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Final Report
Six-Phase Heating Treatability Study at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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CDM Federal Programs Corporation and
Thermal Remediation Services, Inc.

contributed to the preparation of this document and should not be considered an eligible contractor for its review.

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DOE Contract No. DE-AC05-03OR22980
Job. No. 23900
LTR-PAD/EP-DH-04-0023
March 26, 2004

Mr. William E. Murphie, Manager
Portsmouth/Paducah Project Office
U.S. Department of Energy
1017 Majestic Drive, Suite 200
Lexington, KY 40513

Dear Mr. Murphie:

DE-AC05-03OR22980: Transmittal—*Final Report Six-Phase Heating Treatability Study at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE/OR/07-2113&D2)

Enclosed are 16 copies of the subject document for your use. The document incorporates minor changes to text and all finalized data tables as requested in the Commonwealth of Kentucky's and the U.S. Environmental Protection Agency's comments.

Enclosed also is suggested text for the transmittal letter to the regulatory agencies. Please forward ten copies of the enclosed document to the following at the Commonwealth of Kentucky regulatory agencies: Ms. Gaye Brewer, Mr. Steve Hampson, Mr. Tony Hatton (7), and Mr. Eric Scott. Three copies of the enclosed document are to be transmitted to Mr. David Williams at the U.S. Environmental Protection Agency. The remaining three copies are for your use. This document is being distributed in accordance with the *Standard Distribution List for Bechtel Jacobs Company LLC Primary and Secondary Documents (10/23/03).*

If you have any questions or require further information, please contact John Farrell of my staff at (270) 441-5261.

Sincerely,

Glenn VanSickle

Glenn E. VanSickle
Paducah Manager of Projects

GEV:JPF:dfm

Enclosures (2): As stated

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COMMENT RESPONSE SUMMARY
Six-Phase Heating Treatability Study Final Report DOE/OR/07-2113&D1

COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
REVIEWER: Kentucky Department for Environmental Protection			
	General	Page x of the Executive Summary indicates that post-treatment groundwater and soils sample results remain preliminary. Substantiated results must be provided in the D2 revision. The Division cannot approve a treatability study report that contains preliminary data.	Agree. As stated in the D1 version of the report, final results will be included in the D2 report.
	General	The Division cannot approve this report until it knows the location of all post treatment samples. The fifth paragraph on page 1-6 indicates that the locations of the post-treatment UCRS borings will be presented in Figure 1.2 of the D2 revision that depict the three-dimensional distribution of TCE in the UCRS prior to and then following treatment.	Agree. As stated in the D1 version, post sampling locations will be added to the D2 version.
	General	DOE was unable to install all of the 15 variable depth piezometers originally proposed in the work plan. As a result, UCRS soil temperatures were only monitored at a few select locations rather than throughout the entire volume of the treatment cell. What effect does the lack of temperature data have on DOE's ability to successfully evaluate this technology?	The UCRS temperature inside the treatment area was monitored at many locations including 10 depths in the two monitoring wells, spaced every 10 feet between 5-45 feet bgs. There were also thermocouples located at 17 ft bgs, 37 ft bgs, and 57 ft bgs in piezometers 3 and 5 inside the treatment area and piezometers 9, 10, 11, and 13 outside the treatment area. The post-study soil samples are the principal and direct measure of effectiveness. The design called for a greater number of temperature monitoring locations; however, this high monitoring density was a contingency measure to help monitor the movement of steam in the event that steam spread laterally during heating. Because the steam did not spread laterally, the contingent high density temperature monitoring was not necessary.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
	General	Provide an explanation as to why levels of TH-230 and U-238 increased at a few groundwater sample locations. Also, please explain the wide spread increase in gross beta and Tc-99 activity at many of the groundwater sample locations. Does DOE believe that any radionuclides were mobilized as a result of the six-phase test? Why or why not? If so, what kinds of problems would this present if the technology were to be used more extensively?	Concentrations of TH-230 and U-238 are so close to their detection limits that it is difficult to make definitive conclusions about changes that might have occurred during the study. Tc-99 and the resulting gross beta emissions did increase significantly during the study. Other significant changes include increases in chloride ion concentrations and decreases in the concentrations of other dissolved minerals (see table A.51). The attached table separates chlorides because chloride ions could be created from the degradation of TCE during the test. Large effects on other dissolved minerals and Tc-99 were not expected during the study, except for slight concentration changes due to removing distilled water (steam) during the test and due to generally increased mineral solubility with increased groundwater temperature. The changes of dissolved mineral concentrations and Tc-99 concentrations during the test were larger than expected. However, interpretation of these changes is extremely difficult. The data does not exhibit an obvious pattern. Also, the changes were generally more pronounced *outside* the treatment region than *inside* the treatment region. The lack of a pattern suggests that some factor other than the treatability study itself was influencing the measurements. In retrospect, the design of the monitoring wells used in the treatability study was not appropriate. The monitoring wells had multiple screens across both the RGA and the upper McNairy that were separated by internal casing packers after the wells were installed. However, before the packers were installed, it was possible for groundwater to move between the RGA and the McNairy formations. This groundwater movement influenced the pre-SPH groundwater samples and makes interpretation of subtle dissolved mineral changes difficult. Fortunately, the large changes in TCE concentrations during the study are easily observable even with the potential for non-representative pre-SPH sample results due to groundwater mixing. It is recommended that future groundwater monitoring wells should not bridge the two formations. Although, measuring the effects on radionuclides and other dissolved minerals was not an objective of the Treatability Study, laboratory studies suggest that heating may result in relatively slight increases in solubility, with a return to baseline concentrations as the subsurface cools.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
1	Section 2.1.1, Page 2-1, 2nd Paragraph	A 75% reduction in UCRS soil TCE levels is presented as being one of the criteria for success for this treatability study. How was this figure derived? This paragraph refers to a Geo Consultants internal fact sheet titled *Six-Phase Heating Technology Assessment*. Please provide a copy of this fact sheet to the Division for review. If desired, the fact sheet may be added to the report's appendices.	The 75% cited in the GEO Consultants fact sheet is not based on any technical assumption or regulatory criteria. The rationale for the 75% number is as follows: An indication of total success would be 100%. An indication of total failure would be 0%. A reduction of at least 75% over baseline during the treatability study is an indication that the technology is probably viable and would probably achieve a significant reduction in a full scale deployment of a similar technology. A reduction of less than 75% would indicate that the technology is somewhat effective in reducing mass but other technologies might be better suited to remove contaminants from the site. The project reduced the contaminant mass by greater than 98% therefore, the project approached total success. The *Six-Phase Heating Technology Assessment* fact sheet will be included in the appendices of the D2 version of the final report.
2	Section 4.1.2.2, Page 4-10, Table 4.1	Table 4-1 indicates that levels of TCE in monitoring wells MW 406 and MW 407 dropped dramatically within the McNairy Formation following six-phase treatment. The data also shows that samples collected directly above the McNairy Formation and within the RGA dropped somewhat less dramatically. This is an odd occurrence given that heating of the lower RGA was found to be less than ideal. Please speculate as to why TCE levels in the McNairy would fall to a greater degree than those in the overlying RGA.	There is inconclusive evidence as to the cause of this occurrence. However, listed below are two possible theories which that may have contributed to the unexpected change in TCE concentrations. The baseline TCE samples from the McNairy Formation may have been biased high due to the monitoring wells being left open before performing crosswell seismic testing. There may have been some contaminant migration downward during this timeframe. Once the packers were installed in the monitoring wells, the downward contaminant migration was stopped due to the packers providing a sufficient seal to prevent further contamination migration. The initial sampling event (pre-SPH) purging and sampling process may have subsequently removed any contamination that had migrated downward from the upper intervals. Additionally, the McNairy Formation contains a "hydraulic head" that is slightly greater than that of the RGA. This "hydraulic head" may have served as a flushing mechanism and contributed to the decrease in TCE from baseline.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
3	Section 4.1.2.4, Pages 4-16 and 4-17, Tables 4.3 and 4.4	These tables indicate an overall reduction in the levels of TCE in the UCRS soil at the test site. However, they also document isolated locations in the subsurface where TCE appears to have actually increased relative to baseline. This is the case at VP-6 at a depth of 8'-10' where TCE level went from pre-test levels of 43,000 ppb to 112,500 ppb. Please speculate as to why this occurred.	In contrast to soil sampling, an advantage of groundwater sampling is that the mixing of the fluid and diffusion of the dissolved VOC tend to provide more consistent results over time. Additionally, the pre and post test groundwater samples are collected from the same depth and location. Soil sampling always shows far greater variability in VOC concentrations because soil mixing does not occur and VOC diffusion is almost non-existent. Also, it is not possible to sample the same exact spot with pre test and post test sampling. To prevent the sample rods from intersecting the pre test borings, the post test borings could be located as far as 3 ft. away from the original sample locations. For these reasons, the specific case noted should be considered to be a normal statistical soil sample variation. Soil samples routinely show this type of data scatter. A review of the soil sample results does not indicate a non uniform pattern of changes. For example, the soil sample results do not indicate that shallow soils were not remediated as effectively as deeper soils or vice versa.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
REVIEWER: Environmental Protection Agency			
	General	This document is identified as the "Final Report" for the Six-Phase Heating Treatability Study. However, some of the groundwater and soil data presented in the document are noted to be preliminary results. The D2 version of this document must include only final analytical results for all media sampled throughout the study.	Agree. All sample data included in the D2 version of the final report will be final.
1	Section 1.3, Page 1-6, 3rd Paragraph, Last Sentence	It is noted in this sentence that alarm set points were 19 ppmv TCE, 20 ppmv VC, 25 ppmv *cis*-1,2-Dichlororethene, and 25 ppmv *trans*-1,2-Dichloroethene. The technical basis for establishing these various alarm set points should be added to this section of the document.	Agree. The following explanation will be added: "In accordance with Kentucky Department for Air Quality recommendations, Environmental Protection Agency Region 9 Preliminary Remediation Goals were applied at the PGDP fence line. Additionally, air modeling was performed to determine potential exposure levels. The alarms were then set so as not to exceed the Preliminary Remediation Goals.
2	Section 2.1.2, Page 2-3, TCE Removal Rates as a Function of Operational Time and Energy Consumption	This paragraph discusses comparison of TCE removal rates using photoacoustic analyzer and summa canisters as presented in Figure 2.1. In this figure, an explanation is provided for the photoacoustic concentration spike measured on June 18, 2003. However, three additional photoacoustic concentration spikes are plotted in Figure 2.1 after June 18, 2003. This paragraph of the document, and/or Figure 2.1, should be revised to include explanations for the three post-June 18 photoacoustic concentration spikes.	Agree. Contaminant concentrations were measured with the photoacoustic analyzer once per workday. Summa canister samples were integrated once per week for a 24-hour sampling period. Contaminant concentrations could have varied greatly between sample periods with the photoacoustic analyzer. Additionally, contaminant levels often increased if the vacuum blower had been shut down for an extended period of time. However, a definitive explanation is not available for the additional spikes.
3	Section 2.1.2, Page 2-4, Construction and Operation Costs as a Function of TCE Mass Removed or Destroyed (Cost-Effectiveness)	It is noted in this paragraph that an estimated 22,856 lbs of TCE were removed during SPH operations. Did the Department of Energy calculate the mass of TCE present within the study area prior to initiation of heating? If so, the calculated pre-treatment mass should be included in this paragraph of the document.	Pre-treatment TCE mass was not calculated.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
4	Section 3.4.2, Page 3-5, 3rd Paragraph, Last Sentence	This sentence states "No recovery was obtained in the attempt to collect a sample from the interface at MW408". This sentence is unclear and requires revision, particularly with regard to clarification of the meaning of "no recovery was obtained".	Agree. This sentence will be revised as follows: "Based on the lithology observed in the soil cores collected between 90' and 100' bgs, the interface between the RGA/McNairy formations was not clearly evident. Although additional soil cores could not be collected due to sand in the augers, the borehole was advanced to 120' bgs to try to locate the interface by a change in drilling conditions. After advancing the borehole to 120' the boring was terminated with no change in drilling conditions. The RGA/McNairy interface may be shallower or deeper than expected in this location."
5	Section 4.1.2.2, Page 4-9, 1st Paragraph	Near the end of this paragraph, reference is made to Figure 4.5 (graph depicting groundwater sampling results for MW406) and Figure 4.6 (graph depicting groundwater sampling results for MW407). The figure numbers for these graphs are incorrect and should be corrected to indicate that the MW406 graph is Figure 4.7 and the MW407 graph is Figure 4.8.	Agree. The figure numbers will be corrected.

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
6	Table 4.1, Page 4-10	This table presents TCE concentrations detected in groundwater samples collected from the RGA at monitoring wells MW406 and MW407. Data is presented in this table for each of the sampling events performed over the course of the study (baseline, 60%, 87%, two-week post treatment, and four-week post treatment). The data indicate that for the sampling period between baseline and 87%, the depth intervals that experienced the lowest amount of heating experienced the greatest rate of TCE concentration reduction. Since this relationship is opposite to what would be expected, it should be explained. The following are the pertinent facts which illustrate this relationship. According to the timeline of groundwater sampling events presented in Section 2.1.1 of the document, the baseline sampling event was conducted on January 10, 2003, the 60% sampling event was conducted on May 5, 2003, and the 87% sampling event was conducted on June 23, 2003. It is noted in Section 4.1.2.1 of the document that the SPH system increased the subsurface temperatures from 18°C to boiling at the 15 to 75 ft bgs depth interval over a period of approximately 30 days and that the target temperature over this depth interval was maintained for 120 days. It is also noted in Section 4.1.2.1 that the 85 ft bgs interval was not consistently heated to its target temperature of 121°C although the temperature was consistently above the boiling point of pure TCE at 93°C. The subsurface temperature data stated in Section 4.1.2.1 is confirmed by data plotted in Figure 4.1. However, data plotted in Figure 4.1 also clearly illustrates that the average treatment temperatures within the RGA and Upper McNairy for the 95 ft bgs and 105 ft bgs depth intervals were consistently below 93°C.	Agree. The following explanation will be added. The treatability study was not designed to treat the McNairy Formation and it was not the intent of the Final Report to imply that SPH treated the McNairy. Four monitoring wells were installed for the treatability study (MW405 through MW408). These wells included screened intervals in the upper sand unit of the McNairy Formation. The purpose of the screen in the upper McNairy was to check whether the SPH process pushed TCE into deeper soils through some mechanism. The monitoring wells included seven short screened intervals on a single 4-inch casing - one in the lower UCRS, five in the RGA and one in the McNairy. After the wells were drilled, a set of inflatable packers were installed in the wells to seal the casing between the seven screens. In retrospect, it seems likely that contaminated water or a small amount of DNAPL moved from the RGA to the McNairy screened intervals in the period between well installation and packer insertion (up to four months). This mixing between the formations caused the initial McNairy sample to be biased high. Subsequent samples were more representative of true McNairy conditions. It is recommended that future multiple screen groundwater wells should not bridge the two formations and not remain open for extended periods of time.

COMMENT RESPONSE SUMMARY

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
6 (cont)		The temperature versus depth data plotted in Figures 4.5 and 4.6 of the document for monitoring wells MW406 and MW407 was found to be as follows: Based on the information and data summarized above, the following is concluded: ☐ During the timeframe from January 10 through June 23, 2003, the baseline, 60%, and 87% groundwater sampling events were conducted for the study. ☐ During the timeframe from April 14 through August 22, 2003, the average temperature in the 75 ft bgs depth interval at MW406 and MW407 was greater than 93°C and that the average temperature in the 85 ft bgs, 95 ft bgs, and 105 ft bgs depth intervals were less than 93°C. ☐ During the course of the entire study, the maximum observed temperature in the 75 ft bgs, 85 ft bgs, and 95 ft bgs depth intervals at MW406 and MW407 were equal to or greater than 93°C and the maximum observed temperature in the 105 bgs depth interval was less than 93°C. ☐ At no time during the study was the temperature of the 105 ft bgs depth interval ever increased to greater than 93°C. The TCE sample concentration data plotted in Table 4.1 of the document for monitoring wells MW406 and MW407 was found to be as follows:	

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
6 (cont)		Analysis of the concentration versus depth versus time data presented in Table 4.1 appears to suggest that the four deepest intervals examined during the study at MW406 and MW407 contained similar concentration of TCE contamination at the beginning of the study, but that the 106-108 ft bgs depth interval experienced a significantly faster reduction of TCE concentration compared to the three shallower intervals between the baseline sampling event (January 10, 2003) and the 87% sampling event (June 23, 2003). However, the temperature data presented in this document indicated that in general the 75 ft bgs and 85 ft bgs depth levels were heated at some time to temperatures above 93°C, but that the 95 ft bgs and 105 ft bgs depth intervals were never heated to temperatures exceeding 93°C. Section 4.1.2.2 of this document needs to be revised to include an explanation as to why the TCE concentration in the 106-108 ft bgs depth interval in MW406 and MW407 was reduced at a significantly faster rate compared to the 72-74 ft bgs, 80-82 ft bgs, and 86-88 ft bgs depth intervals despite the fact that the 106-108 ft bgs depth interval experienced that least amount of heating of any depth interval during the study. This relationship is opposite to what would be expected.	

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
7	Section 4.2, Page 4-18	This section of the document lists the measures required to verify the quality of work performed and compliance with the specified project requirements. However, the results of implementation of these measures are not discussed. This section of the document should be revised to include a summary of the quality assurance/quality control achieved during performance of the study.	Agree. The following summary will be added. "Internal and external assessments were conducted to ensure that quality was being achieved during construction, operation and sampling of the treatment system. The following are some of the measures taken to ensure quality during the treatability study." Data Quality Control • Collection of Quality Control Samples (i.e. Field Blanks, Equipment Rinseates, and Duplicates) • Sample Custody Control • Review of 100% of all Sample Data • Validation of Analytical Data • Calibration of Water Quality Instrumentation Construction Quality Control • Documented Material and Equipment Inspections (i.e. Steel Shot, Copper, Blower, Power Control Unit, Condenser, etc.) • Pre-startup Checks (i.e. System Interlocks, Alarm Set Points, etc.) • Induced Voltage Surveys Operational Quality Control • Data Collection and Review (Temperature, Electrical, Contaminant Concentration, etc.) • Calibration of Instrumentation

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COMMENT NO.	PAGE/PARAGRAPH/ SECTION	COMMENT	RESPONSE
8	Appendix B, Page B-3, Last Paragraph	It is noted in this paragraph that membrane interface probe (MIP) profiling confirmed the presence of subsurface VOC contamination, and that comparison of MIP profile results to baseline soil sample results show similar increases and decreases in concentration. However, review of the summary logs presented in Appendix B appears to illustrate poor correlation between MIP profile and soil sampling concentrations. For example, the summary log for Point PZ002 illustrates two prominent spikes in TCE concentration for soil samples collected in the depth interval of approximately 7 to 15 feet and the depth interval below 54 feet. While there appears to be good correlation of ECD/PID readings to measured soil concentration for the lower TCE spike, there appears to be no correlation of ECD/PID readings to measured soil concentration for the upper TCE spike. ECD/PID readings are noted to significantly increase at approximately 7 feet which is consistent with the increase detected in soil sampling concentrations from the same depth, but the significant decrease in concentration detected in soil sampling between 15 and 54 feet is not reflected in the ECD/PID readings. If it is the intention of the Department of Energy to utilize MIP profiling for future studies and remedial actions at PGDP, additional explanation and analysis of the MIP profiling results for this study will be required by the Agency.	The primary function of the Membrane Interface Probe is to serve as qualitative screening tool to delineate between soils that contain subsurface VOC contaminants and those that do not.

DOE/OR/07-2113&D2
Secondary Document

Final Report
Six-Phase Heating Treatability Study at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

March 2004

Prepared by
CDM Federal Programs Corporation
Kevil, Kentucky
under subcontract 23900-SC-RM789

Prepared for the
U.S. Department of Energy
Office of Environmental Management

BECHTEL JACOBS COMPANY LLC
managing the
Environmental Management Activities at the
East Tennessee Technology Park
Oak Ridge Y-12 Plant Oak Ridge National Laboratory
Paducah Gaseous Diffusion Plant Portsmouth Gaseous Diffusion Plant
under contract DE-AC05-03OR22980
for the
U.S. DEPARTMENT OF ENERGY

CONTENTS

CONTENTS (continued)

FIGURES

TABLES

ACRONYMS AND ABBREVIATIONS

ACGIH	American Conference for Governmental Industrial Hygienists
bgs	below ground surface
BJC	Bechtel Jacobs Company LLC
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Chain of Custody
DNAPL	dense nonaqueous-phase liquid
DOE	U.S. Department of Energy
EDD	electronic data deliverable
Eh	oxidation-reduction potential
EPA	U.S. Environmental Protection Agency
ERH	electrical resistance heating
FS	feasibility study
ft	feet
GAC	granular activated carbon
GEO	GEO Consultants LLC
GWOU	Groundwater Operable Unit
Hg	mercury
in.	inches
lb	pound
m	meter
McNairy	Upper Cretaceous McNairy
MW	monitoring well
NIOSH	National Institute for Occupational Safety and Health
OREIS	Oak Ridge Environmental Information System
PCU	power control unit
PEMS	Project Environmental Measurements System
photoacoustic analyzer	Innova Model 1314 photoacoustic analyzer
PID	photoionization detector
PGDP	Paducah Gaseous Diffusion Plant
ppb	parts per billion
ppbv	parts per billion by volume
PPE	personal protective equipment
ppm	parts per million
ppmv	parts per million by volume
QA	quality assurance
QC	quality control
QAPP	Quality Assurance Project Plan
RGA	regional gravel aquifer
RI	remedial investigation
SOW	statement of work
SPH	Six-Phase Heating
^{99}Tc	technetium-99
TC	thermocouple
TCE	trichloroethene
TMP	temperature monitoring point
TSWP	treatability study work plan
TWA	time-weighted average
UCRS	upper continental recharge system

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ACRONYMS AND ABBREVIATIONS (continued)

USEC	United States Enrichment Corporation
VC	vinyl chloride
VOC	volatile organic compound
VP	vapor piezometer
VR	vapor recovery
WAG	Waste Area Group

EXECUTIVE SUMMARY

This *Six-Phase Heating Treatability Study Final Report* has been prepared to present results from the Six-Phase Heating (SPH) treatability study. This report follows the outline in the *Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at the Paducah Gaseous Diffusion Plant Paducah, Kentucky* (U. S. Department of Energy [DOE] 2001a).

The SPH treatability study was conducted under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This preliminary record of decision treatability study has provided quantitative treatment and cost data to assess the feasibility of deploying electrical resistance heating technology as a part of the remedial action for the Groundwater Operable Unit. This study was conducted in a manner consistent with the *Federal Facility Agreement for the Paducah Gaseous Diffusion Plant* among the U.S. Department of Energy, the U.S. Environmental Protection Agency (EPA) and the Commonwealth of Kentucky (EPA 1998). The SPH treatability study followed the guidance set forth in EPA's *Guide for Conducting Treatability Studies under CERCLA* (EPA 1992).

The SPH treatability study was intended to test the constructability, remedial effectiveness, and cost effectiveness of full-scale deployment of the technology in the area adjacent to the southeast corner of the C-400 building at the Paducah Gaseous Diffusion Plant.

The primary activities associated with the C-400 building are cleaning machinery parts, disassembling and testing of cascade components, and laundering plant clothes. The two most significant sources of leaks and spills of volatile organic compounds that have been identified are located at the southeast corner of the C-400 building. This is where a drain line from the degreaser sump was connected to a storm sewer and also where the transfer pumps and piping delivered solvents to and from storage to processes in the building.

The treatability study included the installation and operation of one SPH treatment array. The single SPH array consisted of six power electrodes, a center neutral electrode, an electrical power control unit, a steam and contaminant vapor recovery (VR) system, temperature and pressure monitoring systems, four multi-port monitoring wells, and contaminant vapor and water treatment systems. The SPH system was operated by applying electricity to electrodes that were constructed to a total depth of 30 meters (m) (99 feet [ft]) below ground surface, which is slightly below the base of the RGA. As power was applied to the electrodes, the soil matrix resisted the flow of electricity through the electrode treatment area causing the subsurface to be heated. Subsurface temperatures were increased and the trichloroethene (TCE)-contaminated groundwater was volatilized. Steam and volatilized contaminants migrated upward and were collected in the vadose zone by VR wells. Water and contaminant vapors were processed by treatment systems.

The SPH treatability study began on February 14, 2003 and was originally scheduled to operate for 130 days. However, a 45-day extension was implemented due to positive TCE extraction and the desire to increase temperatures at the base of the RGA. Active heating was discontinued on September 6, 2003, marking the end of the 45-day operational extension. The VR system was allowed to continue purging the treatment area of steam for three additional days.

The primary objective as outlined in the *Six-Phase Heating Treatability Study Work Plan* (DOE 2001a), was to demonstrate the implementability of the SPH technology in the unsaturated and saturated soils of the UCRS and in the groundwater of the underlying RGA. The successful implementation of this work has demonstrated that SPH can effectively heat soil in the UCRS and groundwater in the RGA. Data produced during the SPH treatability study indicate that the system can successfully recover and treat steam and the target contaminant vapors.

The removal of TCE in the groundwater of the RGA was assessed by a comparison of the baseline groundwater sample results to post treatment groundwater sampling results. The post treatment groundwater sample results as compared to the baseline groundwater sample results indicate a 99.1 percent reduction in TCE concentration in groundwater which met the removal efficiency criteria outlined in a *Six-Phase Heating Technology Assessment* (GEO 2003).

Two subsequent rounds of groundwater sampling were performed following the post treatment sampling event on September 8, 2003. A two-week post treatment sampling event was completed on September 22, 2003 and a four-week post treatment sampling event was completed on October 7, 2003. The analytical results from these two sampling events indicate slight fluctuations in the reduction percentages with the two-week concentrations indicating 99.2 percent and the four-week concentrations indicating 99.0 percent.

The removal of TCE in the soil was also assessed by a comparison of the baseline soil sample results to the post treatment soil sample results. This comparison indicates an average TCE concentration reduction in soil of 98 percent, from an average of 125,111 ppb to an average of 2,493 ppb.

To assist in the pre-test characterization, a membrane interface probe (MIP) was utilized to provide a direct indication of *in-situ* VOC concentrations within the study area. MIP results can be found in Appendix D of this report.

1. INTRODUCTION

1.1 SITE DESCRIPTION

In August 1988, volatile organic compounds (VOC) and radionuclides were detected in residential wells near the U.S. Department of Energy's (DOE) Paducah Gaseous Diffusion Plant (PGDP). Between 1988 and the present, numerous groundwater investigations have been conducted to identify probable source areas. To address these source areas, a Groundwater Operable Unit (GWOU) Feasibility Study (FS) was issued August 2001 (DOE 2001b). The GWOU FS proposed that the effectiveness of certain treatment technologies being considered for full-scale use be evaluated (based on applicability to specific site conditions). This Treatability Study Final Report is for a treatability study using electrical resistance heating (ERH) in a Six-Phase Heating (SPH) array at the southeast corner of the C-400 building at the PGDP.

1.1.1 Site Name, Location, Stratigraphy and Hydrology

This treatability study was conducted at the southeast corner of the C-400 building (Figure 1.1) at the PGDP, which is a DOE leased uranium enrichment facility located west of Paducah, Kentucky. The PGDP overlies the southern extent of an ancestral channel of the Tennessee River. Site Stratigraphy is divided into three hydrogeologic units for this study. In descending order, they are: the Upper Continental Recharge System (UCRS), the Regional Gravel Aquifer (RGA), and the Upper Cretaceous McNairy (McNairy) Formation.

The UCRS consists primarily of sandy silts and clays, plus occasional gravel lenses and is often saturated with groundwater below 13 meters (m) 39 feet (ft) below ground surface (bgs). Groundwater flows nearly vertically downward through the UCRS and serves as a recharge system for the underlying RGA. The RGA consists of sand and gravel with clay lenses. The top of the RGA is represented by a potentiometric surface at a depth of about 17 m (56 ft) bgs. The RGA is saturated throughout and is slightly artesian across the site. Hydraulic gradients beneath the site direct groundwater flow in the RGA to the north towards the Ohio River. Immediately underlying the RGA is the McNairy Formation of the Upper Cretaceous age. The top of the McNairy is about 28 m (91 ft) bgs. The upper McNairy consists of interbedded silts, sands and clay. The middle McNairy is a silty clay, while the lower portion is primarily sand with some silts and clay.

Previous site investigations have led to the identification of three groundwater contaminant plumes resulting from past activities at the PGDP. All three plumes are located in the RGA. Two of these plumes, currently identified as the Northwest Plume and the Northeast Plume, appear to have received considerable contaminant loading from contaminated areas surrounding the C-400 building. Figure 1.1 presents the relationship between the maximum concentrations (greater than 100,000 parts per billion [ppb]) of trichloroethene (TCE) contamination and the C-400 building area.

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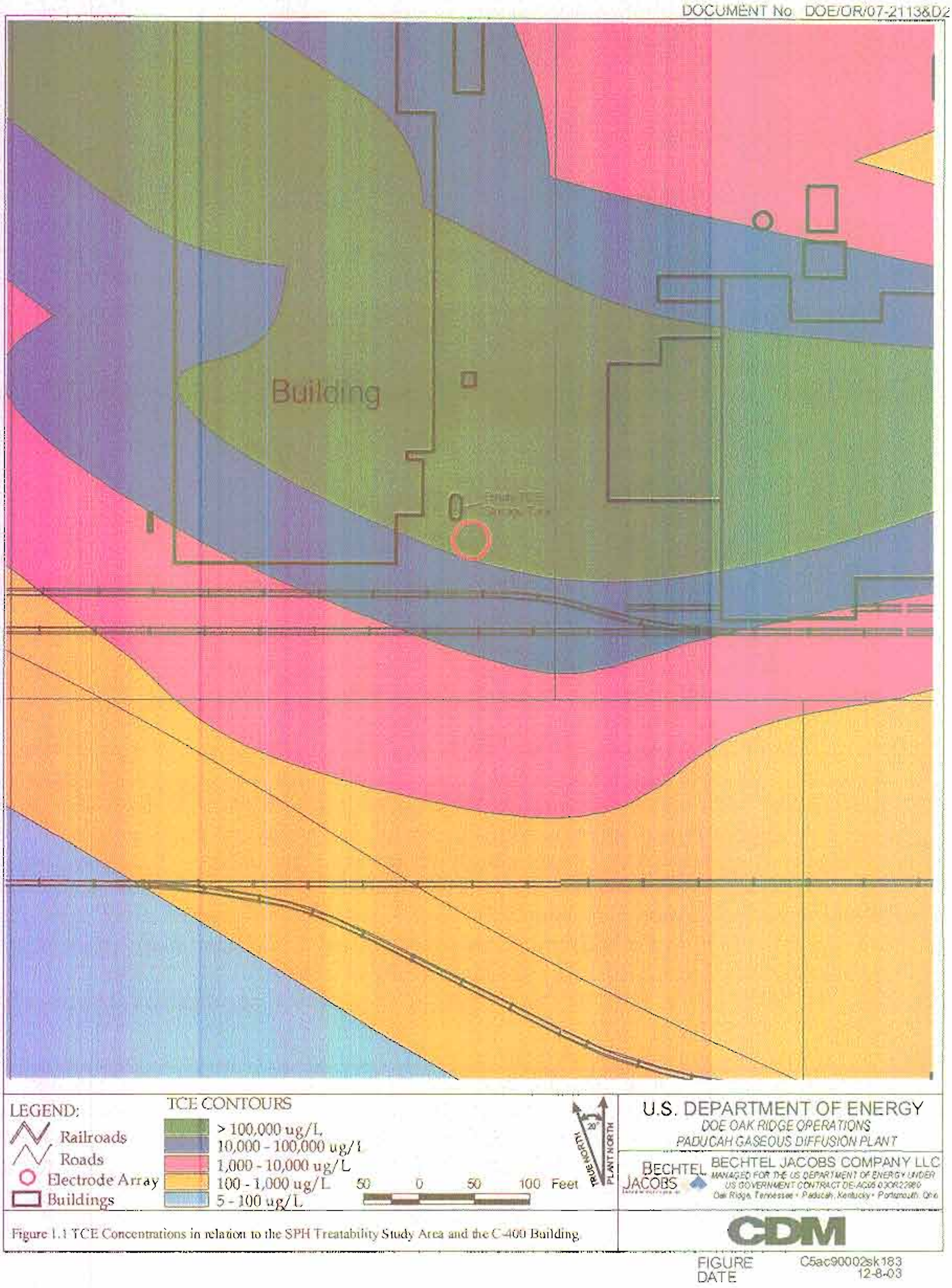

Figure 1.1. TCE Concentrations in relation to the SPH Treatability Study Area and the C-400 Building

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1.1.2 History of Operations

The primary activities associated with the C-400 building are cleaning machinery parts, disassembling and testing of cascade components, and laundering plant clothes. The building also has housed various other activities, including recovery of precious metals and enrichment of radionuclides.

The two most significant sources of leaks and spills of VOCs that have been identified are located at the southeast corner of the C-400 building. This is where a drain line from the degreaser sump was connected to a storm sewer and also where the transfer pumps and piping delivered solvents to and from storage to processes in the building.

In June 1986, a routine construction excavation along the 11th Street storm sewer revealed TCE soil contamination. The cause of the contamination was determined to be a leak in a drain line from the building's basement sump to the storm sewer. The area of contamination became known as the C-400 TCE leak site and was given the designation of Solid Waste Management Unit 11. After the initial discovery of contamination, four borings were installed to better define the extent of the soil contamination.

1.1.3 Prior Removal and Remediation Activities

Following the discovery of the TCE leak in June 1986, a portion of the soils were excavated in an attempt to reduce the contamination in the area. Excavation was halted to prevent structural damage to the adjacent TCE storage tank and to 11th Street. Approximately 300 ft^3 of TCE-contaminated soil was drummed for off-site disposal. The excavation was backfilled with clean soil and the area was capped with a layer of clay.

No additional prior removal or remediation activities have been performed in the vicinity of the C-400 building SPH treatability study area. However, the Waste Area Grouping (WAG) 6 Remedial Investigation (RI) (DOE 1999) characterized the nature and extent of contamination around the C-400 building. The WAG 6 RI concluded that there are areas of TCE dense nonaqueous-phase liquid (DNAPL) that exists in the UCRS and RGA at the C-400 building area. Accordingly, the SPH treatability study was centered on the area with the highest UCRS soil contamination levels and with high TCE levels in RGA groundwater (and possible DNAPL accumulation). The location is boring 400-200, with a 9 ft interval UCRS TCE concentration of 11,055,000 ppb. To encompass boring 400-200, the SPH electrode array was installed near the southeast corner of the C-400 building as shown in Figure 1.2.

1.2 WASTE STREAM DESCRIPTION

1.2.1 Waste Matrices

Waste matrices generated during the SPH project, estimated quantities, and a description of their actual and future disposition are listed in Table 1.1.

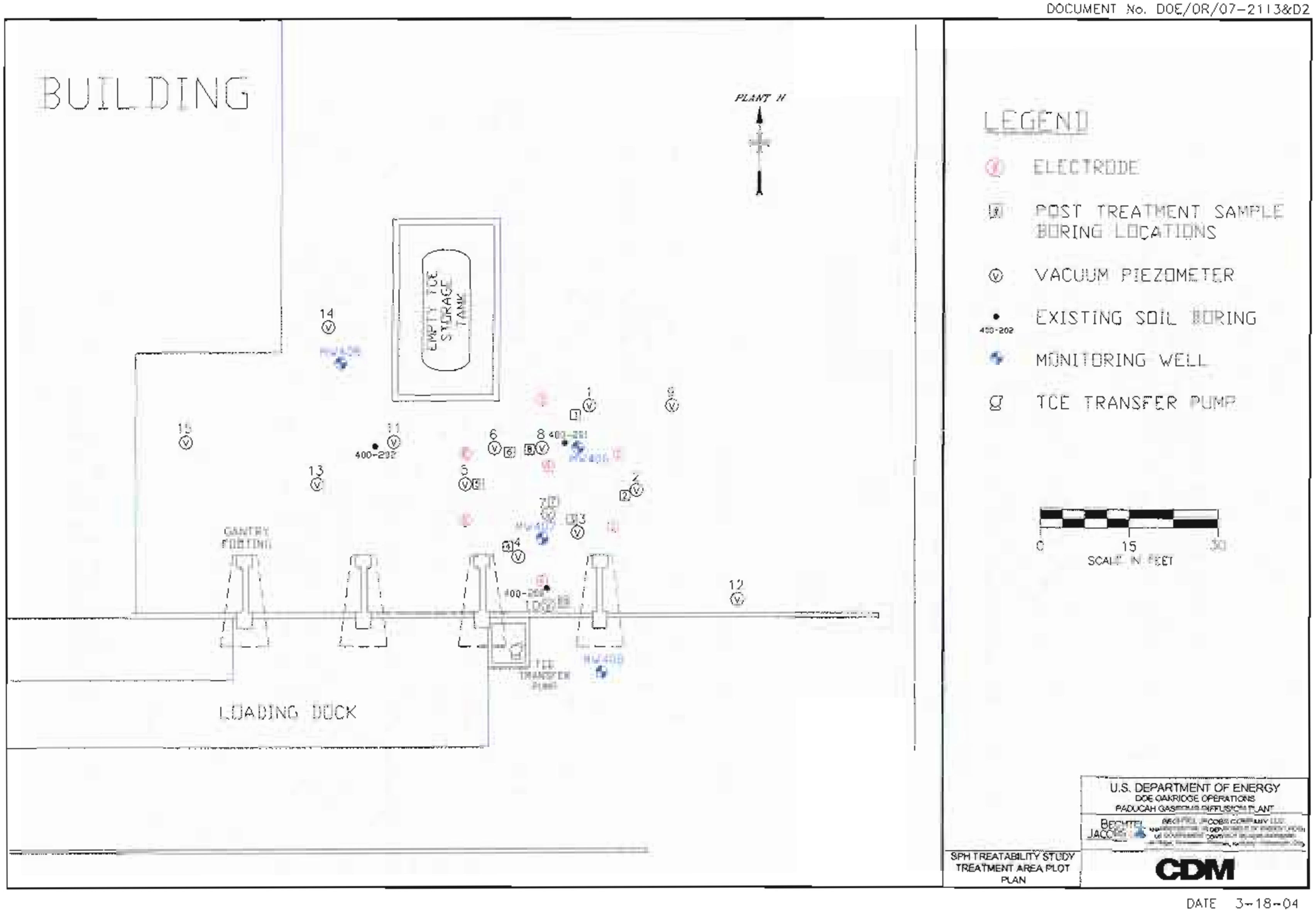

Figure 1.2. SPH Treatability Study Treatment Area Plot Plan

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Table 1.1. Waste Matrices

Matrix	Quantity	Disposition
Soil cuttings and personal protective equipment (PPE)	Three hundred fifty 55-gallon drums	The drums underwent thermal treatment and final disposition was at Envirocare of Utah.
Monitoring well development water	2,000 gallons	Treated through an onsite solids separation unit. The solids will be disposed of at Envirocare of Utah. The water will be treated through an onsite pump and treat facility.
Monitoring well sampling purge water	250 gallons	Treated through an onsite solids separation unit. The solids will be disposed of at Envirocare of Utah. The water will be treated through an onsite pump and treat facility.
Silt from vapor recovery system cleanout	One 55-gallon drum	The solids will be disposed of at Envirocare of Utah.
Decontamination water	1,000 gallons	Treated through an onsite solids separation unit. The solids will be disposed of at Envirocare of Utah. The water will be treated through an onsite pump and treat facility.
Spent liquid-phase granular activated carbon (GAC)	Four 55-gallon drums	The carbon will be disposed of at Envirocare of Utah.
Ion exchange resin	Two 55-gallon drums	The resin will be disposed of at Envirocare of Utah.
Spent vapor-phase granular activated carbon	175,000 pounds (lbs)	Shipped to vendor for thermal regeneration.

1.2.2 Pollutants/Chemicals

The two most significant sources of leaks and spills of TCE that have been identified are located at the southeast corner of the C-400 building. A portion of the mass of TCE released has changed into degradation byproducts based on a review of historic data. TCE degradation byproducts are *cis*-1,2-Dichloroethene, *trans*-1,2-Dichloroethene, and vinyl chloride (VC). Historic data indicates that technetium-99 (^{99}Tc) is also present in the RGA as part of a plume from an independent source; therefore, a small potential for removing ^{99}Tc was present during drilling and operations. However, radiological surveys indicated no detections of ^{99}Tc above any action level or hold point during drilling, operations or demobilization. A comparison of baseline vs. post-heating sample data (excluding TCE) is included in Appendix A.

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1.3 TREATMENT TECHNOLOGY DESCRIPTION

The treatability study included the installation and operation of a single SPH array. The single array treatment system consisted of six power electrodes, a central neutral electrode, an electrical power control unit (PCU), a steam and contaminant recovery system, pressure and temperature monitoring systems, and contaminant vapor and water treatment systems. A total of 35 borings were installed for the project: 4 multi-port groundwater and soil temperature monitoring wells (MW); 7 electrode and co-located vapor recovery (VR) wells; 15 vacuum monitoring piezometers; and 9 post-test assessment borings as shown in Figure 1.2. The treatability study was implemented to test the effectiveness of the SPH technology in the unique (having a broad mix of lithologies) hydrogeology located at the southeast corner of the C-400 building. The electrodes were constructed to a depth of 30 m (99 ft) bgs and consisted of six depth-discrete electrical resistance heating intervals covering the UCRS, the RGA, and the upper interbedded silt, sand, and clay layer of the McNairy formation.

