TETRA TECH

29 May 2008

Mr. Michael Garcia
Air Force Center for Engineering and the Environment
HQ AFCEE/ICS
3300 Sidney Brooks
Brooks City-Base, Texas 78235-5112

Subject: Submittal of Final Corrective Measures Implementation (CMI) Report for Ordnance Support Facility (Facility 1381, SWMU C021) at Cape Canaveral Air Force Station, Florida

Reference: FA8903-04-D-8677, Delivery Order No. 0031

Dear Mr. Garcia:

Please find attached 1 hard copy and 1 electronic copy (CD) of the Final Corrective Measures Implementation (CMI) Report for the referenced task order.

If you have questions or concerns regarding this matter, please feel free to contact me by telephone at (865) 220-4712, or e-mail at mike.higgins@tetratech.com, or in my absence, Mr. Purshotam Juriasingani at (865) 220-4753, or purshotam.juriasingani@tetratech.com. If you have any contractual issues, please contact Barbara Petersen at (805) 681-3100, or by e-mail at barbara.petersen@tetratech.com. We appreciate the opportunity to be of service to AFCEE and CCAFS.

Sincerely,
TETRA TECH, INC.

Michael Higgins

Michael Higgins, P.E.
Project Manager

Enclosures: as stated

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Patrick Air Force Base
Cape Canaveral Air Force Station

FINAL

ORDNANCE SUPPORT FACILITY (FACILITY 1381) SOLID WASTE MANAGEMENT UNIT C021 CAPE CANAVERAL AIR FORCE STATION, FLORIDA

Corrective Measures Implementation Report
Volume I

Revision 0 – May 2008

Prepared for:

U.S. Air Force Space Command
45th CES/CEVR
Patrick Air Force Base, Florida 32925-3343

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USAF Contract No. FA8903-04-D-8677, Delivery Order No. 0031

FINAL

INSTALLATION RESTORATION PROGRAM
45th SPACE WING FACILITIES AT
CAPE CANAVERAL AIR FORCE STATION, FLORIDA

ORDNANCE SUPPORT FACILITY (FACILITY 1381)
SOLID WASTE MANAGEMENT UNIT C021
CAPE CANAVERAL AIR FORCE STATION, FLORIDA

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USAF Contract No. FA8903-04-D-8677, Delivery Order No. 0031

Corrective Measures Implementation Report
Ordnance Support Facility (Facility 1381)
Solid Waste Management Unit C021
Cape Canaveral Air Force Station, Florida

5/29/08

By:

Michael Dale Higgins, P.E.

May 2008

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PREFACE

This document is a Corrective Measures Implementation Report for Ordnance Support Facility (Facility 1381), Solid Waste Management Unit (SWMU) C021, at Cape Canaveral Air Force Station (CCAFS), Florida. Tetra Tech, Inc. conducted the work under contract with the Air Force Center for Engineering and the Environment (AFCEE), Brooks City-Base, Texas, for the 45th Space Wing Facilities. John King was the AFCEE Contracting Officer (CO) and Judith Keith was the AFCEE Contracting Officer's Representative (COR). The Tetra Tech, Inc.'s AFCEE WERC Contract Program Manager was Scott Vick. Tetra Tech, Inc.'s Project Manager and Senior Engineer were Michael Higgins, P.E. and Purshotam Juriasingani, P.E., respectively. Mark Kershner (45th CES/CEVR), provided coordination for the 45th Space Wing Facilities at CCAFS, Florida.

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TABLE OF CONTENTS

VOLUME I CORRECTIVE MEASURES IMPLEMENTATION REPORT

SECTION **PAGE**

FIGURES

Number

TABLES

VOLUME II APPENDICES (CD)

VOLUME III TREATMENT CELL REPORTS (CD)

VOLUME IV FIELD FORMS AND LABORATORY SHEETS (CD)

ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AFCEE	Air Force Center for Environmental Excellence
AHA	Activity Hazard Analysis
AIHA	American Industrial Hygiene Association
AL	Action Level
ANSI	American National Standards Institute
bgs	below ground surface
bhp	brake horsepower
BTU	British Thermal Unit
CAMP	Corrective Action Management Plan
CAP	Corrective Action Plan
CCAFS	Cape Canaveral Air Force Station
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CES/CEVR	Civil Engineering Squadron/Restoration Division
CFR	*Code of Federal Regulations*
CMD	Corrective Measures Design
CMI	Corrective Measures Implementation
CMS	Corrective Measures Study
CO	Contracting Officer
COC	contaminant of concern
COR	Contracting Officer's Representative
CPT	cone penetrometer test
CRZ	contamination reduction zone
DAS	Data Acquisition System
DCA	1,1-dichloroethylene
DCE	dichloroethylene
DPT	direct push technology
DNAPL	dense, non-aqueous phase liquid
EZ	exclusion zone
FAA	Federal Aviation Administration
F.A.C.	*Florida Administrative Code*
FDEP	Florida Department of Environmental Protection
FID	flame ionization detector
FTO	flameless thermal oxidizer
GAC	granular activated carbon
GC	gas chromatograph
GCTL	groundwater cleanup target level
GPR	ground penetrating radar
H&S	Health and Safety
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HCl	hydrochloric acid
HF	hydrofluoric acid
HTRW	Hazardous, Toxic, and Radioactive Waste
IM	Interim Measure
IRP	Installation Restoration Program
KO	knock-out
KSC	Kennedy Space Center
LDA	large diameter auger
MBTU	million British Thermal Unit

mg/L	milligrams per liter
MIP	membrane interface probe
msl	mean sea level
NaOH	sodium hydroxide
NASA	National Aeronautics and Space Administration
NEMA	National Electrical Manufacturers Association
NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollutant Discharge Elimination System
NSC	National Safety Council
ODC	other direct cost
OSHA	Occupational Safety and Health Administration
P&ID	piping and instrumentation diagram
Partnering Team	Cape Canaveral and Patrick Environmental Restoration Partnering Team
PCB	polychlorinated biphenyl
PCE	tetrachloroethylene
PEL	Permissible Exposure Limit
PFD	process flow diagram
PFM	passive flux meter
PLC	Programmable Logic Controller
PPE	personal protective equipment
pph	pounds per hour
ppm	parts per million
psig	pounds per square inch gauge
PVC	polyvinyl chloride
PWQ	Process Waste Questionnaire
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
SCADA	Supervisory Control and Data Acquisition
SCTL	Soil Cleanup Target Level
SJRWMD	Saint Johns River Water Management District
SPCC	Security Police Confidence Course
SSHO	Site Safety and Health Officer
SWPPP	Storm Water Pollution Prevention Plan
SWMU	Solid Waste Management Unit
SZ	source zone
TCA	trichloroethane
TCE	trichloroethylene
TDEM	time domain electromagnetics
TRP	Technical Response Package
TWA	time-weighted average
UIC	Underground Injection Control
USACE	U.S. Army Corps of Engineers
USAF	U.S. Air Force
USEPA	U.S. Environmental Protection Agency
UST	underground storage tank
VCS	vapor conditioning system
VFD	Variable Frequency Drive
VOC	volatile organic compound
VPN	virtual private network
ZVI	zero valent iron

EXECUTIVE SUMMARY

Background

This document is a Corrective Measures Implementation (CMI) Report for the United States (U.S.) Coast Guard Ordnance Support Facility (Facility 1381), at Cape Canaveral Air Force Station (CCAFS), Florida. Facility 1381 is designated as Solid Waste Management Unit (SWMU) C021 in the Corrective Action Management Plan (CAMP) for the 45th Space Wing. This CMI Report has been prepared in accordance with the Resource Conservation and Recovery Act (RCRA) Corrective Action Plan (CAP) guidance. Tetra Tech, Inc. has prepared this CMI Report for the Installation Restoration Program (IRP) of the 45^{th} Space Wing Civil Engineering Squadron/Restoration Division (45th CES/CEVR) in accordance with the approved Final Corrective Measures Design (CMD) prepared by Jacobs Engineering Group, Inc. and the approved CMI Work Plan prepared by Tetra Tech, Inc. This report was prepared under contract with the Air Force Center for Engineering and the Environment (AFCEE), Brooks-City Base, Texas (Contract FA8903-04-D-8677, Delivery Order 0031).

Facility 1381 encompasses approximately seven acres on CCAFS and lies almost equidistant between the Atlantic Ocean and the Banana River. The facility is located on Armory Road, approximately one mile south of the intersection of Central Control Road and Armory Road. Prior to the CMI, Facility 1381 was occupied by the U.S. Coast Guard and served as a primary armory for munitions. The U.S. Coast Guard personnel were relocated to another CCAFS facility prior to project implementation and Facility 1381 became the operations center for the CMI. Several structures and utility features required removal in order to access the source area for treatment. The primary contaminants in groundwater at Facility 1381 included the volatile organic compounds (VOCs) trichloroethylene (TCE), cis-1,2-dichloroethylene (cis-1,2-DCE), and vinyl chloride.

The purpose and objective of this report are to present all CMI activities and the results of the remedial action that addressed the chlorinated solvent source area in the surficial aquifer at Facility 1381. The objective of the CMI was to remove and/or destroy significant contaminant mass including dissolved, sorbed constituents, and dense, non-aqueous phase liquids (DNAPL) in the identified source area in order to achieve cleanup goals within a reasonable time frame for the site. The objective of source treatment at the site was the significant reduction of the contaminant mass via in-situ soil mixing with steam, hot air, and zero valent iron (ZVI).

Several lines of evidence are used in indicating effective contamination removal efficiencies resulting from the application of in-situ soil mixing technology with injection of steam, hot air, and ZVI. The lines of evidence include (1) Comparing baseline and post-remediation concentrations of contaminants in soil and groundwater samples from the performance monitoring locations; (2) Comparing baseline and post- remediation groundwater mass flux results; (3) Presenting the mass removed for each VOC in the off-gas and its percent of total mass removed for Facility 1381; (4) Evaluating re-treatment data from three cells located in the highest contaminated area determined at the site [BQ43 as AX43 (approximately 75 days between treatments), BQ45 as AX45 (approximately 140 days between treatments), and BS44 as AX44 (approximately 163 days between treatments)]; and (5) Estimating the percent reduction in TCE concentration in each cell by comparing the maximum concentration of TCE detected during the early passes of the large diameter auger (LDA) with the maximum concentration detected in the last pass for a given treatment cell.

The source area was defined as the horizontal extent of TCE concentrations in groundwater greater than 10 milligrams per liter (mg/L), resulting in an estimated horizontal area of approximately 0.9 acre. The projected number of cells required to treat the area using an 8-foot diameter auger and utilizing a 6% overlap was 892. The footprint of each treatment cell was 50.24 ft^2 (without overlap). The data indicated that the thickness of the source area varied vertically across the site. Based upon this evidence, the source area was divided into five treatment zones with different areas and target treatment depths. The final number of cells treated and the associated areas, depths, and volume were as follows:

Treatment Zone	No. of Cells Treated	Approximate Area (ft^2)	Target Depth* (ft)	Volume (yd^3)
Zone 1	72	3,617	5-20	2,064
Zone 2	106	5,325	10-20	2,093
Zone 3	140	7,034	10-30	5,451
Zone 4	405	20,347	10-40	28,438
Zone 5	74	3,718	10-50	6,117
Totals	797**	40,041**	-	44,163**

* Actual treatment depths were typically greater than target depths.

** Final number of treatment cells, area, and volume differed from projected due to real-time data assessment and treatment during implementation which maximized mass removal

Treatment System

In-situ soil mixing using an LDA combined with the injection of steam/hot air followed by the injection of ZVI was the remedial technology used for the treatment of soil and groundwater contaminated with high concentrations of VOCs or DNAPL in the source area. This technology, as constructed at the Facility 1381 site, consisted of the following major elements: a mixing and vapor collection system (i.e., the LDA and ancillary equipment), the VOC treatment system (thermal oxidizer and/or granulated activated carbon), and the Supervisory Control and Data Acquisition (SCADA) system. The treatment system utilized a process control and data acquisition system for real-time evaluation that assisted in controlling the process parameters to maximize the VOC removal and supported instant decision making for operation (i.e., depth and duration) of the LDA.

The mixing system was equipped with an LDA (8 feet in diameter) that sheared and mixed the soil as the auger advanced below the ground surface while concurrently injecting steam and hot air. This action caused thermal desorption and volatilization of the VOCs from soil particles and interstitial spaces. The steam and hot air raised the temperature of the soil mass, increased the vapor pressure of the contaminants, volatilized the compounds from the soil particles, and allowed them to be transported to the surface where they were collected in a shroud maintained under vacuum (vapor collection system) covering the active treatment area. The shroud that was 12 feet in diameter provided the ability to capture off-gases beyond the 8-foot diameter auger blades, thus minimizing fugitive emissions. The vapors were transported from the shroud through the vapor conditioning system (VCS) to the VOC treatment system by the blower. VOC removal and treatment was succeeded by placement of ZVI in the mixed soil to enhance reductive dechlorination of VOCs to facilitate the achievement of cleanup target levels in an estimated reasonable time frame.

The VOC treatment system consisted of a VCS and vapor treatment system. Vapor collected in the LDA shroud contained air, water, VOC contaminants, and particulates. The VCS was required to remove water and particulates from the vapor before being processed in the vapor treatment system. The VCS consisted of a knockout tank, pre-chiller, coarse particulate filter, chiller, reheater, and fine particulate filter. The vapor from the conditioning system was then processed in the vapor treatment system consisting of thermal oxidation and/or a vapor phase carbon adsorption to remove VOC contaminants. The thermal oxidation system was capable of destroying 99.9% of VOCs. The vapor phase carbon adsorption system was generally used as a backup during thermal oxidation system shutdown.

Real-time data acquisition was an integral part of the in-situ soil mixing that allowed the operator to determine the efficiency of treatment and maximize the results within the treatment protocols established for the site. The data acquisition system and gas chromatographs (GCs) allow effective coordination and control of various process parameters in the treatment train. The SCADA system also helps in making real-time decisions related to expanding the area of treatment and focusing the interval of treatment.

Data Collection and Evaluation

A SCADA system was used to monitor field instruments and process equipment associated with the in-situ soil treatment system. The SCADA system collected and stored data for reporting, trending, and analysis as well as provided process information for operator control. Standard reports were generated and published on the web so that authorized users can access reports using a web browser over the Internet. Analytical instruments that were integrated with the SCADA system provided data that allowed real-time evaluation and instant decision making, as follows:

- Three flame ionization detectors (FIDs) were used to continuously monitor the effluents (total hydrocarbons) produced by the treatment process. The FIDs were used to measure total VOCs in three sample streams given below:
    - o Off-gas from the treatment process.
    - o Influent to the thermal oxidizer.
    - o Either the stack effluent thermal oxidizer when the unit was on-line, or the stack at the exit of the carbon bed if the carbon bed was being used.

- Four GCs were used to detect, speciate, and quantify target analytes from the treatment process off-gas. Three GCs were cycled at 2 minute intervals throughout the treatment process with one GC being operated when a maximum VOC as measured by the FID was detected. The GCs were computer controlled with the vendor-supplied software that allowed chromatographic analysis of the contaminants of concern, quantitation of analytes, and reporting of concentrations from each sample.

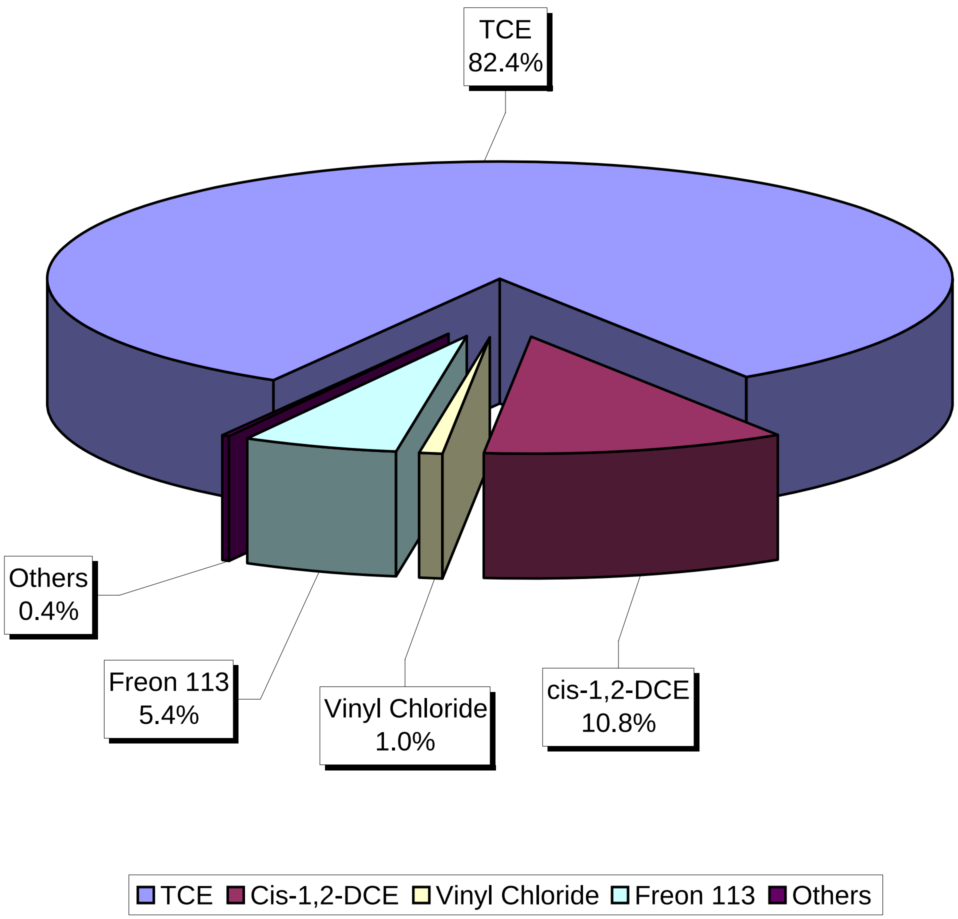
Data from the FIDs and GCs were utilized to determine trends in depth, concentration, and location of contamination requiring treatment. Identified data trends in contamination enabled on-site field personnel and managers to perform real-time decision making on depth placement and treatment times needed for effective and efficient LDA operation and to aid in a real-time determination for adding or deleting treatment cells. Mass removal information was not available in real time but was provided within one or two days, thus allowing field decisions on treatment or no treatment while the LDA was positioned near the area in question. A total of 21 treatment cells were thermally treated as expansion cells due to either elevated TCE concentrations (greater than 100 parts per million (ppm)) and elevated FID concentrations (greater than 400 ppm), or based on mass removal of greater than one pound of TCE mass in the adjacent cells, per treatment protocols.

Results

Treatment of Facility 1381 started in June 2006 and was completed in June 2007; 797 8-foot diameter cells were treated over a period of approximately 12 months to maximum depths of 57 feet below ground surface. Approximately 11,439 pounds of VOCs were removed and destroyed. TCE and cis-1,2-DCE accounted for 93.2% of the total mass removed in relative amounts of 9,249 and 1,236 pounds, respectively. The relative percent of all VOCs removed from the site are shown in Figure ES-1. Data from retreated cells showed that contaminant concentrations continued a downward trend following the initial treatment and that residual concentrations were comparatively very low (one to two orders of magnitude lower). Comparison of the maximum off-gas concentration of TCE from the early thermal passes with the last thermal pass of the LDA for all treated cells showed that concentrations were reduced by greater than 90% in more than 78% of all cells; only 4% of cells attained a less than 50% reduction in concentration.

Baseline soil and groundwater samples have been collected and will be compared to post-remediation samples to be collected from identical locations and depths within the source area; these data will be used to definitively quantify the reduction in concentrations of the target VOCs and the residual concentrations of VOCs in the source are with respect to GCTLs.

Figure ES-1: Percentage of Total Mass Removed from Facility 1381



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1.0 INTRODUCTION

This Corrective Measures Implementation (CMI) Report was prepared by Tetra Tech, Inc. for the United States (U.S) Coast Guard Ordnance Support Facility (Facility 1381) at Cape Canaveral Air Force Station (CCAFS), Florida. Facility 1381 is designated as Solid Waste Management Unit (SWMU) C021 in the Corrective Action Management Plan (CAMP) for the 45th Space Wing. This CMI Report has been prepared in accordance with the Resource Conservation and Recovery Act (RCRA) Corrective Action Plan (CAP) guidance. Tetra Tech has prepared this CMI Report for the Installation Restoration Program (IRP) of the 45th Space Wing Civil Engineering Squadron/Restoration Division (45th CES/CEVR) in accordance with the approved Final Corrective Measures Design (CMD) prepared by Jacobs Engineering Group, Inc. and the approved CMI Work Plan prepared by Tetra Tech, Inc. This report was prepared under contract with the Air Force Center for Engineering and the Environment (AFCEE), Brooks-City Base, Texas (Contract FA8903-04-D-8677, Delivery Order 0031).

The IRP conducts all its projects under the oversight and guidance of the Cape Canaveral and Patrick Environmental Restoration Partnering Team (Partnering Team), which was established to facilitate restoration of SWMUs at 45th Space Wing facilities. The Partnering Team includes representatives of the IRP, AFCEE, the U.S. Environmental Protection Agency (USEPA), the Florida Department of Environmental Protection (FDEP), the U.S. Army Corps of Engineers (USACE), and environmental contractors. The Partnering Team provides input, guidance, in-progress reviews, and final concurrence on management decisions for the 45th Space Wing SWMUs.

1.1 OBJECTIVE

This CMI Report is intended to present all the implementation activities including site preparations, mobilization, system startup and testing, system operation, data acquisition, and performance based sampling. The report also presents the results of the treatment of contaminated saturated subsurface through in-situ soil mixing with steam, hot air, and zero valent iron (ZVI) injection.

1.2 SITE BACKGROUND

CCAFS is located in Brevard County on the central coast of Florida. Facility 1381 served as the U.S. Coast Guard's Ordnance Support Facility prior to the CMI. Past precision cleaning, storage and disposal operations at the site led to its investigation by the IRP and listing as a SWMU. Several investigations identified and described contamination impacts at Facility 1381:

- *Preliminary Assessment #1* (Parsons ES, 1993)
- *RCRA Facility Investigation Report* (Parsons ES, 1998)
- *Supplemental CMS Field Investigation Report* (Parsons ES, 2000)
- *Corrective Measures Study Report* (BEM, 2002)

These investigations identified groundwater contamination that presents potential risk to human and ecological receptors. An interim measure for surface water has been implemented and is ongoing. The *Corrective Measures Study Report* (BEM, 2002) concluded that soil no longer presented a risk to human health, though some residual ecological risk may have persisted. There was a plume of dissolved groundwater contamination emanating from Facility 1381 that consisted primarily of chlorinated volatile organic compounds (VOCs). Within that plume, trichloroethylene (TCE), cis-1,2-dichloroethylene (DCE) and vinyl chloride were present in concentrations that exceeded the State of Florida Groundwater Cleanup Target Levels (GCTLs). BEM ascertained that there was an area on the southeast side of Facility 1381 with very high dissolved concentrations of TCE, suggestive of the presence of that solvent in the form of a dense, non-aqueous phase liquid (DNAPL). That area was the source of continuing groundwater contamination, which subsequently became a source of surface water contamination through discharge to the canal south of the site. The CMS recommended that the source area be addressed to substantially reduce the mass of DNAPL, and presented several alternatives to achieve that objective. The CMS for Facility 1381 was approved by the Partnering Team. The recommended alternative for corrective action was comprised of several steps:

1. Continued operation of a bubbler system in the adjacent canal south of the site to mitigate contaminant discharges to surface water from groundwater;

2. Treatment of the source area (defined as the area where the TCE concentration in groundwater is 10 mg/L or greater) through in-situ soil mixing, with steam and hot air injection via large diameter auger (LDA);

3. Emplacement of ZVI to enhance reductive dechlorination, also via LDA, as a secondary treatment step for the chlorinated compounds;

4. Natural attenuation of groundwater contamination to FDEP groundwater cleanup target levels (GCTLs) for the non-source area, documented by continued monitoring; and

5. Land use controls at the site to prevent exposure to contaminants until cleanup targets are achieved.

The recommended alternative was presented to the U.S. Air Force Space Command Peer Review in June 2003. The Peer Review Committee endorsed this approach as the environmentally responsible and cost-effective remedial strategy for source area contamination at Facility 1381.

1.2.1 Site Location and Operational History

Facility 1381 encompasses approximately seven acres near the center of CCAFS, almost equidistant between the Atlantic Ocean and the Banana River (Figure 1-1). The facility is located on Armory Road, approximately one mile south of the intersection of Central Control Road and Armory Road and was occupied by the U. S. Coast Guard prior to the CMI (Figure 1-2). A canal is located approximately 300 feet south of Facility 1381. Immediately to the south of this canal is the CCAFS landfill. The landfill is currently active and is permitted to receive construction debris. A groundwater well network has been installed around the landfill for purposes of monitoring that facility. Facility 20185, the CCAFS Weather Station, is located approximately 1,400 feet north of Facility 1381. No other facilities are located adjacent to the site. There is a second canal about 2,500 feet north-northwest of the site, which drains to the Banana River Lagoon.

Constructed in 1958, Facility 1381 was operational from 1958 through 1968 as the Guidance Azimuth Transfer Building. From 1968 until 1977, the facility served as the In-Place Precision Cleaning Lab for Pan Am operations. During Pan Am's operations of the In-Place Precision Cleaning Lab, Facility 1381 housed acid and solvent dip tanks to be used for cleaning metal components. TCE was used on-site during cleaning operations. The waste TCE was drummed and taken to Space Launch Complex (SLC) 15 for disposal. Stainless steel acid dip tanks were used on site to clean galvanized steel piping. The waste acids were then disposed of by discharging them into a neutralization pit filled with crushed limestone. The neutralization pit is located southwest of Facility 1381 (the Ordnance Support Facility). A concrete pad containing three dip tanks was located at the Support Facility Equipment Shed (Facility 20299). The dip tanks contained "Fozdip" acid, oil, and water (Parsons ES, 1993).

During the 1960s and 1970s, it is reported that tanker trucks dumped solvents in the woods around the site. The tankers would follow roads present at the site leading into the surrounding woods and would empty the contents of the trucks (Parsons ES, 1993). Since 1977, the site has been operated by the U.S. Coast Guard and serves as their Ordnance Support Facility. There are no ongoing activities that may be a source of the groundwater contamination at Facility 1381. There is currently no route of exposure to the subsurface contaminants, so facility users do not have a potential for contact. In addition, air quality samples collected inside Facility 1381 had no detectable VOCs, so the facility is safe for use.

1.2.2 Existing Site Conditions

This section briefly describes the physical attributes of Facility 1381 including physiography, lithology, and hydrogeology. A complete discussion of geology, hydrogeology, and historical events leading to developing the site conceptual model at Facility 1381 is included in the CMS Report (BEM, 2002).

1.2.2.1 Physiography

The physiography of the area prior to the CMI consisted of natural ground surface elevations at Facility 1381 ranging from approximately 5 to 9 feet above mean sea level (msl). Structures existing prior to the project are depicted in Figure 1-2. The grounds of Facility 1381 are mowed and maintained, and the drainage ditch to the south is periodically dredged for maintenance purposes. The outlying areas are predominantly ruderal or scrub which has restored itself after clearing.

1.2.2.2 Lithology

Lithologic logs, collected prior to the CMI, indicate that from the land surface to approximately 35 feet below land surface (bls), the sediments consist of poorly sorted coarse to fine sands and shell material, with little or no silts and clays present. From approximately 35 to 50 feet bls, sands generally show a decrease in grain size, and the silt and clay content increases. The clay at this depth is disseminated through the sandy materials as loose layers or lenses. At approximately 48 to 50 feet bls, a very competent, plastic, glauconitic clay unit was encountered in all borings. This is interpreted to be the uppermost significant clay layer within the Caloosahatchee Marl. The clay appears to be continuous to at least 60 feet where it grades into an interbedded fine sand, silt, clay, and weathered limestone. Given the thickness, composition and continuity of the upper clay layer, this unit is assumed to act as a significant confining layer within the Facility 1381 area.)

1.2.2.3 Hydrogeology

Groundwater at CCAFS occurs under both unconfined (non-artesian) and confined (artesian) conditions. The surficial aquifer contains groundwater under non-artesian conditions, starting at approximately 4 feet bgs. Water enters the aquifer through direct infiltration as a result of percolation of rainwater. Water in the surficial aquifer moves laterally toward the regional drainage canals.

Surrounding the proximity of Facility 1381, both the upper and lower flow zones as described in the CMS have a north-northwest directional flow. There is a southward flow direction south of Facility 1381 toward the southern drainage canal, reflecting its local influence on the upper surficial aquifer. Groundwater elevations associated within the lower surficial aquifer are generally lower than those groundwater elevations associated in the shallow monitoring wells. However, within the general vicinity of the canals, the vertical gradient becomes higher, which is consistent with the groundwater discharge to canals.

1.2.3 DNAPL Source Area

The RFI and CMS conducted at Facility 1381 focused on areas related to the historical storage, management, and disposal of acids, solvents, and petroleum products at the site. There are no other known activities at the site, nor on surrounding grounds, that would account for the contamination observed.

Potential release mechanisms at Facility 1381 included disposal, discharges, and spills associated with the chemical cleaning lab. The mechanisms that have transported these contaminants were disposal, runoff, and seepage. Both groundwater and surface water (in the adjacent canal) have been affected by these releases. Three potential sources of contamination have been identified at Facility 1381:

- Support Facility Equipment Shed
- Neutralization Pit
- Septic Tank Drain Field

The Facility 1381 treated source area is presented in Figure 1-3. There is presumptive evidence that TCE DNAPL was present because of the very high concentrations of dissolved TCE. A dissolved concentration of 10 mg/L of TCE was accepted by the IRP and the Partnering Team for presumptive identification and delineation of a DNAPL source area. This TCE concentration selection was conservative, offering a 10% protective factor compared to 11 mg/L, which is 1% of solubility for TCE. For this site, the CMS determined that the DNAPL source area was an elongated area oriented northeast to southwest located southeast of Facility 1381. The source area was estimated to be about 160 wide by 380 feet long. The source area was projected to be thickest through its center (from around 10 to 50 feet bgs) thinning out toward the northeast and southwest.

1.3 PURPOSE AND OBJECTIVE

Conditions at Facility 1381 were previously assessed with regard to the quality of groundwater, soil, sediment, and surface water. The primary contaminants of concern (COCs) in groundwater are VOCs, specifically chlorinated solvents. The VOCs listed as COCs include TCE, cis-1,2-DCE, and vinyl chloride. The VOC source area is defined in the CMS (BEM, 2002) and CMD (Jacobs, 2005) based upon dissolved concentrations of TCE in groundwater equal to or greater than 10 mg/L.

1.3.1 Remedial Action Objectives

Without active cleanup, it is anticipated that significantly more than 200 years will be required in order to achieve cleanup target levels for groundwater. However, the Facility 1381 CMS indicated that plume size and cleanup times could be reduced significantly if at least 75% reduction in contaminant mass could be achieved. Therefore, the remedial action objectives as per Statement of Basis for Facility 1381 (IRP, 2005) are as follows:

1. Through an active remedy, remove a significant percentage of solvent source material that remains in the subsurface aquifer (TCE concentration > 10 mg/L is considered “source”).
2. Implement a remedy on the residual groundwater contamination upon termination of the source area treatment action.
3. Achieve final remedial goals for groundwater within 200 years of active remedy implementation. Since this is such a long time frame, interim goals shall be established based on reduction in plume mass:
    - 50% mass reduction in 50 years
    - 75% mass reduction in 100 years
    - 90% mass reduction in 150 years
    - 100% mass reduction in 200 years
4. Continue monitoring of surface water protective measures, until several rounds of sampling data indicate that the groundwater plume no longer intersects or discharges into the canals, thus remaining compliant with State surface water standards for the Banana River Lagoon (F.A.C. 62-302.700).

5. Protect humans from exposure to residual groundwater contamination and prevent consumption of groundwater from the shallow aquifer [while COCs remain above health-based standards for unrestricted (residential) use].

1.3.2 Report Objectives

The objective of the CMI is to remove and/or destroy significant contaminant mass (including dissolved, sorbed constituents, and DNAPL) in the identified source areas. The purpose and objective of this report are to present all implementation activities and results of a remedial action that address groundwater impacts at Facility 1381.

FIGURES

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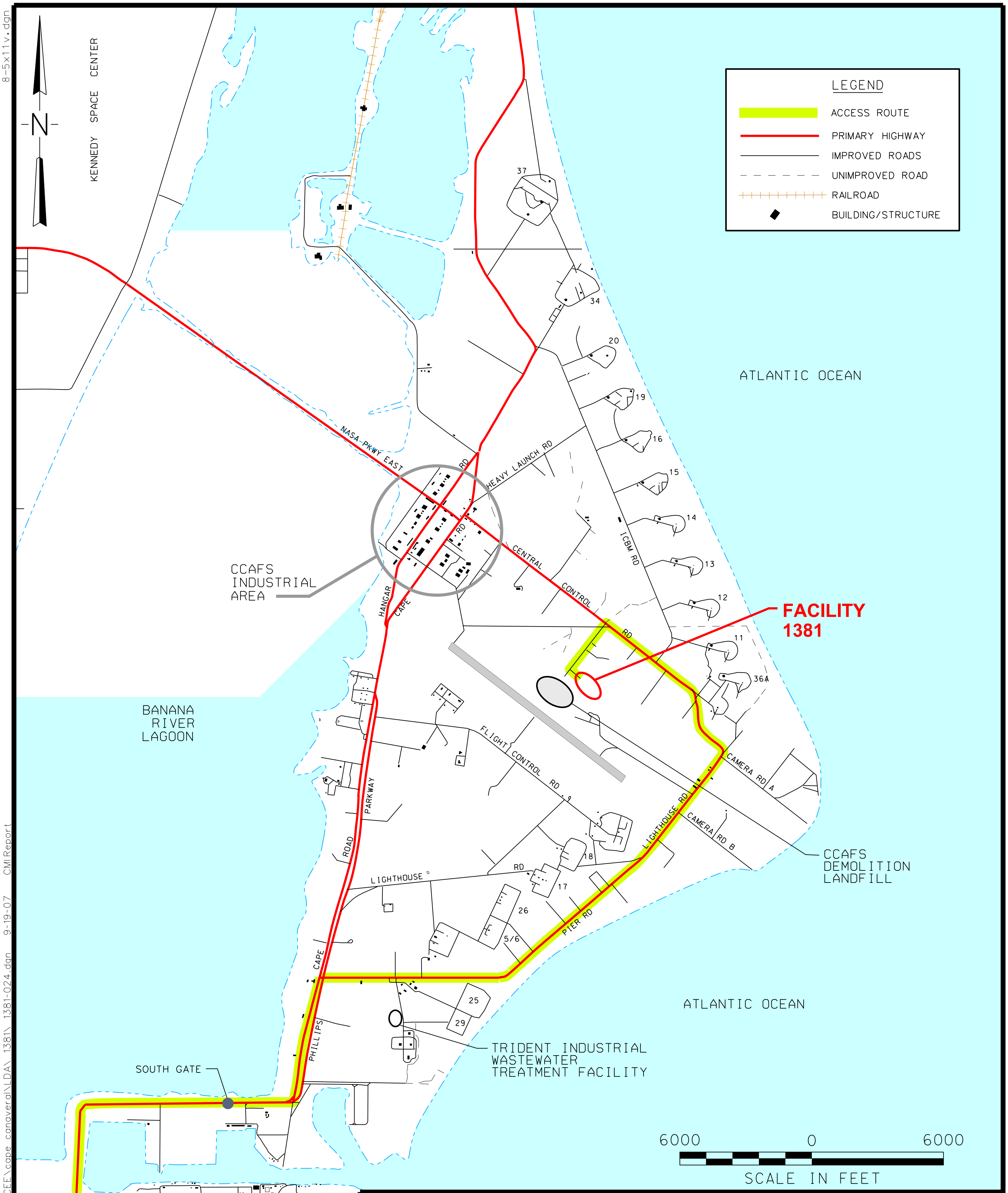
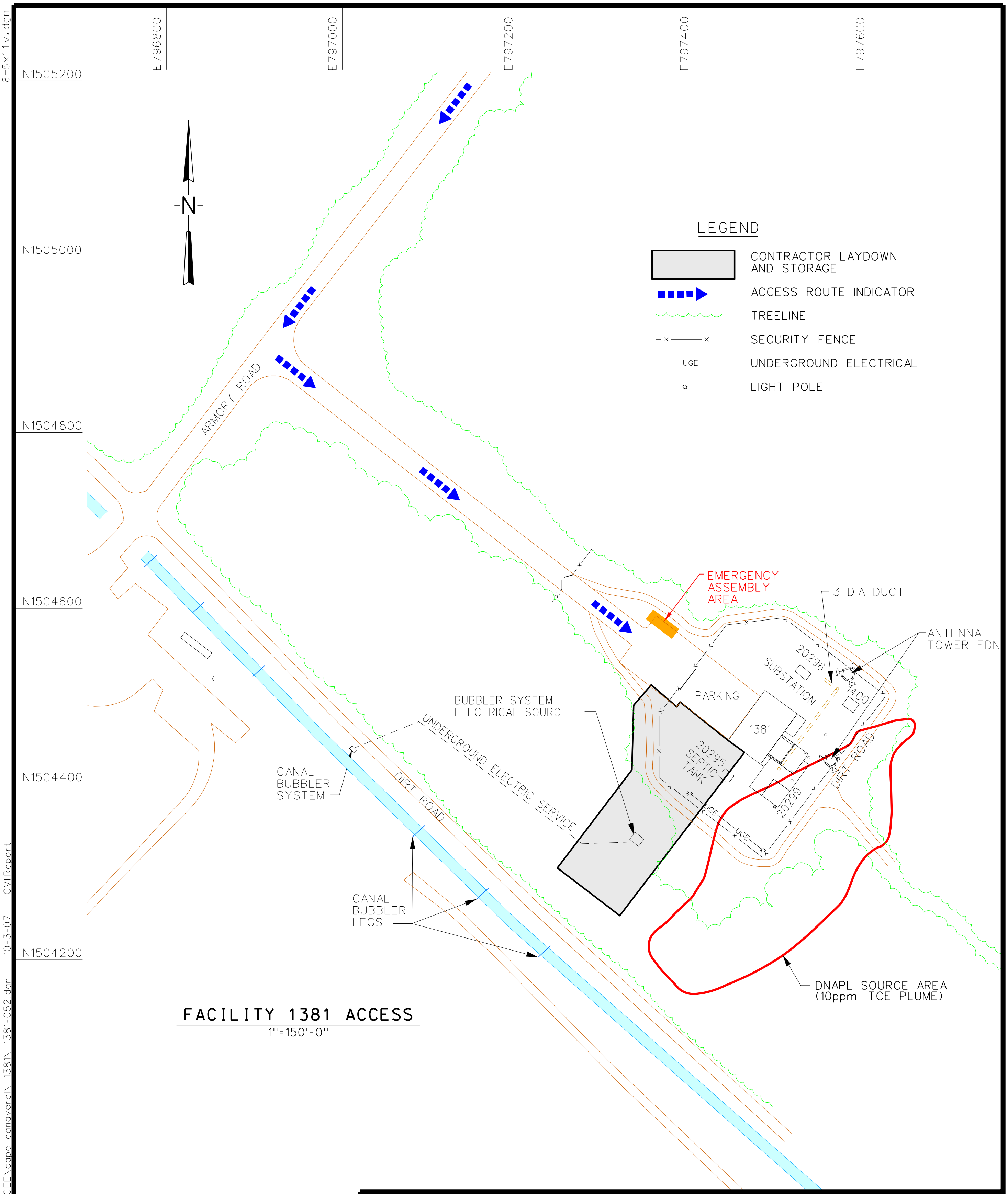


TETRA TECH
OAK RIDGE, TENNESSEE

CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 1-1
SITE LOCATION MAP

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-024.dgn 9-19-07 CMIReport 8-5x11v.dgn



FACILITY 1381 ACCESS

1"=150'-0"

150 0 150

SCALE IN FEET

SOURCE

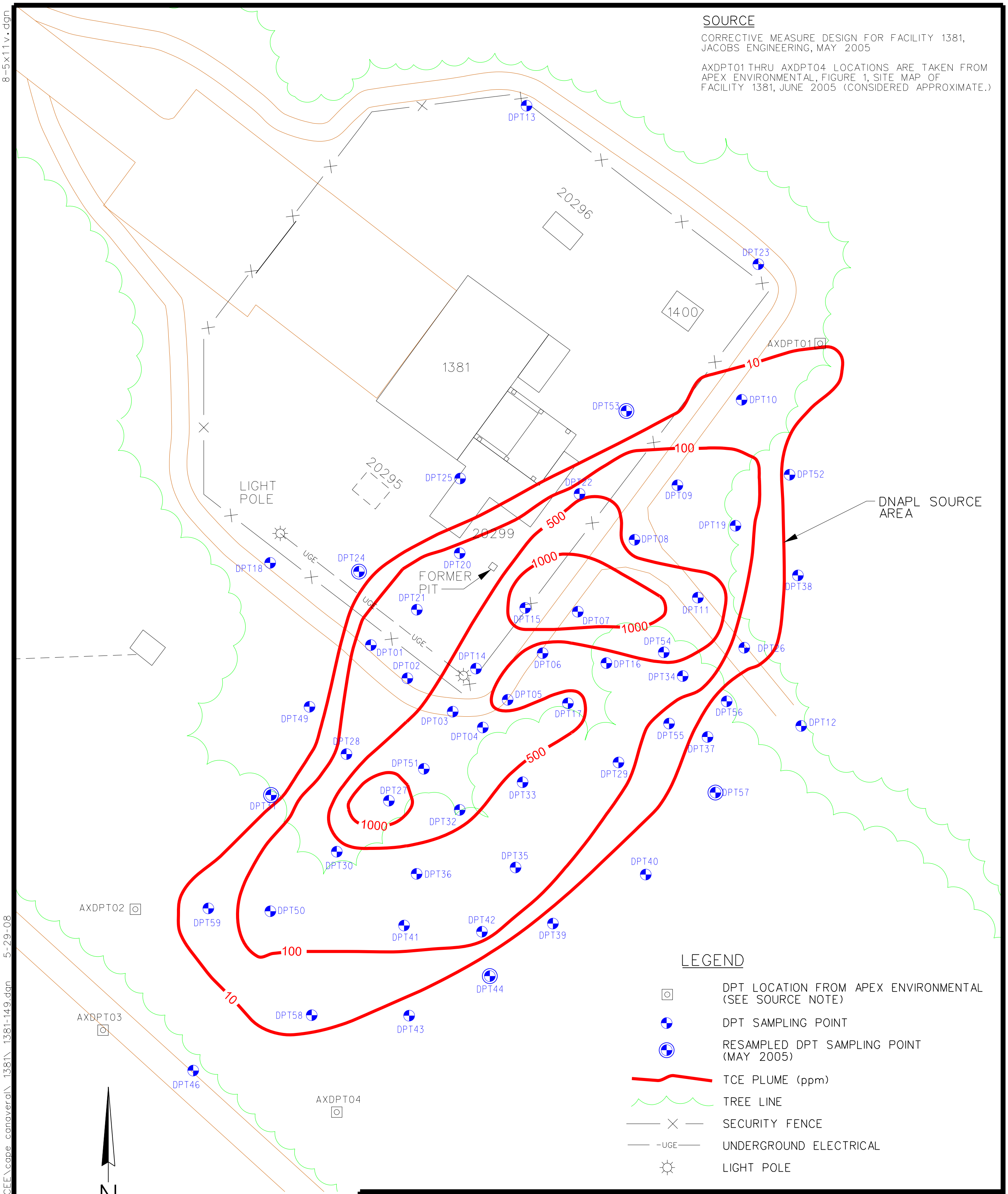
CORRECTIVE MEASURE DESIGN FOR
FACILITY 1381, JACOBS ENGINEERING, MAY 2005

TETRA TECH
OAK RIDGE, TENNESSEE

CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 1-2
SITE MAP

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\ 1381\ 1381-052.dgn 10-3-07 CMI Report 8-5x11v.dgn



SOURCE

CORRECTIVE MEASURE DESIGN FOR FACILITY 1381,
JACOBS ENGINEERING, MAY 2005

AXDPT01 THRU AXDPT04 LOCATIONS ARE TAKEN FROM
APEX ENVIRONMENTAL, FIGURE 1, SITE MAP OF
FACILITY 1381, JUNE 2005 (CONSIDERED APPROXIMATE.)

LEGEND

⊡ DPT LOCATION FROM APEX ENVIRONMENTAL (SEE SOURCE NOTE)

⊕ DPT SAMPLING POINT

⊕ RESAMPLED DPT SAMPLING POINT (MAY 2005)

TCE PLUME (ppm)

TREE LINE

——×—— SECURITY FENCE

——UGE—— UNDERGROUND ELECTRICAL

☼ LIGHT POLE

TETRA TECH
OAK RIDGE, TENNESSEE

CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 1-3
TCE SOURCE AREA

CAD FILE NO./DATE:k:\dan\AFCEE\cape canaveral\ 1381\ 1381-149.dgn 5-29-08 8-5x11v.dgn

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2.0 DESIGN AND CONSTRUCTION

2.1 DESIGN SUMMARY

This section details the remedial equipment that was used for the source area remediation via in-situ soil mixing with injection of steam, hot air, and ZVI at Facility 1381. The process flow diagram (PFD) and piping and instrumentation diagram (P&ID) are illustrated in Figure 2-1 and Figure 2-2, respectively.

2.1.1 Injection Equipment and Materials

The following section describes the method and equipment/materials that were utilized to inject steam, hot air, and ZVI slurry during operation.

2.1.1.1 Hot Air/Steam Equipment

Hot air was generated using ambient air from two electrically powered air compressors, each with a maximum volumetric flow rate of 600 cfm at an operating pressure 150 pounds per square inch gauge (psig). A filter bank was utilized in line prior to the manifold and was utilized to remove any oil from the generated air flow. Air exited the compressors at a temperature of approximately 150^{o}F and flow control was performed remotely by the operator. Injection pressure, temperature, and flow were electronically transmitted and recorded in a database. The photographs of the equipment are presented in Appendix A.

The steam generating equipment consisted of two steam boilers with power ratings of 400 hp and 250 hp, both operating at 135 psig at a temperature of 385°F. The boilers were fired using #2 diesel fuel. Base supplied potable water entering the boiler units was conditioned by a water softening ion exchange unit to prevent scaling of the units. At the maximum operating capacity, the boilers' output exceeded 10.5 million British Thermal Units (MBTUs) per hour (MBTU/hr). Six inch braded steel and rubber hosing transferred the steam from the boilers to the manifold and a 4-inch rubber hose was utilized from the manifold to the drill stem (Kelly Bar). The maximum flow rate obtainable was approximately 13,500 pounds per hour (pph) of saturated steam. Steam injection flow rate was controlled remotely by the operator. Steam injection pressure, temperature, and flow were electronically transmitted and recorded in a database.

2.1.1.2 Zero Valent Iron Injection Equipment and Slurry

Thermal treatment using in-situ soil mixing with steam and hot air injection has been shown to follow pseudo-first order kinetics (BEM, 2005). This indicates that as treatment time increases, the amount of material removed will continue decreasing exponentially. Therefore, in order to maximize contaminant mass removal from each cell and minimize thermal treatment time and costs, a ZVI slurry was prepared and injected throughout the treatment volume after thermal treatment was complete. The ZVI slurry components consist of -50 mesh grade ZVI powder, water, and guar gum that were mixed in the batch plant and pumped down hole through associated piping. Details of the batch plant, ZVI slurry, and associated pipes and pumps are discussed further in Section 3.4.2.3 – Iron Preparation and Treatment.

2.1.1.3 Mixing Equipment and Tools

Major equipment and tools that were utilized for soil mixing included the crane, swivel, auger, Kelly Bar, drill platform, and timber mats. The crane that was used for drilling is a Manitowoc 777 series crane. The swivel was attached to a hook at the end of the crane boom cables and served as the connection point for the Kelly Bar, allowing the bar to rotate freely while drilling. In addition, the swivel (2-inch ID) served as the injection point of material into the Kelly Bar from the 4-inch diameter flexible hose connected to 4-inch diameter hard pipe along the crane boom. The Kelly Bar was 75 feet long with a 13.5 inch x 13.5 inch cross-sectional area. The interior of the hollow Kelly Bar consisted of a 3-inch diameter pipe that transferred the injection material to the auger.

The auger was a multi-bladed 8-foot diameter auger with ½-inch injection ports along both blades for a total of 14 ports. A spare auger of the same diameter was maintained on-site and frequently placed into service for maintenance/welding on the original auger. The Kelly Bar and auger were supported by a high-torque transmission platform attached to the crane. The range of torque exerted by the drill transmission for normal operations was between 100,000 and 453,000 foot-pounds. The crane, supporting the mixing equipment, traversed the site upon 1 foot high by 4 foot wide by 21 foot long hardwood timber mats in order to ensure verticality during drilling and crane traction during movement. Auger depth was determined through the use of a wire-guided position indicator. This measurement was electronically transmitted and recorded in a database during treatment.

2.1.2 <u>Vapor Extraction Equipment</u>

The following section describes the method and equipment that were utilized in extracting and conditioning volatilized contaminants.

2.1.2.1 Vapor Extraction and Conditioning Equipment

As the mixing blade rotated and steam and hot air were injected in the soils, volatilized contaminants escaped to the surface through the annulus created by the rotating square Kelly Bar. The contaminants were collected within a shroud maintained under one to five inches of water vacuum that covered the active treatment area. The shroud was 12 feet in diameter and provided the ability to capture off-gases beyond the 8-foot diameter drilling blades, minimizing fugitive emissions.

The vapors were removed from the shroud by a variable frequency drive blower that was a component of the trailer-mounted vapor conditioning system (VCS). The blower provided for the transport of vapor from the shroud to the VCS and through the treatment system. Vapors generated during the soil mixing process were captured inside the shroud and drawn by the vacuum through a 10-inch diameter flexible hose connected to a 10-inch diameter steel pipe connected ahead of the VCS. Sections of the flexible hose were either added or taken away as treatment progressed throughout the site.

The VCS consisted of the pre-chiller, knock-out (KO)/demister tank, coarse particle filter, chiller, reheater, and the fine particle filter. The vapor entering the shroud from the annulus is saturated with water; therefore, the vapors initially flowed through a liquid vapor KO tank to remove large dirt particles and the condensed moisture. The vapors then flowed from the KO tank into a pre-chiller, which provided an off-gas temperature drop from 170°F to 160°F, and then through 10 to 20 micron filter and into the chiller unit used to cool the gas temperature from approximately 160°F to less than 100°F at a flow rate of approximately 1,500 cfm. Condensate water generated by the KO tank, pre-chiller and chiller were stored in a temporary 1,755 gallon holding tank for on-site air-stripping treatment by a mobile treatment system. Cooled vapor then entered the re-heater (housed in the same unit as the chilling elements) to raise the off-gas temperature by 10-12°F to reduce the off-gas relative humidity to 80%. Vapor then flowed through a 1 micron filter to remove the fine particulates prior to entering a Y junction at the end of the VCS trailer, which were controlled by two pneumatically controlled valves diverting the flow either to the vapor phase, granular activated carbon (GAC) beds or the flameless thermal oxidizer (FTO) treatment systems. Control of the equipment was performed remotely by the operator through an interface with the VCS Programmable Logic Controller (PLC) located on the trailer. Data that were recorded from instruments on the VCS include pressure drop over the chiller/heat exchange unit, vapor temperature after chiller, vapor temperature and relative humidity after reheater, blower frequency, and open/closed status of the valves. The following information provides detailed VCS equipment sizes, models, and specifications.

- **KO Tank** - The KO tank was 44 inches in diameter by 72 inches in height with a 12 inch slip hose connection for processing air in and out. Included on the unit were a 4 inch sludge drain port with a gate valve, 1 inch connection for feeding to a transfer pump, 2 ¼ inch gauge taps, liquid transfer gear pump with ½ hp 115/1/60 motor, and three float switches for pump on/off control and high water alarm. The KO tank was equipped with a demister pad to remove additional water droplets and dust particles.

- **Pre-Chiller Unit –** The pre-chiller unit was designed in an independent housing constructed of 14 gauge galvanized steel. The pre-chiller unit utilized the same air cooled chiller described below for the primary chiller. The chiller unit was designed to cool the incoming air from 170°F to the VCS operating temperature of 160°F.

- **Coarse Particulate Filter** – A 25 inch by 16 inch by 2 inch, 10 – 20 micron filter was included in the chiller/heat exchanger housing.

- **Chiller/Heat Exchange Unit** – The chiller elements and heat exchange coils were designed in the same housing along with a particulate filter. The housing for mounting the elements and coils, inlet filters, inlet and outlet (12 inches round) connections was 14 gauge galvanized steel. The chiller unit was a Trane™ 70 ton (840,000 BTU/hr) air cooled water chiller using Freon 22 as the cooling agent with chilled water entering the cooling elements at 40°F and exiting at 60°F. The heat exchanger was an Aerofin Type Rf coil 34.9 inch by 25 inch, 6 row with copper fins on 5/8 inch copper tubing with a galvanized steel case. The drain pan was 304 stainless steel, 14 gauge, with a ¾ inch drain connection. The heat exchanger was designed to produce 150,000 BTU/hr using 180°F from the boiler preheat tank. A hand valve on the upstream side of the reheater controlled the water flow and subsequent heating capacity.

- **Fine Particulate Filter** - The final filter prior to entering the vapor treatment unit was a 24 inch square by 4 inch thick, 1 micron fiberglass mesh filter housed in 16 gauge galvanized steel.
- **Blower** – The blower used to provide the vacuum was rated for 1,800 cfm at 31 inches total static pressure at 13.4 brake horsepower (bhp) using a 15 hp 230-460/3/60 VAC TEFC premium efficiency motor. A National Electrical Manufacturers Association (NEMA) 4 rated Variable Frequency Drive (VFD) motor speed control rated for a 15 hp motor and 460 VAC/3 phase input from a generator.
- **Pneumatic Control Valves** – Two pneumatically air-actuated valves directed the vapor flow to the FTO or to the GAC beds. The valve in-line with the FTO was normally open (spring loaded open) and the valve to the GAC bed was normally closed (spring loaded closed). A 30-gallon air receiver tank was maintained at a pressure of 100 psig to provide air to the valves for control.

2.1.3 Vapor Treatment Equipment

The following section describes the primary and secondary equipment/materials that were utilized to treat the conditioned contaminant vapor stream.

2.1.3.1 Primary Treatment - Flameless Thermal Oxidizer

The conditioned vapor stream was primarily treated by the FTO model Edge QR™ unit designed by Alzeta Corporation. The FTO was trailer mounted and includes the oxidizer, integral quench chamber, acid gas scrubber, and a PLC. An air bleed valve was placed ahead of the reheater on the VCS trailer to ensure that the air flow to the thermal oxidizer unit was controlled. After the off-gas was burned in the flameless reactor at 1,700°F, it flowed into a quench chamber where it was cooled to 180°F before being neutralized in the acid gas scrubber. The gas from the quench chamber was driven by a secondary blower through the 25-foot packed scrubber column before venting to the atmosphere. Fuel for the FTO was provided by three 1,000-gallon propane tanks. The unit that was utilized for vapor treatment at Facility 1381 was rated at 1500 cfm, 25,000 ppm input of VOCs, and 99% destruction with a 50% turndown.

The FTO burning process generated acid gases from the destruction of TCE, Freon 113, and other chlorinated VOCs. The destruction of TCE and its daughter products (DCE and vinyl chloride) produced hydrochloric acid (HCl). Freon 113 contained both chlorine and fluorine atoms. Its destruction generated both HCl and hydrofluoric acid (HF). As mentioned above, the FTO was equipped with an acid gas scrubber to remove the HCl and HF gases from the vapor stream effluent prior to discharge into the atmosphere. The acid gas scrubber used water for the scrubbing which subsequently became acidic. Sodium hydroxide (NaOH) was metered into the re-circulating tank to raise the pH above 6. The amount of VOC material emitted to the atmosphere from the FTO was less than 1 pound total per day and no more than 0.2 pound per hour. Water generated from the scrubber blowdown was stored on-site in two 20,000-gallon frac tanks connected in parallel and tested to satisfy pre-treatment requirements and discharge parameters established by the Process Waste Questionnaire (PWQ) and set in the Technical Response Package (TRP); both can be found in Appendix B. The water stored in the frac tanks was removed and discharged at the Trident Industrial Wastewater Treatment Facility (see Figure 1-1).

2.1.3.2 Secondary Treatment – Granular Activated Carbon

GAC absorption vessels were used for backup treatment purposes when the FTO shut down. The GAC unit consists of two vessels connected in series; each vessel has the capacity for 13,000 pounds of carbon. A flame ionization detector (FID) was connected to the exhaust stack of the lag carbon vessel as well as connected to the exhaust stack of the FTO to analyze potential organic material exhaust.

2.1.4 Mobile Water Treatment System

A mobile treatment system consisting of a 925-gallon temporary holding tank and a three-tray air stripper was used to treat the condensate water from the VCS unit. Condensate water was treated on-site for a minimum of 12 hours in a closed loop system as part of the off-gas treatment process. Once treated, the water was discharged into the on-site 20,000-gallon frac tanks.

2.1.5 Process Monitoring and Control System

A Supervisory Control and Data Acquisition (SCADA) system was used to monitor field instruments and process equipment associated with the in-situ soil treatment system at the CCAFS Facility 1381. The SCADA system collected data for trending and reporting, as well as provided process information for operator control. The system integrated existing PLCs with new workstations, servers and Iconics Genesis SCADA software. The SCADA/PLC network diagram is illustrated on Figure 2-3.

2.1.5.1 General Description

This SCADA system was utilized for data acquisition and historical collection for devices utilized in the treatment process for the following systems:

- LDA for mixing the soil and injecting steam and hot air,
- Steam generators (10.5 MBTU/hr),
- Air compressors (750 scfm each),
- Vapor extraction and conditioning system,
- Vapor treatment system,
- ZVI slurry injection system,
- Vapor sample conditioning system, and
- Analytical measurement system [gas chromatograph (GC) and FID].

2.1.5.2 System Description

The system:

- Provided an interactive illustration of the treatment system process for operator information and process control,
- Provided equipment status and monitoring functionality,
- Acquired process data for real-time and historical analysis for decision making capabilities,
- Tailored procedural control of the process via parameter modification, and
- Provided advanced reporting, charting, and data analysis capability.

The SCADA system collected process data, as transmitted from process instrumentation, and made the process data available for the following:

- Display to system users for real-time decision making capabilities,
- Historical data collection, and
- Reporting, charting, and analysis.

User Interface graphic screens were designed to facilitate both general process awareness and specific process control tasks. Interface to PLCs and other control systems was over Ethernet network connections. Interface to local instruments and control devices was analog and/or digital process control loops.

The SCADA/HMI system software (Iconics Genesis32) consisted of the following modules:

- GraphWorx,
- TrendWorx,
- AlarmWorx,
- DataWorx,
- ReportWorx, and
- Web HMI.

The SCADA system utilized Microsoft SQL 2000 to store historical data.

2.1.5.3 System Functions and Capabilities

<u>Navigation</u>

A menu system allowed the operator to change screens to the primary operational areas. Additional menus and pop-ups gave access to the monitoring screens and historical data trending screens.

Monitoring Screens

Each operational screen consisted of an overview screen which detailed the values of all instruments and provided easy access to available historical and real-time trending data.

Historical Data Trending

All historical analog data were trended versus time within the system and were viewed in line chart format. Historical data were kept in circular files on each local workstation. The process data were collected and stored every second and copied to a network drive. Archived data were stored for display via a web interface.

Database

The monitored process variables were written to a Microsoft SQL database.

2.1.5.4 USER Interface

The SCADA servers ran Windows Server 2003 with SQL 2000.

2.1.5.5 Server Locations

The SCADA servers were located one each in the Data Acquisition System (DAS) trailer as well as Tetra Tech office. SCADA server 1 was connected via a network switch to the redundant SCADA server 2.

The Webserver, currently located at the Tetra Tech facility in Oak Ridge Tennessee, runs Windows Server 2003 with SQL 2000 and the Iconics web modules. Installed on the webserver are ReportWorX and WebHMI utilized for processing data.

Standard progress reports and progress maps are generated and published on the web so that authorized users can access using a web browser over the Internet.

2.1.6 Sample Handling and Conditioning System

Gas samples from the process streams were collected at four different points for analysis by either FID or GC (Figures 2-1 and 2-2). GCs were used to detect, speciate, and quantify target analytes from the treatment process off-gas. FIDs were used to continuously monitor the effluents produced by the treatment process. Data from the FIDs and GCs were utilized to determine trends in depth, concentration, and location of contamination requiring treatment. Identified data trends in contamination enabled on-site field personnel and managers to perform real-time decisions on treating contamination. The sample extraction points included (1) the 10-inch off-gas line from shroud to the VCS, (2) inlet of the FTO, (3) the stack of the FTO, and (4) effluent from the stack of the lag vessel of the vapor phase carbon system. Due to the high moisture content expected in the sample streams of (1) and (2) above, these streams were conditioned and cooled prior to reaching the analytical units as presented in Figure 2-4.

Temperature controlled, heated sample lines carried the sample to the cooling unit to restrict condensation in the lines. The water content in the sample stream was removed in two independent parallel paths. Two dual stage heat exchange systems were provided. The first stage cooled each path at ambient temperature. The second stage was cooled thermoelectrically and controlled with independent temperature sensors and control circuitry. The goal was to condense the water from a wet gas sample with a minimal loss of the contaminant gas fraction. The separation occurred in a classical impinger which has a highly polished cylindrical surface cooled to the desired dew point temperature. The gas sample is brought to the bottom of the cylinder through an insulated tube and allowed to rise through a narrow annular area at a relatively high Reynolds number to insure the entire sample is influenced by the cold surface. The condensate falls down the cold polished surface in the form of a sheet (as opposed to droplets or the bubbling of the gas sample through the condensate) which minimizes the surface area in contact with the gas sample. The temperature of the cylindrical condensation surface of the heat exchangers is maintained through intimate contact with aluminum heat transfer blocks. The first of the heat transfer blocks in each line is cooled by direct contact with the fan cooled heat sink. The temperature of the first of the two heat exchangers was about 18°F above the temperature of the air passing through the heat sink when under full load conditions. (The temperature differential depends on the amount of heat that is being extracted from the sample, which is a function of the water content of the sample.) The second heat exchanger in each line is cooled by the use of thermoelectric elements to a controlled temperature of 5°C. Once the stream was cooled, it delivered a clean, dry sample stream to the FID and GC for analysis.

2.2 CONSTRUCTION AND IMPLEMENTATION

2.2.1 Treatment Cell/Zone Configuration and Pre-Treatment Cell Assessment

The following section details the proposed treatment cell and treatment zone configuration based on data collected for previous reports (RFI and CMS) and the CMD (Jacobs, 2005). Due to the varying vertical nature of the contamination, treatment zones were established to most effectively target the level of contamination in the subsurface. The treatment zones were based on 10 mg/L TCE contour.

2.2.1.1 Facility 1381 Treatment Cell/Zone Configuration

The source area, illustrated in Figure 1-3, was defined as the horizontal extent of TCE concentrations in groundwater greater than 10 mg/L, resulting in an estimated horizontal area of approximately 1 acre. The original estimated number of cells required to treat the area was 892 with an 8 foot auger utilizing a 6% overlap. However, based on knowledge obtained from treatment at Security Police Confidence Course (SPCC) and review of site characterization data, it was determined that some low contamination areas around the perimeter did not require treatment.. Therefore, the revised source area only required 785 cells to treat. The footprint of each treatment cell is 50.24 ft^2 (without overlap). Figure 2-5 illustrates the treatment cell layout.

Existing data indicated that the thickness of the source area varies vertically across the site. Based upon this evidence, the source area was divided into five treatment zones (Figure 2-5). The planned treatment thickness for each zone is shown in Table 2-1. Slight variations made in the field were based on the treatment protocol.

Table 2-1. Facility 1381 Treatment Zone Configuration

Treatment Zone	Area (ft^2)	Treatment Depth (ft)	Volume (yd^3)	No. of Proposed Treatment Cells
Zone 1	3,717	5-20	2,065	74
Zone 2	3,216	10-20	1,191	107
Zone 3	7,132	10-30	5,283	142
Zone 4	20,095	10-40	22,328	400
Zone 5	3,114	10-50	4,614	62
Totals	37,274	-	37,283	785

2.2.2 Permits

The following permits were obtained for Facility 1381 prior to beginning any work at the site.

2.2.2.1 Excavation and Block Dig Waiver Permits

An Excavation Permit was obtained to facilitate well installation and sampling activities, trenching for Block Dig Waiver Permit, trenching for electrical conduit lines and electrical vault installation. The Excavation Permit activities included a utility locate performed by base personnel, followed by “no impact” approval from various base entities. After approval and Excavation Permit package submittal, the Excavation Permit was issued for the duration of the project.

A Block Dig Waiver Permit was established around the source treatment areas to minimize the amount of down days due to range critical and launch days. Base personnel initiated an Operational Risk Management determination which in turn facilitated the granting of the Block Dig Waiver Permit. The Block Dig Waiver Permit activities included a utility locate performed by Base personnel, followed by trenching around the proposed area to a depth of 5 feet to ensure utilities are not encroaching on the proposed area. Upon completion of the trench, visual inspections by the Cape Superintendent and Site Supervisor were performed. Finally, a package was submitted to the appropriate Base authority briefly describing the project activities and schedule, utility locate results, trenching activities results (including a photo log), and site maps. After the locations were cleared, the Block Dig Waiver Permit was signed by the appropriate Base authorities prior to issuance. Issuance of the Block Dig Waiver Permit did not exempt drilling operation during launch days or shuttle landing days. The Block Dig Waiver Permit is attached in Appendix C.

2.2.2.2 Federal Aviation Administration Notification

The Federal Aviation Administration (FAA) requires notification for any construction or alteration up to 20,000 feet from an airport that is operated by an armed force of the United States. A Notice of Proposed Construction or Alteration was submitted to the FAA at least 30 days prior to the erection of the LDA crane at the site. The distance of the LDA rig at Facility 1381 from the skid strip on CCAFS is approximately 2,500 feet. At this distance, the FAA requires a notice to be filed if the construction or alteration exceeds a height greater than an imaginary surface extending outward and upward at 100 to 1 from the nearest point of the runway. At the maximum height, the crane reached approximately 140 feet above ground surface. The maximum allowable height (25 feet for Facility 1381) was exceeded and required notification. The FAA notification and approval documentation are attached in Appendix D.

2.2.2.3 Publicly Owned Treatment Work Discharge

A significant amount of process wastewater was generated and stored on-site requiring disposal. Process wastewater was disposed of at the Trident Industrial Wastewater Treatment Facility (Figure 1-1). The administrative requirements of the 45th Space Wing and the specific requirements of the permit, the installation's wastewater pre-treatment plants have specific applicability to discharge of scrubber water. Pre-treatment requirements and discharge parameters were established through the PWQ and TRP process provided in Appendix B.

2.2.2.4 Surface Water Runoff

The Facility 1381 construction site's total disturbed area was greater than 1 acre; therefore, under State guidelines, the construction site qualified for a National Pollutant Discharge Elimination System (NPDES) Generic Permit for Storm Water Discharge from Large and Small Construction Sites. The permit required the implementation of proper erosion control practices and materials in order to minimize sediment erosion from the Facility 1381 construction site during periods of rainfall events. In order to obtain a permit, a Storm Water Pollution Prevention Plan (SWPPP), which identifies the practices and materials that were implemented at the Facility 1381 construction site, and a Notice of Intent were developed and submitted to the State. The permit issuance and acknowledgement letter from the State is presented in Appendix E as well as the SWPPP.

2.2.2.5 Flux Well Construction

Permits for the construction and installation of flux wells at Facility 1381 were secured by a driller licensed in the State of Florida. All appropriate information was submitted to the Saint Johns River Water Management District (SJRWMD) to obtain the necessary well construction permits prior to construction and installation of the flux wells.

2.2.2.6 Welding and Hot Work Permit

A Welding and Hot Work Permit was obtained prior to performing any welding activities at the site and renewed throughout the project. The Contractor contacted the Cape Fire Prevention Scheduler and made an appointment for a Fire Inspector at least 24 hours in advance of the work being performed. The Fire Inspector viewed the proposed work and completed the permit on-site and notified the Fire Prevention Office. Welding and Hot Work Permits are included in Appendix F.

2.2.2.7 Underground Injection Control

FDEP does not require an Underground Injection Control (UIC) permit for the injection of iron into the subsurface if the remediation is being implemented under a remedial action plan or other enforceable mechanism approved by the FDEP. Remediation of Facility 1381 is being conducted under the RCRA CAP and in accordance with FDEP-approved CMD. Therefore, UIC permit is not required for this site.

2.2.3 Site Preparations

Several site activities were implemented prior to mobilization of treatment equipment. These activities included:

- Site Surveying
- Utility Locating
- Well Abandonment
- Demolition and Clearing
- Geophysical Survey and Removal
- Site Filling, Grading, and Leveling

2.2.3.1 Site Surveying

An initial site survey of Facility 1381 was completed prior to any site disturbance. The survey established locations of pertinent site features (structures, utilities, wells, and drainage features) as well as establishing baseline site elevations. Three permanent survey monuments were established and used throughout the implementation to provide consistent control.

The survey was used to establish and confirm the location of the source area along with laying out individual treatment cell locations and performance sample locations. Because the planned depth of treatment was all based upon below ground surface elevations, and the understanding that the site will be re-graded prior to set-up of treatment equipment, the elevation survey was also used to correct final depths of treatment to be consistent with the design depth intervals. The survey was also used to confirm and correct sampling depths of baseline and performance sampling, which again were all originally based upon below ground surface elevations.

2.2.3.2 Utility Locating

Utilities across the site were located and marked to support the upcoming mobilization of treatment equipment including initial site preparations along with supporting the acquisition of dig permits/waivers. No “live” utilities were found within the area planned for treatment or within a 50 foot perimeter of the planned treatment area. Utilities around the site were all marked.

2.2.3.3 Well Abandonment

All subsurface obstructions could be detrimental to the operation of the subsurface mixing equipment. Through history of environmental assessments, and pilot studies, Facility 1381 had various well and well-like structures installed in various diameters and lengths. 112 wells and/or well-like structures fell either within the footprint of the planned treatment area, or within 30 feet of the planned treatment area. Based upon these locations and the potential of being an obstruction to the mixing equipment, these wells were abandoned. The abandonment consisted of pulling or over-drilling the wells for casing extraction. The abandoned wells/well structures are listed below and presented in Figure 2-6.

- Seventeen 2-inch and three 3-inch monitoring wells associated with the RCRA Facility, and CMS field investigations
- Ten flux wells
- Four multi-chamber wells
- Eight 1.25-inch piezometer/flow sensor wells
- Forty-four 1-inch diameter Geoprobe micro-wells
- Seven air-sparge wells, 4-inch polyvinyl chloride (PVC) with 0.25-inch stainless inserts
- Eighteen 1-inch air sparge monitoring wells
- Fourteen soil gas monitoring points

Well abandonment was completed by a licensed water well contractor. The well abandonment logs are presented in Appendix G.

2.2.3.4 Demolition and Clearing

The majority of the demolition of structures impacting the source area, including adjacent perimeter, was completed by Spec Pro, Inc. (Base contractor). The demolition included (illustrated on Figure 2-6):

- Removal of security fence around the facility
- Removal of light pole and associated feed line
- Removal of equipment shed, safety shower, and electrical panel, including all underground utilities and concrete pad.
- Removal of small concrete sump south of facility
- Removal of free standing steel-framed enclosure positioned behind the 1381 building extension. This demolition included structural steel, fiberglass siding, cement/asbestos roof panels, and removal of concrete foundation supports.

- Two areas south/southwest of the facility with remnants of remedial/pilot systems were removed. These included pumps, air stripper, electrical panels, various appurtenances, and concrete pads.

Also included as part of the demolition were the leftover foundations of an antenna tower. There were three fully buried concrete foundation supports, approximately 9 feet x 9 feet x 9 feet. These supports were removed by Apex Environmental Inc. All of the demolition debris (both contractors) was properly disposed of at the Base's construction and debris landfill.

An area approximately 84,000 square feet (almost two acres) was cleared and grubbed to provide ample area for treatment, equipment lay-down and adjacent site operations. Figure 2-6 illustrates the areas which were cleared.

2.2.3.5 Geophysical Surveying and Removal

Again, subsurface obstructions could be detrimental to the operation of the subsurface mixing equipment. In order to provide additional assurance the subsurface is clear, a geophysical investigation was conducted across the source area including some additional perimeter. The geophysical investigation area was a plot approximately 200 by 400 feet (~2 acres). Of continued concern was the possible presence of construction debris, building sub-foundations, foundation supports, leftover remedial equipment/objects, well material, etc. buried within the boundaries planned for treatment which would impact the mixing equipment. The investigation used time domain electromagnetics (TDEM) via an EM-61 Buried Metal Detector (EM-61) and ground penetrating radar (GPR).

The EM-61 survey was conducted along parallel lines spaced five feet apart collecting readings every 0.62 feet. A total of 22,556 data readings were collected and contoured, shown on Figure 2-7. The GPR survey was conducted along a series of perpendicular transects spaced five feet apart. Figure 2-8 shows the GPR transects as well as anomalies identified via both GPR and EM-61.

All suspected debris locations identified across the surveyed area (illustrated on Figure 2-8) were investigated either by hand digging or the use of a mini-excavator. Debris, including concrete rubble, rebar, wire mesh, guide wire tie-downs, well material, tubing/hoses, and general trash, was excavated and removed from the area. The geophysical investigation report is presented in Appendix H.

2.2.3.6 Site Filling, Grading and Leveling

Prior to the initiation of equipment mobilization and treatment, the source area and adjacent lay-down areas had to backfilled and leveled. Backfilling/borrowing of grade was needed in the lower lying portions of the source area, to the southwest, in order to raise the grade establishing a vadose zone of approximately five feet. Ample vadose zone is required to safely and adequately transfer and capture steam at the surface during treatment operations. Leveling of the site was needed to provide verticality of operational treatment equipment (mixing/augering) during operation and to provide an even foundation for all of the support equipment.

All fill material used for initial leveling was borrowed or sculpted from “higher” areas immediately adjacent to the source area.

2.2.4 Mobilization

The following section describes the activities associated with mobilization and setup of the remedial equipment at the site.

2.2.4.1 Site Equipment and Materials Lay-down Areas

Site grading and leveling of the equipment and material lay-down and source treatment areas were performed prior to equipment being mobilized to the site. The equipment was positioned in pre-determined areas. Figure 2-9 illustrates the locations of the pre-determined equipment lay-down areas for Facility 1381. In addition, equipment and material storage areas, vehicle parking areas, and utility locations are also illustrated on Figure 2-9.

2.2.4.2 Equipment Setup

All equipment was inspected for damage prior to being assembled and integrated. Equipment requiring electrical connections was connected and/or approved by an electrician licensed in the State of Florida. Connection lines (electrical, propane, water) were buried, wherever possible, to minimize the amount of ground clutter around the equipment and to prevent trip hazards. Boiler connections were performed by a licensed boiler operator. All trailer-mounted equipment was securely anchored to the ground to prevent movement during elevated wind events.

2.2.4.3 Utilities

At Facility 1381, a high voltage transformer (substation 20296, Figure 2-9) was connected to the project transformer in order to supply adequate power to the equipment. All electrical high voltage connections were performed by the Base High Voltage Department.

Water was provided through a connection with the Base's fire water system available on the 1381 site. Pre-conditioning of the water supply, through an ion-exchange system, was performed on water entering the boilers and quench system associated with the oxidizer in order to prevent scaling of the units.

2.2.4.4 Site Zones

Support zones, contamination reduction zones (CRZs), and exclusion zones (EZs) were established at the site to minimize the potential human exposure to VOCs during the remedial activities (Figure 2-10). Temporary fencing was constructed around the zones and signs posted to keep unauthorized personnel from entering the zones. Daily sign-in sheets (Volume IV) were posted at the entrances of the site, and all personnel were required to sign in prior to entering or leaving the areas. Support zones were established containing the remedial and supporting construction equipment (excavators, man-lifts, loaders, etc.), safety and medical materials (eye wash stations, first aid kits, towels, fire extinguishers and decontamination supplies), and materials storing areas. EZs were established at the areas directly related to the soil mixing above the source treatment area. The EZs were delineated through the use of barrier fencing, signage, and caution tape. Access to this area was limited to essential operational personnel involved in the mixing operation. Personnel entering this area were required to wear required personal protective equipment (PPE). Access to the EZ by foot was through the CRZs. This zone served as area for proper disposal and/or cleaning of PPE.

2.2.4.5 Dust Control and Decontamination Procedures

Dust control was implemented to minimize the amount of airborne dust particles due to the movement of equipment. Dust control was performed by water spraying of high traffic areas on an as-needed basis. Decontamination of equipment and personnel was required during various work phases. All equipment was pressure washed down prior to leaving the support zone. Personnel exiting the EZ removed and disposed the required PPE in the CRZ prior to entering the support zone.

2.2.5 Site Closure

The following section describes the activities associated with demobilization and breakdown of the remedial equipment to each site.

2.2.5.1 Site Cleanup and Demobilization

All construction debris, waste materials, and packaging material were containerized in dumpsters for off-site transportation and disposal on a daily basis. A Base-supplied contractor removed the waste from the provided dumpsters approximately once a week. Upon the completion of source area treatment at Facility 1381, electrical disconnections from the CCAFS power grid were performed by the Base High Voltage Department prior to performing any demobilization activities. Equipment disassembly and disconnections commenced once the electricity was shut off. Once power was off, equipment was disconnected, disassembled and mobilized off-site. Once all material and equipment were mobilized off-site, an orange safety fence was installed at a distance of 15 feet from the perimeter of the source area and signage was posted at the access roads to limit entry into the area.

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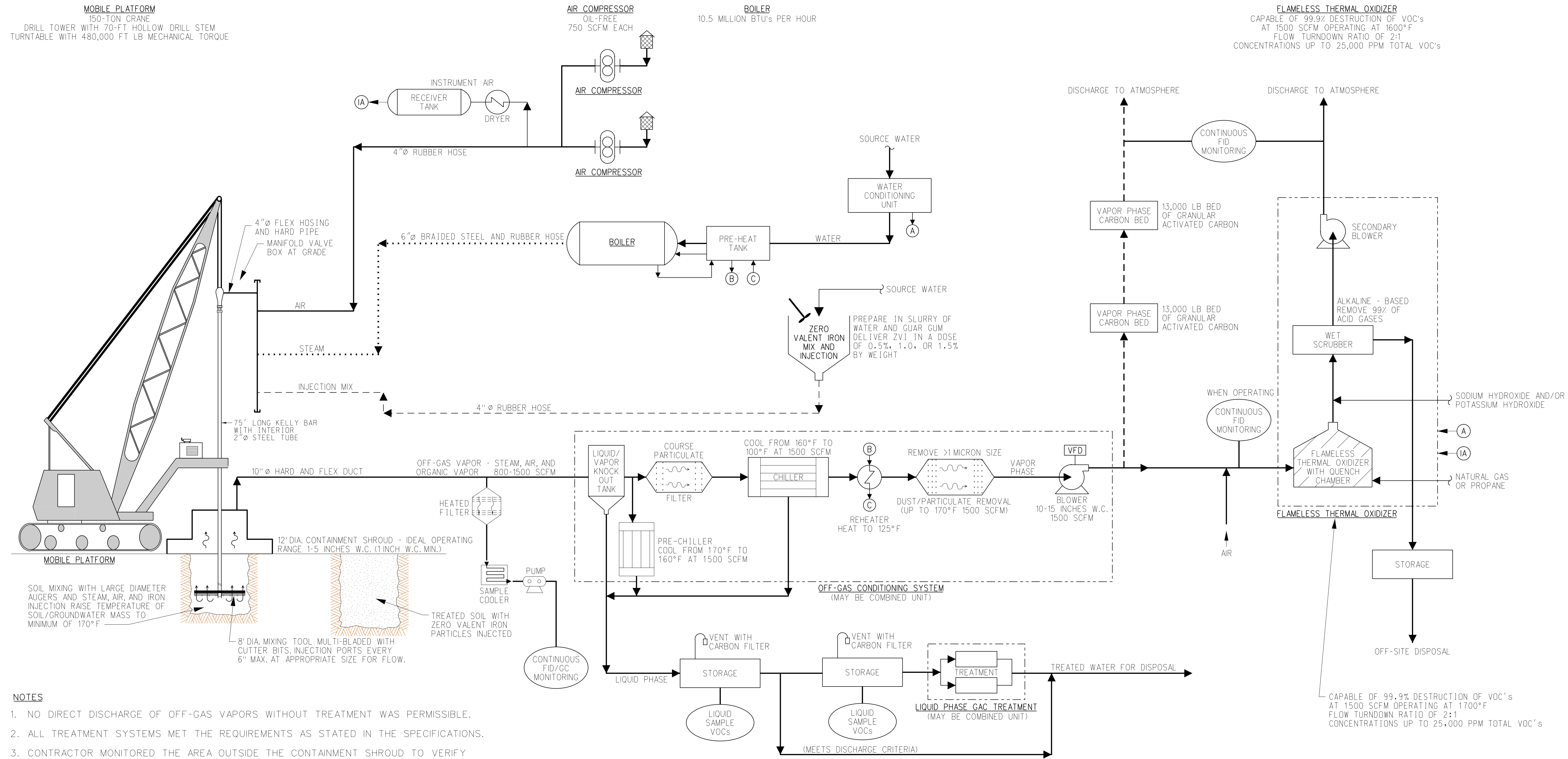
FIGURES



NOTES

1. NO DIRECT DISCHARGE OF OFF-GAS VAPORS WITHOUT TREATMENT WAS PERMISSIBLE.
2. ALL TREATMENT SYSTEMS MET THE REQUIREMENTS AS STATED IN THE SPECIFICATIONS.
3. CONTRACTOR MONITORED THE AREA OUTSIDE THE CONTAINMENT SHROUD TO VERIFY THAT OFF-GAS IS CAPTURED BY THE SHROUD.
4. THE OFF-GAS TREATMENT SYSTEM PROVIDED BY THE CONTRACTOR CONTAINED PROVISIONS FOR PRE- TREATING THE OFF-GAS AS NECESSARY AND PREVENTED INTERFERENCE WITH THE PRIMARY VAPOR TREATMENT UNIT. THE PRE-TREATMENT SYSTEM REDUCED MOISTURE, TEMPERATURE, PRESSURE, PARTICULATE, AND OTHER CHEMICAL CONTENT TO LEVELS THAT ARE WITHIN THE TREATMENT SYSTEM MANUFACTURER'S SPECIFICATIONS FOR TREATING CONTAMINANTS ENCOUNTERED AT THE SITE.
5. THE CONTRACTOR PROVIDED AND OPERATED AN INTEGRATED DATA ACQUISITION SYSTEM (DAS) CAPABLE OF CONTINUOUS MONITORING AND RECORDING ALL PROCESS CONTROL PARAMETERS AT A CENTRAL LOCATION.
6. DAS WAS CAPABLE OF PROVIDING DATA, AS INDICATED, IN REAL TIME FOR PROCESS CONTROL.
7. THE STORAGE TANKS INCLUDED VENTS CONNECTED TO CARBON FILTERS TO CAPTURE FUGITIVE EMISSIONS.
8. THE CONTRACTOR DISPOSED OF THE PROCESS WATER THROUGH THE BASE WASTEWATER TREATMENT SYSTEM, DEPENDING ON THE CONCENTRATION OF THE CONTAMINANTS OR OTHER CONSTITUENTS IN THE CONDENSATE.

