

JV TASK 130 – TECHNOLOGICAL SYNERGIES FOR RECOVERY OF ORGANIC POLLUTANTS FROM A COAL SEAM AT GARRISON, NORTH DAKOTA

PHASE I – SYSTEM DESIGN AND INSTALLATION

Final Report

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ABSTRACT

The Energy & Environmental Research Center (EERC) initiated remediation of hydrocarbon-contaminated soils and groundwater associated with gasoline release at the Farmers Union Oil station in Garrison, North Dakota. The remedial strategy implemented is based on application of two innovative concepts: 1) simultaneous operation of soil vapor and multiphase extraction systems allowing for water table control in challenging geotechnical conditions and 2) controlled hot-air circulation between injection and extraction wells to accelerated in situ volatilization and stripping of contaminants of concern (COC) alternatively using the same wells as either extraction or injection points.

A proactive remedial approach is required to reduce high COC levels in the source and impacted areas and to eliminate long-term health risks associated with contaminant migration to water-bearing zones used as a regional water supply source. This report compiles results of Phase I focused on design, construction, and start-up of remediation systems.

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JV TASK 130 – TECHNOLOGICAL SYNERGIES FOR RECOVERY OF ORGANIC POLLUTANTS FROM A COAL SEAM AT GARRISON, NORTH DAKOTA

EXECUTIVE SUMMARY

At the request of Farmers Union Oil Company and the North Dakota Department of Health, the Energy & Environmental Research Center initiated remediation of hydrocarbon-contaminated soils and groundwater associated with gasoline release at the Cenex station in Garrison, North Dakota. A proactive remedial approach was required to reduce high contaminants of concern (COC) levels in the source and impacted areas and to eliminate long-term health risks associated with contaminant migration to water-bearing zones used as a regional water supply source. The report compiles results of Phase I focused on design, construction, and start-up of remediation systems.

Based on complex geotechnical conditions, the implemented remedial strategy is based on contaminant recovery and in situ degradation using an innovative combination of 1) thermally enhanced soil vapor extraction (SVE) in the source areas and 2) multiphase extraction supporting SVE in saturated impacted areas. The acceleration of COC recovery in hot spots is achieved by thermal enhancement/hot-air injection conducted simultaneously with the operation of the SVE system. The operational principle is based on controlled hot-air circulation between injection and extraction wells to accelerate in situ COC volatilization and stripping alternatively using the same wells as either extraction or injection points.

A total of 18,137 gallons (68.7 m³) of groundwater and 31.4 million ft³ (891,260 m³) of contaminated soil vapor have been extracted from both well fields since extraction start-up. High contaminant recovery efficiency resulted in removal of over 13,693 lb of hydrocarbons during the first month of operation. The mass of recovered contaminant equals approximately 2188 gal of product.

The system construction and its successful start-up concluded the first phase of the project. The operation of recovery systems will continue until contaminant concentration levels in soils and groundwater are reduced to acceptable regulatory limits. Initial performance monitoring data, high contaminant recovery efficiency, and a well-developed radius of influence within the target area provide favorable conditions to achieve COC reduction within an estimated 3-year operation time frame as proposed.

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1.0 INTRODUCTION

At the request of Farmers Union Oil Company and the North Dakota Department of Health (NDDH), the Energy & Environmental Research Center (EERC) initiated remediation of hydrocarbon-contaminated soils and groundwater associated with gasoline release at the Cenex station in Garrison, North Dakota.

This report for Phase I of the project presents a summary of system design and construction activities, including initial operational data. More detailed information, original data sets, and primary documentation are compiled in technical progress reports provided to the sponsors and regulatory agency on a quarterly basis. The project, sponsored by the North Dakota Petroleum Tank Release and Compensation Fund (NDPTRCF) via its policyholder Farmers Union Oil Company and the U.S. Department of Energy (DOE), is supervised by NDDH.

2.0 EXPERIMENTAL

The remedial strategy implemented is based on application of two innovative concepts: 1) simultaneous operation of a soil vapor and multiphase extraction system allowing for water-table control in challenging geotechnical conditions and 2) controlled hot-air circulation between injection and extraction wells to accelerated in situ contaminants of concern (COC) volatilization and stripping alternatively using the same wells as either extraction or injection points.

Complex geotechnical conditions—a high-permeability environment with contaminant transport bound to preferential pathways in the fractured coal seam and abandoned mining voids and cavities—required the combination of remediation technologies capable of:

- Efficiently removing residual free product from the saturated zone while providing for water-table control at desired levels.
- Extracting large volumes of contaminated vapors from the vadose and dewatered zones to accelerate in situ volatilization while being flexible enough to address water-table fluctuation across the contaminant smear zone.
- Stimulating in situ natural biodegradation processes by providing air to the oxygen-depleted target/smear zone.

Additional objectives and requirements for this demonstration were:

- A flexible design and operation of mobile extraction and injection systems to overcome site limitations associated with settings in high-traffic areas.
- Well field design that would not be disruptive to traffic and daily operation of facilities at the site.

The three basic operational steps illustrated in Figure 1 are as follows: Step 1 is based on conventional soil vapor extraction (SVE) extraction, with the primary goal to accelerate volatilization of residual free product in the unsaturated zone; Step 2 employs initiation of hot-air injection and circulation of injected air between injection and extraction wells to promote in situ stripping of residual volatile organic compounds (VOCs); and Step 3 consists of relay of hot-air injection into the next row of wells previously used for extraction.

3.0 RESULTS AND DOCUMENTATION

3.1 Site Characteristics

3.1.1 Site Location and Contaminant Release History

The original source area is at Farmers Union Oil Company, 209 Southwest 4th Avenue, T148N R84W Section 8, McLean County, Garrison, North Dakota. The confirmed impacted zone covers an area of about 40 acres, with hot spots being identified at the Cenex station (location of original release), the downgradient west corner of the Tesoro station, and in mining cavities intercepting the plume south of the release area. The site plan and extraction well field layout, including the inferred contaminant plume, are provided in Figure 2 and Appendix A, respectively.

Gasoline-impacted soil and groundwater were discovered during drilling by the Public Service Commission in September 2005. An inventory loss of 30,000 gallons of gasoline at the Farmers Union Oil Company in Garrison, North Dakota, was reported to NDDH in October 2005. Limited site investigation by Western Plains Consulting in 2005/2006 confirmed COC impact downgradient from the Farmers Union service station. A pilot test and feasibility study for vacuum-enhanced recovery was conducted by the EERC in 2007 [1].

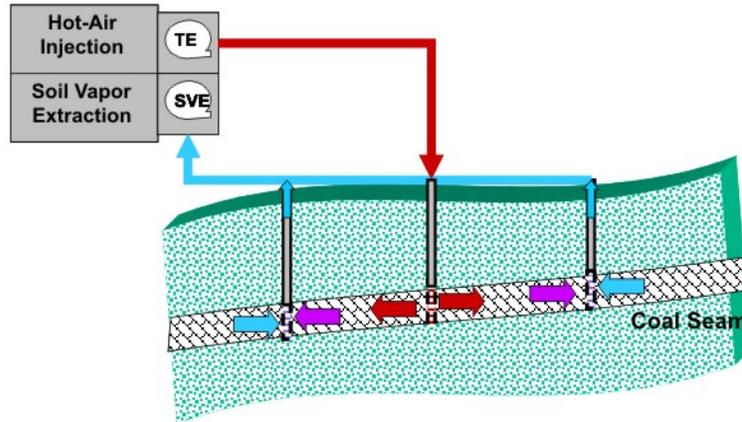
3.1.2 Geotechnical Conditions

The sediment profile intercepted by exploratory drilling in source and impacted areas is dominated by a heterogeneous complex of silty, sandy clays interbedded with several layers of fractured lignite. Fractured coal layers ranging in thickness from inches to several feet provide hydraulic conduits for contaminant transport. The first and most distinguished layer of contaminated lignite is documented from the source area at a depth of 15–20 ft. This layer, plunging south–southwest, is continuously developed downgradient from the contaminant release across the entire impacted area (Appendix A). Because of its thickness, ranging between 5 and 10 ft, the lignite was extensively mined from the beginning to the middle of the last century. The coal core samples and samples from outcrops indicate that slightly plastic lignite is intensively fractured and separates along tension and compression fractures as well as along thin peels/horizontal fissures, reflecting its sedimentary origin. Intensity and aperture of fractures increases in areas of coal exposure (outcrops) or disturbance, such as in cavities.

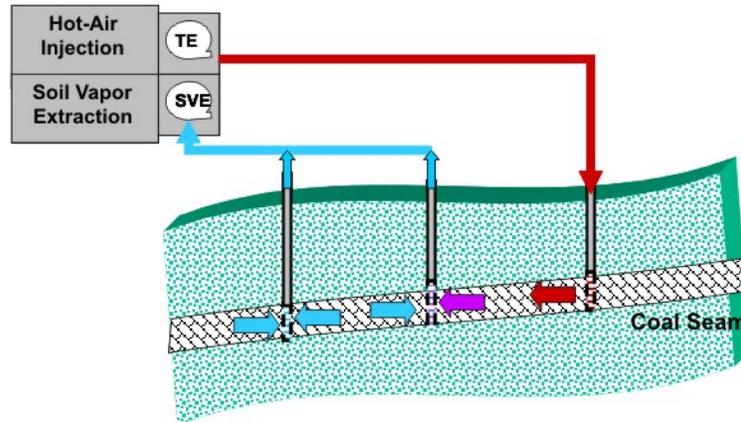
The second continuously developed coal seam used as a primary water source for domestic wells is hydraulically isolated by about 90 ft of silty clays interbedded with discontinuous thinner lignite seams or lenses. This deeper coal seam was not mined, and no contamination has been confirmed from domestic wells to date.

Step 1: Soil Vapor Extraction

EERC JS33837.CDR



Step 2: Soil Vapor Enhanced with Hot-Air Injection – Initial Injection Row



Step 3: Soil Vapor Enhanced with Hot-Air Injection – Relay to Second Injection Row

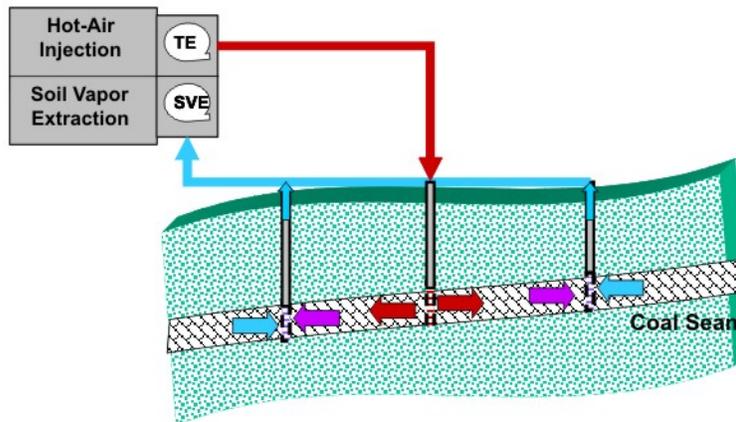


Figure 1. Thermally enhanced SVE – well field relay.

