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October 22, 1998

Project Ref. #3125

Received 10/22/98 w/o fee.
P. Mylotta

Mr. Jim Schmidt
Ms. Pam Mylotta
Wisconsin Department of Natural Resources
2300 N. Dr. Martin Luther King Jr. Drive
Milwaukee, Wisconsin 53212

Re: Village of Whitefish Bay
Good Hope Road Property
5201 W. Good Hope Road
Milwaukee, Wisconsin
Investigation Data/Informational Package Submittal

Dear Jim and Pam,

Sigma Environmental Services, Inc. (Sigma), on behalf of the Village of Whitefish Bay, is hereby submitting three copies of a subsurface investigation data/informational package for the Village's property located at 5201 W. Good Hope Road in Milwaukee, Wisconsin. This package summarizes results of initial subsurface investigative activities completed performed by STS Consultants, LTD on the Village's property, results of additional investigative activities completed by Sigma on the Village's property, and results of investigative activities performed on the Milwaukee Public School property which were conducted jointly by Sigma and Natural Resources Technologies, Inc. (NRT) who is serving as consultant for the Presidio Square property. Specifically, the following information is presented:

Tables

Table 1	Static Groundwater Elevations
Table 2	Summary of Soil Quality Analyticla Results
Table 3	Groundwater Quality Analytical Results
Table 4	Summary of Bioanalytical Results

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Figure 2	Site Plan Map
Figure 3	Soil Quality Map
Figure 4	Groundwater Quality Map
Figure 5	Groundwater Contour Map
Figure 6	Potentiometric Map
Figure 7	Geologic Cross Section

Miscellaneous Information

Borings Logs/Well Construction Details
United States Air Force Natural Attenuation Screening Form
PHOSter II Informational Package

The following summarizes the scope of work for the additional subsurface investigative activities completed on the Village's property and the MPS property.

Additional Subsurface Investigation - Village of Whitefish Bay Property

This phase of the additional subsurface investigation was performed in May and June of 1997 and was overseen by Sigma.

- Installed four well nests on the Village's property between May 19, 1997 and May 29, 1997. Each well nest consisted of one groundwater monitoring well and one piezometer. Well nest MW-A/PZ-A was installed in the northeast corner of the southern portion of the site (Figure 2); well nest MW-B/PZ-B was installed in the southeast corner of the site; well nest MW-C/PZ-C was installed near the center of the southern portion of the site; and well nest MW-D/PZ-D was installed in the southwest corner of the site adjacent to existing monitoring well MW-22. Borehole logs and well construction details are included as an attachment to this letter.

- Abandoned existing damaged monitoring wells MW-9 and MW-16 on May 19, 1997.

- The groundwater monitoring wells were screened to intercept the fill unit at the site and the piezometers were screened to intercept the deeper sand and gravel unit. In addition, the piezometers were installed through 10-inch PVC casing to minimize vertical cross contamination between the lithologic units.

- One groundwater monitoring well, MW-E, was installed on May 27, 1997 adjacent to the existing monitoring well MW-10 on the Village's property.

- Each borehole advanced for installation of the wells and piezometers was continuously logged and sampled for field screening of soil. In addition, one representative soil sample was collected from boreholes PZ-A, PZ-B, PZ-C, and MW-E for laboratory analysis of Volatile Organic Compounds (VOCs). Two representative soil samples were collected from borehole PZ-D for laboratory analysis of VOCs. Results of the soil analytical are presented in Table 2.

- One representative soil sample was collected from boreholes PZ-A, PZ-C, and PZ-D for laboratory analysis of enumeration and nutrient parameters including total organic carbon, nitrate, sulfate, phosphorous, iron, pH, moisture content, total kjeldahl nitrogen, soluble ammonia nitrogen, total manganese, total heterotrophic bacteria plate count and total hydrocarbon degrading bacteria plate count. Results of the biofeasibility analysis are presented in Table 4.

- All site monitoring wells were surveyed for location and elevation to USGS datum.

- All newly installed groundwater monitoring wells and piezometers were developed prior to sampling.

- Hydraulic conductivity testing (slug testing) was performed on MW-A, MW-B, MW-D, PZ-A, PZ-C, and PZ-D.

- Two rounds (6/19/97 and 7/21/97) of water level data were obtained from all site monitoring wells located on the Village's property. Water level data is presented in Table 1.

- All site monitoring wells were sampled on June 19th and 20th. All site monitoring wells were sampled for laboratory analysis of Volatile Organic Compounds (VOCs). Groundwater from wells MW-A, MW-B, and MW-D were also sampled for laboratory analysis of bioremediation and nutrient parameters including nitrate, sulfate, iron, methane, ethane, ethene, total organic carbon, chloride, ammonia nitrogen, total kjeldahl nitrogen, orthophosphate, total heterotrophic bacteria plate count, total hydrocarbon degrading bacteria plate count, and aerobic methanotroph enumeration. Groundwater analytical data is presented in Table 3.

Subsurface Investigation - MPS Property

This phase of the additional investigation was performed in August of 1998. The work plan for this phase of the investigation was developed jointly by Sigma and NRT. The investigative activities for this phase were overseen by NRT personnel.

- Three additional well nests (MPS MW-1/P-1, MPS MW-2/P-2 and MPS MW-3/P-3) were installed between August 12 and August 14, 1998 on the MPS property to the south of the Village's property. These wells were installed as part of a joint investigation effort with Natural Resources Technologies, Inc. who is serving as consultant for the Presidio Square property located to the west of the Village's property.

- The groundwater monitoring wells installed on the MPS property were installed to intersect the shallow groundwater table at the site, and the piezometers were screened to intersect the deeper sand and gravel unit at the site. The piezometers were installed using a double cased approach to minimize the potential for cross contamination between the shallow groundwater unit and the deep groundwater unit. The first 25 feet of the of the piezometers were advanced with 10 inch inside diameter hollow stem augers. The remainder of the boring for each piezometer was completed using 6 inch inner diameter hollow stem augers inserted through the 10 inch casing. Borehole logs and well construction details are included as an attachment to this letter.

- Each borehole advanced for installation of the wells and piezometers was continuously logged and sampled for field screening of soil using a PID.

- Each of the wells installed on MPS property were surveyed for location and elevation to USGS datum.

- Water level measurements were collected from the newly installed MPS wells, the wells on the Village's property, and the wells on the Presidio Square property on August 18, 1998. Water level data is presented in Table 1.

- MPS wells MW-1, P-1, P-2, and P-3 were sampled on August 19, 1998 for analysis of VOCs in accordance with U.S. EPA Method 8260. The wells were also sampled for nitrate-nitrite, sulfate, chloride, iron, methane, ethane, ethene, and total organic carbon analysis. Wells MW-2 and MW-3 were not sampled because they were dry. Groundwater analytical results are presented in Tables 3 and 4.

The following paragraphs summarize the results of the additional investigative activities completed on the Village's and the MPS property.

Site Hydrogeology. Static water levels were measured in the monitoring wells and piezometers, to determine the direction of groundwater flow, calculate horizonal and vertical hydraulic gradients and evaluate temporal fluctuations in the unconsolidated materials. Static water level data is presented in Table 1.

Shallow groundwater elevation and gradients at the site generally reflect surface topography. Groundwater ranged from 7.85 to 18.03 feet bgs in the shallow monitoring wells, and from 8.09 to 24.70 feet bgs in the piezometers (8/18/98 well/piezometer data). A shallow groundwater contour map was drawn from the water level measurements collected from the shallow monitoring wells on August 18, 1998 (Figure 5). A potentiometric surface map was drawn from the water level measurements collected from the piezometers on August 18, 1998 (Figure 4). As shown on the shallow and the potentiometric groundwater contour maps, groundwater flow is generally toward the east-southeast. There are steep horizontal and vertical gradients near the western property line, which is consistent with topography. Groundwater flow gradients flatten out near the central portion of the property. Additional groundwater elevation data in the vicinity of Lincoln Creek will clarify what effect the intermittent nature of the creek has on groundwater flow direction.

Water level measurements (8/18/98 data) from the four well nests installed on the Village's property (MW-A/PZ-A, MW-B/PZ-B, MW-C/PZ-C, and MW-D/PZ-D) were used to calculate vertical hydraulic gradients. Downward gradients ranged from 0.053 to 0.411 feet/foot in the other three well nests (MW-A/PZ-A, MW-B/PZ-B, MW-C/PZ-C). Horizontal hydraulic gradients ranged from 0.0027 to 0.0145 feet/foot in the piezometers with a geometric mean of 0.0067 feet/foot. Horizontal hydraulic gradients ranged from 0.014 to 0.018 feet/foot in the shallow monitoring wells, with a geometric mean of 0.016 feet/foot. Static water elevations and water table elevations, referenced to mean sea level, are presented in Table 1.

Hydraulic conductivities of the unconsolidated materials were calculated from data obtained during slug testing of monitoring wells MW-A, MW-B, and MW-D and piezometers PZ-A, PZ-C, and PZ-D. Hydraulic conductivity values ranged from 1.1 x 10^{-3} to 5.7 x 10^{-3} centimeters per second (cm/sec) in the three groundwater monitoring wells, to 8.2 x 10^{-4} to 3.8 x 10^{-2} cm/sec in the piezometers. The geometric mean conductivity for the upper flow unit is 2.3 x 10^{-3} cm/sec, and the geometric mean for the lower sand and gravel unit is 4.8 x 10^{-3} cm/sec. The calculated values are consistent with the characteristic values for the materials adjacent to the screens of the wells and piezometers (Fetter, 1988). The calculated values represent the horizontal hydraulic conductivity of subsurface materials directly adjacent to the well screen, but may not be indicative of overall aquifer conductivity. Additionally, the effect of disturbing native soil conditions during drilling activities, prior to well installation, may influence the conductivity values.

The average linear velocity for groundwater flow is determined by the formula:

$V=Ki/n_e$

Where:
V = Groundwater Flow Velocity (feet/day)
n_e = Effective Porosity (0.25 for the upper flow zone, 0.30 for the lower flow zone)
K = Hydraulic Conductivity [2.3 x 10^{-3} cm/sec (6.52 ft/day) for the upper zone, 4.8 x 10^{-3} cm/sec (13.61 ft/day) for lower zone]
I = Hydraulic Gradient (0.016 feet/foot for upper zone, 0.0067 feet/foot for the lower zone)

This formula indicates that the average linear groundwater flow velocity for the upper flow zone is 0.42 feet/day and the average linear groundwater flow velocity for the lower saturated sand and gravel unit is 0.30 feet/day. The calculated range of velocities may not be indicative of the actual velocities of contaminant migration, since factors such as degradation, dispersion and adsorption of the contaminants are not accounted for in the formula.

Soil Impacts - Contaminant Degree and Extent. Representative soil samples were collected from boreholes PZ-A, PZ-B, PZ-C, PZ-D, and MW-E for laboratory analysis of VOCs. The results confirm essentially the same combination of VOCs which were found during previous site investigations conducted by STS. The VOCs appear to be a mixture of chlorinated solvents, predominantly tetrachloroethene (PCE) and trichloroethene (TCE), and common petroleum based solvents including ethylbenzene, xylenes and toluene.

The highest concentration of VOCs detected in the soil is in the southwestern portion of the site. Reported concentrations of ethylbenzene and xylenes in the soil sample collected at the 8-10 foot depth interval from PZ-D were over an order of magnitude greater than the soil cleanup standards for those compounds established in Chapter NR 720 of the Wisconsin Administrative Code. Several other VOCs, including PCE and vinyl chloride, were detected at elevated levels in this sample, however, no cleanup standard has been established for these compounds. A second soil sample was collected at PZ-D from the 20-22 foot depth interval. This sample also exhibited exceedances of NR 720 soil cleanup standards for ethylbenzene and xylenes and elevated levels of several other VOCs, including PCE and TCE. The soil sample collected from MW-E also had elevated concentrations of PCE and TCE.

Soil samples collected from boreholes PZ-A and PZ-C both had reportable concentrations of various VOC compounds, but at much lower concentrations than reported for soil samples collected from the southwest portion of the site. In addition, PCE and TCE were not detected in the soil samples collected from these boreholes. The soil sample collected from borehole PZ-B did not have any VOCs detected above the anaytical method detection limit. The soil laboratory analytical results for soil samples collected from PZ-A, B, C, D, and MW-E are summarized in Table 2 and on Figure 3.

The Photoionization Detector (PID) screening data, as noted on the boring logs, indicate that depth of impacts varies from approximately four feet below ground surface to the water table interface. There was a consistent pattern of low PID readings in surface soils to depths of approximately four feet bgs even at locations where underlying soil contamination was relatively high (PZ-D and MW-E). This may be due to clean fill placement which occurred during site grading/closure operations.

Results of the additional investigation confirm that the highest concentration of VOCs in the soil occur in the southwest portion of the site in the area roughly bounded by MW-10 to the north, MW-11 to the east, and MW-D/PZ-D to the southwest. Based on the results of STS's investigation and soil vapor survey, there also appears to be soil contaminant hot spots surrounding soil boring B-21 in the southern midsection of the Village's property and surrounding soil boring B-15 in the central portion of the Village's property. Soil analytical results for the Village's property, including results from the STS investigation, are shown on Figure 3. Figure 3 also provides a preliminary delineation, based on STS and Sigma investigation results, of the areas of highest source soil contamination which would be targeted for remediation. It is estimated that approximately 24,000 cubic yards or 36,000 tons of contaminated soil with PID readings greater than 100 ppm, based on the STS soil gas survey, are present at the site. In general, soil with PID screening results above 100 ppm indicates the presence of elevated VOC concentrations.

No soil impacts above the water table were identified during installation of the additional well nests on the MPS property based on soil field screening performed by NRT.

Groundwater Impacts - Contaminant Degree and Extent. As part of additional investigation, groundwater samples were collected from all the monitoring wells located on the Village's property for laboratory analysis of VOCs on June 19 and 20, 1997. The results of the analysis are summarized on Figure 4 and Table 3. Analytical results for the August 19, 1998 sampling of the MPS property wells are also presented as are analytical results from select wells installed on the Presidio Square property. The results confirm the same combination of VOCs which were found during previous investigations conducted by STS. The VOCs appear to be a mixture of chlorinated solvents and associated daughter compounds, predominantly PCE, TCE, dichloroethenes (DCE) and vinyl chloride, and petroleum based substances including ethylbenzene, toluene and xylenes.

The highest concentration of VOCs on the Village's property were reported at MW-D and PZ-D in the southwest corner of the site. This is consistent with previous investigation results reported by STS. Concentrations of several VOCs including PCE, TCE, cis-1,2-DCE, vinyl chloride, ethylbenzene, toluene and xylenes are reported above the NR 140 Groundwater Enforcement Standards. Enforcement Standards were also exceeded for various VOCs at MW-25, MW-26, MW-4, MW-6, MW-10, MW-11, MW-18, PZ-A, MW-C, PZ-C, and MW-E.

In general, the concentration of VOCs in the groundwater across the Village's property appears to decrease to the north and to the east from the southwest corner of the site (MW-D/PZ-D). Wells MW-B and PZ-B, located in the southeastern corner of the site, did not have any reported Enforcement Standard exceedances for the June 1997 sampling event. Monitoring well MW-A, located in the northeast corner of the southern portion of the site, also did not have any Enforcement Standard exceedances. Well PZ-A, however, did have a reported Enforcement Standard exceedance for vinyl chloride (0.79 μg/L). Monitoring well MW-6, located in the northeast portion of the site, also had only one reported Enforcement Standard exceedance for vinyl chloride (0.37 μg/l) during the June 1997 sampling event.

Groundwater samples were collected by NRT from the MPS monitoring wells on August 19, 1998 for laboratory analysis of VOCs. Samples could not be collected from shallow monitoring wells MPS MW-2 and MPS MW-3 because these wells were dry on the sampling date. The groundwater sample from MPS MW-1 did not have any detections for VOCs. Groundwater samples collected from MPS P-1, P-2 and P-3 all had concentrations of cis-1,2 DCE and vinyl chloride detected above their respective NR 140 Enforcement Standard. No PCE or TCE was detected in any of the groundwater samples collected from the MPS property. The presence of cis-1,2 DCE and vinyl chloride in the deep groundwater zone on the MPS property is likely the result of the natural breakdown or attenuation of PCE and TCE found in upgradient source areas on the Village's property and the Presidio Square property. Based on the results of the groundwater sampling on the MPS property, the down gradient extent of the groundwater plume has not been defined.

As shown on Figure 4, there were also significant concentrations of VOC impacts in groundwater samples collected from monitoring wells on the Presidio Square property. Specifically, MW-27, MW-101 and MW-103 had concentrations of various chlorinated VOCs and BTEX compounds in excess of their respective Enforcement Standards. Based on the presence of these groundwater impacts and the generally easterly flow direction of the groundwater, it can be concluded that off-site impacts from the Presidio Square property are contributing to groundwater impacts observed on the Village's property.

Natural Attenuation Screening. In order to evaluate the potential for natural attenuation of the soil and groundwater contaminants, soil samples from the Village's property and groundwater samples from both the Village's property and the MPS property were collected for analysis of parameters indicative of natural attenuation. Soil samples were collected from boreholes PZ-A, PZ-C, and PZ-D for laboratory analysis of bioremediation and nutrient parameters including total organic carbon, nitrate, sulfate, phosphorous, iron, pH, moisture content, total kjeldahl nitrogen, soluble ammonia nitrogen, total manganese, total heterotrophic plate count and total hydrocarbon degrader plate count. Groundwater samples were collected from MW-A, MW-B and MW-D and analyzed for the same bioremediation and nutrient parameters plus methane, ethane, ethene and methanotroph populations. Groundwater samples were also collected from MPS monitoring wells MW-1, P-1, P-2, and P-3 for analysis of nitrate/nitrite, sulfate, TOC, chloride, methane, ethane, and ethene. Results are presented in Table 4. In addition, water in each monitoring well on both the Village property and the MPS property was field screened for dissolved oxygen content. Dissolved oxygen readings are presented in Table 4.

A review of the data indicates that natural attenuation/biodegradation of the chlorinated solvents is occurring at the site. This conclusion is supported by the following observations:

- Dissolved oxygen readings taken at the site monitoring wells are generally below 1.0 milligram per liter (mg/l) with the exception of monitoring wells MW-E, MW-10, and PZ-C. The low dissolved oxygen readings observed in most of the wells indicate that subsurface conditions are predominantly anaerobic. Dissolved oxygen concentrations were the lowest at MW-D and PZ-D which are located in the most highly impacted area of the site. Downgradient of the source areas, on the MPS property, the groundwater generally becomes more aerobic.

- Vinyl chloride and various isomers of DCE are present at elevated levels across the site. Vinyl chloride and DCE are daughter products resulting from the anaerobic biodegradation of PCE and TCE. Downgradient of the contaminant source areas, on the MPS property, PCE and TCE are no longer present and only the daughter products (DCE and vinyl chloride) are present. In general, the concentrations of PCE and TCE decrease as one moves further downgradient of the contaminant source areas.

- Elevated concentrations of methane, ethane, and ethene are present at monitoring wells MW-A, MW-B, MW-D and in the downgradient MPS wells. These compounds are also breakdown constituents resulting from the anaerobic degradation of chlorinated compounds. It is important to note that concentrations of these breakdown constituents increase in the downgradient direction indicating an accumulation of the breakdown constituents.

- Despite the high concentrations of methane detected at MW-A, MW-B and MW-D, methanotroph populations and chlorinated solvent degrader populations were very low in the groundwater samples collected from these wells. These populations are strict aerobes which utilize methane as an energy source to co-metabolize chlorinated solvents such as trichloroethene. The fact that these populations are so low also indicates that anaerobic conditions exist at the site, which is a primary condition of reductive dechlorination processes.

In order to assess that natural attenuation of the chlorinated solvents is an effective remedial strategy for groundwater contaminants at the site, Sigma performed an initial bioattenuation screening using available site data. The screening process used is presented in the November 1996 United States Air Force guidance document titled *"Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater"*. This guidance document was developed in cooperation with the United States Environmental Protection Agency. The screening process uses site chemical and geochemical data to make a determination of the probability that biodegradation of chlorinated solvents is taking place. The screening form is presented as an attachment to this letter. According to the guidance document, a screening score of greater than 20 indicates strong evidence that subsurface conditions are conducive to biodegradation of chlorinated compounds. The initial screening score for the site was 26 which indicates that there is strong evidence that biodegradation of chlorinated organics is occurring at the site.

Recommended Remedial Strategy

As discussed during our October 23rd meeting, Sigma's recommended remedial approach for the site is source soil control in conjunction with a monitored natural attenuation program. Sigma has evaluated several source control methods including soil vapor extraction, limited excavation in conjunction with off-site or on-site treatment and in-situ treatment. Sigma is recommending that an in-situ treatment technology (PHOSter II) be implemented to address source soil. The PHOSter II process, an in-situ treatment technology, stimulates the growth of indigenous degrader microorganisms by supplying an optimum quantity of food source and nutrients in the subsurface thereby enhancing the biodegradation of chlorinated compounds on-going at the site. Controlled injection of food source (methane gas) and nutrients in the form of phosphate and nitrogen gas mixture is forced into the soil through injection wells. Indigenous microorganisms utilize the injected nutrients to degrade chlorinated solvent and petroleum contamination. This system was originally developed by the U.S. Department of Energy and the Savannah River Technology Center, and is being commercialized by Freeman and Vaughn Engineering, Inc. (FVE) out of Savannah, Georgia. Sigma has teamed with FVE to evaluate the site for PHOSter II implementation. An information package on the PHOSter II technology is included as an attachment to this letter.

Based on a preliminary review of site specific data, the Village's property appears to be a good candidate for implementation of the PHOSter II technology. However, considering the relatively high level of parent products (PCE and TCE) present at the source area and the variability of the subsurface materials, a complete cleanup of the source area to background conditions may not be practicable. Nonetheless, contaminant concentrations are expected to be reduced to less than the 100 parts per billion (ppb) range within a relatively short time by the PHOSter II technology. The PHOSter II technology would be utilized in a two phased approach. During the initial phase, strictly anaerobic conditions would be maintained in the subsurface to accelerate PCE and TCE breakdown to their daughter products. Once PCE concentrations are reduced substantially, aerobic conditions would be created in the subsurface to promote biodegradation of the remaining daughter products. The total duration of both phases is expected to be approximately one year. Once the active injection is stopped, enhanced biodegradation would continue for a period of time as a result of microbial enriched conditions created by the process.

Upon WDNR concurrence with our recommended conceptual approach of source soil control utilizing the PHOSter II technology in conjunction with monitored natural attenuation of groundwater impacts, Sigma will prepare and submit a formal report presenting the subsurface investigation data included herein, as well as more detailed work plans for implementation of the PHOSter II and monitored natural attenuation remedial strategies. In the meantime, if you have any questions regarding the information presented herein, please contact Sigma at 414-768-7144.

Sincerely,
SIGMA ENVIRONMENTAL SERVICES, INC.

James B.Leedom, P.E.
Project Engineer

Mafizul Islam, P.E.
Senior Project Engineer

cc: Mr. Ed Henschel, Village of Whitefish Bay
Mr. Dennis Fisher, Meissner Tierney Fisher & Nichols

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TABLES

TABLE 1
STATIC GROUNDWATER ELEVATIONS
Village of Whitefish Bay Good Hope Road Property
Project #3125

Monitoring Location	Ground Surface Elevation (feet MSL)	Top of Casing Elevation (feet MSL)	Total Well Depth (feet)	Screen Length (feet)	Top of Screen Elevation (feet MSL)	Monitoring Date	Depth to Water (feet)	Groundwater Elevation (feet MSL)
SB-100	708.6	709.91	14.75	10	705.16	08/18/98	11.23	698.68
						08/26/98	11.45	698.46
SB-101	708.86	709.93	13.79	10	706.14	08/18/98	11.4	698.53
						08/26/98	11.57	698.36
SB-102	708.24	709.51		10	719.51	08/18/98	11.4	698.11
						08/26/98	11.61	697.9
SB-103	708.81	709.91	16.9	10	703.01	08/18/98	11.95	697.96
						08/26/98	12.31	697.6
MW-27	unknown	706.61	27.43	10	689.18	06/07/96	9.72	696.89
						12/12/96	11.98	694.63
						01/06/97	11.81	694.8
						06/19/97	10.62	695.99
						07/15/98	10.96	695.65
						08/18/98	11.72	694.89
						08/26/98	10.51	696.1
MW-A	695.01	697.36	16.4	10	690.96	06/19/97	11.89	685.47
						07/21/97	11.27	686.09
						08/18/98	9.62	687.74
PZ-A	695.2	697.2	22	3	678.2	06/19/97	13.2	684
						07/21/97	12.38	684.82
						08/18/98	12.58	684.62
MW-B	691.42	693.04	15.6	10	687.44	06/19/97	8.05	684.99
						07/21/97	7.8	685.24
						08/18/98	7.85	685.19
PZ-B	690.81	692.61	25.3	5	672.31	06/19/97	8.65	683.96
						07/21/97	7.87	684.74
						08/18/98	8.09	684.52
MW-C	698.25	700.24	17	10	693.24	06/19/97	15.78	684.46
						07/21/97	11.97	688.27
						08/18/98	10.02	690.22

TABLE 1
STATIC GROUNDWATER ELEVATIONS
Village of Whitefish Bay Good Hope Road Property
Project #3125

Monitoring Location	Ground Surface Elevation (feet MSL)	Top of Casing Elevation (feet MSL)	Total Well Depth (feet)	Screen Length (feet)	Top of Screen Elevation (feet MSL)	Monitoring Date	Depth to Water (feet)	Groundwater Elevation (feet MSL)
PZ-C	698.1	700.45	28.4	5	677.05	06/19/97	16.41	684.04
						07/21/97	15.64	684.81
						08/18/98	15.86	684.59
MPS MW-1	706.45	708.95	18.23	10	700.72	08/18/98	9.41	699.54
						08/19/98	8.92	700.03
						08/26/98	9.45	699.5
MPS P-1	706.21	708.99	32.26	5	681.73	08/18/98	24.04	684.95
						08/19/98	25.08	683.91
						08/26/98	25.33	683.66
MPS MW-2	700.83	703.42	17.82	10	695.6	08/18/98	DRY	---
						08/19/98	DRY	---
						08/26/98	DRY	---
MPS P-2	700.71	703.58	33.44	5	675.14	08/18/98	19.63	683.95
						08/19/98	19.68	683.9
						08/26/98	19.91	683.67
MPS MW-3	693.22	696.41	10.99	6	691.42	08/18/98	10.73	685.68
						08/19/98	10.82	685.59
						08/26/98	DRY	---
MPS P-3	693.5	696.58	31.05	5	670.53	08/18/98	12.58	684
						08/19/98	12.64	683.94
						08/26/98	12.9	683.68
MW-11	unknown	705.29	27.85	10	687.44	06/07/96	20.78	684.51
						12/12/96	NM	---
						01/06/97	23	682.29
						06/19/97	21.31	683.98
						08/18/98	20.78	684.51
MW-18	unknown	703.65	27.46	10	686.19	06/07/96	16.42	687.23
						12/12/96	NM	---
						01/06/97	21.36	682.29
						06/19/97	19.51	684.14
						08/18/98	17.47	686.18
MW-D	707.08	709.2	19.1	10	700.1	06/19/97	14.2	695
						07/21/97	13.16	696.04
						08/18/98	13.48	695.72

TABLE 1
STATIC GROUNDWATER ELEVATIONS
Village of Whitefish Bay Good Hope Road Property
Project #3125

Monitoring Location	Ground Surface Elevation (feet MSL)	Top of Casing Elevation (feet MSL)	Total Well Depth (feet)	Screen Length (feet)	Top of Screen Elevation (feet MSL)	Monitoring Date	Depth to Water (feet)	Groundwater Elevation (feet MSL)
MW-22	unknown	709.47	32.45	10	687.02	06/07/96	24.31	685.16
						12/12/96	NM	---
						01/06/97	NM	---
						06/19/97	25.57	683.9
						08/18/98	25.02	684.45
PZ-D	707.36	709.17	31.3	5	682.87	06/19/97	25.23	683.94
						07/21/97	24.45	684.72
						08/18/98	24.7	684.47
MW-24D		711				08/18/98	12.31	698.69
						08/26/98	12.84	698.16
MW-24S		711.01				08/18/98	10.26	700.75
						08/26/98	10.14	700.87
MW-25	unknown	705.48	21.84	10	693.64	06/07/96	10.54	694.94
						12/12/96	NM	---
						01/06/97	12.16	693.32
						06/19/97	11.59	693.89
						08/18/98	11.43	694.05
MW-26	unknown	702.47	24.08	10	688.39	06/07/96	17.33	685.14
						12/12/96	NM	---
						01/06/97	20.25	682.22
						06/19/97	18.57	683.9
						07/21/97	17.82	684.65
						08/18/98	18.03	684.44
MW-106	706.83	706.53	17.03	10	699.5	08/18/98	8.65	697.88
						08/26/98	9.06	697.47
P-106	706.86	706.51	31.73	5	679.78	08/18/98	21.78	684.73
						08/26/98	22.05	684.46
MW-107	707.95	707.67	16.76	10	700.91	08/18/98	7.82	699.85
						08/26/98	8.11	699.56
P-107	708.18	707.87	29.76	5	683.11	08/18/98	13.62	694.25
						08/26/98	14.04	693.83
MW-108	707.36	707.07	16.65	10	700.42	08/18/98	8.2	698.87
						08/26/98	8.35	698.72
P-108	707.55	707.18	69.09	5	643.09	08/18/98	21.18	686
						08/26/98	21.82	685.36

TABLE 1
STATIC GROUNDWATER ELEVATIONS
Village of Whitefish Bay Good Hope Road Property
Project #3125

Monitoring Location	Ground Surface Elevation (feet MSL)	Top of Casing Elevation (feet MSL)	Total Well Depth (feet)	Screen Length (feet)	Top of Screen Elevation (feet MSL)	Monitoring Date	Depth to Water (feet)	Groundwater Elevation (feet MSL)
MW-4	unknown	698.42	20.65	10	687.77	06/07/96	13.15	685.27
						12/12/96	NM	---
						01/06/97	16.1	682.32
						06/19/97	14.4	684.02
						08/18/98	13.86	684.56
MW-6	701.1	703.3	20.3	5	688	06/19/97	18.42	684.88
						07/21/97	17.4	685.9
						08/18/98	17.27	686.03
MW-E	707.09	708.68	18.6	10	700.08	06/19/97	12.9	695.78
						07/21/97	12.2	696.48
						08/18/98	13.18	695.5
MW-10	unknown	708.69	30.4	10	688.29	06/07/96	23.44	685.25
						12/12/96	NM	---
						01/06/97	26.37	682.32
						06/19/97	24.7	683.99
						08/18/98	24.15	684.54
MW-101	708.88	708.57	15.05	10	703.52	12/12/96	9.05	699.52
						01/06/97	8.31	700.26
						06/19/97	8.19	700.38
						07/15/98	8.7	699.87
						08/18/98	8.01	700.56
						08/26/98	8.24	700.33
P-101	708.96	708.65	35.4	5	678.25	12/12/96	14.49	694.16
						01/06/97	14.22	694.43
						06/19/97	13.64	695.01
						07/15/98	14.48	694.17
						08/18/98	13.14	695.51
						08/26/98	13.62	695.03
MW-102	707.61	707.42	17.5	10	699.92	12/12/96	12.32	695.1
						01/06/97	12.37	695.05
						06/19/97	10.71	696.71
						07/15/98	11.23	696.19
						08/18/98	10.13	697.29
						08/26/98	10.38	697.04
P-102	706.97	706.53	32.31	5	679.22	08/18/98	18.97	687.56
						08/26/98	19.27	687.26

TABLE 1
STATIC GROUNDWATER ELEVATIONS
Village of Whitefish Bay Good Hope Road Property
Project #3125

Monitoring Location	Ground Surface Elevation (feet MSL)	Top of Casing Elevation (feet MSL)	Total Well Depth (feet)	Screen Length (feet)	Top of Screen Elevation (feet MSL)	Monitoring Date	Depth to Water (feet)	Groundwater Elevation (feet MSL)
MW-103	716.34	715.68	19.05	10	706.63	12/12/96	16.05	699.63
						01/06/97	15.34	700.34
						06/19/97	15.28	700.4
						07/15/98	15.84	699.84
						08/18/98	15.11	700.57
						08/26/98	15.35	700.33
MW-104	709.31	709.23	14.8	10	704.43	12/12/96	9.88	699.35
						01/06/97	9.19	700.04
						06/19/97	8.88	700.35
		709.31	*PVC removed for well repair in June 1997,			07/15/98	9.37	699.94
			estimated elevation change of 0.08 feet.			08/18/98	8.67	700.64
						08/26/98	8.92	700.39

Notes:

NM - water level not measured

Table 2
Summary Soil Quality Analytical Results
Good Hope Road Property
Village of Whitefish Bay, Wisconsin
Project Reference #3125

Analyte	Units	Sample Location/Depth Below Ground Surface (bgs)						NR 720 Soil Clean-up Standards
		PZ-A	PZ-B	PZ-C	PZ-D		MW-E	
		6-8'	8-10'	12-14'	8-10'	20-22'	12-14'	
		05/19/97	05/20/97	05/21/97	05/21/97	05/21/97	05/27/97	
Chlorobenzene	µg/kg	380	ND	ND	ND	ND	ND	NS
1,4-Dichlorobenezene	µg/kg	150	ND	ND	ND	ND	ND	NS
Cis-1,2-Dichlorobenezene	µg/kg	ND	ND	83	69,000	98,000	84	NS
Trichloroethene	µg/kg	ND	ND	190	1,400	2,200	1,200	NS
Sec-Butylbenzene	µg/kg	ND	ND	ND	550	ND	ND	NS
Ethylbenzene	µg/kg	ND	ND	ND	41,000	12,000	ND	2900
o-Xylene	µg/kg	ND	ND	ND	63,000	11,000	ND	4100
m- & p- Xylene	µg/kg	ND	ND	ND	94,000	30,000	ND	4100
Toluene	µg/kg	ND	ND	ND	850	970	ND	1500
Isopropylbenzene	µg/kg	ND	ND	ND	1,300	ND	ND	NS
1,3,5-Trimethylbenzene	µg/kg	ND	ND	ND	2,300	ND	ND	NS
Naphthalene	µg/kg	ND	ND	ND	600	ND	ND	NS
n-Propylbenzene	µg/kg	ND	ND	ND	1,900	ND	ND	NS
n-Butylbenzene	µg/kg	ND	ND	ND	630	ND	ND	NS
1,2,4-Trimethylbenzene	µg/kg	ND	ND	ND	3,900	ND	ND	NS
Tetrachloroethene	µg/kg	ND	ND	ND	2,200	4,700	6000	NS
1,1,1-Trichloroethane	µg/kg	ND	ND	ND	380	ND	ND	NS
Vinyl Chloride	µg/kg	ND	ND	ND	400	ND	ND	NS
trans-1,2-Dichloroethene	µg/kg	ND	ND	ND	ND	300	ND	NS

KEY:
ND = Not detected above the laboratory method of detection limit
µg/kg = micrograms per kilogram
NS = No established standard
▨ = Detected above Wisconsin Administrative Code, Chapter NR 720 Soil Clean-up Standards

Table 3
Groundwater Analytical Results - 11/16/93 through 8/19/98
Village of Whitefish Bay Good Hope Road Property
Project #3125

Analyte	Sample Location/Date																NR 140	
	MW-4				MW-6				MW-9				MW-10				ES	PAL
	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97		
Benzene	<0.2	NA	NA	<0.82	0.3	NA	NA	<0.41	<1.0	NA	NA	NA	0.3	NA	NA	<8.2	5.0	0.5
Carbon Tetrachloride	<0.5	NA	NA	<0.46	<0.5	NA	NA	<0.23	<2.5	NA	NA	NA	<0.5	NA	NA	<4.6	5.0	0.5
1,1-Dichloroethane	2.3	NA	ND	1.60	<0.5	NA	NA	<0.26	<2.5	NA	NA	NA	2.4	NA	ND	<5.2	850	85
1,1-Dichloroethene	1.0	NA	NA	0.72	<0.4	NA	ND	<0.28	<2.0	NA	NA	NA	2.3	NA	NA	<5.6	7.0	0.7
1,2-Dichloroethane	<0.5	NA	NA	<0.48	<0.5	NA	NA	<0.24	<2.5	NA	NA	NA	<0.5	NA	NA	<4.8	5.0	0.5
cis-1,2-Dichloroethene	212	NA	180	150	0.9	NA	ND	0.45	61.6	NA	NA	NA	1,080	NA	740	1,400	70.0	7.0
trans-1,2-Dichloroethene	2.2	NA	ND	0.92	<0.5	NA	ND	<0.25	<2.5	NA	NA	NA	20.2	NA	ND	19	100	20
Ethylbenzene	<1.0	NA	ND	<0.46	<1.0	NA	ND	<0.23	<5.0	NA	NA	NA	<1.0	NA	ND	<4.6	700	140
Tetrachloroethene	87.1	NA	1,400	270	<0.5	NA	ND	<0.27	<2.5	NA	NA	NA	751	NA	300	480	5.0	0.5
Toluene	<1.0	NA	ND	<0.56	<2.0	NA	ND	<0.28	<10.0	NA	NA	NA	<2.0	NA	ND	<5.6	343	68.6
Trichloroethene	104	NA	1,100	170	0.7	NA	ND	<0.20	<1.0	NA	NA	NA	2,740	NA	1,700	2,000	5.0	0.5
1,1,1-Trichloroethane	<0.5	NA	ND	<0.54	<0.5	NA	ND	<0.27	<2.5	NA	NA	NA	<0.5	NA	ND	<5.4	200	40
1,1,2-Trichloroethane	<0.5	NA	NA	<0.60	<0.5	NA	NA	<0.30	<2.5	NA	NA	NA	<0.5	NA	NA	<6.0	5.0	0.5
Vinyl Chloride	38.7	NA	18	18	1.3	NA	ND	0.37	64.7	NA	NA	NA	303	NA	840	820	0.2	0.02
Total Xylenes	<1.0	NA	ND	<1.56	1.0	NA	ND	<0.79	<5.0	NA	NA	NA	<1.0	NA	ND	<15.6	620	124
1,2,4-Trimethylbenzene	NA	NA	NA	<0.60	NA	NA	NA	<0.30	NA	NA	NA	NA	NA	NA	NA	<6.0	--	--
Chlorobenzene	NA	NA	NA	<0.54	NA	NA	NA	<0.27	NA	NA	NA	NA	NA	NA	NA	<5.4	--	--
Chloroethane	NA	NA	NA	<0.50	NA	NA	NA	<0.25	NA	NA	NA	NA	NA	NA	NA	<5.0	400	80
Chloromethane	NA	NA	NA	<0.30	NA	NA	NA	<0.15	NA	NA	NA	NA	NA	NA	NA	<3.0	3.0	0.3
Isopropyl Ether	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	--	--

KEY: All results are reported in micrograms per liter (µg/l) MW-9 and MW-16 abandoned 5/22/98

NA = Not analyzed

ND = Not detected above the laboratory method of detection limit

-- = Standard not established

ES = Wisconsin Administrative Code, Chapter NR 140 Enforcement Standard

PAL = Wisconsin Administrative Code, Chapter NR 140 Preventive Action Limit

▨ = Detected above Wisconsin Administrative Code, Chapter NR 140 ES

▩ = Detected above Wisconsin Administrative Code, Chapter NR 140 PAL

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Table 3 (Continued)
Groundwater Analytical Results - 11/16/93 through 8/19/98
Village of Whitefish Bay Good Hope Road Property
Project #3125

Analyte	Sample Location/Date																NR 140	
	MW-11				MW-16				MW-18				MW-22				ES	PAL
	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97		
Benzene	1.1	NA	NA	<41	<0.2	NA	NA	NA	0.2	NA	NA	<0.41	13.8	<40	NA	NA	5.0	0.5
Carbon Tetrachloride	<0.5	NA	NA	<23	<0.5	NA	NA	NA	<0.5	NA	NA	<0.23	20.1	NA	NA	NA	5.0	0.5
1,1-Dichloroethane	22.9	NA	ND	32	<0.5	NA	NA	NA	2.5	NA	ND	0.94	153.0	<100	ND	NA	850	85
1,1-Dichloroethene	7.0	NA	NA	<28	<0.4	NA	NA	NA	<0.4	NA	NA	0.33	58.7	<80	NA	NA	7.0	0.7
1,2-Dichloroethane	1.1	NA	NA	<24	<0.5	NA	NA	NA	<0.5	NA	NA	<0.24	29.8	<100	NA	NA	5.0	0.5
cis-1,2-Dichloroethene	2,660	NA	28,000	9,300	<0.5	NA	NA	NA	111	NA	15	83	1,830	17,400	73,000	NA	70.0	7.0
trans-1,2-Dichloroethene	21.3	NA	ND	54	<0.5	NA	NA	NA	1.8	NA	ND	1.4	195	<100	ND	NA	100	20
Ethylbenzene	39.8	NA	400	45	<1.0	NA	NA	NA	<1.0	NA	ND	<0.23	3,680	12,600	5,100	NA	700	140
Tetrachloroethene	<0.5	NA	ND	<27	<0.5	NA	NA	NA	<0.5	NA	ND	<0.27	823	7,290	4,100	NA	5.0	0.5
Toluene	30.4	NA	1,000	110	<2.0	NA	NA	NA	<2.0	NA	ND	<0.28	2,310	1,360	NA	NA	343	68.6
Trichloroethene	7.2	NA	ND	<20	<0.3	NA	NA	NA	3.2	NA	1.4	3.2	1,720	13,400	1.4	NA	5.0	0.5
1,1,1-Trichloroethane	21.8	NA	ND	<27	<0.5	NA	NA	NA	<0.5	NA	ND	<0.27	468	251	1,100	NA	200	40
1,1,2-Trichloroethane	<0.5	NA	NA	<30	<0.5	NA	NA	NA	<0.5	NA	NA	<0.30	3.4	<100	NA	NA	5.0	0.5
Vinyl Chloride	1,750	NA	7,500	2,100	<0.2	NA	NA	NA	30.5	NA	2.3	11	770	3,480	2,800	NA	0.2	0.02
Total Xylenes	17.7	NA	850	69	<1.0	NA	NA	NA	<1.0	NA	ND	<0.79	8,300	53,400	20,100	NA	620	124
1,2,4-Trimethylbenzene	NA	NA	NA	<30	NA	NA	NA	NA	NA	NA	NA	<0.30	NA	204	NA	NA	--	--
Chlorobenzene	NA	NA	NA	<27	NA	NA	NA	NA	NA	NA	NA	<0.27	NA	<400	NA	NA	--	--
Chloroethane	NA	NA	NA	<25	NA	NA	NA	NA	NA	NA	NA	<0.25	NA	<400	NA	NA	400	80
Chloromethane	NA	NA	NA	<15	NA	NA	NA	NA	NA	NA	NA	<0.15	NA	ND	NA	NA	3.0	0.3
Isopropyl Ether	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<200	NA	NA	--	--