LEGEND

VFD	VARIABLE FREQUENCY DRIVE
Ⓘ IA	INSTRUMENT AIR
Ⓐ	FROM WATER CONDITIONING UNIT
Ⓑ	FROM BOILER PRE-HEAT WATER TANK (180°F)
Ⓒ	TO BOILER PRE-HEAT WATER TANK (170°F)
BTU	BRITISH THERMAL UNIT
DIA or ø	DIAMETER
°F	DEGREES FAHRENHEIT
FT	FEET
FID/GC	FLAME IONIZATION DETECTOR/GAS CHROMATOGRAM
LB	POUND
SCFM	STANDARD CUBIC FOOT PER MINUTE
MIN	MINIMUM
MAX	MAXIMUM
PPM	PARTS PER MILLION
VOCs	VOLATILE ORGANIC COMPOUNDS
W.C.	WATER COLUMN
ZVI	ZERO VALENT IRON

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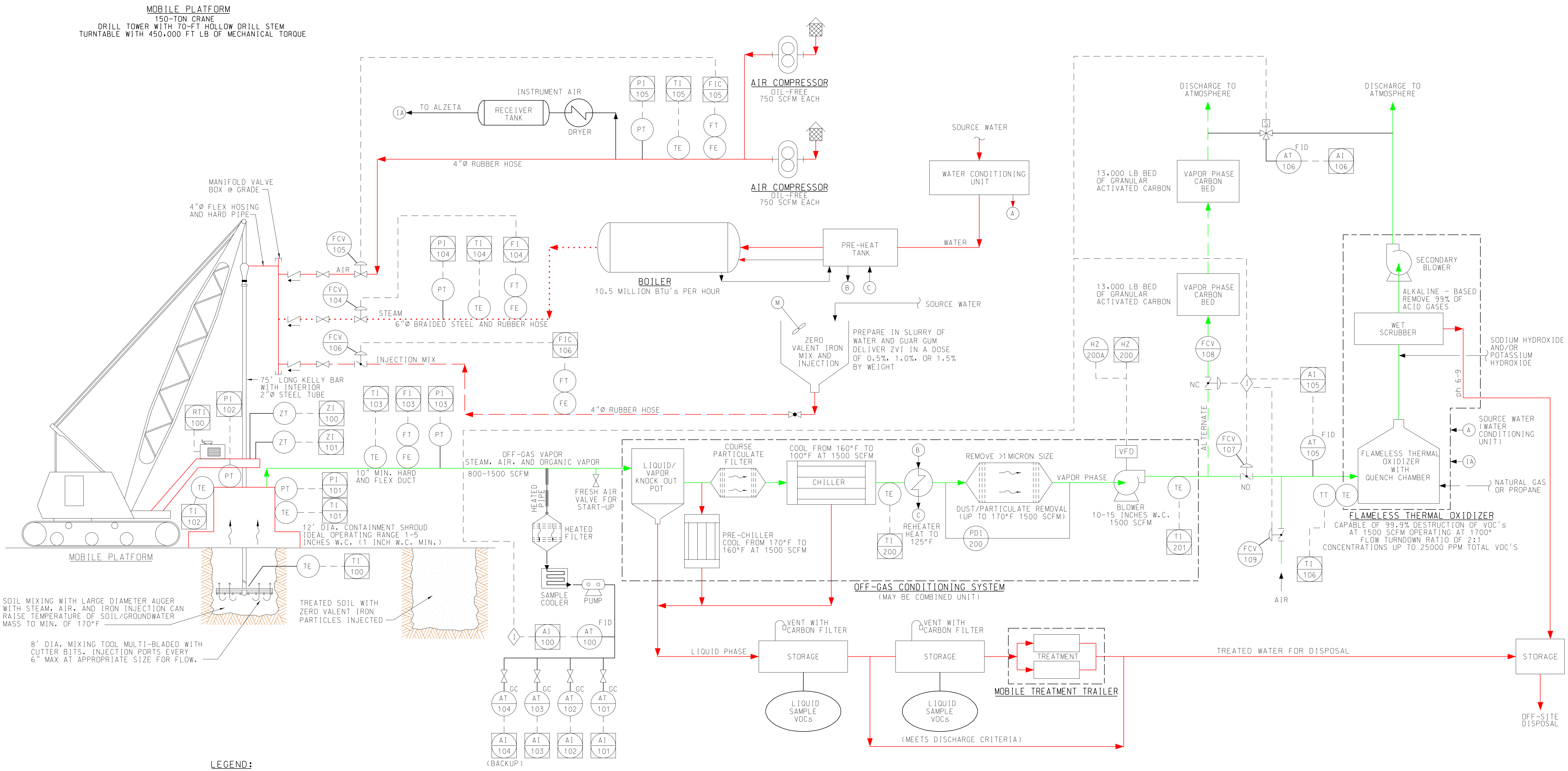
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-1
PROCESS FLOW DIAGRAM

CAD FILE NO./DATE: k:\dgn\AFCEE\cape canaveral\DA 1381\ 1381-139.dgn 5-28-08



LEGEND:

⊟	SCADA SYSTEM
⊖	PANEL MOUNTED INSTRUMENT
○	LOCAL INSTRUMENT
⋈	GATE VALVE
⊿	CHECK VALVE
⧓	BALL VALVE
⧓	BUTTERFLY VALVE
⊤	PNEUMATIC ACTUATED
S	3-WAY SOLENOID VALVE

VFD	VARIABLE FREQUENCY DRIVE
I	INTERLOCK
IA	INSTRUMENT AIR
A	FROM WATER CONDITIONING UNIT
B	FROM BOILER PRE-HEAT WATER TANK (180°F)
C	TO BOILER PRE-HEAT WATER TANK (170°F)
NC	NORMALLY CLOSED
NO	NORMALLY OPEN

AI	ANALYZER INDICATOR
AT	ANALYZER TRANSMITTER
DP	DIFFERENTIAL PRESSURE INDICATION
FCV	FLOW CONTROL VALVE
FE	FLOW ELEMENT
FI	FLOW INDICATION
FIC	FLOW INDICATION CONTROLLER
FID	FLAME IONIZATION DETECTOR
FQI	FLOW TOTALIZING INDICATION
FT	FLOW TRANSMITTER
GC	GAS CHROMATOGRAPH
HZ	FREQUENCY INDICATION AND CONTROL
PI	PRESSURE INDICATION
PT	PRESSURE TRANSMITTER
RH	RELATIVE HUMITY
RT	RUN TIME
TE	TEMPERATURE ELEMENT
TI	TEMPERATURE INDICATION
TT	TEMPERATURE TRANSMITTER
VI	VERTICALITY INDICATION
ZI	POSITION INDICATION

GENERAL ABBREVIATIONS

BTU	BRITISH THERMAL UNIT
DIA or Ø	DIAMETER
°F	DEGREES FAHRENHEIT
FT	FEET
FID/GC	FLAME IONIZATION DETECTOR/GAS CHROMATOGRAM
LB	POUND
SCFM	STANDARD CUBIC FOOT PER MINUTE
MIN	MINIMUM
MAX	MAXIMUM
PPM	PARTS PER MILLION
VOCs	VOLATILE ORGANIC COMPOUNDS
W.C.	WATER COLUMN
ZVI	ZERO VALENT IRON

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CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-2
PIPING AND INSTRUMENTATION DIAGRAM

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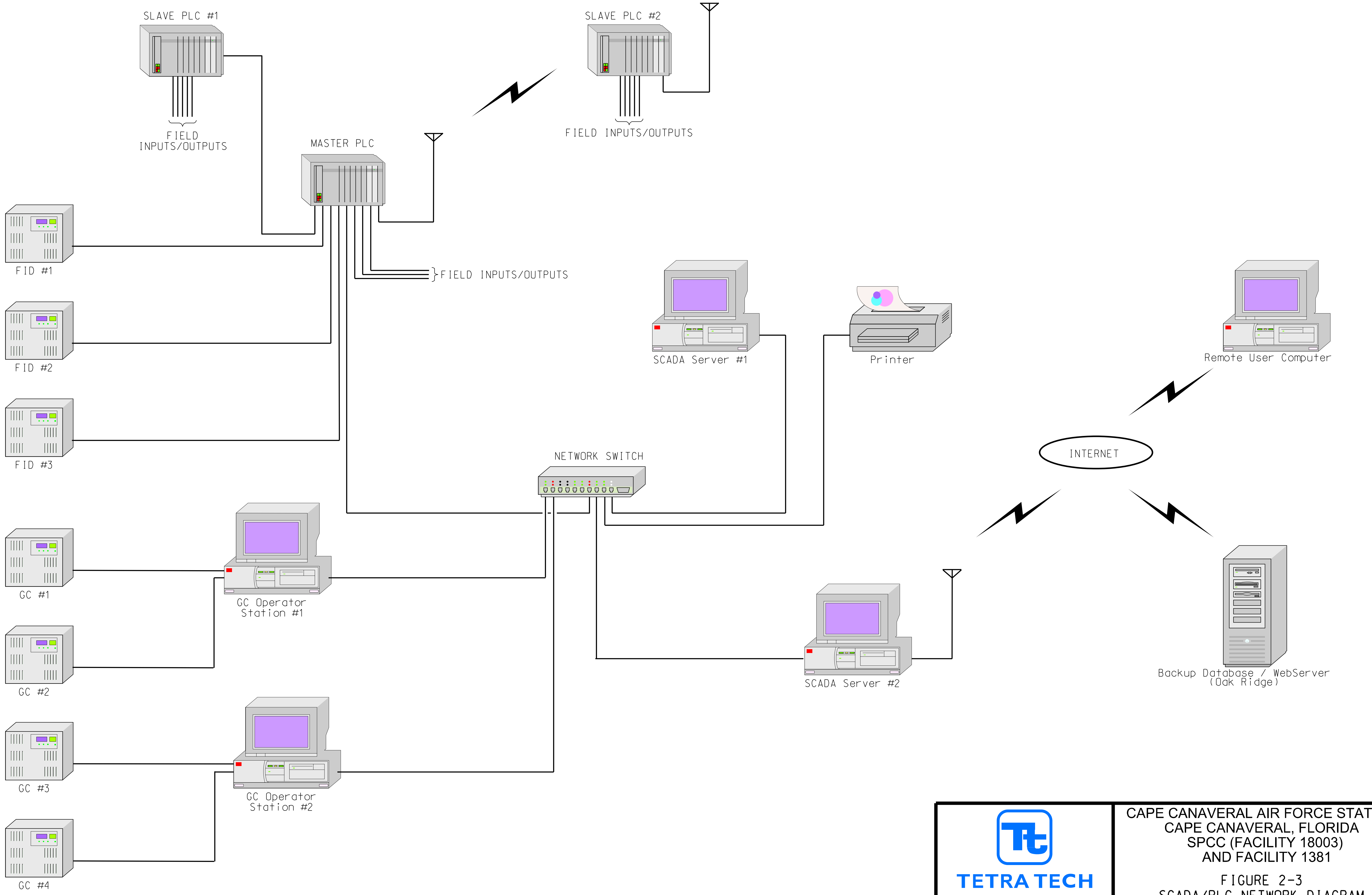

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CAPE CANAVERAL, FLORIDA
SPCC (FACILITY 18003)
AND FACILITY 1381

FIGURE 2-3
SCADA/PLC NETWORK DIAGRAM

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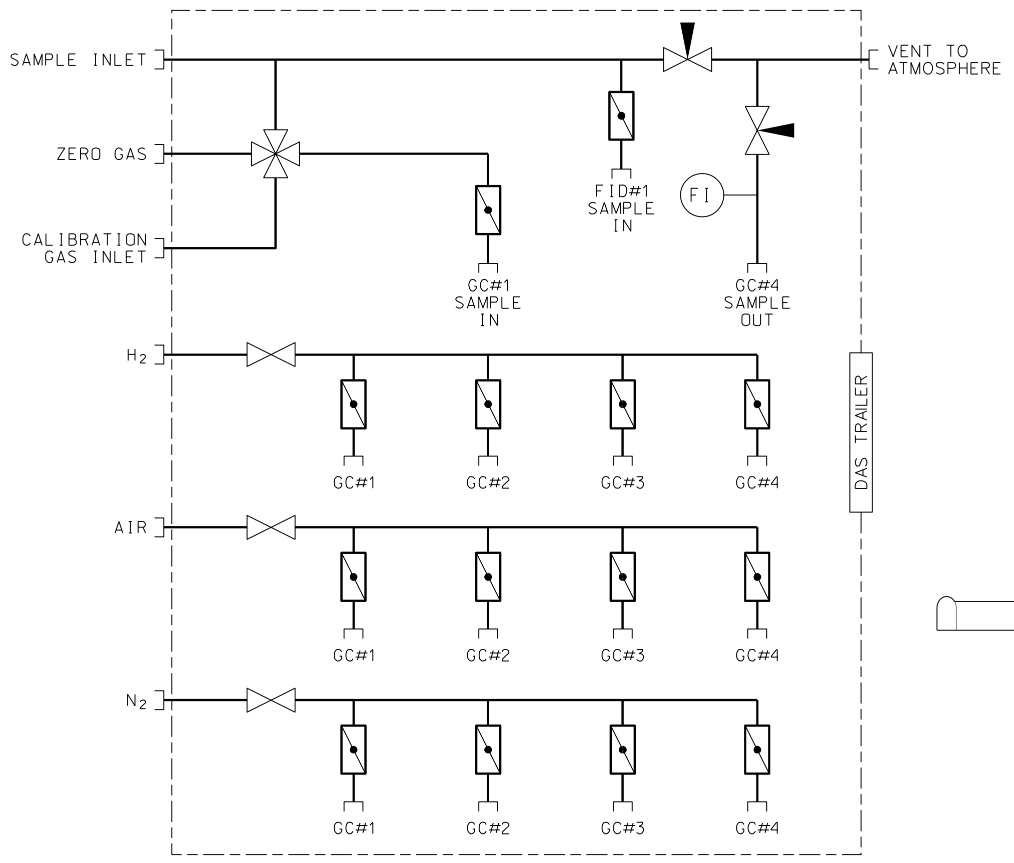
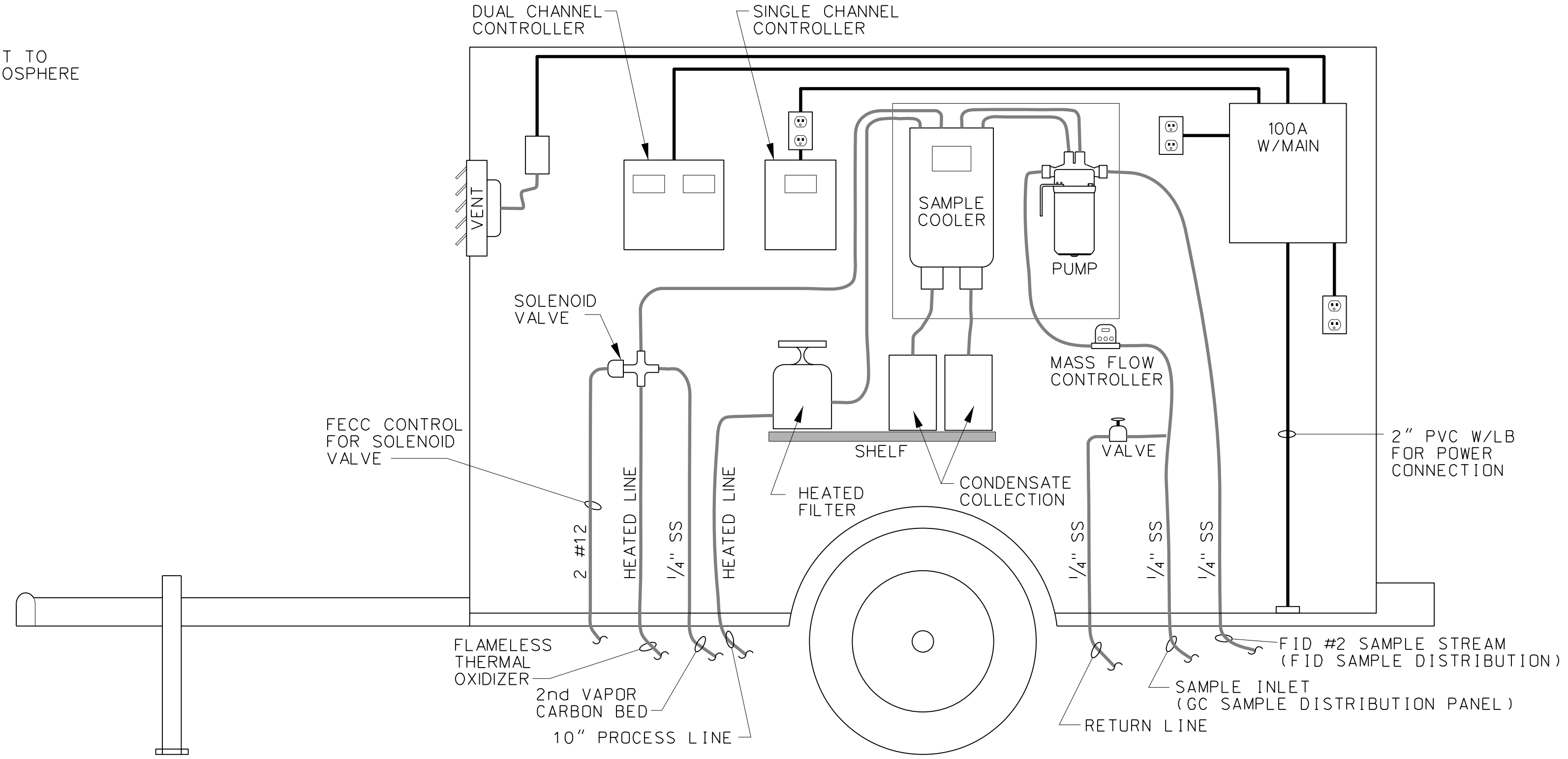
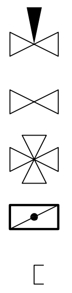


GC SAMPLE DISTRIBUTION PANEL
19" RACK MOUNTABLE



SAMPLE CONDITIONING TRAILER EQUIPMENT LAYOUT

LEGEND



METER VALVE USED TO MAINTAIN 1 TO 2 PSI ON PRESSURE INDICATOR (PI) AND 100 mL/min ON FLOW INDICATOR (FI)

SHUT-OFF VALVE

FOUR-WAY VALVE

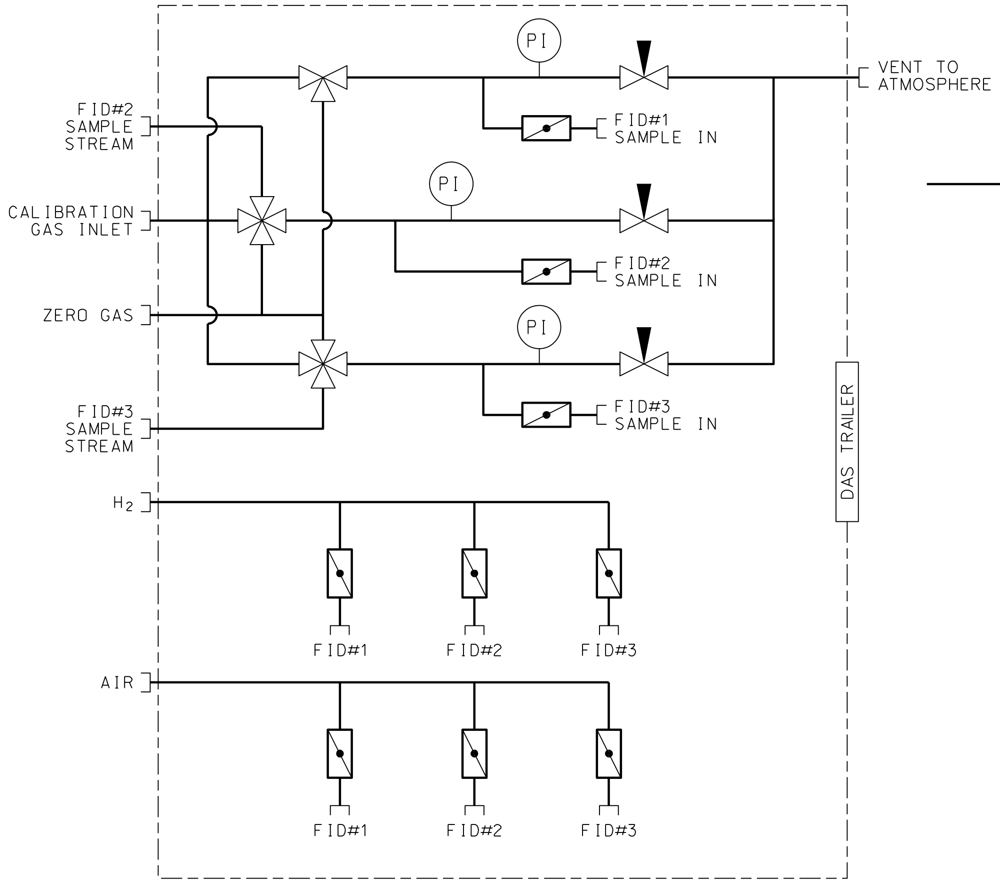
TOGGLE VALVE

1/16" LINE CONNECTION

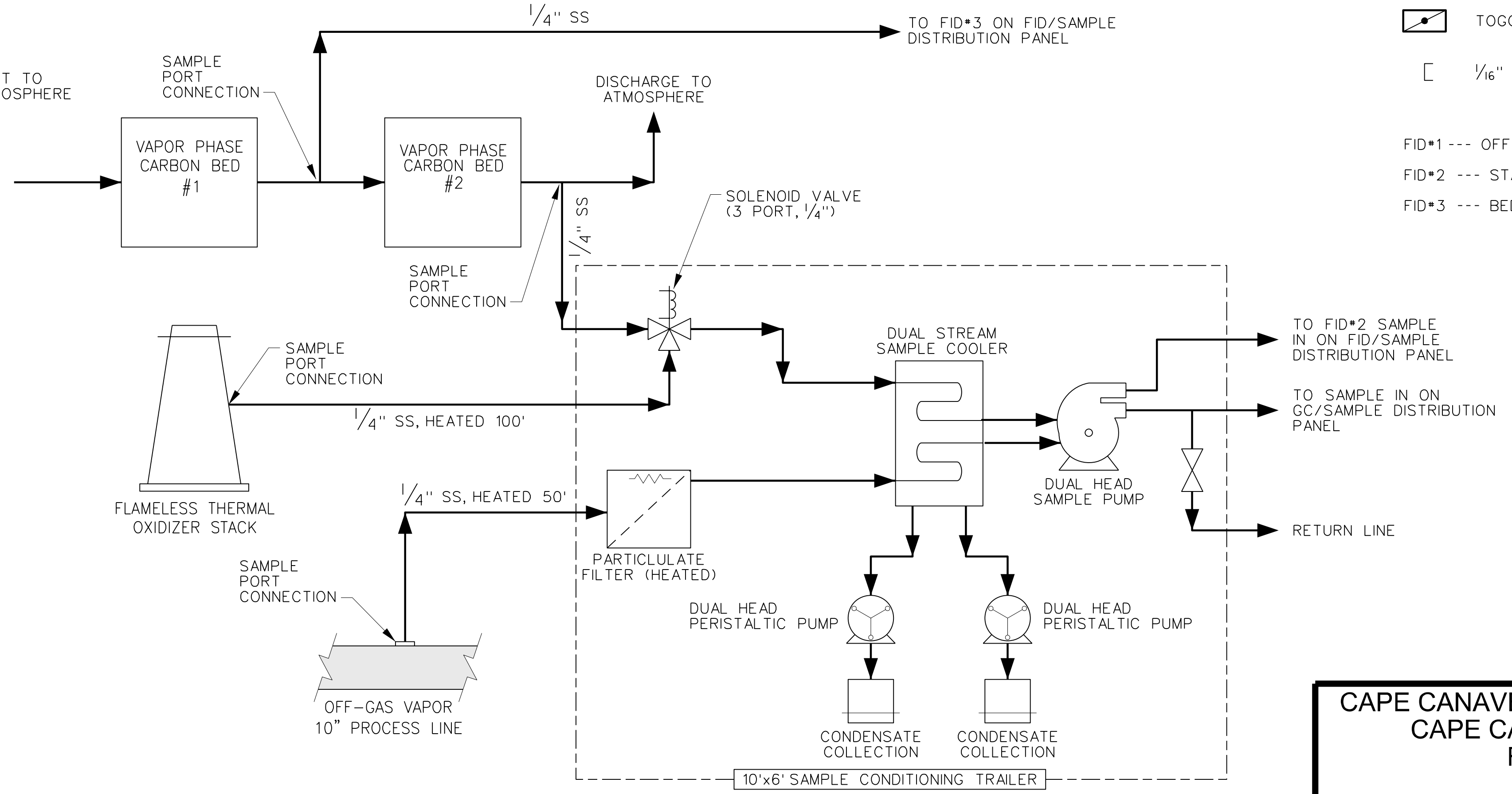
FID•1 --- OFF-GAS

FID•2 --- STACK/BED•2

FID•3 --- BED•1



FID SAMPLE DISTRIBUTION PANEL
19" RACK MOUNTABLE



SAMPLE COLLECTION/CONDITIONING SYSTEM FLOW DIAGRAM

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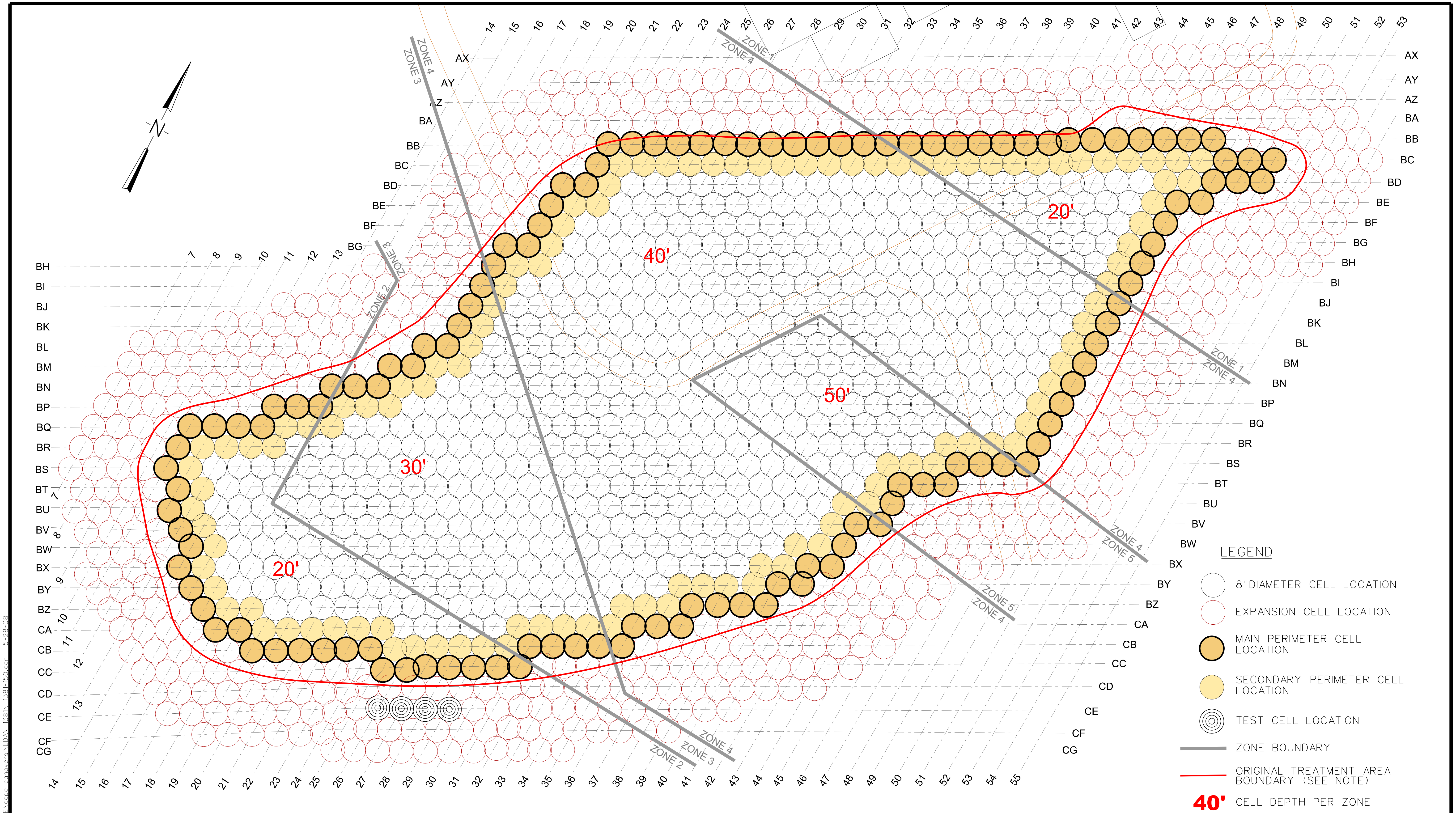
CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-4
SAMPLE CONDITIONING SYSTEM DIAGRAM



NOTE

BASED ON KNOWLEDGE OBTAINED FROM TREATMENT PERFORMANCE AT THE SECURITY POLICE CONFIDENCE COURSE (SPCC) AND REVIEW OF SITE CHARACTERIZATION DATA, THE ORIGINAL TREATMENT AREA BOUNDARY WAS REVISED TO ELIMINATE SOME LOW CONTAMINATION CELLS AROUND THE PERIMETER THAT DID NOT REQUIRE TREATMENT.

30 0 30
SCALE IN FEET

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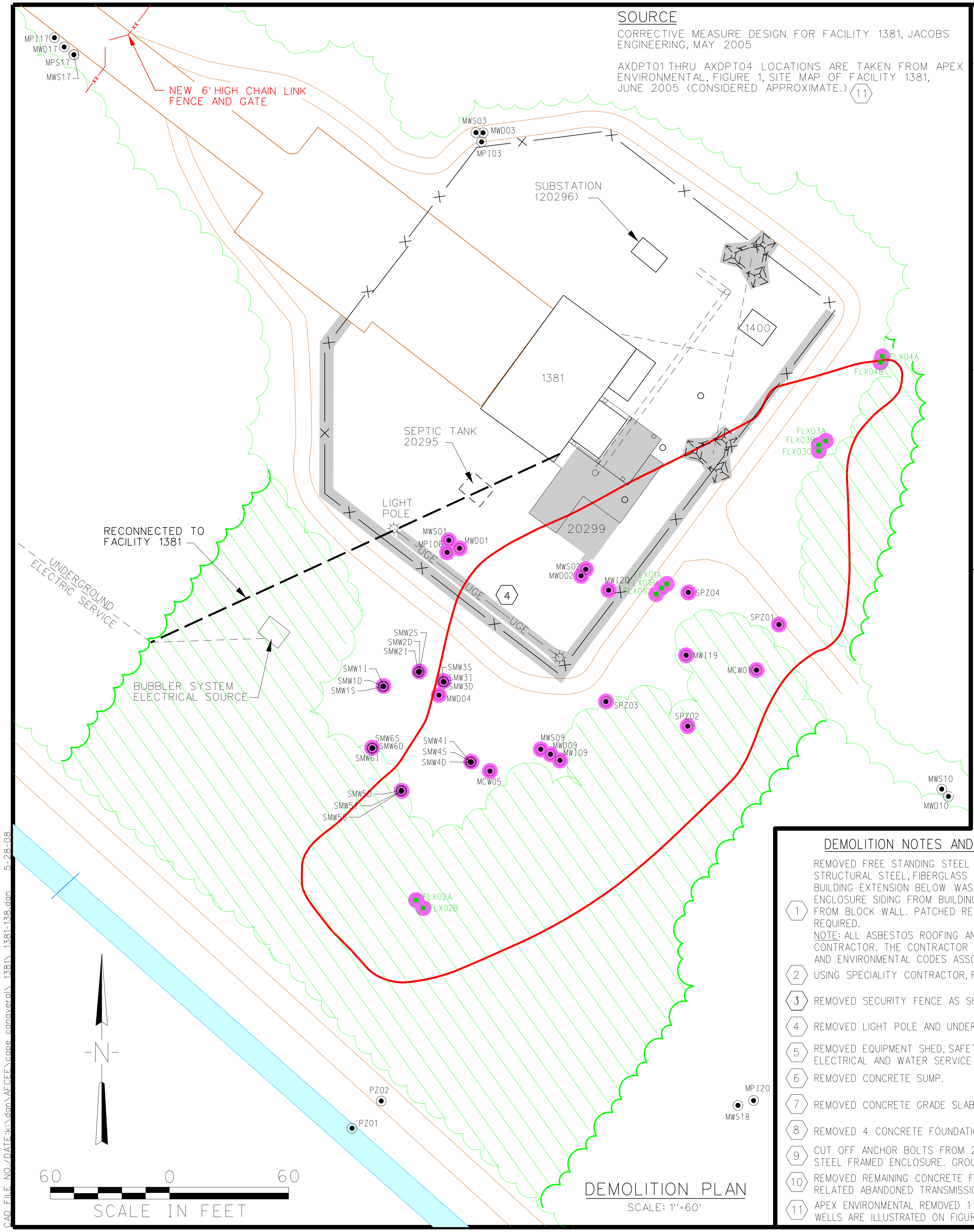
FACILITY 1381

FIGURE 2-5
TREATMENT CELL LAYOUT



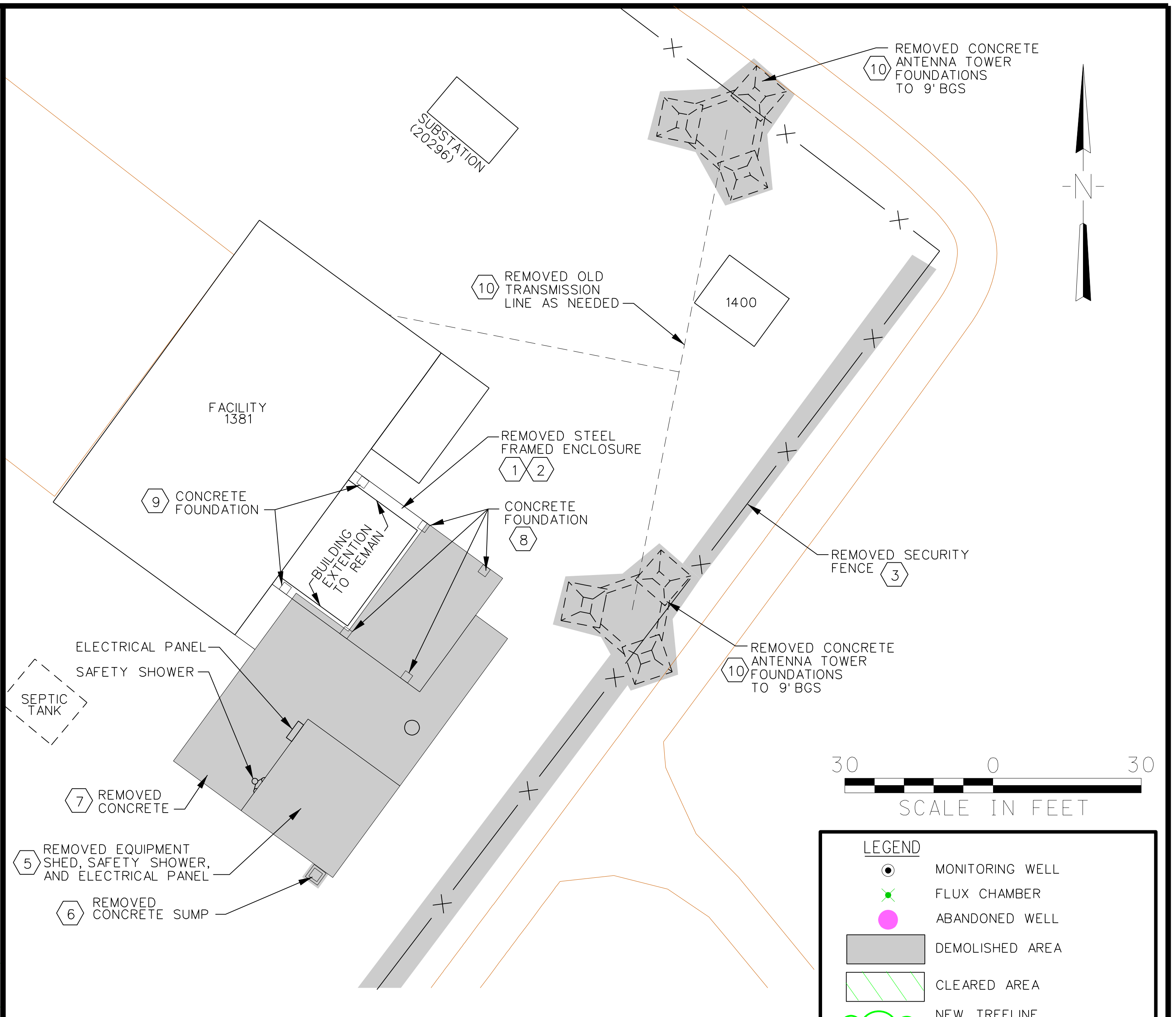
SOURCE

CORRECTIVE MEASURE DESIGN FOR FACILITY 1381, JACOBS ENGINEERING, MAY 2005

AXDPT01 THRU AXDPT04 LOCATIONS ARE TAKEN FROM APEX ENVIRONMENTAL, FIGURE 1, SITE MAP OF FACILITY 1381, JUNE 2005 (CONSIDERED APPROXIMATE.) ⑪

DEMOLITION PLAN

SCALE: 1"=60'



ENLARGED DEMOLITION PLAN

SCALE: 1"=30'

LEGEND

⊙	MONITORING WELL
●	FLUX CHAMBER
●	ABANDONED WELL
▨	DEMOLISHED AREA
▨	CLEARED AREA
︵︵	NEW TREELINE
︵︵	PREVIOUS TREELINE
—	10 ppm DNAPL SOURCE AREA
—×—	SECURITY FENCE
— UGE —	UNDERGROUND ELECTRICAL
☼	LIGHT POLE

DEMOLITION NOTES AND CONSTRUCTION SEQUENCE:

① REMOVED FREE STANDING STEEL FRAMED ENCLOSURE. ENCLOSURE WAS CONSTRUCTED OF STRUCTURAL STEEL, FIBERGLASS SIDING AND CEMENT ASBESTOS ROOF PANELS. ROOF OF BUILDING EXTENSION BELOW WAS PROTECTED FROM DAMAGE DURING DEMOLITION. DISCONNECTED ENCLOSURE SIDING FROM BUILDING BLOCK WALL. REMOVED 3x3 ANGLE AND TOGGLE BOLTS FROM BLOCK WALL. PATCHED REMAINING HOLES IN WALL. REWORKED ROOF DRAINS AS REQUIRED.
NOTE: ALL ASBESTOS ROOFING AND ACCESSORIES WERE REMOVED BY A QUALIFIED SPECIALTY CONTRACTOR. THE CONTRACTOR COMPLIED WITH ALL APPLICABLE LOCAL AND NATIONAL SAFETY AND ENVIRONMENTAL CODES ASSOCIATED WITH REMOVAL OF ASBESTOS MATERIAL.

② USING SPECIALITY CONTRACTOR, REMOVED ASBESTOS ROOFING FROM STEEL FRAMED ENCLOSURE.

③ REMOVED SECURITY FENCE AS SHOWN.

④ REMOVED LIGHT POLE AND UNDERGROUND ELECTRICAL POWER BACK TO REMAINING LIGHT POLE.

⑤ REMOVED EQUIPMENT SHED, SAFETY SHOWER AND ELECTRICAL PANEL . REMOVED UNDERGROUND ELECTRICAL AND WATER SERVICE BACK TO SOURCE AT BUILDING 1381.

⑥ REMOVED CONCRETE SUMP.

⑦ REMOVED CONCRETE GRADE SLAB.

⑧ REMOVED 4 CONCRETE FOUNDATIONS FROM REMOVED STEEL FRAMED ENCLOSURE.

⑨ CUT OFF ANCHOR BOLTS FROM 2 REMAINING CONCRETE FOUNDATIONS FROM REMOVED STEEL FRAMED ENCLOSURE. GROUND SMOOTH AND SEALED REMAINING ENDS OF ANCHOR BOLTS.

⑩ REMOVED REMAINING CONCRETE FOUNDATION FROM OLD ANTENNA TOWER. REMOVED ANY RELATED ABANDONED TRANSMISSION LINES AS NEEDED.

⑪ APEX ENVIRONMENTAL REMOVED 112 WELLS AND/OR WELL LIKE STRUCTURES. NOT ALL ABANDONED WELLS ARE ILLUSTRATED ON FIGURE

GENERAL NOTES:

1. CONTRACTOR COORDINATED ALL WORK WITH THE CLIENT/PROJECT ENGINEER TO MINIMIZE CONFLICT WITH BUILDING, FACILITY OPERATIONS ETC.
2. DEMOLITION WORK WAS PERFORMED BY OTHERS (SpecPro AND APEX ENVIRONMENTAL)

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CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-6
DEMOLITION AND
VEGETATIVE CLEARING AREAS

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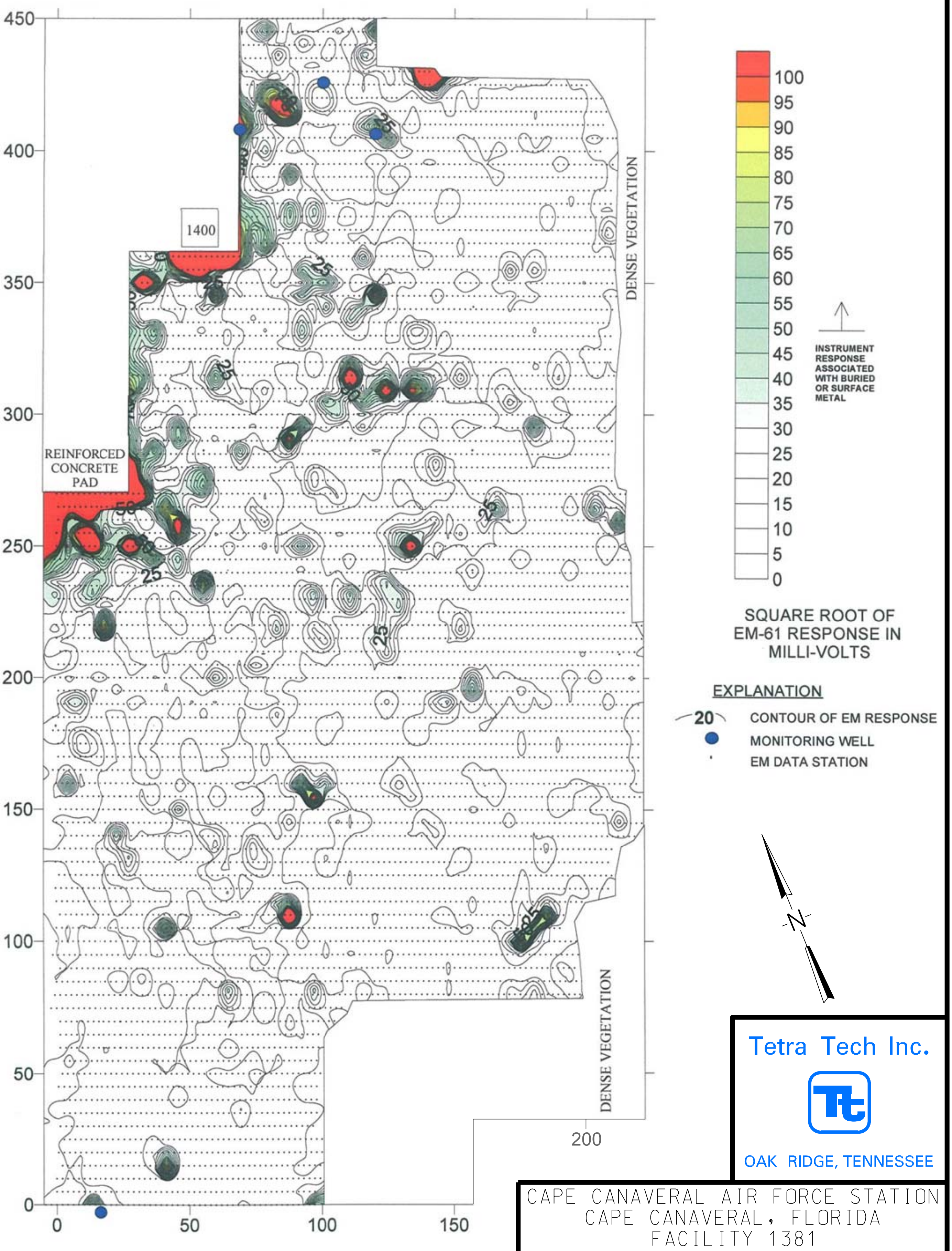

Tetra Tech Inc.

OAK RIDGE, TENNESSEE

SOURCE
TAKEN FROM CORE ENGINEERING
AND CONSTRUCTION, INC
PROJECT 3138, DATED 05-08-06

50 0 50
SCALE IN FEET

CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-7
CONTOUR MAP OF EMI RESPONSE

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8-5x11v.dgn

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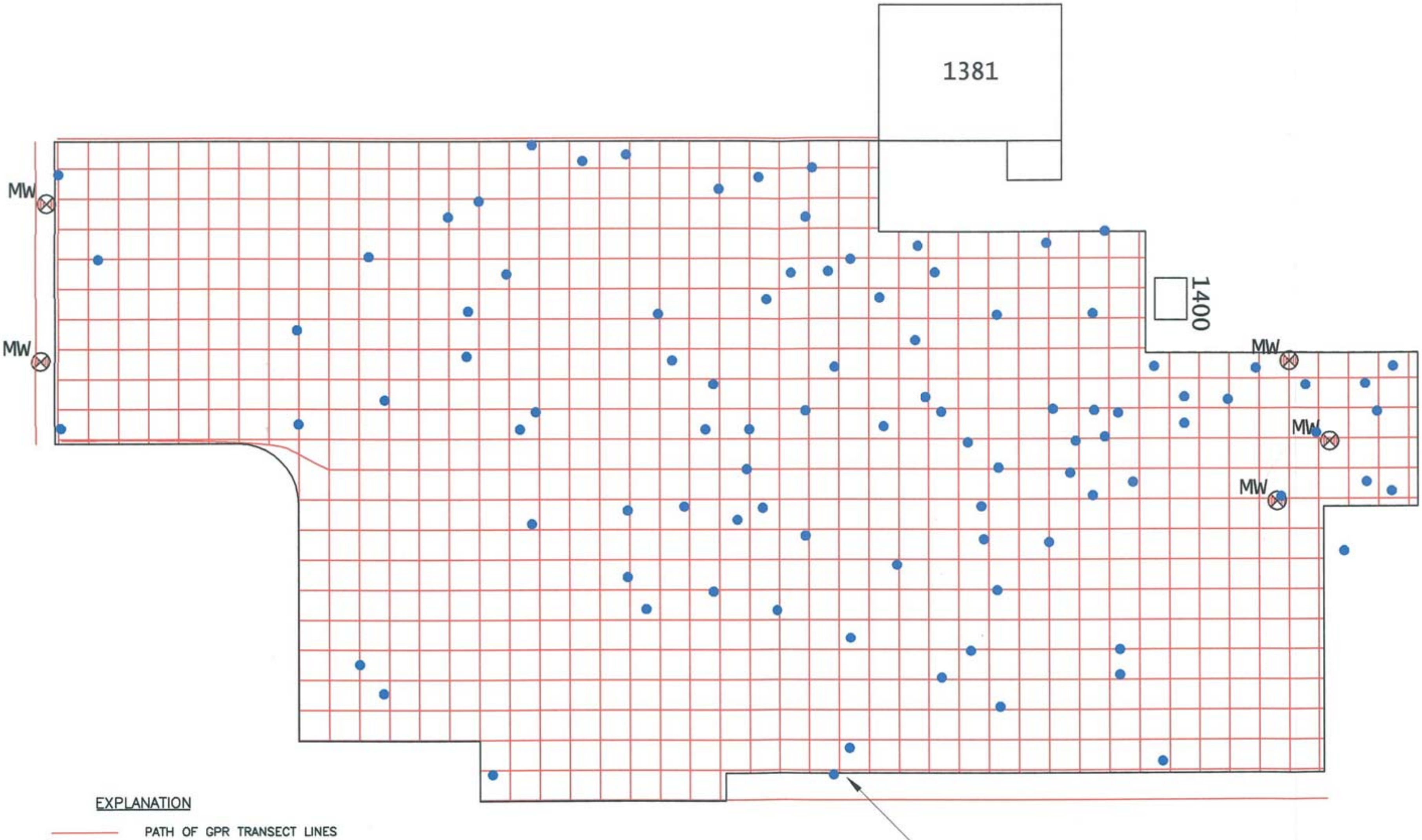
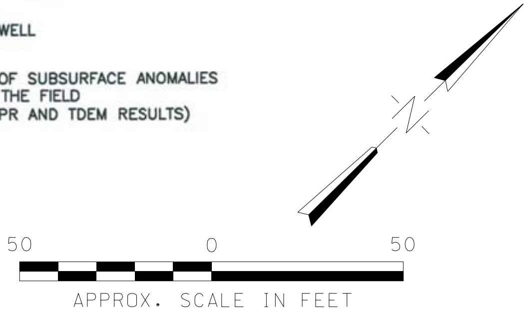


EXPLANATION

―	PATH OF GPR TRANSECT LINES
MW ⊗	LOCATION OF MONITOR WELL
●	APPROXIMATE LOCATION OF SUBSURFACE ANOMALIES THAT WERE FLAGGED IN THE FIELD (BASED ON COMBINED GPR AND TDEM RESULTS)



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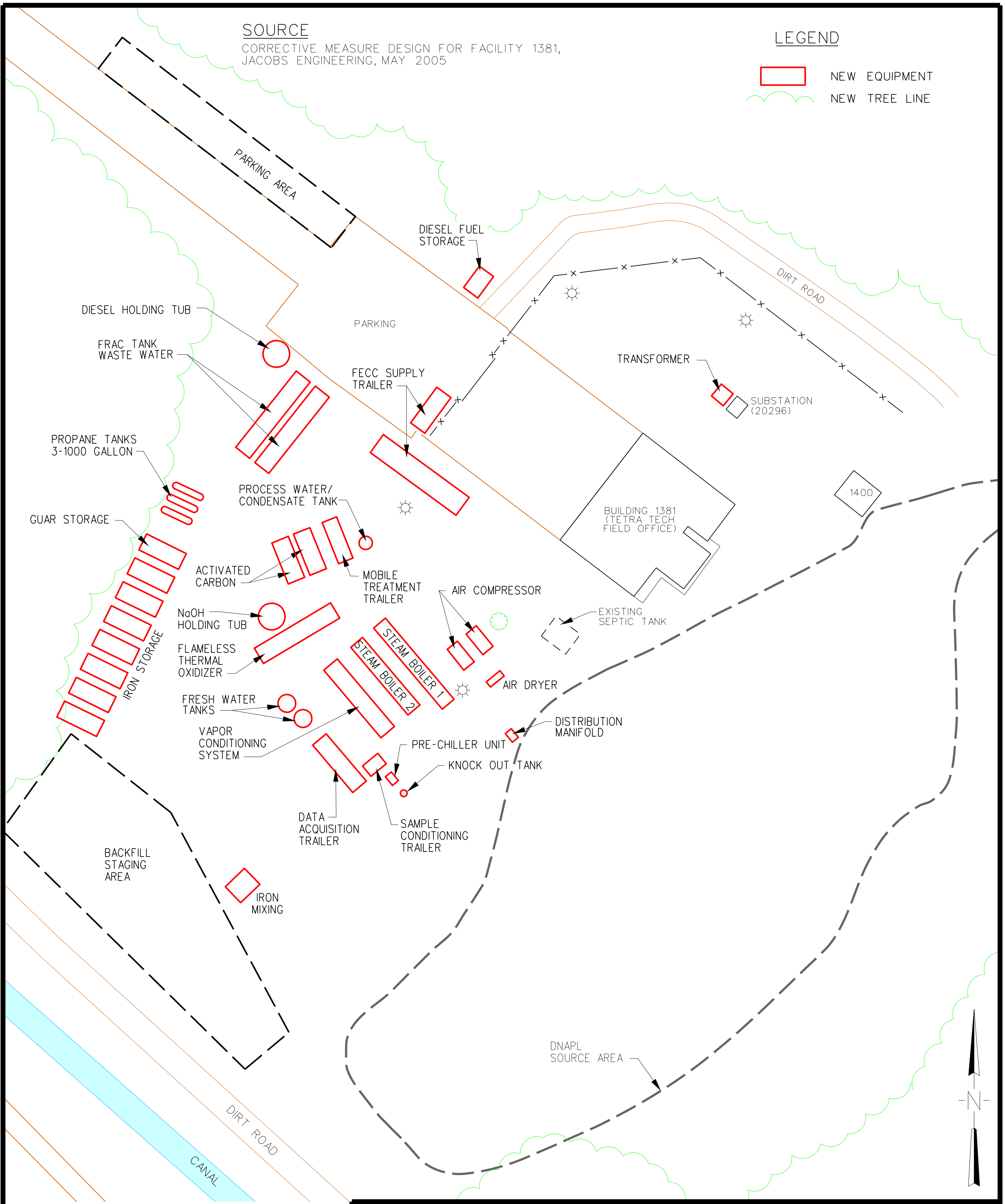
CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-8
SITE MAP SHOWING RESULTS
OF GPR INVESTIGATION



SOURCE
CORRECTIVE MEASURE DESIGN FOR FACILITY 1381,
JACOBS ENGINEERING, MAY 2005

TETRA TECH
OAK RIDGE, TENNESSEE

CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-9
MATERIAL AND EQUIPMENT
LAY-OUT AREA

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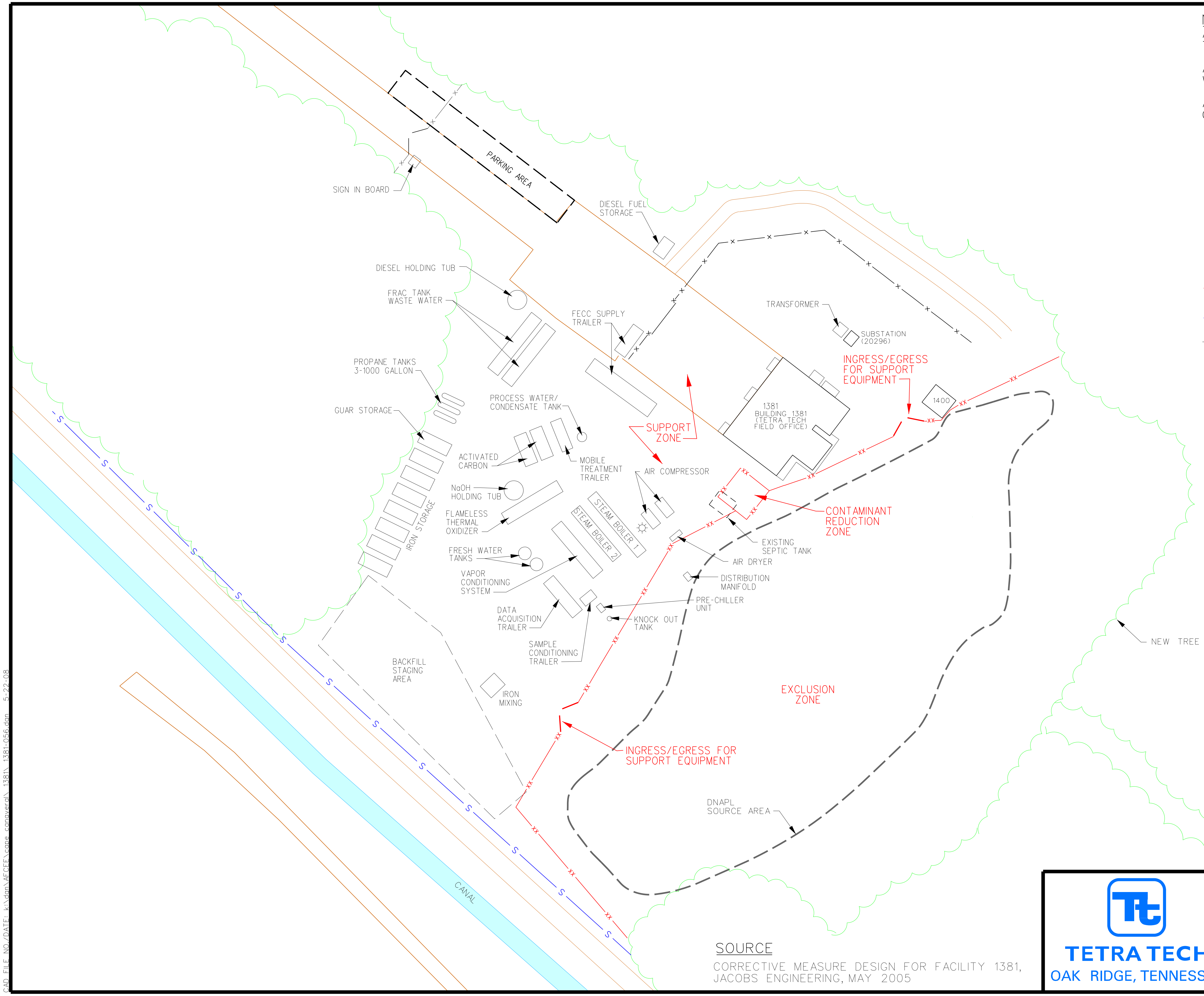

NOTES

ALL EQUIPMENT WAS PRESSURE WASHED PRIOR TO LEAVING THE SITE.

ALL PERSONNEL ENTERING OR LEAVING THE SITE WERE REQUIRED TO SIGN IN AT THE SIGN IN BOARD.

AREAS OF HIGH TRAFFIC AND DUST WERE CONTINUOUSLY SPRAYED DOWN FOR DUST CONTROL.

LEGEND

▭	NEW EQUIPMENT
︵︵︵	NEW TREE LINE
☼	LIGHT POLE
—xx—xx—	BARRIER FENCE (ZONE BOUNDARY)
—S—	SILT FENCING
—x—x—	SECURITY FENCING

-N-

60 0 60
SCALE IN FEET

SOURCE

CORRECTIVE MEASURE DESIGN FOR FACILITY 1381,
JACOBS ENGINEERING, MAY 2005

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CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 2-10
WORK ZONES

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3.0 SYSTEM OPERATION AND EVALUATION

This section details the system operation and evaluation of the in-situ soil mixing with steam, hot air, and ZVI injection by LDA during remedial efforts at Facility 1381.

3.1 STARTUP AND TESTING

3.1.1 Full System Startup and Checkout

Full system startup and checkout were performed once setup was complete and prior to treating any cells at Facility 1381. The purpose of these activities was to ensure all mechanical, electrical, and electronic equipment/instrumentation/software were connected and communicating properly for effective remediation. Activities performed included:

- Ensuring all mechanical and electrical equipment/devices were properly erected, installed, connected and sealed according to manufacturers' design specifications;
- Ensuring all electronic signals being received in the three PLCs (located on the Crane, VCS, and DAS) were checked and scaled appropriately in the SCADA software;
- Ensuring all sampling equipment was properly connected and calibrated to produce accurate data;
- Performing a steam and air test with the auger above surface to ensure adequate flow and appropriate instrument response;
- Ensuring the treatment systems (FTO and GAC) were fully operational and relaying proper instrument response;
- Ensuring data were being collected and stored properly on-site at the desired interval rate for each piece of equipment and performing several simulated data package transmissions to the Oak Ridge server via wireless broadband connection; and
- Properly batching and preparing ZVI slurry in iron batch plants.

Once all the electrical connections were made, a licensed electrician visited the site and inspected all connections. Upon receiving notice from the licensed electrician that connections were adequate and ensuring all the above activities were completed, Tetra Tech authorized the drilling of test cells to simulate active treatment.

3.1.2 Test Cell Treatment

Treatment of test cells was performed to simulate active remediation, to ensure the entire system was functioning efficiently as designed, and to troubleshoot any problems or issues that developed prior to active remediation. The test cells were identified adjacent to but outside the 10 ppm TCE contour line for the purposes of obtaining low-level contaminant data to determine off-gas sample collection proficiency to analyze, store, and display results as well as to validate off-gas treatment by the FTO. Figure 3-1 illustrates the location of two test cells performed prior to active treatment. The test cells on Figure 3-1 are identified as CE29 and CE27. Test cells were also useful in determining the proper water/guar/ ZVI batching ratio and preparation procedures for injection.

Test Cell #1 (CE29)

On June 28, 2006, the first of two test cells was performed to verify adequate drilling ability to 50 feet bgs with hot air and steam and proper FTO. Testing commenced and drilled to 3 feet bgs where debris was encountered preventing additional descent. A return to zero feet was issued and performed. The 0-5 foot interval was dug out with an excavator and tree debris was found and removed. Once the zone was cleared, the auger was re-positioned above the cell and drilling re-commenced. Once the auger reached approximately 10 feet bgs, thermal treatment commenced with hot air and steam; all data appeared to be transmitting and collecting as designed. At approximately 20 feet bgs, the FTO shut down due to inlet high temperature generated from a steam “bubble” due to the slow descent rate and high injection steam flow rates. The auger was held at 34 feet bgs in order to re-start the FTO and the temperature quickly reached 204^{o}F due to the continual injection of steam at one depth. Steam flow rate was reduced to reduce the off-gas temperature until the FTO was operational. Once the FTO was operational, drilling commenced with full steam to 50 feet bgs without further delays; a temperature of 160^{o}F was obtained and maintained during a portion of the thermal treatment pass. The maximum FID obtained during the thermal pass was 1191.7 parts per million (ppm) which consisted of primarily methane, cis-1,2-DCE at 28.33 ppm, and vinyl chloride at 13.57 ppm; no TCE was reported for the test cell. Upon completion of the thermal treatment, the auger was repositioned at 5 feet bgs and an iron quantity of 3000 lbs in a slurry was successfully injected to 50 feet bgs. The test cell was completed upon retracting the auger from the iron treatment pass. The test cell treatment spanned 170 minutes of thermal treatment, a total of 187 minutes total treatment (thermal and iron treatment). Due to the FTO difficulties during the testing, an additional test cell was implemented to verify complete treatment ability with the FTO.

Test Cell #2 (CE27)

On June 28, 2006, testing commenced on test cell CE27. At 11 feet bgs the primary off-gas FID was suspected of not reading correctly; therefore, a retraction to zero was issued and performed. All connections were leak checked and a calibration was re-performed on the FID unit. Once complete the auger was re-positioned over the test cell and drilling commenced to 50 feet bgs successfully without further delay or instrumentation problems. The maximum FID obtained on the test cell was 658 ppm at 50 feet bgs with the primary constituents being methane, TCE at 9.86 ppm, cis-1,2-DCE at 51.97 ppm, and vinyl chloride at 10.65 ppm. The FTO was fully operational during the testing. An iron quantity of 3000 lbs in a slurry was successfully mixed and injected to 50 feet bgs.

The two test cells adequately demonstrated the operational controls, treatment protocol, data collection/analysis/storage of all parameters and contaminants at the desired intervals, and effectively demonstrated the FTO operational capabilities; therefore, Tetra Tech approved the commencement of active treatment on cell CB32 on June 30, 2006.

3.2 SYSTEM OPERATION

3.2.1 Operational Parameters

Treatment of the source area at Facility 1381 was performed in accordance with the established site treatment protocols (detailed in Section 3.4). During treatment, equipment parameters were adjusted to optimal operating ranges for efficient removal of VOCs. Table 3-1 lists the standard operating ranges for the major remedial equipment during treatment.

Table 3-1. Major Equipment Operating Ranges

Major Remedial Equipment	Cell Location	Target First Pass	Range First Pass	Target Successive Passes	Range Successive Passes	Iron Pass
Steam Flow (pph)	All locations	8,000	8,000–10,000 where feasible*	8,000 until 160°F attained in shroud then varied to maintain temp	8,000–10,000; 0–5000 when shroud temperature of 160°F attained	NA
Air Flow (scfm)	Perimeter	200	200-400 where feasible*	400	300-500; 100-200 when shroud temperature of 160°F attained	100
	Inner	400	300-500 where feasible*	400	300-500; 100-200 when shroud temperature of 160°F attained	100
Shroud Pressure (inches H_2O)	All Cells	2	1-5	2	1-5	1-5
Off-Gas Air Flow (scfm)	All Cells	600	200-1500	600	200-1500	600
LDA Descent Rate (feet per minute)	All Cells	2	1-3 where feasible*	1-3	2	2
LDA Rotation per minute	All Cells	8	6-10 where feasible*	8	6-10	6-10
FTO Temperature	All Cells	1700°F	1700°F	1700°F	1700°F	1700°F
Iron Flow (gpm)	All Cells	NA	NA	NA	NA	~25

NA – Not applicable
Scfm – standard cubic feet per minute
°F – degrees Fahrenheit
pph – pounds per hour
gpm – gallons per minute

* - Drilling conditions varied causing a decrease in drilling descent rate and steam flow rate adjustments were required
~- Approximately

3.2.2 Mechanical Issues Causing Delays

Operational maintenance was performed on a daily, weekly and monthly basis to prevent any major mechanical equipment failures during treatment at Facility 1381. Despite the preventative maintenance, several mechanical issues arose causing delays in treatment. Table 3-2 describes the mechanical issues faced and repaired during treatment and the delay each issue generated at Facility 1381.

Table 3-2. Mechanical Issues

Date	Cell	Mechanical Issue	Delay (days)
07/19/06 – 07/22/06	BS11	While drilling on cell noticed that swivel was not properly rotating as designed and periodically locking up. Therefore, retracted auger for inspection and determined the swivel required replacement. Backup swivel replaced that day and drilling re-commenced the next day. Upon re-drilling on cell the replacement swivel began leaking fluid to the shroud and ground. CCAFS officials were notified and the spill cleaned. A mechanic from King Swivels was contacted and design changes were implemented on the onsite swivels to allow for heat dissipation of the steam. Drilling re-commenced on cell the following Monday.	3
08/24/06	-	While drilling during 08/23/06 several cab alarms indicating high pressure were detected and battery problems on crane arose. Crane was re-started with new batteries and was operational until another alarm detected high pressure. Also the platform electronics were not responding properly at the end of the day on 8/23/06. Therefore the problem was isolated to the electronic circuit breaker on the platform. A technician was contacted and inspected and repaired the electronic circuit breaker. Drilling commenced on 08/25/06.	1
08/26/06 – 08/28/06 (mechanical only) 08/28/06 – 09/04-06 (Hurricane)	-	At the end of the day on 08/25/06 a severe electrical storm over the site generated a lightning strike that hit the crane boom, sending an electrical charge throughout the site. Damage resulting from the strike included several electronic switches, air control electronics, Ethernet modules, and CPUs. Repairs commenced and were completed on 08/28/06; however, a HURCON alert was issued due to Hurricane Ernesto and drilling could not commence until hurricane passed. Once passed all electronics were tested and drilling re-commenced on 09/05/06. Total due to damaged lightning strike was 2 working days. Total delay due to weather (hurricane) was 5 working days.	7
10/19/06 – 10/31/06	-	Hydraulic arms on the crane holding boom were inspected and technicians discovered cracks in both arms. All mixing equipment was removed, the boom was lowered and the two hydraulic arms were removed from the crane and sent to the vendor for repairs.	8.5
11/01/06	-	During startup the FTO was not firing off as normal. Upon inspection the propane injection regulator on the FTO trailer required repair due to receiving too much propane from the propane tanks. It appeared as though the propane feed regulators on the tanks were not operating correctly. Amerigas was contacted and replaced the propane feed regulators. The propane injection regulator to the FTO was repaired and the FTO fired off correctly without problems.	1

Date	Cell	Mechanical Issue	Delay (days)
11/13/06 – 11/14/06	-	The shroud bearing was replaced during the morning and additional minor repairs were performed on the shroud bolts; however, during additional inspection, the 3 inch diameter Kelly bar inner pipe was noticed to have fractured off the Kelly Box (location where the inner pipe connects to the base of the Kelly Bar). A certified welder was called to the site and repairs were completed satisfactorily.	2
11/20/06 – 11/21/06	BS24	During treatment on cell BS24 the right angle gear box on the platform became disabled at 14.5 feet bgs. The auger was dug out from this depth and then pulled to the surface. A replacement gear box was ordered and installed the next day. Once installed the platform was fully operational and cell BS24 was resumed and completed.	2
12/22/06 – 12/29/06	BR43	During drilling retraction from 57 feet bgs the shroud suddenly rose several feet in the air and landed back on the ground causing damage to the lifting mechanics of the shroud. The auger was retracted to zero feet bgs and inspection of the damage commenced. Damage resulting from the shroud rise and impact was primarily on the hydraulic shroud lifting system. Therefore a re-design of the hydraulic lifting system was performed and installed. The re-design included discarding the hydraulic system and utilizing the crane cables attached to the lifting arms which were connected to chains on the shroud. The design changes were implemented and drilling re-commenced on 01/02/07. (See Appendix W)	5
01/03/07	-	Work continued on repair and replacement of shroud lifting mechanics. Also it was discovered that there was an O-ring problem in the solenoid block on the platform therefore replaced O-rings and completed lifting mechanics repair/shroud repair and prepared for drilling for next day.	1
01/08/07	-	The 3 inch diameter Kelly bar inner pipe was noticed to have fractured off the Kelly Box again and repairs were required. A certified welder was called to the site and repairs were completed satisfactorily.	1
01/19/07 – 01/20/07		Additional modifications were performed to the shroud lifting mechanics.	1
01/22/07	-	The crane did not startup and mechanics were contacted for inspection and repair. Mechanics determined the electronic box for ignition had corroded interior contacts and a bypass was created until a replacement box arrived. Wind advisories at CCAFS prevented the use of high reaching equipment to re-connect hosing for drilling.	1
01/24/07 – 01/25/07	BM36	During drilling descent it was noticed that a boom lacing (cross member on the boom) had become detached from the boom itself raising a structural stability concern about the boom. The auger was retracted from 40 feet bgs and the crane mechanics were contacted. A certified welder arrived onsite and performed the welding repairs to the boom lacing to the boom. Welding was complete, however, a CCAFS high winds alert prevented repairs the following day.	2

Date	Cell	Mechanical Issue	Delay (days)
01/29/07 – 01/30/07	-	Additional crane starter issues arose and contacted crane mechanics. During repair and additional inspection, the mechanic noted the crane batteries and alternator required replacement. Drilling commenced once the jumper was repaired and batteries and alternator were placed on order.	2
02/08/07	-	Crane did not startup and smoke seen from engine compartment. Contacted mechanics for inspection and repair. Determined the starter required replacement. Replacement performed and commenced drilling that day.	1
02/13/07	BR35	During drilling descent on cell noticed that depth indicator was not reading accurately. Retracted to zero feet from 12 feet bgs to inspect depth indicator. Depth indicator required repair and commenced repairs. Repairs completed and resumed drilling the next day.	0.5
02/15/07	-	The shroud bearings were replaced due to wear generated from uneven loading due to a tilted shroud. Bearings were replaced and drilling commenced the next day.	0.5
02/23/07 – 02/24/07	-	Additional modifications were performed to the shroud lifting mechanics.	1
04/23/07	BN25	After completing treatment on cell it was noticed that the right angle gear box was emanating an unusual sound. Upon inspection metal shavings were detected in the hydraulic fluid and it was determined the gear box required replacement. A replacement gear box was ordered and installed the next Monday. Once installed the platform was fully operational and drilling resumed.	0.5

Note - Total Delay Days for Mechanical Related Issues = **41 days**

3.3 DATA ACQUISITION

3.3.1 Data Collection

3.3.1.1 Gas Chromatograph Data

Description

Four GCs were used to detect, speciate, and quantify target analytes from the treatment process off-gas. Three GCs were cycled at 2 minute intervals throughout the treatment process with one GC being operated when a maximum of the FID was detected. The 4th GC was also used as a backup in the event that one of the three primary GCs did not work.

The sample was delivered to the GCs via a stainless steel sample line. Each GC was equipped with a 1 mL sample loop that was continuously swept with the sample stream except for the injection of the sample. The lag time between the sampling point (off-gas) and the point of analysis was approximately 20 seconds.

The GCs were computer controlled with the vendor-supplied software program called “Peak Simple.” The program controls all aspects of the GC control as well as allowing for the chromatography analysis, quantitation of analytes, and reporting of concentrations from each sample. Two computers operated the four GCs. The software was in two different directories, each associated with a unique COM port. Therefore, each GC was operated independently with each data file being assigned a unique ID for each analytical run.

The GC data were synchronized with the off-gas process data to calculate/estimate the mass removed of each contaminant species.

GC Specifications

- SRI Model 8610C equipped with an FID
- Electronic pressure controls for gases
- Heated oven for the sample loop/valve
- Column: RTX 624 30M x 0.53mm, 3 µm film. Head Pressure setting 11(nominal)
- Detector : FID, 225°C, medium gain, 10 Hz sampling rate
- Oven: 65°C/1.8 min -> 145°C @ 40°C/min
- Sample Loop: 1 mL, on @ 0.05 min., off @ 0.50 min 105°C
- Data System: Peak Simple 3.36

Analytes Tested

The following analytes were reported in ppm (v/v):

- Vinyl chloride
- Freon 113 (1,1,2-Trichloro-2,2,1-trifluoroethane)
- trans-1,2-Dichloroethylene
- 1,1-Dichloroethane
- cis-1,2-Dichloroethylene
- 1,1,1-Trichloroethane
- Benzene
- Trichloroethylene
- Toluene
- Tetrachloroethylene

GC Calibration

Each analyte was calibrated by injecting known quantities of each compound into Tedlar bags to generate calibration curves. The calibration samples were introduced to the GCs by filling the injection loop of each GC and analyzing the contents of the loop. The responses versus concentration were plotted to generate calibration curves. Analyte concentrations were calculated using these calibration curves. The calibration curves were generated using Table 3-3. The table was calculated from the equation:

$$\text{ppm}(v/v) = (\mu g/m^3)(24.43/MW)$$

Where MW is the molecular weight of the analyte.

Table 3-3. Calibration Curve Data

Concentration of analyte in ppm (v/v)	50	100	500	1000	5000	10000	20000
TCE	2.5 mL of 20,000 ppm	5 mL of 20,000 ppm	1.8	3.7	18.4	36.8	73.6
c-1,2-DCE			1.5	3.1	15.5	30.9	61.9
PCE			2.1	4.2	20.9	41.8	83.6
Freon 113			2.4	4.9	24.4	48.8	97.6
1,1-DCA			1.7	3.4	16.9	33.7	67.4
1,1,1-TCA			2.0	4.1	20.3	40.7	81.3
t-1,2-DCE			1.5	3.1	15.5	30.9	61.9
Benzene			1.8	3.6	18.2	36.5	72.9
Toluene			2.1	4.2	21.0	42.0	84.0

Notes: (1) All values of neat compounds in µL/1 liter of air.
(2) 50 and 100 ppm (v/v) use the high standard (20,000) as an intermediate stock.

Due to the toxicity and difficulty in handling vinyl chloride, the concentration of vinyl chloride was calculated from a single point using the certified calibration gas concentration of 2080 ppm.

After prepping each bag the standards were analyzed by filling the sample loops of each GC and analyzing the standards. The response vs concentration is then entered into each analyte's calibration table. After calibration the certified reference gas is analyzed with the vinyl chloride, Freon 113, and TCE concentrations calculated. The concentrations should be within 15%.

The elution order (retention time) of the analyte on the GCs is given in Table 3-4.

Table 3-4. Retention Time of Analyte

Analyte	RT, min.
Methane	0.59
Vinyl Chloride	0.69
Freon 113	0.89
t-1,2-DCE	1.09
1,1-DCA	1.20
cis-1,2-DCE	1.43
1,1,1-TCA	1.59
Benzene	1.79
TCE	2.13
Toluene	2.77
PCE	2.94

3.3.1.2 Flame Ionization Detector

Description

Three total hydrocarbon analyzers manufactured by VIG Industries FID Model 20-S were used to continuously monitor the effluents produced by the treatment process. The FIDs were used to measure total VOCs in three sample streams given below:

1. Off-gas from the treatment process.
2. Influent to the FTO.
3. One of two possible sample streams depending on which treatment process was actively being utilized. If the Alzeta was on-line the stack effluent from the Alzeta was monitored. If the carbon bed was being used then the stack at the exit of the carbon bed was monitored. The effluent selection was made via a solenoid valve that was connected to the PLC that diverts the off-gas to either the Alzeta or the carbon bed. The valve diverted the off-gas from the Alzeta to the carbon bed when the total FID measurement was greater than 20,000 ppm or the Alzeta was off-line.

The samples were transferred via ¼-inch stainless steel lines to the analyzers. The lag time between the sampling points and the point of analysis was as follows:

- Process off-gas: 20 seconds
- FTO influent: 7 seconds
- Stack effluent: 25 seconds

Calibration

The analyzers were calibrated with a certified calibration gas as per the manufacturer's recommended procedure. The calibration gas was 6,000 ppm propane in air. The FIDs were calibrated and verified daily or as deemed necessary using the calibration gas. A zero gas was also plumbed into the system to verify system cleanliness. In order to better approximate the composition of the process off-gas, the calibration gas was changed to a mixture of 1,000 ppm TCE and 5,000 ppm Freon 113 in July 2006.

3.3.2 Data Management

The data measured by the instruments were recorded in the SQL Server database installed on the SCADA servers (SCADA1 and SCADA2) at the site. The frequency of data recording for various instruments is given below:

- FID: one second (FID1, FID2, and FID3)
- GC: approximately every two minutes (either from GC1, GC2, GC3, or GC4)
- Process data: one second

The sequence of data processing is described below.

The measured data were first stored to the SQL Server in ICONICS' proprietary data format and were stored in the **LDATREND** database. Once the measured data had been stored, the ICONICS Report Configurator application ran to transfer the measured data into a readable format. Several internal SQL Server scripts were executed in addition to those generated and controlled by ICONICS to save the data into a logical format by cell in three tables: **GCData**, **HoleCompleteSummaries**, and **MasterData**. The **GCData** table contained information obtained from GCs including contaminant concentrations. The **HoleCompleteSummaries** table contained summary information about each hole including coordinates, dates of treatment, depth of treatment, etc. The **MasterData** table contained information that was summarized by cell every second including process data and GC data. At approximately 11:00 pm, all of the data for the day that was organized by cell from the **GCData**, **HoleCompleteSummaries**, and **MasterData** tables were extracted and exported to *CSV* files within the **D:\SQL Data Sync** directory. The final SQL Server script executed at 11:30 pm and made a copy of the files stored within the **D:\SQL Data Sync** in the **D:\SQL Data Backup** directory with the current date added to the end of each file. These files were not modified, moved, or deleted after creation and served as a permanent record for all data for each day. The last task that was executed copied all of the current day's data from the job site to the **LDAWEB** server in Oak Ridge. Once the files were copied to the Oak Ridge server, the **LDAWEB** server appended all of the data located in the *CSV* files to its own tables (**GCData**, **HoleCompleteSummaries**, and **MasterData)** and were made available for reports.

3.4 TREATMENT PROTOCOL AND COMPLETION CRITERIA

A treatment protocol, which was approved by the Partnering Team, provided the operator and site supervisor the treatment methodology for all treatment cells at Facility 1381. The protocol was primarily created to maximize contaminant mass removal while minimizing the treatment time but also allowed for field-based decisions focused on real-time contaminant data and trends during treatment. Treatment completion was determined by obtaining contaminant concentration reduction values and/or specified performance standards established as completion criteria within the protocol. Various changes were suggested for the primary treatment protocol to accomplish maximum soil volume treatment with the allocated project funds. The changes implemented incorporated the process optimization knowledge gained from prior treatment.

A primary treatment protocol was established during mobilization to Facility 1381 and prior to commencing treatment. This primary treatment protocol was utilized on 83% (662) treatment cells at the site. An alternative treatment protocol was implemented on 17% (135) treatment cells at the site in the final month of treatment. The alternative protocol was established based on additional knowledge gained from contaminant mass removal during thermal and iron treatment gained during treatment. The alternative protocol focused on a more efficient and cost effective treatment approach. The difference between the primary and alternative treatment protocol only involved thermal treatment; Treatment cell setup, iron treatment and treatment cell completion were the same for all cells treated at Facility 1381. Therefore, the following sub-section discussion will differentiate only the thermal treatment between the primary and alternative treatment protocols.

3.4.1 Treatment Cell Setup

Survey equipment was used to locate the anticipated day's treatment cells using the cell coordinates provided in Appendix I for Facility 1381. All the perimeter cells were treated first before treating interior cells. Once the treatment cells were located, the auger center was positioned over the stake and the auger was drilled into the soil until the top of the auger blade was at ground level. At this point the depth indicators were zeroed and the blower used to generate a vacuum in the shroud was activated to a flow rate of approximately 1000 acfm. The shroud was then lowered to the ground surface and monitored to ensure a vacuum pressure of approximately 1 to 5 inches of water was obtained. If the desired shroud pressure was not obtained initially, the auger was advanced approximately 3 feet and backfill was applied around the shroud.

3.4.2 Thermal Treatment

Thermal treatment passes (a pass is considered a movement of auger in one direction, up or down) with steam and hot air initiated the volatile contaminant mass transfer to the surface for capture and treatment. Data collected from off-gas analysis from the FIDs and GCs during the first thermal treatment pass were monitored to aid in real-time decision making process and to determine thermal treatment criteria, completion criteria, and iron dosage quantities.

The thermal treatment pass was initiated when the auger drilled from the ground surface to the starting thermal treatment depth for the zone of treatment at a descent rate of 1 to 3 feet per minute and 6 to 10 revolutions per minute. The three GCs processed samples approximately every 2 minutes for analysis. The FIDs continuously analyzed and processed the off-gas total VOC concentration. The fourth GC was also inline to collect samples during peak FID readings and was not in the cycled rotation. Once the auger reached the target starting depth, the steam valve was opened, steam entered the treatment column, and the auger continued descent to the desired finishing depth.

3.4.2.1 Primary Treatment Protocol

As discussed above, 83% (662 cells) of the treatment cells were treated with the primary treatment protocol. The protocol was primarily FID based, and TCE and PCE values were collected, stored and observed. Once the peak off-gas FID and TCE values were determined from the first pass thermal treatment, the cell thermal treatment criteria and completion criteria were determined according to Figure 3-2. Treatment cells were characterized into any of three categories based on the first pass FID concentrations:

1) **FID less than 400 ppm** – required a minimum of two complete thermal passes; no minimum shroud temperature; a minimum of 8,000 pounds of steam per hour during the passes; and a monitoring of TCE and PCE to ensure concentrations were below 100 ppm and 60 ppm, respectively. Figure 3-3 details the thermal and iron treatment schematic for FID less than 400 ppm.

2) **FID greater than or equal to 400 ppm but less than or equal to 1000 ppm** – required a minimum of two complete thermal passes; a shroud temperature of 160°F maintained throughout the entire complete final pass; focused passes could be implemented after the second pass, however, the final pass must have been completed from finishing treatment depth to surface; and to obtain completion criteria of an FID concentration less than 400 ppm, TCE concentration less than 100 ppm, and PCE concentration less than 60 ppm, or obtain a maximum thermal treatment time of 120 minutes. Figure 3-4 details the thermal and iron treatment schematic for FID greater than or equal to 400 ppm but less than or equal to 1000 ppm.

3) **FID greater than 1000 ppm** - required a minimum of four complete thermal passes; a shroud temperature of 160°F maintained throughout the entire complete final pass; focused passes could be implemented after the second pass, however, the final pass must have been completed from finishing treatment depth to surface; and to obtain completion criteria of an FID concentration less 80% of the highest peak FID value obtained during the first pass, TCE concentration less than 100 ppm, and PCE concentration less than 60 ppm, or obtain a maximum thermal treatment time of 120 minutes. Figure 3-5 details the thermal and iron treatment schematic for FID greater than or equal to 400 ppm but less than or equal to 1000 ppm.

Thermal treatment continued in each cell based on the category of treatment required per each cell. Those cells which required the heating of the soil/water column to 160°F (as defined by the off-gas shroud temperature) continued with successive thermal passes and implemented focused passes where deemed necessary by field managers. Focused passes targeted the interval of highest contamination (based on FID and TCE) and were implemented to efficiently apply thermal treatment to the interval of highest mass removal. Once 160°F was obtained as defined by the off-gas shroud temperature, steam flow rate was reduced to maintain the 160°F off-gas shroud temperature and continue mass removal until all completion criteria had been successfully obtained. Once all the completion criteria had been obtained, all treatment cells requiring the attainment of the 160°F off-gas shroud temperature were required to perform one final pass from the target finishing depth to the starting treatment depth, demonstrating the entire column had obtained the specified 160°F temperature. Thermal treatment was complete when the auger reached the starting treatment depth for iron injection. If completion criteria were not obtained on a cell during the thermal treatment, a maximum thermal treatment time of 120 minutes was implemented. Once the time was obtained, the final pass was performed and the auger was advanced to the surface to prepare for iron injection.

3.4.2.2 Alternative Treatment Protocol

As discussed above, 17% (135 cells) of the treatment cells were treated with the alternative treatment protocol. The protocol was primarily TCE concentration based with the FID and PCE determining values being removed. Once the peak off-gas TCE values were determined from the first pass thermal treatment, the cell thermal treatment criteria and completion criteria were determined according to Figure 3-6. Treatment cells were characterized into any of three categories based on the first pass FID concentrations:

1) **TCE less than 250 ppm** – required a minimum of one complete thermal pass; no minimum shroud temperature; a minimum of 8,000 pounds of steam per hour during the passes; and a monitoring of TCE to ensure concentrations were below 250 ppm. Figure 3-7 details the thermal and iron treatment schematic for TCE less than 250 ppm.

2) **TCE greater than 250 ppm on first pass but less than 250 ppm on second pass** – required a minimum of two complete thermal passes; no minimum shroud temperature, however, if it was determined that TCE mass removal and TCE maximum concentration were significant, 160°F shroud temperature could have been required; TCE concentration less than 250 ppm during final pass. Figure 3-8 details the thermal and iron treatment schematic for TCE greater than or equal to 250 ppm on first pass but less than 250 ppm on second thermal pass.

3) **TCE greater than 250 ppm on first and second thermal passes** - required a minimum of four complete thermal passes; a shroud temperature of 160°F maintained throughout the entire complete final pass; focused passes could be implemented after the second pass, however, the final pass must have been completed from finishing treatment depth to surface; and to obtain completion criteria of an FID concentration less than 80% of the highest peak FID value obtained during the first pass, TCE concentration less than 250 ppm, or obtain a maximum thermal treatment time of 120 minutes. Figure 3-9 details the thermal and iron treatment schematic for TCE greater than or equal to 250 ppm on first and second thermal passes.

Thermal treatment continued as described above in the cells which required additional thermal treatment. Once thermal treatment was completed, the auger was advanced to the starting treatment depth for iron injection.

3.4.2.3 Iron Preparation and Treatment

The ZVI slurry was prepared in two 600-gallon mixing tanks. The required quantity of ZVI-guar slurry mixture for each cell was transferred to the soil mixing auger by a progressive cavity pump. The slurry traveled down a 4-inch flexible hose to a 4-inch pipe connected to the crane. The slurry traveled up the 4-inch pipe then into another 4-inch flex hose and into the swivel. The slurry then traveled down the 2-inch Kelly Bar inner pipe and was injected into the subsurface through the rotating auger which distributed the iron throughout the treatment column. Water was used to flush the iron-guar slurry from the injection plumbing into the column during the retraction from finishing target depth to the surface to ensure that the entire quantity of iron required was injected into the column.

The amount of ZVI injected was determined by reading the maximum FID concentration in the treatment cell during operation. A ZVI quantity of 0.5%, 1.0%, 1.5%, or 2% was mixed in a slurry for injection into the subsurface. Table 3-5 depicts the iron quantity required per treatment zone and maximum FID reading obtained on the cell.

Table 3-5. ZVI Dose in Soil Column

Maximum FID in Off-gas	<1,000 ppm	1,000-5,000 ppm	5,000-10,000 ppm	>10,000 ppm
ZVI Dose	0.5%	1.0%	1.5%	2%+
Perimeter Cells	2,250 lbs	2,250 lbs	3,000 lbs	3,500-4,500 lbs
Zone 1	400 lbs	750 lbs	1,100 lbs	1,450 lbs
Zone 2	250 lbs	500 lbs	750 lbs	1,000 lbs
Zone 3	500 lbs	1,000 lbs	1,500 lbs	2,000 lbs
Zone 4	750 lbs	1,500 lbs	2,250 lbs	3,250 -4,500 lbs
Zone 5	1,000 lbs	2,000 lbs	3,000 lbs	4,000-5,000 lbs
Additional 5 ft of treatment	250 lbs additional were prepared and injected per each 5 feet of additional treatment			

Note – ZVI quantities were approximate values (but conservative) to the required calculated mass percentages based on available bag sizes. Also, 2% iron injection was also based on the concentration of TCE obtained in the treatment cell. Iron values in the 2%+ range varied based on available bag sizes and batch plant operational capabilities at these quantities.

Several treatment cells throughout the site were determined to require deeper thermal treatment based on real-time data. Therefore, for every 5 feet of additional treatment depth, an additional 250 pounds of ZVI were prepared in the batch for injection. It was also determined that the maximum operational capacity of the batch plant was 4,000 pounds of ZVI. Therefore, to reduce stress and additional maintenance requirements to the paddles and pumps, dosages of 4,000 pounds or greater were completed on only 14 treatment cells at the site. However, these 14 treatment cells were consistent with the highest contaminated area at the Facility 1381 site. In addition, 2% values were not anticipated nor encountered during the implementation of the alternative treatment protocol, therefore, a 2% iron dosage was not included in Figure 3-6.

The ZVI used was Peerless P1 with less than a -50 mesh grain size, and was prepared in a slurry of water and guar gum in two 600-gallon mixers. The amount of guar gum utilized was 0.75% of the water weight or 0.06 lb per gallon. This amount of guar gum was determined in order to adequately suspend the maximum amount of iron used for 2% loading. Table 3-6 details the ZVI slurry details required per zone of treatment at Facility 1381.

Table 3-6. Total Pounds of ZVI Slurry per Zone of Treatment

Interval of Treatment per Zone	Zone 1 15 ft	Zone 2 10 ft	Zone 3 20 ft	Zone 4 30 ft	Zone 5 40 ft
Guar Gum Required (lbs)	10.3	6.8	13.8	20.7	27.5
Volume of Water/ZVI Slurry (gal)	193	129	257	385	515
Slurry Depth in Batch Plant Tank (inches)	15	10	20	30	40

Preparation of the iron slurry was performed during the thermal treatment passes in order to adequately suspend the iron in the guar and water mixture. The iron preparation procedures for ZVI slurry preparation were as follows:

1. In guar preparation tank added approximately 100-200 gallons of water and re-circulated.
2. Added the amount of guar required according to Table 3-6 into the tank.
3. Turned on the paddle mixer and added water to the make-up tank to 5 inches less than slurry required according to the Table 3-6. Re-circulated for approximately 30 to 40 minutes at approximately 300 gpm for adequate guar thickening.
4. After thickening the guar/water mixture, added ZVI at approximately 100 lbs to 150 lbs per minute and mixed for approximately 10 minutes or more.
5. Added water to make the desired ZVI slurry depth to obtain the adequate volume according to Table 3-6 and, once added, ready for injection.

Once the auger reached the starting thermal treatment depth, the ZVI slurry was pumped to the auger for injection at a rate of approximately 25 gpm and the air flow remained at a minimal 100 acfm to aid in drilling. Drilling commenced from the starting treatment depth to the finishing treatment depth at a descent rate of approximately 1-2 feet per minute and approximately 10 rpm. FID and GC samples were also collected during the iron treatment. Once the finishing treatment depth was reached and the volume of ZVI slurry was injected, water was introduced to the ZVI agitator tank for a washout of the lines on the way to the surface for cell completion.

3.4.2.4 Treatment Cell Completion

At the completion of each cell, the auger was stopped just below the ground surface and the shroud was lifted. Once the shroud was lifted the auger was removed from the soil and spun several times to remove and loosen dirt from the blades. The crane was swung away from the treatment cell to allow for backfilling and compaction by an excavator. Approximately 3 to 5 cubic yards of soil was mixed with approximately 3 to 4 feet of recently treated cell soil to aid in soil stabilization. These activities were performed to stabilize the soil and bring it back to original grade.

3.4.3 Example Treatment Cell BK28 – Primary Treatment Protocol

Treatment cell BK28 located in Zone 4 at Facility 1381 was treated on April 4, 2007, between starting time of 09:29 and ending time of 11:25. Figure 3-10 details the treatment sequence for cell BK28 and is provided to aid the description that follows. This cell was a Zone 4 treatment cell which required thermal treatment from 12 to 42 feet bgs (minor interval change was associated to grading elevation adjustments). The auger was advanced to 12 feet bgs where thermal treatment commenced down to 42 feet bgs at a steam flow rate of approximately 8,500 pph. FID contaminant levels increased very sharply at approximately 15 feet bgs and significantly dropped below that depth. A peak FID of 7,426 ppm was obtained at 15 feet bgs. The primary COC composed within the off-gas stream was 7,578 ppm TCE as determined from the GC samples collected during the FID spike. The peak also consisted of 1,1,1-TCA at 327 ppm and Freon 113 at 32 ppm. These values characterized the cell as an FID greater than 1000 ppm treatment category requiring a minimum of four thermal treatment passes, shroud temperature of 160°F minimum, and completion criteria of less than 100 ppm TCE and 60 ppm PCE and 80% FID reduction to satisfy all completion criteria. Figure 3-10 illustrates the contaminant response associated with the treatment of cell BK28.

Shroud temperature of 160°F was obtained on the third pass and maintained on the subsequent full treatment passes. The majority of the TCE contamination was removed on the first pass which correlated to an 80% reduction of the FID attainment on the second thermal pass as well as attainment of the less than 100 ppm TCE concentration. Prior to commencing the iron injection the highest FID value seen on the last pass was approximately 248 ppm, which is 97% reduction from the peak FID value. TCE concentrations on the final pass were reduced to 7 ppm. Once thermal treatment was completed, the auger was drilled to 12 feet bgs and iron injection commenced for one pass to 42 feet bgs. Iron injection was completed at 42 feet bgs and the auger was returned to the surface for treatment cell completion.

3.4.4 Example Treatment Cell BE39 – Alternative Treatment Protocol

Treatment cell BE39 located in Zone 4 at Facility 1381 was treated on May 8, 2007, between starting time of 11:46 and ending time of 13:14. Figure 3-11 details the treatment sequence for cell BE39 and is provided to aid the description that follows. This cell was a Zone 4 treatment cell which required thermal treatment from 12 to 42 feet bgs (minor interval change was associated to grading elevation adjustments). The auger was advanced to 12 feet bgs where thermal treatment commenced down to 42 feet bgs at a steam flow rate of approximately 7,000 - 9,000 pph. FID contaminant levels increased very sharply on the first thermal treatment pass at approximately 15 feet bgs and significantly dropped below that depth. A peak FID of 1,289 ppm was obtained at 15 feet bgs. The primary COC composed within the off-gas stream was 1,144 ppm TCE as determined from the GC samples collected during the FID spike. The peak also consisted of Freon 113 at 138 ppm, cis-1,2-DCE at 55 ppm, and 1,1,1-DCA at 26 ppm. Upon retraction on the second pass a TCE concentration peak of 52 ppm was observed. These values characterized the cell as TCE greater than 250 ppm on first pass but less than 250 ppm on the second pass treatment category requiring a minimum of two thermal treatment passes, no shroud temperature requirement, and completion criteria of less then 250 ppm TCE. Figure 3-11 illustrates the contaminant response associated with the treatment of cell BE39.