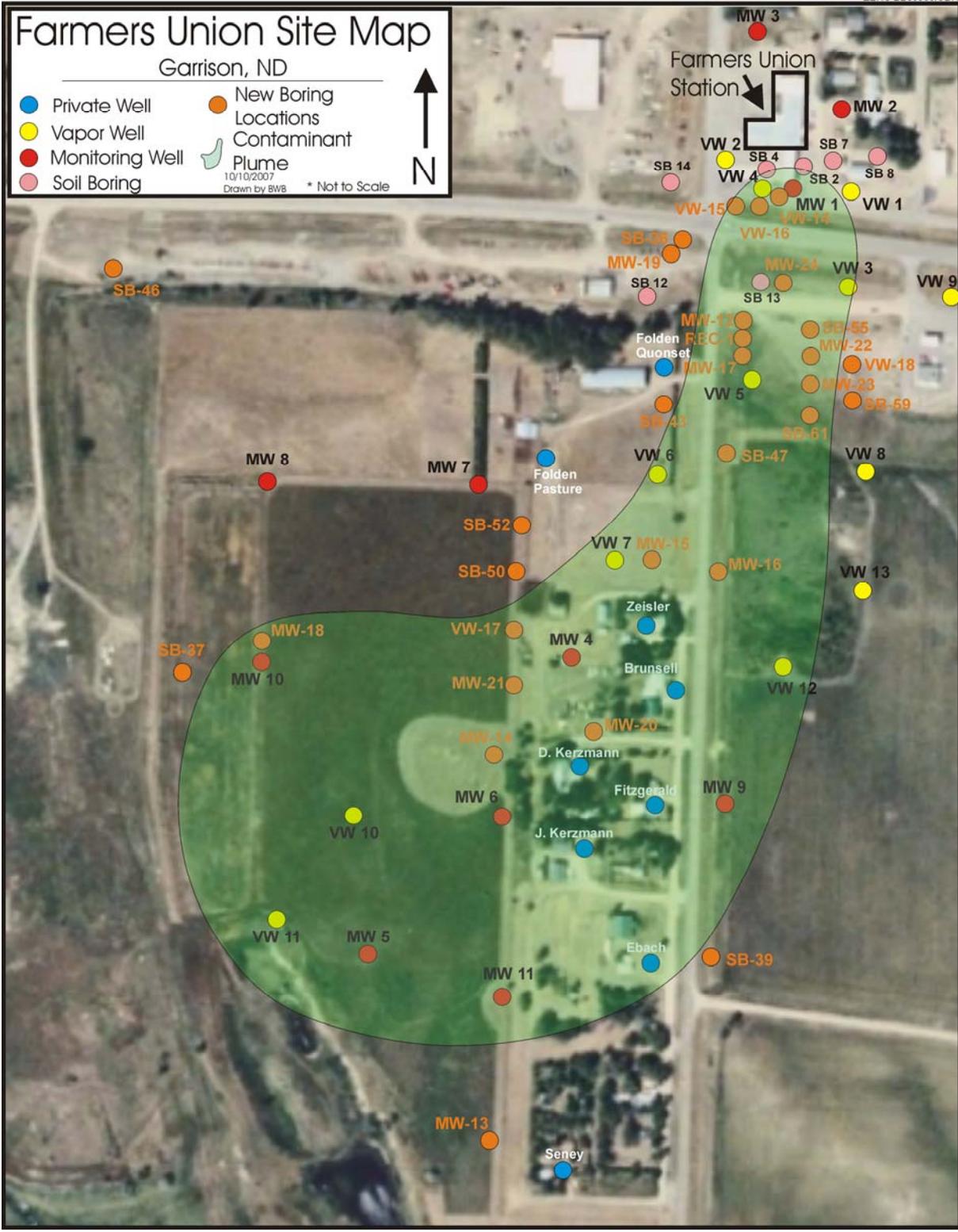


Figure 2. Site plan (conditions prior to system installation).

3.1.3 Hydrogeology and Contaminant Transport

Depth to groundwater across the source and impacted areas exhibits high temporal and spatial variability and reflects the occurrence of abandoned mining cavities that altered the natural gradient and provide for accelerated drainage. The groundwater table configuration for the source and wider area is presented in Appendix B. Primary groundwater occurrence is bound to the fractured coal aquifer, with the dominant flow direction to the south toward Lake Sakakawea.

The targeted sediment profile in the source/contaminant release area (Cenex corner) is not continuously saturated. The groundwater occurs only at the bottom of the coal seam at a depth of about 20 ft (well MW-1), and its level is controlled by relatively quick transport to the south via fractured coal. Coal is more saturated at the Tesoro corner. Depth to water ranged between 19.5 and 26 ft belowground, with about 50% of the coal seam submerged under the water table [1]. Similarly to the release area, the properties of the coal provide for accelerated drainage further magnified by the presence of a discrete network of abandoned cavities. A water table drop from 20 to 25 ft belowground in the source area to 60 ft in the center of the downgradient plume translates into a relatively steep hydraulic gradient. The presence of cavities allowing for relatively unhindered groundwater flow to areas not controlled by natural gradient likely explains the COC occurrence in distant wells MW-10 and MW-18 far west of the dominant flow direction. In addition to aqueous-phase contaminant migration, cavities provide vapor flow channels that allow for migration of gaseous (vapor)-phase volatile organics in response to soil thermal gradients. EERC coal testing confirmed that soils and coal exposed to contaminated vapors can serve as a secondary source of contaminants after resaturation [1].

Contrary to flow acceleration, partial or full collapse of cavities, including structural fill injected during the stabilization effort by the state in 1992–1993, may form underground barriers that dam the flow within the cavities and result in mounding, formation of saturated pockets, or even partial aquifer confinement. Higher saturation of the coal seam is documented in the center of the impacted area around wells MW-6, 14, and 20.

Considering all factors presented, the conceptual migration model is based on repeated saturation and drainage of the contaminated coal seam in the source/recharge area with relatively active COC migration downgradient. The primary factors contributing to off-source migration are highly permeable fractured coal, abandoned mining cavities, and vapor transport. While fast off-site migration would result in a relatively narrow plume (such as the geometry documented at the Cenex and Tesoro corners), the presence of perpendicularly intercepting cavities provides for fast lateral as well as downgradient spreading of COCs. Concentrations of COCs stabilized in the source area; however, slightly increasing trends are documented from some downgradient monitoring wells [1].

Groundwater chemistry at the site is dominated by sodium, calcium, and sulfate ions, with a high concentration of iron (40 mg/l in well MW-20), hardness exceeding 1300 mg/l, and electrical conductivity (EC) over 2500 $\mu\text{S}/\text{cm}$. Biodegradation parameters exhibit trends typical of an anaerobic contaminant plume, with suppressed oxygen, nitrate, phosphorus, and sulfate concentrations and elevated concentrations of iron and manganese (Appendix E-2). While nitrogen–nitrate concentrations are exceeding the drinking water standard of 10 mg/l in upgradient wells (MW-2), analyses from wells within and downgradient of the impacted area indicate that nitrate is effectively consumed to below detection limit within the dissolved benzene, toluene, ethylbenzene, and xylenes (BTEX) plume.

3.2 Extraction, Monitoring, and Injection Well Fields

The extraction well fields consist of 24 dual-purpose SVE–hot-air-sparging (AS) wells and five (5) multiphase extraction (MPE) wells. The SVE and sparging well field at the Cenex corner consists of ten (10) wells. Fourteen (14) SVE–AS wells and five (5) MPE wells comprise the extraction well field at the Tesoro corner. While the primary extraction load will be carried by the thermally enhanced SVE system, the MPE system at the Tesoro corner was designed to provide for water-table control and recovery of dissolved-phase COC in areas with a partially saturated contaminated target zone.

Extraction wells are located approximately 40 ft apart, with a projected pneumatic radius of influence of about 40–50 ft. In addition, the MPE well alignment allows for groundwater flow intercept and water-table control between the most impacted areas and downgradient coal seam. Spacing of MPE wells (50–55 ft) and their completion provide for dewatering of the partially saturated contaminant smear zone bound to the coal seam, thus allowing air to be a primary carrier for contaminant removal.

SVE wells were advanced by a 4-in.-i.d. (8-in.-o.d.) hollow-stem auger using a CME 75 drill rig. Wells were completed with 2-in.-diameter flush-threaded PVC, Schedule 40, with a 0.010-in. slot screen and No. 45-55 red flint gravel pack. SVE wells were equipped with 2-in. Schedule 40 Tee adaptors installed approximately 3–4 ft belowground and connected to the SVE–AS system using 2-in. pipes.

MPE wells were advanced by a 6-in.-i.d. (10-in.-o.d.) hollow-stem auger using a CME 75 drill rig. Wells were completed with 4-in.-diameter flush-threaded PVC, Schedule 40, with a 0.020-in. slot screen and No. 30 red flint gravel pack. MPE extraction wells are equipped with pitless adaptors installed approximately 4 ft belowground with 1-in. PVC suction tubes extending 4 ft below the water table (at the time of construction). All extraction and monitoring wells are further equipped with pressure and water-table-monitoring ports with a ¾-in. drop tube extending to <1 ft from the bottom of the well. Well completion data including geologic and survey logs are provided in the Technical Progress Report for March – September 2008 [2].

3.3 Remediation and Treatment Systems

The extraction and treatment system at the Cenex site consists of a 30-hp positive displacement blower package rated for 900 acfm @ 9" Hg and the 60-gal air–liquid separator (ALS). Water from the separator is treated in a 60-lb granular activated carbon (GAC) unit. The AS package includes a 20-hp (140 cfm @ 30 psig) oil-free rotary claw blower system. The entire system is enclosed in a 10- × 20-ft building.

The extraction and treatment system at the Tesoro corner integrates two extraction units (SVE and MPE) with combined water treatment and an AS package. The SVE system consists of a 20-hp centrifugal blower package rated for 1250 acfm @ 40-in. H₂O. Extracted air and soil moisture undergo separation in a 60-gal air–water separator. Water from the separator is conveyed to the MPE treatment system. The MPE extraction and treatment system consists of an SSI four-stage oil-free regenerative vacuum blower rated for 150 acfm and end vacuum of 20-in. Hg. Because no free product is anticipated at the site, recovered water and air pass through the 60-gal vapor–liquid separator (VLS) directly to a low-profile QED LP-2.4P air stripper. Effluent-treated water from the AS is conveyed to a drainage ditch west of the treatment building. The AS package includes a 7.5-hp (100 cfm @ 10 psig) positive displacement blower system. The entire system is enclosed in a 10- × 24-ft building.

Both remediation systems are equipped with a NEMA 4 controller, Simatic S-7-200 programmable logical controller (PLC), and CP 243-1 IT communications processor telemetry package, allowing for both on-site and telemetric control of the power circuits for motors for individual system units. The schematic system layouts including process and instrumentation diagrams are provided in Appendix C; suction links from individual extraction wells are presented in Appendix A.

3.3.1 Initial System Performance Monitoring

The SVE and MPE system at the Tesoro site started operation on November 13, 2008. The SVE system at the Cenex site started break-in operation on November 13, 2008. After a brief period of system optimization and installation of a high-performance exhaust silencer, full-scale operation started November 25, 2008. Performance monitoring for the noted remediation systems consists of water quality monitoring of effluents from individual system units and treated effluent, offgas monitoring using charcoal tubes, and real-time monitoring of total petroleum hydrocarbons (TPH), CO₂, and O₂ in offgas using a multiparameter hydrocarbon analyzer, flame ionization detector (FID), and photoionization detector (PID).

The current MPE extraction well field consists of wells MPE 1–5; active SVE well fields consist of wells SVE 1–10 at the Cenex site and SVE 11–24 at the Tesoro corner. Operation of the AS subsystem will be initiated after target zone dewatering in the spring months. Initial operational parameters for remediation systems are summarized in Tables 1 and 2.