KEY: All results are reported in micrograms per liter (µg/l) MW-9 and MW-16 abandoned 5/22/98

NA = Not analyzed

ND = Not detected above the laboratory method of detection limit

-- = Standard not established

ES = Wisconsin Administrative Code, Chapter NR 140 Enforcement Standard

PAL = Wisconsin Administrative Code, Chapter NR 140 Preventive Action Limit

▨ = Detected above Wisconsin Administrative Code, Chapter NR 140 ES

▦ = Detected above Wisconsin Administrative Code, Chapter NR 140 PAL

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Table 3 (Continued)
Groundwater Analytical Results - 11/16/93 through 8/19/98
Village of Whitefish Bay Good Hope Road Property
Project #3125

Analyte	Sample Location/Date																NR 140	
	MW-24S				MW-24D				MW-25				MW-26				ES	PAL
	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97		
Benzene	<0.2	NA	NA	NA	<0.2	NA	NA	NA	NA	<4.0	NA	<4.1	NA	<20	NA	<4.1	5.0	0.5
Carbon Tetrachloride	<0.5	NA	NA	NA	<0.5	NA	NA	NA	NA	<10	NA	<2.3	NA	<50	NA	<2.3	5.0	0.5
1,1-Dichloroethane	<0.5	NA	ND	NA	<0.5	NA	ND	NA	NA	<10	ND	<2.6	NA	<50	ND	<2.6	850	85
1,1-Dichloroethene	<0.4	NA	NA	NA	<0.4	NA	NA	NA	NA	<8.0	NA	7.1	NA	<40	NA	<2.8	7.0	0.7
1,2-Dichloroethane	<0.5	NA	NA	NA	<0.5	NA	NA	NA	NA	<10	NA	<2.4	NA	<50	NA	<2.4	5.0	0.5
cis-1,2-Dichloroethene	<0.5	NA	ND	NA	<0.5	NA	ND	NA	NA	632	19	1,000	NA	3070	1,100	1,000	70.0	7.0
trans-1,2-Dichloroethene	<0.5	NA	ND	NA	<0.5	NA	ND	NA	NA	<10	ND	6.6	NA	<50	ND	9.0	100	20
Ethylbenzene	<1.0	NA	ND	NA	<1.0	NA	ND	NA	NA	<20	ND	<2.3	NA	<100	ND	<2.3	700	140
Tetrachloroethene	<0.5	NA	ND	NA	<0.5	NA	ND	NA	NA	<10	ND	<2.7	NA	<50	ND	<2.7	5.0	0.5
Toluene	<2.0	NA	NA	NA	5.9	NA	NA	NA	NA	<40	NA	<2.8	NA	<200	NA	<2.8	343	68.6
Trichloroethene	0.5	NA	ND	NA	<0.3	NA	ND	NA	NA	<4	ND	<2.0	NA	<20	ND	<2.0	5.0	0.5
1,1,1-Trichloroethane	<0.5	NA	ND	NA	<0.5	NA	ND	NA	NA	<10	ND	<2.7	NA	<50	ND	<2.7	200	40
1,1,2-Trichloroethane	<0.5	NA	NA	NA	<0.5	NA	NA	NA	NA	<10	NA	<3.0	NA	<50	NA	<3.0	5.0	0.5
Vinyl Chloride	<0.2	NA	ND	NA	<0.2	NA	ND	NA	NA	59.5	1.8	250	NA	712	880	350	0.2	0.02
Total Xylenes	<1.0	NA	ND	NA	<1.0	NA	ND	NA	NA	<20	ND	<7.9	NA	<100	ND	<7.9	620	124
1,2,4-Trimethylbenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	<20	NA	<3.0	NA	<100	NA	<3.0	--	--
Chlorobenzene	NA	NA	NA	NA	NA	NA	NA	NA	NA	<40	NA	<2.7	NA	<200	NA	<2.7	--	--
Chloroethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	<40	NA	<2.5	NA	<200	NA	<2.5	400	80
Chloromethane	NA	NA	NA	NA	NA	NA	NA	NA	NA	ND	NA	<1.5	NA	ND	NA	<1.5	3.0	0.3
Isopropyl Ether	NA	NA	NA	NA	NA	NA	NA	NA	NA	<20	NA	NA	NA	<100	NA	NA	--	--

KEY: All results are reported in micrograms per liter (μg/l) MW-9 and MW-16 abandoned 5/22/98

NA = Not analyzed

ND = Not detected above the laboratory method of detection limit

-- = Standard not established

ES = Wisconsin Administrative Code, Chapter NR 140 Enforcement Standard

PAL = Wisconsin Administrative Code, Chapter NR 140 Preventive Action Limit

░ = Detected above Wisconsin Administrative Code, Chapter NR 140 ES

▨ = Detected above Wisconsin Administrative Code, Chapter NR 140 PAL

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Table 3 (Continued)
Groundwater Analytical Results - 11/16/93 through 8/19/98
Village of Whitefish Bay Good Hope Road Property
Project #3125

Analyte	Sample Location/Date																					NR 140	
	MW-27				MW-27D				MW-A	PZ-A	MW-B	PZ-B	MW-C	PZ-C	MW-D	PZ-D	MW-E	MPS MW-1	MPS P-1	MPS P-2	MPS P-3	ES	PAL
	11/16/93	06/27/95	06/07/96	06/20/97	11/16/93	06/27/95	06/07/96	06/20/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/97	06/19/98	06/19/98	06/19/98	06/19/98		
Benzene	NA	4.7	NA	NA	NA	4.5	NA	NA	0.45	2.1	<0.41	<0.41	<2.0	<0.41	<100	<41	<8.2	<0.27	<5.4	<2.7	<0.54	5.0	0.5
Carbon Tetrachloride	NA	<0.5	NA	NA	NA	<0.5	NA	NA	<0.23	<0.23	<0.23	<0.23	<1.2	<0.23	<58	<23	<4.6	<0.34	<6.8	<3.4	<0.68	5.0	0.5
1,1-Dichloroethane	NA	40.8	ND	NA	NA	37.2	ND	NA	<0.26	<0.26	<0.26	<0.26	<1.3	0.89	120	81	<5.2	<0.35	8.4	5.2	<0.70	850	85
1,1-Dichloroethene	NA	8.8	NA	NA	NA	7.8	NA	NA	<0.28	<0.28	<0.28	<0.28	<1.4	0.62	<70	42	<5.6	<0.43	<8.6	<4.3	<0.86	7.0	0.7
1,2-Dichloroethane	NA	3.9	NA	NA	NA	7.0	NA	NA	<0.24	<0.24	<0.24	<0.24	<1.2	<0.24	<60	<24	<4.8	<0.37	<7.4	<3.7	<0.74	5.0	0.5
cis-1,2-Dichloroethene	NA	4,270	7,700	NA	NA	6,110	ND	NA	<0.28	0.64	0.34	0.48	270	110	26,000	19,000	390	<0.28	2,600	1,000	320	70.0	7.0
trans-1,2-Dichloroethene	NA	80.6	ND	NA	NA	49.5	ND	NA	<0.25	<0.25	<0.25	<0.25	3.4	2.3	62	64	<5.0	<0.79	<16	8.9	1.7	100	20
Ethylbenzene	NA	<1.0	ND	NA	NA	<1.0	ND	NA	<0.23	0.59	<0.23	<0.23	<1.2	<0.23	1,800	36	<4.6	<0.32	<6.4	<3.2	<0.64	700	140
Tetrachloroethene	NA	7.5	ND	NA	NA	6.8	ND	NA	<0.27	1.0	<0.27	<0.27	73	0.27	4,500	51	510	<0.43	<8.6	<4.3	<0.86	5.0	0.5
Toluene	NA	10.6	NA	NA	NA	10.1	NA	NA	<0.28	0.74	<0.28	<0.28	<1.4	<0.28	660	<28	<5.6	<0.27	<5.4	<2.7	<0.54	343	68.6
Trichloroethene	NA	63.9	ND	NA	NA	57.4	ND	NA	<0.20	2.0	<0.20	<0.20	540	1.5	9,800	1,800	2700	<0.37	<7.4	<3.7	<0.74	5.0	0.5
1,1,1-Trichloroethane	NA	<0.5	ND	NA	NA	<0.5	ND	NA	<0.27	<0.27	<0.27	<0.27	<1.4	<0.27	400	<27	<5.4	<0.30	<6.0	<3.0	<0.60	200	40
1,1,2-Trichloroethane	NA	<0.5	NA	NA	NA	<0.5	NA	NA	<0.30	<0.30	<0.30	<0.30	<1.5	<0.30	<75	<30	<6.0	<0.61	<12	<6.1	<1.2	5.0	0.5
Vinyl Chloride	NA	4,100	8,700	NA	NA	4,110	ND	NA	<0.23	0.79	<0.23	<0.23	14	150	520	4,100	<4.6	<0.20	820	810	150	0.2	0.02
Total Xylenes	NA	<1.0	ND	NA	NA	<1.0	ND	NA	<0.79	2.59	<0.79	<0.79	<3.9	<0.79	6,900	149	<15.6	<0.43	<8.6	4.6	<0.86	620	124
1,2,4-Trimethylbenzene	NA	<1.0	NA	NA	NA	<1.0	NA	NA	<0.30	0.59	<0.30	<0.30	<1.5	<0.30	130	<30	<6.0	<0.22	<4.4	<2.2	<0.44	--	--
Chlorobenzene	NA	6.8	NA	NA	NA	2.9	NA	NA	<0.27	0.61	<0.27	<0.27	<1.4	<0.27	<68	<27	<5.4	<0.23	<4.6	<2.3	<0.46	--	--
Chloroethane	NA	6.4	NA	NA	NA	4.6	NA	NA	<0.25	<0.25	<0.25	<0.25	<1.2	<0.25	<62	<25	<5.0	<0.54	<11	<5.4	<1.1	400	80
Chloromethane	NA	ND	NA	NA	NA	ND	NA	NA	1.5	0.94	1.1	0.97	<0.75	0.72	<38	<15	<3.0	<0.61	<12	<6.1	<1.2	3.0	0.3
Isopropyl Ether	NA	5.6	NA	NA	NA	5.4	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.55	<11	<5.5	<1.1	--	--

KEY: All results are reported in micrograms per liter (µg/l) MW-9 and MW-16 abandoned 5/22/98

NA = Not analyzed

ND = Not detected above the laboratory method of detection limit

-- = Standard not established

ES = Wisconsin Administrative Code, Chapter NR 140 Enforcement Standard

PAL = Wisconsin Administrative Code, Chapter NR 140 Preventive Action Limit

░ = Detected above Wisconsin Administrative Code, Chapter NR 140 ES

▒ = Detected above Wisconsin Administrative Code, Chapter NR 140 PAL

TABLE 4
SUMMARY OF BIOANALYTICAL RESULTS
Good Hope Road Property
Village of Whitefish Bay, Wisconsin
Project Reference #3125

		SOIL			GROUNDWATER						
Analyte	Units	PZ-A 8'-10' 05/22/97	PZ-C 12'-14' 05/22/97	PZ-D 14'-16' 05/22/97	MW-A 06/19/97	MW-B 06/19/97	MW-D 06/19/97	MPS MW-1 08/19/98	MPS P-1 08/19/98	MPS P-2 08/19/98	MPS P-3 08/19/98
Bacterial Plate Counts:											
Heterotrophic Plate Count	CFU/gm	1.4E+04	2.4E+05	4.7E+0.2	NA	NA	NA	NA	NA	NA	NA
	CFU/ml	NA	NA	NA	5.9E+05	2.7E+04	7.1E+04	NA	NA	NA	NA
Petroleum Hydrocarbon Degraders	CFU/gm	2.5E+03	1.1E+05	1.40E+02	NA	NA	NA	NA	NA	NA	NA
	CFU/ml	NA	NA	NA	2.3E+05	1.6E+04	5.8E+04	NA	NA	NA	NA
Methanotrophs	CFU/gm	NA	NA	NA	48	19	62	NA	NA	NA	NA
Putative Chlorinated Solvent Degraders	CFU/gm	NA	NA	NA	0.92	12	6.4	NA	NA	NA	NA
Nutrients:											
Total Organic Carbon	ppm	1.4E+05	7.0E+04	1.16E+05	20	8	49	11	52	6	4.8
Total Kjeldhal Nitrogen	ppm	1803.5	698.9	1071.7	31.4	5.8	2.6	NA	NA	NA	NA
Nitrogen, Ammonia	ppm	8.3	0.5	0.1	<0.1	0.2	0.2	NA	NA	NA	NA
Phosphate	ppm	1.2	1.0	1.2	<0.1	<0.1	<0.1	NA	NA	NA	NA
Total Organic Nitrogen	ppm	1595.2	698.4	1071.6	31.4	5.3	2.4	NA	NA	NA	NA
Sulfate, Total	ppm	<0.1	97.9	189	196.5	90	205	67	146	156	136
Nitrate	ppm	<0.1	<0.1	<0.1	0.9	0.5	0.9	0.018	0.22	0.11	0.15
Manganese	ppm	540	580	690	NA	NA	NA	NA	NA	NA	NA
Chloride	ppm	NA	NA	NA	NA	NA	NA	49	266	210	258
Iron, Total	ppm	6.1	2.0	10.9	0.5	0.5	2.3	NA	NA	NA	NA
Other Biofeasibility Indicators:											
Moisture	%	11.6	12.3	17.6	NA	NA	NA	NA	NA	NA	NA
pH	unitless	7.6	8.0	7.8	7.2	7.1	7.3	NA	NA	NA	NA
Methane	ng/l	NA	NA	NA	341,663	170,461	407,794	1,582	539,293	185,948	200,588
Ethane	ng/l	NA	NA	NA	356	107	22,792	63	1,189	1,647	1,925
Ethylene	ng/l	NA	NA	NA	168	64	38,009	214	120,611	13,181	4,485
In Situ Field Measurements											
Dissolved Oxygen	mg/l	NA	NA	NA	0.62	0.45	0.27	3.67	3.39	2.70	3.49

Key:

CFU/gm = Colony Forming Units per gram

CFU/ml = Colony Forming Unit per milliliter

mg/l = Milligrams per liter

ng/l = Nanograms per liter

mg/kg = Milligrams per Kilogram

% = Percentage

NA = Not Analyzed

BORING LOGS/WELL CONSTRUCTION DETAILS

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☒ Other ____________

SOIL BORING LOG INFORMATION

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Facility/Project Name **Village of Whitefish Bay**	License/Permit/Monitoring Number	Boring Number **PZ-A**

Boring Drilled By (Firm name and name of crew chief) **Midwest Engineering Services** **Dennis**	Date Drilling Started 05 / 19 / 97 MM DD YY	Date Drilling Completed 05 / 23 / 97 MM DD YY	Drilling Method **Hollow Stem Auger**

DNR Facility Well No.	WI Unique Well No.	Common Well Name PZ-A	Final Static Water Level ______ Feet MSL	Surface Elevation 695.2 Feet MSL	Borehole Diameter 12.25 inches

Boring Location
State Plane ____________ N, ____________ E S
____ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ___°___'___"
Long ___°___'___"
Local Grid Location (If applicable)
______ Feet ☐ N ☐ S ______ Feet ☐ E ☐ W

County **Milwaukee**	DNR County Code 41	Civil Town/City/ or Village **Village of Whitefish Bay**

Sample: Number and Type	Sample: Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties: Compressive Strength	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
				Blind drill ground surface to 2 feet bgs.										
1	24	12 16 7 6	2.0	2.0 to 4.0 **Top 4" Silty CLAY, dark gray (10YR 4/1:M/W), organic debris, 2" crushed rock at 6". Bottom 18" Sitly CLAY, brown (10YR 5/3:M), medium stiff to stiff, low plasticity, trace gravel. Bottom 2" gray mottling.**	OL			0.0		M				
2	8	4 3 3 3	4.0	4.0 to 6.0 **Silty CLAY, black (2.5Y/1:M), trace broken glass, paper and orgainc debris, medium stiff to stiff, medium plasticity. Bottom 3" of sample grayish green, 5G 5/1.**	OL			293		M				
3	14	2 3 2 6	6.0	6.0 to 8.0 **Silty, sandy, CLAY, dark gray (10YR 4/1:M/W), loose, low plasticity, sand fine. Bottom 4" Silty CLAY, gray (10YR 5/1:M), soft, medium plasticity, trace roots.**	SM			48.6		M/W				
4	20	4 8 9 13	8.0	8.0 to 10.0 **Clayey SILT, brown (10YR 5/3:M/W), soft to medium stiff, low plasticity, plastic, paper and metal fill debris.**	SC			143		M/W				
5	18	4 8 12 10	10.0		SM			28.2		W				

Depth scale: 1.0, 2.0, 3.0, 4.0, 5.0, 6.0, 7.0, 8.0, 9.0, 10.0, 11.0, 12.0

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature James M. Wateman

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

This form is authorized by Chapters 144, 147 and 162, Wis. Stats. Completion of this report is mandatory. Penalties: Forfeit not less than $10 nor more than $5,000 for each violation. Fined not less than $10 or more than $100 or imprisoned not less than 30 days or both for each violation. Each day of continued violation is a separate offense, pursuant to ss 144.99 and 162.06, Wis. Stats.

3125S3

State of Wisconsin
Department of Natural Resources
Boring Number PZ-A

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT
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Rev. 5-92

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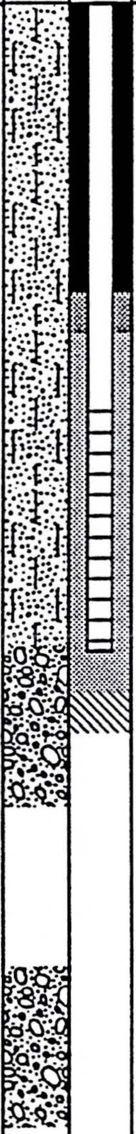

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
6	12	4 5 10 5	13.0	10.0 to 12.0 Top 10" Clayey SILT, grayish brown (2.5Y 5/2:W), soft, trace fine sand. Bottom 8" Silty SAND grayish brown (2.5Y 5/2:W), soft, loose, sand fine.	SM			11.2		W				
7	8	2 3 4 4	14.0 15.0	12.0 to 14.0 Silt and SAND, grayish brown (2.5Y 5/2:W), soft, medium dense to loose, trace medium gravel.	SM			22.5		W				
8	8	2 2 2 3	16.0 17.0	14.0 to 16.0 Silt and SAND, grayish brown (2.5Y 5/2:W), soft, loose to medium dense, trace gravel, sand fine.	SM			11.2		W				
				16.0 to 18.0 Same as above.										
9	12	2 8 11 8	18.0 19.0	18.0 to 20.0 Same as above with coarse gravel seams.	SM			0.0		W				
10	2	4 11 6 11	20.0 21.0	20.0 to 22.0 Coarse sand and GRAVEL, gray (10YR 5/1:W), loose, some broken rock.	GW			0.0		W				
			22.0 23.0											
11	--	- - -	24.0 25.0	24.0 to 26.0 Blind drilled to 26 feet bgs and encountered resistance. Hammered 6" with bolder breaker, tryed to drill still had resistance. Set well screen 21 to 18 feet bgs.	GW			-		W				
			26.0 27.0 28.0 29.0 30.0 31.0 32.0											

Village of Whitefish Bay

3125S3

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ______

SOIL BORING LOG INFORMATION
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Facility/Project Name **illage of Whitefish Bay Demolition Landfill**	License/Permit/Monitoring Number	Boring Number **MW-A**

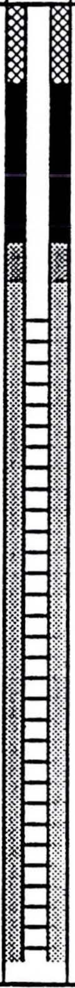
Boring Drilled By (Firm name and name of crew chief) **Midwest Engineering Services** **Dennis**	Date Drilling Started 05 / 23 / 97 MM DD YY	Date Drilling Completed 05 / 23 / 97 MM DD YY	Drilling Method **Hollow Stem Auger**

DNR Facility Well No.	WI Unique Well No.	Common Well Name **MW-A**	Final Static Water Level ______ Feet MSL	Surface Elevation 695.0 Feet MSL	Borehole Diameter 8.25 inches

Boring Location
State Plane ______ N, ______ E S
______ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ° ' "
Long ° ' "

Local Grid Location (If applicable)
______ Feet ☐ N ☐ S ______ Feet ☐ E ☐ W

County **Milwaukee**	DNR County Code **41**	Civil Town/City/ or Village **Village of Whitefish Bay**

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
				Blind drilled to 15 feet bgs.										
-			1.0											
			2.0											
			3.0											
-			4.0											
			5.0											
			6.0											
			7.0											
			8.0											
			9.0											
			10.0											
			11.0											
			12.0											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature James M. Detemann

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

his form is authorized by Chapters 144, 147 and 162, Wis. Stats. Completion of this report is mandatory. Penalties: Forfeit not less han $10 nor more than $5,000 for each violation. Fined not less than $10 or more than $100 or imprisoned not less than 30 days or both for each violation. Each day of continued violation is a separate offense, pursuant to ss 144.99 and 162.06, Wis. Stats.

312553

State of Wisconsin
Department of Natural Resources
Boring Number MW-A

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Rev. 5-92

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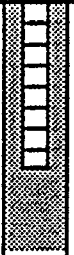
Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
			13.0											
			14.0											
			15.0	Terminated boring at 15 bgs. Set screen 14 to 4 feet bgs.										
			16.0											
			17.0											
			18.0											
			19.0											
			20.0											
			21.0											
			22.0											
			23.0											
			24.0											
			25.0											
			26.0											
			27.0											
			28.0											
			29.0											
			30.0											
			31.0											
			32.0											

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☒ Other

SOIL BORING LOG INFORMATION

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Facility/Project Name: Village of Whitefish Bay
License/Permit/Monitoring Number:
Boring Number: PZ-B

Boring Drilled By (Firm name and name of crew chief): Midwest Engineering Services, Dennis
Date Drilling Started: 05 / 20 / 97 (MM DD YY)
Date Drilling Completed: 05 / 23 / 97 (MM DD YY)
Drilling Method: Hollow Stem Auger

DNR Facility Well No.:
WI Unique Well No.:
Common Well Name: PZ-B
Final Static Water Level: ______ Feet MSL
Surface Elevation: 690.8 Feet MSL
Borehole Diameter: 12.25 inches

Boring Location
State Plane ______ N, ______ E S
______ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location (If applicable): ______ Feet ☐ N ☐ S ______ Feet ☐ E ☐ W

County: Milwaukee
DNR County Code: 41
Civil Town/City/ or Village: Village of Whitefish Bay

Sample Number and Type	Sample Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties: Compressive Strength	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			1.0	Blind drilled ground surface to 2 feet bgs.										
1	12	4 4 5 8	2.0 3.0	2.0 to 4.0 Silty CLAY, very dark gray (10YR 3/1:M), high organic contents, roots and other organic debris, soft to medium stiff.	OL			0.0		M				
2	15	4 3 8 5	4.0 5.0	4.0 to 6.0 CLAY and SILT, dark yellowish brown (10YR 4/4:M/W), soft, medium dense to dense. Bottom 2" medium GRAVEL, yellowish brown (10YR 5/4:W), loose, some medium sand.	ML			0.0		W				
3	18	10 18 19 5	6.0 7.0	6.0 to 8.0 Coarse sand and GRAVEL yellowish brown (10YR 5/6:W), loose. Sand and gravel angular. Bottom 2" Clayey SILT, grayish brown (10YR 5/2:W) soft, dense.	GM			2.5		W				
4	20	5 5 5 6	8.0 9.0	8.0 to 10.0 Top 4" coarse sand and GRAVEL, grayish brown (10YR 5/2:W), medium dense. Bottom 16" Clayey SILT, graysih brown (10YR 5/2:W) soft to medium stiff, trace medium sand.	ML			12.0		W				
5	22	4 5 6 5	10.0 11.0	10.0 to 12.0 Same as above.	ML			9.5		W				
			12.0											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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State of Wisconsin
Department of Natural Resources
Boring Number PZ-B

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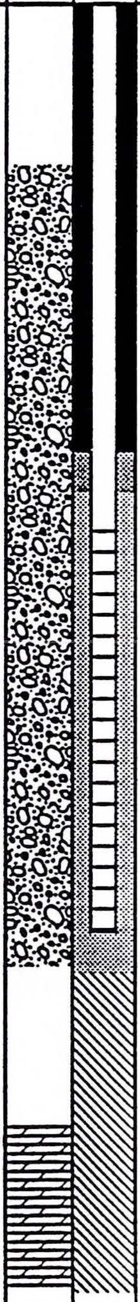
Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
6	-	3 3 58	13.0	12.0 to 14.0 No recovery rock in spoon.										
7	16	4 6 10 11	14.0 15.0	14.0 to 16.0 Coarse sand and GRAVEL, gray (10YR 6/1:W), loose.	GW			10.2		W				
8	6	7 15 50/4	16.0 17.0	16.0 to 18.0 Same as above. Medium dense.	GW			1.0		W				
9	8	10 20 23 17	18.0 19.0	18.0 to 20.0 Same as above.	GW			10		W				
10	10	30 32 20 25	20.0 21.0	20.0 to 22.0 Same as above. Dense.	GW			0.8			W			
11	2	36 31 12 30	22.0 23.0	22.0 to 24.0 Rock cought in spoon.	GW			-			W			
12	-	15 11 8 17	24.0 25.0	24.0 to 26.0 No recovery. Rock chips in spoon. Bedrock ?				-			W			
13	4	15 50/4	26.0 27.0	26.0 to 28.0 Rock chips in spoon. Dark gray in color. Terminated boring at 28 feet bgs.	DOLO			-			W			
			28.0 29.0 30.0 31.0 32.0											



Village of Whitefish Bay
312553

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ____

SOIL BORING LOG INFORMATION
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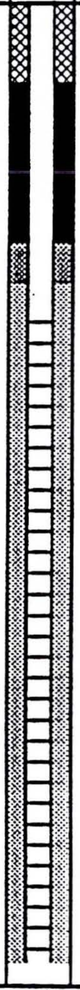
acility/Project Name **illage of Whitefish Bay Demolition Landfill**	License/Permit/Monitoring Number	Boring Number **MW-B**

Boring Drilled By (Firm name and name of crew chief) **Midwest Engineering Services** **Dennis**	Date Drilling Started 05 / 23 / 97 MM DD YY	Date Drilling Completed 05 / 23 / 97 MM DD YY	Drilling Method **Hollow Stem Auger**

DNR Facility Well No.	WI Unique Well No.	Common Well Name **MW-B**	Final Static Water Level ____ Feet MSL	Surface Elevation 691.4 Feet MSL	Borehole Diameter 8.25 inches

Boring Location
State Plane ____ N, ____ E S
____ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ____ ° ____ ' ____ "
Long ____ ° ____ ' ____ "
Local Grid Location (If applicable)
____ Feet ☐ N ☐ S ____ Feet ☐ E ☐ W

County **Milwaukee**	DNR County Code 41	Civil Town/City/ or Village **Village of Whitefish Bay**

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0	**Blind drilled to 15 feet bgs.**										

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

is form is authorized by Chapters 144, 147 and 162, Wis. Stats. Completion of this report is mandatory. Penalties: Forfeit not less an $10 nor more than $5,000 for each violation. Fined not less than $10 or more than $100 or imprisoned not less than 30 days or both for each violation. Each day of continued violation is a separate offense, pursuant to ss 144.99 and 162.06, Wis. Stats.

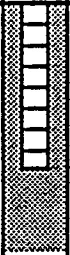
3125S3

State of Wisconsin
Department of Natural Resources
Boring Number MW-B

SOIL BORING LOG INFORMATION SUPPLEMENT
Form 4400-122A
Rev. 5-92

Use only as an attachment to Form 4400-122.

Page 2 of 2

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			13.0	Boring terminated at 15 feet bgs. Well screen set 14 to 4 feet bgs.										
			14.0											
			15.0											
			16.0											
			17.0											
			18.0											
			19.0											
			20.0											
			21.0											
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			23.0											
			24.0											
			25.0											
			26.0											
			27.0											
			28.0											
			29.0											
			30.0											
			31.0											
			32.0											

Village of Whitefish Bay Demolition Landfill

3125S3

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ____

SOIL BORING LOG INFORMATION
Form 4400-122 Rev. 5-92

Page 1 of 2

Facility/Project Name: **Village of Whitefish Bay**
License/Permit/Monitoring Number:
Boring Number: **PZ-C**

Boring Drilled By (Firm name and name of crew chief): **Midwest Engineering Services Dennis**
Date Drilling Started: 05 / 21 / 97 (MM DD YY)
Date Drilling Completed: 05 / 23 / 97 (MM DD YY)
Drilling Method: **Hollow Stem Auger**

DNR Facility Well No.: ____
WI Unique Well No.: ____
Common Well Name: PZ-C
Final Static Water Level: ____ Feet MSL
Surface Elevation: 698.1 Feet MSL
Borehole Diameter: 12.25 inches

Boring Location
State Plane ____ N, ____ E S
____ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ____ ° ____ ' ____ "
Long ____ ° ____ ' ____ "
Local Grid Location (If applicable) ____ Feet ☐ N ☐ S ____ Feet ☐ E ☐ W

County: **Milwaukee**
DNR County Code: 41
Civil Town/City/ or Village: **Village of Whitefish Bay**

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			1.0	**Blind drilled ground surface to 2 feet bgs.**										
1	12	5 5 5 4	2.0 3.0	2.0 to 4.0 **Top two inches silty CLAY, brown (10YR 5/3:M), stiff, grass and roots. Bottom 10" clay silt and medium sand, black (10YR 2/1:M), loose, trash odor, fill materal.**	OL			5.9		M				
2	-	5 2 2 2	4.0 5.0	4.0 to 6.0 **No recovery.**				-		-				
3	4	5 4 4 5	6.0 7.0	6.0 to 8.0 **Silty CLAY, brown (10YR 5/3:M), stiff, trace roots and organic materal. Bottom 1" coarse sand and gravel, black (10YR 2/1:M), loose, trace metal debris cought in spoon.**	ML			0.5		M				
4	16	4 4 7 10	8.0 9.0	8.0 to 10.0 **Silty CLAY, light olive brown (2.5Y 5/3:M), medium stiff, medium plasticity, trace fine sand and coarse gravel.**	ML			5.0		M				
5	24	4 7 9 10	10.0 11.0 12.0	10.0 to 12.0 **Clay SILT, light olive green (2.5Y 5/3:M), stiff, low plasticity, trace medium gravel and metal debris.**	ML			8.2		M				

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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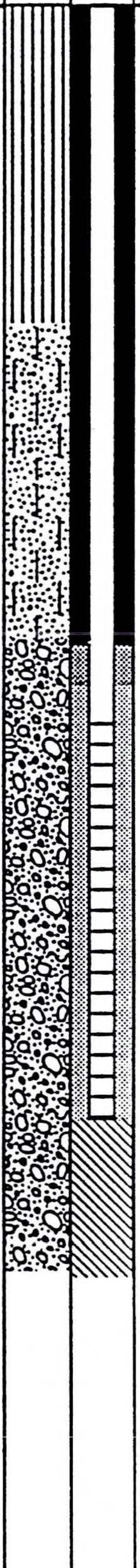
3125S3

State of Wisconsin
Department of Natural Resources
Boring Number PZ-C

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT
Form 4400-122A Rev. 5-92

Page 2 of 2



Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit				U S C S	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)											Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
6	22	2 3 4 7	13.0	12.0	to	14.0	Clayey SILT, gray (10YR 5/1:M/W), soft, medium plasticity.	ML			2.7		M/W				No Odor
7	14	3 4 7 7	14.0 15.0	14.0	to	16.0	Same as above with fine sand.	ML			-		W				
8	22	4 5 5 4	16.0 17.0	16.0	to	18.0	Clayey SILT and FINE SAND, gray (10YR 5/1:W) soft, medium plasticity. Top 10" contain some medium to fine gravel.	SM			-		W				
9	2	3 3 7 9	18.0 19.0	18.0	to	20.0	Same as above.	SM			-		W				
10	4	5 7 11 12	20.0 21.0	20.0	to	22.0	Coarse sand and GRAVEL, gray (10YR 5/1:W), loose to medium dense.	GW			-		W				
11	12	13 15 25 38	22.0 23.0	22.0	to	24.0	Sand and GRAVEL, gray (10YR 5/1:W), loose to medium dense. Chips of rock in spoon. Rock grayish brown. Sand and gravel coarse.	GW			1.1		W				No Odor
12	18	13 18 21 26	24.0 25.0	24.0	to	26.0	Same as above.	GW			1.6		W				
13	12	7 34 22 17	26.0 27.0	26.0	to	28.0	Same as above. Terminated boring at 28 feet bgs.	GW			3.2		W				
			28.0 29.0 30.0 31.0 32.0														

Village of Whitefish Bay
312553

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ____________

SOIL BORING LOG INFORMATION
Form 4400-122 Rev. 5-92

Page 1 of 2

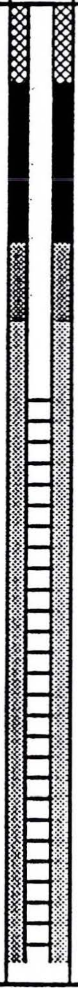
Facility/Project Name: illage of Whitefish Bay Demolition Landfill
License/Permit/Monitoring Number:
Boring Number: **MW-C**

Boring Drilled By (Firm name and name of crew chief): **Midwest Engineering Services** **Dennis**
Date Drilling Started: 05 / 21 / 97 (MM DD YY)
Date Drilling Completed: 05 / 21 / 97 (MM DD YY)
Drilling Method: **Hollow Stem Auger**

DNR Facility Well No. ___ WI Unique Well No. ___
Common Well Name: MW-C
Final Static Water Level: ______ Feet MSL
Surface Elevation: 698.5 Feet MSL
Borehole Diameter: 8.25 inches

Boring Location
State Plane ______________ N, ______________ E S
_____ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location (If applicable) _______ Feet ☐ N ☐ S _______ Feet ☐ E ☐ W

County: Milwaukee
DNR County Code: 41
Civil Town/City/ or Village: Village of Whitefish Bay

Sample									Soil Properties						
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			1.0 2.0 3.0 4.0 5.0 6.0 7.0 8.0 9.0 10.0 11.0 12.0	**Blind drilled to 16 feet bgs.**										

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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312/S3

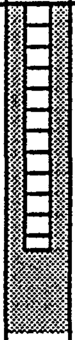
State of Wisconsin
Department of Natural Resources
Boring Number MW-C

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT

Form 4400-122A
Rev. 5-92

Page 2 of 2

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
			13.0	**Boring terminated at 16 feet bgs. well screen set 15 to 5 feet bgs.**										
			14.0											
			15.0											
			16.0											
			17.0											
			18.0											
			19.0											
			20.0											
			21.0											
			22.0											
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			25.0											
			26.0											
			27.0											
			28.0											
			29.0											
			30.0											
			31.0											
			32.0											

Village of Whitefish Bay Demolition Landfill

3125S3

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ____________

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

Page 1 of 2

Facility/Project Name: illage of Whitefish Bay
License/Permit/Monitoring Number:
Boring Number: **PZ-D**

oring Drilled By (Firm name and name of crew chief): **Midwest Engineering Services**
Dennis
Date Drilling Started: 05 / 21 / 97 (MM DD YY)
Date Drilling Completed: 05 / 29 / 97 (MM DD YY)
Drilling Method: **Hollow Stem Auger**

DNR Facility Well No.: ___
WI Unique Well No.: ___
Common Well Name: PZ-D
Final Static Water Level: ______ Feet MSL
Surface Elevation: 707.6 Feet MSL
Borehole Diameter: 12.25 inches

Boring Location
State Plane ______________ N, ______________ E S
______ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location (If applicable)
________ Feet ☐ N ☐ S
________ Feet ☐ E ☐ W

County: Milwaukee
DNR County Code: 41
Civil Town/City/ or Village: Village of Whitefish Bay

Sample: Number and Type	Sample: Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Soil Properties: Compressive Strength	Soil Properties: Moisture Content	Soil Properties: Liquid Limit	Soil Properties: Plasticity Index	Soil Properties: P 200	RQD/ Comments
			1.0	**Blind drilled ground surface to 2 feet bgs.**										
1	16	6 4 3 4	2.0 3.0	**2.0 to 4.0 Clayey SILT, brown (7.5YR 4/4:D/M), stiff, crumbly, trace to some roots and organic debris.**	OL			2.1		D/M				
2	14	4 4 5 4	4.0 5.0	**4.0 to 6.0 Clay SILT, dark yellowish brown (10YR 3/4:M), medium stiff, crumbly, wood particals-fill materal.**	ML			5.2		M				
3	16	1 7 9 8	6.0 7.0	**6.0 to 8.0 Silty, sandy, GRAVEL, dark yellowish brown (10YR 4/4:D/M), stiff crumbly, gravel medium, sand coarse to fine.**	GM			2850		D/M				
4	12	5 4 2 3	8.0 9.0	**8.0 to 10.0 Same as above with some fill materal including metal debris. 2" SILT seam, dark yellowish brown (10YR 4/4:M/W) sweet odor. Bottom 2' of sample wet.**	GM			2287		M/W				Sweet Odor
5	24	5 5 7 11	10.0 11.0 12.0	**10.0 to 12.0 SILT, grayish brown (10YR 5/2:M), soft, trace fine sand, strong odor paint smell.**	ML			>2500		M				Sweet Odor

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: James M. Watermann
Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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State of Wisconsin
Department of Natural Resources
Boring Number PZ-D

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT

Form 4400-122A
Rev. 5-92

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit		U S C S	PID/FID	Soil Properties					RQD/ Comments
Num and Type	Length Att. & Recovered (in)							Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
6	18	8 10 11 11	13.0	12.0 to 14.0	SILT, grayish brown (10YR 5/2:M), soft, trace fine sand. Strong odor.	ML	>2500		M				Sweet Odor
7	17	5 8 11 16	14.0 15.0	14.0 to 16.0	Same as above. Bottom 8" grayish brown (10YR 5/2:W), strong sweet paint odor.	ML	>2500		W				Sweet Odor
8	20	8 15 15 19	16.0 17.0	16.0 to 18.0	SILT, gray (10YR 5/1:M/D), stiff, crumbly, strong odor.	ML	1040		M/D				Sweet Odor
9	24	9 14 19 23	18.0 19.0	18.0 to 20.0	Same as above.	ML	1502		M/D				Sweet Odor
10	24	7 15 19 22	20.0 21.0	20.0 to 22.0	Same as above. Odor not as strong.	ML	693		M/D				Sweet Odor
11	24	9 18 15 50/3	22.0 23.0	22.0 to 24.0	Same as above. Bottom 1" sand. Wet.	ML	625		M				Sweet Odor
			24.0 25.0		Blind drilled.								
12	6	37 13 20 15	26.0 27.0	26.0 to 28.0	Coarse SAND and GRAVEL, gray (10YR 5/1:W), loose. Sweet paint odor.	GW	0.8		W				
			28.0 29.0 30.0 31.0 32.0		Blind drilled to 30 feet bgs. Terminated boring at 30 feet bgs.								

Village of Whitefish Bay
3125S3

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☒ Other ____________

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

Page 1 of 2

Facility/Project Name **Village of Whitefish Bay**	License/Permit/Monitoring Number	Boring Number **MW-D**

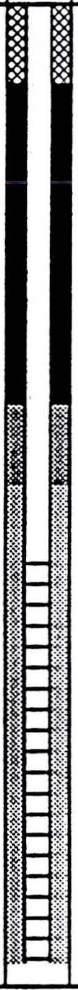
Boring Drilled By (Firm name and name of crew chief) **Midwest Engineering Services** **Dennis**	Date Drilling Started 05 / 22 / 97 MM DD YY	Date Drilling Completed 05 / 22 / 97 MM DD YY	Drilling Method **Hollow Stem Auger**

DNR Facility Well No.	WI Unique Well No.	Common Well Name **MW-D**	Final Static Water Level ______ Feet MSL	Surface Elevation 707.6 Feet MSL	Borehole Diameter 8.25 inches

Boring Location
State Plane ______________ N, ______________ E S
______ 1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location (If applicable)
________ Feet ☐ N ☐ S ________ Feet ☐ E ☐ W

County **Milwaukee**	DNR County Code **41**	Civil Town/City/ or Village **Village of Whitefish Bay**

Sample									Soil Properties						
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
				Blind drilled to 18 feet bgs.										
			1.0											
			2.0											
			3.0											
			4.0											
			5.0											
			6.0											
			7.0											
			8.0											
			9.0											
			10.0											
			11.0											
			12.0											



I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature James W. Westerman

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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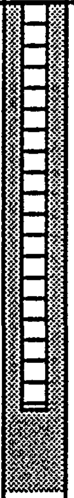
312-S3

State of Wisconsin
Department of Natural Resources
Boring Number MW-D

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT
Form 4400-122A
Rev. 5-92
Page 2 of 2

Sample									Soil Properties					
Num. and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	U S C S	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
			13.0											
			14.0											
			15.0	**Boring terminated at 18 feet bgs. Well screen set 17 to 7 feet bgs.**										
			16.0											
			17.0											
			18.0											
			19.0											
			20.0											
			21.0											
			22.0											
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			29.0											
			30.0											
			31.0											
			32.0											

Village of Whitefish Bay

3125S3

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☒ Other

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

Page 1 of 2

Facility/Project Name llage of Whitefish Bay	License/Permit/Monitoring Number	Boring Number MW-E

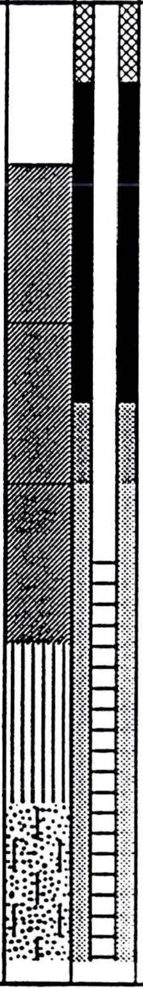
oring Drilled By (Firm name and name of crew chief) Midwest Engineering Services Dennis	Date Drilling Started 05 / 27 / 97 MM DD YY	Date Drilling Completed 05 / 27 / 97 MM DD YY	Drilling Method Hollow Stem Auger

DNR Facility Well No.	WI Unique Well No.	Common Well Name MW-E	Final Static Water Level Feet MSL	Surface Elevation 707.9 Feet MSL	Borehole Diameter 8.25 inches

Boring Location
State Plane N, E S
1/4 of NW 1/4 of Section 23, T 8 N, R 21 E
Lat ° ' "
Long ° ' "

Local Grid Location (If applicable)
Feet ☐ N ☐ S
Feet ☐ E ☐ W

County Milwaukee	DNR County Code 41	Civil Town/City/ or Village Village of Whitefish Bay



Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
				Blind drilled ground surface to 2 feet bgs.										
1	11	4 5 7 7	2.0	2.0 to 4.0 Top 8" silty CLAY, dark yellowish brown (10YR 4/4:D/M), stiff, no odor. Bottom 3" Silt and fine SAND, very dark gray (10YR 3/1:D), loose, trace gravel.	CL			0.0		D				
2	11	3 3 4 3	4.0	4.0 to 6.0 Silty CLAY, strong brown (7.5Y 5/6:M), medium stiff, medium plasticity, trace roots and organic materal, no odor.	CL			1.6		M				
3	16	3 3 6 9	6.0	6.0 to 8.0 Silty CLAY, yellowish brown (10YR 5/4:M). Bottom 8" Silty CLAY, very dark grayish brown (10YR 3/2:M), medium stiff, trace gray mottling and medium gravel.	CL			5.4		M				
4	16	6 9 11 12	8.0	8.0 to 10.0 Clayey, sandy, SILT, strong brown (7.5Y 5/6:M/W), loose, soft. Sand fine. Trace fine gravel.	ML			3.6		M/W				
5	17	5 9 9 10	10.0	10.0 to 12.0 Silty SAND, yellowish brown (10YR 5/4:W), loose to medium dense, sand medium to fine, no odor.	SM			11.0		W				
			12.0											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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312SS3

State of Wisconsin
Department of Natural Resources
Boring Number MW-E

Use only as an attachment to Form 4400-122.