Prior to commencing the iron injection the highest FID value seen on the last pass was approximately 496 ppm, which was primarily methane in composition. TCE concentrations on the final pass were reduced to 52 ppm. Once thermal treatment was completed, the auger was drilled to 12 feet bgs and iron injection commenced for one pass to 42 feet bgs. At the completion of the iron injection at 42 bgs, the auger was advanced to 57 feet bgs in order to maintenance the swivel due to elevated winds at the site and man-lift restrictions. During the additional depth descent the FID spiked higher than the first pass FID spike. GC breakout of the composition of COCs in the off-gas revealed the main component was methane. Once maintenance on the swivel was completed, the auger was returned to the surface for treatment cell completion.

3.5 DATA USE

3.5.1 Mass Calculations

The purpose of this calculation is to determine the estimated amount (mass) of VOCs extracted during the treatment of cells. The mass is calculated using the concentrations of the constituents detected by GC for the following compounds: PCE; TCE; cis-1,2-DCE; trans-1,2-DCE; vinyl chloride; 1,1,2-trichloro-1,2,2-trifluorethane (Freon 113); benzene; toluene; ethylbenzene; 1,1-DCA; and 1,1,1-TCA. The approach and the calculation to determine the mass of VOCs are given below.

Assumptions:

- The off-gas line is saturated with water at temperatures between 130 and 208°F.
- The amount of water vapor in the conditioned sample stream can be neglected.

- The mass of solids and liquid water in the bulk stream can be neglected.
- Some of the VOC mass removed may not be captured in the shroud and may emit into the atmosphere as a minor fugitive emission around the shroud.
- Ideal gas law applies
- Each analyte concentration measured by GC is constant for the 2 minute interval until the next GC concentration for each analyte is measured.

Approach:

F_m = Mole fraction of contaminant = μ–moles/mole * 10^{-6} moles/μ–mole.

C_w = Correction factor for water in the bulk stream is based on curve fit of steam tables data for saturated steam from 130 to 208°F.

C_m = Conversion from moles to mass = Molecular weight of contaminant: (grams/g-mole) * 0.00220462 lbs/gram.

M = Mass of contaminant

n = Total moles of a gas = PV/RT (Assuming ideal gas behavior applies)

P = absolute pressure = ambient pressure (P_a) – vacuum pressure (gage) (P_g)

V = volume of gas

R = Ideal gas constant: 0.654882 in-H_2O-ft^3/g-mole °R

T = Temperature degrees Rankin = degrees F + 459.4

Therefore, $M = F_m * n * C_w * C_m$

Applying the above approach, the expression to calculate total mass of the contaminant can be calculated by the following equation:

$$\mathbf{M_{ij} = [C_{ij} * MW_i * (4.01463E\text{-}1 * P_{Aj} - P_{1j}) * V_{1j} * 3.36635E\text{-}9/(T_{1j} + 459.4)] * [1\text{-}(4.64711E\text{-}7 * T_{1j}^3 - 1.45239E\text{-}4 * T_{1j}^2 + 1.84674E\text{-}2 * T_{1j} - 8.17509E\text{-}1)]}$$

Where:

b = GC sample interval (min.).(Extrapolated constant interval in minutes=1/60 min.)

C_{ij} = concentration of contaminant i at sample interval j

g_{1k} = incremental flow rate reading in the off-gas line (cfm)

MW_i = molecular weight of individual contaminant compound (g/g-mole)

P_{Aj} = ambient pressure at sample interval j (millibar absolute)

PA (in-H2O) = Pa(millibar)*0.401463 (in-H2O/millibar)

P_{1j} = average vacuum reading in the off-gas line at sample interval j (in-H_2O gage)

T_{1j} = average temperature reading in the off-gas line at sample interval j (^oF)

V_{1j} = volume of gas at sample interval j (ft^3)

Also, $V_{1j}=b*g_{1k}$

M = Total mass of contaminant compounds (pounds)

M_i = Total mass of the individual contaminant compound i (pounds)

M_{ij} = mass of the individual contaminant compound i at sample interval j (pounds)

m = number of contaminant compounds detected by the GCs.

$$M_i = \sum_{j=1}^{n} M_{ij}$$

$$M = \sum_{i=1}^{m} M_i$$

3.5.2 Treatment Summary and Data Presentation

Total cells treated at the site were 797 treatment cells which equaled to a total volume of 44,163 cubic yards. Table 3-7 depicts the total cell and volume breakout per zone.

Table 3-7. Treatment Cells and Volume per Zone of Treatment

Treatment Zone	Treatment Cells	Treatment Volume (yd3)
Zone 1	72	2,064
Zone 2	106	2,093
Zone 3	140	5,451
Zone 4	405	28,438
Zone 5	74	6,117
TOTALS	797	44,163

As cells were treated, the raw data were uploaded on the web server in Oak Ridge. The reports were then executed using ICONICS Reportworks software that used the custom template to generate the reports. During this project, four reports were generated:

- Mass removed for entire site,
- Mass removed for individual cell,
- Methane summary for individual cell, and
- Treatment summary for individual cell.

Mass removed for entire site report presents the mass of contaminants removed from every cell. These contaminants include PCE; TCE; cis-1,2-DCE; trans-1,2-DCE; vinyl chloride; Freon 113; benzene; toluene; 1,1-DCA; and 1,1-TCA. This report also includes the total mass removed of each contaminant as well as the total mass removed from the site.

Mass removed for individual cell report presents treatment cell information that includes coordinates, date and time of treatment, treatment depth, off-gas VOC concentrations estimated by GC (ppm), process parameters used in the calculation of mass removal, and mass removed from cell. The report also presents the graph of VOCs in Off-Gas vs. Time. The graph presents the amount of VOC concentration in ppm removed from the cell with respect to time in seconds. It also represents the depth of auger in feet versus time in seconds.

Methane summary for individual cell report presents a graph of methane concentrations. The graph represents the amount of PCE; TCE; cis-1,2-DCE; methane and FID in ppm with respect to time in seconds. It also represents the depth of auger in feet versus time in seconds.

Treatment summary for individual cell report presents three graphs of the summarized data. The first graph is entitled VOCs in Off-Gas and Depth versus Time. This graph represents the total VOCs as measured by the FID with respect to time in seconds. It also represents the depth of auger in feet versus time in seconds. The second graph represents the air temperature, steam injection temperature, off-gas temperature, and shroud temperature, all in degrees Fahrenheit with respect to time. The third graph represents the air flow and off-gas flow in acfm with respect to time in seconds. In addition, it represents the steam injection rate in pph with respect to time in seconds. The individual cell reports are presented in Volume III.

From these reports, six figures were created and updated daily. Figure 3-12 shows the treatment sequence of the cells. The cells are numbered and shaded as to the order they were treated. The treatment progress for each cell is presented in Figure 3-13. In this figure the maximum FID and TCE values are shown for each cell. In addition, each cell is color coordinated depending upon the FID and TCE value (i.e., FID less than 400 ppm and TCE less than 100 ppm; FID greater than or equal to 400 ppm and less than 1000 ppm and/or TCE greater than or equal to 100 ppm and less than 200 ppm; FID greater than or equal to 1000 ppm or TCE greater than or equal to 120 ppm). Figure 3-14 shows the TCE, DCE, PCE, and total VOC contamination mass for each cell. The ZVI injection percentage and mass for each cell are shown in Figure 3-15. Additional thermal treatment depth and thermal treatment time added to selected cells are depicted in Figure 3-16 and Figure 3-17, respectively.

3.6 DATA EVALUATION

Each treatment cell represents the location of a vertical penetration of the 8-foot diameter LDA. Per the plan, the source area was divided into five zones wherein the depth of treatment was specific for the depth of contamination determined from background sampling previously conducted in each zone area. The off-gas from each cell was sampled and analyzed using gas chromatography during treatment and the concentration data were used to calculate pounds of chemical mass removed from each cell. The concentrations of VOCs in the off-gas were used to determine the chemical-specific mass removed as described in Section 3.5.1. The total mass removed for each VOC represents all phases that were present in the subsurface (e.g., pure phase, sorbed, dissolved). Operational parameters discussed in Section 3.2.1 were recorded to facilitate real-time decisions. The data represented by chemical mass, concentration, and operational parameters are evaluated and presented below.

3.6.1 VOC Mass, Concentration, and Steam Injection Analysis

3.6.1.1 Total Mass Removed Per Cell

The total mass removed for each treatment cell location is represented in Figures 3-18 through 3-22 using plan-view color contour plots to represent the mass removed in pounds for TCE, cis-DCE, vinyl chloride, 1,1,1-TCA, and Freon 113. These five VOCs represent 99.87% of the total mass removed during the remedial action, and the figures demonstrate where the bulk of the contamination was located and removed from the site. Figure 3-23 is included for methane which represents a biogenic gas produced during the reductive dechlorination of chlorinated solvents such as TCE and cis-DCE. The incremental total mass removed per successive, 10-foot depth intervals for each treatment cell is demonstrated in oblique-view color contour plots provided in Figures 3-24 through 3-29. The depth-interval figures provide additional information on the vertical and horizontal distribution of the VOC mass that was encountered and removed from the site. For all plots the mass removed per cell was assigned to a point representing the center of each treatment cell, and the data were contoured using a kriging algorithm in the SURFER® software program. The total mass removed for each treatment cell location is presented in Appendix J.

The plan and oblique view plots show that the majority of the mass was located across the northern and eastern portions of the source area. Furthermore, TCE, cis-DCE, and methane tended to be more ubiquitous across the entire source area compared to vinyl chloride, 1,1,1-TCA, and Freon 113. A similar distribution is shown in the depth interval plots, although TCE, the chlorinated solvent parent material, shows a persistent vertical distribution between 10 and 60 feet, whereas daughter products (i.e., cis-DCE, vinyl chloride) and biogenic gases (e.g., methane) resulting from reductive dechlorination of TCE tend to increase laterally and/or with depth. Cis-DCE and vinyl chloride appear to have their largest lateral distribution between 10 and 40 feet, whereas methane appears to increase in lateral extent down to 60 feet.

Freon 113 and 1,1,1-TCA show relatively limited lateral distribution with respect to TCE and cis-DCE; however, the loci of the greatest mass removed are consistent. Additionally, vertical migration of all these VOCs appears to have occurred at similar geographic locations suggesting their coincidence with a surface release point or with a preferred vertical pathway through the subsurface.

The greatest TCE mass per cell removed occurred in the 40 to 50 feet depth interval. Figures 3-24 through 3-29 show little increase in the lateral extent of the source area, but rather suggest a downward movement or deeper increase in cis-DCE and vinyl chloride mass to about 50 feet that follows the reductive dechlorination pathway going from TCE to cis-DCE to vinyl chloride (shallow to deep). Similarly, methane shows a downward increase in lateral extent, suggesting that reducing conditions are becoming stronger and wider spread with depth. The downward changes in the source area chemistry are consistent with a hydrogeologic model of a surface recharge area with downward (perhaps dominantly) and lateral components of flow toward both the northern and southern drainage ditches where groundwater discharges. In addition to potential gravity flow of DNAPL following the release of TCE, this observation suggests that downgradient advective flow of groundwater is at least partially responsible for the vertical distribution of all VOCs. Overall, the distinct areas of greatest mass (see Figure 3-18) and the persistent vertical trace of greatest mass for TCE, cis-DCE, and Freon 113 (see Figures 3-24, 3-25 and 3-26) suggest that localized, gravity-driven flow of DNAPL may have occurred downward through the subsurface.

Vinyl chloride was only present in the areas (both laterally and vertically) where a relatively high mass of chlorinated solvents was present. This suggests that geochemical conditions in the mostly highly contaminated portion of the source area may have prevented complete dechlorination of less oxidized daughter products such as vinyl chloride thus resulting in its accumulation in this area. Areas surrounding the high VOC mass areas where little vinyl chloride mass was present could indicate where conditions were favorable for further dechlorination or even complete mineralization of the daughter products. Alternatively, based on the hydrogeologic model, flow conditions may not be favorable for lateral spreading of the daughter products.

3.6.1.2 Concentration and Mass Removed Profiles

Profile plots demonstrating the maximum concentrations of VOCs and the mass removed per foot of LDA penetration were prepared to further demonstrate the lateral and vertical distribution of the predominant VOCs encountered and removed in the source area. Five profiles, A-A’, B-B’, C-C’, D-D’, and E-E’ as shown on Figure 3-30, were selected based on the horizontal and vertical distribution of the total mass of VOCs removed (see Section 3.6.1) that follow the track of the largest mass removed. Plots were prepared for only TCE, cis-DCE, and Freon 113 since these three VOCs represent the lateral and vertical extent of contamination at the site and the majority of the mass removed.

Figures 3-31 through 3-45 show the maximum concentrations of TCE, cis-DCE, and Freon 113 that were detected per foot of LDA penetration along profiles A-A' through E-E'. The figures show that the highest range of concentrations (i.e., greater than 50,000 ppm) were encountered predominantly within the 10 to 20 and the 40 to 50 feet depth intervals; however, the entire vertical section between approximately 20 to

55 feet contained high concentrations at cell BQ49 (see C-C'). These loci of highest concentrations were typically associated with continuous vertical concentrations exceeding 10,000 ppm. However, one interval of highest concentration at cell BN29 (see A-A') was vertically isolated. In general, concentrations of TCE were more than 10 times higher than cis-DCE or Freon 113, but the location of the highest concentrations and their vertical distribution were similar for all three chemicals. The highest TCE concentration of 164,632 ppm was detected between a depth of 45 to 46 feet bgs at cell BQ48; the second highest concentration of 154,467 ppm was detected between a depth of 40 to 41 feet bgs at cell BT44. Numerous cells encountered by the cross sections demonstrate an extensive vertical distribution of VOCs suggesting downward migration of contamination at these locations; high concentrations of TCE within a few feet of the surface at cell BN38 suggest that a release may have occurred in this area of the site.

Figures 3-46 through 3-60 show the mass of PCE, TCE, and cis-DCE that was removed per foot of LDA penetration along profiles A-A' and B-B'. The pattern of high mass removal is consistent with the areas where the highest concentrations were detected, as expected. Collectively, the profile Figures (3-31 through 3-60) indicate that relatively high concentrations and significant mass of TCE were removed, but indicate that some chemical mass may extend below the depth of LDA penetration at several of the cells containing the highest vertical contamination profiles. To further investigate the mass remaining at the bottom of the treatment zone, oblique plan-view plots showing the change in mass across the bottom 4 feet of each cell (regardless of total depth) are presented in Figures 3-61 through 3-63 for TCE, cis-DCE, and Freon 113. These data indicate that additional contamination (i.e., >5 lbs/foot) exists below the depth of LDA penetration in the areas of cells BL42, BL43, BQ43, BQ44, BQ48, BR44, BR45, BR46, BS44, BT43, BT44, and BT45. As shown on the figures, the depth of treatment (cell bottom) was typically 55 to 57 feet at these locations.

Finally, a set of three-dimensional views are presented in Figure 3-64 that provide an overall picture of how the total mass of TCE was distributed through the source area. The mass of TCE removed is presented as three transparent isosurfaces, ranging from low to high pounds/foot removed, which provide an aspect of the plume that is not afforded by the two-dimensional figures previously presented. Views 1 and 4 clearly demonstrate how the most highly contaminated areas located along the eastern side of the source area (refer to Figure 3-18) extend vertically through the subsurface whereas the other highly contaminated areas are more vertically isolated. The figure also demonstrates how the majority of the mass was located in a relatively limited area of what was defined as the source area target for the LDA. It should be noted that due to the transparency of the isosurfaces, views 1 and 4, and views 2 and 3, are essentially mirror images looking from opposite directions through the source area.

3.6.1.3 Steam Injection Profiles

Profiles A-A' through E-E' were also utilized to demonstrate the duration (minutes/foot) and quantity (pounds/foot) of steam that was injected via the LDA, as shown in Figures 3-65 through 3-74. Both the duration and quantity of steam injected were proportional to the instantaneous operation parameters (temperature, pressure, flow volume of the steam generation system) and to the concentration of VOCs detected in the off-gas system (i.e., additional auger passes and time were applied to highly contaminated areas per protocols). Therefore, as can be seen in the figures, the areas of highest duration and quantity of steam injection generally coincide with the areas where the highest concentrations and greatest VOC mass were removed from the source area.

3.6.2 Operational Parameters and Contaminant Trend Analysis

In an effort to determine the relationship between important operational parameters and the contaminant removal, the data collected and saved during the implementation phase of the project were specifically queried with respect to LDA passes and source area zones. The results of the queries were then plotted to present and evaluate the information. Only data from the first five thermal passes and the two iron passes have been plotted since, in general, thermal passes after the fifth thermal pass were typically focused passes. The target treatment depth in each zone was presented in Table 2-1. In general, the target treatment depths increased with zone number except for Zone 1 and Zone 2 where the target treatment depths were essentially the same. The parameters that have been plotted with respect to passes and/or zones are presented below:

- TCE Concentrations
- Average Temperature
- TCE Mass
- Treatment Time
- VOC Mass
- Average Depth
- Steam (lbs)

The plots are categorized into two major groups that present the information described below:

- The parameter as a percent of all cells (Figures 3-75 through 3-77)
- The parameter with its value ((Figures 3-78 through 3-81)

Figure 3-75 shows the percent of cells where the maximum TCE concentration was observed with respect to pass number. As per the chart, the peak or maximum TCE concentration was recorded in the first pass in approximately 85.5% (i.e., 681of 797) of the cells treated. Similarly, the number of cells where the peak or maximum TCE concentration was detected in the second pass was 5.3% and totaled approximately 9.2% for all the subsequent passes.

Figure 3-76 shows the average temperature attained as a percent of cells per pass for five temperature ranges: (1) less than 100°F, (2) greater than 100°F and less than 120°F, (3) greater than 120°F and less than 140°F, (4) greater than 140°F and less than 160°F, and (5) greater than 160°F. The chart shows that the highest temperature range was achieved for the largest number of cells only after the 4th or 5th LDA pass. However, nearly 80% of all cells attained a temperature greater than 120°F within the first three passes.

Figure 3-77 shows the average TCE mass removed as a percent of cells per pass for five categories of mass removal ranging from zero pound to greater than 100 pounds. The chart demonstrates that relatively few cells, as a percent, contained a high mass of TCE (i.e., greater than 1 pound), and that the highest mass removed (i.e., greater than 100 pounds) occurred in only a few cells. The chart also indicates that after the first pass the LDA rarely encountered cells contributing more than 1 pound of mass.

Figure 3-78 presents average TCE mass/cell for each of the five zones that was removed by each successive pass of the LDA. The chart also reiterates that most of the mass was removed from Zone 4 and Zone 5 (see Section 3.6.1) and between Pass 1 and Pass 5 of the LDA.

The primary focus of Figure 3-79 is to present the trends (plotted linearly) of the various parameters including average treatment time per cell, average VOC mass per cell, average treatment depth per cell, average temperature per cell, and average steam in pounds per cell with respect to zones in the first pass. For example, the figure shows that the highest VOC mass removal occurred in Zone 5 that was treated to the greatest depth, which required more than 4000 lbs of steam to maintain the average temperature of approximately 105°F, and which required an average treatment time of approximately 40 minutes in the first pass.

Figure 3-80 presents average temperature per cell for each of the five zones with respect to each pass. Similarly, Figure 3-81 presents average VOC mass per cell for each of the five zones with respect to each pass plotted in relation to average maximum treatment depths. The chart indicates that most of the mass was removed between Pass 1 and Pass 5 from Zone 4 and Zone 5 with an average maximum treatment depth between 45.6 and 53.8 feet.

3.7 REAL-TIME DECISIONS

Data from the FIDs and GCs were utilized to determine trends in depth, concentration, and location of contamination requiring treatment. These identified data trends in contamination enabled on-site field managers to perform real-time decisions on treating identified contamination (within the 10 ppm TCE contour and zone intervals) as described in the treatment protocols. In addition, the data trends enabled field managers to assess if additional contamination was present beyond and below the identified area and zones of contamination. The following section describes the three forms of real-time decisions that were made to treat additional contamination discovered beyond the identified bounds at Facility 1381. The real-time decisions were:

- Deeper Contamination Treatment and Contaminant Trending
- Expansion Cell Treatment
- Additional Thermal Treatment Time

The SCADA screen shots consisting of operator screen and trending graph for each cell are presented in Volume III. The documentation of real-time decisions is provided in field notes and presented in Volume IV.

3.7.1 Deeper Contamination Treatment and Contaminant Trending

During active treatment on a cell, the off-gas FID was monitored to determine the approximate location and/or interval of the highest level of VOC concentration in the treatment cell, and the GCs provided the chemical constituent breakdown of each COC at that particular depth. If it was determined that FID values were rising near the target finishing treatment depth and exceeded 400 ppm (with TCE concentration from GC greater than 100 ppm), then it was indicative that significant TCE contamination may be present below planned depth and an additional 5 feet of treatment was utilized to treat contamination on the third pass. If contamination was present within the additional 5 feet of thermal treatment and levels continued to rise, additional thermal treatment footage was implemented in 5 foot intervals until contamination. The maximum depth attainable with the setup of the drilling equipment at Facility 1381 was 57 feet bgs. Figure 3-16 depicts the treatment cells where additional treatment depth was required based on the discovery of contamination at or nearing the target finishing treatment depth. Once the additional 5+ feet of treatment was implemented, the maximum treatment depth for the cell was modified to the new depth and iron quantities were adjusted accordingly.

Contaminant trending involved the analysis of adjacent treated cell information (primarily FID concentration and depth location, TCE concentration and depth location) to estimate the magnitude and location of contamination in untreated cells in order to target the appropriate treatment interval. Generalized trends of contamination in treated cells at specific depths were observed throughout the site (contamination peaks were seen below the designed treatment zone in Zone 4 near Zone 5 as well as in Zone 5 and raised to 15-20 feet bgs near the Facility) and contaminant trending utilized the generalized trends to maximize efficient treatment. Due to the high amount of treatment cells requiring maximum depth (57 feet bgs) treatment in Zone 4 and Zone 5, contaminant trending facilitated the re-establishment zone interval treatment (i.e. in zone 4 treating from a 57 foot bgs treatment cell back to the designed 40 foot bgs). Periodic maximum thermal treatment was performed to ensure that contamination did not exist below the treatment zone. FID and GC monitoring continued during each treatment cell to determine if deeper treatment was required, as described above.

3.7.2 Expansion Cell Treatment

Contaminant data were analyzed by on-site personnel and managers to determine areas where additional treatment may be required beyond the bounds assessed prior to implementation. A combination of peak FID values, peak TCE values, and mass removal information was analyzed to aid in determining the quantity of additional cells required. Mass removal information was not available in real time but was provided within one or two days after treatment to make adequate field decisions on treatment or no treatment while positioned near the area of question. The addition of treatment cells beyond the assessed treatment area was discussed and approved by the Partnering Team.

A total of 21 treatment cells were thermally treated as expansion treatment cells. Expansion treatment cells were added adjacent to perimeter cells that contained significant TCE mass and were expanded out until the TCE mass removal was less than an approximate one pound of TCE. Table 3-8 lists the expansion cells added for treatment at Facility 1381. Figure 3-1 illustrates the expansion treatment cell locations treated at Facility 1381.

Table 3-8. Expansion Treatment Cells

Cell ID	Treatment Date	Zone	Cell ID	Treatment Date	Zone
BP49	9/11/06	4	BV46	10/6/06	5
BQ49	9/11/06	4	BU47	10/6/06	5
BR49	9/12/06	4	BV47	10/6/06	5
BS49	9/12/06	4	BQ50	10/6/06	4
BT47	9/19/06	5	BR50	10/9/06	4
BT46	9/19/06	5	BS50	10/9/06	4
BU46	9/20/06	5	BW46	6/4/07	5
BU44	10/5/06	5	BW45	6/4/07	4
BU45	10/5/06	5	BT49	6/5/07	5
BV44	10/5/06	5	BT48	6/5/07	5
BV45	10/6/06	5			

3.7.3 Additional Thermal Treatment Time

Another real-time decision that was made in the field was utilizing additional thermal treatment time to continue reduction of the TCE concentrations observed in the off-gas. When nearing the maximum thermal treatment time of 120 minutes if completion criteria had not been yet obtained, the FIDs and GCs were monitored for contamination reduction trends over the entire thermal treatment. If it was determined that contamination remained at elevated levels (FID above 1000 ppm and TCE, as analyzed by GC, above 1000 ppm), 30 additional minutes of thermal treatment time were added until contamination levels were reduced to FID below 1000 ppm and TCE, as analyzed by GC, below 1000 ppm. Table 3-9 depicts the treatment time breakout and additional time breakout implemented at Facility 1381. In addition, the table depicts the number of cells where additional treatment time was implemented for continued mass removal. The average thermal treatment time per cell was approximately 63.08 minutes and an average thermal treatment time per cubic yard was approximately 1.13 minutes.

Table 3-9. Treatment Time Percentage at Facility 1381

Time (minutes)	Number of Cells	Percentage
Equal to or less than 30	186	23%
30 – 60	207	26%
60 – 90	230	29%
90 – 120	147	18%
Greater than 120 (additional time)	27	3%

3.8 HEALTH AND SAFETY

The success of every project lies in the implementation of a thorough plan with health and safety in the forefront of every activity. The LDA CMI project was no exception to this principle. The CMI Work Plan and Health and Safety Plan (HASP) (Tetra Tech, 2005) were source documents in providing a safe and operational effective remediation at Facility 1381. The HASP (USAF Contract No. FA8903-04-D-8677, Delivery Order No. 0031) was prepared to provide health and safety procedures and guidelines for Tetra Tech employees and subcontractor personnel engaged in on-site activities.

The publications listed below were the basis of regulatory guidelines followed in preparation of the HASP.

- American Conference of Governmental Industrial Hygienists (ACGIH), 2006. *Threshold Limit Values for Chemical Substances and Physical Agents Biological Exposure Indices.*
- American National Standards Institute (ANSI), 1998. Z358.1.
- National Institute for Occupational Safety and Health (NIOSH), 1985. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.*
- Occupational Safety and Health Administration (OSHA), *Safety and Health Regulations for General Industry,* Title 29 *Code of Federal Regulations* (CFR), Part 1910.
- OSHA, *Safety and Health Regulations for Construction,* 29 CFR 1926.
- U.S. Army Corps of Engineers (USACE), 2000. *Safety and Occupational Health Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities,* ER 385-1-92.
- USACE, 2003. *Safety and Health Requirements Manual,* EM 385-1-1.

The HASP provided the framework for the Site Safety and Health Officer (SSHO) and Health and Safety (H&S) personnel to follow throughout the CMI activities. This section focuses on several key elements performed during CMI activities to ensure the health and safety for Tetra Tech employees, subcontractor personnel, and on-site visitors.

During the initial stages of the CMI activities, the SSHO met with subcontractor H&S personnel to review the HASP and discuss any pertinent health and safety concerns. Details on submission of employee training records, medical surveillance documentation, initial site-specific training and correspondence measures were discussed in a meeting held prior to commencing field activities. In this meeting the SSHO provided copies of the HASP, and a training package was developed for initial site-specific training. In addition, the scope of tailgate topics was compiled specific to CMI activities.

CMI activities were categorized into five major activities:

- Groundwater Sampling

- Mobilization/Demobilization
- In-Situ Soil Mixing with Steam, Hot Air, and ZVI Injection by LDA
- Vapor Extraction, Conditioning, and Treatment
- Equipment and Personal Decontamination

The following elements detail actions monitored by the SSHO to ensure a safe and healthy work environment for all site personnel: training, tailgate safety meetings, monitoring, site access, injury/illness reporting, equipment inspections, and hot work permit.

3.8.1 Training

Prior to commencing field activities at Facility 1381, the SSHO compiled training documentation and certification records mandated in the OSHA Hazardous Waste Operations and Emergency Response (HAZWOPER) standard. All on-site workers were required to have the following HAZWOPER training:

- Initial General Site Worker Training (normally 40 hours off-site training) [29 CFR 1926.65 (e)(3)(i)]
- Three days of field experience under direct supervision of a trained, experienced supervisor [29 CFR 1926.65 (e)(3)(i)]
- Refresher Training (at least 8 hours on specific health and safety items) for all on-site workers, if it has been more than a year since completion of initial general site worker training [29 CFR 1926.65 (e)(8)]
- Supervisor Training for site supervisors in addition to the above requirements (an additional 8 hours of specialized training) [29 CFR 1926.65 (e)(4)]

A spreadsheet was developed to track all on-site workers' training information by their respective employer (Appendix K). The SSHO provided periodic updates to subcontractor supervision to ensure personnel maintained training competency.

All on-site workers were briefed by the SSHO on the HASP prior to commencing CMI activities. These sessions addressed pertinent areas under the HASP based on the respective major activity. Topics covered included:

- Names of personnel and alternates responsible for health and safety on-site and for the project
- Site layout (see Figure 1-2)
- Specific safety, health, and other hazards
- PPE requirements
- Work practices and restrictions, and personnel/equipment decontamination procedures
- Air monitoring program
- Spill containment and emergency procedures
- Accident and incident reporting

3.8.2 Tailgate Safety Meetings

Prior to the start of a workday, a tailgate safety meeting was held informing on-site workers of the potential hazards associated with planned daily activities. The meetings provided an open line of communication for supervisors and safety personnel to educate and increase workers' awareness on protective measures and hazards associated with each activity. In addition, the Activity Hazard Analysis (AHA) for a particular major site activity was reviewed prior to performing an activity during these sessions. These meetings were documented on Daily Tailgate Safety Meeting Forms. Topics included:

- Chemical hazards (hazard communication, material safety data sheets, exposure limits)
- Physical hazards (fall protection, heavy equipment pinch points, ladder safety)
- Environmental and biohazards (insects, snakes, poisonous plants)
- Air monitoring results (FID readings)
- Decontamination procedures (proper decontamination for sampling equipment)
- PPE (respirators, gloves, hard hats)
- Emergency procedures (emergency contact phone numbers, location of nearest hospital)
- Other pertinent information (use of hand-free devices when talking on cell phone while driving on base, lightning phase advisory)

3.8.3 Monitoring

Monitoring workers' safety encompasses medical, heat strain, and air monitoring for all HAZWOPER-related activities.

3.8.3.1 Medical Monitoring

Medical monitoring involves the approval of a licensed physician certifying the employee fit-for-duty and able to wear any required PPE under normal work site conditions. All on-site workers required medical surveillance examinations prior to commencing work activities on-site. The SSHO ensured all Tetra Tech personnel and subcontractor employees were fit-for-duty to perform their respective activities. The SSHO maintained the physician's written opinion on file at the site indicating the fit-for-duty status and individual worker limitation, if any. Examination dates and any limitations were noted and tracked on the Training Worksheet.

3.8.3.2 Heat Strain Monitoring

Heat stress is one of the health factors H&S personnel assessed during CMI activities. The National Safety Council (NSC) recognizes three significant risk factors that contribute towards heat stress: environment, work activity, and additional protective clothing. These stressors can greatly inhibit a worker's performance in conducting activities on a work site. Heat strain is the physiological effect of heat stress produced in the body.

There are three methods of evaluating heat strain in the workplace: body core temperature, heart rate, and sweating. During CMI activities, both body core temperature and heart rate methods were implemented to evaluate heat stress exposures. The body core temperature method involves measuring the oral temperature of a worker. Fifteen minutes prior to a worker eating or drinking, a thermometer is placed into the worker's mouth and, with the mouth closed, a measurement is taken. By adding 1^{o}F to the oral temperature, an equivalent body core temperature can be registered. NSC recommends not exceeding 102.2^{o}F for industrial exposure to heat stress.

The heart rate method uses the recovery heart rate after one minute to indicate whether protective heat stress measures are effective. This method focuses on the demand on the cardiovascular system to move blood from the body to the skin. As skin temperature increases, more blood is required to reach the skin to aid in the cooling of the body. Heart rate measurements are taken once the worker stops working in an environment, performs an activity, or wears protective clothing which may lead to heat strain. The worker is seated and a pulse rate after one minute recorded. NSC recommends the pulse rate after one minute be at or below 110 beats per minute.

As aforementioned, three risk factors contribute to heat stress. Workers were briefed during tailgate sessions on forecasted weather conditions and advised of preventive measures to take during elevated ambient temperatures. In addition, when ambient temperatures reached levels above 85^{o}F, H&S personnel increased vigilance of workers' performance. During CMI activities at Facility 1381, H&S personnel noted 13 days where significant heat stress factors were evident. Workers were monitored and all personnel were below the recommended guidelines indicating protective measures were functioning effectively.

3.8.3.3 Ambient Air Monitoring

A comprehensive Air Monitoring Program for the LDA project was developed during the initial mobilization phase of the project and added to the HASP. The program set forth the criteria necessary to conduct air monitoring as part of a comprehensive site evaluation that accomplishes the following:

- Identifies work areas and activities that require the use of engineering or work technique controls or require the use of higher level of protection using PPE devices
- Provides data to confirm that levels of protection afforded by the assigned PPE and engineering or work technique controls are adequate to protect workers
- Provides data to ensure that all necessary controls and precautions are being taken to protect the public and the environment
- Complies with 29 CFR 1910.120(c)(6) and (h)

The program detailed the instruments available, instrument calibration procedures, monitoring locations, frequency of monitoring, and documentation of monitoring activities to adequately assess personal and ambient environmental conditions while performing CMI treatment activities as well as support activities.

3.8.3.4 Equipment Familiarization and Calibration

The SSHO ensured H&S personnel received training on the use, maintenance, limitations, and field operational testing of the specific direct reading instruments utilized on-site. The SSHO or an H&S technician calibrated monitoring equipment in accordance with manufacturers' instructions. All direct reading instruments require calibration before use and after each use. A span gas check (bump test) using a Tedlar bag with a specific concentration of a known gas was used to ensure the instrument operated within manufacturer's calibration parameters. Methane gas of a known concentration was used for calibrating direct reading instruments.

Documentation of instrument calibration was performed using an Equipment Calibration Log worksheet (Appendix L). Each calibration event was noted on the worksheet. For portable monitoring instruments such as the hand-held FID, the information recorded included the following:

- Instrument type, brand, model, serial numbers, and other information such as lamp specifications
- Date of calibration
- Time of calibration
- Concentration and source of calibration gas standard
- Instrument scale range
- Name of person calibrating instrument

The primary means of ambient air monitoring during CMI activities was a direct reading instrument, hand-held FID. This instrument provided real-time measurements for designated H&S personnel to assess ambient air levels throughout the site. The FID was used to account for the total VOC in work zones.

Other devices were utilized to better indicate the presence of specific VOCs in the air. These devices included color-change detector tubes specific to a contaminant or a group of contaminants.

3.8.3.5 FID Functionality

FID functionality involves the response to any molecule with a carbon-hydrogen bond. Since the FID is mass sensitive, not concentration sensitive, changes in carrier gas flow rate have little effect on the detector response. It is preferred for general hydrocarbon analysis, with a detection range from 0.1 to 2000 ppm. This instrument is generally strong and easy to operate, but because it uses a hydrogen diffusion flame to ionize compounds for analysis, it destroys the sample in the process. The accuracy of detection for an FID can vary significantly from one organic substance to another. Also, an FID will not respond to inorganic substances, or to particulates in air. The instrument is designed to operate within a wide range of relative humidity, 5% to 95%. The FID is insensitive to water, inert gases, and inorganic compounds.

3.8.3.6 Initial Site Assessment

Background initial monitoring was performed prior to task initiation. The ambient levels indicated on the FID were documented on Direct Reading Instrument Log sheets (Appendix M). These levels provided reading adjustments, if necessary, to all ambient and breathing zone screening measurements. The initial site assessment indicated levels below 1 ppm under normal working conditions. Therefore, all measurements taken during the workday reflected this background reading.

3.8.3.7 Periodic Monitoring Activities

Any elevated readings for total VOCs lasting one minute or longer in the worker's breathing zone required site activities to be suspended and site personnel instructed to move upwind of the treatment area. Personnel would be instructed on where to assemble to ensure the safety of all site personnel. These procedures were briefed to all on-site workers during emergency response discussions in a tailgate forum. The Field Operations Supervisor is responsible for taking a roll call to ensure that all persons are accounted for and to stop all activities until the problem is resolved. The HASP indicates the action level triggering specific employee protection actions such as donning of respirators or evacuation of the work area. These levels are listed in Table 3-10.

Table 3-10. Action Levels

Potential Air Contaminant	Instrument 1*	Action Levels	Level of Respiratory Protection
Organic Vapors	FID	Continuous sustained readings of <5 ppm in the breathing zone	Level D
Organic Vapors	FID	Continuous sustained readings of >5 ppm but < 50 ppm above background in the breathing zone	Apply engineering controls and retest. If condition persists, employ Level C.
Organic Vapors	FID	Continuous sustained readings of > 50 ppm above background in the breathing zone	Apply engineering controls and retest. If condition persists, evacuate area.

*The H&S Manager or SSHO must approve an equivalent unit.

Periodic monitoring using the hand-held FID was performed during each hazardous, task-specific activity with 2-4 minute intervals at the worker's breathing zone area (4-5 feet in height). Periodic monitoring areas included support activity areas (batch plant, CRZs, and boilers), EZ fencing and inside the EZ. The periodic monitoring protocol used during CMI activities is listed in Table 3-11.

Table 3-11. Periodic Monitoring Guidelines

Personnel	Zones	Levels	Additional Guidelines
Crane operator and support personnel downwind from shroud	Inside EZ, EZ perimeter fence line and areas where personnel are working.	If 5 ppm FID sustained for more than 1 minute, upgrade PPE to Level C. If 50 ppm FID sustained for more than 1 minute, evaluate work area and re-assess operations.	Check on GC reading. If vinyl chloride is indicated, use colorimetric sampling device for confirmation of vinyl chloride concentration in the work areas.
Support personnel downwind and crosswind from shroud	Support areas and EZ perimeter fence line.	Same as above.	Same as above.
Crane operator is crosswind from shroud with wind speeds less than 10 knots	Inside EZ, EZ perimeter fence line and areas where personnel are working.	Same as above.	Same as above.
Crane operator and support personnel upwind from shroud with wind speeds greater than 10 knots	EZ perimeter fence line	Same as above.	Same as above.

The above monitoring is the minimal requirement. Additional monitoring based on process FID and GC measurements was added to better assess the airborne concentration of concerned contaminants. Table 3-12 lists the cell category color scheme used to indicate the probability of risk associated with ambient airborne contaminants.

Table 3-12. Cell Category Color Scheme

Color	Concentration Range	Risk
Green	FID: <400 ppm; and TCE: <60 ppm	Minimal to no risk for exceeding AL.
Orange	FID: ≥400 ppm ≤1000 ppm; or TCE: ≥ 60 ppm ≤120 ppm	Low risk for exceeding AL.
Red	FID: >1000 ppm <10000 ppm; or TCE: > 120 ppm <1000 ppm	Moderate risk for exceeding AL.
Pink	FID: ≥10000 ppm: or TCE: ≥1000 ppm	High risk for exceeding AL.

All periodic monitoring measurements, using a hand-held FID, were documented on Direct Reading Instrument Log sheets (Appendix M). Throughout the CMI treatment activities, there were only five recorded measurements exceeding the 5 ppm action level excluding measurements within Facility 1381 during vapor intrusion sampling event. The Periodic Measurements table (Table 3-13) lists dates, location of the elevated air monitoring levels, and action taken to reduce elevated levels.

Table 3-13. Periodic Measurements

Date	Cell	Location	Levels (ppm)	Action Taken
Dec 2, 2006, 1120 hrs	BP44	Blower of vapor conditioning trailer	17	Personnel brief to remain upwind of shroud. Restricted access to area until readings below 1 ppm. Readings after 10 minutes down to less than 1 ppm.
Jan 12, 2007, 0914 hrs	BJ34	North edge of Exclusion Zone	35	Personnel brief to remain upwind of shroud. Restricted access to area until readings below 1 ppm. Readings after 10 minutes down to less than 1 ppm.
Jan 23, 2007, 0755 hrs	BP38	East of crane	60	Restricted access to area downwind of shroud for all personnel. After 15 minutes, readings were below 1 ppm.
Jan 27, 2007, 0810 hrs	BL35	South of CRZ	16.5	Personnel brief to enter exclusion zone from heavy equipment entrance due to wind direction.
Feb 1, 2007 0852 hrs	BK33	CRZ near Facility 1381	8.8	Personnel brief to enter exclusion zone from heavy equipment entrance due to wind direction.

3.8.3.8 Vapor Intrusion Monitoring Activities

Prior to starting source area treatment on the grounds of Facility 1381, Tetra Tech requested the use of Facility 1381 as the field office during this project. Tetra Tech planned on performing periodic monitoring within the facility to ensure the health and safety of personnel working in the facility. The Air Force agreed and granted Tetra Tech access for use of the facility. The facility also provided a restroom for all site personnel to use.

On June 29, 2006, baseline air monitoring within Facility 1381 was performed by the Tetra Tech SSHO. Measurements were taken using a Photovac MicroFID I/S, serial # CZRM309. The MicroFID instrument was calibrated prior to and after use with Methane gas of 100 ppm. All the office work desk areas as well as the unoccupied work bays were evaluated at the worker's breathing zone (3-5 feet above ground level). In addition, measurements were taken of the floor electrical vault within the large work bay area. The vault was identified as a potential vapor intrusion pathway for vapors to enter the facility during treatment. The baseline measurements showed all measurements below 1 ppm. This baseline monitoring was conducted prior to the start of any treatment activity.

Perimeter treatment commenced on June 30, 2006. As the treatment advanced towards the facility, monitoring within the facility increased. On August 4, 2006, during treatment of cell BC23, notable values of organic vapors were detected (i.e., ppm values between 10.6 and 29.7). The shroud was approximately 75 feet way from the exterior wall of Facility 1381. The SSHO quickly activated control measures to improve air quality within the facility which included opening doors and windows to allow cross flow ventilation with ambient air since wind direction was moving away from facility providing adequate fresh air. These actions reduce organic vapor concentrations below 5 ppm.

The SSHO placed in motion an extensive air monitoring plan from August 4-17, 2006. These dates coincide with the shroud placement nearest the facility. The plan included integrated sampling using a calibrated pump connected to solid absorbent charcoal tubes and sending samples to a certified laboratory as well as continued direct reading measurements using MicroFID and Drager CMS Analyzer.

Air samples were collected using NIOSH Methods 1003 and 1007. These methods require specific sample flow volumes for accurate concentration values. All sampling pumps were pre- and post-calibrated using a calibrated BIOS Dry-Cal calibrator. All samples were collected in the operator's breathing zone. A media blank was submitted to the analytical laboratory for quality control purposes and was below the laboratory detection limit.

At the conclusion of the sampling effort, all samples were shipped by Federal Express using chain-of-custody protocols to DataChem's Cincinnati, Ohio laboratory to be analyzed using NIOSH protocols. DataChem is an American Industrial Hygiene Association (AIHA) accredited laboratory in the analysis of samples for industrial hygiene evaluation.

Analytical samples were compared directly to the Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for determining compliance. OSHA PELs are the airborne concentration level allowed by law for a specific contaminant. 29 CFR 1910.1000 Table Z-2 and 29 CFR 1910.1017 prescribe the PEL for TCE and vinyl chloride, respectively. PELs are based on an 8-hour time-weighted average (TWA) airborne concentration. Table 3-14 shows results of sampling conducted using NIOSH Methods 1003 and 1007.

Table 3-14. Summary of Air Sample Results

Date	Sample #	Location	Contaminant	8-hr TWA Conc. (ppm)	OSHA PEL (ppm)
Aug 9, 2006	1381-CSC-0001A&B; 1381-CSC-0002A&B	SCADA Work Desk in Small Office area	TCE	1.86	100
Aug 9, 2006	1381-CSC-0001A&B; 1381-CSC-0002A&B	SCADA Work Desk in Small Office area	Vinyl Chloride	0.39	1
Aug 10, 2006	1381-CSC-0003A&B; 1381-CSC-0005A&B	SCADA Work Desk in Small Office area	TCE	7.75	100
Aug 10, 2006	1381-CSC-0003A&B; 1381-CSC-0005A&B	SCADA Work Desk in Small Office area	Vinyl Chloride	1.40	1
Aug 10, 2006	1381-CSC-0004A&B; 1381-CSC-0006A&B	Conference Table in Large Office area	TCE	27.29	100
Aug 10, 2006	1381-CSC-0004A&B; 1381-CSC-0006A&B	Conference Table in Large Office area	Vinyl Chloride	2.51	1
Aug 15, 2006	1381-CSC-0007A&B	SCADA Work Desk in Small Office area	TCE	0.43	100
Aug 15, 2006	1381-CSC-0007A&B	SCADA Work Desk in Small Office area	Vinyl Chloride	0.09	1
Aug 15, 2006	1381-CSC-0008A&B	Conference Table in Large Office area	TCE	0.69	100
Aug 15, 2006	1381-CSC-0008A&B	Conference Table in Large Office area	Vinyl Chloride	0.11	1
Aug 17, 2006	1381-CSC-0009A&B	SCADA Work Desk in Small Office area	TCE	0.43	100
Aug 17, 2006	1381-CSC-0009A&B	SCADA Work Desk in Small Office area	Vinyl Chloride	0.09	1
Aug 17, 2006	1381-CSC-0010A&B	Conference Table in Large Office area	TCE	0.69	100
Aug 17, 2006	1381-CSC-0010A&B	Conference Table in Large Office area	Vinyl Chloride	0.11	1

As noted above, the potential for exposure to levels above the PEL were more probable for vinyl chloride than TCE. The analytical results correlated with the direct reading measurements taken with the Draeger CMS Analyzer. This instrument uses reagent substance specific chips to analyze color reaction with a mass flow controller producing results of the substance specific in parts per million in concentration of air. Chips for TCE and vinyl chloride were used to determine specific concentration of organic vapors detected using MicroFID instrument.

On August 10, 2007, all personnel were evacuated from within Facility 1381. During the treatment of cells BC31, BB32, BC32, and BB33, FID measurements ranged from 165 up to 184 ppm inside Facility 1381. These measurements correlated with the highest vinyl chloride values recorded during integrated sampling event. Corrective measures to reduce organic vapor concentrations included opening a communication manhole between Facility 1381 and the treatment zone, purchasing floor fans to circulate ambient fresh air into the facility, and opening facility doors as well as windows to move ambient fresh air into the facility. FID measurements dropped down to less than 10 ppm with vinyl chloride values below 1 ppm. Again, the FID measurements and integrated sampling correlated well to indicate that actions taken reduced personnel's potential exposure to TCE and vinyl chloride concentrations below the PELs.

As the shroud positioning moved further away from the facility, the detection of organic vapors inside Facility 1381 drastically reduced to levels less than 1 ppm. Another integrated sampling event on May 7-9, 2007, showed no levels of TCE or vinyl chloride during treatment of cells within Zones 1 and 4 nearest the facility.

3.8.3.9 Structural Monitoring Activities

On April 10, 2007, standard and corner telltale crack gauges were procured to determine if Facility 1381 was structurally stable. These crack gauges were positioned in various locations along the southeast masonry block walls and one reinforced concrete column.

A Tetra Tech Structural Engineer performed a site visit and inspected Facility 1381 (Appendix N). The findings concluded that the original building and both building additions are not structurally damaged and safe to use. The column hairline cracks are due to slight tension stress on the column face. This column is still in good condition and capable of carrying its intended design loads. The masonry walls of the two additions are in good condition with no visible cracks and capable of supporting the roof trusses. Readings from installed wall and column displacement measuring gauges will determine if movement is still occurring. There should be minimal continual movement due to having completed the soil mixing activities at the site, planned limited equipment activity near the building, and measures taken to eliminate or minimize rainwater run-off erosion.

3.8.4 Site Access

All personnel gained access to the Facility 1381 grounds via a personal badge issued by the Pass and Identification offices after the Air Force IRP office approved badge request submittal. Access to the site was controlled using a fence line between the major roadway to the site, Armory Road, and the support zone (Figure 1-2). The fence line had one gate for accessing the site. The western gate provided direct access to the support zone. Personnel parked along the sides of the Facility 1381 access road. All support supplies were transported on-site via this access road.

All personnel visiting the site were required to sign in at the western gate. Tracking of personnel on-site was accomplished using Daily Sign-in Sheets. These sheets fulfilled two purposes: first, a record of personnel on-site should an emergency occur and second, the source document for compiling worker's hours for illness or injury reporting.

Once inside the fence line, the site was partitioned into three zones: support zone, CRZ, and EZ (See Figure 2-10). Visitors to the site were restricted to the support zone and escorted by a member of Tetra Tech or subcontractor supervision. Under no circumstance were visitors allowed into the CRZ or EZ during treatment activities. Only when treatment ceased and H&S personnel declared the area safe, were specialized workers (e.g., crane mechanic) allowed entry inside the EZ with appropriate supervision. No one was allowed to enter either the CRZ or EZ unless all the training requirements were met while active treatment activities occurred.

3.8.5 Injury/Illness Reporting

As stated in the beginning of this section, a thorough plan aids in the accomplishment of a successful project. Even though planning is accomplished and implemented, there is always the possibility for an incident to occur. The misfortune of an accident or incident diminishes workers' morale and reduces productivity. Every effort is made to minimize the risk factors of an accident or incident.

3.8.5.1 OSHA Recordkeeping Requirements

OSHA mandates recording of injuries or illnesses if the incident meets one or more of the general recording criteria listed in 29 CFR 1904.7 (b). First, the injury or illness must be work-related. The OSHA regulation, 29 CFR 1904.5, defines work environment as "the establishment and other locations where one or more employees are working or are present as a condition of their employment. The work environment includes not only physical locations, but also the equipment or materials used by the employee during the course of his or her work."

3.8.5.2 OSHA Injury or Illness Categories

Second, the injury or illness must have resulted in one or more of the following:

- Death.
- Days away from work.
- Restricted work or transfer to another job.
- Medical treatment beyond first aid.
- Loss of consciousness.
- A significant injury or illness diagnosed by a physician or other licensed health care professional.

3.8.5.3 On-Site Incident Information

During the CMI activities at Facility 1381, one OSHA recordable incident occurred during the treatment phase of the project. The incident involved a subcontractor employee and was classified as OSHA recordable based on medical treatment performed on the individual as a result of the incident and restricted duty ordered by a licensed physician. Subcontractor H&S personnel investigated the incident and reported findings to the

SSHO. The SSHO in turn contacted the Tetra Tech Project Manager and Air Force personnel within the appropriate time limit, fulfilling notification requirements. The respective subcontractor H&S personnel provided the SSHO a written report showing that the incident was properly recorded. The SSHO completed Tetra Tech Incident Reporting documents and the Tetra Tech Project Manager as well as the SSHO signed the report. The completed incident and daily health and safety report forms are attached in Appendix O.

The sole incident occurred on February 16, 2007, during a routine maintenance of one of the batch plant mixing tanks. The worker was working on cleaning out the iron mixing vat. The lid on the top of the vat was open to gain access to the tank. Strong winds blew the lid shut. The worker's right hand was positioned at the lid opening when the lid slammed down on the worker's right wrist causing a fracture of styloid process of the ulna.

H&S personnel investigated the incident and discovered that the tank lid was not manufactured with a locking device to secure the lid in place while the lid was open. Fasteners were installed to secure the lid when in the open position. During the following Daily Tailgate Safety meeting, all personnel were instructed to use fasteners to secure lid when the lid was open.

3.8.6 Equipment Inspections

One of the most effective means of preventing incidents or accidents from occurring on a work site is implementing tools to inspect machinery and equipment prior to utilizing these devices. Equipment inspection checklists provide operators with memory jogging reminders of areas and steps to follow for ensuring the safe operation of equipment and machinery. In addition, OSHA mandates the employer to have a competent person to inspect all machinery and equipment prior to each use to make sure it is in safe operating condition [29 CFR 1926.550 (a)(5)].

The following machinery and equipment were inspected daily prior to use:

- Heavy equipment: Front loader, excavator, and manlift
- Machinery: Crane, drill platform, and boilers

The heavy equipment was inspected using a week-long inspection checklist with inspection items listed to ensure safe operation of devices (Appendix P). The operator performed the inspection and checking off each inspection item. Any discrepancy was noted on the log and briefed to the Site Supervisor. H&S personnel were responsible for following up on discrepancies. Items rendering the equipment unsafe were corrected immediately or the equipment was red-tagged. There were no discrepancies during CMI activities at Facility 1381 which resulted in equipment being red-tagged.

A specific crane inspection worksheet was developed by the crane operators based on information found in the manufacturer owner's manual. This inspection addressed items required for safe operating conditions of the crane on site (Appendix Q). In addition, items for inspecting the drill platform were placed on the crane inspection worksheet to facilitate inspection procedures. The operator inspected the crane prior to the daily operations. These daily inspections provide early warning signs and assist with scheduling of specialized tasks. An oil leak was noticed during a daily inspection which resulted in a specialized crane mechanic to come on-site and rectify the problem.

The final machinery with a checklist was the boilers. A startup inspection worksheet provided operators with step-by-step instructions on the safe startup procedures. The worksheet notes specific safety features to check and operational settings.

3.8.7 Hot Work Permit

Hot work is classified as activities where an open-flame or spark-producing apparatus is used to perform an activity which may produce a flammable atmosphere. These activities include, but are not limited to, welding, cutting, burning, grinding, and related heat-producing jobs.

Several CMI activities involved hot work. The primary hot work activity was hard facing of the auger. This activity was performed daily. Other activities included grinding, cutting and welding metal materials.

Cape Operating Procedures for IRP Sites provided guidance on obtaining a Hot Work Permit on CCAFS. The SSHO contacted Cape Support to schedule an inspection with a Fire Inspector. This notification was performed at least 24 hours in advance. Cape Support personnel would issue a work request number to confirm the appointment. The Fire Inspector would meet the on-site point-of-contact to perform the inspection. If conditions were acceptable, the Fire Inspector issued a burn permit on the spot. The permit would normally be for a 30-day period. A CCAFS/KSC Welding and Hot Work Permit (see Appendix F), KSC Form 2-13 indicated the requirements of the permit. As a minimum, dry chemical fire extinguishers at specific locations and fire watch were required. The fire watch involved at least one individual dedicated solely to the look-out and control of stray fires. This individual was required to remain in the immediate area until hot work was completed plus an additional 30 minutes to ensure the risk of a fire was avoided.

3.9 OPERATIONAL WASTE DISPOSAL

The proper management of waste by-products generated during the LDA Project at Facility 1381 was the responsibility of the prime contractor, Tetra Tech. All regulated waste streams were managed in accordance with federal, state, and local laws and regulations. In addition, the Tetra Tech Waste Coordinator utilized the 45th Space Wing's O Plan 19-14, "Waste Petroleum Products and Hazardous Waste Management Plan" and CCAFS Operating Procedures for categorizing, managing, and disposing of wastes generated at Facility 1381. All waste generated at Facility 1381 resulted directly from CMI activities. These waste streams were categorized into three general waste classes: industrial wastewater, spill response and clean up activities, and equipment waste. The waste tracking packages and manifests are presented in Appendix R.

3.9.1 Industrial Wastewater

The primary waste by-product generated was industrial wastewater. Industrial wastewater was produced from two sources: Vapor Conditioning System (knockout tank, pre-chiller, and chiller), and vapor treatment system (FTO). Treatment of industrial wastewater was handled on base utilizing the Trident Industrial Wastewater Treatment Facility off Pier Road (see Figure 1-1). This plant is the primary receiving facility for the disposal of qualifying, IRP generated wastewaters.

Coordination between SGS Utilities, the IRP office, and Tetra Tech resulted in a plan to manage and dispose of industrial wastewater in the most efficient and economical means possible. The final plan involved the use of two 20,000-gallon capacity frac tanks as collection containers with scheduled pick-ups through the SGS Water/Wastewater Supervisor for transport to the Trident Industrial Wastewater Treatment Facility. Prior to commencing remediation activities, Tetra Tech completed a Process Waste Questionnaire (PWQ), Appendix B, describing the projected waste composition, chemical and physical characteristics, and analytical results of similar wastewater. PWQ # CEM040179 was submitted to the SGS Waste Management Group via the IRP office. A Technical Response Package (TRP) was issued on February 13, 2006, by SGS to the IRP office. Instructions on how to manage waste stream were detailed in the TRP.

Condensate off-gas water from the knockdown tank and vapor conditioning system was plumbed and treated by the mobile treatment system on-site. This system consists of a 950-gallon temporary holding tank and a three-tray stripper to remove VOCs prior to transferring water into the 20,000-gallon frac tanks. The water was treated for approximately 24 hours. Once treated, the water was discharged into one of the frac tanks. Blowdown water generated from the thermal oxidizer scrubber tower was directly plumbed and pumped into the frac tanks.

Frac tanks were interchangeable to allow continuous collection of industrial wastewater. Once a frac tank reached capacity, samples for VOC concentrations using USEPA Method 8260B, total dissolved solids, pH, fluoride, chloride, and specific gravity were collected in accordance with the USAF Installation Restoration Program 45th Space Wing Facilities Draft Field Sampling Procedures, June 2004. Samples were sent to a contract laboratory for waste determination analysis. All samples collected indicated industrial wastewater generated during CMI activities at Facility 1381 were non-hazardous and therefore within the limits for disposal through the Trident Industrial Wastewater Treatment Facility. Table 3-15 provides a summary of industrial wastewater transported to the Trident Industrial Wastewater Treatment Facility.

After 23 analytical samples were collected over two sites, the Tetra Tech Contractor Waste Coordinator requested an elimination of analytical sampling for waste determination based on process “Knowledge.” All previous analytical results showed a waste determination of Non-Hazardous. Therefore, the Contractor Waste Coordinator was granted approval of elimination of analytical sampling from Russ Carson, Trident Wastewater Plant Maintenance Engineer (Appendix S). The Contractor Waste Coordinator continued recording pH and total dissolved solids measurements on-site. These measurements were used to validate wastewater conditions remained consistent with previous sampling information.

Table 3-15. Summary of Industrial Wastewater

Location	IRP Internal Manifest #	Date Sampled	Date Disposed	Waste Determination	Estimated Volume Disposed (pounds)
Facility 1381	IRP-06-010	20 Jul 06	28 Jul 06	Non-Hazardous	167,000
Facility 1381	IRP-06-012	3 Aug 06	14 Aug 06	Non-Hazardous	167,000
Facility 1381	IRP-06-013	17 Aug 06	5 Sep 06	Non-Hazardous	167,000
Facility 1381	IRP-06-014	13 Sep 06	20 Sep 06	Non-Hazardous	167,000
Facility 1381	IRP-06-015	22 Sep 06	3 Oct 06	Non-Hazardous	167,000
Facility 1381	IRP-06-016	6 Oct 06	16 Oct 06	Non-Hazardous	167,000
Facility 1381	IRP-06-017	17 Oct 06	25 Oct 06	Non-Hazardous	167,000
Facility 1381	IRP-06-018	8 Nov 06	17 Nov 06	Non-Hazardous	167,000
Facility 1381	IRP-06-019	22 Nov 06	4 Dec 06	Non-Hazardous	167,000
Facility 1381	IRP-06-025	4 Dec 06	12 Dec 06	Non-Hazardous	167,000
Facility 1381	IRP-06-026	13 Dec 06	20 Dec 06	Non-Hazardous	167,000
Facility 1381	IRP-07-001	5 Jan 07	12 Jan 07	Non-Hazardous	167,000
Facility 1381	IRP-07-002	23 Jan 07	29 Jan 07	Non-Hazardous	167,000
Facility 1381	IRP-07-003	1 Feb 07	9 Feb 07	Non-Hazardous	167,000
Facility 1381	IRP-07-004	15 Feb 07	27 Feb 07	Non-Hazardous	167,000
Facility 1381	IRP-07-005	1 Mar 07	12 Mar 07	Non-Hazardous	167,000
Facility 1381	IRP-07-011	15 Mar 07	27 Mar 07	Non-Hazardous	167,000
Facility 1381	IRP-07-012	2 Apr 07	3 Apr 07	Non-Hazardous	167,000
Facility 1381	IRP-07-013	19 Apr 07	23 Apr 07	Non-Hazardous	167,000
Facility 1381	IRP-07-014	1 May 07	4 May 07	Non-Hazardous	167,000
Facility 1381	IRP-07-015	22 May 07	23 May 07	Non-Hazardous	167,000
Facility 1381	IRP-07-016	5 Jun 07	6 Jun 07	Non-Hazardous	91,850

The elimination of analytical results expedited removal of wastewater from the site which in turn eliminated the potential for work stoppage due to frac tanks reaching full capacity. This action was very effective during the latter part of this project with the changes to cell treatment protocol.

3.9.2 Spill Response and Clean-up Activities

During the course of this project, there were four spill response and clean-up activities which occurred on-site. All four were reported to the appropriate authorities in accordance with Cape Operating Procedures and required documentation completed (Appendix T). The Table 3-16 summarizes these events.

Table 3-16. Summary of Spill Response and Clean-up Activities

Location	Material Spilled	Date Spill Occurred	Estimated Volume	Action Taken
Exclusion Zone, cell BS11	Gear Oil	20 Jul 06	4-5 gallons	Absorbent pads used to clean-up affected equipment and soil placed in 55-gallon waste drum
Exclusion Zone	Motor Oil	21 Nov 06	2 gallons	Soil placed in 55-gallon waste drum
Exclusion Zone, near cell BJ36	Biodegradable Hydraulic Fluid	2 Jan 07	2 ounces	Soil placed in 55-gallon waste drum
Exclusion Zone, near cell BD28	Diesel Fuel	21 Mar 07	2 ounces	Absorbent pads used to clean-up affected equipment and soil placed in 55-gallon waste drum

At the conclusion of the project, the waste drum used to collect soil was disposed of as non-hazardous waste for final disposition.

3.9.3 Equipment Waste

The most common waste by-product from equipment operations during CMI activities involved used oil and oil filters. These items are primarily generated from drill platform maintenance activities. Other items included spray paint cans, ethylene glycol, biodegradable hydraulic fluid, and spent absorbent pads. These waste by-products were primarily categorized as “non-hazardous” waste and were segregated based on waste profile into respective 55-gallon drums. Proper disposal procedures were coordinated with IRP personnel.

3.10 TREATMENT TIMELINE

A treatment timeline schedule detailing the work plan, permitting, site preparation, corrective measures implementation, and demobilization activities performed at Facility 1381 is provided in Figure 3-82. The total duration of the field activities (site preparation, corrective measures implementation and demobilization) was approximately 460 work days. Work delays consisted of a total of 5 days due to launching and mission activities at CCAFS. One hurricane (Ernesto) impacted the project and caused a 5 day delay in which a partial demobilization was issued. Hurricane Ernesto did not impact nor cause any damage at the site.

FIGURES

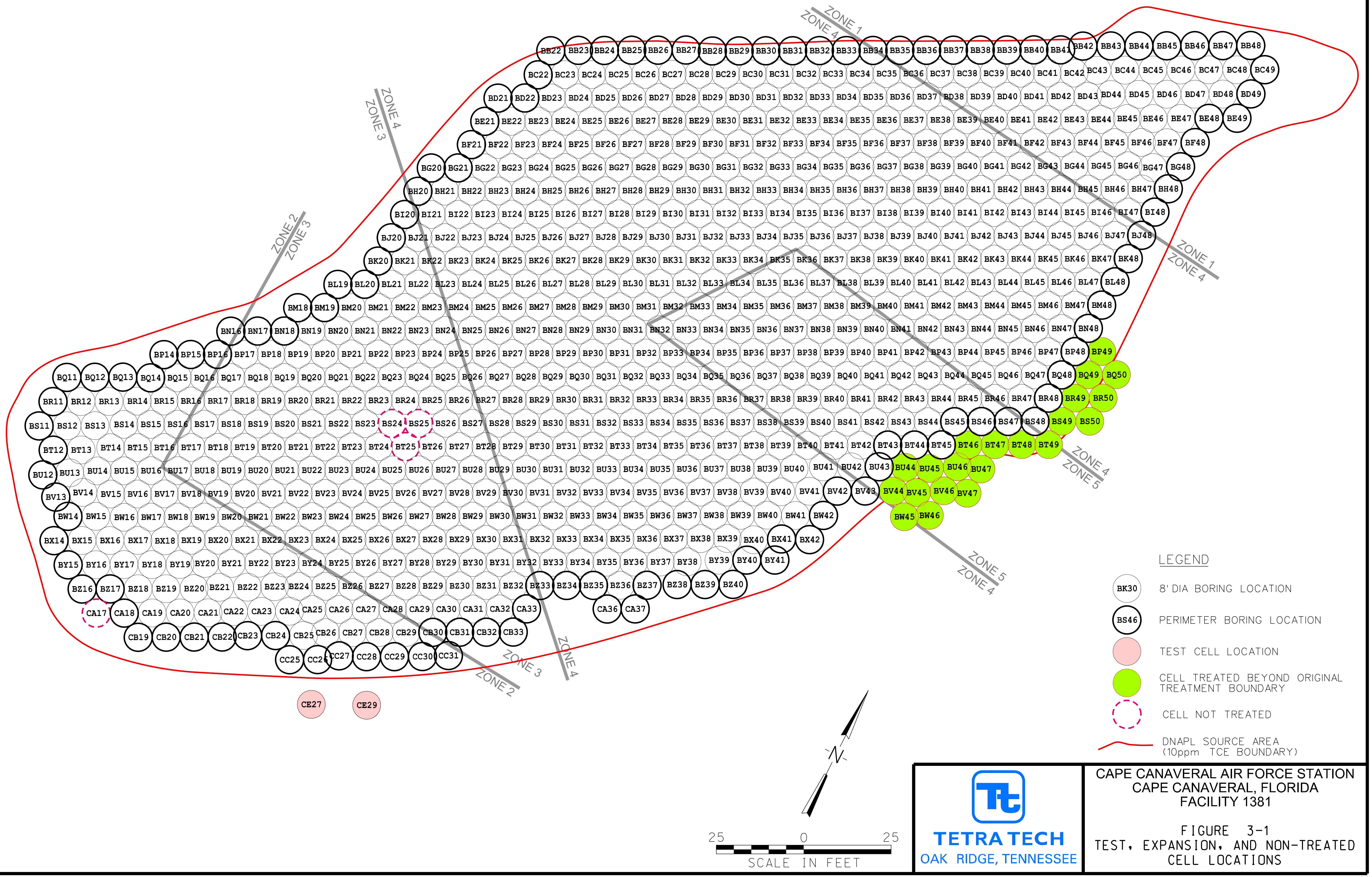

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FIGURE 3-1
TEST, EXPANSION, AND NON-TREATED
CELL LOCATIONS

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FIGURE 3-2: PRIMARY TREATMENT PROTOCOL

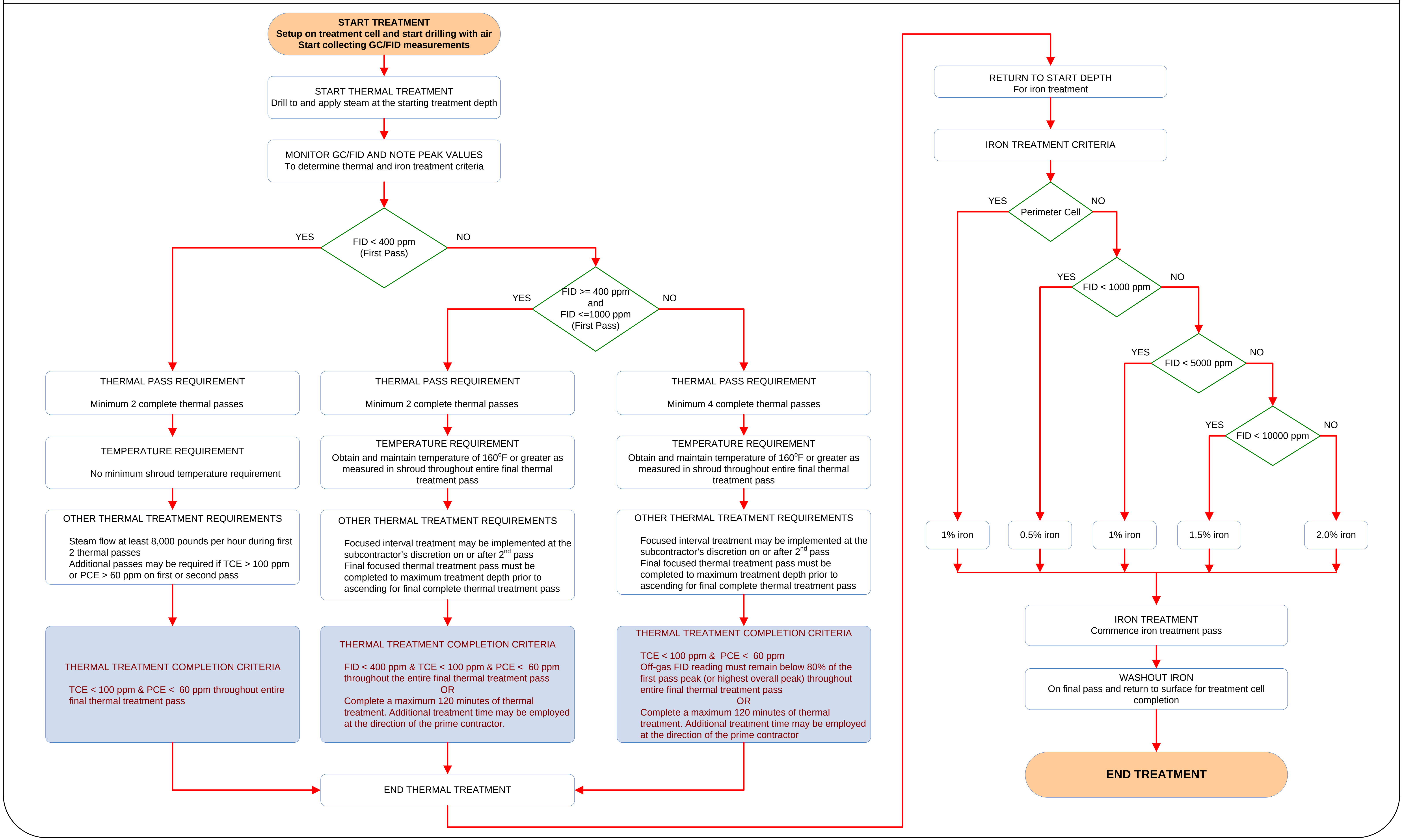

FIGURE 3-2: PRIMARY TREATMENT PROTOCOL

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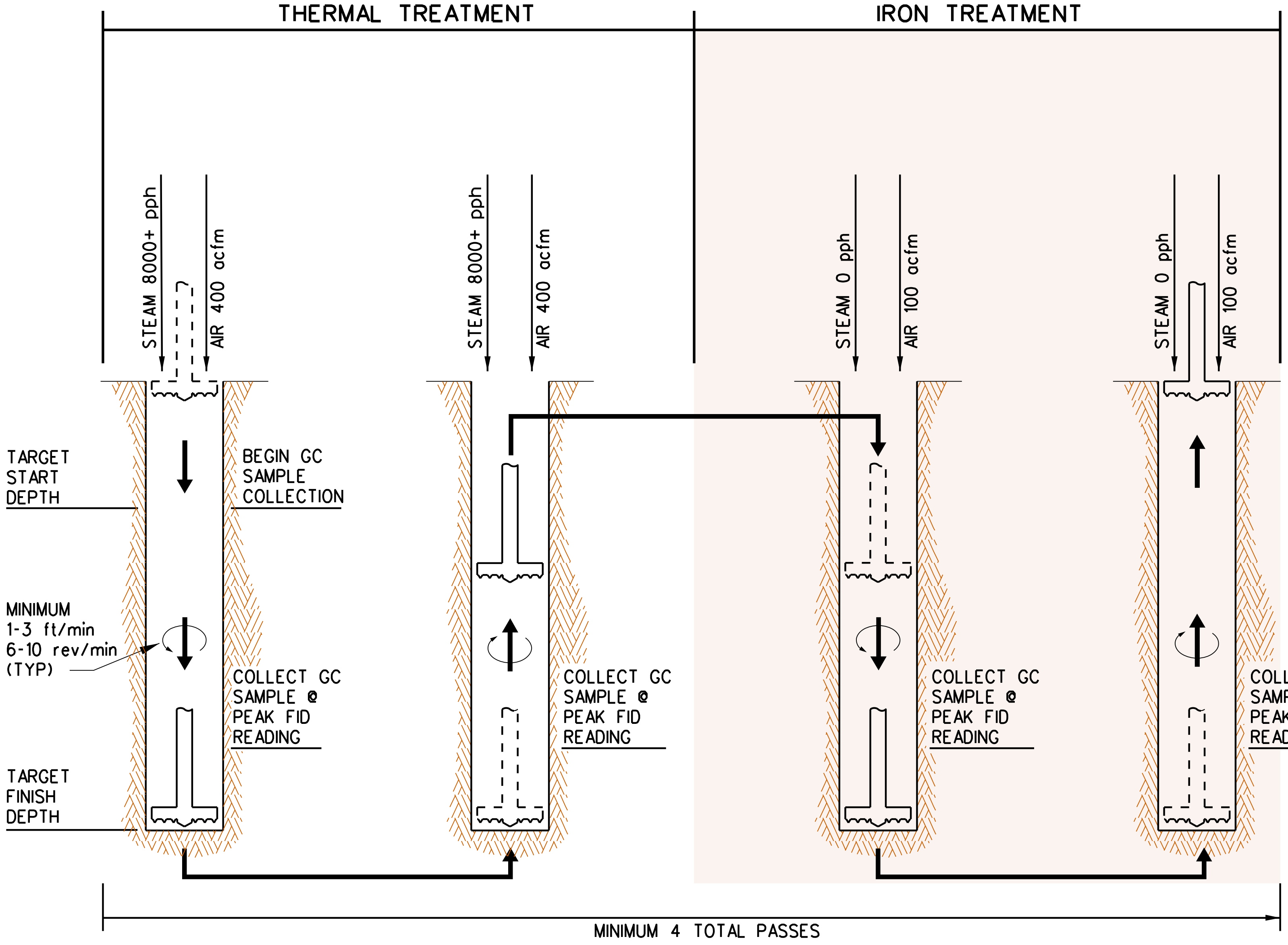

NOTES

1. REDUCE STEAM WHEN AUGER POSITION IS ABOVE 15 FEET BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.

NOT TO SCALE

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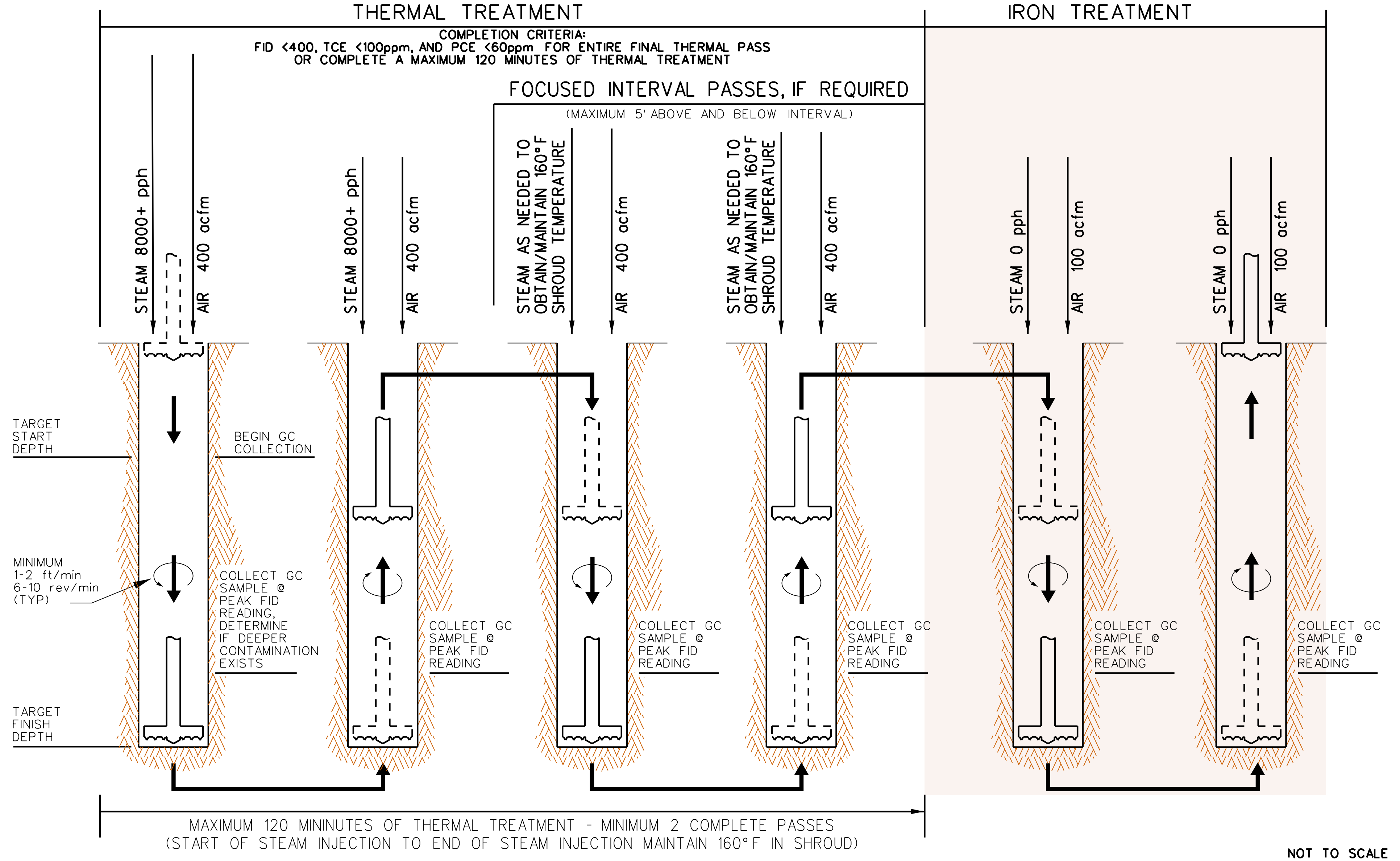
FIGURE 3-3
PRIMARY TREATMENT PROTOCOL
FIRST PASS PEAK FID LESS THAN 400ppm



NOT TO SCALE

NOTES

1. REDUCE STEAM WHEN AUGER POSITION IS ABOVE 15 ft BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.

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FIGURE 3-4
PRIMARY TREATMENT PROTOCOL
MAXIMUM FIRST PASS PEAK FID
GREATER THAN 400ppm AND LESS THAN 1000ppm

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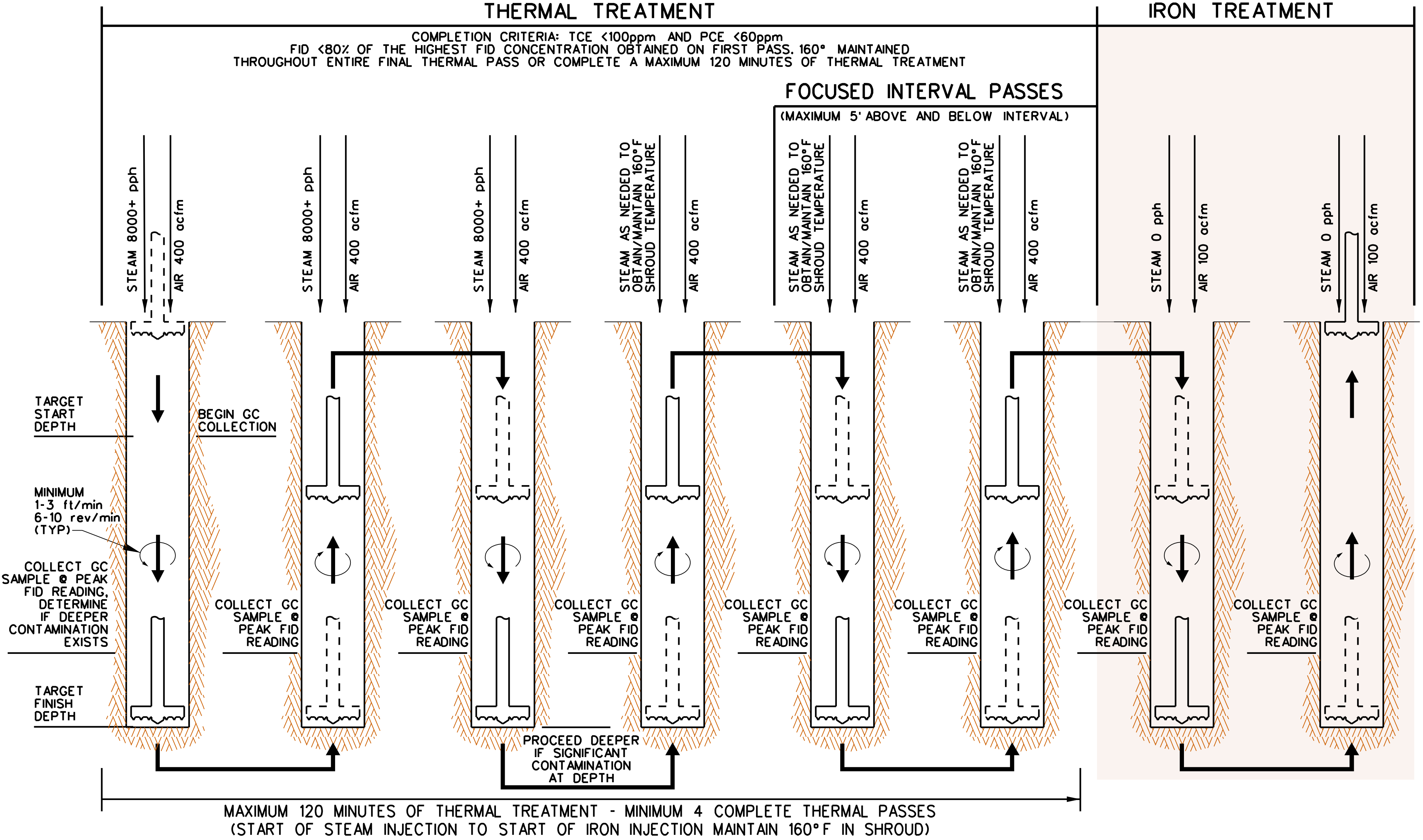

NOT TO SCALE

NOTES

1. IF FOCUSED PASSES WERE IMPLEMENTED, THE FINAL FOCUSED PASS REQUIRED DESCENDING TO TARGET FINISHING DEPTH PRIOR TO STARTING FINAL THERMAL PASS.

2. REDUCED STEAM WHEN AUGER POSITION IS ABOVE 15 ft BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.

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FIGURE 3-5
PRIMARY TREATMENT PROTOCOL
FIRST PASS PEAK FID GREATER THAN 1000ppm

FIGURE 3-6: ALTERNATIVE TREATMENT PROTOCOL

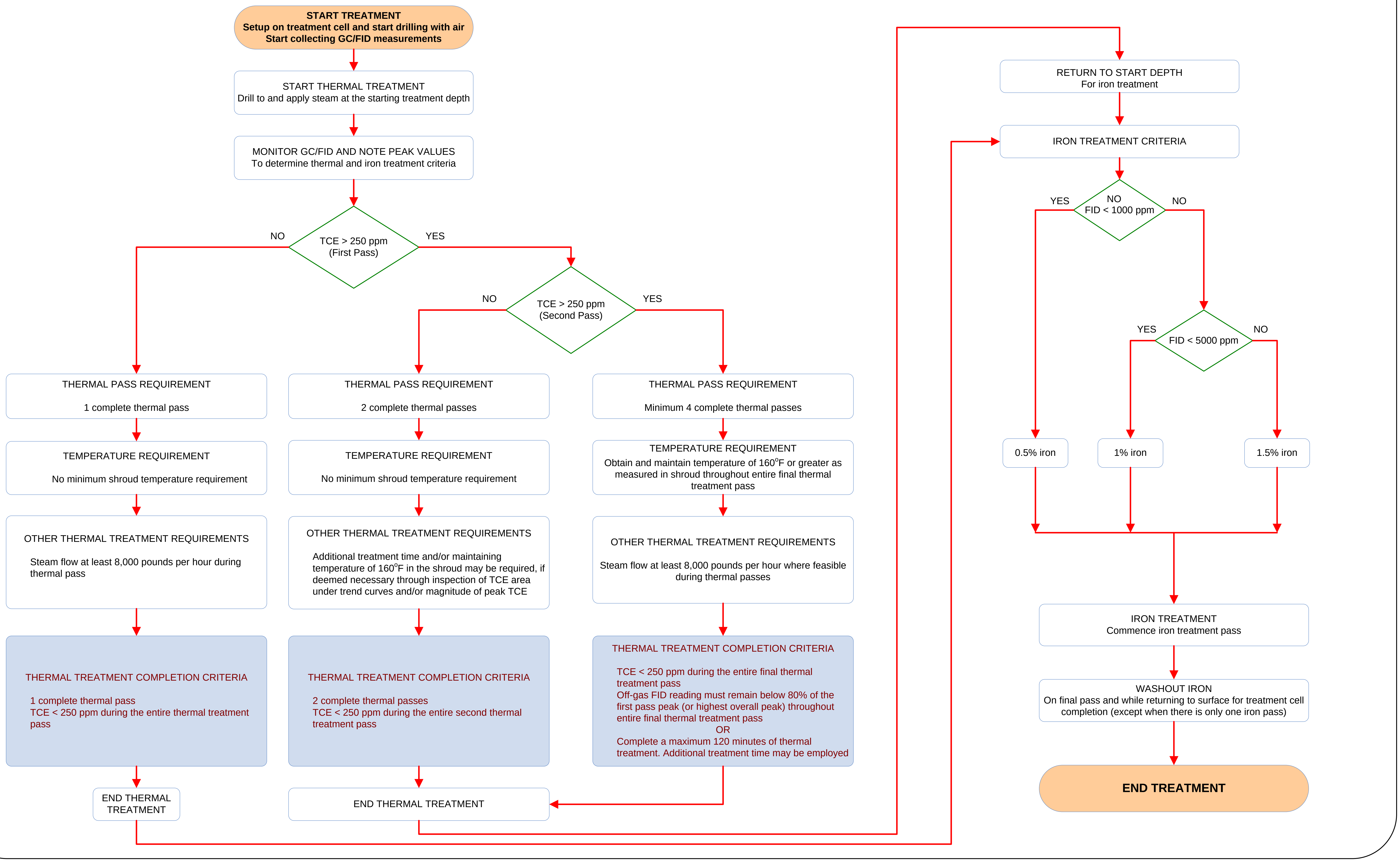
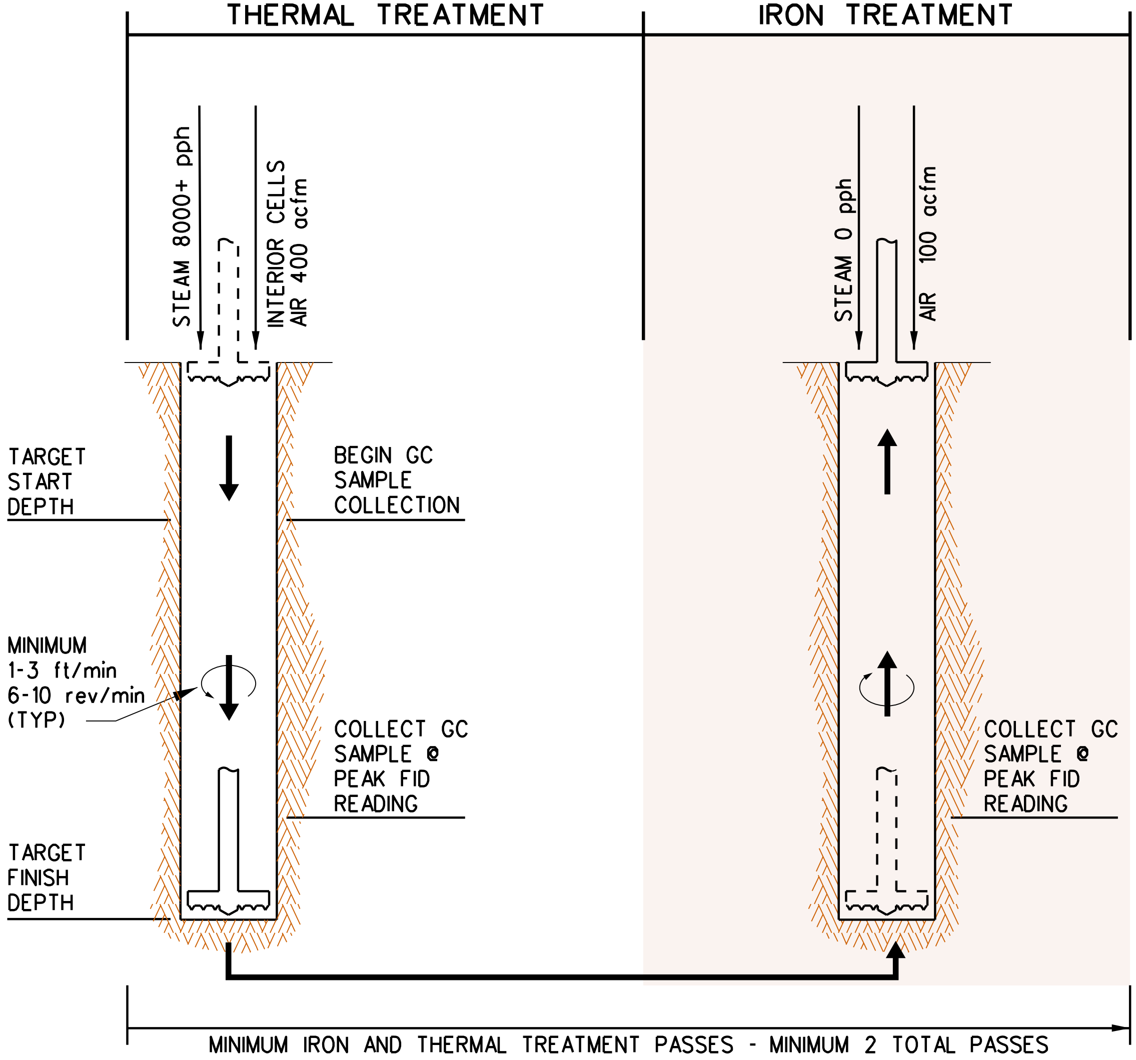


FIGURE 3-6: ALTERNATIVE TREATMENT PROTOCOL



NOTES

1. REDUCE STEAM WHEN AUGER POSITION IS ABOVE 15 FEET BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.

NOT TO SCALE

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FIGURE 3-7
ALTERNATIVE TREATMENT PROTOCOL
FIRST PASS
TCE PEAK LESS THAN 250ppm

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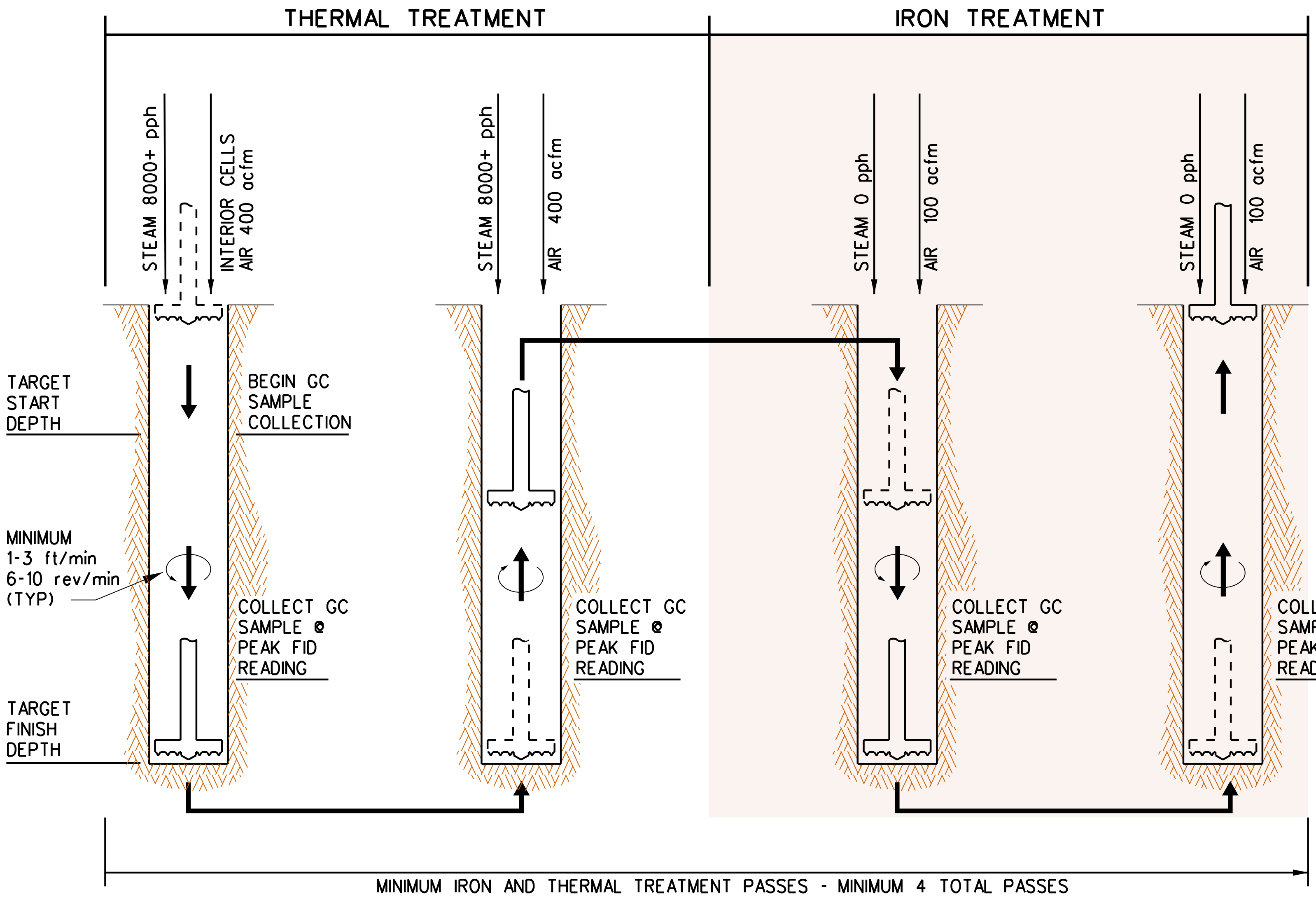

NOTES

1. REDUCE STEAM WHEN AUGER POSITION IS ABOVE 15 FEET BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.
2. ADDITIONAL TIME OR 160°F REQUIREMENT MAY HAVE BEEN IMPLEMENTED IF SIGNIFICANT MASS REMOVAL WAS ANTICIPATED WHEN TCE WAS LESS THAN 250ppm.