As power was applied to the electrodes, the soil matrix became an electrical resistance heater, raising the temperature of the soil within the treatment area (subsurface area affected by elevated temperatures) to a level that caused contaminated groundwater to boil and the target contaminants to be volatilized. The contaminants and steam were then removed from the subsurface using VR wells. The steam was condensed and the liquid and vapor waste streams were then treated separately.

The treatment process for the vapor waste stream consisted of two 12,500 lb GAC beds configured in series. The primary and secondary configuration allowed for the secondary vessel to capture any TCE that may have "broken through" the primary vessel. The effluent of the secondary vessel was continuously monitored during project operations using an Innova Model 1314 photoacoustic analyzer (photoacoustic analyzer). The analyzer was configured to monitor for four contaminants (TCE, *cis*-1,2-Dichloroethene, *trans*-1,2-Dichloroethene, and VC). The analyzer was designed to alarm and shut down the SPH system if the effluent of the secondary vessel was measured above the alarm set points. The alarm set points were 19 ppmv TCE; 20 ppmv VC; 25 ppmv *cis*-1,2-Dichloroethene; and 25 ppmv *trans*-1,2-Dichloroethene. These alarm set points were established in accordance with Kentucky Division of Air Quality recommendations by applying Environmental Protection Agency Region 9 Preliminary Remediation Goals at the PGDP fence line. Additionally, air modeling was performed to determine potential exposure levels. The alarms were then set so as not to exceed the Preliminary Remediation Goals.

The treatment process for the liquid waste stream passed through an ion exchange resin vessel to capture any ^{99}Tc that may have been collected. The liquid waste stream also passed through liquid GAC vessels, two 150-lb carbon drums placed in parallel, to remove TCE. The GAC vessels were placed in parallel to allow sufficient volume to flow through the vessels once silt began to collect within the original vessel.

The SPH treatability study was scheduled to operate for 130 days. However, a 45-day extension was implemented due to positive TCE extraction and the desire to determine if an increase in temperatures at the base of the RGA could be achieved. Upon completion of the study, the remedial effectiveness of the system in the UCRS was verified by collecting post-treatment soil samples from new borings adjacent to selected baseline borings. Sample locations will be placed in Figure 1.2 in the D2 version of this report. Post-treatment groundwater samples were collected from the multi-port monitoring wells, and the data compared to the baseline data to determine the treatment system effectiveness. A comparison of groundwater sampling data is presented in Section 4.

1.3.1 Treatment Process and Scale

This treatability study was intended to provide the performance data needed to determine the feasibility of electrical resistance heating (ERH) to treat TCE sources at the PGDP. The scale of the treatability study involved integration and performance of the components of a full-scale, multiple electrode ERH system in a single treatment area field test. The volume of soil treated is governed by the power delivery capability of the SPH transformer. For this treatability study, the SPH array treatment area was 9 m (30 ft) in diameter, heating a subsurface treatment area measuring 13 m (43 ft) in diameter.

1.3.2 Operating Features

The following are examples of operational features that were included in the SPH treatment system design to conduct the treatability study safely and efficiently at the southeast corner of the C-400 building:

- The exhaust of the treated vapor stream was continuously monitored by a photoacoustic analyzer. The photoacoustic analyzer measured the contaminant concentrations approximately every 63 seconds. If the vapor stream exceeded the alarm set points, the analyzer would trigger an alarm and the SPH system would automatically shut down and operators would be notified through an automated auto-dialer system.

- The vapor treatment process was maintained at a slight vacuum (negative pressure); in the event of a leak, outside air would be drawn into the piping and vessels instead of releasing TCE vapors to the atmosphere prior to treatment.

- A negative pressure vapor treatment process also provided the ability to dilute the vapor stream for optimal loading of the GAC vessels to prevent an excessive GAC temperature rise through heat adsorption.

- A total of 15 vacuum piezometers, as shown in Figure 1.2, were installed within and around the treatability study area. The piezometers were used to monitor temperature increases and steam migration along the UCRS and RGA interface. The piezometers within the treatment area contained screens and were connected to the VR system to collect any potential steam migration before it exited the treatment area.

1.4 PREVIOUS TREATABILITY STUDIES AT THE SITE

Three treatability studies have been conducted to investigate methods for reducing or remediating the VOC contamination at the C-400 building.

The first, using a chemical co-solvent, was conducted in 1994 at the southeast corner of the C-400 building using existing monitoring wells. The results are reported in the *In- Situ Decontamination of Sand and Gravel Aquifers by Chemically Enhanced Solubilization of*

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Multiple-Component DNAPLs with Surfactant Solutions, submitted by Intera Inc., in January 1995 (INTERA 1995).

Two additional studies were bench scale studies conducted as part of the WAG 6 RI. One looked at other surfactants and co-solvents, while the other looked at chemical oxidation. The results of these studies are documented in *Surfactant Enhanced Subsurface Remediation Treatability Study Report for the Waste Area Grouping* 6 *at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1788&D2, and in *Bench Scale In-Situ Chemical Oxidation Studies of Trichloroethene in Waste Area Grouping* 6 *at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07- 1788&D2, respectively.

2. CONCLUSIONS AND RECOMMENDATIONS

2.1 CONCLUSIONS

2.1.1 Primary Objective

The primary objective of the treatability study as described in the *Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant*, Paducah, Kentucky (DOE 2001a) was to demonstrate the implementability of this technology for the unsaturated and saturated areas of the UCRS soil and for the groundwater of the RGA. A successful implementation would heat the soils in the UCRS and groundwater in the RGA to a temperature that allows steam and vapors containing the TCE to rise and be removed by the VR wells and treated by the vapor treatment system.

Removal efficiency criteria were outlined in a fact sheet titled *Six-Phase Heating Technology Assessment* (GEO 2003) included as Appendix B. The criteria for evaluating the success of the SPH treatability study are the assessment of removal efficiency using co-located soil and groundwater sampling. The criteria for success included a greater than 75 percent reduction of TCE soil concentrations in the UCRS and a reduction of TCE groundwater concentrations to less than 1 percent (11,000 ppb) solubility in the RGA.

The removal efficiency of TCE in the UCRS can be assessed by a comparison of baseline soil sampling results to post treatment soil sampling results. The following timeline shows the dates of soil sampling events.

July-August, 2002	Baseline soil sampling performed
September, 2003	Post treatment soil sampling performed

Baseline soil sampling results indicated an average TCE concentration of 125,111 ppb, with a maximum concentration of 2,900,000 ppb found at piezometer VP-4. Post treatment soil sampling results indicated an average TCE concentration of 2,493 ppb, with a maximum of 112,500 ppb found next to piezometer VP-6. The average reduction in TCE concentration was 98 percent, which significantly exceeded the target of 75 percent reduction in soil concentrations.

The removal efficiency of TCE in the groundwater of the RGA can be assessed by a comparison of baseline groundwater sampling results to post treatment groundwater sampling results. The following timeline shows the dates of groundwater sampling events.

January 10, 2003	Baseline groundwater sampling performed
May 5, 2003	60 Percent groundwater sampling performed
June 23, 2003	87 Percent groundwater sampling performed
September 8, 2003	Post Treatment groundwater sampling performed
September 22, 2003	Two-week Post Treatment groundwater sampling performed
October 7, 2003	Four-week Post Treatment groundwater sampling performed

Comparison of results from these sampling events indicates that the TCE removal efficiency criteria were met as a result of the SPH treatability study. The average baseline groundwater concentration from monitoring wells MW406 and MW407, located within the treatment area, was 645,000 ppb. Results of the post treatment groundwater sampling from these same locations indicated an average TCE concentration of 5,770 ppb, with a maximum of 9,440

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ppb in MW406. All groundwater samples from locations inside the electrode treatment area were reduced to less than 1 percent TCE solubility (11,000 ppb) and accounted for a 99.1 percent reduction in TCE concentrations in groundwater from baseline concentrations. While a number of the two- and four-week post treatment sample concentrations have increased from the post treatment results, all samples have remained below the 1 percent TCE solubility limit of 11,000 ppb. TCE concentrations in groundwater are summarized in Table 4.1 of Section 4.1.2.2.

2.1.2 Operational Parameters

The following operational parameters were evaluated to determine the effectiveness of the system and the impact of the SPH technology on current PGDP operations:

Steam and Temperature Decay Rates - The steam and temperature decay rates of the treatment area are based on three data points collected since the conclusion of active heating on September 6, 2003. The post-heating average temperatures from the treatment area are listed below in Table 2.1.

Table 2.1. Average Decay of Heat inside the Treatment Area

Depth (ft. bgs)	Average Treatment Area Temperature at Shutdown (9/5/03)	Average Treatment Area Temperature after 5 days (9/10/03)	Average Treatment Area Temperature after 64 days (10/29/03)	Average Daily Heat Loss
5	75*	62	46	-0.5
15	85	77	64	-0.4
25	97	89	76	-0.4
35	102	95	83	-0.4
45	102	99	93	-0.2
55	105	102	96	-0.2
65	110	105	74	-0.7
75	107	86	53	-1.0
85	95	70	46	-0.9
95	69	68	49	-0.4
105	53	54	46	-0.1

* All temperatures are presented in °C

The rate of heat loss varied between the UCRS and the upper McNairy formation. The upper unsaturated zone of the UCRS, which is losing heat faster than the lower saturated UCRS, is likely experiencing the impact of ambient air moving through the pore spaces of the formation. The saturated UCRS and upper McNairy formation are cooling slower than the other depth zones due to the insulating effect of the saturated soil and the relatively slow movement of groundwater flow. As expected, the saturated zone of the RGA is cooling faster than all other depth zones in the treatment area. The rapid movement of groundwater through the treatment area is the mechanism that is removing more heat than other depth intervals.

The rate of heat loss since the conclusion of active heating has been consistent with the temperature changes observed during the SPH application. The retention of heat by the subsurface has no detrimental effects on a full-scale application of the SPH technology and is also consistent with the rate of heat loss seen at many other SPH applications. The heat loss in the

RGA further asserts the need for a full-scale electrode design that can compensate for the rapidly moving groundwater of the formation.

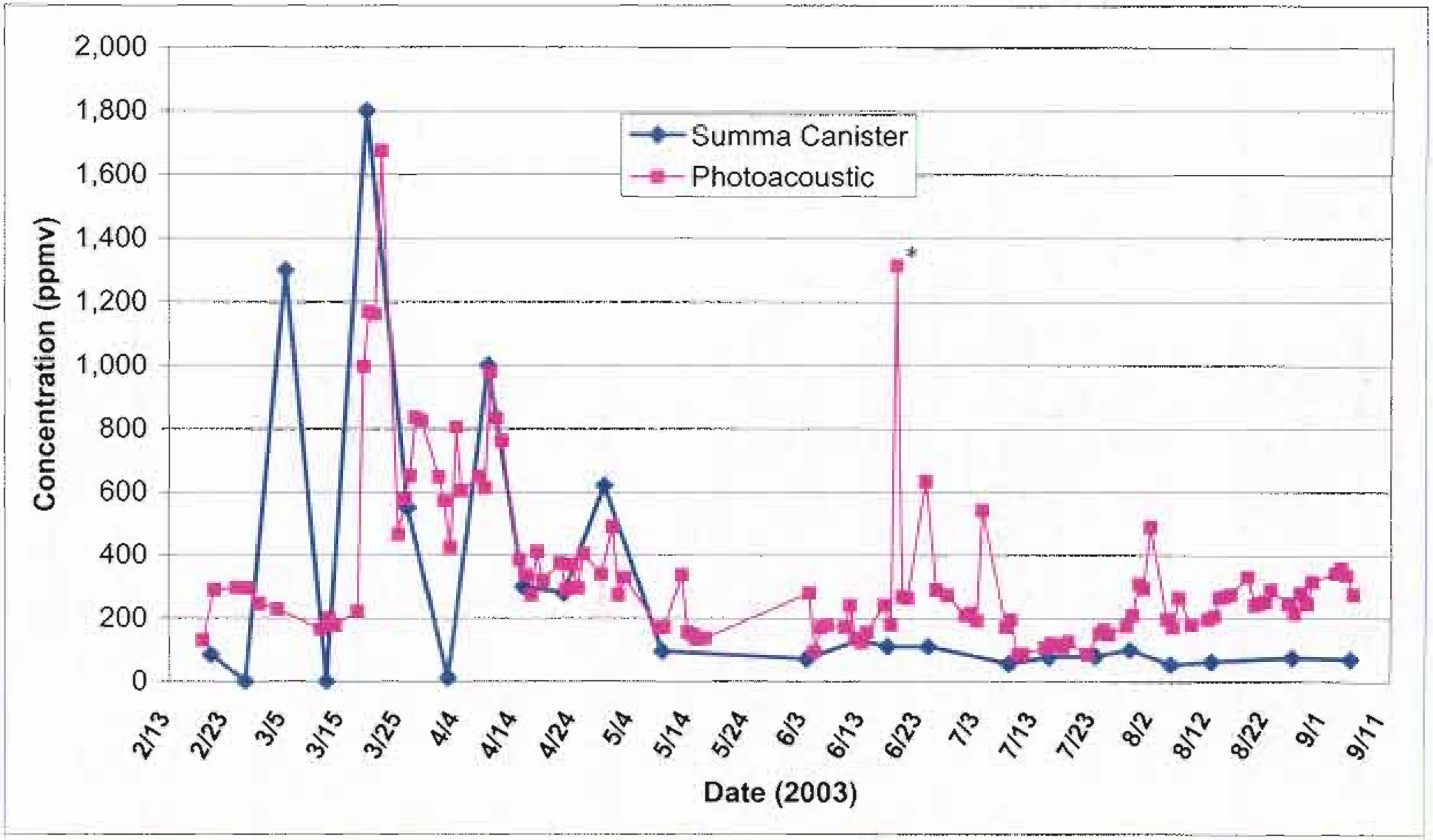
Temperature Gradients throughout the Test Cell – The criterion used to evaluate temperature gradient was the uniform heating of the treatment area to the boiling point of water at depth inside the electrode treatment area. As described in Section 4.1, this goal was achieved in the UCRS and shallow RGA from 1.5 to 23 m (5 to 75 ft) bgs but not in the deep RGA from 23 to 29 m (75 to 95 ft) bgs. The technology has the ability to heat the subsurface at the southeast corner of the C-400 building but did not fully reach the temperature goal due to electrode malfunctions in electrode design as described in Section 2.2. However, the treatment system did heat the treatment region to above the boiling point of TCE DNAPL. The implementation of recommendations described in Section 2.2 could be used in a full-scale application for improved electrode performance.

TCE Removal Rates as a Function of Operational Time and Energy Consumption - The TCE removal rate was quantified by two different sampling methods during treatability study operations, daily using a photoacoustic analyzer and weekly using summa canisters configured to collect a 24-hour integrated sample. A comparison of the TCE removal rates using photoacoustic analyzer and summa canisters is displayed in Figure 2.1. The vapor recovery system extracted a baseline TCE concentration of 130 ppmv from the non-heated treatment area prior to active heating. As shown in Figure 2.1, the trending of the daily photoacoustic analyzer readings shows a sharp increase in vapor waste stream concentration to approximately 1,700 ppmv on March 20, 2003. The analytical results from the summa canister collected on March 19, 2003 show a similar peak in concentration of 1,800 ppmv. The TCE concentration decreases by both measurement techniques over the next three weeks yet still averaged approximately 600 ppmv. The vapor waste stream decreased further around April 20, 2003 and did not consistently return to greater than 400 ppmv for the remainder of active heating. These data, combined with the results of the 60 percent groundwater sampling event starting on May 3, 2003, indicate that a significant amount of the TCE contamination was removed during the first 60 percent of energy application.

The amount of energy input to the subsurface was closely aligned with the original estimate for the treatability study operation. A total of 2,283,850 kilowatt-hours were input into the subsurface, while the original estimate was 1,927,000 kilowatt-hours for remediation of the treatment area.

Constructability of the System in the C-400 Building Area – The constructability of a full-scale application of a SPH system should only be impaired by the accessibility to the south side of the C-400 building during electrode installation. Electrodes would be installed in the areas of highest contaminant concentration based on existing plume maps, historic and SPH treatability study data. A large bay door on the south side of the C-400 building is used by the United States Enrichment Corporation (USEC) personnel to transport materials in and out of the building. The electrodes could be installed and operated below grade without interfering with the daily operations of the building. However, the bay door would be obstructed during electrode installation and system construction. Angled electrode borings and other construction methods could be implemented to minimize the impact to the C-400 building operations. Angled electrode borings could be used to remediate areas under the outside TCE-storage tank, gantry crane, building bay door and loading pad without requiring demolition. Angled electrodes could also be used to extend the treatment area 6 to 9 m (20 to 30 ft) under the C-400 building footprint.

Construction and Operation Costs as a Function of TCE Mass Removed or Destroyed (Cost-Effectiveness) – An estimated 22,856 lbs of TCE was removed from the vapor waste stream during SPH operations (described in Section 4.1.1). Using a unit weight for TCE of 12.11 lbs per gallon, a total of 1,887 gallons were removed. Using an estimated cost for the treatability study of $6.3 million would relate to a cost of $3,338 per gallon of TCE removed.



* The photoacoustic sample from June 18, 2003, was collected immediately after system restart following an extended shutdown. Process knowledge has shown that TCE extraction rates increase following startup after an extended shutdown.

Note: Additional concentration spikes from the photoacoustic analyzer may have occurred due to contaminant concentrations being measured with the photoacoustic analyzer once per workday versus summa canister samples being integrated once per week for a 24-hour sampling period. Contaminant concentrations could have varied greatly between sample periods with the photoacoustic analyzer. Additionally, contaminant levels often increased if the vacuum blower had been shut down for an extended period of time.

Figure 2.1. Vapor Waste Stream Comparison, Photoacoustic and Summa Canister Data

The Effect of the SPH System on Adjacent Utilities and Facilities – Air samples were collected at four separate subsurface locations adjacent to the SPH treatability study site. Samples were collected to ensure and document that workers in adjacent facilities were not being exposed to VOC contaminants generated by SPH operations.

During the first 30 days of system operation, air samples were collected daily from the C-400 building basement and from three locations in a tunnel located just east of the SPH site. The samples were collected using gas indicator tubes designed to identify TCE and VC. Neither contaminant was detected during the initial 30-day time period. Therefore, the sampling frequency was reduced to weekly. Gas indicator tubes indicated no detections of TCE or VC for the duration of SPH operations. The detection limits were 2 parts per million (ppm) for TCE and 0.5 ppm for VC.

Additionally, for the first 10 weeks of SPH operations, air samples were collected weekly at the same four locations using summa canisters configured to collect a 24-hour integrated sample. Summa canisters were analyzed for VOCs with detection limits of 0.5 ppmv. During the week of March 17, 2003, TCE was detected at 2.8 ppmv in the summa canister sample collected from the C-400 basement. The positive TCE result was evaluated and determined to have originated from seep water in the sump surrounding an abandoned TCE storage tank located in the C-400 building. However, as a precaution, and for the remainder of the project, one of the summa canister sample locations was changed from the tunnel to the office area of the C-400 building. Additionally, sample collection was reduced from weekly to bi-weekly for the remainder of the project. All results from samples collected in the C-400 building office area were non-detect.

An additional TCE detection occurred during SPH operations. The C-400 basement sample collected during the week of May 12, 2003 had an estimated TCE detection of 0.5 ppm. The positive TCE result was again determined to have originated from the seep water in the sump surrounding the abandoned TCE tank in the C-400 building. There were no other detections of the contaminants of concern throughout SPH operations.

2.2 LESSONS LEARNED AND RECOMMENDATIONS

Topic

Heated groundwater may have migrated from the treatment area.

Description

Thermocouples located in the borings of monitoring wells MW405 and MW408 outside the treatment area indicated that heated groundwater may have migrated from the treatment area during the treatability study (Figures 4.3 and 4.4), particularly near the middle of the RGA at approximately 23 m (75 ft) bgs. However, the heated groundwater did not appear to carry significant TCE mass because the VOC concentrations in MW405 and MW408 decreased as the heated groundwater encroached upon them. The horizontal flow of groundwater is discussed further in Section 4.1.

Solution / Recommendation

A hydraulic control system could be incorporated into a full-scale design to prevent the spread of heated groundwater; however, the cost of such a system may not be justified because of the lack of detrimental effects shown during the treatability study. Edge effects, including hot groundwater spreading, become relatively less important as the treatment area increases.

Topic
Electrodes failed to heat six discrete intervals.

Description
The treatability study electrodes were designed to include six independent electrically conductive elements at various depths. Steel shot was used as an electrode backfill. During electrode installation, the high density of the steel shot column potentially displaced the electrical insulating materials (bentonite) that separated the six elements and, therefore, caused each electrode to function as a single element with no vertical differentiation. The high backfill density and structural instability could have disconnected the two deepest electrode intervals and prevented sufficient power from reaching these depths for active water boiling.

Solution / Recommendation
The electrode design should be adapted in a full-scale application to prevent the electrical connection, settling, and weight issues discovered during the SPH treatability study. The density of the conductive backfill material could be lowered by using a combination of steel and graphite backfill to reduce the electrode's ability to shift within an unstable RGA formation. The cable that supplies power to the individual electrode intervals should have one electrical connection and one structural connection that will absorb the stress of any movement or settling. A simpler electrode design would incorporate three electrode elements (one each in the UCRS, the RGA, and the upper McNairy formation) rather than the six intervals used during the treatability study. The electrodes were not able to create a thermal barrier or "hot floor" as designed, but no evidence suggests that DNAPL migrated down to the McNairy Formation, as a result of heating during the treatability study and the use of a thermal barrier may not be warranted in a full scale application. The electrode element isolators should be made of cement grout or sand to prevent dissipation and failure; bentonite should not be used in a weight bearing application.

Topic
Influx of sediments into the treatment system clogged system components

Description
The shallow vapor recovery screens located from 1.5 to 2 m (5 to 7 ft) bgs were pulling sediments into the condenser knockout pots. Periods of rain would saturate the surface soil and lower the permeability of the shallow soil of the treatment area, which would then begin to act as a vacuum cap. The vacuum inside the treatment area would increase due to the lack of airflow through the soil. The elevated vacuum in the shallow soil created air channels to the surface around the electrode's concrete surface seal. The velocity of the ambient air stream moving through a small channel transported a high volume of sediments into the vapor recovery wells and into the condenser. These sediments accumulated in the knockout pots and eventually clogged the liquid GAC vessels resulting in system shutdown.

Solution / Recommendation
The air channels were filled with concrete and the electrode seals were extended horizontally away from the electrodes to provide better surface isolation. A 6-millimeter Visqueen™ cap was installed over the treatment area to help maintain stable soil permeability. Additionally, the vacuum applied to the treatment area was decreased. These changes drastically reduced the amount of sediment collected in the condenser components during remaining operations. The design of a full-scale application should incorporate a treatment area cap where shallow vapor recovery is necessary. The cap should be constructed of plastic sheeting, concrete, or asphalt to

maintain stable permeability. Particulate filters should be installed prior to the condensate water treatment system to aid in capturing any fine sediment that may be pulled into the condenser by the vapor recovery system.

Topic

Higher than expected VOC readings observed in the breathing zone during subsurface installation.

Description

Photoionization detector (PID) readings indicated VOCs in ambient air in the vicinity of the borings during drilling, sample collection, and other installation activities. Based on historical data and process knowledge, VOCs measured in the ambient air during installation activities were probably vapors from the volatilization of TCE. However, due to the detection of larger quantities of VOCs and an elevated PID reading in the breathing zone of an employee (>300 ppmv), the presence of TCE degradation byproducts (specifically VC) became a concern.

Solution / Recommendation

Two summa canister grab samples were collected from the open boring of Electrode #4 at two depths. One sample was collected at approximately 6 m (20 ft) bgs and the other sample collected at approximately 15 m (50 ft) bgs. Results from these samples estimated the presence of small quantities of VC in the boring (16,000 and 14,000 parts per billion by volume [ppbv]). However, the presence of extremely high levels of TCE (380,000 ppbv) resulted in high detection limits and VC sample results could not be validated to a high degree of certainty. Area monitoring was conducted for a period of 10 working days to confirm the presence of VC in the work area. Monitoring was performed in conjunction with the use of level B PPE and feasible engineering controls. The monitoring consisted of the continuous collection of carbon tube samples in the breathing zone of workers when the potential existed for worker exposure to VC. The sample media were changed every 15 minutes in order to obtain a 15 minute Time Weighted Average (TWA). The sampling was conducted in accordance with National Institute for Occupational Safety and Health (NIOSH) Method 1007 to obtain a 95 percent confidence level for VC concentrations.

The VC charcoal tube samples were shipped to an American Conference for Governmental Industrial Hygienists (ACGIH) accredited industrial hygiene laboratory for analysis. All laboratory sample results for the VC samples were non-detect below the regulatory limits of 1 ppm TWA and a 5 ppm ceiling. Results of these analyses can be found in Appendix C. As a result, PPE requirements were downgraded from Level B to Level C.

3. TREATABILITY STUDY APPROACH

3.1 TEST OBJECTIVES AND RATIONALE

The primary objective of the treatability study as described in the *Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant*, Paducah, Kentucky (DOE 2001a) was to demonstrate the implementability of this technology for the unsaturated and saturated soils of the UCRS and for the groundwater of the RGA. A successful implementation would heat the soils and groundwater in both the UCRS and RGA to a temperature that allows steam and vapors containing the TCE to rise and be removed by the VR wells and treated by the vapor treatment system.

Removal efficiency criteria were outlined in the *Six-Phase Heating Technology Assessment* (GEO 2003). The criteria for evaluating the success of the SPH treatability study are the assessment of removal efficiency using co-located soil and groundwater sampling. The criteria for success included a greater than 75 percent reduction of TCE soil concentrations in the UCRS and a reduction of TCE groundwater concentrations to less than 1 percent solubility (11,000 ppb) in the RGA.

The removal efficiency of TCE in the UCRS can be assessed by a comparison of baseline soil sampling results to post treatment soil sampling results. The following timeline shows the dates of soil sampling events.

July-August, 2002	Baseline soil sampling performed
September, 2003	Post treatment soil sampling performed

Baseline soil sampling results indicated an average TCE concentration of 125,111 ppb. Post treatment soil sampling results indicated an average TCE concentration of 2,493 ppb. The average reduction in TCE concentration was 98 percent, which significantly exceeded the target of 75 percent reduction in soil concentrations.

The removal efficiency of TCE in the groundwater of the RGA can be assessed by a comparison of baseline groundwater sampling results to post treatment groundwater sampling results. The following timeline shows the dates of groundwater sampling events.

January 10, 2003	Baseline groundwater sampling performed
May 5, 2003	60 Percent groundwater sampling performed
June 23, 2003	87 Percent groundwater sampling performed
September 8, 2003	Post Treatment groundwater sampling performed
September 22, 2003	Two-week Post Treatment groundwater sampling performed
October 7, 2003	Four-week Post Treatment groundwater sampling performed

Comparison of results from these sampling events indicates that the TCE removal efficiency criteria were met as a result of the SPH treatability study. The average baseline groundwater concentration from monitoring wells MW406 and MW407, located within the treatment area, was 645,000 ppb. Results of the post treatment groundwater sampling from these same locations indicated an average TCE concentration of 5,770 ppb, with a maximum of 9,440 ppb in MW406. All groundwater samples from locations inside the electrode treatment area were reduced to less than 1 percent TCE solubility (11,000 ppb) and accounted for a 99.1 percent reduction in TCE concentrations in groundwater from baseline concentrations. While a number of the two- and four-week post treatment sample concentrations have increased from the post treatment results, all samples have remained below the 1 percent TCE solubility limit of 11,000 ppb. TCE concentrations in groundwater are summarized in Table 4.1 of Section 4.1.2.2.

3.2 EXPERIMENTAL DESIGN AND PROCEDURES

The design process involved adapting field-proven and successful SPH designs to the unique hydrogeology (having a broad mix of lithologies) of the C-400 building area. Unique characteristics of the C-400 lithology included the extremely high permeability of the RGA, which is overlaid by the lower permeability UCRS and included the depth of desired treatment (about 30 m [98 ft] bgs). Design features were incorporated to address these unique features and are described below.

3.2.1 Electrode Design Adaptation for C-400 Building Lithology

When performing a treatability study of any remedial technique, the study must include rigorous verification that the remedial technique does not spread the contamination or have other undesirable side effects. In the case of the SPH treatability study at the C-400 building, the principal potential side effect was considered to be lateral spread of TCE-laden steam, either in the saturated or vadose zones. In particular, a steam bubble might collect at the top of the highly permeable RGA instead of migrating through the UCRS. If such a steam bubble grew to a sufficient size, then steam could move laterally along the underside of the UCRS and carry TCE mass from the treatment area without being treated.

The treatability study incorporated several electrode features to reduce the potential for the spread of TCE vapors such as co-located vapor recovery wells in the same borehole. The SPH treatability study electrodes included three independent vapor recovery mechanisms with separate casings:

- A shallow vapor recovery well at 1 to 2 m (3 to 6 ft) bgs
- A deep vadose zone vapor recovery well 7 to 9 m (23 to 30 ft) bgs
- A steam vent that was capable of allowing steam recovery from near the top of the UCRS water table 10 to 11.5 m (32 to 37 ft) bgs and from the top of the RGA 15 to 18 m (51 to 59 ft) bgs

In addition to the three vapor recovery/steam casings, the electrodes were constructed of highly permeable steel shot and sand. The permeable backfill allowed for vertical migration of any steam generated at depth in the RGA.

To enhance vapor recovery, the vapor recovery wells were initially operated at a vacuum of 10 to 15 inches of mercury (in. Hg). As the study progressed, the high vacuum was not required to maintain vapor capture, and the applied vacuum was decreased to a range of 4 to 6 in. Hg.

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3.2.2 Vacuum Piezometer Design Adaptation for C-400 Building Lithology

Because of concerns regarding the potential for steam and TCE vapor to spread laterally during the study (especially at the UCRS/RGA interface), 15 vacuum piezometers were installed at the site. The vacuum piezometers provided monitoring capability at four depths bgs: 3m (10 ft), 6m (20 ft), 9m (30 ft), and at the top of the RGA, 15 to 18 m (49 to 59 ft).

Nine of the vacuum piezometers were installed within the electrode treatment area vacuum piezometers (VP-1 through VP-8 and VP-10). The RGA vents of the internal piezometers were connected to the VR system to aid in the recovery of a potential steam bubble. However, monitoring data collected during operations showed no indication that a steam bubble had formed at the top of the RGA.

Thermocouples were installed in VP-3, VP-5, VP-9, and VP-10 within the treatment area and in VP-11 and VP-13 outside the treatment area. The thermocouple depths were 5, 11, and 17 m (17, 37, and 57 ft) bgs. Manual readings from thermocouples installed within the treatment area indicated that the surrounding soil was heated as expected. Thermocouples in VP-11 and VP-13 were expected to indicate slow heating through thermal conduction. The thermocouple at 17 m (56 ft) bgs in VP-11 indicated that temperatures had reached the boiling point of water very late in the treatability study – on or around July 9, 2003. However, VP-11 did not indicate the buildup of positive pressure to suggest that a steam bubble had spread to this location.

All 15 vacuum piezometers also provided for vacuum measurement at three depths in the vadose zone. A review of data throughout system operations did not provide evidence that TCE vapor was spread laterally during the treatability study.

3.2.3 Design Adaptations Due to Depth of Treatment

SPH treatability study depth extended from near ground surface to about 30 m (99 ft) bgs. This is almost twice as deep as previously constructed SPH systems. Although the increased depth interval was not a complicating factor in itself, the greater depth did cause the study to intersect more varied lithologic zones than at previous SPH sites. The greater depth also provided an impetus to evaluate the variations in effectiveness with depth and lithologic zone. This led to a design that included six different electrode elements to independently direct heat to various depth zones: 1.5 to 5 m (5 to 16 ft) bgs (shallow vadose zone), 5 to 12 m (16 to 39 ft) bgs (deep vadose zone), 12 to 17 m (39 to 56 ft) bgs (saturated UCRS), 17 to 23 m (56 to 75 ft) bgs (shallow RGA), 23 to 27 m (75 to 89 ft) bgs (deep RGA), and 27 to 30 m (89 to 98 ft) bgs (upper McNairy formation). The design also allowed for the 27 to 30 m (89 to 98 ft) bgs electrode interval to be heated before the electrode interval above it to provide a thermal barrier or "hot floor" to prevent potential downward DNAPL migration.

The design included a combination of borings used for electrodes and VR functions. As described above, the VR wells incorporated three independent casings and the electrodes incorporate six independent depth elements. Ideally, two boreholes would have better contained all of the components. However, the treatability study region was small and the desire to thoroughly monitor TCE vapor capture using 15 vacuum piezometers and groundwater quality using four monitoring wells resulted in a high density of borings. An additional 14 borings would have been required if the electrodes and VR wells were installed in separate borings. Ultimately, limited space led to a decision to place all electrode and VR functions in a single borehole, resulting in a total of seven co-located electrodes and VR well borings.

3.3 EQUIPMENT AND MATERIALS

The following list provides the primary equipment and materials that were necessary for installation of the SPH system. A complete list and specifications can be found in the *Construction Quality Control Plan for the Six-Phase Heating Treatability Study at the Paducah Gaseous Diffusion Plant* (DOE 2001c).

- CME-75 Drill Rig
- 10-1/4" augers
- 8-1/4" augers
- 4-1/4" augers
- Support vehicles and decontamination equipment
- Components to construct electrodes, monitoring wells, and piezometers
- Boom truck for electrical installation
- Forklift
- SPH power control unit
- Electric utility supply line
- Computer
- Data acquisition software
- Temperature sensors
- Steam and vapor treatment system and accessories
- VR system
- Phone line, remote telemetry unit

3.4 SAMPLING AND ANALYSIS

The overall sampling strategy for the SPH treatability study focused on the soils in the UCRS and groundwater in the RGA. Analytes of interest were the organic compounds TCE and its degradation byproducts, as well as benzene, carbon tetrachloride, and chloroform; radionuclides; metals; geochemical parameters such as pH, oxidation-reduction potential (Eh), conductivity, dissolved oxygen, temperature, and soil moisture; and major anions and cations.

Sampling for the SPH treatability study consisted of groundwater and soil sampling as described below.

3.4.1 Groundwater Sampling

Four multi-port monitoring wells were installed to collect groundwater samples. One of the groundwater monitoring wells was placed upgradient (south) of the treatment area, two of the monitoring wells were placed within the treatment area, and one monitoring well was placed downgradient (north) of the treatment area (Figure 1.2). Each multi-port monitoring well has seven sampling ports, which made each well equivalent to a multi-well cluster. Each of the four multi-port monitoring wells contains seven independent sampling ports. The shallowest port located in the lower UCRS 11 m (36 ft) bgs never yielded groundwater. Five ports were located in the RGA formation 20 to 27 m (66 to 89 ft) bgs, and the deepest port was located in the McNairy formation at 32 m (105 ft) bgs.

The first groundwater sampling event was conducted on January 10, 2003, prior to heating activities to establish a baseline. Progress groundwater sampling events were conducted during the operational phase of the treatability study. In accordance with the SPH design, one groundwater sampling event occurred when SPH operations were approximately 60 percent complete and a second groundwater sampling event occurred when SPH operations were at about 87 percent complete. Beginning on September 8, 2003, at the completion of the extended soil heating operational period (before the soil and groundwater had a chance to cool down), groundwater samples were collected again to compare to the baseline sample data to evaluate the performance of the technology. A comparison of the data is presented in Section 4.

Two additional groundwater sampling events for TCE analysis only were added to the scope following post operation sampling to assess and quantify the amount of contaminant rebound. The sampling events were conducted beginning on September 22, 2003 and October 7, 2003, respectively. A comparison of this data is presented in Section 4.

3.4.2 Soil Sampling

Soil sampling was conducted during the subsurface installation phase of the treatability study to quantify the amount of TCE in the UCRS prior to remediation. Soil samples were taken at piezometer locations VP-1 through VP-8 inside the treatment area and piezometer locations VP-9 through VP-11 surrounding the treatment area (Figure 1.2). Samples were collected in 2- ft intervals from the surface to 58 ft bgs.

At the conclusion of heating, nine soil borings were installed to measure soil residual contamination concentrations after applying the technology. These borings were located adjacent to piezometer locations (VP-1 through VP-8 and VP-10) where baseline soil samples were collected to establish pre-test contaminant levels. The soil samples were collected from the same depths as the baseline samples and analyzed for the same analytes and parameters tested for in the baseline soil samples. Post treatment soil sampling results show an average reduction in TCE concentration of 98 percent, which is significantly higher than the target reduction of 75 percent. The average TCE concentration was reduced from a pre-test level of 125,111 ppb to a post treatment average of 2,493 ppb.

In each of the monitoring well installation borings that extend to the base of the RGA, a soil sample was collected across the RGA/McNairy formation interface, or within the uppermost McNairy formation, to aid in determining the presence of pooled DNAPL. Field analysis of this soil sample, based on readings of a PID and visual observations, were used to assess the local presence of a DNAPL pool. No significant thickness of pooled DNAPL was identified in any of the soil samples. However, based on the lithology observed in the soil cores collected at MW-408 between 90' and 100' bgs, the interface between the RGA/McNairy formations was not clearly evident. Although additional soil cores could not be collected due to sand that back-filled the augers, the borehole was advanced to 120' bgs to try to locate the interface by a change in drilling conditions. After advancing the borehole to 120' the boring was terminated after experiencing no change in drilling conditions. The RGA/McNairy interface may be shallower or deeper than expected in this location.

3.5 DATA MANAGEMENT

3.5.1 Data Management Activities

Data management activities for the treatability study encompassed managing the life cycle of environmental data from planning through the collection, review, and actual usage of the data for decision-making purposes to the long-term storage of data. The environmental measurements data management process contained the following major activities: sampling and analysis planning, field preparation, field data collection, data review, data assessment, and data consolidation and use.

The data coordinator and the Project Environmental Measurements System (PEMS) coordinator, as well as the data manager and BJC sample manager, performed data management activities. The Data Coordinator ensured that the requirements of the data management plan were met. The Data Coordinator was responsible for managing the site characterization data for the treatability study. This management activity includes accumulation, control, validation, and storage of site characterization and performance data as part of the treatability study. Data, including chain-of-custody information, field measurements, and laboratory data, were entered into Paducah PEMS.

Paducah PEMS is the data management tracking system for the treatability study, which includes field forms, chain-of-custody records, and hard copy data packages as well as electronic data deliverables (EDD). Laboratory chain-of-custody (COC) forms, labels, and logbook stickers were generated from Paducah PEMS. Paducah PEMS was used to identify, track, and monitor each sample and associated data from point of collection through final data reporting.

The BJC Sample Manager developed the analytical statement of work (SOW) to be implemented by a laboratory for analysis of treatability study samples. Analytical methods, detection limits, minimum detectable activities, and deliverable requirements were specified in this SOW. The BJC Sample Manager provided the SOW information to the CDM Data Coordinator for populating the Paducah PEMS database. Once samples were delivered and analyzed by the analytical laboratory, the BJC Sample Manager received the EDDs and performed a contractual screening/verification. The BJC Sample Manager interacted with the Data Coordinator to ensure that hard copy and EDD formats were properly specified and interface with the laboratory to ensure that the requirements were understood and met.

The BJC Data Manager interfaced with the Data Coordinator for oversight of Paducah PEMS and to ensure that data deliverables met BJC requirements. The BJC Data Manager entered information related to the fixed-base laboratory data packages and the tracking associated with samples once the samples were shipped from the laboratory and receipt of samples was verified. The fixed-base laboratory EDDs and the field measurement data were loaded into Paducah PEMS by the PEMS Coordinator. The Data Coordinator was responsible for data verification, validation, assessment, and preparing the data for transfer from Paducah PEMS to the Paducah Oak Ridge Environmental Information System (OREIS). The BJC Data Manager was responsible for transferring the data from the ready-to-load files supplied by the data coordinator to the Paducah OREIS database.

3.5.2 Field Data Collection

Prior to field sampling, sample containers, labels, preservatives, chain-of-custody records, and procedures for collecting samples were generated or prepared for performing the sampling event. Field measurements were collected during groundwater sampling using a Horiba Model U-22 Water Quality Meter and consisted of conductivity, dissolved oxygen, Eh, pH, and temperature. A Hach test kit was used to analyze for total residual chlorine in groundwater samples. Soil, groundwater samples, and wastewater were collected according to the following procedures:

CDM-005	Development, Completion and Control of Data Forms and Logbooks
CDM-006	Sample Chain of Custody
CDM-008	Sample Tracking and Handling Guidance
CDM-009	Collection of Field Quality Control Samples
CDM-012	Groundwater Monitoring Sampling
CDM-024	Subsurface Soil Sampling
CDM-031	Containerized Waste Sampling

The appropriate frequency of field quality control (QC) samples was collected during the treatability project. Field duplicates, field blanks and equipment rinseates were collected one per every twenty environmental samples. Trip blanks were collected for each cooler that contained samples being analyzed for VOCs. Sample custody was maintained in the field by the field samplers until custody of the samples was transferred to the laboratory for analysis. Samples that were unable to be collected due to poor recovery were noted on the COC, in the field logbook and in Paducah PEMS. Calibration of field measurement equipment (i.e., Horiba) was performed according to manufacturer instructions and recorded in the field logbook.