SOIL BORING LOG INFORMATION SUPPLEMENT
Form 4400-122A
Rev. 5-92

Page 2 of 2

Sample									Soil Properties					
Num and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geological Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
6	20	4 6 10 16	13.0	12.0 to 14.0 SILT, yellowish brown (10YR 5/4:M) stiff, crumbly, no odor.	ML			16.0		WM				
7	13	13 14 14 16	14.0 15.0	14.0 to 16.0 SILT, gray (10YR 5/1:M), very stiff, low plasticity, no odor.	ML			12.9		M				
8	20	11 10 14 17	16.0 17.0	16.0 to 18.0 Same as above. Terminated boring at 17.5 feet bgs.	ML			1.4		M				
			18.0 19.0 20.0 21.0 22.0 23.0 24.0 25.0 26.0 27.0 28.0 29.0 30.0 31.0 32.0											

Village of Whitefish Bay
31253

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ________ ft. ☐ N. ☐ S. ________ ft. ☐ E. ☐ W.

Well Name: **MW-A**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number

Type of Well: Water Table Observation Well ☒ 11 Piezometer ☐ 12

St. Plane ________ ft. N, ________ ft. E.

Date Well Installed: 0 5 / 2 3 / 9 7 (m m / d d / y y)

Distance Well Is From Waste/Source Boundary ______ ft.

Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm)
Midwest Engineering Services
Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☒ Downgradient n ☐ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL
B. Well casing, top elevation _ _ 697.36 ft. MSL
C. Land surface elevation _ _ 695.0 ft. MSL
D. Surface seal, bottom _ _ 695.0 ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☒ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50
Hollow Stem Auger ☒ 41
Other ☐ ____________

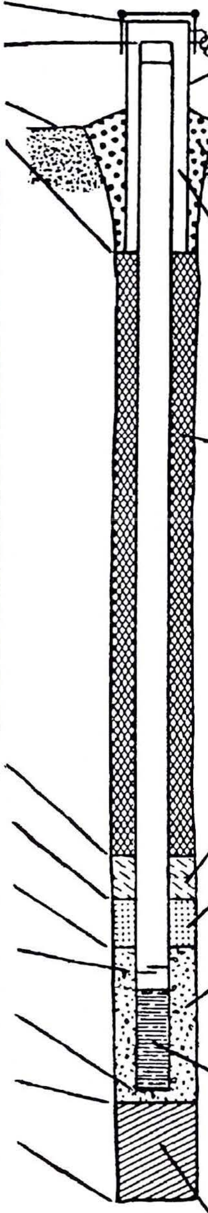
15. Drilling fluid used: Water ☐ 02 Air ☐ 01
Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ____________

17. Source of water (attach analysis):
____

E. Bentonite seal, top _ _ 694.0 ft. MSL or _ _ 1.0 ft.
F. Fine sand, top _ _ 692.0 ft. MSL or _ _ 3.0 ft.
G. Filter pack, top _ _ 691.5 ft. MSL or _ _ 3.5 ft.
H. Screen joint, top _ _ 691.0 ft. MSL or _ _ 4.0 ft.
I. Well bottom _ _ 681.0 ft. MSL or _ _ 14.0 ft.
J. Filter pack, bottom _ _ 680.0 ft. MSL or _ _ 15.0 ft.
K. Borehole, bottom _ _ 680.0 ft. MSL or _ _ 15.0 ft.
L. Borehole, diameter _ 8.25 in.
M. O.D. well casing _ 2.37 in.
N. I.D. well casing _ 2.07 in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: _ _ _ in.
   b. Length: _ _ _ ft.
   c. Material: Steel ☒ 04; Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: **Concrete**
3. Surface seal: Bentonite ☐ 30; Concrete ☒ 01; Other ☐
4. Material between well casing and protective pipe: Bentonite ☒ 30; Annular space seal ☐; Other ☐
5. Annular space seal: a. Granular Bentonite ☐ 33
   b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
   e. ______ Ft³ volume added for any of the above
   f. How installed: Tremie ☐ 01; Tremie pumped ☐ 02; Gravity ☒ 08
6. Bentonite seal: a. Bentonite granules ☐ 33
   b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   c. ____________ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. **Red Flint #45**
   b. Volume added .17 ft³
8. Filter pack material: Manufacturer, product name & mesh size
   a. **Red Flint #30**
   b. Volume added 3.91 ft³
9. Well casing: Flush threaded PVC schedule 40 ☒ 23; Flush threaded PVC schedule 80 ☐ 24; Other ☐
10. Screen material: **PVC**
    a. Screen type: Factory cut ☒ 11; Continuous slot ☐ 01; Other ☐
    b. Manufacturer **Timco**
    c. Slot size: 0.010 in.
    d. Slotted length: _ 0.2 ft.
11. Backfill material (below filter pack): None ☒ 14; Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

Please complete both sides of this form and return to the appropriate DNR office listed at the top of this form as required by chs 144,147 & 160, Wis Stats, and ch NR 141, Wis Ad Code. In accordance with ch 144, Wis Stats, failure to file this form may result in a forfeiture of not less than $10, nor more than $5000 for each day of violation. In accordance with ch 147, Wis Stats, failure to file this form may result in a forfeiture of not more than $10,000 for each day of violation. NOTE: Shaded areas are for DNR use only. See instructions for more information including where the completed form should be sent.

3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒ ______

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **PZ-A**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number: ___ ___ ___ ___ ___ ___

Type of Well: Water Table Observation Well ☐ 11 Piezometer ☒ 12

St. Plane ______ ft. N, ______ ft. E.

Date Well Installed: 0 5 / 2 3 / 9 7 (m m d d y y)

Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

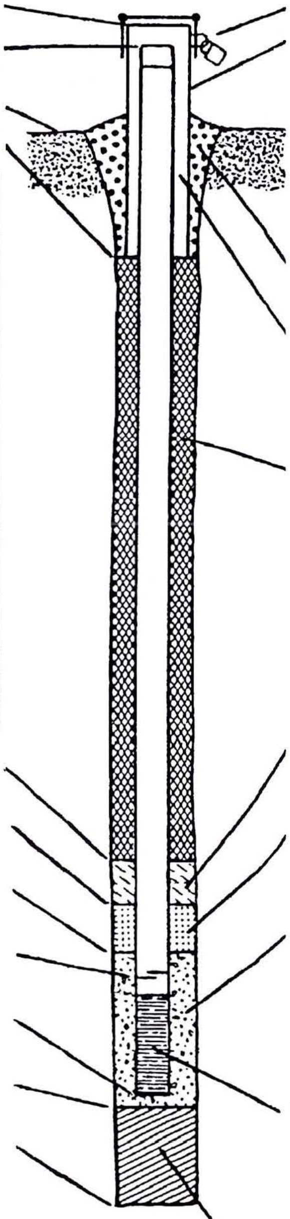
Distance Well Is From Waste/Source Boundary: ______ ft.

Well Installed By: (Person's Name and Firm) **Midwest Engineering Services**

Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☒ Downgradient n ☐ Not Known



A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _697.20_ ft. MSL

C. Land surface elevation _ _695.2 ft. MSL

D. Surface seal, bottom _ _695.2_ ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☒ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50
Hollow Stem Auger ☒ 41
______ Other ☐

15. Drilling fluid used: Water ☐ 02 Air ☐ 01
Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):
______

E. Bentonite seal, top _ _694.2_ ft. MSL or _ _1.0_ ft.

F. Fine sand, top _ _679.7_ ft. MSL or _ _15.5_ ft.

G. Filter pack, top _ _679.2_ ft. MSL or _ _16.0_ ft.

H. Screen joint, top _ _678.2_ ft. MSL or _ _17.0_ ft.

I. Well bottom _ _675.2_ ft. MSL or _ _20.0_ ft.

J. Filter pack, bottom _ _674.7_ ft. MSL or _ _20.5_ ft.

K. Borehole, bottom _ _674.2_ ft. MSL or _ _21.0_ ft.

L. Borehole, diameter _12.25 in.

M. O.D. well casing _ 2.37 in.

N. I.D. well casing _ 2.07 in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: _ _ _ in.
b. Length: _ _ _ ft.
c. Material: Steel ☒ 04
______ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30
Concrete ☒ 01
______ Other ☐

4. Material between well casing and protective pipe:
Bentonite ☒ 30
Annular space seal ☒
______ Other ☐

5. Annular space seal: a. Granular Bentonite ☐ 33
b.______Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
c.______Lbs/gal mud weight ..... Bentonite slurry ☐ 31
d. **15** % Bentonite .... Bentonite-cement grout ☒ 50
e. **min 8** Ft³ volume added for any of the above
f. How installed: Tremie ☒ 01
Tremie pumped ☐ 02
Gravity ☐ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
c. ______ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. **Red Flint #45**
b. Volume added **0.17** ft³

8. Filter pack material: Manufacturer, product name & mesh size
a. **Red Flint #30**
b. Volume added **1.7** ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23
Flush threaded PVC schedule 80 ☐ 24
______ Other ☐

10. Screen material: **PVC**
a. Screen type: Factory cut ☒ 11
Continuous slot ☐ 01
______ Other ☐
b. Manufacturer **Timco**
c. Slot size: 0.010 in.
d. Slotted length: _0.2_ ft.

11. Backfill material (below filter pack): None ☒ 14
______ Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **PZ-B**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number

Type of Well: Water Table Observation Well ☐ 11 Piezometer ☒ 12

St. Plane ______ ft. N, ______ ft. E.

Date Well Installed: 0 5 / 2 3 / 9 7 (m m d d y y)

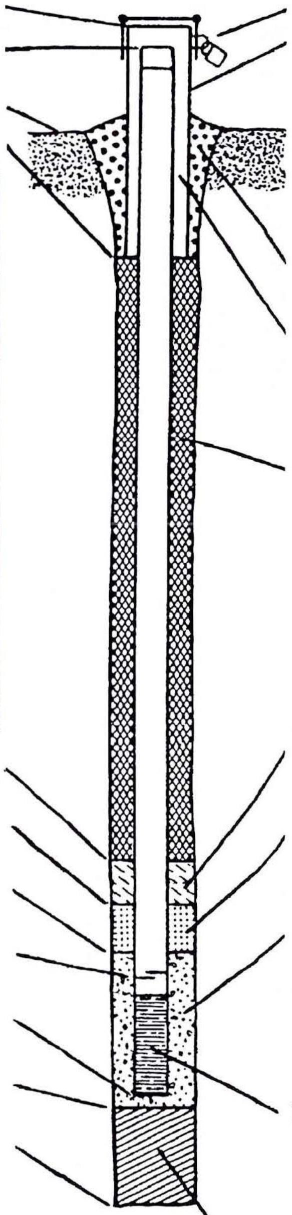
Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

Distance Well Is From Waste/Source Boundary: ______ ft.

Well Installed By: (Person's Name and Firm) **Midwest Engineering Services** **Dennis**

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☒ Downgradient n ☐ Not Known

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No



A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _**692.61** ft. MSL

C. Land surface elevation _ _**690.8** ft. MSL

D. Surface seal, bottom _ _**690.8** ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen: GP ☐ GM ☐ GC ☐ GW ☒ SW ☐ SP ☐ SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐ Bedrock ☐
13. Sieve analysis attached? ☐ Yes ☒ No
14. Drilling method used: Rotary ☐ 50; Hollow Stem Auger ☒ 41; Other ☐ ______
15. Drilling fluid used: Water ☐ 02; Air ☐ 01; Drilling Mud ☐ 03; None ☒ 99
16. Drilling additives used? ☐ Yes ☒ No
Describe ______
17. Source of water (attach analysis): ______

E. Bentonite seal, top _ _**689.8** ft. MSL or _ _**1.0** ft.

F. Fine sand, top _ _**673.3** ft. MSL or _ _**17.5** ft.

G. Filter pack, top _ _**672.8** ft. MSL or _ _**18.0** ft.

H. Screen joint, top _ _**672.3** ft. MSL or _ _**18.5** ft.

I. Well bottom _ _**667.3** ft. MSL or _ _**23.5** ft.

J. Filter pack, bottom _ _**666.8** ft. MSL or _ _**24.0** ft.

K. Borehole, bottom _ _**662.8** ft. MSL or _ _**28.0** ft.

L. Borehole, diameter _**12.25** in.

M. O.D. well casing _**2.37** in.

N. I.D. well casing _**2.07** in.

1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   - a. Inside diameter: _ _ _ in.
   - b. Length: _ _ _ ft.
   - c. Material: Steel ☒ 04; Other ☐ ______
   - d. Additional protection? ☒ Yes ☐ No — If yes, describe: **Concrete**
3. Surface seal: Bentonite ☐ 30; Concrete ☒ 01; Other ☐ ______
4. Material between well casing and protective pipe: Bentonite ☒ 30; Annular space seal ☐; Other ☐ ______
5. Annular space seal: a. Granular Bentonite ☐ 33
   - b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   - c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   - d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
   - e. ______ Ft³ volume added for any of the above
   - f. How installed: Tremie ☐ 01; Tremie pumped ☐ 02; Gravity ☒ 08
6. Bentonite seal: a. Bentonite granules ☐ 33
   - b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   - c. ______ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   - a. **Red Flint #45**
   - b. Volume added **0.17** ft³
8. Filter pack material: Manufacturer, product name & mesh size
   - a. **Red Flint #30**
   - b. Volume added **3.48** ft³
9. Well casing: Flush threaded PVC schedule 40 ☒ 23; Flush threaded PVC schedule 80 ☐ 24; Other ☐ ______
10. Screen material: **PVC**
    - a. Screen type: Factory cut ☒ 11; Continuous slot ☐ 01; Other ☐ ______
    - b. Manufacturer **Timco**
    - c. Slot size: 0.**010** in.
    - d. Slotted length: _**0.2** ft.
11. Backfill material (below filter pack): None ☒ 14; Other ☐ ______

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **MW-B**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

St. Plane ________ ft. N, ________ ft. E.

Wis. Unique Well Number: _ _ _ _ _ DNR Well Number: _ _ _

Type of Well: Water Table Observation Well ☒ 11
Piezometer ☐ 12

Date Well Installed: 0 5 / 2 3 / 9 7 (m m d d y y)

Distance Well Is From Waste/Source Boundary ______ ft.

Section Location of Waste/Source: __ 1/4 of NW 1/4 of Sec. 23, T. 8 N, R. 21 ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm)
Midwest Engineering Services
Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source:
u ☐ Upgradient s ☐ Sidegradient
d ☒ Downgradient n ☐ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _693.04 ft. MSL

C. Land surface elevation _ _691.4 ft. MSL

D. Surface seal, bottom _ _691.4 ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☒ SW ☐ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50
Hollow Stem Auger ☒ 41
Other ☐
____

15. Drilling fluid used: Water ☐ 02 Air ☐ 01
Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ________________

17. Source of water (attach analysis):
____

E. Bentonite seal, top _ _690.4 ft. MSL or _ _1.0 ft.

F. Fine sand, top _ _688.4 ft. MSL or _ _3.0 ft.

G. Filter pack, top _ _687.9 ft. MSL or _ _3.5 ft.

H. Screen joint, top _ _687.4 ft. MSL or _ _4.0 ft.

I. Well bottom _ _677.4 ft. MSL or _ _14.0 ft.

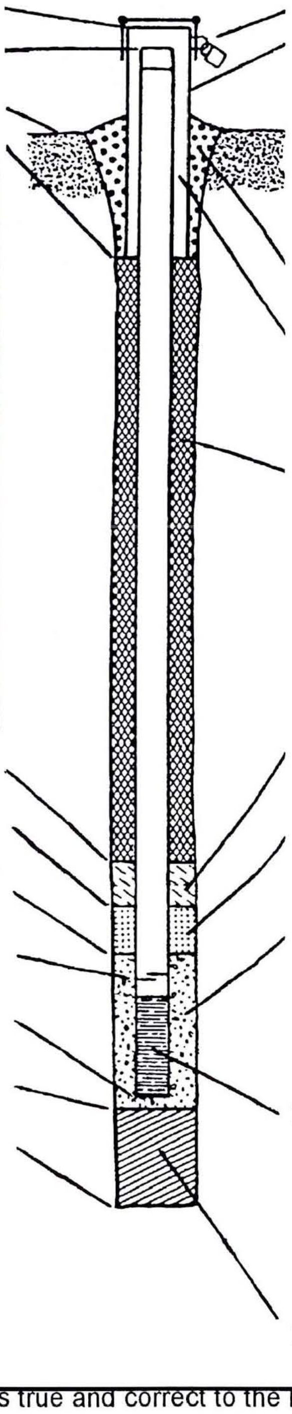
J. Filter pack, bottom _ _676.4 ft. MSL or _ _15.0 ft.

K. Borehole, bottom _ _676.4 ft. MSL or _ _15.0 ft.

L. Borehole, diameter _8.25 in.

M. O.D. well casing _2.37 in.

N. I.D. well casing _2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: _ _ _ in.
b. Length: _ _ _ ft.
c. Material: Steel ☒ 04
________________ Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30
Concrete ☒ 01
________________ Other ☐

4. Material between well casing and protective pipe:
Bentonite ☒ 30
Annular space seal ☐
________________ Other ☐

5. Annular space seal: a. Granular Bentonite ☐ 33
b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
e. ________ Ft³ volume added for any of the above
f. How installed: Tremie ☐ 01
Tremie pumped ☐ 02
Gravity ☒ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
c. ________________ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. **Red Flint #45**
b. Volume added .17 ft³

8. Filter pack material: Manufacturer, product name & mesh size
a. **Red Flint #30**
b. Volume added 3.91 ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23
Flush threaded PVC schedule 80 ☐ 24
________________ Other ☐

10. Screen material: **PVC**
a. Screen type: Factory cut ☒ 11
Continuous slot ☐ 01
________________ Other ☐
b. Manufacturer **Timco**
c. Slot size: 0.010 in.
d. Slotted length: _0.2 ft.

11. Backfill material (below filter pack): None ☒ 14
________________ Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **MW-C**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ______ Long. ______ or

Wis. Unique Well Number: ______ DNR Well Number: ______

Type of Well: Water Table Observation Well ☒ 11
Piezometer ☐ 12

St. Plane ______ ft. N, ______ ft. E.

Date Well Installed: 0 5 / 2 1 / 9 7 (m m / d d / y y)

Distance Well Is From Waste/Source Boundary: ______ ft.

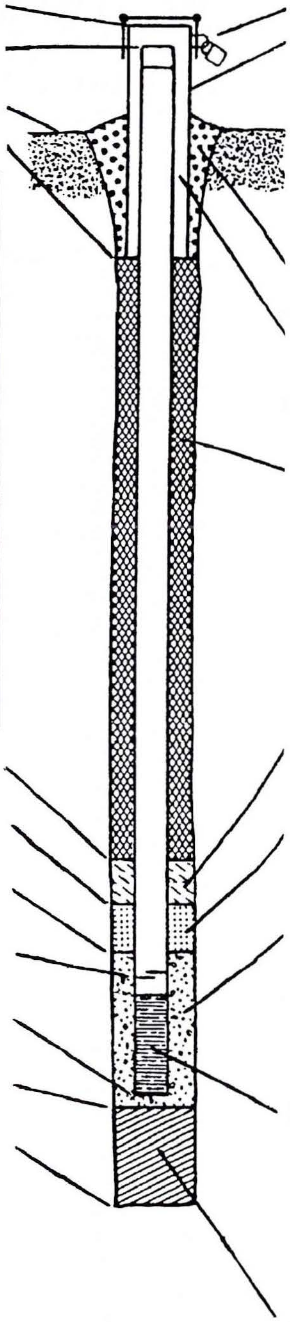
Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm)
Midwest Engineering Services
Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source:
u ☐ Upgradient s ☐ Sidegradient
d ☒ Downgradient n ☐ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL
B. Well casing, top elevation _ _ **700.24** ft. MSL
C. Land surface elevation _ _ **698.5** ft. MSL
D. Surface seal, bottom _ _ **698.5** ft. MSL or _ _ _ _ ft.



12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☒ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used:
Rotary ☐ 50
Hollow Stem Auger ☒ 41
Other ☐ ______

15. Drilling fluid used: Water ☐ 02 Air ☐ 01
Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis): ______

E. Bentonite seal, top _ _ **697.5** ft. MSL or _ _ **1.0** ft.
F. Fine sand, top _ _ **695.5** ft. MSL or _ _ **3.0** ft.
G. Filter pack, top _ _ **694.5** ft. MSL or _ _ **4.0** ft.
H. Screen joint, top _ _ **693.5** ft. MSL or _ _ **5.0** ft.
I. Well bottom _ _ **683.5** ft. MSL or _ _ **15.0** ft.
J. Filter pack, bottom _ _ **682.5** ft. MSL or _ _ **16.0** ft.
K. Borehole, bottom _ _ **682.5** ft. MSL or _ _ **16.0** ft.
L. Borehole, diameter _ **8.25** in.
M. O.D. well casing _ **2.37** in.
N. I.D. well casing _ **2.07** in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: _ _ _ in.
b. Length: _ _ _ ft.
c. Material: Steel ☒ 04
Other ☐
d. Additional protection? ☒ Yes ☐ No
If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30
Concrete ☒ 01
Other ☐

4. Material between well casing and protective pipe:
Bentonite ☒ 30
Annular space seal ☐
Other ☐

5. Annular space seal: a. Granular Bentonite ☐ 33
b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
e. ______ Ft³ volume added for any of the above
f. How installed: Tremie ☐ 01
Tremie pumped ☐ 02
Gravity ☒ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
c. ______ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
a. **Red Flint #45**
b. Volume added **.34** ft³

8. Filter pack material: Manufacturer, product name & mesh size
a. **Red Flint #30**
b. Volume added **4.08** ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23
Flush threaded PVC schedule 80 ☐ 24
Other ☐

10. Screen material: **PVC**
a. Screen type: Factory cut ☒ 11
Continuous slot ☐ 01
Other ☐
b. Manufacturer **Timco**
c. Slot size: 0.**010** in.
d. Slotted length: **0.2** ft.

11. Backfill material (below filter pack): None ☒ 14
Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

Please complete both sides of this form and return to the appropriate DNR office listed at the top of this form as required by chs 144,147 & 160, Wis Stats, and ch NR 141, Wis Ad Code. In accordance with ch 144, Wis Stats, failure to file this form may result in a forfeiture of not less than $10, nor more than $5000 for each day of violation. In accordance with ch 147, Wis Stats, failure to file this form may result in a forfeiture of not more than $10,000 for each day of violation. NOTE: Shaded areas are for DNR use only. See instructions for more information including where the completed form should be sent.

3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ________ft. ☐ N. ☐ S. ________ft. ☐ E. ☐ W.

Well Name: **PZ-C**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number

Type of Well: Water Table Observation Well ☐ 11 Piezometer ☒ 12

St. Plane ________ ft. N, ________ ft. E.

Date Well Installed **0 5 / 2 3 / 9 7** (m m / d d / y y)

Distance Well Is From Waste/Source Boundary ft.

Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm)
Midwest Engineering Services

Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☒ Downgradient n ☐ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL
B. Well casing, top elevation _ _ **700.45** ft. MSL
C. Land surface elevation _ _ **698.1** ft. MSL
D. Surface seal, bottom _ _ **698.1** ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☒ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50
Hollow Stem Auger ☒ 41
Other ☐

15. Drilling fluid used: Water ☐ 02 Air ☐ 01
Drilling Mud ☐ 03 None ☒ 99

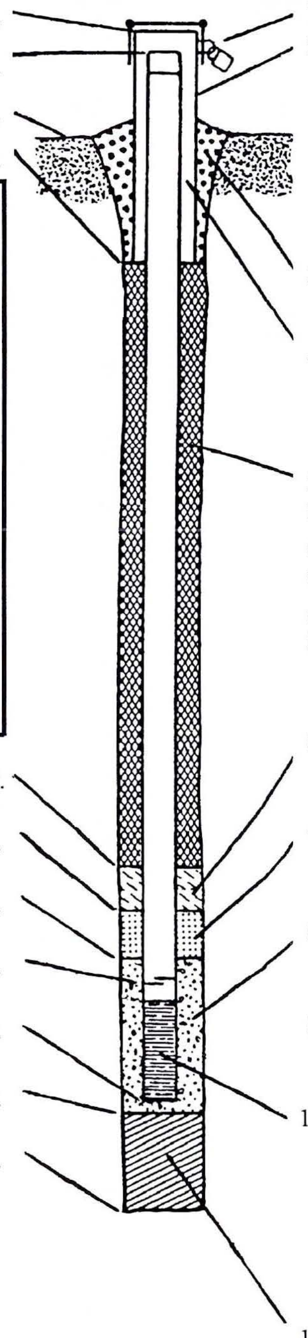
16. Drilling additives used? ☐ Yes ☒ No

Describe ____________________

17. Source of water (attach analysis):

____

E. Bentonite seal, top _ _ **697.1** ft. MSL or _ _ **1.0** ft.
F. Fine sand, top _ _ **678.1** ft. MSL or _ **20.0** ft.
G. Filter pack, top _ _ **677.6** ft. MSL or _ **20.5** ft.
H. Screen joint, top _ _ **677.1** ft. MSL or _ **21.0** ft.
I. Well bottom _ _ **672.1** ft. MSL or _ **26.0** ft.
J. Filter pack, bottom _ _ **672.1** ft. MSL or _ **26.0** ft.
K. Borehole, bottom _ _ **670.1** ft. MSL or _ **28.0** ft.
L. Borehole, diameter **12.25** in.
M. O.D. well casing _ **2.37** in.
N. I.D. well casing _ **2.07** in.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: _ _ _ in.
   b. Length: _ _ _ ft.
   c. Material: Steel ☒ 04
   Other ☐
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: **Concrete**
3. Surface seal: Bentonite ☐ 30
   Concrete ☒ 01
   Other ☐
4. Material between well casing and protective pipe:
   Bentonite ☒ 30
   Annular space seal ☐
   Other ☐
5. Annular space seal: a. Granular Bentonite ☐ 33
   b. ______Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   c. ______Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   d. **15** % Bentonite .... Bentonite-cement grout ☒ 50
   e. ________Ft³ volume added for any of the above
   f. How installed: Tremie ☒ 01
   Tremie pumped ☐ 02
   Gravity ☐ 08
6. Bentonite seal: a. Bentonite granules ☐ 33
   b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   c. ____________________ Other ☐
7. Fine sand material: Manufacturer, product name & mesh size
   a. **Red Flint #45**
   b. Volume added **0.75** ft³
8. Filter pack material: Manufacturer, product name & mesh size
   a. **Red Flint #30**
   b. Volume added **4.125** ft³
9. Well casing: Flush threaded PVC schedule 40 ☒ 23
   Flush threaded PVC schedule 80 ☐ 24
   Other ☐
10. Screen material: **PVC**
    a. Screen type: Factory cut ☒ 11
    Continuous slot ☐ 01
    Other ☐
    b. Manufacturer **Timco**
    c. Slot size: 0.**010** in.
    d. Slotted length: _ **0.2** ft.
11. Backfill material (below filter pack): None ☒ 14
    Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

Please complete both sides of this form and return to the appropriate DNR office listed at the top of this form as required by chs 144,147 & 160, Wis Stats, and ch NR 141, Wis Ad Code. In accordance with ch 144, Wis Stats, failure to file this form may result in a forfeiture of not less than $10, nor more than $5000 for each day of violation. In accordance with ch 147, Wis Stats, failure to file this form may result in a forfeiture of not more than $10,000 for each day of violation. NOTE: Shaded areas are for DNR use only. See instructions for more information including where the completed form should be sent.

3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **MW-D**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number

Type of Well: Water Table Observation Well ☒ 11; Piezometer ☐ 12

St. Plane ______ ft. N, ______ ft. E.

Date Well Installed: 0 5 / 2 2 / 9 7 (m m d d y y)

Distance Well Is From Waste/Source Boundary ______ ft.

Section Location of Waste/Source: ___ 1/4 of NW 1/4 of Sec. 23, T. 8 N, R. 21 ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm)
Midwest Engineering Services
Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☒ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _709.20_ ft. MSL

C. Land surface elevation _ _707.6_ ft. MSL

D. Surface seal, bottom _ _707.6_ ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☒ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50; Hollow Stem Auger ☒ 41; Other ☐ ______

15. Drilling fluid used: Water ☐ 02 Air ☐ 01 Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis): ______

E. Bentonite seal, top _ _706.6_ ft. MSL or _ _1.0_ ft.

F. Fine sand, top _ _702.6_ ft. MSL or _ _5.0_ ft.

G. Filter pack, top _ _701.6_ ft. MSL or _ _6.0_ ft.

H. Screen joint, top _ _700.6_ ft. MSL or _ _7.0_ ft.

I. Well bottom _ _690.6_ ft. MSL or _ _17.0_ ft.

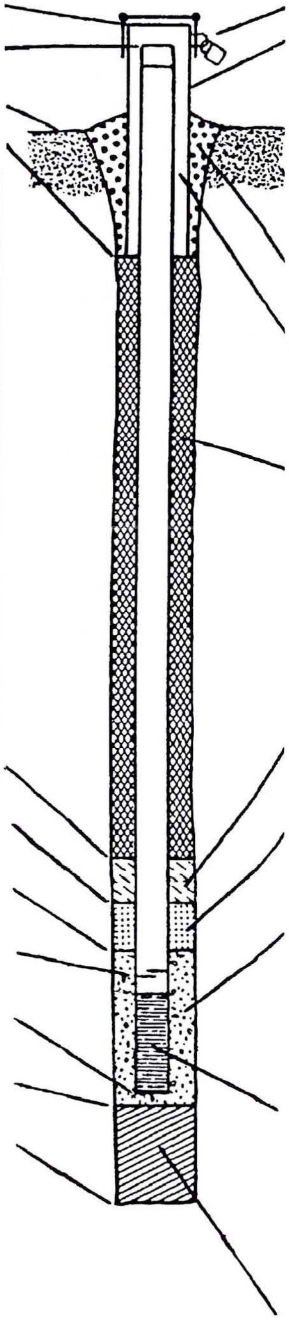
J. Filter pack, bottom _ _689.6_ ft. MSL or _ _18.0_ ft.

K. Borehole, bottom _ _689.6_ ft. MSL or _ _18.0_ ft.

L. Borehole, diameter _8.25 in.

M. O.D. well casing _2.37 in.

N. I.D. well casing _2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
   - a. Inside diameter: _ _ _ in.
   - b. Length: _ _ _ ft.
   - c. Material: Steel ☒ 04; Other ☐
   - d. Additional protection? ☒ Yes ☐ No — If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30; Concrete ☒ 01; Other ☐

4. Material between well casing and protective pipe: Bentonite ☒ 30; Annular space seal ☐; Other ☐

5. Annular space seal: a. Granular Bentonite ☐ 33
   - b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   - c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   - d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
   - e. ______ Ft³ volume added for any of the above
   - f. How installed: Tremie ☐ 01; Tremie pumped ☐ 02; Gravity ☒ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
   - b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   - c. ______ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
   - a. **Red Flint #45**
   - b. Volume added **.34** ft³

8. Filter pack material: Manufacturer, product name & mesh size
   - a. **Red Flint #30**
   - b. Volume added **3.74** ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23; Flush threaded PVC schedule 80 ☐ 24; Other ☐

10. Screen material: **PVC**
   - a. Screen type: Factory cut ☒ 11; Continuous slot ☐ 01; Other ☐
   - b. Manufacturer **Timco**
   - c. Slot size: 0.010 in.
   - d. Slotted length: _0.2_ ft.

11. Backfill material (below filter pack): None ☒ 14; Other ☐

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ____ft. ☐ N. ☐ S. ____ft. ☐ E. ☐ W.

Well Name: **PZ-D**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number

Type of Well: Water Table Observation Well ☐ 11 Piezometer ☒ 12

St. Plane ________ ft. N, ________ ft. E.

Date Well Installed: 0 5 / 2 9 / 9 7 (m m d d y y)

Distance Well Is From Waste/Source Boundary ____ ft.

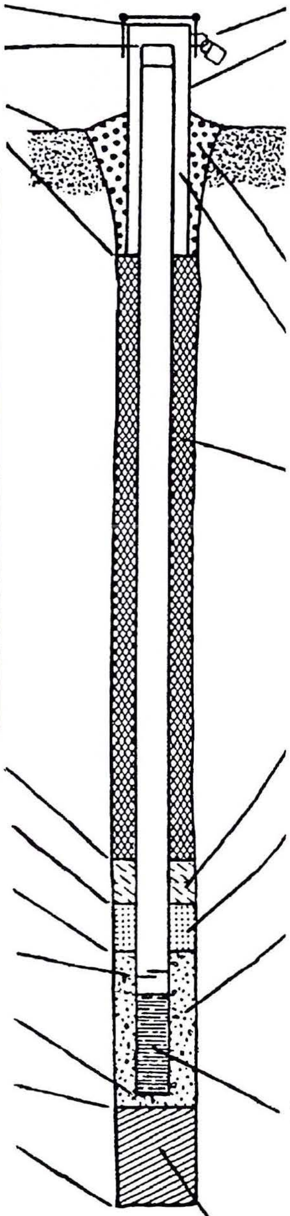
Section Location of Waste/Source: ___ 1/4 of **NW** 1/4 of Sec. **23**, T. **8** N, R. **21** ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm) **Midwest Engineering Services**

Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☐ Sidegradient d ☐ Downgradient n ☒ Not Known



A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _709.17_ ft. MSL

C. Land surface elevation _ _707.6 ft. MSL

D. Surface seal, bottom _ _707.6_ ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☒ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☒ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50 Hollow Stem Auger ☒ 41 Other ☐ ________

15. Drilling fluid used: Water ☐ 02 Air ☐ 01 Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ________________

17. Source of water (attach analysis): ________________

E. Bentonite seal, top _ _706.6_ ft. MSL or _ _1.0_ ft.

F. Fine sand, top _ _684.1_ ft. MSL or _ _23.5_ ft.

G. Filter pack, top _ _683.6_ ft. MSL or _ _24.0_ ft.

H. Screen joint, top _ _683.1_ ft. MSL or _ _24.5_ ft.

I. Well bottom _ _678.1_ ft. MSL or _ _29.5_ ft.

J. Filter pack, bottom _ _677.6_ ft. MSL or _ _30.0_ ft.

K. Borehole, bottom _ _677.6_ ft. MSL or _ _30.0_ ft.

L. Borehole, diameter _12.25 in.

M. O.D. well casing _2.37_ in.

N. I.D. well casing _2.07_ in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
   a. Inside diameter: _ _ _ in.
   b. Length: _ _ _ ft.
   c. Material: Steel ☒ 04 Other ☐ ________
   d. Additional protection? ☒ Yes ☐ No
   If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30 Concrete ☒ 01 Other ☐ ________

4. Material between well casing and protective pipe: Bentonite ☒ 30 Annular space seal ☐ Other ☐ ________

5. Annular space seal: a. Granular Bentonite ☐ 33
   b. ______Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   c. ______Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   d. **15** % Bentonite .... Bentonite-cement grout ☒ 50
   e. ________Ft³ volume added for any of the above
   f. How installed: Tremie ☒ 01 Tremie pumped ☐ 02 Gravity ☐ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
   b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   c. ________ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
   a. **Red Flint #45**
   b. Volume added **0.75** ft³

8. Filter pack material: Manufacturer, product name & mesh size
   a. **Red Flint #30**
   b. Volume added **4.5** ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23 Flush threaded PVC schedule 80 ☐ 24 Other ☐ ________

10. Screen material: **PVC**
   a. Screen type: Factory cut ☒ 11 Continuous slot ☐ 01 Other ☐ ________
   b. Manufacturer **Timco**
   c. Slot size: 0.010 in.
   d. Slotted length: _0.2_ ft.

11. Backfill material (below filter pack): None ☒ 14 Other ☐ ________

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

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3127S3

State of Wisconsin
Department of Natural Resources

Route to: Solid Waste ☐ Haz. Waste ☐ Wastewater ☐
Env. Response & Repair ☐ Underground Tanks ☐ Other ☒

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 4-90

Facility/Project Name: **Village of Whitefish Bay**

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: **MW-E**

Facility License, Permit or Monitoring Number: _ _ _ _ _ _ _ _

Grid Origin Location: Lat. ___ ___ ___ Long. ___ ___ ___ or

Wis. Unique Well Number DNR Well Number: _ _ _ _ _ _ _ _

Type of Well: Water Table Observation Well ☒ 11 Piezometer ☐ 12

St. Plane ______ ft. N, ______ ft. E.

Date Well Installed: 0 5 / 2 7 / 9 7 (m m d d y y)

Distance Well Is From Waste/Source Boundary: ______ ft.

Section Location of Waste/Source: ___ 1/4 of NW 1/4 of Sec. 23, T. 8 N, R. 21 ☒ E. ☐ W.

Well Installed By: (Person's Name and Firm) **Midwest Engineering Services**

Dennis

Is Well A Point of Enforcement Std. Application? ☐ Yes ☒ No

Location of Well Relative to Waste/Source: u ☐ Upgradient s ☒ Sidegradient d ☐ Downgradient n ☐ Not Known

A. Protective pipe, top elevation _ _ _ _ _ _ ft. MSL

B. Well casing, top elevation _ _708.68 ft. MSL

C. Land surface elevation _ _707.9 ft. MSL

D. Surface seal, bottom _ _707.9 ft. MSL or _ _ _ _ ft.

12. USCS classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☒ SC ☒ ML ☐ MH ☐ CL ☒ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☒ No

14. Drilling method used: Rotary ☐ 50 Hollow Stem Auger ☒ 41 Other ☐ ______

15. Drilling fluid used: Water ☐ 02 Air ☐ 01 Drilling Mud ☐ 03 None ☒ 99

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis): ______

E. Bentonite seal, top _ _706.9 ft. MSL or _ _1.0 ft.

F. Fine sand, top _ _702.9 ft. MSL or _ _5.0 ft.

G. Filter pack, top _ _701.9 ft. MSL or _ _6.0 ft.

H. Screen joint, top _ _700.9 ft. MSL or _ _7.0 ft.

I. Well bottom _ _690.9 ft. MSL or _ _17.0 ft.

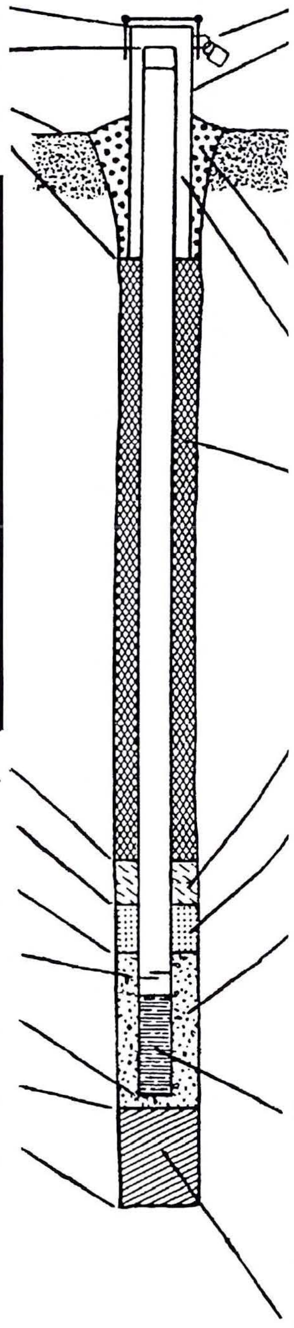
J. Filter pack, bottom _ _690.4 ft. MSL or _ _17.5 ft.

K. Borehole, bottom _ _690.4 ft. MSL or _ _17.5 ft.

L. Borehole, diameter _8.25 in.

M. O.D. well casing _2.37 in.

N. I.D. well casing _2.07 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
   a. Inside diameter: _ _ _ in.
   b. Length: _ _ _ ft.
   c. Material: Steel ☒ 04 Other ☐ ______
   d. Additional protection? ☒ Yes ☐ No If yes, describe: **Concrete**

3. Surface seal: Bentonite ☐ 30 Concrete ☒ 01 Other ☐ ______

4. Material between well casing and protective pipe: Bentonite ☒ 30 Annular space seal ☐ Other ☐ ______

5. Annular space seal: a. Granular Bentonite ☐ 33
   b. ______ Lbs/gal mud weight..Bentonite-sand slurry ☐ 35
   c. ______ Lbs/gal mud weight ..... Bentonite slurry ☐ 31
   d. ______ % Bentonite .... Bentonite-cement grout ☐ 50
   e. ______ Ft³ volume added for any of the above
   f. How installed: Tremie ☐ 01 Tremie pumped ☐ 02 Gravity ☒ 08

6. Bentonite seal: a. Bentonite granules ☐ 33
   b. ☐ 1/4 in. ☐ 3/8 in. ☒ 1/2 in. Bentonite pellets ☐ 32
   c. ______ Other ☐

7. Fine sand material: Manufacturer, product name & mesh size
   a. **Red Flint #45**
   b. Volume added .34 ft³

8. Filter pack material: Manufacturer, product name & mesh size
   a. **Red Flint #30**
   b. Volume added 3.74 ft³

9. Well casing: Flush threaded PVC schedule 40 ☒ 23 Flush threaded PVC schedule 80 ☐ 24 Other ☐ ______

10. Screen material: **PVC**
   a. Screen type: Factory cut ☒ 11 Continuous slot ☐ 01 Other ☐ ______
   b. Manufacturer **Timco**
   c. Slot size: 0.010 in.
   d. Slotted length: _0.2 ft.