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FIGURE 3-8
ALTERNATIVE TREATMENT PROTOCOL
FIRST PASS PEAK TCE GREATER THAN 250ppm
SECOND PASS PEAK TCE LESS THAN 250ppm

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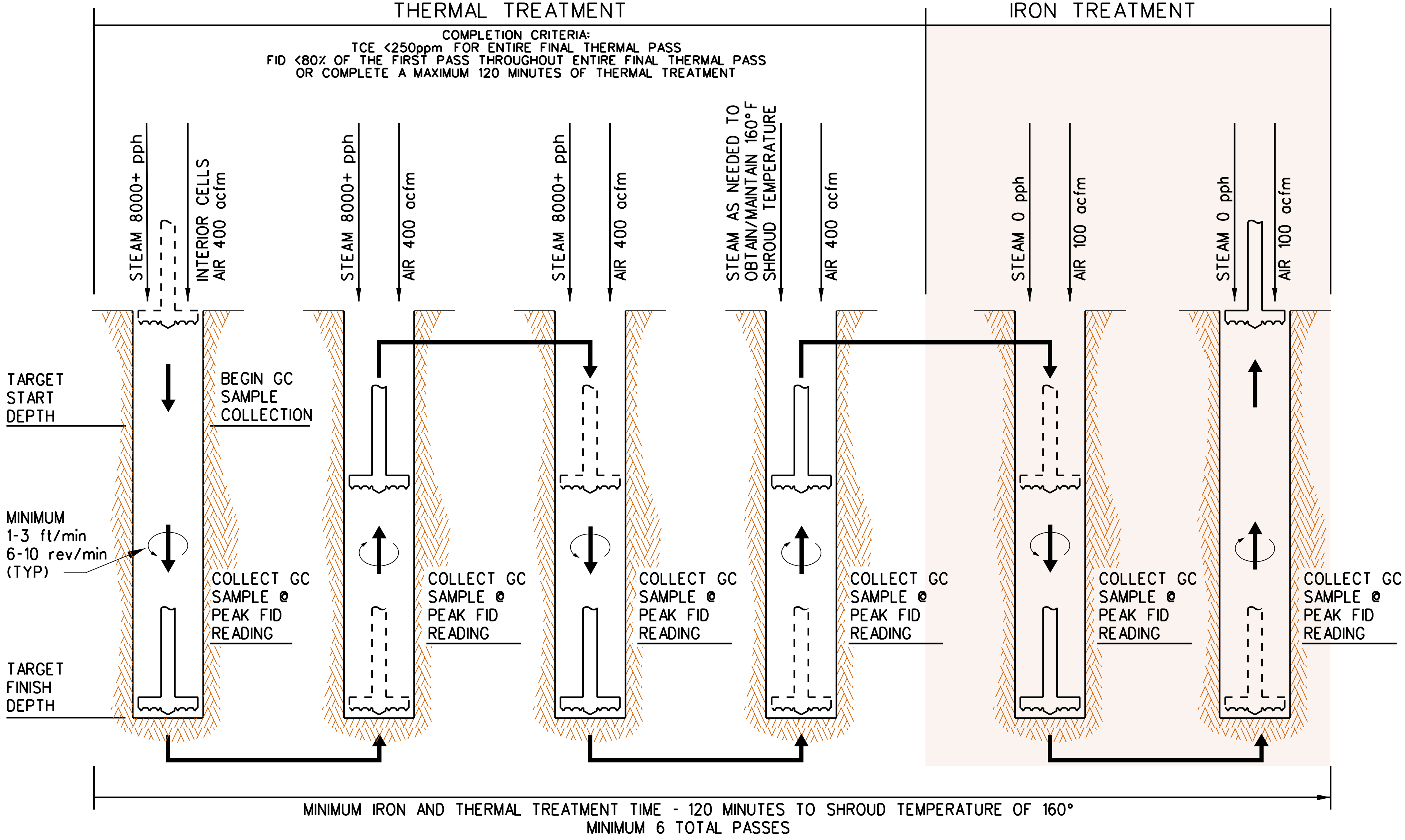

NOT TO SCALE

NOTES

1. REDUCE STEAM WHEN AUGER POSITION IS ABOVE 15 ft BELOW GROUND SURFACE OR AS DEEMED NECESSARY TO PREVENT BREAKTHROUGH AND LIMIT HEALTH AND SAFETY CONCERNS.

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FIGURE 3-9
ALTERNATIVE TREATMENT PROTOCOL
FIRST PASS PEAK TCE GREATER THAN 250ppm
SECOND PASS PEAK TCE GREATER THAN 250ppm

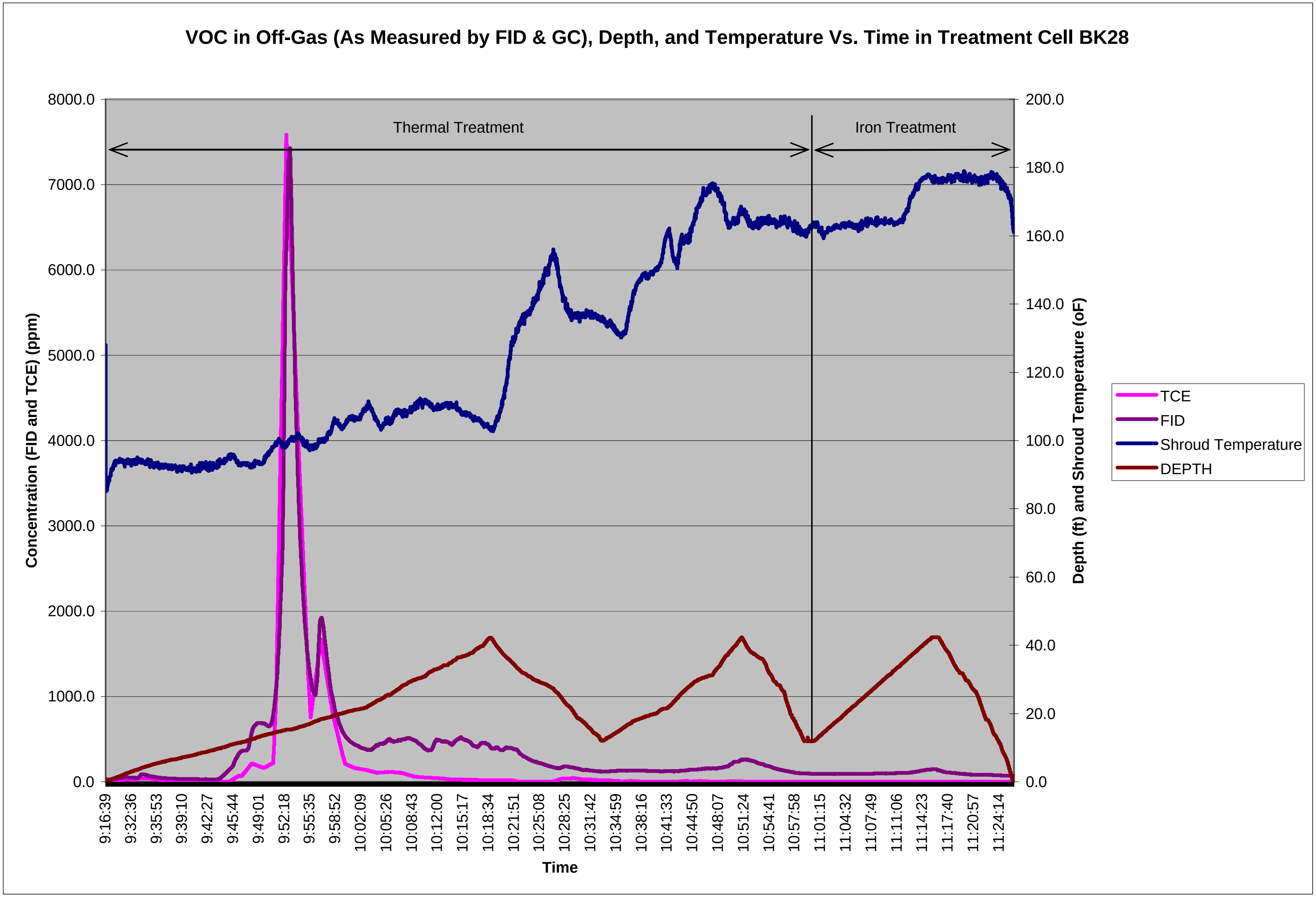


Figure 3-10: VOC in Off-Gas (As Measured by FID and GC), Depth, and Temperature Vs. Time in Treatment Cell BK28

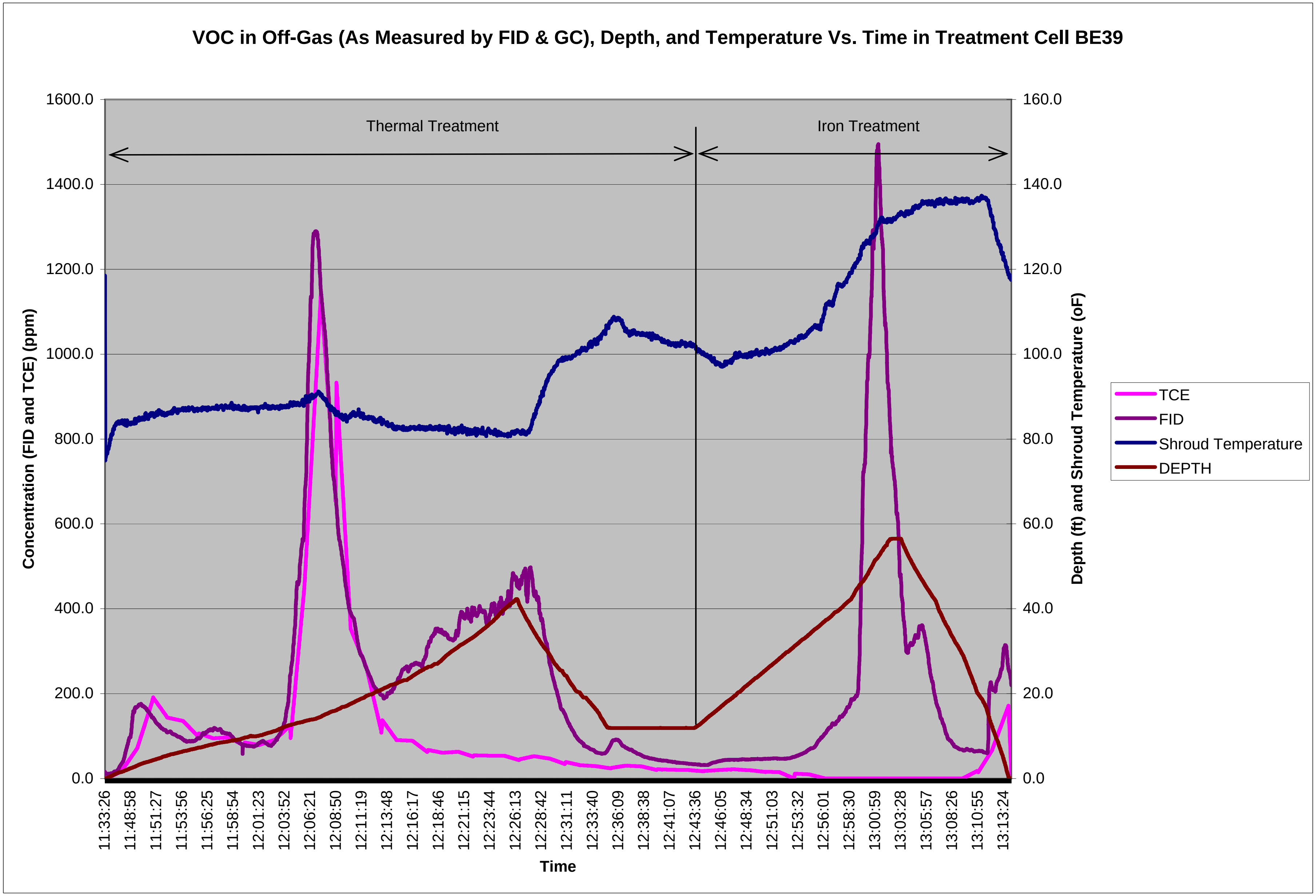
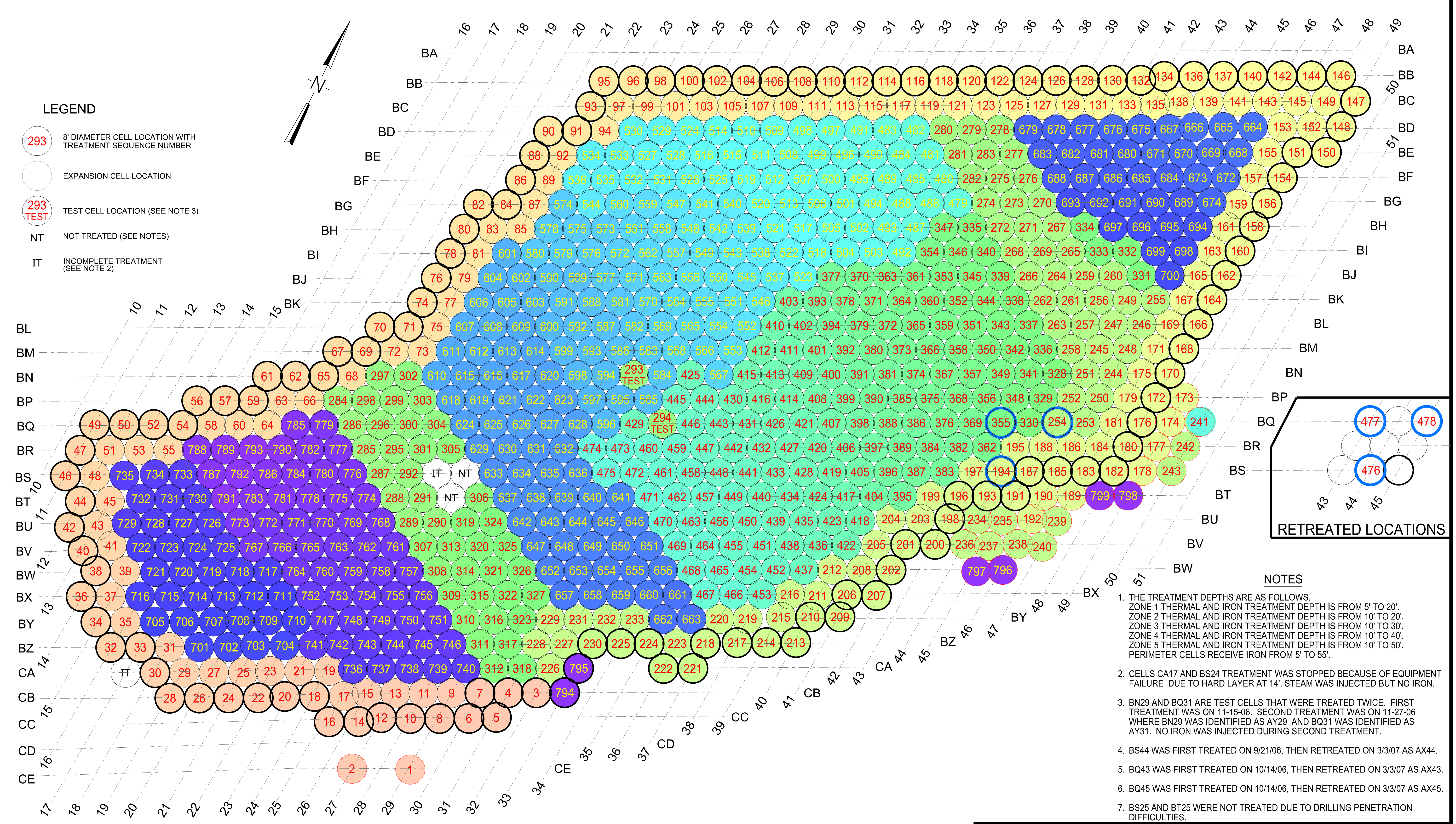


Figure 3-11: VOC in Off-Gas (As Measured by FID and GC), Depth, and Temperature Vs. Time in Treatment Cell BE39



NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.
2. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.
3. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.
4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.
5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.
6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.
7. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.

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FIGURE 3-12
CELL TREATMENT SEQUENCE
(TREATMENT COMPLETE)

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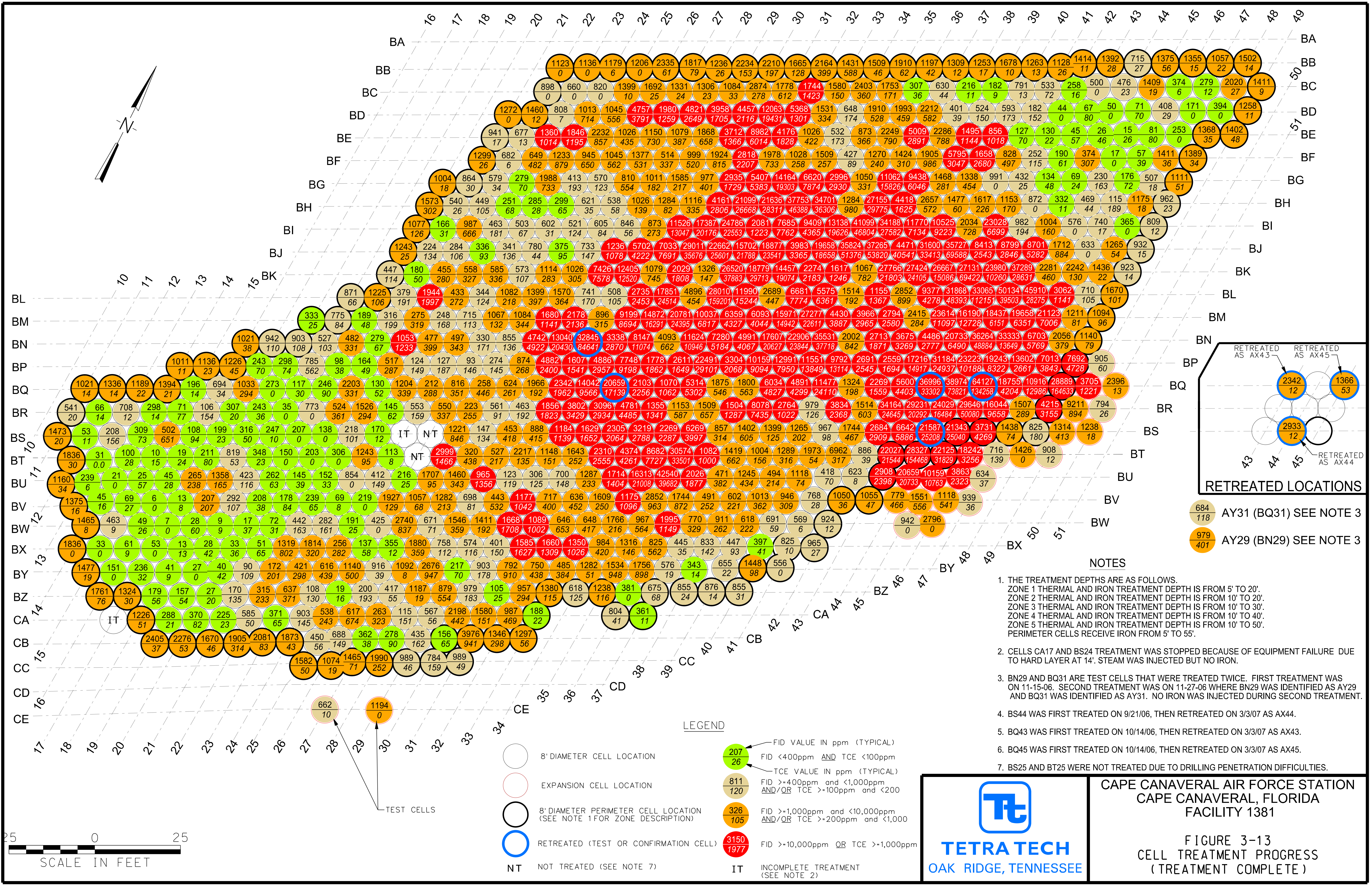

NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.
2. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.
3. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.
4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.
5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.
6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.
7. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.

LEGEND

○	8' DIAMETER CELL LOCATION	207 26	FID VALUE IN ppm (TYPICAL) FID <400ppm AND TCE <100ppm TCE VALUE IN ppm (TYPICAL)
○	EXPANSION CELL LOCATION	811 120	FID >=400ppm and <1,000ppm AND/OR TCE >=100ppm and <200
○	8' DIAMETER PERIMETER CELL LOCATION (SEE NOTE 1 FOR ZONE DESCRIPTION)	326 105	FID >=1,000ppm and <10,000ppm AND/OR TCE >=200ppm and <1,000
○	RETREATED (TEST OR CONFIRMATION CELL)	3150 1977	FID >=10,000ppm OR TCE >=1,000ppm
NT	NOT TREATED (SEE NOTE 7)	IT	INCOMPLETE TREATMENT (SEE NOTE 2)

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FIGURE 3-13
CELL TREATMENT PROGRESS
(TREATMENT COMPLETE)

RETREATED LOCATIONS

AY31 (BQ31) SEE NOTE 2

AY29 (BN29) SEE NOTE 2

NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.

2. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.

3. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.

4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.

5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.

6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.

7. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.

LEGEND

○	8' DIAMETER CELL LOCATION	TCE / CIS-1,2 DCE / PCE / TOTAL VOCs	CONTAMINATION MASS (LBS PER CELL)
○	EXPANSION CELL LOCATION	○	RETREATED (TEST OR CONFIRMATION CELL)
○	8' DIAMETER PERIMETER CELL LOCATION (SEE NOTE 1 FOR ZONE DESCRIPTION)	NT	NOT TREATED (SEE NOTE 7)
		IT	INCOMPLETE TREATMENT (SEE NOTE 3)

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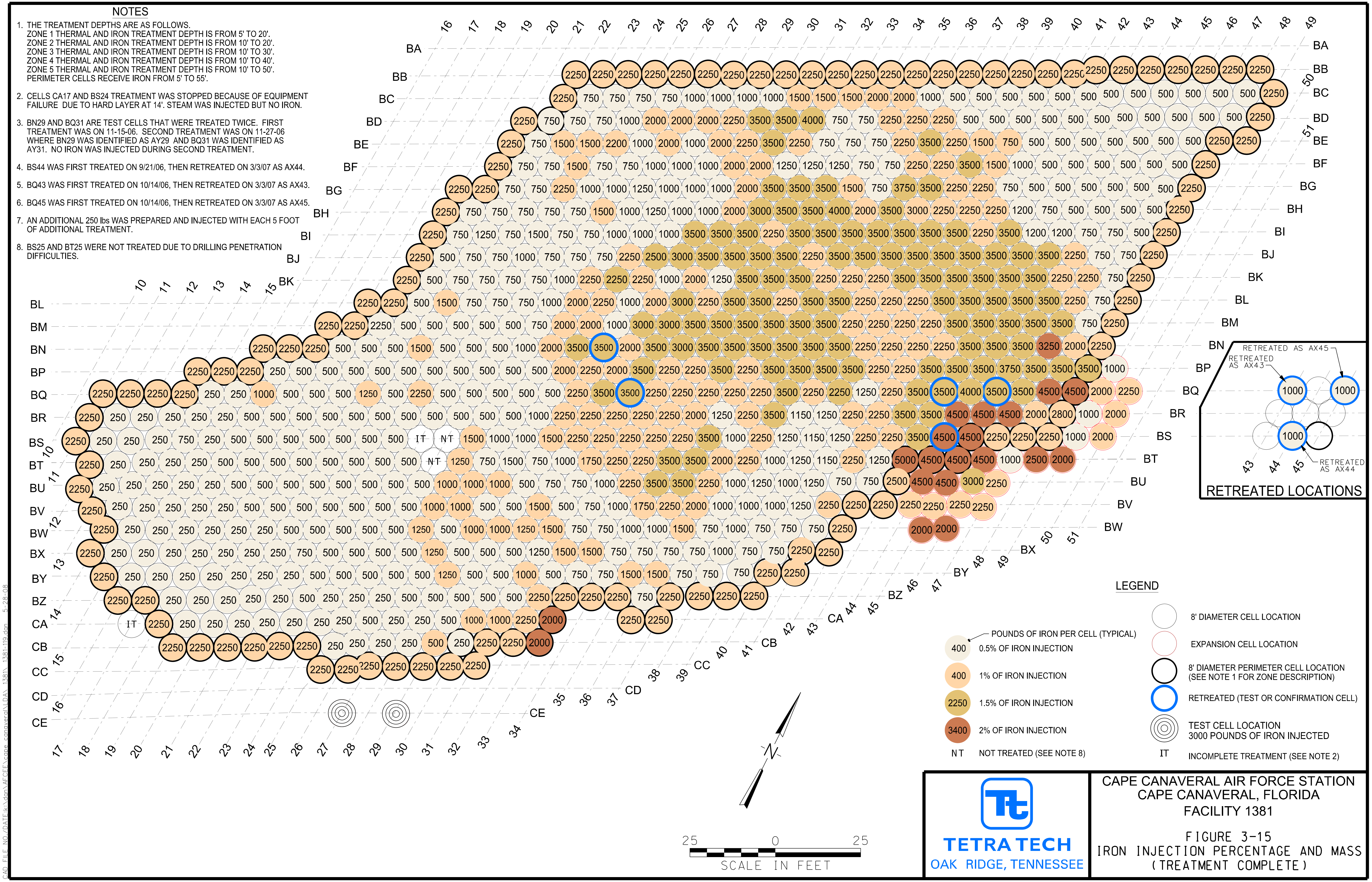
FIGURE 3-14
CONTAMINATION MASS DATA FOR
TCE, DCE, PCE AND TOTAL VOCs
(TREATMENT COMPLETE)

NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.
2. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.
3. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.
4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.
5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.
6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.
7. AN ADDITIONAL 250 lbs WAS PREPARED AND INJECTED WITH EACH 5 FOOT OF ADDITIONAL TREATMENT.
8. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.



LEGEND

400	POUNDS OF IRON PER CELL (TYPICAL) 0.5% OF IRON INJECTION
400	1% OF IRON INJECTION
2250	1.5% OF IRON INJECTION
3400	2% OF IRON INJECTION
NT	NOT TREATED (SEE NOTE 8)
○	8' DIAMETER CELL LOCATION
○	EXPANSION CELL LOCATION
○	8' DIAMETER PERIMETER CELL LOCATION (SEE NOTE 1 FOR ZONE DESCRIPTION)
○	RETREATED (TEST OR CONFIRMATION CELL)
◎	TEST CELL LOCATION 3000 POUNDS OF IRON INJECTED
IT	INCOMPLETE TREATMENT (SEE NOTE 2)

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FIGURE 3-15
IRON INJECTION PERCENTAGE AND MASS
(TREATMENT COMPLETE)

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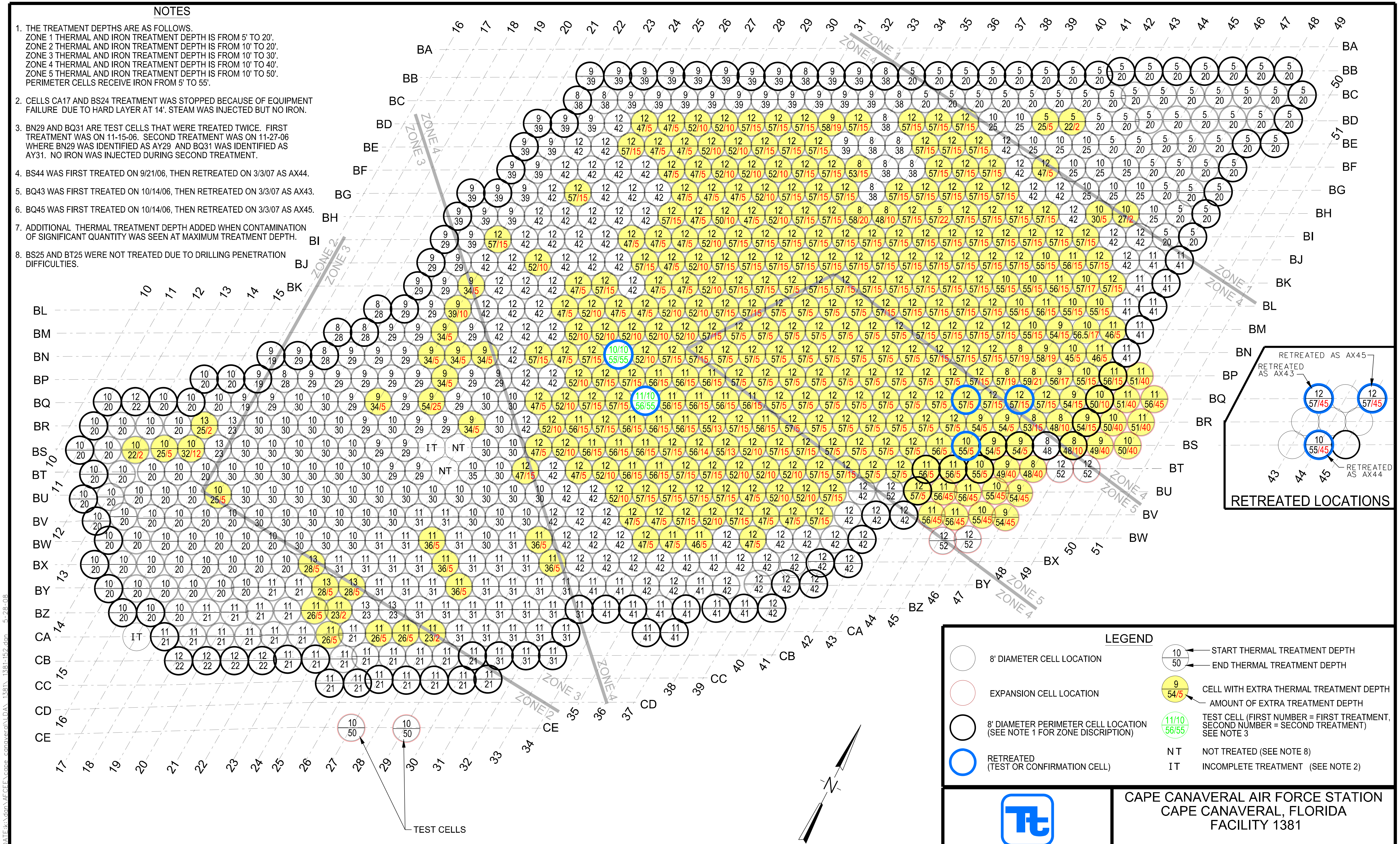
NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.
2. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.
3. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.
4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.
5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.
6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.
7. ADDITIONAL THERMAL TREATMENT DEPTH ADDED WHEN CONTAMINATION OF SIGNIFICANT QUANTITY WAS SEEN AT MAXIMUM TREATMENT DEPTH.
8. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.



LEGEND

○	8' DIAMETER CELL LOCATION	10/50	START THERMAL TREATMENT DEPTH END THERMAL TREATMENT DEPTH
○	EXPANSION CELL LOCATION	9/54/5	CELL WITH EXTRA THERMAL TREATMENT DEPTH AMOUNT OF EXTRA TREATMENT DEPTH
○	8' DIAMETER PERIMETER CELL LOCATION (SEE NOTE 1 FOR ZONE DISCRIPTION)	11/10 56/55	TEST CELL (FIRST NUMBER = FIRST TREATMENT, SECOND NUMBER = SECOND TREATMENT) SEE NOTE 3
○	RETREATED (TEST OR CONFIRMATION CELL)	NT	NOT TREATED (SEE NOTE 8)
		IT	INCOMPLETE TREATMENT (SEE NOTE 2)

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FIGURE 3-16
THERMAL TREATMENT DEPTH
(TREATMENT COMPLETE)

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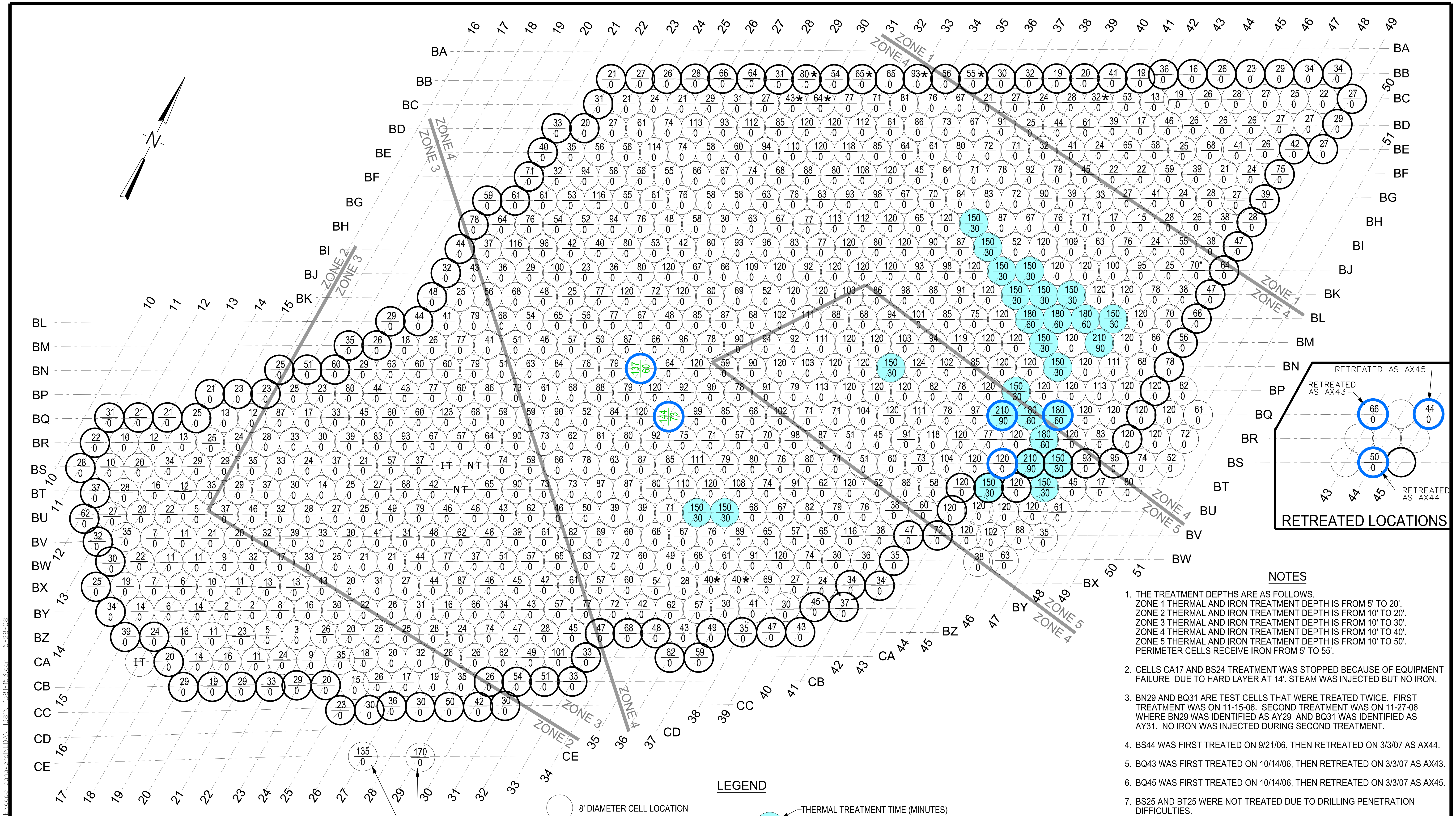

25 0 25

SCALE IN FEET

NOTES

1. THE TREATMENT DEPTHS ARE AS FOLLOWS.
   ZONE 1 THERMAL AND IRON TREATMENT DEPTH IS FROM 5' TO 20'.
   ZONE 2 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 20'.
   ZONE 3 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 30'.
   ZONE 4 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 40'.
   ZONE 5 THERMAL AND IRON TREATMENT DEPTH IS FROM 10' TO 50'.
   PERIMETER CELLS RECEIVE IRON FROM 5' TO 55'.
2. CELLS CA17 AND BS24 TREATMENT WAS STOPPED BECAUSE OF EQUIPMENT FAILURE DUE TO HARD LAYER AT 14'. STEAM WAS INJECTED BUT NO IRON.
3. BN29 AND BQ31 ARE TEST CELLS THAT WERE TREATED TWICE. FIRST TREATMENT WAS ON 11-15-06. SECOND TREATMENT WAS ON 11-27-06 WHERE BN29 WAS IDENTIFIED AS AY29 AND BQ31 WAS IDENTIFIED AS AY31. NO IRON WAS INJECTED DURING SECOND TREATMENT.
4. BS44 WAS FIRST TREATED ON 9/21/06, THEN RETREATED ON 3/3/07 AS AX44.
5. BQ43 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX43.
6. BQ45 WAS FIRST TREATED ON 10/14/06, THEN RETREATED ON 3/3/07 AS AX45.
7. BS25 AND BT25 WERE NOT TREATED DUE TO DRILLING PENETRATION DIFFICULTIES.

LEGEND

○	8' DIAMETER CELL LOCATION
○	EXPANSION CELL LOCATION
◯	8' DIAMETER PERIMETER CELL LOCATION (SEE NOTE 1 FOR ZONE DESCRIPTION)
◯	RETREATED (TEST OR CONFIRMATION CELL)
30 0	THERMAL TREATMENT TIME (MINUTES) * INDICATES APPROXIMATED TIME EXTRA THERMAL TREATMENT TIME (MINUTES) ALSO INDICATED WITH FILL
144/73	TEST CELL (LEFT SIDE SHOWS FIRST TREATMENT, RIGHT SIDE SHOWS SECOND TREATMENT) SEE NOTE 3
NT	NOT TREATED (SEE NOTES)
IT	INCOMPLETE TREATMENT (SEE NOTE 2)

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FIGURE 3-17
THERMAL TREATMENT TIME
(TREATMENT COMPLETE)

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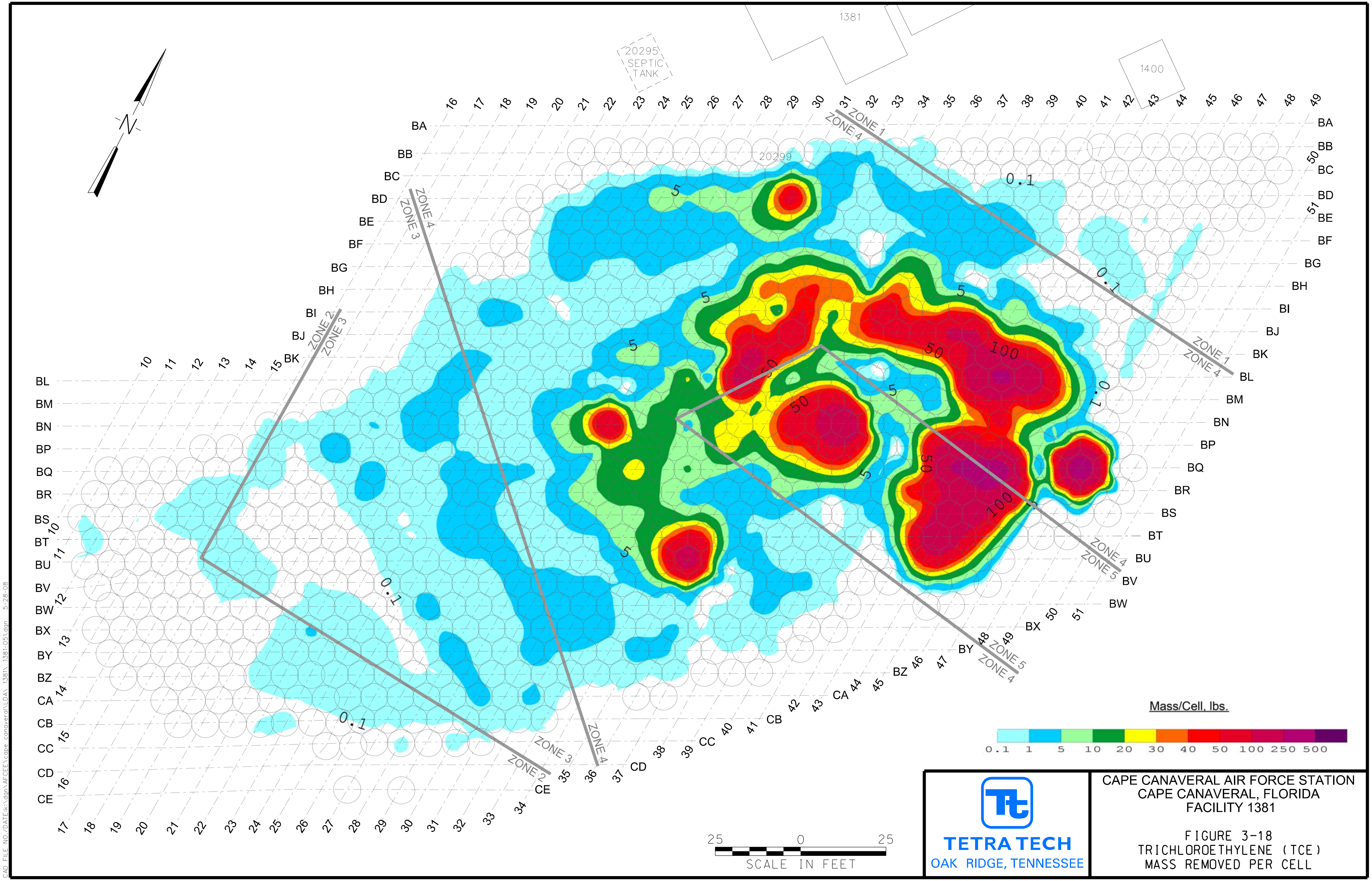

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FIGURE 3-18
TRICHLOROETHYLENE (TCE)
MASS REMOVED PER CELL

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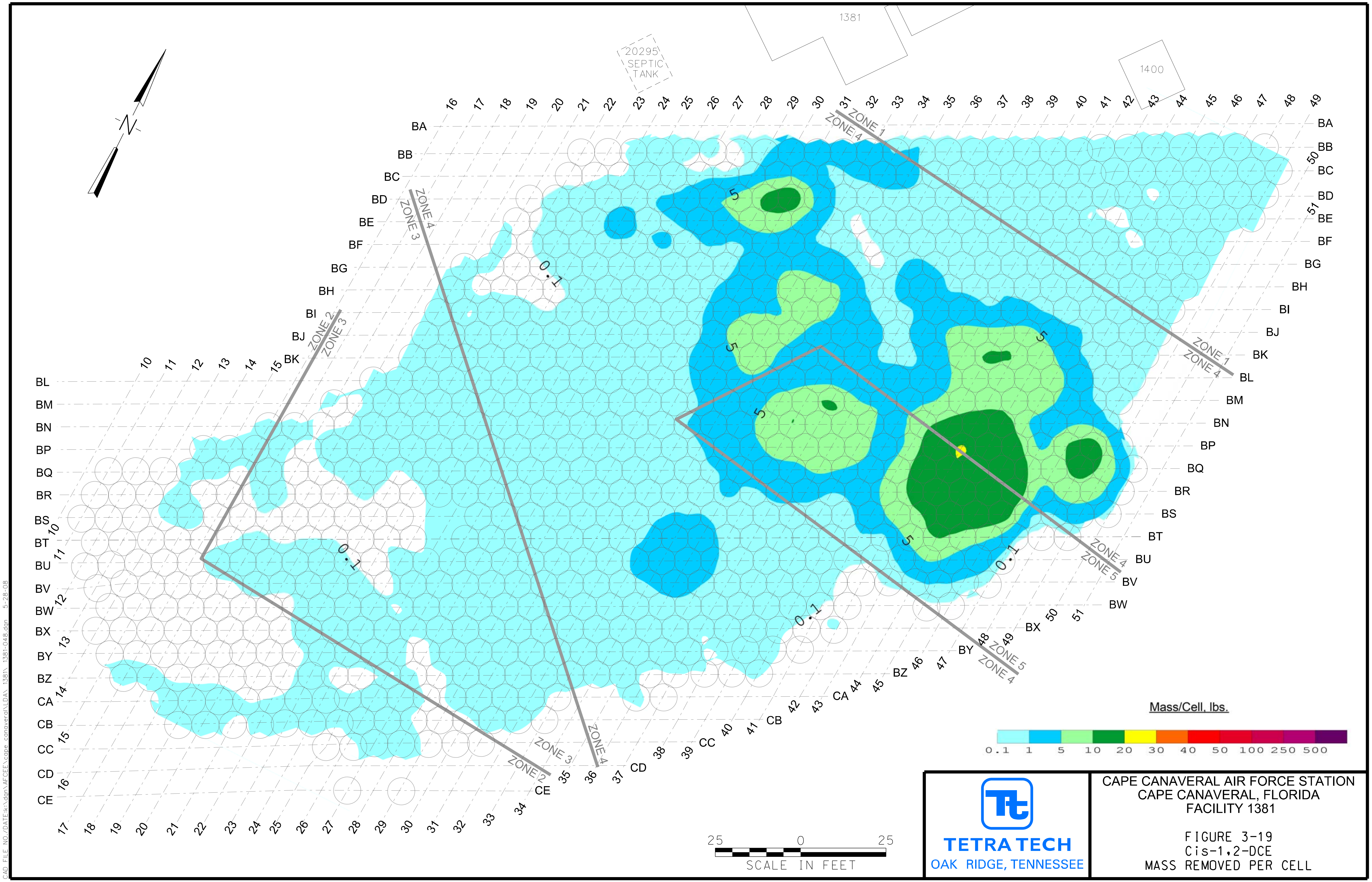

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FIGURE 3-19
Cis-1,2-DCE
MASS REMOVED PER CELL

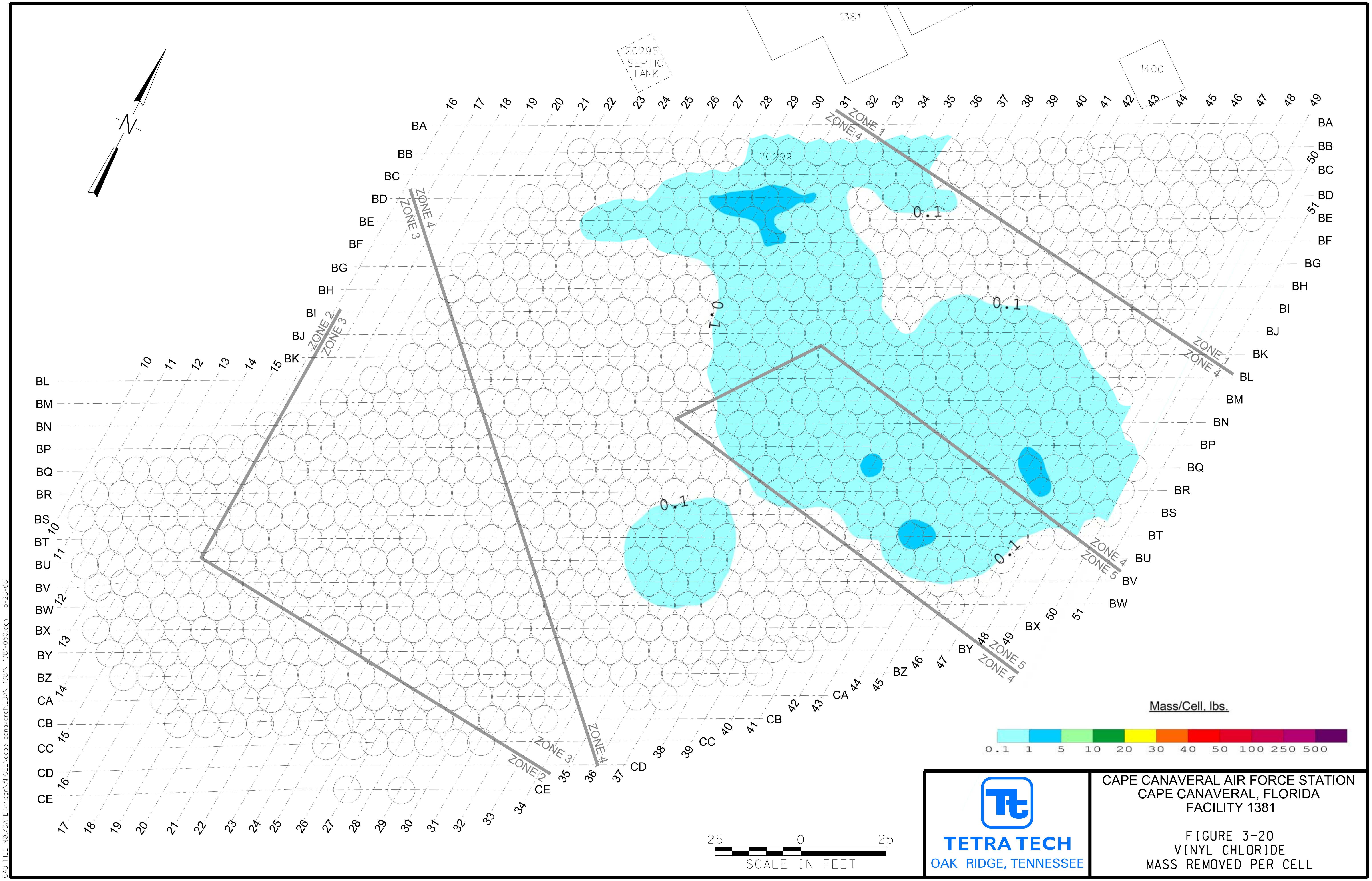

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FIGURE 3-20
VINYL CHLORIDE
MASS REMOVED PER CELL

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-050.dgn 5-28-08

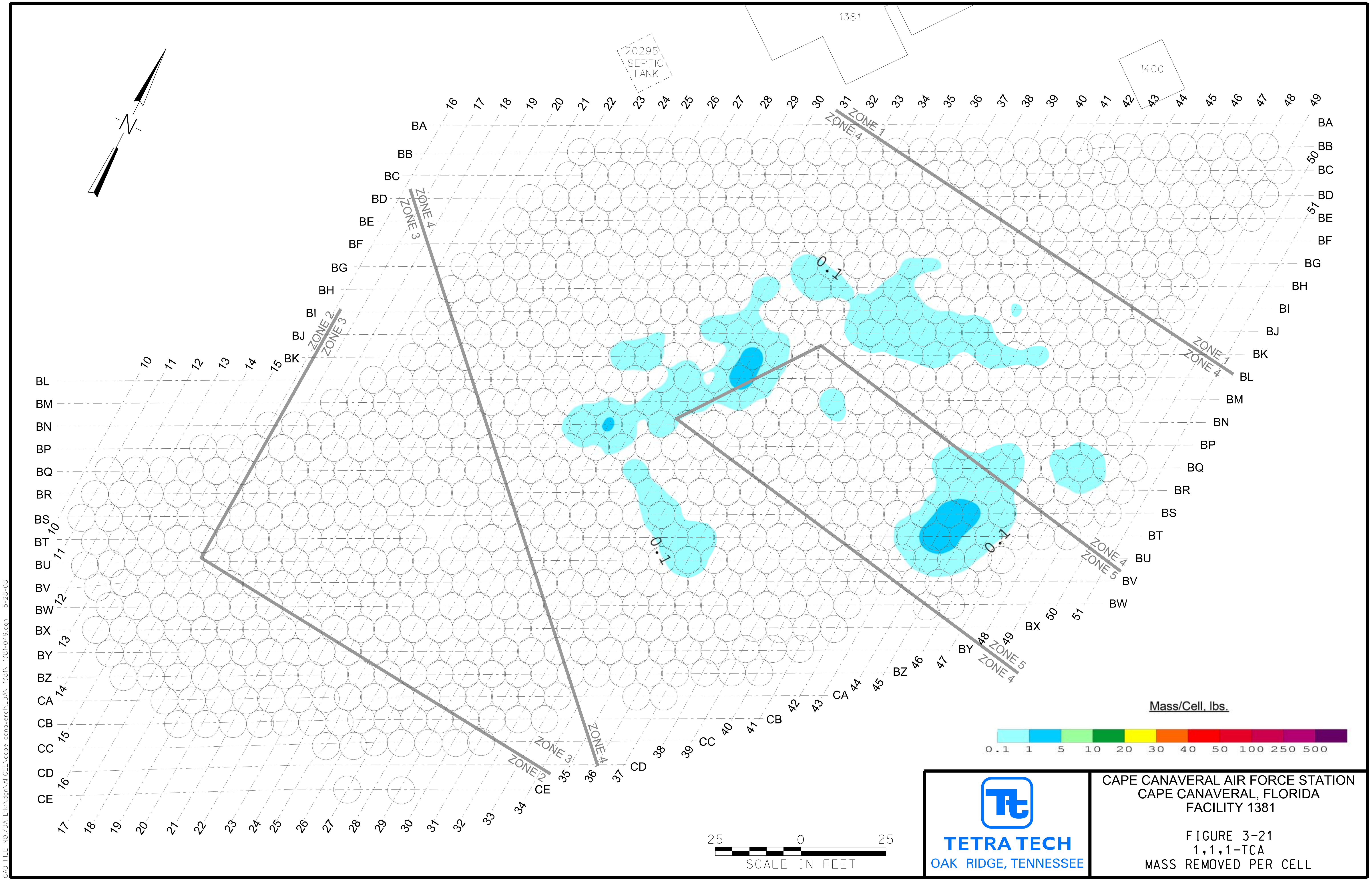

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FIGURE 3-21
1,1,1-TCA
MASS REMOVED PER CELL

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-049.dgn 5-28-08

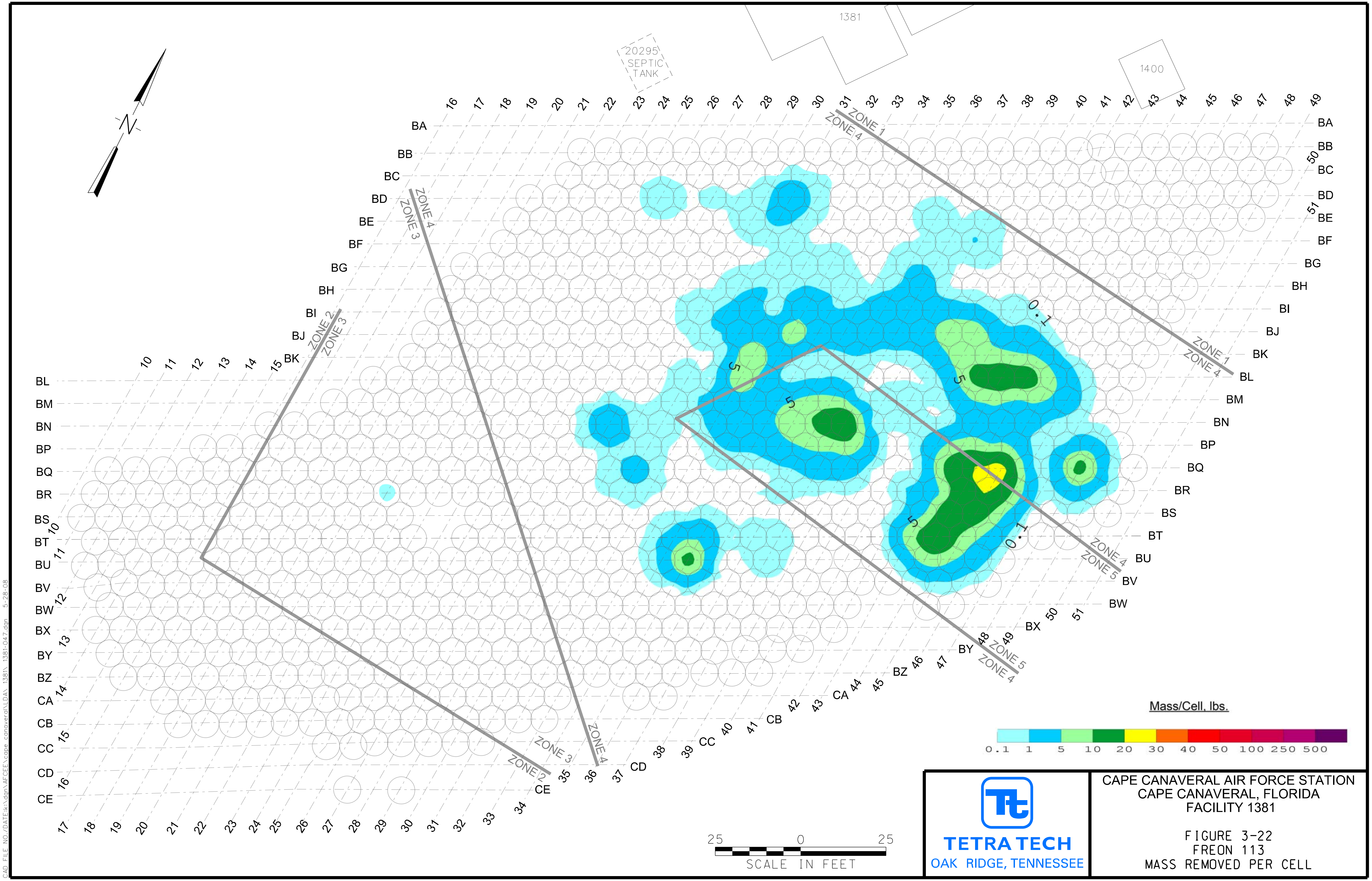

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FIGURE 3-22
FREON 113
MASS REMOVED PER CELL

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-047.dgn 5-28-08

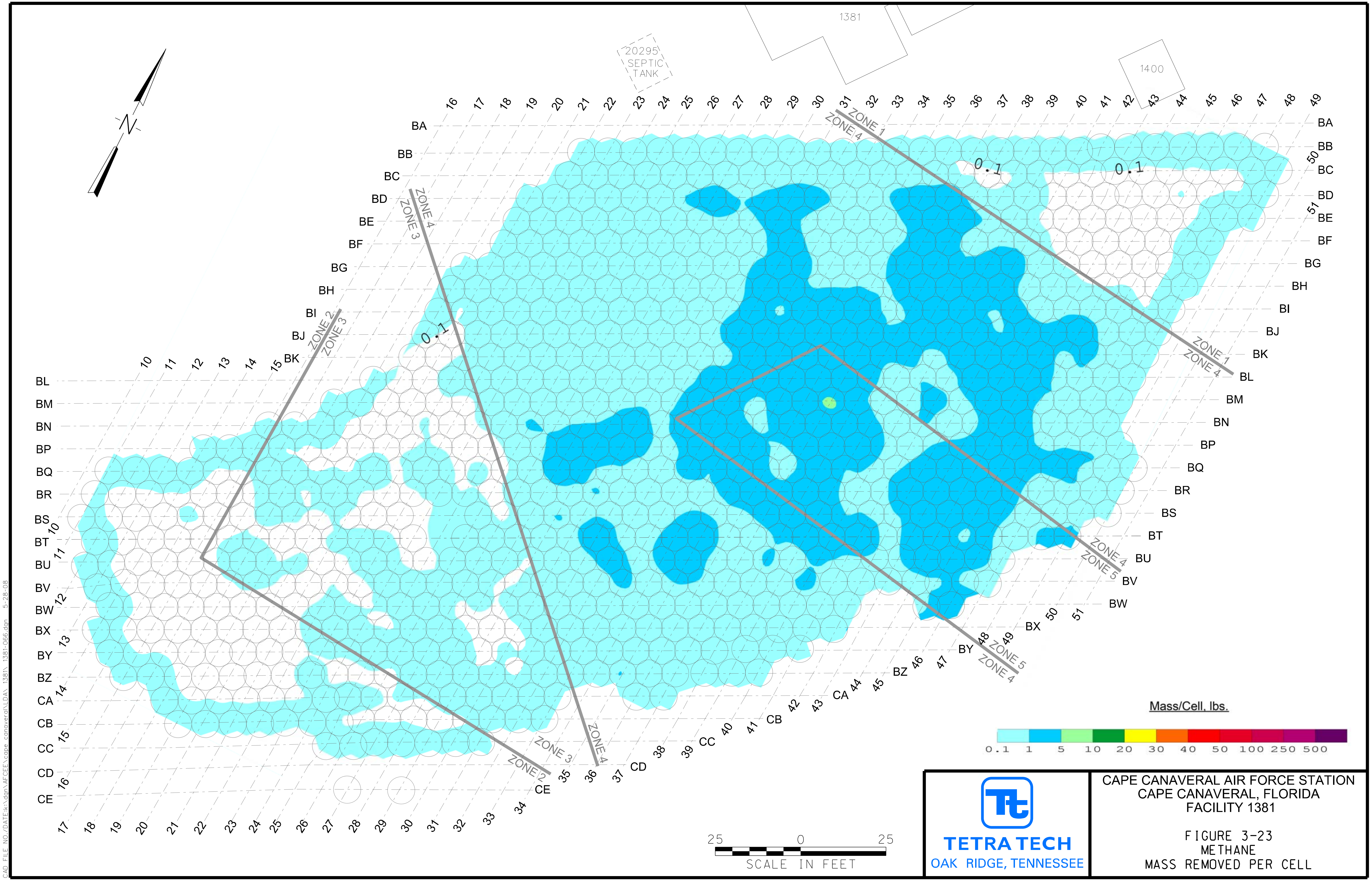

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FIGURE 3-23
METHANE
MASS REMOVED PER CELL

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CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-068.dgn 5-28-08

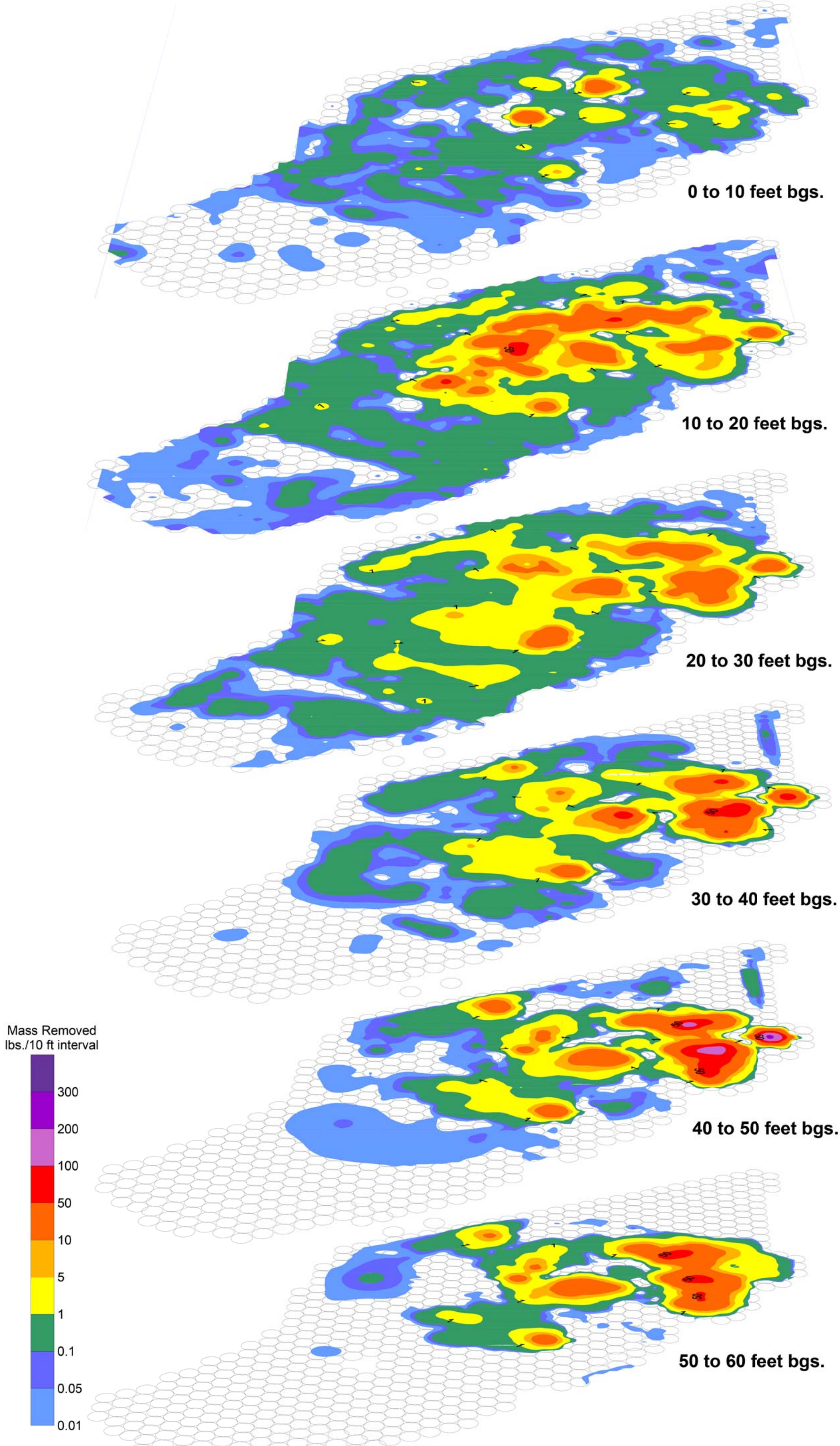

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FIGURE 3-24
TRICHLOROETHYLENE (TCE)
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-067.dgn 5-28-08

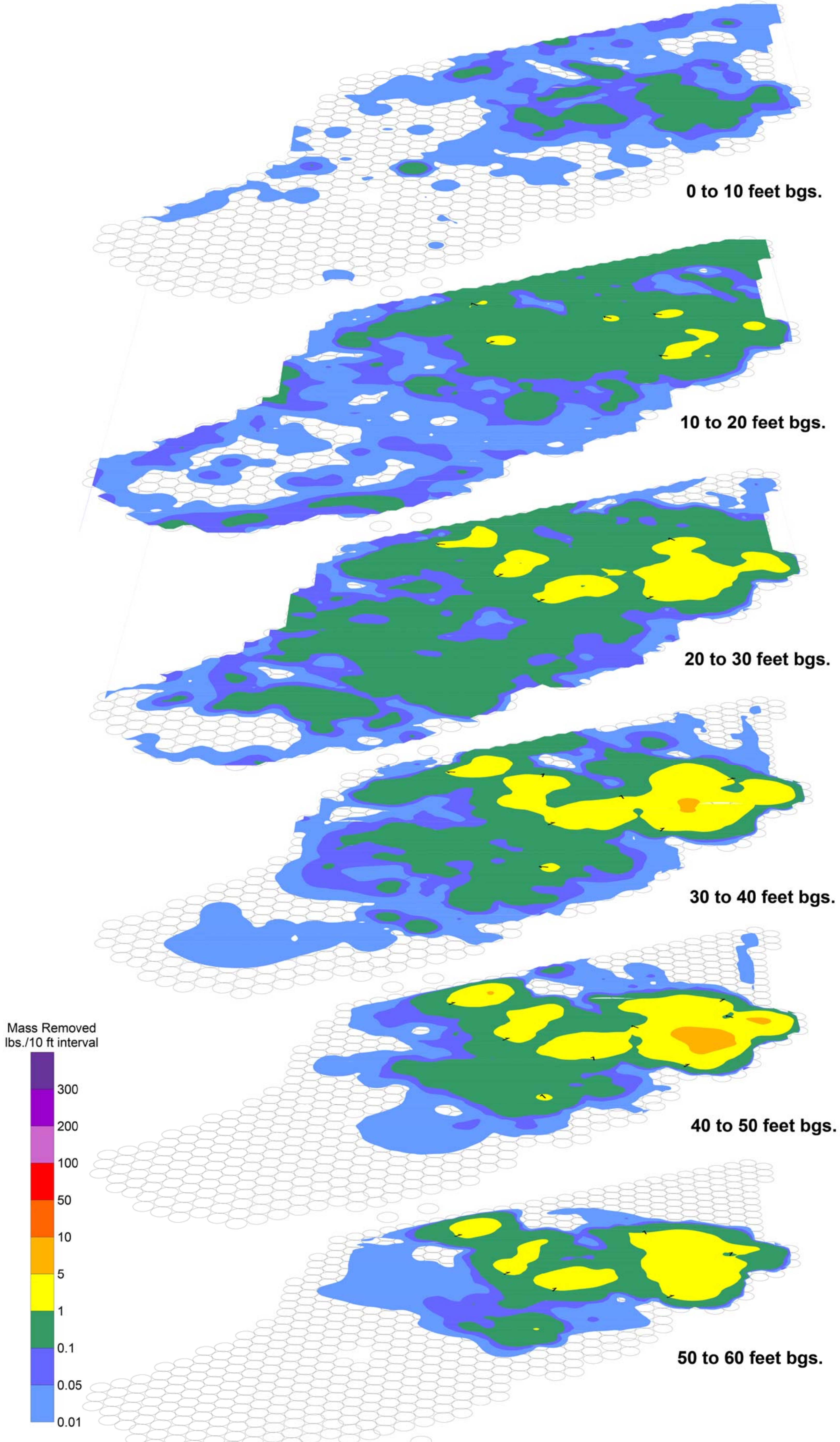

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FIGURE 3-25
Cis-1,2-DCE
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

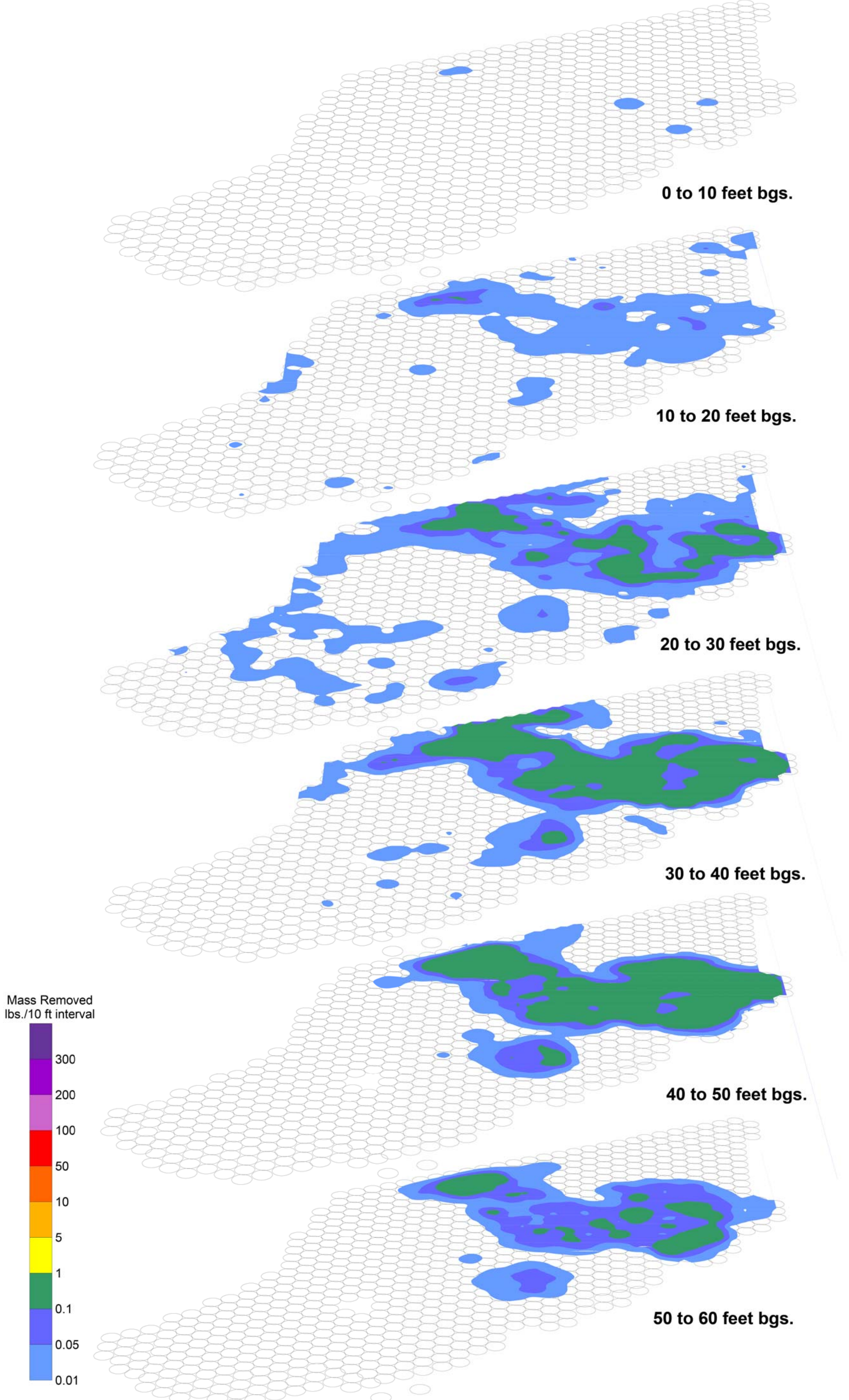

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FIGURE 3-26
VINYL CHLORIDE
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

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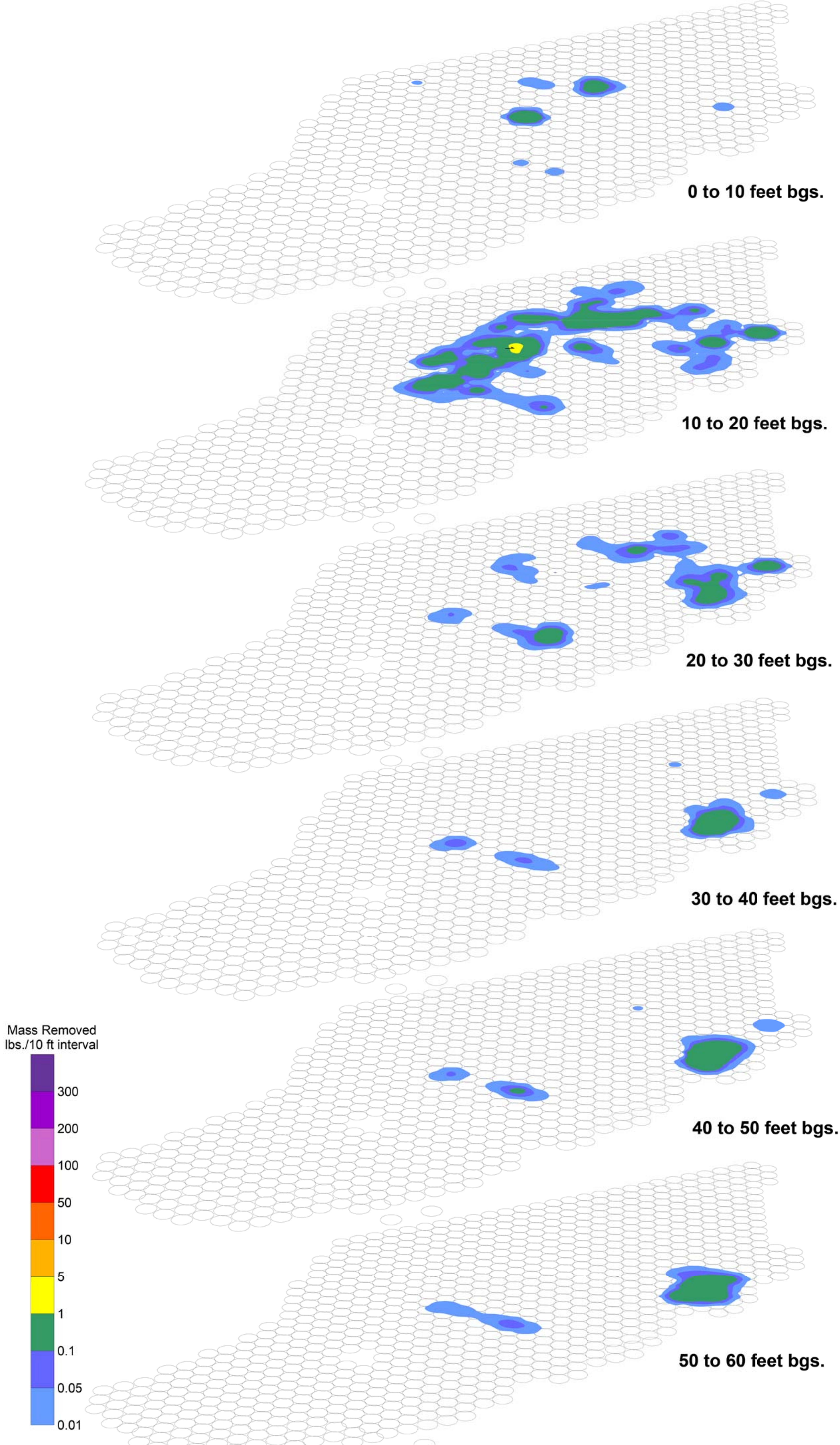

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FIGURE 3-27
1,1,1-TCA
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

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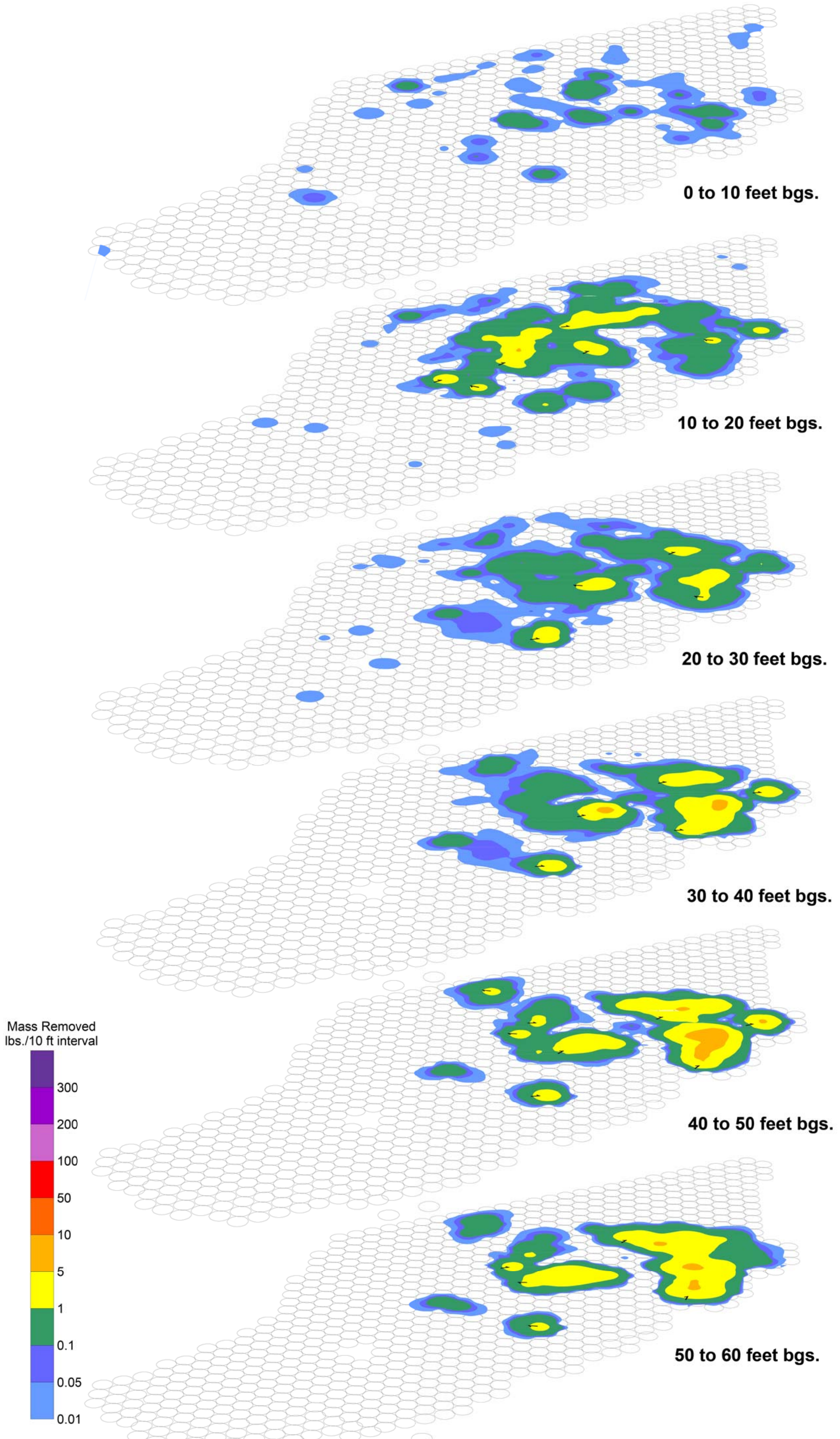

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FIGURE 3-28
FREON 113
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

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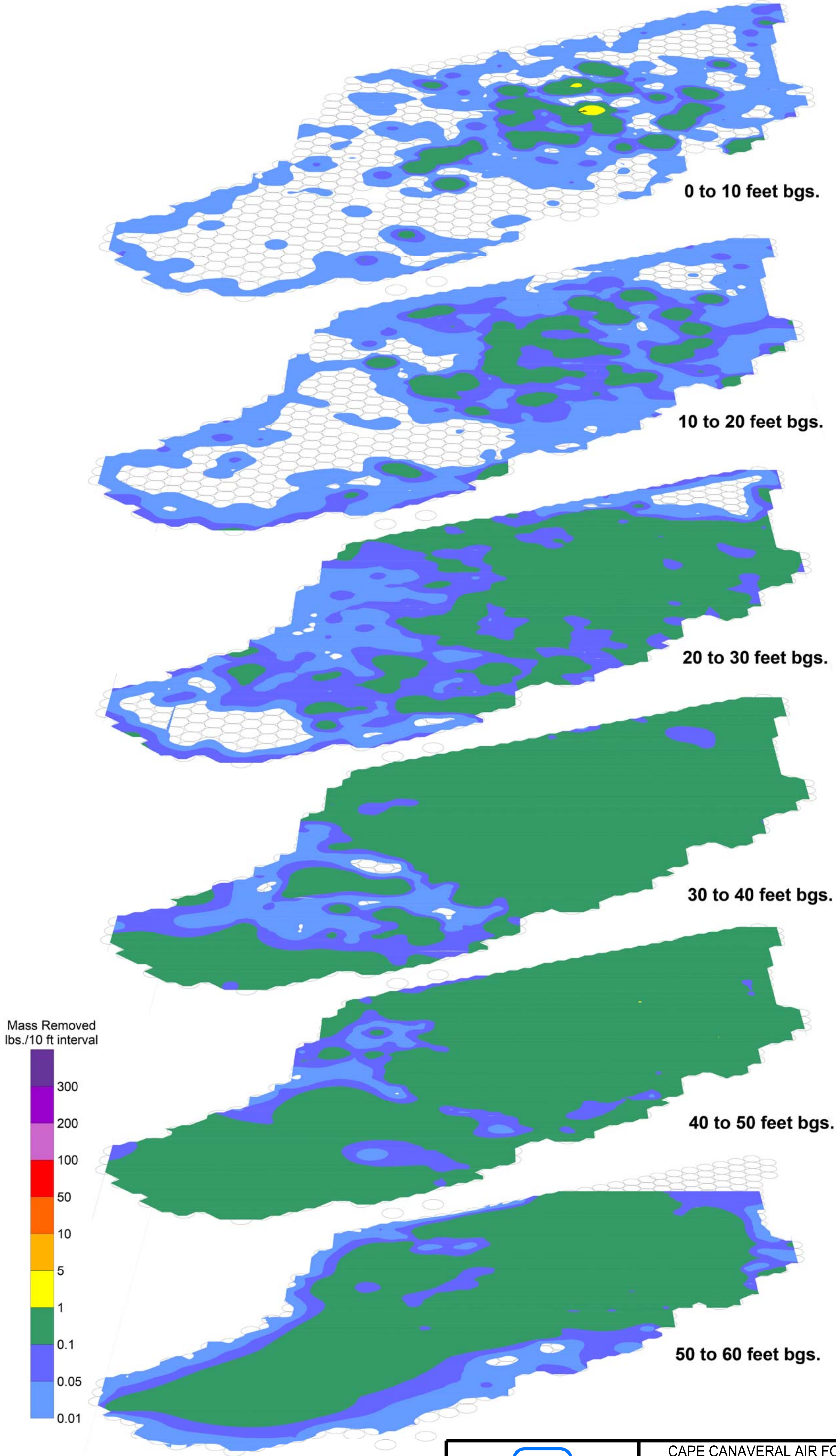

