup
9/92	1,2,3	10.0	69.0	15.0	0.425	10 on/10 off	-
10/92	1,2,3	0.0	0.0	0.0	0.0	Changed to 20 on/10 off	SVE(c) blower failed
11/92	1,2,3	8.0	55.2	9.0	0.255	20 on/10 off	New SVE blower
12/92	1,2,3	11.0	75.8	16.0	0.453	100% on	No off AS cycles
3/93	1,2,3	10.0	69.0	8.0	0.227	100% on	Adjust manifold
6/93	1,2,3	14.0	96.5	12.0	0.340	100% on	-
7/93	1,2,3	15.0	103.4	11.0	0.312	100% on	System down; breaker off
8/93	1,2,3	14.0	96.5	11.5	0.326	100% on	-
9/93	1,2,3	18.0	124.1	9.0	0.255	2 AS points on	#3 AS off

(a) AS - Air sparge
(b) - Estimated air flow
(c) SVE - Soil vapor extraction

TABLE 5. Site #2: Groundwater quality summary.

	Groundwater quality parameters (milligrams/liter)					
	Location:	MW-3	MW-4	MW-8	MW-9	MW-15
Date:						
1/93	DO(a)	1.0	1.0	0.8	0.6	NM(d)
	Fe^{3+}(b)	NM	NM	NM	NM	NM
	Fe^{2+}(c)	NM	NM	NM	NM	NM
10/93	DO	1.0	4.0	2.0	1.0	1.0
	Fe^{3+}	NM	NM	NM	NM	NM
	Fe^{2+}	NM	NM	NM	NM	NM
10/93		AS/SVE	Initiated	---------	---------	--------->
12/93	DO	4.0	5.0	1.0	3.0	1.0
	Fe^{3+}	0.8	0.6	0.4	0.8	NM
	Fe^{2+}	0.3	0.4	0.2	0.4	NM
2/94	DO	NM	5.0	5.0	3.0	2.0
	Fe^{3+}	NM	2.0	2.0	2.0	10.0
	Fe^{2+}	NM	1.0	0.8	0.8	10.0
5/94	DO	5.0	4.0	5.0	5.0	4.0
	Fe^{3+}	0.8	7.0	0.2	0.4	0.2
	Fe^{2+}	0.1	1.0	0.1	0.2	0.1
8/94	DO	2.0	5.0	4.0	5.0	4.0
	Fe^{3+}	0.4	10.0	4.0	10.0	0.8
	Fe^{2+}	0.1	10.0	1.0	10.0	0.6
11/94	DO	6.0	8.0	6.0	6.0	2.0
	Fe^{3+}	10.0	10.0	5.0	10.0	2.0
	Fe^{2+}	5.0	10.0	2.0	10.0	2.0
2/95	DO	5.0	6.0	5.0	6.0	2.0
	Fe^{3+}	3.0	1.0	4.0	10.0	1.0
	Fe^{2+}	1.0	0.4	1.0	7.0	0.2

(a) DO - Dissolved oxygen
(b) Fe^{3+} - Total iron
(c) Fe^{2+} - Dissolved iron
(d) NM - Not measured

TABLE 6. Site #2: System operating log.

Date	SVE(a) cycle points	AS(b) cycle points	Pressure (psi/kPa)	Air flow (cfm/m^3/min)	Nutrient delivery (ND)(c)	Recovery well operation	Notes
10/93	1,4,5,8,9/ 2,3,6,7,10	1,2,5,6,9,11/ 3,4,7,8,10,12	4.0/27.6	46.0/1.30	Zones 2-7; 302 liters at 6 ml/min	RW-2: 7.56 l/min; RW-3: 11.3 l/min	System startup
11/93	NC(d)	NC	6.0/41.4	45.0/1.27	132 liters added	NC	ND floats sticking
12/93	NC	NC	8.0/55.2	44.0/1.25	Restarted at 6 ml/min	Mercury switches installed	NC
3/4/94	NC	10 & 11 off	9.0/62.1	44.0/1.25	Increased to 10 ml/min	NC	AS points off to observe MW-4
3/10/94	NC	NC	9.0/62.1	42.0/1.19	Zone 9 on; up to 13 ml/min	NC	Nutrient levels low in MW-9
6/94	All points on continuously	10 & 11 on	10.0/69.0	42.0/1.19	Zones 8 & 10 on; down to 6 ml/min	NC	Nutrient levels low by MW-4
7/94	NC	NC	10.0/69.0	40.0/1.13	ND halted	NC	75.6 liters of nutrients added
9/94	1 & 3 off	1,2,3,5 off	10.0/69.0	40.0/1.13	Zones 2-7 off; 3 ml/min to zones 8,9,10	NC	Western half of site GW(e) clean
10/94	NC	NC	10.0/69.0	40.0/1.13	System stops if >3 cycles/hr	NC	Cycle counter for excess ND to GW
12/94	3 on	3 on	10.0/69.0	40.0/1.13	Zone 5 on; up to 10 ml/min	NC	BTEX detect/MW-3

