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Final Remedial Action Report for Lasagna™ Phase IIb In-Situ Remediation of Solid Waste Management Unit 91 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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Final Remedial Action Report for Lasagna™ Phase IIb In-Situ Remediation of Solid Waste Management Unit 91 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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ACRONYMS

ACWP	Actual Cost of Work Performed
AHA	Activity Hazard Analysis
BCWS	Budgeted Cost of Work Scheduled
BJC	Bechtel Jacobs Company LLC
CDM	CDM Federal Programs Corporation
DOE	United States Department of Energy
DQO	data quality objective
EPA	United States Environmental Protection Agency
FFA	Federal Facilities Agreement
FY	fiscal year
ft	foot
gal	gallon
GC-MS	gas chromatograph – mass spectrometry
KDWM	Kentucky Department of Waste Management
Lasagna™	Lasagna™ *in-situ* Remediation Technology
LMES	Lockheed Martin Energy Systems
MW	monitoring well
O&M	operation and maintenance
PGDP	Paducah Gaseous Diffusion Plant
POE	Point of Exposure
PVC	Polyvinyl Chloride
RA	Remedial Action
RCI	Record Commercialization Initiative
ROD	Record of Decision
STR	Subcontract Technical Representative
SWMU	Solid Waste Management Unit
TCE	Trichloroethene

EXECUTIVE SUMMARY

This Final Remedial Action (RA) Report was written in accordance with the requirements of the Federal Facilities Agreement (FFA) among the United States Department of Energy (DOE), United States Environmental Protection Agency (EPA), and the Commonwealth of Kentucky. This report documents that the Phase IIb Lasagna™ *In-situ* Remediation Technology (Lasagna™) at Solid Waste Management Unit (SWMU) 91, located at the Paducah Gaseous Diffusion Plant (PGDP), has been implemented in accordance with specifications and has met the performance standards specified in the Record of Decision (ROD). As required by the FFA, the Final RA Report outline was followed in the development of this report. The following elements are included:

- Site and Remedy Description,
- Chronology of Events,
- Performance Standards and Construction Quality Control,
- Construction Activities,
- Final Inspection,
- Certification Remedy is Operational and Functional,
- Operation and Maintenance, and
- Summary of Project Costs.

SWMU 91, also known as the Cylinder Drop Test Area, is located at the south end of the C-745-B Cylinder Storage Yard in the northwest quadrant of the PGDP. From late 1964 until early 1965 and in February 1979, cylinder drop tests were conducted to test the structural integrity of steel cylinders used to store and transport uranium hexafluoride. A pit that was lined with plastic and filled with trichloroethene (TCE) and dry ice was used as part of the testing process. As a result of these tests, the surrounding shallow soil and groundwater were contaminated with TCE.

Various site investigations were undertaken between 1992 and 1995 to determine the level of contamination and extent. Oak Ridge National Laboratory-Grand Junction, under the direction of Lockheed Martin Energy Systems (LMES), collected soil samples from the area and determined the average soil concentration was 84 mg/kg with a high concentration of over 1500 mg/kg TCE, indicating the presence of pure phase product in the soil.

In 1994, SWMU 91 was selected for the demonstration of the Lasagna™ technology, an *in-situ* remedial technology designed to reduce TCE contamination in low-permeability soils. Lasagna™ uses an applied direct current electric field to drive TCE-contaminated soil-water through treatment zones installed in the contaminated soil. The treatment zones are vertical zones comprised of iron filings and Kaolin clay. Ultimately, the TCE is broken down into nonhazardous compounds as it comes in contact with the iron particles in the treatment zones. Lasagna™ Phase I began in January 1995 and lasted for 120 days. The purpose of Phase I was to collect sufficient experience and information for site-specific design, installation, and operations of the Lasagna™ technology. Lasagna™ Phase IIa began in August 1996 and lasted 12 months. The purpose of Phase IIa was to perfect methods for installing treatment and electrode zones. During these phases of the technology demonstration, the average concentration of TCE in the target soil was reduced by approximately 95%.

In July 1998, DOE issued the *Record of Decision for Remedial Action at Solid Waste Management Unit 91 of Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1998a). The ROD designated Lasagna™ as the selected remedial alternative for reducing the concentration of TCE in SWMU 91. Following installation, the Lasagna™ system was operated for two years to reduce the concentration of TCE in SWMU 91 soil from

an average of 84 mg/kg to an average of less than 5.6 mg/kg. There was an option to operate an additional 12 months, if necessary, to achieve the cleanup level of 5.6 mg/kg.

Prior to start-up of the full scale Lasagna™ process, baseline soil samples were collected in November/December 1999. These samples, showed a reduced level of TCE in the soil. The average TCE soil concentration was determined to be 4.4 mg/kg with a high concentration of only 29.6 mg/kg. These results were assumed, by the technical team, to be biased low and Phase IIb commenced. The 6,480-ft^2 full-scale application of the Lasagna™ treatment system began Phase IIb in December 1999.

After approximately ten months of Phase IIb operations of the Lasagna™ treatment system, subsurface soil samples were collected to compare against previous samples. Progress soil sampling event A samples were collected in August 2000. These samples resulted in an average TCE soil concentration of 43.3 mg/kg with a high concentration of 552 mg/kg.

Progress sampling event B was undertaken in August 2001. This sampling event showed that Lasagna™ had reduced the soil concentrations to an average less than 1.5 mg/kg with a high of only 27 mg/kg.

The system was shut down in December 2001. Verification sampling was conducted from April 30 through May 8, 2002. The verification sampling and analysis plan was reviewed and approved by the Kentucky Division of Waste Management. The results of the verification sampling indicate the average concentration of TCE was 0.38 mg/kg with a high concentration of 4.5 mg/kg.

1. INTRODUCTION

1.1 GENERAL DESCRIPTION OF SITE

1.1.1 Site Location

Solid Waste Management Unit (SWMU) 91, also known as the Cylinder Drop Test Area, is located at the south end of the C-745-B Cylinder Storage Yard in the northwest quadrant of the Paducah Gaseous Diffusion Plant (PGDP) as shown in Fig. 1.1 provided in Appendix A. The southeast corner coordinates of the SWMU are 6868-W and 1020-S.

1.1.2 Site Description

SWMU 91 is a 72-ft by 90-ft area that encompasses the former drop test pad, the trichloroethene (TCE) pit used during the drop tests, three monitoring wells, and the former Lasagna™ Phase I and Phase IIa areas.

1.1.3 Site History

From late 1964 until early 1965 and in February 1979, cylinder drop tests were conducted in this area of the PGDP to test the structural integrity of steel cylinders used to store and transport uranium hexafluoride. Before the cylinders were tested, they were chilled in a pit containing TCE and dry ice. The cylinders were then lifted by crane and dropped on a concrete and steel pad to test their integrity. The TCE was not removed from the pit after the tests and eventually leaked into the surrounding soil and shallow groundwater.

Various site investigations were undertaken between 1992 and 1995 to determine the extent and level of contamination. Oak Ridge National Laboratory-Grand Junction, under the direction of Lockheed Martin Energy Systems (LMES), collected soil samples from the area. It was determined that the average soil concentration was 84 mg/kg with a high concentration of over 1500 mg/kg TCE, indicating the presence of pure phase product in the soil. Detailed characterization information on the selected test site can be found in the *Preliminary Site Characterization/Baseline Risk Assessment/Lasagna™ Technology Demonstration at Solid Waste Management Unit 91 of the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (LMES 1996).

In 1994, SWMU 91 was selected for the demonstration of the Lasagna™ technology, an *in-situ* remedial technology designed to reduce TCE contamination in low-permeability soils. A research consortium consisting of Monsanto, Dupont, and General Electric with support from the Department of Energy (DOE) and the United States Environmental Protection Agency (EPA) developed the Lasagna™ treatment technology. The success of the initial 120-day demonstration (Phase I), that began in January 1995, led to a full-scale field demonstration (Phase IIa) in August 1996.

The purpose of Phase I was to collect sufficient experience and information for site-specific design, installation, and operation of the Lasagna™ technology. The Phase I demonstration was conducted over a four-month period and resulted in a 98.4% reduction of TCE levels in the soils within the treatment area. The detailed results of the Phase I demonstration are documented in the *Preliminary Site Characterization/Baseline Risk Assessment/Lasagna™ Technology Demonstration at Solid Waste Management Unit 91 of the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (LMES 1996).

Lasagna™ Phase IIa began in August 1996 and lasted 12 months. The purpose of Phase IIa was to perfect methods for installing treatment and electrode zones. Lasagna™ Phase IIa treated a volume of SWMU 91 soil measuring approximately 21 ft x 30 ft x 45 ft deep. Post-test soil sampling conducted for the Phase IIa demonstration indicated that the cleanup effectiveness of TCE ranged from 50% to 100%. The detailed results of the Phase IIa demonstration are documented in the *Rapid Commercialization Initiative (RCI) Final Report for an Integrated In-Situ Remediation Technology (Lasagna™)* (DOE 1998b).

In July 1998, DOE issued the *Record of Decision for Remedial Action at Solid Waste Management Unit 91 of Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1998a), which the EPA and DOE signed on August 10, 1998. The Record of Decision (ROD) designated Lasagna™ as the selected remedial alternative to reduce the concentration of TCE in SWMU 91. In March 1999, Bechtel Jacobs Company, LLC (BJC) awarded CDM Federal Programs Corporation (CDM) a subcontract (No. 23900-SC-RM058) for the installation and operation of Lasagna™ Phase IIb at SWMU 91.

1.2 GENERAL DESCRIPTION OF REMEDY

1.2.1 Components of Remedy

Lasagna™ uses an applied direct current electric field to move soil-water through treatment zones installed in the contaminated soil. This induced soil-water flow is called electro-osmosis. The soil-water flow, induced by the direct current, travels from the anode electrode to the cathode electrode. Soil-water containing TCE is driven away from the anode electrode toward the cathode electrode, which is located in the center of the treatment area, and passes through a series of iron particle treatment zones installed between the electrodes. Ultimately, the TCE is broken down into nonhazardous compounds as it comes in contact with the iron particles in the treatment zones. The treatment zones are designed to allow enough reaction time for the TCE reduction to proceed completely to ethene or ethane without the generation of chlorinated degradation products (notably cis-1,2-dichloroethene and vinyl chloride). Elevated soil temperature is a direct result of current flow through the soil and contributes to contaminant mobility and destruction. Temperature is controlled by current input to ensure that boiling off of the soil pore water does not occur. For this site, the maximum temperature limit was initially set at 90 °C, then lowered to 80 °C. Figures 1.2 and 1.3 shows the conceptual model of the Lasagna™ treatment process and typical electrode configuration, respectively.

The Lasagna™ technology has been tested as a multiphase project at SWMU 91. The first of three phases was Phase I, which was an experimental installation and field test of the technology in a 150 ft^2 area. Phase IIa was a yearlong commercial-scale demonstration test on a 600-ft^2 site. Phase IIb, which began operation in December 1999, was a 6,480-ft^2 full-scale application of a Lasagna™ treatment system designed to perform soil remediation at SWMU 91. The Lasagna™ system was operated for two years ending December 2001 in an attempt to reduce the concentration of TCE in SWMU 91 soil from an average of 84 mg/kg to an average of less than 5.6 mg/kg according to the ROD for this site. If the approved cleanup objective was not achieved, the previous plan required an additional twelve months of operation.

Prior to start-up of the full scale Lasagna™ process, baseline soil samples were collected in November/December 1999. These samples showed a reduced level of TCE in the soil. The average TCE soil concentration was determined to be 4.4 mg/kg with a high concentration of only 29.6 mg/kg. These results were assumed by the technical team to be biased low and Phase IIb commenced.

After approximately twenty months of Phase IIb operations of the Lasagna™ treatment system, subsurface soil samples were collected to compare against baseline. Progress soil sampling event A samples were collected in August 2000. These samples resulted in an average TCE soil concentration of 43.3 mg/kg with a high concentration of 552 mg/kg.

Progress sampling event B was undertaken in August 2001. This sampling event showed that Lasagna™ had reduced the soil concentrations to an average less than 1.5 mg/kg with a high of only 27 mg/kg.

The system was shut down in December 2001. The verification sampling and analysis plan was reviewed and approved by the KDWM. Verification sampling was conducted from April 30 through May 8, 2002, and the results show that Lasagna™ did indeed reduce the TCE soil concentrations to a level well below the ROD mandated 5.6 mg/kg. The results of the verification sampling indicate the average concentration of TCE was 0.38 mg/kg with a high concentration of 4 mg/kg.

1.2.2 Contaminants Dealt With

The only contaminant targeted for remediation using the Lasagna™ treatment system at SWMU 91 was TCE; however, the analytical results indicated that TCE impurities and breakdown products were analyzed for and generally found to be non-detectable or at extremely low levels throughout the sampling events.

2. CHRONOLOGY OF EVENTS

The installation of the full-scale Lasagna™ treatment system began in August and was completed in December 1999. Operations began on December 31, 1999. CDM provided operations and maintenance (O&M) support during normal operations by performing activities such as routine maintenance and weekly equipment and system checks of key process variables, to record operational data, and ensure effective and safe system operation. The weekly site inspections included verifying that the water recycling system was functioning correctly and the sump had sufficient water to keep the anodes "wetted." CDM maintained an automatic telephone dialer, when predetermined system conditions were identified, the automatic dialer called designated on-call personnel who responded.

Baseline soil sampling started on November 17 and was completed on December 3, 1999. Approximately nine months after system startup, progress soil sampling event A was conducted in August 2000. Progress soil sampling event B was conducted in August 2001. For the first several months of operations, the system was operated continuously. When the soil temperature reached 90°C, the system was operated in pulse mode to prevent overheating. Pulse operations allowed the system to operate for one to four days before the temperature limit was reached. The system was then shut down and allowed to cool for several days until the system was restarted.