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FIGURE 3-29
METHANE
MASS REMOVED PER CELL
SHOWN IN 10' INTERVALS

LEGEND

○ 8' DIAMETER CELL LOCATION

● SECTION A CELLS

● SECTION B CELLS

● SECTION C CELLS

● SECTION D CELLS

● SECTION E CELLS

— ZONE BOUNDARY

— TREATMENT AREA BOUNDARY

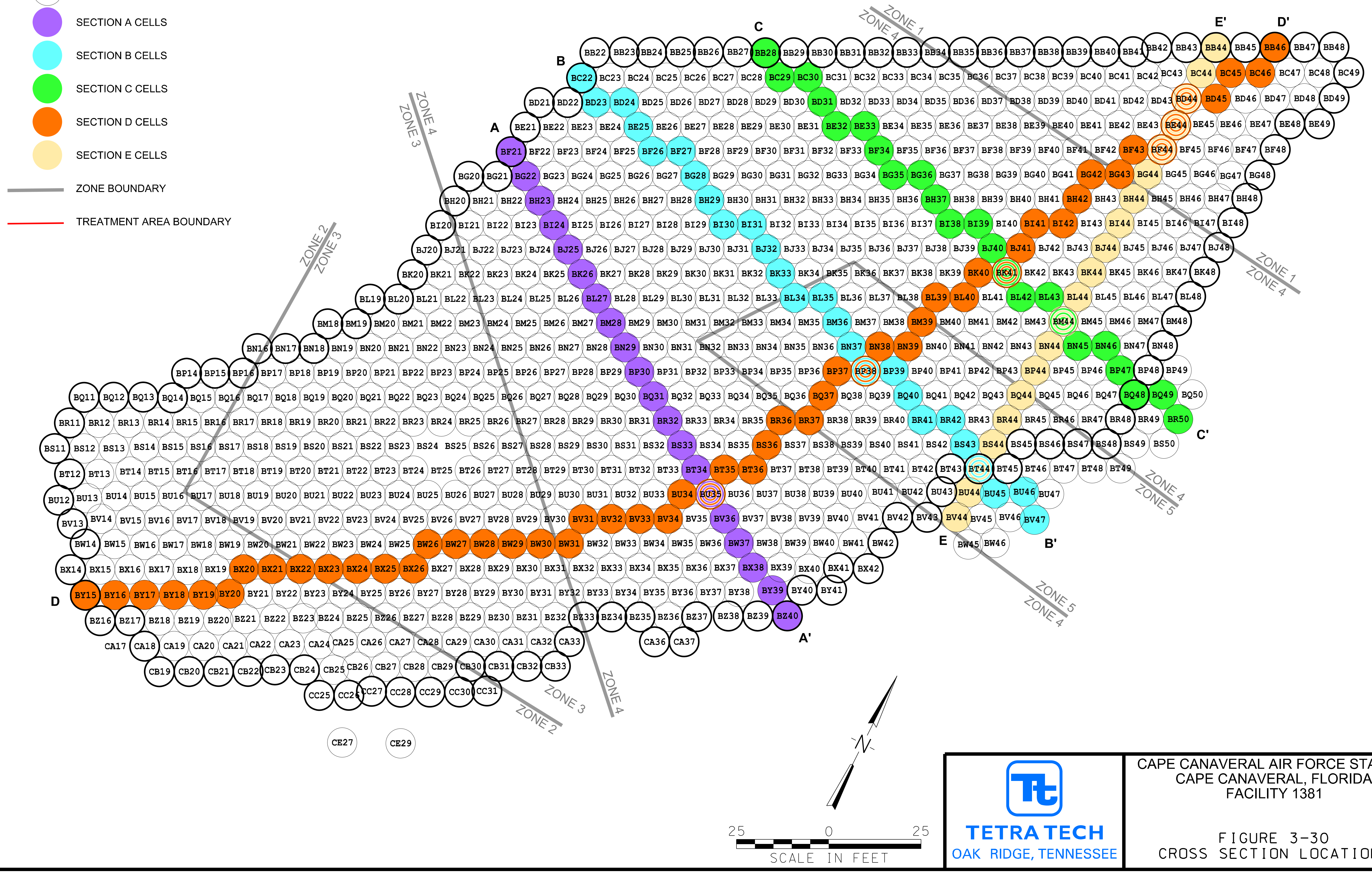

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FIGURE 3-30
CROSS SECTION LOCATIONS

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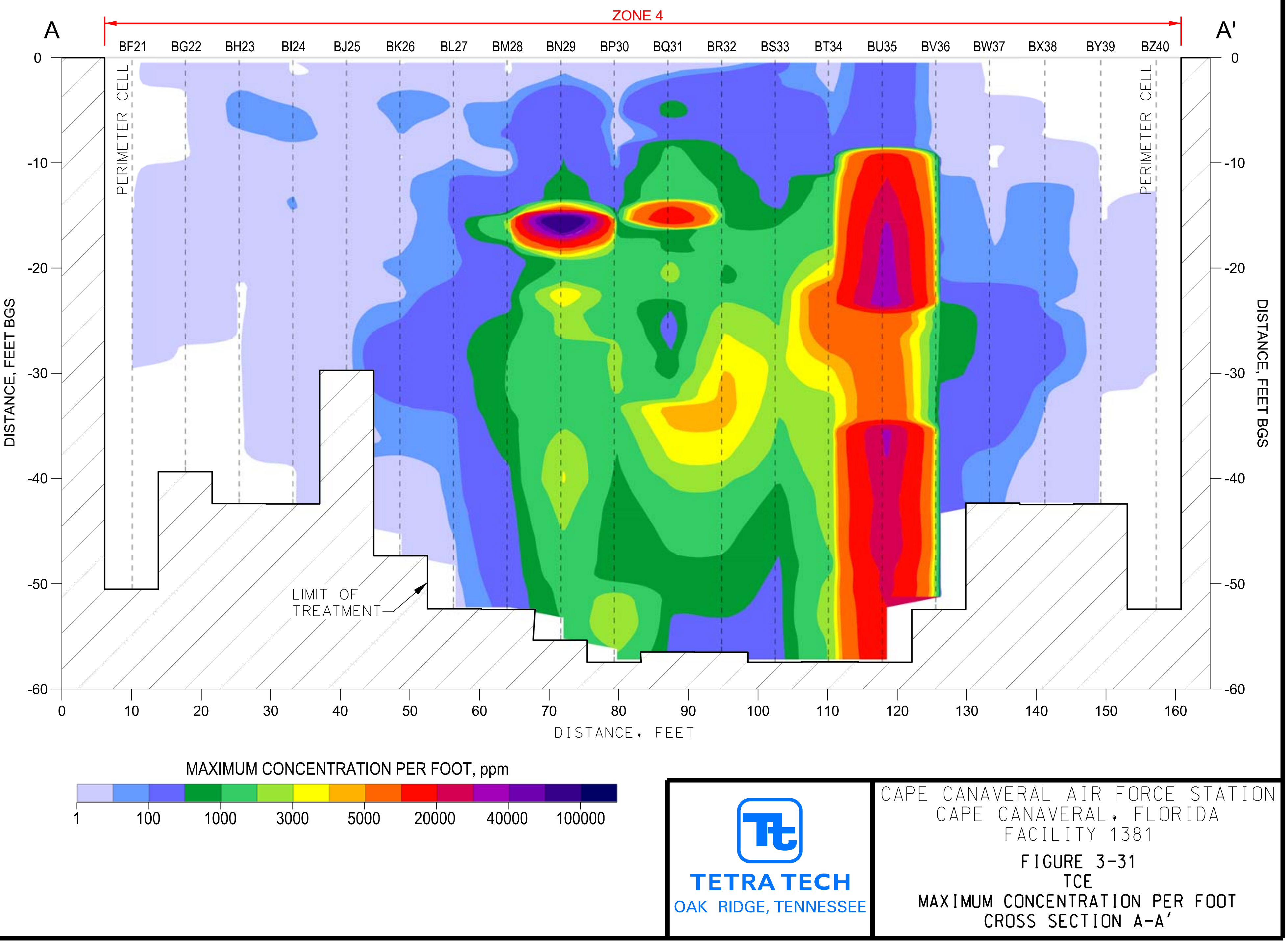

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FIGURE 3-31
TCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION A-A'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-074.dgn 10-2-07 CMI Report

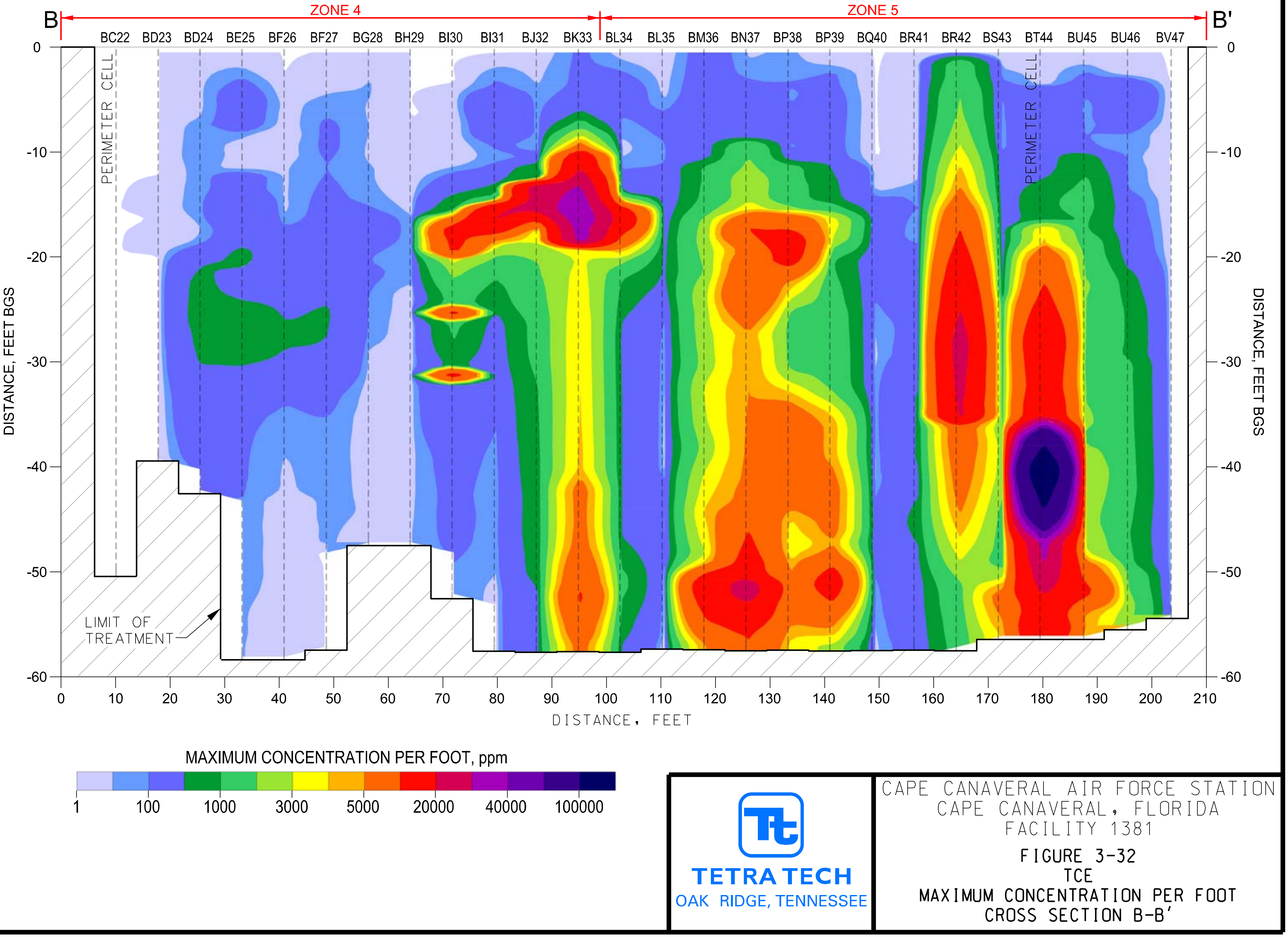

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FIGURE 3-32
TCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-084.dgn 10-2-07 CMI Report

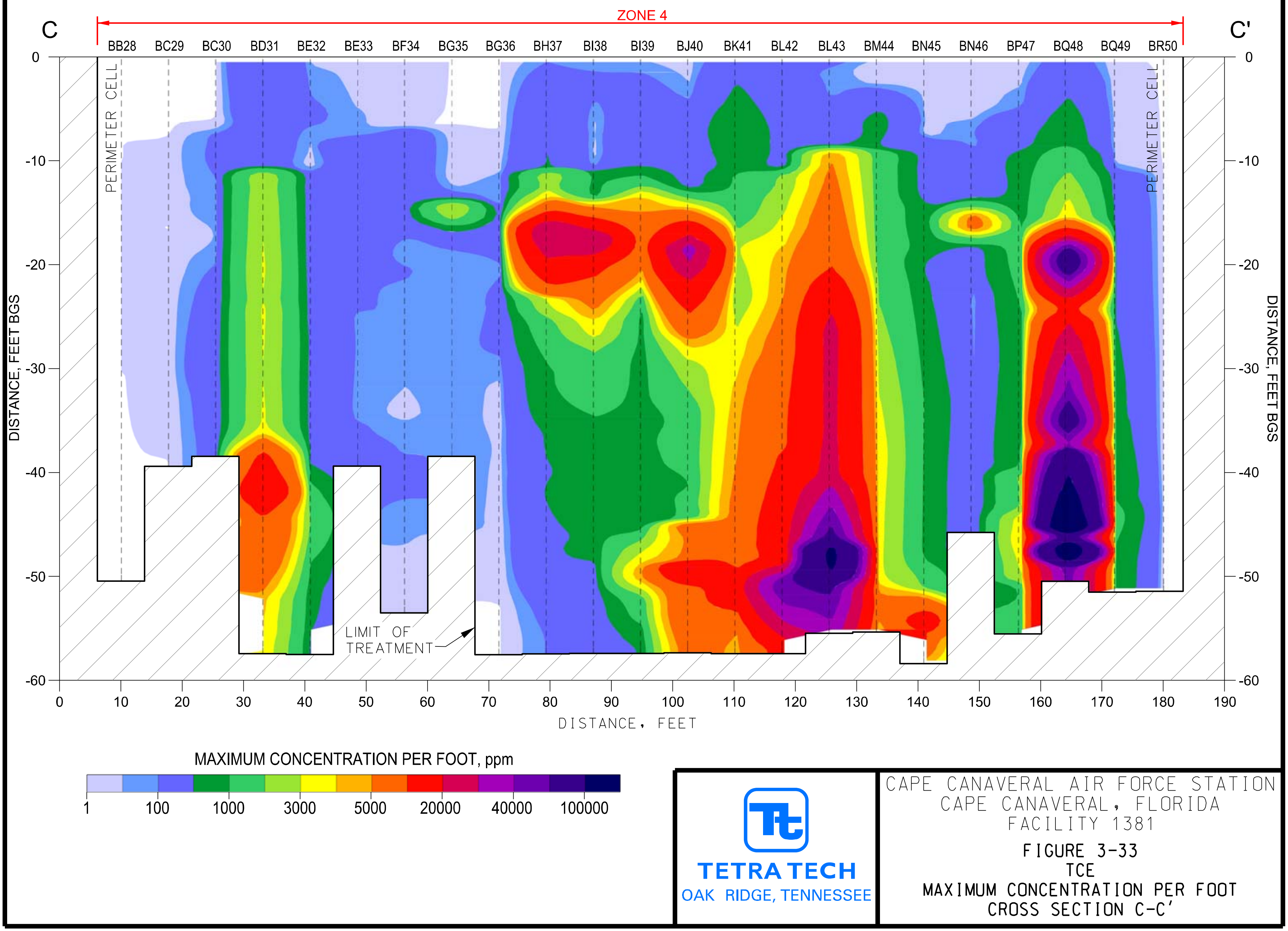

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FIGURE 3-33
TCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION C-C′

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-086.dgn 10-2-07 CMI Report

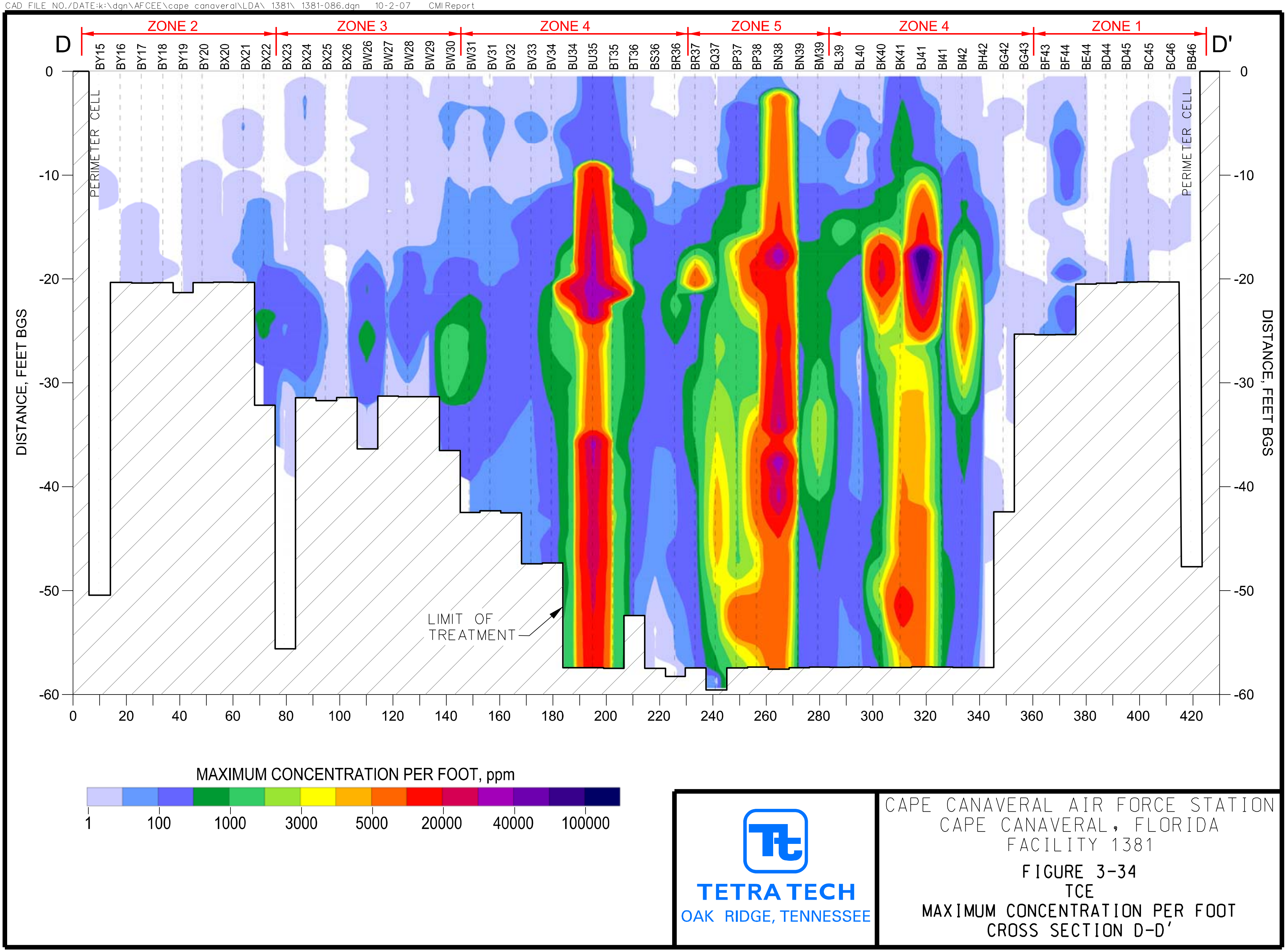

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FIGURE 3-34
TCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-089.dgn 10-2-07 CMI Report

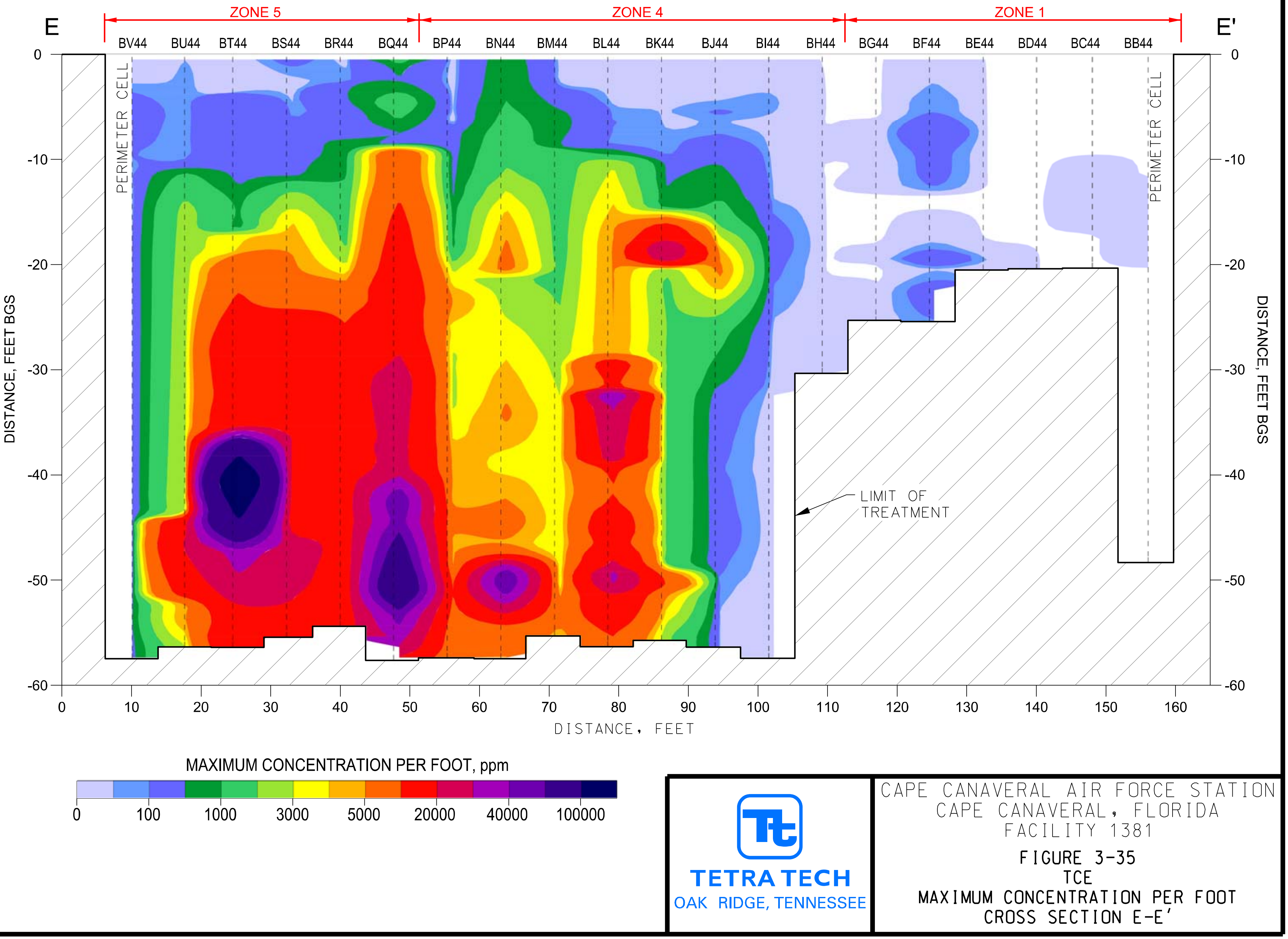

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FIGURE 3-35
TCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION E-E'

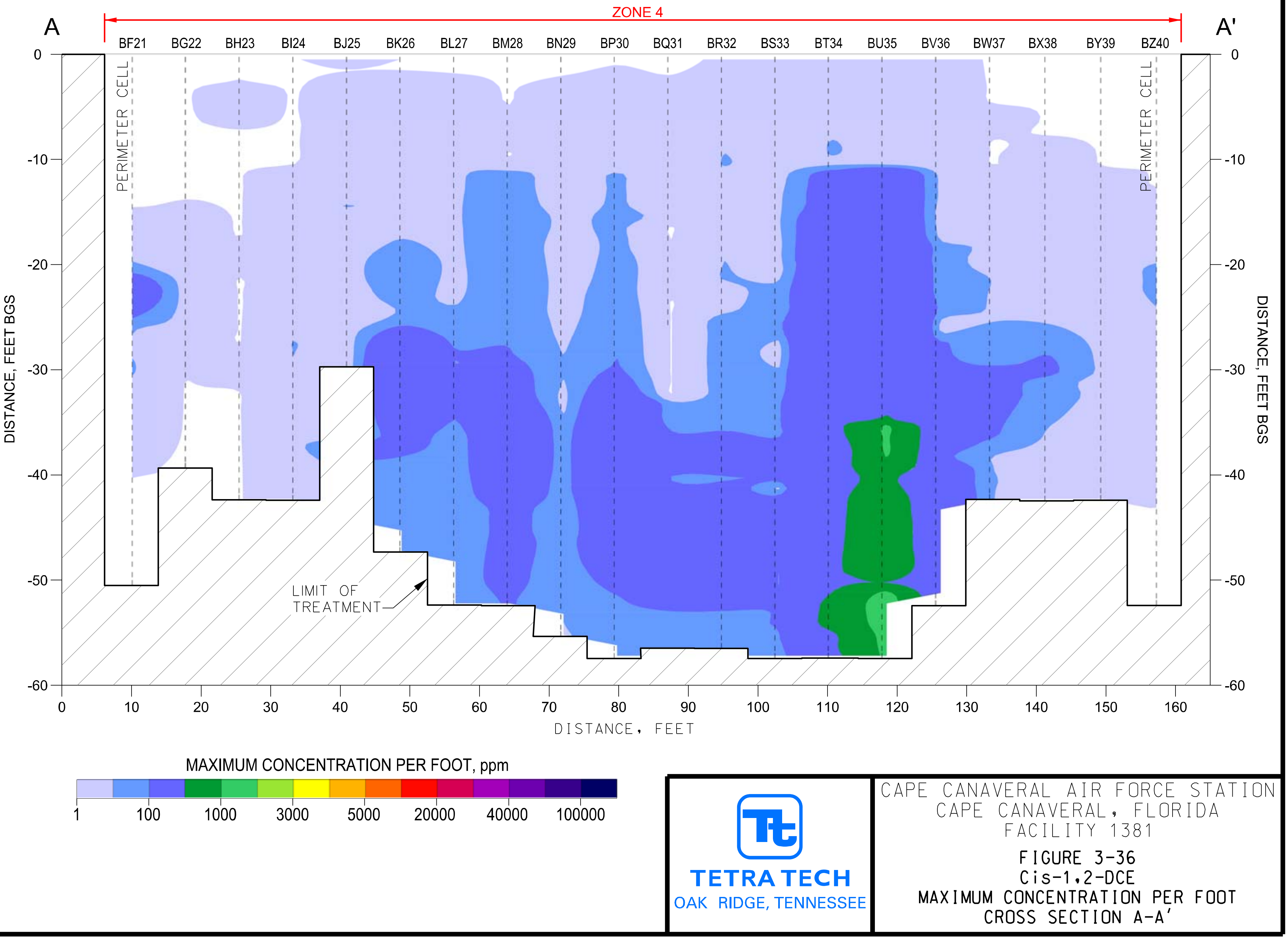

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FIGURE 3-36
Cis-1,2-DCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION A-A'

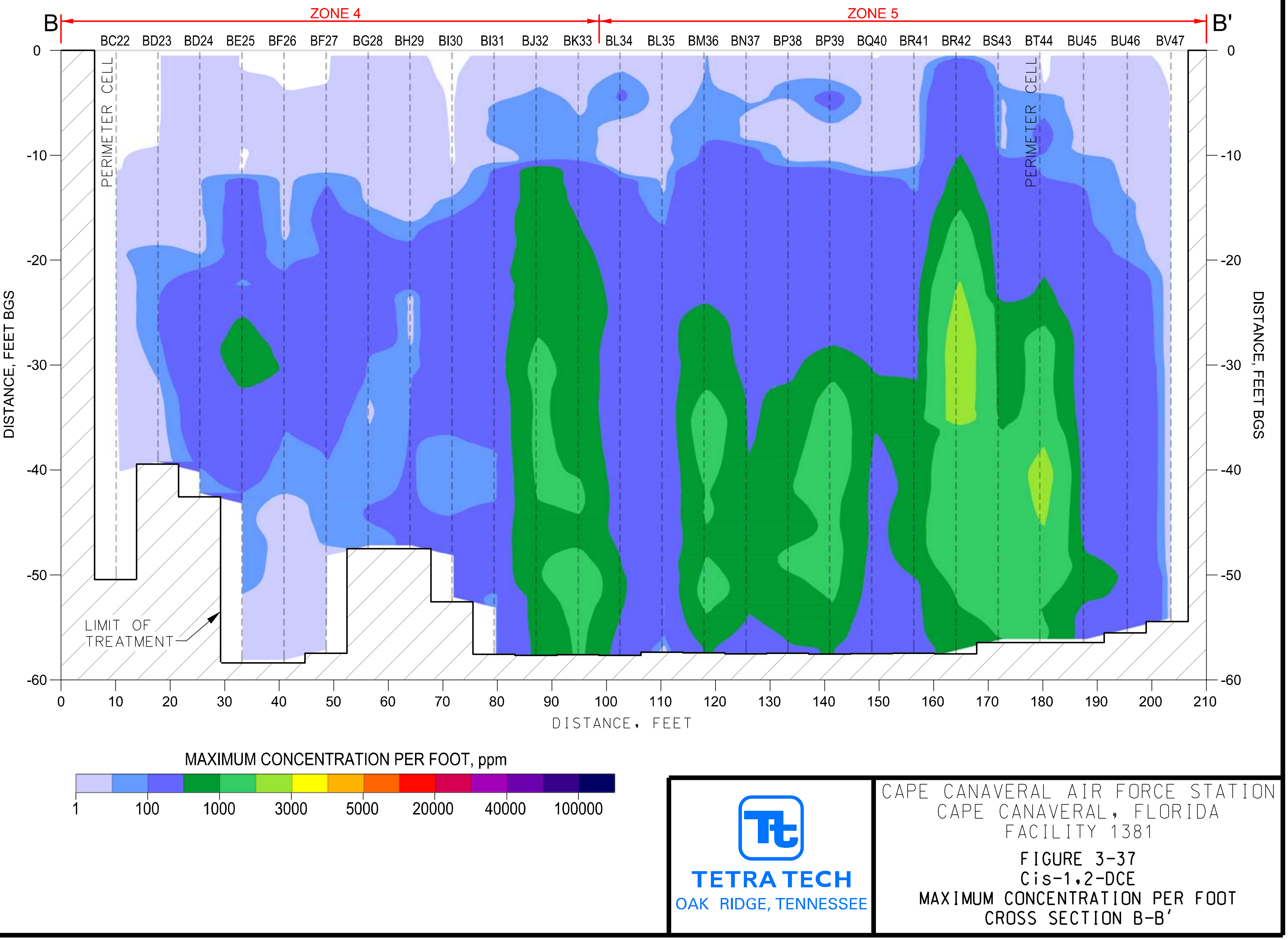

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FIGURE 3-37
Cis-1,2-DCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-083.dgn 10-15-07 CMI Report

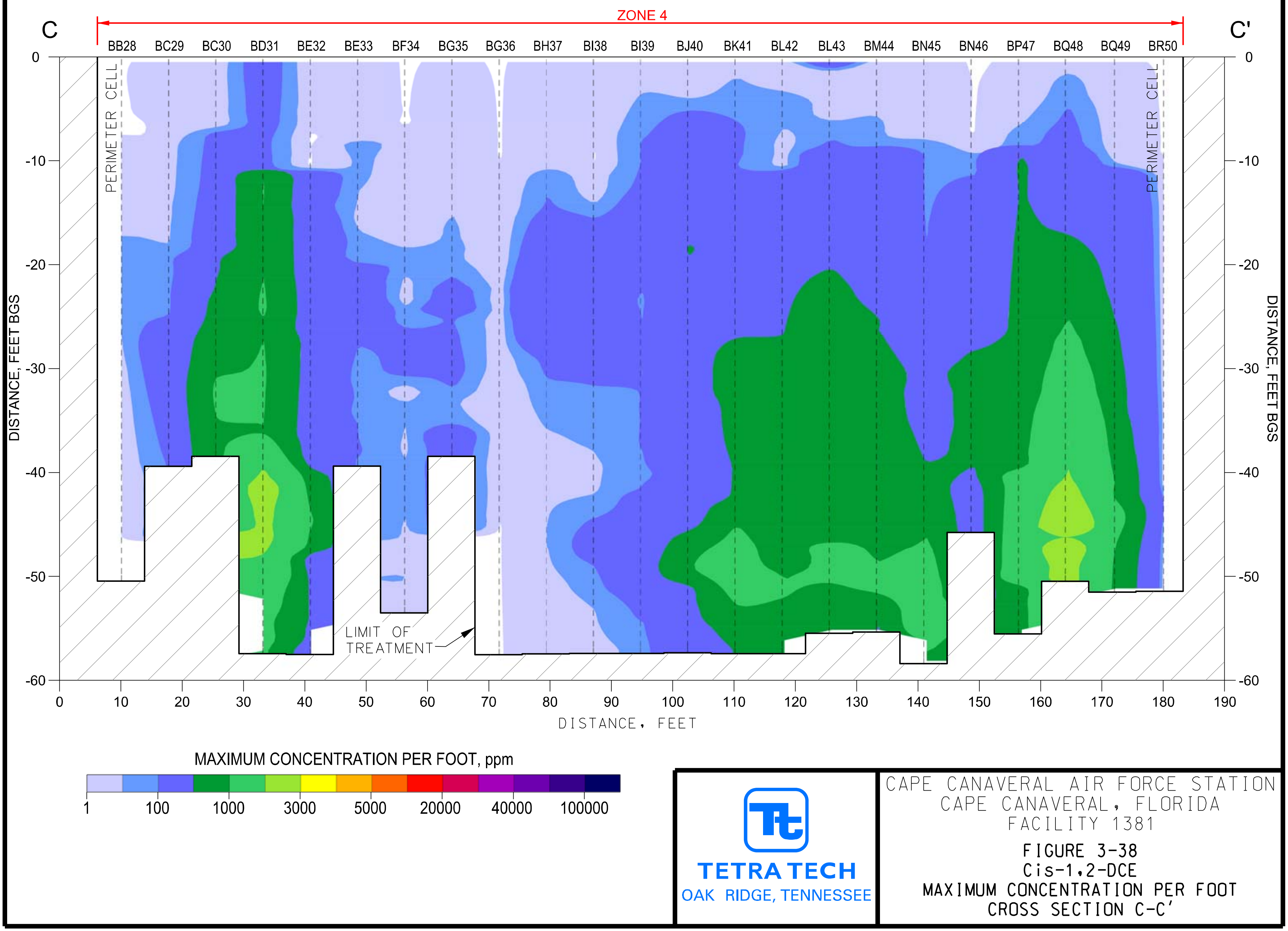

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FIGURE 3-38
Cis-1,2-DCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION C-C'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-085.dgn 10-15-07 CMI Report

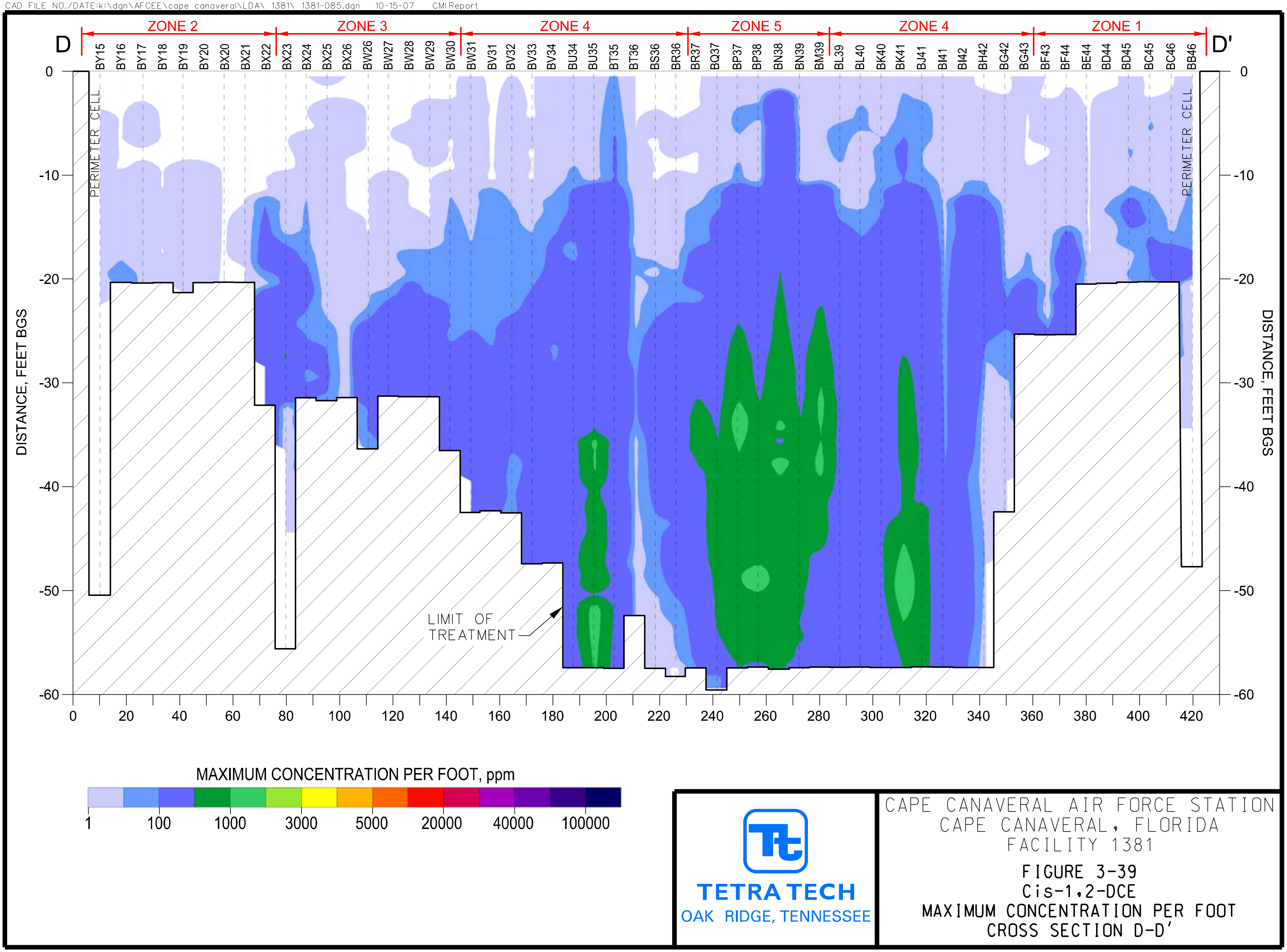

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FIGURE 3-39
Cis-1,2-DCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION D-D'

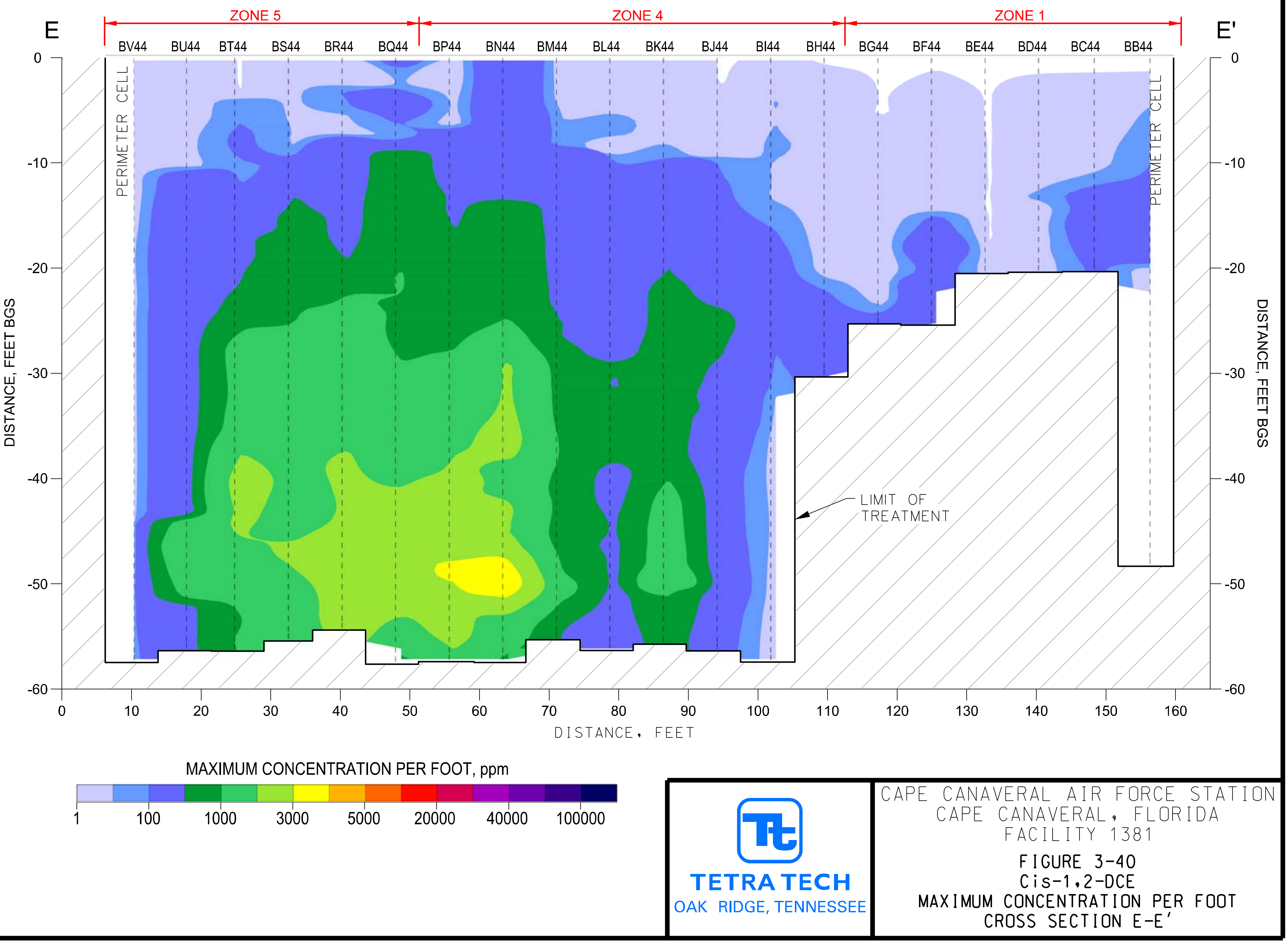

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FIGURE 3-40
Cis-1,2-DCE
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION E-E'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-094.dgn 10-2-07 CMI Report

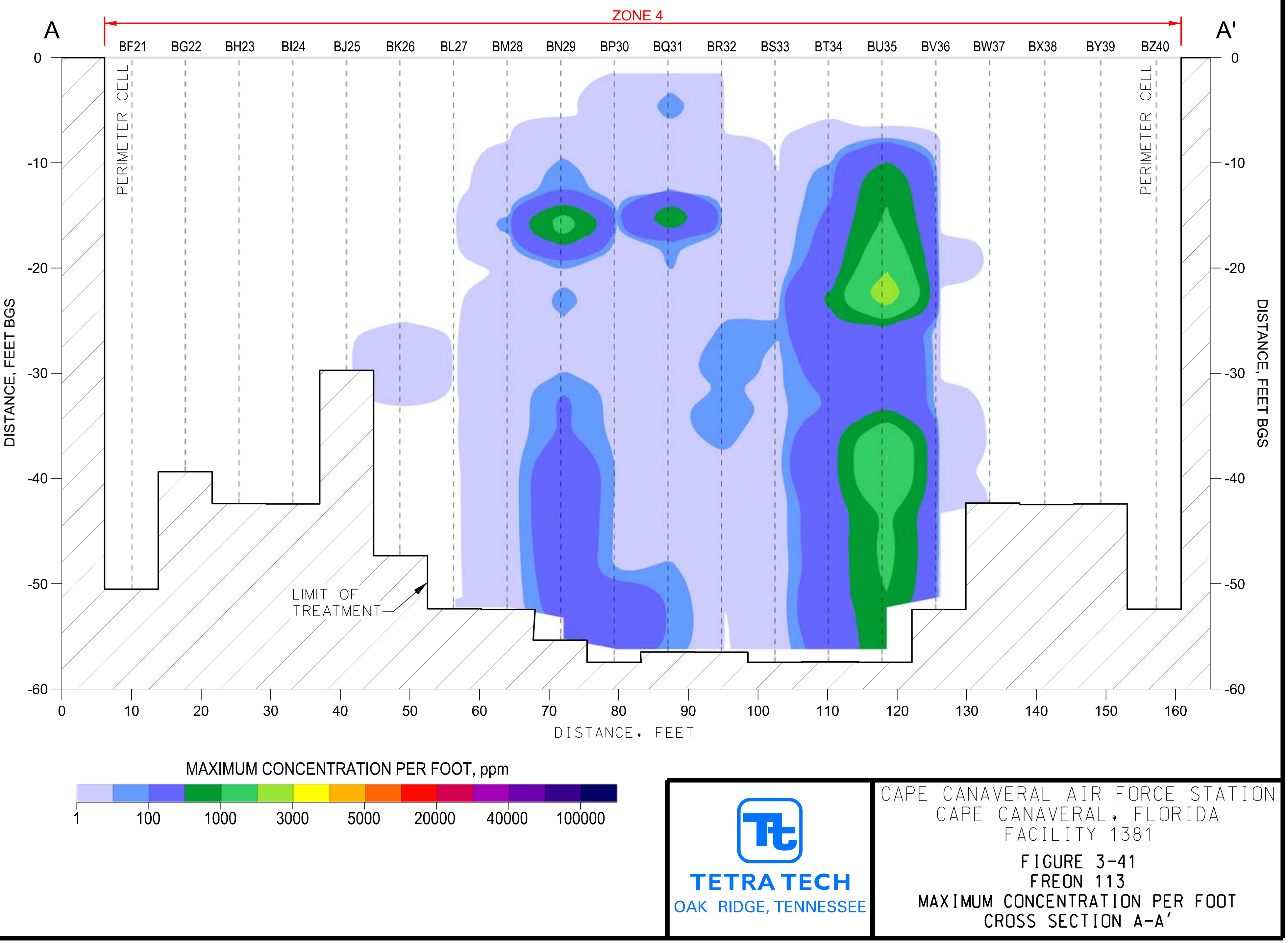

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FIGURE 3-41
FREON 113
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION A-A'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-096.dgn 10-2-07 CMI Report

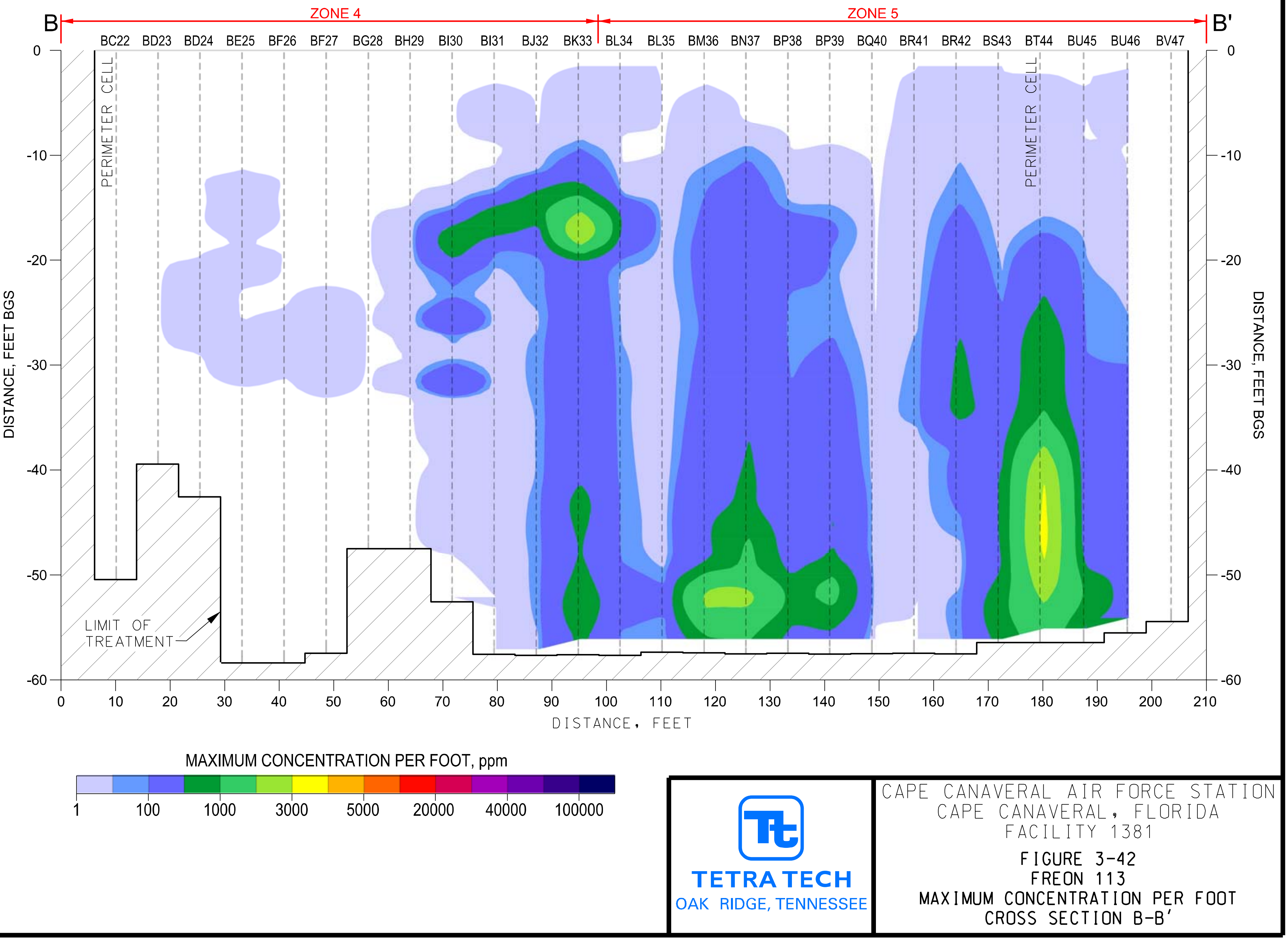

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FIGURE 3-42
FREON 113
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION B-B'

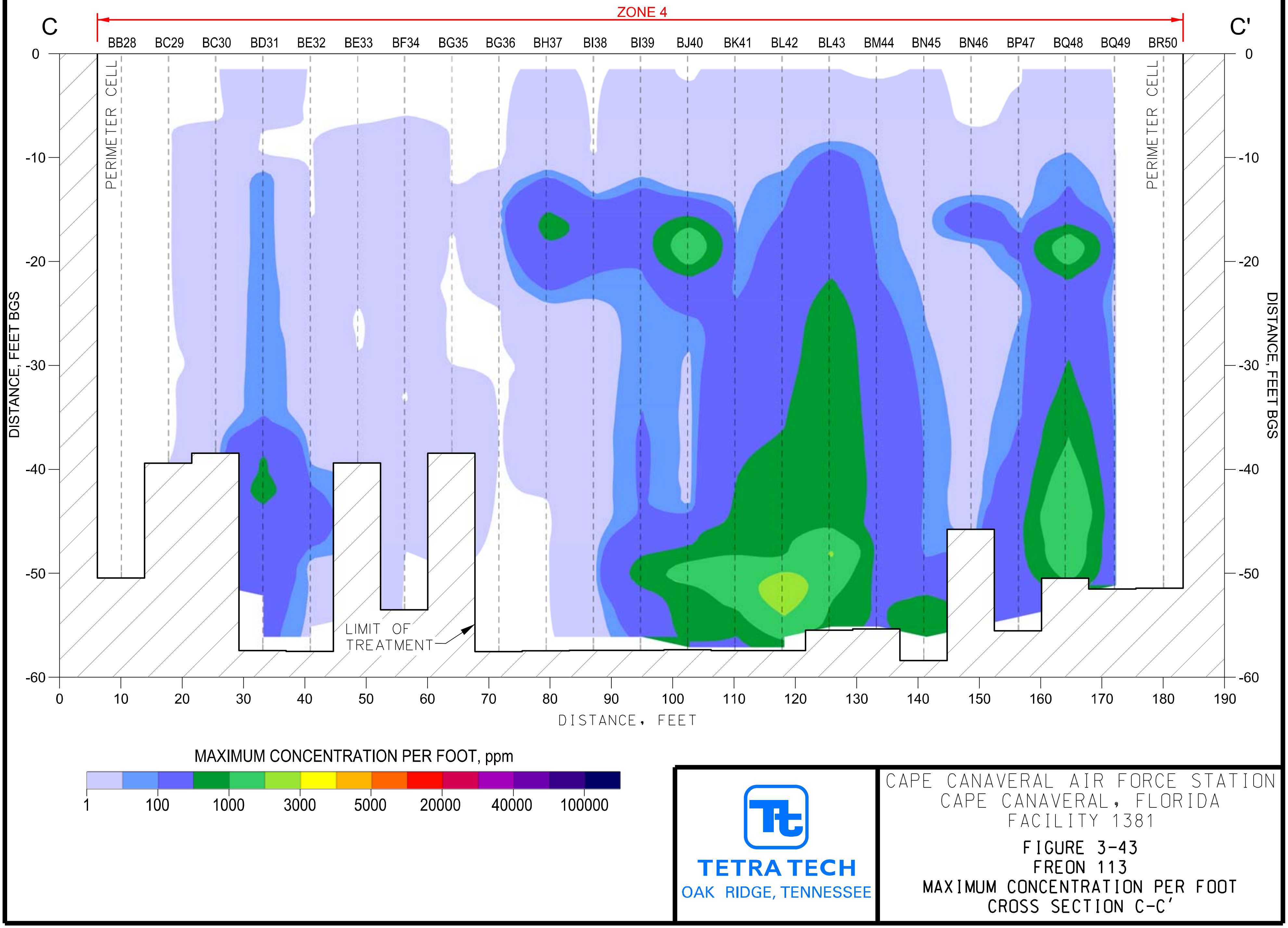

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FIGURE 3-43
FREON 113
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION C-C′

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-100.dgn 10-2-07 CMI Report

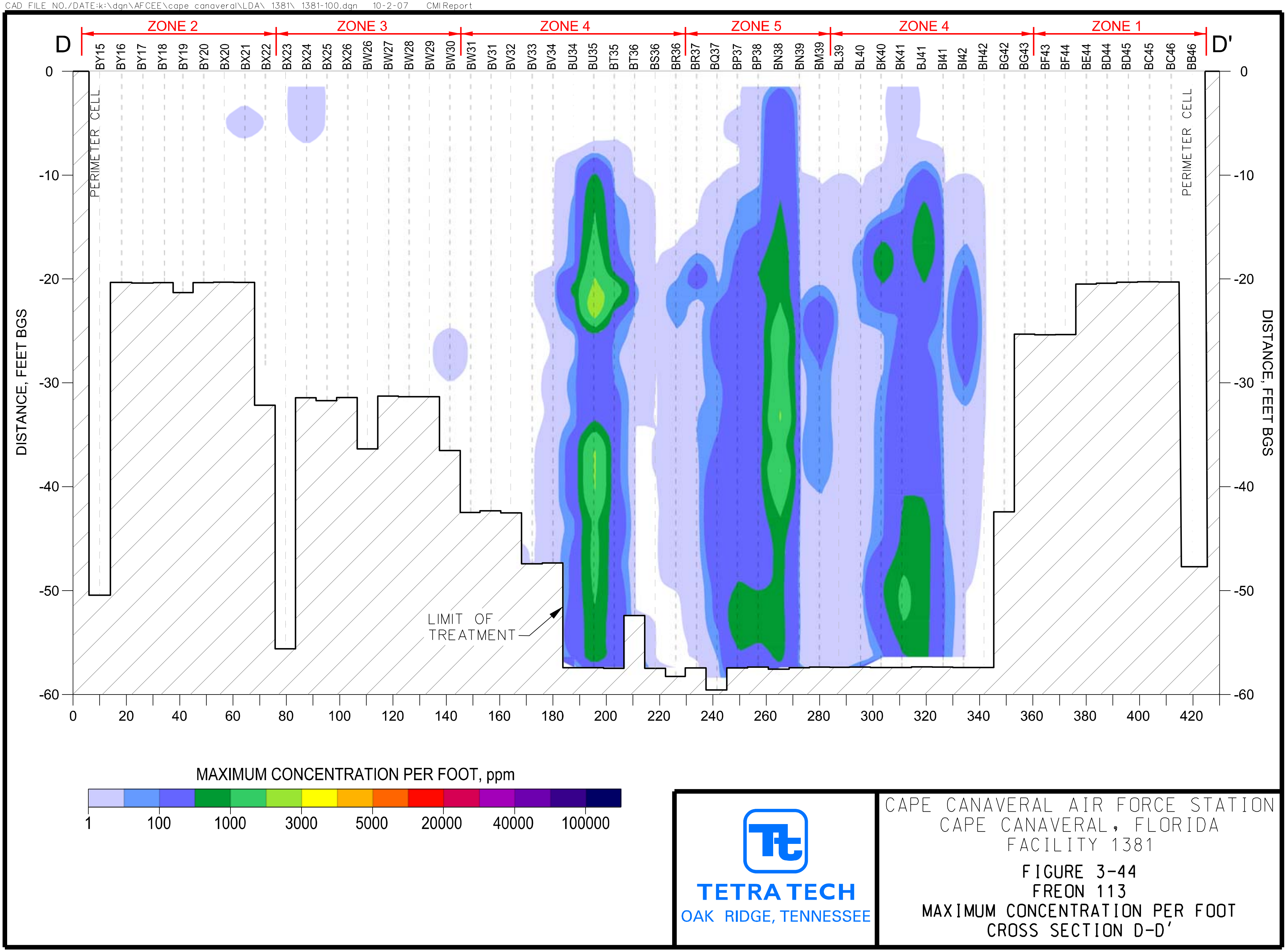

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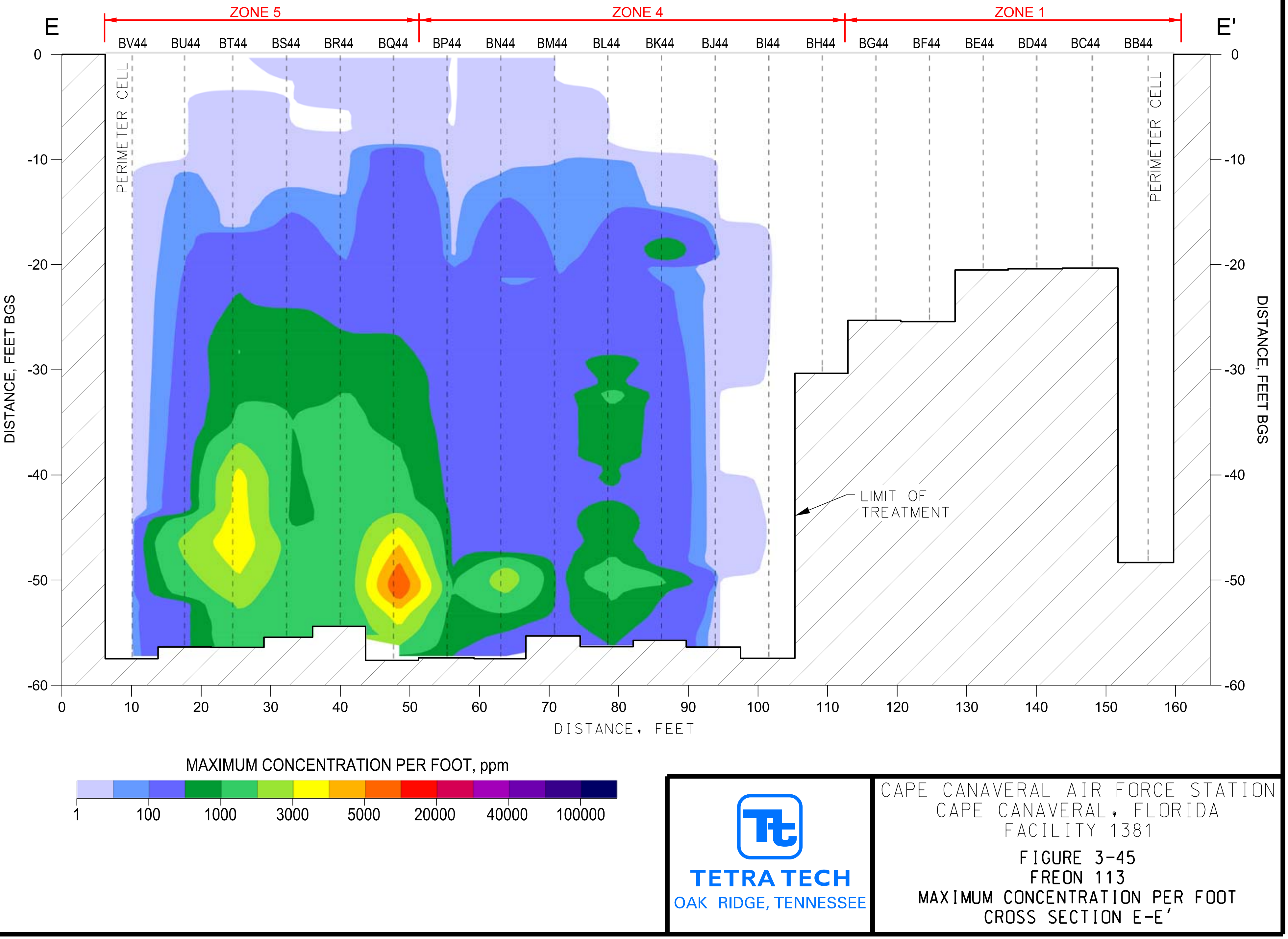
FIGURE 3-44
FREON 113
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-102.dgn 10-4-07 CMI Report



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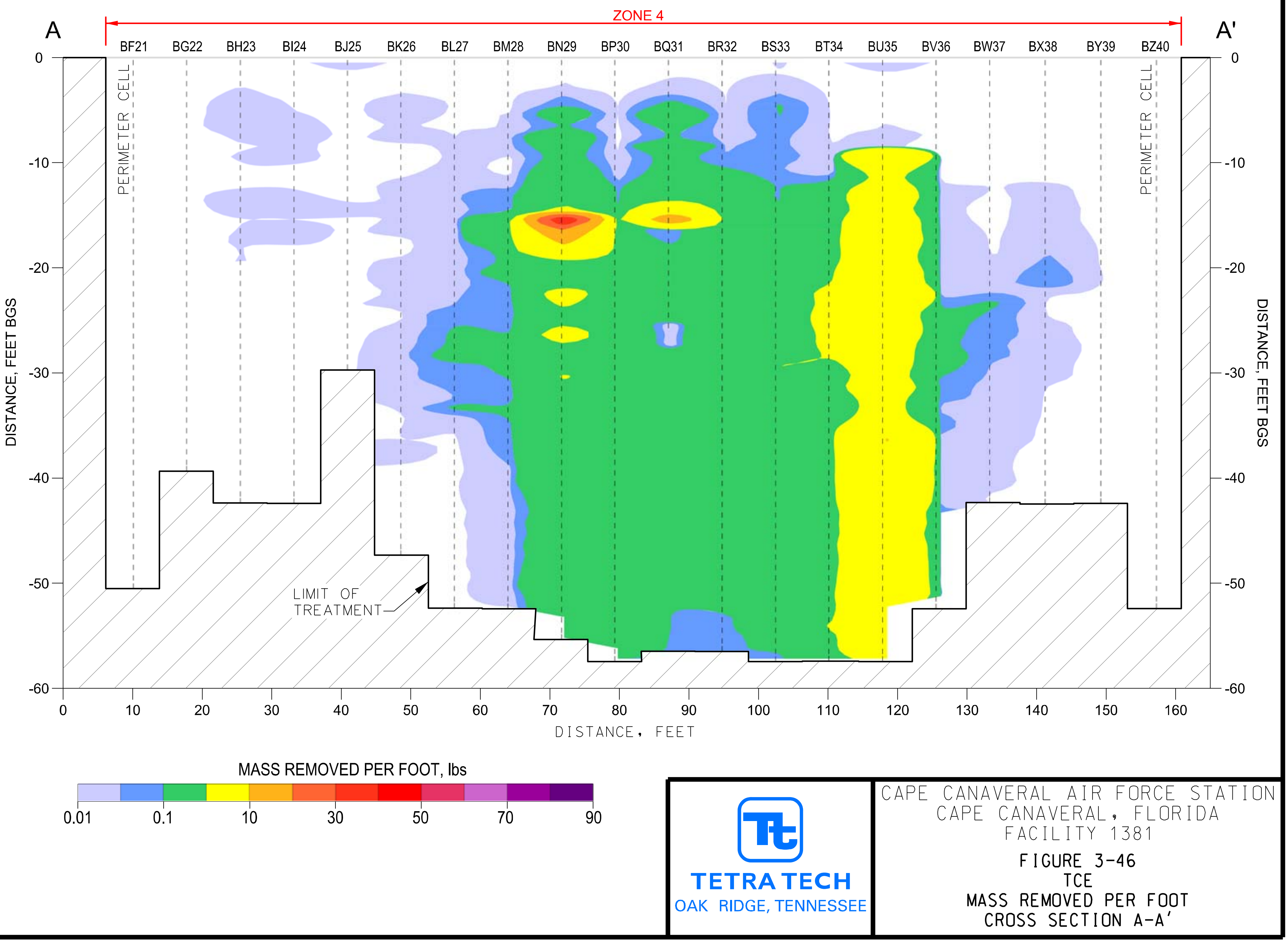
FACILITY 1381

FIGURE 3-45
FREON 113
MAXIMUM CONCENTRATION PER FOOT
CROSS SECTION E-E'



TETRA TECH
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CAPE CANAVERAL AIR FORCE STATION
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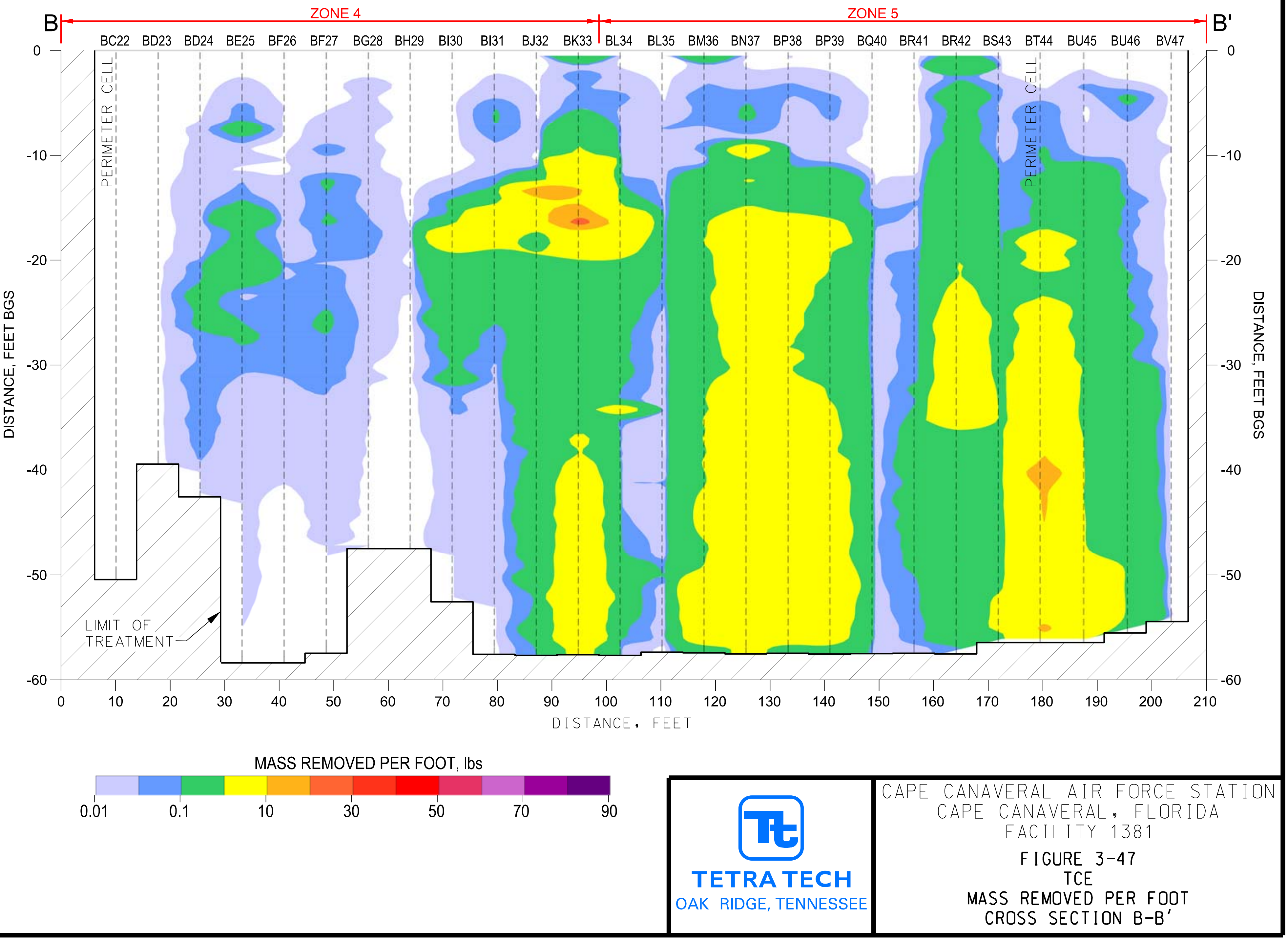
FACILITY 1381

FIGURE 3-46
TCE
MASS REMOVED PER FOOT
CROSS SECTION A-A'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-076.dgn 10-2-07 CMI Report



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CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 3-47
TCE
MASS REMOVED PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-082.dgn 10-2-07 CMI Report

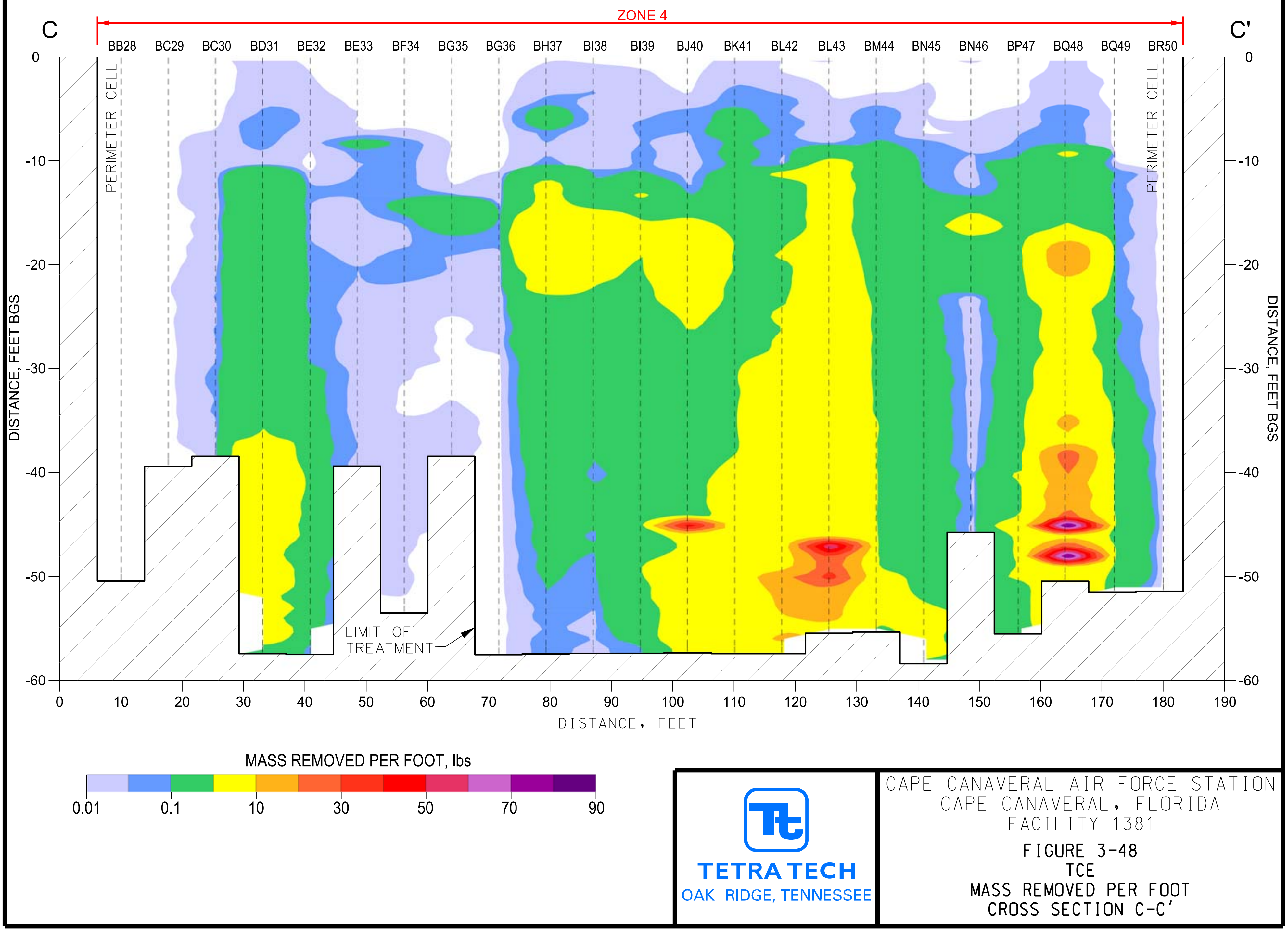

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FIGURE 3-48
TCE
MASS REMOVED PER FOOT
CROSS SECTION C-C'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-087.dgn 10-2-07 CMI Report

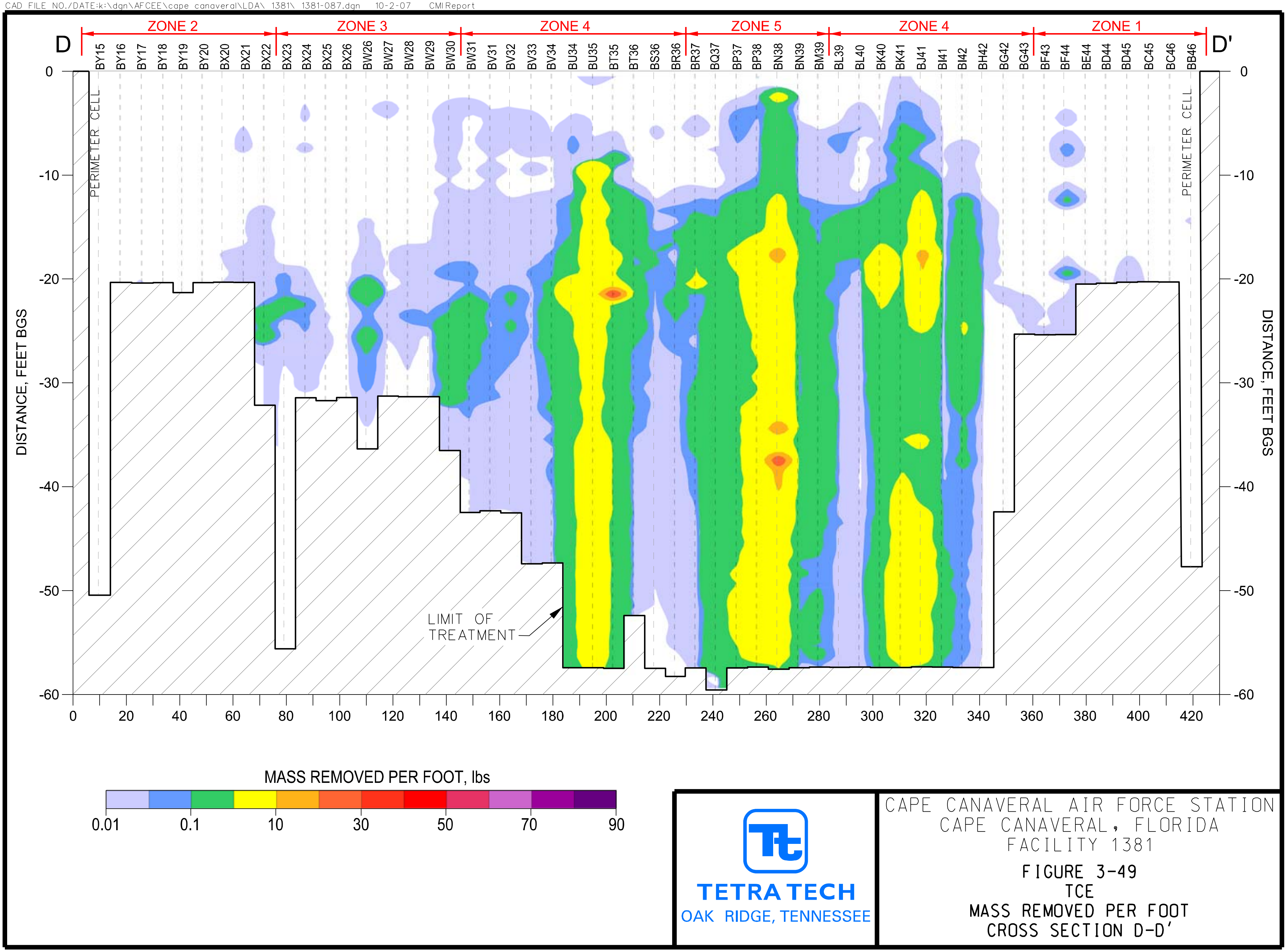

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FIGURE 3-49
TCE
MASS REMOVED PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-092.dgn 10-2-07 CMI Report

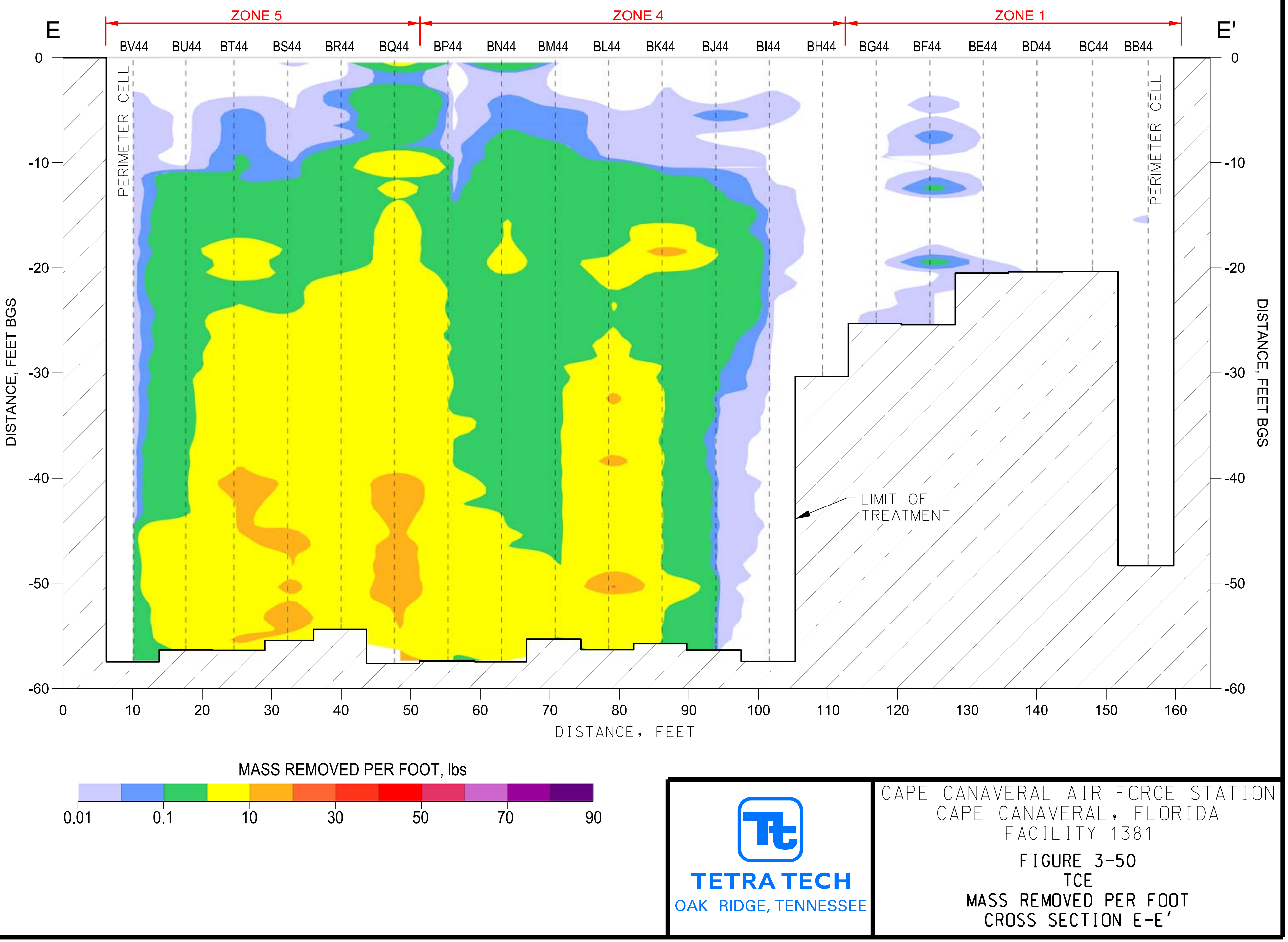

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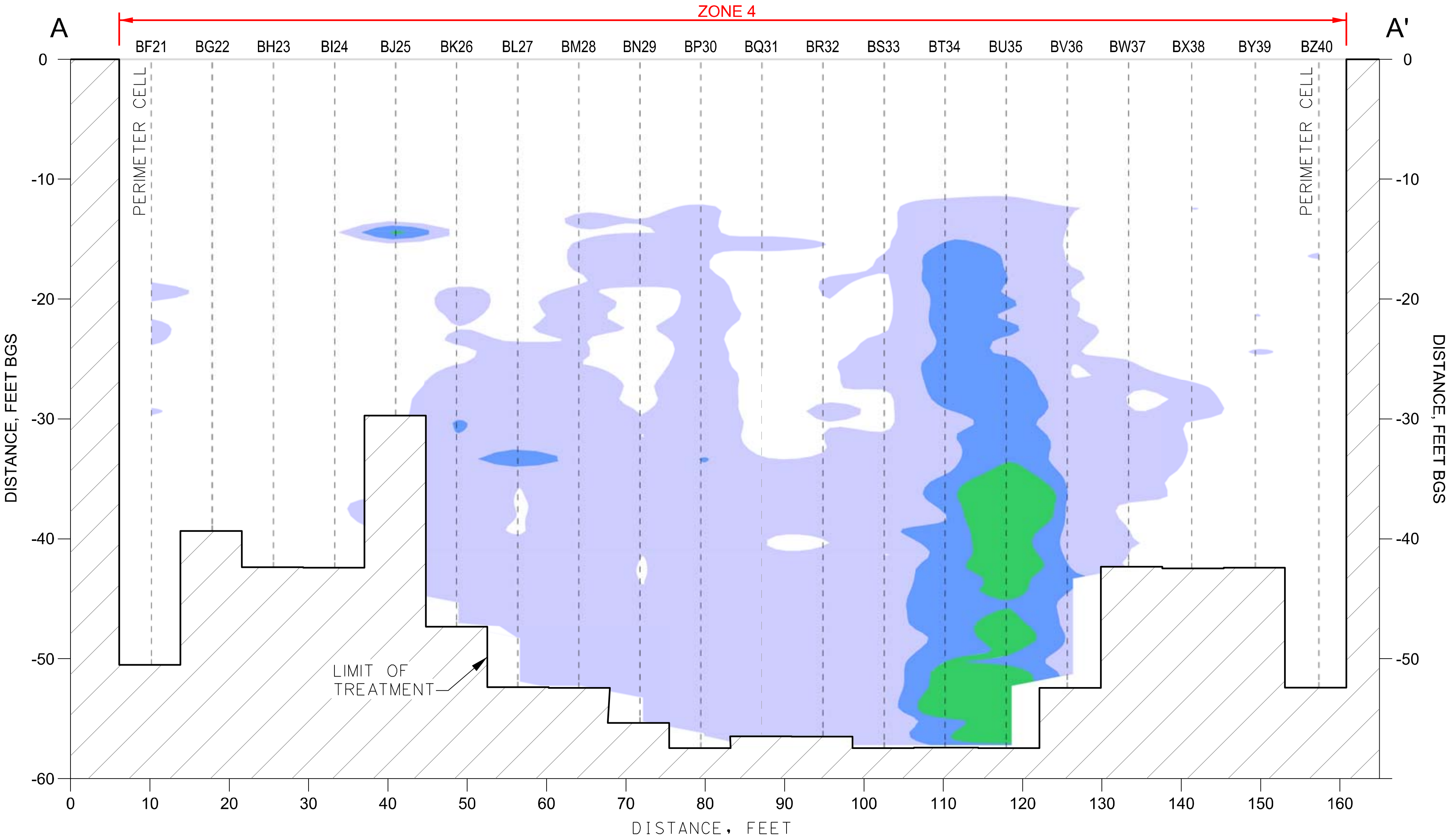
FIGURE 3-50
TCE
MASS REMOVED PER FOOT
CROSS SECTION E-E'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-079.dgn 10-15-07 CMI Report



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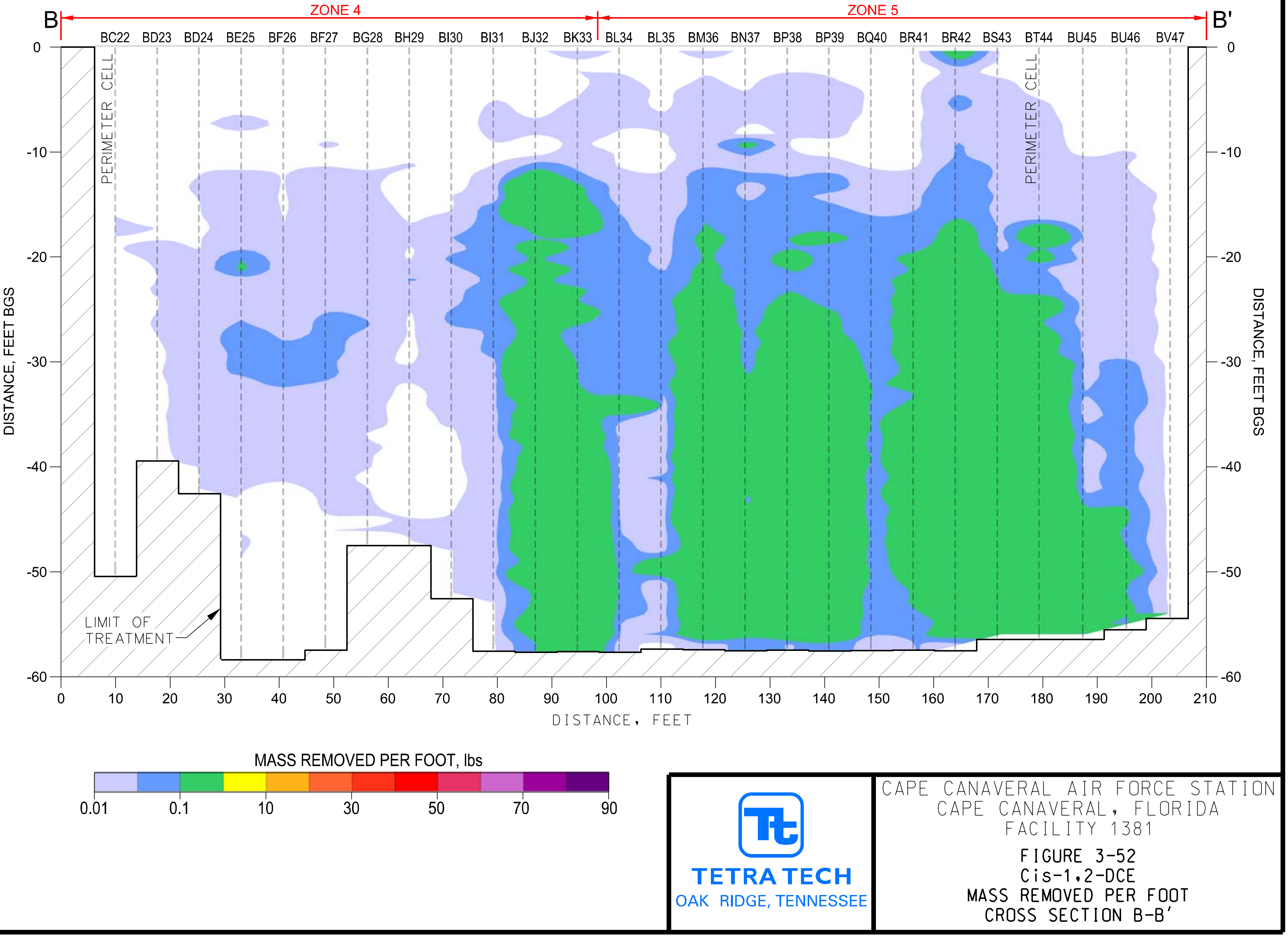
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 3-51
Cis-1,2-DCE
MASS REMOVED PER FOOT
CROSS SECTION A-A'