(a) SVE - Soil vapor extraction
(b) AS - Air sparge
(c) ND - Nutrient delivery
(d) NC - No change in operation
(e) GW - Groundwater

FIGURE 1. Site Map: Site #1

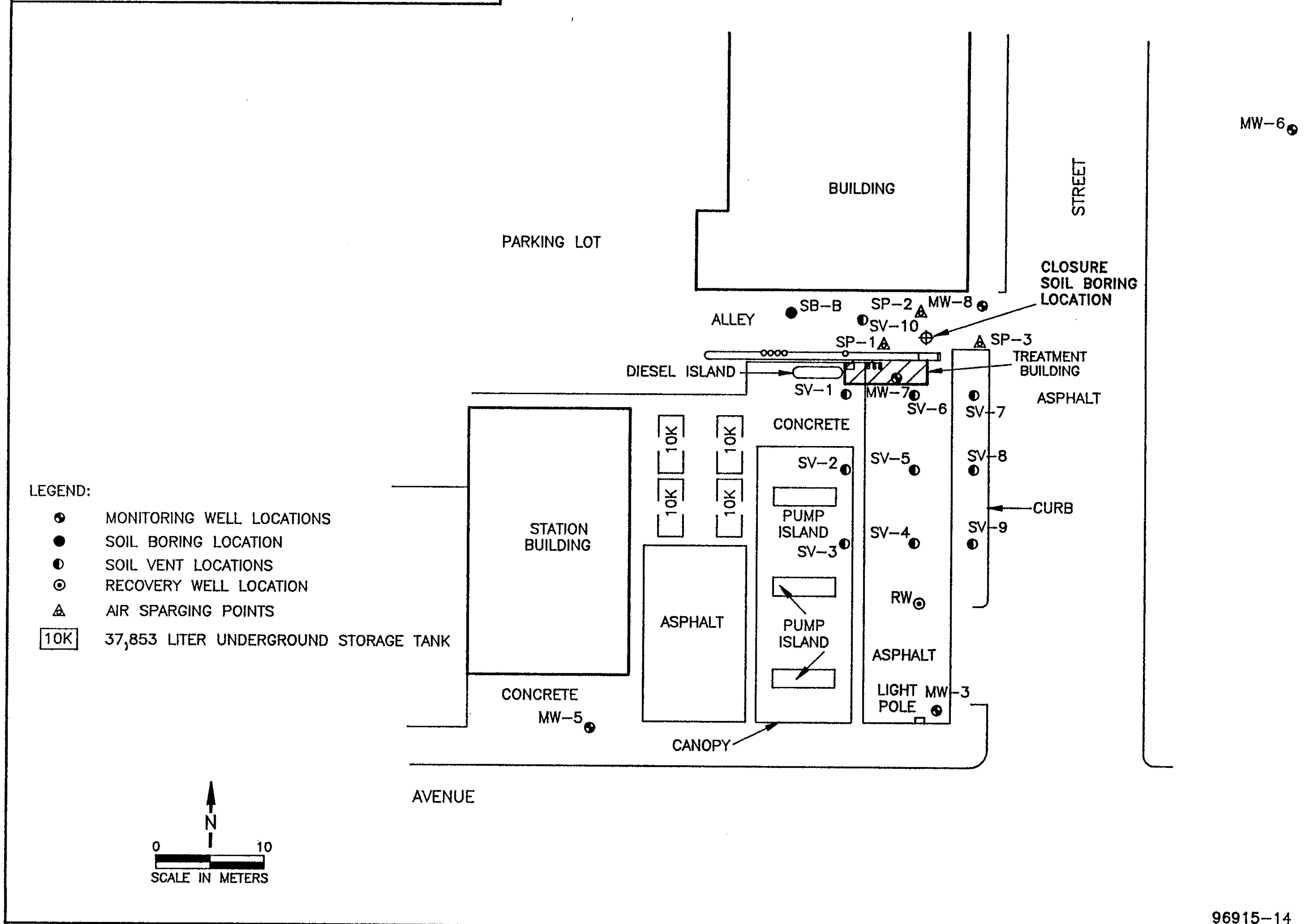


FIGURE 2. Site #1: Process and instrumentation diagram.