The treatment system was taken off line for approximately eight weeks during August 2001 because of problems with the rectifier. The rectifier converts incoming AC current into DC current. The rectifier supplies the DC current to the treatment zone. The rectifier manufacturer technical representative was brought on site to repair the rectifier. Additional operational problems encountered since system startup included:

- several unscheduled power outages;
- system shutdown because of a blown fuse in the 480-volt circuit for the power supply;
- make-up water tank rising above ground because of heavy rains;
- sediment in the east line;
- installation of a vent hose to prevent false high sump readings because of air in the sump; and
- occurrences of spikes in the sump level sensor because of electrical interference from the treatment system.

Corrective actions, as appropriate, were taken to address each of the above operational problems and additional details are provided in Sect. 4.5.

The Lasagna™ technology has been tested as a multi-phase project. Phase I was an experimental installation and field test of the technology in a 150-ft^2 area. Phase IIa was a yearlong, commercial-scale demonstration test on a 600-ft^2 site. Phase IIb, which began operation in January 2000, was a full-scale application of a Lasagna™ treatment system designed to perform soil remediation at SWMU 91. In accordance with the ROD, the Lasagna™ system was operated for two years in an attempt to reduce the concentration of TCE in SWMU 91 soil from an average of 84 mg/kg to an average of less than 5.6 mg/kg. If after two years the regulatory approved cleanup level of 5.6 mg/kg had not been achieved, the system was to operate an additional twelve months to attempt to achieve the cleanup level.

After approximately twenty months of Phase IIb operations at the Lasagna™ treatment system, subsurface soil samples were collected to compare against baseline and progress soil sampling event A samples, which were collected in November/ December 1999 and August 2000, respectively.

The system was shut down in December 2001. Verification sampling and analysis was conducted in April/May 2002 and showed that the process cleanup target had been met. The average soil concentration was found to be 0.38 mg/kg, well below the target of 5.6 mg/kg. Demobilization of the site is planned to be completed by September 2002.

3. PERFORMANCE STANDARDS AND CONSTRUCTION QUALITY CONTROL

3.1 STANDARDS

Performance standards for remediation of TCE from subsurface soils at SWMU 91 were specified in the ROD. Based on groundwater modeling, reduction of average TCE concentrations in soils to 5.6 mg/kg will result in a groundwater concentration that is less than 5 ug/L at the PGDP security fence. Achieving this low concentration of TCE in groundwater reduces human health risk for future potential groundwater users at the DOE property boundary to within acceptable limits.

3.2 RESULTS OF FIELD SAMPLING

Preliminary site characterization sampling was performed in March 1996 as part of Phase IIa. The results of this sampling showed TCE concentrations in the soil ranged from non-detect to greater than 1500 mg/kg. This sampling effort was part of a project to better identify the extent of the contamination and to provide data of sufficient quality to be used for a fate and transport model as part of a risk assessment. More information is presented in the report *Preliminary Site Characterization/ Baseline Risk Assessment/Lasagna™ Technology Demonstration at Solid Waste Management Unit 91 of the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (LMES 1996). The document referenced above outlines the premise of the need to remediate this area and the boundary limits for cleanup. The risk-based cleanup target of 5.6 mg/kg is also proposed and defended as well.

Prior to beginning the Lasagna™ process, Phase IIb full-scale operation, a baseline soil-sampling event was performed in November 1999. The results of the baseline sampling showed unexpectedly low TCE soil concentrations. The range was from nondetect to about 29.6 mg/kg, much lower than any previous sampling data (nondetect to 1500 mg/kg, LMES 1996). Some of the lower results may have been due to the operation of the Lasagna™ demonstration sites that were located within the boundary of the full scale Lasagna™. Results from the baseline-sampling event are located in Appendix B.

During the operation of the full-scale Lasagna™ system, two progress-sampling events were undertaken to determine the ongoing effectiveness of the Lasagna™ process. The first such event (event A) showed the TCE at the 20 ft depth range, where the highest previous measured TCE concentrations (Baseline Sampling and KY/EM-128 reports) were located, had been greatly reduced as can be seen in the data located in Appendix B; however, a great deal of TCE had migrated vertically upwards to a depth of about 5 to 15 ft bgs above the area where DNAPL had previously been suspected based on high soil concentrations (LMES 1996). This was most likely due to the elevated temperatures encountered during the initial operational time when the soil temperatures at the center of the treatment area reached 96° C. The high levels (up to 500 mg/kg) encountered during this sampling event were more in line with the higher amounts of TCE seen by LMES sampling events.

Elevated soil temperature is a normal condition of passing current through the soil and is called resistive heating. This soil heating is beneficial in mobilizing volatile materials. Most of the TCE should be transported horizontally towards the cathode and through the treatment materials by electro-osmosis, or mobilized upward by volatilization where the vapors should condense near the surface or react with emplaced treatment zones or treatment zone materials spread three inches over the top of the site. Progress sampling event A was conducted in August 2000. Data from sampling event A are located in Appendix C.

Progress sampling event B showed much improvement in the average concentrations, especially in the upper soil regions. The average TCE concentration of the sampled locations was 3.5 mg/kg, below the target average of 5.6 mg/kg. For the second event, samples were collected only in areas of known elevated TCE concentrations or above those known areas. Statistically, TCE results for this sampling event should be biased high since the samples near the perimeter, where TCE concentrations have been historically lower or were non-detect for sampling event A, were not sampled. Sampling event B was used to try and determine the "worst-case" concentrations of TCE remaining in the soil, determine the effectiveness of the treatment system, and to determine the vertical mobilization of the TCE. If areas that were not sampled are added into the average as non-detects, the site average is less than 1.5 mg/kg. There were only 4 out of 28 sampled locations that were above the target average (5.6 mg/kg) with the highest being 27 mg/kg. Progress sampling event B was conducted in August 2001. Data from sampling event B are located in Appendix D.

Verification sampling, conducted in April-May 2002, confirms Lasagna™ has remediated the site to TCE soil concentrations below the target concentration of 5.6 mg/kg. A statistically based sampling scheme was employed. The TCE results averaged 0.38 mg/kg with a high concentration of 4.5 mg/kg; 34 of the 72 soil samples were below method detection limits.

To satisfy the data quality objectives (DQOs) for this project, soil samples were also collected from outside the treatment area as well as above and below the treatment area. No significant concentrations were seen outside the treatment area. Selected soil samples were submitted for gas chromatograph-mass spectrometry (GC-MS) scan analysis (SW-846 method 8260A) to determine the presence and magnitude of breakdown products. No vinyl chloride and very little cis-1,2-dichloroethylene (one sample had 0.010 mg/kg and one sample had 0.002 mg/kg) were detected. Data from the final verification sampling event are provided in Appendix E.

A more detailed summary of results from the baseline sampling event, progress sampling events A and B, and the final verification sampling event is included in Appendix F.

Table 3.1 presents the average and highest TCE concentrations detected from each sampling event conducted at SWMU 91.

Table 3.1. Summary of Soil Sampling Events at SWMU-91

Sampling Event	Average TCE Concentration (mg/kg)	Highest TCE Concentration (mg/kg)
Site Investigations (LMES, 1996)	84	1500
Baseline (CDM, 1999)	4.4	29.6
Progress Event A (CDM, 2000)	43	552
Progress Event B (CDM, 2001)	1.5	27
Verification Sampling (CDM, 2002)	0.38	4.5

3.3 LOCATIONS AND FREQUENCY OF TESTS

Based on EPA reference documents (EPA QA/G-5S), the number of sample locations for the verification sampling event was calculated to be 69 or greater. Using data from the last progress sampling report (event B), the mean and variance of the TCE values were calculated and used in equation 1 to derive the required number of samples for verification sampling.

$$\boxed{n = \frac{\left(z_{1-a} + z_{1-b}\right)^2 s^2}{d^2} + 0.5 z_{1-a}{}^2} \quad \textbf{Equation 1}$$

A false negative and false positive error rate (a, ß) of 5 percent (95% confidence interval) was chosen for this sampling event (z = .645) as a conservative assumption, since this was not outlined in the DQOs for this project. The population variance (s^2) was calculated to be 25 with a mean of 1.5 mg/kg using data from progress sampling event B with all nondetects set equal to the detection limit of 0.001 mg/kg. The locations not sampled in event B were also assumed to be at/or below the detection limit based on past sampling and professional judgment and set equal to the detection limit. Since the extremely conservative mean (using only sampled, detected results) calculated from the progress-sampling event B was about 3.6 mg/kg TCE, a target tolerance (d) of 2 mg/kg TCE (5.6-3.6) was selected. Inserting these values into equation 1 results in 69 samples required to statistically determine if the premise, the soil average is less than 5.6 mg/kg, is true with a confidence interval of 95%.

Since at least 69 samples were required, a total of 72 sample locations were selected based on the geometry of the site. The three dimensional aspect of the soil volume remediated dictates a sampling grid with dimensions roughly proportional to the overall dimensions. The remediated volume measured 72 ft wide by 90 ft in length and 45 ft deep. A sample grid of 4 points (width) by 6 points (length) by 3 points (depth) was chosen. The dimensions for each grid node volume are equal to 18 ft by 15 ft by 15 ft. Using the center of each grid section as the sampling location results in samples taken at depths of 8 ft, 23 ft, and 38 ft below the surface grid. The depths chosen were appropriate due to the fact that historical data showed the highest concentrations between 20 and 25 ft below the surface while the Progress Report A showed the highest concentrations were found at the 6-ft depth. The 38-ft depth samples were to determine significant downward migration. The surface grid locations were across the length at 8 ft, 23 ft, 38 ft, 53 ft, 68 ft, and 83 ft and across the width at 9 ft, 27 ft, 45 ft and 63 ft. The southwest corner, at the ground surface, was taken as the origin. Figure 3.1 shows grid sections and centerlines. Soil samples were collected from as close to intersection of centerlines as possible without sampling in treatment zones.

To address the DQOs for this process, samples were collected at four locations (North, South, East, and West) outside the remediation area boundaries to confirm that the contamination has not migrated beyond the remediation area. A total of three samples were collected from each location at depths of 8 ft, 23 ft, and 38 ft. The same locations used during the baseline-sampling event were used during this event. Two samples were also collected near the surface (4 ft deep) above the center region of the site, at location BOR15 and BOR16, and two more samples were collected from below the site (48 ft deep) at locations BOR16 and BOR20. These samples were used to confirm no vertical migration.

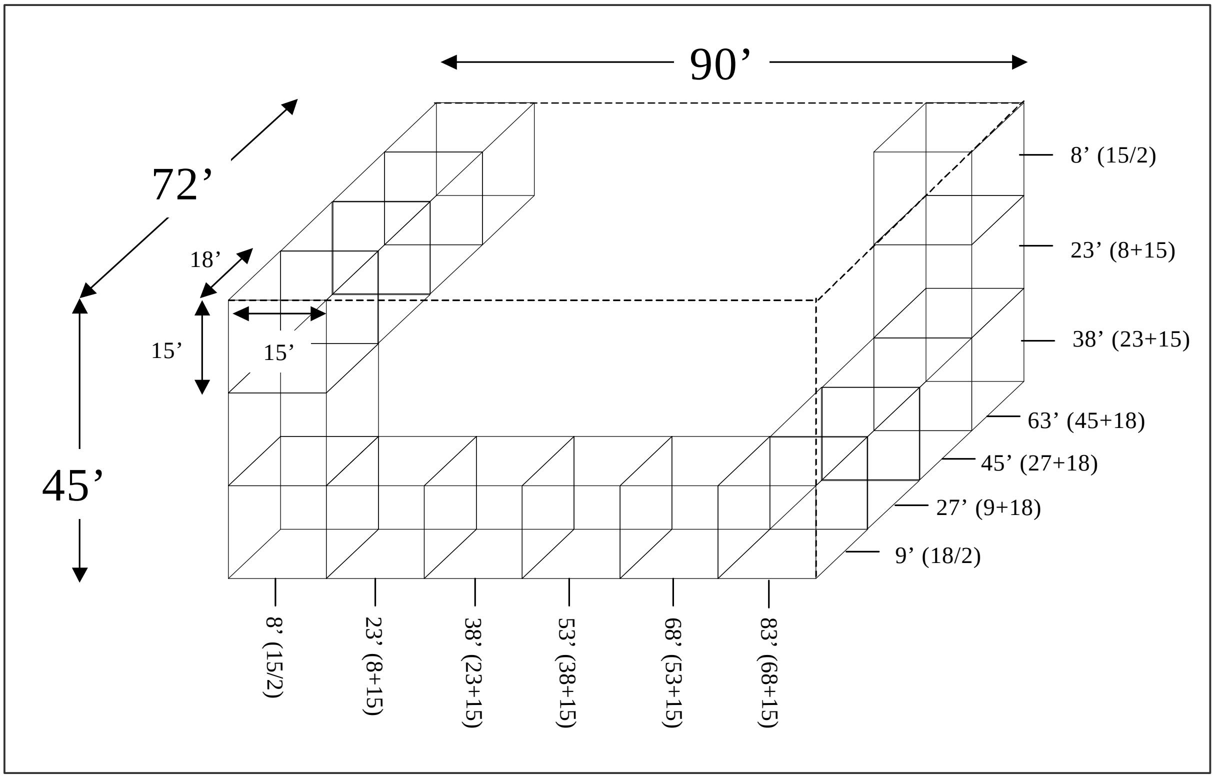


Figure 3.1. Sample Grid Size and Centerlines

3.4 BASIS FOR DETERMINATION THAT STANDARDS WERE MET

The ROD for this site requires Lasagna™ to remediate the site to a soil based TCE concentration of 5.6 mg/kg. Using the results of the verification-sampling event, the average (simple mean) soil TCE concentration was determined to be 0.38 mg/kg. There were 72 samples taken in a uniform three-dimensional array throughout the site. These 72 samples were used to calculate the average soil concentration. Approximately half of the samples (35) were non-detects, at 0.001 mg/kg detection level. Using the detection level as the result for the non-detect samples yields a simple mean of 0.38 mg/kg with a standard deviation of 0.91. The 95% upper confidence limit of the mean for this data set is calculated to be 2.8 mg/kg (Gilbert, 1987, equation 13.13). This means there is a 95% chance the average concentration of TCE for the whole site volume is less than 2.8 mg/kg.