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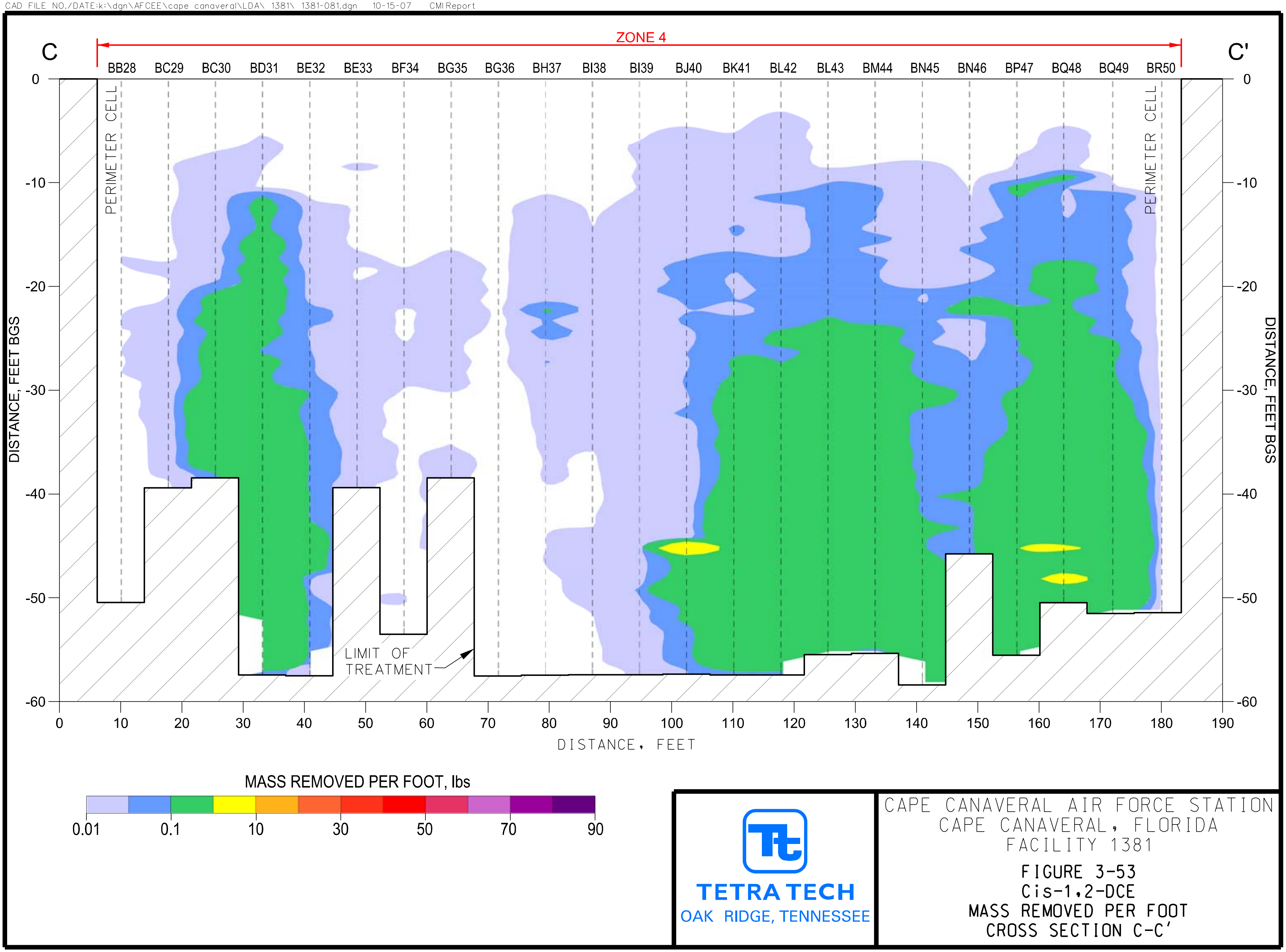
FACILITY 1381

FIGURE 3-52
Cis-1,2-DCE
MASS REMOVED PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-081.dgn 10-15-07 CMI Report



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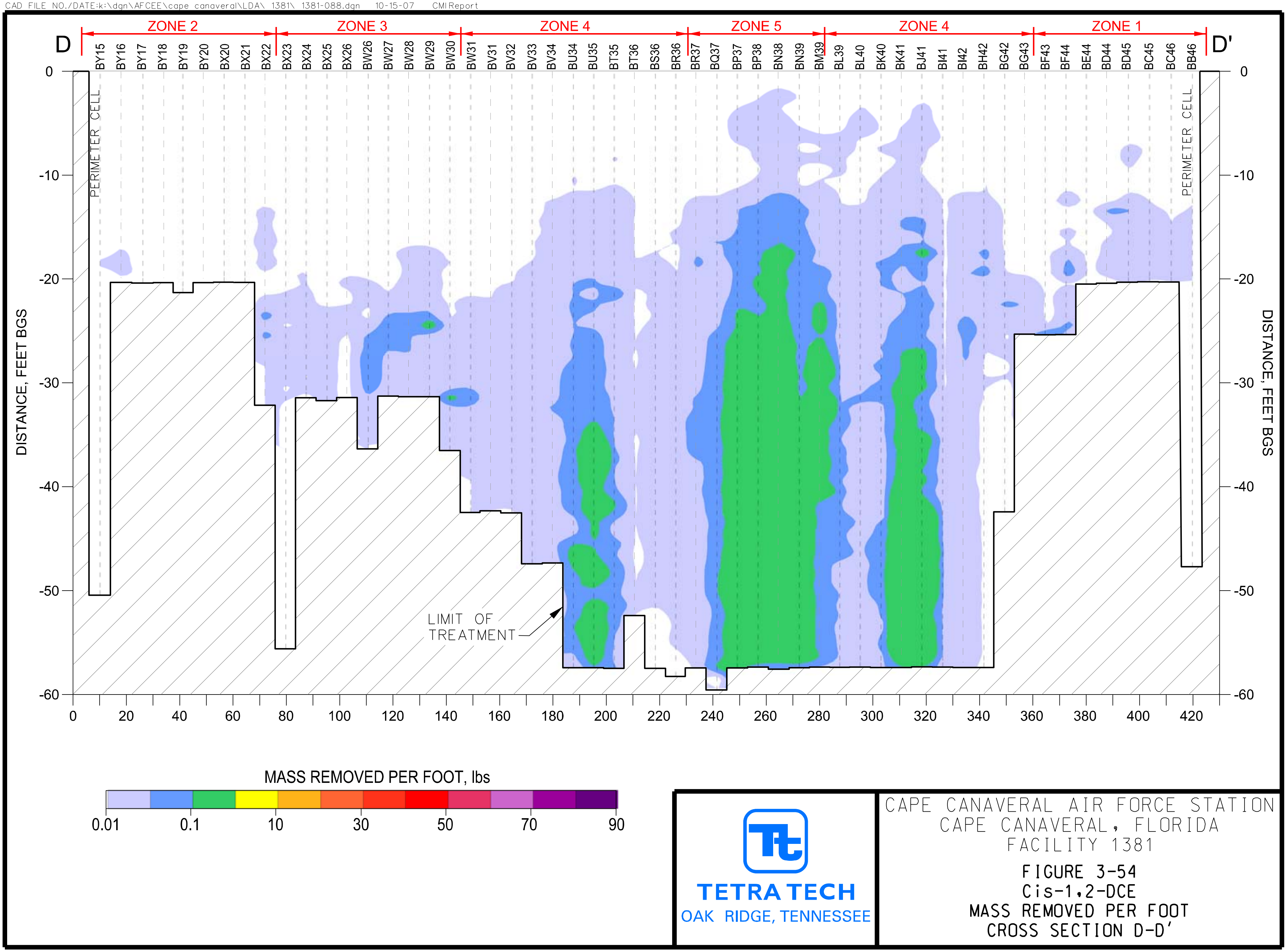
FACILITY 1381

FIGURE 3-53
Cis-1,2-DCE
MASS REMOVED PER FOOT
CROSS SECTION C-C'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-088.dgn 10-15-07 CMI Report



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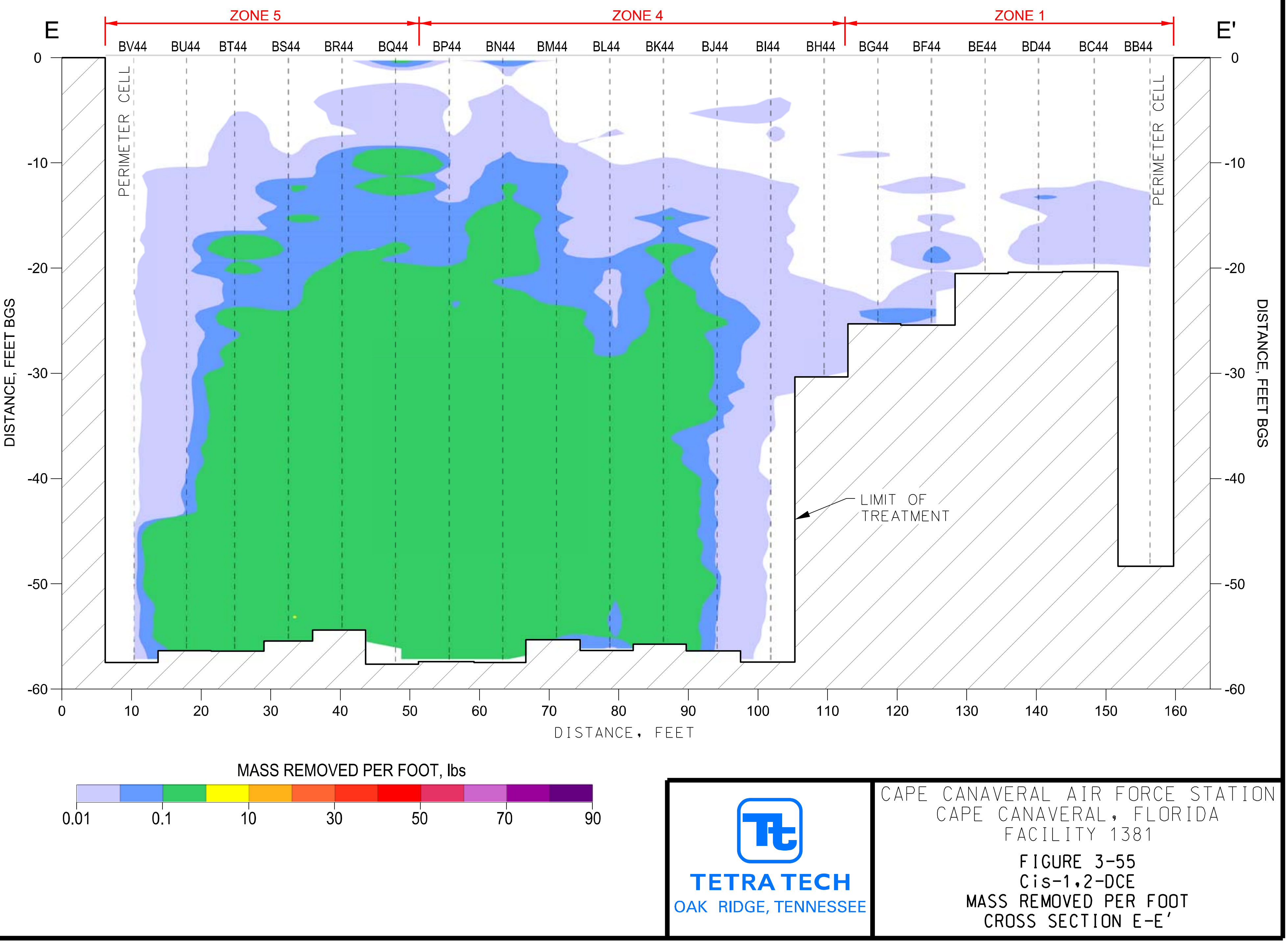
FACILITY 1381

FIGURE 3-54
Cis-1,2-DCE
MASS REMOVED PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-091.dgn 10-15-07 CMI Report



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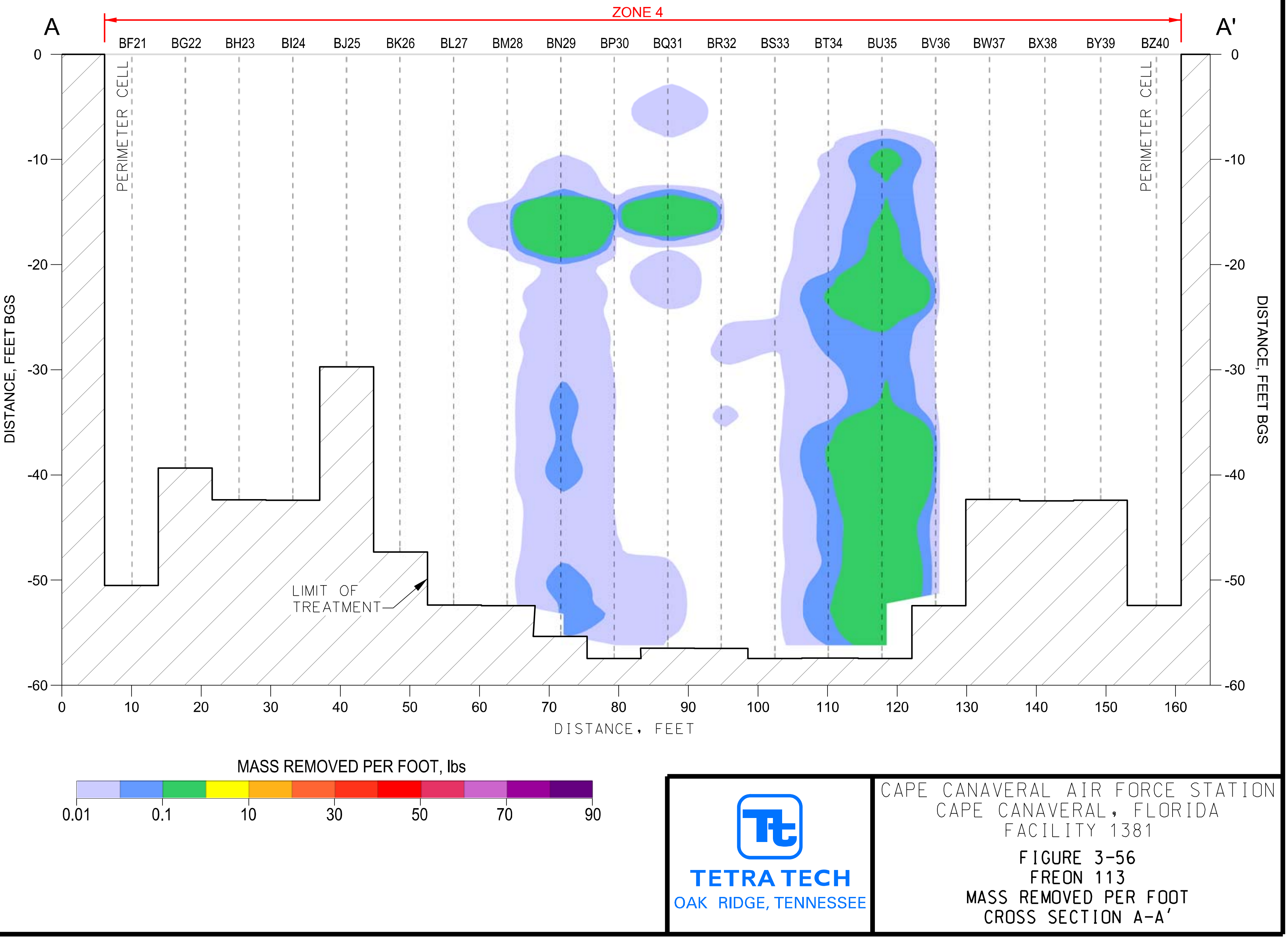
CAPE CANAVERAL AIR FORCE STATION
CAPE CANAVERAL, FLORIDA
FACILITY 1381

FIGURE 3-55
Cis-1,2-DCE
MASS REMOVED PER FOOT
CROSS SECTION E-E'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-095.dgn 10-2-07 CMI Report



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FACILITY 1381

FIGURE 3-56
FREON 113
MASS REMOVED PER FOOT
CROSS SECTION A-A'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-097.dgn 10-2-07 CMI Report

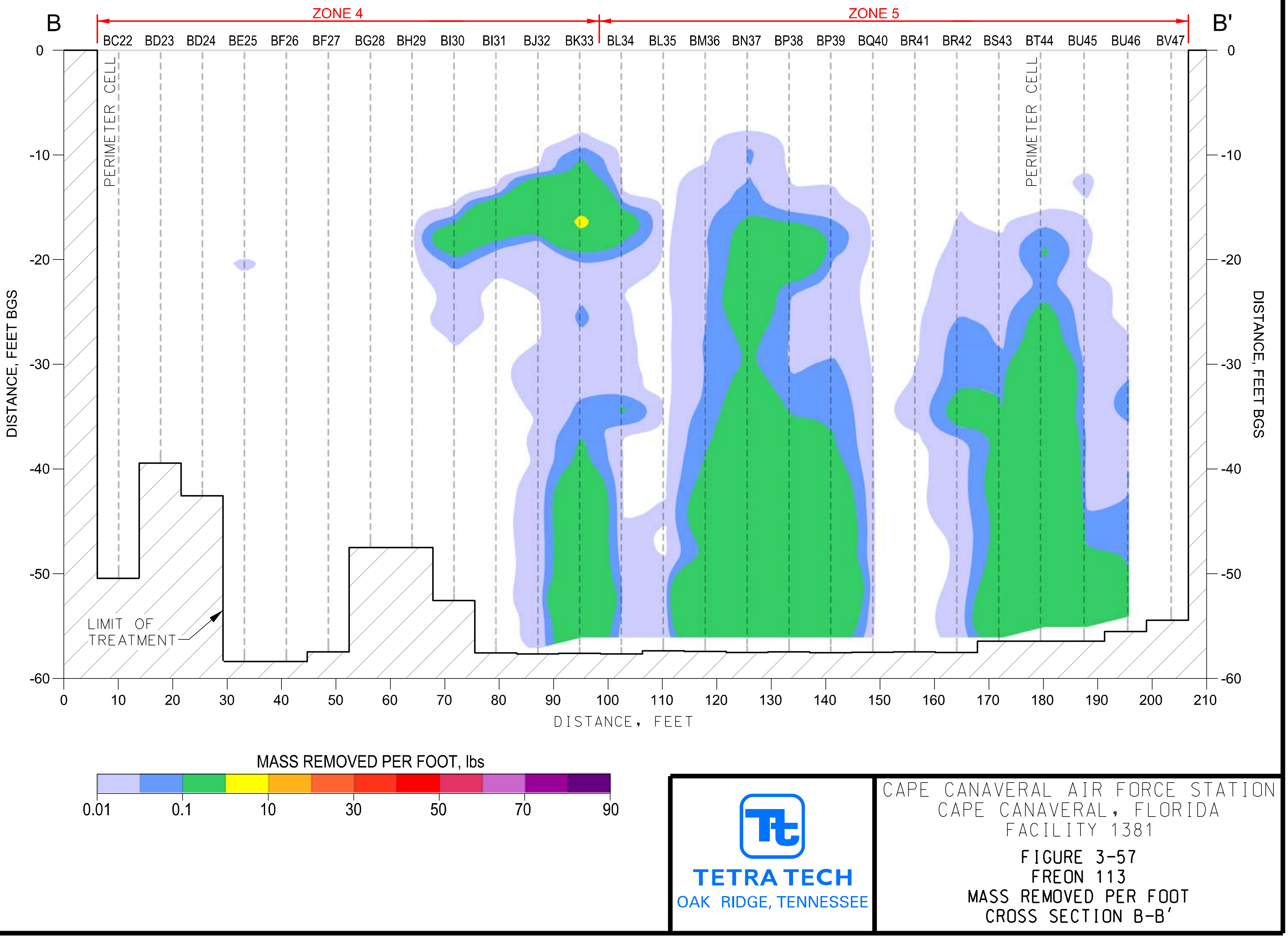

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FIGURE 3-57
FREON 113
MASS REMOVED PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-099.dgn 10-2-07 CMI Report

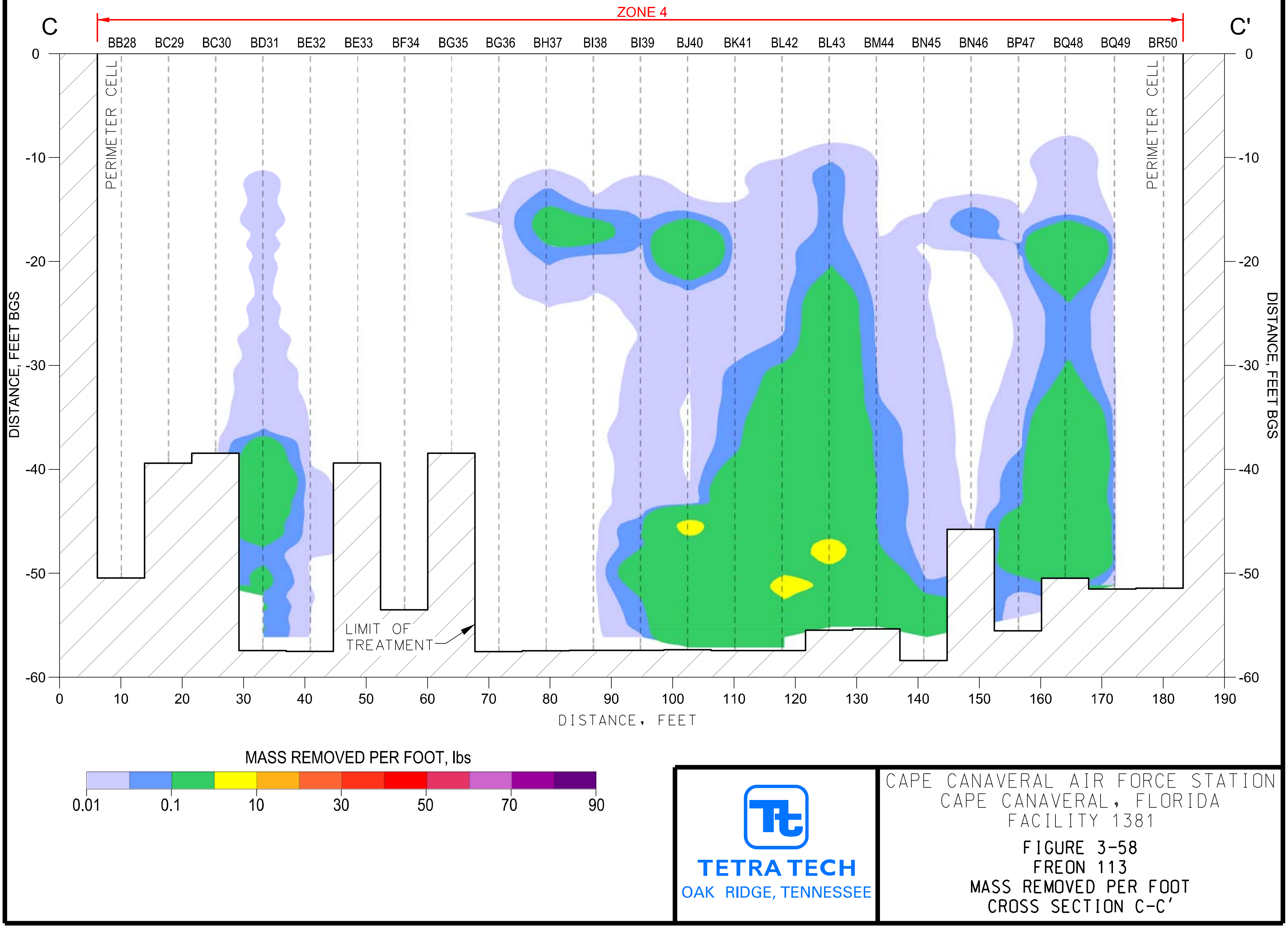

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FIGURE 3-58
FREON 113
MASS REMOVED PER FOOT
CROSS SECTION C-C'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-101.dgn 10-2-07 CMI Report

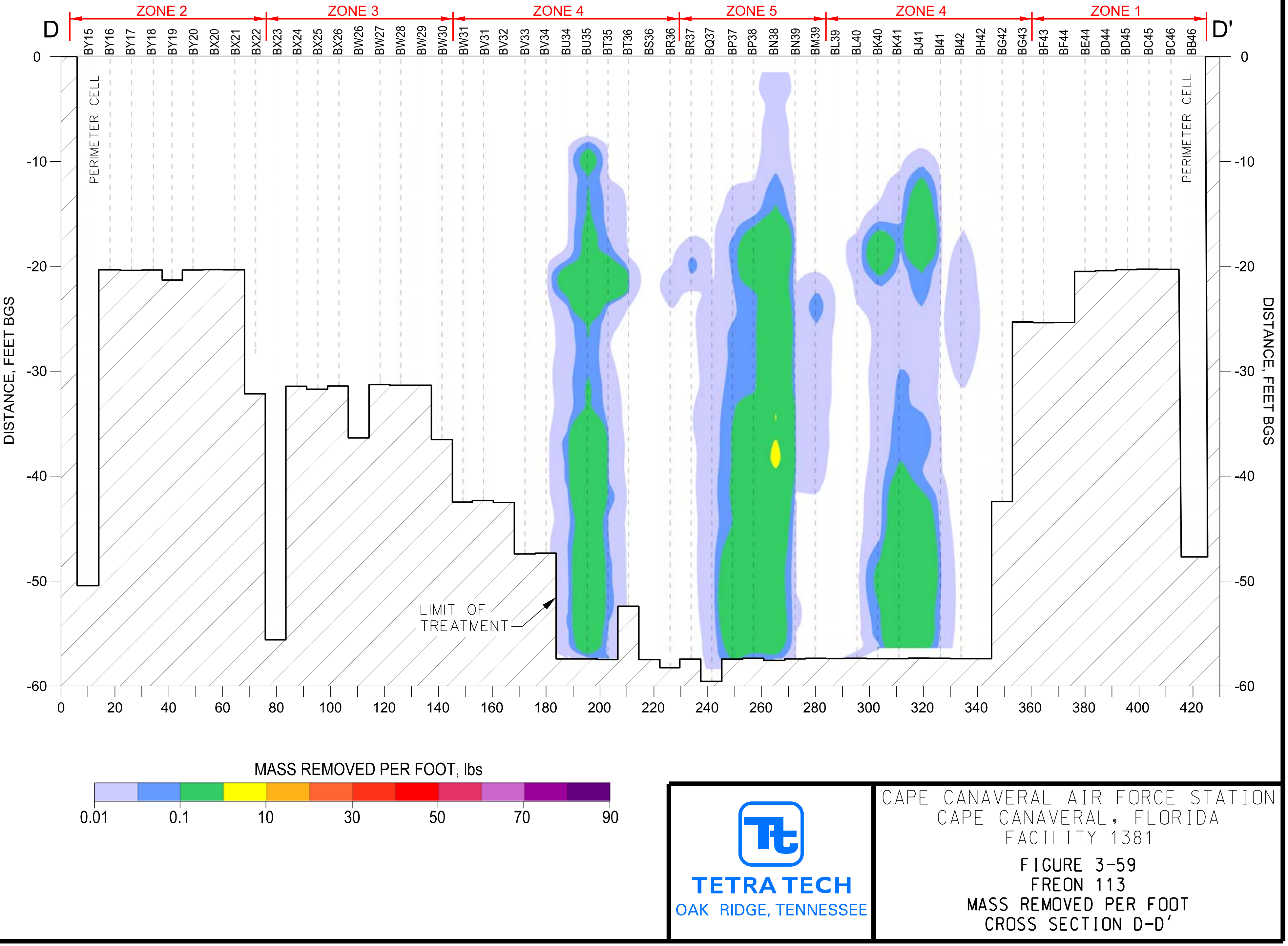

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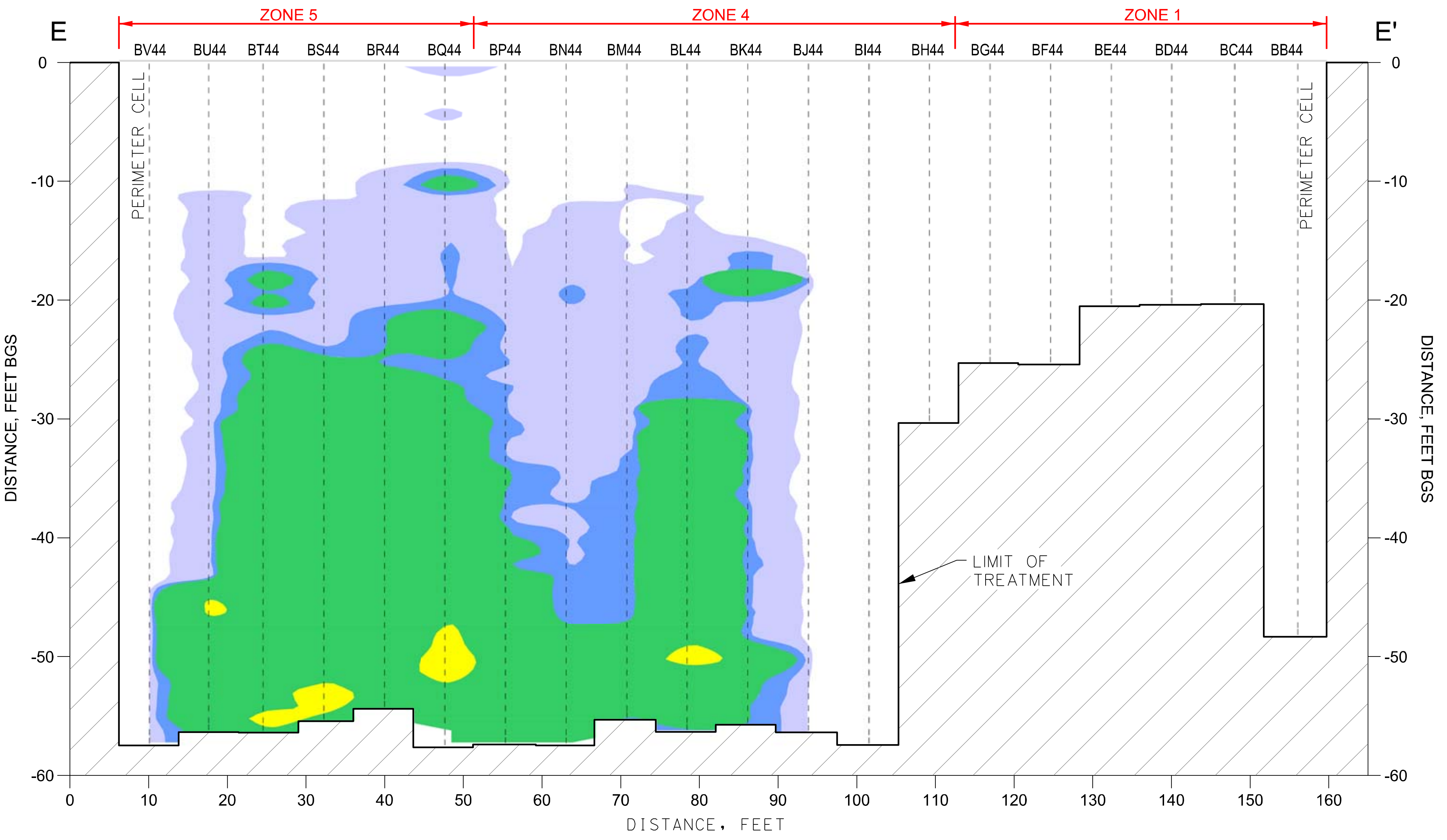
FIGURE 3-59
FREON 113
MASS REMOVED PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-103.dgn 10-4-07 CMI Report



MASS REMOVED PER FOOT, lbs

0.01	0.1	10	30	50	70	90

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FIGURE 3-60
FREON 113
MASS REMOVED PER FOOT
CROSS SECTION E-E'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-106.dgn   5-29-08

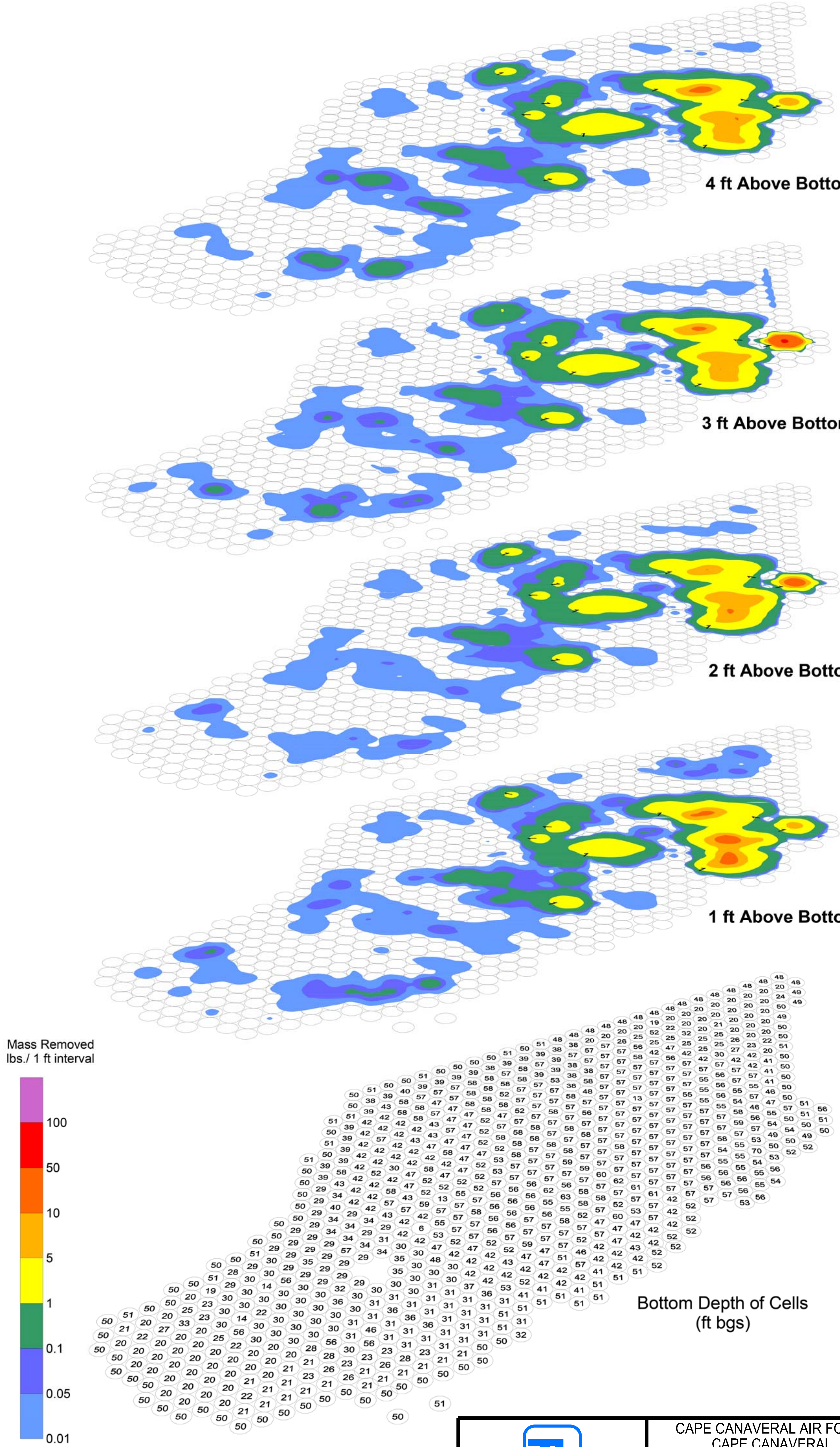

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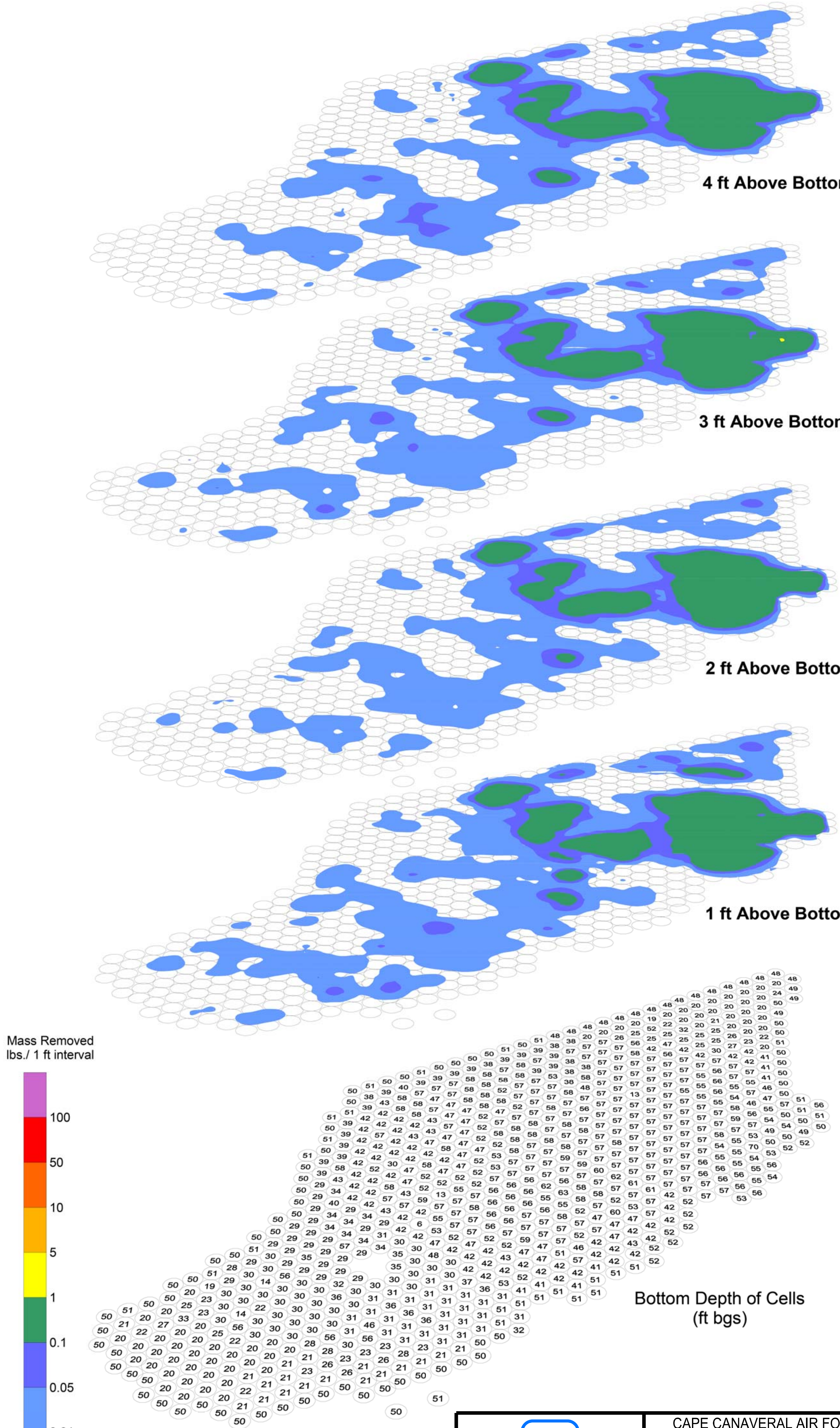
FIGURE 3-61
TCE
MASS REMOVED
IN BOTTOM 4 FEET OF EACH CELL

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-104.dgn 10-15-07 CMI Report



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FACILITY 1381
FIGURE 3-62
Cis-1,2-DCE
MASS REMOVED
IN BOTTOM 4 FEET OF EACH CELL

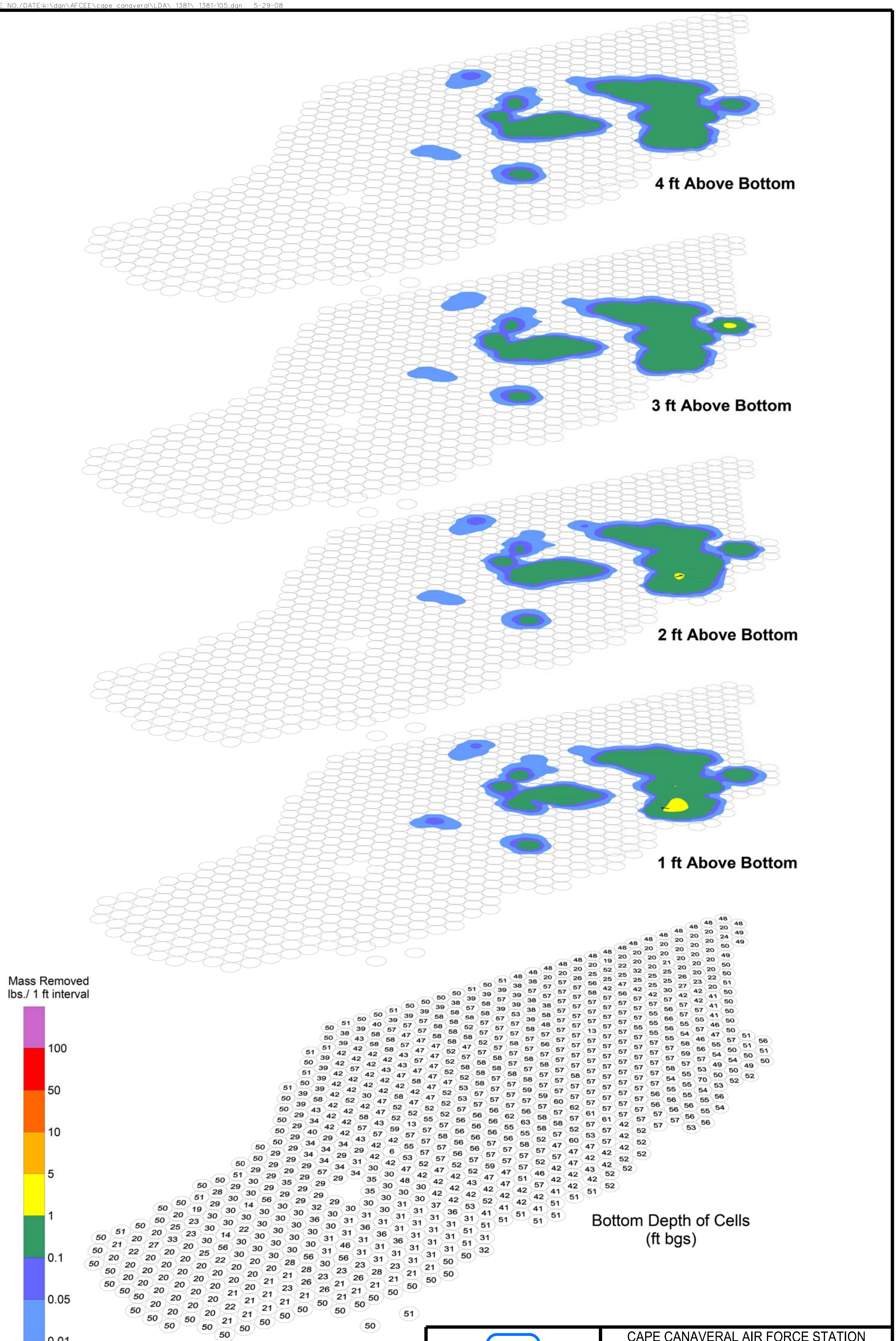

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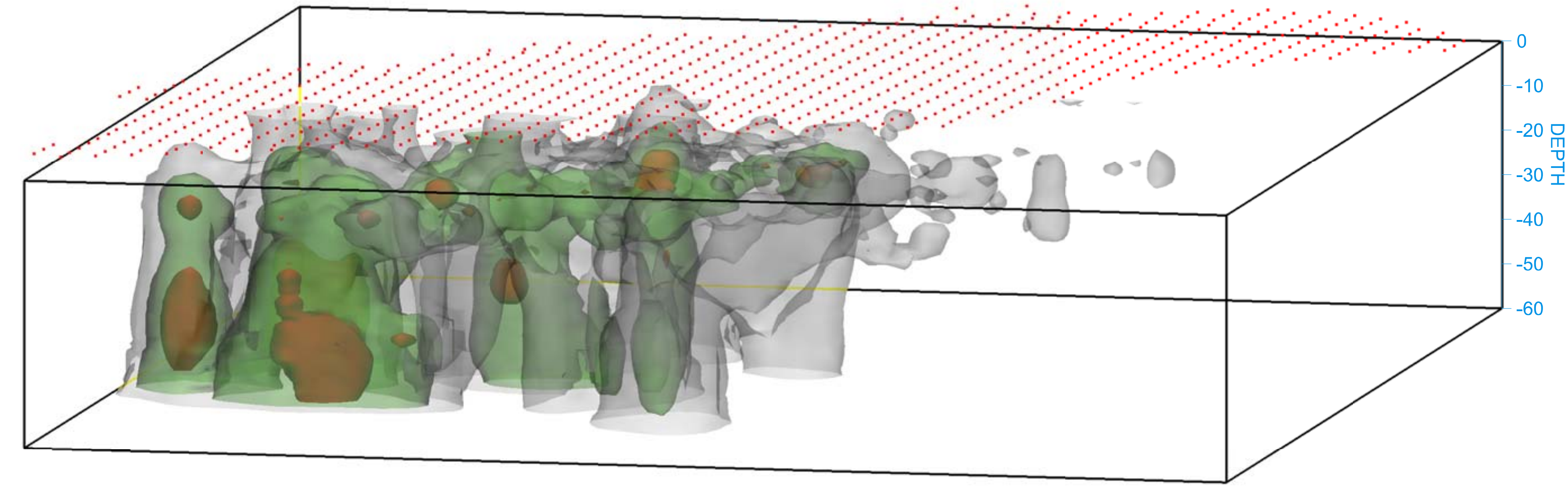
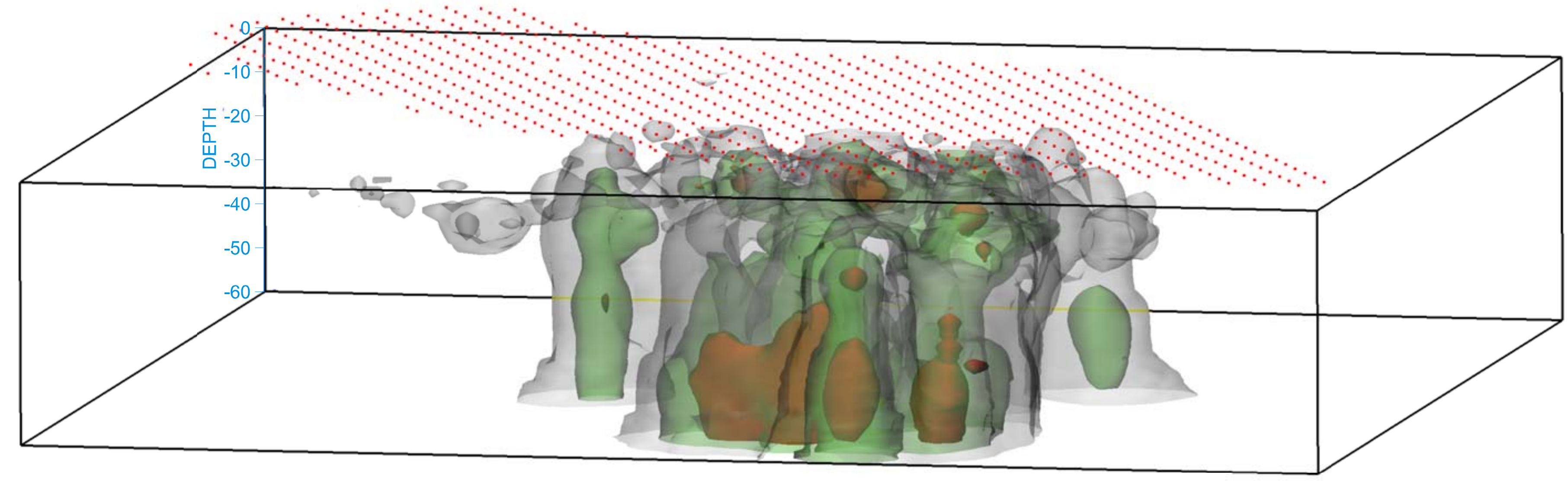
FIGURE 3-63
FREON 113
MASS REMOVED
IN BOTTOM 4 FEET OF EACH CELL

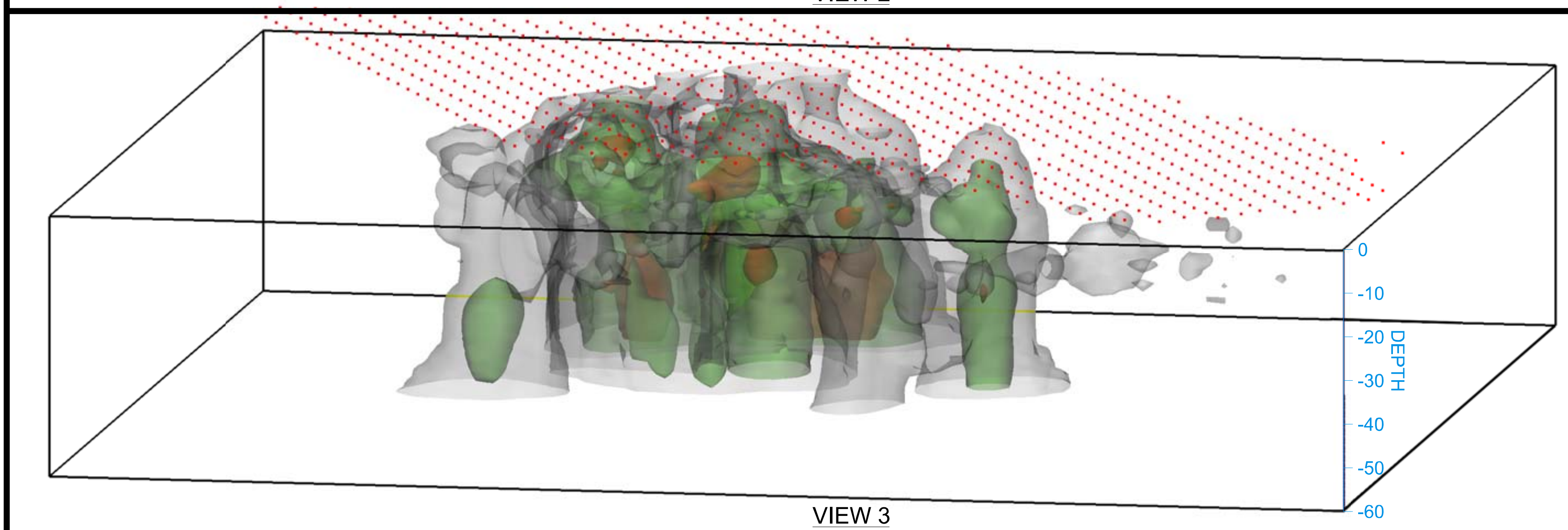
CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-135.dgn 5-29-08



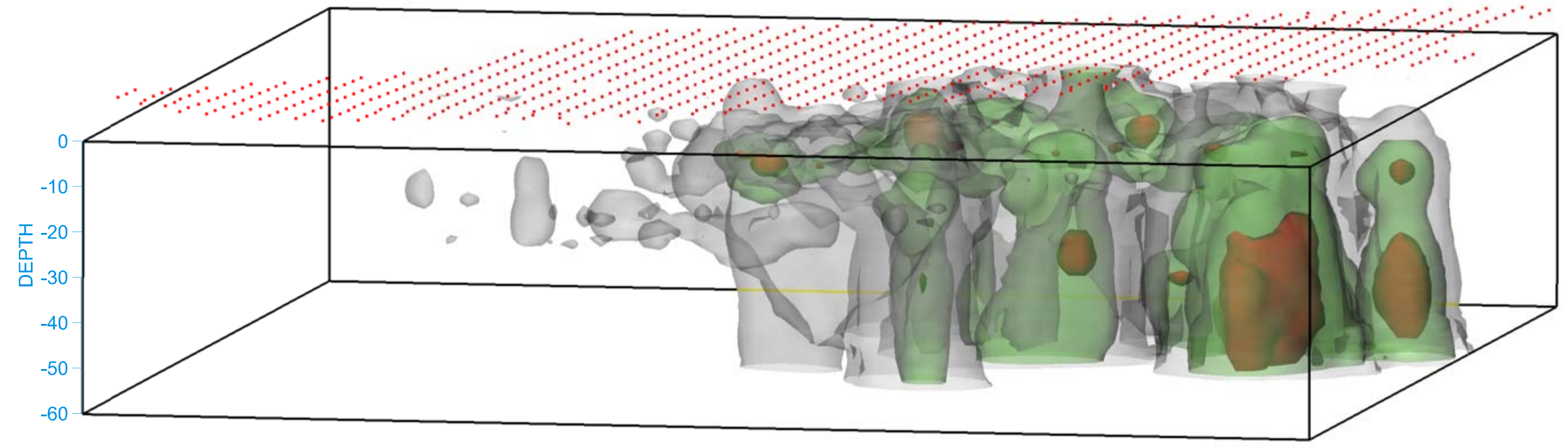
VIEW 1



VIEW 2



VIEW 3



VIEW 4

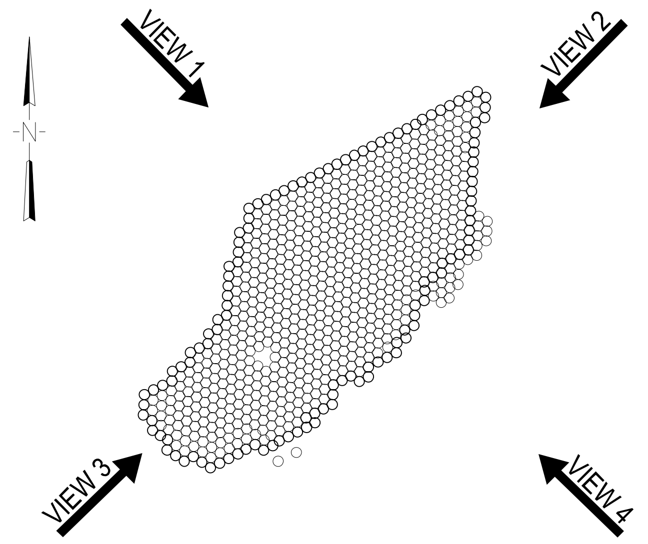


IMAGE KEY PLAN

NOT TO SCALE

LEGEND

TCE REMOVED 0.1 lbs/ft	⬜
TCE REMOVED 1.0 lbs/ft	🟩
TCE REMOVED 5.0 lbs/ft	🟥

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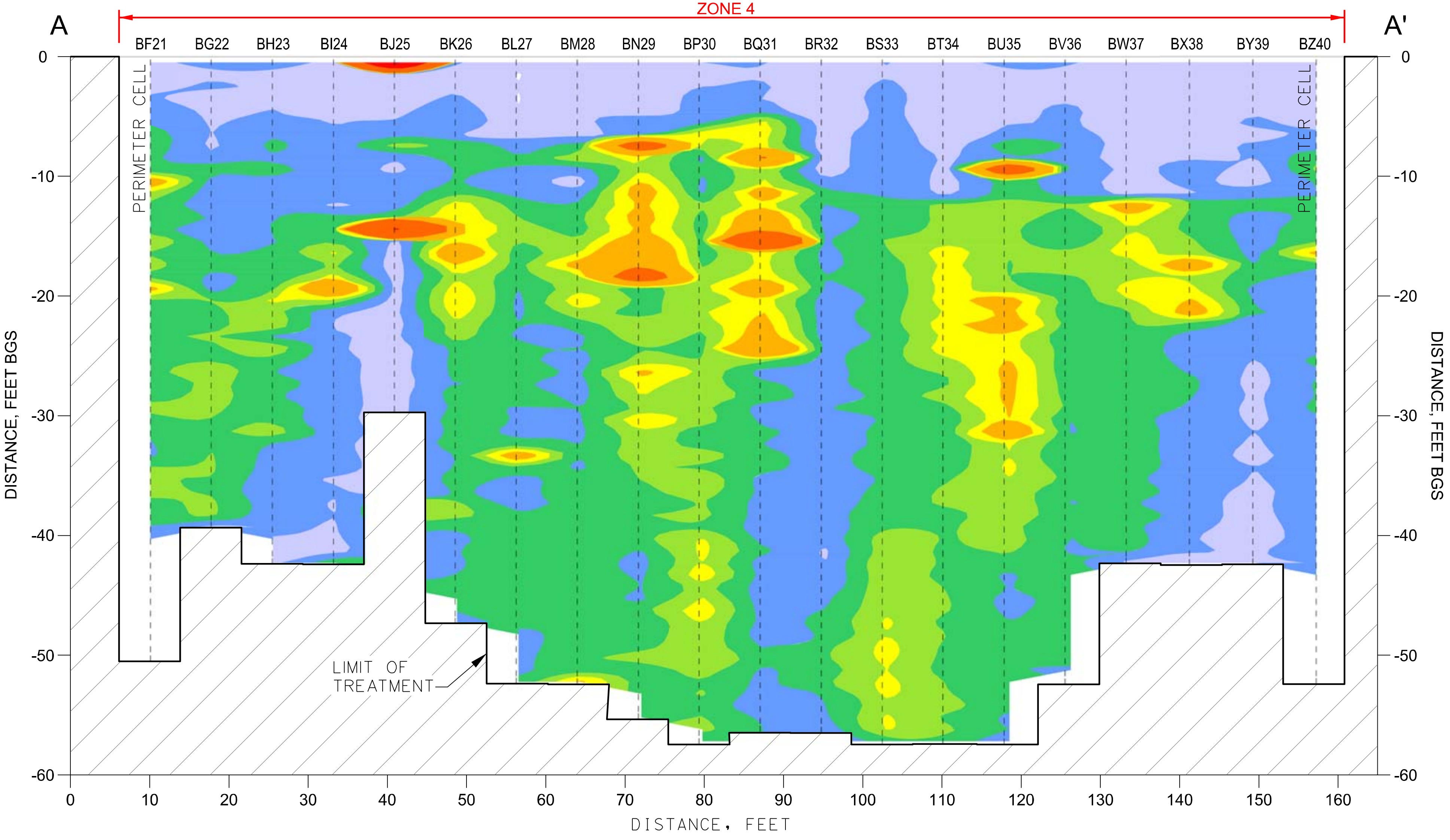
FIGURE 3-64
3-DIMENSIONAL VIEWS
OF TCE MASS REMOVED

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-125.dgn 10-15-07 CMI Report



STEAM INJECTION, MINUTES PER FOOT

0.1	1	2	3	4	5	10	50	100

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FIGURE 3-65
STEAM INJECTION, MINUTES PER FOOT
CROSS SECTION A-A'

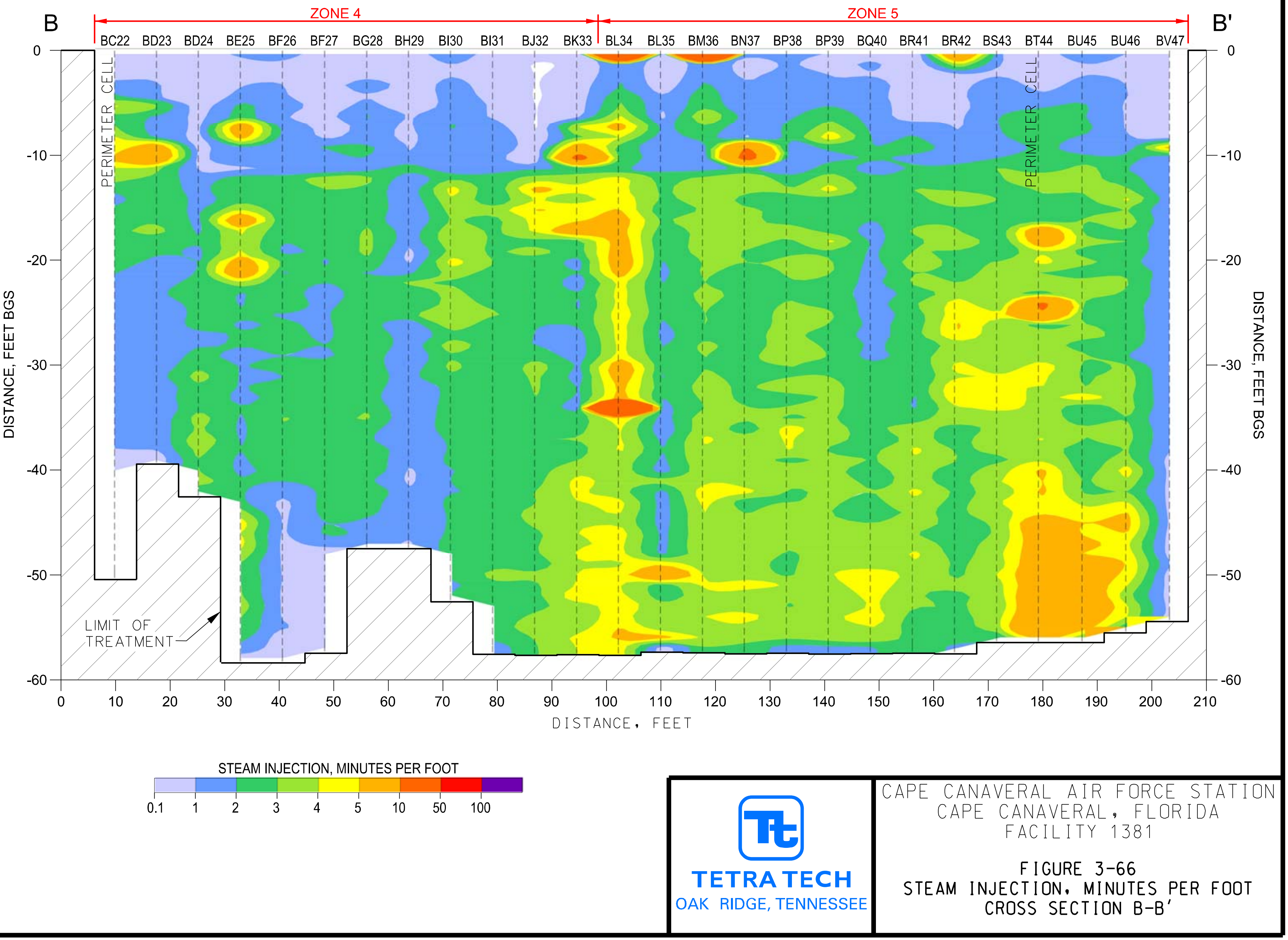

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FIGURE 3-66
STEAM INJECTION, MINUTES PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-129.dgn 10-3-07 CMI Report

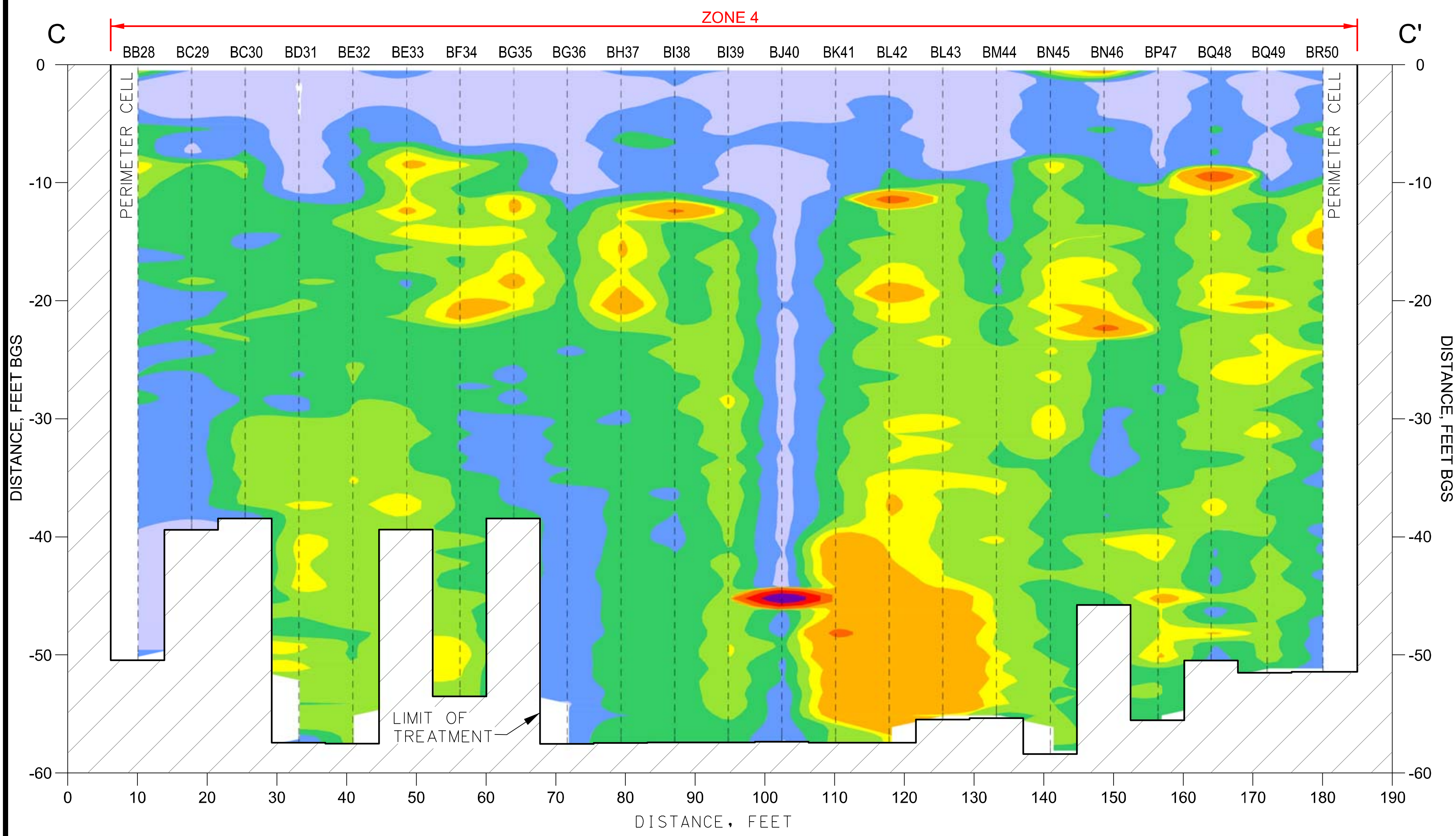

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FIGURE 3-67
STEAM INJECTION, MINUTES PER FOOT
CROSS SECTION C-C'

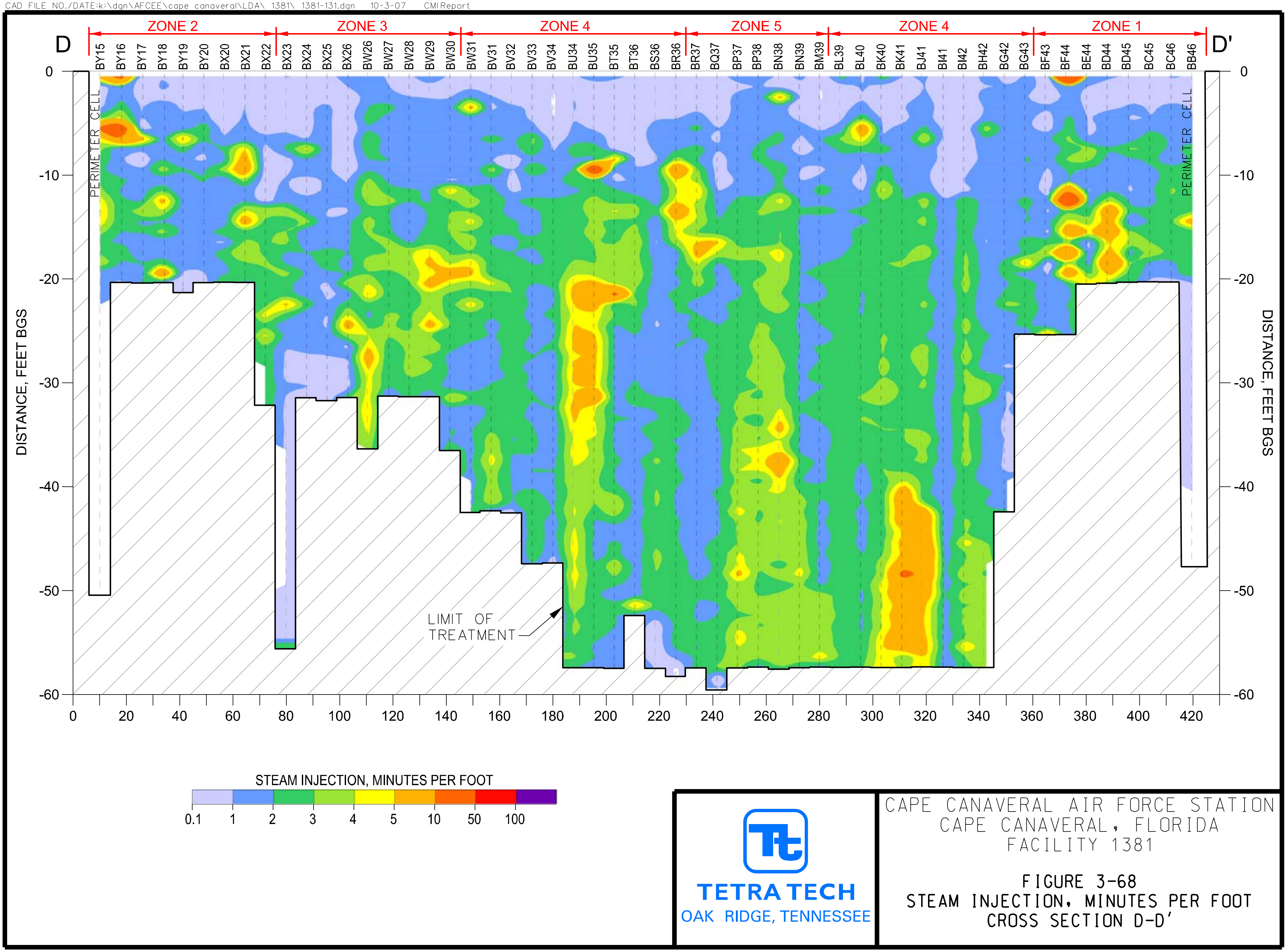

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FIGURE 3-68
STEAM INJECTION, MINUTES PER FOOT
CROSS SECTION D-D'

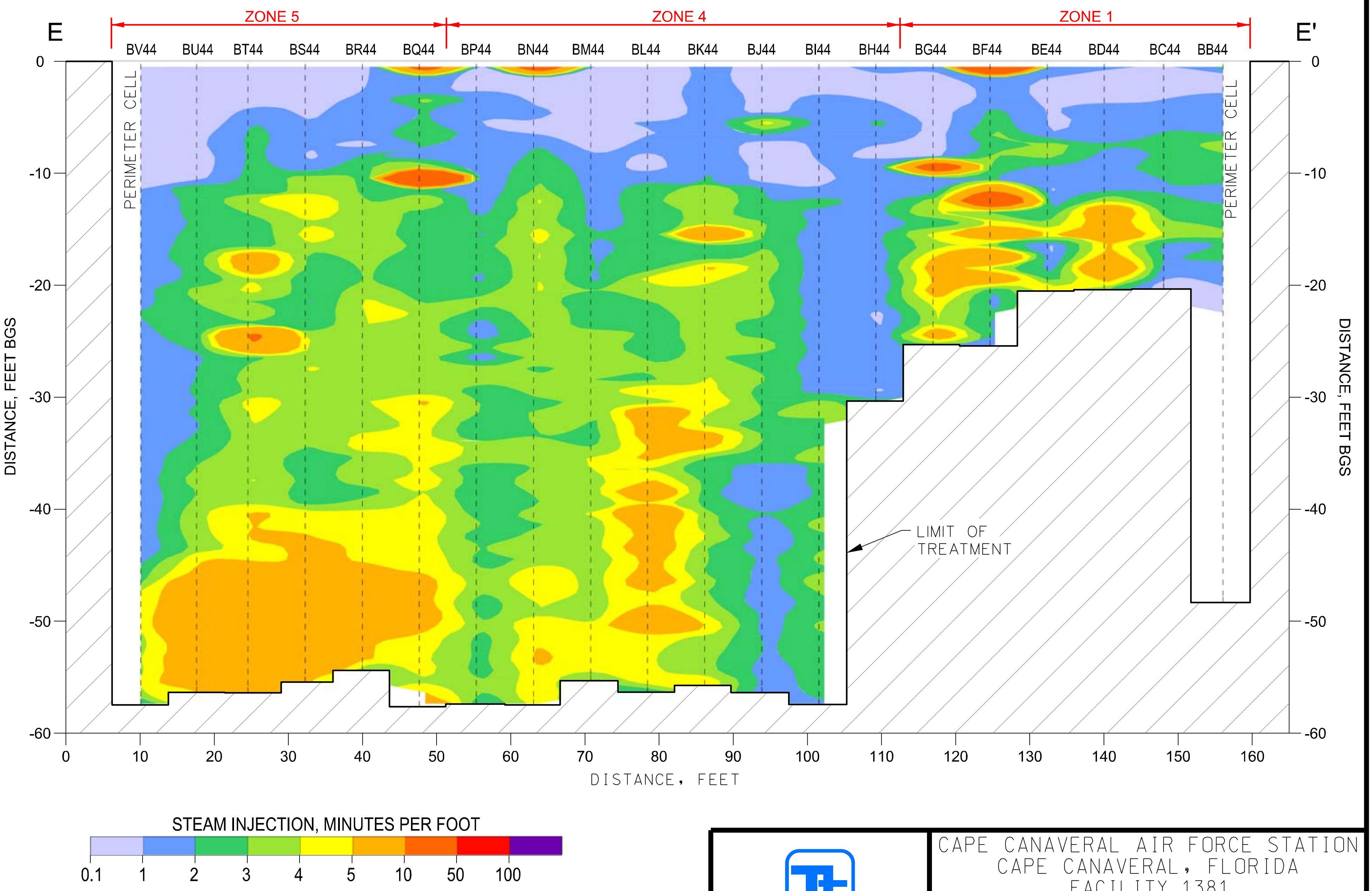

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FIGURE 3-69
STEAM INJECTION, MINUTES PER FOOT
CROSS SECTION E-E'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-126.dgn 10-15-07 CMI Report

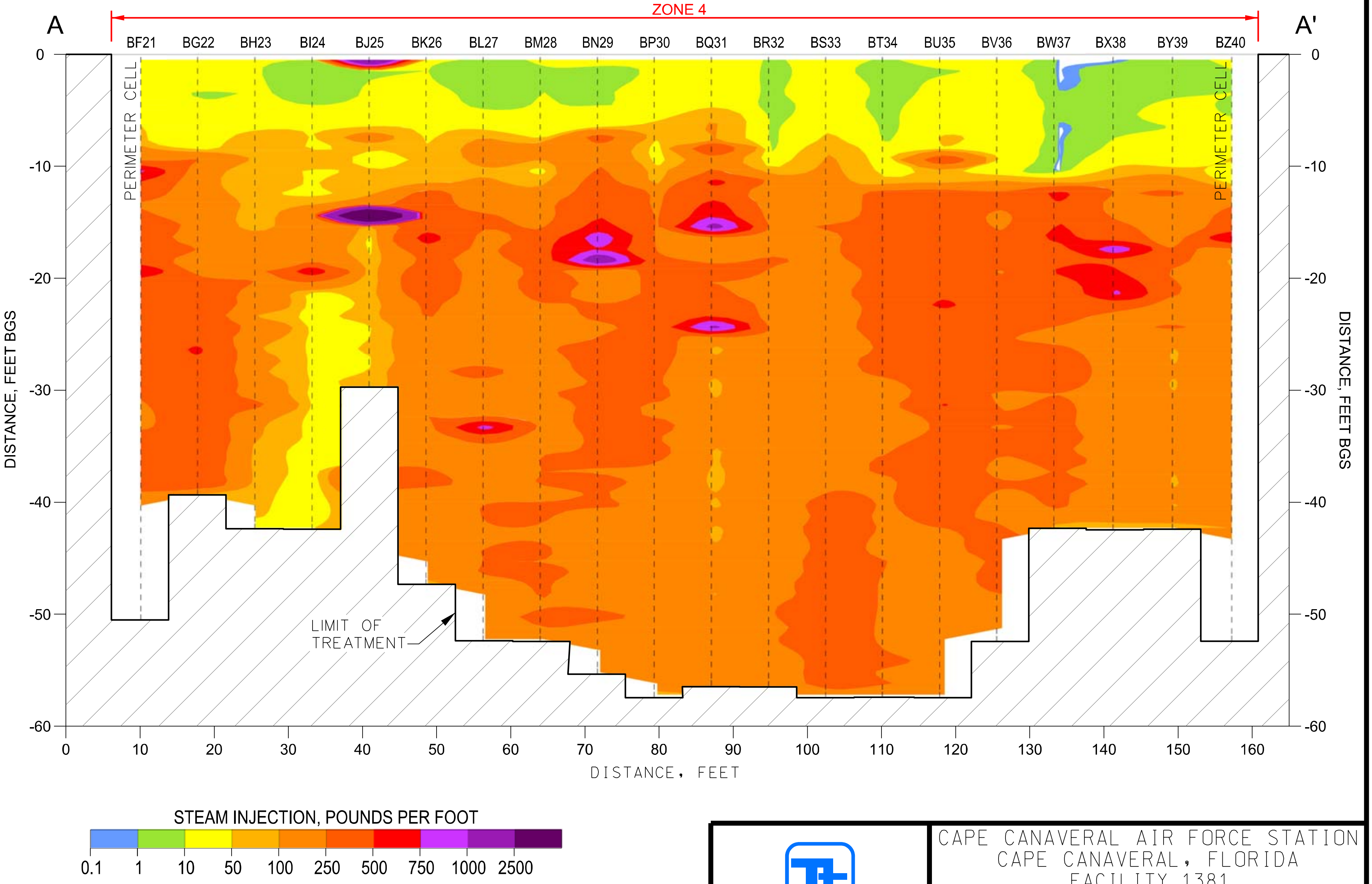

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FIGURE 3-70
STEAM INJECTION, POUNDS PER FOOT
CROSS SECTION A-A'

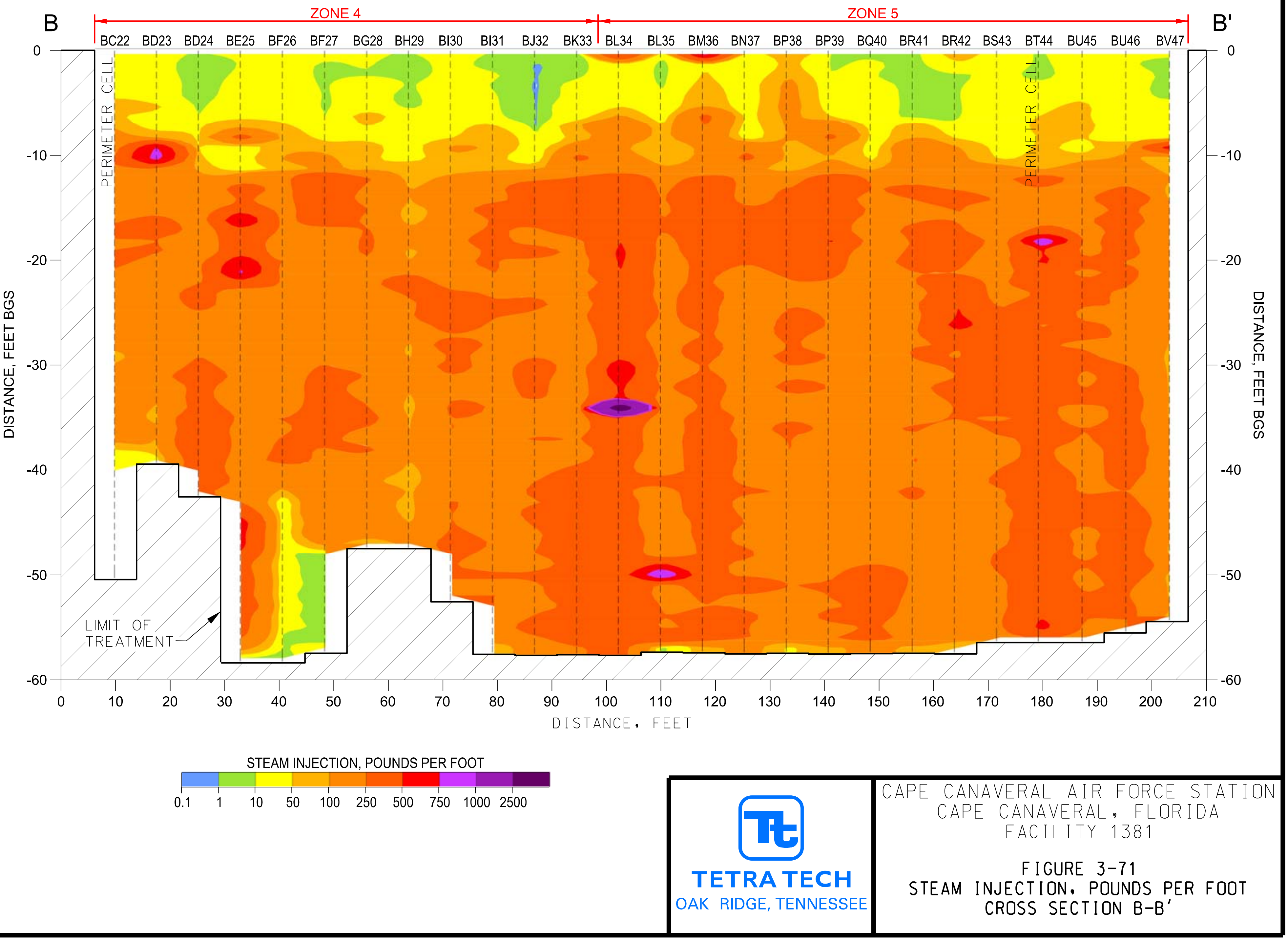

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FIGURE 3-71
STEAM INJECTION, POUNDS PER FOOT
CROSS SECTION B-B'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-130.dgn 10-3-07 CMI Report

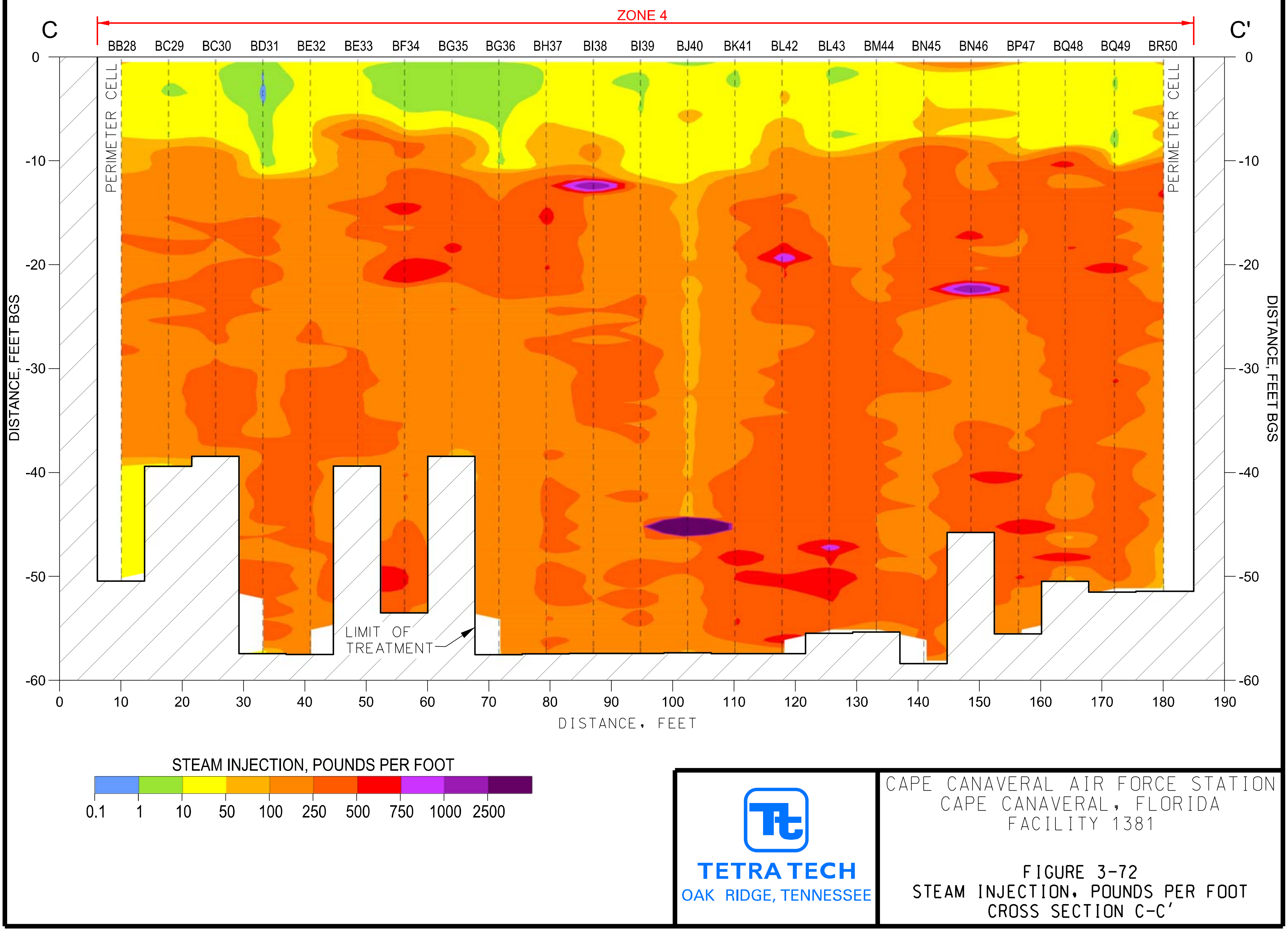

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FIGURE 3-72
STEAM INJECTION, POUNDS PER FOOT
CROSS SECTION C-C'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-132.dgn 10-3-07 CMIReport

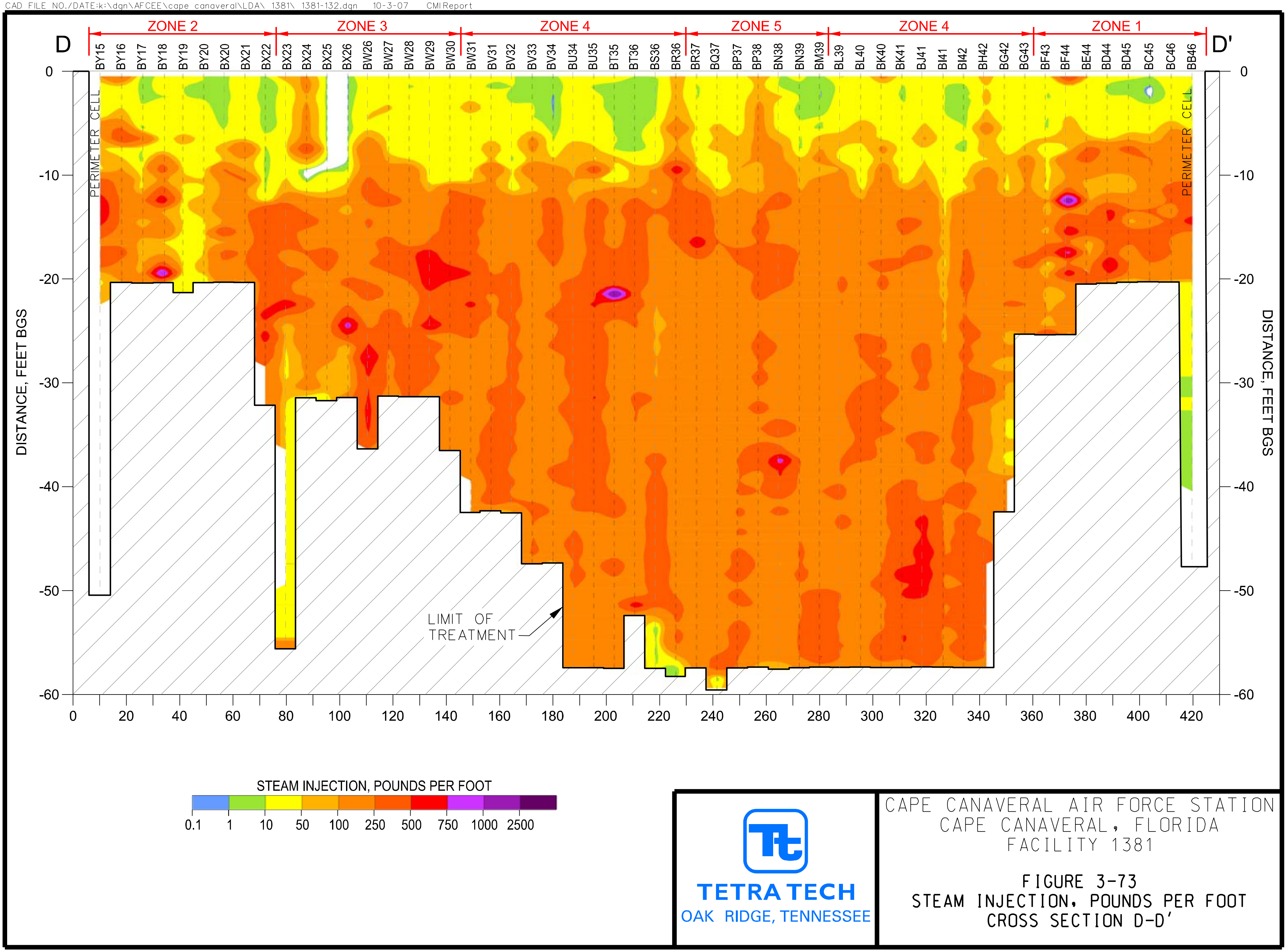

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FIGURE 3-73
STEAM INJECTION, POUNDS PER FOOT
CROSS SECTION D-D'

CAD FILE NO./DATE:k:\dgn\AFCEE\cape canaveral\LDA\ 1381\ 1381-134.dgn 10-3-07 CMI Report