Table 1. SVE System Operational Parameters

Site	Cenex	Tesoro
Well Field	SVE – 1 through 10	SVE – 11 through 24
Well Field Operated (date)	11/25/08–12/16/08	11/13/08–12/15/08
Blower Vacuum (in. H ₂ O)	103–124	45–46
Wellhead Vacuum (in. H ₂ O)	66.3–107.8	0.7–44.3
Combined Airflow (scfm)	438–521	275–305
Run Time – total (h) (operation %)	521.4 (100%)	794.5 (100%)
Down Time – total (h)	0	0

Table 2. MPE System Operational Parameters

Well Field	MPE– 1, 2, 3, 4, 5
Well Field Operated (date)	11/13/08–12/15/08
Blower Vacuum (in. Hg)	10.5–12.0
Wellhead Vacuum (in. H ₂ O)	12.3–61.6
Groundwater Flow (gpm)	0.2–0.4
Groundwater Recovered – total (gal)	17,208
Combined Airflow (scfm)	98–110
Run Time – total (h) (operation %)	757.9 (95%)
Down Time – total (h)	39.0

3.3.2 System Water Quality

Samples of extracted water and treated effluent were analyzed for COC (BTEX, phenols, and TPH as gasoline range organics [GRO]), total iron and manganese, and suspended solids. Field-measured parameters included pH, EC, and temperature. A summary of initial extraction and treatment data is provided in Appendix D-1; complete analytical documentation is in the respective technical progress reports.

3.3.3 Offgas Quality

Offgas quality from individual system exhausts is monitored using charcoal tubes and real-time monitoring of hydrocarbons, CO₂, and O₂ using a MiniRae[®] multiparameter analyzer, PID, and FID. Initial offgas-sampling results using charcoal tube desorption analyzed by gas chromatography (GC)/FID are summarized in Appendix D-2.

Offgas samples from the Cenex SVE system were collected in a 1-l Tedlar bag filled for 60 seconds at a rate of approximately 0.3 l/min. Charcoal tube samples were subsequently collected from the Tedlar bag using an SKC pump, with flow regulated at 0.28 l/min and a sample interval of 60 seconds. The same procedure was used for sampling of the MPE system at the Tesoro well field. Because of high discharge velocity and negative pressure at the Tesoro SVE system exhaust, offgas samples are collected directly using the SKC pump and flow through the charcoal tube regulated at 0.28 l/min for 60 seconds.

Airflow is measured using a Dwyer[®] handheld manometer to monitor differential pressure at the Pitot tubes (DS-300 flow sensor) mounted on exhaust manifolds from individual blowers. The resulting flow values are presented after conversion to standard conditions. In case air dilution is necessary to lower extraction vacuum, the flow at the dilution valve is subtracted from the exhaust flow values. Effluent airflow at the Cenex SVE system ranged from 438 to 521 scfm; offgas temperature fluctuated between 128° and 148°F. Airflow from the Tesoro SVE system ranged from 275 to 305 scfm, with an offgas temperature between 123° and 130°F; MPE system airflow ranged from 98 to 110 scfm, with temperature fluctuating between 145° and 150°F.

Carbon dioxide and oxygen trends in extracted vapors were monitored using the MiniRae[®] multiparameter analyzer (Appendix D-2). Observed data for CO₂ (4%–5%) and oxygen (10%–17%) are characteristic of the coal seam, with limited air exchange and active biodegradation processes resulting in an oxygen-deficient environment with surplus of methane and carbon dioxide. These trends will reverse as a result of dynamic soil air exchange in response to SVE and MPE system operation.

3.3.4 Hydraulic and Pneumatic Response

Hydraulic response in the area impacted by operation of extraction well fields is monitored during monthly maintenance and sampling events. Depth to water within the area influenced by extraction well fields ranged from 19.35 to 26.56 ft belowground between August 25 and December 16, 2008, indicating a relatively flat configuration in the source with south–southwest gradient. In spite of the high hydraulic conductivity of the target zone (fractured coal seam) and extremely wet fall of 2008, the observed water-table decline on monitoring wells of up to 0.34 ft (well MW-24) is documented within the first month of operation. Vacuum-induced depression and water-table control in response to MPE operation resulted in efficient operation of the SVE well field at the Tesoro site without production of excessive moisture from SVE wells.

Extraction well vacuums ranged from 0.6 to 107.8 in. H₂O and resulted in up to 5.5 ft of water-table drawdown or temporary dewatering of extraction well MPE-3. Pneumatic impact of the robust extraction systems is observed as far as 400 ft (MW-9) from the center of the extraction well field.

3.4 Initial Contaminant Recovery Estimates

The contaminant mass removal estimates were determined using the volumes for extracted groundwater and vapor and average VOC concentration obtained between two consecutive sampling events. A total of 18,137 gallons (68.7 m³) of groundwater and 31.4 million ft³ (891,260 m³) of contaminated soil vapor have been extracted from both well fields since extraction start-up, resulting in removal of over 13,693 lb of hydrocarbons prior to stripping and an additional 0.7 lb from the treated groundwater. The mass of recovered contaminant equals approximately 2188 gal of product, assuming specific gravity for gasoline of 0.75 g/cm³. The average liquid flow rate since MPE system start-up was approximately 0.3 gpm, ranging from 0.2–0.4 gpm; the airflow rate for SVE systems ranged from 275 to 521 scfm. Initial mass removal calculations are provided in Tables 3 and 4; cumulative recovery is presented in Figure 3.

3.5 Groundwater Quality Monitoring

3.5.1 Sampling Program

Monitoring and extraction wells will be sampled for BTEX, GRO, and biodegradation indicators on a semiannual basis to document overall remediation system impact on groundwater quality compared to original background site data collected in August 2008 (prior to system start-up).

Table 3. Contaminant Recovery – Liquid Phase

Date	Totalizer (gal)	Flow (gpm)	TPH _{water} mg/l	BTEX _{water} mg/l	TPH _{mass} (lb)	BTEX _{mass} (lb)
Cenex						
11/25/08	227	0.3	31.50	15.5	0.1	0.029
12/16/08	929	0.0	13.79	5.6	0.1	0.061
Tesoro						
11/13/08	339	0.2	9.49	3.8	0.0	0.011
11/25/08	6835	0.4	2.57	1.1	0.3	0.131
12/15/08	17,208	0.4	0.98	0.3	0.2	0.060
Total					0.7	0.3

Table 4. Contaminant Recovery – Vapor Phase

Date	Runtime (cum. h)	Q _{air} (scfm)	Volume (1000 ft ³)	TPH _{air} ¹ (mg/m ³)	BTEX _{air} ¹ (mg/m ³)	TPH _{mass} (lb)	BTEX _{mass} (lb)
Cenex SVE							
11/25/08	20.2	521	172	4180	807.0	45	8.6
12/16/08	521.4	438	13183	1510	433.5	2341	507.4
Tesoro MPE							
11/13/08	25.1	98	104	32,850	441.0	212	2.9
11/25/08	318.1	107	1876	1815	91.1	962	31.2
12/15/08	757.9	110	2895	936	40.0	249	11.8
Tesoro SVE							
11/13/08	25.1	305	230	41,300	433.0	592	6.2
11/25/08	318.1	275	5100	10,383	444.3	5766	138.8
12/15/08	794.5	278	7912	3890	270.0	3525	175.4
Total			31,471			13,693	882

¹ Mean values from replicate samples.

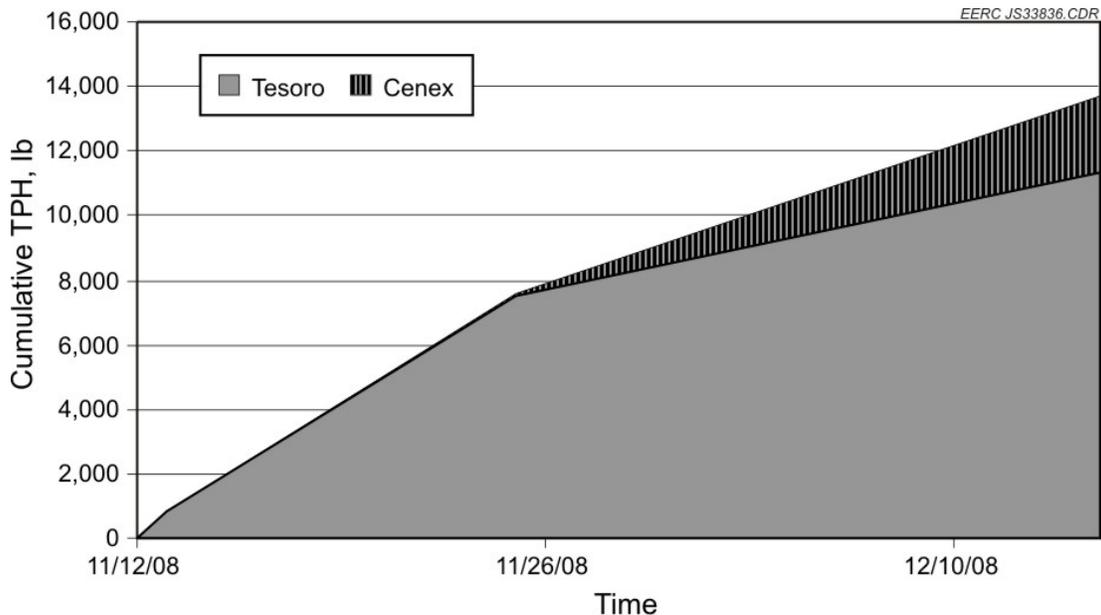


Figure 3. Total hydrocarbon removal.

Groundwater samples were collected using disposable PVC bailers, preserved on-site, and stored on ice prior to and during shipment. Analyses were conducted by MVTL in Bismarck, North Dakota, and New Ulm, Minnesota. Quality assurance/quality control samples included duplicates, equipment blanks, field blanks, and trip blanks for each sampling event. Field-monitored water quality parameters were measured in wells with an YSI-556 multiprobe. In addition to EERC background sampling conducted prior to initiation of remedial system operation, COC trends and previous analysis were evaluated based on documentation provided by NDDH (Appendix E).

4.0 CONCLUSIONS

This report for Phase I of the project presents a summary of system design and construction activities, including initial operational data. The SVE and MPE system at the Tesoro site started break-in operation on November 13, 2008, the SVE system at the Cenex site has operated since November 25, 2008.