11. Backfill material (below filter pack): None ☒ 14 Other ☐ ______

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm: **Sigma Environmental Services, Inc.**
220 E. Ryan Road, Oak Creek, WI 53154 (414) 768-7144

Please complete both sides of this form and return to the appropriate DNR office listed at the top of this form as required by chs 144,147 & 160, Wis Stats, and ch NR 141, Wis Ad Code. In accordance with ch 144, Wis Stats, failure to file this form may result in a forfeiture of not less than $10, nor more than $5000 for each day of violation. In accordance with ch 147, Wis Stats, failure to file this form may result in a forfeiture of not more than $10,000 for each day of violation. NOTE: Shaded areas are for DNR use only. See instructions for more information including where the completed form should be sent.

3127S3

State of Wisconsin
Department of Natural Resources

GROUNDWATER MONITORING WELL INFORMATION FORM

Chapter 144. Wis. Stats.
Form 4400-89 Rev. 1-90

Facility Name	Facility ID Number	Date	Completed By (Name and Firm)
Village of Whitefish Bay		07/08/97	Sigma Environmental Services, Inc.

Well Name	DNR Well ID Number	Well Location	N	E	S	W	Date Established	Well Casing		Elevations		Reference		Screen Length	Well Depth	Type of Well (3)						Enf. Stds. Apply	Gradient U,S,D or N
								Diam.	Type	Top of Well Casing	Ground Surface	MSL (3)	Site Datum (3)			Piez	OW	PW	LYS	Other	Aban-doned		
MW-A							05/23/97	2.07	SCH40	697.36	695.0	X		10.0	14.0		X					NO	D
PZ-A							05/23/97	2.07	SCH40	697.20	695.2	X		3.0	20.0	X						NO	D
MW-B							05/23/97	2.07	SCH40	693.04	691.4	X		10.0	14.0		X					NO	D
PZ-B							05/23/97	2.07	SCH40	692.61	690.8	X		5.0	23.5	X						NO	D
MW-C							05/21/97	2.07	SCH40	700.24	698.5	X		10.0	15.0		X					NO	D
PZ-C							05/23/97	2.07	SCH40	700.45	698.1	X		5.0	26.0	X						NO	D
PZ-D							05/29/97	2.07	SCH40	709.17	707.6	X		5.0	29.5	X						NO	N
MW-D							05/22/97	2.07	SCH40	709.20	707.6	X		10.0	17.0		X					NO	N
MW-E							05/27/97	2.07	SCH40	708.68	707.9	X		10.0	17.0		X					NO	S
							/ /																
							/ /																

Location Coordinates Are:

LocalGrid System ☐ (preferred)

State Plane Coordinates
☐ Northern
☐ Central

Remarks :

PSS Use:

File Maint. Completed: ______________

Other ______________

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☑ Other:

DRAFT

SOIL BORING LOG INFORMATION
Form 4400-122 Rev. 5-92

Page 1 of 2

lity/Project Name: *Presidio Square Apts./Milw. Public School Property*
License/Permit/Monitoring Number:
Boring Number: *MPS P-2*

Boring Drilled By (Firm name and name of crew chief): *Boart Longyear* / *Paul Dickinson*
Date Drilling Started: *8/13/98*
Date Drilling Completed: *8/13/98*
Drilling Method: *6 1/4" HSA/mud rotary*

DNR Facility Well No.:
WI Unique Well No.:
Common Well Name:
Final Static Water Level: *Feet MSL*
Surface Elevation: *700.71 Feet MSL*
Borehole Diameter: *inches*

Boring Location State Plane: *3309.10* **Feet N** *7346.34* **Feet E**
NE1/4, NW1/4, Sec. 23, T8N, R21E
Lat
Long
Local Grid Location (if applicable): ☐ N ☐ S ☐ E ☐ W

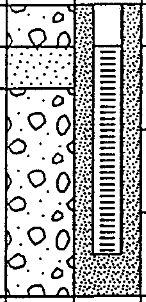
County: *Milwaukee*
DNR County Code: *41*
Civil Town/City/ or Village: *Milwaukee*

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
				Grass and organic topsoil.	OL									
P-2 2	14	7	2	SILTY CLAY: light brown, some fine sand, trace gravel, moist, no odor, mottled orange.	CL			1.9		M				
P-2 4	16	5	4					9.7		M				
6	12	5	6	Same as above, organic odor.				41.5		M				
P-2 8	16	10	8					2.7		M				
P-2 10	12	8	10	SANDY SILT: light brown, trace clay and gravel, no odor, moist, mottled orange. At 10.5' fine sand seam (1"), light brown, moist.	ML			3.0		M				
P-2 12	8	2	12	SILTY CLAY: trace gravel, light brown, moist, no odor.	CL			2.8		M				
P-2 14	16	12	14	SANDY GRAVEL: light brown, medium and coarse grained sand, moist, slight weathered fuel odor.	GP			5.5		M				
P-2 16	16	27	16					5.5		W				
P-2 18	10	21	18	same as above, wet, moderate weathered fuel odor.				6.9		W				
P-2 20	12	23	20					18.0		W				
P-2 22	20	32	22	same as above, color becomes gray.				35.2		W				
P-2 24	22	28						30.2		W				

I hereby certify that the information on this form is true and correct to the best of my knowledge.

nature
Firm **Natural Resource Technology**

This form is authorized by Chapters 144.147 and 162, Wis. Stats. Completion of this report is mandatory. Penalties: Forfeit not less than $10 nor more than $5,000 for each violation. Fined not less than $10 or more than $100 or imprisoned not less than 30 days, or both for each violation. Each day of continued violation is a separate offense, pursuant to ss 144.99 and 162.06, Wis. Stats.



Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comme.
P-2 24	22	28			GP			30.2		W				
P-2 26	24	18	26	SAND: uniform, fine and medium grained, weathered fuel odor, wet.	SP			28.5		W				
				SANDY GRAVEL: angular gravel fragments, wet, gray, weathered fuel odor.	GP									
P-2 28	16	nr	28					36.3		W				
P-2 30	12	20	30					11.0		W				
			32	End of Boring at 31 feet.										
			34											
			36											
			38											
			40											
			42											
			44											
			46											
			48											
			50											
			52											
			54											
			56											
			58											
			60											
			62											

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☐ Other:

DRAFT

SOIL BORING LOG INFORMATION
Form 4400-122
Rev. 5-92

Page 1 of 1

lity/Project Name *Presidio Square Apts./Milw. Public School Property*

License/Permit/Monitoring Number

Boring Number *MPS MW-3*

Boring Drilled By (Firm name and name of crew chief) *Boart Longyear*
Paul Dickinson

Date Drilling Started *8/14/98*

Date Drilling Completed *8/14/98*

Drilling Method *6.25" HSA*

DNR Facility Well No.

WI Unique Well No.

Common Well Name

Final Static Water Level *Feet MSL*

Surface Elevation *693.22 Feet MSL*

Borehole Diameter *8 inches*

Boring Location
State Plane *3486.70* **Feet N** *7454.89* **Feet E**
NE1/4, NW1/4, Sec. 23, T8N, R21E

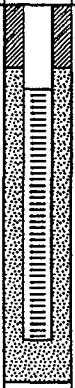
Lat
Long

Local Grid Location (if applicable)
☐ N ☐ S ☐ E ☐ W

County *Milwaukee*

DNR County Code *41*

Civil Town/City/ or Village *Milwaukee*

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
			2 4 6 8	Drilled borehole without sampling to 9 feet. Refer to MPS P-3 boring log for soil descriptions.										
			10 12 14 16 18 20 22	End of Boring at 9 feet.										

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nature

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State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☐ Other:

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

Page 1 of 2

DRAFT

Facility/Project Name: *Presidio Square Apts./Milw. Public School Property*
License/Permit/Monitoring Number:
Boring Number: *MPS P-3*

Boring Drilled By (Firm name and name of crew chief)
Boart Longyear
Paul Dickinson
Date Drilling Started: *08/13/98*
Date Drilling Completed: *08/14/98*
Drilling Method: *6 1/4" HSA/mud rotary*

DNR Facility Well No.:
WI Unique Well No.:
Common Well Name:
Final Static Water Level: *Feet MSL*
Surface Elevation: *693.50 Feet MSL*
Borehole Diameter: *inches*

Boring Location
State Plane *3490.56* **Feet N** *7454.80* **Feet E**
NE1/4, NW1/4, Sec. 23, T8N, R21E
Lat
Long
Local Grid Location (if applicable) ☐ N ☐ S ☐ E ☐ W

County: *Milwaukee*
DNR County Code: *41*
Civil Town/City/ or Village: *Milwaukee*

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
				Grass and organic topsoil.	OL									
P-3 2	8	7	2	SILTY CLAY; light brown, some fine sand, trace gravel, moist, no odor, mottled orange, organics (roots, grass).	CL			15.6		M				
P-3 4	12	8	4	Same as above, 2" angular gravel layer at 4 feet, moist.				3.2		M				
P-3 6	8	8	6					3.0		W				
P-3 8	10	6	8					3.7		W				
P-3 10	20	9	10	SANDY GRAVEL; gray, slight weathered petroleum odor, trace silt, wet.	GP			5.9		W				
P-3 12	6	6	12					7.4		W				
P-3 14	12	26	14					11.4		W				
P-3 16	10	46	16					16.1		W				
P-3 18	20	34	18					28.4		W				
P-3 20	22	36	20					18.8		W				
P-3 22	20	19	22					7.6		W				
P-3 24	24	17		SAND; uniform, medium grained, wet, slight weathered fuel odor.	SP			8.6		W				

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Natural Resource Technology**

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State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☐ Other:

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

Page 1 of 1

DRAFT

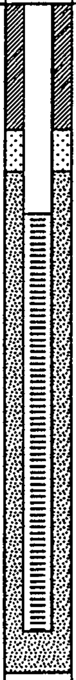
Facility/Project Name *Presidio Square Apts./Milw. Public School Property*	**License/Permit/Monitoring Number**	**Boring Number** *MPS MW-2*

Boring Drilled By (Firm name and name of crew chief) *Boart Longyear* *Paul Dickinson*	**Date Drilling Started** *8/12/98*	**Date Drilling Completed** *8/12/98*	**Drilling Method** *6.25" HSA*

DNR Facility Well No.	**WI Unique Well No.**	**Common Well Name**	**Final Static Water Level** *Feet MSL*	**Surface Elevation** *700.83 Feet MSL*	**Borehole Diameter** *8 inches*

Boring Location **State Plane** *3308.42* **Feet N** *7340.98* **Feet E** *NE1/4, NW1/4, Sec. 23, T8N, R21E*	**Lat** **Long**	**Local Grid Location (if applicable)** ☐ *N* ☐ *E* ☐ *S* ☐ *W*

County *Milwaukee*	**DNR County Code** *41*	**Civil Town/City/ or Village** *Milwaukee*

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
			2	Drilled borehole without sampling to 16 feet. Refer to MPS P-2 boring log for soil descriptions.										
			4											
			6											
			8											
			10											
			12											
			14											
			16	End of Boring at 16 feet.										
			18											
			20											
			22											

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature	Firm **Natural Resource Technology**

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Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
P-1 24	12	nr						74.2		W				
P-1 26	15	30	26					73.1		W				
P-1 28	6	16	28					33.3		W				
P-1 30	7	21	30	same as above, trace silt.	GP			30.3		W				
P-1 32	12	24	32					36.8		W				
P-1 34	6	20	34					22.6		W				
			36	End of Boring at 35 feet.										
			38											
			40											
			42											
			44											
			46											
			48											
			50											
			52											
			54											
			56											
			58											
			60											
			62											

State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste
☐ Emergency Response
☐ Wastewater
☐ Superfund
☐ Haz. Waste
☐ Underground Tanks
☐ Water Resources
☐ Other:

DRAFT

SOIL BORING LOG INFORMATION
Form 4400-122
Rev. 5-92

Page 1 of 1

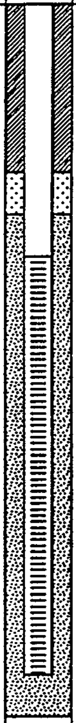
ility/Project Name *Presidio Square Apts./Milw. Public School Property*
License/Permit/Monitoring Number
Boring Number *MPS MW-1*

Boring Drilled By (Firm name and name of crew chief) *Boart Longyear*
Paul Dickinson
Date Drilling Started *8/12/98*
Date Drilling Completed *8/12/98*
Drilling Method *6.25" HSA*

DNR Facility Well No.
WI Unique Well No.
Common Well Name
Final Static Water Level *Feet MSL*
Surface Elevation *706.45 Feet MSL*
Borehole Diameter *8 inches*

Boring Location
State Plane *3369.62* **Feet N** *7077.26* **Feet E**
NE1/4, NW1/4, Sec. 23, T8N, R21E
Lat
Long
Local Grid Location (If applicable) ☐ N ☐ S ☐ E ☐ W

County *Milwaukee*
DNR County Code *41*
Civil Town/City/ or Village *Milwaukee*

Sample		Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Soil Properties					RQD/ Comments
Number and Type	Length Att. & Recovered (in)								Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	
			2 4 6 8 10 12 14 16	Drilled borehole without sampling to 17 feet. Refer to MPS P-1 boring log for soil descriptions.										
			18 20 22	End of Boring at 17 feet.										

I hereby certify that the information on this form is true and correct to the best of my knowledge.

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State of Wisconsin
Department of Natural Resources

Route To:
☐ Solid Waste ☐ Haz. Waste
☐ Emergency Response ☐ Underground Tanks
☐ Wastewater ☐ Water Resources
☐ Superfund ☐ Other:

SOIL BORING LOG INFORMATION

Form 4400-122 Rev. 5-92

DRAFT

Page 1 of 2

Facility/Project Name *Presidio Square Apts./Milw. Public School Property*
License/Permit/Monitoring Number
Boring Number *MPS P-1*
Boring Drilled By (Firm name and name of crew chief) *Boart Longyear* *Paul Dickinson*
Date Drilling Started *8/12/98*
Date Drilling Completed *8/12/98*
Drilling Method *6 1/4" HSA/mud rotary*
DNR Facility Well No.
WI Unique Well No.
Common Well Name
Final Static Water Level *Feet MSL*
Surface Elevation *706.21 Feet MSL*
Borehole Diameter *inches*
Boring Location State Plane *3367.82* **Feet N** *7082.64* **Feet E**
NE1/4, NW1/4, Sec. 23, T8N, R21E
Lat
Long
Local Grid Location (if applicable) ☐ *N* ☐ *S* ☐ *E* ☐ *W*
County *Milwaukee*
DNR County Code *41*
Civil Town/City/ or Village *Milwaukee*

Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
				Grass and organic topsoil.										
P-1 2	4	4	2		OL			25.6		M				
P-1 4	12	6	4					4.8		M				
P-1 6	8	12	6	SANDY SILT: light brown, trace clay and gravel, no odor. orange and black mottling	ML			10.3		M				
P-1 8	10	19	8					5.0		M				
P-1 10	10	12	10					4.7		M				
P-1 12	16	1	12	SILTY CLAY: gray, very soft, wet, trace fine sand, no odor, trace gravel, 1 cm sand seam at 12.1 feet.	CL			2.6		W				
P-1 14	20	12	14	same as above, firm				2.6		W				
P-1 16	12	24	16					2.4		W				
P-1 18	20	30	18					3.5		W				
P-1 20	22	45	20					3.3		W				
P-1 22	20	33	22					61.7		W				
P-1 24	12	nr		SANDY GRAVEL: wet, slight odor, gray, medium and coarse-grained sand, angular and rounded gravel fragments.	GP			74.2		W				

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm **Natural Resource Technology**

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Sample									Soil Properties					
Number and Type	Length Att. & Recovered (in)	Blow Counts	Depth in Feet	Soil/Rock Description And Geologic Origin For Each Major Unit	USCS	Graphic Log	Well Diagram	PID/FID	Compressive Strength	Moisture Content	Liquid Limit	Plasticity Index	P 200	RQD/ Comments
P-3 24	24	17			SP			8.6		W				
P-3 26	24	21	26	<u>GRAVEL W/SAND</u>: wet, slight odor, medium and coarse grained sand.				8.2		W				
P-3 28	24	50	28		SP			16.3		W				
P-3 30	24	43	30					12.2		W				
			32	End of Boring at 31 feet.										
			34											
			36											
			38											
			40											
			42											
			44											
			46											
			48											
			50											
			52											
			54											
			56											
			58											
			60											
			62											

State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐

MONITORING WELL CONSTRUCTION

Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: MPS MW-1

Facility License, Permit or Monitoring No.

Grid Origin Location (Check if estimated: ☐)
Lat. ___ ° ___ ' ___ " Long. ___ ° ___ ' ___ " or
St. Plane ______ ft. N, ______ ft. E. S / C / N

Wis. Unique Well No

DNR Well Number

Facility ID: 3410-9604

Date Well Installed: 08/12/1998

Type of Well: Well Code 11/mw

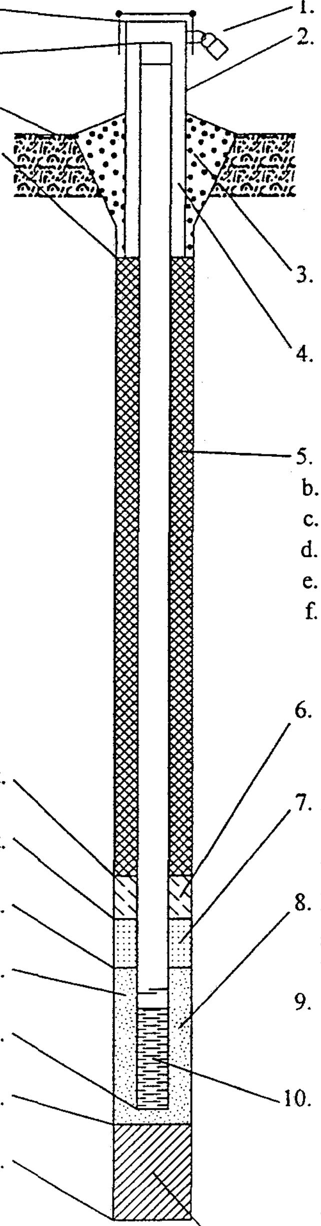
Section Location of Waste/Source: ___ 1/4 of ___ 1/4 of Sec. ___, T. ___ N, R. ___ ☐ E ☐ W

Well Installed By: (Person's Name and Firm: Paul Dickinson, Boart Longyear

Distance Well Is From Waste/Source Boundary ______ ft.

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known

A. Protective pipe, top elevation ______ ft. MSL
B. Well casing, top elevation ______ ft. MSL
C. Land surface elevation ______ ft. MSL
D. Surface seal, bottom ______ ft. MSL or 0.0 ft.



1. Cap and lock? ☒ Yes ☐ No
2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 5.0 ft.
   c. Material: Steel ☒ 0 4
      ______ Other ☐ ▨
   d. Additional protection? ☐ Yes ☒ No
      If yes, describe: ______
3. Surface seal: Bentonite ☒ 3 0
   Concrete ☐ 0 1
   ______ Other ☐ ▨
4. Material between well casing and protective pipe:
   Bentonite ☐ 3 0
   SAND Other ☒ ▨
5. Annular space seal: a. Granular Bentonite ☒ 3 3
   b. ______ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
   c. ______ Lbs/gal mud weight . . . Bentonite slurry ☐ 3 1
   d. ______ % Bentonite . . . Bentonite-cement grout ☐ 5 0
   e. ______ Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ 0 1
      Tremie pumped ☐ 0 2
      Gravity ☒ 0 8
6. Bentonite seal: a. Bentonite granules ☐ 3 3
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
   c. ______ Other ☐ ▨
7. Fine sand material: Manufacturer, product name and mesh siz
   a. #7 Badger ▨
   b. Volume added ______ ft^3
8. Filter pack material: Manufacturer, product name and mesh si
   a. #30 American Material ▨
   b. Volume added ______ ft^3
9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
   Flush threaded PVC schedule 80 ☐ 2 4
   ______ Other ☐ ▨
10. Screen material: PVC ▨
    a. Screen Type: Factory cut ☒ 1 1
       Continuous slot ☐ 0 1
       ______ Other ☐ ▨
    b. Manufacturer Boart Longyear
    c. Slot size: 0.010 in.
    d. Slotted length: 10.0 ft.
11. Backfill material (below filter pack): None ☒ 1 4
    ______ Other ☐ ▨

12. USC classification of soil near screen:
GP ☐ GM☐ GC ☐ GW☐ SW☐ SP ☐
SM ☐ SC ☐ ML☐ MH☐ CL ☐ CH ☐
Bedrock☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐ ▨

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☐ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):

E. Bentonite seal, top ______ ft. MSL or 0.0 ft.
F. Fine sand, top ______ ft. MSL or 4.0 ft.
G. Filter pack, top ______ ft. MSL or 5.0 ft.
H. Screen joint, top ______ ft. MSL or 6.0 ft.
I. Well bottom ______ ft. MSL or 16.0 ft.
J. Filter pack, bottom ______ ft. MSL or 17.0 ft.
K. Borehole, bottom ______ ft. MSL or 17.0 ft.
L. Borehole, diameter 8.0 in.
M. O.D. well casing 2.37 in.
N. I.D. well casing 2.06 in.

reby certify that the information on this form is true and correct to the best of my knowledge.

gnature

Firm BOART LONGYEAR
101 ALDERSON ST.. P.O. BOX 109 SCHOFIELD, WI 54476

Tel: 715-359-7090
Fax:

Please complete both Forms 4400-113A and 4400-113B and return to the appropriate DNR office and bureau. Completion of these reports is required by chs. 160, 281, 283, 289, 291, 292, 293, 295, and 299, Wis. Stats., and ch. NR 141, Wis. Adm. Code. In accordance with chs. 281, 289, 291, 292, 293, 295, and 299, Wis. Stats., failure to file these forms may result in a forfeiture of between $10 and $25,000, or imprisonment for up to one year, depending on the program and condut involved. Personally identifiable information on these forms is not intended to be used for any other purpose. NOTE: See the instructions for more information, including where the completed forms should be sent.

State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: MPS P-1

Facility License, Permit or Monitoring No.

Grid Origin Location (Check if estimated: ☐)
Lat. ___° ___' ___" Long. ___° ___' ___" or

Wis. Unique Well No

DNR Well Number

Facility ID: 3410-9604

St. Plane ______ ft. N, ______ ft. E. S/C/N

Date Well Installed: 08/12/1998

Type of Well: Well Code 12/pz

Section Location of Waste/Source: ___ 1/4 of ___ 1/4 of Sec. ___, T. ___ N, R. ___ ☐ E ☐ W

Well Installed By: (Person's Name and Firm)
Paul Dickinson
Boart Longyear

Distance Well Is From Waste/Source Boundary ______ ft.

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known

A. Protective pipe, top elevation ______ ft. MSL

B. Well casing, top elevation ______ ft. MSL

C. Land surface elevation ______ ft. MSL

D. Surface seal, bottom ______ ft. MSL or 1.0 ft.

12. USC classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☒ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐ ▨

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☒ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):

______

E. Bentonite seal, top ______ ft. MSL or 20.0 ft.

F. Fine sand, top ______ ft. MSL or 22.0 ft.

G. Filter pack, top ______ ft. MSL or 23.0 ft.

H. Screen joint, top ______ ft. MSL or 25.0 ft.

I. Well bottom ______ ft. MSL or 30.0 ft.

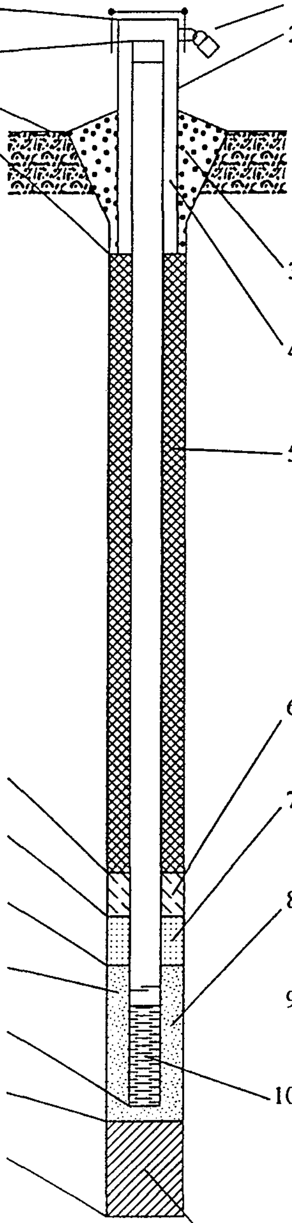
J. Filter pack, bottom ______ ft. MSL or 31.0 ft.

K. Borehole, bottom ______ ft. MSL or 35.0 ft.

L. Borehole, diameter 10.0 in.

M. O.D. well casing 2.37 in.

N. I.D. well casing 2.06 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 7.0 ft.
c. Material: Steel ☒ 0 4
______ Other ☐ ▨
d. Additional protection? ☐ Yes ☒ No
If yes, describe: ______

3. Surface seal: Bentonite ☒ 3 0
Concrete ☐ 0 1
______ Other ☐ ▨

4. Material between well casing and protective pipe:
Bentonite ☐ 3 0
SAND Other ☒ ▨

5. Annular space seal: a. Granular Bentonite ☐ 3 3
b. ______ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
c. Y Lbs/gal mud weight . . . Bentonite slurry ☒ 3 1
d. ______ % Bentonite . . . Bentonite-cement grout ☐ 5 0
e. ______ Ft^3 volume added for any of the above
f. How installed: Tremie ☐
Tremie pumped ☒ 0 2
Gravity ☐ 0 8

6. Bentonite seal: a. Bentonite granules ☐ 3 3
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
c. ______ Other ☐ ▨

7. Fine sand material: Manufacturer, product name and mesh size
a. #7 Badger ▨
b. Volume added ______ ft^3

8. Filter pack material: Manufacturer, product name and mesh size
a. #30 Flint ▨
b. Volume added ______ ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
Flush threaded PVC schedule 80 ☐ 2 4
______ Other ☐ ▨

10. Screen material: PVC ▨
a. Screen Type: Factory cut ☒ 1 1
Continuous slot ☐ 0 1
______ Other ☐ ▨
b. Manufacturer Boart Longyear
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☒ 1 4
______ Other ☐ ▨

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm BOART LONGYEAR
101 ALDERSON ST., P.O. BOX 109 SCHOFIELD, WI 54476
Tel: 715-359-7090
Fax:

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State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Remediation/Redevelopment ☐ Waste Management ☐ Other ☐

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: MPS MW-2

F--ility License, Permit or Monitoring No.:

Grid Origin Location (Check if estimated: ☐)
Lat. ___° ___' ___" Long. ___° ___' ___" or

Wis. Unique Well No | DNR Well Number

Facility ID: 3410-9604

St. Plane ______ ft. N, ______ ft. E. S/C/N

Date Well Installed: 08/13/1998

Type of Well: Well Code 11/mw

Section Location of Waste/Source
____ 1/4 of ____ 1/4 of Sec. ____, T. ____ N, R. ____ ☐ E ☐ W

Well Installed By: (Person's Name and Firm
Paul Dickinson
Boart Longyear

Distance Well Is From Waste/Source Boundary ______ ft.

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known

A. Protective pipe, top elevation ______ ft. MSL

B. Well casing, top elevation ______ ft. MSL

C. Land surface elevation ______ ft. MSL

D. Surface seal, bottom ______ ft. MSL or 1.0 ft.

12. USC classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☐ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):

E. Bentonite seal, top ______ ft. MSL or 0.0 ft.

F. Fine sand, top ______ ft. MSL or 3.0 ft.

G. Filter pack, top ______ ft. MSL or 4.0 ft.

H. Screen joint, top ______ ft. MSL or 5.0 ft.

I. Well bottom ______ ft. MSL or 15.0 ft.

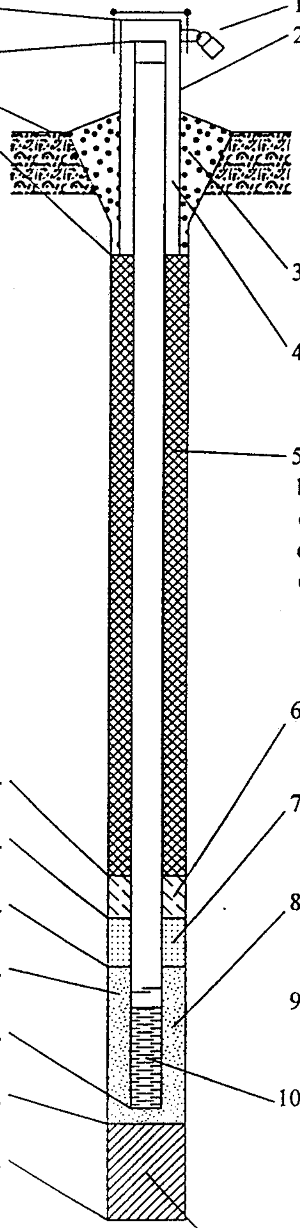
J. Filter pack, bottom ______ ft. MSL or 16.0 ft.

K. Borehole, bottom ______ ft. MSL or 16.0 ft.

L. Borehole, diameter 8.0 in.

M. O.D. well casing 2.37 in.

N. I.D. well casing 2.06 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 5.0 ft.
c. Material: Steel ☒ 0 4
Other ☐
d. Additional protection? ☐ Yes ☒ No
If yes, describe: ______

3. Surface seal: Bentonite ☒ 3 0
Concrete ☐ 0 1
Other ☐

4. Material between well casing and protective pipe:
Bentonite ☐ 3 0
SAND Other ☒

5. Annular space seal: a. Granular Bentonite ☒ 3 3
b. ____ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
c. ____ Lbs/gal mud weight . . . Bentonite slurry ☐ 3 1
d. ____ % Bentonite . . . Bentonite-cement grout ☐ 5 0
e. ____ Ft^3 volume added for any of the above
f. How installed: Tremie ☐ 0 1
Tremie pumped ☐ 0 2
Gravity ☒ 0 8

6. Bentonite seal: a. Bentonite granules ☐ 3 3
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
c. ______ Other ☐

7. Fine sand material: Manufacturer, product name and mesh siz
a. #7 Badger
b. Volume added ______ ft^3

8. Filter pack material: Manufacturer, product name and mesh si
a. #30 American Material
b. Volume added ______ ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
Flush threaded PVC schedule 80 ☐ 2 4
Other ☐

10. Screen material: PVC
a. Screen Type: Factory cut ☒ 1 1
Continuous slot ☐ 0 1
Other ☐
b. Manufacturer Boart Longyear
c. Slot size: 0.010 in.
d. Slotted length: 10.0 ft.

11. Backfill material (below filter pack): None ☒ 1 4
Other ☐

-reby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm BOART LONGYEAR
101 ALDERSON ST., P.O. BOX 109 SCHOFIELD, WI 54476
Tel: 715-359-7090
Fax:

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State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Waste Management ☐ Remediation/Redevelopment ☐ Other ☐

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ____ ft. ☐ N. ☐ S. ____ ft. ☐ E. ☐ W.

Well Name: MPS P-2

Facility License, Permit or Monitoring No.

Grid Origin Location (Check if estimated: ☐)
Lat. ___° ___' ___" Long. ___° ___' ___" or
St. Plane ______ ft. N, ______ ft. E. S/C/N

Wis. Unique Well No

DNR Well Number

Facility ID: 3410-9604

Section Location of Waste/Source: ___ 1/4 of ___ 1/4 of Sec. ___, T. ___ N, R. ___ ☐ E ☐ W

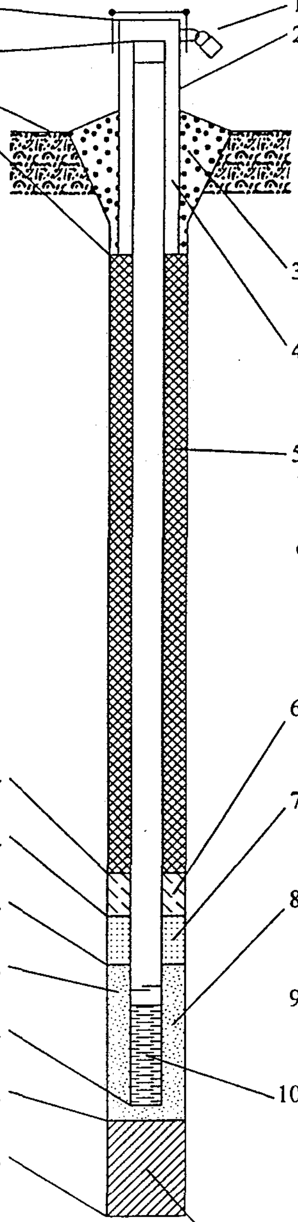
Date Well Installed: 08/13/1998

Type of Well: Well Code 12/pz

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known

Well Installed By: (Person's Name and Firm
Paul Dickinson
Boart Longyear

Distance Well Is From Waste/Source Boundary ____ ft.



A. Protective pipe, top elevation ______ ft. MSL

B. Well casing, top elevation ______ ft. MSL

C. Land surface elevation ______ ft. MSL

D. Surface seal, bottom ______ ft. MSL or 1.0 ft.

12. USC classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☒ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐ ▨

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☒ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe______

17. Source of water (attach analysis):

______

E. Bentonite seal, top ______ ft. MSL or 20.0 ft.

F. Fine sand, top ______ ft. MSL or 22.0 ft.

G. Filter pack, top ______ ft. MSL or 23.0 ft.

H. Screen joint, top ______ ft. MSL or 25.0 ft.

I. Well bottom ______ ft. MSL or 30.0 ft.

J. Filter pack, bottom ______ ft. MSL or 31.0 ft.

K. Borehole, bottom ______ ft. MSL or 31.0 ft.

L. Borehole, diameter 10.0 in.

M. O.D. well casing 2.37 in.

N. I.D. well casing 2.06 in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 7.0 ft.
c. Material: Steel ☒ 0 4
______ Other ☐ ▨
d. Additional protection? ☐ Yes ☒ No
If yes, describe:______

3. Surface seal: Bentonite ☒ 3 0
Concrete ☐ 0 1
______ Other ☐ ▨

4. Material between well casing and protective pipe:
Bentonite ☐ 3 0
SAND Other ☒ ▨

5. Annular space seal: a. Granular Bentonite ☐ 3 3
b. ______ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
c. Y Lbs/gal mud weight . . . Bentonite slurry ☒ 3 1
d. ______ % Bentonite . . . Bentonite-cement grout ☐ 5 0
e. ______ Ft^3 volume added for any of the above
f. How installed: Tremie ☐
Tremie pumped ☒ 0 2
Gravity ☐ 0 8

6. Bentonite seal: a. Bentonite granules ☐ 3 3
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
c. ______ Other ☐ ▨

7. Fine sand material: Manufacturer, product name and mesh siz
a. #7 Badger ▨
b. Volume added ______ ft^3

8. Filter pack material: Manufacturer, product name and mesh si
a. #30 American Material ▨
b. Volume added ______ ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
Flush threaded PVC schedule 80 ☐ 2 4
______ Other ☐ ▨

10. Screen material: PVC ▨
a. Screen Type: Factory cut ☒ 1 1
Continuous slot ☐ 0 1
______ Other ☐ ▨
b. Manufacturer Boart Longyear
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☒ 1 4
______ Other ☐ ▨

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm BOART LONGYEAR
101 ALDERSON ST., P.O. BOX 109 SCHOFIELD, WI 54476
Tel: 715-359-7090
Fax:

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State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐

MONITORING WELL CONSTRUCTION
Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: MPS MW- 3

Facility License, Permit or Monitoring No.:

Grid Origin Location (Check if estimated: ☐)
Lat. ___° ___' ___" Long. ___° ___' ___" or

Wis. Unique Well No:

DNR Well Number:

Facility ID: 3410-9604

St. Plane ______ ft. N, ______ ft. E. S / C / N

Date Well Installed: 08/14/1998

Type of Well: Well Code 11/mw

Section Location of Waste/Source: ___1/4 of ___ 1/4 of Sec. ___ T. ___ N, R. ___ ☐ E ☐ W

Well Installed By: (Person's Name and Firm)
Paul Dickinson
Boart Longyear

Distance Well Is From Waste/Source Boundary ______ ft.

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known

A. Protective pipe, top elevation ______ ft. MSL

B. Well casing, top elevation ______ ft. MSL

C. Land surface elevation ______ ft. MSL

D. Surface seal, bottom ______ ft. MSL or 1.5 ft.

12. USC classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used: Rotary ☐ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐ ▨

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☐ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):

E. Bentonite seal, top ______ ft. MSL or 0.0 ft.

F. Fine sand, top ______ ft. MSL or N/A ft.

G. Filter pack, top ______ ft. MSL or 1.5 ft.

H. Screen joint, top ______ ft. MSL or 2.0 ft.

I. Well bottom ______ ft. MSL or 8.0 ft.

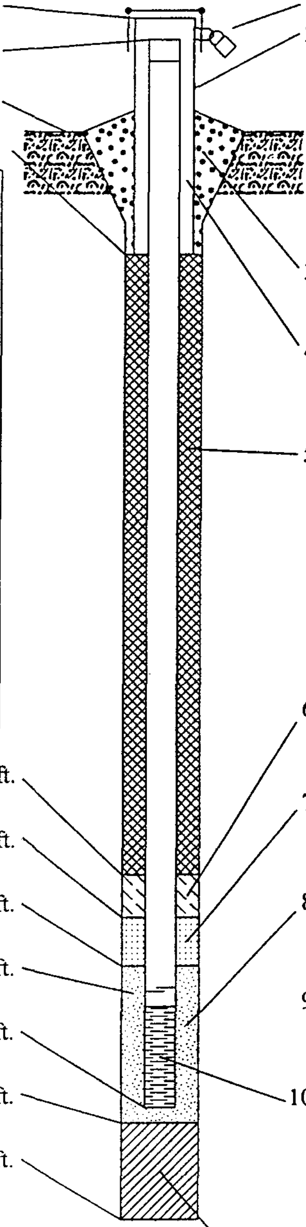
J. Filter pack, bottom ______ ft. MSL or 9.0 ft.

K. Borehole, bottom ______ ft. MSL or 9.0 ft.

L. Borehole, diameter 8.0 in.

M. O.D. well casing 2.37 in.

N. I.D. well casing 2.06 in.



1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
   a. Inside diameter: 4.0 in.
   b. Length: 4.0 ft.
   c. Material: Steel ☒ 0 4
   ______ Other ☐ ▨
   d. Additional protection? ☐ Yes ☒ No
   If yes, describe: ______

3. Surface seal: Bentonite ☒ 3 0
   Concrete ☐ 0 1
   ______ Other ☐ ▨

4. Material between well casing and protective pipe:
   Bentonite ☐ 3 0
   SAND Other ☒ ▨

5. Annular space seal: a. Granular Bentonite ☒ 3 3
   b. ______ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
   c. ______ Lbs/gal mud weight . . . Bentonite slurry ☐ 3 1
   d. ______ % Bentonite . . . Bentonite-cement grout ☐ 5 0
   e. ______ Ft^3 volume added for any of the above
   f. How installed: Tremie ☐ 0 1
   Tremie pumped ☐ 0 2
   Gravity ☒ 0 8

6. Bentonite seal: a. Bentonite granules ☐ 3 3
   b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
   c. ______ Other ☐ ▨

7. Fine sand material: Manufacturer, product name and mesh siz
   a. N/A ▨
   b. Volume added ______ ft^3

8. Filter pack material: Manufacturer, product name and mesh si
   a. #30 American Material ▨
   b. Volume added ______ ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
   Flush threaded PVC schedule 80 ☐ 2 4
   ______ Other ☐ ▨

10. Screen material: PVC ▨
   a. Screen Type: Factory cut ☒ 1 1
   Continuous slot ☐ 0 1
   ______ Other ☐ ▨
   b. Manufacturer Boart Longyear
   c. Slot size: 0.010 in.
   d. Slotted length: 6.0 ft.

11. Backfill material (below filter pack): None ☒ 1 4
   ______ Other ☐ ▨

:reby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm BOART LONGYEAR
101 ALDERSON ST., P.O. BOX 109 SCHOFIELD, WI 54476

Tel: 715-359-7090
Fax:

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State of Wisconsin
Department of Natural Resources

Route To: Watershed/Wastewater ☐ Remediation/Redevelopment ☐ Waste Management ☐ Other ☐

MONITORING WELL CONSTRUCTION

Form 4400-113A Rev. 6-97

Facility/Project Name: Presidio Square Apartments

Local Grid Location of Well: ______ ft. ☐ N. ☐ S. ______ ft. ☐ E. ☐ W.

Well Name: MPS P-3

Facility License, Permit or Monitoring No.

Grid Origin Location (Check if estimated: ☐)
Lat. ___ ° ___ ' ___ " Long. ___ ° ___ ' ___ " or
St. Plane ______ ft. N, ______ ft. E. S/C/N

Wis. Unique Well No

DNR Well Number

Facility ID: 3410-9604

Date Well Installed: 08/14/1998

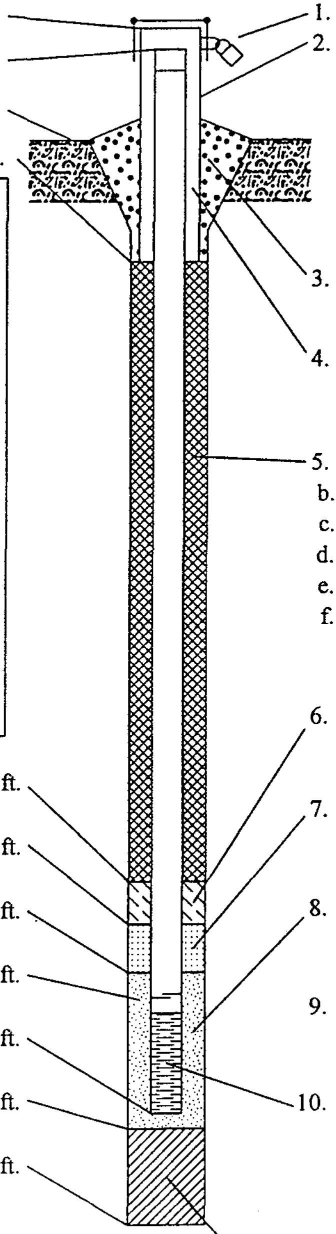
Section Location of Waste/Source: ___ 1/4 of ___ 1/4 of Sec. ___, T. ___ N. R. ___ ☐ E ☐ W

Type of Well: Well Code 12/pz

Well Installed By: (Person's Name and Firm
Paul Dickinson
Boart Longyear

Distance Well Is From Waste/Source Boundary ______ ft.