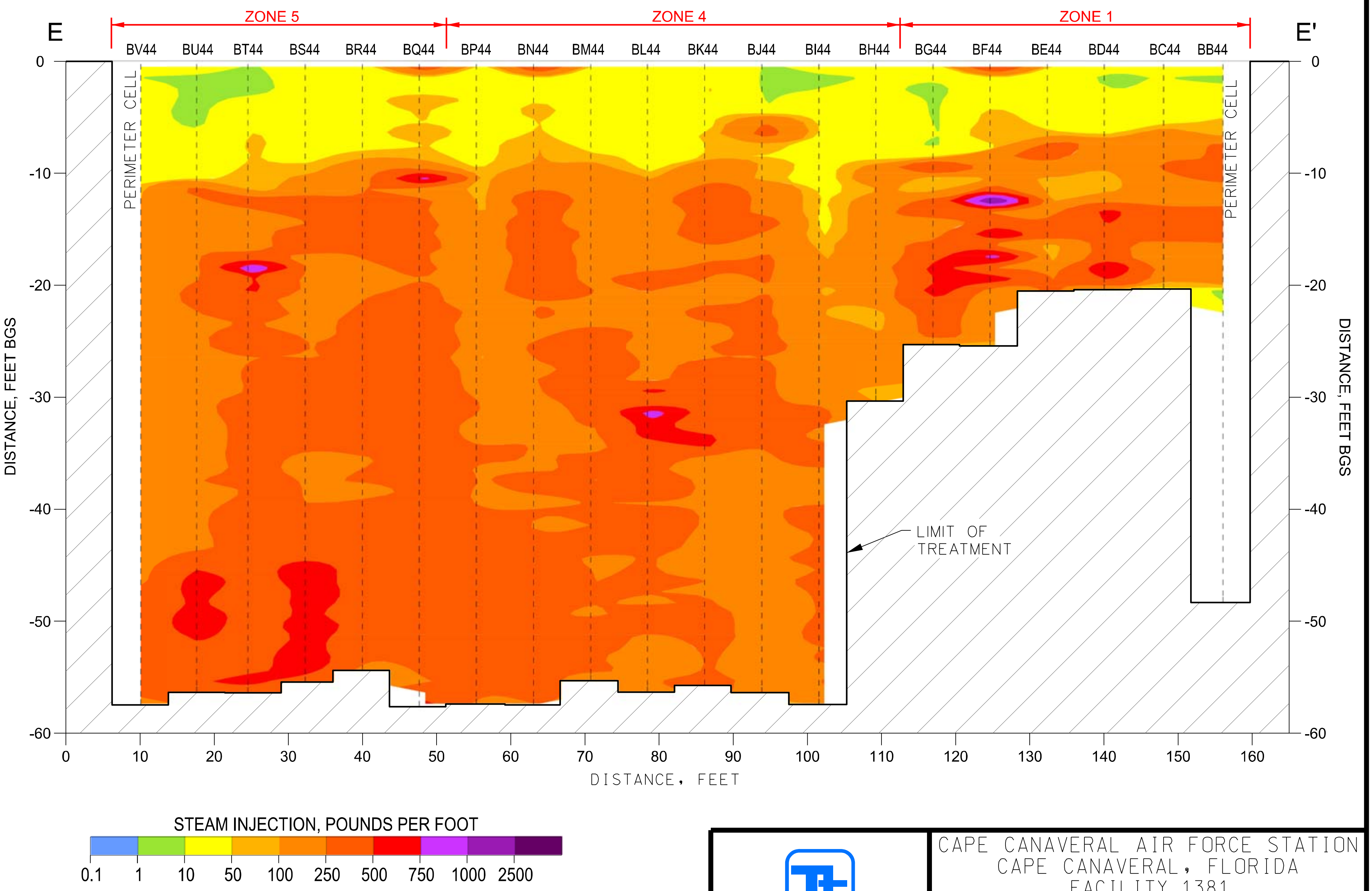

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FIGURE 3-74
STEAM INJECTION, POUNDS PER FOOT
CROSS SECTION E-E'

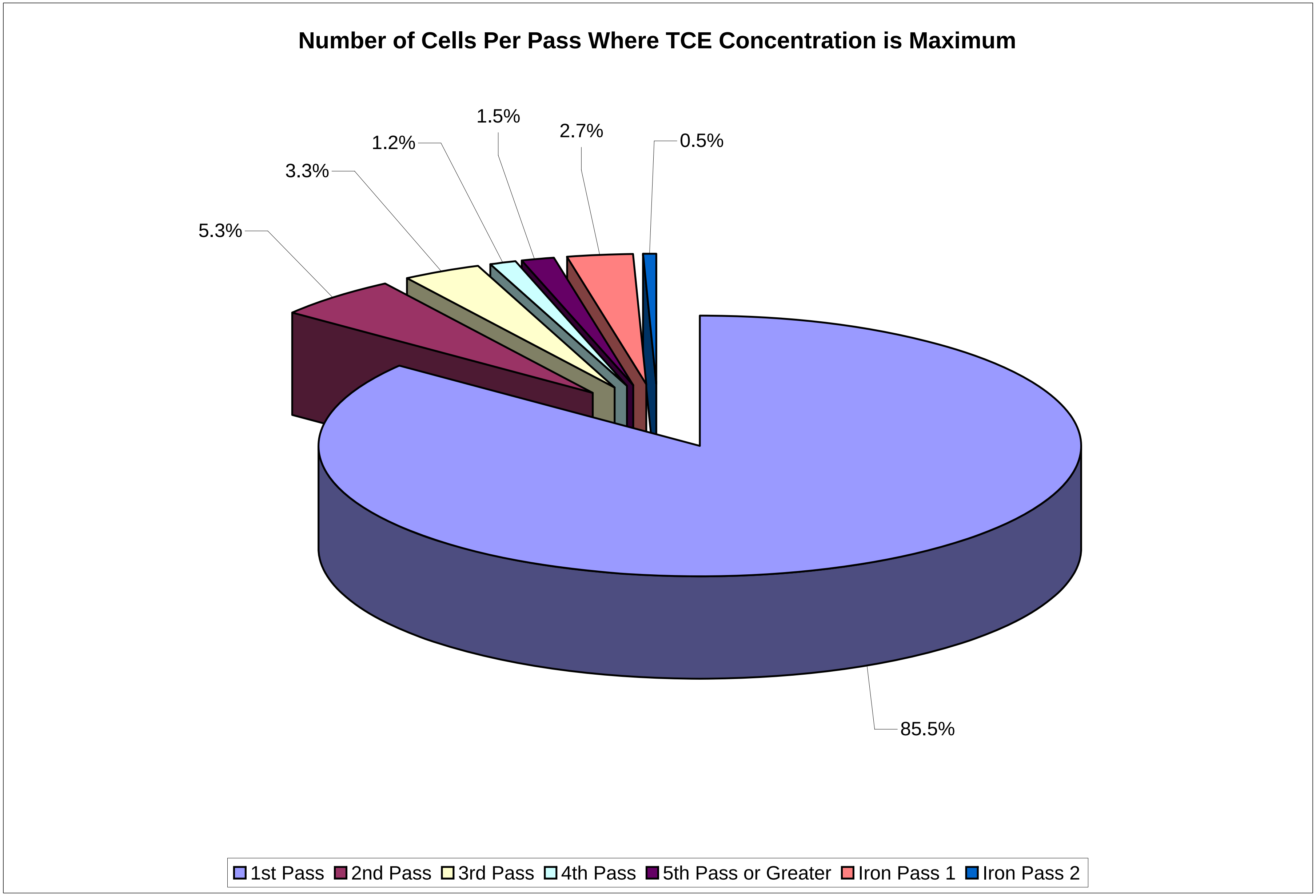

Figure 3-75: Number of Cells Per Pass Where TCE Concentration is Maximum

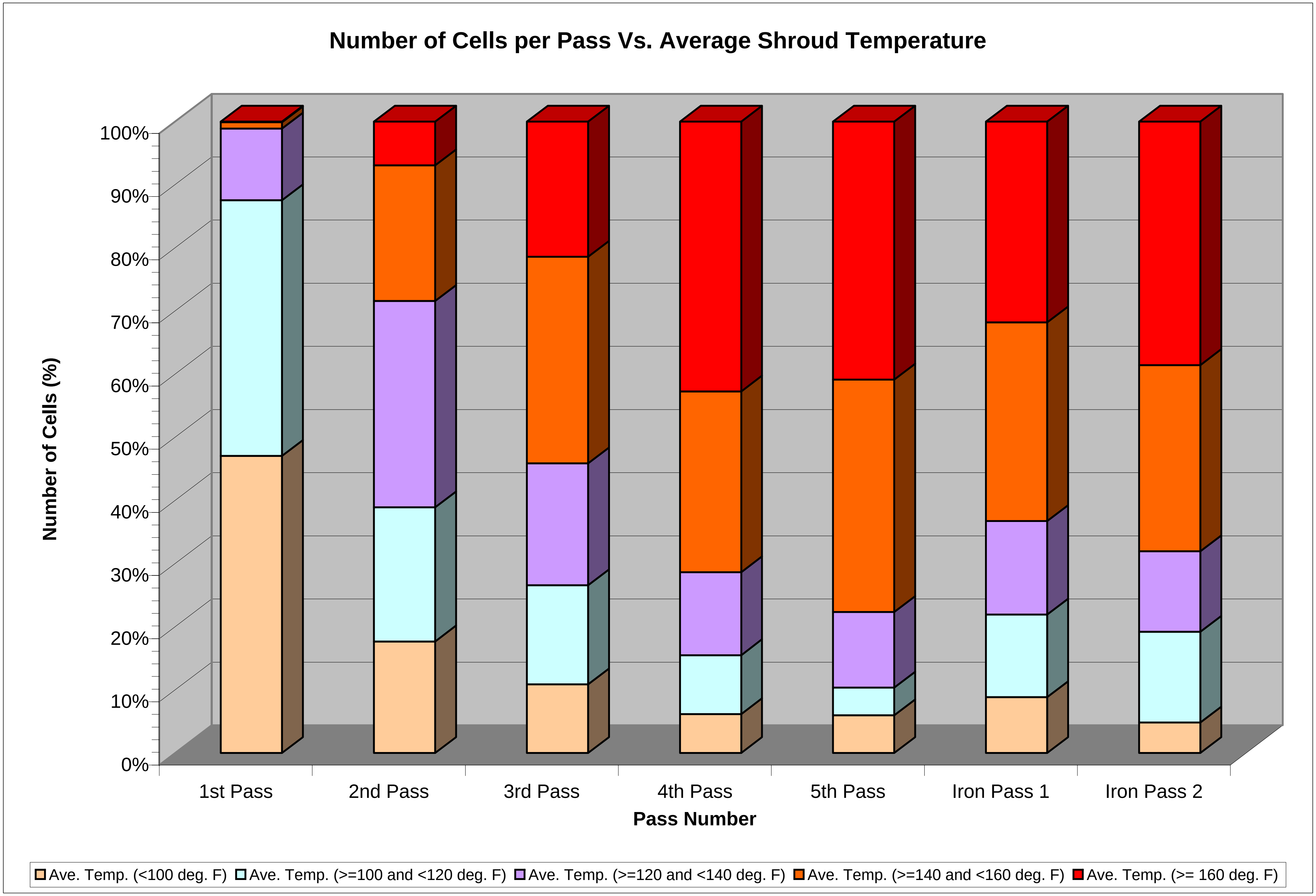

Figure 3-76: Number of Cells per Pass Vs. Average Shroud Temperature

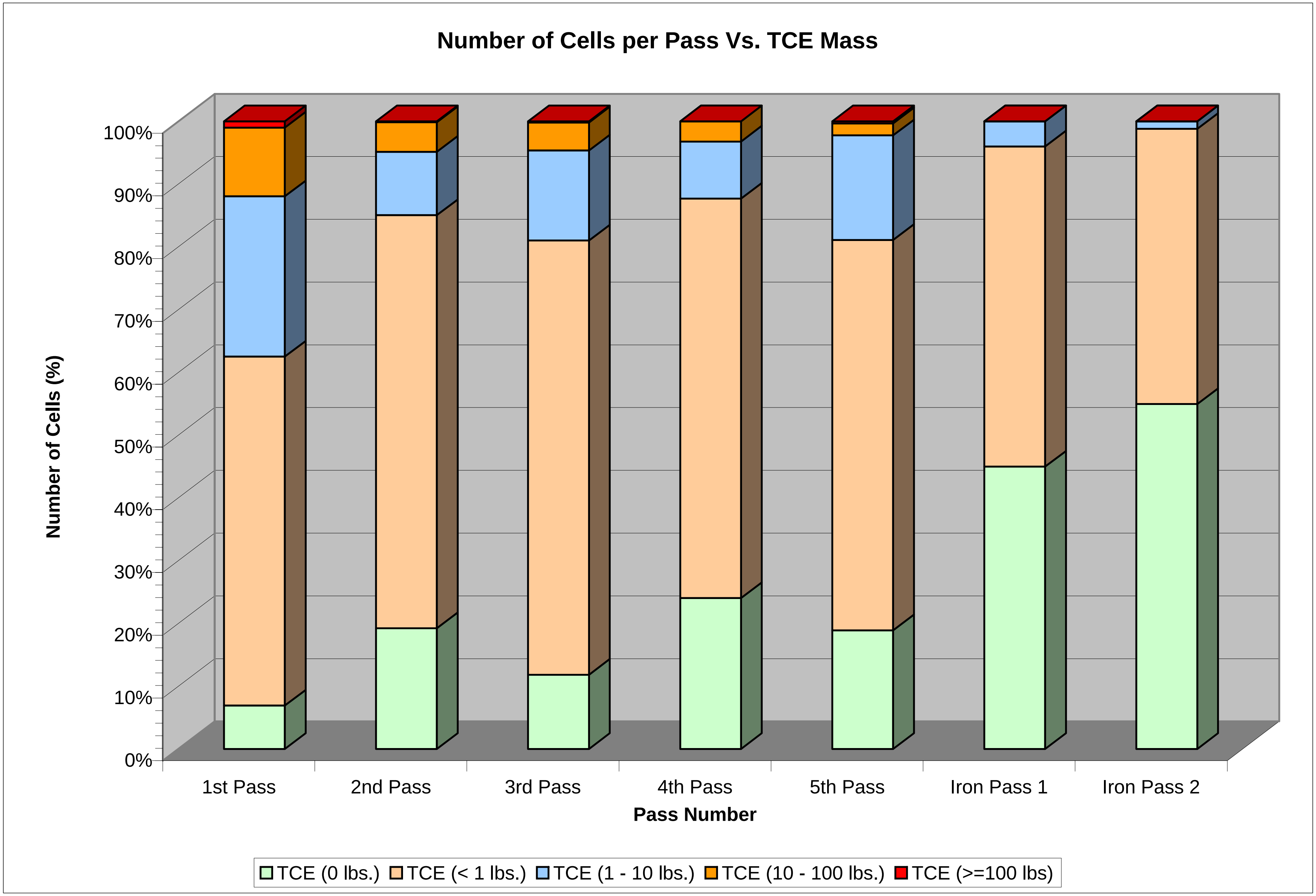

Figure 3-77: Number of Cells per Pass Vs. TCE Mass

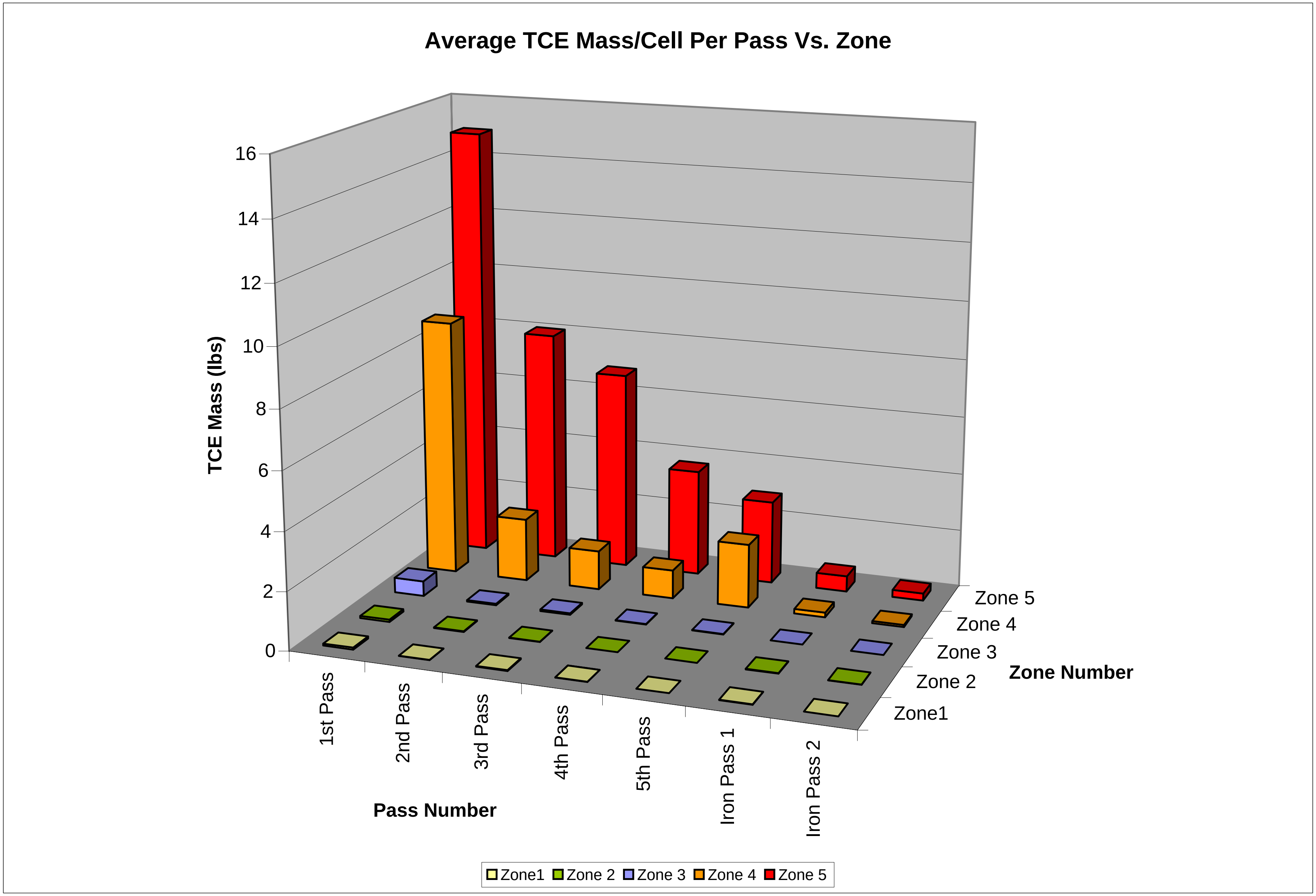

Figure 3-78: Average TCE Mass/Cell Per Pass Vs. Zone

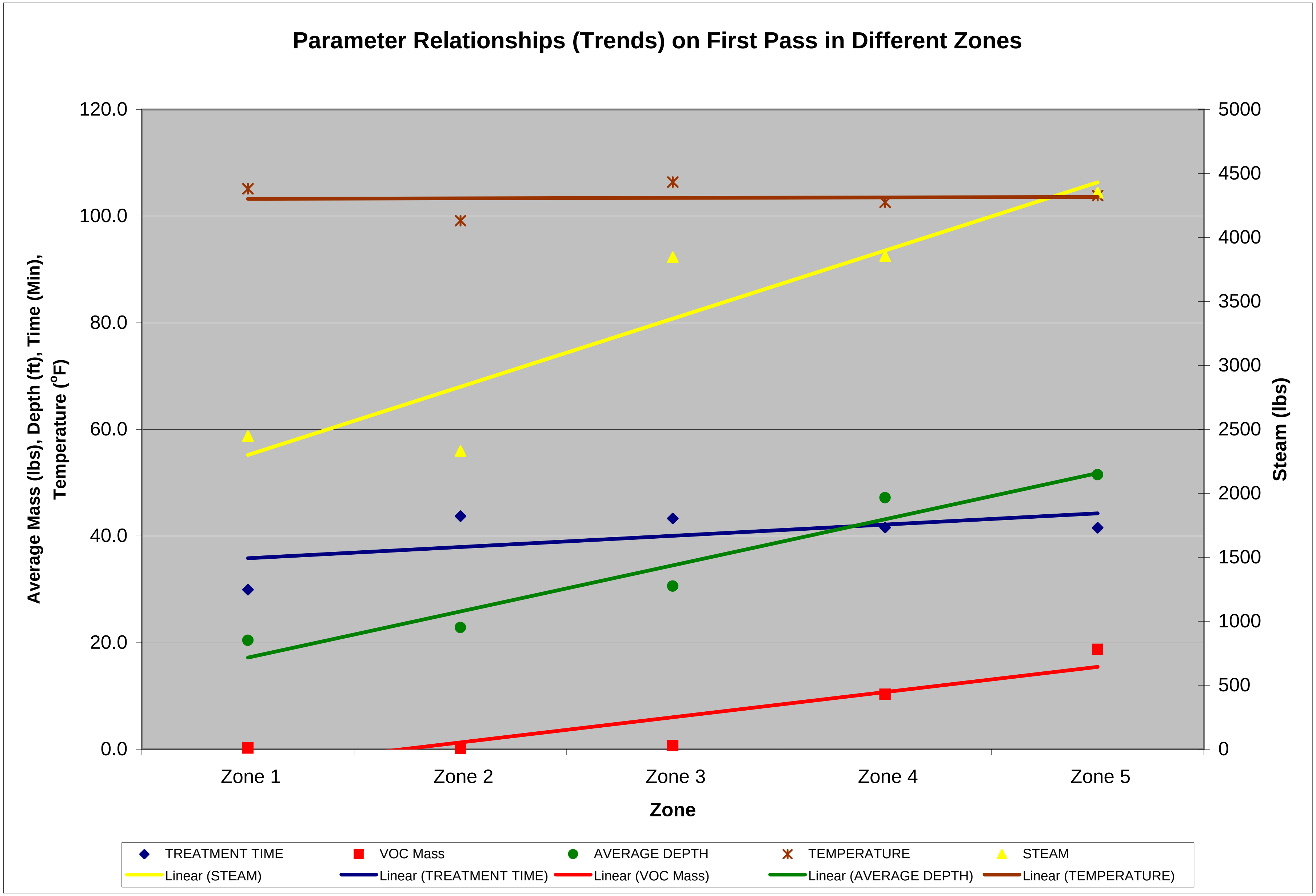

Figure 3-79: Parameter Relationships (Trends) on First Pass in Different Zones

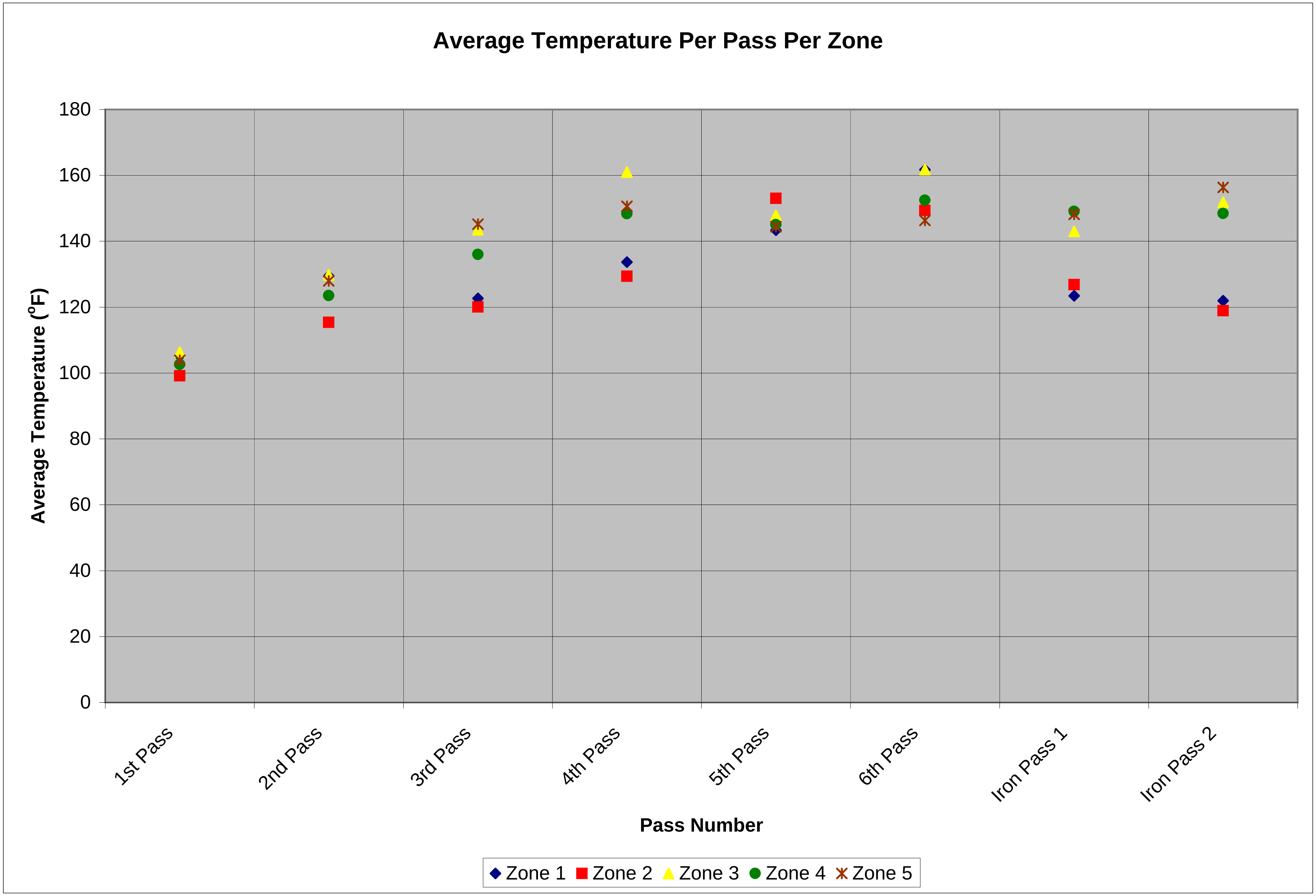

Figure 3-80: Average Temperature Per Pass Per Zone

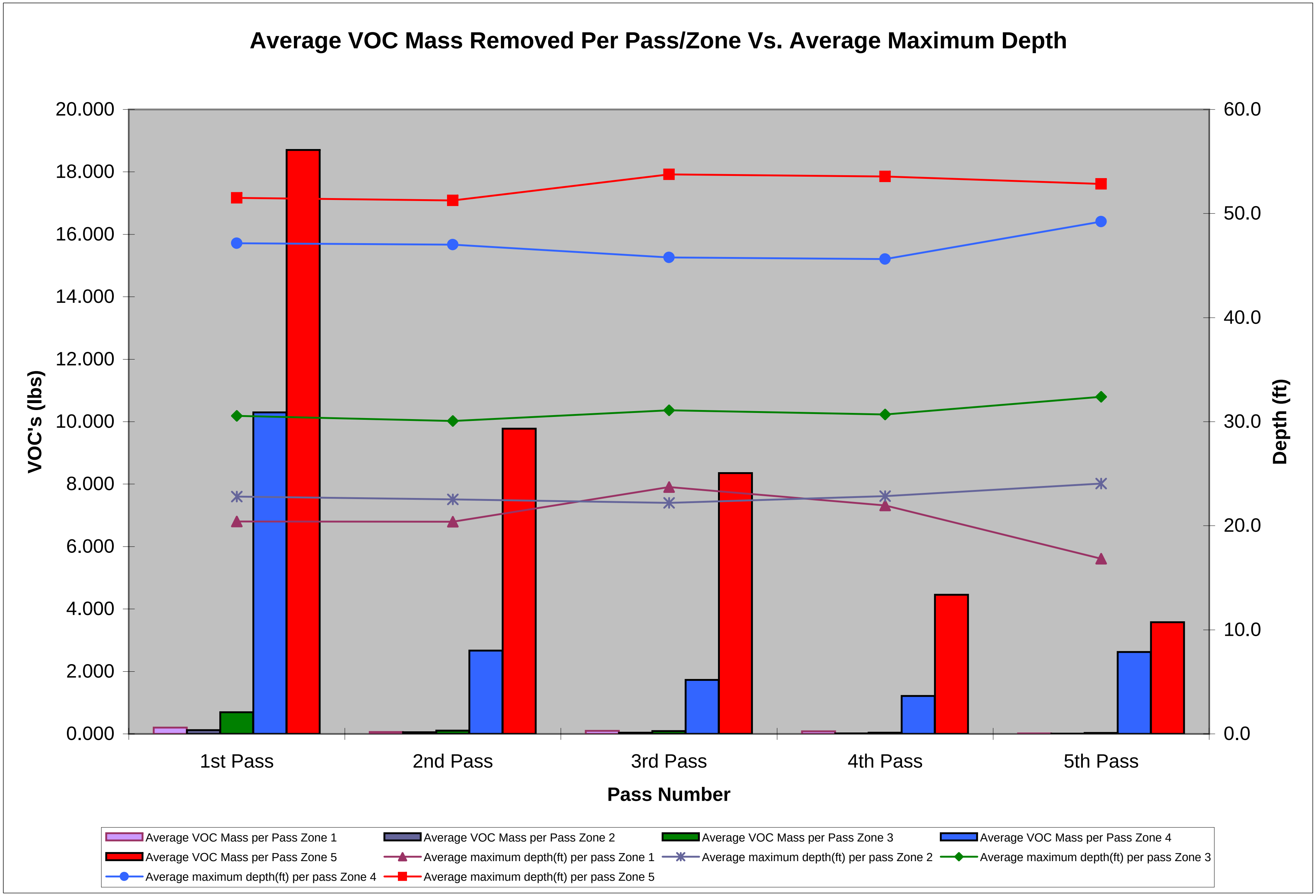

Figure 3-81: Average VOC Mass Removed Per Pass/Zone Vs. Average Maximum Depth

Treatment Timeline

ID	Task Name	Duration	Start	Finish
1	**Planning, Permitting, and Pre-Construction Submittals**	**143 days**	**Thu 7/21/05**	**Mon 2/13/06**
2	Prepare Work Plan	51 days	Thu 7/21/05	Fri 9/30/05
3	Review Work Plan	20 days	Mon 10/3/05	Mon 10/31/05
4	Revise Work Plan	5 days	Tue 11/1/05	Mon 11/7/05
5	Work Plan approval	1 day	Mon 12/12/05	Mon 12/12/05
6	**Prepare permit requests**	**87 days**	**Tue 10/11/05**	**Mon 2/13/06**
7	Dig Waivers Issued	1 day	Tue 11/1/05	Tue 11/1/05
8	FAA Permit Issued	26 days	Tue 10/11/05	Tue 11/15/05
9	Process Waste Questionnaire Submitted and TRP Issued	47 days	Wed 12/7/05	Mon 2/13/06
10	**Site Preparation for Facility 1381**	**90 days**	**Mon 2/6/06**	**Wed 6/14/06**
11	Survey Topography and Sample Locations	5 days	Mon 2/6/06	Fri 2/10/06
12	Structural demolition at Facility 1381 (by other contractors)	19 days	Mon 4/10/06	Fri 5/5/06
13	Trenching for Block Dig Waiver	4 days	Tue 5/2/06	Fri 5/5/06
14	Ground Penetrating Radar Survey	2 days	Thu 5/4/06	Fri 5/5/06
15	Site Leveling and Grading	6 days	Wed 5/31/06	Wed 6/7/06
16	Post Grading Survey	3 days	Mon 6/12/06	Wed 6/14/06
17	Block Dig Waiver Issued	1 day	Wed 6/14/06	Wed 6/14/06
18	**Corrective Measures Implementation at Facility 1381**	**331 days**	**Tue 2/14/06**	**Tue 6/5/07**
19	Flux Wells Pretreatment sampling	23 days	Tue 2/14/06	Fri 3/17/06
20	Laboratory Analysis	20 days	Mon 3/20/06	Fri 4/14/06
21	**Launch Delays**	**110 days**	**Fri 9/8/06**	**Fri 2/16/07**
22	Space Shuttle STS-115 Launch Delay	1 day	Fri 9/8/06	Fri 9/8/06
23	Delta II launch from SLC-17 Delay	1 day	Mon 9/25/06	Mon 9/25/06
24	Delta II launch from SLC-17 Delay	2 days	Thu 11/16/06	Fri 11/17/06
25	Mission Critical Delay	1 day	Tue 11/21/06	Tue 11/21/06
26	Space Shuttle STS-116 Launch Delay	1 day	Thu 12/7/06	Thu 12/7/06
27	Delta II launch from SLC-17 Delay	1 day	Fri 2/16/07	Fri 2/16/07
28	**Maintenance Delays**	**194 days**	**Wed 7/19/06**	**Mon 4/23/07**
29	Swivel Delay	4 days	Wed 7/19/06	Sat 7/22/06
30	Circuit Breaker Delay	1 day	Thu 8/24/06	Thu 8/24/06
31	Lightning Strike Delay	2 days	Sat 8/26/06	Mon 8/28/06
32	Hurricane Ernest Delay	6 days	Tue 8/29/06	Tue 9/5/06
33	Crane Hydraulics Arm Maintenance Delay	9 days	Thu 10/19/06	Tue 10/31/06
34	Propane Regulator Delay	1 day	Wed 11/1/06	Wed 11/1/06
35	Kelly Bar Tube Delay	2 days	Mon 11/13/06	Tue 11/14/06
36	Gear Box Replacement Delay	2 days	Mon 11/20/06	Tue 11/21/06
37	Shroud Damage Delay	5 days	Fri 12/22/06	Fri 12/29/06
38	O Ring on Platform Delay	1 day	Wed 1/3/07	Wed 1/3/07
39	Kelly Bar Tube Delay	1 day	Mon 1/8/07	Mon 1/8/07
40	Shroud Lifting Mechanics Modification Delay	1 day	Fri 1/19/07	Fri 1/19/07
41	Crane Startup Delay	1 day	Mon 1/22/07	Mon 1/22/07
42	Boom Lacing Delay	2 days	Wed 1/24/07	Thu 1/25/07
43	Elevated Wind Delay from Crane Maintenance	1 day	Fri 1/26/07	Fri 1/26/07
44	Crane Startup Delay	2 days	Mon 1/29/07	Tue 1/30/07
45	Crane Startup Delay	1 day	Thu 2/8/07	Thu 2/8/07
46	Shroud Lifting Mechanics and Modification Delay	1 day	Fri 2/23/07	Fri 2/23/07
47	Gear Box Replacement	1 day	Mon 4/23/07	Mon 4/23/07
48	**System mobilization and set-up**	**26 days**	**Mon 5/22/06**	**Tue 6/27/06**
49	Electrical Transformer Connection	14 days	Mon 5/22/06	Fri 6/9/06
50	Power Available to the Site	1 day	Mon 6/12/06	Mon 6/12/06
51	Mobilization of Remedial Equipment and Utility Connection	26 days	Mon 5/22/06	Tue 6/27/06
52	System checkout, commissionings and test cells	2 days	Wed 6/28/06	Thu 6/29/06
53	Treatment of Facility 1381 source area	236 days	Fri 6/30/06	Tue 6/5/07
54	Process monitoring and analysis	236 days	Fri 6/30/06	Tue 6/5/07
55	**Demobilization**	**38 days**	**Wed 6/6/07**	**Mon 7/30/07**
56	Demobilize Equipment and Post Treatment Grading	33 days	Wed 6/6/07	Mon 7/23/07
57	Final Cleanup	5 days	Tue 7/24/07	Mon 7/30/07

Facilities 18003 and 1381 Corrective Measures Implementation
Cape Canaveral Air Force Station, Florida

Task	▭	Progress	▬	Summary	▬	External Tasks	▭	Deadline	⇩
Split	┄	Milestone	◆	Project Summary	▬	External Milestone	◆		

Figure 3-82: Treatment Timeline

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4.0 PERFORMANCE SUMMARY

Site investigations conducted during the RFI and in support of the CMS and CMD documented the presence of a groundwater plume with very high dissolved concentrations of TCE (≥ 10 mg/L) suggestive of the presence of DNAPL. The area suspected to contain DNAPL was considered the source of a dissolved groundwater plume that flows to the north from the northeastern end of the source area toward a drainage canal, but that also flows northwest and southwest from the southern end of the source area toward the southern drainage canal. The performance objective was to remove and/or destroy significant contaminant mass (including dissolved, sorbed constituents, and DNAPL) in the identified source area. The following discussion presents a summary of the baseline and post-remediation conditions, and an evaluation of the performance effectiveness of the completed remedial action. As outlined in the Work Plan (Tetra Tech, 2005), the effectiveness of the remedial action will be evaluated by:

- Comparing baseline and post-remediation concentrations of contaminants in soil and groundwater samples from the performance monitoring locations;
- Comparing baseline and post- remediation groundwater mass flux results; and
- Presenting the results from post-remediation monitoring wells to be installed across the site to demonstrate changes in plume concentrations and dimensions.

4.1 BASELINE SAMPLING

Baseline conditions refer to the distribution, frequency, concentration, and mass flux of key VOC chemicals that were present in the treatment area (source zone) or migrating immediately down-gradient of the source zone as interpreted from the results of the baseline soil, groundwater, and groundwater flux sampling. All baseline sampling was conducted prior to the initiation of the remedial action (i.e., in-situ soil mixing with steam, hot air, and ZVI injection). The sampling locations are shown on Figure 4-1. The following baseline sampling was conducted:

- Soil samples were collected at 13 locations (SS-01 through SS-13) distributed within the treatment area between February 28 and March 6, 2006. Multiple soil samples were collected at each location at discrete depths using direct push technology (DPT) sampling tools.
- Groundwater samples were collected at 14 locations (GW-01 through GW-14) distributed within the treatment area between February 14 and 23, 2006. Multiple groundwater grab samples were collected at each location at discrete depths using DPT sampling tools.
- Passive flux meters (PFMs) were installed in the groundwater flux monitoring wells on March 3, 2006, and were retrieved after 14 days on March 17, 2006. The PFMs were analyzed in the laboratory to estimate the groundwater flow rate and mass flux of VOCs flowing out of different portions of the source area.

4.1.1 Baseline Soil Sampling

Baseline soil samples were collected at 13 locations across the identified 5 zones within the source area as shown in Figure 4-1: 1 location in Source Zone 1 (SZ-1); 2 in SZ-2; 2 in SZ-3; 7 in SZ-4; and 1 in SZ-5. All samples were analyzed for VOCs using USEPA Method 8260 and for total iron using USEPA Method 6010. Soil samples were collected at up nine depths ranging between 10 and 55 feet bgs, depending on location, as follows: between 10 and 30 feet bgs in SZ-1 and SZ-2 located at the northern and southern ends of the source zone, respectively; between 10 and 40 feet bgs in SZ-3 located in the south-central portion of the source zone; between 10 and 50 feet bgs in SZ-4 located in the center of the source zone; and between 10 and 55 feet bgs in SZ-5 located in the eastern portion of the source zone. Sampling was conducted to greater depths in SZ-4 and SZ-5 (i.e., down to 55 feet bgs) due to the greater depth of source zone contamination in those areas.

A summary of the chemicals detected, number of detections, concentration range, and exceedances of the industrial direct contact and leaching to groundwater soil cleanup target levels (SCTLs) are provided in Table 4-1. Figures 4-2 through 4-4 present the baseline soil concentrations for TCE, cis-1,2-DCE, and vinyl chloride at all depths at each sampling location. The laboratory analysis reports are presented in Volume IV of this report. As shown in the table, TCE and cis-1,2-DCE were the most frequently detected VOCs (>50% of samples), and these chemicals were present at the highest concentrations of all VOCs that were detected. As a point of reference, it is noted that these three VOCs exceeded the industrial direct contact SCTL; all VOCs, except carbon disulfide, exceeded the leaching SCTL. Although it was frequently detected, carbon disulfide is not considered a contaminant released at the site or a breakdown product, and did not exceed the referenced SCTLs.

Table 4-1. Soil Detection Summary - Baseline Samples

Parameter	No. Detects	No. Samples	Minimum Concentration	Maximum Concentration	Industrial SCTL[(a)]	Leaching SCTL[(a)]
Trichloroethylene	78	100	2	765,000	9,300	30
cis-1,2-Dichloroethylene	74	100	1.6	220,000	180,000	400
Carbon disulfide	41	100	1.9	20.7	1.5E+06	5,600
Vinyl chloride	40	100	2	43,300	800	7
trans-1,2-Dichloroethylene	15	100	8.2	719	290,000	700
1,1-Dichloroethane	10	100	4.3	2,330	2.1E+06	400
1,1-Dichloroethylene	9	100	3.3	1,460	510,000	60
1,1,1-Trichloroethane	2	100	6.9	4,650	3.9E+06	1,900
Iron	100	100	872	30,500	NA	NA

All concentration units are µg/kg, except iron which is in mg/kg. Duplicate samples were not included.
[(a)] SCTL shaded if exceeded.

4.1.2 Baseline Groundwater Sampling

Baseline groundwater samples were collected at 14 locations across the identified 5 zones within the source area as shown in Figure 4-1: 1 location in Source Zone 1 (SZ-1); 2 in SZ-2; 4 in SZ-3; and 6 in SZ-4; and 1 in SZ-5. All samples were analyzed for VOCs using USEPA Method 8260 and for total iron using USEPA Method 6010. Groundwater samples were collected at up seven depths ranging between 10 and 60 feet bgs, depending on location, but the sample depths were not always consistent within any given zone. In general, samples were collected as follows: between 10 and 30 feet bgs in SZ-1 and SZ-2 located at the northern and southern ends of the source zone, respectively; between 13 and 40 feet bgs in SZ-3 located in the south-central portion of the source zone; between 10 and 50 feet bgs (60 feet at one location) in SZ-4 located in the center of the source zone; and between 13 and 60 feet bgs in SZ-5 located in the eastern portion of SZ-4. Sampling was conducted to greater depths in SZ-4 and SZ-5 (i.e., down to 60 feet bgs) due to the greater depth of source zone contamination in those areas.

A summary of the chemicals detected, number of detections, concentration range, and exceedances of the GCTLs are provided in Table 4-2. Figures 4-5 through 4-7 present the baseline concentrations for TCE, cis-1,2-DCE, and vinyl chloride at all depths at each sampling location. The laboratory analysis reports are presented in Volume IV of this report. As shown in the table, cis-1,2-DCE, TCE, and vinyl chloride were the most frequently detected VOCs (>50% of samples), and these chemicals were present at the highest concentrations of all VOCs that were detected. Comparison of Tables 4-1 and 4-2 demonstrates consistency in the VOCs present in soil and groundwater and their relative level of contribution to the total mass of contaminants in the source area.

Table 4-2. Groundwater Detection Summary - Baseline Samples

Parameter	No. Detects	No. Samples	Minimum Concentration	Maximum Concentration	GCTL[(a)]
cis-1,2-Dichloroethylene	69	76	0.66	316,000	70
Trichloroethylene	68	76	2.1	997,000	3
Vinyl chloride	57	76	0.74	41,700	1
trans-1,2-Dichloroethylene	32	76	0.61	4,000	100
1,1-Dichloroethylene	23	76	0.51	6,190	7
1,1-Dichloroethane	13	76	0.65	4,130	70
Acetone	8	76	6.1	62.2	6300
1,1,1-Trichloroethane	6	76	0.61	6,390	200
Trichlorofluoromethane	5	76	1.9	747	2100
Chloroform	2	76	1.6	63.5	70
1,2-Dichloroethane	1	76	1.5	1.5	3
Carbon disulfide	1	76	2.3	2.4	700
Iron	75	76	5,310	449,000	300

All concentration units are µg/L. Duplicate samples were not included.
[(a)] GCTL shaded if exceeded.

4.1.3 Baseline Groundwater Mass Flux

Multiple lines of evidence are being used to evaluate the performance of the TCE source area remedial approach via in-situ soil mixing enhanced with steam, hot air, and ZVI. One line of evidence being looked at to measure success or performance is mass flux. There is a measurable amount of contaminant mass output by the source area which ultimately creates the dissolved phase groundwater plume. This output or flux is being measured both baseline and post-remediation to support treatment effectiveness evaluations.

Contaminant flux emanating from the TCE source area was measured using a passive type device known as a PFM that was installed in wells in and along the downgradient perimeter of the source area. These PFMs record contaminant flux by measuring the mass of ambient groundwater and contaminant flow per unit area at a measured point in a well screen averaged over a given time period. Based upon this general definition, the units associated with mass flux are determined as:

$$flux = \frac{mass}{area \cdot time} = \left[\frac{M}{L^2 T}\right]$$

where the terms M, L, and T represent the base units of mass, length, and time, respectively. For consistency with common practice, the ambient groundwater flux was evaluated in terms of the specific discharge or Darcy velocity, which is the volumetric water flux (or flowrate) through a specified cross-sectional area of the aquifer. The resulting units are L/T, Darcy velocity, which is represented with the units of cm/day. For this performance evaluation the contaminant flux is discussed in terms of mass flux ($M/(L^2T)$) and represented with the units of ($mg/(m^2day)$) or ($g/(m^2day)$) depending on the magnitude of the observed flux values.

Based upon previous site assessments, the expected contaminants at Facility 1381 were PCE, TCE, and dechlorination products DCE, vinyl chloride, and ethene. In summary, the intent of measuring flux is to compare the contaminant mass discharge or flux from the source zone before and post-remediation in order to demonstrate a decrease in contribution to the dissolved plume from the source area.

4.1.3.1 Flux Monitoring Network Setup and Baseline Sampling

Flux well installation began on March 3, 2006. A network of six 1.5-inch diameter flux wells (FC-01, FC-02, FC-03, FC-04, FC-05, and FC-06) was installed for PFM deployment. All six flux wells were installed with a screen length of 30 feet, from 10 feet to 40 feet bgs, to intercept the perceived interval of highest contaminant concentrations; the wells represent a control plane for mass discharge estimations. Three of the flux wells (FC-01, FC-02, and FC-03) were located along the northwestern, downgradient perimeter of the source area. Well FC-04 was located along the north-central, downgradient perimeter of the source zone. Two flux wells (FC-05 and FC-06) were located along the southeastern, downgradient perimeter of the source zone near the drainage canal. Locations of the flux wells are shown on Figure 4-1.

Following flux well installation and development, the PFMs were installed in the flux wells. The initial deployment took place March 3, 2006. Each PFM was successfully deployed in the six wells. PFMs were deployed as 5-foot units with six PFMs per each well (matching the screen length of 30 feet). PFM retrieval took place on March 17, 2006 (corresponding to a deployment length of 14 days). During retrieval all six of the PFMs in each of the six wells were recovered for a total of 36 PFMs.

4.1.3.2 Baseline Flux Sampling Results

The flux data are summarized in Tables 1 and 2 in Appendix U. The data are displayed in Figure 1 in Appendix U. It should be noted that the units (mg/(m^2day)) are the same as (mg/m^2/day).

In general the trends and magnitudes observed between the six wells are comparable. The general trend of high Darcy flux in the upper portion of the wells that decreases with depth agrees with the local hydrogeology that includes more conductive sediments in the shallow portion of the aquifer. The Darcy velocities in the upper 5 feet of the screened interval (10 to 15 ft bgs) ranged between approximately 3 to 9 cm/day (36 to 108 ft/yr), and approximately 2.5 cm/day (30 ft/yr) or less in the lower 25 feet of the screened interval (15 to 40 ft bgs). Three of the wells showed an increase in the bottom 5 feet of the screened interval.

For analysis of the Facility 1381 data, wells FC-01 through FC-03 and wells FC-04 and FC-05 can be used to form two control planes with a well spacing of 30 and 50 feet, respectively, to evaluate mass flow leaving the northern and southern ends of the source area. The mass discharges for each well are presented in Table 4-3.

Table 4-3. Integral estimates of mass discharge per unit width of aquifer for each flux well

Well	TCE (mg/m/day)	Cis-DCE (mg/m/day)	Vinyl Chloride (mg/m/day)	Ethene (mg/m/day)
FC-01	0.00	205	177	6.81
FC-02	0.00	362	198	18.1
FC-03	138	436	24.5	11.9
FC-04	0.00	57.6	89.8	5.29
FC-05	238	341	45.4	2.0
FC-06	127	165	29.3	1.88

The maximum local mass flux (229 mg/m^2/day) was observed for cis-DCE in the upper portion of well FW-03. Significant cis-DCE (224 mg/m^2/day) was also observed at a depth of 11 feet in FW-05. Maximum TCE mass flux of 204 mg/m^2/day was also observed at a depth of 11 feet in well FW-05. The local flux values were integrated to find mass discharges for each well. The contaminant mass flux values measured at the local scale (1.5 foot vertical intervals) in each of the wells can be represented in terms of mass discharge per unit width of aquifer (mg/m/day) and are summarized in Table 4-3. These values can in turn be used to estimate the mass discharge (mg/day) through a portion of the aquifer corresponding to a specified width. The highest observed mass discharge was 436 mg/m/day (mass discharge per unit width of aquifer).

It was noted that the mass flux from well FC-04 located along the northwest perimeter of the source area was distinctly lower for all VOCs; this is consistent with the local hydrogeology that indicates that flow to the northwest occurs typically during the low-recharge season when the groundwater gradient will also be lower. It was also noted that only one of the three northern transect wells showed a flux of TCE. These wells are approximately 30 feet apart along what is expected to be similar groundwater streamlines; no reason for this discrepancy is apparent, particularly when the mass removed data presented in Section 3.6 suggest that the largest amount of TCE mass and highest concentrations are located in the northwestern portion of the source area.

This data set provides a baseline for comparison for the data set to be collected during the post-treatment flux sampling at the site.

4.2 POST-REMEDIATION SAMPLING

Post-remediation conditions refer to the distribution, frequency, concentration, and mass flux of key VOC chemicals that were present in the treatment area following completion of the in-situ soil mixing with steam, hot air, and ZVI injection that was performed at Facility 18003. Post-remediation soil and groundwater sampling was conducted at the same locations and at the same depths, and using the sample DPT technology and sampling methodology as described above for the baseline sampling (see Section 4.1), with some exceptions as noted below:

- Soil samples were collected at 13 locations (SS-01 through SS-13) distributed within the treatment area between November 15 and 26, 2007. Multiple soil samples were collected at each location at discrete depths using DPT sampling tools.
- Groundwater samples were collected at 14 locations (GW-01 through GW-14) distributed within the treatment area between November 19 and 29, 2007. Multiple groundwater grab samples were collected at each location at discrete depths using DPT sampling tools.
- PFMs will be installed in the flux wells at a future date to provide data on the post-remediation groundwater flow rate and mass flux of VOCs.

4.2.1 Post-Remediation Soil Sampling

Post-remediation soil samples were collected at 13 locations across the identified 5 zones within the source area as shown in Figure 4-1: 1 location in SZ-1; 2 in SZ-2; 2 in SZ-3; 7 in SZ-4; and 1 in SZ-5. All samples were analyzed for VOCs using USEPA Method 8260 and for total iron using USEPA Method 6010. Soil samples were collected at up nine depths ranging between 10 and 55 feet bgs, depending on location, as follows: between 10 and 30 feet bgs in SZ-1 and SZ-2 located at the northern and southern ends of the source area, respectively; between 10 and 40 feet bgs in SZ-3 located in the south-central portion of the source area; between 10 and 50 feet bgs in SZ-4 located in the center of the source area; and between 10 and 55 feet bgs in SZ-5 located in the eastern portion of the source area. As previously mentioned, sampling was conducted to greater depths in SZ-4 and SZ-5 (i.e., down to 55 feet bgs) due to the greater depth of contamination in those areas.

A summary of the chemicals detected, number of detections, concentration range, and exceedances of the industrial direct contact and soil leaching to groundwater cleanup target levels are provided in Table 4-4. As shown in the table, TCE, cis-1,2-DCE, and vinyl chloride that were frequently detected VOCs in the baseline sampling were present in the post-remediation samples but were detected at a lower frequency and at greatly reduced concentrations; trans-1,2-DCE was not detected in the post-remediation samples. Because of the reduction in the maximum concentrations of VOCs that were detected in the post-remediation samples, compared to the baseline samples, the detection limits achieved by the laboratory were significantly lower for most VOCs. As a result, VOCs such as carbon disulfide, and suspected laboratory contaminants such as acetone, were detected at a greater frequency than in the baseline samples. As a point of reference, it is noted that none of the post-remediation samples contained concentrations of TCE, cis-1,2-DCE, or vinyl chloride that exceeded the industrial direct contact SCTLs.

Table 4-4. Soil Detection Summary – Post-Remediation Samples

Parameter	No. Detects	No. Samples	Minimum Concentration	Maximum Concentration	Industrial SCTL[(a)]	Leaching SCTL[(a)]
Carbon Disulfide	99	100	3	159	1.5E+06	5,600
Methylene chloride	96	100	4.6	41.6	26,000	20
Acetone	50	100	22.3	361	6.8E+07	25,000
Methyl ethyl ketone	31	100	9.8	79.8	1.1E+08	17,000
cis-1,2-Dichloroethene	17	100	2.3	3740	180,000	400
Vinyl chloride	14	100	8.2	732	800	7
Toluene	10	100	1.9	3.5	6.0E+07	500
Trichloroethene	5	100	1.7	3.1	9,300	30
Benzene	3	100	2.5	4.9	1,700	7
1,1-Dichloroethane	2	100	3.7	5.7	2.1E+06	400
1,1-Dichloroethene	1	100	4.7	4.7	510,000	60
Styrene	1	100	2.8	2.8	2.3E+07	3,600
Total Xylenes	1	100	2.5	2.5	700,000	200
Iron	100	100	1280	27200	na	na

All concentration units are µg/kg.
(a) SCTL shaded if exceeded.

4.2.2 Post-Remediation Groundwater Sampling

Post-remediation groundwater samples were collected at 14 locations across the identified 5 zones within the source area as shown in Figure 4-1: 1 location in Source Zone 1 (SZ-1); 2 in SZ-2; 4 in SZ-3; and 6 in SZ-4; and 1 in SZ-5. All samples were analyzed for VOCs using USEPA Method 8260 and for total iron using USEPA Method 6010. Groundwater samples were collected at up to eight depths ranging between

10 and 60 feet bgs, depending on location, but samples could not be collected at certain depths at some locations. In general, samples were collected as follows: between 10 and 30 feet bgs in SZ-1 and SZ-2 located at the northern and southern ends of the source zone, respectively; between 13 and 40 feet bgs in SZ-3 located in the south-central portion of the source zone; between 10 and 50 feet bgs (60 feet at one location) in SZ-4 located in the center of the source zone; and between 13 and 60 feet bgs in SZ-5 located in the eastern portion of SZ-4. As previously mentioned, sampling was conducted to greater depths in SZ-4 and SZ-5 (i.e., down to 60 feet bgs) due to the greater depth of source zone contamination in those areas.

A summary of the chemicals detected, number of detections, concentration range, and exceedances of the GCTLs are provided in Table 4-5. As shown in the table, VOCs such as TCE, cis-1,2-DCE, trans-1,2-DCE, and vinyl chloride that were frequently detected VOCs in the baseline sampling were present in the post-remediation samples, although at greatly reduced concentrations and at a lower frequency of detection. Because of the greater reduction in the maximum concentrations of VOCs that were detected in the post-remediation samples, compared to the baseline samples, the detection limits achieved by the laboratory were significantly lower for most VOCs. As a result, non-target VOCs such as toluene and benzene, and suspected laboratory contaminants such as acetone, were detected at a greater frequency than in the baseline samples.

Table 4-5. Groundwater Detection Summary – Post-Remediation Samples

Parameter	No. Detects	No. Samples	Minimum Concentration	Maximum Concentration	GCTL[(a)]
Acetone	36	62	10.7	2760	6300
Toluene	36	62	0.45	25.9	40
Benzene	28	62	0.21	5.4	1
cis-1,2-Dichloroethene	28	62	0.29	25000	70
Vinyl chloride	28	62	0.45	9350	1
Carbon Disulfide	22	62	0.32	9.6	700
Methyl ethyl ketone	21	62	2	592	4200
Ethylbenzene	13	62	0.21	1.4	30
1,1-Dichloroethane	12	62	0.55	246	70
2-Hexanone	8	62	3.6	39.5	280
trans-1,2-Dichloroethene	8	62	0.41	120	100
4-Methyl-2-pentanone	7	62	2.4	12.7	560
Total Xylenes	7	62	0.6	1.3	20
Methyl chloride	3	62	0.46	0.82	2.7
Trichloroethene	3	62	1.2	314	3
Chloroform	2	62	0.25	0.31	70
1,1-Dichloroethene	1	62	0.93	0.93	7
Methylene chloride	1	62	13.5	13.5	5
Iron	56	56	2450	550000	300

All concentration units are µg/L.

(a) GCTL shaded if exceeded.

4.2.3 Post-Remediation Groundwater Mass Flux Sampling

All six flux wells were replaced following the completion of the remedial activity. Post-remediation installation of PFMs in the flux wells is planned; results were not available for inclusion in this report.

4.3 PERFORMANCE EVALUATION

The goal of the remedial action at Facility 1381 was to reduce the mass of contaminants in the source area. The source area was defined as an area of the aquifer that contained greater than 10 ppm of TCE in the groundwater. Based on data presented in the CMS and CMD reports, the source area was divided into five treatment zones based on the depth of contamination. This section will evaluate the performance of the remedial action using four primary metrics, as follows:

- Comparison of the baseline and post-remediation concentrations of TCE and associated chlorinated VOCs in the soil
- Comparison of the baseline and post-remediation concentrations of TCE and associated chlorinated VOCs in the groundwater
- Comparison of changes in the groundwater contaminant flux through the source zone and immediately downgradient
- Documentation of changes in the groundwater plume and the presence/absence of groundwater "source" concentrations at the site based on monitoring well data

As indicated above, the mass removal strategy was based on the concentration of TCE in the groundwater within the source area. In addition, the baseline sample data for soil and groundwater (see Tables 4-1 and 4-2, respectively) demonstrated that TCE and associated chlorinated VOCs cis-1,2-DCE, and vinyl chloride were the primary VOCs present in the source area groundwater. Furthermore, the mass removal data presented in Section 5.1 show that these VOCs accounted for the majority of chemical mass in the source area. Therefore, the data and discussion presented in this section focuses on these three "target" VOC contaminants. Post-remediation samples were collected at all locations to be consistent with the baseline sampling. However, only samples that were collected from depths treated by the LDA are used in this performance evaluation. Samples collected at depths that were not directly treated do not provide data on the performance of the technology.

As noted in the following sections, post-remediation flux monitoring and documentation of groundwater quality using monitoring well data (metrics three and four above) are scheduled to be conducted and the results were not available for inclusion in this report.

4.3.1 Soil Evaluation

Baseline and post-remediation soil sampling results were presented in Sections 4.1.1 and 4.2.1. The samples were collected at the same locations and depth intervals as shown in Table 4-6. Also noted in the table are the sample intervals at depths greater than the depth of LDA penetration at each sample location.

Table 4-6. Comparison of Baseline and Post-Remediation Soil Sample Density

Location	Soil Sample Depth, feet									
	10	15	20	25	30	35	40	45	50	55
SS-01	X	X	X	X	X					
SS-02	X	X	X	X	X	X	X	X	X	
SS-03	X	X	X	X	X	X	X	X	X	
SS-04	X		X		X	X	X	X	X	X
SS-05	X	X	X	X	X	X	X	X	X	
SS-06	X	X	X	X	X					
SS-07	X	X	X	X	X					
SS-08	X	X	X	X	X	X	X			
SS-09	X	X	X	X	X	X	X			
SS-10	X	X	X	X	X	X	X	X	X	
SS-11	X	X	X	X	X	X	X	X	X	
SS-12	X	X	X	X	X	X	X	X	X	
SS-13	X	X	X	X	X	X	X	X	X	

X - Samples collected during both sampling events; blank cell indicates not sampled.
B - Baseline only; P - Post-remediation only.
Shading indicates samples below LDA penetration depth.

One measure of performance consists of comparing the concentrations of target VOCs in the soil before and after completion of the remediation. The baseline and post-remediation maximum concentrations of the target VOCs in soil are presented in Table 4-7 and the percent reduction in the maximum concentration is provided. The concentration of iron is also provided in the table as a point of interest related to the injection of ZVI during the remedial action. It should be noted that the maximum concentrations of VOCs presented in Table 4-4 represent only sample depth intervals that were treated (i.e., within the depth penetrated by the LDA).

As can be seen in Table 4-7, maximum concentrations were reduced by two to five orders of magnitude, and the reduction in maximum concentrations for each of the target VOCs were greater than 98%. A location by location and depth by depth comparison of the reduction in concentrations achieved by the remedial action can be seen in Figures 4-2 through 4-5 that present the baseline and post-remediation concentrations for each target VOC at all depths at each sampling location. Samples that were collected

Table 4-7. Comparison of Maximum Concentrations in Soil

Chemical	Baseline Maximum	Post Maximum	Percent Reduction
Trichloroethylene	765,000	3.1	99.9+
cis-1,2-Dichloroethylene	220,000	3740	98.3
Vinyl chloride	43,300	261	99.4
Iron	30,500	27,200	decrease

All concentration units are μg/kg, except iron is mg/kg.

below the depth of LDA penetration are noted on the figures; data from these locations were not used in the performance evaluation. The post-remediation maximum concentrations presented in Table 4-7 all occurred at location SB-02 in the sample from a depth of 40 ft (i.e., the maximum depth of LDA penetration). The overall maximum concentration of vinyl chloride detected in post-remediation samples (732 μg/kg) occurred at location SB-06 in the sample from a depth of 25 ft that was just below the maximum depth of LDA penetration (see Figures 4-4).

It was observed that the baseline maximum concentrations for TCE and cis-1,2-DCE occurred in SZ-5 (SB-04) at depths between 35 and 40 feet bgs; the maximum for vinyl chloride occurred in SZ-4 (SB-05) at a depth of 25 feet. A review of the data presented for all sample locations in SZ-4 and SZ-5 (Figures 4-2 through 4-5) reveals the high degree of concentration reduction that was achieved in these areas.

4.3.2 Groundwater Evaluation

Baseline and post-remediation groundwater sampling results were presented in Sections 4.1.2 and 4.2.2. The samples were collected at the same locations and depth intervals with exceptions as indicated in Table 4-8. Also noted in the table are the sample intervals at depths greater than the depth of LDA penetration at each sample location. Typically, post-remediation groundwater samples were not collected at depths below the depth of LDA penetration.

One measure of performance consists of comparing the concentrations of target VOCs in the groundwater before and after completion of the remediation. The baseline and post-remediation maximum concentrations of the target VOCs in groundwater are presented in Table 4-9 and the percent reduction in the maximum concentration is provided. The concentration of iron is also provided in the table as a point of interest related to the injection of ZVI during the remedial action. It should be noted that the baseline and post-remediation maximum concentrations for TCE and cis-1,2-DCE (shown in Tables 4-2 and 4-5) occurred in samples below the depth of LDA penetration. The maximum concentrations of VOCs presented in Table 4-9 represent only sample depth intervals that were treated (i.e., within the depth penetrated by the LDA).

Table 4-8. Comparison of Baseline and Post-Remediation Groundwater Sample Density

Location	10	13*	20	25	30	35	40	50	55	60
GW-01		X	X		X		X	B		
GW-02		B	X		X		X	B		
GW-03		X	X	X	X	X	X			
GW-04	X	X	X	X	X					
GW-05		X	X		X		B	B		
GW-06		X	X		X		X	B		
GW-07		X	X		X		X	X		
GW-08		B	X	X	X	X	X			
GW-09		X	X	X	X					
GW-10		X	X	X	X	X	X			
GW-11		X	X		X		B	X	X	B
GW-12		X	X		X		X	X		
GW-13		X	X		X		X	X		
GW-14	B	P	X		X		B	B	B	B

* - Depth is 15 ft at location GW04.

X - Samples collected during both sampling events; blank cell indicates not sampled.
B - Baseline only; P - Post-remediation only.
Shading indicates samples below LDA penetration depth.

Table 4-9. Comparison of Maximum Concentrations in Groundwater

Chemical	Baseline Maximum	Post Maximum	Percent Reduction
Trichloroethylene	602,000	ND	99.9+
cis-1,2-Dichloroethylene	219,000	61.6	99.9+
Vinyl chloride	41,700	1500	96.4
Iron	449,000	550,000	increase

All concentration units are μg/L.

As can be seen in Table 4-9, maximum concentrations of target VOCs were reduced by one to five orders of magnitude, and the reduction in maximum concentrations ranged from greater than 96% to 99%. A location by location and depth by depth comparison of the reduction in concentrations achieved by the remedial action can be seen in Figures 4-6 through 4-9 that present the baseline and post-remediation concentrations for each target VOC at all depths at each sampling location. Samples that were collected below the depth of LDA penetration are noted on the figures; as indicated above, data from these depths were not used in the performance evaluation.

It was observed that all of the baseline maximum concentrations of TCE, cis-1,2-DCE, and vinyl chloride occurred in SZ-4 (GW-06, -13, and -01, respectively) at depths between 20 and 40 feet bgs. The post-remediation maximum concentrations for cis-1,2-DCE and vinyl chloride also occurred in SZ-4 at locations GW-14 (13 feet bgs) and GW-10 (20 feet bgs), respectively; TCE was ND in all post remediation samples collected from depths penetrated by the LDA.

4.3.3 Groundwater Flux Evaluation

Baseline groundwater flux measurement results were presented in Section 4.1.3. The post-remediation flux measurements results were not available for inclusion in this report.

4.3.4 Source Area and Plume Evaluation

Multi-chamber monitoring wells have been installed at 14 locations within the treatment zone consistent with the locations of the DPT samples (see Section 4.2.2 and Figure 4-1). Sampling is scheduled to be conducted from these wells to confirm the DPT groundwater sampling results presented above, to define the post-remediation presence/absence of a source area, to define any residual dissolved groundwater contamination, and to monitor the long-term impacts of the remedial action on groundwater quality. Results from these wells were not available for inclusion in this report.

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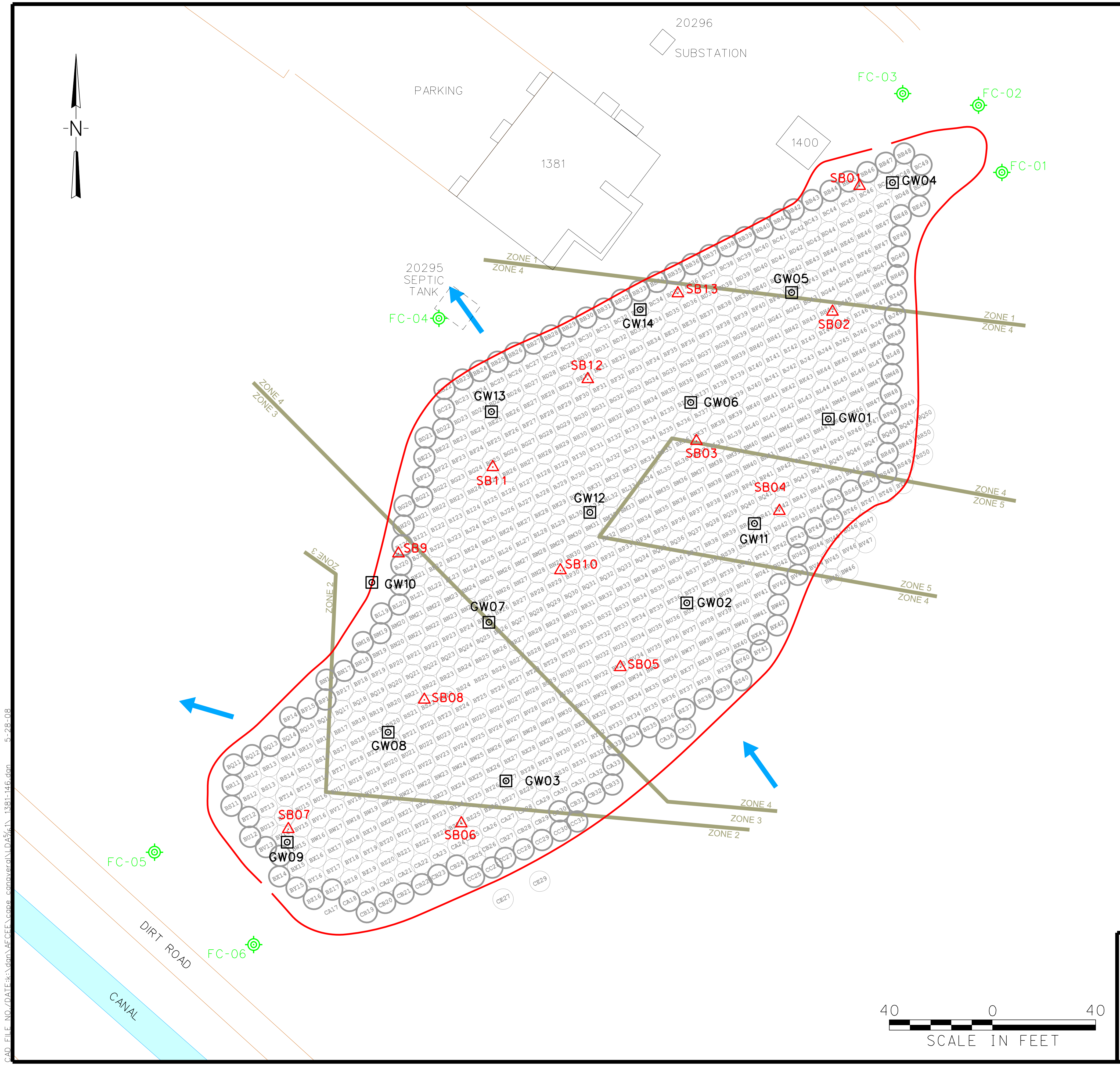
FIGURES



PERFORMANCE MONITORING LOCATIONS		
WELL ID	NORTHING	EASTING
GW01	1504361	797590
GW02	1504290	797535
GW03	1504221	797465
GW04	1504453	797615
GW05	1504410	797576
GW06	1504367	797536
GW07	1504282	797458
GW08	1504239	797419
GW09	1504197	797380
GW10	1504298	797413
GW11	1504320	797561
GW12	1504325	797497
GW13	1504364	797459
GW14	1504403	797517
SB01	1504451	797602
SB02	1504402	797591
SB03	1504352	797539
SB04	1504325	797571
SB05	1504265	797509
SB06	1504204	797447
SB07	1504202	797380
SB08	1504252	797433
SB09	1504309	797423
SB10	1504302	797486
SB11	1504342	797460
SB12	1504376	797497
SB13	1504410	797531

LEGEND

- DNAPL SOURCE AREA
- △ PRE-TREATMENT SOIL SAMPLE
- ⊡ PRE-TREATMENT GROUNDWATER SAMPLE
- ◎ FLUX CHAMBER (10'-40' BGS)
- ← APPROXIMATE GROUNDWATER FLOW DIRECTION
- ○ LARGE DIAMETER AUGER BORING LOCATION WITH GRID IDENTIFIER

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FIGURE 4-1
PERFORMANCE SAMPLING LOCATIONS

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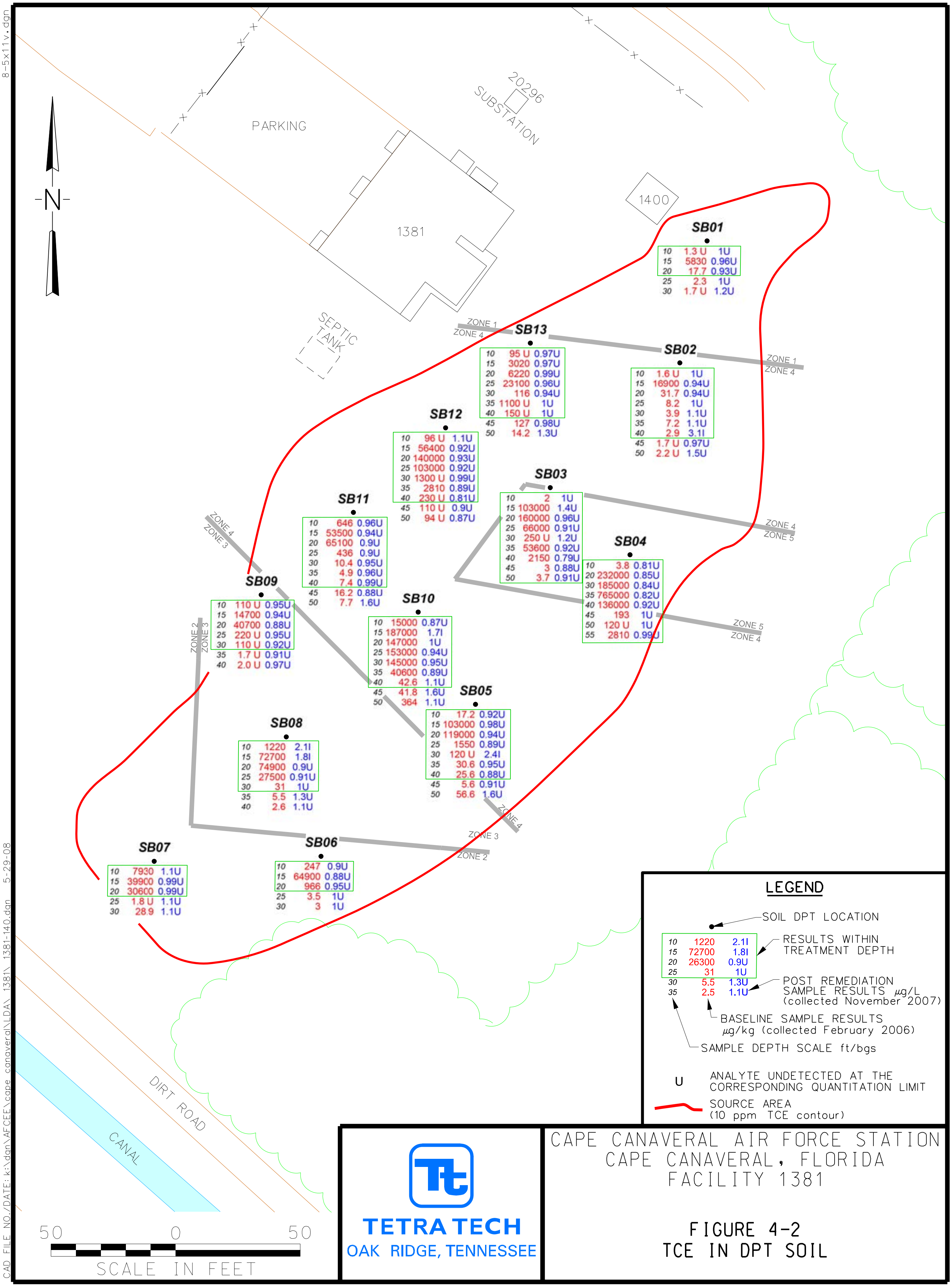

SB01

10	1.3 U	1U
15	5830	0.96U
20	17.7	0.93U
25	2.3	1U
30	1.7 U	1.2U

SB13

10	95 U	0.97U
15	3020	0.97U
20	6220	0.99U
25	23100	0.96U
30	116	0.94U
35	1100 U	1U
40	150 U	1U
45	127	0.98U
50	14.2	1.3U

SB02

10	1.6 U	1U
15	16900	0.94U
20	31.7	0.94U
25	8.2	1U
30	3.9	1.1U
35	7.2	1.1U
40	2.9	3.1I
45	1.7 U	0.97U
50	2.2 U	1.5U

SB12

10	96 U	1.1U
15	56400	0.92U
20	140000	0.93U
25	103000	0.92U
30	1300 U	0.99U
35	2810	0.89U
40	230 U	0.81U
45	110 U	0.9U
50	94 U	0.87U

SB03

10	2	1U
15	103000	1.4U
20	160000	0.96U
25	66000	0.91U
30	250 U	1.2U
35	53600	0.92U
40	2150	0.79U
45	3	0.88U
50	3.7	0.91U

SB11

10	646	0.96U
15	53500	0.94U
20	65100	0.9U
25	436	0.9U
30	10.4	0.95U
35	4.9	0.96U
40	7.4	0.99U
45	16.2	0.88U
50	7.7	1.6U

SB04

10	3.8	0.81U
20	232000	0.85U
30	185000	0.84U
35	765000	0.82U
40	136000	0.92U
45	193	1U
50	120 U	1U
55	2810	0.99U

SB09

10	110 U	0.95U
15	14700	0.94U
20	40700	0.88U
25	220 U	0.95U
30	110 U	0.92U
35	1.7 U	0.91U
40	2.0 U	0.97U

SB10

10	15000	0.87U
15	187000	1.7I
20	147000	1U
25	153000	0.94U
30	145000	0.95U
35	40600	0.89U
40	42.6	1.1U
45	41.8	1.6U
50	364	1.1U

SB05

10	17.2	0.92U
15	103000	0.98U
20	119000	0.94U
25	1550	0.89U
30	120 U	2.4I
35	30.6	0.95U
40	25.6	0.88U
45	5.6	0.91U
50	56.6	1.6U

SB08

10	1220	2.1I
15	72700	1.8I
20	74900	0.9U
25	27500	0.91U
30	31	1U
35	5.5	1.3U
40	2.6	1.1U

SB07

10	7930	1.1U
15	39900	0.99U
20	30600	0.99U
25	1.8 U	1.1U
30	28.9	1.1U

SB06

10	247	0.9U
15	64900	0.88U
20	966	0.95U
25	3.5	1U
30	3	1U

LEGEND

● SOIL DPT LOCATION

10	1220	2.1I
15	72700	1.8I
20	26300	0.9U
25	31	1U
30	5.5	1.3U
35	2.5	1.1U

RESULTS WITHIN TREATMENT DEPTH

POST REMEDIATION SAMPLE RESULTS µg/L (collected November 2007)

BASELINE SAMPLE RESULTS µg/kg (collected February 2006)

SAMPLE DEPTH SCALE ft/bgs

U ANALYTE UNDETECTED AT THE CORRESPONDING QUANTITATION LIMIT

SOURCE AREA (10 ppm TCE contour)

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FIGURE 4-2
TCE IN DPT SOIL

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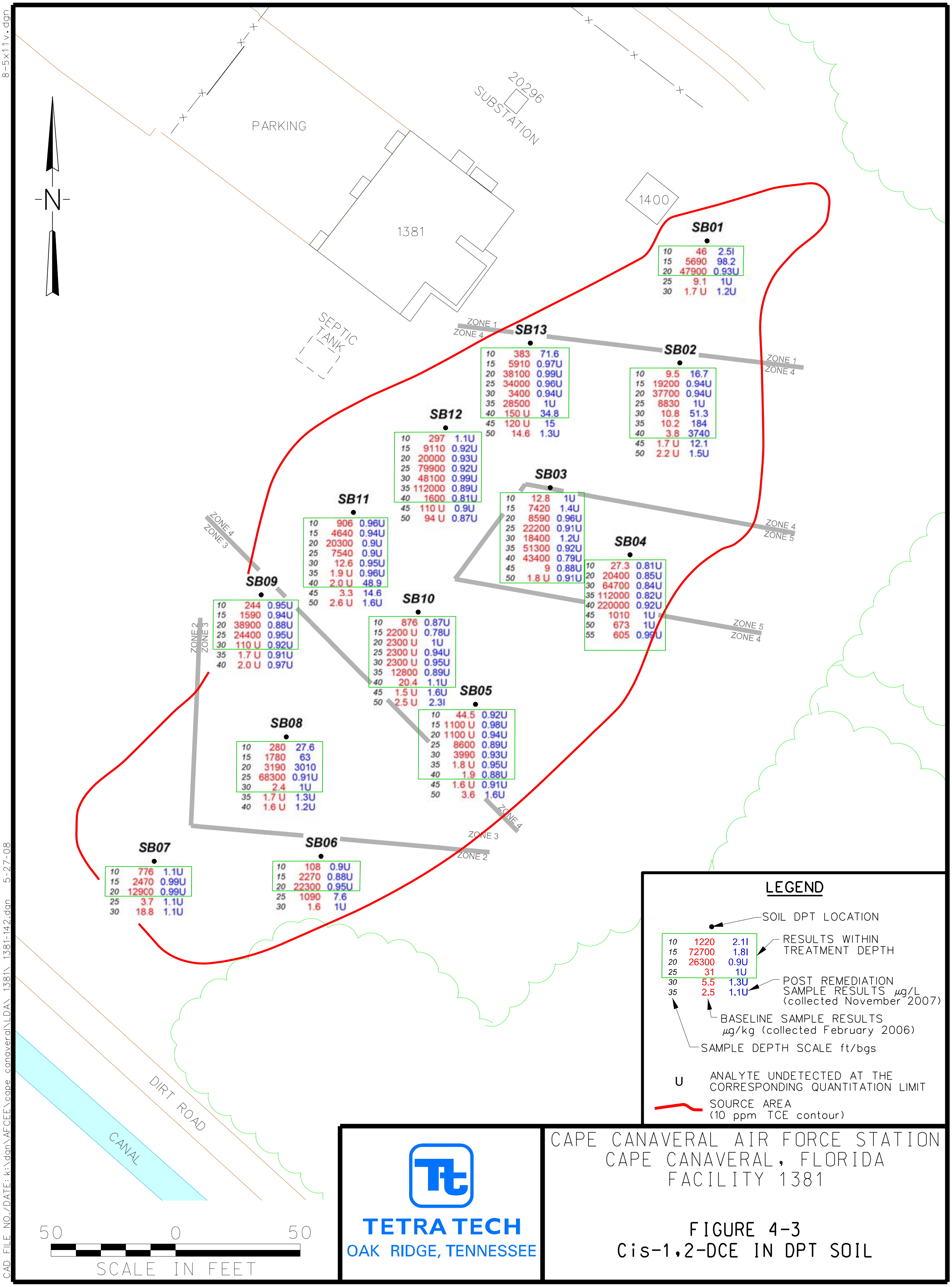

8-5x11v.dgn

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FIGURE 4-3
Cis-1,2-DCE IN DPT SOIL

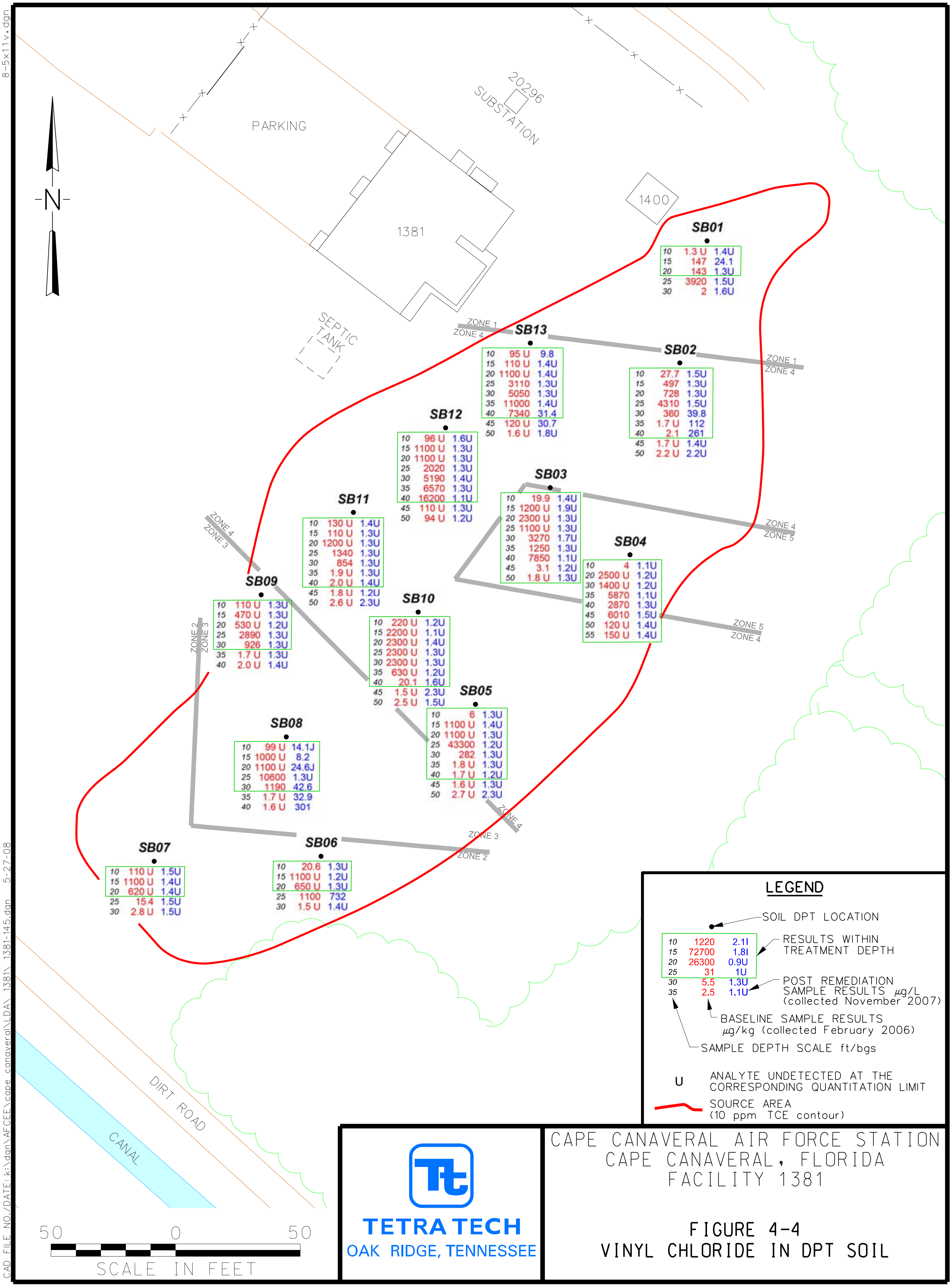

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FIGURE 4-4
VINYL CHLORIDE IN DPT SOIL

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8-5x11v.dgn

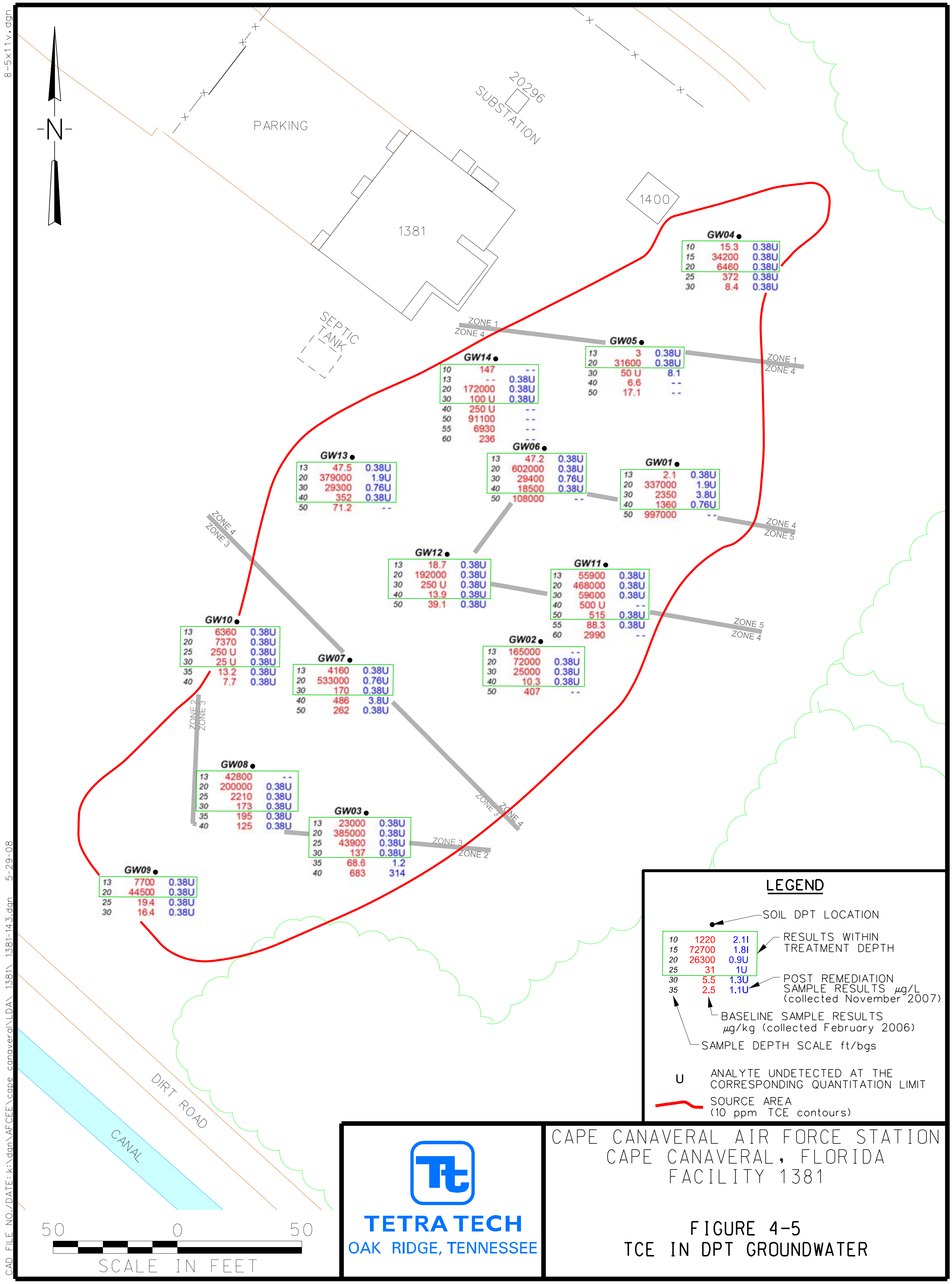

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FIGURE 4-5
TCE IN DPT GROUNDWATER

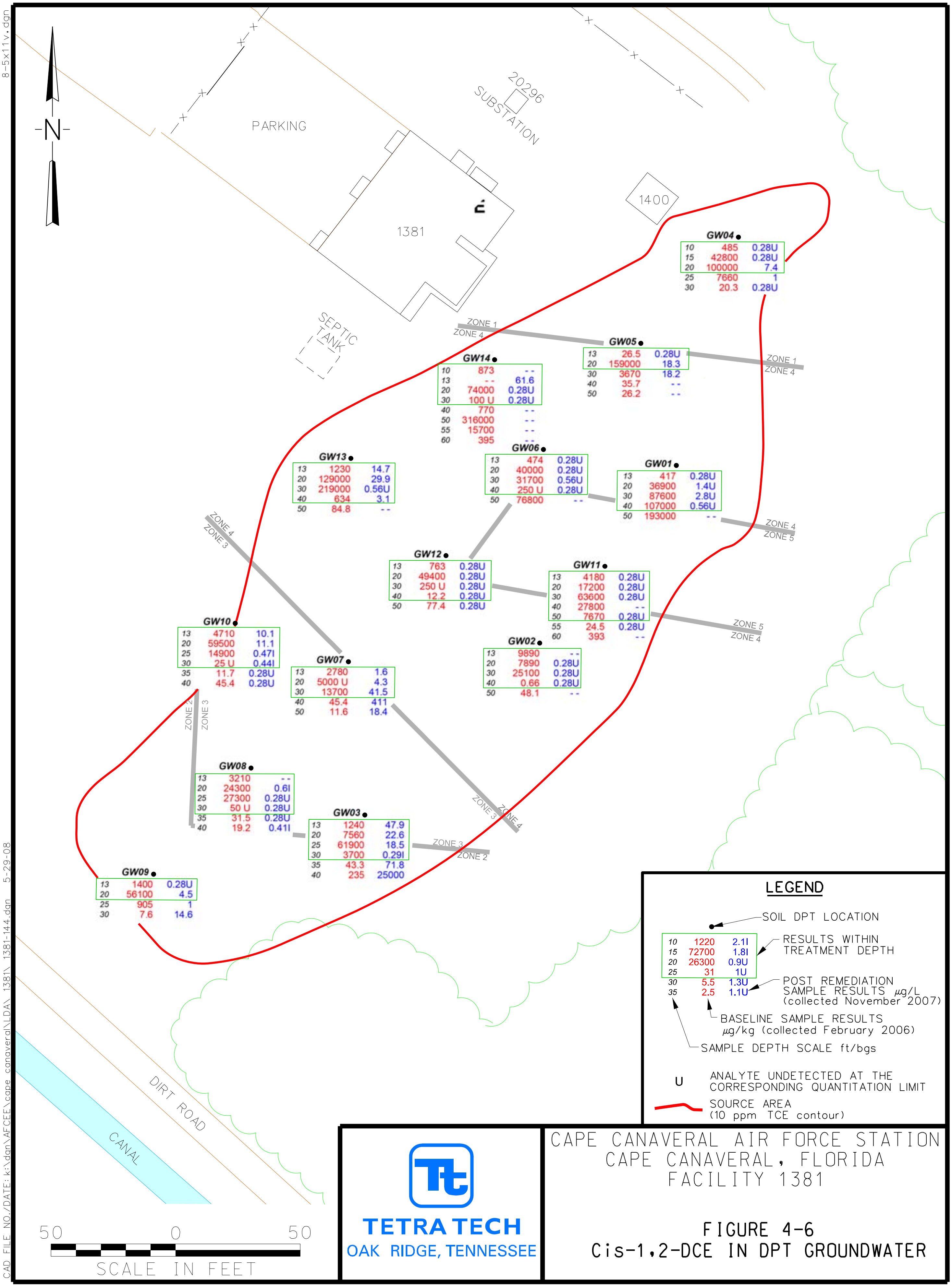

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FIGURE 4-6
Cis-1,2-DCE IN DPT GROUNDWATER

8-5x11v.dgn

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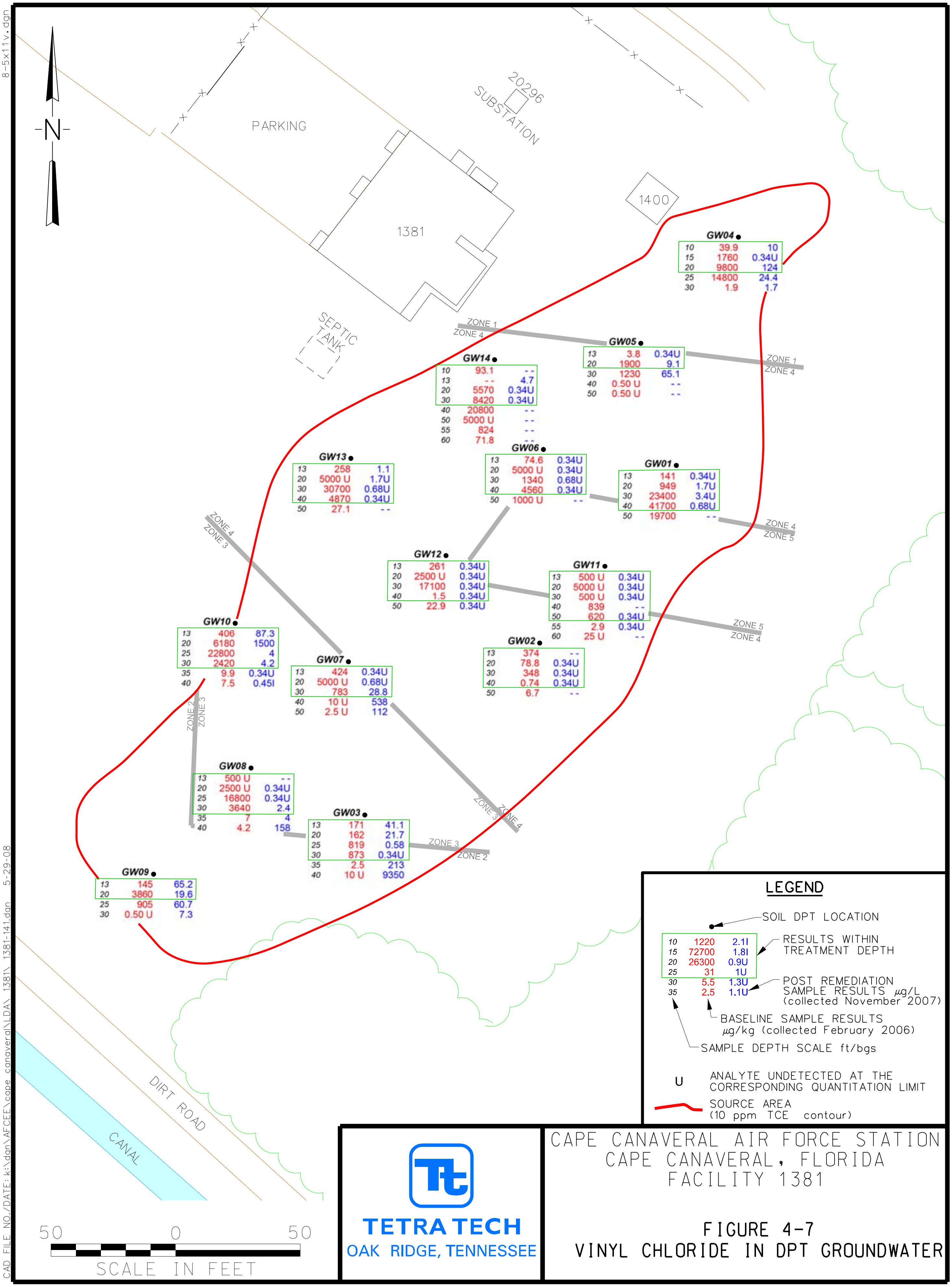

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FIGURE 4-7
VINYL CHLORIDE IN DPT GROUNDWATER

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5.0 CONCLUSIONS

5.1 TECHNOLOGY PERFORMANCE AND REMEDIATION EFFECTIVENESS

This section presents various lines of evidence for evaluating the effectiveness of in-situ soil mixing with injection of steam, hot air, and ZVI. The plan view, oblique view, and cross section profiles presented in Section 3.6 were used in evaluating the remediation effectiveness of this technology.