Selected soil samples were split and submitted to the PGDP site laboratory for GC-MS analysis using EPA Method 8260A. A total of five samples from within the site boundary, two samples around the perimeter and one sample from below the treated area were analyzed for TCE and breakdown products. The primary breakdown products are cis-1,2-dichloroethylene and vinyl chloride. No vinyl chloride was detected in any samples and cis-dichloroethylene was found at very low levels in two samples (0.010 and 0.002 mg/kg).

4. CONSTRUCTION ACTIVITIES

4.1 NARRATIVE DESCRIPTION

Lasagna™ IIb construction was completed without major delays and required minimal design modifications. Some of the delays and modifications resulted from unexpected encounters with an extremely hard geologic formation at about 25 ft and 35 ft. This formation was not encountered during the first two phases of the Lasagna™ construction. This condition was concentrated at the south end of the remediation site, which was not included in Phases I and IIa. Other delays and modifications were caused by difficulties encountered during the startup of the construction work. These included the reconfiguration of the clamp and mounting plate for the hammer, failure of the hammer hydraulic pump starter, and several other minor issues. These issues are discussed in Sect. 4.5.

4.2 TABULAR SUMMARIES

4.2.1 Quantities Excavated

The SWMU 91 cylinder drop test area included the use of a concrete pit lined with plastic and filled with TCE and dry ice. During Phase I and Phase IIa activities, the boundaries of this pit were determined. Excavation, demolition, removal, and disposal of pit materials (approximately 600 yd^3) were conducted in accordance with the Remedial Design Report (DOE 1999). Pit materials were removed successful, and an old cylinder cradle was found in the bottom of the pit during the excavation process. The cylinder cradle was scanned by Radiological Technicians, provided by a BJC subcontractor, and low levels of fixed radiological contamination were discovered. The contaminated cylinder cradle was transferred to BJC Waste Operations.

The BJC Subcontract Technical Representative (STR) was onsite and observed the pit excavation and removal and performed regular inspections of the work.

4.2.2 Cleanup Levels Achieved

A summary table of results from the baseline sampling event, the progress sampling events A and B, and a table of the final verification sampling event are included in Appendix F. Final verification sampling data indicate that cleanup levels following Phase IIb were achieved. TCE concentrations in soil samples averaged 0.38 mg/kg, which is below the performance standard of <5.6 mg/kg specified in the ROD. The 95% upper confidence limit of the mean for the verification sample set was calculated to be 2.8 mg/kg. *This means that there is a 95% chance the true mean concentration for the whole site is less than 2.8 mg/kg*.

4.2.3 Material and Equipment Used

Installation of electrodes was completed by driving a hollow mandrel into the ground using a vibrating pile driver. The mandrel was approximately 45-ft long by 10-in wide by 2-in thick. The pile driver and mandrel were suspended within a 65-ft mast attached to a large trackhoe.

Installation of treatment zones, also were completed by driving a hollow mandrel into the ground using a vibrating pile driver. The treatment zones contain a slurry mixture of cast iron particles and Kaolin clay. The 22-in wide mandrel was fitted with a hopper to feed the treatment mixture into the hollow mandrel. The mixture was 60% by weight iron particles in a 40% by weight Kaolin slurry. The treatment zone slurry was prepared offsite and transported to the

Lasagna™ site in a concrete mixer truck. The slurry was transferred from the concrete mixer truck into a concrete bucket that was raised with a forklift to the height of the hopper on the mandrel and emptied. The mandrel was then withdrawn from the ground leaving the slurry mixture in the ground as a treatment zone. The mast/mandrel assembly was moved and a new insertion was initiated beside the previous one.

After the electrode and treatment zones were in place, a water handling system was installed. The water handling system consists of polyvinyl chloride (PVC) piping, a collection sump, and a 400 gallon (gal) storage tank.

4.3 NAMES AND ROLES OF MAJOR DESIGN AND REMEDIAL ACTION CONTRACTORS

Work performed during construction was performed under BJC subcontract No. 23900-SC-RM058 for the DOE under contract DE-AC05-98OR22700. CDM served as the construction contractor for this work. Seven construction subcontractors were retained by CDM to perform the Lasagna™ Phase IIb construction. Table 4.1 is a list of subcontractors and their associated roles and responsibilities.

Table 4.1 Subcontractor Roles and Responsibilities

Subcontractors	Roles/Responsibilities
Alliance Environmental, Inc.	Monitoring Well Abandonment
API Contractors	Mobilization and Site Preparation Drop Test Pit Removal Remedial Action Construction Assistance Fence Construction
Dummer Surveying & Engineering Services Inc.	Site Survey Support
GEO Consultants, LLC	Geotechnical Consultants
Meeks Electrical Inc.	Electric Utility Construction Construction Electrical Activities
Enviro-Chem Systems, a Monsanto Company	Lasagna™ Technical Consultant
Nilex Corporation	Lasagna™ Electrode and Treatment Zone Installation

Construction oversight was supplied by the BJC STR. The STR requested support of specialized BJC resources (e.g., Hydrogeologist, and Electrical Engineer, as appropriate).

4.4 PARTICIPATION BY OTHER FEDERAL AGENCIES

Copies of the baseline, progress sampling event A and progress sampling event B reports were submitted for information to the EPA and KDWM. The verification SAP and this report require review and approval by the EPA and KDWM.

4.5 LESSONS LEARNED FROM CONSTRUCTION PROBLEMS, OPTIONS CONSIDERED, AND SOLUTIONS SELECTED

4.5.1 General Startup

In addition to the difficulties detailed below, some difficulties were encountered during the startup of the construction work. These included the reconfiguration of the clamp and mounting plate for the hammer, failure of the hammer hydraulic pump starter, and several other minor issues. These modifications and startup difficulties resulted in a schedule delay for completing construction. Construction was completed on December 22, 1999, versus the original schedule date of October 15, 1999 as outlined in the *Remedial Design Report—90%, Remedial Action Work Plan, and Construction Quality Control Plan for Remedial Action at Solid Waste Management Unit 91 Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1999).

4.5.2 Monitoring Well Abandonment

Monitoring Wells (MW) MW-158, MW-159, and MW-160 were abandoned at the start of this project. Some difficulties were encountered while abandoning two of the three monitoring wells. Well abandonment forms, displaying the location of each abandoned well, were filed with the Commonwealth of Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water Groundwater Branch, by Alliance Environmental and are contained in Appendix G.

During the abandonment of MW-159, the well casing was cut while conducting the required overdrilling process. Field observations indicated that the well was not completely vertical but rather was installed at a slight angle. Several attempts were made to remove all 70 feet of the well casing; however, only 35 feet was actually removed and the well was grouted in place.

The same situation was encountered during the abandonment of MW-160. The drilling subcontractor removed 92 feet of the total 110 feet of casing. A BJC Hydrogeologist recommended that further overdrilling not be conducted and the well was grouted in place.

4.5.3 Electrical Construction

Modifications were made as described in the following sections. Although not specified in the original design, an insulator was installed on the air disconnect switch. The BJC STR and an Electrical Engineer requested the insulator.

The original design did not require the installation of railings around the transformer platform. This discrepancy was noted by the BJC STR. Railings were installed on all sides of the transformer platform.

4.5.4 Treatment Zone and Electrodes

4.5.4.1 Treatment Zone Installation

During the first two treatment zone installation attempts, the treatment material would not drop out of the mandrel as the mandrel was vibrated out of the ground. The treatment zone material slurry of Kaolin clay and cast iron aggregate was closely examined. It was determined that too many large particles existed in the iron aggregate. This caused the iron aggregate particles to adhere to one another in the slurry thereby impeding flow. After discussions with the iron aggregate supplier, it was determined that the material manufacturing process was slightly different than the methods used to generate iron aggregate for previous Lasagna™ phases. The manufacturer supplied new material, with a smaller grain size, and the problem was solved.

While driving the hollow mandrel used for treatment zone installation into the ground, a very hard geologic formation was encountered at a depth of approximately 35 feet at the southern portion of the 72-ft by 92-ft treatment area. This required frequent repairs of the mandrel. Additionally, in some cases, it was not possible to penetrate the formation to the desired depth of 45 feet with the mandrel designed for this work. In these cases, the treatment zones were installed at the maximum obtainable depth. The depth of refusal (refusal is defined as no progress after approximately one minute of driving) was determined in the field by the BJC Hydrogeologist and a representative from the Nilex Corporation.

Surface runoff from adjacent cylinder yard C-745-B is carried by several underground culverts in and around the treatment area. One of these culverts is located where treatment zone T-15 was to be placed. The culvert could not be removed so the treatment zone T-15 was eliminated and treatment zones T-14 and T-16 were lengthened (North to South) to compensate. This decision was made in consultation with the BJC STR, CDM Project Manager, and Lasagna™ Technical Consultant.

The location of each treatment zone is displayed in the site layout as-built drawing contained in Appendix H. Figures 4.1 through 4.19 display the final configuration of each treatment zone and are included in Appendix A.

4.5.4.2 Electrode Installations

During installation of the electrodes, the same geologic formation previously noted during treatment zone installation was encountered. In a similar fashion, the mandrel was driven to refusal, the electrode assembly was installed, and electrode length was shortened.

During the installation of the first few electrodes, the construction team encountered difficulty removing the electrodes from the mandrel as it was removed from the soil. It was determined that the amount of iron aggregate added inside the geotextile fabric had to be reduced to prevent binding inside of the mandrel; therefore, the amount of iron aggregate used in each assembly was reduced. To compensate for the reduced iron aggregate, an additional 4-in wide by 30-ft long by ¼-in thick steel plate was welded to the steel electrode. Additionally, a layer of drain board (a material which allows water to flow over the entire electrode) was added. The additional iron was needed to insure the electrode would have enough iron to last up to three years of operation. This decision was made in consultation with the BJC STR, CDM Project Manager, and Lasagna™ Technical Consultant.

The location of each electrode is displayed in the site layout as-built drawing contained in Appendix H. Figures 4.20 and 4.21 contained in Appendix A display the final configuration of west anode (A-1) and east anode (A-2), respectively. Figure 4.22 contained in Appendix A displays the final configuration of the cathode (C-1).

4.5.5 Water Handling System

After the site survey was completed by Dummer Surveying & Engineering Services, Inc., it was decided that the sump should be moved from the southwest end of the site to the northwest end. It was determined that the natural site grade decreases from south to north. The design of the water handling system called for all recycle lines to be approximately the same elevation and, if the sump was to remain on the south end, the excavation for the sump and recycle lines would have needed to be approximately 5 ft. Also, the PVC culvert in the ditch to the south of the site would have interfered with the original recycle lines and the sump placement; therefore, it was decided to move the sump to the northwest end. The sump depth was approximately 4 ft and the recycle lines were placed at a depth of approximately 2–3 ft. This location also afforded easier access to refill the makeup water tank. Additionally, 3/8-in braided metal lifting cables, anchored to 4,000 lb. concrete barriers, were installed over the water makeup tank to prevent it from rising out of the ground (due to buoyancy) during heavy rainfall events. These decisions were made in consultation with the BJC STR, CDM Project Manager, and Lasagna™ Technical Consultant.

Figure 4.23 contained in Appendix A displays the plan view location of the water recycle system on the site. Figure 4.24 contained in Appendix A displays the side views for the water recycle system. Figure 4.25 contained in Appendix A displays a typical end view configuration of the water recycle system used at each electrode.

4.5.6 Causes of Delays

As previously mentioned, some difficulties were encountered during the startup of the construction work. These included the reconfiguration of the clamp and mounting plate for the hammer, failure of the hammer hydraulic pump starter, and several other minor issues. These modifications and startup difficulties resulted in a schedule delay for completing construction. Construction was completed on December 22, 1999, versus the original schedule date of October 15, 1999. Process shutdowns for reasons other than temperature limit exceedances are shown in Table 4.2

Table 4.2 Lasagna™ Process Shutdown Summary

Shutdown Date	Restart Date	Reason
06/01/2000	07/08/2000	West side shut down to let east temperature align with the west temperature
10/09/2000	10/12/2000	First progress sampling event
10/18/2000	12/13/2000	Extended cooling period
07/19/2001	11/22/2001	Second sampling event and rectifier repairs

4.5.7 Innovative Solutions

Replacing the granular iron filings and coke with ¼ steel ribbon and drain board eliminated the problems associated with electrode installations. The steel was required to supplement the iron loading in the electrode and allow for sacrificial corrosion while the drain board allowed for water management, especially in the anodes.

4.5.8 Time- or Cost-Saving Measures

To maximize the efficiency of the electrical input, the system was operated in pulse mode once the maximum operating temperature was reached. The rectifier was most efficient when the output voltage was nominally equal to the input voltage. After February 3, 2000, the primary voltage (AC) side was lowered from 440 volts to 240 volts as the output voltage was dropped from 420 to 220 volts (DC). This was a scheduled event when the soil temperatures approached 50 ºC. Once the soil reached 80 ºC, the rectifier was operated two or three days per week at the 220-volt level rather than lowering the output voltage to 70 volts. Operating the rectifier at such a low voltage would have resulted in very high AC ripple from the rectifier output. The AC component results in temperature rise only with no electro-osmosis. To minimize the AC component and maximize the DC component, the rectifier was operated at conditions that matched the input and output voltages.