Location of Well Relative to Waste/Source
u ☐ Upgradient s ☐ Sidegradient
d ☐ Downgradient n ☐ Not Known



A. Protective pipe, top elevation ______ ft. MSL
B. Well casing, top elevation ______ ft. MSL
C. Land surface elevation ______ ft. MSL
D. Surface seal, bottom ______ ft. MSL or 1.0 ft.

12. USC classification of soil near screen:
GP ☐ GM ☐ GC ☐ GW ☐ SW ☐ SP ☐
SM ☐ SC ☐ ML ☐ MH ☐ CL ☐ CH ☐
Bedrock ☐

13. Sieve analysis attached? ☐ Yes ☐ No

14. Drilling method used:
Rotary ☒ 5 0
Hollow Stem Auger ☒ 4 1
______ Other ☐ ▨

15. Drilling fluid used: Water ☐ 0 2 Air ☐ 0 1
Drilling Mud ☒ 0 3 None ☒ 9 9

16. Drilling additives used? ☐ Yes ☒ No

Describe ______

17. Source of water (attach analysis):

______

E. Bentonite seal, top ______ ft. MSL or 19.0 ft.
F. Fine sand, top ______ ft. MSL or 22.0 ft.
G. Filter pack, top ______ ft. MSL or 23.0 ft.
H. Screen joint, top ______ ft. MSL or 25.0 ft.
I. Well bottom ______ ft. MSL or 30.0 ft.
J. Filter pack, bottom ______ ft. MSL or 31.0 ft.
K. Borehole, bottom ______ ft. MSL or 31.0 ft.
L. Borehole, diameter 10.0 in.
M. O.D. well casing 2.37 in.
N. I.D. well casing 2.06 in.

1. Cap and lock? ☒ Yes ☐ No

2. Protective cover pipe:
a. Inside diameter: 4.0 in.
b. Length: 7.0 ft.
c. Material: Steel ☒ 0 4
______ Other ☐ ▨
d. Additional protection? ☐ Yes ☒ No
If yes, describe: ______

3. Surface seal: Bentonite ☒ 3 0
Concrete ☐ 0 1
______ Other ☐ ▨

4. Material between well casing and protective pipe:
Bentonite ☐ 3 0
SAND Other ☒ ▨

5. Annular space seal: a. Granular Bentonite ☐ 3 3
b. ______ Lbs/gal mud weight . Bentonite-sand slurry ☐ 3 5
c. Y Lbs/gal mud weight . . . Bentonite slurry ☒ 3 1
d. ______ % Bentonite . . . Bentonite-cement grout ☐ 5 0
e. ______ Ft^3 volume added for any of the above
f. How installed: Tremie ☐ 0 1
Tremie pumped ☒ 0 2
Gravity ☐ 0 8

6. Bentonite seal: a. Bentonite granules ☐ 3 3
b. ☐ 1/4 in. ☒ 3/8 in. ☐ 1/2 in. Bentonite pellets ☒ 3 2
c. ______ Other ☐ ▨

7. Fine sand material: Manufacturer, product name and mesh siz
a. #7 Badger ▨
b. Volume added ______ ft^3

8. Filter pack material: Manufacturer, product name and mesh si
a. #30 American Material ▨
b. Volume added ______ ft^3

9. Well casing: Flush threaded PVC schedule 40 ☒ 2 3
Flush threaded PVC schedule 80 ☐ 2 4
______ Other ☐ ▨

10. Screen material: PVC ▨
a. Screen Type: Factory cut ☒ 1 1
Continuous slot ☐ 0 1
______ Other ☐ ▨
b. Manufacturer Boart Longyear
c. Slot size: 0.010 in.
d. Slotted length: 5.0 ft.

11. Backfill material (below filter pack): None ☒ 1 4
______ Other ☐ ▨

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm BOART LONGYEAR
101 ALDERSON ST., P.O. BOX 109 SCHOFIELD, WI 54476

Tel: 715-35[illegible]90
Fax:

Please complete both Forms 4400-113A and 4400-113B and return to the appropriate DNR office and bureau. Completion of these reports is required by chs. 160, 281, 283, 289, 291, 292, 293, 295, and 299, Wis. Stats., and ch. NR 141, Wis. Adm. Code. In accordance with chs. 281, 289, 291, 292, 293, 295, and 299, Wis. Stats., failure to file these forms may result in a forfeiture of between $10 and $25,000, or imprisonment for up to one year, depending on the program and condut involved. Personally identifiable information on these forms is not intended to be used for any other purpose. NOTE: See the instructions for more information, including where the completed forms should be sent.

USAF NATURAL ATTENUATION SCREENING FORM

VILLAGE OF WHITEFISH BAY-GOOD HOPE ROAD PROPERTY

Initial Site Screening for
Implementation of Natural Attenuation

Parameter	Parameter Criteria	Comment	Possible Score[1]	Site Data	Site Score
Oxygen	<0.5 mg/l	Promotes reduction	3	0.22	3
	>1 mg/l	Indicative of aerobic degradation	-3		
Nitrate	<1 mg/l	Indicative of reduction	2	<0.1	2
Iron II	>1 mg/l	Reductive pathway possible	3	NA	0
Sulfate	<20 mg/l	Indicative of reduction	2	>20	0
Sulfide	>1 mg/l	Reductive pathway possible	3	NA	0
Methane	<0.5 mg/l	Vinyl Chloride is oxidized	0		
	>0.5 mg/l	Ultimate reductive daughter product	3	max 0.54 mg/l	3
Redox Potential	<50 mV	Reductive pathway possible	1	NA	0
	<-100 mV	Reductive pathway likely	2		
pH	5<pH<9	Indicative of reduction	1	7.2 to 7.4	1
	5>pH>9	Outside optimal range for reduction	-2		
TOC	>20 mg/l	Carbon and energy source that drives dechlorination	2	1.16 E +05 @ PZ-D	2
Carbon Dioxide	>2x background	Ultimate oxidative daughter product	1	NA	0
Alkalinity	>2x background	Indicative of presence of carbon dioxide	1	NA	0
Chloride	>2x background	Daughter product of organic chlorine	2	NA	0
Hydrogen	>1 nM	Indicative of reduction	3	NA	0
BTEX	>0.1 mg/l	Carbon and energy source	2	5.3	2
Tetrachloroethene		Parent product	0	YES	0
Trichloroethene		Parent product	0		
		Daughter product	2	YES	2
Dichloroethene		Parent product	0		
		Daughter product of TCE (likely if cis is greater than 80% of total)	2	YES	2
Vinyl Chloride		Parent product	0		
		Daughter product of DCE	2	YES	2
Ethene		Daughter product of vinyl chloride	3	YES	3
Ethane		Daughter product of ethene	2	YES	2
Chloroethane		Daughter product of vinyl chloride under reducing conditions	2	<MDL	0
1,1,1-Trichloroethane		Parent product	0	ND	0
1,2-dichlorobenzene		Parent product	0	ND	0
1,3-dichlorobenzene		Parent product	0	ND	0
1,4-dichlorobenzene		Parent product	0	ND	0
Chlorobenzene		Parent product	0		
		Daughter product of dichlorobenzene	2	<MDL	0
1,1-Dichloroethene		Daughter product of TCE or chemical reaction of 1,1,1-TCA	2	YES @ MW-4	2
				TOTAL	26

-Screening document taken from the November 1996 Technical Protocol for Evaluating Natural Attenuation of Chlorinated Solvents in Groundwater - developed by the US Air Force in cooperation with the USEPA

-NA: Data Not Available

PHOSTER II INFORMATION PACKAGE

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Freeman & Vaughn Engineering, Inc.
PHOSter II™ Vapor Phase Nutrient Injection Technology

Background

Natural attenuation, of VOC and semi-VOC contaminants, occurs as indigenous microbes derive energy from cometabolizion of particular components within the contaminant's molecular structure. The growth rate of microbial population numbers (MPN) directly correlates to the rate and volume of contaminant degradation. The rate of growth of MNP are limited to the availability of one or more essential factors; food source, nutrients, oxygen, moisture and pH. Properly supplied with the correct ratio of carbon to nitrogen to phosphorous and oxygen, MNP can grow from 10 colonies per cubic centimeter to over 10 *billion colonies per cubic centimeter within a week.*

Process Development

Delivery of essential nutrients to contaminated soil and groundwater has historically been limited by the hydraulic conductivity of the impacted soil. Liquid nutrient delivery system limitation thresholds are reached at soil permeability of 10^{-4}, with the tendency to over stimulate microbial growth at the "end of the pipe line", thus prohibiting nutrient delivery throughout the impacted areas. Department of Energy (DOE) scientist at the Savannah River Technology Center and Oak Ridge National Laboratory determined that a vapor delivery system could more effectively distribute nutrients through soils with permeability as dense as 10^{-9}. *In the largest DOE pilot demonstration to date, the feasibility of such a delivery system was* dramatically proven at Savannah River Site's "M" Seepage Basin. In some areas of the demonstration, 10,000 ppb of PCE and TCE were degraded *to* <2 ppb *in* 13 weeks, while overall levels of PCE and TCE were reduces by >95%.

Pilot Demonstration Summary

Abstract from "Summary of In-Situ Bioremediation Demonstration (Methane Biostimulation) Via Horizontal Wells At The Savannah River Site Integrated Demonstration Project" by T. C. Hazen, K. H. Lombard, B. B. Loony, M. V. Ensien, J. M. Dougherty, C. B. Fliermans, J. Wear and C. A. Eddy-Dilek. Thirty-Third Hanford Symposium on Health and the Environment, November 7-11, 1994, Pasco, Washington.

"The U. S. Department of Energy's Office of Technology Development has been sponsoring full-scale environmental restoration technology demonstrations for the past 4 years. The Savannah River Site (SRS) Integrated Demonstration focuses on "Clean-up of Soils and Groundwater Contaminated with Chlorinated VOC." Several laboratories, including SRS, had demonstrated the ability of methanotropic bacteria (found in soil and aquifer material) to completely degrade or mineralize chlorinated solvents. The test consisted of injecting methane mixed with air into the contaminated aquifer via a horizontal well and extracting it from the vadose zone via a parallel horizontal well. Groundwater was monitored biweekly from 13 wells for a variety of chemical and microbiological parameters. The water from wells in affected areas showed increases in methanotrops of more than 1 order of magnitude every 2 weeks for several weeks after 1% methane in air injection started. Simultaneous with the increase in methanotrops was a decrease in water and soil gas concentrations of trichloroethylene (TCE) and tetrachloroethylene (PCE). In two wells, the TCE/PCE concentration in the water declined by more than 90%, to below 2 ppb. All of the wells in the effected zone showed significant decreases in contaminates in less than 1 month. Chloride concentrations in the water were inversely correlated with TCE/PCE concentration. In four of the five vadose zone piezometers (each with three sampling depths) declined from concentrations as high as 10,000 ppb (vol/vol) to less than 5 ppb in less than six weeks. The fifth cluster also declined by more than 95%. A variety of microbial parameters increased with methane injection, indicating the extent and type of stimulation than had occurred. History-matching models constructed by Los Alamos National Laboratories (LANL) have shown that 41% more TCE is removed by bioremediation than by physical stripping alone. The LANL model has also shown that in-situ bioremediation can reach a lower concentration than in-situ air-stripping or pump-and-treat methods and that the time required to reach 95% removal is less than half the time required by the physical process."

Freeman & Vaughn Engineering, Inc.

PHOSter II™ Vapor Phase Nutrient Injection Technology

"HOW THE CONCEPT WAS PROVEN" from The U. S. Department of Energy's Savannah River Technology Center publication "IN-SITU BIOREMEDIATION OF CHLORINATED SOLVENTS WITH NATURAL GAS" Terry C. Hazen, Ph. D., C. B. Fliermann, Ph. D., M. Enzien, Ph. D. and K. Lombard of the Savannah River Technology Center.

Key Results

- During the demonstration period, 4,838 lbs of PCE/TCE VOCs were degraded and mineralized.
- Mass balance calculations indicated that bioremediation destroyed 40% more PCE/VCE VOCs than simple air sparging (based on previous in situ air sparging demonstration).
- Gaseour nutrient injection of carbon, nitrogen, and phosphorus was achieved simultaneously for the first time and better mass transfer than previous methods of liquid injection.
- This nutrient injection strategy stimulated a specific functional group of bacteria that is known to *degrade specific contaminants.*
- No toxic intermediates were produces by the bioremediation strategy. Contaminants were completely *mineralized.*
- The best operating campaign used continuos air and nutrient (N & P) plus the pulsed addition of 4% methane.
- Los Alamos National Laboratory completed a cost-benefit analysis showing that ISB could reduce costs by over 30%compared to the baseline technology of an integrated Soil Vapor Extraction/Pump- and-Treat System (SVE/PT).
- ISB could reduce the time required to remediate a site by 5-7 years compared to the technology of SVE/PT.

Through a cooperative agreement with the Southeastern Technology Center in Augusta, GA and the Savannah River Technology Center in Aiken, SC, Freeman and Vaughn Engineering, Inc. (FVE) was awarded the rights to privatize the technology. FVE commercialized the technology under the name of PHOSter II™.

Process Description

PHOSter II™ is a patented biostimulation process that delivers a measured and predetermined combination of phosphorous, nitrogen, oxygen and, if required, methane in a pulsed injection of vapor to VOC and/or semi-VOC contaminated soil and groundwater. The volume and mixture of gaseous nutrient, flow rate, pressure and frequency of the pulsed injections are determined by the types and volumes of contaminants of concern. Calculations are also based on site conditions such as soil types, groundwater flow rates, dissolved oxygen in the groundwater, base line nutrients levels and microbial plate counts.

The gas injection volumes and rates are far below the levels that could induce air sparging and the methane injection levels are well below the Lower Explosion Limits. Because nutrients are injected in a mixture with air, the terms bioventing, (defined as "air slowly injected into the unsaturated soils") and biosparging, (defined as "air and specific gases injected into saturated sediments"), may be applied to the PHOSter II™ process. Injection points are sealed against air, gases or vaporized contaminates venting to the atmosphere.

Injection of gaseous nutrients into soil and groundwater can be administered through vertical or horizontal Air Injection Wells or may incorporate existing monitoring wells through specially fitted ports in the well heads. If there is a sufficient monitoring well matrix on site, no additional injection wells may be required.

Freeman & Vaughn Engineering, Inc.

PHOSter II™ Vapor Phase Nutrient Injection Technology

Biodegradation Process of Chlorinated Contaminants

Aerobic degradation of TCE and less complex chlorinated VOCs such as DCE and VC by microbial communities, if fed a measured vapor mixture of nitrogen, phosphorous, oxygen and methane, has been demonstrated in laboratory studies, pilot studies and field applications. PCE dechlorination has only been observed in anaerobic conditions, degrading to TCE, DCE and finally VC. During in-situ bioremediation, the system must become aerobic once the breakdown of PCE has occurred to prevent the formation of VC. The responsible organisms for degradation, Methanotrops, do not appear to derive energy from transformation of chlorinated compounds. The conversion is brought about by co-metabolism, an interaction of the VOC chlorine atoms with enzymes, or co-factors produced by the microorganisms for other purposes. Methanotrop bacteria derives their energy from the oxidation of methane, secreting an enzyme, methane monooxygenese (MMO), to catalyze the oxidation of methane to methanol. MMO is not very substrate-specific, and will oxidize the chlorine to an unstable epoxide, which then undergoes decomposition into a chloride salt. Degradation of the resulting declorinated VOC molecules are accomplished by heterotrophic microbes.

Unit Description

The basic PHOSter II™ units are self contained and housed in a covered metal trailer with lockable double rear entry doors. The standard unit conforms to all DOT standards for size and weight, and are towed by a full size pickup truck or utility vehicle. Once mobilized to a site, one project engineer or technician can set up, program and operate four units. The units require a 220 volt, single phase electrical power supply. Some units may require a telephone line for off site monitoring via modem. Specific gases used are nitrous oxide, vapor phase triethyl-phosphate, ambient air and methane. Basic units are equipped to through, up to, 10 separate injection ports, but can be modified for additional injection ports. Site size and other factors will dictate the number of units to be employed, but a basic unit can easily treat a site of about 2 acres in surface area.

Sampling and Treatment Confirmation

During operations of the PHOSter II™ units, FVE's technicians, project engineer and/or qualified subcontractor will conduct confirmatory testing to determine the increase in population growth of methanotrophs and other degrading organisms. Other test to be conducted will include, confirmation of chloride in the saturated zone, pH decrease, and analysis to quantify the reduction in the mass of contaminants after stimulation of indigenous organisms. These test are the accepted criteria for biodegradation evidence as detailed by the National Research Council, 1994.

Data Required Prior to Proposal Preparation

Site assessment, Corrective Action Plan or the equivalent, containing current and accurate analysis of the types and levels of contaminants in soil and ground water, location of existing monitoring wells, direction of flow of ground water, soil type, and soil permeability. We also will need to know the regulatory clean up levels for the contaminants of concern, soil moisture levels, baseline nutrient levels of phosphorous and nitrogen and microbial plate counts to determine the presence and abundance of indigenous bacterial colonies.

PHOSter II™ Fact Sheet

In Situ Bioremediation of a Sanitary Landfill

Implementation of PHOSter ™ for remediation of VOC plume, excerpted from document WSRC-TC-96-0065, Rev. 1, April 1, 1996, Executive Summary, **"Sanitary Landfill In Situ Bioremediation Optimization Test Final Report"** (U for unclassified)

"...In the early 1970's, these areas were consolidated into a single sanitary landfill located near the center of SRS (Savannah River Site), on Road C near Upper Three Runs Creek."

"SRS Sanitary Landfill began receiving solid waste from site construction areas, offices, shops, and cafeterias in 1974 in its original 32 acre site. In 1987, as the original area reached capacity, a 16 acre Northern Expansion was filled and ceased operations in 1993. The Northern Expansion, also known as the Interim Sanitary Landfill (ISL) continued to receive SRS solid waste on a case by case basis and is rigorously controlled to ensure that hazardous waste is not accepted. During the course of its operation, Sanitary Landfill received numerous materials that can leach or generate hazardous compounds, e.g., paints, thinner, solvents, batteries, and rags and wipes used with F-listed waste..."

"On March 31, 1994 a Corrective Action Plan (CAP) based on the assumption that the ACL (Alternate Concentration Limit) Demonstration would be approved was submitted to SCDHEC (South Carolina Department of Health and Environmental Control) which addressed corrective actions to remediate the groundwater at the Sanitary Landfill. Based on an evaluation of groundwater analytical data for the period of 1984 through 1993 (up to and including 2Q93), as described in the CAP, the GWPS has been exceeded at or downgradient of the Point of Compliance (POC) for vinyl chloride (VC) and trichloroethylene (TCE)."

"Bioremediation has been found to be among the least costly technologies in applications where it is feasible. Full scale demonstrations of this technology have already been completed as part of the SRS Integrated Demonstration at a solvent disposal basin system in M-area (Hazen, 1994). Because the M basin differed from the Sanitary Landfill in having only TCE and tetrachloroethylene (PCE), no other waste disposal, and a groundwater that was only aerobic (>2 mg/L dissolved oxygen), it was decided that a treatability study was prudent for the Sanitary Landfill. The nine week bench-scale treatability test was done to determine: 1) if the contaminants of concern (COC), (VC, TCE, and chlorobenzene) were biodegradable in the specific soil and groundwater samples. This included determining if pretreatment was necessary to dilute inhibitory compounds, 2) the rate of biodegradation of COCs, 3) the extent of contaminant biodegradation, and 4) the optimal conditions for biodegradation, including nutrient optimization and choice of inoculum."

"The treatability study using soil columns to simulate both vadose and groundwater conditions used soil and groundwater from the most contaminated areas of the Sanitary Landfill (WSRC-TR-94-0119). These studies showed that all of the COCs were biodegradable by indigenous soil bacteria and that their ability to degrade the COCs to undetectable levels greatly exceeded the highest concentrations found at the Sanitary Landfill. The soil column simulations showed that the biostimulated soil microbes could reduce more than 100,000 ppb of the contaminants in the water to undetectable levels in just a few days...The treatability study showed that the COCs were biodegraded in both the saturated and unsaturated columns. The major limitation to soil microbes at the SRC Sanitary Landfill was oxygen, supplemental carbon sources...trace nutrients (phosphorus and nitrogen), in that order."

"Historical groundwater data and landfill usage information confirmed that there existed two separate plumes of concern. One plume contained TCE as its major contaminant of concern and the other plume contained VC as its major constituent. Because these two plumes were also quite different in terms of dissolved oxygen concentration, total organic, and other trace nutrients a pilot-scale optimization test was

PHOSter II™ Fact Sheet

deemed necessary to determine the best strategy for both plumes and also to gather critical physical and chemical information an input for the final remediation system for the two parts of the landfill..."

"Site 1 and Site 2 were also significantly different in terms of COCs, dissolved oxygen, chloride, nitrite, and nitrate concentrations, and response to nutrient stimulation, thus each site is considered separately. Overall, both sites were found to have indigenous microorganisms that could be stimulated to degrade chlorobenzene, trichlorlethylene and, its daughter products, vinyl chloride in situ by the addition of oxygen ...nutrients, and methane to the contaminated zone. Biostimulation at both resulted in undetectable levels of COCs and many other organics in both the groundwater and vadose zones. It was also shown that chloride concentrations in the groundwater at both sites increased significantly as bacteria densities increased. This correlation shows that biodegradation of chlorinated solvents in situ was complete and resulted in production of chloride."

"Site 1...When gaseous nutrients were added to the air some decrease in TCE concentration was observed; however, when methane was also added to the nutrient air mixture, the TCE concentration in all affected wells declined to non detect levels (<2 ppb). After the air/nutrient/methane injection was ceased the TCE was detectable in 7 days and reached low pre-injection levels within 3-4 weeks. Biodegrader densities increased only slightly during air alone injections, but increased 2-3 orders of magnitude after air/nutrient/methane injection started. The densities of biodegraders slowly declined over the course of the campaign. After several weeks the densities of biodegraders still had not reached pre-injection levels. Statistical analyses showed that there was a significant positive correlation between DO (dissolved oxygen) and biodegrader density, i.e. as the DO increases, the number of bacteria increased...All of the data from the site demonstrate that oxygen is limiting to the biodegraders at this site. Carbon, nitrogen and phosphate must be supplied to bioremediate the site to non detect concentrations. Biodegrader activity at this site can be maintained at a level effective for groundwater bioremediation by pulsed injection of gaseous nutrients and carbon source. Monthly groundwater monitoring should be sufficient to maintain an appropriate pulse schedule."

Site 2...VC and chlorobenzenes as COCs...reflects the nature of the point source as being refuse that was put in the landfill many years earlier...This has allowed more leaching and thus more biological activity which created the VC from TCE under anaerobic conditions caused by the high carbon content...Monthly monitoring and pulsed injection of air with occasional nitrogen and phosphorous gaseous supplements should be all that is necessary to maintain complete bioremediation of solvents at this site."

Remediation Technology

PHOSter's Phosphorus-Charged Bacteria Speeds Cleanups

A new technology that uses phosphorus to stimulate naturally-occurring bacteria that consume hydrocarbons provides a cheaper, more effective remediation technology for owners of contaminated underground storage tank (UST) sites, according to its marketer, Freeman & Vaughn Engineering Inc.

The new technology, known as PHOSter II, is a scaled-down version of a bioremediation technology developed by the Department of Energy (DOE). Because it does not require expensive equipment and takes place in situ, PHOSter II offers an inexpensive and more effective bioremediation alternative, said Vaughn Adams of Augusta, Ga.-based Freeman & Vaughn. 706-790-3700

-3008

According to Adams, PHOSter II technology works well in many different environments, such as sands, silts and sands, sandy clays and dense clays. He estimates that contamination at most leaking UST sites can be cleaned in about 90 days with this technology. "Pump and treat or air stripping can take more than a year," Adams said. DOE studies show that vapor injection, such as that used by PHOSter II, penetrates soils with permeability as low as 10^{-9} centimeters per second (cm/s). This compares favorably with liquid nutrient injection that will not penetrate soils with permeability lower than 10^{-4} cm/s.

Adams also said the PHOSter II technology is less expensive than other technologies. "Depending on the site, the cost is around $22 to $25 per pound of soil and groundwater remediated, or about $10 less per cubic foot than pump and treat or air sparging technologies," Thomas said.

How it Works

PHOSter II injects a gas mixture containing phosphorus into the soil to stimulate the naturally-occurring aerobic bacteria already present in the soil at most contaminated sites. Once stimulated, the bacteria—called methanotropes—"eat up" volatile organic compounds, such as benzene, toluene and xylene at an increased pace.

PHOSter II units are mounted on trailers—about the size of a horse trailer—so they can be located at any site (see figure). Each unit consists of the gas source, compressor, regulating equipment, timers and a modem. "The units are capable of remote monitoring and control via modem so no one even has to be onsite," said Adams. Freeman & Vaughn performs screening at each site to determine if the necessary methanotropes are already present, which they often are at older sites. These bacteria sometimes are not present at younger sites simply because the bacteria colonies have not fully formed. "If they aren't present, they can be introduced," Adams said.

Using the number of methanotropes and the size of the contamination plume, the contractor calculates the mixture of phosphorus and nitrogen from the ambient air it will need to inject to stimulate the microorganisms. "We hook the system up to the monitoring wells and seal the well-heads so there is no volatilizing contamination," Adams said. The unit then pulses the gas mixture into the wells. The plume size and microbe population determine the number and length of the pulses. "You don't want to overstimulate the microbes either because too many microbes can clog up the particles of soil," Adams said.

Freeman & Vaughn monitors the progress from off site and visits the site every two weeks to measure the remediation progress by monitoring the carbon dioxide created by the hydrocarbon degradation. The units are shut down and the wells are allowed to recharge with water once a sufficient level of hydrocarbon degradation has been reached. If groundwater monitoring shows that hydrocarbon contamination has not been sufficiently reduced, the process is repeated.

The target hydrocarbons are mineralized by the microbes, leaving no secondary waste products and requiring no additional treatment to achieve a cleanup level of less than 5 parts per billion (ppb), the company said.

Demonstration Sites

At several demonstration sites, PHOSter II has effectively removed hydrocarbons from soil and groundwater. At an old leaking UST site in Augusta-Richmond County, Ga., PHOSter II was used to clean up an old public works facility. "The site was a fueling station for the city," said Jim Leiper, with the city of Augusta. City officials noticed water in their diesel fuel and a subsequent investigation revealed groundwater contamination from a leaking UST, Leiper explained. Benzene was detected at levels as high as 1,400 ppb, and toluene was detected at levels as high as 8,200 ppb.

"The PHOSter II technology was used for about 90 days, but 95 percent of the cleanup was done after

45 days," Leiper said. Because of the age of the contamination, the methanotrope colony was already well established, and the PHOSter II technology supercharged it. "We are very pleased with the outcome," said Leiper.

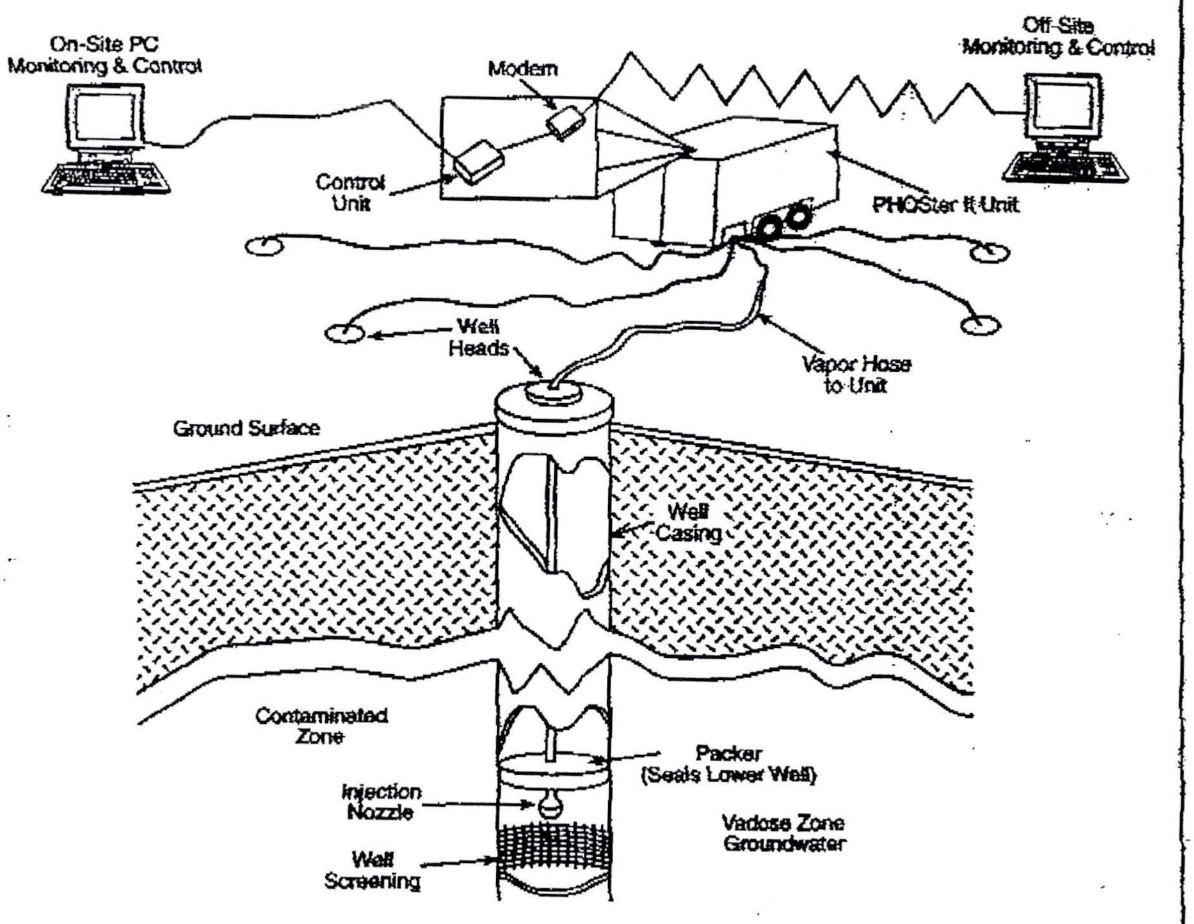
The city of Aiken, S.C., also benefited from a demonstration project, according to Assistant City Manager Frances Thomas. An abandoned gas station in downtown Aiken had significant hydrocarbon contamination, with xylene levels as high as 21,000 ppb. "The site was abandoned for about five or six years, and it was a real eyesore," Thomas said.

After six months of treatment with the PHOSter II technology, the site was certified for no further action by the South Carolina Department of Health and Environmental Control. "Since then, the city has sold the property to the Chamber of Commerce to build a tourist center," Thomas said. The city was very happy with the remediation results, she said.

History of the Technology

In 1995, DOE demonstrated that naturally occurring methanotropic bacteria, if properly stimulated, would completely degrade or mineralize hydrocarbons. The Savannah River Technology Center developed PHOSter II and demonstrated it successfully. In 1996, Freeman & Vaughn, working with the Southeastern Technology Center and the Oak Ridge National Laboratory, redesigned the large and immobile PHOSter prototype for commercial applications nationwide. PHOSter II features hardware appropriate for smaller sites and is mounted on trailers for easy mobility. O

Diagram of PHOSter II System



Source: Freeman & Vaughn Inc.

SRTC

In Situ Bioremediation of Chlorinated Solvent With Natural Gas

Terry C. Hazen, Principal Investigator K. H. Lombard, B. B. Looney, C. B. Fliermans, C. A. Eddy-Dilek

Westinghouse Savannah River Company
Savannah River Technology Center
Savannah River Site
Aiken, SC 29808 (USA)
Terry C. Hazen
803/557-7713; 803/557-7223

Primary Contacts

Description

This patented bioremediation technology combines natural gas injection and air stripping to stimulate microbes to completely degrade and remove chlorinated solvents *in situ* in groundwater and sediment in a short time, at a low cost, without harmful side effects. This technology has global applications: almost every highly developed country in the world has used chlorinated solvents for industrial purposes and suffers from the concomitant contamination.

Primary Function

Bioremediation with natural gas injection harnesses the natural cleansing capacity of the environment to decontaminate underground water and soil. What we did was stimulate naturally occurring microbes to degrade chlorinated solvents, such as trichlorethylene (TCE) and tetrachlorethylene (PCE). This technology represents a significant breakthrough in environmental remediation: we showed that resistant contaminants can be degraded very effectively *in situ* by injection of natural gas (methane). Furthermore, we proved this technology to be much more efficient and cost effective than any preexisting commercial technique.

Our technique remediates to 2 ppb (undetectable levels), rather than to 1000 ppb, as is common through other remediation techniques in a heterogeneous environment. Our technique collapses the time needed to achieve 95% contaminant removal from >10 years to <4 years. The cost of remediation falls from as much as $38/lb to less than $21/lb when using our technique.

Chlorinated solvent contaminants are known to exist in thousands of sites in the U. S. and in industrialized countries around the world. Such contamination damages the ecosystem and poses serious potential health problems if local groundwater is used as a source of drinking water or irrigation water or if the soil is used for growing crops. Contamination of groundwater by organic compounds is recognized as one of the most important pollution problems of the industrialized nations. It is estimated that more than 15% of community drinking water in the U. S. is already contaminated with chlorinated hydrocarbons.

The specific microbes used in this process are called methanotrophs--methane oxidizing bacteria. Methanotrophs exist everywhere, but generally in populations too small to have an effect on coexisting contamination. We injected very low concentrations of methane through a well drilled horizontally below the water table in a test site to stimulate the growth of the bacterial population. We withdrew air through an upper, parallel well to increase air flow. We determined that methanotrophic bacteria could effectively remove chlorinated solvents and their breakdown products with no harmful side effects. This process cut the time for *in situ* cleanup in half.

The concept of methane-induced bioremediation had been demonstrated in the laboratory, but no *in situ* demonstration had been done, nor had the wide-scale effectiveness or cost of the technology been determined. Proving this concept was the final task of a continuing Savannah River Site technology project that focused on the selection, full-scale demonstration, and evaluation of *in situ* environmental remediation processes for treating soil and ground water contaminated with TCE/ PCE and associated daughter products. In the final project phase, we combined biostimulation and biodegradation with an air stripping process.

We used a test bed located along an abandoned process sewer line at the Savannah River Site for this entire project. Over many years, solvents had been disposed of in a basin under the sewer. In 1986, the basin was closed and the sewer line removed. We drilled two horizontal wells in the test site: one below the water table, and one above. The horizontal orientation was chosen to maximize the area of decontamination, since the plume was horizontal in shape, and to enhance the distribution of the microbes. Air and methane were then injected into the lower well and were withdrawn from the upper well. Methane was injected in several low concentrations to stimulate microbial growth. Samples of sediment, soil gas, and ground water were taken at regular intervals during the study to monitor progress.

Our tests showed that the methane injection caused the density of contaminant-degrading bacteria to increase by 7 orders of magnitude (10 million times). Biostimulation was immediate with injection of low concentrations of methane. Concentrations of TCE/PCE in water, soil gas, and sediment decreased by as much as 99%, reaching below detectable limits. In fact, our process removed 42% more TCE than did air stripping (the underlying process) alone.

This technology demonstrated the validity of the theories of biostimulation and biodegradation to achieve effective environmental remediation. These theories were turned into methodologies that work more effectively than conventional technologies.

Competitors

Our technology includes important new concepts, such as a defined approach for injecting methane as a nutrient to stimulate and enhance microorganism breakdown of contaminants, as well as an innovative application of horizontal well drilling technology.

In situ bioremediation is a well-known process; however, many of the techniques developed so far are too costly to execute and are not effective enough to overcome barriers to commercial development. A slow-paced process, for example, or a process that produces other toxins, such as vinyl chloride, fails to overcome barriers to successful commercialization.

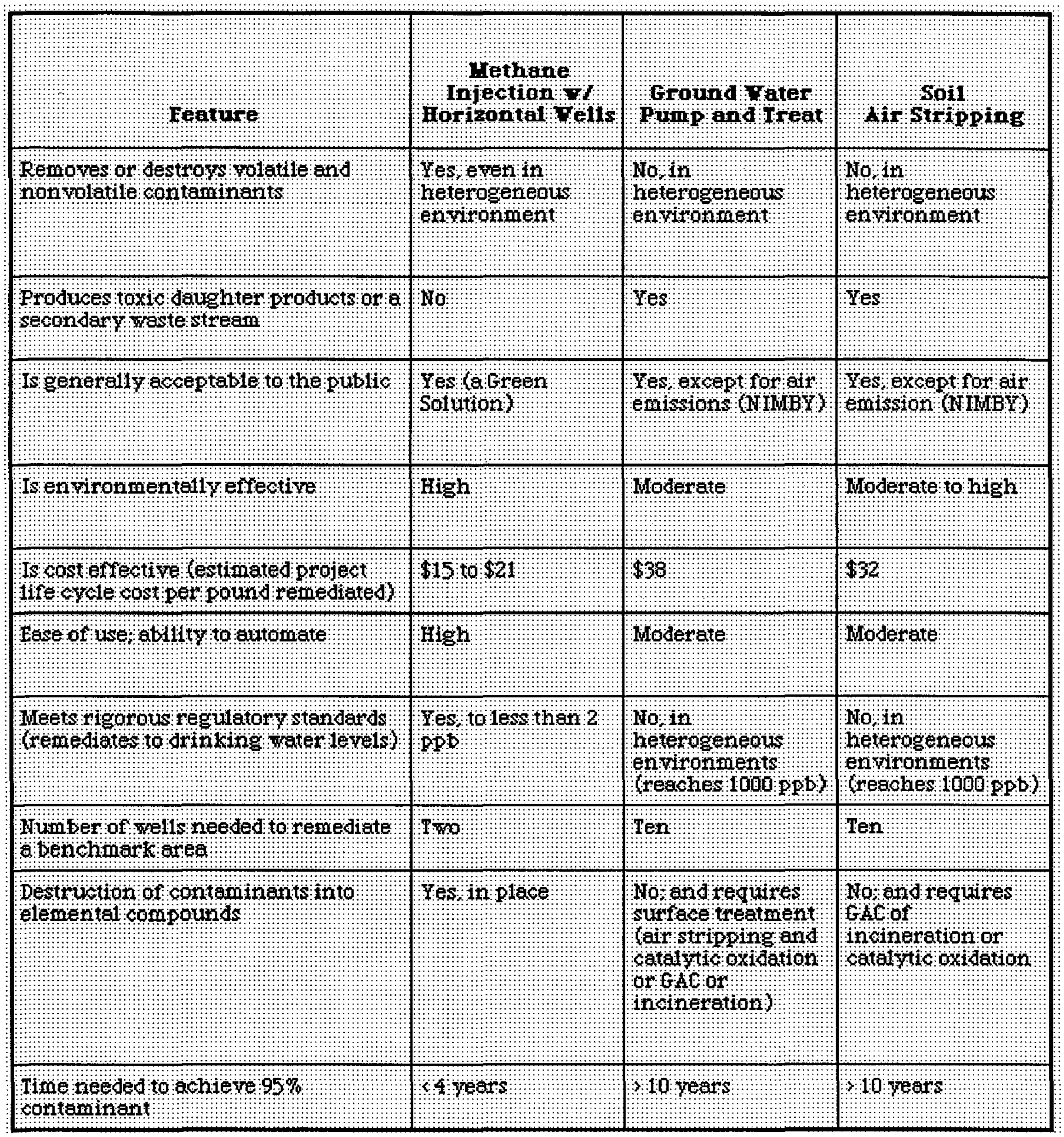
The principal existing method for remediation of TCE-contaminated ground water is pump and treat, followed by air stripping. Unsaturated sediment contamination can only be remediated by vapor extraction. None of these are TCE destruction technologies: the TCE is either discharged to the atmosphere or captured for subsequent disposal (incineration).

Since the overall SRS project was a collaborative effort of industry, academia, and government partners, our results were independently verified by several labs which were project participants. We determined that destruction of contaminants *in situ* was complete and that no harmful daughter products had been produced.

For this entry, we are comparing our technology to alternate existing remediation techniques such as pump and treat, vapor extraction, and air stripping.

Product Comparison

Comparison Matrix



Feature	Methane Injection w/ Horizontal Wells	Ground Water Pump and Treat	Soil Air Stripping
Removes or destroys volatile and nonvolatile contaminants	Yes, even in heterogeneous environment	No, in heterogeneous environment	No, in heterogeneous environment
Produces toxic daughter products or a secondary waste stream	No	Yes	Yes
Is generally acceptable to the public	Yes (a Green Solution)	Yes, except for air emissions (NIMBY)	Yes, except for air emission (NIMBY)
Is environmentally effective	High	Moderate	Moderate to high
Is cost effective (estimated project life cycle cost per pound remediated)	$15 to $21	$38	$32
Ease of use; ability to automate	High	Moderate	Moderate
Meets rigorous regulatory standards (remediates to drinking water levels)	Yes, to less than 2 ppb	No, in heterogeneous environments (reaches 1000 ppb)	No, in heterogeneous environments (reaches 1000 ppb)
Number of wells needed to remediate a benchmark area	Two	Ten	Ten
Destruction of contaminants into elemental compounds	Yes, in place	No; and requires surface treatment (air stripping and catalytic oxidation or GAC or incineration)	No; and requires GAC of incineration or catalytic oxidation
Time needed to achieve 95% contaminant	< 4 years	> 10 years	> 10 years

Product Advantages

Our process destroys and removes contaminants in their original location. To remove contaminants at concentrated sites, the traditional environmental methods involve transferring toxic wastes from one medium to another -- from water to air, for example.

When the total degradation into elemental components such as carbon dioxide and oxygen is required, existing methods favor incineration for breaking down polluted materials. But the public outcry over this process is so pronounced that it is no longer an attractive option.

Our technology is superior to competing technologies in several respects, but especially in that the decontamination is to drinking water levels. Figure 1 shows the location of the contaminant plume in our demonstration site and shows schematically the system we used to inject methane for subsurface microbial stimulation.

Our technology is more effective than any other. Our tests demonstrated that PCE was biodegraded when methane was injected into the site, even though PCE can only be degraded anaerobically. Our data proved that enough anaerobic pockets were created by the increasing biomass to allow a significant amount of anaerobic reductive dechlorination of PCE to TCE, which was then oxidized by methanotrophs.

Determining the correct nutrient, methane, and the correct methane concentrations for biostimulation (1% of air or pulses of 4% of air), was just part of the total solution. Combining biostimulation with a unique nutrient delivery system is an important part of our technology. We drilled horizontal wells, which bear on both performance and cost.