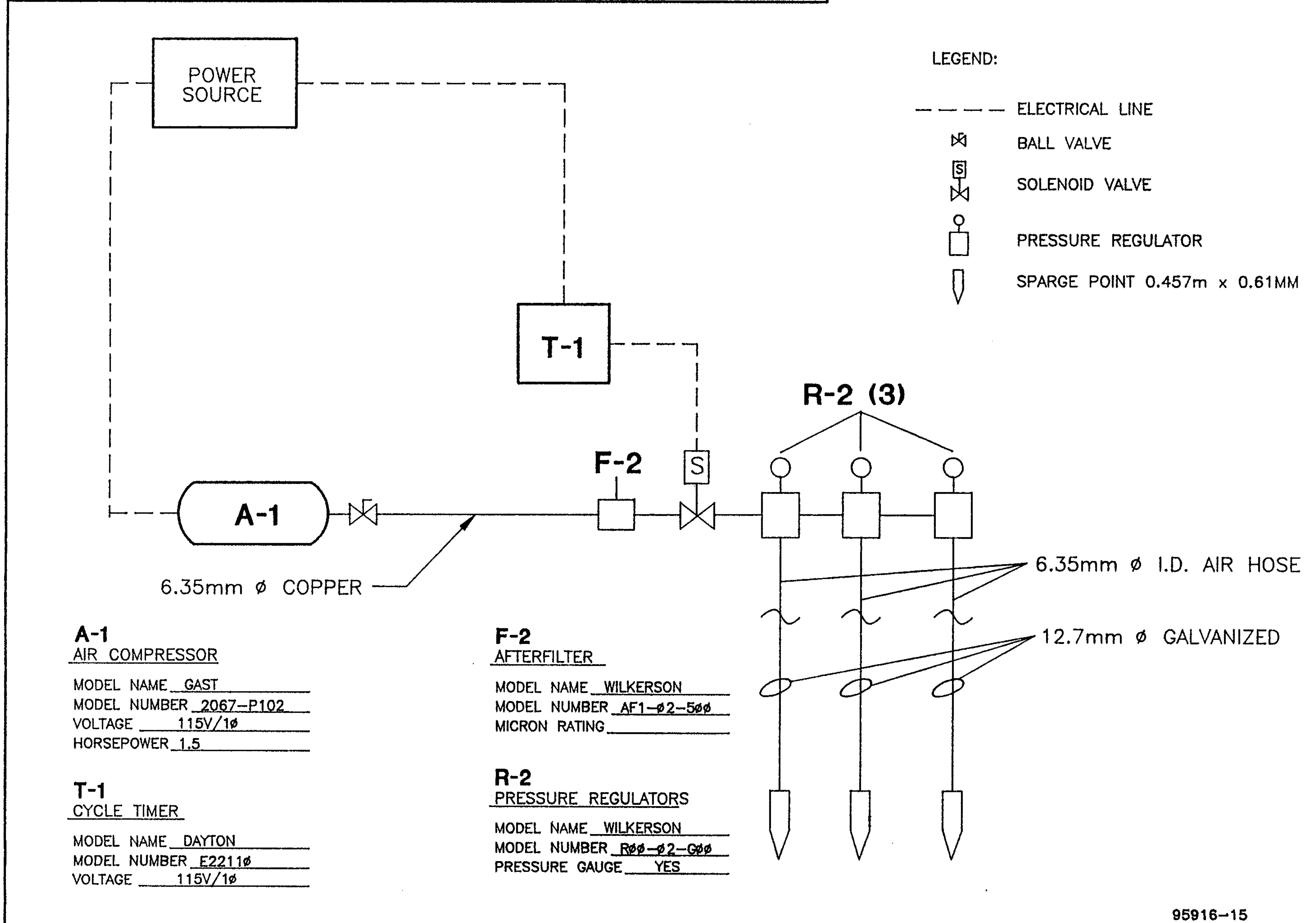


FIGURE 3. Site Map: Site #2