Another cost savings measure was to monitor the system remotely using a data acquisition system and a computer with dial-in capabilities. The system also had dial-out and shutdown capabilities for fault conditions.

5. INSPECTIONS, DEFICIENCIES, AND RESOLUTIONS BY ACTIVITY

5.1 WELL ABANDONMENT

Monitoring wells MW-158, MW-159, and MW-160 were abandoned using the overdrill method as stated in procedure PTSA-4307, Monitoring Well Abandonment, and outlined in the Remedial Design Report (DOE 1999). Difficulties encountered during this work are described in Sect. 4.5.2.

Well abandonment work was inspected and approved by the BJC STR and Hydrogeologist. Well abandonment forms, displaying the location of these abandoned wells, were filed with the Commonwealth of Kentucky Natural Resources and Environmental Protection Cabinet, Division of Water – Groundwater Branch, by Alliance Environmental and are contained in Appendix G.

5.2 DROP TEST PIT REMOVAL

The SWMU 91 cylinder drop test area included the use of a concrete pit with a plastic liner that is a probable source of TCE contamination. During Phase I and Phase IIa activities, the boundaries of this pit were determined. Excavation, demolition, removal, and disposal of pit materials were conducted in accordance with the Remedial Design Report (DOE 1999). Although the pit was removed successfully, an old cylinder cradle was found in the bottom of the pit during the excavation process. The cylinder cradle was scanned by Radiological Technicians, provided by a BJC subcontractor, and low levels of fixed radiological contamination was discovered. The contaminated cylinder cradle was removed and transferred to BJC Waste Operations.

The BJC STR was onsite and observed the pit excavation and removal and performed regular inspections of the work performed.

5.3 ELECTRICAL CONSTRUCTION

New overhead electrical utility lines, power transformers, electrical switching center, and associated equipment were installed to provide power to the Lasagna™ site. Electrical work was completed in accordance with the Remedial Design Report (DOE 1999) with the exception of the modifications discussed in Sect. 4.5.3.

Product data sheets, shop drawings, and manufacturer specifications for equipment and material used during electrical construction were submitted to BJC and were approved.

The BJC STR and Electrical Engineer conducted a prefinal inspection of the overhead electrical utility lines. The following items were identified and corrected:

- Each new pole required permanent labeling.
- Joints made under the transformer platform required trimming.
- One ground wire inside the main disconnect switch required additional tightening.

- One grounding rod did not pass required ground rod resistance testing; therefore, an additional rod was installed. The two ground rods were connected and retested as one unit with satisfactory results.

5.4 TREATMENT ZONES AND ELECTRODE INSTALLATIONS

With the exception of the modifications listed in Section 4.5.4, treatment zones and electrodes were installed in accordance with the Remedial Design Report (DOE 1999).

Installation of electrodes was completed by driving a hollow mandrel into the ground using a vibrating pile driver. The mandrel was approximately 45-ft long by 10-in wide by 2-in thick. The pile driver and mandrel were suspended within a 65-ft mast attached to a large trackhoe. Electrode zones were constructed of granular carbon, ¼-in carbon steel plate, wickdrain material, geotextile material, ¼-in aircraft cable, and number 10 insulated copper wire. After the 10-in wide hollow mandrel was driven into the soil, an electrode assembly containing a 9-in wide by 40-ft long carbon steel plate, a 4-in wide by 45-ft long wickdrain, and carbon wrapped inside a geotextile material was lowered into the hollow mandrel. The hollow mandrel was withdrawn from the soil leaving the electrode assembly in the ground. The mandrel was moved beside the previous drive location and the process repeated. Three electrode zones, each 72-ft long, were installed. Installation of all three-electrode zones required approximately 260 drives. Figure 1.3 contained in Appendix A displays the typical configuration for an electrode (this includes both anodes and cathodes). The location of each electrode is displayed in the site layout as-built drawing contained in Appendix H. Figures 4.20 and 4.21 contained in Appendix A display the final configuration of west anode (A-1) and east anode (A-2) respectively. Figure 4.22 contained in Appendix A displays the final configuration of the cathode (C-1).

Installation of treatment zones were completed by driving a hollow mandrel into the ground using a vibrating pile driver. The treatment zones contain a slurry mixture of cast iron particles and Kaolin clay. The 22-in wide mandrel was fitted with a hopper to feed the treatment mixture into the hollow mandrel. The mixture was 60% by weight iron particles in a 40% by weight Kaolin slurry. The treatment zone slurry was prepared offsite and transported to the Lasagna™ site in a concrete mixer truck. The slurry was transferred from the concrete mixer truck into a concrete bucket that was raised with a forklift to the height of the hopper on the mandrel and emptied. The mandrel was then withdrawn from the ground leaving the slurry mixture in the ground as a treatment zone. The mast/mandrel assembly was moved and a new insertion was initiated beside the previous one. The process was repeated until all treatment zones were completed. Twenty-seven treatment zones were installed requiring approximately 1,000 drives. The location of each treatment zone is displayed in the site layout as-built drawing contained in Appendix H. Figures 4.1 through 4.19 included in Appendix A display the final configuration of each treatment zone.

Pre-final inspections of the treatment zones and electrode installations were conducted and approved by the BJC STR and the Lasagna™ Technical Consultant.

5.5 WATER HANDLING SYSTEM

After the electrode and treatment zones were in place, a water handling system was installed. The water handling system consisted of PVC piping, a collection sump, and a 400-gal storage tank. The water handling system was installed in accordance with the Remedial Design Report (DOE 1999), with the exception of the modifications discussed in Section 4.55. Figure 4.23 contained in Appendix A displays the plan view location of the water recycle system on the site. Figure 4.24 contained in Appendix A displays the side views for the water recycle system.

Figure 4.25 contained in Appendix A displays a typical end view configuration of the water recycle system used at each electrode.

Pre-final inspections of the water handling system were conducted and approved by the BJC STR and the Lasagna™ Technical Consultant.

5.6 ELECTRICAL CONTROLS AND INSTRUMENTATION

The required temperature and voltage probes, water level sensors, remote control boxes, computer hardware and software, data conditioning box, telephone lines, auto-dialer, and modems were installed in accordance with the Remedial Design Report (DOE 1999). Only minor modifications were required.

Pre-final inspections of the electrical controls and instrumentation were conducted and approved by the Lasagna™ Technical Consultant.

6. CERTIFICATION THAT REMEDY IS OPERATIONAL AND FUNCTIONAL

6.1 STATEMENT OF WORK WAS PERFORMED WITHIN DESIRED SPECIFICATIONS

The Lasagna™ treatment system was demonstrated, installed, operated, and maintained in accordance with BJC contract requirements. Performance standards and DQOs specified were achieved.

6.2 AFFIRMATION THAT PERFORMANCE STANDARDS HAVE BEEN MET

The ROD for this SWMU states that Lasagna™ must clean the site to a soil based TCE concentration of 5.6 mg/kg or less. Based on the ROD language, it was assumed the concentration basis was for an average concentration for the entire contaminated volume. Using this premise, Lasagna has met the target for site cleanup. Following an approved verification sampling and analysis plan, the actual mean for the sample data was calculated to be 0.38 mg/kg. The 95% Upper Confidence Level of the mean was calculated to be 2.8 mg/kg. The DQOs regarding vertical or horizontal migration were met. All safety and operational DQOs were met.

6.3 BASIS FOR DETERMINATION

The verification sampling and analysis plan was reviewed and approved by The Commonwealth of Kentucky, EPA Region 4, DOE, and BJC prior to performing the sampling event. All procedures were followed and documented. All DQOs were met for this site.

7. OPERATIONS AND MAINTENANCE

7.1 HIGHLIGHTS OF O&M PLAN

7.1.1 Overview of Operational Strategy and System Controls

The objective of this remedial action was to reduce the concentration of TCE in SWMU 91 soil from an average of 84 mg/kg to an average of less than 5.6 mg/kg. The Lasagna™ system was operated for two years to reduce TCE concentrations at the site. If, after two years, the regulatory-approved cleanup level of 5.6 mg/kg had not been achieved, the system was to continue to be operated an additional year in an attempt to reach the cleanup levels. The system was designed to operate around-the-clock with minimal operational oversight and maintenance.

Access to the process trailer, the treatment area, and other system components was controlled with perimeter fencing and lockable access gates with controlled keys. Visitors to the site were required to contact the CDM Project Manager or BJC STR for authorization before entering the treatment area.

During normal operations, the system had the capability to operate with minimal operational support; however, weekly site visits were made by operations staff to inspect the system.

The system was operated in a manner that would expedite TCE reductions while operating within safe limits of voltage and temperature. There was a period when the west half of the system heated up faster than the east for some unknown reason. The west side was turned off while the east side was operated until the temperature of the east side matched the west. From that point on, the two sides trended together. A temperature limit of 90^{o}C was imposed initially. Later, as concerns of extreme volatilization arose, the temperature limit was reduced to 80 ^{o}C. When the soil temperature in the center of the unit reached the temperature limit, the system would be temporarily shut down and the soil was allowed to cool. Diffusion, as well as electro-osmotic flow is responsible for mobilizing the TCE towards the vertical treatment zones spaced 2.5 or 5 ft apart or the treatment zone materials placed on the surface of the unit. Operational data, including temperature and pore water travel plots, are included graphically in Appendix I. The erratic nature of the temperature plots in Figure I.1 show the on and off cycles of the system and the temperature control. Figure I.2 shows cumulative water travel for each segment over time. One can see where the west segment was turned off to allow the east segment to catch up. The treatment zone spacing of 5 feet translates to one pore volume being equal to 152 cm of pore water travel. A total of 1.5 pore volumes (7.5 ft) of water were moved through the soil.

7.1.2 Operator Checks

During weekly site visits, operations personnel conducted equipment inspections and system checks, manually recorded operational data, and ensured effective and safe system operation. During the weekly site inspections, operators ensured that the water recycling system was functioning properly and sufficient water was in the sump to keep the anodes "wetted." Computer data backups were also performed.

The manually recorded operational data included temperature and voltage readings from eight probes spaced evenly along the anodes. The probes measured the field voltages at 5-ft intervals along the entire depth of the anodes. The probes also measured soil temperature at depths of 10-ft, 25-ft, and 40-ft. These probes were wired to individual data monitoring stations mounted on the exterior of the perimeter fencing. The stations were environmentally sealed and had recessed terminals. Voltage and temperature measurements were read using hand-held multi-meters and digital thermometers. The treatment system had to be energized while these measurements were taken. An operator aid and data collection form was developed with step-by-step instructions for conducting voltage and temperature measurements. Health and safety issues related to this activity were covered in a task-specific Activity Hazard Analysis (AHA).

Weekly inspections of the water recycling system required that operational personnel enter the treatment area. During these inspections, the system had to be de-energized. Health and safety issues related to this activity were covered in a task-specific AHA.

7.1.3 Operating Procedures

Lasagna™ was operated in accordance with approved work instructions, equipment manuals, and sound engineering practices. Procedures, work instructions, and operator aids were developed, as necessary, during Lasagna™ installation, startup, and normal operations.

7.1.4 Operations Training

Personnel training activities regarding procedures and work instructions were completed and documented during the system startup period. New personnel were required to complete training pertaining to procedures and work instructions before performing work at Lasagna™. General training requirements regarding health and safety and PGDP requirements for onsite work were identified in the Lasagna™ Environment, Safety and Health Plan.

7.1.5 System Maintenance and Calibration

The Lasagna™ system consisted primarily of electrical and passive treatment components that required no routine preventative maintenance or calibration. Any required corrective maintenance of Lasagna™ system components was performed in accordance with equipment manufacturer's recommendations and sound engineering practices. Maintenance and calibration requirements were further defined during Lasagna™ installation, startup, and normal operations.

7.1.6 Configuration Management

Specific structures, systems, and components identified as being important to overall system integrity were controlled in accordance with PMCM-1000, Rev.2, *Paducah Configuration Management Program.*

7.1.7 Communication

Communications equipment utilized during Lasagna™ operations included:

- pagers,
- land line telephone system, and
- two-way radio communications (PGDP).

7.1.8 Waste Handling

During normal operations, minimal waste was generated. A modest amount of waste was generated during soil sampling events associated with the project. Waste generated during routine operations and sampling is awaiting final disposition at the PGDP landfill.

7.2 POTENTIAL PROBLEMS OR CONCERNS

7.2.1 System Alarms And Operating Conditions

Key operational parameters were monitored by a computer located onsite in the support trailer. The computer monitored the following data points:

- date and time,
- voltage and current levels in the west treatment segment,
- voltage and current levels in the east treatment segment,
- temperature in the east and west treatment segment,
- temperature at the center of the cathode, and
- the sump level.

The computer system acquired and stored these data at least twice daily. The data were accessed by the Project Manager and consulting engineer using modem-based software.

Several of the monitored data points listed above had defined system operational ranges. If any of these key operational parameters strayed from pre-set ranges, the auto-dialer paged the CDM Project Manager, or designee, and the computer system initiated a shutdown of the rectifier. The Project Manager, or designee, could then call into the system to find out what alarm condition(s) were active. If on-call personnel did not properly acknowledge the alarm, the auto-dialer will continue to dial the programmed numbers in the callout sequence until the alarm was properly acknowledged.

Table 7.1 lists alarm conditions normal, operating ranges for key parameters, and probable system condition(s) related to each alarm condition.

Table 7.1 Alarm Conditions, Operating Ranges, and System Condition

Alarm Condition	Parameter Operating Range	Probable System Condition(s)
1. Treatment area voltage out of range	10 – 500 volts DC	The rectifier may have failed. There may be problems with the AC power supply. The system will shut down.
2. Treatment area temperature out of range	10º – 80º C	Rectifier output power may be too high or too low or there may be problems with the AC power supply. The system will shut down.
3. Anode temperature out of range	10º – 80º C	Rectifier output power may be too high or too low or there may be problems with the AC power supply. The system will shut down.
4. High or low sump level	1-ft from bottom to 3-ft below grade	The water recycle system is not functioning properly. Distribution piping may be blocked. The system will shut down.