The horizontal wells greatly extend the area in which the microbes can penetrate. A pair of horizontal wells can run as far as 1500 feet underground and affect an area 300 to 400 feet wide.

The actual area decontaminated during our test was about the size of a football field, 300 feet long by 150 wide by 200 feet deep. Furthermore, the horizontal wells can reach hard-to-treat places, such as beneath existing buildings and structures (such as a runway).

Bioremediation reached extremely high levels using our combined nutrient injection and well drilling concepts. Water concentrations of TCE and PCE decreased by as much as 95%, reaching concentrations below detectable limits (<2 ppb). Soil gas TCE and PCE declined by more than 99%, also reaching undetectable limits.

In comparison, conventional technologies usually level off at about 1000 ppb in heterogeneous environments, a probable limitation of ground water and soil adsorption/desorption properties. Homogeneous environments are not common; therefore, finding a suitable remediation technique must be in the context of a heterogeneous environment.

Our demonstration showed that 42% more TCE/PCE was degraded and removed by our bioremediation process than by *in situ* air stripping alone.

A pump and treat system may not be effective over the long term at some sites because it does not remove contaminants bonding with soils and clays. The contaminants which remain slowly leach back into the cleaned up areas and ground water.

Air stripping systems also leave residual contaminants in clay soils. Vapors removed from ground water and soil require further treatment, usually some form of incineration. Offgas systems not only incur additional cost, but are not generally acceptable to the public.

Our combined biostimulation and air stripping process is cost and time effective. *In situ* air stripping is more cost effective than baseline technologies (soil vapor extraction and ground water pump and treat).

The *in situ* bioremediation process tested was 40% less expensive than the baseline technology.

With this technology, we removed more contaminant than either *in situ* air stripping or pump and treat systems. The added cost of methane injection to air stripping was only 8%.

As little as 900 pounds of contaminant needs to be biodegraded to offset this additional cost to the *in situ* air stripping system. Further, our demonstration showed that when methane is added to a process such as air stripping, cleanup that would normally take 10 years to reach acceptable levels (95%) could be achieved in about 4 years to undetectable levels (<2 ppb).

This difference alone would result in a $1.5 million savings over the conventional system for just the Savannah River Site demonstration area.

For the entire Savannah River Site, savings would be multiple millions. Since bioremediation destroys contaminants *in situ*, before they contaminate underlying groundwater, the cost of any pump and treat system is reduced.

When we coupled in situ bioremediation with air stripping, we saw a significant reduction in the time required to complete the remediation because bioremediation provides a second simultaneous pathway for removal (destruction) of TCE. Also, the microbes, when stimulated by methane, reached TCE in the vadose zone and aquifer matrixes that was very difficult to remove by air stripping, and which was not removable by the pump and treat method.

This technology is easy to use. Our system is completely automated and extremely trouble-free. It is so easy to use that one technician can operate at least six systems at once. Concurrently, the technician can be responsible for site monitoring equipment.

Conventional risks are avoided altogether. Since *in situ* bioremediation technology is based on biological destruction of the contaminants at the site, risks associated with handling, transporting, treating, and storing contaminated residuals are avoided. This is a significant reduction of risk to workers and to the public.

This technology is generally acceptable. Bioremediation techniques enjoy relatively high regulatory acceptability. Further, bioremediation is generally acceptable to the public, because it is accurately perceived to be a natural environmental cleanup solution.

Figure 1

Schematic diagram of the methane air and nutrient injection into a horizontal well below the water table with parallel vapor extraction from above the water table. The enlargement shows how oxygen and methane from the injection gas stream is taken up by methane oxidizing bacteria in the sediment and converted into chloride and CO2. Contaminants in the vapor extracted for the initial demonstration from unsaturated (vadose) zone was thermal catalytically converted to CO2 and chloride.

Figure 2

This three-dimensional portrayal shows the trichlorethylene concentration in sediment before the in *in situ* bioremediation test.

Figure 3

This three-dimensional portrayal shows the trichlorethylene concentration in sediment after the *in situ* bioremediation test.

Figure 4

This portrayal shows the densities of methanotrophs (methane-oxidizing bacteria) after the *in situ* bioremediation test-after stimulation. Densities are in log units and pre-test densities were less than 10.

Source: All figures are from SRTC internal data generated during the in situ bioremediation demonstration.

Principal Applications

This technology applies to contaminated sites around the world. The primary application of our technology is environmental remediation at sites where principal contaminants are chlorinated solvents. This technology can be used anywhere in the world where underground chlorinated solvent contaminants exist which are susceptible to aerobic microbial actions.

The contamination of soil and ground water with contaminants such as TCE and PCE is a wide-spread problem existing at more than 1600 government and industry sites in the United States. It is also a significant problem in industrialized countries around the globe.

According to a recent EPA paper (ref. 11), chlorinated volatile organic compounds are by far the most common organic contaminant. Most contaminated sites require both groundwater and soil remediation, and our technology addresses both of these. About 26 million cubic yards of soil, sludge, and sediment need to be cleaned up, just in 1600 U. S. sites.

The second-most common contaminant (after metals) on the National Priorities List of polluted sites is chlorinated volatile organic compounds such as TCE and PCE. Figure 5 gives the data.

Other Applications

Our demonstration test showed that this technique for bioremediation could be extended to other contaminants of similar composition, such as benzene, xylene, and toluene, or any biodegradable organic where <10 ppm cleanup standards are required.

Potential Applications

There are no other known applications for this technology which are not feasible. This technology works for any biodegradable organic solvent; the *in situ* approach makes the technology applicable in a wide variety of soils, geographical situations, and overall environments.

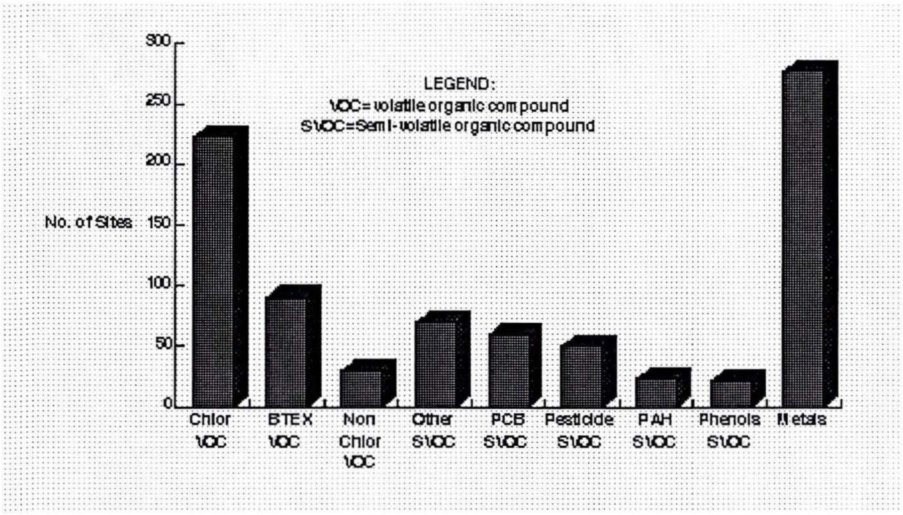


Figure 5. Frequency of Contaminants Present in National Priorities List Sites (Source: U. S. EPA, Technology Innovation Office, site assessment data, 1992.)

Summary

Our patented bioremediation process is already in use in industry. The process moved directly from full-scale demonstration to commercial application, with seven different environmental firms acquiring licenses immediately.

The potential savings from our bioremediation technology are so large as to be difficult to quantify in easily grasped numbers. For example, just in the demonstration area at the Savannah River Site--the area of a football field, 200 feet deep--savings over existing methods total $1.2 million. For the 1600 sites in the U. S., savings would be in the billions. Worldwide, savings accumulate beyond billions.

Our technology resulted from one of the most comprehensive R&D projects ever performed in the field of environmental remediation. The overall project, of which our technique was the ultimate result, represents the best ideas and most rigorously tested methods collected from industry, government, and academic researchers in the country. The comprehensive base of integrated demonstrations of various remediation technologies upon which our technique rests has caused it to be an immediate commercial success.

The Department of Energy, which owns the Savannah River Site, has already granted seven commercial licenses to environmental firms, and a dozen more companies have either applied for a license to use this technology or have expressed a serious interest in it. In addition, a U. S. patent has been granted on our methane injection technology. SRTC holds two additional patents on the integrated horizontal well technology also.

Although various bioremediation processes have been demonstrated in the lab and in bioreactors, ours is the first to show full-scale applicability to *in situ* bioremediation for industrial sites. Our technology is a solution to environmental contamination which offers in-place destruction of contaminants without harmful side effects and delivers value for the money spent on the cleanup.

The technology lends itself to cost effectiveness because it is less capital intensive, takes less time than conventional means, incorporates conventional means to achieve remediation, and can be automated for low-cost and easy operation.

We see global applications for our technology: the microbe central to the process occurs naturally everywhere, and the types of contaminants it removes are chlorinated solvents that were used extensively in all industrial nations of the world.

In general, bioremediation enjoys wide public acceptance, and our specific technique is expected to be accepted by both the public and the regulatory agencies. It is a long-term solution to environmental cleanup which creates no harmful side effects and is perceived to be a natural process.

In summary, our technology works, and works effectively:

1. We showed that naturally occurring bacteria capable of degrading TCE/PCE can be stimulated *in situ* by adding relatively simple and naturally occurring nutrients.

2. We proved that biostimulation and biodegradation occurred *in situ* without production of toxic daughter products such as vinyl chloride.

3. Our automated process is easy to use.

4. The cost of adding the methane injection capability is low and is easily recovered during the lifetime of the remediation.

5. Gaseous nutrient injection represents a significant new delivery technique for *in situ* bioremediation.

6. Combined with air stripping, this technology represents a significant decrease in cost (about 50%) and a significant improvement in efficiency (to undetectable levels) over conventional technologies (pump and treat, vapor extraction) now used for remediation of chlorinated solvent.

Remediation to drinking water levels (<5 ppb) was achieved in less than half the time (<4 years), at less than half the cost, with our *in situ* bioremediation technique than would have been possible with any existing systems. In fact, this bioremediation process may be the only one that can achieve drinking water standards at many sites.

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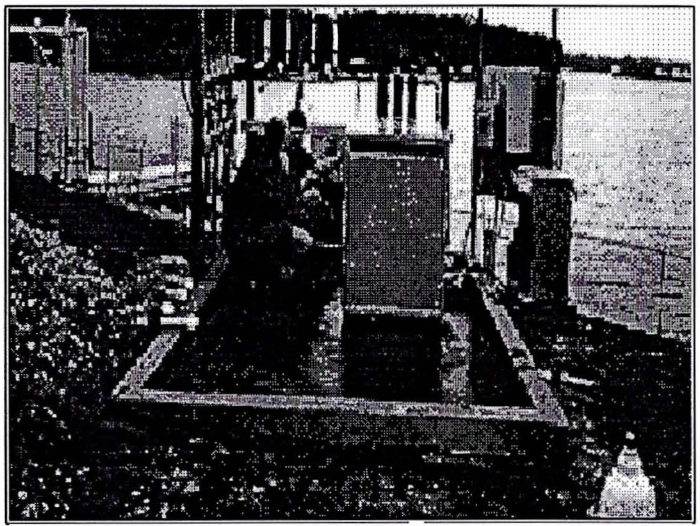

In Situ Bioremediation System Using PHOSter® at an Industrial Site in Florida

PHOSter®

Site Need

- Cost-effectively treat soils contaminated with VOCs, particularly as a result of petrochemical contamination.

Technology Description

- PHOSter® is a patented system that effectively delivers phosphorous to stimulate microorganisms in bioremediation systems. A mixture of air and triethyl phosphate is injected through wells to a contaminated area. The nutrient encourages the growth of naturally occurring microbes that destroy contaminants in situ, which reduces the risk of personnel exposure and of surface release of contaminants.

Benefit

- Application of the PHOSter® system is inexpensive and effective.
- The system has broad applicability across the DOE complex and in the commercial sector.
- PHOSter® is a Research and Development (R&D) 100 award winner.

Point-of-Contact

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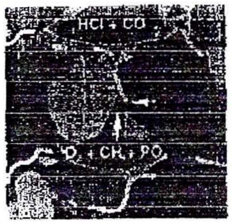
Controlled addition of phosphorus aids bioremediation



PHOSter™

Technology Brief

Highlights

- Scientists at the Savannah River Technology Center, in partnership with *Oak Ridge National Laboratory* and Ecova Corporation, have developed a new, improved process to control the addition of vapor-phase phosphorus to bioremediation systems.
- Called the PHOSter system, this process offers *significant advantages over* existing technologies, including *successful field applica*tions, timed-release action, low potential for over-stimulation and high regulatory acceptability.
- PHOSter is a 1996 R&D 100 Award winner, and *received a 1995 Federal* Laboratory Consortium Award of Excellence in technology transfer
- The Savannah River Technology Center is the applied research and development laboratory serving the Savannah River Site. Westinghouse Savannah River Company operates the center for the Department of Energy.

In bioremediation processes that are phosphorus-limited (where the amount of phosphorus determines biomass growth and reaction rates), controlled addition of this nutrient is the key to effective process control and to reducing time needed to destroy contaminants.

The PHOSter system is a new, improved process to control the addition of vapor-phase phosphorus to bioremediation systems, bioreactors and other biotechnology applications. Developed by scientists at the Savannah River Technology Center, in partnership with Oak Ridge National Laboratory and Ecova Corporation, PHOSter offers significant advantages over existing technologies, such as the use of liquid fertilizer or phosphoric acid vapor.

A timed-release system

For example, in a bioventing process used to remediate an oil-contaminated site, air is drawn through the soil to stimulate aerobic bacteria, which break down the contaminant. The PHOSter system allows a controlled amount of a relatively safe form of organic phosphorus to be added to the air, providing a uniform "timed-release" stimulation of biomass growth. The operator can maximize oil degradation without overstimulating the microbes.

Traditional approaches of adding phosphorus at remediation sites are based on the addition of liquid fertilizer solutions to the ground surface or to wells. Such systems have been shown to influence very small areas, overstimulating them, and resulting in negative consequences like formation clogging.

Adding phosphoric acid vapor has also been proposed as an alternative, but like the other inorganic system, this approach tends to overstimulate a relatively small area because of the high solubility/ionizability of the acid. Moreover, full-scale process control and efficient utilization of such a system have never been demonstrated.

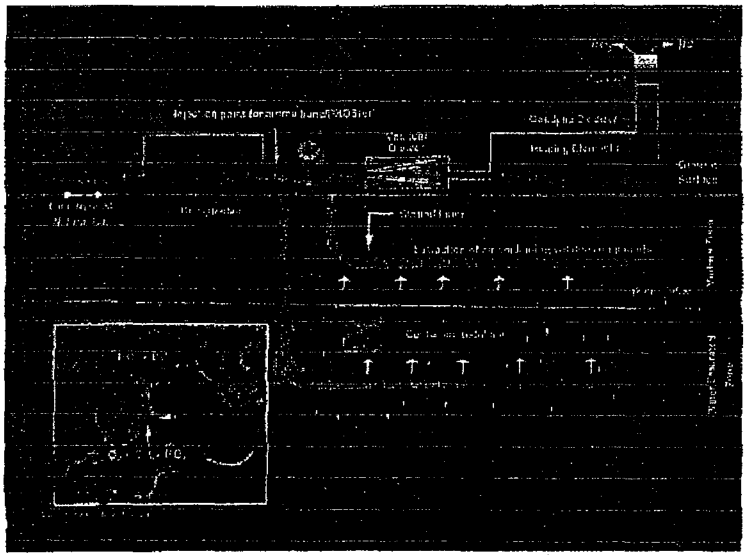
Faster rate of bioremediation

When added to a full-scale, field demonstration utilizing horizontal well technology, the PHOSter system's stimulation of indigenous methanotrophs resulted in major improvements in the *in situ* destruction of chlorinated solvents in soil and ground water at the site. In a second test, a customer using the invention at a bioventing site saw an increase in the bioremediation rate of a factor of five in the first 40 hours of use. Successful field applications include remediation of leaking underground storage tanks, regional gasoline terminals, and industrial facilities.

The PHOSter process can improve most environmental bioremediation and biotechnology activities. It is flexible for use in

[redacted]

bioventing and other *in situ* bioremediation projects, as well as in surface bioreactors and other processes that are phosphorus-limited. PHOSter may also enhance biological-based production of chemicals and pharmaceuticals.



Injecting a mixture of air and triethyl phosphate through horizontal wells encourages the growth of microorganisms that destroy contaminants *in situ*. The process reduces exposure of personnel to potential risk and prevents surface release of contaminants.

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Summary Performance Assessment of In Situ *Remediation Technologies Demonstrated at Savannah River*

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Bruce A. Robinson
Kay H. Birdsell
Bryan J. Travis

Los Alamos
NATIONAL LABORATORY

SUMMARY PERFORMANCE ASSESSMENT OF *IN SITU* REMEDIATION TECHNOLOGIES DEMONSTRATED AT SAVANNAH RIVER

by

Nina D. Rosenberg, Bruce A. Robinson, Kay H. Birdsell and Bryan J. Travis

ABSTRACT

The Office of Technology Development (OTD) in the Department of Energy's (DOE) Office of Environmental Restoration and Waste Management is investigating new technologies for "better, faster, cheaper, safer" environmental remediation. A program at DOE's Savannah River site was designed to demonstrate innovative technologies for the remediation of volatile organic compounds (VOCs) at nonarid sites. Two remediation technologies, *in situ* air stripping and *in situ* bioremediation—both using horizontal wells, were demonstrated at the site between 1990-1993. This brief report summarizes the conclusions from three separate modeling studies on the performance of these technologies.

Volatile organic compounds (VOCs) including chlorinated solvents such as trichloroethylene (C_2HCl_3, TCE) are among the most common contaminants in groundwater and soils. A common remediation approach has been to pump the contaminated groundwater to the surface where the water is treated to remove the contaminants. This pump-and-treat approach has been successful in containing contamination and removing much of the contaminant mass at many sites. It has been less successful at remediating sites to the low levels of residual contamination required by regulatory agencies. Moreover, cleanup efforts based on pump-and-treat are often costly and slow, and they do nothing to remediate VOCs in the vadose zone which may be a long-term source of groundwater contamination.

The Office of Technology Development (OTD) in the Department of Energy's (DOE) Office of Environmental Restoration and Waste Management is investigating new technologies for "better, faster, cheaper, safer" environmental remediation. A program at DOE's Savannah River site was designed to demonstrate innovative technologies for the remediation of sites contaminated with VOCs in nonarid environments. The Savannah River Integrated Demonstration (SRID) focused on two *in situ* remediation technologies aimed at remediating VOC contamination in both the groundwater and the vadose zone at one location at Savannah River facility.

The first technology, *in situ* air stripping, was demonstrated during a field test in 1990 (Looney et al. 1991). *In situ* air stripping is a combination of air injection below the water table and vacuum extraction in the vadose zone. A second technology, *in situ* bioremediation, was demonstrated using the same wells during a field test in 1992-1993 (Hazen 1992). The goal of the *in situ* bioremediation demonstration was to stimulate naturally occurring methanotrophic bacteria at the site with injection of various amounts of methane, air and air-phase nutrients (nitrogen and phosphate) such that significant amounts of the chlorinated solvents present in the subsurface would be degraded.

Both the *in situ* air stripping and *in situ* bioremediation demonstrations used a pair of horizontal wells. Wells used for site remediation are typically vertical. Over the past few years, however, there has been an increased interest in horizontal wells for environmental remediation. In some cases, such as remediating areas where vertical access is limited, such as under buildings or waste sites, horizontal wells are clearly advantageous. In cases where access is not an issue, the advantage of horizontal over vertical wells is less clear.

We assessed the performance of the remediation technologies demonstrated at the SRID site using numerical simulation as a tool. We believe that significant value is added to the technology demonstrations through the assessment and evaluation of field data combined with flow and transport modeling. Field demonstrations of *in situ* remediation technologies are complex and expensive. Moreover, a field demonstration provides data on only one particular design implementation at one particular place and time. We have used modeling to learn more about the fundamental flow, transport and chemical processes involved in technology performance. We also suggest possible improvements to the technology design, predict technology performance over longer time and at different sites, and compare the performance of these and other remediation technologies.

We divided our performance assessment work into three separate studies. The first study is based on the construction of a history-match model of the *in situ* air stripping demonstration using the FEHM computer code. The second study is based on site-specific simulations of the *in situ* bioremediation demonstration using the TRAMP code. The third study is more general. It focuses on the relative performance of horizontal versus vertical vapor extraction wells in highly simplified systems using the code TRACR3D The main conclusions from these studies are give below. For details about these modeling studies, see Robinson et al. (1994), Birdsell et al. (1994) and Travis and Rosenberg (1994). Information about the computer codes is given in Travis and Birdsell (1991), Zyvoloski (1992) and Travis (1993).

In Situ Air Stripping

- The TCE concentration at the extraction well versus time can be simulated very well using a relatively, simple model with a dual porosity formulation. The model assumes a mass transfer limitation between liquid-phase TCE held up in clay lenses and the moving air, which travels mainly in the surrounding sandy zones of higher permeability.
- Cyclic operation of the system may offer substantial cost savings for only a marginal performance cost. Similarly, operating the system at lower flow rates may offer substantial cost savings for only a marginal performance cost.
- The injection of heated air through the lower well is unlikely to result in increased TCE removal. This is because only a small region is heated at any one time and as soon as air travels from a heated region to one at ambient temperature, any "extra" TCE in the air phase will redissolve.
- Aligning the injection and extraction wells at any particular angle to one another is probably not necessary. Heterogeneities in the medium are likely to be the dominant factor in governing the spreading of air in the saturated zone and for any reasonable configuration, it is very unlikely that TCE stripped from the saturated zone would not be captured by the extraction well. The injection well should be directly aligned with the major axis of the plume in the horizontal plane for the greatest likelihood of adequate air sweep through the plume.
- The TCE removal curve is asymptotic.
- The main characteristic in assessing the performance of this technology at another site is the heterogeneity of the site. For a site with 10 times less heterogeneity (as measured by the

average effective clay lens size) than the Savannah River site but otherwise identical, removing 95% of contamination would take about half the time.

- Replacing the lower air injection well with a groundwater pumping well (also horizontal) results in more TCE being extracted from the groundwater, but the amount of TCE below the water table that is removed in both cases is small.
- Time required for remediation is decreased dramatically if *in situ* destruction methods can be successfully employed in the field.

In Situ Bioremediation

- A successful strategy should include pulsing of methane. It is important to remember, however, that the diffusivity of methane in air is about 10,000 times larger than in water. Therefore, pulsing in the unsaturated zone is less effective at saturated zone pulsing rates because discrete pulses of methane will not remain as spatially separated.
- Addition of nutrients significantly accelerates the biodegradation process by allowing the methanotroph population to grow rapidly. However, nutrient injection must be controlled to prevent explosive growth of bacteria near the injection wells, resulting in pore clogging and consumption of all the food substrate (methane) before it has a chance to spread throughout the system.
- If the methane and nutrients have the same transport properties (e.g., Henry's Law coefficient), then one should inject them together. If the methane and nutrients have significantly different transport properties, as in the Savannah River demonstration, then pulsing nutrients out of phase with the methane injection and systematically varying the phase lag would allow a larger region to be remediated efficiently and effectively.
- The goal in pulsing should be to maintain discrete pulses, without creating regions where methane and nutrient levels are too low (the bacteria will die) or too high (the bacteria will grow too much). To achieve this goal, several smaller wells may be more effective than a single pair of wells in some cases.
- The total amount of TCE extracted or biodegraded by *in situ* bioremediation is significantly (~40%) higher than the amount that would have been extracted in an otherwise identical remediation without microbial degradation (*in situ* air stripping).
- In addition to removing a greater total amount of TCE from the system, *in situ* bioremediation results in lower residual levels of TCE than *in situ* air stripping—in places by a factor of three to six lower.
- Many of these same limitations of *in situ* air stripping apply to *in situ* bioremediation (e.g., long remediation times due mainly to VOCs in lower permeability clays), but *in situ* bioremediation can reduce remediation times and residual contaminant levels substantially.
- The main requirement for success is that methanotrophic bacteria exist at the site. Since methanotrophs are fairly common bacteria, this should not be a problem.
- *In situ* bioremediation with methanotrophs is not very dependent on site-specific factors at Savannah River, so the basic design of this technology should work at other sites.
- The details of technology implementation (e.g., injection strategy, well placement) which are key to its success, however, must be carefully evaluated for each new site. Site-specific scoping calculations will be necessary at each new site to determine the optimal number of wells, injection/extraction strategy, and so forth. Site-specific testing to obtain biokinetic rates to support these scoping calculations (i.e., laboratory tests on samples from the site which cover the range of nutrient, food and contaminant concentrations likely to be used or encountered) is strongly recommended.

- If VOC concentrations are much higher than at the SRID site, *in situ* bioremediation may not be effective. This is because at high concentrations, the contaminants can be poisonous to bacteria. In this case, *in situ* air stripping should be used to reduce the levels of VOCs to more moderate values before *in situ* bioremediation is attempted.

Horizontal versus Vertical Vacuum Extraction Wells

- Horizontal wells have the advantage only for long, linear plumes or if surface capping or vertical access is problematic. Often several vertical wells with site capping outperforms a single horizontal well (and may be less expensive).
- A system consisting of a horizontal air injection well and vertical extraction well(s) in the vadose zone with surface capping may be an optimal *in situ* air stripping system, provided access is not an issue and capping is possible.
- Intuition and modeling assumptions that commonly hold for saturated flow must be reexamined for vapor extraction. Also, the success of horizontal wells in the oil industry is not directly relevant to the success of horizontal vapor extraction wells—the economics and hydrological environment are significantly different.
- For maximum removal efficiencies during vapor extraction the following guidelines are suggested. Surface capping should be used with vertical extraction wells. Both horizontal and vertical wells should be screened over the entire length of the plume. A horizontal well should be placed at the lower edge of the plume and aligned with the plume's major axis in the horizontal plane. A vertical well should be placed in the center of the plume.

Both *in situ* air stripping and *in situ* bioremediation as demonstrated at Savannah River, while not a panacea for VOC remediation, are valuable additions to the existing "toolkit" of technologies available for environmental remediation. Details are contained in Robinson et al. (1994), Birdsell et al. (1994) and Travis and Rosenberg (1994).

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Effect of gaseous nitrogen and phosphorus injection on in situ bioremediation of a trichloroethylene-contaminated site

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JOURNAL OF HAZARDOUS MATERIALS

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Incidents: prevention, control, clean-up, communication, labelling, sources of information and assistance, case histories

Assessment: economic and general risk assessment, insurance, test methods, technical aspects of risk assessment of industrial hazards, reliability and consequence modelling, decision-making in risk management

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Abstract

Methane and air were injected through a horizontal well into a trichloroethylene-contaminated site at a depth of 160 ft below ground surface to stimulate methanotrophic biodegradation of trichloroethylene (TCE). Sediment samples were analyzed after 35 weeks of methane and air injection, and after 13 weeks of methane and air injection supplemented with injection of the gases nitrous oxide and triethyl phosphate. Methanotroph most-probable-number (MPN) values were very low in most of the samples prior to the addition of nitrogen and phosphorus to the site, and increased several orders of magnitude following the addition. Similarly, the frequency of TCE biodegradative potential in methanotrophic enrichments increased approximately three orders of magnitude after the addition of nitrogen and phosphorus to the site. The MPN and biodegradative potential data indicated that the zone of influence after the addition of nitrogen and phosphorus extended to at least 60 ft from the injection well in both the vertical and horizontal directions.

1. Introduction

Trichloroethylene (TCE) and other chlorinated solvents are major contaminants on industrial and government sites. Cost-efficient strategies are needed for bioremediating these contaminants in deep (>50 ft) subsurface environments. The use of horizontal wells to efficiently deliver multiple gaseous nutrients to stimulate the growth and activity of indigenous microflora able to degrade TCE has been the focus of an Integrated Demonstration funded by the US Department of Energy at the Savannah

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River Site near Aiken, South Carolina [1,2]. Horizontal injection and extraction wells, as compared to vertical wells, maximize the volume of the treatment zone with a minimum number of wells. In addition, the injection of carbon, nitrogen, and phosphorus as gases promotes nutrient transport over greater distances. The use of methane as the carbon source targeted the stimulation of the indigenous methanotrophic microorganisms at the site [3]. Under aerobic conditions, these microorganisms oxidize both methane and TCE using the methane monooxygenase enzyme, but do not derive energy from TCE oxidation [4,5].

TCE contamination of the site occurred between 1952 and 1982 from a leaking process sewer line [1]. At the beginning of the bioremediation demonstration, ground water TCE concentrations were <1–14 ppm and sediment concentrations were <1 ppm with most samples below detection (2 ppb) [6]. The highest TCE concentrations were in the layers with high clay content. While non-aqueous phase TCE exists at the end of the sewer line, several lines of evidence indicate that non-aqueous TCE probably did not exist at the site of the bioremediation demonstration [6–8]. The majority of the TCE was located at 100–140 ft below ground surface (bgs) in a stratum termed the tan clay zone, which is composed of discontinuous, interlayered sand and clay beds of varying thickness [9]. The water table at the site was 130–140 ft bgs. The lower horizontal well was located in the aquifer at 160 ft bgs and the upper horizontal well was located in the unsaturated zone at 70 ft bgs. Injection of gaseous nutrients through the lower well and a vacuum exerted on the upper well moved nutrients through the contaminated region to promote the growth and activity of methanotrophic microorganisms. A 21-week air stripping demonstration (i.e., air injection only) was performed prior to the bioremediation demonstration (air, methane, and later, nitrogen and phosphorus injection) as a control experiment to monitor TCE removal in the absence of injected microbial nutrients [2]. The geology, hydrology, geochemistry, and microbiology of the site and the distribution of contaminants have been summarized [9]. Complete descriptions of sampling, permits, the oversight panel, and the components and operating conditions of the field system have been published [1, 10].

The objective of the bioremediation demonstration was to demonstrate and document that injection of microbial nutrients would result in enhanced TCE removal compared to air-stripping alone. The bioremediation demonstration consisted of a 35 week injection of 1–4% methane (by volume) in air, followed by a 13 week injection of 4% methane supplemented with nitrous oxide (0.07% by volume) and triethyl phosphate (0.007% by volume). Analyses included contaminant inventories in ground water, sediment, soil gas, and the extraction well; methanotroph numbers, biodegradative potential, and activity; and site-specific numerical simulations of the bioremediation demonstration versus air-stripping [1, 6].

In this paper we report on the effect of the nitrogen and phosphorus addition, by comparing the density of culturable methanotrophs and TCE biodegradative potential under methanotrophic enrichment conditions, in sediment samples from the 100 to 140 ft depths immediately before, and after, nitrogen and phosphorus addition to the site.

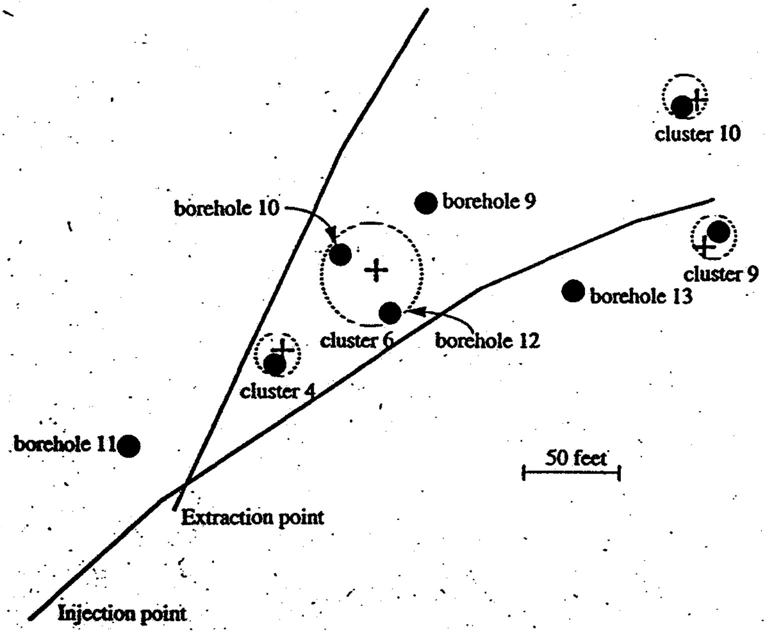

Fig. 1. Plan view of borehole locations, borehole clusters, and horizontal injection and extraction wells at the Savannah River Area M bioremediation site: (crosses) boreholes sampled before nitrogen and phosphorus addition; (solid circles) boreholes sampled after nitrogen and phosphorus addition.

2. Procedures

2.1. Sampling

Fig. 1 shows the location of boreholes from which sediment samples were analyzed. Aseptic sampling techniques were used, including sterile lexan liners, steam cleaning of core barrels, and use of sediment from only the inner portion of the cores [1]. The four locations selected for resampling at the end of the N/P/pulsed 4% methane injection are designated as clusters. At 10 ft intervals, 2 ft of core was homogenized and approximately 200 g was bagged, and samples were shipped by overnight Federal Express in insulated boxes containing ice to maintain a temperature of approximately 4 °C.

2.2. MPN enumerations

The number of culturable methanotrophs was estimated in enrichments set up in a 3-vial/dilution MPN format [11]. Upon receipt of sediment samples, a 10-g aliquot of homogenized sediment was added to 95 ml 0.1% pyrophosphate (pH 7.0) and shaken at 180 rpm for 30 min on a reciprocating shaker before carrying out serial dilutions (1 ml inoculum) to 20 ml headspace vials containing 10 ml of media. The medium was Shelton's mineral salts [12] amended with 2 μM cupric sulphate and 1 ml of a vitamin mixture [13] per liter. After inoculation, the vials were closed with silicon septa, methane was added to 25% of the headspace, and the vials were sealed with aluminum crimp closures. Inoculated vials were incubated at room temperature. The presence of turbidity, a biofilm, or suspended or floating pellicles after 4 months incubation was scored as a positive result. MPNs below the detection limit (<3/g) and exceeding the upper detection limit (>2400/g) were assigned values of 50% and 200% of the calculated MPN, respectively, to allow an approximate mean value to be calculated for specific boreholes [14].

2.3. Biodegradative potential

Biodegradative potential under methanotrophic enrichment conditions was assessed using the same format, medium, and inoculum as described above. An additional medium was employed by omitting copper from the Shelton's mineral salts medium. A very low (<1 *μM*) to zero copper concentration results in expression of the soluble form of the methane monooxygenase (sMMO) enzyme, whereas higher copper concentrations result in expression of the membrane-associated or particulate form of the methane monooxygenase (pMMO) enzyme [5, 15]. Glassware was not acid-washed to remove all traces of copper from the latter medium because low levels of copper are present in most sediments and ground water. Immediately before vials were sealed, a gas-tight syringe was slipped alongside the 20-mm-thick Teflon-lined rubber septa and 10 μl of methanol containing 10.9 m*M* TCE was delivered to the headspace to give an actual concentration (calculated using Henry's constant) of 7.8 *μM* (1.0 μg/ml) in the medium. Enrichments from samples taken after the addition of nitrogen and phosphorus were set up in replicate sets of vials and an equal amount of TCE was delivered in water instead of methanol. Vials were immediately sealed with the septa and an aluminium crimp closure. No-sediment controls with TCE added were included to account for abiotic losses. Vials were incubated inverted in the dark at room temperature. Headspace in the vials was analyzed after 14–22 weeks using a Hewlett-Packard 5880A series gas chromatograph equipped with a Supelco Vocal capillary column (105 m, 53 mm i.d., 3 μm film thickness), an electron capture detector, and an automatic headspace sampler. The column was operated at 50 °C for 1 min, 7 °C increase/min to 150 °C, and a 25 °C increase/min to 200 °C with a helium carrier gas flow of 58 ml/min and a flow of 24 ml/min from the headspace sampler. TCE had a retention time of 12.8 min under these conditions. Due in part to the extended incubation time, 5–15% loss of TCE was common in the control vials. Much greater losses were infrequently (<5% of the time) encountered, probably due to a poor seal. Therefore, a positive result was conservatively defined as removal of ≥75% of the TCE in at least two of the triplicate vials.

3. Results

3.1. Methanotroph MPN index in response to addition of nitrogen and phosphorus

The methanotroph MPN index was <3/g in 79% of the sediment samples prior to the addition of nitrogen and phosphorus to the site (Fig. 2). The addition of nitrogen

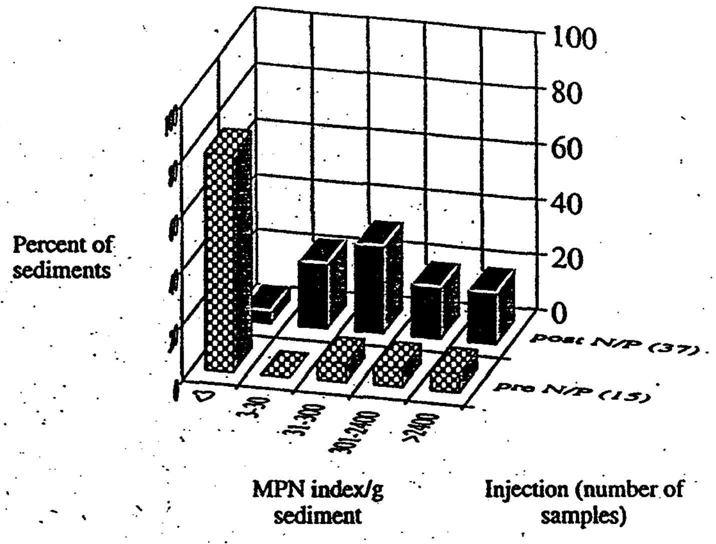

Fig. 2. Percent of 100–140 ft sediment samples containing levels of methanotrophs before and after nitrogen and phosphorus addition.

and phosphorus resulted in an approximately one to three order of magnitude increase in the methanotroph MPN index, with only 3% of the samples containing <3/g and 19% of the samples containing >2400/g.

3.2. Zone of influence as defined by methanotroph MPN index

Mean values for methanotroph MPN indexes had high standard deviations (Fig. 3). Due to the assumptions made for the purpose of determining approximate means, actual means and standard deviations were likely greater than shown in Fig. 3. Prior to the addition of nitrogen and phosphorus, 12 of the 15 samples were below detection and methanotrophs were not detected in clusters 4 and 6, the two locations closest to both the injection and extraction wells. The mean for cluster 10 resulted from a single sample (165 1/g) above detection. Following 13 weeks of nitrogen and phosphorus addition, methanotroph MPN means increased approximately two orders of magnitude in clusters 4 and 6, and one order of magnitude in cluster 9. Only one of the 37 samples was below detection after nitrogen and phosphorus addition. MPN indexes >2400/g were present in borehole 12 (three samples), borehole 9 (one sample), cluster 10 (one sample), and cluster 9 (two samples). The mean MPN index at 140 ft (3192/g) was 4 times greater than the means at the 100, 110, 120, and 130 ft depths (data not shown).

3.3. TCE biodegradative potential in response to addition of nitrogen and phosphorus

Prior to the addition of nitrogen and phosphorus to the site, TCE degradation under methanotrophic enrichment conditions (copper omitted, TCE delivered in

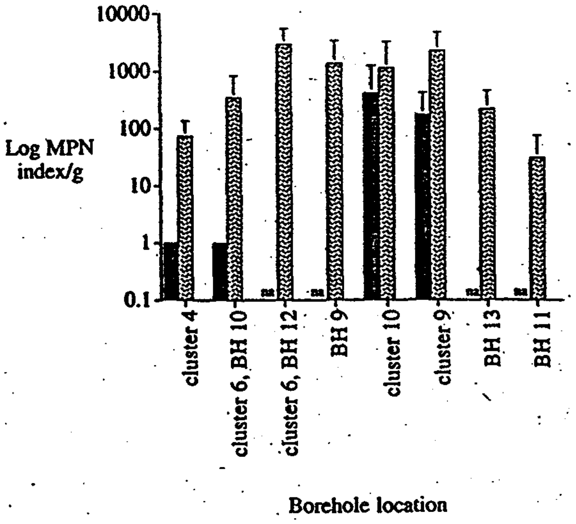

Fig. 3. Mean methanotroph MPN index in 100–140 ft sediment samples by borehole location. The positive standard deviation is shown by the vertical lines: (solid bar) before nitrogen and phosphorus addition; (stippled bar) after nitrogen and phosphorus addition. na, borehole location was not analyzed for methanotroph MPN before nitrogen and phosphorus addition.

methanol) was not observed with an inoculum equivalent to 100 mg sediment/vial. After the addition of nitrogen and phosphorus to the site, TCE degradation (copper omitted, TCE delivered in methanol) occurred in 81% of the samples with an equivalent of 100 mg sediment/vial, and in 68% of the sediment samples with a equivalent of 1 mg sediment/vial (data not shown). Thus, the frequency of TCE biodegradative potential increased by approximately three orders of magnitude in response to the addition of nitrogen and phosphorus.

The presence of methanol can inhibit methane and TCE oxidation in some methanotrophs [16,17]. To ascertain if the use of methanol as the carrier for TCE affected the measurement of TCE biodegradative potential, separate enrichments were performed with and without methanol as the carrier for samples taken after the addition of nitrogen and phosphorus. The results for enrichments in the absence and presence of methanol were very similiar (data not shown). This was true for enrichments lacking exogenous copper (permissive of soluble methane monooxygenase [sMMO] expression) and containing exogenous copper (permissive of particulate methane monooxygenase [pMMO] expression). Thus, over the length of the incubation and with the criteria used for a positive result, the presence of methanol did not significantly effect TCE biodegradative potential.

TCE biodegradative potential was examined under methanotrophic conditions selective for both forms of the methane monoxygenase enzyme. Three of 7 locations (boreholes 10, 9, and 13) showed a much higher frequency of TCE biodegradative potential under conditions permissive of one form of the methane monooxygenase versus the other form (Fig. 4). Because all methanotrophs are thought to contain the

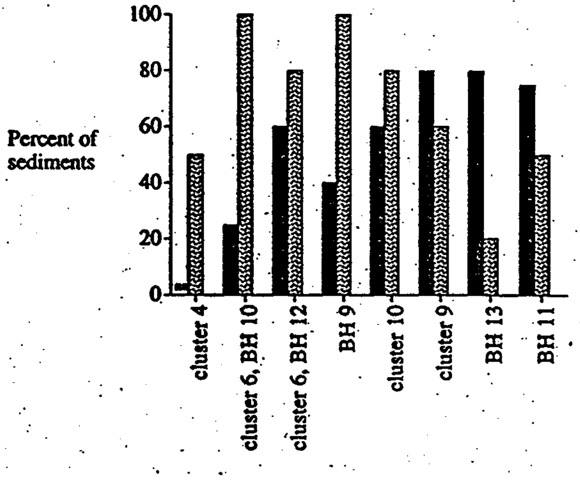

Fig. 4. Percent of 100–140 ft sediment samples from each borehole showing TCE biodegradative potential under methanotrophic conditions (TCE delivered in water), after the addition of nitrogen and phosphorus to the site: (solid bar) conditions permissive of sMMO expression; (stippled bar) conditions permissive of pMMO expression). na, not analyzed for TCE biodegradative potential.

pMMO gene while only some contain both the sMMO and pMMO genes [18], the common occurrence across the site of TCE degradation under enrichment conditions selective for both forms of the methane monooxygenase enzyme suggest that methanotrophs containing the sMMO gene were dominant at the site after the addition of nitrogen and phosphorus. However, the form of the enzyme that was actually expressed in situ cannot be determined from these results.