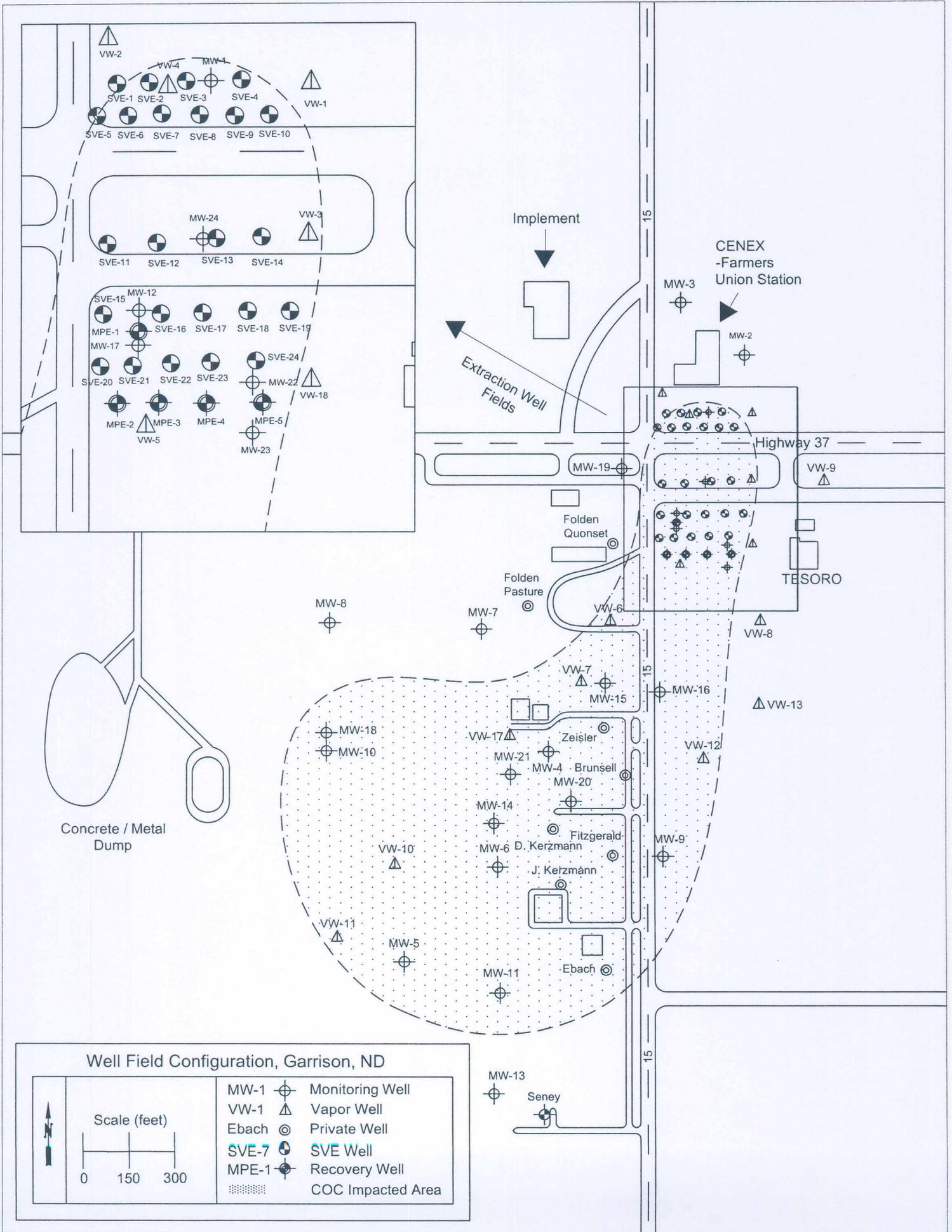
Initial performance monitoring data suggest high contaminant recovery efficiency and a well-developed radius of influence within the targeted area. A total of 18,137 gallons (68.7 m³) of groundwater and 31.4 million ft³ (891,260 m³) of contaminated soil vapor have been extracted from both well fields within the first month of operation, resulting in removal of over 13,693 lb of hydrocarbons. The mass of recovered contaminant equals approximately 2188 gal of product, assuming specific gravity for gasoline of 0.75 g/cm³.

5.0 REFERENCES

1. Solc J., 2007, *Risk Assessment and Feasibility of Remedial Alternatives for Coal Seam at Garrison, North Dakota*. Final Report 2007-EERC-10-10; Energy & Environmental Research Center; Grand Forks, ND, 2007.
2. Solc J.; and Botnen, B., 2008, *Technological Synergies for Recovery of Organic Pollutants from a Coal Seam at Garrison, North Dakota*. Technical Progress Report: March–September 2008. Energy & Environmental Research Center; Grand Forks, ND, 2008.

APPENDIX A

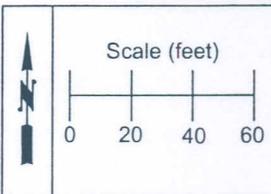
**SITE PLAN AND EXTRACTION/INJECTION WELL
FIELDS**



Well Field Configuration, Garrison, ND

	<p>Scale (feet)</p>	MW-1		Monitoring Well
		VW-1		Vapor Well
		Ebach		Private Well
		SVE-7		SVE Well
		MPE-1		Recovery Well
				COC Impacted Area

Trenching and System Layout, Garrison, ND



MW-1		Monitoring Well
VW-1		Vapor MW
SVE-1		Dual-Purpose Wells
MPE-1		MPE Wells
		Pipe Layout

Cenex



SVE/AS System



Highway 37



Extraction System



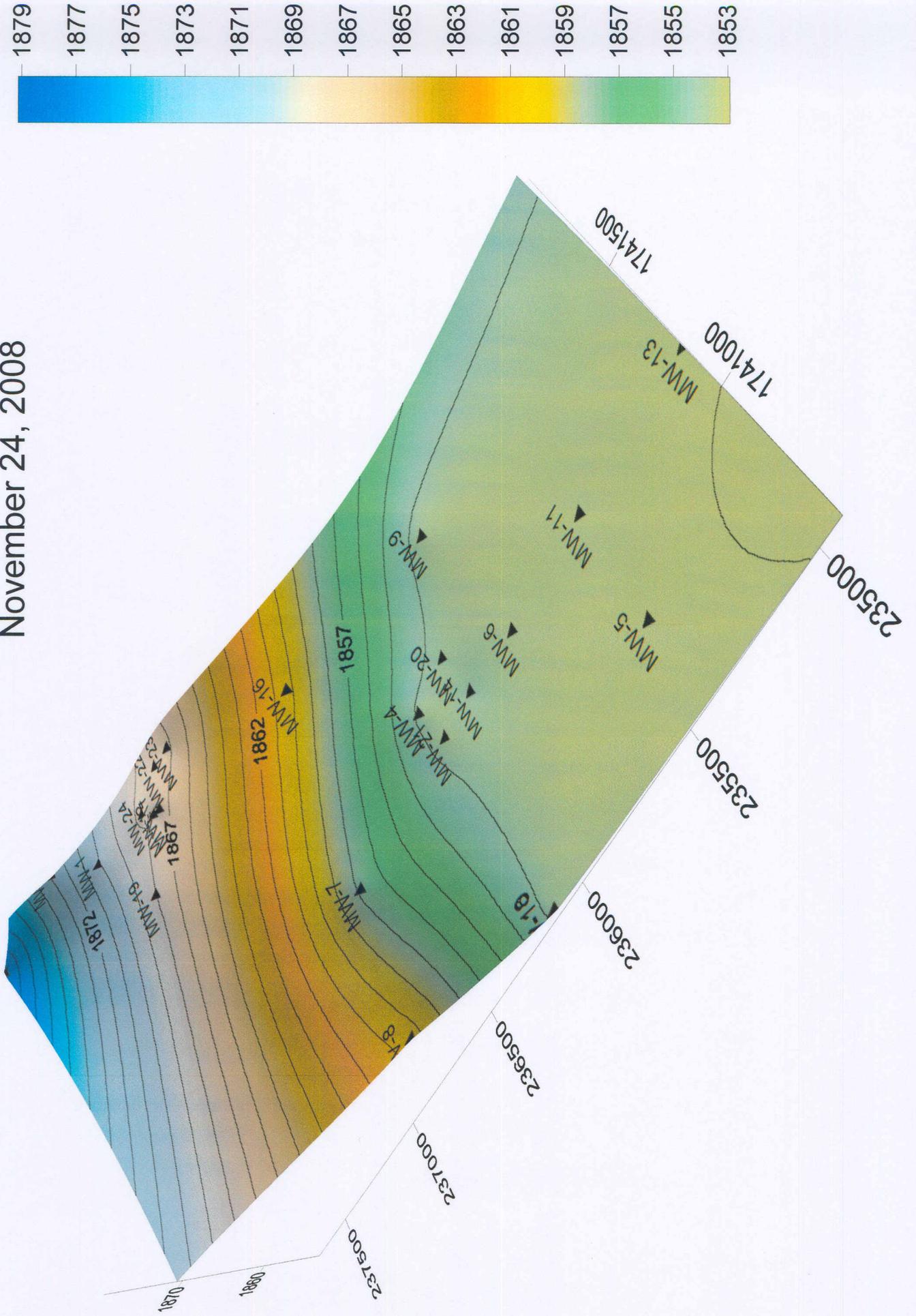
Tesoro

APPENDIX B

GROUNDWATER TABLE MONITORING – SUMMARY OF DATA

Groundwater Table Configuration

November 24, 2008



Groundwater Levels

Elevations in feet

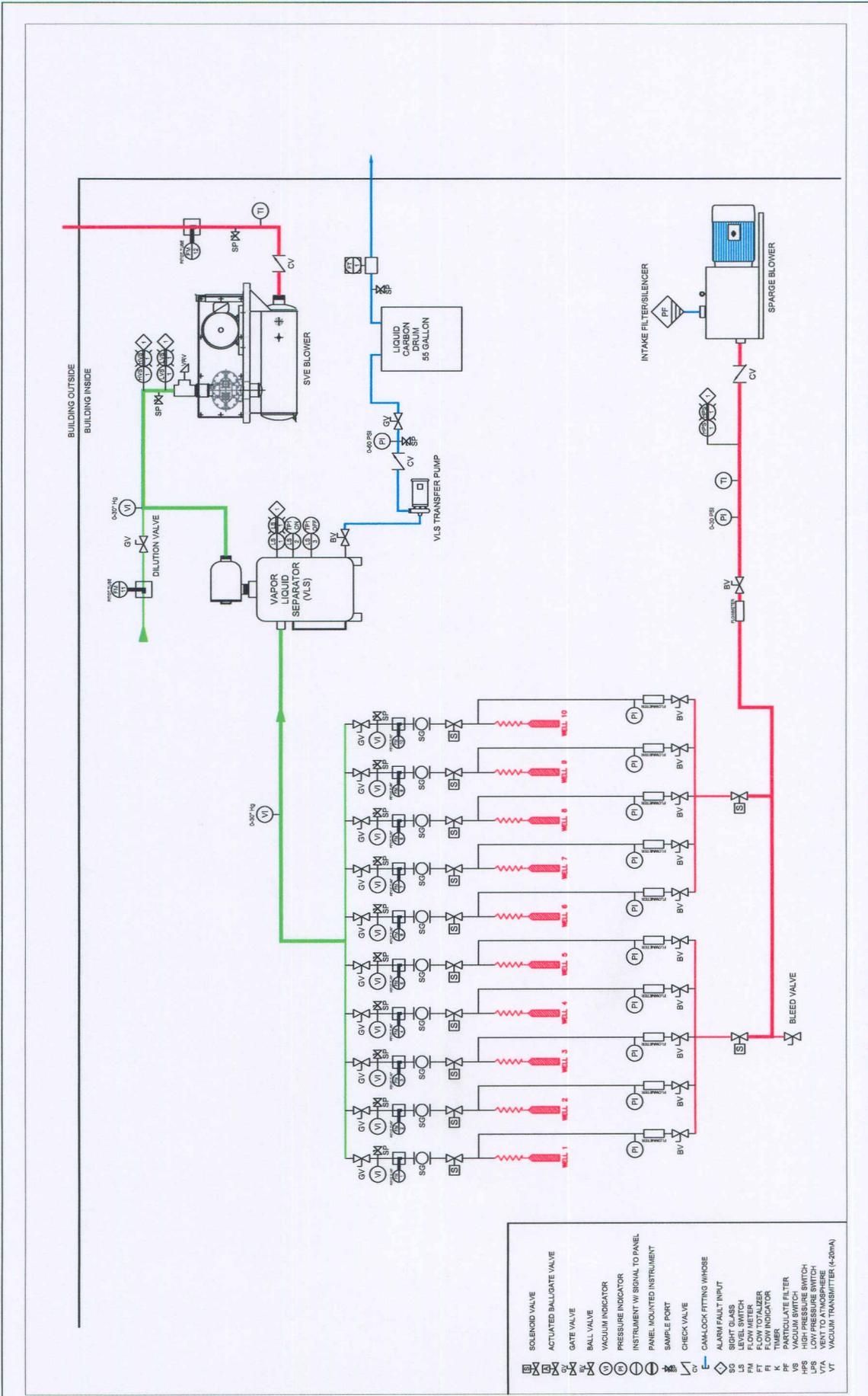
Well ID	MP (TOC) ¹	Ground	08/25/08	11/24/08	12/18/08
Monitoring Wells					
MW-1	1889.58	1889.74	1869.71	1870.06	1869.96
MW-2	1890.36	1890.65	1872.76	1872.80	nm
MW-3	1893.63	1891.66	1879.13	1879.23	nm
MW-4	1913.73	1911.36	1853.98	1853.76	nm
MW-5	1902.26	1899.13	1853.26	1853.14	nm
MW-6	1907.61	1905.11	1853.61	1853.41	nm
MW-7	1901.30	1898.81	1857.71	1857.73	nm
MW-8	1899.29	1896.28	1860.50	1860.56	nm
MW-9	1907.19	1907.37	1853.67	1853.51	nm
MW-10	1891.06	1888.03	1854.87	1853.70	nm
MW-11	1905.89	1902.74	1853.39	1853.26	nm
MW-12	1888.63	1888.93	1867.90	1868.12	1867.72
MW-13	1900.35	1900.70	1858.18	1853.10	nm
MW-14	1896.90	1897.63	1854.38	1853.95	nm
MW-15	1899.23	1899.41	1856.60	nm	nm
MW-16	1895.83	1895.94	1859.21	1860.37	nm
MW-17	1887.81	1888.12	1867.54	1867.31	1867.32
MW-18	1887.95	1888.41	1853.90	1853.74	nm
MW-19	1885.15	1885.24	1868.23	1868.00	nm
MW-20	1899.45	1899.92	1853.98	1853.78	nm
MW-21	1906.45	1906.76	1854.02	1853.61	nm
MW-22	1890.49	1890.76	1867.57	1867.65	1867.27
MW-23	1886.63	1886.76	1867.28	1867.33	1867.11
MW-24	1889.31	1889.71	1867.72	1867.66	1867.38
MPE-1	1888.25	1888.47	1867.61	1862.90	1863.94