When paged by the system, the Project Manager or designee responded to the site to investigate. When the alarm condition(s) had been corrected, the system was manually reset and restarted. The BJC STR was notified of auto-dialer callouts.

7.2.2 Response And Notification Procedures

To troubleshoot and correct system problems, personnel followed appropriate procedures, work instructions, manufacturers' equipment manuals, and would seek any necessary outside technical assistance. Lasagna™ operators recorded events, actions taken, and other pertinent information in a project logbook. The BJC STR was notified and was responsible for reporting the information to the appropriate personnel and government agencies.

8. SUMMARY OF PROJECT COSTS

8.1 FINAL COSTS

The ROD for the full-scale implementation of the Lasagna™ system was approved by all regulatory agencies on August 10, 1998. Costs of all work associated with the post-ROD activities included remedial design, mobilization, construction, operations and maintenance, sampling and analysis, reporting, demobilization and management and integration. These actual costs are reported from the beginning of Fiscal Year (FY) 1999 through the end of FY 2002, and include overhead.

- 1999: Remedial Design, Remedial Action Work Plan, Mobilization and Construction start: $2,510,000.

- 2000: Construction complete, Post Construction Report, Operations and Maintenance Plan and begin Operations and Maintenance: $906,000. (This number includes $785,000 for Construction and $121,000 for Operations and Maintenance.)

- 2001: Continue Operations and Maintenance, Interim Sampling Report A: $263,000.

- 2002: Interim Sampling Report B, Complete Operations and Maintenance period, Verification Sampling and Analysis Plan, Remedial Action Report: $279,000.

8.2 COMPARISION OF FINAL COSTS TO ORIGINAL ESTIMATE

Table 8.1 shows comparison of the Budgeted Cost of Work Scheduled (BCWS) to the Actual Cost of Work Performed (ACWP) for the years FY 1999 through FY 2002.

Table 8.1 BCWS vs. ACWP for Lasagna™
(Costs in thousands; includes overhead)

Fiscal Year	BCWS	ACWP	Variance	Explanation
1999	$3,147	$2,510	($637)	Cost of 23900-SC-RM058, Construction and O&M Subcontract, less than baselined.
2000	$1,068	$906	($162)	Cost of 23900-SC-RM058, Construction and O&M Subcontract, less than baselined and system used less electricity than baselined.
2001	$314	$263	($51)	System used less electricity than baselined.
2002	$313	$279	($34)	System used less electricity than baselined.

8.3 NEED FOR AND COST OF MODIFICATIONS

There were four significant modifications to the scope of the Remedial Action:

In 1999, during Remedial Design, additional electrical requirements were identified to tie into the existing United States Enrichment Corporation electrical network. The cost of these electrical requirements was $118,000 plus overhead.

In 1999, during negotiation of the Lasagna™ Phase IIB Construction Operations and Maintenance Subcontract, it was determined that Subcontractor Environmental Liability insurance would be required due to the innovative technology being installed. The cost of maintaining 10 million dollars of Environmental Liability insurance for the period of the subcontract was $117,000 plus overhead.

In 2001, after review of the subcontract requirements against the Integrated Safety Management System, changes were made to incorporate additional requirements. The cost of implementing these requirements was $42,000 plus overhead.

In 2002, the results of the Interim Remedial Sampling Event B indicated that the Lasagna™ system was operating above expected parameters. The scope for the operation and maintenance of the Lasagna™ system for a third year, to be executed as an option, was removed from the subcontract. This resulted in a cost savings of $316,000 plus overhead.

8.4 SUMMARY OF REGULATORY AGENCY OVERSIGHT COSTS

There were no regulatory agency oversight costs associated with the Lasagna™ project.

9. REFERENCES

DOE 1998a. *Record of Decision for Remedial Action at Solid Waste Management Unit 91 of Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/06-1527&D2, United States Department of Energy Office of Environmental Management, July 1998.

DOE 1998b. *Rapid Commercialization Initiative Final Report for an Integrated in-situ Remediation Technology (Lasagna™)*, Monsanto Company, March 1998.

DOE 1999. *Remedial Design Report—90%, Remedial Action Work Plan, and Construction Quality Control Plan for Remedial Action at Solid Waste Management Unit 91 Waste Area Group 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/OR/07-1811&D1, United States Department of Energy Office of Environmental Management, April 1999.

LMES 1996. *Preliminary Site Characterization/Baseline Risk Assessment Lasagna™ Technology Demonstration at Solid Waste Management Unit 91 of The Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, KY/EM-128, Lockheed Martin Energy Systems, Inc., May 1996.

APPENDIX A

FIGURES

LEGEND:

Not to Scale

TRUE NORTH
PLANT NORTH
20°

U.S. DEPARTMENT OF ENERGY
DOE OAK RIDGE OPERATIONS
PADUCAH GASEOUS DIFFUSION PLANT

BECHTEL JACOBS COMPANY LLC
MANAGED FOR THE US DEPARTMENT OF ENERGY UNDER
US GOVERNMENT CONTRACT DE-AC-05-98OR22700
Oak Ridge, Tennessee • Paducah, Kentucky • Portsmouth, Ohio