3.4. *Zone of influence as defined by TCE biodegradative potential*

The zone of influence after the 13-week injection of nitrogen and phosphorus included all borehole locations (Fig. 4). TCE biodegradative potential showed a trend of increased frequency with greater depth over the 100–140 ft interval (data not shown).

4. Discussion

The Savannah River bioremediation demonstration represents the first use of horizontal well technology to deliver nutrients for bioremediation and the first time that carbon, nitrogen, and phosphorus nutrient sources have all been injected as gases. The well configuration and gaseous nutrient injection strategy were used to maximize the volume of the treatment zone with a minimum number of wells and to promote more efficient delivery of nutrients to subsurface microorganisms. Culturable methanotroph populations and methanotrophic TCE biodegradative potential in sediment samples were analyzed before and after the injection of gaseous sources of nitrogen and phosphate to assess the magnitude and spatial extent of the nitrogen and phosphorus addition.

Methane injection was initially at 1% by volume in air (15 weeks), followed by 4% methane (11 weeks), and pulsed 4% methane (9 weeks) [19]. Prior to methane injection, air was injected for 21 weeks as a control experiment to monitor TCE removal in the absence of injected microbial nutrients. Samples analyzed after 15 weeks of 1% methane injection, as compared to after 21 weeks of air injection, showed a rapid and large increase in the density of methanotrophic microorganisms and in methanotrophic TCE biodegradative potential as measured by $^{14}CO_2$ evolution from ^{14}C-TCE [19–21]. This increase was followed by a decline in methanotroph populations and TCE biodegradative potential over the next 20 weeks of methane injection. Total microbial biomass in sediments, as measured by acridine orange direct microscopic counts, increased only 30-fold during the 35 weeks of methane and air injection. These results suggested that the increase in biomass was limited by bioavailable nitrogen and/or phosphorus. This situation may have led to a transient, less stable microbial community that was subject to successional processes (i.e., one or more groups of organisms replace other groups of organisms). In an effort to increase the methanotrophic population and improve biodegradative performance, the oversight panel decided to add the gases nitrous oxide and triethyl phosphate to the site. Injection of the nutrients as gases served to maximize the travel distance of the nutrients and minimize the potential for plugging of the injection well by excessive microbial growth in two ways. First, injection of air and methane caused water saturation in the 130–140 ft bgs (initially saturated) sediments to drop 40–50% over the entire site, resulting in much higher diffusivities for any gaseous nutrient (diffusivities in a pure air phase are approximately 10 000 times greater than in a pure liquid phase) [6]. Secondly, nitrous oxide and triethyl phosphate are not readily assimilated by most microorganisms and must be transformed before they can be taken into the cell.

Delivery of nutrients as gases resulted in a zone of bioremediation influence that extended at least 60 ft above and to each side of the horizontal injection well. Prior to the injection of nitrogen and phosphorus, methanotroph MPN indexes were high in clusters 9 and 10, the locations with the least communication with the injection well (based on methanotroph populations and biodegradative potential, and TCE and methane present in ground water and soil gas [19–21]), and below detection in clusters 4 and 6, the locations in good communication with the injection well. The pattern of lowest methanotroph populations near the injection well is consistent with nitrogen and phosphorus limitation caused by injection of electron donor and electron acceptor, and replacement of the methanotrophs by other microorganisms. Indirect evidence that nitrous oxide and triethyl phosphate were delivered 60 ft above and to each side of the horizontal injection well was shown by the two order of magnitude increase in methanotrophic MPN indexes in clusters 4 and 6 and the one order of magnitude increase in cluster 9, and the much higher levels of TCE biodegradative potential at all sampled locations of the site. The addition of nitrogen and phosphorus in previous field bioremediation efforts had been unsuccessful [22, 23], probably because the nutrients (ammonia, nitrate, and trimetaphosphate) were delivered to the vadose zone by surface irrigation and did not reach the volume of sediment being remediated due to sorption to the solid phase and utilization by microorganisms near the surface.

After the addition of nitrogen and phosphorus to the site, increases in methanotrophic TCE biodegradative potential were greater than increases in methanotroph MPN indexes. This result may be, in part, because the addition of nitrogen and phosphorus to the site improved the physiological status of the methanotrophic population and/or caused changes in other portions of the community structure in situ, resulting in improved ability to degrade TCE in the subsequent enrichments.

Methanotroph MPN indexes are generally assumed to be an estimate of the numbers of culturable methanotrophs in sediments. Given that the methanotrophs were the population targeted for stimulation by addition of methane and air, the relatively low methanotroph MPN indexes (generally $<2400/g$) were surprising. Methanotroph MPN indexes in sediment samples were several orders of magnitude lower than in ground water samples [19–21]. A contributing factor may be that sampling of ground water favors recovery of water from high conductivity regions and preferential flow paths. Methane and oxygen availability to microorganisms is likely to be greater at these locations as compared to the average sediment sample. A second factor may be that sediment-associated methanotrophic microcolonies are not easily disrupted into individual cells or small groups of cells despite the rigorous treatment prior to carrying out dilutions in the MPN method. In support of this possibility, a nucleic acid probe specific for the soluble methane monooxygenase gene suggested that the MPN method underestimated methanotrophic biomass in sediment samples [24].

The absence of TCE biodegradative potential in 12 of the 15 samples prior to the addition of nitrogen and phosphorus to the site was not unexpected due to the low MPN indexes. However, three of the 15 samples had MPN indexes $>30/g$ (with one sample at $>2400/g$), yet TCE degradation was not observed with an inoculum equivalent to 100 mg of sediment. This result could be an artifact of sampling (i.e., due to spatial heterogeneity). It is also possible that methanotrophs unable to oxidize TCE were selected for at the site, because intermediates of TCE degradation inhibit cellular metabolism [25]. In sediment samples taken after the addition of nitrogen and phosphorus, the opposite situation was observed: 32 of the 37 samples showed TCE biodegradative potential in one or both of the media with an inoculum equivalent to 1 mg sediment, yet 23 of the samples had MPN indexes $<250/g$. This may result from the underestimation of methanotrophic biomass by the MPN method due to inability to disrupt sediment-associated microcolonies, or due to a growth habit in the enrichment that prevents the attainment of cell densities which are high enough to detect with the naked eye.

Bioremediation performance was also assessed by measuring TCE concentrations in soil gas, ground water, and sediment, and by numerical simulations that modeled the bioremediation process. Simulations were critical because contaminated water and air were constantly moving into the treatment zone due to vertical recharge (i.e., heavy precipitation events), horizontal recharge, induced water flow created by the injection process, and influx of air from the very large areal influence of the (vadose zone) extraction well. The simulations showed that the addition of nitrogen and phosphorus to the site resulted in a 5-fold lower residual level of TCE and a doubling of the TCE removal rate [6]. Thus, the higher culturable methanotroph populations and greater methanotrophic TCE biodegradative potential after, as compared to before, the methane–air–nitrogen–phosphorus injection were consistent with TCE inventories and the numerical simulations.

Considering the entire bioremediation demonstration (35 weeks of methane and air injection plus 13 week of methane–air–nitrogen–phosphorus injection), simulations showed that TCE removal was 41% higher than for air-stripping alone [6]. In addition, in situ bioremediation acheived a final TCE concentration 3–6 times lower than that acheived by in situ air-stripping alone. Bioreactor studies using Savannah River sediment, ground water, and groundwater flow rates estimated that an average of 1.5 mg TCE was biodegraded/m^3/d throughout the demonstration, a rate similar to that estimated by the simulations [26]. Sediment concentrations of TCE declined to below detection (<2 ppb) over most of the site [19]. Soil gas TCE declined by more than 99%, with samples from near the injection well consistently being below detection by the end of the methane–air–nitrogen–phosphorus injection. Ground water concentrations of TCE decreased by as much as 95%, reaching concentrations below detection in some ground water monitoring wells. Moreover, direct chemical evidence that losses were due to bioremediation was indicated by the inverse correlation between ground water chloride concentrations and TCE concentrations in most samples.

5. Conclusions

1. Methanotroph MPN indexes in sediment samples taken after the addition of nitrogen and phosphorus, as compared to before the addition, increased approximately one to three orders of magnitude.
2. The frequency of TCE biodegradative potential increased by approximately three orders of magnitude in response to the addition of nitrogen and phosphorus to the site.
3. Spatial analysis of the methanotroph MPN and TCE biodegradative potential results indicate that the delivery of methane, oxygen, nitrogen, and phosphorus as gases resulted in a zone of bioremediation influence that extended at least 60 ft above and to each side of the horizontal injection well.
4. The higher culturable methanotroph populations and greater methanotrophic TCE biodegradative potential after, as compared to before, the methane–air–nitrogen–phosphorus injection were consistent with TCE inventories and the results of numerical simulations.

Acknowledgements

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IN SITU METHANOTROPHIC BIOREMEDIATION USING HORIZONTAL WELL TECHNOLOGY

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ABSTRACT

The demonstration consisted of injection of methane mixed with air into the contaminated aquifer via a horizontal well and extraction from the vadose zone via a parallel horizontal well. This configuration has the advantage of simultaneously stimulating methanotrophic activity in both the groundwater and vadose zone, and inhibiting spread of the plume. Groundwater was monitored biweekly from 13 wells for a variety of chemical and microbiological parameters. Groundwater from wells in affected areas showed increases in methanotrophs of more than one order of magnitude every two weeks for several weeks after 1% methane in air injection was started. Some wells had increases as much as 7 orders of magnitude. Simultaneous with the increase in methanotrophs was a decrease in water and soil gas concentrations of trichloroethylene (TCE) and tetrachloroethylene (PCE). Two wells declined in TCE/PCE concentration in the water by more than 90% to below 2 ppb. All of the wells in the affected zone showed significant decreases in contaminants in less than 1 month. Chloride concentrations in the water were inversely correlated with TCE/PCE concentration. Four of

five vadose zone piezometers (each with three sampling depths) declined from concentrations as high as 10,000 ppm (vol/vol) to less than 5 ppm in less than six weeks. The fifth cluster also declined by more than 95%. After only 3 months of injection >30% decline in TCE/PCE in the sediment was also observed, with TCE/PCE being undetectable in most sediments at the end of the 14 month test. Gene probes and direct isolation form the water and sediment revealed that the right types of methanotrophs were being stimulated, ie. those producing soluble methane monooxygenase, and that isolates could degrade TCE at a high rate. A variety of other microbial parameters increased with methane injection indicating the extent and type of stimulation that had occurred.

In Situ Methanotrophic Bioremediation using Horizontal Well Technology

INTRODUCTION

The U.S. Department of Energy, Office of Technology Development, has been sponsoring full-scale environmental restoration technology demonstrations for the past three years. The Savannah River Site Integrated Demonstration focuses on the clean-up of soils and groundwater contaminated with chlorinated volatile organic compounds (VOCs). To optimize resources, the project is simultaneously evaluating and testing a large number of drilling, monitoring, characterization, and remediation technologies developed by SRS, other DOE sites, national labs, industry and universities. During fiscal year 1992 alone, more than 44 different technologies were tested at the site. The principal remediation technology being tested during 1992 was **in situ** bioremediation. **In situ** air stripping was the first remediation technology demonstrated at the test site during 1990 using parallel horizontal wells (one below the water table and one above). This first very successful demonstration provided the impetus and the characterization and monitoring data to serve as an excellent control for the **in situ** biostimulation demonstration. Several laboratories including our own had demonstrated the ability of methanotrophic bacteria to completely degrade or mineralize chlorinated solvents, and these bacteria were naturally found in soil and aquifer material (1, 2). Thus the test consisted of injection of methane mixed with air into the contaminated aquifer via a horizontal well and extraction from the vadose zone via a parallel horizontal well. This configuration has the advantage of simultaneously stimulating methanotrophic activity in both the groundwater and vadose zone, and inhibiting spread of the plume.

This project is designed to demonstrate **in situ** bioremediation of groundwater and sediment contaminated with chlorinated solvents. Indigenous microorganisms were stimulated to degrade TCE, PCE and their daughter products **in situ** by addition of nutrients to the contaminated zone. **In situ** biodegradation is a highly attractive technology for remediation because contaminants are destroyed, not simply moved to another location or immobilized, thus decreasing costs, risks, and time, while increasing efficiency and public and regulatory acceptability. Bioremediation has been found to be among the least costly technologies in applications where it will work (3).

Subsurface soils and water adjacent to an abandoned process sewer line at the SRS have been found to have elevated levels of TCE (4). This area of subsurface and groundwater contamination is the focus of a current integrated demonstration of new remediation technologies utilizing horizontal wells (Figure 1). Bioremediation has the potential to enhance the performance of **in situ** air stripping as well as offering stand-alone remediation of this and other contaminated sites (5). Horizontal wells could also be used to enhance the recovery of groundwater contaminants for bioreactor conversions from deep or inaccessible areas (e.g., under buildings) and to enhance the distribution of nutrient or microbe additions in an **in situ** bioremediation.

MATERIALS AND METHODS

The horizontal wells that form the basis for the SRS Integrated Demonstration are expected to provide significant advantages over conventional bioremediation nutrient delivery techniques. The increased surface area allows better delivery of nutrients and easier recovery of gas and water, as well as minimizing formation clogging and plugging phenomena. The principal nutrient to be supplied via the horizontal wells in this test was methane, at a low concentration in air (<4%). The lower horizontal well provides a very efficient delivery of gas throughout the contaminated region (Figure 2). A vacuum was applied to the upper well (vadose zone) to encourage air/methane movement through the upper saturated zone and lower vadose zone and inhibit spreading of the plume. Air/methane mixtures have been demonstrated to stimulate selected members of the indigenous microbial community that have the capability to degrade TCE (2, 6). An extensive characterization and monitoring program using existing monitoring wells and periodic borings for sediment was used to measure the response of the soil and water following injection of air/methane (7). In addition, offgas from the upper horizontal well was assayed for methane, total VOC, TCE, PCE, and potential break down products of TCE/PCE (e.g., DCE, VC, and carbon dioxide). For a complete listing of all analytical assays, protocols, permits, collaborators, expert panel, etc. see Hazen (8).

Initially 1% methane/air was injected continuously into the lower well; however, to ensure process optimization (i.e., to further stimulate the indigenous microorganisms to peak biodegradation rates and efficiencies), the injection protocol was altered for subsequent campaigns. At three-month intervals during the 14-month demonstration, the data from the current operating campaign and process support activities were examined by an expert panel and a decision was made as to how to alter the injection protocol for the subsequent campaign. Thus, the final test consisted of the following operating campaigns:

1. air extraction alone from the upper well at 240 scfm (2/26/92-3/18/92)
2. air only injection was added at 200 scfm (3/18/92-4/20/92)
3. injection with 1% methane/air (4/20/92-8/5/92)
4. injection with 4% methane/air (8/5/92-10/23/92)
5. pulsing 4% methane/air (10/23/92-1/25/93)
6. pulsing 4% methane and continuous injection of nitrous oxide at 0.07% in air and tri-ethyl phosphate at 0.007% in air (1/25/93-4/30/93)

RESULTS AND DISCUSSION

The flow and vacuum conditions of the extraction system have remained constant with a flow rate of 240 scfm and 7.6 in. Hg. VOCs in the offgas were composed entirely of TCE and PCE. Dissolved oxygen content in the water did not changed during this period. Overall VOC concentrations increased slightly during the first 5 days and then steadily declined. During the previous extraction demonstration with this same well the VOC concentration started 10 times higher and declined rapidly over the next 5 days. Since the previous test extraction rate was double the current rate, the current stabilized VOC concentration is about what would be expected at the end of the previous demonstration, taking into consideration the lower flow rate. Because the previous demonstration finished nearly 15 months ago, we believe this result indicates that the effect of this type of extraction is long term and that a permanent reduction has occurred in the amount VOCs in the vadose zone at the site. Comparison of VOCs in pretest and post-test borings support this observation since sediment concentrations decreased by more than 30%. Interim borings at four holes done at the end of the 1% methane injection also reveal a further 50% decline in the amount of VOCs in the sediment (Figure 3). Indeed, few of these samples had detectable levels remaining.

Air injection (200 scfm) seemed to have little effect on the extraction efficiency. One percent and 4% methane injection had little effect on extraction efficiency or offgas quality though overall there was a small but significant decline in VOC concentration over time for both operating campaigns. In addition, the ratio of TCE/PCE significantly and consistently declined over time. This observation is consistent with our knowledge that methanotrophs will degrade TCE but not PCE and that PCE is degraded at a slower rate by syntrophic anaerobes. However, pulsing of methane injection has caused a significant decrease in VOC concentration in the extraction well. When the methane was injected again for five days after air-alone injection, the VOC concentration increased but declined again as soon as this pulse was stopped. These observations coincide with our understanding of competitive inhibition (i.e., when the methane is withdrawn once high biomass is achieved, more contaminants are degraded since there is more available enzyme active sites). In addition, it appears that the long interval pulsing decreased methanotroph density - during the first six weeks of the pulsing campaign; during the subsequent six weeks, the short-interval pulsing increased methanotroph densities. Carbon dioxide concentrations from the extraction well suggest an upward trend beginning 2-3 weeks post air-injection startup; this may be indicative of increased microbial respiration in the subsurface caused by the air injection. There is also a striking positive correlation between VOC concentration in vadose zone soil gas and CO_2 concentrations. After VOCs disappeared, the CO_2 concentration subsequently declined. When new VOCs move into the area, the CO_2 concentrations subsequently increase until after the VOCs have declined again. Since pulsing began vadose zone concentrations declined significantly and then increased in some wells. Since nitrogen and phosphorus (N&P) injection began, the concentration of VOC in all vadose zone wells has declined dramatically, more than 90%. This again supports the theory of competitive inhibition and nutrient limitations discussed above. More than 108,206,345 scf of air were injected during this test. As expected, even though more than 1,392,774 scf of methane were injected into the subsurface during 53 weeks, only trace quantities of methane were detected in the extraction wells or any of the vadose zone piezometers during the 1% methane injection campaign (i.e., most if not all of the methane injected was consumed by the subsurface TCE-degrading microflora). Simultaneous injection of helium as a conservative tracer has shown that more than 50% of the injected methane is being consumed.

Monitoring of the groundwater has shown that methanotrophs increased at the rate of one order of magnitude every two weeks since methane injection (1%) began (Figure 4). However, increases substantially slowed and began declining slightly. This change coincides with reduction in nitrates in the water of these same wells. Several other measures of microbial activity and abundance have also increased dramatically concomitantly with the start of methane injection and have shown a similar response to nitrates. After 4% methane injection was started (8/5/92), methanotroph densities continued to increase. The wells showing the greatest decrease in TCE/PCE concentrations have experienced as much as a five order-of-magnitude increase in methanotrophs. These same wells have also shown increased concentrations of chloride in the water, an aerobic biodegradation end product for TCE. Stimulation of biodegradation activity by the indigenous microflora appears to have been great during the initial phase of the 1% methane injection. After two months of the 4% methane/air campaign, it appeared that the methanotroph population was further stimulated but that nitrogen-fixing bacteria may have been inhibited causing severe nitrogen limitations. However, the outer wells started showing significant densities of methanotrophs and for the first time the concentrations of TCE/PCE either remained the same or declined slightly. Prior to this they had been slowly increasing. The 4% methane injection may have been inhibitory to nitrogen-transforming bacteria; therefore, we began the pulsing campaign, which initially consisted of air injection alone for 5-14 days, followed by injection of 1% methane for 4-5 days. It was believed this would reduce competitive inhibition of the methane and TCE for the same enzyme and reduce the inhibition of nitrogen fixers shown to be stimulated by air injection alone. Pulsing caused a significant increase in nitrogen-transforming bacteria, a decrease in TCE in the well water and vadose zone (Figure 5), and a decrease in methanotroph densities. On December 11, 1992, we started a short pulse interval of 8 h of 4% methane every other day. The final campaign (1/25/93) included pulsed injection of methane and continuous injection of nitrous oxide at 0.07% in air and tri-ethyl phosphate at 0.007% in air. This decision was based on enrichment and mineralization studies. It was felt that this last injection would overcome both N&P limitations and allow higher biomass and higher degradation rates of TCE to be achieved by the methane-stimulated subsurface bacteria. For a partial discussion of nucleic acid probe studies conducted during this demonstration see Bowman et al. (9). Since injection of N&P started, and with only limited analyses complete, we can report that densities in the water have gone up, and TCE concentration in the vadose zone and water has declined.

The test has demonstrated that gaseous nutrient injection stimulates indigenous soil bacteria to degrade TCE and PCE without risk of formation plugging or fouling.

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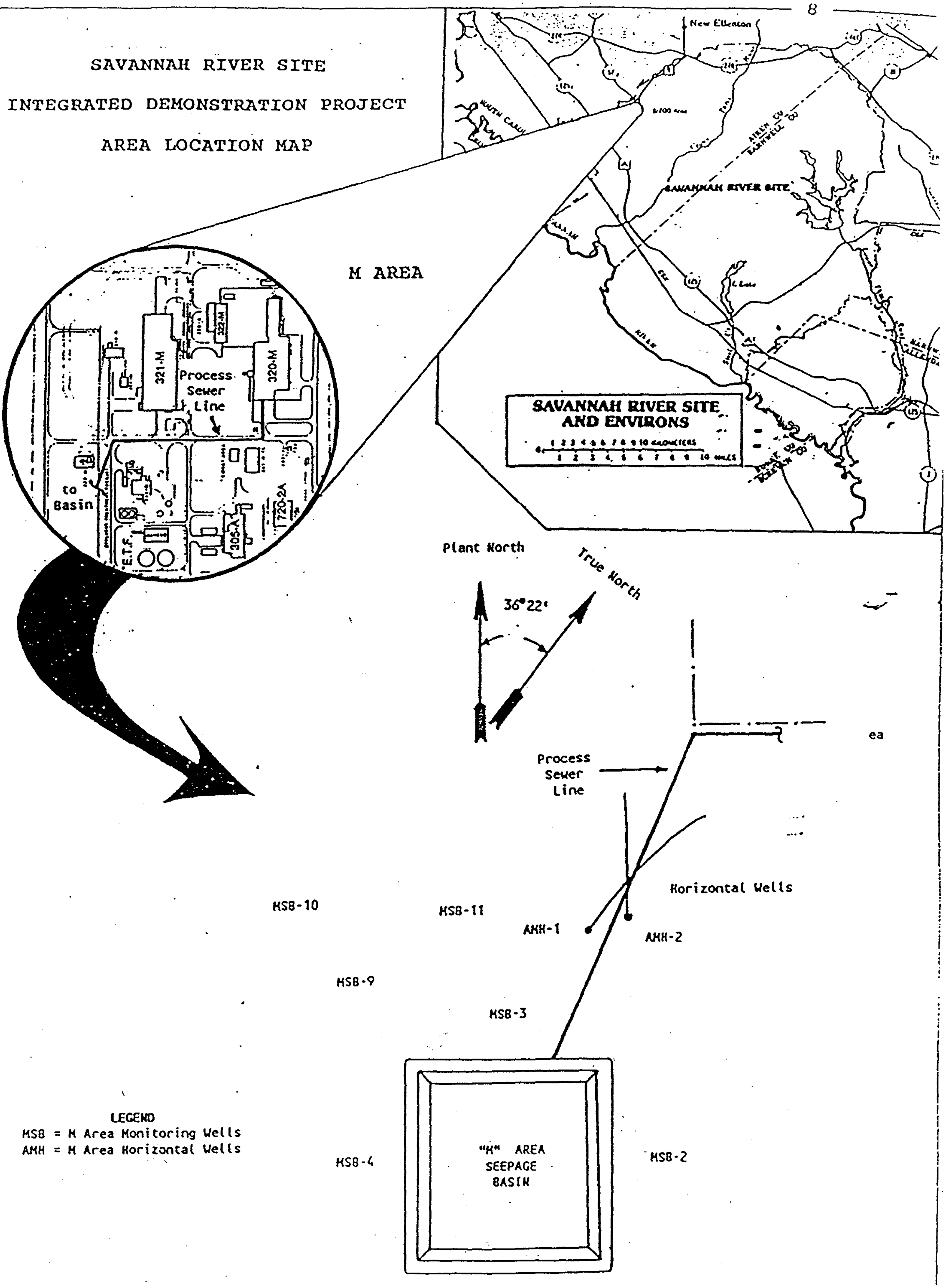
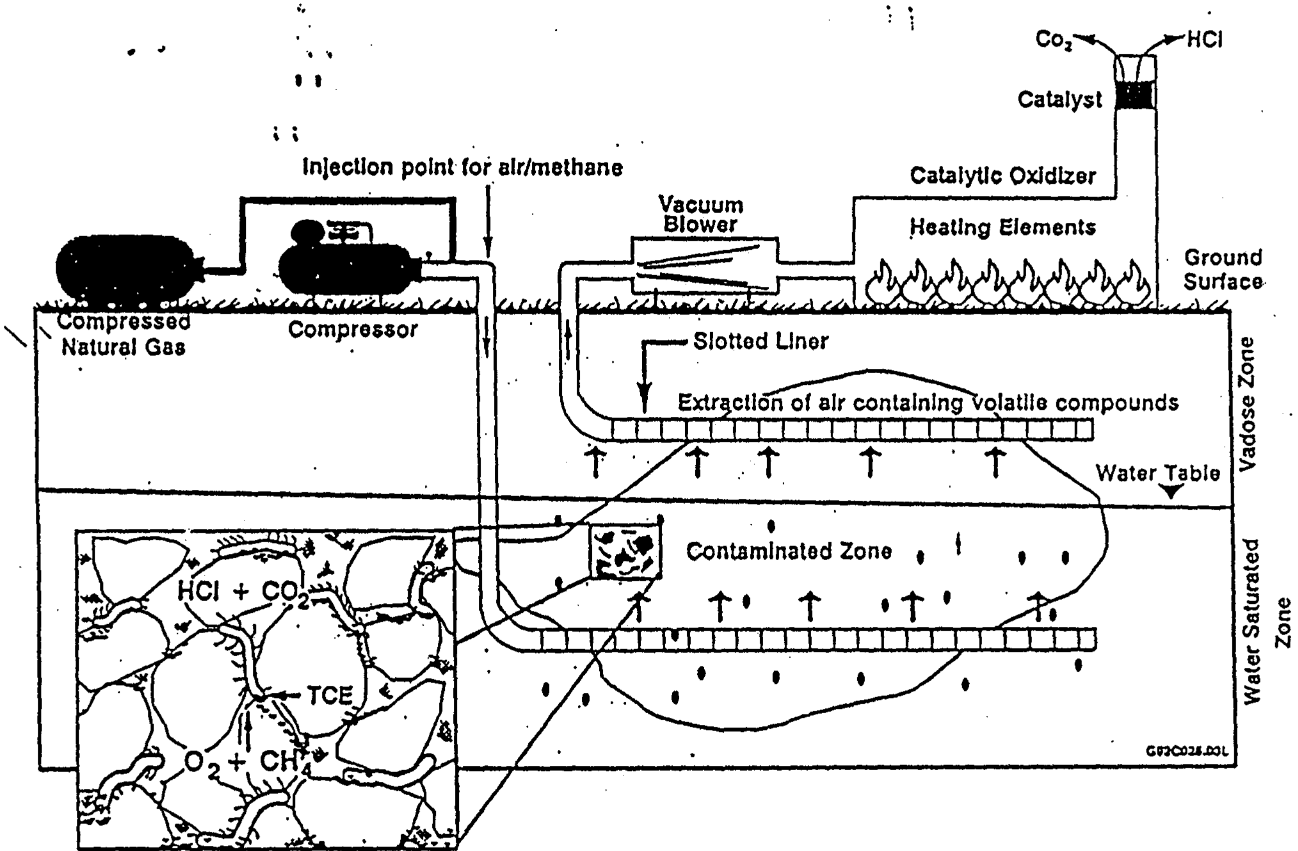
FIGURE LEGENDS

Figure 1. Map of M-area site.
Figure 2. Schematic of horizontal wells and process configuration.
Figure 3. Concentrations of Trichloroethylene in the sediment profile before and after 3 months of methane injection at Cluster 10.
Figure 4. Densities of Methanotrophs vs. Concentrations of Trichloroethylene over time in well MHT-2C.
Figure 5. Concentration of Total VOC (TCE/PCE) in the soil gas at three depths (A=100 ft, B=75 ft, C=40 ft) over time in vadose zone piezometer MHV5.

SAVANNAH RIVER SITE
INTEGRATED DEMONSTRATION PROJECT
AREA LOCATION MAP





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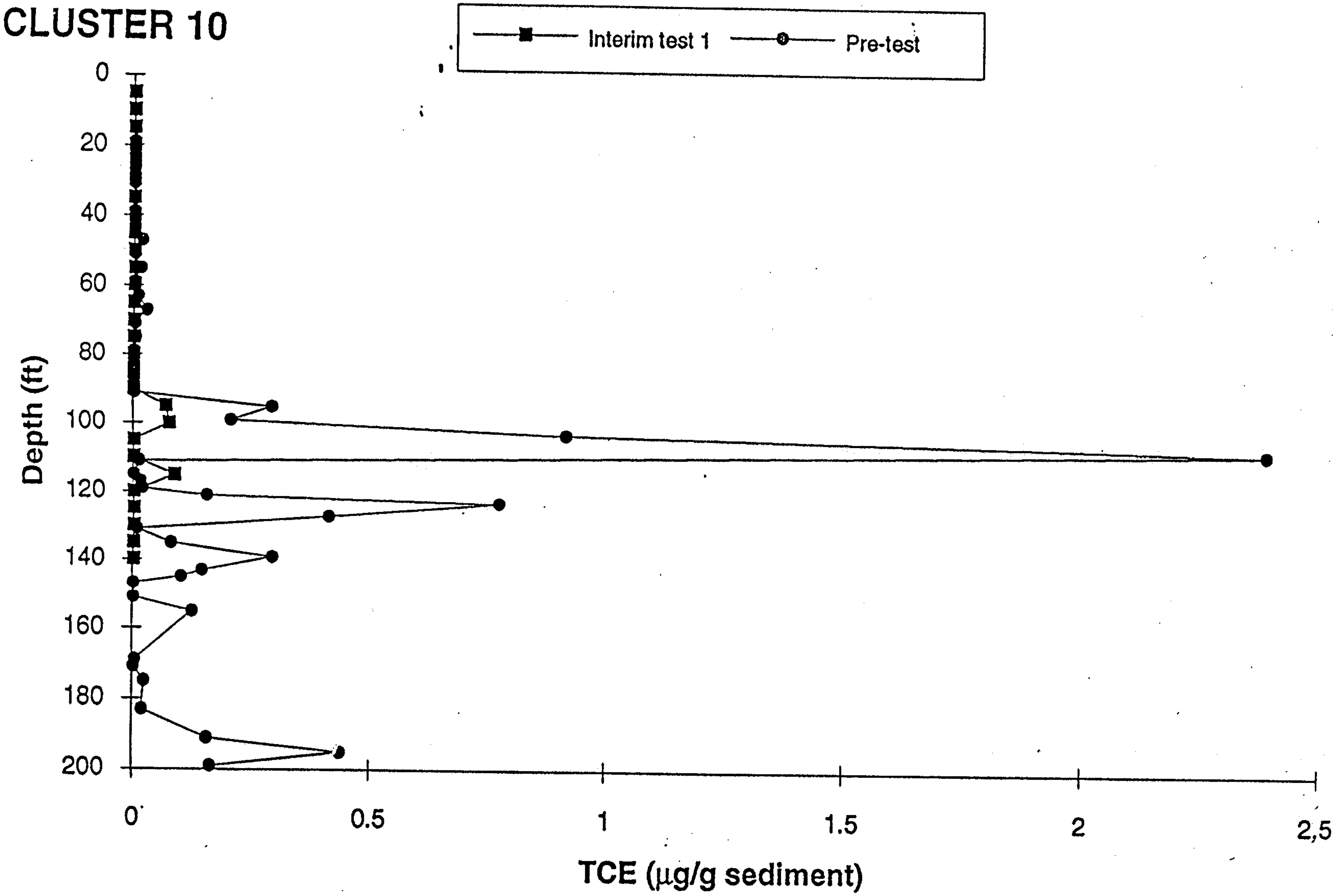
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Pre-test
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20
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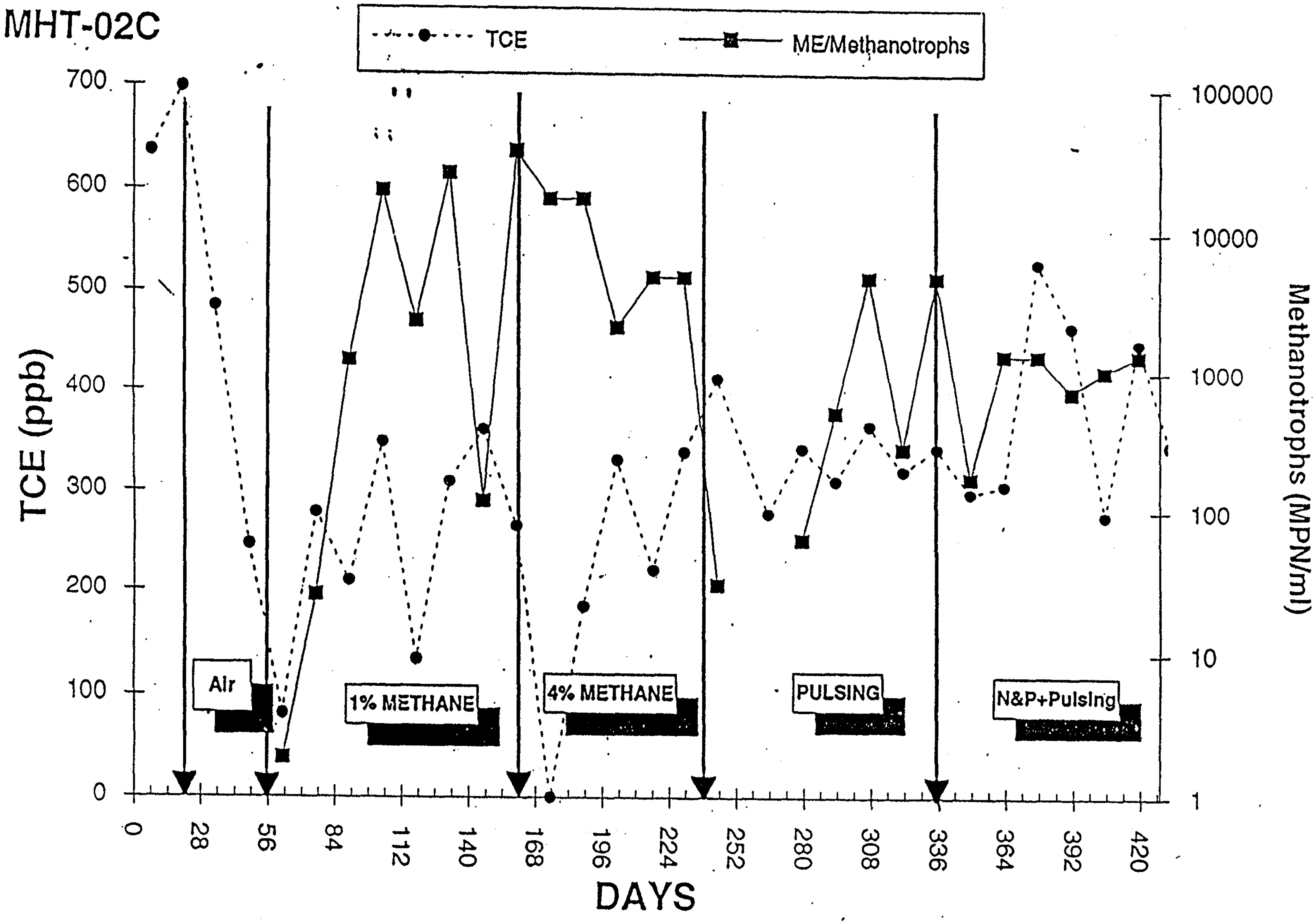
80
100
120
140
160
180
200
0
0.5
1
1.5
2
2,5
TCE (µg/g sediment)


MHT-02C
TCE
ME/Methanotrophs
TCE (ppb)
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600
500
400
300
200
100
0
Methanotrophs (MPN/ml)
100000
10000
1000
100
10
1
Air
1% METHANE
4% METHANE
PULSING
N&P+Pulsing
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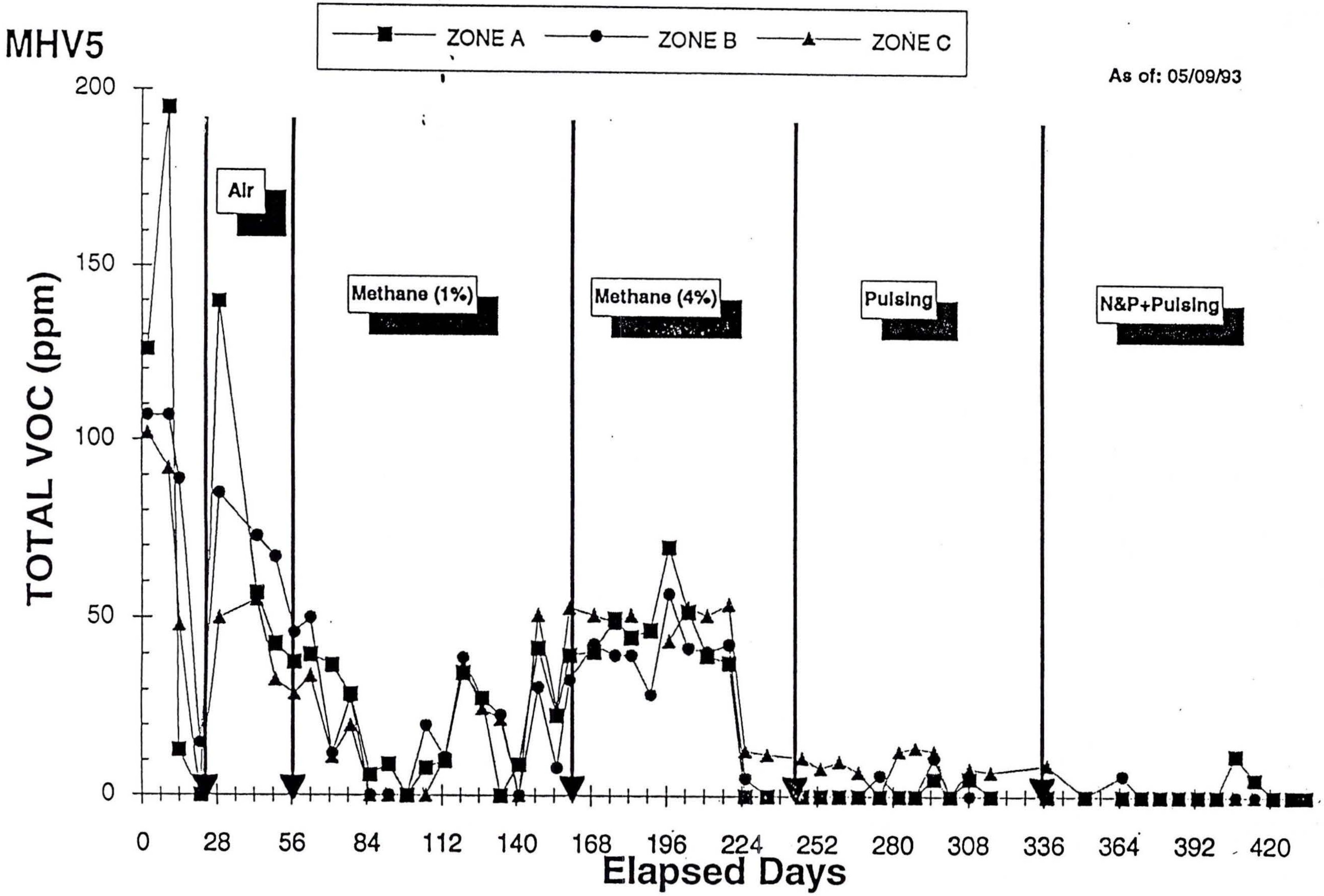
MHV5
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ZONE B
ZONE C
As of: 05/09/93
TOTAL VOC (ppm)
200
150
100
50
0
Air
Methane (1%)
Methane (4%)
Pulsing
N&P+Pulsing
0
28
56
84
112
140
168
196
224
252
280
308
336
364
392
420
Elapsed Days

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Secretary

August 8, 1997

Mr. Vaughn Adams
Freeman & Vaughn Engineering, Inc.
P.O. Box 767601
Roswell, Georgia 30076

Re: PHOSter Nutrient Injection System

Dear Mr. Adams:

The Bureau of Petroleum Storage Systems thanks you and Ms. Regina Porter for the May 29, 1997 briefing about the PHOSter vapor-phase nutrient injection system, for in situ bioremediation of petroleum hydrocarbons in soil and groundwater by indigenous microorganisms. It is our understanding that this system was developed by the U.S. Department of Energy and the Savannah River Technology Center, and that the technology is being transferred through a cooperative agreement with the Southeastern Technology Center and commercialized by Freeman & Vaughn Engineering.

The process is a pulsed injection system that stimulates the growth of indigenous petrophilic microorganisms by supplying an optimum quantity and ratio of oxygen, nitrogen, and phosphorus. Briefly, compressed air (the oxygen source) is contacted with liquid triethylphosphate (TEP) (the phosphate source) in a vessel, and emerges as air laden with triethylphosphate. This TEP-laden air is mixed with nitrous oxide (the nitrogen source) and the entire air-TEP-nitrous oxide mixture is then forced into the soil or groundwater to be remediated via injection wells, each of which has a timer to control its pulsed injection cycle. Indigenous microorganisms utilize the injected nutrients to aerobically degrade petroleum contamination, producing biomass, carbon dioxide, and water. A schematic of the system is enclosed.