Field sampling information, such as date and time collected and field measurements, were obtained from the COCs and field logbooks, respectively, and were manually entered into Paducah PEMS according to CDM-007, Data Management Coordination. A QC check was performed, which involves comparing printouts of the data in Paducah PEMS to the COCs and field logbooks.

Operational data were collected in accordance with approved work instructions. Work instructions are located in Appendix D of this report.

3.5.3 Sample Analysis

The BJC Sample Manager coordinated with the analytical laboratory to perform the analysis of treatability study samples. Samples were analyzed according to SW-846 procedures. When not available, other nationally recognized methods such as those of EPA, DOE, and the American Society of Testing and Materials were used. The BJC Sample Manager ensured that hard-copy deliverables and EDDs from the laboratories contained the appropriate information and were in the correct formats.

3.5.4 Laboratory Analytical Data

All data packages and EDDs received from the laboratory were tracked, reviewed, and maintained in a secure environment. Paducah PEMS and/or Paducah OREIS were used for tracking all data. The primary individual responsible for these tasks was the BJC Sample Manager. The following information was tracked: sample delivery group number, date received, number of samples, sample analyses, receipt of EDD, and comments. The PEMS Coordinator downloaded analytical data into Paducah PEMS and then initiated the data review process.

3.5.5 Data Review

The data review process consisted of the verification, validation, and assessment of environmental measurements, waste management data, and analytical data from fixed-base laboratories. The data verification process determined if results were returned for all samples, if the proper analytical and field methods were used, if analyses were performed for the desired parameters, and if the requirements of any laboratory subcontracts were met. The data validation process determined whether proper QC methods were used and whether the results met established QC criteria. The data assessment process determined whether data were adequate for its intended use. Any problems found during the review process were documented and resolved.

3.5.6 Data Verification and Validation

The Data Coordinator was responsible for ensuring that data verification and data validation occurred as outlined in CDM-004, Quality Assured Data. Verification of analytical data can be broken down into two steps: laboratory contractual screening and electronic Paducah PEMS verification. Laboratory contractual screening was the process of evaluating a set of data against the requirements specified in the analytical SOW to ensure that all requested information was received. The contractual screening included, but was not limited to, the COC, number of samples, analytes requested, total number of analyses, method used, QC samples analyzed, EDDs, units, holding times, and reporting limits achieved. The BJC Sample Manager was primarily responsible for the screening upon receipt of data from the analytical laboratory. Electronic Paducah PEMS verification was the process for comparing a data set against a set standard or contractual requirement, specific to the project. The data coordinator performed this electronic verification. Data were flagged, as necessary, and qualifiers were stored in Paducah PEMS for transfer to Paducah OREIS.

Verification of field measurements data consisted of establishing that data are recorded correctly and that field instruments were properly calibrated and ensuring the accuracy and completeness of all field forms and logbooks (e.g., sample information forms, chain-of-custody forms, requests for samples analysis, etc.). Any problems with the data were documented as appropriate in Paducah PEMS.

Data validation was performed in accordance with EPA procedures and was validated at a target frequency of a minimum of 10 percent of all data packages. Data validation is the process of screening data and accepting, rejecting, or qualifying the data on the basis of sound criteria. Data were validated, as appropriate, based on holding times, initial calibration, continuing calibration, blank results, and other QC sample results. The independent Data Validator performed validation according to the following procedures:

CDM-025	Volatile and Semivolatile Analytical Data Validation
CDM-026	Inorganic Analytical Data Validation
CDM-027	Pesticide and PCB Analytical Data Validation
CDM-028	Radiochemical Analytical Data Validation
CDM-029	Wet Chemistry Analytical Data Validation

Upon receipt of validated Form I's, the validated packages were tracked. Validated results were manually entered into Paducah PEMS. These results included data validation qualifiers. A QC check was made of the electronic data against the hard copy and validated Form I's. If the EDD did not match the Form I, either the laboratory was required to resubmit the EDD or manual changes were made to the data in Paducah PEMS.

3.5.7 Data Assessment

Data assessment was conducted and documented according to procedure CDM-004, Quality Assured Data. The data review process determines whether a set of environmental data satisfies the data requirements defined in the project scoping phase. This process involves the integration and evaluation of all information associated with a result. Data review consists of an evaluation of the following: data authenticity; data integrity; data usability; outliers; and precision, accuracy, completeness, and comparability parameters.

3.5.8 Data Consolidation, Analysis, and Use

The data consolidation process consisted of the activities necessary to prepare the evaluated data for the users. The main users for the treatability study were the project team, which used the data to develop project data reports, including this treatability study report.

3.5.9 Records Management and Document Control

All field logbooks, site logbooks, chain-of-custody forms, data assessment and validation packages with associated quality assurance (QA)/QC information, validation forms, were assigned document control numbers and maintained according to the requirement for a satellite document management center defined in CDM-003, Records Management.

3.6 DEVIATION FROM THE WORK PLAN

The following is a summary of deviations from the treatability study work plan (DOE 2001a) that occurred to address implementation and construction issues identified during the SPH system startup and operation.

3.6.1 Piezometer Temperature Monitoring Point

Each vacuum piezometer had a co-located temperature monitoring point (TMP) tube installed to 18 m (59 ft) bgs. The design called for installation of a thermocouple (TC) in each tube to monitor for potential steam migration as well as to measure temperatures from 1.5 to 18 m (5 to 59 ft) bgs. During system construction, the 1/8-in. TC would not slide more than 3 m (10 ft)

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down the 3/8-in. Teflon tubing. The 3/8-in. tubing was potentially crushed during piezometer installation. Attempts were then made to install ½-in. Teflon tubing inside the deep vacuum piezometer for temperature monitoring without interfering with VR. The ½-in. tubing would not allow the TC to pass more than 6 m (20 ft) down the piezometer. A group of three TCs were then pulled to the bottom of the ½-in. tubing for permanent placement. Each TC was located at 1.5, 5 and 11 m (5, 16 and 36 ft) bgs and installed in piezometers VP-3, VP-5, VP-9, VP-10, VP-11, and VP-13. This arrangement allowed for monitoring of steam migration around the perimeter of the treatment area at piezometers VP-9 and VP-11. Piezometer locations VP-3 and VP-5 provided additional temperature information inside the treatment area, and piezometer VP-13 was used as a downgradient (north) monitoring location.

The density of thermocouples in the original design was a contingency measure to help monitor the movement of steam in the event that steam spread laterally during heating. Because the steam did not spread laterally, the contingent high density temperature monitoring was not necessary.

3.6.2 Sequential Heating of Electrode Intervals

Another deviation identified was the sequential heating of the electrode intervals in a downward pattern. The operations and maintenance plan originally called for heating the treatment cell starting at the top and progressing downward as the vapor stream concentration began decreasing within the online interval. The heating pattern would then skip the electrode interval at the bottom of the RGA and proceed to heat the deepest electrode interval (upper McNairy) next to create a thermal barrier or "hot floor" to prevent potential migration of DNAPL downward. Once the thermal barrier reached the boiling point of TCE at depth the electrode interval above it would be energized to volatize any DNAPL at the bottom of the RGA. This heating pattern was designed to quantify the amount of TCE contamination within each of the electrode depth zones while also allowing the creation of a "hot floor" below the RGA. Upon energizing the electrodes and monitoring the heating pattern versus depth, it became apparent that all electrode intervals were heating simultaneously. The layers of bentonite and sand that had been installed to separate and isolate each of the six depth intervals were potentially compromised by the weight of the steel shot in the electrode column. The lack of interval isolation resulted in a single electrode instead of six independent electrode elements inside each borehole. The only course of action to mitigate the problem was to place all electrode power supply cables on line and heat the entire depth of the treatment area as one unit.

3.6.3 Elevated Vinyl Chloride Levels

When the vapor recovery vacuum blowers were energized during startup testing, the photoacoustic analyzer detected levels of VC that were higher than anticipated. The analyzer was initially set at a VC alarm limit of 0.5 ppmv, yet upon startup, the discharge vapor stream reached as high as 20 ppmv VC. An agreement was reached with the Kentucky Division for Air Quality to adjust the VC release limit to an hourly average not to exceed 20 ppmv in accordance with site modeling. This action permitted the system to be operated within state regulatory guidelines. The VC concentration in the vapor stream diminished after the first month of operations. There were no exceedances of any hourly average set points throughout operations. A thermal oxidization unit would be better suited to remove VC if elevated levels occur during full-scale operations.

The elevated VC levels were not a result of the treatability study. Rather, anaerobic dechlorination produced the VC in the years before the treatability study began. Start-up of the treatability study vapor recovery system extracted the existing VC and brought it to the surface for detection.

4. RESULTS AND DISCUSSION

4.1 DATA ANALYSIS AND INTERPRETATION

4.1.1 Analysis of Waste Stream Characteristics

TCE concentrations were measured daily at the influent of the primary GAC vessel using a photoacoustic analyzer. The vapor waste stream velocity was also measured daily using a hand-held flow meter. The resulting measurements were then used to calculate the approximate TCE loading for each GAC vessel. The following formula and assumption was used to calculate that an estimated 22,856 lbs of TCE were removed from the vapor waste stream during SPH operations.

Formula: TCE (lbs/day) = (velocity x pipe cross-sectional area) x (TCE concentration/186) x 0.0898

Assumption: TCE and velocity were measured once per weekday using the photoacoustic analyzer with the rate of loading per day applied to each GAC vessel until the next sample was taken (i.e., Saturday and Sunday).

Air samples were also collected weekly from the influent of the primary GAC using summa canisters. The summa canisters were configured to collect a 24-hour integrated sample. The air samples were sent offsite for laboratory analysis using analytical method TO-14A. The TCE measurement results obtained from the photoacoustic analyzer compared to summa canister results are presented in Figure 2.1.

4.1.2 Analysis of Treatability Study Data

4.1.2.1 Subsurface Temperature Data

The ability to heat the subsurface and maintain temperatures that resulted in volatilization of TCE was an important operational parameter of the SPH treatability study. The SPH system achieved and maintained the target temperature at depth, which is the boiling point of water, throughout the majority of the treatment area, as illustrated in Figures 4.1 and 4.2. The SPH system increased the subsurface temperatures from (18°C) to boiling at the 4.5 to 23 m (15 to 75 ft) bgs interval over a period of approximately 30 days. The target temperature at depth was maintained from 4.5 to 23 m (15 to 75 ft) bgs for 120 days, not including extended shutdown periods. As expected, the 1.5 to 4.5 m (5 to 15 ft) bgs interval was heated to a lower temperature due to the influence of ambient air being drawn into the subsurface by the VR system.

The 26 m (85 ft) bgs interval was not consistently heated to its target temperature of 121°C although the temperature was consistently above the boiling point of pure TCE at 93°C. The 26 m (85 ft) bgs interval temperature decreased rapidly, by as much as 30°C, when active heating was discontinued for a period greater than 5 hours. The influence of rapid moving groundwater in the RGA was most evident in the 26 m (85 ft) bgs interval. The heat loss influenced by groundwater flow can be seen at the 26 m (85 ft) bgs TMP interval at MW405 and MW408, as illustrated in Figures 4.3 and 4.4. In the early stages of subsurface heating, the 26 m (85 ft) and 29 m (95 ft) bgs intervals increased in temperature faster than the intervals above

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them. However, the rapid temperature increases began to diminish around March 25, 2003. The two deepest electrode intervals 23 to 29 m (75 to 95 ft) bgs probably lost most or all of their electrical connection to the surface and were therefore not able to deliver sufficient power to the deep RGA to actively boil groundwater in the interval. This assumption is based on the decrease in heating response and the lack of response to power application rates over the remainder of the project at the 29 m (95 ft) bgs interval. The 26 m (85 ft) bgs interval may have been close enough to the electrode interval above to receive some conductive heating, but it did not sustain the high temperatures that were achieved in the shallower intervals that showed a rapid increase in temperature. The temperature deficiency at 26 m (85 ft) and 29 m (95 ft) is believed to be the result of mal-functioning electrodes because the two deep RGA intervals were heating faster than the intervals above until February 28, 2003.

Initial, average heated, and maximum observed temperatures for MW406 and MW407 are depicted in Figures 4.5 and 4.6, respectively. Throughout most of the remediation the temperature at the bottom of the RGA did not exceed the boiling point of TCE in contact with water. However, the maximum observed temperature (recorded in July) exceeded the TCE boiling temperature throughout the RGA.

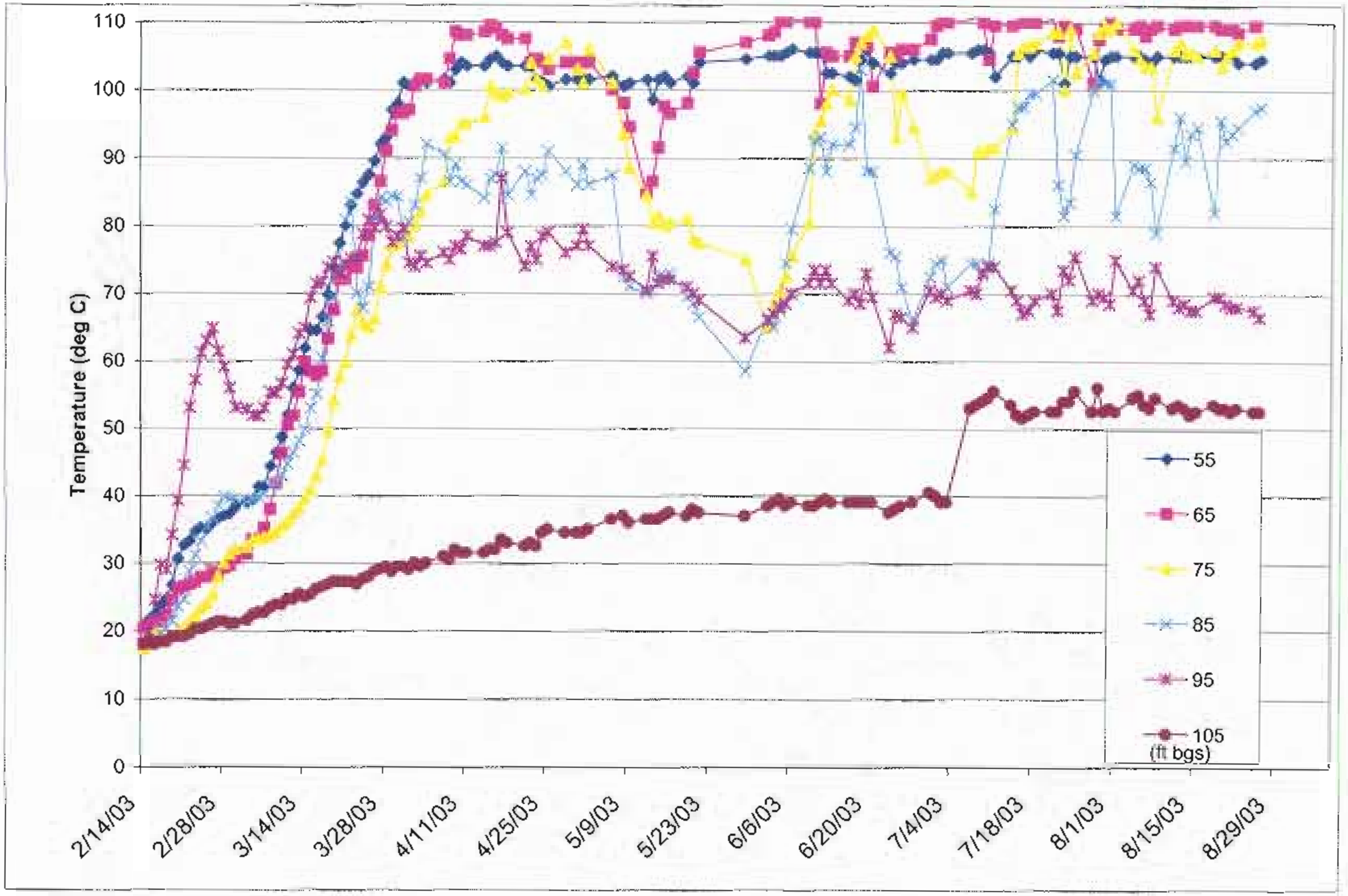

Figure 4.1. Average Treatment Area Temperature within the RGA and Upper McNairy

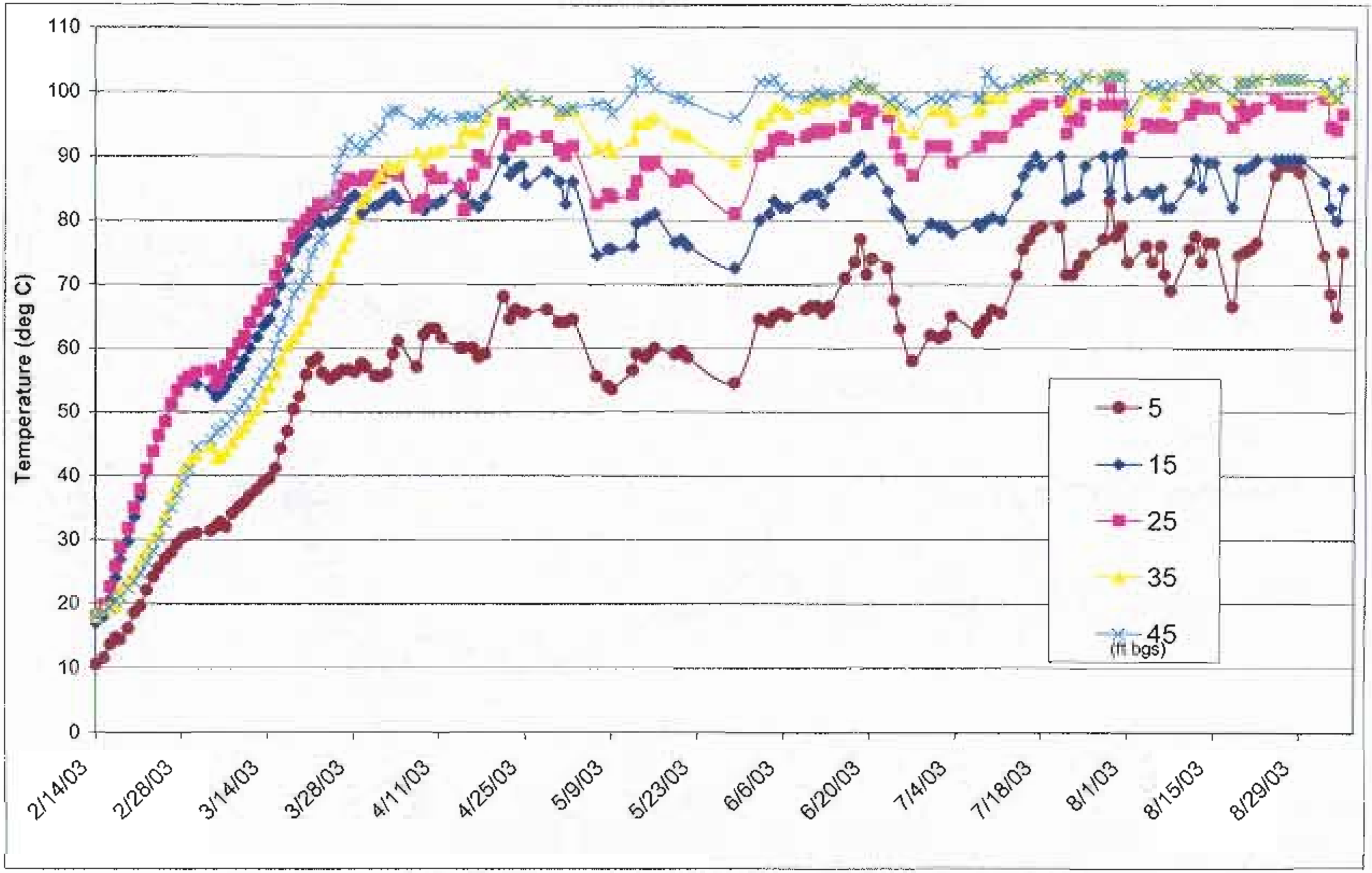

Figure 4.2. Average Treatment Area Temperature within the UCRS

Figure 4.3. MW405 Temperature versus Time

* The 75 ft bgs lead was not functioning between 6/27/03 through 8/11/03.

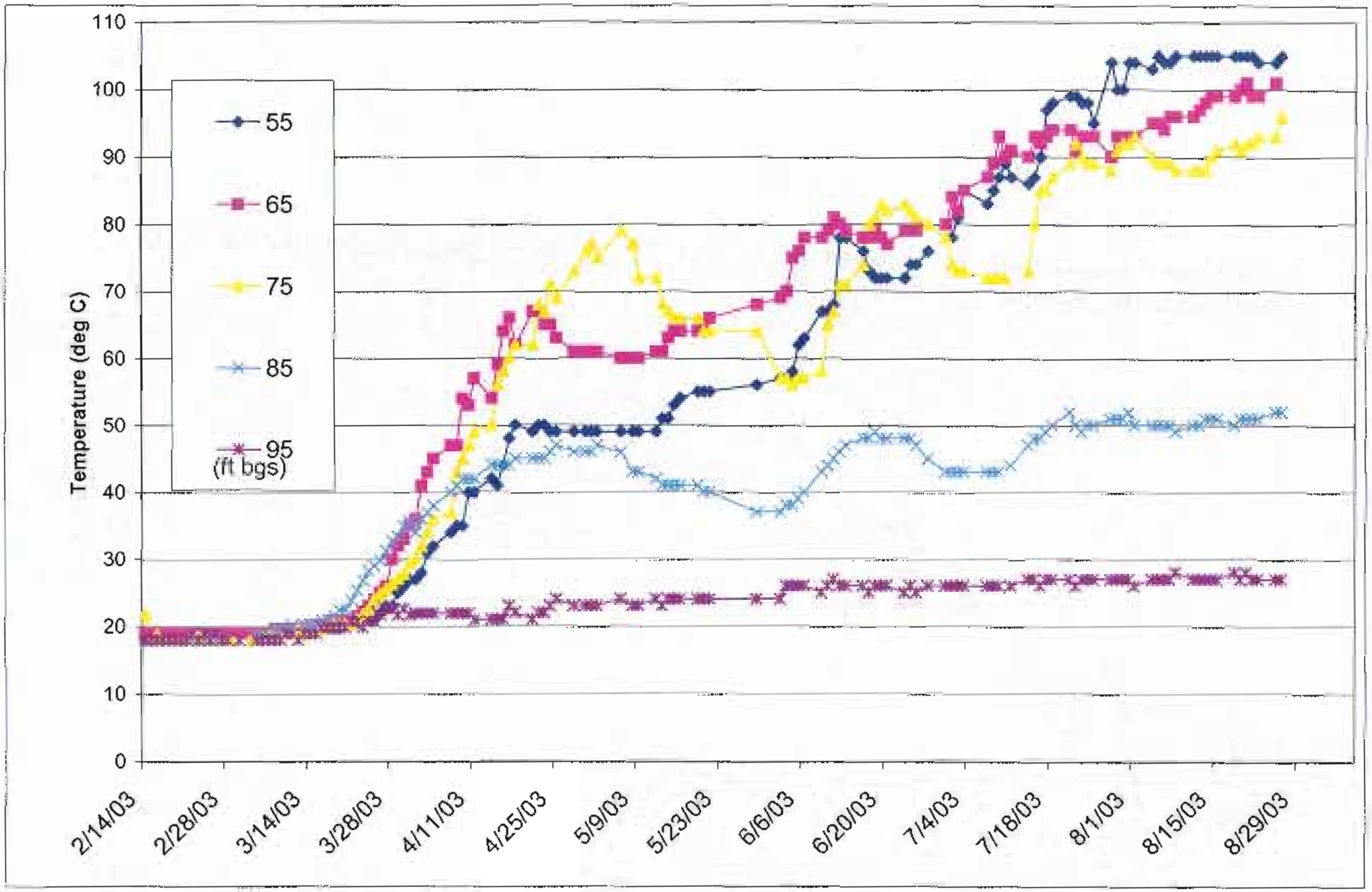

Figure 4.4. MW408 Temperature versus Time

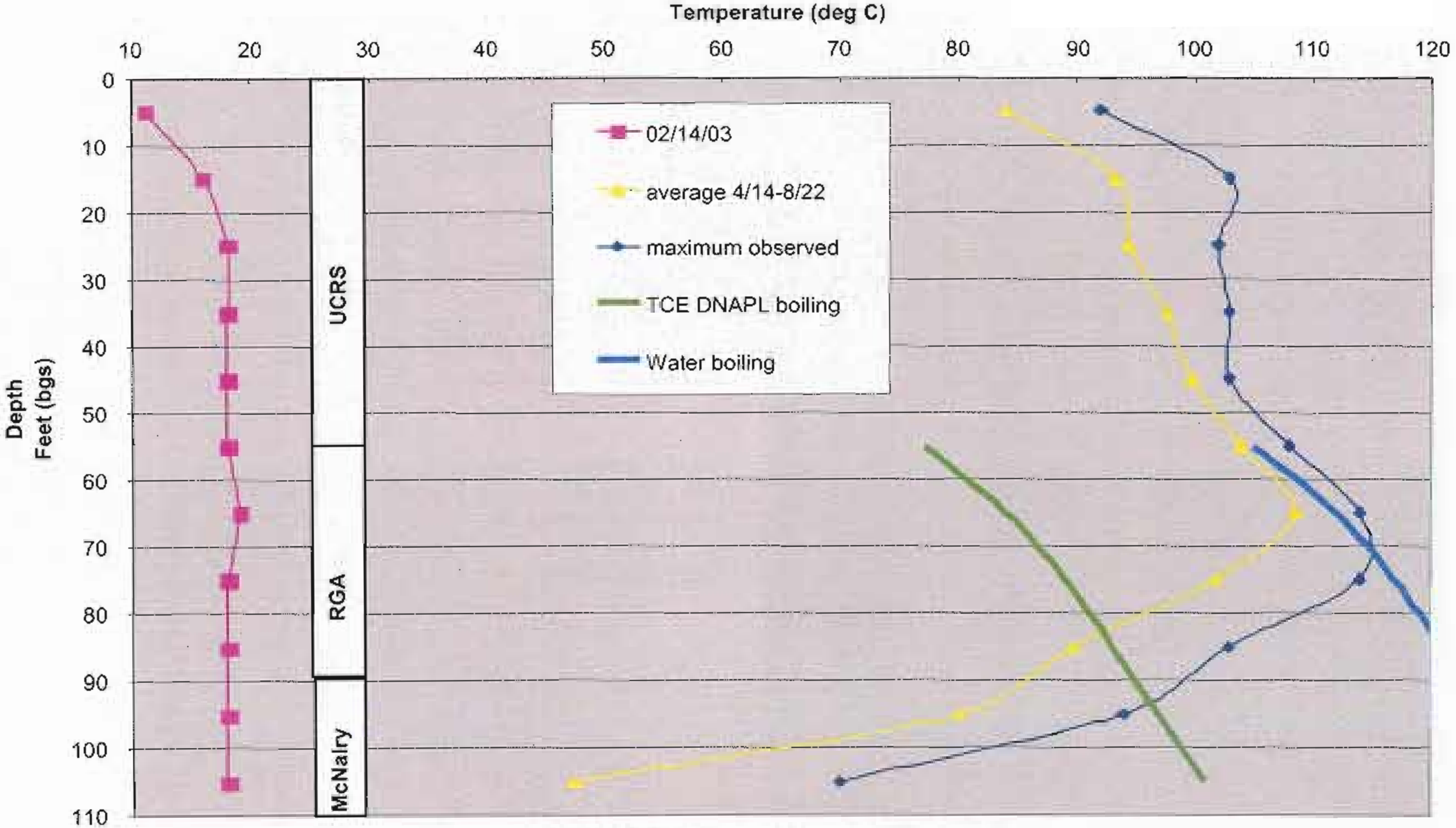

Figure 4.5. MW406 Temperature versus Depth

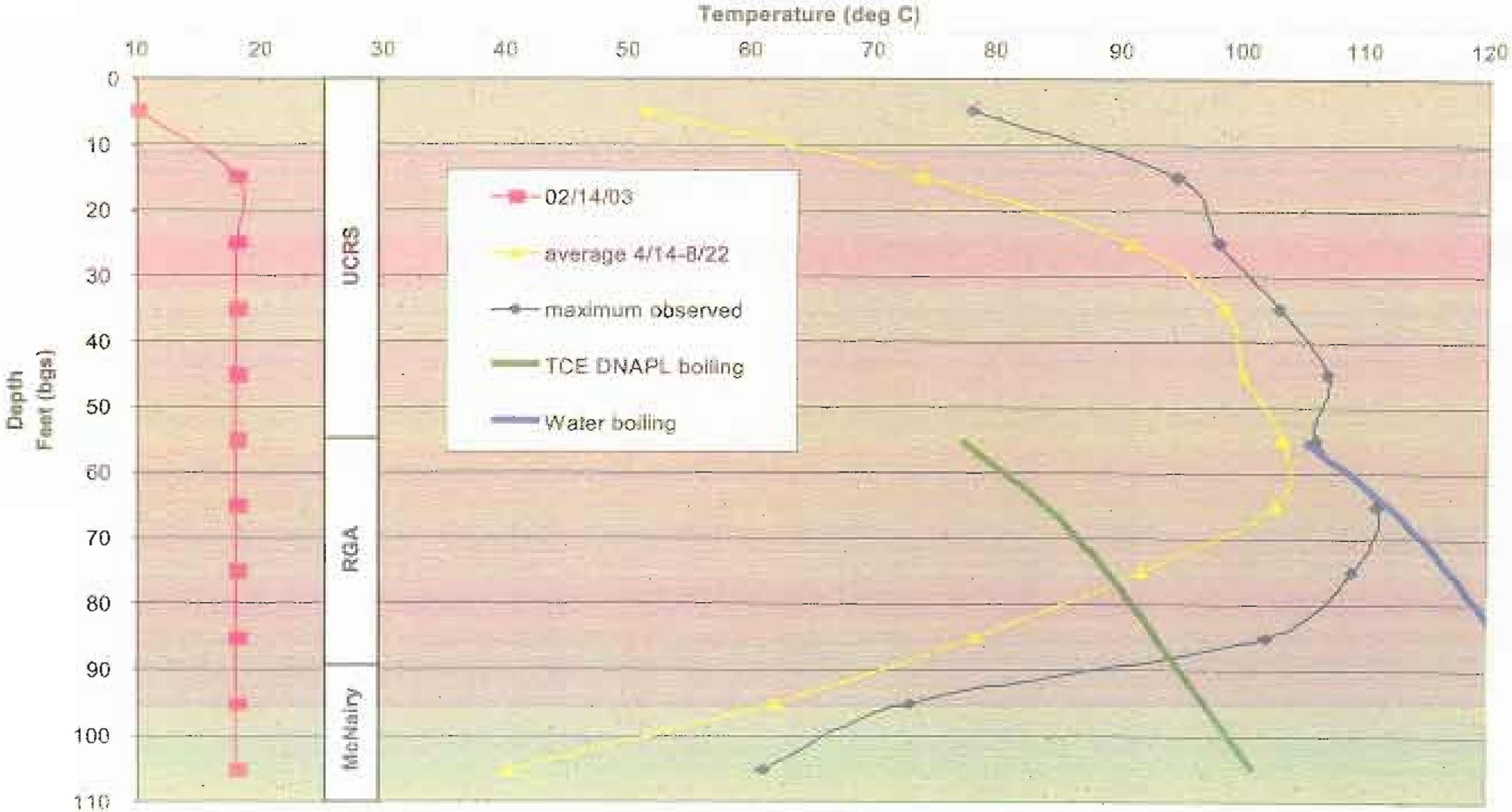

Figure 4.6. MW407 Temperature versus Depth

4.1.2.2 Groundwater Sampling Inside the Treatment Area (MW406 and MW407)

Groundwater sampling of the four multi-port monitoring wells was conducted at pre-heating, 60 percent completion, 87 percent completion, post-treatment, two-week post treatment and four-week post treatment. The groundwater contaminant removal efficiency criterion for the treatment area was a reduction in TCE to less than 1 percent of its solubility limit in water (1 percent is approximately 11,000 ppb). Treatment area groundwater contaminant concentrations are listed in Table 4.1 and are illustrated in Figure 1.1. The sample ports within the treatment area (MW406 and MW407) area ranged from a 98.3 percent to 99.9 percent reduction in TCE concentration and also met the removal efficiency criteria of less than 1percent solubility limit of TCE goal for the project. A graph depicting groundwater sampling results for MW406 is located in Figure 4.7. A graph depicting groundwater sampling results for MW407 is located in Figure 4.8.

Each of the four multi-port monitoring wells contains seven independent sampling ports. The shallowest port located in the lower UCRS 11 m (36 ft) bgs never yielded groundwater. Five ports were located in the RGA formation 20 to 27 m (66 to 89 ft) bgs, and the deepest port was located in the McNairy formation at 32 m (105 ft) bgs.

Additional groundwater sampling events were performed after the post treatment groundwater sampling event to assess and quantify the amount of contaminant rebound. The two-week post treatment groundwater sampling event was initiated on September 22, 2003. The four-week post treatment groundwater sampling event began on October 7, 2003. The sample results from the two post treatment events are included in Table 4.1. The original post treatment sampling event yielded a reduction of 99.1 percent in TCE concentration. The two-week post treatment sampling event shows 99.2 percent reduction, and the four-week post treatment sampling event shows a 99.0 percent TCE reduction. The maximum concentration found in the latest sampling events is 10,090 ppb, which remains below the target of 11,000 ppb.

Although the treatability study was not designed to treat the McNairy Formation, TCE concentrations in the 106-108 ft bgs depth interval in MW406 and MW407 were reduced at a significantly faster rate as compared to the 72-74 ft bgs, 80-82 ft bgs, and 86-88 ft bgs depth intervals despite the fact that the 106-108 ft bgs depth interval experienced the least amount of heating. There is inconclusive evidence as to the cause of this occurrence. However, one possible theory that may have contributed to the unexpected change in TCE concentrations is that the four monitoring wells installed for the treatability study included screened intervals in the upper sand unit of the McNairy Formation. The purpose of the screen in the upper McNairy was to check whether the SPH process pushed TCE into deeper soils through some mechanism. The monitoring wells included seven short screened intervals on a single 4-inch casing - one in the lower UCRS, five in the RGA and one in the McNairy. After the wells were drilled, a set of inflatable packers were installed in the wells to seal the casing between the seven screens. In retrospect, it seems likely that contaminated water or a small amount of DNAPL moved from the RGA to the McNairy screened intervals in the period between well installation and packer insertion (up to four months). This mixing between the formations caused the initial McNairy sample to be biased high. Subsequent samples were more representative of true McNairy conditions due to a flushing effect. It is recommended that future multiple screen groundwater wells should not bridge the two formations and not remain open for extended periods of time.

Table 4.1. RGA Groundwater TCE Sample Results from MWs 406 and 407

Monitoring Well	Depth Interval (ft bgs)	Baseline (ppb)	60% (ppb)	87% (ppb)	Post (ppb)	TCE Reduction	Removal Criteria (ppb)	Remediation Goal Met?	Two-Week Post Treatment (ppb)	Four-Week Post Treatment (ppb)
MW406	36-38	No Sample	No Sample	No Sample	No Sample	No Sample	11,000	No Sample	No Sample	No Sample
	60-62	810,000	8,600	10,500	5,880	99.3%	11,000	Yes	6,850	7,080
	66-68	730,000	25,200	9,360	6,680	99.1%	11,000	Yes	9,440	10,090
	72-74	520,000	42,800	17,500	9,650	98.1%	11,000	Yes	7,890	9,430
	80-82	520,000	41,700	18,400	10,100	98.1%	11,000	Yes	8,110	8,810
	86-88	540,000	41,000	20,000	8,590	98.4%	11,000	Yes	6,250	7,960
	106-108	630,000	1,330	770	1,170	99.8%	*	*	2,590	1,500
MW407	36-38	No Sample	No Sample	No Sample	No Sample	No Sample	11,000	No Sample	No Sample	No Sample
	60-62	340,000	4,040	3,400	2,080	99.4%	11,000	Yes	980	5,120
	66-68	290,000	5,100	4,900	3,040	99.0%	11,000	Yes	3,585	4,170
	72-74	960,000	11,300	7,830	6,290	99.3%	11,000	Yes	5,070	3,625
	80-82	830,000	11,600	3,420	5,310	99.4%	11,000	Yes	4,835	5,265
	86-88	910,000	14,200	5,550	6,320	99.3%	11,000	Yes	4,690	5,780
	106-108	980,000	2,500	500	570	99.9%	*	*	1725	4005

*This interval is located outside the treatment area. There were no removal criteria for groundwater outside the treatment area.

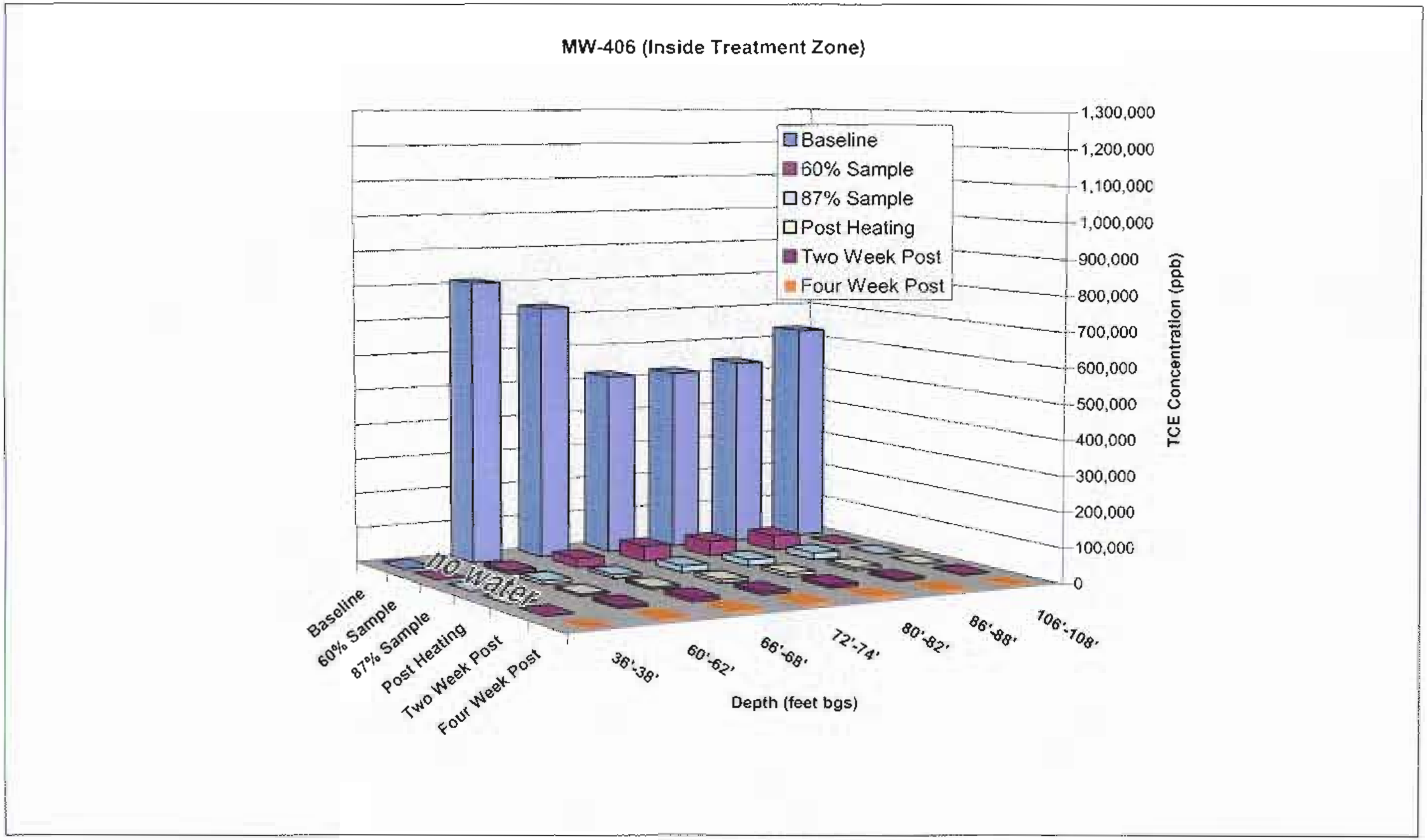

Figure 4.7. MW406 Groundwater Concentrations

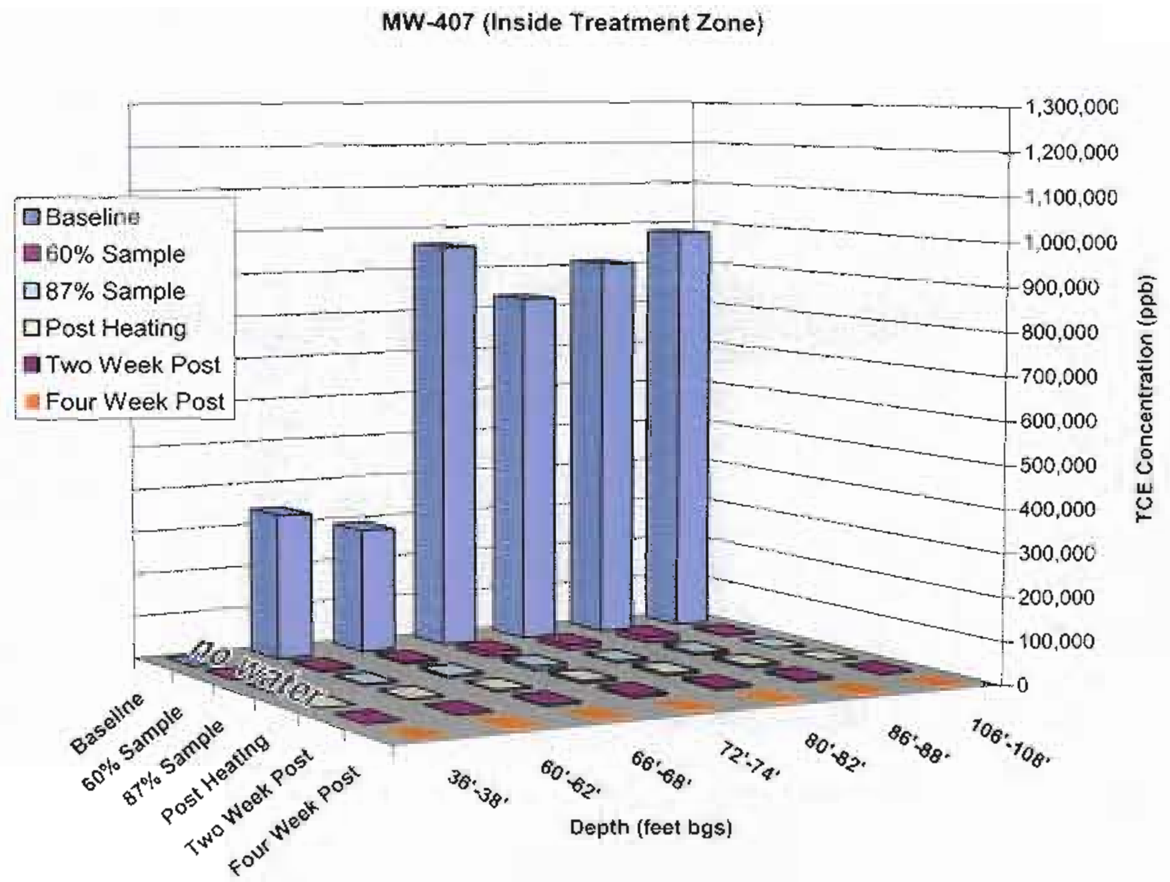

Figure 4.8. MW407 Groundwater Concentrations

4.1.2.3 Groundwater Concentrations Outside the Treatment Area (MW405 and MW408)

During the treatability study, groundwater TCE contamination outside of the treatment area was monitored at the same frequency as the groundwater inside the treatment area. The region outside the treatment area had levels of TCE contamination similar to those inside the treatment area during the baseline sampling event. Groundwater sample results from outside the treatment area are summarized in Table 4.2. No removal efficiency criteria were established for groundwater sample analysis outside of the treatment area although the surrounding data could be used to confirm contamination was removed from the treatment area instead of moving out of the treatment area.