CDM

Figure 1.1 SWMU91 Location Map

DATE 4-24-02

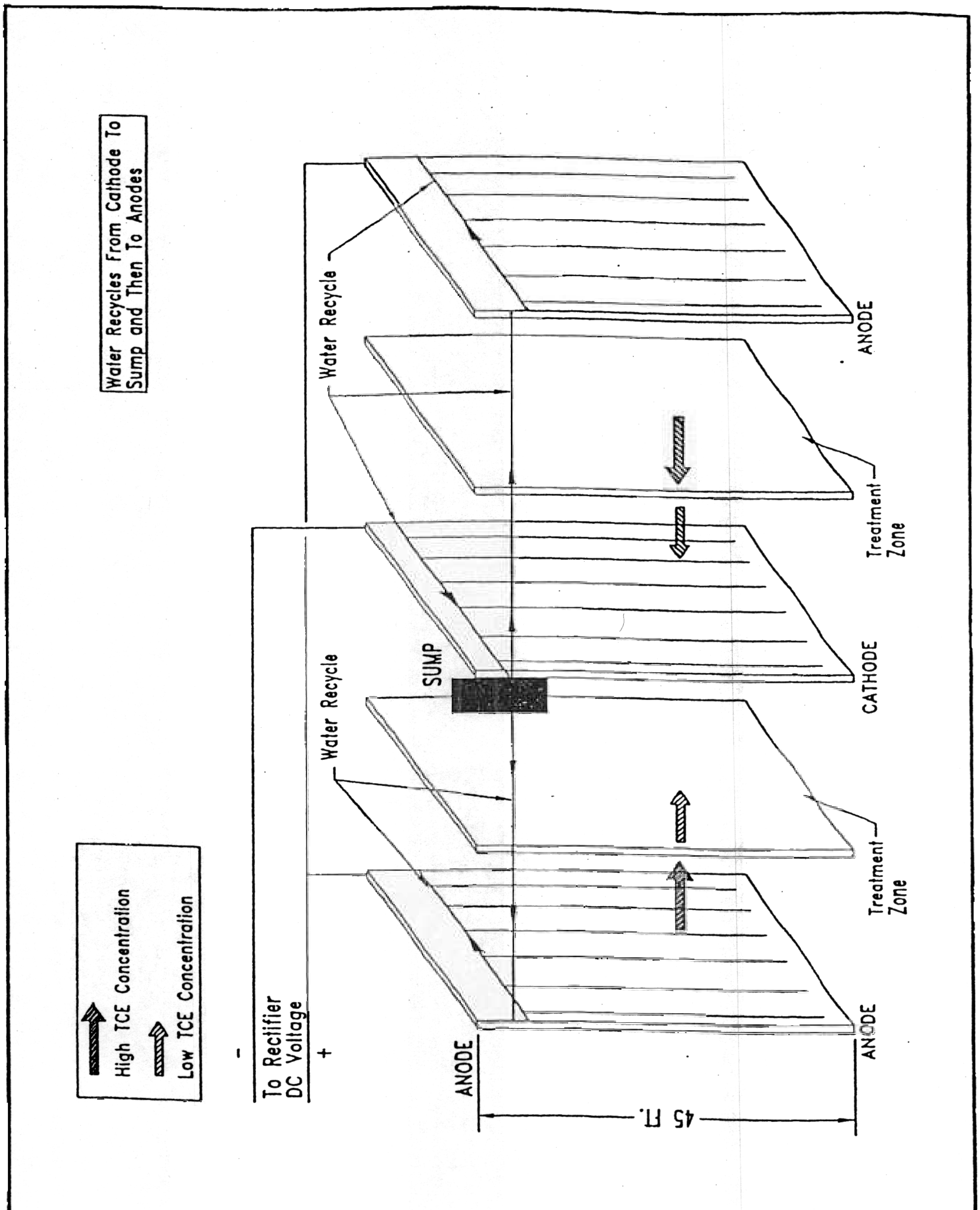


Figure .2 Conceptual Model of the Lasagna™ Treatment Process

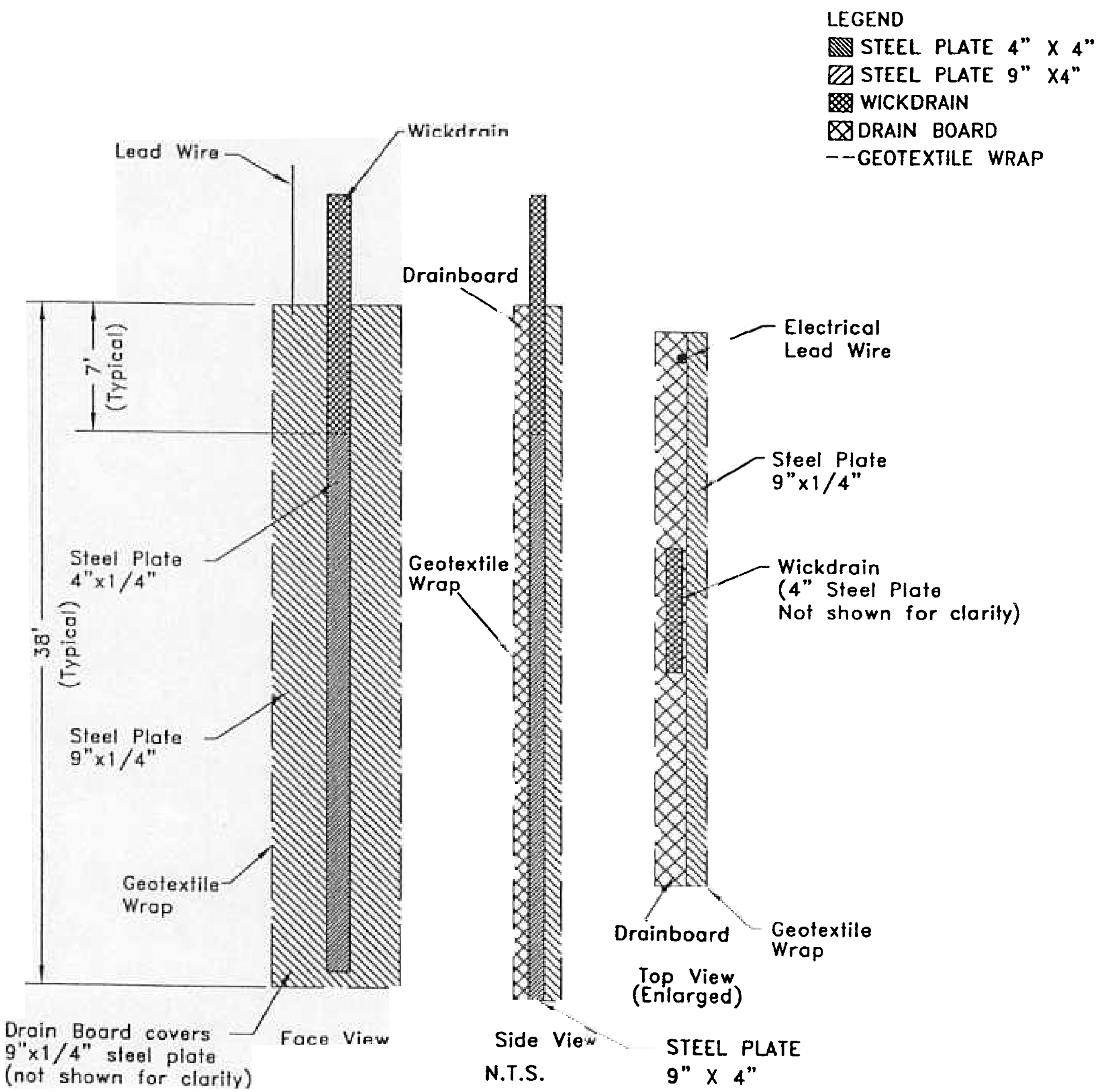


Figure 1.3 Typical Electrode Configuration

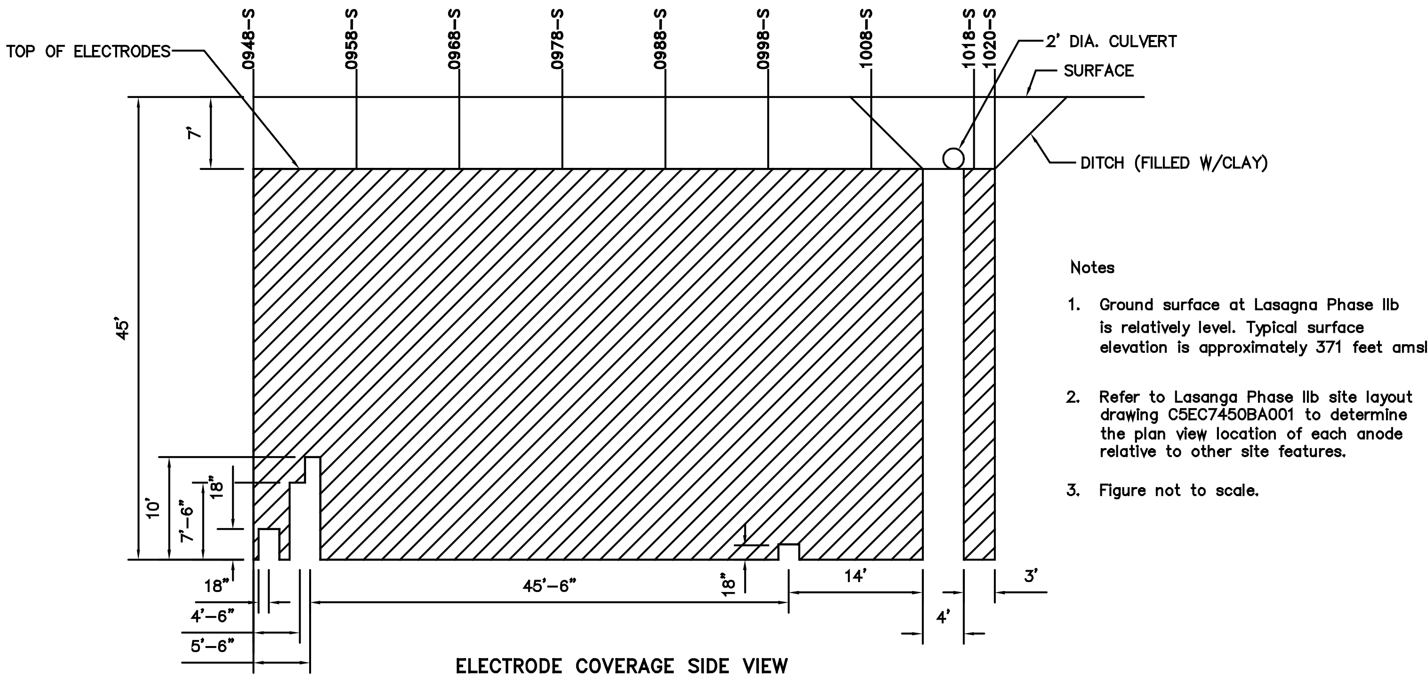


Figure 4.21 Final Configuration of East Anode (A-2)

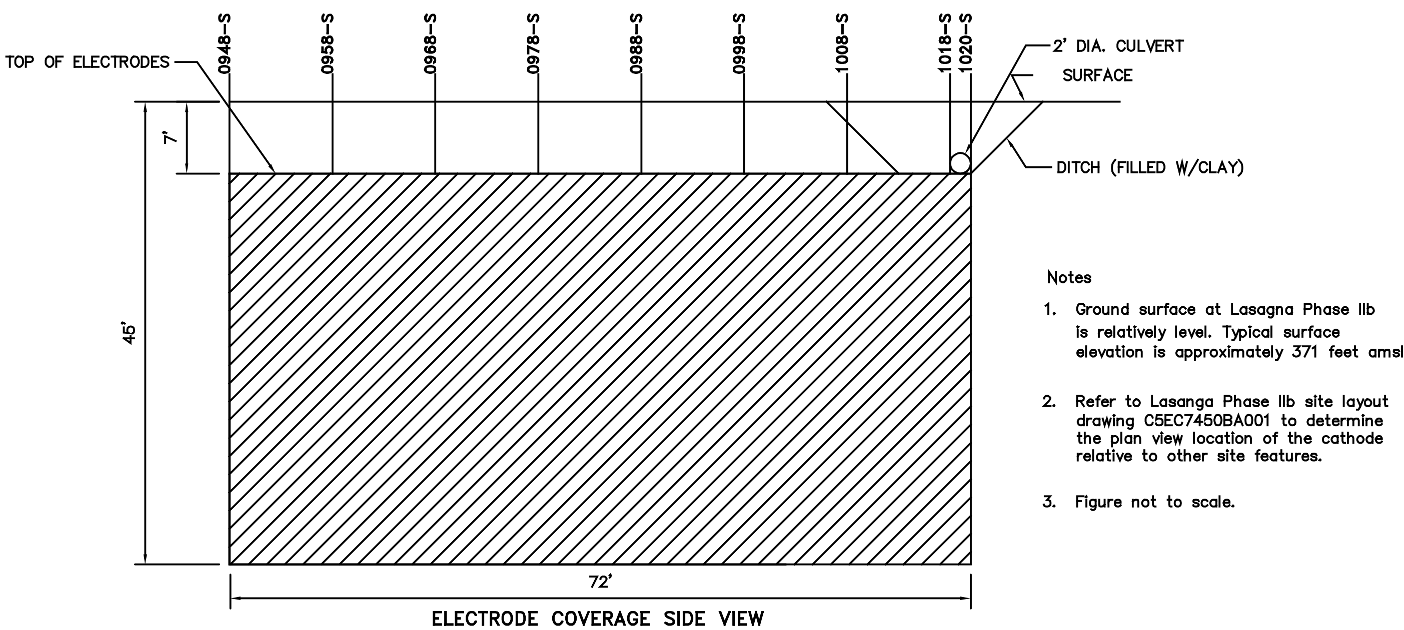


Figure 4.22 Final Configuration of Cathode (C-1)

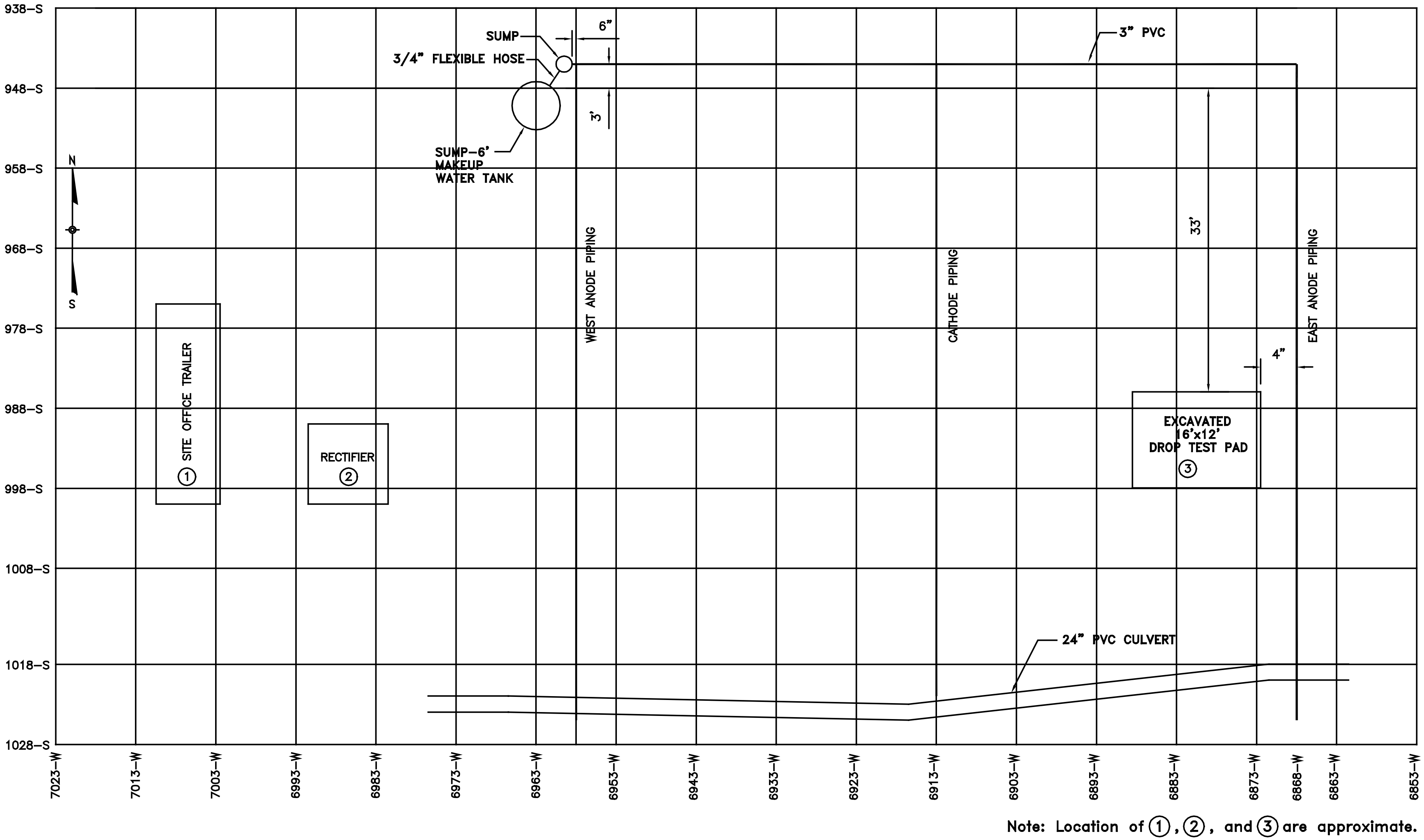
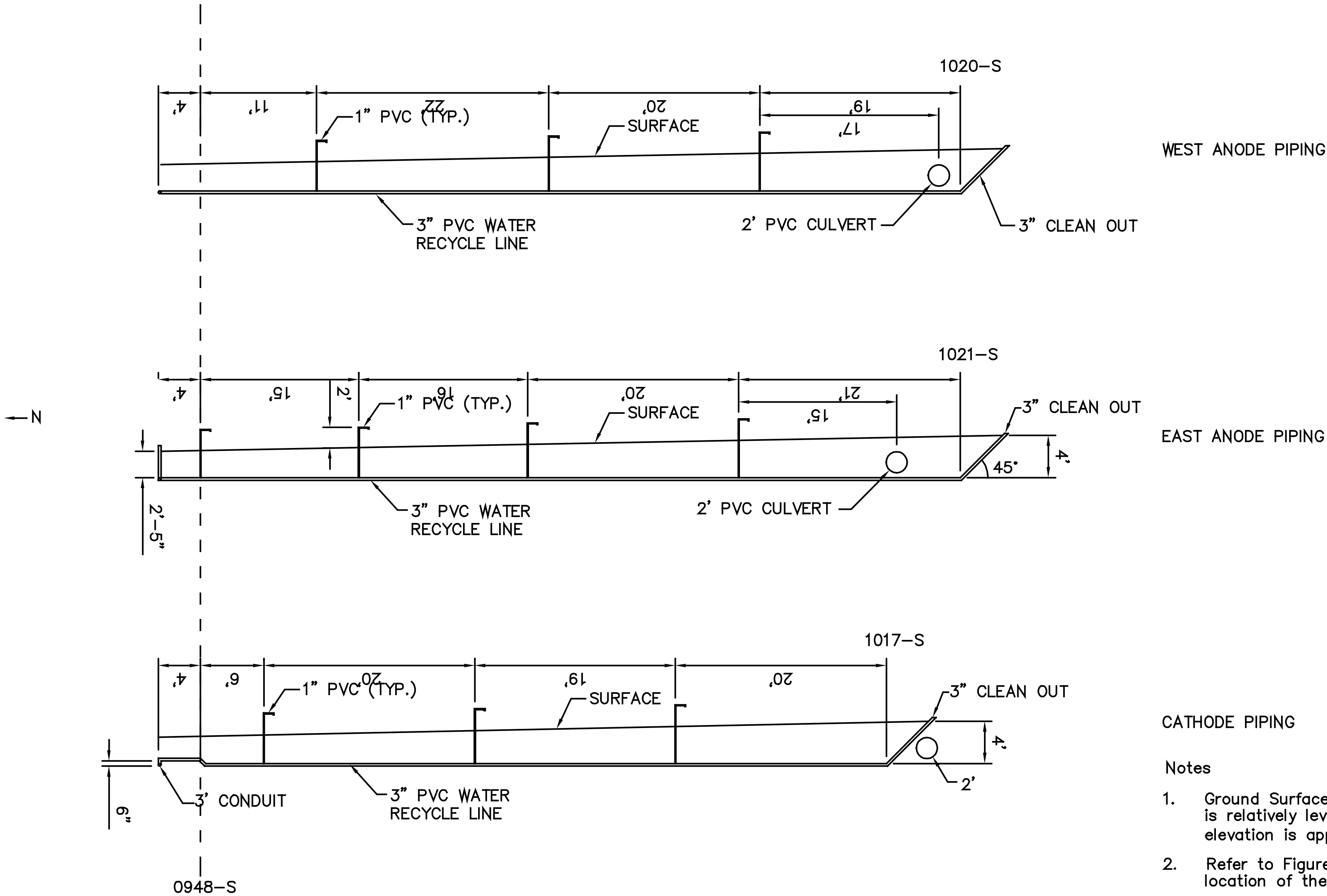


Figure 4.23 Water Recycle System Plan View



Notes

1. Ground Surface at Lasagna Phase IIb is relatively level. Typical surface elevation is approximately 371 feet amsl.
2. Refer to Figure 2.24 for the plan view location of the water recycle system.
3. Figure not to scale.