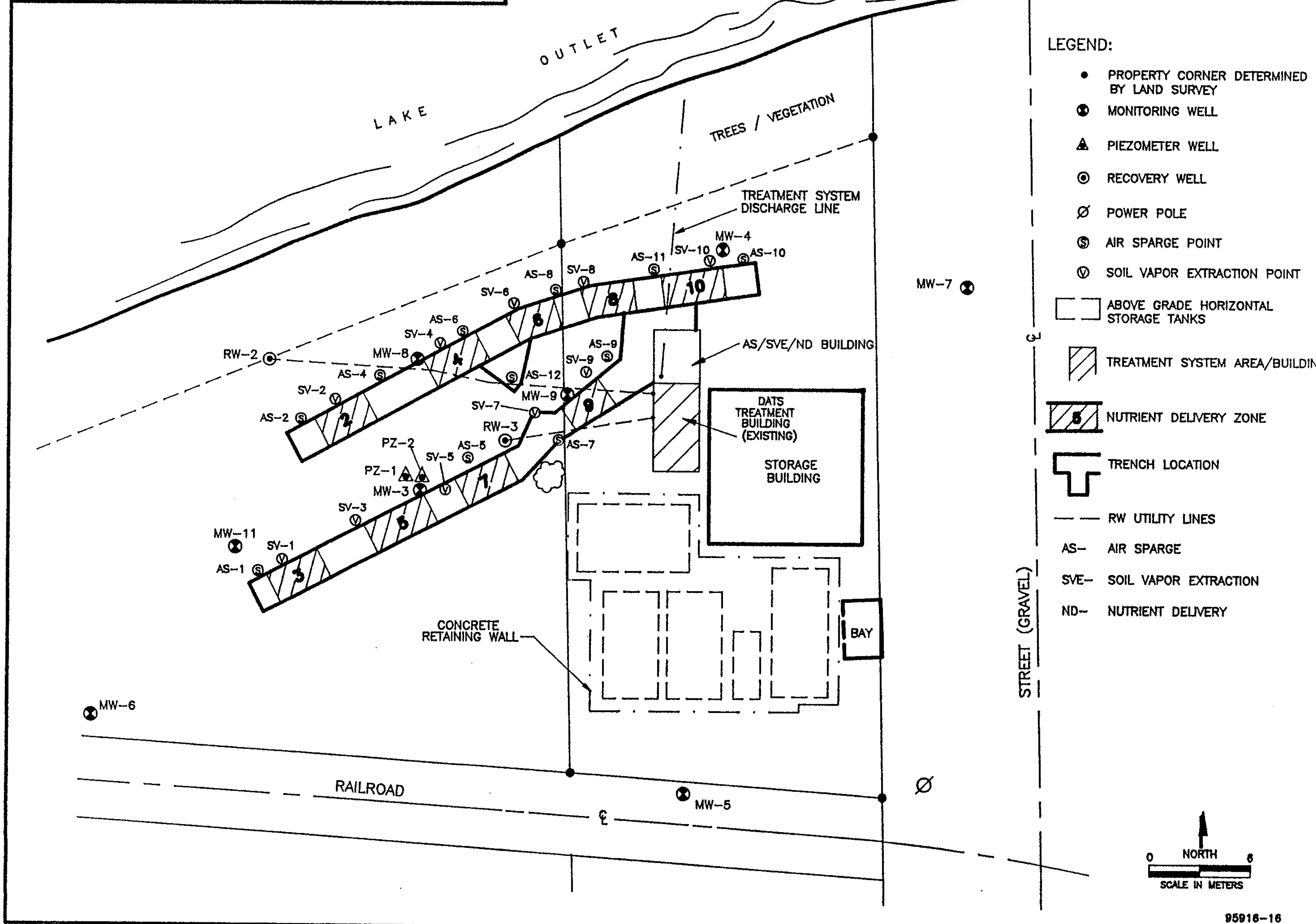
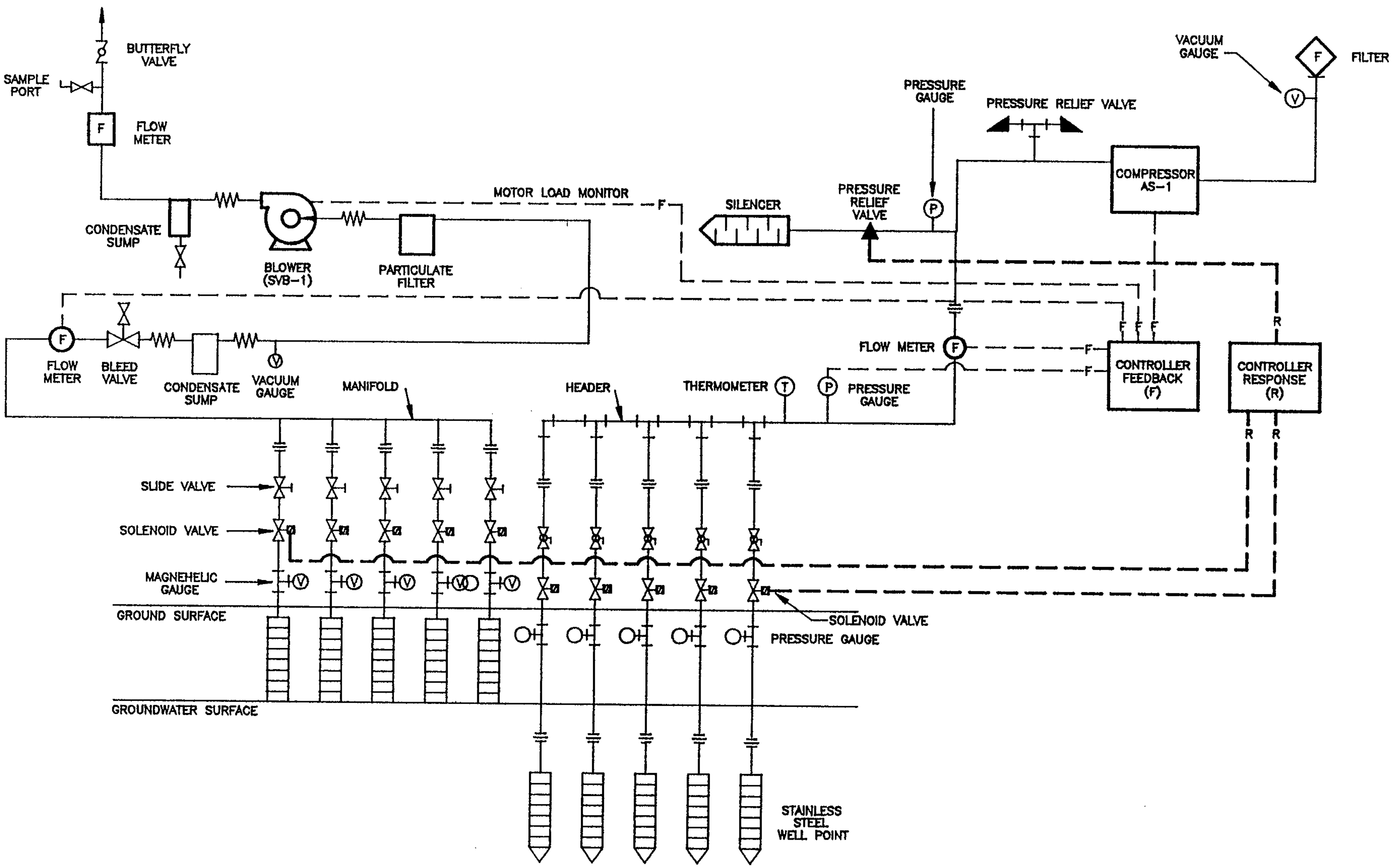


FIGURE 4. Process and instrumentation diagram.



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