The radial migration of heated water had a significant temperature impact on groundwater sample ports from 20 to 23 m (66 to 75 ft) bgs at MW405 and MW408. The temperature at these depth intervals was increased to near the boiling point of water toward the conclusion of active heating (Figure 4.3 and 4.4). The heated water was removed from the treatment area by groundwater flow. The resulting impact on TCE concentration was a reduction in TCE concentrations from baseline, except one, which remained relatively unchanged.

During the 87 percent completion and post-heating groundwater sample events, DNAPL was removed through the sample port in the 31 to 32 m (102 to 105 ft) bgs of MW408. There was little temperature influence at MW408, which indicates the absence of a driving force to move DNAPL out of the treatment area and into the vicinity of MW408. The thermocouple installed at the 32 m (105 ft) bgs interval did not function properly after installation, but the interval above 29 m (95 ft) bgs only increased 10°C above the normal ambient temperature. The subsurface temperatures at MW408 (Figure 4.4) are similar to subsurface temperatures recorded in MW405 (Figure 4.3). The TCE concentrations in the RGA and McNairy formation were near the solubility limit at baseline and indicated that DNAPL was most likely present around MW408 before the treatability study began, as shown in Table 4.2. During well installation of MW408 the thin confining layer that established the RGA/McNairy formation interface was not identified during drilling of MW408. The absence of a confining layer in this location could allow DNAPL to flow into the McNairy formation from the RGA above.

4.1.2.4 Soil Sampling

The soil removal efficiency criterion for the treatability study was a 75 percent reduction of TCE concentration in the unsaturated area of the UCRS. Soil sampling was conducted during the subsurface installation phase of the treatability study to quantify the levels of TCE contamination located in the unsaturated area prior to remediation. Soil samples were collected at each of the piezometer locations inside the treatment area (VP-1 through VP-8) and the three piezometer locations surrounding the treatment area (VP-9 through VP-11). Samples were

Table 4.2 RGA Groundwater TCE Sample Results from Outside the Treatment Area*

Monitoring Well	Depth Interval (ft bgs)	Baseline (ppb)	60% (ppb)	87% (ppb)	Post (ppb)	TCE Reduction
MW405	36-38	No sample	No sample	No sample	No sample	N/A
	60-62	640,000	45,500	117,000	138,000	78.4%
	66-68	450,000	196,000	115,500	177,250	60.6%
	72-74	800,000	226,000	119,500	165,250	79.3%
	80-82	190,000	324,000	157,800	210,500	-10.8%
	86-88	210,000	370,000	328,000	142,250	32.3%
	106-108	350,000	310,000	156,000	162,000	53.7%
MW408	34-36	No sample	No sample	No sample	No sample	N/A
	58-60	1,200,000	106,000	100,800	6,640	99.4%
	64-66	950,000	79,300	408,000	51,500	94.6%
	70-72	1,200,000	77,600	293,300	54,000	95.5%
	78-80	1,000,000	82,100	476,500	69,000	93.1%
	84-86	1,100,000	204,000	471,200	186,000	83.1%
	104-106	790,000	249,000	DNAPL	DNAPL	N/A

* There were no removal criteria for groundwater outside the treatment area.

collected in 2-ft intervals from ground surface to the top of the RGA. The results of the baseline sampling event are summarized in Table 4.3.

Post treatment soil sample results are also included in Table 4.4. A comparison of these sample data indicate that the TCE concentrations in soil were reduced from an average of 125,111 ppb to an average of 2,493 ppb, which is a 98 percent decrease. This is significantly higher than the target reduction of 75 percent that was established prior to the Treatability Study as the soil removal efficiency criterion.

4.1.3 Comparison To Primary Test Objective

The primary objective of the treatability study as described in the *Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant, Paducah, Kentucky Treatability* (DOE 2001a) was to demonstrate the implementability of the SPH technology for the unsaturated and saturated areas of the UCRS and for the groundwater of the RGA. A successful implementation would heat the soils and groundwater in both the UCRS and RGA to a temperature that allows steam and vapors containing the TCE to rise and be moved by the VR wells are treated by the vapor treatment system.

Removal efficiency criteria were outlined in the *Six-Phase Heating Technology Assessment* (GEO 2003). The criteria for evaluating the success of the SPH treatability study are the assessment of removal efficiency using co-located soil and groundwater sampling. The criteria for success included a greater than 75 percent reduction of TCE soil concentrations in the UCRS and a reduction of TCE groundwater concentrations to less than 1 percent solubility (11,000 ppb) in the RGA.

The removal efficiency of TCE in the UCRS can be assessed by a comparison of baseline soil sampling results to post treatment soil sampling results. Post treatment soil sample results indicate that this goal was achieved based on comparison of the data that indicates an average reduction in soil of 98 percent

The removal efficiency of TCE in the groundwater of the RGA can be assessed by a comparison of baseline groundwater sampling results to post treatment groundwater sampling results. Post treatment groundwater sample results indicate that this goal was achieved based on comparison of the data that indicates an average reduction in groundwater of 99.1 percent at the end of active heating, 99.2 percent at two-week post treatment, and 99.0 percent at four-week post treatment.

Table 4.3. Pre-Treatment TCE Concentrations in Soil

Depth (ft bgs)	Pre-Treatment TCE Concentration (ug/kg or ppb) Average	VP-1	VP-2	VP-3	VP-4	VP-5	VP-6	VP-7	VP-8	VP-9	VP-10	VP-11
0-2	1,465	14	--	*45	3,000	*19	*48.5	7,000	--	77	400	130
2-4	3,946	2,100	--	400	--	16,000	4,500	2,900	1,600	--	--	120
4-6	382,598	*135	*46	50,000	2,900,000	8,700	--	33,000	66,000	*44	8,800	2,900
6-8	116,066	1,700	*48	180,000	14,000	13,000	1,400	830,000	750	*39	200,000	3,700
8-10	163,190	670	*44	190,000	460,000	16,000	43,000	730,000	12,000	*45	430,000	17,000
10-12	18,630	570	3,200	7,200	45,000	6,700	16,000	50,000	27,000	*47	150,000	12,000
12-14	42,773	560	1,600	26,000	230,000	26,000	14,000	68,000	1,800	*43	100,000	17,000
14-16	16,174	330	140	11,000	99,000	11,000	*36	360	14,000	*46	33,000	9,700
16-18	13,532	290	*46	1,600	35,000	9,100	12,000	50,000	220	*46	73,000	--
18-20	26,303	21	*45	12,000	46,000	*47	14,000	150,000	220	*46	120,000	92
20-22	29,756	11	*47	17,000	190,000	120	*46	59,000	1,400	*44	87,000	180
22-24	8,586	540	*44	29,000	30,000	*48.5	8,600	8,800	180	*47	25,000	60
24-26	738	11	*47	190	4,200	250	*41	1,100	--	*44	11,000	63
26-28	127,045	800	*50	360	1,000,000	5,100	*650	5,700	14,000	*46	2,400,000	3,700
28-30	403,799	720	--	20,000	2,700,000	1,400	6,900	97,000	8,000	*47	370,000	570
30-32	3,231	630	340	110	11,000	10,000	290	3,100	88	*43	2,800,000	380
32-34	182,903	610	*46	4,100	1,400,000	2,000	3,700	52,000	52,000	*44	--	770
34-36	12,324	710	260	--	72,000	*650	260	--	--	--	130,000	61
36-38	2,271	25	*42	*45	13,000	2,400	*48	340	--	*17	42,000	--
38-40	57,261	ND	--	4,600	--	8,500	--	270,000	38	*18	--	3,200
40-42	23,765	150	*42	--	59,000	68,000	1,400	14,000	--	*17	6,700	--
42-44	8,991	310	*43	3,100	33,000	--	--	8,500	600	*19	14,000	--
44-46	3,784	420	*49	2,400	4,400	5,200	1,400	3,400	3,200	*20	6,700	13,000
46-48	7,291	880	*44	1,700	24,000	8,800	1,400	12,000	2,000	*19	17,000	9,500
49-50	16,177	1,400	440	1,700	--	1,600	100,000	5,500	7,700	*16	--	2,600
50-52	13,603	3,200	120	2,900	32,000	50,000	2,500	5,100	3,400	4,300	1,700	13,000
52-54	15,917	1,900	--	10,000	27,000	6,300	9,000	2,600	3,500	*19	3,600	45,000
54-56	342,871	19,000	29,000	2,300,000	37,000	22,000	4,300	2,400	120,000	19,000	4,100,000	8,400
Average	**125,111**	1,347	1,556	114,538	378,744	10,825	9,821	91,548	11,379		463,746	

🟨 Indicates data that lacks a corresponding location "before and after" comparison and therefore values are not used in averages.

-- Indicates no results due to poor sample recovery.

* Indicates non-detect. Non-detect samples are reported at one-half of the detection limit.

Table 4.4. Post Treatment TCE Concentrations in Soil

Depth (ft bgs)		Post-Treatment TCE Concentration (ug/kg or ppb)										
	Average	VP-1	VP-2	VP-3	VP-4	VP-5	VP-6	VP-7	VP-8	VP-9	VP-10	VP-11
0-2	190	22	50	39	85	*650	500	140	36	Not in treatment region, no post-treatment samples collected	*150	Not in treatment region, no post-treatment samples collected
2-4	4,222	81	28	26	660	880	25,400	3,800	2,900		12,000	
4-6	3,213	290	11	73	390	33	20,800	810	3,300		5,600	
6-8	108	*5	*5	320	*18.5	23	300	130	63		16,000	
8-10	14,239	13	20	430	760	82	112,500	25	79		4,300	
10-12	427	*5	18	73	210	*5	2,900	*5	200		7,200	
12-14	1,239	*5	59	11	260	*5	9,400	72	99		16,000	
14-16	704	*5	*5	42	3,900	*5	1,500	86	89		4,300	
16-18	13	*5	*5	17	*33	*5	49	*5	*5		4,400	
18-20	50	*5	27	--	41	250	14	*5	*5		9,600	
20-22	839	*5	290	12	*5	200	6,100	93	*5		*55	
22-24	48	*5	290	10	*180	*5	*5	*5	14		7,800	
24-26	153	16	460	*5	550	21	*5	11	Hit refusal		10,700	
26-28	70	51	51	*5	260	*5	*5	110			80	
28-30	122	610	75	69	39	*5	*5	*5			79	
30-32	305	*5	1,900	17	200	5	*5	*5			25	
32-34	731	24	12	2,400	15	40	18	*5			51	
34-36	27	*5	29	12,000	19	79	*5	*5			260	
36-38	176	810	320	17	46	26	*5	*5			36	
38-40	683	*5	3,700	41	100	30	*5	900			*5	
40-42	589	1,800	*26.5	82	2,200	*5	*5	*5			15,200	
42-44	1,249	1,700	*50	24	6,800	*5	*5	160			*105	
44-46	774	3,000	*180	220	1,700	*5	120	190			49,200	
46-48	5,529	780	28,000	1,100	8,400	*5	230	190			23,700	
49-50	3,612	490	1,400	5,200	15,700	14	2,400	79			500	
50-52	6,159	3,200	870	35,900	*60	*5	75	3,000			1,300	
52-54	3,848	5,900	960	12,500	300	--	200	340			13,800	
54-56	1,458	210	11	6,900	1,500	--	14	110			6,100	
Average	**2,493**	680	1,480	2,722	1,258	96	6,470	381	614		8,166	
Reduction	**98.0%**	49%	5%	98%	99.7%	99%	34%	99.6%	95%		98%	

🟨 Indicates data that lacks a corresponding location "before and after" comparison and therefore values are not used in averages.

-- Indicates no results due to poor sample recovery.

* Indicates non-detect. Non-detect samples are reported at one-half of the detection limit.

4.2 Quality Assurance/Quality Control

The measures required to verify the quality of work performed and compliance with the specified project requirements include successful completion of internal field reviews; the inspection of materials, equipment and workmanship before and during the performance of each task comprising the SPH system installation effort; and the resolution of all reported deficiencies and nonconformance issues. Additionally, internal and external assessments were conducted to ensure that quality was being achieved during construction, operation and sampling of the treatment system. Listed below are some of the measures taken to ensure quality during the treatability study:

Data Quality Control

- Collection of Quality Control Samples (i.e. Field Blanks, Equipment Rinseates, and Duplicates)
- Sample Custody Control
- Review of 100% of all Sample Data
- Validation of Analytical Data
- Calibration of Water Quality Instrumentation

Construction Quality Control

- Documented Material and Equipment Inspections (i.e. Steel Shot, Copper, Blower, Power Control Unit, Condenser, etc.)
- Pre-startup Checks (i.e. System Interlocks, Alarm Set Points, etc.)
- Induced Voltage Surveys

Operational Quality Control

- Data Collection and Review (Temperature, Electrical, Contaminant Concentration, etc.)
- Calibration of Instrumentation

4.3 COSTS/ SCHEDULE FOR PERFORMING THE TREATABILITY STUDY

The estimated cost for performing the SPH treatability study was $6.3 million. Construction of the SPH system began in June, 2002 and was completed in January, 2003. Operations began in February, 2003 and ended in September, 2003. This included the 45 day extension for heating.

4.4 KEY CONTACTS

Bechtel Jacobs Company LLC

Craig Jones	Project Manager
John Farrell	Subcontract Technical Representative
Larry Young	GWOU Lead Engineer

CDM

Joe Tarantino	Project Manager

Barry Swift	Project Superintendent
Jonathan Hubbard	Environment, Safety, and Health Representative
Mickey McKenty	Environmental Technician

Department of Energy

Gary Bodenstein	Project Manager

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Greg Beyke	Design Engineer
Chris Blundy	Project Manager
Jerry Wolf	Operations Manager

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APPENDIX A

GROUNDWATER DATA COMPARISON FOR NON-VOLATILE PARAMETERS

DATA COMPARISON FOR NON-VOLATILES PARAMETERS

During the planning phases of the SPH treatability study as described in the *Treatability Study Work Plan for Six-Phase Heating, Groundwater Operable Unit, at Paducah Gaseous Diffusion Plant*, Paducah, Kentucky (DOE 2001a), it was determined that non-volatile analytical parameters would be evaluated upon Post Treatment of the treatability study. In order to assess any impacts that the implementation of the study would have on other contaminants in the groundwater, samples were collected during the baseline groundwater sampling event and the post treatment groundwater sampling event for radionuclides, metals, other non-volatile indicator parameters.

Tables A.1 through A.24 below present sample results from the baseline and the post groundwater sampling events. Samples were collected at the four monitoring wells for Ports 2 through 7, with the exception of MW408 Port 7 during the post treatment event. Technetium-99 (^{99}Tc) was the radionuclide present in most samples for all four wells. Results were inconsistent from the baseline and the post treatment event; however, no particular pattern resulted. Table A.25 shows the results and the percent difference from the baseline to the post treatment values. Thorium-230 (Th^{230}) was identified in the post treatment samples for MW407 Ports 3, 6, 7. Th^{230} was not detected in any baseline samples or any other post-treatment wells. Uranium-238 (U^{238}) was identified in post treatment samples for MW406 Ports 6 and 7, MW405 Port 7, and MW408 Port 6. U^{238} was not detected in any baseline samples or any other post-treatment wells.

Table A.1 MW405 Port 2 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 2	60-62 ft	Activity of U-235	ND	ND
MW405 Port 2	60-62 ft	Alpha activity	15.3	ND
MW405 Port 2	60-62 ft	Americium-241	ND	ND
MW405 Port 2	60-62 ft	Beta activity	75.9	110
MW405 Port 2	60-62 ft	Cesium-137	ND	ND
MW405 Port 2	60-62 ft	Cobalt-60	ND	ND
MW405 Port 2	60-62 ft	Neptunium-237	ND	ND
MW405 Port 2	60-62 ft	Potassium-40	258	NA
MW405 Port 2	60-62 ft	Pu-239/240	ND	ND
MW405 Port 2	60-62 ft	Technetium-99	43.7	148
MW405 Port 2	60-62 ft	Thorium-230	ND	ND
MW405 Port 2	60-62 ft	Uranium-234	NA	ND
MW405 Port 2	60-62 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.2 MW405 Port 3 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 3	66-68 ft	Alpha activity	14	ND
MW405 Port 3	66-68 ft	Americium-241	ND	ND
MW405 Port 3	66-68 ft	Beta activity	34.2	106
MW405 Port 3	66-68 ft	Cesium-137	ND	ND
MW405 Port 3	66-68 ft	Cobalt-60	ND	ND
MW405 Port 3	66-68 ft	Neptunium-237	ND	ND
MW405 Port 3	66-68 ft	Pu-239/240	ND	ND
MW405 Port 3	66-68 ft	Technetium-99	42.2	139
MW405 Port 3	66-68 ft	Thorium-230	ND	ND
MW405 Port 3	66-68 ft	Uranium-234	NA	ND
MW405 Port 3	66-68 ft	Uranium-238	ND	ND

Table A.3 MW405 Port 4 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 4	72-74 ft	Alpha activity	ND	ND
MW405 Port 4	72-74 ft	Americium-241	ND	ND
MW405 Port 4	72-74 ft	Beta activity	30.1	107
MW405 Port 4	72-74 ft	Cesium-137	ND	ND
MW405 Port 4	72-74 ft	Cobalt-60	ND	ND
MW405 Port 4	72-74 ft	Neptunium-237	ND	ND
MW405 Port 4	72-74 ft	Pu-239/240	ND	ND
MW405 Port 4	72-74 ft	Technetium-99	35.8	154
MW405 Port 4	72-74 ft	Thorium-230	ND	ND
MW405 Port 4	72-74 ft	Uranium-234	NA	ND
MW405 Port 4	72-74 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.4 MW405 Port 5 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 5	80-82 ft	Alpha activity	7.26	ND
MW405 Port 5	80-82 ft	Americium-241	ND	ND
MW405 Port 5	80-82 ft	Beta activity	36.5	88.9
MW405 Port 5	80-82 ft	Cesium-137	ND	ND
MW405 Port 5	80-82 ft	Cobalt-60	ND	ND
MW405 Port 5	80-82 ft	Neptunium-237	ND	ND
MW405 Port 5	80-82 ft	Pu-239/240	ND	ND
MW405 Port 5	80-82 ft	Technetium-99	54.4	153
MW405 Port 5	80-82 ft	Thorium-230	ND	ND
MW405 Port 5	80-82 ft	Uranium-234	NA	ND
MW405 Port 5	80-82 ft	Uranium-238	NA	ND

Table A.5 MW405 Port 6 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 6	86-88 ft	Alpha activity	ND	ND
MW405 Port 6	86-88 ft	Americium-241	ND	ND
MW405 Port 6	86-88 ft	Beta activity	68.6	105
MW405 Port 6	86-88 ft	Cesium-137	ND	ND
MW405 Port 6	86-88 ft	Cobalt-60	ND	ND
MW405 Port 6	86-88 ft	Neptunium-237	ND	ND
MW405 Port 6	86-88 ft	Potassium-40	248	NA
MW405 Port 6	86-88 ft	Pu-239/240	ND	ND
MW405 Port 6	86-88 ft	Technetium-99	92.1	147
MW405 Port 6	86-88 ft	Thorium-230	ND	ND
MW405 Port 6	86-88 ft	Uranium-234	NA	ND
MW405 Port 6	86-88 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.6 MW405 Port 7 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW405 Port 7	106-108ft	Alpha activity	ND	ND
MW405 Port 7	106-108ft	Americium-241	ND	ND
MW405 Port 7	106-108ft	Beta activity	34.4	94.6
MW405 Port 7	106-108ft	Cesium-137	ND	ND
MW405 Port 7	106-108ft	Cobalt-60	ND	ND
MW405 Port 7	106-108ft	Neptunium-237	ND	ND
MW405 Port 7	106-108ft	Pu-239/240	ND	ND
MW405 Port 7	106-108ft	Technetium-99	50.7	152
MW405 Port 7	106-108ft	Thorium-230	ND	ND
MW405 Port 7	106-108ft	Uranium-234	NA	ND
MW405 Port 7	106-108ft	Uranium-238	NA	0.985

Table A.7 MW406 Port 2 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 2	60-62 ft	Activity of U-235	ND	ND
MW406 Port 2	60-62 ft	Alpha activity	ND	ND
MW406 Port 2	60-62 ft	Americium-241	ND	ND
MW406 Port 2	60-62 ft	Beta activity	22.5	44.5
MW406 Port 2	60-62 ft	Cesium-137	ND	ND
MW406 Port 2	60-62 ft	Cobalt-60	ND	ND
MW406 Port 2	60-62 ft	Neptunium-237	ND	ND
MW406 Port 2	60-62 ft	Pu-239/240	ND	ND
MW406 Port 2	60-62 ft	Technetium-99	18.2	49.8
MW406 Port 2	60-62 ft	Thorium-230	ND	ND
MW406 Port 2	60-62 ft	Uranium-234	NA	ND
MW406 Port 2	60-62 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.8 MW406 Port 3 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 3	66-68 ft	Alpha activity	ND	ND
MW406 Port 3	66-68 ft	Americium-241	ND	ND
MW406 Port 3	66-68 ft	Beta activity	14.8	47.4
MW406 Port 3	66-68 ft	Cesium-137	ND	ND
MW406 Port 3	66-68 ft	Cobalt-60	ND	ND
MW406 Port 3	66-68 ft	Neptunium-237	ND	ND
MW406 Port 3	66-68 ft	Pu-239/240	ND	ND
MW406 Port 3	66-68 ft	Technetium-99	17.5	46.9
MW406 Port 3	66-68 ft	Thorium-230	ND	ND
MW406 Port 3	66-68 ft	Uranium-234	NA	ND
MW406 Port 3	66-68 ft	Uranium-238	NA	ND

Table A.9 MW406 Port 4 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 4	72-74 ft	Alpha activity	ND	ND
MW406 Port 4	72-74 ft	Americium-241	ND	ND
MW406 Port 4	72-74 ft	Beta activity	ND	52.2
MW406 Port 4	72-74 ft	Cesium-137	ND	ND
MW406 Port 4	72-74 ft	Cobalt-60	ND	ND
MW406 Port 4	72-74 ft	Neptunium-237	ND	ND
MW406 Port 4	72-74 ft	Pu-239/240	ND	ND
MW406 Port 4	72-74 ft	Technetium-99	ND	44.2
MW406 Port 4	72-74 ft	Thorium-230	ND	ND
MW406 Port 4	72-74 ft	Uranium-234	NA	ND
MW406 Port 4	72-74 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.10 MW406 Port 5 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 5	80-82 ft	Alpha activity	ND	ND
MW406 Port 5	80-82 ft	Americium-241	ND	ND
MW406 Port 5	80-82 ft	Beta activity	18.4	54.6
MW406 Port 5	80-82 ft	Cesium-137	ND	ND
MW406 Port 5	80-82 ft	Cobalt-60	ND	ND
MW406 Port 5	80-82 ft	Neptunium-237	ND	ND
MW406 Port 5	80-82 ft	Pu-239/240	ND	ND
MW406 Port 5	80-82 ft	Technetium-99	17.2	51.3
MW406 Port 5	80-82 ft	Thorium-230	ND	ND
MW406 Port 5	80-82 ft	Uranium-234	NA	ND
MW406 Port 5	80-82 ft	Uranium-238	NA	ND

Table A.11 MW406 Port 6 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 6	86-88 ft	Alpha activity	ND	ND
MW406 Port 6	86-88 ft	Americium-241	ND	ND
MW406 Port 6	86-88 ft	Beta activity	19.3	63.5
MW406 Port 6	86-88 ft	Cesium-137	ND	ND
MW406 Port 6	86-88 ft	Cobalt-60	ND	ND
MW406 Port 6	86-88 ft	Neptunium-237	ND	ND
MW406 Port 6	86-88 ft	Pu-239/240	ND	ND
MW406 Port 6	86-88 ft	Technetium-99	22.5	71.2
MW406 Port 6	86-88 ft	Thorium-230	ND	ND
MW406 Port 6	86-88 ft	Uranium-234	NA	ND
MW406 Port 6	86-88 ft	Uranium-238	NA	0.76

NA – Not Analyzed
ND – Not Detected

Table A.12 MW406 Port 7 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW406 Port 7	106-108ft	Alpha activity	ND	ND
MW406 Port 7	106-108ft	Americium-241	ND	ND
MW406 Port 7	106-108ft	Beta activity	28.3	ND
MW406 Port 7	106-108ft	Cesium-137	ND	ND
MW406 Port 7	106-108ft	Cobalt-60	ND	ND
MW406 Port 7	106-108ft	Neptunium-237	ND	ND
MW406 Port 7	106-108ft	Pu-239/240	ND	ND
MW406 Port 7	106-108ft	Technetium-99	33.3	ND
MW406 Port 7	106-108ft	Thorium-230	ND	ND
MW406 Port 7	106-108ft	Uranium-234	NA	ND
MW406 Port 7	106-108ft	Uranium-238	NA	0.89

Table A.13 MW407 Port 2 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 2	60-62 ft	Activity of U-235	ND	ND
MW407 Port 2	60-62 ft	Alpha activity	ND	2.55
MW407 Port 2	60-62 ft	Americium-241	ND	ND
MW407 Port 2	60-62 ft	Beta activity	13.4	18
MW407 Port 2	60-62 ft	Cesium-137	ND	ND
MW407 Port 2	60-62 ft	Cobalt-60	ND	ND
MW407 Port 2	60-62 ft	Neptunium-237	ND	ND
MW407 Port 2	60-62 ft	Pu-239/240	ND	ND
MW407 Port 2	60-62 ft	Technetium-99	30.8	ND
MW407 Port 2	60-62 ft	Thorium-230	ND	ND
MW407 Port 2	60-62 ft	Uranium-234	NA	ND
MW407 Port 2	60-62 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.14 MW407 Port 3 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 3	66-68 ft	Activity of U-235	ND	ND
MW407 Port 3	66-68 ft	Alpha activity	ND	4.91
MW407 Port 3	66-68 ft	Americium-241	ND	ND
MW407 Port 3	66-68 ft	Beta activity	17.2	16.4
MW407 Port 3	66-68 ft	Cesium-137	ND	ND
MW407 Port 3	66-68 ft	Cobalt-60	ND	ND
MW407 Port 3	66-68 ft	Neptunium-237	ND	ND
MW407 Port 3	66-68 ft	Pu-239/240	ND	ND
MW407 Port 3	66-68 ft	Technetium-99	36.1	ND
MW407 Port 3	66-68 ft	Thorium-230	ND	0.87
MW407 Port 3	66-68 ft	Uranium-234	NA	ND
MW407 Port 3	66-68 ft	Uranium-238	NA	ND

Table A.15 MW407 Port 4 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 4	72-74 ft	Activity of U-235	ND	ND
MW407 Port 4	72-74 ft	Alpha activity	ND	4.57
MW407 Port 4	72-74 ft	Americium-241	ND	ND
MW407 Port 4	72-74 ft	Beta activity	26.2	21.9
MW407 Port 4	72-74 ft	Cesium-137	ND	ND
MW407 Port 4	72-74 ft	Cobalt-60	ND	ND
MW407 Port 4	72-74 ft	Neptunium-237	ND	ND
MW407 Port 4	72-74 ft	Pu-239/240	ND	ND
MW407 Port 4	72-74 ft	Technetium-99	34.4	23.5
MW407 Port 4	72-74 ft	Thorium-230	ND	ND
MW407 Port 4	72-74 ft	Uranium-234	NA	ND
MW407 Port 4	72-74 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.16 MW407 Port 5 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 5	80-82 ft	Activity of U-235	ND	ND
MW407 Port 5	80-82 ft	Alpha activity	ND	ND
MW407 Port 5	80-82 ft	Americium-241	ND	ND
MW407 Port 5	80-82 ft	Beta activity	25.7	20.5
MW407 Port 5	80-82 ft	Cesium-137	ND	ND
MW407 Port 5	80-82 ft	Cobalt-60	ND	ND
MW407 Port 5	80-82 ft	Neptunium-237	ND	ND
MW407 Port 5	80-82 ft	Pu-239/240	ND	ND
MW407 Port 5	80-82 ft	Technetium-99	30.5	28.5
MW407 Port 5	80-82 ft	Thorium-230	ND	ND
MW407 Port 5	80-82 ft	Uranium-234	NA	ND
MW407 Port 5	80-82 ft	Uranium-238	NA	ND

Table A.17 MW407 Port 6 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 6	86-88 ft	Activity of U-235	ND	ND
MW407 Port 6	86-88 ft	Alpha activity	ND	ND
MW407 Port 6	86-88 ft	Americium-241	ND	ND
MW407 Port 6	86-88 ft	Beta activity	22	21.3
MW407 Port 6	86-88 ft	Cesium-137	ND	ND
MW407 Port 6	86-88 ft	Cobalt-60	ND	ND
MW407 Port 6	86-88 ft	Neptunium-237	ND	ND
MW407 Port 6	86-88 ft	Pu-239/240	ND	ND
MW407 Port 6	86-88 ft	Technetium-99	44.1	29.7
MW407 Port 6	86-88 ft	Thorium-230	ND	0.925
MW407 Port 6	86-88 ft	Uranium-234	NA	ND
MW407 Port 6	86-88 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.18 MW407 Port 7 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW407 Port 7	106-108ft	Activity of U-235	ND	ND
MW407 Port 7	106-108ft	Alpha activity	ND	ND
MW407 Port 7	106-108ft	Americium-241	ND	ND
MW407 Port 7	106-108ft	Beta activity	25.2	8.96
MW407 Port 7	106-108ft	Cesium-137	ND	ND
MW407 Port 7	106-108ft	Cobalt-60	ND	ND
MW407 Port 7	106-108ft	Neptunium-237	ND	ND
MW407 Port 7	106-108ft	Pu-239/240	ND	ND
MW407 Port 7	106-108ft	Technetium-99	40.2	ND
MW407 Port 7	106-108ft	Thorium-230	ND	2.84
MW407 Port 7	106-108ft	Uranium-234	NA	ND
MW407 Port 7	106-108ft	Uranium-238	NA	ND

Table A.19 MW408 Port 2 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 2	60-62 ft	Activity of U-235	ND	ND
MW408 Port 2	60-62 ft	Alpha activity	ND	ND
MW408 Port 2	60-62 ft	Americium-241	ND	ND
MW408 Port 2	60-62 ft	Beta activity	24	76.2
MW408 Port 2	60-62 ft	Cesium-137	ND	ND
MW408 Port 2	60-62 ft	Cobalt-60	ND	ND
MW408 Port 2	60-62 ft	Neptunium-237	ND	ND
MW408 Port 2	60-62 ft	Pu-239/240	ND	ND
MW408 Port 2	60-62 ft	Technetium-99	48.9	111
MW408 Port 2	60-62 ft	Thorium-230	ND	ND
MW408 Port 2	60-62 ft	Uranium-234	NA	ND
MW408 Port 2	60-62 ft	Uranium-238	NA	ND

NA – Not Analyzed
ND – Not Detected

Table A.20 MW408 Port 3 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 3	66-68 ft	Activity of U-235	ND	ND
MW408 Port 3	66-68 ft	Alpha activity	ND	ND
MW408 Port 3	66-68 ft	Americium-241	ND	ND
MW408 Port 3	66-68 ft	Beta activity	20.5	64.3
MW408 Port 3	66-68 ft	Cesium-137	ND	ND
MW408 Port 3	66-68 ft	Cobalt-60	ND	ND
MW408 Port 3	66-68 ft	Neptunium-237	ND	ND
MW408 Port 3	66-68 ft	Pu-239/240	ND	ND
MW408 Port 3	66-68 ft	Technetium-99	41.4	109
MW408 Port 3	66-68 ft	Thorium-230	ND	ND
MW408 Port 3	66-68 ft	Uranium-234	NA	ND
MW408 Port 3	66-68 ft	Uranium-238	NA	ND

Table A.21 MW408 Port 4 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 4	72-74 ft	Activity of U-235	24.1	ND
MW408 Port 4	72-74 ft	Alpha activity	ND	ND
MW408 Port 4	72-74 ft	Americium-241	ND	ND
MW408 Port 4	72-74 ft	Beta activity	24.6	70.1
MW408 Port 4	72-74 ft	Cesium-137	ND	ND
MW408 Port 4	72-74 ft	Cobalt-60	ND	ND
MW408 Port 4	72-74 ft	Neptunium-237	ND	ND
MW408 Port 4	72-74 ft	Pu-239/240	ND	ND
MW408 Port 4	72-74 ft	Technetium-99	41.3	119
MW408 Port 4	72-74 ft	Thorium-230	ND	ND
MW408 Port 4	72-74 ft	Uranium-234	NA	ND
MW408 Port 4	72-74 ft	Uranium-238	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.22 MW408 Port 5 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 5	80-82 ft	Activity of U-235	ND	ND
MW408 Port 5	80-82 ft	Alpha activity	ND	ND
MW408 Port 5	80-82 ft	Americium-241	ND	ND
MW408 Port 5	80-82 ft	Beta activity	23	77.7
MW408 Port 5	80-82 ft	Cesium-137	ND	ND
MW408 Port 5	80-82 ft	Cobalt-60	ND	ND
MW408 Port 5	80-82 ft	Neptunium-237	ND	ND
MW408 Port 5	80-82 ft	Pu-239/240	ND	ND
MW408 Port 5	80-82 ft	Technetium-99	38.5	108
MW408 Port 5	80-82 ft	Thorium-230	ND	ND
MW408 Port 5	80-82 ft	Uranium-234	NA	ND
MW408 Port 5	80-82 ft	Uranium-238	NA	ND

Table A.23 MW408 Port 6 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 6	86-88 ft	Activity of U-235	ND	ND
MW408 Port 6	86-88 ft	Alpha activity	ND	ND
MW408 Port 6	86-88 ft	Americium-241	ND	ND
MW408 Port 6	86-88 ft	Beta activity	25.3	58.2
MW408 Port 6	86-88 ft	Cesium-137	ND	ND
MW408 Port 6	86-88 ft	Cobalt-60	ND	ND
MW408 Port 6	86-88 ft	Neptunium-237	ND	ND
MW408 Port 6	86-88 ft	Pu-239/240	ND	ND
MW408 Port 6	86-88 ft	Technetium-99	25	75.6
MW408 Port 6	86-88 ft	Thorium-230	ND	ND
MW408 Port 6	86-88 ft	Uranium-234	NA	ND
MW408 Port 6	86-88 ft	Uranium-238	NA	0.383

NA – Not Analyzed
ND – Not Detected

Table A.24 MW408 Port 7 Radiological Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (pCi/L)	Post Treatment (pCi/L)
MW408 Port 7	104-106 ft	Activity of U-235	ND	NA
MW408 Port 7	104-106 ft	Alpha activity	ND	NA
MW408 Port 7	104-106 ft	Americium-241	ND	NA
MW408 Port 7	104-106 ft	Beta activity	21.5	NA
MW408 Port 7	104-106 ft	Cesium-137	ND	NA
MW408 Port 7	104-106 ft	Cobalt-60	ND	NA
MW408 Port 7	104-106 ft	Neptunium-237	ND	NA
MW408 Port 7	104-106 ft	Pu-239/240	ND	NA
MW408 Port 7	104-106 ft	Technetium-99	19.3	NA
MW408 Port 7	104-106 ft	Thorium-230	NA	NA

Table A.25 Tc^{99} Data Comparison from Baseline to Post Treatment.

Location	Depth	Baseline (pCi/L)	Post Treatment (pCi/L)	Percent Difference
MW408 Port 2	60-62 ft	48.9	111	127%
MW407 Port 2	60-62 ft	30.8	0	-100%
MW405 Port 2	60-62 ft	43.7	148	239%
MW406 Port 2	60-62 ft	18.2	49.8	174%
MW405 Port 3	66-68 ft	42.2	139	229%
MW408 Port 3	66-68 ft	41.4	109	163%
MW406 Port 3	66-68 ft	17.5	46.9	168%
MW407 Port 3	66-68 ft	36.1	ND	-100%
MW407 Port 4	72-74 ft	34.4	23.5	-32%
MW406 Port 4	72-74 ft	0	44.2	--
MW408 Port 4	72-74 ft	41.3	119	188%
MW405 Port 4	72-74 ft	35.8	154	330%
MW406 Port 5	80-82 ft	17.2	51.3	198%
MW405 Port 5	80-82 ft	54.4	153	181%
MW408 Port 5	80-82 ft	38.5	108	181%
MW407 Port 5	80-82 ft	30.5	28.5	-7%
MW405 Port 6	86-88 ft	92.1	147	60%
MW406 Port 6	86-88 ft	22.5	71.2	216%
MW407 Port 6	86-88 ft	44.1	29.7	-33%
MW408 Port 6	86-88 ft	25	75.6	202%
MW405 Port 7	106-108 ft	50.7	152	200%
MW408 Port 7	106-108 ft	19.3	NA	--
MW407 Port 7	106-108 ft	40.2	ND	-100%
MW406 Port 7	106-108 ft	33.3	ND	-100%

NA – Not Analyzed
ND – Not Detected

Tables A.26 through A.50 below identify inorganic sampling results from the baseline and post groundwater sampling events. The majority of results did not show a significant difference between the baseline and the post event. Analyses having more than a 300 percent increase are listed in Table A.50. Only three metals (magnesium, manganese, and barium) had results with more than 300 percent difference. This occurred in both unfiltered and filtered samples. In only one case, nitrate as nitrogen showed a 4280 percent increase; however, the initial result was very low. Other samples for nitrate as nitrogen showed very little change.

Table A.51 summarizes changes in groundwater-dissolved chlorides and other dissolved minerals. Previous SPH remediation sites have shown signs of accelerated degradation of TCE and other chlorinated solvents. Such degradation is reflected as an increase in dissolved chlorides. SPH remediation is a steam distillation process; removed of distilled water in the form of steam results in concentration of dissolved minerals in the remaining groundwater. For this reason, Table A.51 also tracks the changes in dissolved minerals other than chloride to provide some indication of the concentration effect.

A comparison of data indicated that dissolved minerals (other than chloride) did not concentrate during the treatability study – the dissolved minerals became more dilute. Groundwater mixing or groundwater flow during the treatability study might explain why the dissolved minerals did not increase significantly during the treatability study; however, it is difficult to explain a decrease due to these effects. In contrast to the other dissolved minerals, chlorides did increase during the treatability study. This provides an indication that TCE degradation did increase during the treatability study. Chloride increases were observed in all wells - both inside and outside the treatment region. Chloride is a very mobile ion and would be expected to spread with groundwater flow and through diffusion – this could account for the chloride increases in all monitoring wells. In summary, data suggests that a significant amount of TCE degraded during the treatability study but it is not possible to quantify the mass of TCE that degraded. TCE degradation was probably a less important removal mechanism than vapor phase recovery during this treatability study.