Figure 4.24 Water Recycle System Side Views

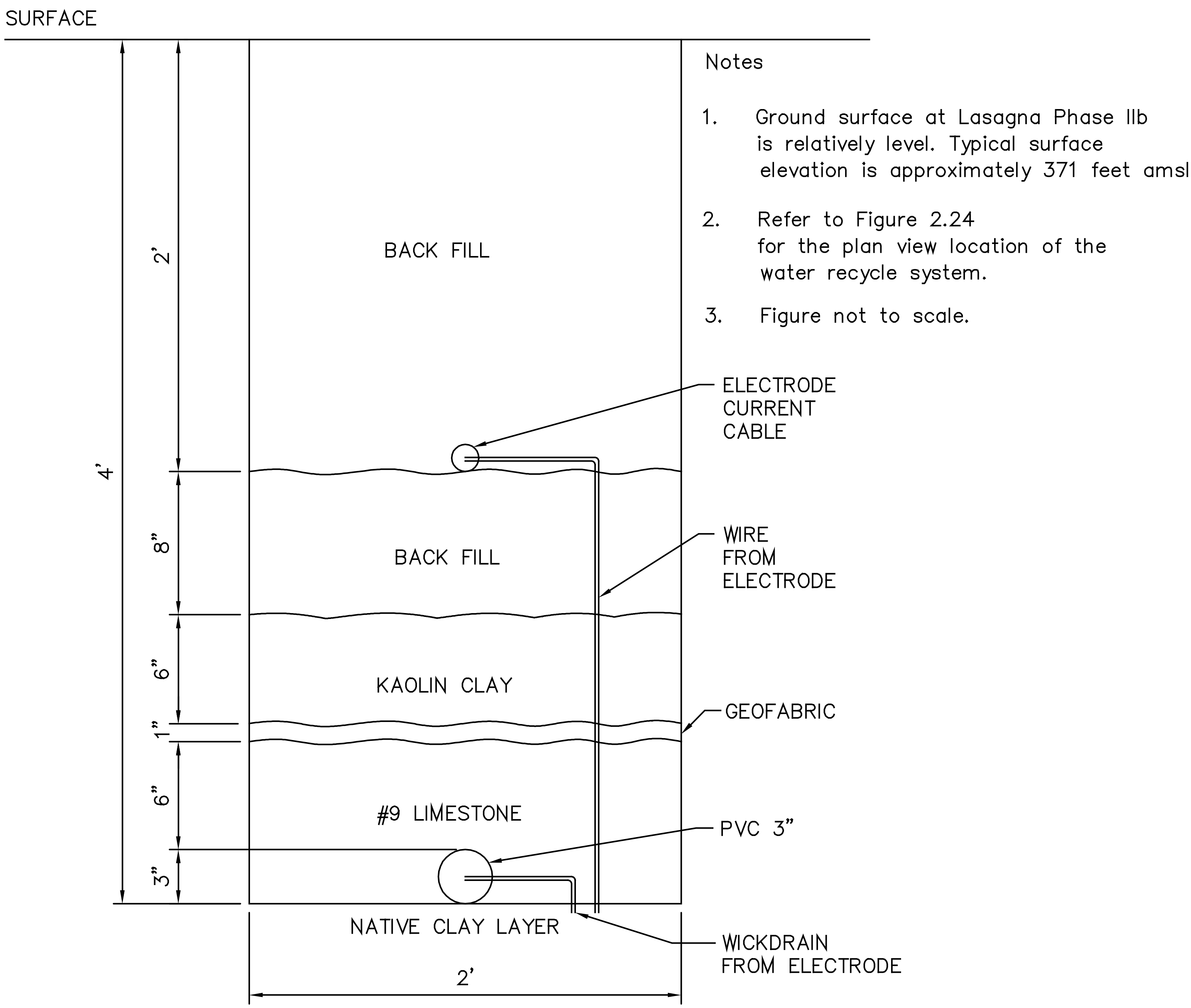


Figure 4.25 Typical Water Recycle System End View

Table F.1 TCE Concentrations
Baseline, Progress Event A, and Progress Event B

Sample Location	Sample Depth (ft bgs)	Baseline TCE Concentration (ppm)	Progress Sampling Event A TCE Concentration (ppm)	Progress Sampling Event B TCE Concentration (ppm)
1a	6	Non-detect	Not sampled	Not sampled
	11	Non-detect	Not sampled	Not sampled
	16	Non-detect	Not sampled	Not sampled
	21	Non-detect	Not sampled	Not sampled
1b	26	Non-detect	Not sampled	Not sampled
	31	Non-detect	Not sampled	Not sampled
	38	Non-detect	Not sampled	Not sampled
	41	Non-detect	Not sampled	Not sampled
	46	Non-detect	Not sampled	Not sampled
2	6	Non-detect	Not sampled	Not sampled
	11	Non-detect	Not sampled	Not sampled
	16	Non-detect	Not sampled	Not sampled
	21	Non-detect	Not sampled	Not sampled
	26	Non-detect	Not sampled	Not sampled
	31	Non-detect	Not sampled	Not sampled
	36	Non-detect	Not sampled	Not sampled
	41	Non-detect	Not sampled	Not sampled
	46	Non-detect	Not sampled	Not sampled
3	7	Non-detect	Not sampled	Not sampled
	11	Non-detect	Not sampled	Not sampled
	16	Non-detect	Not sampled	Not sampled
	21	Non-detect	Not sampled	Not sampled
	26	Non-detect	Not sampled	Not sampled
	31	Non-detect	Not sampled	Not sampled
	36	Non-detect	Not sampled	Not sampled
	41	Non-detect	Not sampled	Not sampled
	46	Non-detect	Not sampled	Not sampled
4	6	Non-detect	Not sampled	Not sampled
	11	Non-detect	Not sampled	Not sampled
	16	Non-detect	Not sampled	Not sampled
	21	Non-detect	Not sampled	Not sampled
	26	0.002	Not sampled	Not sampled
	33	Non-detect	Not sampled	Not sampled
	36	Non-detect	Not sampled	Not sampled
	41	.0019	Not sampled	Not sampled
	49	Non-detect	Not sampled	Not sampled
5a	6	Non-detect	Not sampled	Not sampled
	11	0.0025	Not sampled	Not sampled
	16	0.0577	Not sampled	Not sampled
	21	Non-detect	Not sampled	Not sampled
	26	0.365	Not sampled	Not sampled
	31	0.358	Not sampled	Not sampled
5b	36	Non-detect	Not sampled	Not sampled
	41	0.0052	Not sampled	Not sampled
	46	Non-detect	Not sampled	Not sampled

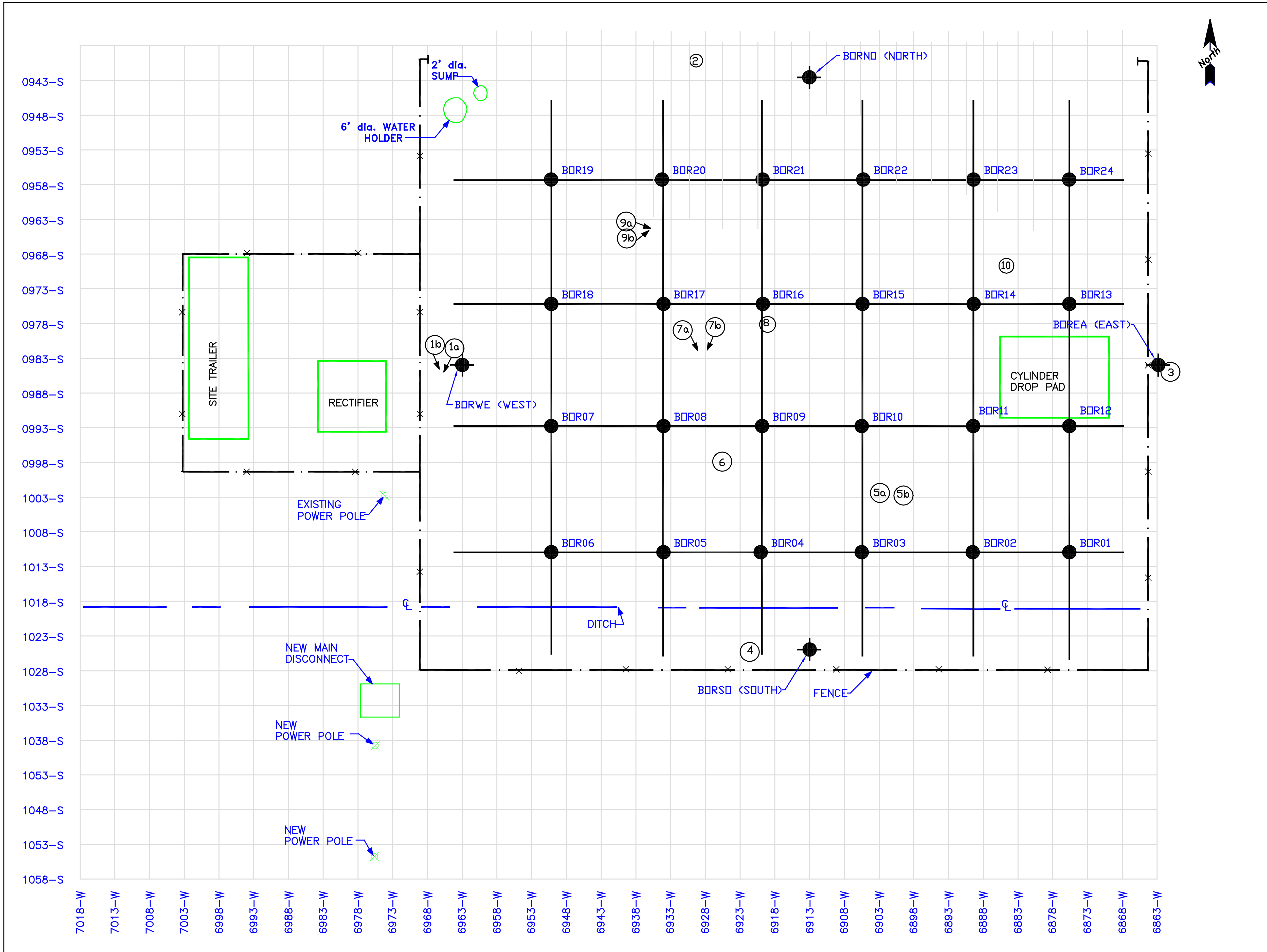
Table F.1 TCE Concentrations
Baseline, Progress Event A, and Progress Event B

Sample Location	Sample Depth (ft bgs)	Baseline TCE Concentration (ppm)	Progress Sampling Event A TCE Concentration (ppm)	Progress Sampling Event B TCE Concentration (ppm)
6	6	3.10	Not sampled	21.5
	11	5.10	Not sampled	7.90
	16	29.4	1.82	0.197
	21	1.80	Not sampled	0.594
	26	26.4	0.232	0.025
	31	2.00	Not sampled	Not sampled
	36	0.110	Not sampled	Not sampled
	41	0.021	Not sampled	Not sampled
	46	Non-detect	Not sampled	Not sampled
7a	6	3.40	552	6.70
	11	6.80	131	27.0
7b	16	4.00	44.0	2.90
	21	9.90	16.0	0.092
	26	12.7	1.60	12.2
	31	26.3	1.10	1.90
	36	14.9	0.959	0.035
	41	0.0037	0.543	0.044
	46	0.0034	Not sampled	Non-detect
8	6	0.002	Not sampled	0.780
	11	0.273	Not sampled	Non-detect
	16	0.176	Not sampled	Non-detect
	21	21.70	1.99	Non-detect
	26	3.60	Not sampled	Not sampled
	31	0.594	Not sampled	Not sampled
	36	0.0015	Not sampled	Not sampled
	41	Non-detect	Not sampled	Not sampled
	46	0.0018	Not sampled	Not sampled
9a	6	0.353	Not sampled	Non-detect
9b	11	3.60	Not sampled	Non-detect
	16	5.00	Not sampled	Non-detect
	21	16.3	28.0	Non-detect
	26	29.6	0.110	Non-detect
	31	3.70	0.004	Not sampled
	36	0.0016	0.010	Not sampled
	41	0.616	Not sampled	Not sampled
	46	0.0069	Not sampled	Not sampled
10	6	0.0277	Not sampled	Non-detect
	11	Non-detect	Not sampled	Non-detect
	16	0.741	Not sampled	Non-detect
	21	1.250	Not sampled	Non-detect
	26	0.113	Not sampled	Non-detect
	31	0.115	Not sampled	Not sampled
	36	1.40	0.009	Not sampled
	41	0.290	0.009	Not sampled
	46	0.254	0.020	Not sampled

Table F.2 TCE Concentrations
Final Verification Sampling

Final Sample Location	Sample Depth (ft bgs)	TCE Concentration (ppm)
BOR01	8	Non-detect
	23	0.0026
	38	Non-detect
BOR02	8	Non-detect
	23	0.0414
	38	0.0083
BOR03	8	0.014
	23	Non-detect
	38	0.0079
BOR04	8	Non-detect
	23	Non-detect
	38	Non-detect
BOR05	8	Non-detect
	23	Non-detect
	38	Non-detect
BOR06	8	Non-detect
	23	Non-detect
	38	Non-detect
BOR07	8	Non-detect
	23	Non-detect
	38	Non-detect
BOR08	8	0.0025
	23	0.0013
	38	0.0029
BOR09	8	0.0072
	23	Non-detect
	38	0.011
BOR10	8	Non-detect
	23	Non-detect
	38	0.0072
BOR11	8	0.276
	23	0.0132
	38	0.0019
BOR12	8	0.0375
	23	2.442
	38	4.506
BOR13	8	Non-detect
	23	2.503
	38	2.722
BOR14	8	Non-detect
	23	2.426
	38	3.214
BOR15	4	Non-detect
	8	Non-detect
	23	0.975
	38	2.325