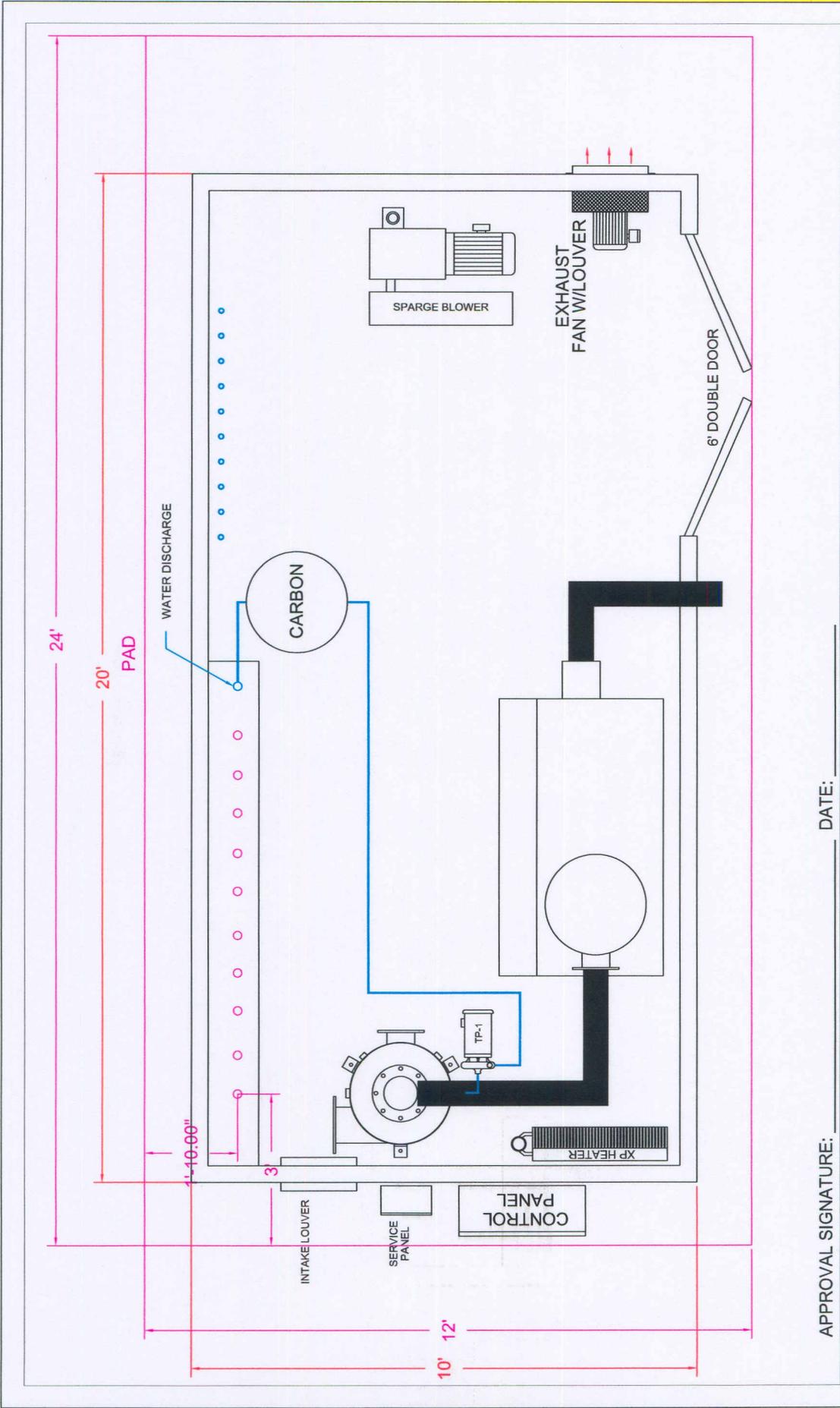
¹MP (TOC) - measuring point after wellhead instrumentation or top of casing