Table A.26 MW405 Port 2 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 2	60-62 ft	Aluminum	ND	ND
MW405 Port 2	60-62 ft	Arsenic	ND	ND
MW405 Port 2	60-62 ft	Barium	0.081	0.284
MW405 Port 2	60-62 ft	Barium, Dissolved	NA	0.287
MW405 Port 2	60-62 ft	Calcium	37	32.2
MW405 Port 2	60-62 ft	Calcium, Dissolved	NA	33.7
MW405 Port 2	60-62 ft	Chloride	19.7	75
MW405 Port 2	60-62 ft	Chromium	ND	ND
MW405 Port 2	60-62 ft	Fluoride	ND	ND
MW405 Port 2	60-62 ft	Iron	ND	ND
MW405 Port 2	60-62 ft	Lead	ND	ND
MW405 Port 2	60-62 ft	Magnesium	4.49	8.62
MW405 Port 2	60-62 ft	Magnesium, Dissolved	NA	8.61
MW405 Port 2	60-62 ft	Manganese	0.044	ND
MW405 Port 2	60-62 ft	Manganese, Dissolved	NA	ND
MW405 Port 2	60-62 ft	Mercury	ND	ND
MW405 Port 2	60-62 ft	Nickel	ND	ND
MW405 Port 2	60-62 ft	Nitrate as Nitrogen	ND	14.8
MW405 Port 2	60-62 ft	Potassium	28.8	3.56
MW405 Port 2	60-62 ft	Potassium, Dissolved	NA	3.46
MW405 Port 2	60-62 ft	Selenium	ND	ND
MW405 Port 2	60-62 ft	Sodium	44.8	39.9
MW405 Port 2	60-62 ft	Sodium, Dissolved	NA	43.9
MW405 Port 2	60-62 ft	Sulfide	ND	ND
MW405 Port 2	60-62 ft	Uranium	ND	ND
MW405 Port 2	60-62 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.27 MW405 Port 3 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 3	66-68 ft	Aluminum	ND	ND
MW405 Port 3	66-68 ft	Arsenic	ND	ND
MW405 Port 3	66-68 ft	Barium	0.078	0.268
MW405 Port 3	66-68 ft	Barium, Dissolved	NA	0.28
MW405 Port 3	66-68 ft	Calcium	36.8	30
MW405 Port 3	66-68 ft	Calcium, Dissolved	NA	32.5
MW405 Port 3	66-68 ft	Chloride	14	74.8
MW405 Port 3	66-68 ft	Chromium	ND	ND
MW405 Port 3	66-68 ft	Fluoride	ND	ND
MW405 Port 3	66-68 ft	Iron	ND	ND
MW405 Port 3	66-68 ft	Lead	ND	ND
MW405 Port 3	66-68 ft	Magnesium	4.83	7.88
MW405 Port 3	66-68 ft	Magnesium, Dissolved	NA	8.18
MW405 Port 3	66-68 ft	Manganese	0.109	ND
MW405 Port 3	66-68 ft	Manganese, Dissolved	NA	ND
MW405 Port 3	66-68 ft	Mercury	ND	ND
MW405 Port 3	66-68 ft	Nickel	ND	ND
MW405 Port 3	66-68 ft	Nitrate as Nitrogen	ND	3.3
MW405 Port 3	66-68 ft	Potassium	4.2	3.56
MW405 Port 3	66-68 ft	Potassium, Dissolved	NA	3.45
MW405 Port 3	66-68 ft	Selenium	ND	ND
MW405 Port 3	66-68 ft	Sodium	25.2	39
MW405 Port 3	66-68 ft	Sodium, Dissolved	NA	44
MW405 Port 3	66-68 ft	Sulfide	ND	ND
MW405 Port 3	66-68 ft	Uranium	ND	ND
MW405 Port 3	66-68 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.28 MW405 Port 4 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 4	72-74 ft	Aluminum	ND	ND
MW405 Port 4	72-74 ft	Arsenic	ND	ND
MW405 Port 4	72-74 ft	Barium	0.098	0.274
MW405 Port 4	72-74 ft	Barium, Dissolved	NA	0.282
MW405 Port 4	72-74 ft	Calcium	42.5	30.9
MW405 Port 4	72-74 ft	Calcium, Dissolved	NA	33.7
MW405 Port 4	72-74 ft	Chloride	22.6	73.5
MW405 Port 4	72-74 ft	Chromium	ND	ND
MW405 Port 4	72-74 ft	Fluoride	ND	ND
MW405 Port 4	72-74 ft	Iron	ND	ND
MW405 Port 4	72-74 ft	Lead	ND	ND
MW405 Port 4	72-74 ft	Magnesium	6.43	8.15
MW405 Port 4	72-74 ft	Magnesium, Dissolved	NA	8.43
MW405 Port 4	72-74 ft	Manganese	0.047	ND
MW405 Port 4	72-74 ft	Manganese, Dissolved	NA	ND
MW405 Port 4	72-74 ft	Mercury	ND	ND
MW405 Port 4	72-74 ft	Nickel	ND	ND
MW405 Port 4	72-74 ft	Nitrate as Nitrogen	42.1	1.4
MW405 Port 4	72-74 ft	Potassium	3.16	3.54
MW405 Port 4	72-74 ft	Potassium, Dissolved	NA	3.51
MW405 Port 4	72-74 ft	Selenium	ND	ND
MW405 Port 4	72-74 ft	Sodium	37.7	39.8
MW405 Port 4	72-74 ft	Sodium, Dissolved	NA	44.9
MW405 Port 4	72-74 ft	Sulfide	ND	ND
MW405 Port 4	72-74 ft	Uranium	ND	ND
MW405 Port 4	72-74 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.29 MW405 Port 5 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 5	80-82 ft	Aluminum	0.282	ND
MW405 Port 5	80-82 ft	Aluminum, Dissolved	ND	NA
MW405 Port 5	80-82 ft	Arsenic	ND	ND
MW405 Port 5	80-82 ft	Barium	0.033	0.299
MW405 Port 5	80-82 ft	Barium, Dissolved	0.037	0.287
MW405 Port 5	80-82 ft	Calcium	35.5	38.1
MW405 Port 5	80-82 ft	Calcium, Dissolved	38.7	39.1
MW405 Port 5	80-82 ft	Chloride	20.9	73.1
MW405 Port 5	80-82 ft	Chromium	ND	ND
MW405 Port 5	80-82 ft	Fluoride	1.1	ND
MW405 Port 5	80-82 ft	Iron	ND	ND
MW405 Port 5	80-82 ft	Lead	ND	ND
MW405 Port 5	80-82 ft	Magnesium	2	10.7
MW405 Port 5	80-82 ft	Magnesium, Dissolved	2.28	10.6
MW405 Port 5	80-82 ft	Manganese	ND	ND
MW405 Port 5	80-82 ft	Manganese, Dissolved	NA	ND
MW405 Port 5	80-82 ft	Mercury	ND	ND
MW405 Port 5	80-82 ft	Mercury, Dissolved	ND	NA
MW405 Port 5	80-82 ft	Nickel	ND	ND
MW405 Port 5	80-82 ft	Nitrate as Nitrogen	ND	2.1
MW405 Port 5	80-82 ft	Potassium	3.88	3.44
MW405 Port 5	80-82 ft	Potassium, Dissolved	3.99	3.3
MW405 Port 5	80-82 ft	Selenium	ND	ND
MW405 Port 5	80-82 ft	Sodium	17	44.1
MW405 Port 5	80-82 ft	Sodium, Dissolved	18	45.5
MW405 Port 5	80-82 ft	Sulfide	ND	ND
MW405 Port 5	80-82 ft	Uranium	ND	ND
MW405 Port 5	80-82 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.30 MW405 Port 6 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 6	86-88 ft	Aluminum	0.713	ND
MW405 Port 6	86-88 ft	Aluminum, Dissolved	0.518	NA
MW405 Port 6	86-88 ft	Arsenic	ND	ND
MW405 Port 6	86-88 ft	Barium	0.028	0.256
MW405 Port 6	86-88 ft	Barium, Dissolved	0.03	0.247
MW405 Port 6	86-88 ft	Calcium	47.6	39
MW405 Port 6	86-88 ft	Calcium, Dissolved	50.6	37.2
MW405 Port 6	86-88 ft	Chloride	33	74.9
MW405 Port 6	86-88 ft	Chromium	ND	ND
MW405 Port 6	86-88 ft	Fluoride	ND	ND
MW405 Port 6	86-88 ft	Iron	ND	ND
MW405 Port 6	86-88 ft	Lead	ND	ND
MW405 Port 6	86-88 ft	Magnesium	1.38	10.6
MW405 Port 6	86-88 ft	Magnesium, Dissolved	1.59	10.4
MW405 Port 6	86-88 ft	Manganese	ND	ND
MW405 Port 6	86-88 ft	Mercury	ND	ND
MW405 Port 6	86-88 ft	Mercury, Dissolved	ND	NA
MW405 Port 6	86-88 ft	Nickel	ND	ND
MW405 Port 6	86-88 ft	Nitrate as Nitrogen	ND	1.8
MW405 Port 6	86-88 ft	Potassium	5.55	3.09
MW405 Port 6	86-88 ft	Potassium, Dissolved	5.65	2.94
MW405 Port 6	86-88 ft	Selenium	ND	ND
MW405 Port 6	86-88 ft	Sodium	21.1	41.8
MW405 Port 6	86-88 ft	Sodium, Dissolved	22.9	39.6
MW405 Port 6	86-88 ft	Sulfide	ND	ND
MW405 Port 6	86-88 ft	Uranium	ND	ND
MW405 Port 6	86-88 ft	Vanadium	0.028	ND

NA – Not Analyzed
ND – Not Detected

Table A.31 MW405 Port 7 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW405 Port 7	106-108 ft	Aluminum	0.971	ND
MW405 Port 7	106-108 ft	Aluminum, Dissolved	0.501	NA
MW405 Port 7	106-108 ft	Arsenic	0.009	ND
MW405 Port 7	106-108 ft	Arsenic, Dissolved	0.009	NA
MW405 Port 7	106-108 ft	Barium	ND	0.25
MW405 Port 7	106-108 ft	Barium, Dissolved	NA	0.259
MW405 Port 7	106-108 ft	Calcium	33.8	71.2
MW405 Port 7	106-108 ft	Calcium, Dissolved	33	68.9
MW405 Port 7	106-108 ft	Chloride	11.3	77.7
MW405 Port 7	106-108 ft	Chromium	ND	ND
MW405 Port 7	106-108 ft	Fluoride	1.2	ND
MW405 Port 7	106-108 ft	Iron	0.581	ND
MW405 Port 7	106-108 ft	Iron, Dissolved	ND	NA
MW405 Port 7	106-108 ft	Lead	ND	ND
MW405 Port 7	106-108 ft	Magnesium	0.458	11.8
MW405 Port 7	106-108 ft	Magnesium, Dissolved	0.446	12
MW405 Port 7	106-108 ft	Manganese	ND	ND
MW405 Port 7	106-108 ft	Manganese, Dissolved	NA	ND
MW405 Port 7	106-108 ft	Mercury	ND	ND
MW405 Port 7	106-108 ft	Mercury, Dissolved	ND	NA
MW405 Port 7	106-108 ft	Nickel	ND	ND
MW405 Port 7	106-108 ft	Nitrate as Nitrogen	ND	1.4
MW405 Port 7	106-108 ft	Potassium	5.47	3.71
MW405 Port 7	106-108 ft	Potassium, Dissolved	5.08	3.66
MW405 Port 7	106-108 ft	Selenium	ND	ND
MW405 Port 7	106-108 ft	Sodium	30.7	41
MW405 Port 7	106-108 ft	Sodium, Dissolved	18	43.5
MW405 Port 7	106-108 ft	Sulfide	ND	ND
MW405 Port 7	106-108 ft	Uranium	ND	ND
MW405 Port 7	106-108 ft	Vanadium	0.041	0.026
MW405 Port 7	106-108 ft	Vanadium, Dissolved	0.032	0.031

NA – Not Analyzed
ND – Not Detected

Table A.32 MW406 Port 2 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 2	60-62 ft	Aluminum	ND	ND
MW406 Port 2	60-62 ft	Arsenic	ND	ND
MW406 Port 2	60-62 ft	Barium	0.141	0.36
MW406 Port 2	60-62 ft	Barium, Dissolved	0.127	0.357
MW406 Port 2	60-62 ft	Calcium	55.8	46.5
MW406 Port 2	60-62 ft	Calcium, Dissolved	50.8	49.7
MW406 Port 2	60-62 ft	Chloride	55.7	130.1
MW406 Port 2	60-62 ft	Chromium	ND	ND
MW406 Port 2	60-62 ft	Fluoride	ND	ND
MW406 Port 2	60-62 ft	Iron	0.593	ND
MW406 Port 2	60-62 ft	Iron, Dissolved	ND	NA
MW406 Port 2	60-62 ft	Lead	ND	ND
MW406 Port 2	60-62 ft	Magnesium	12.7	14.7
MW406 Port 2	60-62 ft	Magnesium, Dissolved	11.6	14.7
MW406 Port 2	60-62 ft	Manganese	0.361	0.469
MW406 Port 2	60-62 ft	Manganese, Dissolved	0.328	0.283
MW406 Port 2	60-62 ft	Mercury	ND	ND
MW406 Port 2	60-62 ft	Mercury, Dissolved	ND	NA
MW406 Port 2	60-62 ft	Nickel	ND	ND
MW406 Port 2	60-62 ft	Nitrate as Nitrogen	1	1.2
MW406 Port 2	60-62 ft	Potassium	16.7	12.2
MW406 Port 2	60-62 ft	Potassium, Dissolved	15.6	12.2
MW406 Port 2	60-62 ft	Selenium	ND	ND
MW406 Port 2	60-62 ft	Sodium	55.4	55.1
MW406 Port 2	60-62 ft	Sodium, Dissolved	53	59.9
MW406 Port 2	60-62 ft	Sulfide	ND	ND
MW406 Port 2	60-62 ft	Uranium	ND	ND
MW406 Port 2	60-62 ft	Vanadium	ND	0.034
MW406 Port 2	60-62 ft	Vanadium, Dissolved	NA	0.035

NA – Not Analyzed
ND – Not Detected

Table A.33 MW406 Port 3 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 3	66-68 ft	Aluminum	ND	ND
MW406 Port 3	66-68 ft	Arsenic	ND	ND
MW406 Port 3	66-68 ft	Barium	0.21	0.354
MW406 Port 3	66-68 ft	Barium, Dissolved	0.174	0.374
MW406 Port 3	66-68 ft	Calcium	39.9	45.3
MW406 Port 3	66-68 ft	Calcium, Dissolved	33.4	50.9
MW406 Port 3	66-68 ft	Chloride	40.8	142.8
MW406 Port 3	66-68 ft	Chromium	ND	ND
MW406 Port 3	66-68 ft	Fluoride	ND	ND
MW406 Port 3	66-68 ft	Iron	ND	ND
MW406 Port 3	66-68 ft	Lead	ND	ND
MW406 Port 3	66-68 ft	Magnesium	11.2	14.1
MW406 Port 3	66-68 ft	Magnesium, Dissolved	9.6	15.2
MW406 Port 3	66-68 ft	Manganese	0.23	0.322
MW406 Port 3	66-68 ft	Manganese, Dissolved	0.203	0.352
MW406 Port 3	66-68 ft	Mercury	ND	ND
MW406 Port 3	66-68 ft	Mercury, Dissolved	ND	NA
MW406 Port 3	66-68 ft	Nickel	ND	ND
MW406 Port 3	66-68 ft	Nitrate as Nitrogen	ND	1.4
MW406 Port 3	66-68 ft	Potassium	6.51	11.5
MW406 Port 3	66-68 ft	Potassium, Dissolved	5.65	12
MW406 Port 3	66-68 ft	Selenium	ND	ND
MW406 Port 3	66-68 ft	Sodium	54.7	53.3
MW406 Port 3	66-68 ft	Sodium, Dissolved	50	61
MW406 Port 3	66-68 ft	Sulfide	ND	ND
MW406 Port 3	66-68 ft	Uranium	ND	ND
MW406 Port 3	66-68 ft	Vanadium	ND	0.031
MW406 Port 3	66-68 ft	Vanadium, Dissolved	NA	0.037

NA – Not Analyzed
ND – Not Detected

Table A.34 MW406 Port 4 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 4	72-74 ft	Aluminum	ND	ND
MW406 Port 4	72-74 ft	Arsenic	ND	ND
MW406 Port 4	72-74 ft	Barium	0.147	0.38
MW406 Port 4	72-74 ft	Barium, Dissolved	0.117	0.368
MW406 Port 4	72-74 ft	Calcium	62.7	49.3
MW406 Port 4	72-74 ft	Calcium, Dissolved	50.8	49.9
MW406 Port 4	72-74 ft	Chloride	62.3	138.8
MW406 Port 4	72-74 ft	Chromium	ND	ND
MW406 Port 4	72-74 ft	Fluoride	ND	ND
MW406 Port 4	72-74 ft	Iron	4.75	ND
MW406 Port 4	72-74 ft	Iron, Dissolved	2.02	NA
MW406 Port 4	72-74 ft	Lead	ND	ND
MW406 Port 4	72-74 ft	Magnesium	15.1	14
MW406 Port 4	72-74 ft	Magnesium, Dissolved	12.6	13.8
MW406 Port 4	72-74 ft	Manganese	0.739	0.158
MW406 Port 4	72-74 ft	Manganese, Dissolved	0.617	0.151
MW406 Port 4	72-74 ft	Mercury	ND	ND
MW406 Port 4	72-74 ft	Mercury, Dissolved	ND	NA
MW406 Port 4	72-74 ft	Nickel	0.075	ND
MW406 Port 4	72-74 ft	Nickel, Dissolved	0.071	NA
MW406 Port 4	72-74 ft	Nitrate as Nitrogen	ND	1
MW406 Port 4	72-74 ft	Potassium	4.66	11.9
MW406 Port 4	72-74 ft	Potassium, Dissolved	4.19	11.1
MW406 Port 4	72-74 ft	Selenium	ND	ND
MW406 Port 4	72-74 ft	Sodium	51.2	55.7
MW406 Port 4	72-74 ft	Sodium, Dissolved	43.4	57.3
MW406 Port 4	72-74 ft	Sulfide	ND	ND
MW406 Port 4	72-74 ft	Uranium	ND	ND
MW406 Port 4	72-74 ft	Vanadium	ND	0.033
MW406 Port 4	72-74 ft	Vanadium, Dissolved	NA	0.034

NA – Not Analyzed
ND – Not Detected

Table A.35 MW406 Port 5 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 5	80-82 ft	Aluminum	ND	ND
MW406 Port 5	80-82 ft	Arsenic	ND	ND
MW406 Port 5	80-82 ft	Barium	0.098	0.384
MW406 Port 5	80-82 ft	Barium, Dissolved	0.101	0.388
MW406 Port 5	80-82 ft	Calcium	57.1	49.7
MW406 Port 5	80-82 ft	Calcium, Dissolved	59.1	52
MW406 Port 5	80-82 ft	Chloride	81.4	153
MW406 Port 5	80-82 ft	Chromium	ND	ND
MW406 Port 5	80-82 ft	Fluoride	ND	ND
MW406 Port 5	80-82 ft	Iron	ND	ND
MW406 Port 5	80-82 ft	Lead	ND	ND
MW406 Port 5	80-82 ft	Magnesium	8.97	14.1
MW406 Port 5	80-82 ft	Magnesium, Dissolved	9.16	14.4
MW406 Port 5	80-82 ft	Manganese	0.129	0.133
MW406 Port 5	80-82 ft	Manganese, Dissolved	0.137	0.137
MW406 Port 5	80-82 ft	Mercury	ND	ND
MW406 Port 5	80-82 ft	Mercury, Dissolved	ND	NA
MW406 Port 5	80-82 ft	Nickel	ND	ND
MW406 Port 5	80-82 ft	Nitrate as Nitrogen	ND	1.2
MW406 Port 5	80-82 ft	Potassium	6.91	11.8
MW406 Port 5	80-82 ft	Potassium, Dissolved	6.91	11.6
MW406 Port 5	80-82 ft	Selenium	ND	ND
MW406 Port 5	80-82 ft	Sodium	69	56.4
MW406 Port 5	80-82 ft	Sodium, Dissolved	70.9	60.9
MW406 Port 5	80-82 ft	Sulfide	ND	ND
MW406 Port 5	80-82 ft	Uranium	ND	ND
MW406 Port 5	80-82 ft	Vanadium	ND	0.034
MW406 Port 5	80-82 ft	Vanadium, Dissolved	NA	0.034

NA – Not Analyzed
ND – Not Detected

Table A.36 MW406 Port 6 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 6	86-88 ft	Aluminum	ND	ND
MW406 Port 6	86-88 ft	Arsenic	ND	ND
MW406 Port 6	86-88 ft	Barium	0.063	0.379
MW406 Port 6	86-88 ft	Barium, Dissolved	0.055	0.396
MW406 Port 6	86-88 ft	Calcium	41	48
MW406 Port 6	86-88 ft	Calcium, Dissolved	36.5	52.8
MW406 Port 6	86-88 ft	Chloride	75.6	157.3
MW406 Port 6	86-88 ft	Chromium	ND	ND
MW406 Port 6	86-88 ft	Fluoride	1	ND
MW406 Port 6	86-88 ft	Iron	ND	ND
MW406 Port 6	86-88 ft	Lead	ND	ND
MW406 Port 6	86-88 ft	Magnesium	4.13	13.7
MW406 Port 6	86-88 ft	Magnesium, Dissolved	3.66	14.5
MW406 Port 6	86-88 ft	Manganese	0.102	0.129
MW406 Port 6	86-88 ft	Manganese, Dissolved	0.095	0.131
MW406 Port 6	86-88 ft	Mercury	ND	ND
MW406 Port 6	86-88 ft	Mercury, Dissolved	ND	NA
MW406 Port 6	86-88 ft	Nickel	ND	ND
MW406 Port 6	86-88 ft	Nitrate as Nitrogen	ND	1.2
MW406 Port 6	86-88 ft	Potassium	5.25	11.6
MW406 Port 6	86-88 ft	Potassium, Dissolved	4.69	11.6
MW406 Port 6	86-88 ft	Selenium	ND	ND
MW406 Port 6	86-88 ft	Sodium	68.5	55.6
MW406 Port 6	86-88 ft	Sodium, Dissolved	58.4	61.7
MW406 Port 6	86-88 ft	Sulfide	ND	ND
MW406 Port 6	86-88 ft	Uranium	ND	ND
MW406 Port 6	86-88 ft	Vanadium	ND	0.032
MW406 Port 6	86-88 ft	Vanadium, Dissolved	NA	0.037

NA – Not Analyzed
ND – Not Detected

Table A.37 MW406 Port 7 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW406 Port 7	106-108 ft	Aluminum	2.72	0.948
MW406 Port 7	106-108 ft	Aluminum, Dissolved	ND	ND
MW406 Port 7	106-108 ft	Arsenic	ND	ND
MW406 Port 7	106-108 ft	Barium	0.114	0.096
MW406 Port 7	106-108 ft	Barium, Dissolved	0.083	0.099
MW406 Port 7	106-108 ft	Calcium	62.4	17.1
MW406 Port 7	106-108 ft	Calcium, Dissolved	48.2	18.7
MW406 Port 7	106-108 ft	Chloride	137.1	4.3
MW406 Port 7	106-108 ft	Chromium	ND	ND
MW406 Port 7	106-108 ft	Fluoride	ND	ND
MW406 Port 7	106-108 ft	Iron	2.35	1.75
MW406 Port 7	106-108 ft	Iron, Dissolved	ND	ND
MW406 Port 7	106-108 ft	Lead	ND	ND
MW406 Port 7	106-108 ft	Magnesium	7.47	6.94
MW406 Port 7	106-108 ft	Magnesium, Dissolved	7.02	7.2
MW406 Port 7	106-108 ft	Manganese	0.111	0.312
MW406 Port 7	106-108 ft	Manganese, Dissolved	0.028	0.314
MW406 Port 7	106-108 ft	Mercury	ND	ND
MW406 Port 7	106-108 ft	Mercury, Dissolved	ND	NA
MW406 Port 7	106-108 ft	Nickel	ND	ND
MW406 Port 7	106-108 ft	Nitrate as Nitrogen	1.3	ND
MW406 Port 7	106-108 ft	Potassium	7.8	3.68
MW406 Port 7	106-108 ft	Potassium, Dissolved	7.38	3.57
MW406 Port 7	106-108 ft	Selenium	ND	ND
MW406 Port 7	106-108 ft	Sodium	89.6	11.3
MW406 Port 7	106-108 ft	Sodium, Dissolved	83.9	12.5
MW406 Port 7	106-108 ft	Sulfide	ND	ND
MW406 Port 7	106-108 ft	Uranium	ND	ND
MW406 Port 7	106-108 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.38 MW407 Port 2 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 2	60-62 ft	Aluminum	ND	ND
MW407 Port 2	60-62 ft	Arsenic	ND	ND
MW407 Port 2	60-62 ft	Barium	0.127	0.117
MW407 Port 2	60-62 ft	Barium, Dissolved	0.113	0.115
MW407 Port 2	60-62 ft	Calcium	56.1	20.2
MW407 Port 2	60-62 ft	Calcium, Dissolved	50.6	20.5
MW407 Port 2	60-62 ft	Chloride	37.5	10.1
MW407 Port 2	60-62 ft	Chromium	ND	ND
MW407 Port 2	60-62 ft	Fluoride	ND	ND
MW407 Port 2	60-62 ft	Iron	ND	ND
MW407 Port 2	60-62 ft	Lead	ND	ND
MW407 Port 2	60-62 ft	Magnesium	10.8	10.4
MW407 Port 2	60-62 ft	Magnesium, Dissolved	9.84	9.95
MW407 Port 2	60-62 ft	Manganese	0.335	0.203
MW407 Port 2	60-62 ft	Manganese, Dissolved	0.29	0.187
MW407 Port 2	60-62 ft	Mercury	ND	ND
MW407 Port 2	60-62 ft	Mercury, Dissolved	ND	NA
MW407 Port 2	60-62 ft	Nickel	ND	ND
MW407 Port 2	60-62 ft	Nitrate as Nitrogen	1.8	ND
MW407 Port 2	60-62 ft	Potassium	5.92	3.51
MW407 Port 2	60-62 ft	Potassium, Dissolved	5.39	3.27
MW407 Port 2	60-62 ft	Selenium	ND	ND
MW407 Port 2	60-62 ft	Sodium	52.8	13.2
MW407 Port 2	60-62 ft	Sodium, Dissolved	48.8	14.3
MW407 Port 2	60-62 ft	Sulfide	ND	ND
MW407 Port 2	60-62 ft	Uranium	ND	ND
MW407 Port 2	60-62 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.39 MW407 Port 3 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 3	66-68 ft	Aluminum	ND	ND
MW407 Port 3	66-68 ft	Arsenic	ND	ND
MW407 Port 3	66-68 ft	Barium	0.16	0.116
MW407 Port 3	66-68 ft	Barium, Dissolved	0.139	0.118
MW407 Port 3	66-68 ft	Calcium	57.2	19.9
MW407 Port 3	66-68 ft	Calcium, Dissolved	48.9	21.1
MW407 Port 3	66-68 ft	Chloride	35.9	12.3
MW407 Port 3	66-68 ft	Chromium	ND	ND
MW407 Port 3	66-68 ft	Fluoride	ND	ND
MW407 Port 3	66-68 ft	Iron	ND	ND
MW407 Port 3	66-68 ft	Lead	ND	ND
MW407 Port 3	66-68 ft	Magnesium	12	9.82
MW407 Port 3	66-68 ft	Magnesium, Dissolved	10.5	9.91
MW407 Port 3	66-68 ft	Manganese	0.202	0.182
MW407 Port 3	66-68 ft	Manganese, Dissolved	0.176	0.171
MW407 Port 3	66-68 ft	Mercury	ND	ND
MW407 Port 3	66-68 ft	Mercury, Dissolved	ND	NA
MW407 Port 3	66-68 ft	Nickel	ND	ND
MW407 Port 3	66-68 ft	Nitrate as Nitrogen	1.7	2.1
MW407 Port 3	66-68 ft	Potassium	4.01	3.3
MW407 Port 3	66-68 ft	Potassium, Dissolved	3.68	3.27
MW407 Port 3	66-68 ft	Selenium	ND	ND
MW407 Port 3	66-68 ft	Sodium	53.4	14.2
MW407 Port 3	66-68 ft	Sodium, Dissolved	48.3	15.3
MW407 Port 3	66-68 ft	Sulfide	ND	ND
MW407 Port 3	66-68 ft	Uranium	ND	ND
MW407 Port 3	66-68 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.40 MW407 Port 4 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 4	72-74 ft	Aluminum	ND	ND
MW407 Port 4	72-74 ft	Arsenic	ND	ND
MW407 Port 4	72-74 ft	Barium	0.225	0.135
MW407 Port 4	72-74 ft	Barium, Dissolved	0.198	0.131
MW407 Port 4	72-74 ft	Calcium	52.4	21.9
MW407 Port 4	72-74 ft	Calcium, Dissolved	46.7	21.8
MW407 Port 4	72-74 ft	Chloride	47.1	18.6
MW407 Port 4	72-74 ft	Chromium	ND	ND
MW407 Port 4	72-74 ft	Fluoride	ND	ND
MW407 Port 4	72-74 ft	Iron	ND	ND
MW407 Port 4	72-74 ft	Lead	ND	ND
MW407 Port 4	72-74 ft	Magnesium	12.1	9.12
MW407 Port 4	72-74 ft	Magnesium, Dissolved	11	8.9
MW407 Port 4	72-74 ft	Manganese	0.12	0.155
MW407 Port 4	72-74 ft	Manganese, Dissolved	0.108	0.148
MW407 Port 4	72-74 ft	Mercury	ND	ND
MW407 Port 4	72-74 ft	Mercury, Dissolved	ND	NA
MW407 Port 4	72-74 ft	Nickel	ND	ND
MW407 Port 4	72-74 ft	Nitrate as Nitrogen	1.4	ND
MW407 Port 4	72-74 ft	Potassium	3.41	3.38
MW407 Port 4	72-74 ft	Potassium, Dissolved	3.18	3.2
MW407 Port 4	72-74 ft	Selenium	ND	ND
MW407 Port 4	72-74 ft	Sodium	50.1	17
MW407 Port 4	72-74 ft	Sodium, Dissolved	47.6	17.2
MW407 Port 4	72-74 ft	Sulfide	ND	ND
MW407 Port 4	72-74 ft	Uranium	ND	ND
MW407 Port 4	72-74 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.41 MW407 Port 5 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 5	80-82 ft	Aluminum	ND	ND
MW407 Port 5	80-82 ft	Arsenic	ND	ND
MW407 Port 5	80-82 ft	Barium	0.051	0.13
MW407 Port 5	80-82 ft	Barium, Dissolved	0.046	0.132
MW407 Port 5	80-82 ft	Calcium	70.6	21.4
MW407 Port 5	80-82 ft	Calcium, Dissolved	66.7	22.4
MW407 Port 5	80-82 ft	Chloride	46.1	15.6
MW407 Port 5	80-82 ft	Chromium	ND	ND
MW407 Port 5	80-82 ft	Fluoride	ND	ND
MW407 Port 5	80-82 ft	Iron	ND	ND
MW407 Port 5	80-82 ft	Lead	ND	ND
MW407 Port 5	80-82 ft	Magnesium	11.6	9.76
MW407 Port 5	80-82 ft	Magnesium, Dissolved	11.1	9.95
MW407 Port 5	80-82 ft	Manganese	0.032	0.169
MW407 Port 5	80-82 ft	Manganese, Dissolved	0.031	0.169
MW407 Port 5	80-82 ft	Mercury	ND	ND
MW407 Port 5	80-82 ft	Mercury, Dissolved	ND	NA
MW407 Port 5	80-82 ft	Nickel	ND	ND
MW407 Port 5	80-82 ft	Nitrate as Nitrogen	1	ND
MW407 Port 5	80-82 ft	Potassium	4.94	3.3
MW407 Port 5	80-82 ft	Potassium, Dissolved	4.78	3.12
MW407 Port 5	80-82 ft	Selenium	ND	ND
MW407 Port 5	80-82 ft	Sodium	43.8	16.2
MW407 Port 5	80-82 ft	Sodium, Dissolved	44.4	17.2
MW407 Port 5	80-82 ft	Sulfide	ND	ND
MW407 Port 5	80-82 ft	Uranium	ND	ND
MW407 Port 5	80-82 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

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Table A.42 MW407 Port 6 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 6	86-88 ft	Aluminum	ND	ND
MW407 Port 6	86-88 ft	Arsenic	ND	ND
MW407 Port 6	86-88 ft	Barium	0.054	0.15
MW407 Port 6	86-88 ft	Barium, Dissolved	0.049	0.145
MW407 Port 6	86-88 ft	Calcium	60.6	24.1
MW407 Port 6	86-88 ft	Calcium, Dissolved	54.4	23.9
MW407 Port 6	86-88 ft	Chloride	46.8	21.4
MW407 Port 6	86-88 ft	Chromium	ND	ND
MW407 Port 6	86-88 ft	Fluoride	1.2	ND
MW407 Port 6	86-88 ft	Iron	ND	ND
MW407 Port 6	86-88 ft	Lead	ND	ND
MW407 Port 6	86-88 ft	Magnesium	8.83	10.7
MW407 Port 6	86-88 ft	Magnesium, Dissolved	7.98	10.5
MW407 Port 6	86-88 ft	Manganese	0.039	0.159
MW407 Port 6	86-88 ft	Manganese, Dissolved	0.039	0.158
MW407 Port 6	86-88 ft	Mercury	ND	ND
MW407 Port 6	86-88 ft	Mercury, Dissolved	ND	NA
MW407 Port 6	86-88 ft	Nickel	ND	ND
MW407 Port 6	86-88 ft	Nitrate as Nitrogen	1.5	67.2
MW407 Port 6	86-88 ft	Potassium	4.1	3.24
MW407 Port 6	86-88 ft	Potassium, Dissolved	4	3.04
MW407 Port 6	86-88 ft	Selenium	ND	ND
MW407 Port 6	86-88 ft	Sodium	47.5	17.9
MW407 Port 6	86-88 ft	Sodium, Dissolved	44.1	18.4
MW407 Port 6	86-88 ft	Sulfide	ND	ND
MW407 Port 6	86-88 ft	Uranium	ND	ND
MW407 Port 6	86-88 ft	Vanadium	0.025	ND

NA – Not Analyzed
ND – Not Detected

Table A.43 MW407 Port 7 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW407 Port 7	106-108 ft	Aluminum	ND	ND
MW407 Port 7	106-108 ft	Arsenic	ND	ND
MW407 Port 7	106-108 ft	Barium	0.11	0.092
MW407 Port 7	106-108 ft	Barium, Dissolved	0.103	0.087
MW407 Port 7	106-108 ft	Calcium	70	16.9
MW407 Port 7	106-108 ft	Calcium, Dissolved	63.1	16.1
MW407 Port 7	106-108 ft	Chloride	40.1	4.3
MW407 Port 7	106-108 ft	Chromium	ND	ND
MW407 Port 7	106-108 ft	Fluoride	ND	ND
MW407 Port 7	106-108 ft	Iron	ND	ND
MW407 Port 7	106-108 ft	Lead	ND	ND
MW407 Port 7	106-108 ft	Magnesium	12.7	7.51
MW407 Port 7	106-108 ft	Magnesium, Dissolved	11.7	7.06
MW407 Port 7	106-108 ft	Manganese	0.167	0.186
MW407 Port 7	106-108 ft	Manganese, Dissolved	0.166	0.172
MW407 Port 7	106-108 ft	Mercury	ND	ND
MW407 Port 7	106-108 ft	Mercury, Dissolved	ND	NA
MW407 Port 7	106-108 ft	Nickel	ND	ND
MW407 Port 7	106-108 ft	Nitrate as Nitrogen	1.3	ND
MW407 Port 7	106-108 ft	Potassium	4.15	3.54
MW407 Port 7	106-108 ft	Potassium, Dissolved	3.84	3.25
MW407 Port 7	106-108 ft	Selenium	ND	ND
MW407 Port 7	106-108 ft	Sodium	51.6	11.9
MW407 Port 7	106-108 ft	Sodium, Dissolved	45.3	12
MW407 Port 7	106-108 ft	Sulfide	ND	ND
MW407 Port 7	106-108 ft	Uranium	ND	ND
MW407 Port 7	106-108 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.44 MW408 Port 2 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 2	60-62 ft	Aluminum	ND	ND
MW408 Port 2	60-62 ft	Arsenic	ND	ND
MW408 Port 2	60-62 ft	Barium	0.137	0.269
MW408 Port 2	60-62 ft	Barium, Dissolved	0.138	0.265
MW408 Port 2	60-62 ft	Calcium	40.4	27.5
MW408 Port 2	60-62 ft	Calcium, Dissolved	38.2	28.8
MW408 Port 2	60-62 ft	Chloride	41.2	75
MW408 Port 2	60-62 ft	Chromium	ND	ND
MW408 Port 2	60-62 ft	Fluoride	ND	ND
MW408 Port 2	60-62 ft	Iron	ND	0.205
MW408 Port 2	60-62 ft	Iron, Dissolved	NA	ND
MW408 Port 2	60-62 ft	Lead	ND	ND
MW408 Port 2	60-62 ft	Magnesium	9.34	6.35
MW408 Port 2	60-62 ft	Magnesium, Dissolved	8.55	6.83
MW408 Port 2	60-62 ft	Manganese	0.151	0.029
MW408 Port 2	60-62 ft	Manganese, Dissolved	0.156	ND
MW408 Port 2	60-62 ft	Mercury	ND	ND
MW408 Port 2	60-62 ft	Mercury, Dissolved	ND	NA
MW408 Port 2	60-62 ft	Nickel	ND	ND
MW408 Port 2	60-62 ft	Nitrate as Nitrogen	ND	4.8
MW408 Port 2	60-62 ft	Potassium	7.92	2.87
MW408 Port 2	60-62 ft	Potassium, Dissolved	7.92	2.97
MW408 Port 2	60-62 ft	Selenium	ND	ND
MW408 Port 2	60-62 ft	Sodium	54	37.5
MW408 Port 2	60-62 ft	Sodium, Dissolved	48	37.8
MW408 Port 2	60-62 ft	Sulfide	ND	ND
MW408 Port 2	60-62 ft	Uranium	ND	ND
MW408 Port 2	60-62 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