Final Sample Location	Sample Depth (ft bgs)	TCE Concentration (ppm)
BOR16	4	1.126
	8	1.751
	23	Non-detect
	38	Non-detect
	48	0.059
BOR17	8	Non-detect
	23	0.0093
	38	Non-detect
BOR18	8	Non-detect
	23	Non-detect
	38	Non-detect
BOR19	8	0.0011
	23	Non-detect
	38	Non-detect
BOR20	8	0.005
	23	Non-detect
	38	Non-detect
	48	Non-detect
BOR21	8	Non-detect
	23	0.577
	38	1.213
BOR22	8	Non-detect
	23	0.252
	38	0.259
BOR23	8	Non-detect
	23	0.511
	38	1.239
BOR24	8	0.0324
	23	0.0084
	38	0.0011
BOREA	8	Non-detect
	23	Non-detect
	38	Non-detect
BORNO	8	Non-detect
	23	0.003
	38	Non-detect
BORSO	8	Non-detect
	23	Non-detect
	38	Non-detect
BORWE	8	Non-detect
	23	Non-detect
	38	Non-detect



LEGEND

℄ (Centerline) Ditch

Fence

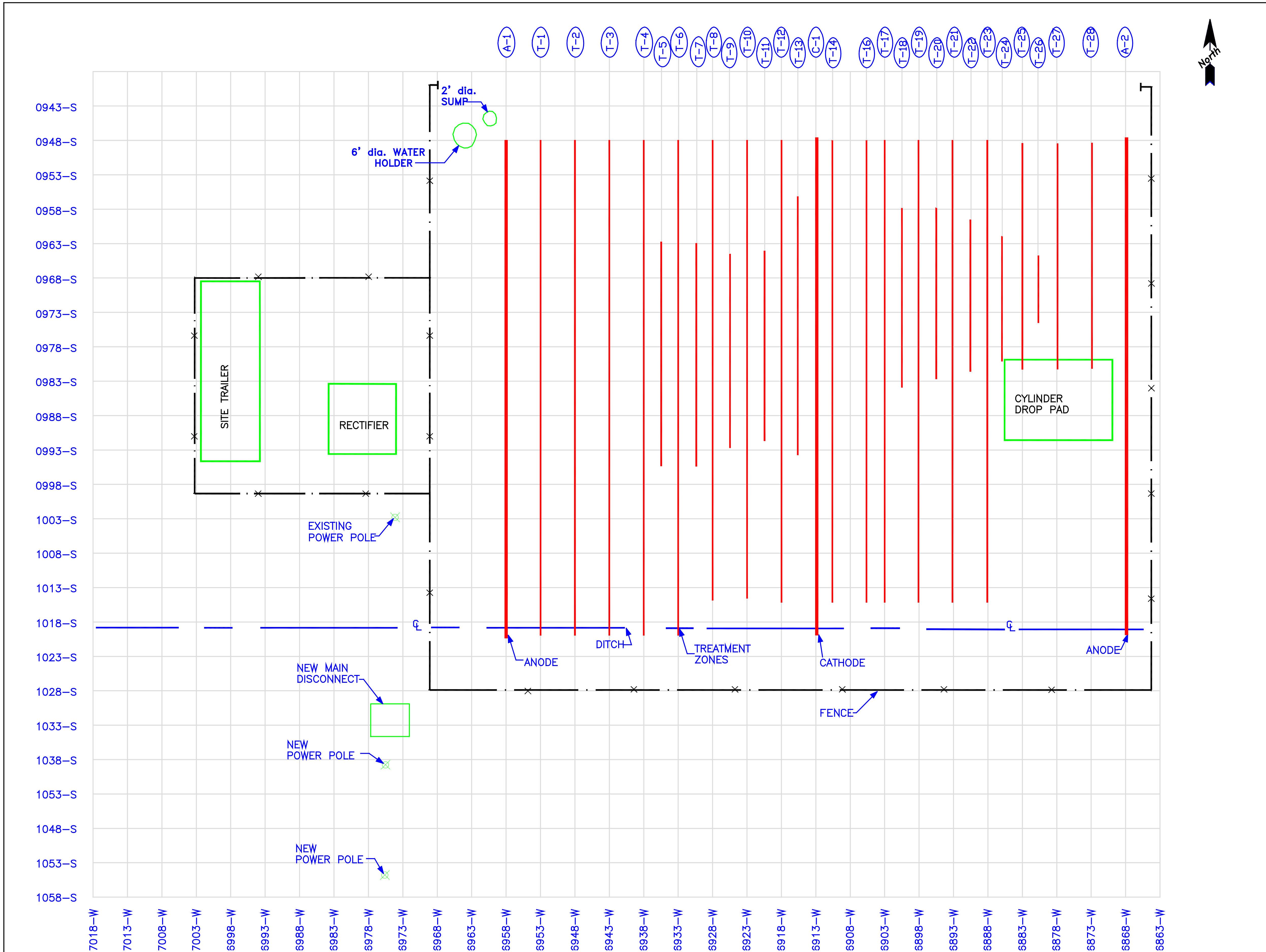
BOR01 Final Verification Soil Sample Location

1a Baseline/Progress Soil Sample Location (a)

5 Foot Grid

DRAWN BY: SLA	REVISED:	APPROVED BY: CJA
		DATE: 11/07/01
		DRAWING NAME: h.1.dwg

Figure H.1. Lasagna Phase IIb sample location layout

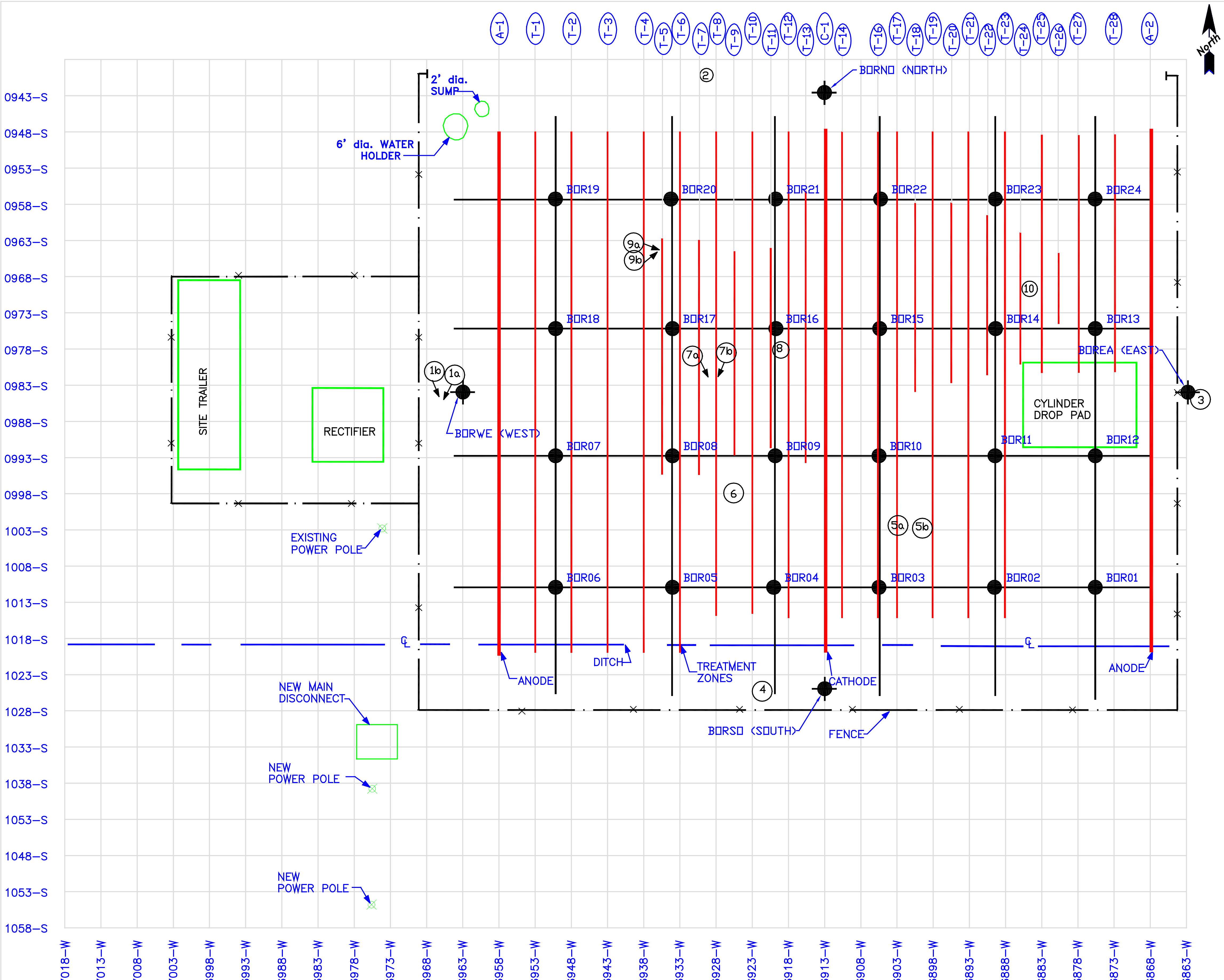


LEGEND

A– = ANODE ZONE
T– = TREATMENT ZONE
℄ (Centerline) Ditch
Fence
Anode/Cathode
Treatment Zone
5 Foot Grid

DRAWN BY: SLA	REVISED:	APPROVED BY: CJA
		DATE: 11/07/01
		DRAWING NAME: h.2.dwg

Figure H.2. Lasagna Phase IIb site layout showing treatment zones



LEGEND

A– = ANODE ZONE
T– = TREATMENT ZONE
℄ (Centerline) Ditch
Fence
Anode/Cathode
Treatment Zone
BOR01 Final Verification Soil Sample Location
1a Baseline/Progress Soil Sample Location (a)
5 Foot Grid

DRAWN BY: SLA	REVISED:	APPROVED BY: CJA
		DATE: 11/07/01
		DRAWING NAME: h.3.dwg

Figure H.3. Lasagna Phase IIb site layout

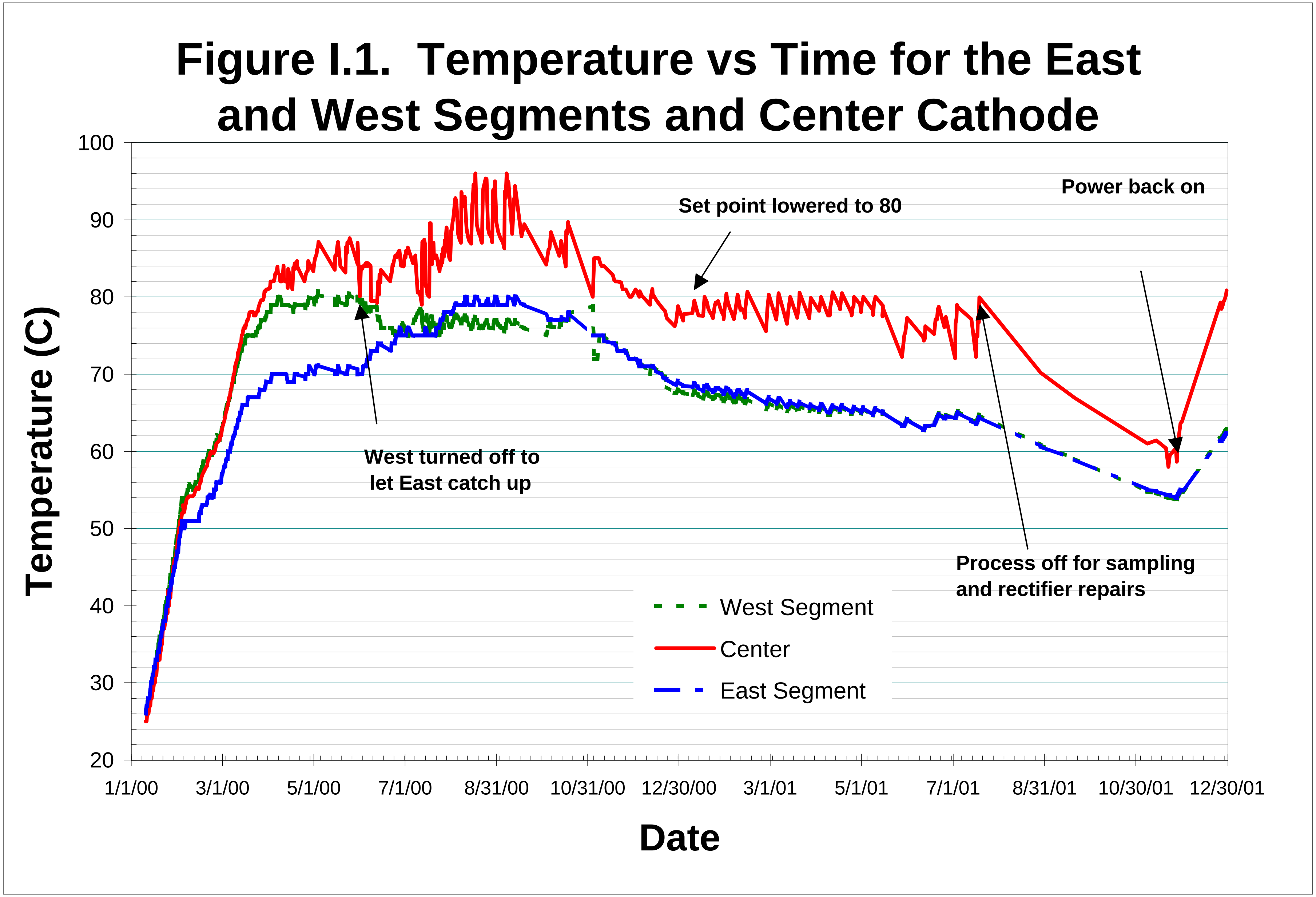


Figure I.1. Temperature vs Time for the East and West Segments and Center Cathode
Temperature (C)
100
90
80
70
60
50
40
30
20
1/1/00
3/1/00
5/1/00
7/1/00
8/31/00
10/31/00
12/30/00
3/1/01
5/1/01
7/1/01
8/31/01
10/30/01
12/30/01
Date
Set point lowered to 80
Power back on
West turned off to let East catch up
Process off for sampling and rectifier repairs
West Segment
Center
East Segment

Figure I.2. East and West Segments Pore Water Travel Distance