nm Not measured, inaccessible due to ice and snow cover

APPENDIX C
REMEDIAL SYSTEM DESIGN

APPENDIX C-1
CENEX SVE/AS SYSTEM



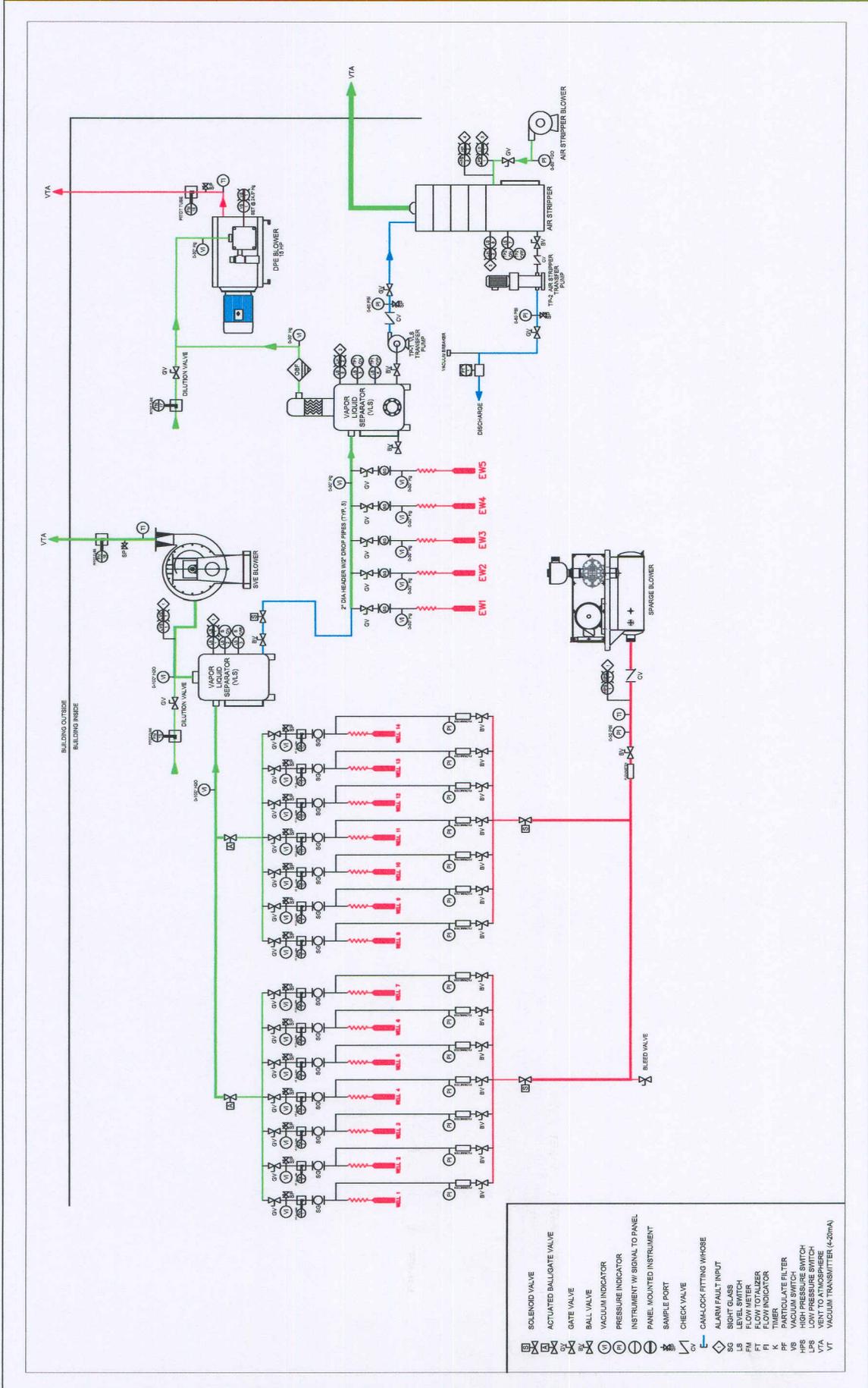


APPROVAL SIGNATURE: _____ DATE: _____

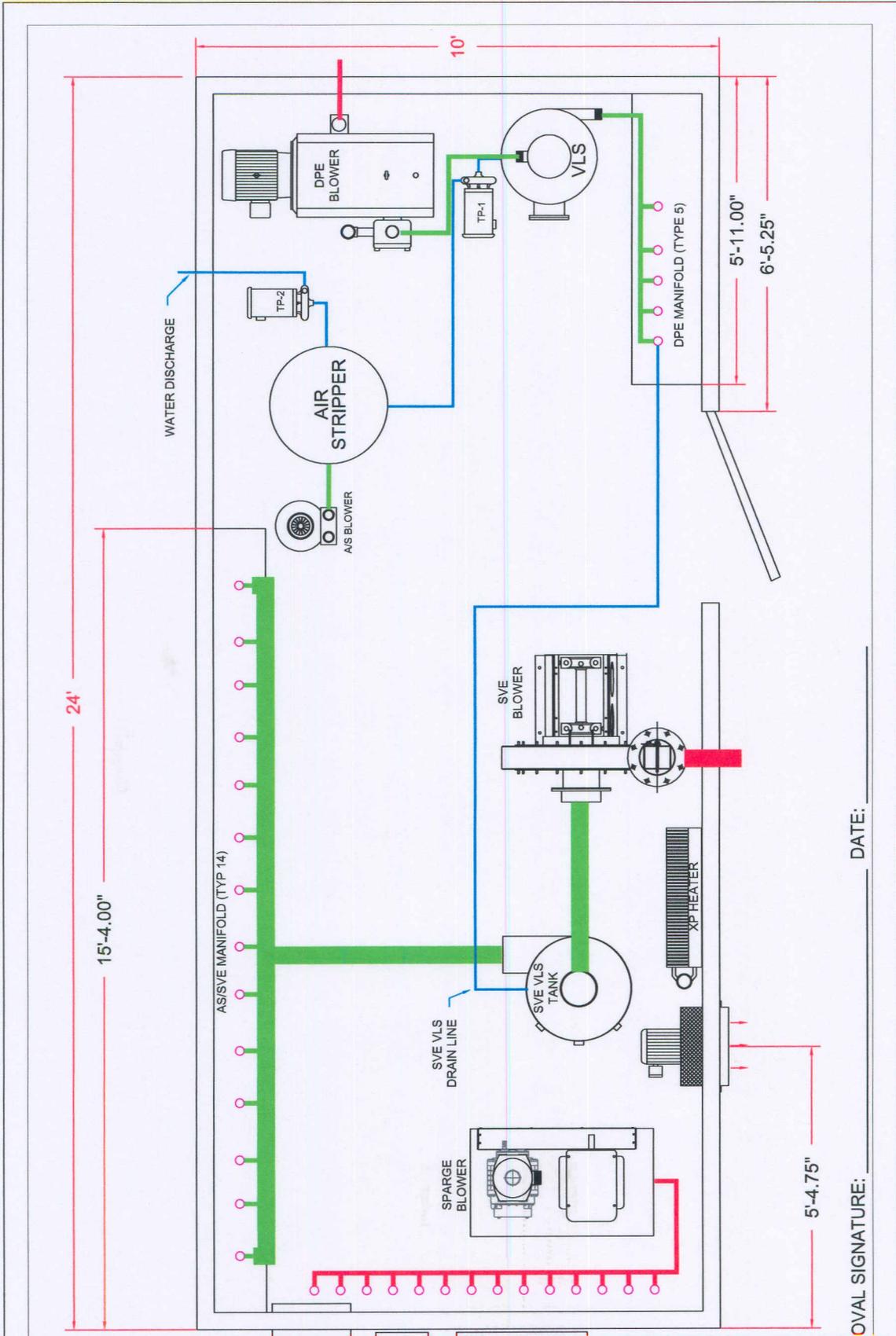
TITLE: EQUIPMENT LAYOUT - PLAN VIEW		DWG: MV	DATE: 8/27/08
EERC		CHKD: SB	DRAWING #:
Garrison ND - CENEX Site		REV: 1	1027-Plan View

APPENDIX C-2

TESORO SVE/AS AND MPE SYSTEM



TITLE: PROCESS & INSTRUMENTATION DIAGRAM		DATE: 10/9/2008	
EERC - GARRISON, ND TESORO SITE		DWN: MV	CHKD: SB
AS/SVE/DPE SYSTEM		REV: 1	DRAWING # 1046-PID



DATE: _____

Signature line

TITLE: EQUIPMENT LAYOUT - PLAN VIEW		DATE: 10/15/2008	
DWN: MV	CHKD: SB	DRAWING #: 1046-Plan View	
REV.: 1			

APPENDIX D

SUMMARY OF DATA – SYSTEM MONITORING

APPENDIX D-1
WATER QUALITY

SYSTEM WATER QUALITY MONITORING

VLS		Tesoro			Cenex	
		11/13/08	11/25/08	12/15/08	11/25/08	12/15/08
MBTE	ppb	<10	<10	<1	<100	<50
Benzene	ppb	1584	377.1	93.3	4800	576
Toluene	ppb	725.8	211.6	44.1	6544	1990
Ethylbenzene	ppb	216.5	46.1	11.4	590.7	351.6
Xylenes (Total)	ppb	1260	421.6	180.8	3535	2685
GRO (TPH)	mg/l	9.49	2.57	0.98	31.50	13.79

Selected Parameters		VLS			Cenex	
VLS		11/13/08	11/25/08	12/15/08	11/25/08	12/15/08
pH		6.8	6.9	7.0	6.3	6.42
EC	μS/cm	1105	1093	1116	2175	2093
T	°C	11.2	14.8	10.9	15.29	6.32

Effluent		Tesoro			Cenex	
		11/13/08	11/25/08	12/15/08	11/25/08	12/15/08
MBTE	ppb	<1	<1	<1	<1	<1
Benzene	ppb	274.4	102.2	21.5	13	4.2
Toluene	ppb	133.7	59.7	12.8	16.8	11.1
Ethylbenzene	ppb	35.8	10.9	3	1.6	1.6
Xylenes (Total)	ppb	202.0	121.0	54.5	12.4	14.3
Phenols (Total)	ppb	19.8	42.6	36.7	<10	<10
GRO (TPH)	mg/l	1.81	0.78	1.01	0.34	<0.2

Selected Parameters		Tesoro			Cenex	
Effluent		11/13/08	11/25/08	12/15/08	11/25/08	12/15/08
Fe (total)	mg/l	7.25	6.87	3.52	14.20	32.40
Mn (total)	mg/l	0.76	0.66	0.52	2.67	2.93
TSS	mg/l	56	8	21	117	57
pH		7.2	7.4	7.5	7.2	6.5
EC	μS/cm	1157	1097	1102	2181	2240
T	°C	12.8	17.9	15.8	9.9	5.7

VLS-Vapor/Liquid Separator Sample Port

APPENDIX D-2
OFFGAS QUALITY

OFFGAS QUALITY MONITORING - TESORO SYSTEM

Organic Vapors by Charcoal Tube Desorption, MiniRae Multiparameter Analyzer, and Photo Ionization Detector

Date/Time	Collection Interval	Sampling Flow Rate (L/min)	GRO (mg/m ³)	TPH (mg/m ³)	MTBE (mg/m ³)	Benzene (mg/m ³)	Toluene (mg/m ³)	Ethyl				CO ₂ %	O ₂ (ppm)
								Benzene (mg/m ³)	Xylenes (mg/m ³)	PID (ppm)			
Tesoro corner													
MPE													
11/13/08 17:55	¹ CT-60 s	0.28	20600	33100	ND	152	101	36	161	1104	4.1	15.4	
11/13/08 18:05	¹ CT-60 s	0.28	21000	32600	ND	151	97	34	150				
11/25/08 23:00	¹ CT-60 s	0.28	1340	1930	ND	50	22	3	17	247	4.0	16.6	
11/25/08 23:05	¹ CT-60 s	0.28	1180	1700	ND	47	24	3.2	16				
12/15/08 09:50	¹ CT-60 s	0.28	521	821	ND	14	6.4	ND	16	123	2.4	19.1	
12/15/08 09:20	¹ CT-60 s	0.28	679	1050	ND	15	8.6	ND	20				
SVE													
11/13/08 18:30	CT-120 s	0.28	ND	ND	ND	ND	ND	ND	ND	1871	8.3	5	
11/13/08 18:40	CT-120 s	0.28	24300	41300	ND	89	130	44	170				
11/25/08 21:30	CT-40 s	0.28	7450	9750	ND	133	113	36	178	983	5.0	10.1	
11/25/08 21:30	CT-90 s	0.28	8050	10800	ND	116	98	37	170				
11/25/08 21:30	CT-120 s	0.28	7960	10600	ND	120	106	40	186				
12/15/08 19:30	CT-60 s	0.28	3140	3960	ND	58	58	12	131	418	3.8	16.1	
12/15/08 19:35	CT-60 s	0.28	2990	3820	ND	65	60	12	144				

¹Charcoal tube sample collected from Tedlar bag

GRO - Gasoline Range Organics
 TPH - Total Purgeable Hydrocarbons
 FID - Flame Ionization Detector
 PID - Photoionization Detector
 Summit - Summit HydrocarbonAnalyzer
 CT - Charcoal Tube
 TB - Tedlar Bag

ND - Not Detected
 OL - Over detection limit
 >10,000 ppm for Summit (calibrated with hexane)
 >10,000 ppm for PID (calibrated with isobutylene)
 >50,000 ppm for FID (calibrated with methane)

OFFGAS QUALITY MONITORING - CENEX SYSTEM

Organic Vapors by Charcoal Tube Desorption, MiniRae Multiparameter Analyzer, and Photo Ionization Detector

Date/Time	Collection Interval	Sampling Flow Rate (L/min)	GRO (mg/m ³)	TPH (mg/m ³)	MTBE (mg/m ³)	Benzene (mg/m ³)	Toluene (mg/m ³)	Ethyl			CO ₂ %	O ₂ %
								Benzene (mg/m ³)	Xylenes (mg/m ³)	PID (ppm)		
11/25/08 19:30	¹ CT-60 s	0.28	4430	5500	ND	212	546	60	233	1420	4.95	10.7
11/25/08 19:35	¹ CT-60 s	0.28	2320	2860	ND	174	239	28	121			
12/16/08 16:45	¹ CT-60 s	0.28	1190	1430	ND	56	159	34	171	282	>5	17.1
12/16/08 16:50	¹ CT-60 s	0.28	1320	1590	ND	61	180	35	171			

¹Charcoal tube sample collected from Tedlar bag

GRO - Gasoline Range Organics
 TPH - Total Purgeable Hydrocarbons
 FID - Flame Ionization Detector
 PID - Photoionization Detector
 Summit - Summit Hydrocarbon Analyzer
 CT - Charcoal Tube
 TB - Tedlar Bag

ND - Not Detected
 OL - Over detection limit
 >10,000 ppm for Summit (calibrated with hexane)
 >10,000 ppm for PID (calibrated with isobutylene)
 >50,000 ppm for FID (calibrated with methane)