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Table A.45 MW408 Port 3 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 3	66-68 ft	Aluminum	ND	ND
MW408 Port 3	66-68 ft	Arsenic	ND	ND
MW408 Port 3	66-68 ft	Barium	0.136	0.288
MW408 Port 3	66-68 ft	Barium, Dissolved	0.126	0.263
MW408 Port 3	66-68 ft	Calcium	41.4	29.4
MW408 Port 3	66-68 ft	Calcium, Dissolved	37.2	28.2
MW408 Port 3	66-68 ft	Chloride	33.9	76.5
MW408 Port 3	66-68 ft	Chromium	ND	ND
MW408 Port 3	66-68 ft	Fluoride	ND	ND
MW408 Port 3	66-68 ft	Iron	ND	ND
MW408 Port 3	66-68 ft	Lead	ND	ND
MW408 Port 3	66-68 ft	Magnesium	9.85	6.75
MW408 Port 3	66-68 ft	Magnesium, Dissolved	8.99	6.56
MW408 Port 3	66-68 ft	Manganese	0.125	0.027
MW408 Port 3	66-68 ft	Manganese, Dissolved	0.115	ND
MW408 Port 3	66-68 ft	Mercury	ND	ND
MW408 Port 3	66-68 ft	Mercury, Dissolved	ND	NA
MW408 Port 3	66-68 ft	Nickel	ND	ND
MW408 Port 3	66-68 ft	Nitrate as Nitrogen	1	1.6
MW408 Port 3	66-68 ft	Potassium	5.85	3.1
MW408 Port 3	66-68 ft	Potassium, Dissolved	5.41	2.96
MW408 Port 3	66-68 ft	Selenium	ND	ND
MW408 Port 3	66-68 ft	Sodium	52.7	40.3
MW408 Port 3	66-68 ft	Sodium, Dissolved	47.6	37.3
MW408 Port 3	66-68 ft	Sulfide	ND	ND
MW408 Port 3	66-68 ft	Uranium	ND	ND
MW408 Port 3	66-68 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.46 MW408 Port 4 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 4	72-74 ft	Aluminum	ND	ND
MW408 Port 4	72-74 ft	Arsenic	ND	ND
MW408 Port 4	72-74 ft	Barium	0.134	0.296
MW408 Port 4	72-74 ft	Barium, Dissolved	0.127	0.261
MW408 Port 4	72-74 ft	Calcium	49.7	31
MW408 Port 4	72-74 ft	Calcium, Dissolved	47	28.4
MW408 Port 4	72-74 ft	Chloride	36.9	75.7
MW408 Port 4	72-74 ft	Chromium	ND	ND
MW408 Port 4	72-74 ft	Fluoride	ND	ND
MW408 Port 4	72-74 ft	Iron	ND	ND
MW408 Port 4	72-74 ft	Lead	ND	ND
MW408 Port 4	72-74 ft	Magnesium	10.2	7.54
MW408 Port 4	72-74 ft	Magnesium, Dissolved	9.58	6.72
MW408 Port 4	72-74 ft	Manganese	0.11	0.028
MW408 Port 4	72-74 ft	Manganese, Dissolved	0.103	ND
MW408 Port 4	72-74 ft	Mercury	ND	ND
MW408 Port 4	72-74 ft	Mercury, Dissolved	ND	NA
MW408 Port 4	72-74 ft	Nickel	ND	ND
MW408 Port 4	72-74 ft	Nitrate as Nitrogen	1.2	3.3
MW408 Port 4	72-74 ft	Potassium	6.8	3.03
MW408 Port 4	72-74 ft	Potassium, Dissolved	6.42	2.84
MW408 Port 4	72-74 ft	Selenium	ND	ND
MW408 Port 4	72-74 ft	Sodium	56.2	40.6
MW408 Port 4	72-74 ft	Sodium, Dissolved	51.2	37.3
MW408 Port 4	72-74 ft	Sulfide	ND	ND
MW408 Port 4	72-74 ft	Uranium	ND	ND
MW408 Port 4	72-74 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.47 MW408 Port 5 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 5	80-82 ft	Aluminum	ND	ND
MW408 Port 5	80-82 ft	Arsenic	ND	ND
MW408 Port 5	80-82 ft	Barium	0.101	0.326
MW408 Port 5	80-82 ft	Barium, Dissolved	0.104	0.263
MW408 Port 5	80-82 ft	Calcium	43.5	33.5
MW408 Port 5	80-82 ft	Calcium, Dissolved	44.5	29
MW408 Port 5	80-82 ft	Chloride	38.4	74.7
MW408 Port 5	80-82 ft	Chromium	ND	ND
MW408 Port 5	80-82 ft	Fluoride	1	ND
MW408 Port 5	80-82 ft	Iron	ND	ND
MW408 Port 5	80-82 ft	Lead	ND	ND
MW408 Port 5	80-82 ft	Magnesium	8.66	9.21
MW408 Port 5	80-82 ft	Magnesium, Dissolved	8.77	7.7
MW408 Port 5	80-82 ft	Manganese	0.095	0.026
MW408 Port 5	80-82 ft	Manganese, Dissolved	0.098	ND
MW408 Port 5	80-82 ft	Mercury	ND	ND
MW408 Port 5	80-82 ft	Mercury, Dissolved	ND	NA
MW408 Port 5	80-82 ft	Nickel	ND	ND
MW408 Port 5	80-82 ft	Nitrate as Nitrogen	1	1.8
MW408 Port 5	80-82 ft	Potassium	5.92	3.41
MW408 Port 5	80-82 ft	Potassium, Dissolved	5.89	3.1
MW408 Port 5	80-82 ft	Selenium	ND	ND
MW408 Port 5	80-82 ft	Sodium	47.9	43
MW408 Port 5	80-82 ft	Sodium, Dissolved	48.2	37.4
MW408 Port 5	80-82 ft	Sulfide	ND	ND
MW408 Port 5	80-82 ft	Uranium	ND	ND
MW408 Port 5	80-82 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.48 MW408 Port 6 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 6	86-88 ft	Aluminum	ND	ND
MW408 Port 6	86-88 ft	Arsenic	ND	ND
MW408 Port 6	86-88 ft	Barium	0.053	0.235
MW408 Port 6	86-88 ft	Barium, Dissolved	0.048	0.215
MW408 Port 6	86-88 ft	Calcium	35	48.9
MW408 Port 6	86-88 ft	Calcium, Dissolved	32.4	36.9
MW408 Port 6	86-88 ft	Chloride	36	73.4
MW408 Port 6	86-88 ft	Chromium	ND	ND
MW408 Port 6	86-88 ft	Fluoride	1.1	ND
MW408 Port 6	86-88 ft	Iron	ND	ND
MW408 Port 6	86-88 ft	Lead	ND	ND
MW408 Port 6	86-88 ft	Magnesium	4.17	9.12
MW408 Port 6	86-88 ft	Magnesium, Dissolved	4.41	7.42
MW408 Port 6	86-88 ft	Manganese	ND	0.063
MW408 Port 6	86-88 ft	Manganese, Dissolved	NA	0.039
MW408 Port 6	86-88 ft	Mercury	ND	ND
MW408 Port 6	86-88 ft	Mercury, Dissolved	ND	NA
MW408 Port 6	86-88 ft	Nickel	ND	ND
MW408 Port 6	86-88 ft	Nitrate as Nitrogen	ND	1.2
MW408 Port 6	86-88 ft	Potassium	9.47	6.54
MW408 Port 6	86-88 ft	Potassium, Dissolved	8.46	4.51
MW408 Port 6	86-88 ft	Selenium	ND	ND
MW408 Port 6	86-88 ft	Sodium	47.8	45.2
MW408 Port 6	86-88 ft	Sodium, Dissolved	48.1	37.8
MW408 Port 6	86-88 ft	Sulfide	ND	ND
MW408 Port 6	86-88 ft	Uranium	ND	ND
MW408 Port 6	86-88 ft	Vanadium	ND	ND

NA – Not Analyzed
ND – Not Detected

Table A.49 MW408 Port 7 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)
MW408 Port 7	104-106 ft	Aluminum	0.528	NA
MW408 Port 7	104-106 ft	Aluminum, Dissolved	0.261	NA
MW408 Port 7	104-106 ft	Arsenic	ND	NA
MW408 Port 7	104-106 ft	Barium	0.066	NA
MW408 Port 7	104-106 ft	Barium, Dissolved	0.051	NA
MW408 Port 7	104-106 ft	Calcium	57.1	NA
MW408 Port 7	104-106 ft	Calcium, Dissolved	50.5	NA
MW408 Port 7	104-106 ft	Chloride	36.6	NA
MW408 Port 7	104-106 ft	Chromium	ND	NA
MW408 Port 7	104-106 ft	Fluoride	ND	NA
MW408 Port 7	104-106 ft	Iron	0.376	NA
MW408 Port 7	104-106 ft	Iron, Dissolved	ND	NA
MW408 Port 7	104-106 ft	Lead	ND	NA
MW408 Port 7	104-106 ft	Magnesium	2.22	NA
MW408 Port 7	104-106 ft	Magnesium, Dissolved	1.01	NA
MW408 Port 7	104-106 ft	Manganese	ND	NA
MW408 Port 7	104-106 ft	Mercury	ND	NA
MW408 Port 7	104-106 ft	Mercury, Dissolved	ND	NA
MW408 Port 7	104-106 ft	Nickel	ND	NA
MW408 Port 7	104-106 ft	Nitrate as Nitrogen	ND	NA
MW408 Port 7	104-106 ft	Potassium	12.7	NA
MW408 Port 7	104-106 ft	Potassium, Dissolved	11.2	NA
MW408 Port 7	104-106 ft	Selenium	ND	NA
MW408 Port 7	104-106 ft	Sodium	35.1	NA
MW408 Port 7	104-106 ft	Sodium, Dissolved	34.3	NA
MW408 Port 7	104-106 ft	Sulfide	ND	NA
MW408 Port 7	104-106 ft	Uranium	ND	NA
MW408 Port 7	104-106 ft	Vanadium	ND	NA

NA – Not Analyzed
ND – Not Detected

Table A.50 Inorganic Data Comparison from Baseline to Post Treatment.

Location	Depth	Analysis	Baseline (ppm)	Post Treatment (ppm)	Percent Difference
MW407 Port 6	86-88 ft	Nitrate as Nitrogen	1.5	67.2	4380%
MW406 Port 7	106-108 ft	Manganese, Dissolved	0.028	0.314	1021%
MW407 Port 5	80-82 ft	Manganese, Dissolved	0.031	0.169	445%
MW407 Port 6	86-88 ft	Manganese, Dissolved	0.039	0.158	305%
MW407 Port 5	80-82 ft	Manganese	0.032	0.169	428%
MW407 Port 6	86-88 ft	Manganese	0.039	0.159	308%
MW405 Port 5	80-82 ft	Magnesium, Dissolved	2.28	10.6	365%
MW405 Port 6	86-88 ft	Magnesium, Dissolved	1.59	10.4	554%
MW405 Port 7	106-108 ft	Magnesium, Dissolved	0.446	12	2591%
MW405 Port 5	80-82 ft	Magnesium	2	10.7	435%
MW405 Port 6	86-88 ft	Magnesium	1.38	10.6	668%
MW405 Port 7	106-108 ft	Magnesium	0.458	11.8	2476%
MW405 Port 3	66-68 ft	Chloride	14	74.8	434%
MW405 Port 7	106-108 ft	Chloride	11.3	77.7	588%
MW405 Port 5	80-82 ft	Barium, Dissolved	0.037	0.287	676%
MW405 Port 6	86-88 ft	Barium, Dissolved	0.03	0.247	723%
MW406 Port 6	86-88 ft	Barium, Dissolved	0.055	0.396	620%
MW408 Port 6	86-88 ft	Barium, Dissolved	0.048	0.215	348%
MW405 Port 5	80-82 ft	Barium	0.033	0.299	806%
MW405 Port 6	86-88 ft	Barium	0.028	0.256	814%
MW406 Port 6	86-88 ft	Barium	0.063	0.379	502%
MW408 Port 6	86-88 ft	Barium	0.053	0.235	343%

NA – Not Analyzed
ND – Not Detected

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Table A.51 Chloride and Other Dissolved Mineral Changes During Treatment.

Well Screen Intervals Inside Treatment Region

Well	Screen Depth (ft bgs)	Pre-SPH Chloride (mg/l)	Post-SPH Chloride (mg/l)	Change	Pre-SPH other minerals (mg/l)	Post-SPH other minerals (mg/l)	Change
MW-406	60-62	55.7	130.1	134%	142	129	-9%
MW-406	66-68	40.8	142.8	250%	113	124	10%
MW-406	72-74	62.3	138.8	123%	140	131	-6%
MW-406	80-82	81.4	153.0	88%	142	132	-7%
MW-406	86-88	75.6	157.3	108%	120	130	8%
MW-407	60-62	37.5	10.1	-73%	126	47	-63%
MW-407	66-68	35.9	12.3	-66%	126	47	-63%
MW-407	72-74	47.1	18.6	-61%	117	51	-56%
MW-407	80-82	46.1	15.6	-66%	132	50	-62%
MW-407	86-88	46.8	21.4	-54%	123	56	-54%
average		**52.9**	**80.0**	**51%**	**128.1**	**89.7**	**-30%**
Equivalent TCE decrease (mg/l):			100.3				

Well Screen Intervals Outside Treatment Region

Well	Screen Depth (ft bgs)	Pre-SPH Chloride (mg/l)	Post-SPH Chloride (mg/l)	Change	Pre-SPH other minerals (mg/l)	Post-SPH other minerals (mg/l)	Change
MW-405	60-62	19.7	75.0	281%	115	85	-26%
MW-405	66-68	14.0	74.5	432%	71	81	14%
MW-405	72-74	22.6	73.5	225%	90	83	-8%
MW-405	80-82	20.9	73.1	250%	60	96	60%
MW-405	86-88	33.0	74.9	127%	76	95	25%
MW-408	60-62	41.2	75.0	82%	111	75	-32%
MW-408	66-68	33.9	76.5	126%	110	79	-28%
MW-408	72-74	36.9	75.7	105%	123	80	-35%
MW-408	80-82	38.4	74.7	95%	108	89	-18%
MW-408	86-88	36.0	73.4	104%	97	110	13%
McNairy							
MW-405	106-108	11.3	77.7	588%	73	128	75%
MW-406	106-108	137.1	4.3	-97%	172	42	-76%
MW-407	106-108	40.1	4.3	-89%	139	41	-71%
MW-408	104-106	36.6	DNAPL			DNAPL	
average		**37.3**	**64.0**	**72%**	**103.5**	**83.4**	**-19%**
Equivalent TCE decrease (mg/l):			99.0				

NA – Not Analyzed
ND – Not Detected

APPENDIX B

SIX-PHASE HEATING TECHNOLOGY ASSESSMENT

Background

A Six-Phase Heating (SPH) Treatability Study is being conducted at the Paducah Gaseous Diffusion Plant (PGDP) to generate quantitative treatment and cost data to evaluate the technology for possible deployment as part of future remedial actions. The study is consistent with the *Federal Facility Agreement* among the U. S. Department of Energy, the U.S. Environmental Protection Agency (EPA) and the Commonwealth of Kentucky (EPA 1998).

The SPH treatability study involves treating both the shallow Upper Continental Recharge System (UCRS) and the underlying Regional Gravel Aquifer (RGA), and addresses remedial effectiveness, system performance, and costs associated with deploying the technology in the area adjacent to the C-400 Building. A successful implementation will heat the soil and groundwater in both the UCRS and RGA to a temperature that allows steam and vapors containing trichloroethene (TCE) to rise and to be moved by the vapor recovery wells, to be treated by the vapor treatment system, and to be removed from the treatability study test cell.

Following the treatability study and technology performance assessment, the SPH will be compared to alternative technologies. Decision analysis techniques, accommodating life cycle cost, time, performance measures, and decision maker preferences, will be utilized for selecting the most appropriate technology for deployment. This approach was used previously at PGDP to screen and select technologies included in the Groundwater Operable Unit (GWOU) Feasibility Study.

System Overview

The treatability study includes the design, installation, and operation of one SPH array. This array consists of six power electrodes, a central neutral electrode, an electrical power control unit, temperature and pressure monitoring systems, a steam and contaminant vapor recovery (VR) system, and contaminant vapor and condensate treatment systems. The SPH system operates by applying electricity to electrodes that have been placed at specified depths in the subsurface. As power is applied to the electrodes, the soil matrix resists the flow of electricity between the electrodes causing the subsurface to be heated. Subsurface temperatures are increased to the boiling point of groundwater and targeted contaminants are volatilized. Steam and volatilized contaminants migrate upward and are collected in the vadose zone by VR wells. Steam then is condensed to water, and contaminant vapors are processed by the vapor treatment system. Electrodes are to be installed to a total depth of about 30 m (97 ft) below ground surface.

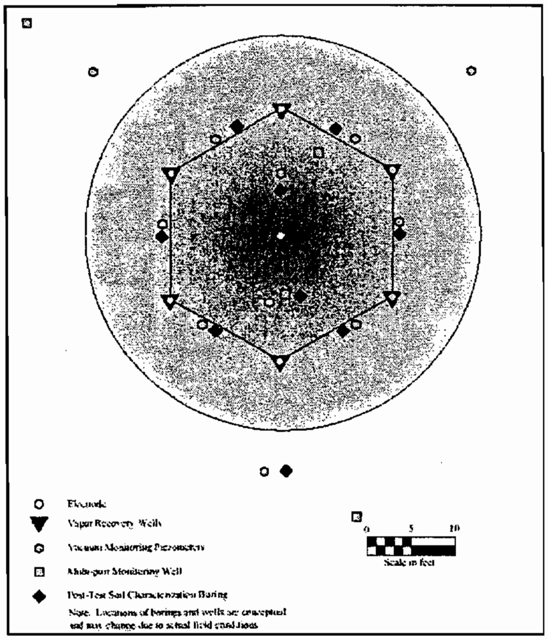

Fig. 1. General layout of test cell.

Technology Assessment

SPH performance evaluation will be based upon the analysis and interpretation of co-located pre- and post-study soil and groundwater sample results and data from systems operational monitoring. Collectively, these data will support assessment of the remedial effectiveness, system performance, and cost.

This treatability study is not a remedial action, but an evaluation of a technology that may be deployed to meet negotiated remedial action objectives. Because the treatability study is being conducted in the center of a larger TCE-contaminated area, diffusion and fluid mixing will introduce additional TCE into the treatment area during and after operations. Additionally, the initial dense nonaqueous phase liquid (DNAPL) mass-in-place can only be estimated. Consequently, establishing removal efficiency based on mass balance is speculative, and direct measurements of soil and groundwater will not be definitive. For these reasons, operational parameters also will be evaluated to determine if the system performed as designed. Operational performance is an indirect indicator of effectiveness, and these data, when combined with pre- and post-test sampling, will be collectively evaluated to assess overall effectiveness. The technology then will be compared to competing technologies before a deployment recommendation is made.

Remedial Effectiveness

DNAPL removal efficiency will be assessed by comparing the results from co-located soil and groundwater analyses collected before and after the treatability study. While both soil and groundwater analyses yield quantitative data, both media samples are discrete volumes that, at best, can only approximate the in-place conditions. The primary means of analyzing the data will be comparison of the percent contaminant removal in adjacent samples. Bar graphs will be a primary means of presenting the data.

System Performance and Cost

During the operation phase of the treatability study, several parameters will be measured to ensure optimum performance of the overall system and to determine the operating requirements and costs of the system. The parameters to be measured include the following.

- Energy usage
- Contaminant recovery
- Steam extraction
- Vacuum readings
- Subsurface temperature profile
- The VOC adsorption efficiency of the granular activated carbon
- Operating parameters of system components
- Surface voltages and the induced voltages on metal objects and utilities

These parameters will be tracked and grouped by the three major lithologic units: the vadose UCRS, the saturated UCRS, and the RGA/McNairy. These data will support assessment of key performance indicators, as shown in Table 2, along with the success criteria.

Full-Scale Deployment

At the completion of the SPH treatability study, a large quantity of information concerning the operations, contaminant removal effectiveness, infrastructure impacts, etc., will be available. If SPH performs as designed and the removal efficiency meets the criteria for success (see Fig. 1), then SPH will be evaluated against competing technologies, such as dynamic underground stripping (see Fig. 2).

A decision and risk analysis model will be used to select the best applicable remedial technology for use at the C-400 site. Decision and risk analysis provides a systematic way of approaching difficult decisions. By applying this approach, the site can limit or control the impacts of opinions, various uncertainties, and conflicting objectives that can lead to the biasing of a decision. The decision analysis approach will quantitatively value key criteria for the selection of a remediation technology such as contaminant removal effectiveness, implementability, cost, potential risks, etc. The quantitative values will result in the decision maker having a numerical ranking of candidates based on the identified criteria and analysis. Furthermore, the analysis system provides for a highly defensible decision. The decision models for DNAPL site remediation were developed at the PGDP with the assistance of the Air Force Institute of Technology under funding from the U.S. Department of Energy.

Table 1. Assessment of removal efficiency using co-located soil and groundwater sampling

Property	Assessment	Criteria for Success
UCRS TCE Soil Concentrations	TCE removal efficiency	> 75% reduction
RGA TCE Groundwater Concentration	TCE removal efficiency	TCE concentration < 1% solubility

Table 2. Assessment of performance and vost using operational data

Performance Indicator	Criteria for Success
Temperature gradients	Uniform heating ranging from 100° to 125° Celsius
TCE removal rates	Asymptotic removal curve within 130 days
Constructability	Feasible as full-scale implementation
Construction and operating costs	Competitive with comparable technologies
Effect on adjacent facilities	No occurrences
United States Enrichment Corporation operational impacts	No operational impacts

115

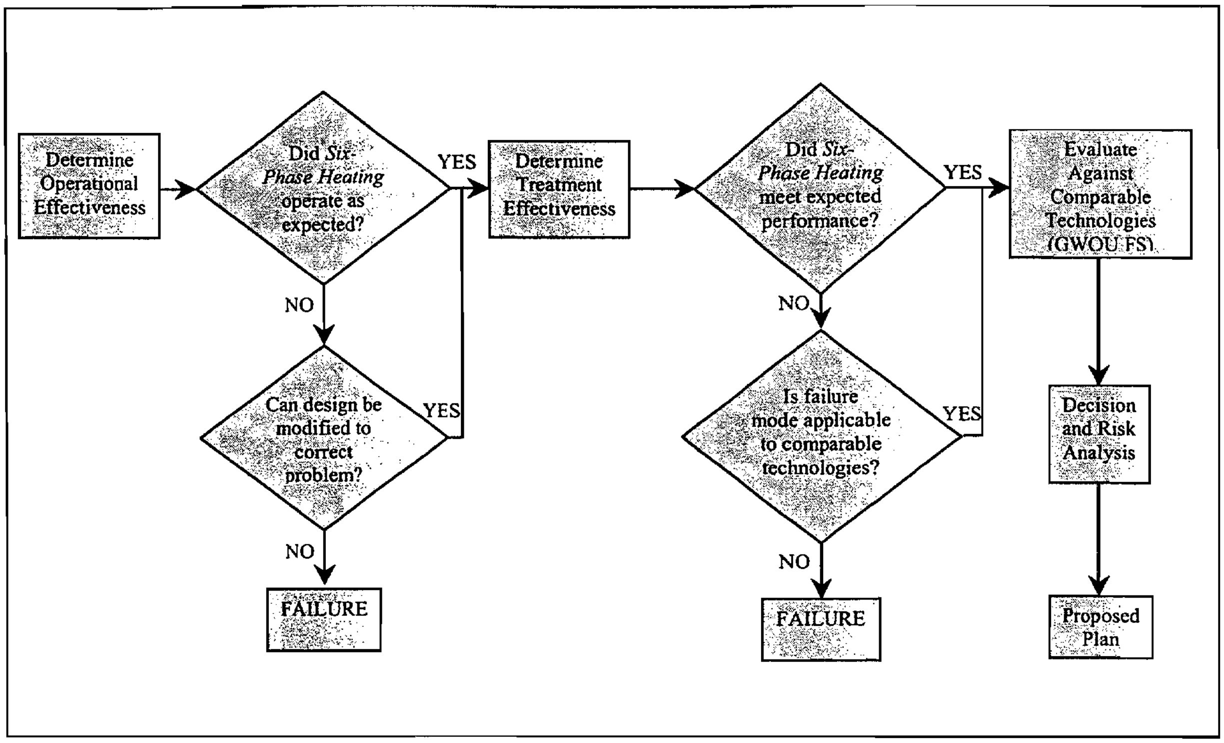

Fig. 2. Performance assessment.

APPENDIX C

VINYL CHLORIDE SAMPLING RESULTS

Travelers

90 Lamberton Road, Windsor, CT 06095
Phone #: 1-800-842-0355
Fax#: 860-687-7430
AIHA Accredited Laboratory # 80

Report Issued To: Sherry McKenty

Sherry McKenty
CDM Federal Programs Corp.
325 Kentucky Avenue
Kevil, KY 42053

Report Date: 10/10/2002
Date Samples Received: 10/4/2002
Work Order: 2002100076

Location Sampled: CDM Federal Programs Corp.
Sample Submitter: Sherry McKenty

Vinyl chloride

Sample ID	Sample Description	Results ppm	Results µg
VC043	Area	LT 0.30	LT 1.1
VC044	Area	LT 0.30	LT 1.1
VC045	Area	LT 0.30	LT 1.1
VC046	Area	LT 0.30	LT 1.1
VC047	Area	LT 0.30	LT 1.1
VC048	Area	LT 0.30	LT 1.1
VC049	Area	LT 0.30	LT 1.1
VC050	Area	LT 0.30	LT 1.1
VC051	Area	LT 0.30	LT 1.1
VC052	Area	LT 0.30	LT 1.1
VC053	Area	LT 0.30	LT 1.1
VC054	Area	LT 0.30	LT 1.1
VC055	Area	LT 0.30	LT 1.1
VC056	Area	LT 0.30	LT 1.1
VC057	Area	LT 0.30	LT 1.1
VC058	Area	LT 0.30	LT 1.1
VC059	Area	LT 0.30	LT 1.1
VC060	Area	LT 0.30	LT 1.1
VC061	Area	LT 0.30	LT 1.1
VC062	Area	LT 0.30	LT 1.1
VC063	Area	LT 0.30	LT 1.1
VC064	Area	LT 0.30	LT 1.1
VC065	Area	LT 0.30	LT 1.1
VC066	Area	LT 0.30	LT 1.1
VC067	Area	LT 0.30	LT 1.1
VC068	Area	LT 0.30	LT 1.1
VC069	Area	LT 0.30	LT 1.1
VC070	Area	LT 0.30	LT 1.1
VC071	Area	LT 0.30	LT 1.1
VC072	Area	LT 0.30	LT 1.1
VC073	Area	LT 0.30	LT 1.1
VC074	Area	LT 0.30	LT 1.1
VC075	Area	LT 0.30	LT 1.1
VC076	Area	LT 0.30	LT 1.1
VC077	Area	LT 0.30	LT 1.1
VC078	Area	LT 0.30	LT 1.1

Sample ID	Sample Description	Results

Analyte	Media type	LOQ	Reference Method	Analysis Date
Vinyl chloride	Tandem 226-01	1.1 µg	GC/FID - NIOSH 1007	10/9/2002

Please Note: The limits of quantitation (LOQs) listed are for normally processed samples. Sample requiring special processing (i.e. dilutions) may have elevated LOQs.

N.A. = Not Applicable

WORKORDER COMMENTS:

The reported data relate only to the samples as received by the Laboratory. The reported air concentrations have been calculated using information supplied by the customer and have NOT been adjusted to represent a Time Weighted Average (TWA). "LT" indicates less than the limit of quantitation (LOQ). The contaminant may or may not be present at levels below this concentration. This report shall not be reproduced except in full, without written approval of the laboratory. The samples have not been blank corrected unless otherwise noted.

Approved by:	Josef Chrzanowski	George E. Johnson	Marcel F. Baril
	Josef Chrzanowski Production Group Leader	George E. Johnson QA Group Leader	Marcel F.Baril Laboratory Manager

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Travelers

90 Lamberton Road, Windsor, CT 06095
Phone #: 1-800-842-0355
Fax#: 860-687-7430

AIHA Accredited Laboratory # 80

Report Issued To: Sherry McKenty

Sherry McKenty
CDM Federal Programs Corp.
325 Kentucky Avenue
Kevil, KY 42053

Report Date: 10/14/2002
Date Samples Received: 10/10/2002
Work Order: 2002100183

Location Sampled: CDM Federal Programs Corp.
Sample Submitter: Sherry McKenty

Sample ID	**Sample Description**	**Results**	
Vinyl chloride		**ppm**	**µg**
6PHSVC098	Area	LT 0.29	LT 1.1
6PHSVC099	Area	LT 0.29	LT 1.1
6PHSVC100	Area	LT 0.29	LT 1.1
6PHSVC101	Area	LT 0.29	LT 1.1
6PHSVC102	Area	LT 0.29	LT 1.1
6PHSVC103	Area	LT 0.29	LT 1.1
6PHSVC104	Area	LT 0.29	LT 1.1
6PHSVC105	Area	LT 0.29	LT 1.1
6PHSVC106	Area	LT 0.29	LT 1.1
6PHSVC107	Area	LT 0.29	LT 1.1
6PHSVC108	Area	LT 0.29	LT 1.1
6PHSVC109	Area	LT 0.29	LT 1.1
6PHSVC110	Area	LT 0.29	LT 1.1
6PHSVC111	Area	LT 0.29	LT 1.1
6PHSVC112	Area	LT 0.29	LT 1.1
6PHSVC113	Area	LT 0.29	LT 1.1
6PHSVC114	Area	LT 0.29	LT 1.1
6PHSVC115	Area	LT 0.29	LT 1.1
6PHSVC116	Area	LT 0.29	LT 1.1
6PHSVC117	Area	LT 0.29	LT 1.1
6PHSVC118	Area	LT 0.29	LT 1.1
6PHSVC119	Area	LT 0.29	LT 1.1
6PHSVC120	Area	LT 0.29	LT 1.1
6PHSVC121	Area	LT 0.29	LT 1.1
6PHSVC122	Area	LT 0.29	LT 1.1
6PHSVC123	Area	LT 0.29	LT 1.1
6PHSVC124	Area	LT 0.29	LT 1.1
6PHSVC125	Area	LT 0.29	LT 1.1
6PHSVC126	Area	LT 0.29	LT 1.1
6PHSVC127	Area	LT 0.29	LT 1.1
6PHSVC128	Area	LT 0.29	LT 1.1
6PHSVC129	Area	LT 0.29	LT 1.1
6PHSVC130	Area	LT 0.29	LT 1.1
6PHSVC131	Area	LT 0.29	LT 1.1
6PHSVC132	Area	LT 0.29	LT 1.1
6PHSVC133	Area	LT 0.29	LT 1.1
6PHSVC134	Area	LT 0.29	LT 1.1
6PHSVC135	Area	LT 0.29	LT 1.1
6PHSVC136	Area	LT 0.29	LT 1.1
6PHSVC137	Area	LT 0.29	LT 1.1
6PHSVC138	Area	LT 0.29	LT 1.1
6PHSVC139	Area	LT 0.29	LT 1.1
6PHSVC140	Area	LT 0.29	LT 1.1

Sample ID	Sample Description	Results	
6PHSVC141	Area	LT 0.29	LT 1.1
6PHSVC142	Area	LT 0.29	LT 1.1
6PHSVC143	Area	LT 0.29	LT 1.1
6PHSVC144	Area	LT 0.29	LT 1.1
6PHSVC145	Area	LT 0.29	LT 1.1
6PHSVC146	Area	LT 0.29	LT 1.1

Analyte	Media type	LOQ	Reference Method	Analysis Date
Vinyl chloride	Tandem 226-01	1.1 µg	GC/FID - NIOSH 1007	10/11/2002

Please Note: The limits of quantitation (LOQs) listed are for normally processed samples. Sample requiring special processing (i.e. dilutions) may have elevated LOQs.
N.A. = Not Applicable

WORKORDER COMMENTS:

The reported data relate only to the samples as received by the Laboratory. The reported air concentrations have been calculated using information supplied by the customer and have NOT been adjusted to represent a Time Weighted Average (TWA). "LT" indicates less than the limit of quantitation (LOQ). The contaminant may or may not be present at levels below this concentration. This report shall not be reproduced except in full, without written approval of the laboratory. The samples have not been blank corrected unless otherwise noted.

Approved by: Josef Chrzanowski — George E. Johnson — Marcel F. Baril

Josef Chrzanowski
Production Group Leader

George E. Johnson
QA Group Leader

Marcel F.Baril
Laboratory Manager

Travelers

90 Lamberton Road, Windsor, CT 06095
Phone #: 1-800-842-0355
Fax#: 860-687-7430
AIHA Accredited Laboratory # 80

Report Issued To: Sherry McKenty

Sherry McKenty
CDM Federal Programs Corp.
325 Kentucky Avenue
Kevil, KY 42053

Report Date: 10/14/2002
Date Samples Received: 9/26/2002
Work Order: 2002090422
Revision: 1

Location Sampled: CDM Federal Programs Corp.
Sample Submitter: Sherry McKenty

Vinyl chloride

Sample ID	Sample Description	Results ppm	Results µg
6PHSVC005F&B	Area	LT 0.29	LT 1.1
6PHSVC006F&B	Area	LT 0.29	LT 1.1
6PHSVC007F&B	Area	LT 0.29	LT 1.1
6PHSVC008F&B	Area	LT 0.29	LT 1.1
6PHSVC009F&B	Area	LT 0.29	LT 1.1
6PHSVC010F&B	Area	LT 0.29	LT 1.1
6PHSVC011F&B	Area	LT 0.29	LT 1.1
6PHSVC012F&B	Area	LT 0.29	LT 1.1
6PHSVC013F&B	Area	LT 0.29	LT 1.1
6PHSVC014F&B	Area	LT 0.28	LT 1.1
6PHSVC015F&B	Area	LT 0.29	LT 1.1
6PHSVC016F&B	Area	LT 0.28	LT 1.1
6PHSVC017F&B	Area	LT 0.28	LT 1.1
6PHSVC018F&B	Area	LT 0.29	LT 1.1
6PHSVC019F&B	Area	LT 0.29	LT 1.1
6PHSVC020F&B	Area	LT 0.29	LT 1.1
6PHSVC021F&B	Area	LT 0.29	LT 1.1
6PHSVC022F&B	Area	LT 0.29	LT 1.1
6PHSVC023F&B	Area	LT 0.29	LT 1.1
6PHSVC024F&B	Area	LT 0.29	LT 1.1
6PHSVC025F&B	Area	LT 0.29	LT 1.1
6PHSVC026F&B	Area	LT 0.29	LT 1.1

Sample ID	Sample Description	Results

Analyte	Media type	LOQ	Reference Method	Analysis Date
Vinyl chloride	Tandem 226-01	1.1 µg	GC/FID - NIOSH 1007	10/3/2002

Please Note: The limits of quantitation (LOQs) listed are for normally processed samples. Sample requiring special processing (i.e. dilutions) may have elevated LOQs.

N.A. = Not Applicable

WORKORDER COMMENTS:

PO # 5147-001-07-AL

Revision to Sample Description per client. vmw

The reported data relate only to the samples as received by the Laboratory. The reported air concentrations have been calculated using information supplied by the customer and have NOT been adjusted to represent a Time Weighted Average (TWA). "LT" indicates less than the limit of quantitation (LOQ). The contaminant may or may not be present at levels below this concentration. This report shall not be reproduced except in full, without written approval of the laboratory. The samples have not been blank corrected unless otherwise noted.

The report was revised due to the change(s) noted below:

Revision 1 sample MC; workorder MC 10/14/2002.

Approved by: Josef Chrzanowski
Josef Chrzanowski
Production Group Leader

George E. Johnson
George E. Johnson
QA Group Leader

Marcel F. Baril
Marcel F.Baril
Laboratory Manager

Travelers

90 Lamberton Road, Windsor, CT 06095
Phone #: 1-800-842-0355
Fax#: 860-687-7430
AIHA Accredited Laboratory # 80

Report Issued To: Sherry McKenty

Sherry McKenty
CDM Federal Programs Corp.
325 Kentucky Avenue
Kevil, KY 42053

Report Date: 10/14/2002
Date Samples Received: 9/30/2002
Work Order: 2002090462
Revision: 1

Location Sampled: CDM Federal Programs Corp.
Sample Submitter: Sherry McKenty

Sample ID	Sample Description	Results	
Vinyl chloride			
		ppm	**µg**
6PHSVC027	Area	LT 0.29	LT 1.1
6PHSVC028	Area	LT 0.29	LT 1.1
6PHSVC029	Area	LT 0.29	LT 1.1
6PHSVC030	Area	LT 0.30	LT 1.1
6PHSVC031	Area	LT 0.29	LT 1.1
6PHSVC032	Area	LT 0.29	LT 1.1
6PHSVC033	Area	LT 0.29	LT 1.1
6PHSVC034	Area	LT 0.29	LT 1.1
6PHSVC035	Area	LT 0.29	LT 1.1
6PHSVC036	Area	LT 0.28	LT 1.1
6PHSVC037	Area	LT 0.29	LT 1.1
6PHSVC038	Area	LT 0.29	LT 1.1
6PHSVC039	Area	LT 0.29	LT 1.1
6PHSVC040	Area	LT 0.29	LT 1.1
6PHSVC041	Area	LT 0.29	LT 1.1
6PHSVC042	Area	LT 0.29	LT 1.1

Sample ID	Sample Description	Results

Analyte	Media type	LOQ	Reference Method	Analysis Date
Vinyl chloride	Tandem 226-01	1.1 μg	GC/FID - NIOSH 1007	10/3/2002

Please Note: The limits of quantitation (LOQs) listed are for normally processed samples. Sample requiring special processing (i.e. dilutions) may have elevated LOQs.

N.A. = Not Applicable

WORKORDER COMMENTS:

PO # 5147-001-07-AL

Revision to sample description per client. vmw

The reported data relate only to the samples as received by the Laboratory. The reported air concentrations have been calculated using information supplied by the customer and have NOT been adjusted to represent a Time Weighted Average (TWA). "LT" indicates less than the limit of quantitation (LOQ). The contaminant may or may not be present at levels below this concentration. This report shall not be reproduced except in full, without written approval of the laboratory. The samples have not been blank corrected unless otherwise noted.

The report was revised due to the change(s) noted below:
Revision 1 sample MC; workorder MC 10/14/2002.

Approved by: Josef Chrzanowski
Josef Chrzanowski
Production Group Leader

George E. Johnson
George E. Johnson
QA Group Leader

Marcel F. Baril
Marcel F.Baril
Laboratory Manager

Travelers

90 Lamberton Road, Windsor, CT 06095
Phone #: 1-800-842-0355
Fax#: 860-687-7430
AIHA Accredited Laboratory # 80

Report Issued To: Sherry McKenty

Sherry McKenty
CDM Federal Programs Corp.
325 Kentucky Avenue
Kevil, KY 42053

Report Date: 10/14/2002
Date Samples Received: 10/4/2002
Work Order: 2002100089
Revision: 1

Location Sampled: CDM Federal Programs Corp.
Sample Submitter: Sherry McKenty

Vinyl chloride

Sample ID	Sample Description	Results	
		ppm	**µg**
6PHSVC079	Area	LT 0.29	LT 1.1
6PHSVC080	Area	LT 0.29	LT 1.1
6PHSVC082	Area	LT 0.29	LT 1.1
6PHSVC083	Area	LT 0.29	LT 1.1
6PHSVC084	Area	LT 0.28	LT 1.1
6PHSVC085	Area	LT 0.29	LT 1.1
6PHSVC086	Area	LT 0.29	LT 1.1
6PHSVC087	Area	LT 0.28	LT 1.1
6PHSVC088	Area	LT 0.29	LT 1.1
6PHSVC089	Area	LT 0.28	LT 1.1
6PHSVC090	Area	LT 0.29	LT 1.1
6PHSVC091	Area	LT 0.28	LT 1.1
6PHSVC092	Area	LT 0.29	LT 1.1
6PHSVC093	Area	LT 0.29	LT 1.1
6PHSVC094	Area	LT 0.29	LT 1.1
6PHSVC095	Area	LT 0.29	LT 1.1
6PHSVC097	Area	LT 0.29	LT 1.1

Sample ID	Sample Description	Results

Analyte	Media type	LOQ	Reference Method	Analysis Date
Vinyl chloride	Tandem 226-01	1.1 µg	GC/FID - NIOSH 1007	10/7/2002

Please Note: The limits of quantitation (LOQs) listed are for normally processed samples. Sample requiring special processing (i.e. dilutions) may have elevated LOQs.

N.A. = Not Applicable

WORKORDER COMMENTS:

PO # 5147-001-07-AL

Revision to sample description per client. vmw

The reported data relate only to the samples as received by the Laboratory. The reported air concentrations have been calculated using information supplied by the customer and have NOT been adjusted to represent a Time Weighted Average (TWA). "LT" indicates less than the limit of quantitation (LOQ). The contaminant may or may not be present at levels below this concentration. This report shall not be reproduced except in full, without written approval of the laboratory. The samples have not been blank corrected unless otherwise noted.

The report was revised due to the change(s) noted below:
Revision 1 sample MC; workorder MC 10/14/2002.

Approved by:

Josef Chrzanowski
Josef Chrzanowski
Production Group Leader

George E. Johnson
George E. Johnson
QA Group Leader

Marcel F. Baril
Marcel F.Baril
Laboratory Manager

APPENDIX D

MEMBRANE INTERFACE PROBE

MEMBRANE INTERFACE PROBE

To assist in the pre-test characterization, a membrane interface probe (MIP) was utilized to provide a direct indication of *in- situ* volatile organic compound (VOC) concentrations within the SPH treatability study area.

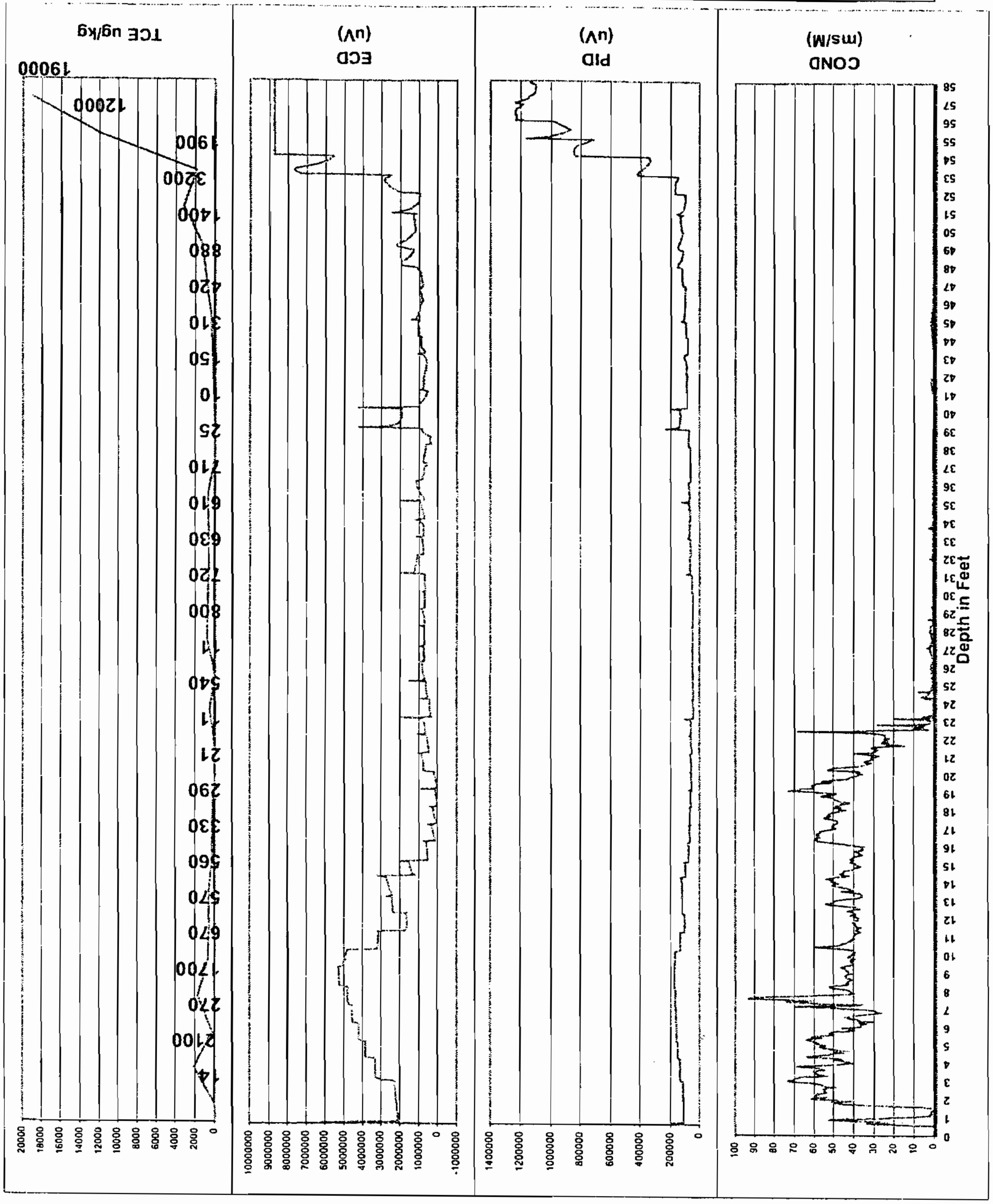
The MIP allowed for continuous vertical profiling of VOCs by pushing a heated source and porous membrane probe to depth using direct push technology. The heat source volatilized VOCs at the tip of the probe. The vapors entered the porous membrane and were transported through tubing to the surface where the vapors were analyzed with an array of detectors in a portable gas chromatograph (GC). The probe also measured electrical conductivity. The compilation of these three sets of data provide continuous profiles with depth of VOC concentrations and soil conductivity giving the user a clearer picture of the relative contamination.