The Bureau recognizes the PHOSter system as a viable technology for the remediation of petroleum contaminated sites in Florida, pursuant to Chapter 62-770, Florida Administrative Code (F.A.C.). There are no objections to its use, provided: (a) the considerations of this letter are taken into account; (b) a Remedial Action Plan is approved by the Department for each site prior to the commencement of work; and (c) appropriate and applicable underground injection control rules are observed. For your information, the following Florida Administrative Code chapters are cited as pertinent, as portions of them may be applicable: Chapter 62-550, F.A.C., for primary and secondary water quality standards; Chapter 62-520, F.A.C for groundwater classes and standards; Chapter 62-522, F.A.C., for groundwater permitting and monitoring requirements; and Chapter 62-528, F.A.C., for underground injection control, particularly Part V, for Class V, Group 4 aquifer remediation projects.

Even though Chapter 62-528, F.A.C., is a comprehensive document pertaining to underground injection, it could not have anticipated technological advances creating the need to regulate vapor-phase injection concentrations for the purpose of aquifer remediation, just those of a liquid. And Chapter 62-550, F.A.C., whose primary and secondary drinking water standards are cited as criteria for the underground injection of fluids, pertains only to liquid-phase concentrations as well. The Department, in response to this situation, instead of using a front-end approach to protecting groundwater quality by ensuring that injected liquids meet drinking water standards, will seek assurance, through monitoring, that no primary or secondary water quality standards or background values are exceeded. The onus shall therefore be on users of the PHOSter system to ensure that all applicable groundwater contaminant standards will be met at the time of project completion for any residuals associated with the injected substances, any byproducts produced as a result of the chemical transformation of those substances or the petroleum, and the remaining traces of the original petroleum contaminants.

While the Department of Environmental Protection does not provide endorsement of specific or brand name remediation products or processes, it does recognize the need to determine their acceptability from an environmental standpoint with respect to applicable rules and regulations, and the interests of public health, safety, and welfare. Vendor's must then market the products and processes on their own merits regarding performance, cost, and safety in comparison to competing alternatives in the marketplace. For the PHOSter system, the major environmental and regulatory items of interest are below.

a. Background samples: Prior to commencement of remediation, at least one (1) monitoring well located outside the petroleum contamination plume shall be sampled and analyzed for background concentration of nitrates, nitrites, and phosphorus.

If only one well is sampled, then it should be upgradient, pursuant to Rule 62-520.420(3), F.A.C. If more than one well is sampled, then the average value of each parameter can be used as the background value for the site. As a matter of good practice, but not as a regulatory requirement, it may be beneficial to obtain background values of dissolved oxygen, pH, temperature, total dissolved solids, hydraulic conductivity, moisture content of soil (if soil is to be remediated) and other pertinent bioremediation parameters or micronutrients of interest.

b. Groundwater monitoring: During active remediation, the appropriate petroleum contaminants of concern shall be sampled in accordance with the frequency specified in Rule 62-770.700(3)(i), F.A.C. For the cleanup of sites where the period of active remediation is expected to be brief (60 to 90 days for example) it may be necessary to conduct sampling more frequently than quarterly, in order to accurately gauge the progress of the cleanup.

Like any other petroleum site remediation project, PHOSter system projects shall include at least one (1) year of quarterly post remediation groundwater monitoring for the petroleum contaminants of concern, at a minimum of two (2) wells, one located in the area of maximum contamination, the other downgradient, pursuant to Section 62-770.750, F.A.C.

For underground injection control, during both the active and post remediation periods, the Department has determined that the frequency and parameters of groundwater monitoring, for tracking PHOSter system byproducts, shall be at least quarterly, for nitrates, nitrites, and total phosphorus. The sampling shall be conducted at a minimum of two (2) wells, one located in the central region of the PHOSter injection points, the other downgradient. For a given remediation site, costs may be kept to a minimum by installing two monitoring wells in locations such that they may serve as both the petroleum remediation tracking wells, pursuant to Section 62-770.750, F.A.C., and the PHOSter parameters tracking wells, pursuant to Rule 62-528.615(2), F.A.C. The PHOSter system parameters to be sampled for comparison to drinking water standards listed in Chapter 62-550, F.A.C., (or a site's background concentrations) are as follows: nitrate [10,000 micrograms per liter (ug/L) maximum, as nitrogen, N], nitrite (1,000 ug/L maximum, as N), and total phosphorus [groundwater concentration not regulated, (as P)].

The selection of nitrate, nitrite, and phosphorus for underground injection monitoring purposes is a technical decision to track the fate of nitrogen and phosphorus atoms contained in the originally injected nitrous oxide and triethylphosphate, neither of which is a regulated primary or secondary drinking water contaminant. In the event that chemical or biochemical processes transform the nitrogen to nitrate and/or nitrite, in concentrations which exceed primary drinking water standards, then monitoring will detect the problem.

Phosphorus tracking does not allow for a comparison to groundwater or primary or secondary drinking water standards, since phosphorus compounds in groundwater are not regulated. Attention usually focuses on the eutrophication of surface waters. So, in cases where a PHOSter groundwater remediation project may impact surface water, it is advised that the concentration of phosphorus in the surface water not be raised above the 0.1 microgram per liter (ug/L), as P, concentration set forth in Rule 62-302.530(54), F.A.C., for surface water quality standards.

For oxygen injected by the PHOSter system in the form of compressed air, the Department determines that tracking shall not be mandatory for injection control purposes, since the presence of dissolved oxygen in a groundwater is generally not considered to be a problem. It is, however, recommended that dissolved oxygen concentration be measured as a matter of good bioremediation practice.

c. UIC Inventory: PHOSter system Remedial Action Plans shall include information pursuant to Rule 62-528.630(2)(c)1 through 6, F.A.C., for the inventory purposes of underground injection control. Per Rule 62-528.630(2)(c), F.A.C., aquifer remediation projects involving injection wells are authorized under the provisions of a Remedial Action Plan, provided the construction, operation, and monitoring requirements of Chapter 62-528, F.A.C., are met. A memorandum outlining the information to be transferred from the Bureau of Petroleum Storage Systems to the Underground Injection Control Section within the Department is enclosed.

d. Operation:

1. Avoidance of migration: Injection of nutrients shall be performed in such a way, and at such a rate and volume, that no undesirable migration of either nutrients or petroleum contaminants in the aquifer results, pursuant to Rule 62-528.630(3), F.A.C. Placing injection points around the perimeter of the contamination plume may be one way of preventing migration, since groundwater flowing out of the plume area will be treated as it passes through those points.

2. Operating permit: Although an operating permit is not required for aquifer remediation wells pursuant to Rule 62-528.640(1)(b), and 62-528.640(1)(c), F.A.C., since no movement of the petroleum contamination plume is expected to accompany the PHOSter treatment process, the Department requests that the information items listed in Rule 62-528.640(1)(b), F.A.C., be considered and included in Remedial Action Plan proposals as a matter of good and thorough design practice. Briefly summarized, they are: quality of water in the aquifer; quality of the injected fluid; existing and potential uses of the affected aquifer; and well construction details. Additionally, each Remedial Action Plan should include an estimate of the total mass of nutrients to be injected over the life of the project, with a breakdown showing at least the number of pounds of nitrous oxide (on a pure basis) and the number of pounds of triethylphosphate (on a pure basis).

e. Abandonment: Upon issuance of a petroleum Site Rehabilitation Completion Order, or a declaration of "No Further Action", PHOSter system injection wells shall be abandoned pursuant to Section 62-528.645, F.A.C. The Underground Injection Control Section of the Department shall be notified so that the injection wells can be removed from the inventory tracking list.

Preparers of Remedial Action Plans for state-funded cleanups may wish to include a copy of this letter in the appendix of plans they submit, and call attention to it in the text of their document. In this way, technical reviewers throughout the state and its contracted local reviewing programs will be informed that you have contacted the Department of Environmental Protection to inquire about the environmental acceptability of this process. To aid those reviewers, the Bureau of Petroleum Storage Systems lists some items below.

a. Nutrient ratio: **The 20:12:1 molar ratio of oxygen, nitrogen, and phosphorus is the cornerstone of the PHOSter technology. The objective is to encourage microorganism growth by supplying these essential nutrients in a ratio that closely approximates their molar ratios in a standard cell of composition $C_{60}H_{87}O_{23}N_{12}P$.** The general equations describing the biological oxidation process for a hydrocarbon, and an example of an approximately balanced equation for the oxidation of ethylbenzene (C_8H_{10}), using nitrous oxide (N_2O) as the nitrogen source and triethylphosphate [$(C_2H_5O)_3PO$] as the phosphorus source are:

HYDROCARBON + OXYGEN + NITROGEN + PHOSPHORUS --> CELL MASS + CARBON DIOXIDE + WATER

$$C_8H_{10} + 2.857O_2 + 0.857N_2O + 0.143\ (C_2H_5O)_3PO \dashrightarrow 0.143\ C_{60}H_{87}O_{23}N_{12}P + 0.286CO_2 + 2.43\ H_2O$$

It should be noted that not all of the carbon in the ethylbenzene is converted directly to carbon dioxide, and that a large portion is assimilated as cell mass, which will, in turn, degrade when the microorganisms die.

b. Mass ratios: If the molar ratios of the equation in the preceding paragraph are converted to mass ratios, then for every pound of C_8H_{10} contaminant degraded it can be seen that 0.862 pounds of O_2, 0.356 pounds of N_2O, and 0.232 pounds of $(C_2H_5O)_3PO$ must be injected via the PHOSter system. Since ethylbenzene is one of the heaviest molecules in the BTEX group (benzene, toluene, ethylbenzene, and xylene), thereby requiring the largest injection quantities of N_2O, O_2, and $(C_2H_5O)_3PO$ for degradation, it may be reasonable to use the above mass ratios to make a quick and conservatively high estimate of the injection amounts needed to remediate a BTEX mixture of any proportions at any site.

c. Nitrogen source: Bottled nitrous oxide is used as the nitrogen source because it readily dissolves in water: 1.0 liter of it dissolves in 1.5 liters of water at 20 degrees Centigrade and 2 atmospheres. Atmospheric nitrogen (N_2), which enters the system by way of the air compressor, is not believed to play a substantial role in the PHOSter process, as not all microorganisms are capable of directly utilizing the diatomic molecule.

d. Cleanup time: 3 to 6 months, or less, depending on site conditions and the nature of contaminants.

e. Free product: The PHOSter system may be able to handle a small amount of free product if it is 1/8-inch or less in thickness.

f. Installation: trailer-mounted.

g. Design and operating parameters: Remedial Action Plans prescribing the PHOSter system should include all pertinent design and operating parameters, including but not necessarily limited to: radius of influence; number of injection cycles per day; number of injection wells; location of injection wells; injection gas flow rates; the mass of petroleum contaminants to be remediated; the mass of nutrients to be injected over the life of the project; injection pressure; well construction details; a sampling plan, including a pre-remediation background sampling for nitrates, nitrites, and phosphorus; and the estimated cleanup time.

h. Pulsing: Injection of vapor-phase nutrients is pulsed on a timed cycle to keep microorganisms fed at an optimum rate. Too little nutrient addition causes them to die, while too much will be wasteful. For the petroleum test sites in Georgia and South Carolina, the vapor-phase nutrient injection portion of the cycle was 3 hours, followed by nutrient utilization of at least 3 hours. **The strategy of the PHOSter system is to inject vapor-phase nutrients in small enough timed intervals and quantities to keep the microorganisms fed at an**

optimum rate. Therefore, very little injected material is wasted, and the risk of overdosing is minimal, which in turn minimizes the risk of injecting unnecessary and excessive quantities of nitrogen and phosphorus into the aquifer.

i. Test sites: The PHOSter system has been used at petroleum test sites in Georgia, South Carolina, and Panama City, Florida. Baseline total phosphate at the Panama City site was measured at 800 and 1,100 ug/L in the upgradient and downgradient monitoring wells, respectively.

j. Equipment: A refrigerated compressed air dryer is used to cool and dry the compressed air, and a filter is used to remove oil prior to injection.

k. Triethylphosphate: This compound is also known as triethyl ester phosphoric acid. Its vapor pressure is 1 millimeter of mercury (mm Hg) at 39°C. It has been indicated to the Department that microorganisms utilize the phosphorus component of this molecule as a nutrient, and consume the ethyl groups as a food source.

l. Phosphorus: There are no groundwater or primary or secondary drinking water standards for phosphorus. For reference purposes only, it may be helpful to know that the European Economic Community guide level is 400 micrograms per liter (ug/L), as P_2O_5, for drinking water, and that a recent surficial aquifer sample at a petroleum remediation site in Volusia County contained 1,200 ug/L of naturally occurring phosphorus, as PO_4. This concentration may not be unusual for Florida.

m. Advantage of vapor-phase injection: **It is believed that quicker and more thorough dispersal of nutrients can occur if they are injected in the vapor-phase, rather than as liquids or solids, especially at sites where permeability of the soil is low**. For a petroleum test site in Aiken, South Carolina, where significant contaminant reductions were obtained in 131 days, the soil permeability was relatively low: 10^{-8} cm^2.

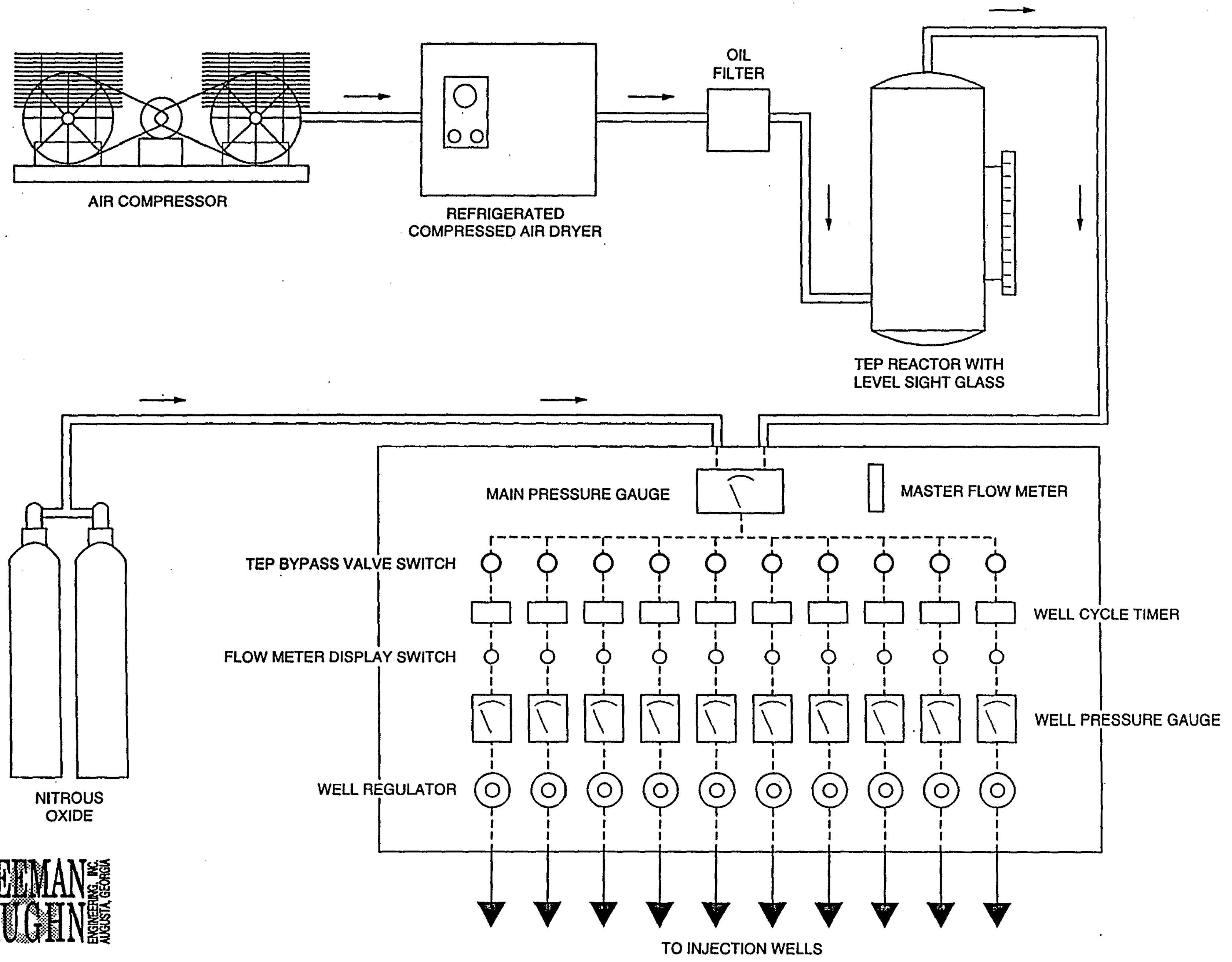
n. Radius of influence: A pilot test to determine a site specific radius of influence, for design purposes, may be necessary. Such a test could be more of a quick and inexpensive pressure sensing at various distances from an air injection point, and not an expensive in depth study involving all aspects of bioremediation. Also, the Department should not object to the bypassing of a radius of influence pilot test if the preparer of a Remedial Action Plan believes he or she has enough experience and data on hand for geologically similar sites in Florida. The radii of influence for petroleum test sites in Aiken, South Carolina and Augusta, Georgia were 5 and 15 feet, respectively. The delivery system producing those radii for those sites operated at 4 standard cubic feet per minute (scfm) and 30 pounds per square inch (psi) in Aiken and 1 scfm and 10 psi in Augusta.

o. Dedication of monitoring wells: Nutrients should not be injected into monitoring wells which are intended to track the progress of remediation at a site, since a premature and false indication of complete remediation may result when those wells are sampled. However, if there is an abundance of monitoring wells at a site, and not all of them are needed for tracking the progress of remediation, then some of the spare monitoring wells can be used as injection points.

p. Air emissions: No air emissions monitoring is necessary for the PHOSter system since injection gas flow rates will not be high enough to volatilize appreciable amounts of petroleum.

q. Underground Injection Control notification: Reviewers of PHOSter system Remedial Action Plans, regardless of whether in Tallahassee, district offices, or local programs, must fill in the blanks on the enclosed memorandum, whose subject is "Proposed Injection Well(s) for In Situ Aquifer Remediation at a Petroleum Remedial Action Site". The completed form must be submitted to the Underground Injection Control Section at 2600 Blair Stone Road, Tallahassee, Florida 32399-2400. It will be necessary to modify appropriate portions of the memorandum to report PHOSter system vapor-phase injections in terms of pounds of gas, purity of gas, and cubic feet per minute, instead of the units

PHOSter™ Concept Flow Diagram



FREEMAN VAUGHN ENGINEERING, INC. AUGUSTA, GEORGIA listed, which were intended to cover only liquid-phase injections.

The Department reserves the right to revoke its acceptance of a product or process if the nature or composition of either or any of its principal and proprietary ingredients, or the performance of the process, has been falsely represented. Additionally, Department acceptance of any product or process does not imply it has been deemed applicable for all cleanup situations, or that it is preferred over other treatment or cleanup techniques in any particular case. A site specific evaluation of applicability and cost-effectiveness must be considered for any product or process, whether conventional or innovative, and adequate site specific design details must be provided in Remedial Action Plans prescribing the product or process. You may contact me at 850/487-3299 if there are any questions.

Sincerely,

Rick Ruscito

Rick Ruscito, P.E.
Bureau of Petroleum Storage Systems

RR/rr

cc: Regina Porter - Southeastern Technology Center
501 Greene Street
Augusta, Georgia 30903

T. Conrardy - FDEP/Tallahassee

W. Evans - FDEP/Tallahassee

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A site map showing the areal extent of the groundwater contamination plume and the location and spacing of injection wells is attached.

Excerpts from the remedial action plan which describe the site lithology are attached. The following is a summary description of the affected aquifer:

Name of aquifer:______________________________
Depth to groundwater (feet):___________________
Aquifer thickness (feet):______________________

A schematic of the injection well(s) is attached. The following is a summary:

Depth of well (feet):_________________________
Screened interval:_____ to ______ feet below surface
Well casing diameter (inches):________________
Bore hole diameter:___________________________
If direct-push type well(s), describe
diameter (inches):________ and depth (feet):_______

The in situ injection-type aquifer remediation plan for this petroleum contaminated site is a design intended to meet the groundwater petroleum cleanup criteria set forth in Chapter 62-770, F.A.C. Additionally, all other groundwater standards will be met at the time of project completion for any residuals associated with the ingredients of the injected remediation products, and any byproducts or intermediates produced as a result of the chemical or biochemical transformation of those ingredients or the contaminating petroleum during their use. Applicable primary and secondary drinking water standards are set forth in Chapter 62-550, F.A.C., and additional groudwater quality criteria are set forth in Chapter 62-520, F.A.C.

The remedial action plan estimates that the site remediation will take _________ months. We will notify you if there are any modifications to the remediation strategy which will affect the injection well design or the chemical composition and volume of the injected remediation product(s).

The proposed remediation system was approved on ___________ by a Remedial Action Plan Approval Order signed by the Director of the Division of Waste Management (copy attached). The remediation system installation is expected to commence within 60 days. Please call me at ___________ if you require any additional information.

Memorandum

Florida Department of
Environmental Protection

TO: Richard Deuerling
Division of Water Facilities
Bureau of Resource Protection
Underground Injection Control Section

FROM: ______________________
______________________ (local program)
____

DATE: ______________________

SUBJ **Proposed Injection Well(s) for In Situ Aquifer Remediation at a Petroleum Remedial Action Site**

This is to notify you of proposed injection well(s) construction for the in situ remediation of groundwater at a petroleum contaminated site. The following is a description of the site location.

Name: ______________________
Address: ______________________
City/County: ______________________
Latitude/Longitude: ______________________
FDEP Facility Number: ______________________

The design of the injection-type aquifer remediation system consists of the following:

Areal extent of contamination (square feet): _____
Number of injection wells: ______________________
Composition of injected fluid (See notes 1 &2)
(ingredient, wt. %): ______________________
____
____
____
____
Injection volume per well (gallons): ____________
Single or multiple injection events: ____________
Injection volume total (all wells, all
events): ______________________

Note 1. Proprietary formulations must at least disclose principal ingredients; their concentrations are optional. Chapter 62-528, Florida Administrative Code, requires that injected fluids meet primary and secondary water standards, unless a waiver is obtained.

Note 2. Prior acceptance by the Department of product(s) to be injected must be obtained.

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Reductive Dechlorination of Trichloroethylene and Tetrachloroethylene under Aerobic Conditions in a Sediment Column

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Biodegradation of trichloroethylene and tetrachloroethylene under aerobic conditions was studied in a sediment column. Cumulative mass balances indicated 87 and 90% removal for trichloroethylene and tetrachloroethylene, respectively. These studies suggest the potential for simultaneous aerobic and anaerobic biotransformation processes under bulk aerobic conditions.

Biodegradation of trichloroethylene (TCE) and tetrachloroethylene (PCE) has been demonstrated in pure cultures (11, 12, 16, 22, 25, 27, 28), mixed cultures (1, 2, 3, 14, 15, 17), microcosms (18, 21), and soil columns (29, 30). Field demonstrations of in situ bioremediation of chlorinated solvents have included biostimulation of indigenous methane-oxidizing bacteria (methanotrophs) (24) and bioaugmentation with a metabolic, nutrient inducer (23). Both demonstrations were aerobic systems and focused on biodegradation of vinyl chloride (VC), dichloroethylene (DCE), and TCE.

Aerobic stimulation of methanotrophs may encourage the in situ cometabolic biodegradation of TCE but not PCE. Although TCE is degraded under both aerobic and anaerobic conditions (3, 15, 17), PCE transformation has been demonstrated only under anaerobic conditions (3, 12, 17). Laboratory studies have shown that anaerobic dechlorination of chlorinated ethylenes can proceed to nontoxic, biodegradable products such as ethylene and ethane (7, 8, 17); however, there is the tendency for significant amounts of VC and *cis*-1,2-dichloroethylene (cDCE) to accumulate under anaerobic conditions (5, 26). Although stimulation of reductive dechlorination of PCE and TCE may be a viable alternative at sites where aquifers are already anaerobic, it may be unacceptable to create anaerobic conditions in an aerobic aquifer. It would be desirable, therefore, if both (i) anaerobic PCE or TCE dechlorination and (ii) aerobic TCE, DCE, and VC degradation could occur in sediments maintained under "bulk" aerobic conditions. Phelps et al. demonstrated that this phenomenon does occur in methanotrophic expanded-bed bioreactors (23a). Anaerobic dechlorination of PCE or TCE would produce products, e.g., VC or cDCE, more amenable to subsequent aerobic transformation.

In collaboration with the U.S. Department of Energy (DOE) Office of Technology Development Integrated Technology Demonstration at the Savannah River Site for the in situ bioremediation of chlorinated solvents (19), a sediment column study was conducted to investigate the biodegradation potentials of TCE and PCE during aerobic methanotrophic biostimulation.

Soil column design and operation. A 122-cm sediment column was assembled with composite sediments from three sediment horizons collected during site characterization at the Savannah River Site. Composite A consisted of sediments from the saturated zone at depths of 53.3 to 59.4 m. Composites B and C consisted of sediments from the unsaturated zone at depths of 22.9 to 30.5 and 9.1 to 13.7 m, respectively. Table 1 lists composite sediment characteristics. The column was separated into three sections corresponding to composite types A to C (Fig. 1). Ports for obtaining liquid samples were placed in each section and in influent and effluent lines. Eight side ports were installed in each section for sediment sampling. Sediment samples were taken with a sterile 10-ml syringe barrel and replaced by extruding similar composite sediments from a 10-ml syringe back into the side port. A 5-liter Tedlar gas sampling bag was connected to the column carboy feed water with Viton tubing. The gas bag served two functions: (i) to replace volume lost in the carboy as water levels dropped and (ii) to maintain stable concentrations of nutrients (air, oxygen, and CH_4 in the gas phase) which were in equilibrium with column feed water.

Groundwater from an uncontaminated well was pumped through the column in an upflow direction with a peristaltic pump at an average flow rate of 1.2 ml/min. Column detention time was ≈30 h. Operating conditions with respect to nutrient and TCE and PCE additions to column feed water are listed in Table 2. CH_4 and O_2 were added to column feed water by sparging separate aliquots of well water with either gas and then mixing methane- or oxygen-saturated aliquots in appropriate ratios (Table 2). TCE and PCE (Aldrich, Milwaukee, Wis.) were added to a final concentration of 500 μg/liter to the column feed by using a methanol-based stock solution. The resultant methanol concentration in the feed water was 2.5 mM. Volatile organic carbon (VOC) concentrations in influent and effluent samples were measured twice daily. The column was maintained at room temperature, 18 to 25°C, during the entire experiment. Cumulative masses of TCE and PCE were calculated by Euler integration (6). This stepwise integration was needed because of variations in measured influent concentrations.

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† Present address: Energy Systems Division, Argonne National Laboratory, Argonne, IL 60439.

‡ Present address: School of Public and Environmental Affairs, Indiana University, Bloomington, IN 47405.

TABLE 1. Characteristics of composite sediments

Composite	Zone	Clay/sand/ gravel ratio	Porosity	TOC[a] (ppm)	Moisture content (%)
A	Saturated	1.7/98.2/0.1	0.33	74.0	18.7
B	Lower vadose	1.6/98.2/0.2	0.35	43.0	1.0
C	Upper vadose	5.2/92.2/2.6	0.32	46.0	2.7

[a] TOC, total organic carbon.

TABLE 2. Experimental conditions of column feed water

Days	Gas[a]
0–178	Air
178–262	CH_4-O_2
262–315[b]	CH_4-O_2
315–402	CH_4-O_2
402–436	O_2

[a] CH_4 and O_2 concentrations were used in various ratios of percent saturation from 80:20 to 20:80 for CH_4/O_2. Air and O_2 alone were used at 100% saturation. PCE and TCE (500 μg/liter each) were added beginning at day 140. The column was maintained at room temperature, 18 to 25°C, during the experiment.

[b] Nitrate (940 μM) was added.

Analytical methods. TCE, PCE, cDCE, and VC concentrations in pore fluids were measured on a Hewlett-Packard 5890A gas chromatograph equipped with a Hewlett-Packard 19395A automated gas headspace analyzer, an electron capture detector, and a 60-m Vocol (Supelco, Bellefonte, Pa.) column. Column temperature was held at 35°C for 8 min and then was increased (5°/min) to 80°C. Helium was used as the carrier gas at a flow rate of 12 ml/min. Samples (1 ml each) were dispensed into headspace vials containing 9 ml of deionized H_2O, which were immediately crimped, and then the samples were equilibrated at 75°C for 1 h prior to analysis. Prior time course analyses indicated 1-h equilibration to be sufficient for VOC partitioning into headspace. Standards containing 10 ml were made with each run, eliminating the need to use Henry's constant for calculations. Detection limits for TCE, PCE, VC, and DCE were, 1.0, 1.0, 150, and 50.0 μg/liter, respectively. Dissolved oxygen and pH were measured with microelectrodes (Microelectrodes Inc., Londonderry, N.H.) following a two-point calibration. Dissolved oxygen measurements of oxygen-free water, sampled by the same technique as pore waters, confirmed that oxygen was not introduced into pore water samples during sampling.

Microbial characterization. Aerobic heterotrophic bacteria were enumerated by the most probable number (MPN) technique on 1% PTYG medium (3). Tenfold serial dilutions were not used, since calculations of MPN were performed by using a computer program which allowed for more flexible dilution schemes (20). Positive aerobic MPN tubes were scored on the basis of turbidity after 3 to 5 days. MPN enumerations of anaerobic bacteria were done in anaerobic culture tubes equipped with butyl rubber stoppers and aluminum crimp seals (Bellco, Vineland, N.J.). The medium used for enumeration of anaerobes contained (per liter) 2.0 g of KH_2PO_4, 0.3 g of NH_4Cl, 0.5 g of NaCl, 0.7 g of Na_2SO_4, 0.4 g of $MgCl_2 \cdot 2H_2O$, 0.5 g of KCl, 0.2 g of $CaCl_2 \cdot 2H_2O$, 0.5 g of Na acetate, 0.4 g of Na formate, 0.5 g of tryptone, 1.0 g of yeast extract, 2.5 g of $NaHCO_3$, 0.5 g of cysteine, 0.5 g of $Na_2S \cdot 9H_2O$, 1.0 mg of resazurin, 2.0 mg of $FeNH_4(SO_4)_2$, 5.0 mg of $NiCl_2$, and 10 ml of trace metal solution. The pH was adjusted to 7.2. The trace metal solution contained (per liter) 1.5 g of nitrilotriacetic acid, 2.0 g of $MgSO_4 \cdot 7H_2O$, 0.5 g of $MnSO_4 \cdot H_2O$, 1.0 g of NaCl, 0.1 g of $FeSO_4 \cdot 7H_2O$, 0.18 g of $CoCl_2 \cdot 6H_2O$, 0.18 g of $ZnSO_2 \cdot 7H_2O$, 14.0 mg of $CuSO_4 \cdot 5H_2O$, 10.0 mg of H_3BO_3, and 10.0 mg of $NaMoO_4 \cdot 2H_2O$. Tubes were pressurized (10 lb/in^2) with oxygen-free 80:20% H_2-CO_2. This medium was not selective for any specific anaerobic population and was meant to support both facultative and strict anaerobes. Tubes for anaerobic enumerations were incubated horizontally at 25°C and scored on the basis of turbidity after 30 days. For all MPN enumerations, a 1:10 sediment-medium slurry served as the initial sample for subsequent dilutions.

Column experiment. Aerobic conditions were maintained in

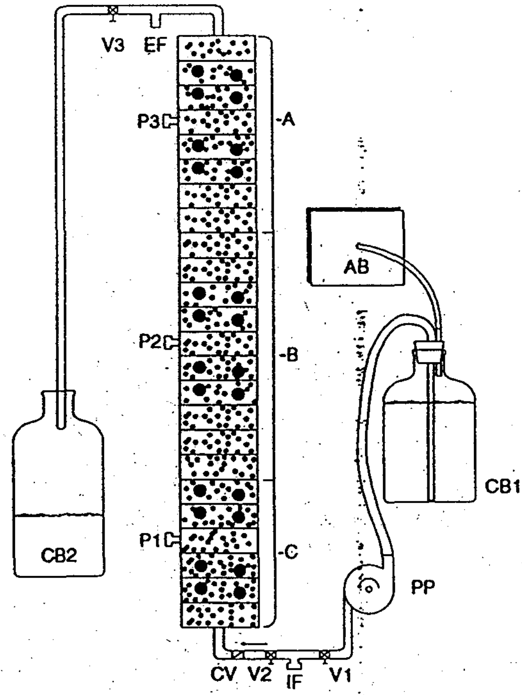

FIG. 1. Diagram of the column. Section A contained composite sediments from the saturated zone; section B and C sediments were from unsaturated zones. Side ports were for sampling sediments and pore waters. V1 to -3, valves; CB1, column-feed water carboy; CB2, collection carboy; AB, Teflon gas bag; CV, check valve; P1 to -3, pore water sampling ports; IF and EF, influent and effluent sampling ports, respectively; PP, peristaltic pump. Large solid circles, sediment sampling ports.

TABLE 3. Oxygen trends

Port	Oxygen (mg/liter)		
	Mean	Maximum	Minimum
Days 0–337			
Influent	11.0	26.3	3.2
Effluent	4.8	10.4	2.4
A	4.8	9.8	2.4
B	4.3	8.8	1.9
C	5.2	11.1	1.6
Days 338–436			
Influent	15.1	24.7	6.3
Effluent	5.1	7.4	3.5
A	3.8	5.3	2.7
B	4.5	6.5	2.7
C	4.2	6.1	3.1

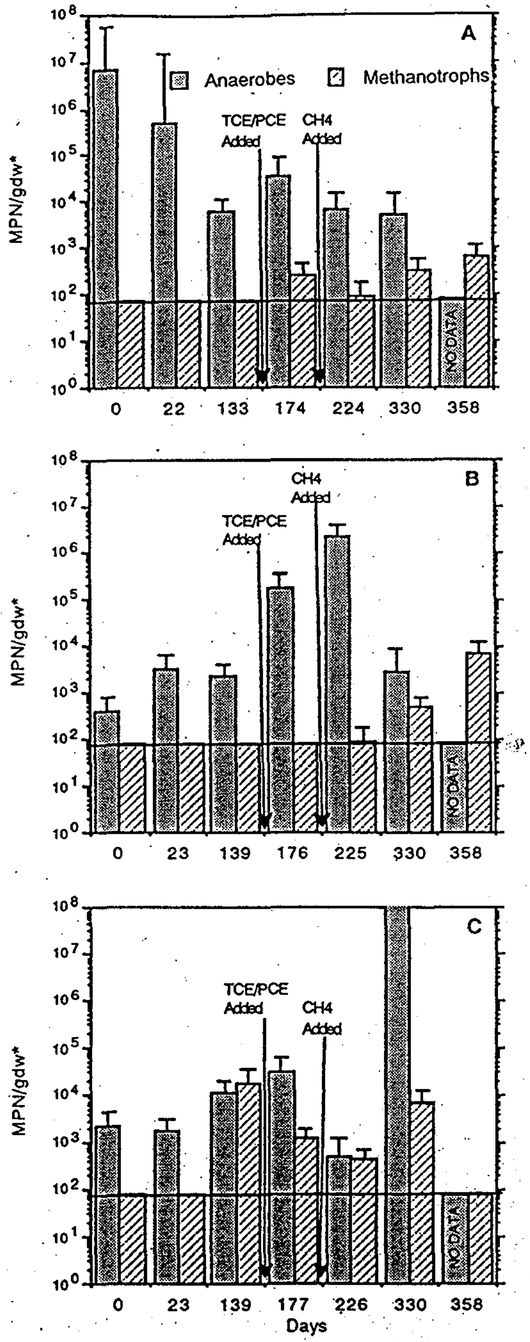

FIG. 2. MPN enumeration of aerobic heterotrophic bacteria in 1% PTYG medium compared with anaerobic bacteria. gdw, grams (dry weight).

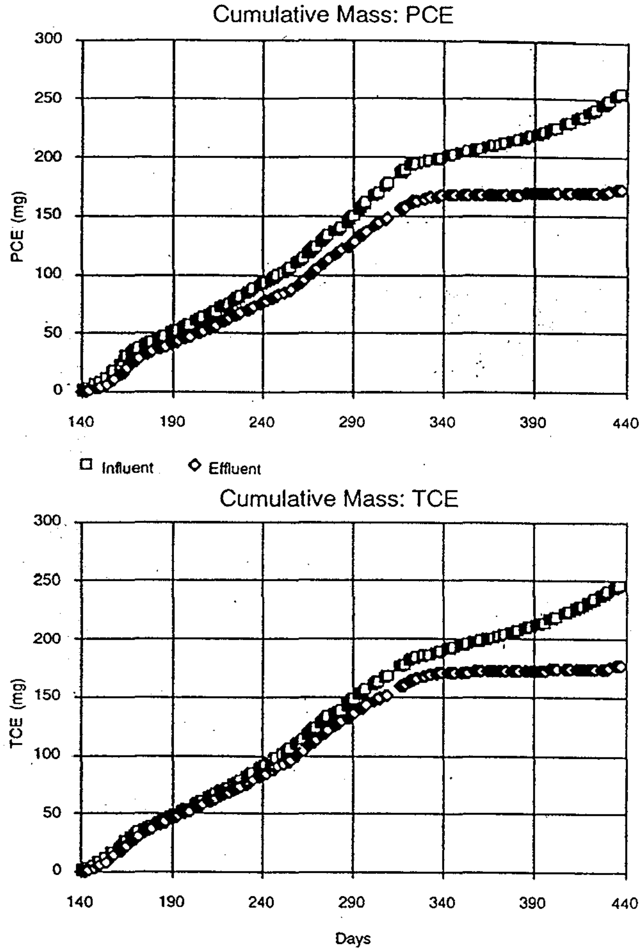

FIG. 3. Cumulative masses for TCE and PCE were derived by Euler integration from concentrations between sampling periods. The influent curve represents total mass loading of TCE and PCE. The difference between the influent and effluent curves represents the amount removed.

the column throughout the experiment (Table 3). In no case were concentrations less than 1.6 mg/liter, i.e., approximately 20% of saturation in air, detected. This low concentration of dissolved oxygen at port C may have resulted from microsite conditions at the sampling port; concentrations in the bulk pore fluids were probably even higher, as indicated by higher concentrations at downstream ports. During the period of greatest TCE and PCE removal, days 338 to 436, the lowest dissolved oxygen concentration was only 2.7 mg/liter (Table 3).

Results of MPN enumerations of aerobic heterotrophs and anaerobes are illustrated in Fig. 2. It is evident that abundant populations of both aerobic and anaerobic microorganisms were present throughout the experiment. A significant portion of the anaerobic enumerations may actually represent facultative anaerobes capable of growing under strictly anaerobic conditions. Methane was measured in pore waters of all sampling ports and in MPN enumeration tubes, suggesting that methanogens were present throughout the column. This suggests that microsites which were capable of supporting strict anaerobes existed in the soil column. Methanotrophs were detected in all three sections of the column (data not shown) at low densities. Even after 6 months of CH_4 exposure, the maximum number of methanotrophs detected was 100 MPN/g (dry weight). However, both methane and dissolved oxygen concentrations were adequate to support methanotroph populations.

TCE and PCE transformation. Significant differences ($P < 0.0001$) in influent and effluent concentrations for TCE and PCE were observed during the first 6.5 months (period 1, days 140 to 337) and the last 3.5 months (period 2, days 338 to 436). Transformation of TCE and PCE was much greater, however, during period 2. Cumulative mass balances indicated 87 and 90% removal for TCE and PCE, respectively, during period 2 compared with 9 and 16% during period 1 (Fig. 3). TCE and

PCE disappearance during period 1 could be due entirely to abiotic losses, i.e., adsorption, volatilization, or abiotic transformation. Losses during period 1 can be subtracted from losses in period 2 to conservatively estimate removal by biotransformation during the latter period. In this manner, conservative TCE and PCE biotransformation rates during period 2 were 76 and 74%, respectively. During period 2, cDCE was observed as the major product of both TCE and PCE transformation. No VC or other chlorinated products were detected.

Considering the low biomass of methanotrophs and the presence of cDCE, cometabolic biodegradation of TCE by methanotrophs was probably insignificant compared with anaerobic dechlorination. Anaerobic conditions apparently developed in microsites since column pore waters remained aerobic. Reductive dechlorination of TCE and PCE under methanogenic conditions can proceed to VC (8, 17, 29), whereas cDCE has tended to accumulate under sulfate-reducing conditions (3, 21). Accumulation of VC and cDCE may occur when there is an insufficient supply of electron donors (8, 9, 17). The addition of 2.5 mM methanol in these studies provided sufficient reducing equivalents to completely reduce the added TCE and PCE to ethylene. Recent studies of anaerobic dechlorination of PCE have shown that the form of carbon substrate determines the dechlorination potential of a selected microbial community (18). In our study methanol may have been effective in stimulating methanogenesis but not in promoting complete reductive dechlorination. The apparent accumulation of cDCE, therefore, suggests that (i) methanogens may not have been solely responsible for the dechlorination of TCE and PCE or (ii) dechlorination activity may have been partially inhibited by oxygen.

Kastner (21) also observed cDCE accumulation in microcosms under sulfate-reducing conditions and suggested that facultative anaerobes may have been responsible for reductive dechlorination on the basis of the dependency of aerobic consortia in microcosms. Facultative anaerobes may also have been, at least partially, responsible for reductive dechlorination activity in our studies. Enumerations of aerotolerant and facultative anaerobic bacteria showed that such populations were comparable in size to aerobic populations (data not shown).

The results from this study clearly show that anaerobic dechlorination of TCE and PCE can be observed in a column maintained under bulk aerobic conditions. Previous work with fluidized expanded-bed bioreactors with Savannah River site consortia from the same site had the same results (23a). Methanogenesis in the column strongly suggests that anaerobic zones or microsites existed, allowing the simultaneous presence of both aerobic and anaerobic microorganisms. These results have important implications for both in situ and on-site PCE and TCE bioremediation projects in which complete anaerobic conditions are either environmentally undesirable or unacceptable by regulatory standards. Sequential anaerobic and aerobic treatments have been suggested to anaerobically dehalogenate fully halogenated compounds and, subsequently, aerobically transform less-halogenated analogs (10, 13). The studies described here suggest that both anaerobic and aerobic populations may be stimulated simultaneously while maintaining an aquifer under bulk aerobic conditions. Data from the Savannah River Site methane injection demonstration also suggest that this is true, since PCE decreased in sediments at some sites in the absence of soil vapor extraction. Pilot and field demonstrations of both strategies, i.e., stimulation of anaerobic microsites in an aerobic aquifer and sequential anaerobic and aerobic treatments, are needed in order to determine the applicability of these remediation designs.

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