APPENDIX E

GROUNDWATER QUALITY MONITORING – SUMMARY OF DATA

APPENDIX E-1
COC IN GROUNDWATER

Garrison - BTEX Trends

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX ppb	BTEX trend
Monitoring Wells									
MW-1	08/14/06	ND	50500	78200	4160	25800	NA	158,660	
MW-1	12/12/06	<1000	49580	40210	3104	16770	250.0	109,664	
MW-1	01/17/07	<500	53880	55280	5888	33300	420.5	148,348	
MW-1	02/21/07	<1000	63150	60710	4308	24070	320.7	152,238	-
MW-1	03/28/07	Dry							
MW-1	04/25/07	<1000	72200	67500	5196	30510	348.4	175,406	
MW-1	05/15/07	<1000	59610	66580	10420	62580	551.4	199,741	
MW-1	06/13/07	<1000	52880	51040	4026	25020	288.2	133,254	
MW-1	09/11/07	<1000	56510	51880	3737	22820	237.3	135,184	
MW-2	08/14/06	ND	ND	ND	ND	ND	NA	0	
MW-2	09/18/06	ND	ND	ND	ND	ND	NA	0	
MW-2	12/12/06	<1	<1	<1	<1	<3	<0.2	0	
MW-2	01/17/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	02/21/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	03/28/07	Frozen							-
MW-2	04/25/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	05/15/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	06/12/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	09/11/07	<1	<1	<1	<1	<3	<0.2	0	
MW-2	08/26/08	<1	<1	<1	<1	<3	<0.2	0	
MW-3	08/14/06	ND	ND	ND	ND	ND	NA	0	
MW-3	09/18/06	ND	ND	ND	ND	ND	NA	0	
MW-3	12/12/06	<1	<1	<1	<1	<3	<0.2	0	
MW-3	01/17/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	02/21/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	03/28/07	<1	<1	<1	<1	<3	<0.2	0	-
MW-3	04/25/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	05/15/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	06/12/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	09/11/07	<1	<1	<1	<1	<3	<0.2	0	
MW-3	08/25/08	<1	<1	<1	<1	<3	<0.2	0	
MW-4	08/14/06	ND	986	ND	ND	ND	NA	986	
MW-4	09/18/06	ND	958	ND	ND	11.4	NA	969	
MW-4	10/20/06	ND	858	ND	ND	ND	NA	858	
MW-4	12/12/06	<1	1784	1.1	21.1	44.1	3.47	1,850	
MW-4	01/17/07	<1	1339	1.1	18.4	18.3	1.50	1,378	
MW-4	02/21/07	<20	2728	<20	85.2	85.1	6.28	2,905	▼
MW-4	03/28/07	<20	3349	42.1	121.5	160.4	7.17	3,680	
MW-4	04/25/07	<10	4689	59.2	248.9	462.7	9.65	5,469	
MW-4	05/15/07	<20	6732	497.8	719	1962	18.89	9,930	
MW-4	06/13/07	<10	3598	35.8	363.9	828	10.84	4,826	
MW-4	09/11/07	<10	4120	<10	423	782.7	10.44	5,326	
MW-4	08/25/08	<10	2818	<10	336.4	408.3	8.44	3,571	
MW-5	08/14/06	ND	15.7	ND	ND	ND	NA	16	
MW-5	09/18/06	ND	68.3	ND	3	5.74	NA	77	
MW-5	10/20/06	ND	71.4	ND	ND	ND	NA	71	
MW-5	12/12/06	<1	91.8	<1	1.9	<3	0.21	94	
MW-5	01/17/07	<1	67.8	1.7	2.8	4.1	0.21	76	
MW-5	02/21/07	<1	56.8	12.2	7.4	16.6	0.40	93	
MW-5	03/28/07	<10	123.1	455	248	1305	6.69	2,138	▼
MW-5	04/25/07	<20	107.7	166.1	217.3	1084	6.00	1,581	
MW-5	05/15/07	<10	127.8	199.4	185.8	920.5	6.81	1,440	
MW-5	06/13/07	<10	226.5	115.2	113.2	554.8	5.10	1,015	
MW-5	09/11/07	<10	684.9	15.2	103.9	349.9	6.11	1,160	
MW-5	08/25/08	<10	340.4	<10	48.8	237.6	3.75	631	

Garrison - BTEX Trends (Continued)

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX ppb	BTEX trend
MW-6	08/14/06	ND	138.0	ND	ND	ND	NA	138	
MW-6	09/18/06	ND	259.0	ND	ND	ND	NA	259	
MW-6	10/20/06	ND	5.8	ND	ND	ND	NA	6	
MW-6	12/12/06	<1	665.2	<1	<1	3.1	0.957	668	
MW-6	01/17/07	<1	460.2	<1	<1	<3	0.803	460	
MW-6	02/21/07	<1	442.7	<1	<1	<3	0.760	443	
MW-6	03/28/07	<1	669.6	2.9	1.1	3.3	0.944	677	▼
MW-6	04/25/07	<1	1118.0	38.9	27.1	77.2	2.553	1,264	
MW-6	05/15/07	<10	1833.0	97.6	115.4	329.1	4.389	2,379	
MW-6	06/13/07	<10	1109.0	14.4	89.3	206.3	3.170	1,422	
MW-6	09/12/07	<10	1176.0	<10	51.8	63.2	2.640	1,294	
MW-6	08/25/08	<10	975.6	<10	118.8	136.4	3.510	1,234	
MW-7	08/14/06	ND	4.4	ND	ND	ND	NA	4	
MW-7	09/18/06	ND	5.3	ND	ND	ND	NA	5	
MW-7	12/12/06	<1	8.3	<1	<1	<3	0.786	8	
MW-7	01/17/07	<1	6.5	<1	<1	<3	0.761	7	
MW-7	02/21/07	<1	5.9	<1	<1	<3	0.785	6	
MW-7	03/28/07	<1	8.2	<1	<1	<3	1.156	8	▼
MW-7	04/25/07	<1	11.5	<1	<1	<3	1.096	12	
MW-7	05/15/07	<1	12.1	<1	<1	<3	1.259	12	
MW-7	06/13/07	<1	10.1	<1	<1	<3	1.110	11	
MW-7	09/11/07	<1	9.5	<1	<1	<3	0.852	10	
MW-7	08/25/08	<1	7.3	<1	<1	<3	0.924	8	
MW-8	08/14/06	ND	ND	ND	ND	ND	NA	0	
MW-8	09/18/06	ND	ND	ND	ND	ND	NA	0	
MW-8	12/12/06	<1	<1	<1	<1	<3	<0.2	0	
MW-8	01/17/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	02/21/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	03/28/07	<1	<1	<1	<1	<3	<0.2	0	-
MW-8	04/25/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	05/15/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	06/13/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	09/11/07	<1	<1	<1	<1	<3	<0.2	0	
MW-8	08/25/08	<1	<1	<1	<1	<3	<0.2	0	
MW-9	08/14/06	ND	2600	60.5	80.5	374	NA	3,115	
MW-9	09/18/06	ND	3080	208	308	1190	NA	4,786	
MW-9	10/20/06	ND	3110	92	340	1070	NA	4,612	
MW-9	12/12/06	<10	3547	12.5	282.6	410.7	9.616	4,253	
MW-9	01/17/07	<10	4166	22	298.4	501.2	10.30	4,998	
MW-9	02/21/07	<10	2933	19.1	254.9	522.7	9.23	3,739	
MW-9	03/28/07	<10	3836	31.7	332.6	747.1	10.01	4,957	▼
MW-9	04/25/07	<50	4034	122.5	602.6	1975	15.93	6,750	
MW-9	05/15/07	<50	3760	169.1	1135	5112	30.67	10,207	
MW-9	06/13/07	<50	3819	410.2	703.3	2590	21.67	7,544	
MW-9	09/11/07	<50	3302	<50	836	2524	21.55	6,684	
MW-9	08/26/08	<50	2313	87.5	492.2	901.7	16.49	3,811	
MW-10	08/14/06	ND	14200	55600	6400	36700	NA	112,900	
MW-10	09/18/06	ND	14600	53200	12100	75100	NA	155,000	
MW-10	12/12/06	FP	0.1 ft						
MW-10	01/17/07	FP	0.2 ft						
MW-10	02/21/07	FP	0.19 ft						
MW-10	03/28/07	FP	0.19 ft						▼
MW-10	04/25/07	FP	0.03 ft						
MW-10	05/15/07	<500	10610	22310	4199	30660	140.6	67,920	
MW-10	06/13/07	<500	7941	13160	2823	23930	118.5	47,973	
MW-10	09/11/07	<200	7468	3673	3810	23730	90.32	38,771	
MW-10	08/25/08	<100	5095	320.2	3457	15720	76.3	24,669	

Garrison - BTEX Trends (Continued)

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX ppb	
MW-11	08/14/06	ND	150.0	ND	ND	ND	NA	150	
MW-11	09/18/06	ND	106.0	ND	ND	ND	NA	106	
MW-11	10/20/06	ND	256.0	ND	ND	ND	NA	256	
MW-11	12/12/06	<1	194.6	<1	<1	<3	0.338	195	
MW-11	01/17/07	<1	188	<1	<1	<3	0.383	188	
MW-11	02/21/07	<1	159.5	<1	<1	<3	0.319	160	
MW-11	03/28/07	<1	166.1	<1	<1	<3	0.274	166	▲
MW-11	04/25/07	<1	170.3	<1	<1	<3	0.285	170	
MW-11	05/15/07	<1	182.9	<1	<1	<3	0.275	183	
MW-11	06/13/07	<1	419.5	<1	<1	<3	0.653	420	
MW-11	09/12/07	<1	704.2	<1	10	6.6	1.135	722	
MW-11	08/25/08	<1	501.3	<1	11.3	<3	0.972	514	
MW-12	06/13/07	<100	3730	3357	1271	7145	39.35	15,542	
MW-12	09/11/07	<100	2132	293.2	760.8	3755	22.47	6,963	▲
MW-12	08/25/08	<100	2761	1104	1070	4306	28.16	9,269	
MW-13	06/13/07	<1	<1	<1	<1	<3	<0.2	0	
MW-13	09/12/07	<1	<1	<1	<1	<3	<0.2	0	—
MW-13	08/26/08	<1	<1	1.6	<1	<3	<0.2	2	
MW-14	06/13/07	<1	<1	<1	<1	<3	<0.2	0	
MW-14	09/12/07	<1	<1	<1	<1	<3	<0.2	0	▲
MW-14	08/25/08	<1	47.6	<1	1.5	<3	<0.2	49	
MW-15	06/13/07	<100	4976	704.6	808.3	3966	27.25	10,482	
MW-15	0/11/06	<50	3384	<50	228.9	468.6	7.966	4,089	▼
MW-15	08/26/08	<10	2273	11.8	167.3	197.1	6.080	2,655	
MW-16	06/13/07	<100	2615	1756	795.1	5110	27.88	10,304	
MW-16	09/11/07	<100	2737	716.6	756.1	4587	24.48	8,821	▼
MW-16	08/26/08	<50	2130	671.2	590	2865	18.08	6,274	
MW-17	06/13/07	<100	4323	5374	1620	8815	48	20,180	
MW-17	09/11/07	<100	2126	470.8	769	4049	22.63	7,437	▲
MW-17	08/26/08	<50	3404	2037	1146	5430	31.44	12,048	
MW-18	06/13/07	<100	7620	7792	2913	17030	76.84	35,432	
MW-18	09/11/07	<100	5926	572.7	2527	12570	51.55	21,647	▼
MW-19	06/13/07	<1	<1	<1	<1	<3	<0.2	0	
MW-19	09/11/07	<1	<1	<1	<1	<3	<0.2	0	—
MW-19	08/26/08	<1	<1	<1	<1	<3	<0.2	0	
MW-20	06/13/07	<10	2170	71.8	79.9	231.1	4.56	2,557	
MW-20	09/12/07	<10	1377	<10	37.3	42.7	2.716	1,460	▲
MW-20	08/25/08	<10	1772	<10	130	146.2	4.190	2,052	
MW-21	09/26/07	<100	1866	<10	76.5	91.4	3.69	2,038	
MW-21	08/26/08	<5	471.3	<5	18.3	15	1.38	506	▼
MW-22	09/26/07	<1	364.6	49.6	42.7	259.3	3.089	719	
MW-22	08/26/08	<1	173.2	3.7	1.9	5.6	0.666	185	▼
MW-23	09/26/07	<10	567.6	<10	234.4	1027	5.78	1,835	
MW-23	08/26/08	<2	110	4.6	16.1	23.9	0.872	155	▼
MW-24	09/26/07	<10	2609	1954	330.2	1675	12.81	6,581	
MW-24	08/26/08	<10	1049	16.2	40.4	58.5	3.67	1,168	▼