MIP profiling was conducted at all 15 piezometer locations shown in Figure 1.2 of this report. Also, during installation of the piezometers, soil samples were collected at 2 foot (ft) intervals to a depth of 56 ft from 11 of the 15 piezometer locations. The figures on the following pages show a comparison of 11 MIP borings vs. the 11 piezometer locations from which soil samples were collected.

The piezometer location is specified on the right hand title block (i.e., Point PZ001 is piezometer VP01) on the following figures. The reviewer can compare the top graph (labeled TCE ug/kg on the right side) to the next two lower graphs (ECD [uV] and PID [uV])to compare the baseline soil sample results to the MIP readings at the same depth. The graph at the top of each page depicts the soil concentrations from the baseline soil sampling event in parts per billion. The two lower graphs provide the MIP real time results for the Photoionization Detector and Electron Capture Detector in micro Volts. The graph at the bottom of the page (COND [ms/M]) shows the corresponding electrical conductivity at depth.

The use of MIP profiling confirmed the presence of subsurface VOC contamination at the proposed treatability study area. The MIP profile results when compared to the baseline soil sample results show similar increases and decreases in concentrations.

ZEBRA EC/MIP Summary Log, Point PZ001
KY

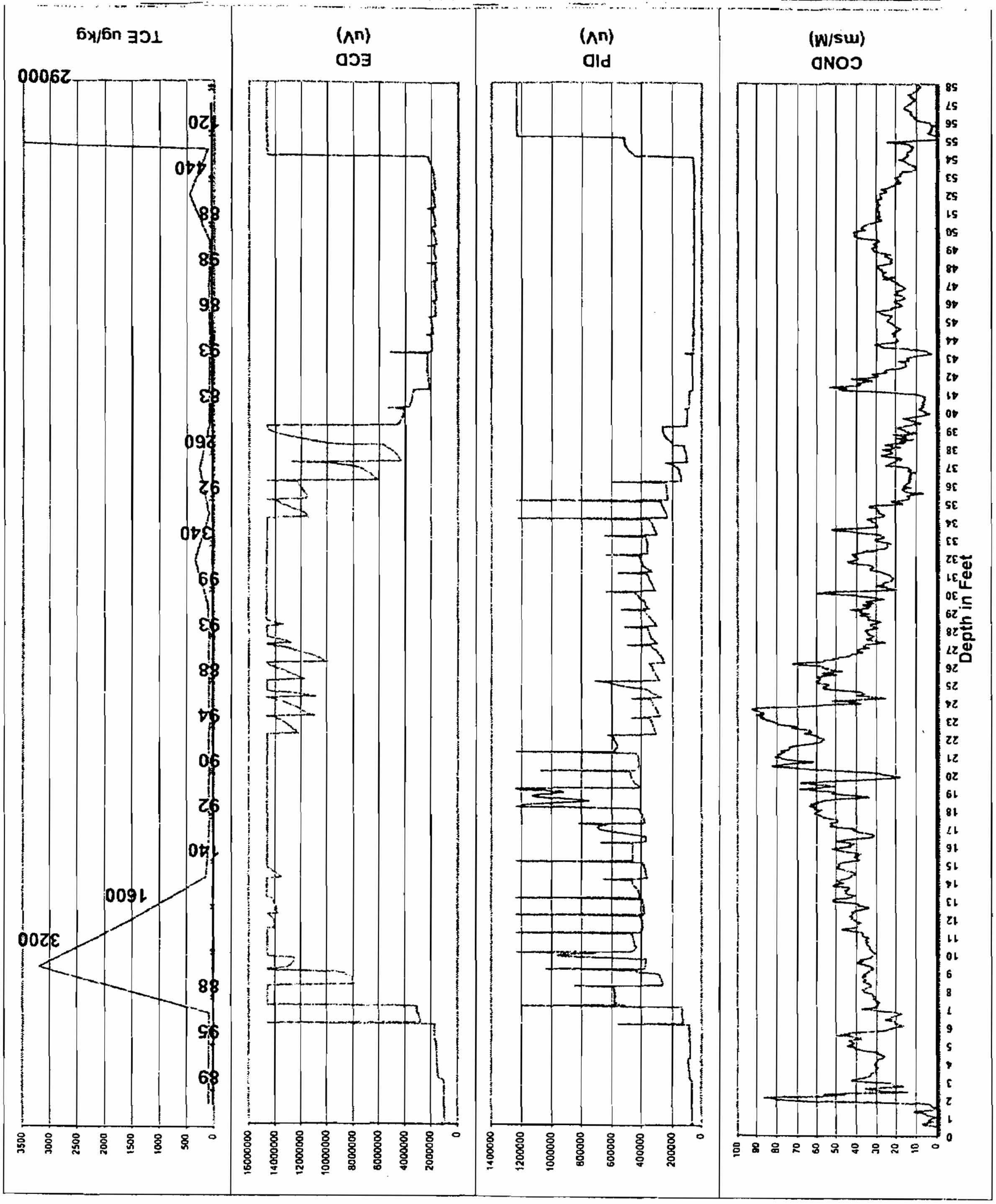


for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/11/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 11 of 17

130

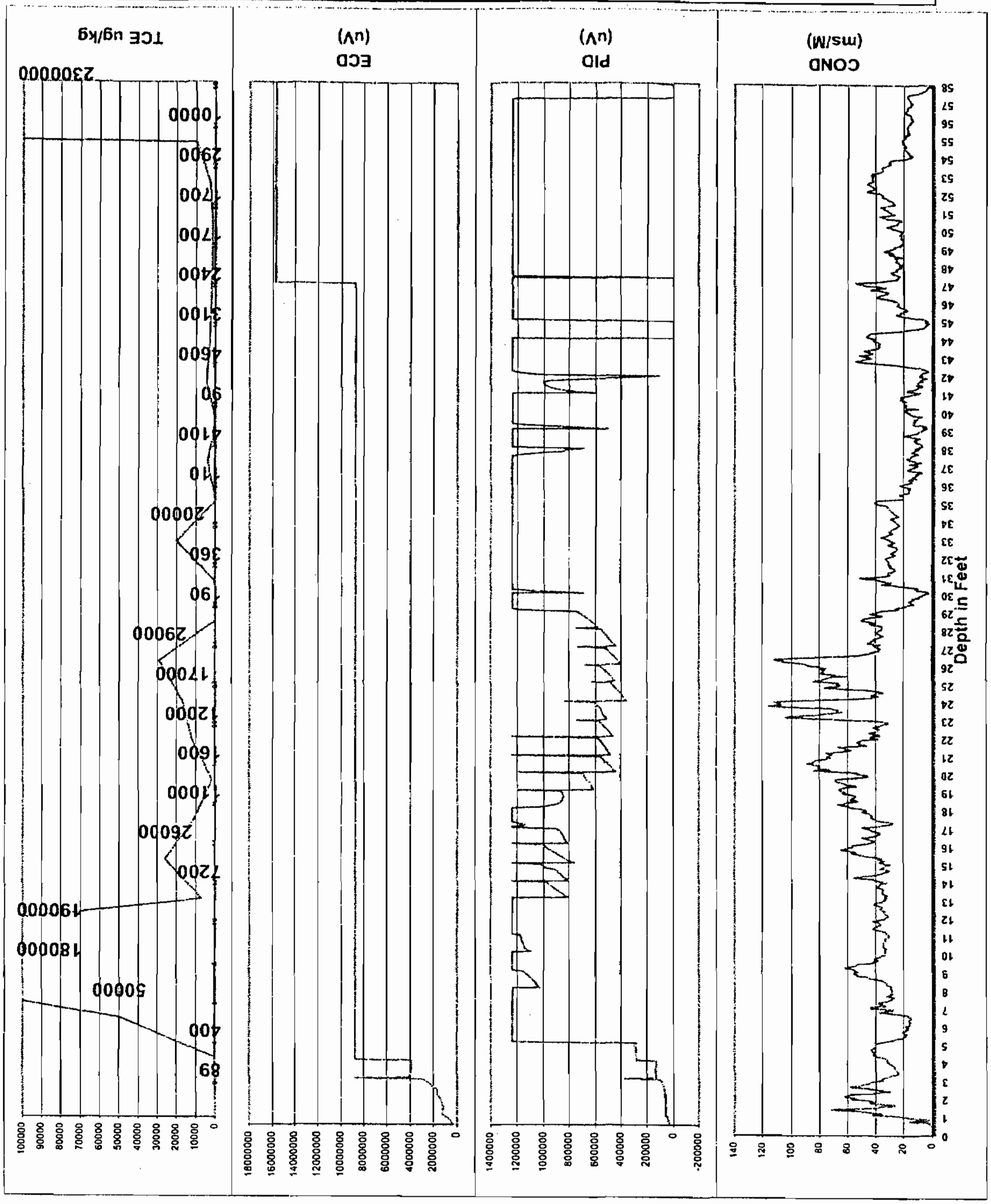
ZEBRA EC/MIP Summary Log, Point PZ002
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/10/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 8 of 17

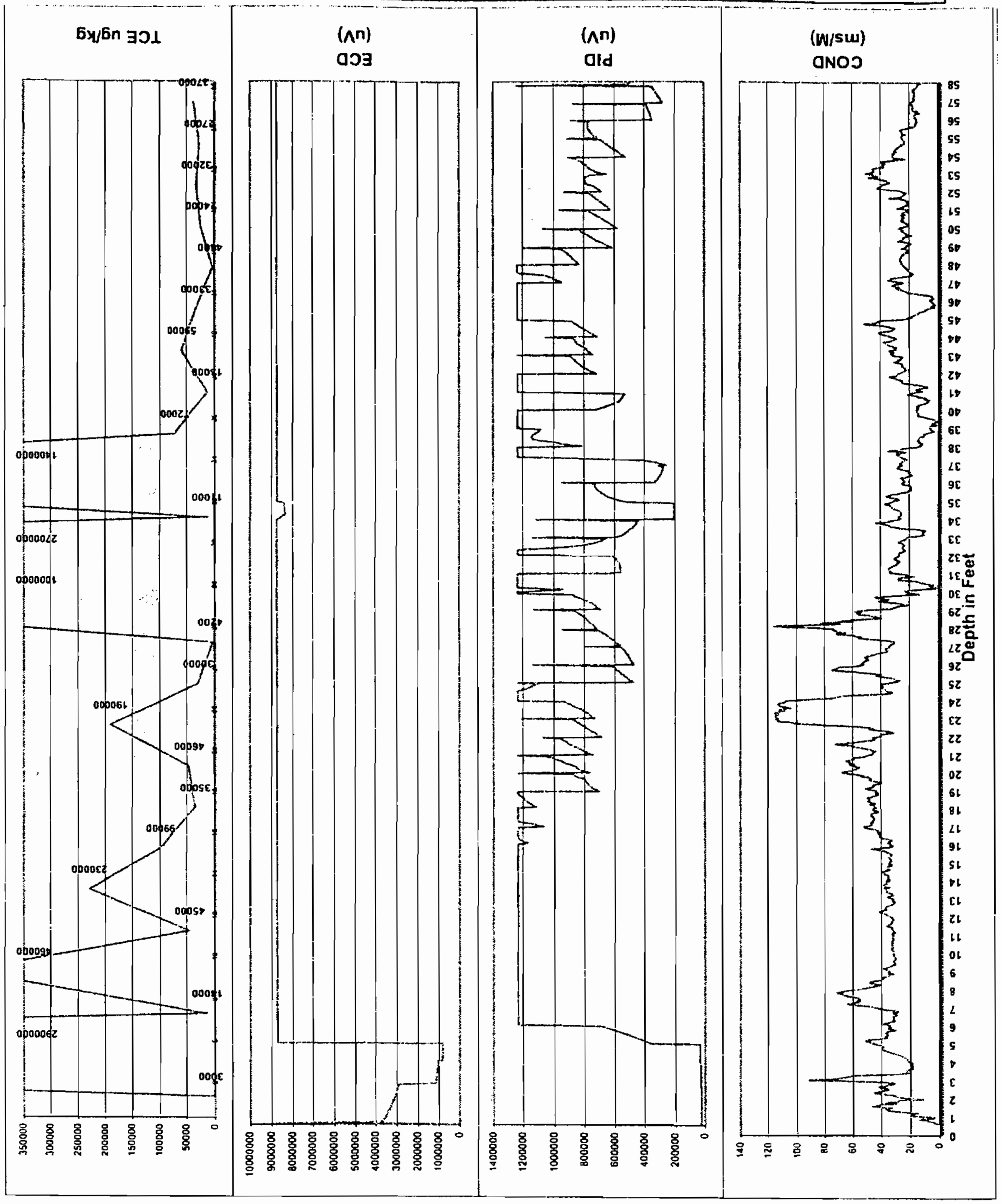
ZEBRA EC/MIP Summary Log, Point PZ003
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/9/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 6 of 17

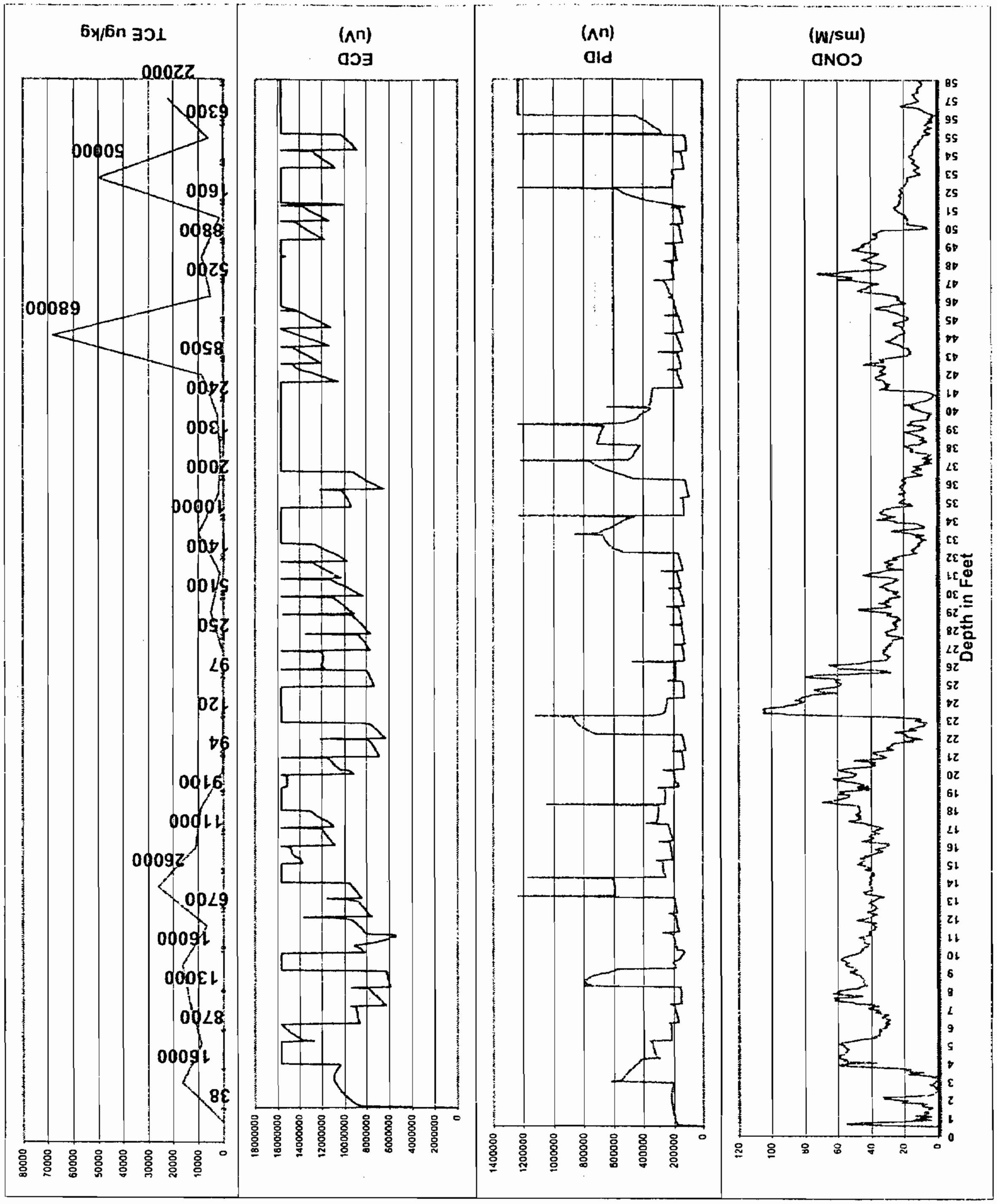
ZEBRA EC/MIP Summary Log, Point PZ004
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/8/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 4 of 17

ZEBRA EC/MIP Summary Log, Point PZ005
KY

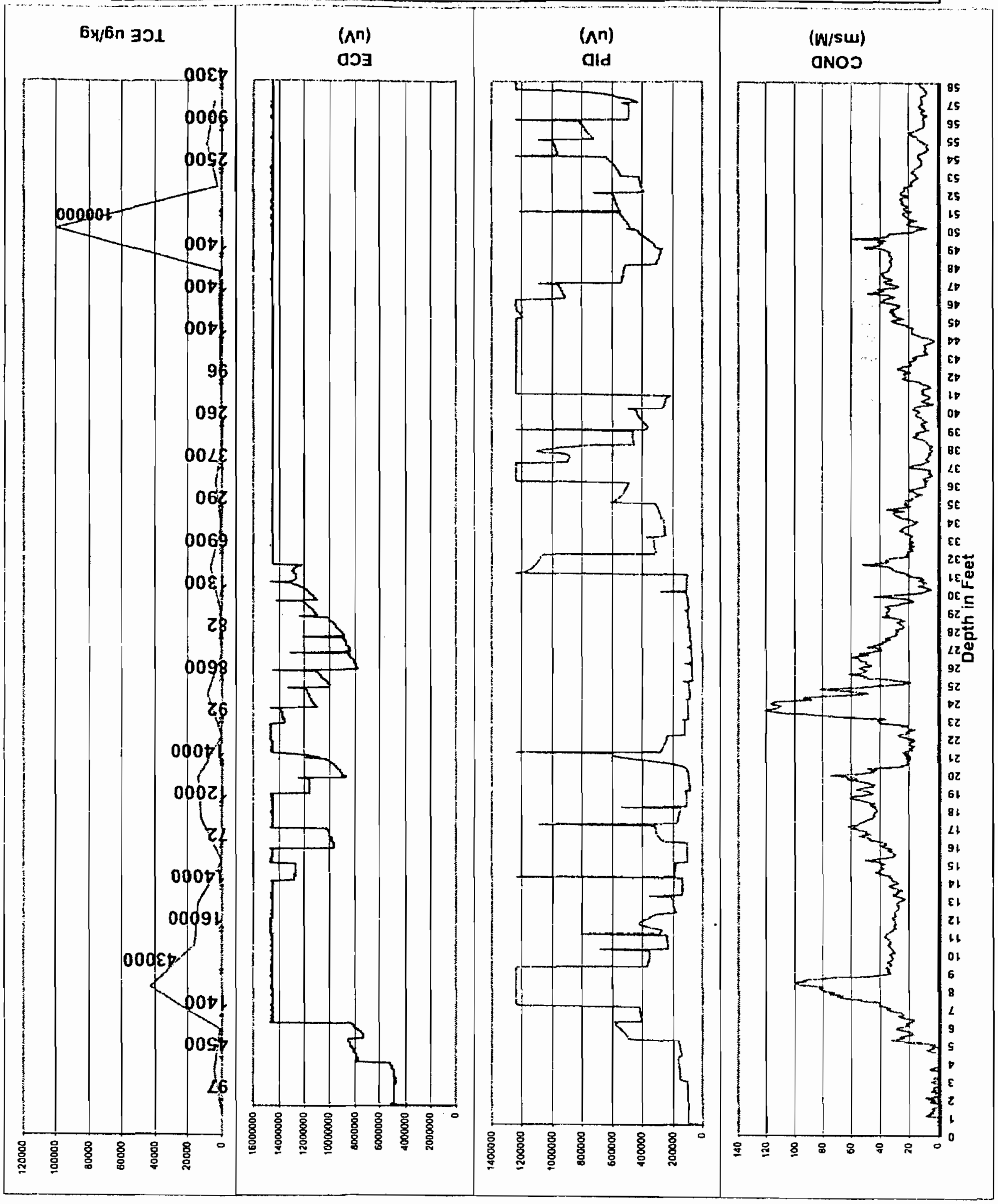


ZEBRA

for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/7/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 3 of 17

ZEBRA EC/MIP Summary Log, Point PZ006
KY

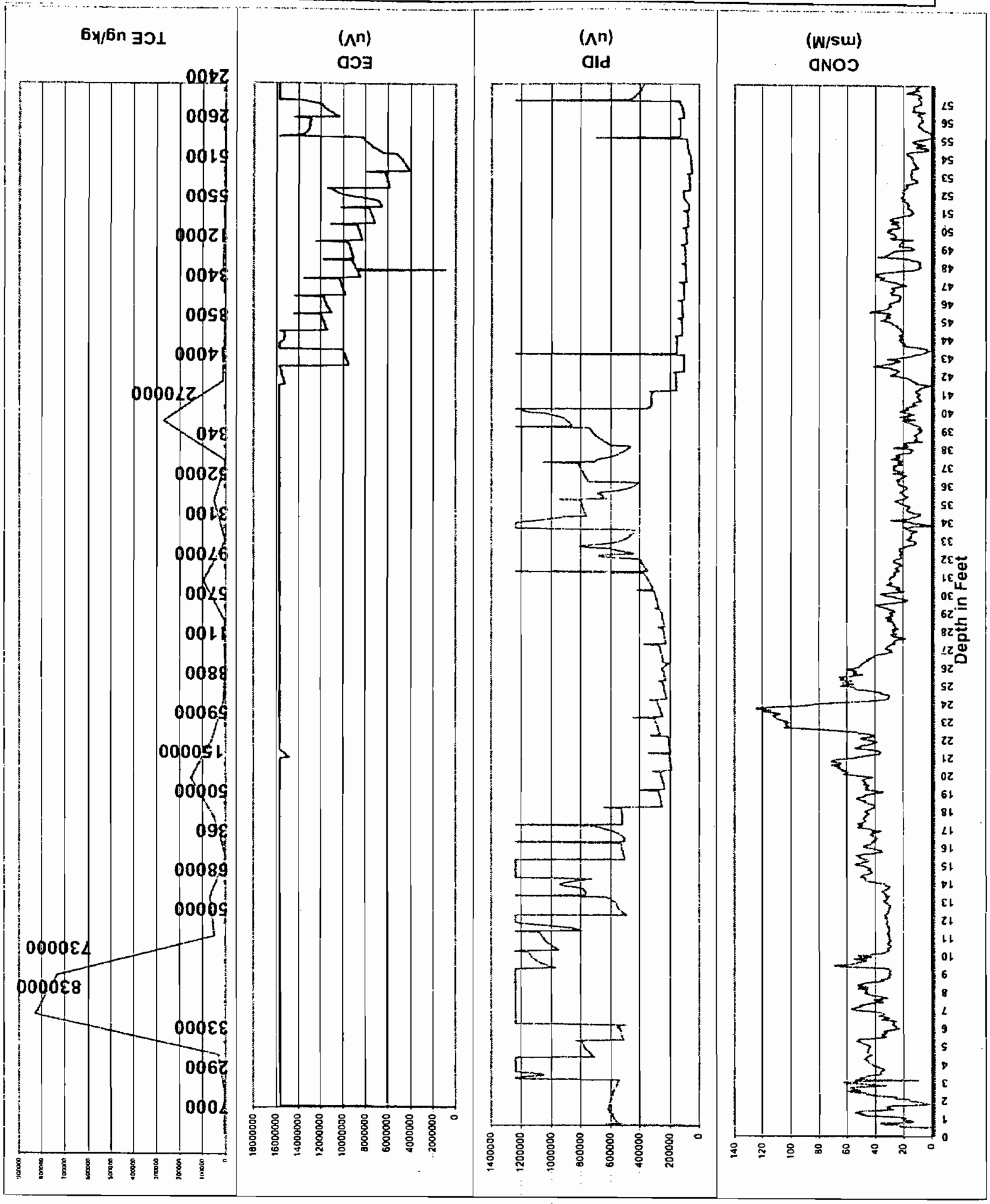


ZEBRA

for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/13/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 15 of 17

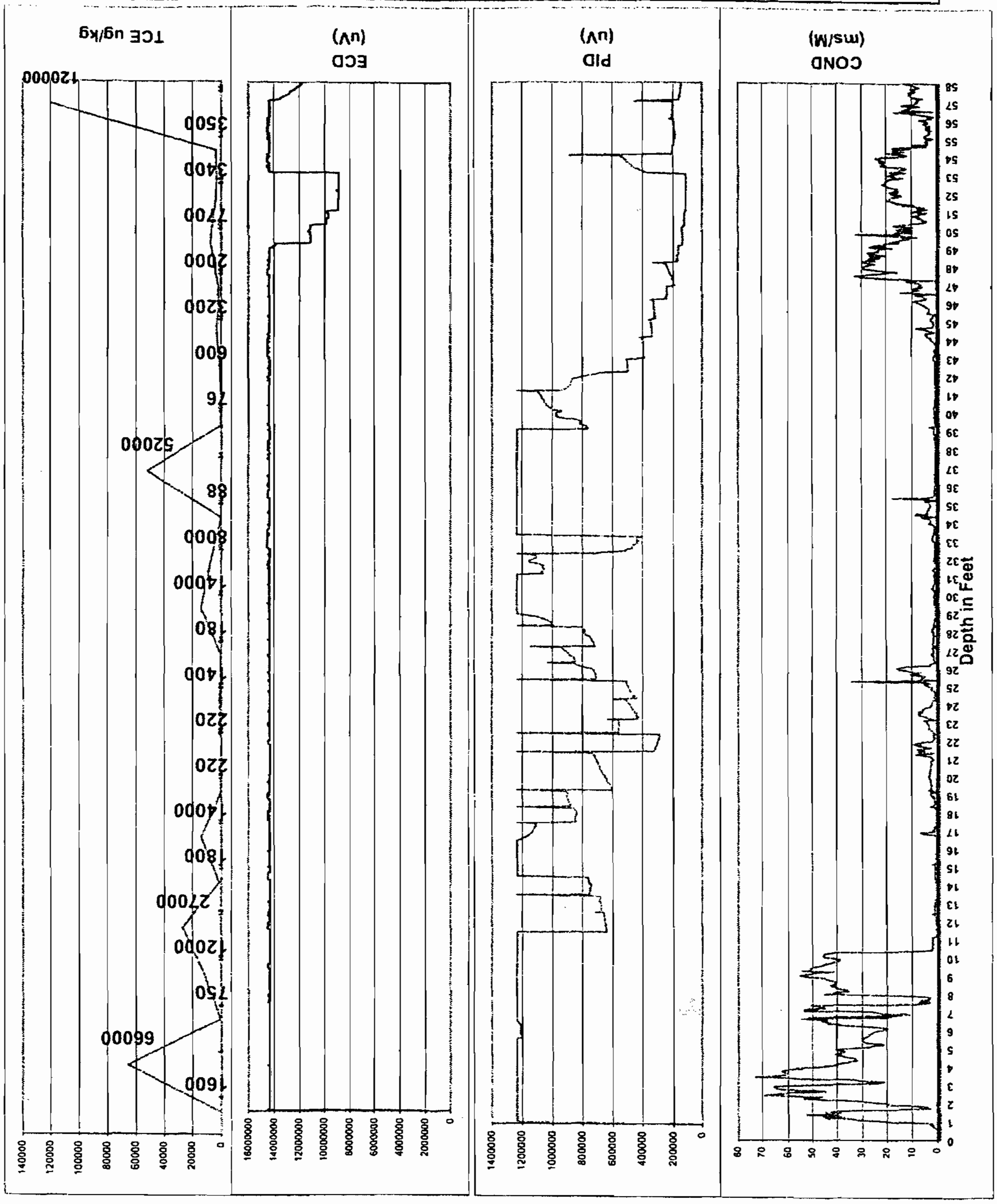
ZEBRA EC/MIP Summary Log, Point PZ007
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/8/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 5 of 17

ZEBRA EC/MIP Summary Log, Point PZ008
KY



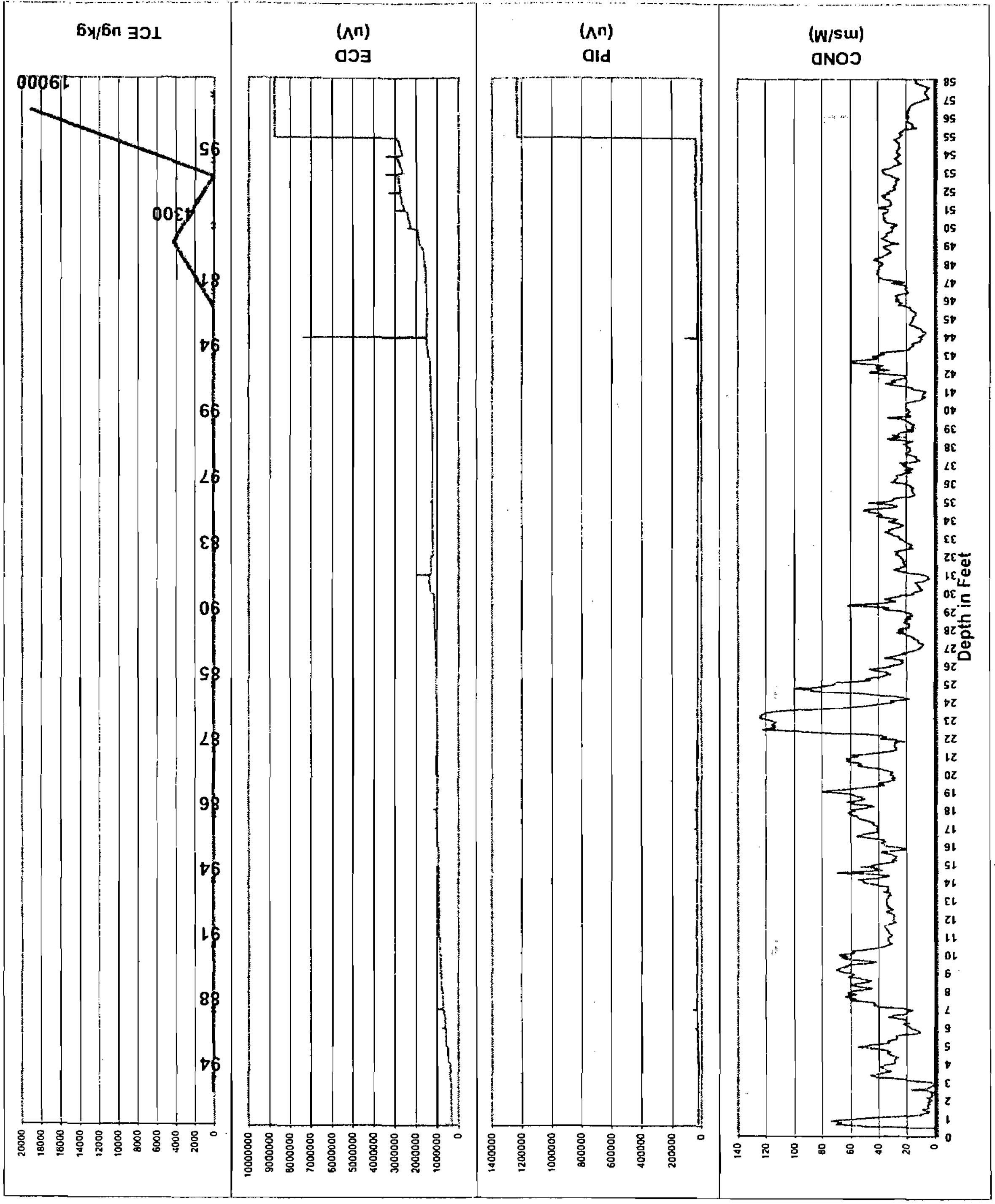
ZEBRA

for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/12/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 12 of 17

137

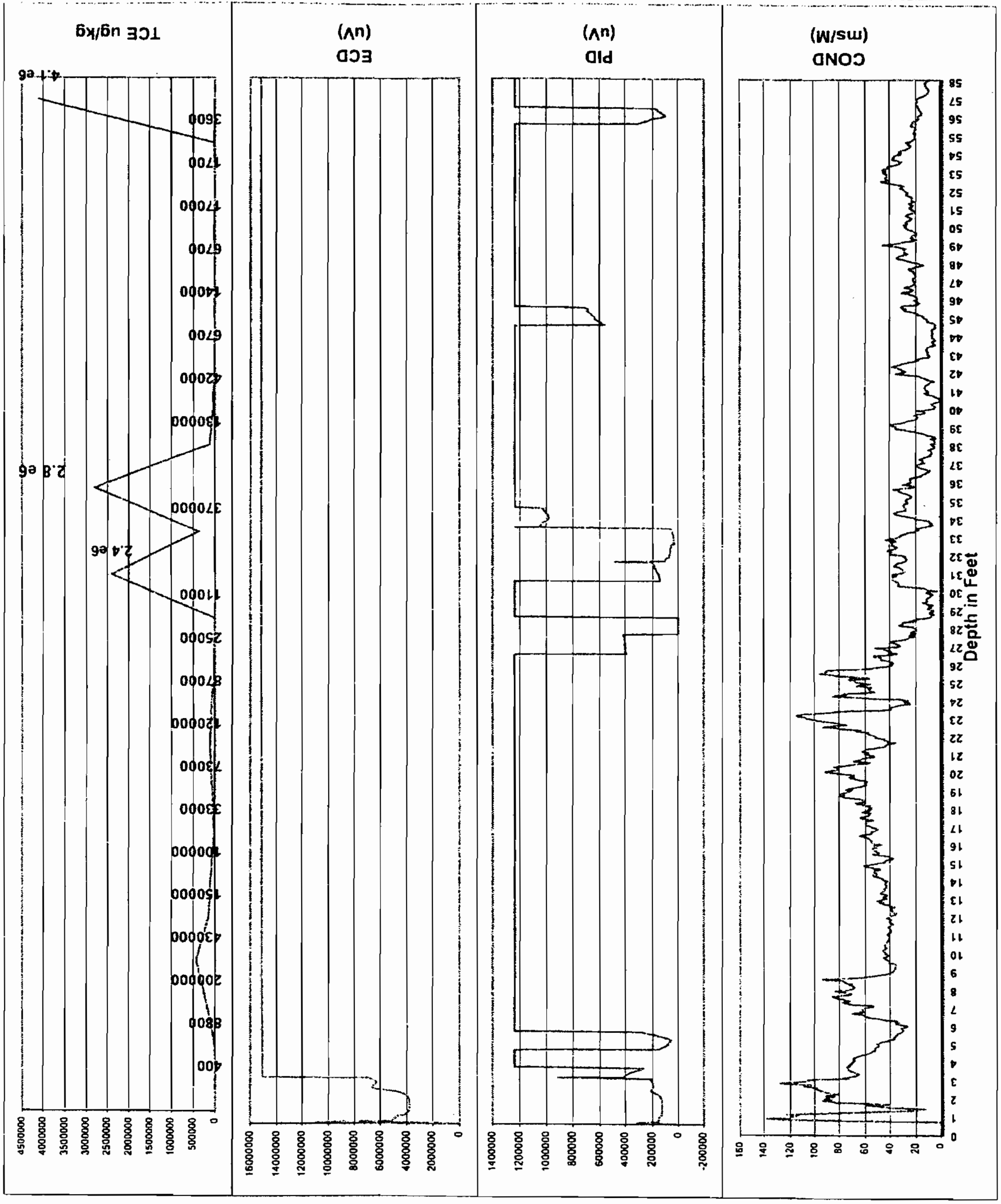
ZEBRA EC/MIP Summary Log, Point PZ009
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/11/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 10 of 17

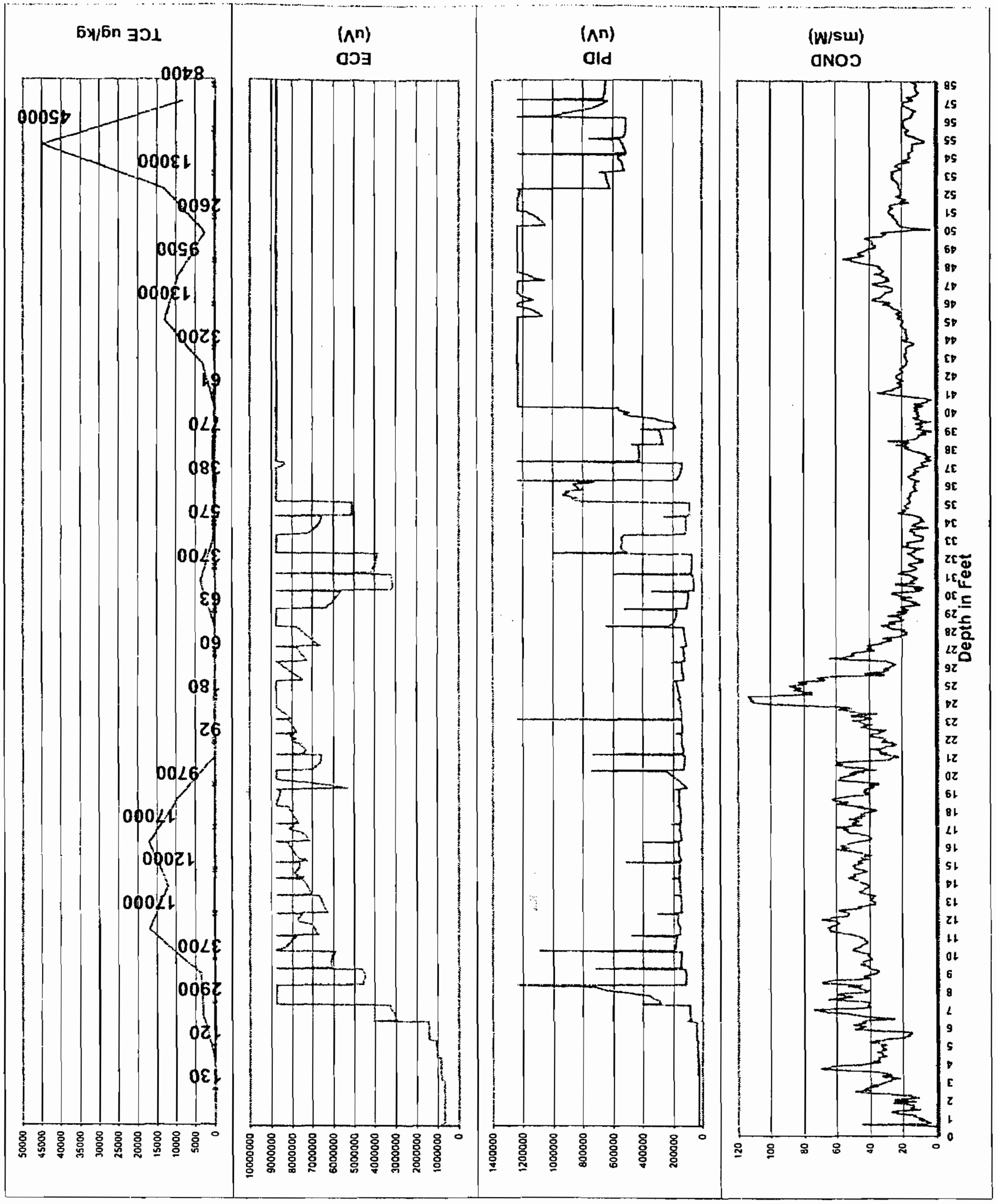
ZEBRA EC/MIP Summary Log, Point PZ010
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/9/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 7 of 17

ZEBRA EC/MIP Summary Log, Point PZ011
KY



for: CDM
by: Zebra Environmental
30 No. Prospect Avenue
Lynbrook, NY 11563
(516) 596-6300

Date: 6/13/2002
Proj. Name: CDM/Pad., KY
Proj. #: ZDS5539
Operators: JS
Point 14 of 17

APPENDIX E

WORK INSTRUCTIONS

SUBJECT: Startup and Normal Operation of the Six-Phase Heating System

---

1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to startup and place in normal operation the Six-Phase Heating (SPH) system in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies to the activities associated with starting up and operating the SPH system.

This work instruction will be performed in response to complete shutdown (planned or unplanned) of the SPH system.

3.0 CONDUCTED BY:

This work instruction will be performed by Thermal Remediation Systems, Inc. (TRS) personnel or SPH system personnel trained to operate the SPH system, under the supervision of TRS.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks"; WI-SPH-005, Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units; Operations and Maintenance Manual, Six-Phase Heating Treatability Study.

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies:

Dwyer Series 471 Thermo Anemometer

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction.

7.0 PRE-PERFORMANCE ACTIVITIES:

7.1 Obtain approval from the Operations Manager before executing this work instruction.

7.2 Obtain support from TRS before executing this work instruction.

7.3 Align the SPH system valves as specified in the SPH system valve alignment checklist (see Appendix B, Six-Phase Heating System Valve Alignment Checklist).

8.0 WHAT TO DO:

8.1 Verify system has appropriate Electrode Cable Alignment with TRS and Operations Manager before executing this work instruction.

A. Startup Condenser

8.2 Verify that at least 3 feet of water is available in the water holding tank through the holding tank site glass.

8.3 Verify that water is present in the cooling tower at mid-level or higher on the sight glass.

8.4 Move the C1 Condenser Skid Main Disconnect Switch to the "ON" position or verify the switch is in the "ON" position at the Condenser Skid Control Panel.

NOTE: The recycle pump is normally almost silent in its operation. Upon startup you will hear water begin spraying and falling through the cooling tower packing. The water level in the cooling tower will drop slightly as water fills the piping and heat exchangers.

8.5 Switch the C1 Recycle Pump (J2) to the "ON" position at the Condenser Skid Control Panel.

NOTE: The discharge pressure might occasionally fluctuate over the first minute as air is purged from the recycle loop.

8.6 Verify that the C1 Recycle Pump (J2) discharge pressure is greater than 5 pounds per square inch gage (psig) using the C1 Recycle Pump Discharge Pressure Gauge (P-502).

NOTE: Upon performing the next operation, you will hear the fan spin. A brief belt squeal upon startup is normal. The cooling fan has a thermostat that controls its operation. In cold weather (below 40°F), the cooling fan might not start or might operate intermittently – this is normal. The water temperature in the recycle loop will stabilize near ambient temperatures. The water level in the cooling tower will automatically stabilize near 75% of the sight glass (LI-503) – a float valve adds water from the holding tank as necessary.

8.7 Switch the cooling tower fan to the "ON" position at the Condenser Skid Control Panel.

8.8 Place the C1 Condensate Pump (J1) in automatic operation by switching it to the "AUTO" position at the Condenser Skid Control Panel.

NOTE: The following steps (8.9 through step 8.175) apply to the initial start-up of the condenser only. They are not required for routine start-up.

INFORMATION ONLY

8.9 Using a garden hose, add water to the C1 outlet vapor liquid separator until the water is mid-level on the sight glass (LI-501).

8.10 Close the Condensate Pump Discharge Throttle Valve (HV-503). Close the Condensate Pump Air Vent / Equalization Valve (HV-516).

8.11 Place the C1 Condensate Pump (J1) switch in the "hand" position to start the pump.

8.12 Throttle open the Condensate Pump Air Vent / Equalization Valve (HV-516) until air bubbles and water are observed to rise through the ½-inch transparent discharge tubing at a rate of about 1 foot per second.

8.13 Throttle open the Condensate Pump Discharge Throttle Valve (HV-503) until timed observation of the Condensate Pump Totalizing Flow Meter (FM-501) indicates that the flow rate is about 9 gallons per minute or until the Condensate Pump Discharge Pressure Gauge (P-501) indicates 5 psig, whichever occurs first.

8.14 Place the C1 Condensate Pump (J1) in automatic operation by switching it to the "AUTO" position at the Condenser Skid Control Panel.

8.15 Place the C1 Blowdown Valve (LCV-501) in automatic operation by switching it to the "AUTO" position at the Condenser Skid Control Panel.

B. Startup Dilution Blower

NOTE: One of the dilution dampers must be open to operate the Dilution Blower.

NOTE: Refer to WI-SPH-005, Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon (GAC) Units prior to performing this operation.

8.16 Verify if the on-service primary GAC vessel has reached Volatile Organic Compound (VOC) breakthrough. If it has not reached breakthrough, proceed to Step 8.177 and skip Step 8.188. If it has reached breakthrough, proceed to Step 8.188 and skip Step 8.177.

8.17 Open or verify open, the GAC Inlet Dilution Damper (HV-603) and close or verify closed, the Inter-GAC Dilution Damper (HV-608).

8.18 Close or verify closed, the GAC Inlet Dilution Damper (HV-603) and open or verify open, the Inter-GAC Dilution Damper (HV-608).

8.19 Move Dilution Blower Main Disconnect Switch to the "ON" position or verify in the "ON" position at the Dilution Blower Control Panel.

NOTE: Upon performing the next step, you will hear the blower spin. After a few seconds, the blower should operate with a smooth hum, and be free of vibration.

INFORMATION ONLY

8.20 Switch the dilution blower to the "ON" position at the Dilution Blower Control Panel.

NOTE: The dilution blower has a capacity limit of 2400 standard cubic feet per minute (scfm).

8.21 Measure the stack airflow to verify that it is less than 2400 scfm at the GAC Dilution Blower Anemometer Port (F7). 2400 scfm is 6,885 feet per minute (fpm) in the 8" diameter stack (scfm=0.35 x fpm, in an 8" duct).

8.22 Verify that the Blower Discharge Heat Exchanger Outlet Pressure Gauge (P5) is less than 10 inches H_2O. (It will normally be less than 1 in. H_2O.)

8.22.1 If the Blower Discharge Pressure Heat Exchanger Outlet Gauge (P5) is greater than 10 inches H_2O, verify that either the GAC Inlet Dilution Damper (HV-603) or the Inter-GAC Dilution Damper (HV-608) is fully open

C. Startup Vapor Recovery (VR) Blower

NOTE: The condenser (C1) must be running with no alarm conditions in order to start the VR blower.

8.23 Switch the VR Blower Skid Main Disconnect Switch to the "ON" position at the VR Blower Control Panel.

8.24 Open the B1 VR Blower Inlet Bleed Valve (HV-301).

NOTE: A brief belt squeal upon B1 startup is normal. After a few seconds, the blower should operate with a smooth but loud hum or growl, and be free of vibration.

8.25 Switch the VR Blower to the "AUTO" position at the VR Blower Control Panel.

8.26 Switch the VR Blower cooling fan to the "AUTO" position at the VR Blower Control Panel.

8.27 Throttle the B1 VR Blower Inlet Bleed Valve (HV-301) shut until the C1 Discharge Pressure Gauge (P3) reads 14 inches of Hg or until HV-301 is fully shut.

8.28 Check the condenser and system piping for obvious air leaks – a hissing sound as air is drawn into the vacuum vessels/piping.

8.29 Check the blower discharge heat exchanger outlet vacuum using the B1 Discharge Pressure Gauge (P4). If the outlet is at a positive pressure use a photoionization detector to scan positive pressure piping for VOC leaks. The positive pressure piping begins at VR Blower B1 and ends at the blower discharge heat exchanger inlet. If VOCs are detected, shut down the VR system and repair the leak.

D. Startup Power Control Unit (PCU)

NOTE: At this time, the normal procedure is to call a TRS operator on the telephone and the TRS operator will start-up and monitor the PCU remotely. However, under some circumstances the TRS operator might request local start-up. If local start-up is requested, the TRS operator will direct the following steps.

8.30 Press the "electrode power on" button. This will start electrode power. A "clunk" will be heard as the contactor (automatic switch) closes.

8.31 The TRS operator will periodically monitor and adjust the PCU as required.

NOTE: Locking and tagging out the PCU Output (Electrodes) will be necessary for on-site personnel to perform intrusive tasks inside the treatment area (example: groundwater sampling, electrode head work, etc). If lockout/taggout is required, please follow the procedure below.

8.32 Pull the handle down to the "OFF" position on the PCU Output Disconnect located on the fence, left of the access gate.

9.0 POST-PERFORMANCE ACTIVITIES:

9.1 Record activities in the Daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 "Development, Completion, and Control of Data Forms and Logbooks"

WI-SPH-005 "Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units"

Operations and Maintenance Manual, Six-Phase Heating Treatability Study

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________________ Date: ____________
(Operations Manager)

APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

fpm	Feet per minute
GAC	Granular Activated Carbon
PCU	Power Control Unit
psig	Pounds per Square Inch Gauge
scfm	Standard Cubic Feet per Minute
SPH	Six-Phase Heating
TRS	Thermal Remediation Services Inc.
VOC	Volatile Organic Compound
VR	Vapor Recovery

DEFINITIONS

None

APPENDIX B

SIX PHASE HEATING SYSTEM INITIAL START-UP VALVE ALIGNMENT CHECKLIST

Vapor Recovery Well #

VALVE	VALVE NAME	POSITION
SV-#	Vapor Recovery Well # Steam Vent Valve	OPEN
VR-#D	Vapor Recovery Well # Deep Valve	OPEN
VR-#S	Vapor Recovery Well # Shallow Valve	OPEN

Where # represents the vapor recovery well number (1-7).

Vacuum Piezometers 1-8

VALVE	VALVE NAME	POSITION
VP-#D	VP-# Deep Vent Valve	OPEN
VP-#S	VP-# Shallow Vent Valve	CLOSED
VV-#D	VP-# Deep Vacuum Valve	CLOSED
VV-#S	VP-# Shallow Vacuum Valve	CLOSED

Where # represents the vacuum piezometer number (1-8).

Vacuum Piezometers 9-15

VALVE	VALVE NAME	POSITION
VP-#D	VP-# Deep Vent Valve	CLOSED
VP-#S	VP-# Shallow Vent Valve	CLOSED
VV-#D	VP-# Deep Vacuum Valve	CLOSED
VV-#S	VP-# Shallow Vacuum Valve	CLOSED

Where # represents the vacuum piezometer number (9-15).

Condenser Skid **C1**

VALVE	VALVE NAME	POSITION
HV-501	C1 Inlet Vapor-Liquid Separator Drain Valve	CLOSED
HV-502	C1 Outlet Vapor-Liquid Separator Drain Valve	OPEN
HV-503	C1 Condensate Pump Discharge Throttle Valve	THROTTLED
HV-504	C1 Condensate Makeup Valve to Recycle	OPEN
HV-505	C1 Blower Heat Exchanger Recycle Return Valve	OPEN
HV-506	C1 Recycle Pump Inlet Valve	OPEN
HV-507	C1 Blower Heat Exchanger Condensate Return Valve	OPEN
HV-508	C1 Blower Heat Exchanger Recycle Supply Valve	OPEN
HV-509	C1 Liquid Phase GAC Bypass Valve	CLOSED
HV-510	C1 Manual Blowdown Valve	CLOSED
HV-511	C1 Injection Pump Inlet Valve (Out of Service)	CLOSED
HV-512	C1 Secondary Condensate Feed Valve (?)	CLOSED ?
HV-513	C1 Condenser Heat Exchanger Discharge Valve	OPEN

HV-514	C1 Cooling Tower Low Drain Valve	CLOSED
HV-515	C1 Cooling Tower High Drain Valve	CLOSED
HV-516	C1 Condensate Pump Air Vent / Equalization Valve	THROTTLED

VR Blower Skid	**B1**	
VALVE	VALVE NAME	POSITION
HV-301	VR Blower Bleed Valve	OPEN

Electrode #	**E#**	
VALVE	VALVE NAME	POSITION
Drip Valves will be opened to varying degrees to achieve a flow rate of 0.2 gpm		
HV-#W	E# Shallow Electrode Wetting Drip Valve	THROTTLED
HV-#Y	E# Shallow-Intermediate Electrode Wetting Drip Valve	THROTTLED
HV-#YY	E# Intermediate Electrode Wetting Drip Valve	THROTTLED
HV-#R	E# Intermediate-Deep Electrode Wetting Drip Valve	THROTTLED
HV-#RR	E# Deep Electrode Wetting Drip Valve	THROTTLED

Where # represents the vapor recovery well number (1-8).

GAC

VALVE	VALVE NAME	POSITION
HV-603	GAC Inlet Dilution Damper	OPEN
HV-604	GAC1 Inlet Header Damper	OPEN
HV-605	GAC3/GAC4 Inlet Header Damper	CLOSED
HV-606	GAC2 Inlet Header Damper	CLOSED
HV-608	GAC Inter-GAC Dilution Damper	CLOSED
HV-609	GAC1 Inter-GAC Header Damper	OPEN
HV-610	GAC3 Inter GAC Header Damper	CLOSED
HV-611	GAC2 Inter-GAC Header Damper	OPEN
HV-612	GAC1 Outlet Header Damper	CLOSED
HV-613	GAC3/GAC4 Outlet Header Damper	CLOSED
HV-614	GAC2 Outlet Header Damper	OPEN
HV-615	GAC4 Inter GAC Header Damper	CLOSED

SUBJECT: Shutdown of the Six-Phase Heating System

1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to perform short-term, long-term, and emergency shutdown of the Six-Phase Heating (SPH) system, in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies to the basic activities associated with shutting down the SPH system. This work instruction will be performed for short-term, long-term, and emergency shutdown of the SPH system (planned or unplanned).

3.0 CONDUCTED BY:

This work instruction will be performed by Thermal Remediation Services, Inc. (TRS) personnel or SPH system personnel trained to operate the SPH system, under the supervision of TRS.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks"; Operations and Maintenance Manual, Six-Phase Heating Treatability Study.

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies: none

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction for a routine shutdown.

7.0 PRE-PERFORMANCE ACTIVITIES:

Contract the Operations Manager (unless an emergency shutdown is required) to determine which shutdown is required.

8.0 WHAT TO DO:

8.1 Precede to the applicable shutdown instructions. For a Long-Term Shutdown proceed to step 8.2. For a Short-Term Shutdown proceed to step 8.6. For an Emergency Shutdown proceed to step 8.7.

A. Long-Term Shutdown of the SPH system

NOTE: Obtain support from TRS before executing this work instruction.

NOTE: At this time, the normal procedure is to call a TRS operator on the telephone for support in shutting down the SPH system.

8.2 Shutdown the Power Control Unit by pressing the "electrode power off" button. A "clunk" will be heard as the contactor (automatic switch) opens.

NOTE: Prior to initiating shutdown of the Vapor Recovery (VR) Blower, wait approximately one hour after shutdown of the Power Control Unit (PCU) to allow the VR system to process residual steam. Stopping the VR blower is all that is necessary to cease active VR operation.

8.3 Shutdown the Dilution Blower by switching the blower switch to the "OFF" position at the VR Blower Control Panel.

NOTE: It is not necessary to turn off the dilution blower for most VR system shut downs. Continued operation of the dilution blower maintains a very slight vacuum on the VR system and ensures that any residual Volatile Organic Compounds (VOCs) are treated by the Granular Activated Carbon adsorbers.

8.4 Switch the dilution blower switch to the "OFF" position at the Dilution Blower Control Panel.

8.5 Shutdown Condenser

NOTE: Unless necessary for maintenance or other activities, continued operation of the condenser recycle pump (J2) is desired. Condenser operation reduces the risk of freeze damage.

8.5.1 Switch the cooling tower fan to the "OFF" position at the Condenser Skid Control Panel.

8.5.2 If necessary, switch the C1 Recycle pump (J2) to the "OFF" position at the Condenser Skid Control Panel.

8.5.3 If necessary, turn the C1 Condensate Pump (J1) off by switching it to the "OFF" position at the Condenser Skid Control Panel.

8.5.4 Close the C1 Blowdown Valve (LCV-501) by switching it to the "OFF" position at the Condenser Skid Control Panel.

INFORMATION ONLY

B. Short-Term Shutdown of the SPH system

NOTE: Obtain support from TRS before executing this work instruction.

NOTE: At this time, the normal procedure is to call a TRS operator on the telephone for support in shutting down the SPH system.

NOTE: Short-term shutdown of the SPH system can be performed for various sampling and/or maintenance events. Refer to appropriate work control documents for sampling and maintenance activities.

8.6 Shutdown Power Control Unit by pressing the "electrode power off" button. A "clunk" will be heard as the contactor (automatic switch) opens.

C. Emergency Shutdown of the SPH system

NOTE: Emergency shutdown procedures will not be implemented if there is a condition that threatens personnel safety.

NOTE: Emergency shutdown procedures will be implemented in the event of a small fire, leak, or spill, or other condition as determined by the Operations Manager.

8.7 Open (turn off) the PCU emergency shutdown switch.

8.8 Switch the VR Blower to the "OFF" position at the VR Blower Control Panel.

8.9 Switch the cooling tower fan to the "OFF" position at the C1 Condenser Control Panel.

8.10 Switch the water recycle pump to the "OFF" position at the C1 Condenser Control Panel.

NOTE: The following step is optional based on the threat of personnel safety.

8.11 Switch the dilution blower to the "OFF" position at the Dilution Blower Control Panel.

9.0 POST-PERFORMANCE ACTIVITIES:

Record activities in the Daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 "Development, Completion, and Control of Data Forms and Logbooks"

Operations and Maintenance Manual, Six-Phase Heating Treatability Study

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________________ Date: __________
(Operations Manager)

APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

PCU	Power Control Unit
SPH	Six-Phase Heating
TRS	Thermal Remediation Services Inc.
VOCs	Volatile Organic Compounds
VR	Vapor Recovery

DEFINITIONS

None

INFORMATION ONLY

SUBJECT: Operational Data Collection for the Six-Phase Heating System

1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to perform operational data collection for the Six-Phase Heating (SPH) system, in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies to the activities associated with collecting operational data at the SPH system.

3.0 CONDUCTED BY:

This work instruction will be performed by SPH system personnel trained to operate the SPH system.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks"; WI-SPH-005, Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units; WI-SPH-002 Shutdown of the Six-Phase Heating System; Operations and Maintenance Manual, Six-Phase Heating Treatability Study.

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies:

5.1 Dwyer Series 471 Thermo Anemometer

5.2 Dwyer Series 477 Digital Manometer for pressure measurements

5.3 Summa Canisters

5.4 Photo Ionization Meter (PID) or Photo Acoustic Analyzer (PAA)

5.5 Omega HH21 digital thermometer (thermocouple reader)

5.6 Fluke Model 179 True RMS Multimeter with NIST-Traceable Calibration Certificate

5.7 Fluke 80i-600A Clamp-on Ammeter

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction.

7.0 PRE-PERFORMANCE ACTIVITIES: NONE

8.0 WHAT TO DO:

On - Site Daily Sampling and Monitoring (Each Work Day)

First Set-Daily Log Sheet

8.1 Measure the eight-hour time weighted average Volatile Organic Compound (VOC) concentration using the area PID.

8.2 Verify that the condenser parameters are within range of the typical readings presented below.

- 8.2.1 C1 Inlet Pressure Indicator (P2): 6-13 in. Hg.(Vacuum range due to soil moisture content)
- 8.2.2 C1 Discharge Pressure Gauge (P3): 7-15 in. Hg. (Vacuum range due to soil moisture content)
- 8.2.3 C1 Inlet Temperature Indicator (T2): Up to 82°C when the site is boiling.
- 8.2.4 C1 Discharge Temperature Indicator (T3): Ambient ±5°C or 4°C, whichever is higher.
- 8.2.5 C1 Recycle Pump Discharge Pressure Gauge (P-502): 5-10 psig.
- 8.2.6 Record the Vapor Recovery Blower hour-meter on the control panel.
- 8.2.7 Record the Vapor Recovery Blower outlet temperature.
- 8.2.8 Heat Exchanger Discharge Pressure (P-503): 4-8 psig
- 8.2.9 C1 heat Exchanger Discharge Temperature (T-502): 4°C to 49°C.
- 8.2.10 C1 Recycle Pump Discharge Temperature Indicator (T-501): Ambient temperature or 4°C, whichever is higher.

8.3 Record the condensate totalizer reading at the C1 Condensate Pump Totalizing Flow Meter (FM-501).

8.4 Record the totalizer reading at the C1 Makeup Water Totalizing Flow Meter (FM-502).

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8.5 Check the water holding tank level through the water holding tank site glass. If the tank level is greater than 6 feet, schedule an excess condensate water transfer and schedule a condensate water sample from the tank. Shutdown is not required.

8.6 Record the B1 Vapor Recovery (VR) Blower Discharge Pressure (P4). If P4 is a positive pressure, use a PID to scan positive pressure piping for VOC leaks. The positive pressure piping begins at VR Blower B1 and ends at the blower discharge heat exchanger inlet. If VOCs are detected, shut down the VR system and repair the leak.

8.7 Record the Blower Heat Exchanger Outlet Temperature (T5).

8.8 Record the megawatt-hr number off of the Power Control Unit (PCU) display.

8.9 Verify PCU cooling fan operation and check that the doors are secured, note in PCU/Electrode field normal box.

8.10 Observe and listen to the well field. If you hear a vacuum leak, telephone the Operations Manager to shut down the PCU and schedule a repair.

8.11 Record the overall SPH energy by kW-hr meter at the SPH system PCU.

8.12 Record the subsurface temperatures from the six temperature monitoring points (TMPs) located inside the treatment area at VP3 and VP5.

8.13 Routine housekeeping of the site, remove all debris and keep the areas around the carbon vessels free of combustible materials.

Daily Second Set - Vapor Stream Concentration Log

8.14 Using the PAA, measure and record the vapor stream concentrations of trichloroethene, VC, and DCE in the inlet GAC header (G5), inter GAC header (G6), and the GAC dilution blower sample port (G7). All vapor stream concentrations will be stored on the accompanying computer.

8.15 If the concentration at the outlet of the primary GAC (S6) is greater than one-half the concentration measured at GAC Inlet Header Sample Port (S5), conduct the appropriate procedure described in Section A, Primary GAC Initial Breakthrough Operations in WI-SPH-005, Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units.

8.16 Using the anemometer, measure and record the velocity (feet per minute) and temperature (°F) of the vapor stream in the inlet GAC header (F5), inter GAC header (F6) and the GAC dilution blower sample port (F7).

Daily Third Set-Temperature Monitoring Points

8.17 Record temperatures from subsurface TMPs and process TMPs listed on the log sheet using a Digital Thermoreader.

Remote Daily Monitoring (Each Work Day)

NOTE: Remote monitoring is conducted in an office environment. Data is recorded directly into a spreadsheet for logging and analysis.

8.18 Measure the energy to each electrode by dividing the overall energy among the electrodes in proportion to the measured power of each at the SPH system PCU.

Weekly Sampling and Monitoring

Weekly First Set-Current Log (amps)

NOTE: First set sampling and monitoring can be performed any time during the week.

8.19 Measure and record the current flow to each electrode element using a clamp-on ammeter.

Weekly Second Set- Piezometer and Vapor Recovery Well Vacuum Measurement and Piezometer Temperature Log

8.20 Measure and record the subsurface temperatures at the 6 vacuum piezometer locations using the procedure in section E.

8.21 Measure and record vacuum influence at the 15 vacuum piezometers using the procedure in section E.

8.22 Measure and record the vacuum or pressure at the steam vents of the piezometers using the procedure in section E.

8.23 Measure and record the vacuum at the fourteen VR wells (VR-#D and VR-#S), where # equals the VR Well ID, using a vacuum gage.

Piezometer Measurements (Weekly, Second Set)

8.24 Measure the subsurface temperatures at each vacuum piezometer location using the following procedure:

8.24.1 Measure the 17, 37, and 57 ft below ground surface (bgs) interval for each of the six piezometer thermocouples.

8.25 Measure vacuum influence at the 15 vacuum piezometers at depths of 10, 20 and 30 feet bgs using a manometer. Piezometers V1 through V11 are within the expected radius of vacuum influence and should have a measurable vacuum at all three depths. If any of these piezometers does not show a vacuum, verify that the sample line is clear by blowing a small amount of air into the tubing. Piezometers V12 through V15 are outside the region of expected vacuum influence and may show a slight vacuum or a slight positive pressure. If any of these piezometers show a positive pressure, review the atmospheric barometric pressure changes over the past 2-3 days for a decrease in pressure, also check if piezometers that lie closer to the treatment region, but on a similar radial, show a vacuum.

8.26 Measure the vacuum or pressure at the steam vents of the piezometers. Steam vents V1 through V8 are connected to the vapor recovery system and will be under a vacuum during VR operation. Steam vents V9 though V15 have screens below the water table and will not normally provide an accurate indication of subsurface pressure or vacuum. However, these steam vents will show a sustainable pressure if a steam bubble collects at the top of the Regional Gravel Aquifer. Check for influence of a steam bubble using the following procedure:

8.26.1 Review the temperatures measured at 57 feet bgs for each piezometer. The presence of the steam bubble requires a temperature of at least 100°C. If a temperature of less than 95°C was recorded then a steam bubble is not expected.

8.26.2 For steam vents V1 through V8, shut the wellhead vacuum valve and monitor wellhead pressure until it stabilizes, but not longer than one minute. Record the pressure and open the wellhead valve. A pressure of greater than 1 pounds per square inch gage (psig) indicates that a steam bubble would probably collect at that location, if it were not for the removal action of the steam vent.

8.26.3 For steam vents V9 through V15, vent the wellhead via a ¼-inch connection for one minute, and then measure the wellhead pressure. A pressure of greater than 1 psig in conjunction with a temperature of greater than 95°C at 57 feet bgs indicates that a steam bubble has moved to that location from the heated region. Connect this steam vent to the VR system using a 1" steam hose.

9.0 POST-PERFORMANCE ACTIVITIES:

9.1 Record activities in the Daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 "Development, Completion, and Control of Data Forms and Logbooks"

WI-SPH-002 "Shutdown of the Six-Phase Heating System"

WI-SPH-005 "Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units"

Operations and Maintenance Manual, Six-Phase Heating Treatability Study

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________ Date: __________
(Operations Manager)

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APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

bgs	below ground surface
PAA	Photo Acoustic Analyzer
PCU	Power Control Unit
PID	Photo Ionization Detector
psig	Pounds per Square Inch Gauge
SPH	Six-Phase Heating
TMPs	Temperature Monitoring Points
VOC	Volatile Organic Compound
VR	Vapor Recovery

DEFINITIONS

None

APPENDIX B

SIX-PHASE HEATING SYSTEM OPERATIONAL DATA COLLECTION SHEETS

See attached data collection sheets pages 1 through 4.

INFORMATION ONL

SUBJECT: Maintenance and Calibration of the Six-Phase Heating System

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1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to perform maintenance and calibration to the Six-Phase Heating (SPH) system, in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies to the activities associated with performing routine maintenance and calibration of the SPH system.

3.0 CONDUCTED BY:

This work instruction will be performed by SPH system personnel trained to operate the SPH system.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks."

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies:

5.1 Vapor Recovery (VR) Blower cooling fan belt

5.2 NLGI Grade 2-Lithium Grease

5.3 Grease Pump

5.4 Power Control Unit (PCU) Filter (20" ×20" ×2" pleated HVAC filter)

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction.

7.0 PRE-PERFORMANCE ACTIVITIES: NONE

8.0 WHAT TO DO:

NOTE: For all bearings, the appropriate grease is NLGI grade 2-lithium grease, such as Mobilith AW2.

A. Weekly Maintenance

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NOTE: VR blower shutdown is not required for greasing.

8.1 Grease the VR blower by applying five pumps of the grease gun to each bearing or until grease is noted coming out of the vent, whichever is less.

8.2 Inspect PCU filters. Change the filters if obviously dirty. Verify cooling fan operation if ambient temperatures are greater than 20°F.

B. Monthly Maintenance

8.3 Shut down the PCU and danger tag out the PCU Input Disconnect.

8.4 Inspect PCU cooling fan belts for deterioration and tightness and replace if necessary.

8.5 Shut down the VR Blower and danger tag out the VR Blower Disconnect Switch.

8.6 Inspect VR Blower cooling fan belts for deterioration and tightness and replace if necessary.

NOTE: The VR blower requires an oil change every 1500 hours.

8.7 If the VR Blower has been operating for more than 1000 hours since the last oil change, change the blower oil per the Roots blower operating manual and record the hour meter reading. Clear danger tag.

NOTE: Dilution Blower shutdown is not required for greasing.

8.8 Grease the dilution blower by applying two pumps of the grease gun to each shaft bearing or until slight grease purging is noted at the seals, whichever is less.

C. Six-Month Maintenance

8.9 Shut down the PCU and danger tag out the input disconnect.

8.10 Apply two pumps of the grease gun to each fan bearing or until slight grease purging is noted at the seals, whichever is less.

8.11 Grease the PCU tap-changer bearings. Apply two pumps of the grease gun to each bearing or until slight grease purging is noted at the seals, whichever is less.

8.12 Vacuum the PCU interior.

8.13 Inspect PCU cables for chafing.

8.14 Check bolt tightness on all electrical connections using a 3/4" socket wrench.

8.15 Close and lock all PCU access doors. Remove danger tag.

8.16 Cycle the tap changers through a full range of travel.

INFORMATION ONLY

9.0 POST-PERFORMANCE ACTIVITIES:

Record activities in the Daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 "Development, Completion, and Control of Data Forms and Logbooks"

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________________ Date: __________
(Operations Manager)

APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

PCU	Power Control Unit
SPH	Six-Phase Heating
VR	Vapor Recovery

DEFINITIONS

None

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APPENDIX B

SIX-PHASE HEATING SYSTEM MAINTANENCE AND CALIBRATION SHEET

See attached sheet.

SUBJECT: **Operations and Maintenance of the Six-Phase Heating System Vapor Phase Granular Activated Carbon Units**

1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to operate and maintain the vapor phase Granular Activated Carbon (GAC) vessels for the Six-Phase Heating (SPH) system, in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies only to the activities associated with determining Volatile Organic Compound (VOC) breakthrough and performing changeout operations for the vapor phase granular activated carbon units and determining the GAC inlet flow rate at the SPH system.

3.0 CONDUCTED BY:

This work instruction will be performed by SPH system personnel trained to operate the SPH system.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks".

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies:

5.1 Photo Acoustic analyzer (PAA).

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction.

7.0 PRE-PERFORMANCE ACTIVITIES: NONE

8.0 WHAT TO DO:

NOTE: Initial breakthrough of the primary GAC adsorber is indicated when the VOC concentration exiting the vessel (S6) is greater than 50 percent of the GAC inlet header concentration (S5). If initial breakthrough is reached, the operator will perform procedures outlined in Section A, Primary GAC Breakthrough Operations.

NOTE: This action increases the trichloroethene (TCE) vapor concentration to the primary GAC adsorber and allows this unit to achieve a higher VOC mass loading. During this second loading of the primary GAC adsorber, the temperature rise in the mass transfer

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zone is much less than observed during the initial loading and TCE concentrations of up to 20,000 parts per million by volume (ppmv) (108 mg/l) are acceptable. At a constant TCE extraction rate, the primary adsorber will reach second breakthrough in about one-half the time required to reach initial breakthrough. This estimate can be helpful for planning purposes to schedule when to have the next GAC adsorber delivered to the site.

NOTE: Operational data collection for the SPH system directing that routine housekeeping of the site include keeping areas around carbon vessels free of combustible materials.

A. Primary GAC Initial Breakthrough Operations

8.1 Open the Inter-GAC Dilution Damper (HV-608).

8.2 Shut the GAC Inlet Dilution Damper (HV-603).

8.3 Measure the stack airflow to verify that it is less than 2400 standard cubic feet per minute (scfm) at the GAC Dilution Blower Anemometer Port (F7). 2400 scfm is 6,885 feet per minute (fpm) in the 8" diameter stack. If the stack velocity is greater than 6,885 fpm, throttle HV-608 to achieve 6,885 fpm.

8.4 Estimate time to reach second breakthrough of Primary GAC vessel.

NOTE: When the primary GAC adsorber reaches VOC breakthrough a second time, with undiluted recovered vapor, the GAC adsorber is spent and a vessel changeout is required. The operator will perform the procedures outlined in Section B, GAC Vessel Changeout.

B. GAC Vessel Changeout

8.5 Contact the Operations Manager to obtain the specific valve alignments required to execute steps 8.6 through 8.20.

8.6 Connect the inlet hose of the spare GAC adsorber to the inter-GAC header (HV-609, HV-610, HV-611, or HV-615). Connect the outlet hose of the spare GAC adsorber to the GAC outlet header (HV-612, HV-613, or HV-614).

8.7 Open the GAC outlet header blast gate (HV-612, HV-613, or HV-614) for the spare GAC adsorber. Open the inter-GAC header blast gate (HV-609, HV-610, HV-611, or HV-615) for the spare GAC adsorber. The spare GAC adsorber is now on service.

8.8 Shut the GAC outlet header blast gate (HV-612, HV-613, or HV-614) to the secondary GAC adsorber. Shut the inter-GAC header blast gate (HV-609, HV-610, HV-611, or HV-615) to the secondary GAC adsorber.

8.9 Connect the inlet hose of the secondary GAC adsorber to the GAC inlet header (HV-604, HV-605, or HV-606). Connect the outlet hose of the secondary GAC adsorber to the inter-GAC header (HV-609, HV-610, HV-611, or HV-615).

8.10 Open the GAC inlet dilution damper (HV-603). Shut the inter-GAC dilution damper (HV-608).

8.11 Open the inter-GAC header blast gate (HV-609, HV-610, HV-611, or HV-615) for the secondary GAC adsorber. Open the GAC inlet header blast gate (HV-604, HV-605, or HV-606) for the secondary GAC adsorber. The secondary GAC adsorber has been returned to service.

8.12 Shut the inter-GAC header blast gate (HV-609, HV-610, HV-611, or HV-615) to the spent GAC adsorber. Shut the GAC inlet header blast gate (HV-604, HV-605, or HV-606) to the spent GAC adsorber.

8.13 Disconnect the spent GAC adsorber outlet hose at both the vessel and at the inter-GAC header.

8.14 Open the GAC inlet header blast gate (HV-604, HV-605, or HV-606) for the spent GAC adsorber. Shut the GAC inlet dilution damper (HV-603). This will purge the spent GAC adsorber with fresh air in the backflow direction.

8.15 After one minute of purging, open the GAC inlet dilution damper (HV-603). Shut the GAC inlet header blast gate (HV-604, HV-605, or HV-606) to the spent GAC adsorber.

8.16 Disconnect the spent GAC adsorber inlet hose at both the vessel and at the GAC inlet header.

8.17 Remove the "Secondary GAC" magnetic sign from the former secondary GAC adsorber and place it on the former spare GAC adsorber. Remove the "Primary GAC" magnetic sign from the spent GAC adsorber and place it on the new primary (former secondary) GAC adsorber.

8.18 Measure the GAC Inlet Header (S5) VOC concentration using a Photo Ionization Detector or the PAA. If the TCE concentration at the GAC adsorber inlet is greater than 1500 ppmv, telephone the Operation Manager to briefly shut down the SPH system and conduct an evaluation to determine how to reduce the inlet concentration during operations. After the SPH has been shut down for one hour, it is usually appropriate to re-start the SPH system at a power level that is proportionately lower by the ratio of the desired to measured VOC concentration.

8.19 As soon as practical (typically less than 5 days), remove the spent GAC adsorber and replace it with a new spare GAC adsorber.

8.20 Connect the inlet hose of the new spare GAC adsorber to the inter-GAC header (HV-609, HV-610, HV-611, or HV-615). Connect the outlet hose of the spare GAC adsorber to the GAC outlet header (HV-612, HV-613, or HV-614).

NOTE: This procedure is for determining the GAC inlet flow rate at the GAC Inlet Header Anemometer Port (F5) or stack flow at the GAC Dilution Blower Anemometer Port

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(F7).

C. GAC Inlet Flow Rate Determination

8.21 The digital thermo anemometer has a telescoping measurement wand. Grasp the wand by the knurled tip and pull the inner telescoping tube out slightly to expose the flow measuring port (with the thin wire) and the temperature measuring port (with the rectangular chip).

8.22 Push the inner telescope tubing in until 1/2" of the tube is exposed below the temperature measurement port. The tube is scored at this depth. Placing the telescoping tube at this depth will position the flow measuring port at the correct pipe radius to obtain the most accurate flow measurement.

8.23 Insert the anemometer into the GAC Inlet Header Anemometer Port (F5) or the Stack Anemometer Port (F7) as appropriate. Ensure that the holes in the anemometer are oriented parallel to the pipe flow. The anemometer should be inserted into the pipe until the end of second smallest telescoping tube is flush with the pipe outer wall.

8.24 If measuring the flow rate at the GAC Inlet Header Anemometer Port (F5) measure and record the flow velocity at the GAC Inlet Header Anemometer Port (F5) in fpm.

8.25 If measuring the flow rate at the GAC Dilution Blower Anemometer Port (F7), measure and record the flow velocity at the Stack Anemometer Port (F7) in feet per minute (fpm).

8.26 Calculate the flow. The flow equation is:

$$scfm = 0.79 ft^2 \times fpm$$

Where scfm = standard cubic feet per minute; 0.79 ft^2 = cross-sectional area of a 12-inch pipe; fpm = feet per minute

8.27 Estimate the VOC recovery rate. The equation is:

$$lb/day = 0.00048 * scfm * ppmvTCE$$

Where lb/day = pounds of VOCs recovered per day; and ppmv TCE is the vapor concentration.

9.0 POST-PERFORMANCE ACTIVITIES:

Record activities in the Daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

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10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 “Development, Completion, and Control of Data Forms and Logbooks”

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________________ Date: ____________
(Operations Manager)

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APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

fpm	feet per minute
GAC	granular activated carbon adsorber
PAA	photoacoustic analyzer
ppmv	parts per million by volume
scfm	standard cubic feet per minute
SPH	Six Phase Heating
TCE	trichloroethene
VOC	Volatile Organic Compound

DEFINITIONS

None

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SUBJECT: Electrode Current Surveys

1.0 PURPOSE:

The objective of this work instruction is to define the required equipment and steps necessary to conduct electrode current surveys at the Six Phase Heating (SPH) Treatability Study, in the vicinity of building C-400 at the Paducah Gaseous Diffusion Plant.

2.0 APPLIES TO:

This work instruction applies only to the activities associated with determining the electrical current to the six depth zones in each electrode.

3.0 CONDUCTED BY:

This work instruction will be performed by SPH system personnel trained to operate the SPH system.

4.0 TRAINING AND OTHER PREREQUISITES:

Training consists of OSHA 1910-131-137 (approved for working on energized equipment /systems) and of a walk down of the general operation of the SPH system and this work instruction by the Operations Manager or designee. In addition, SPH system Operators will be trained on the following procedures, work instructions, and operator aids: CDM-005, "Development, Completion, and Control or Data Forms and Logbooks".

Meet the requirements of Activity Hazard Analysis for Testing Energized Equipment >50 volts.

5.0 SPECIAL TOOLS, EQUIPMENT, PARTS, AND SUPPLIES:

The execution of this work instruction requires the following special equipment and supplies:

5.1 Lineman's Gloves – either Class 00 (500V) or Class 0 (1000V) gloves as appropriate for the applied electrode voltage. Class 00 gloves are more flexible.

5.2 Flame Retardant Coveralls

5.3 Face Shield

5.4 Clamp-on Ammeter - connected to a multimeter with NIST traceable calibration certificate

5.5 Electrically Insulated Screwdriver – conforms to IEC900 and A1505-94STMF

5.6 Small or Medium Fuse Puller (**optional**) – can be used to grab and reposition cables

6.0 APPROVALS AND NOTIFICATIONS:

Obtain approval from the Operations Manager before executing this work instruction.

7.0 PRE-PERFORMANCE ACTIVITIES: NONE

8.0 WHAT TO DO:

NOTE: Survey must be performed with power applied to the electrodes

8.1 Personnel to be taking current measurements must don proper personal protective equipment (Gloves, flame retardant apron, and face shield). Verify that the gloves have been tested within the past six months.

8.2 Enter the active treatment area with a partner for documentation and emergency response ("two man rule").

8.3 Using insulated screwdriver, open electrode head cover and place aside.

8.4 Clamp the ammeter around each of the connected electrode cables. Cables can be repositioned using: a gloved hand, a fuse puller, an insulated screwdriver or the jaws of the clamp-on ammeter.

8.5 Record data.

8.6 Return cover to electrode head and fasten screws.

8.7 Repeat steps 8.1- 8.6 for each of the electrodes until complete.

8.8 If the glove test is more than five months old, schedule glove re-testing.

9.0 POST-PERFORMANCE ACTIVITIES:

Record activities in the daily Six-Phase Heating System Data Collection and Maintenance Sheets in accordance with CDM-005 "Development, Completion, and Control of Data Forms and Logbooks".

10.0 RECORDS:

Daily SPH system Operational Data Collection and Maintenance Sheets.

11.0 REFERENCES:

CDM-005 "Development, Completion, and Control of Data Forms and Logbooks"

All applicable equipment manuals

12.0 WRITTEN BY:

Thermal Remediation Services Inc.

13.0 APPROVAL:

Approved By: ______________________________ Date: ____________
(Operations Manager)

APPENDIX A

ACRONYMS AND DEFINITIONS

ACRONYMS

IEC	International Electrical Code
NIST	National Institute of Standards and Testing
SPH	Six Phase Heating

DEFINITIONS

None

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