NA - not analyzed

ND - not detected

GROUNDWATER QUALITY MONITORING (Continued)

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l	BTEX ppb
<i>Domestic Wells</i>								
D K. Well	11/03/05	ND	764	ND	ND	ND	ND	764
D K. Well	12/22/05	ND	2320	ND	ND	ND	ND	2,320
D K. Well	01/24/06	ND	3080	ND	ND	ND	ND	3,080
D K. Well	03/07/06	ND	2930	ND	ND	ND	ND	2,930
D K. Well	05/18/06	ND	4770	20.4	6.8	26.2	ND	4,823
D K. Well	08/14/06	ND	5360	ND	ND	95	ND	5,455
D K. Well	09/18/06	ND	6240	20.6	94	222	ND	6,577
D K. Well	10/20/06	ND	5500	ND	82	230	ND	5,812
D K. Well	01/29/07	Broken piping - no access						
D K. Well	04/24/07	Broken piping - no access						
D K. Well	07/23/07	<10	3704	<10	348.6	766.1	10.74	4,819
Folden Q.	09/29/05	ND	ND	ND	ND	ND	ND	
Folden Q.	10/20/06	ND	ND	ND	ND	ND	ND	
Folden Q.	01/29/07	<1	<1	<1	<1	<3	<0.2	
Folden Q.	04/24/07	<1	<1	<1	<1	<3	<0.2	
Folden Q.	07/23/07	<1	<1	<1	<1	<3	<0.2	
Folden Q.	09/11/07	<1	<1	<1	<1	<3	<0.2	
Folden Q.	08/27/08	<1	<1	<1	<1	<3	<0.2	
Folden Pas	01/29/07	<1	<1	<1	<1	<3	<0.2	
Folden Pas	04/24/07	<1	<1	<1	<1	<3	<0.2	
Folden Pas	07/23/07	<1	<1	<1	<1	<3	<0.2	
Folden Pas	09/11/07	<1	<1	<1	<1	<3	<0.2	
Folden Pas	08/27/08	<1	<1	<1	<1	<3	<0.2	
Brunsell	10/20/06	ND	ND	ND	ND	ND	ND	
Brunsell	01/29/07	<1	<1	<1	<1	<3	<0.2	
Brunsell	04/24/07	<1	<1	<1	<1	<3	<0.2	
Brunsell	07/23/07	<1	<1	<1	<1	<3	<0.2	
Brunsell	09/12/07	<1	<1	<1	<1	<3	<0.2	
Brunsell	08/27/08	<1	<1	<1	<1	<3	<0.3	
Zeisler	10/20/06	ND	ND	ND	ND	ND	ND	
Zeisler	01/29/07	<1	<1	<1	<1	<3	<0.2	
Zeisler	04/24/07	<1	<1	<1	<1	<3	<0.2	
Zeisler	07/23/07	<1	<1	<1	<1	<3	<0.2	
Zeisler	09/12/07	<1	<1	<1	<1	<3	<0.2	
Zeisler	08/27/08	<1	<1	<1	<1	<3	<0.2	
Fitzgerald	10/20/06	ND	ND	ND	ND	ND	ND	
Fitzgerald	01/29/07	Owner absent - no access						
Fitzgerald	02/21/07	<1	<1	<1	<1	<3	<0.2	
Fitzgerald	04/24/07	<1	<1	<1	<1	<3	<0.2	
Fitzgerald	07/23/07	<1	<1	<1	<1	<3	<0.2	
Fitzgerald	09/12/07	<1	<1	<1	<1	<3	<0.2	
Fitzgerald	08/27/08	<1	<1	<1	<1	<3	<0.2	
Seney	10/20/06	ND	ND	ND	ND	ND	ND	
Seney	01/29/07	<1	<1	<1	<1	<3	<0.2	
Seney	04/24/07	<1	<1	<1	<1	<3	<0.2	
Seney	07/23/07	<1	<1	<1	<1	<3	<0.2	
Seney	09/12/07	<1	<1	<1	<1	<3	<0.2	
Seney	08/27/08	<1	<1	<1	<1	<3	<0.2	

GROUNDWATER QUALITY MONITORING (Continued)

Well ID	Date	MTBE ppb	Benzene ppb	Toluene ppb	Ethylbenz. ppb	Xylenes (total) ppb	GRO (TPH) mg/l
Joe K.	10/20/06	ND	ND	ND	ND	ND	ND
Joe K.	01/29/07	<1	<1	<1	<1	<3	<0.2
Joe K.	04/24/07	<1	<1	<1	<1	<3	<0.2
Joe K.	07/23/07	<1	<1	<1	<1	<3	<0.2
Joe K.	09/12/07	<1	<1	<1	<1	<3	<0.2
Joe K.	08/27/08	<1	<1	<1	<1	<3	<0.2
Ebach	07/23/07	<1	<1	<1	<1	<3	<0.2
Ebach	09/12/07	<1	<1	<1	<1	<3	<0.2

NA - not analyzed

ND - not detected

APPENDIX E-2
BIODEGRADATION INDICATORS

COC AND SELECTED BIODEGRADATION INDICATORS

	MW-2	MW-2	MW-3	MW-3	MW-3	MW-6	MW-6	MW-6	MW-9	MW-9	MW-9	
	06/12/07	09/11/07	08/26/08	06/12/07	09/11/07	08/25/08	06/13/07	09/12/07	08/25/08	06/13/07	09/11/07	08/26/08
MTBE	<1	<1	<1	<1	<1	<1	<10	<10	<10	<10	<50	<50
Benzene	<1	<1	<1	<1	<1	<1	1109	1176	975.6	3819	3302	2313
Toluene	<1	<1	<1	<1	<1	<1	14.4	<10	<10	410.2	<50	87.5
Ethyl Benzene	<1	<1	<1	<1	<1	<1	89.3	51.8	118.8	703.3	836	492.2
Xylenes Total)	<3	<3	<3	<3	<3	<3	206.3	63.2	136.4	2590	2524	901.7
Sulfate	3100	2990	2680	329	193	174	344	424	229	550	731	310
Nitrate-Nitrite as N	18.5	23.4	20.7	5.14	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ammonia-Nitrogen as N	0.3	0.12	0.15	0.27	0.32	0.28	0.23	0.27	0.29	0.11	0.36	0.43
Phosphorus P (total)	0.43	0.75	0.32	0.19	0.2	0.18	0.41	0.32	0.65	0.93	0.94	1.01
BOD	<2	<2	<2	<2	<2	2.12	62.6	<20	15.2	17.9	<20	10.9
Fe (total)	1.27	7.8	1.21	8.4	7.05	7.17	16.5	12	18.3	22.3	9.38	12.9
Mn (total)	0.79	1.01	1.02	0.44	0.43	0.76	0.68	0.69	0.74	1.93	0.51	0.49
DO	0.63	2.63	4.16	2.43	1.35	2.63	1.5	2.16	2.11	1.07	1.85	2.18
ORP	48.3	105.3	123.1	12.1	110.4	-14.2	-82.2	38.1	125.2	-119.8	-45.2	59.2
EC	4971	5390	5572	1743	1462	1342	1600	1263	1325	2189	2270	1722
pH	6.35	5.78	6.28	7.63	6.85	7.17	7.35	6.55	6.9	7.53	6.43	6.7
Temperature	9.23	10.6	9.28	8.97	10.5	9.2	8.94	7.58	8.03	9.38	9.32	8.8

BOD - Biological Oxygen Demand

DO - Dissolved Oxygen

ORP - Oxidation/Reduction Potential

EC - Electrical Conductivity

NA - Not analyzed, low sample volume

Wells were sampled for BTEX on 9/12/07 and for biodegradation indicators on 10/3/2007

C AND SELECTED BIODEGRADATION INDICATORS

	MW-11 06/13/07	MW-11 09/12/07	MW-11 08/25/08	MW-12 06/13/07	MW-12 09/11/07	MW-12 08/25/08	MW-13 06/13/07	MW-13 09/12/07	MW-13 08/26/08	MW-18 06/13/07	MW-18 09/11/07
IE	<1	<1	<1	<100	<100	<100	<1	<1	<1	<100	<100
zene	419.5	704.2	501.3	3730	2132	2761	<1	<1	<1	7620	5926
ene	<1	<1	<1	3357	293.3	1104	<1	<1	1.6	7792	572.7
l Benzene	<1	10	11.3	1271	760.8	1070	<1	<1	<1	2913	2527
nes Total)	<3	6.6	<3	7145	3755	4306	<3	<3	<3	17030	12570
ate	950	777	376	1200	1030	552	782	720	715	412	260
ite-Nitrite as N	<0.1	<0.1	<0.1	0.83	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
nonia-Nitrogen as N	0.24	0.27	0.73	1.91	0.59	0.44	0.44	0.39	0.53	0.33	0.44
sphorus P (total)	0.85	0.42	0.53	0.41	0.39	0.61	0.16	0.19	0.24	0.29	0.55
)	6.09	<20	9.6	47	41.2	57.1	<6	<20	2.82	40.4	NA
total)	13.7	9.48	14.1	23.8	25.7	23.6	3.71	3.92	6.81	7.84	12.7
total)	0.71	0.52	0.63	1.54	1.39	1.03	0.47	0.42	0.35	1.06	1.22
	1.76	1.56	2.8	1.29	3.38	2.37	1.17	1.5	3.18	2.37	3.19
	-19.8	40.3	54.6	-32.7	-36.9	64.6	-12.2	41.8	121.6	-46.3	-51.2
	2011	2156	1999	2569	2447	2292	2112	2381	1187	1855	1980
	6.84	6.19	6.97	6.76	6.29	6.7	6.86	6.36	6.72	6.86	6.63
perature	9.75	8.35	8.85	11.75	10.41	9.7	9.68	9.45	8.8	8.6	7.76

) - Biological Oxygen Demand

- Dissolved Oxygen

) - Oxidation/Reduction Potential

Electrical Conductivity

Not analyzed, low sample volume

s were sampled for BTEX on 9/12/07 and for biodegradation indicators on 10/3/2007

COC AND SELECTED BIODEGRADATION INDICATORS

	MW-20		MW-20	
	06/13/07	09/12/07	09/12/07	08/25/08
MTBE	<10	<10	<10	<10
Benzene	2170	1377	1772	1772
Toluene	71.8	<10	<10	<10
Ethyl Benzene	79.9	37.3	130	130
Xylenes Total)	231.1	42.7	146.2	146.2
Sulfate	1620	929	429	429
Nitrate-Nitrite as N	<0.1	<0.1	<0.1	<0.1
Ammonia-Nitrogen as N	4.31	0.4	0.46	0.46
Phosphorus P (total)	2.71	0.97	0.93	0.93
BOD	240	56.9	14.8	14.8
Fe (total)	120	38	41.3	41.3
Mn (total)	4.86	1.74	1.6	1.6
DO	2.16	1.99	3.64	3.64
ORP	-64.2	38.8	93.3	93.3
EC	1704	2634	2009	2009
pH	7.07	6.34	6.71	6.71
Temperature	10.06	8.37	9.48	9.48

BOD - Biological Oxygen Demand

DO - Dissolved Oxygen

ORP - Oxidation/Reduction Potential

EC - Electrical Conductivity

NA - Not analyzed, low sample volume

Wells were sampled for BTEX on 9/12/07 and for biodegradation indicators on 10/3/2007