5.1.1 Total Mass Removal

A total of 9429, 1236, 109, and 618 pounds of TCE, cis-1,2-DCE, vinyl chloride, and Freon 113, respectively, were removed from the source area (i.e., sum of all treatment cells). These chemicals accounted for 99.6% of the total VOC mass removed (11,439 pounds). Individually, TCE, cis-1,2-DCE, vinyl chloride, and Freon 113 accounted for 82.4, 10.8, 0.95 and 5.4%, respectively, of the total VOC mass removed by the remedial action. The total mass removed for each VOC represents all phases that were present in the subsurface (e.g., pure phase, sorbed, dissolved). The PCE, trans-1,2-DCE, toluene, 1,1-DCA, and 1,1,1-TCA were present in limited areas; however, their total mass represented less than 1% of the total mass removed from the source area. These respective ratios of the VOCs removed are generally consistent with the site characterization data that showed the source area contamination to consist primarily of the more highly oxidized chlorinated VOCs. The total mass removed for each VOC and its percent of total mass removed for Facility 1381 is presented in Table 5-1. The total mass removed for each treatment cell location is presented in Appendix J and is presented in graphic form for the VOCs with the largest mass removed in Figures 3-18 through 3-23.

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Table 5-1. Total Mass Removed From Facility 1381

Contaminants	PCE	TCE	cis-1,2-DCE	trans-1,2-DCE	Vinyl Chloride	Freon 113	Benzene	Toluene	Ethyl-benzene	1,1-DCA	1,1,1-TCA
Mass (lbs)	1.33	9428.67	1236.07	2.78	109.00	618.11	0.00	1.48	0.003	9.42	32.05
Percent of Total Mass for Facility 1381	0.01	82.43	10.81	0.02	0.95	5.40	0.00	0.01	0.00	0.08	0.28

Notes:

The mass removal numbers do not account for any fugitive emissions from vapors reaching the surface not captured in the shroud.
The mass removal numbers do not account for any in-situ residual mass breakdown from the ZVI.
PCE – Tetrachloroethylene
TCE – Trichloroethylene
Cis-1,2-DCE – Cis-1,2-Dichloroethene
Trans-1,2-DCE – Trans-1,2-Dichloroethene
1,1-DCA – 1,1-Dichloroethane
1,1,1-TCA – 1,1,1-Trichloroethane
lbs - pounds

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5.1.2 Evaluation of Off-Gas VOC Reduction in a Previously Treated Area

On March 3, 2007, cells BQ43, BS44, and BQ45 were retreated to evaluate and compare the contaminant reduction and mass removal between the initial treatment and retreatment. Cells BQ43, BS44, and BQ45 were selected for retreatment since these cells were some of the highest contaminated cells at the site. Figure 3-12 illustrates the locations of BQ43, BS44, and BQ45, and Figure 3-14 shows the mass of TCE removed from these cells. The initial treatment and retreatment information is summarized in Table 5-2.

Table 5-2: Initial Treatment/Retreatment Information for Cells BQ43, BS44, and BQ45

Treatment Cell	Initial Treatment					Re-Treatment	
	Date Treated	Highest TCE Value on Final Pass (ppm)	TCE Value on Iron Pass (ppm)	Extra Thermal Treatment Time (min)	Iron Treatment (lbs)	Date Re-treated	Highest TCE Value on Re-treat (ppm)
BQ43	12/18/2006	1527 (55'); 1373 (20')	448	90	3500	3/3/2007	12
BS44	9/21/2006	2017	514	0	4500	3/3/2007	12
BQ45	10/14/2006	1615	45	60	3500	3/3/2007	54

ppm – parts per million
lbs – pounds
min - minutes

The total of seven figures were prepared for each of the three retreatment cells (Figures 5-1 through 5-21), as follows:

- A series of four figures showing plots of the concentration versus depth over treatment time for TCE, cis-DCE, methane, and FID readings, for both the initial and retreatment LDA passes.
- A pair of figures showing plots of the TCE concentration versus depth during the last thermal pass of the initial treatment and for the retreatment, and a plot with an expanded concentration scale to demonstrate the relatively low concentrations present during the retreatment passes.
- A single figure showing a plot of the methane concentration versus depth during the last thermal pass of the initial treatment and the retreatment.

The initial treatment plots presented in each of the first two figures for each cell (e.g., Figures 5-1 and 5-2 for cell BQ43) demonstrate that the treatment process was effective at reducing the concentrations of TCE and cis-DCE by successive passes of the LDA. It can be observed in the figures for each of these three cells that the TCE and cis-DCE concentrations are distinctly lower during the last thermal pass compared to the earlier series of thermal passes. It should be noted that the last pass of the LDA represents iron injection and does not reflect the thermal input of earlier passes. The third and fourth figures for each cell (e.g., Figures 5-3 and 5-4 for cell BQ43) show how methane and total FID readings varied over the course of treatment. In general, methane does not show a sustained decrease in concentration during the initial treatment. On the other hand, the total FID readings do show a decrease over treatment time that reflects the reduction in VOCs as they are removed from the subsurface, but it must be noted that the FID readings also reflect the methane concentration in the off-gas.

The TCE concentration reduction during the initial treatment was greater than 93% for each of these three cells; however, because the initial maximum concentrations were relatively high (e.g., 33,302 ppm at BQ43) the residual concentration shown for the last thermal pass was also relatively high (e.g., 1466 ppm at BQ43). Per the protocols, each of these cells was given additional passes of the LDA. It was noted that the retreatment plots presented in each of the first two figures for each cell demonstrate that the TCE and cis-DCE concentrations were significantly lower during the first thermal pass of the retreatment event (note that the concentration scale on the left side of each plot has changed for the retreatment data). A detailed comparison of the TCE concentration during the last thermal pass of the initial treatment with the TCE concentration during the retreatment pass is shown in the fifth figure for each cell (e.g., Figure 5-5 for BQ43). The “red line” shown in Figure 5-5 tracks the reduction in TCE concentration between the two treatment events that were separated by 75 days for cell BQ43. These data show a two orders of magnitude reduction in TCE concentration that occurred during the period of inactivity between the two treatment events and is attributed, at least in part, to the action of the ZVI emplaced, together with heat and time, in the subsurface. Additional attenuation mechanisms may include residual volatilization of VOCs due to residual heat, dilution, and other biological activity. The sixth figure (e.g., Figure 5-6 for BQ43) uses an expanded concentration scale to show the depth verses concentration relationship of TCE observed during only the retreatment. These plots suggest that a residual, low-range concentration of TCE remains across the treated zone for each of the three cells (e.g., 8 to 12 ppm TCE for cell BQ43) due to the mixing action of the LDA and the ongoing destruction of VOCs by the ZVI (and other attenuation mechanisms), which reflects the high percentage of mass removed,.

The seventh figure presented for each cell (e.g., Figure 5-7 for cell BQ43) focuses on the methane observed during the last thermal pass of the initial treatment and the methane observed during the retreatment event. Again, for each of the three cells, a minimum of 75 days of inactivity occurred between the two treatment events. The data show a clear increase in the concentration of methane (up to an order of magnitude at cells BQ43 and BS44) between the two treatment events; however, the mechanism responsible for the increase has not been determined. One possible explanation incorporates a flourish of biological activity, following sufficient cooling of the subsurface, spurred by the presence of a substrate offering favorable geochemical conditions and a source of easily accessible electron donors (residual VOCs) provided by the mixing action of the LDA.

Figure 5-22 illustrates the mass removal comparison between initial treatment and retreatment of cells BQ43, BS44, and BQ45. As was shown above by the reduction in the concentrations of VOCs, there was essentially little mass present in the subsurface when the retreatment was performed. Therefore, it is evident that the initial thermal and iron treatment of cells BQ43, BS44, and BQ45, in some of the highest contaminated areas of the site, effectively removed VOCs from the source area.

5.1.3 Off-Gas VOC Removal Efficiency

Mass removal from the source area is a key indicator of the LDA technology feasibility. Inspection of the maximum concentration and mass removal figures presented in Section 3.6.1 (e.g., compare Figures 3-31 and 3-46) show where high concentrations of TCE were encountered and where high mass removal was achieved; thus, a reduction in the concentration of VOCs in the off-gas is a direct indicator of mass depletion. Based on this correlation, an evaluation was performed to estimate the mass removal efficiency by comparing the maximum concentration of TCE detected during the first pass of the LDA with the maximum concentration detected in the last pass for each treatment cell; the percent reduction in concentration is deemed an indicator of the mass removal efficiency.

TCE was selected for the removal efficiency analysis because it represents 82.4% of the total mass removed and was detected at higher concentrations than any other VOC. For this analysis, the TCE concentration data from the off-gas analysis performed for all cells was used, including the most highly and least contaminated cells, with two exceptions: (1) 45 cells that showed no TCE concentration during the first pass were not included, and (2) 25 cells that showed no reduction in TCE, primarily because the protocols did not require a second pass of the LDA, were not included since insufficient data were available for the first/last pass analysis. Subsequently, the data from 726 cells were used in the analysis.

The TCE removal efficiency data are summarized in Table 5-3 and are organized from the highest to the lowest percent of reduction (first column). The last column in the table shows the cumulative percent of all cells that fall into each reduction level. As shown by this analysis, greater than 90% reduction was achieved in over 78% of the cells treated (569 of 726 cells) and, because all cells were the same size, the data show that 90% TCE reduction was achieved over 78% of the source area. The complete data set showing the first and last TCE concentration data and percent reduction for each cell is provided in Appendix V. Inspection of the summary data in the table for the first pass average concentration column shows a range of concentrations between 23,108 and 132 ppm, or a range of two orders of magnitude; these data represent the concentration of TCE encountered during the first passes of the LDA. A similar range is noted for the median concentration column. The table also shows the last pass average (and median) range of maximum concentrations between 185 and 55 ppm, or a range of concentration reduction of up to two orders of magnitude between the first and last LDA passes for all cells with greater than 50% reduction. A regression analysis of the maximum concentration versus the removal efficiency for all cells with a first pass concentration greater than 10,000 ppm (83 cells) shows no correlation, indicating that the ability of the technology to remove VOCs was not exceeded by the concentrations encountered in the source area.

All cells were grouped together below 50% reduction due to the relatively small number of cells in this category (32 out of 726 cells, or approximately 4% of treated cells; see Table 5-3). A review of the operations data for these cells showed that limited treatment was performed because the TCE concentrations did not exceed, or were marginally above, either the standard or alternate protocol concentrations. Only one of the cells (BQ23) in this category appears to have been under-treated due to the TCE increasing slightly above 250 ppm on final pass at 18 feet bls; however, iron injection had already been started in cell when the elevated TCE concentration was determined. Approximately 2,250 pounds of iron was injected in cell and the residual TCE noticed at 18 feet bls is anticipated to have been reduced. Upon retraction from the iron injection pass, TCE values of approximately 25 ppm were obtained in the off-gas.

Table 5-3. TCE Removal Efficiencies in Off-gas

Percent Reduction	No. Cells	1st Pass Ave. Conc. (ppm)	1st Pass Median Conc. (ppm)	Last Pass Ave. Conc. (ppm)	Last Pass Median Conc. (ppm)	Cumulative % Cells
100	257	464	55	0	0	35.4
>99	72	23108	15372	96	42	45.3
>95	157	8981	2064	185	58	66.9
>90	83	2550	532	173	37	78.4
>80	62	495	153	66	21	86.9
>70	30	240	87	55	20	91.0
>60	20	179	87	64	27	93.8
>50	13	132	132	57	57	95.6
<50	32	106	71	74	48	4.4

5.2 TREATMENT COST ANALYSIS

The cost for treatment at Facility 1381 can be broken down into two separate costs: total project cost and cost for thermal treatment per cubic yard. The contract structure for source area treatment utilizing in-situ soil mixing with steam and hot air with ZVI injection included cost for treatment at SPCC and Facility 1381; therefore, cost items such as mobilization and equipment procurement and other direct costs (ODCs) were shared between the two projects. The following sections discuss the two separate cost values for treatment at Facility 1381.

5.2.1 Total Project Cost per Cubic Yard

The total project cost for treatment at Facility 1381 includes the cost for thermally treating the volume of soil as well as all associated project management, construction oversight, survey activities, figure generation, database management, sampling activities, report preparation and finalization, on-site chemist/engineer/ health and safety, permitting activities, equipment procurement, travel cost, ZVI cost, and fuel cost. Cost not reflected in this total cost includes wastewater disposal cost associated with the removal of the FTO blow-down water off-site and treatment at the base Trident Industrial Wastewater Treatment Facility, site demolition, and monitoring well removal. The total project cost for treatment of approximately 44,292 cubic yards at Facility 1381 was approximately $9,000,000. Comparing the total cost to the total cubic yards treated, this breaks down into a cost of approximately $203 per cubic yard of soil treated at the site.

5.2.2 Thermal Treatment Cost per Cubic Yard

Thermal treatment cost only includes the cost for thermally treating the soil column (and minimal cost for injection of the ZVI). Items included in this cost are remedial equipment cost, mobilization and demobilization, anticipated down days, site preparation and closure activities. Items not reflected in this thermal treatment cost include cost for associated survey activities, figure generation, database management, sampling activities, report preparation and finalization, on-site chemist/engineer/health and safety, permitting activities, equipment procurement, travel cost, ZVI cost, and fuel cost. The total cost for thermally treating the 44,292 cubic yards of soil was approximately $5,000,000. This breaks down into a cost of approximately $113 per cubic yard of soil treated at the site.

5.3 LESSONS LEARNED

The following section details the observations and lessons learned during the implementation of remedial efforts at Facility 1381. These observations and lessons learned have been generated from field experience and data analysis in order to optimize system operation for the implementation of in-situ thermal soil mixing with steam and hot air and ZVI injection for Facility 1381 and future projects involving this technology.

5.3.1 Subsurface Thermocouple Investigation

Five subsurface thermocouples were installed to a maximum depth of 29 feet bgs in five treated cells thermally treated within 5 days of the thermocouple investigation. The purpose for this investigation was to verify and correlate the soil column temperature related to the shroud temperature obtained during treatment of the cell. The thermocouples were installed utilizing ¾-inch galvanized steel pipe casing driven to the maximum depth of 29 feet bgs with a fence post driver. Very little resistance was experienced placing the thermocouples at depth once the backfill was driven through. As a health and safety precaution, personnel were suspended over the treatment cell in a man-lift in order to prevent foot traffic on the cell itself. Table 5-4 provides the data of the five subsurface thermocouples collected at the project site.

All five treatment cells under subsurface thermal investigation were Zone 5 cells requiring the heating of a 40 foot column (at a minimum). Treatment cells BP38 and BL35 were treated thermally to 160^{o}F as required in the treatment protocols for high contamination. Treatment cells BN34, BM33, and BP34 were only treated to 150^{o}F to test the subsurface thermal temperature with the thermocouples. The data from the thermocouples (although not spanning through the entire column) indicated that in all cases temperatures were elevated to within an approximate 10^{o}F of the shroud temperature (160^{o}F) in the zone tested, therefore verifying adequate heating of the column causing vaporization of the COCs.

5.3.2 Shroud Lifting Events and Mechanics

Shroud lifting events occurred throughout the project during thermal treatment (steam and hot air application). Lifting events generally caused the shroud to rise off the ground 1-2 feet, causing it to land

Table 5-4. Subsurface Thermocouple Data within Previously Treated Cells

Depth (ft bgs)	Collected on 1/27/07		Collected on 2/5/07		Collected on 2/6/07
	Temperature (degrees F)				
	BP38 (Treated 1/23/07 to 160°F shroud temp)	BL35 (Treated 1/27/07 to 160°F shroud temp)	BN34* (Treated 2/5/07 to 150°F shroud temp)	BM33* (Treated 2/5/07 to 150°F shroud temp)	BP34* (Treated 2/6/07 to 150°F shroud temp)
29	--	--	--	--	162
28.5	172	173	159	--	--
20	--	--	--	153	--
19	--	--	--	--	161
18.5	171	175	161	--	--
18	--	--	161	--	--
17.5	--	--	161	--	--
17	--	--	160	--	--
15	--	--	--	148	--
14	--	--	--	--	161
13.5	170	175	--	--	--
10	--	--	--	132	--
9	--	--	--	--	158
8.5	168	174	--	--	--
4	--	--	--	--	158
3.5	152	176	--	--	--
1	115	173	--	--	155

-- Indicates not collected

* Treated cell to 150°F for investigation

heavily onto the surface. These lifting events usually occurred on Zone 4 and Zone 5 cells (deeper drilled cells) in an area of higher clay content and during periods of prolonged thermal treatment. On December 22, 2006 while drilling on cell BR43, a shroud lifting occurrence caused major damage to the shroud lifting mechanics and several days delay. During drilling retraction from 57 feet bgs, the shroud suddenly rose several feet in the air and landed back on the ground, causing damage to the lifting mechanics of the shroud. The auger was retracted to zero feet bgs and inspection of the damage commenced. Damage resulting from the shroud rise and impact was primarily on the hydraulic shroud lifting system. The speculated cause of the shroud lifting was determined to have been generated from the application of steam and hot air into a volume of soil with low permeability and higher clay content. Continual application of steam and hot air within this zone (especially during focused passes) caused the buildup of pressure within that soil column. Upon retracting from the 57 foot treatment depth, the pressure buildup was suddenly released and drawn to the surface into the shroud. The hydraulic lifting system for the shroud locked the shroud into position over the treatment cell, not allowing the pressure buildup to release adequately. Due to this restraint, the force caused by the pressure buildup was greater than the force holding the shroud in position, which resulted in the shroud lifting event and extensive damage. Due to this event, a re-design of the shroud lifting system was performed and implemented focused around a restraint free lifting system to adequately relieve potential pressure releases from the cell. The re-design included discarding the hydraulic system and utilizing the existing crane cables on the crane boom and attaching them to the shroud lifting arms. The shroud lifting arms were then connected to chains on the shroud.

After the implementation of the re-designed shroud lifting system, pressure releases were periodically observed and recorded; however, shroud lifting occurrences were very minimal. Design drawings of the shroud re-design are included in Appendix W.

5.4 SUMMARY

Various lines of evidence have been presented for evaluating the effectiveness of in-situ soil mixing with injection of steam, hot air, and ZVI. Summarized below are the important indicators of the success of the remedial action at Facility 1381:

- Approximately 11,439 pounds of VOCs were removed and destroyed from 797 8-foot diameter treatment cells. TCE and cis-1,2-DCE accounted for 93.2% of the total mass removed in relative amounts of 9,249 and 1,236 pounds, respectively.

- Assuming that the original release consisted primarily of pure-phase solvent, and using a TCE density of 1.47 grams per cubic centimeter, calculations indicate that 2,854 liters, or 754 gallons, of TCE were removed from the aquifer. Due to its density and its relatively low partition coefficient, TCE has a tendency to result in a large dissolved plume in porous sediments given sufficient time for distribution of the chemical through the aquifer. Based on a volume of 754 gallons of TCE in the source area and neglecting degradation and attenuation., calculations for a hypothetical 40-feet thick aquifer indicate that an area of 944 acres around Facility 1381 could become contaminated at a concentration of 300 μg/L (i.e., two orders of magnitude greater than the GCTL) if left untreated.

- The peak concentration of TCE was observed on the first pass in 85.5% of the first pass of the LDA in the treated cells. This observation demonstrates that the first pass data is a reliable indicator of contamination and can be used to establish treatment protocols.

- Retreatment data show a two orders of magnitude reduction in TCE concentration that occurred during the period of inactivity between the two treatment events. This reduction is primarily attributed to the action of the ZVI emplaced in the subsurface. Therefore, injection of ZVI is considered as an essential step for treating the residual VOCs.

- Comparison of the maximum off-gas concentration of TCE from the early thermal passes with the last thermal pass of the LDA for all treated cells showed that concentrations were reduced by greater than 90% in more than 78% of all cells; only 4% of cells attained a less than 50% reduction in concentration.

The data demonstrate that operational protocols that incorporate systematic planning, dynamic decisions, and real time measurements provide a successful remedial strategy resulting in attaining the goals of mass reduction through the source area.

FIGURES

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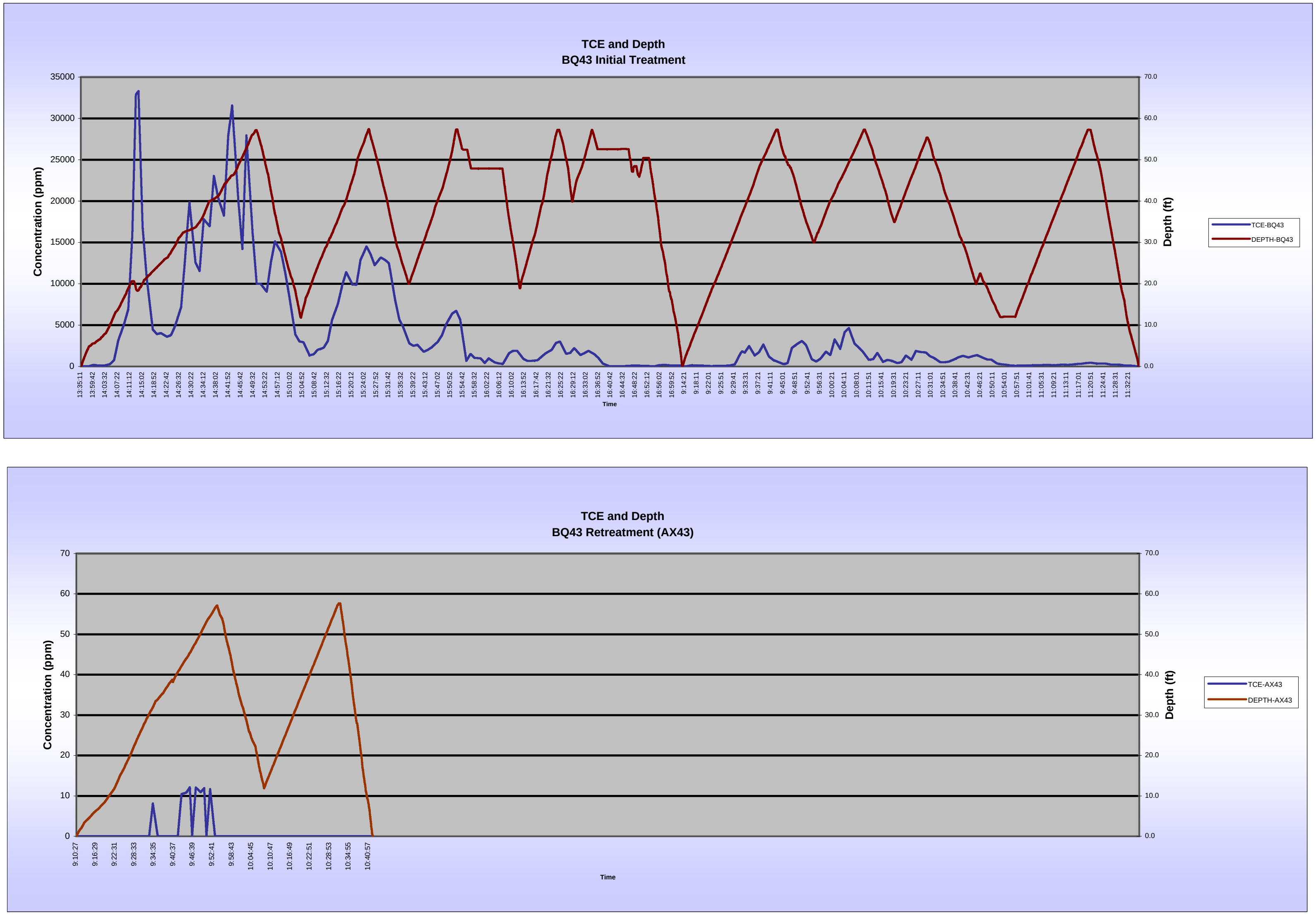
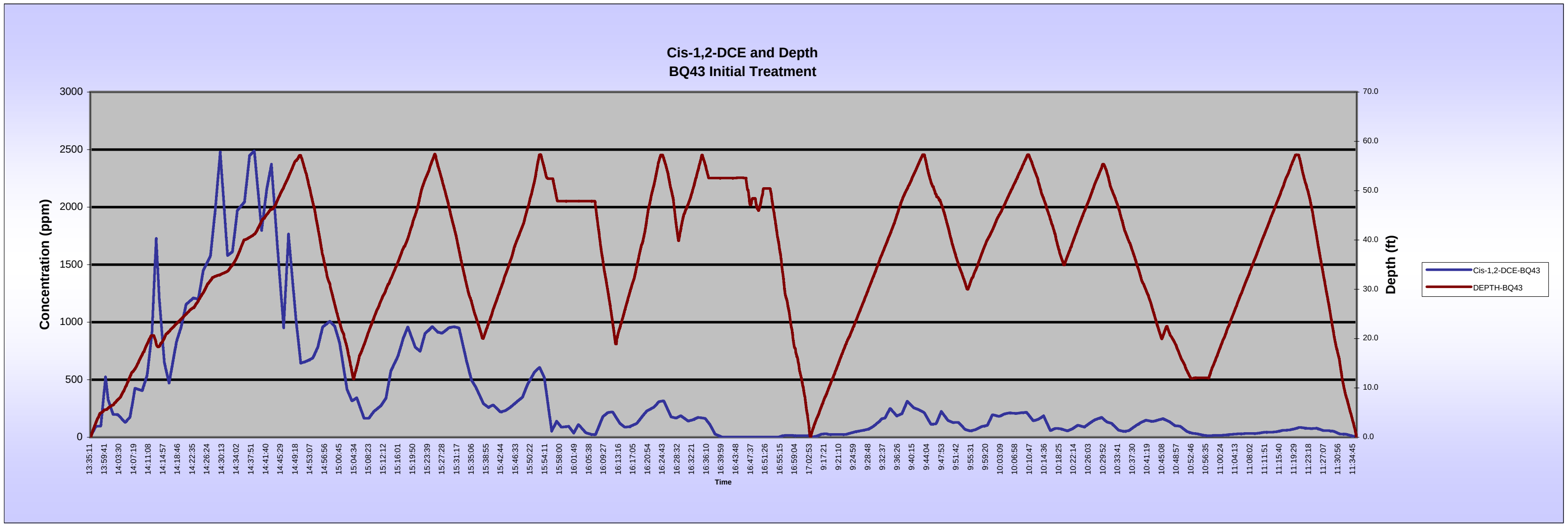


Figure 5-1: TCE Vs. Depth for BQ43 and BQ43 Retreatment



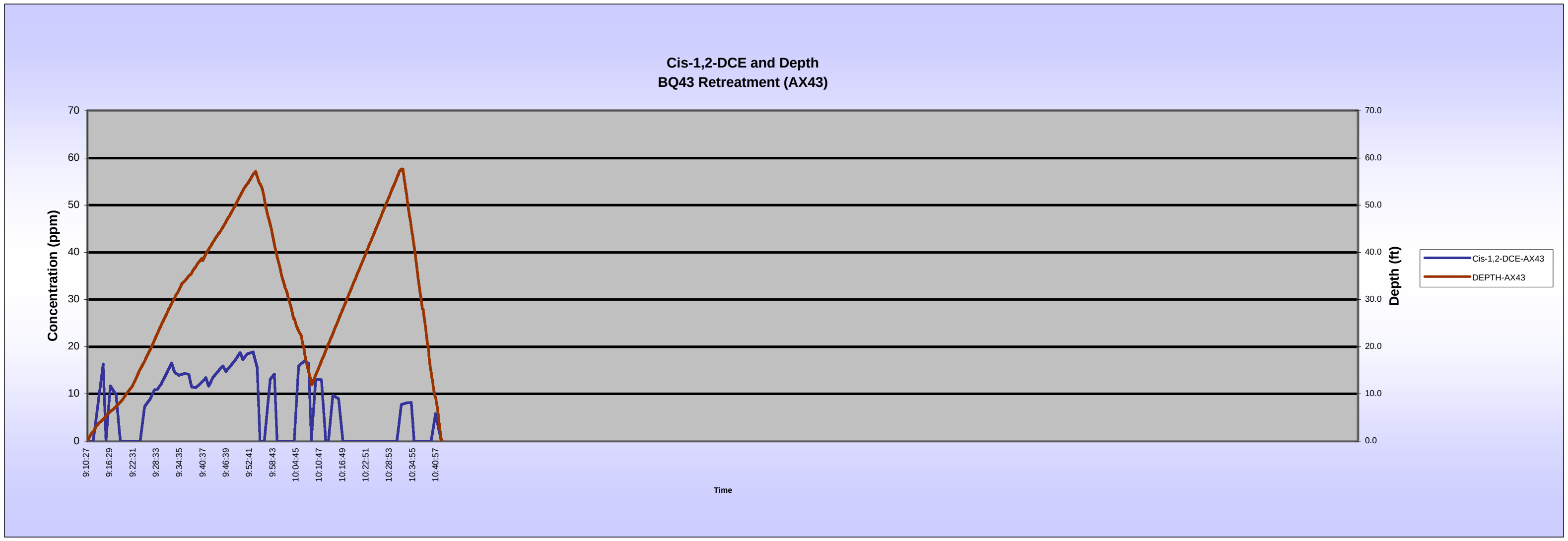


Figure 5-2: Cis-1,2-DCE Vs. Depth for BQ43 and BQ43 Retreatment

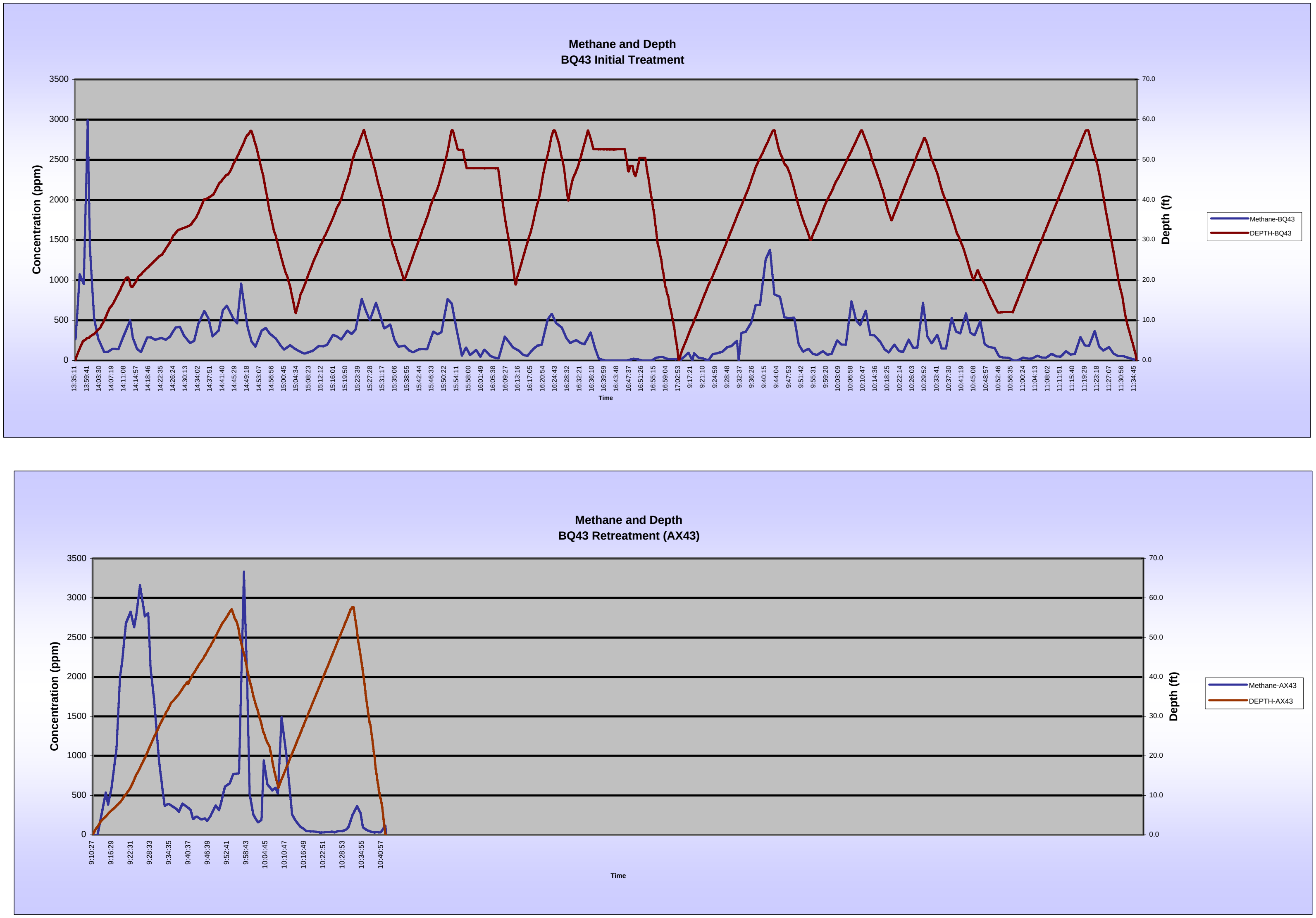


Figure 5-3: Methane Vs. Depth for BQ43 and BQ43 Retreatment

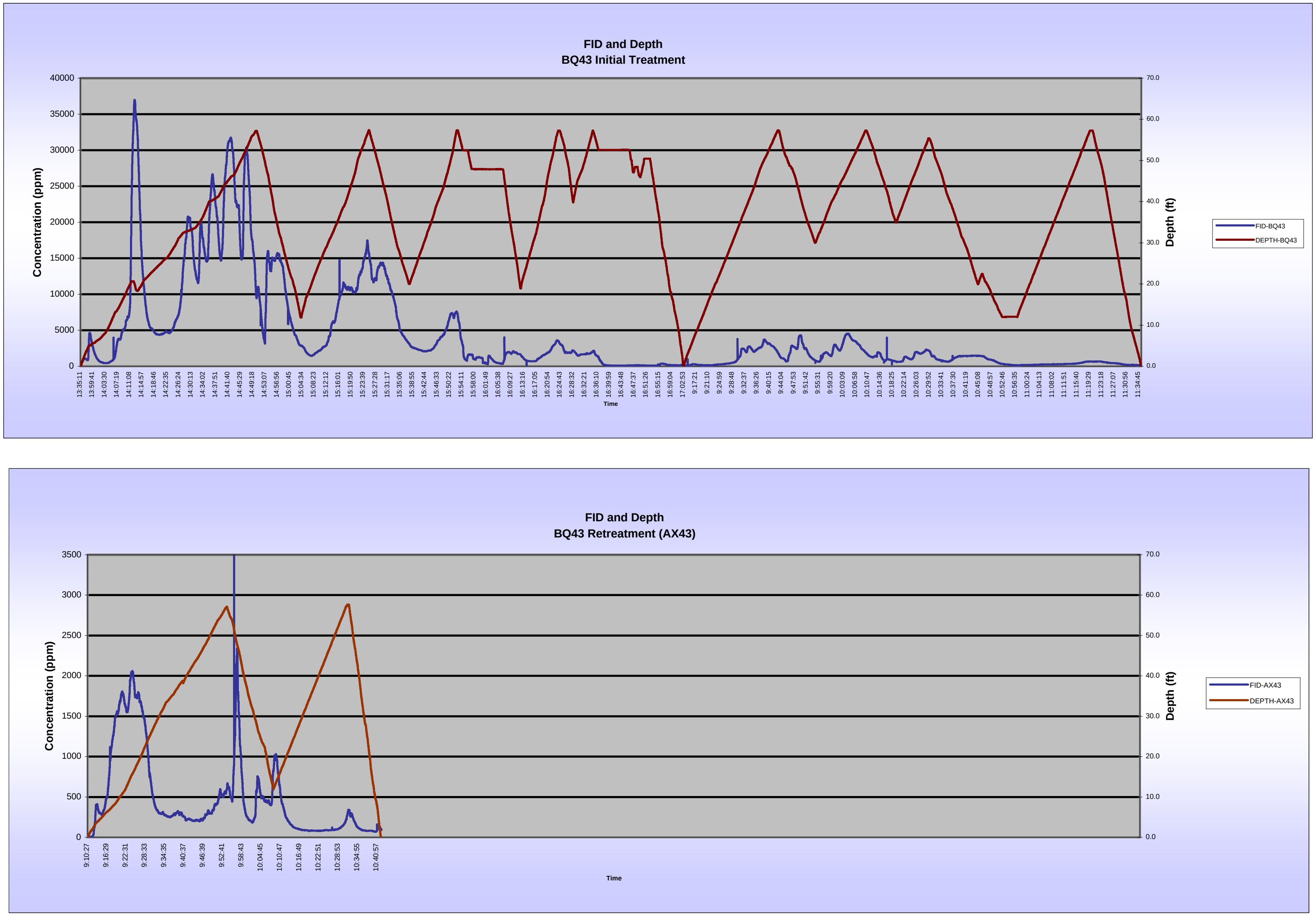


Figure 5-4: FID Vs. Depth for BQ43 and BQ43 Retreatment

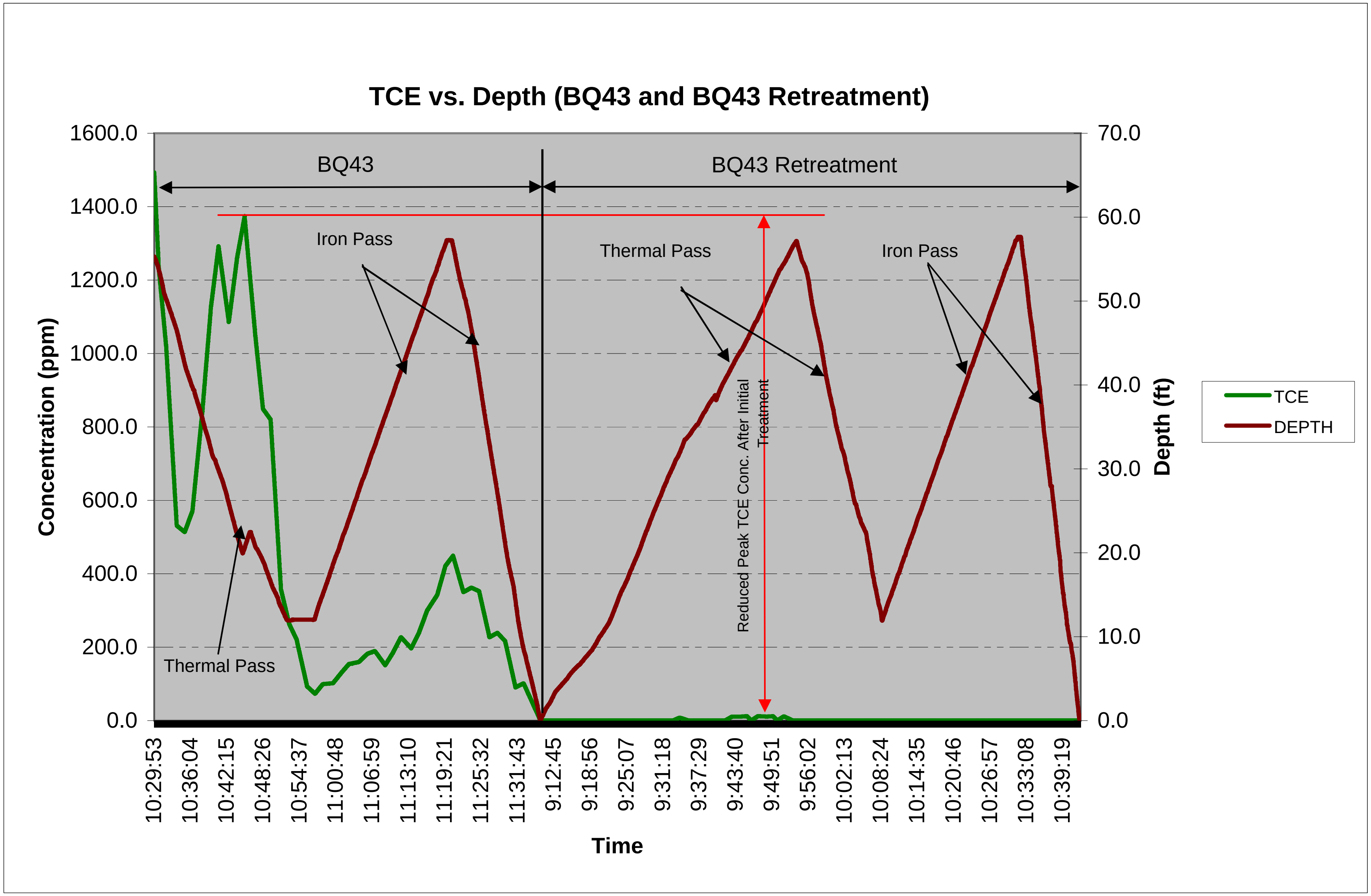


Figure 5-5: TCE Vs. Depth for BQ43 and BQ43 Retreatment Showing Reduction in Peak TCE Concentration Between Treatments

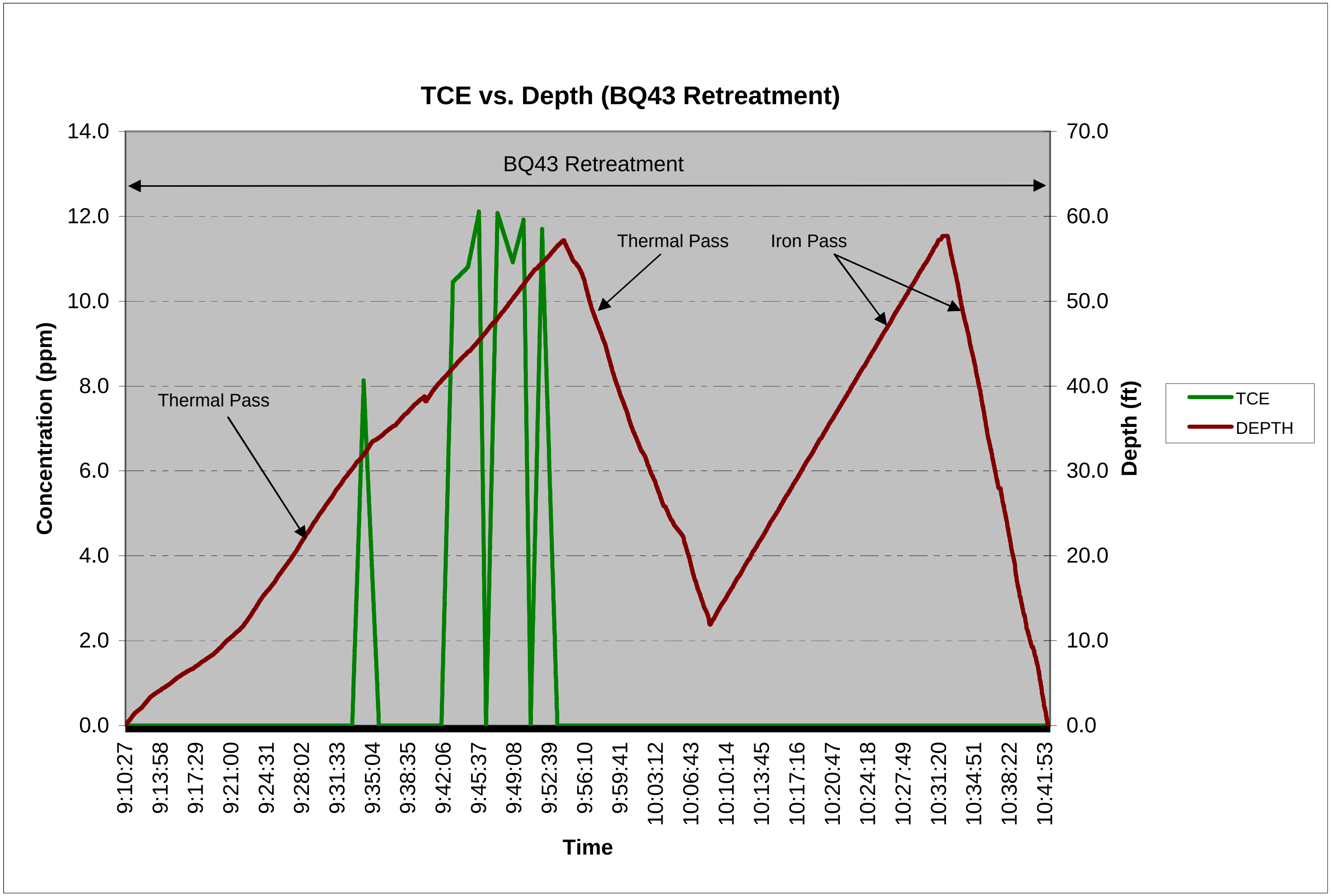


Figure 5-6: TCE Vs. Depth for BQ43 Retreatment

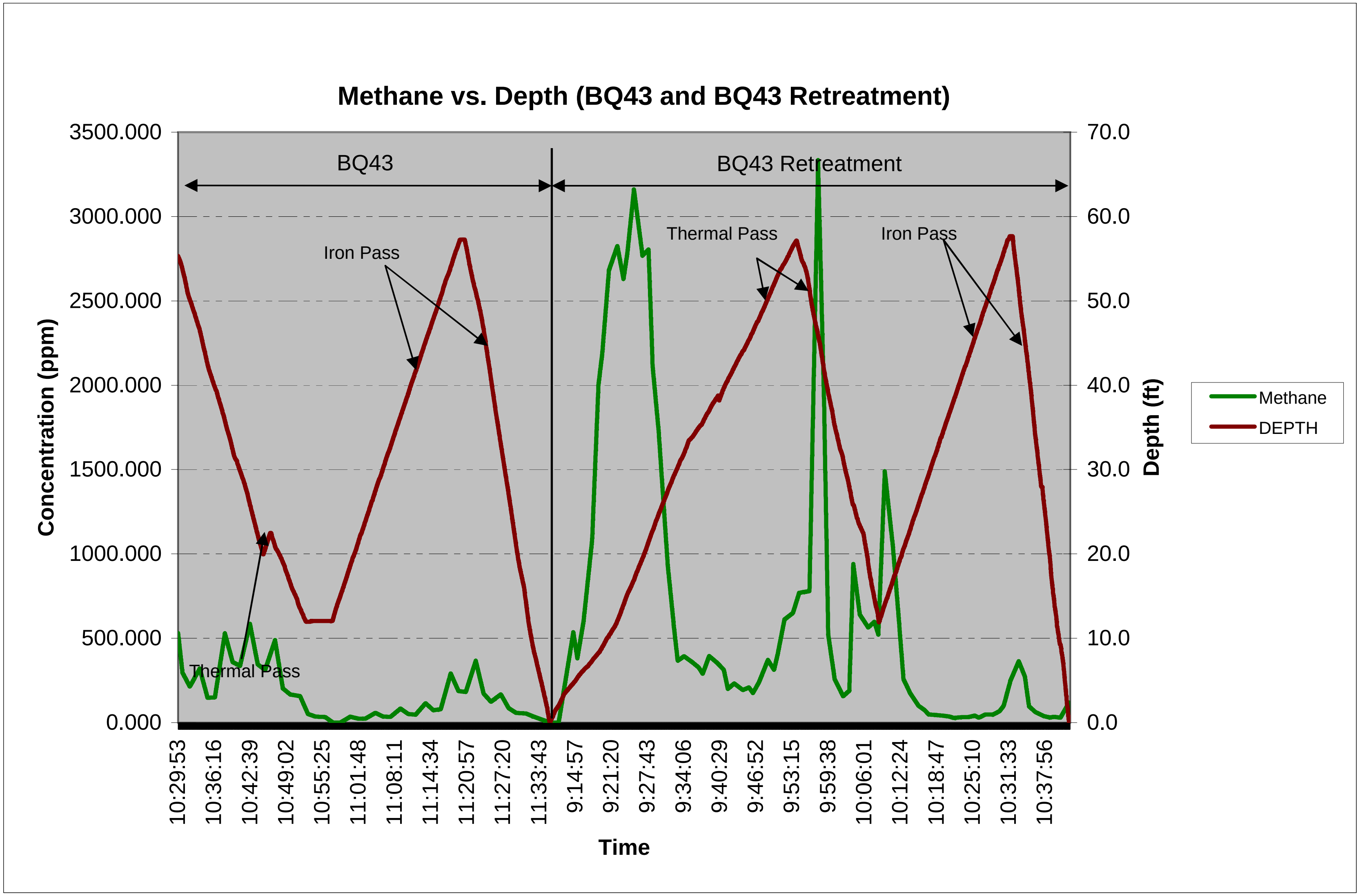
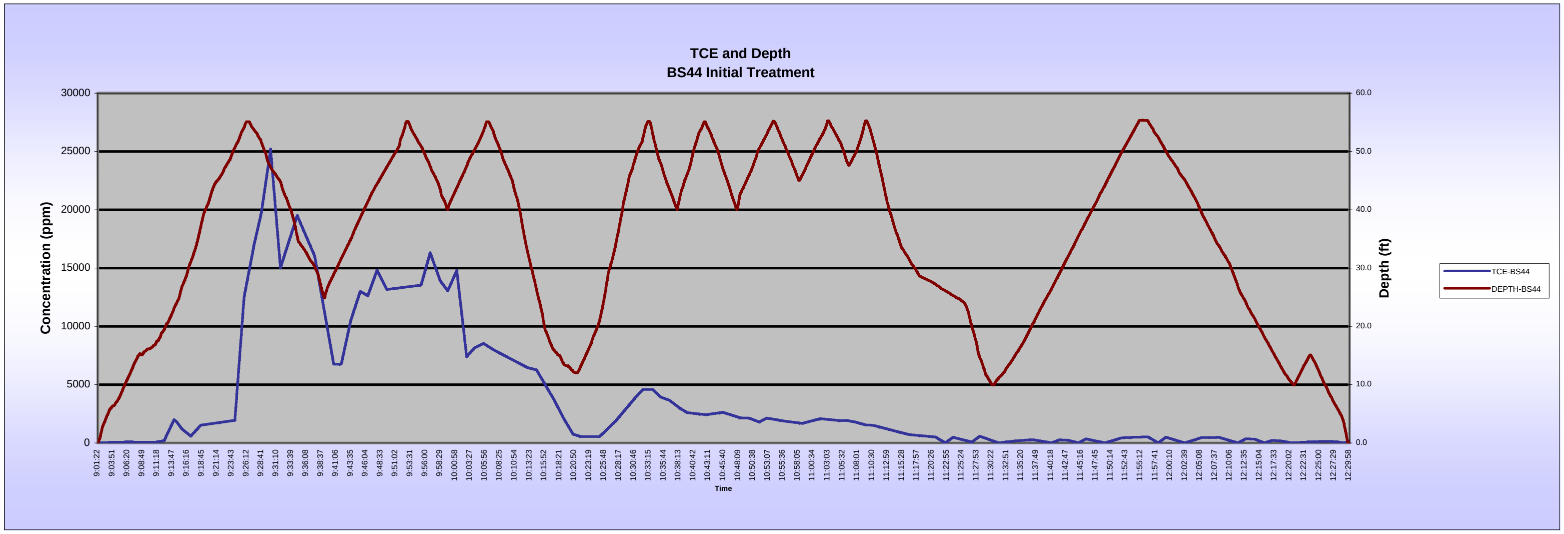


Figure 5-7: Methane Vs. Depth for BQ43 and BQ43 Retreatment Showing Increase in Methane Production After Initial Treatment



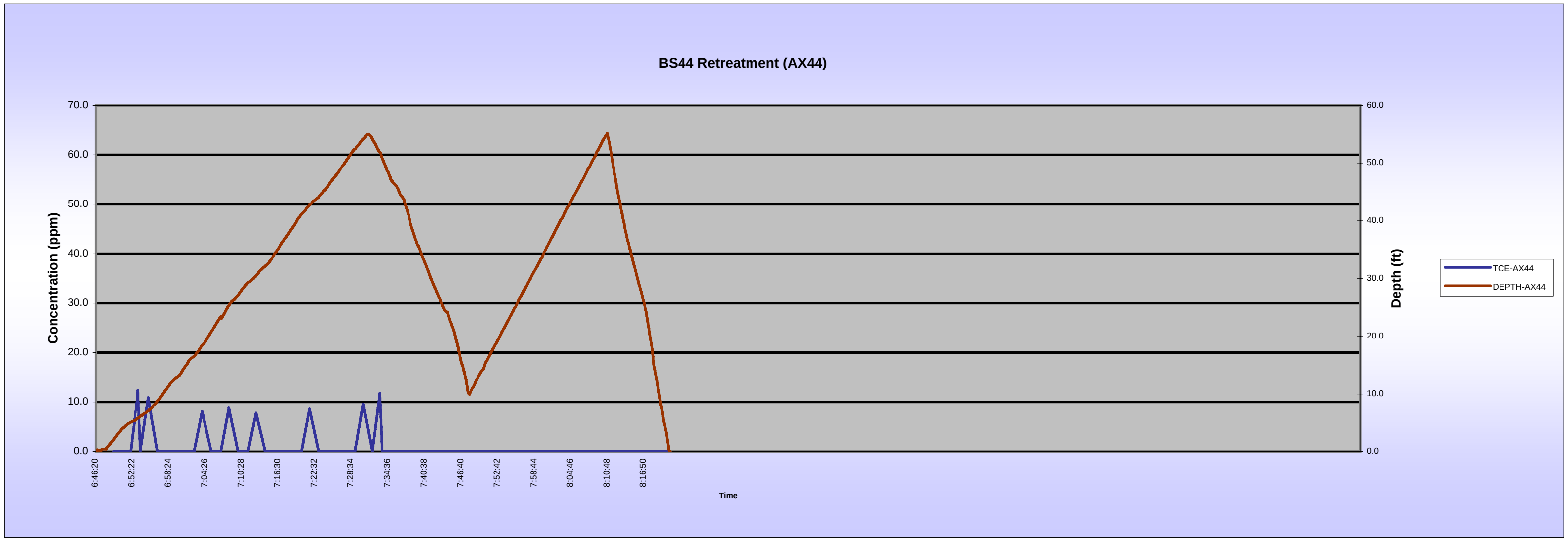
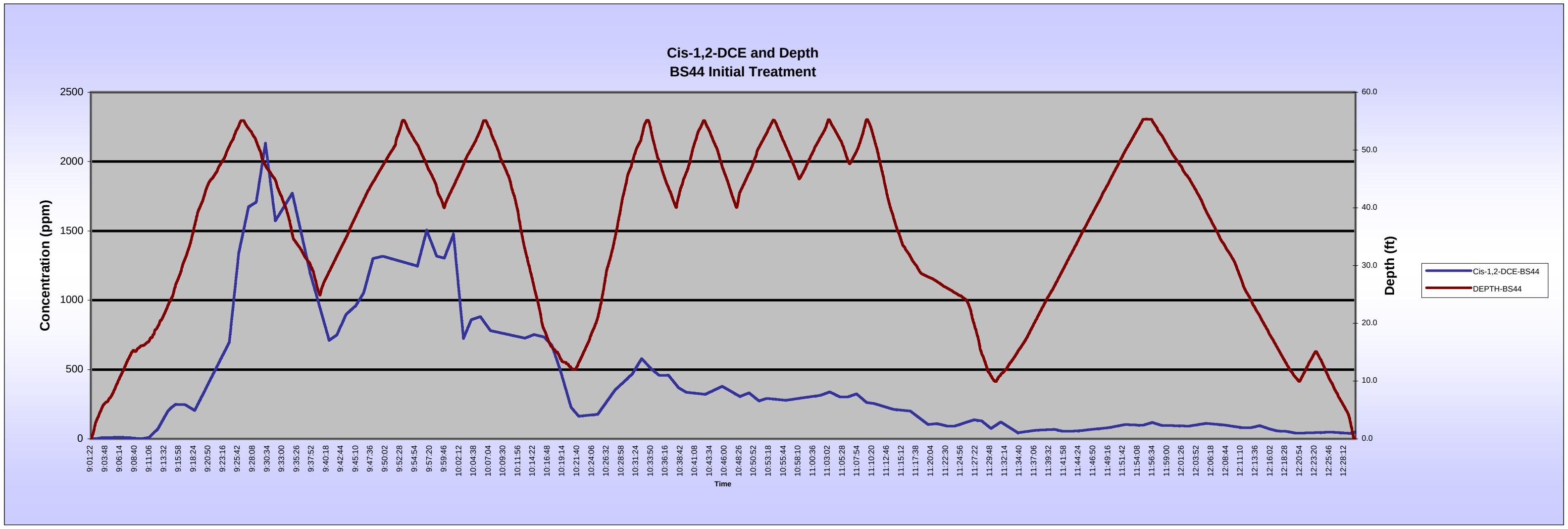


Figure 5-8: TCE Vs. Depth for BS44 and BS44 Retreatment



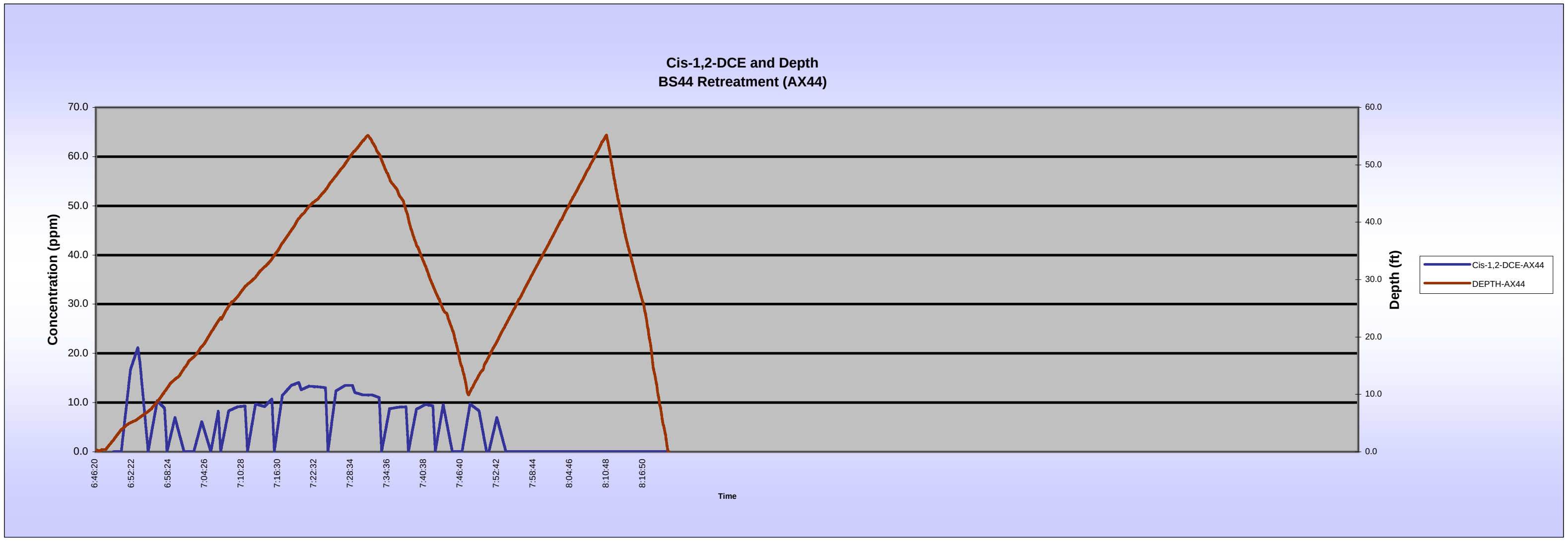


Figure 5-9: Cis-1,2-DCE Vs. Depth for BS44 and BS44 Retreatment

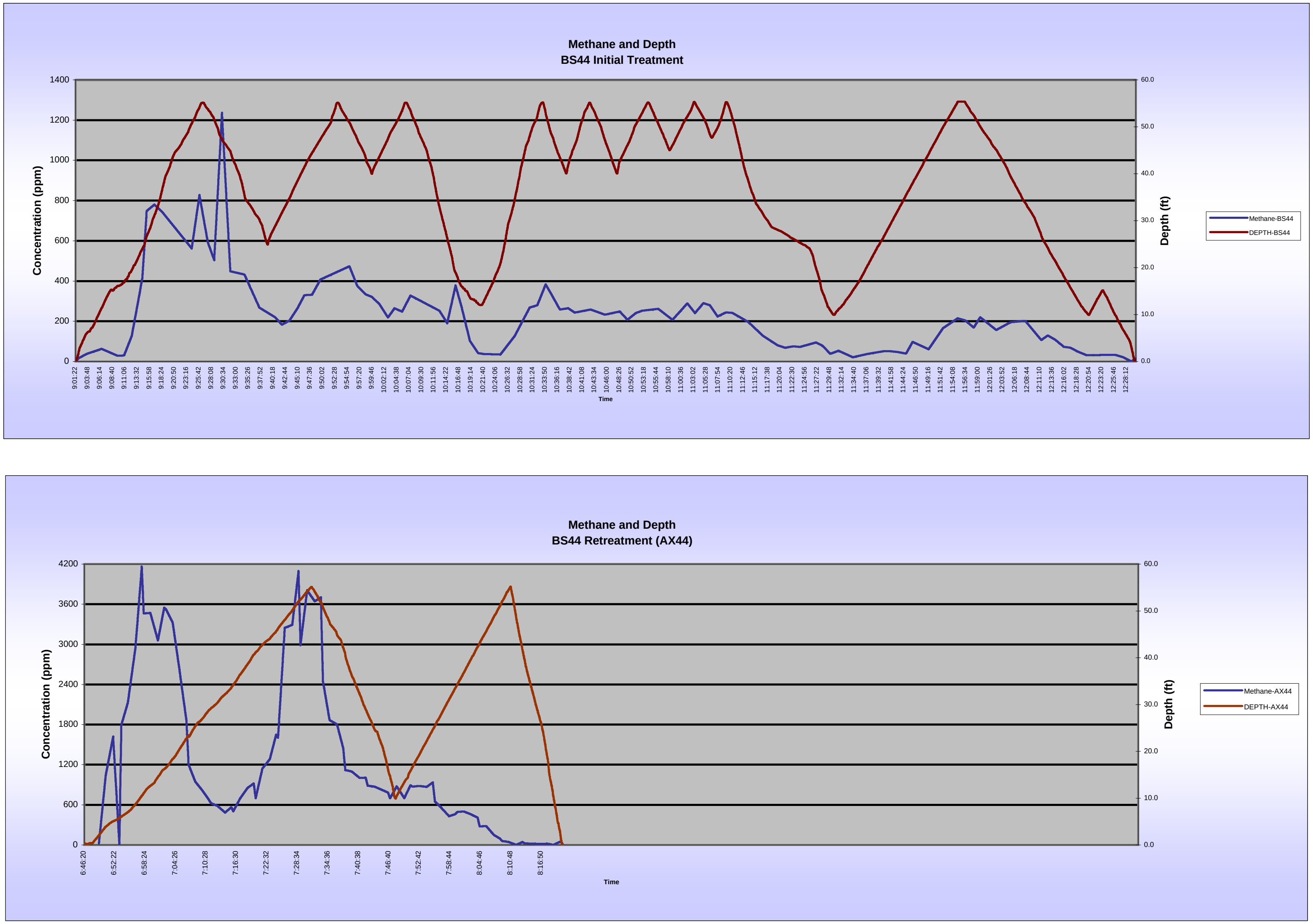


Figure 5-10: Methane Vs. Depth for BS44 and BS44 Retreatment

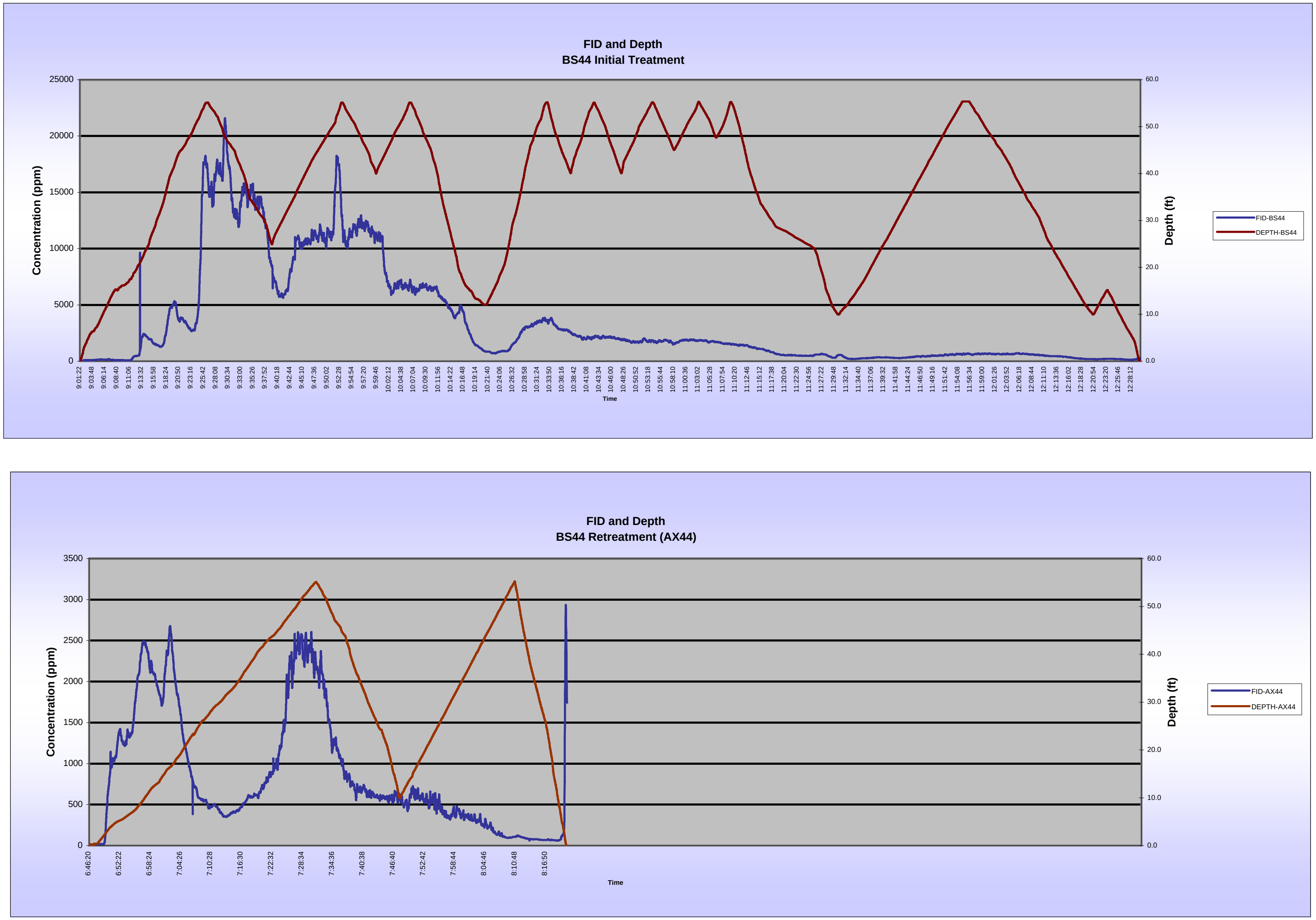


Figure 5-11: FID Vs. Depth for BS44 and BS44 Retreatment

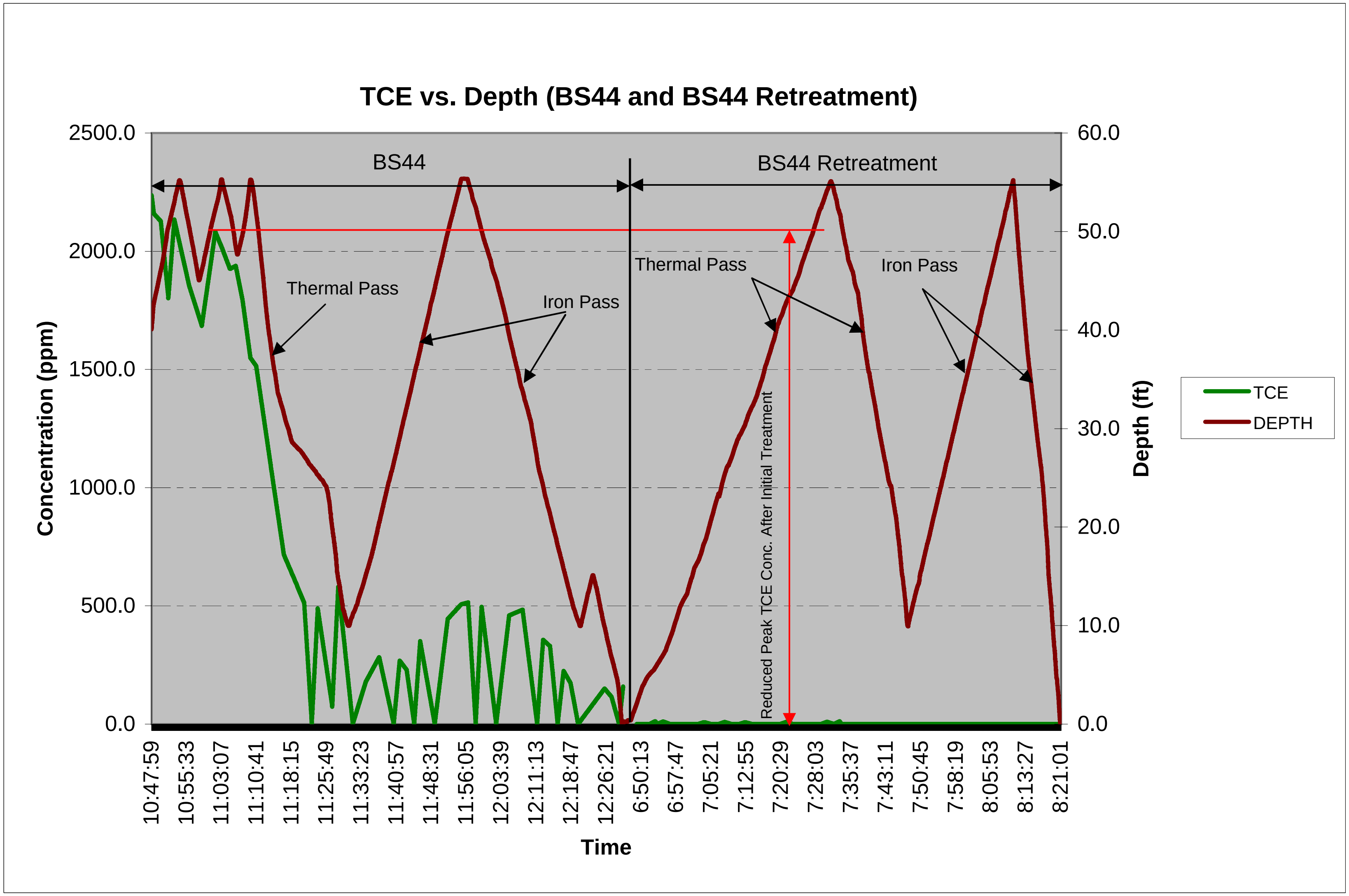


Figure 5-12: TCE Vs. Depth for BS44 and BS44 Retreatment Showing Reduction in Peak TCE Concentration Between Treatments

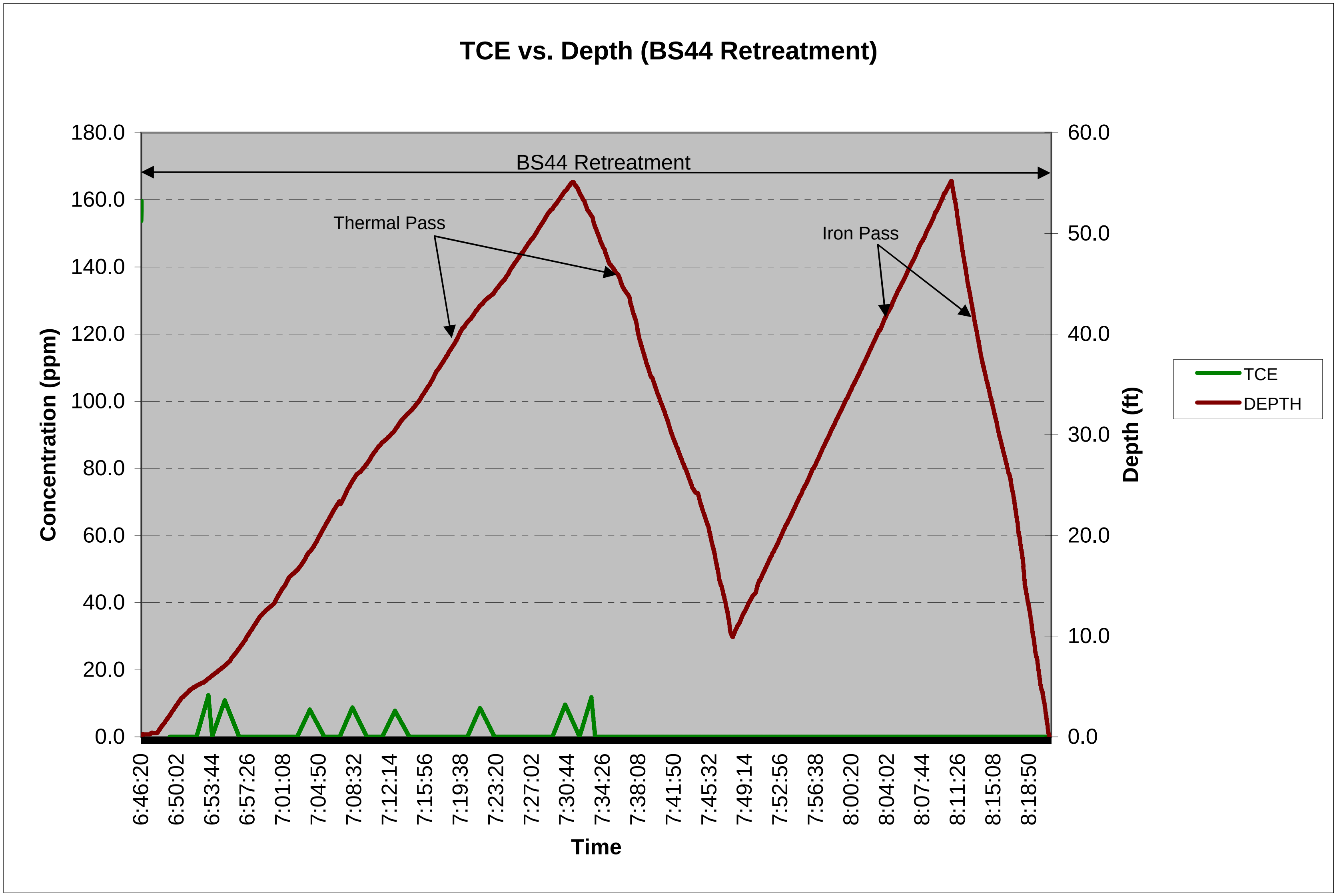


Figure 5-13: TCE Vs. Depth for BS44 Retreatment

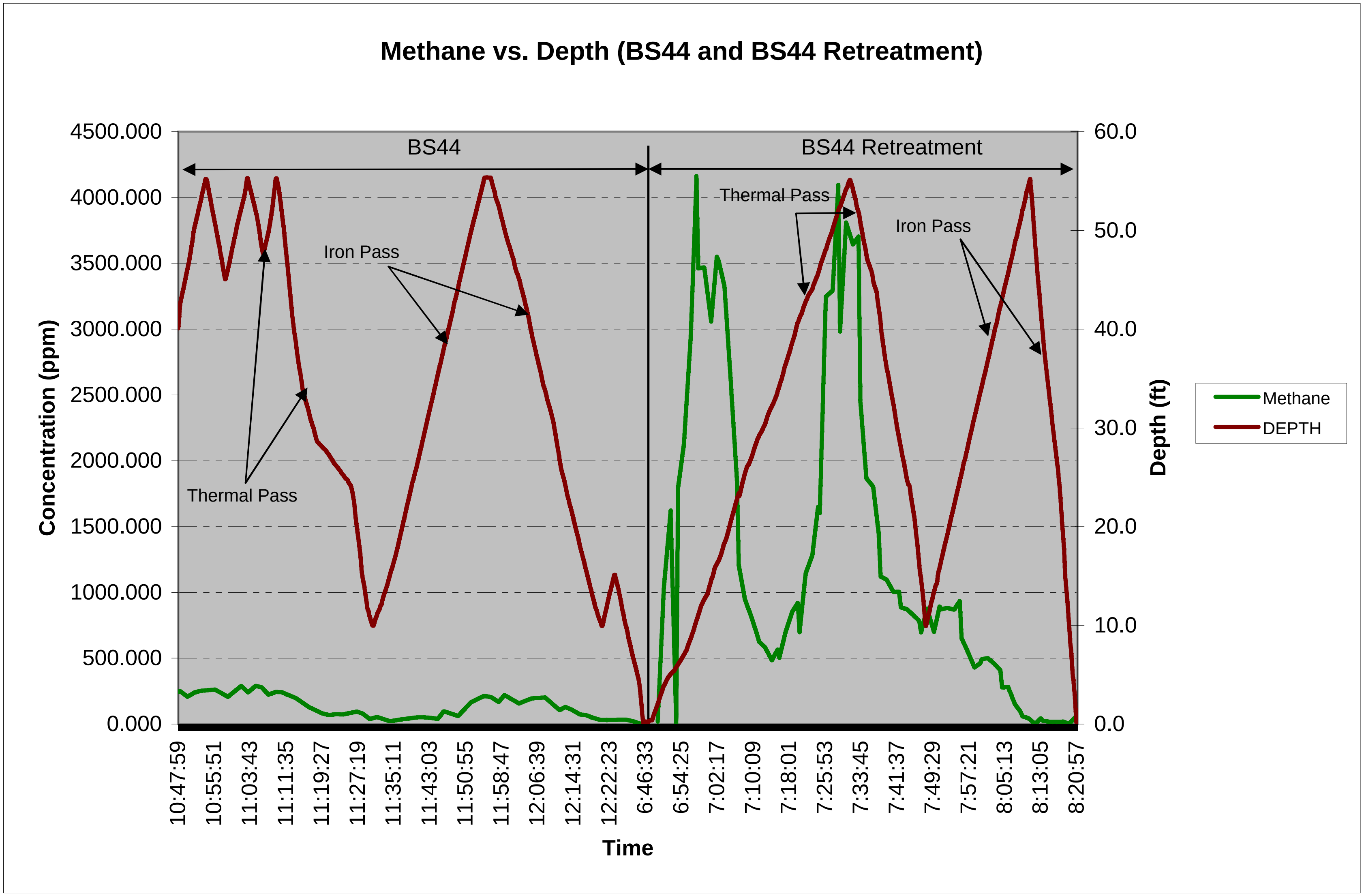


Figure 5-14: Methane Vs. Depth for BS44 and BS44 Retreatment Showing Increase in Methane Production After Initial Treatment

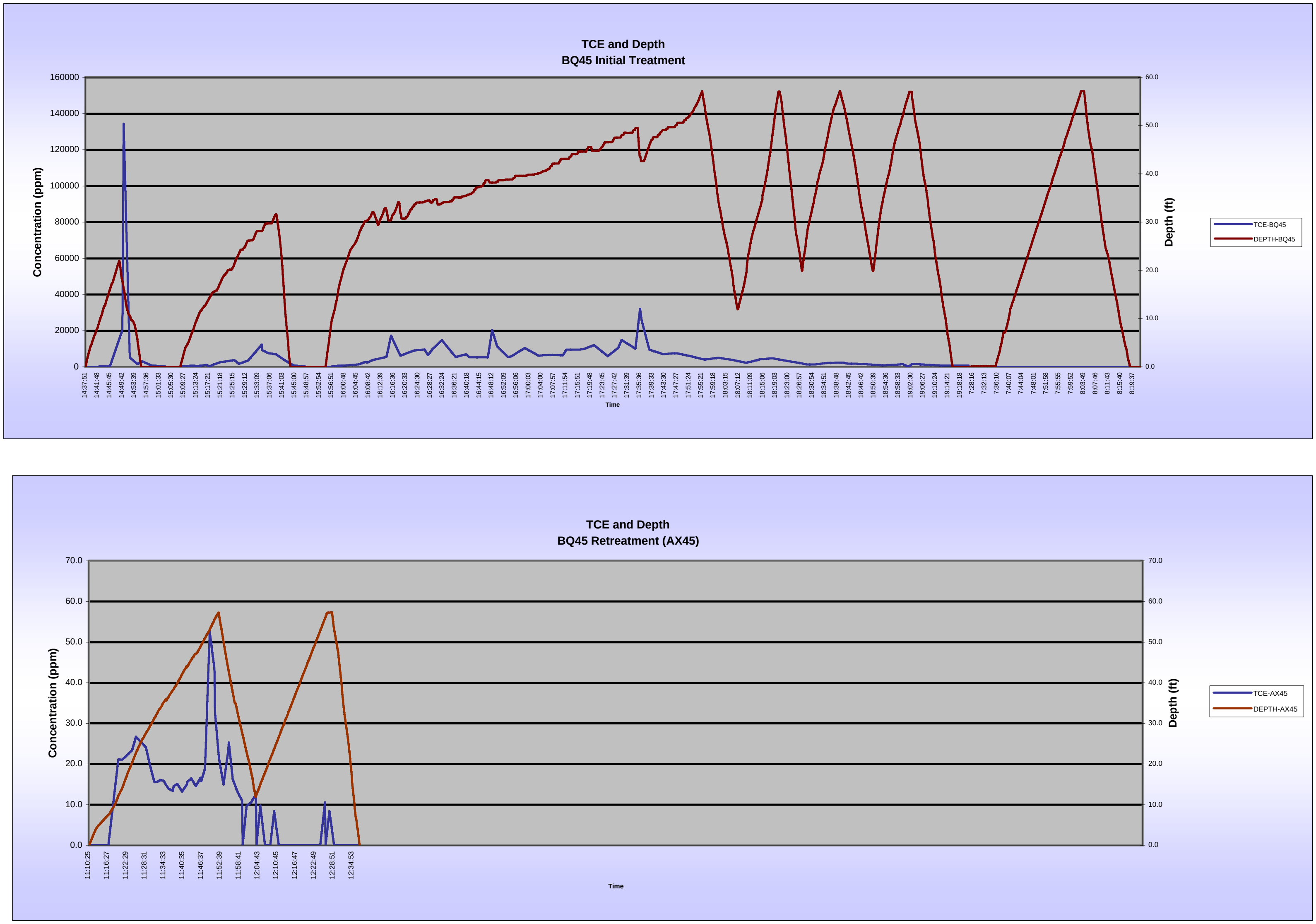
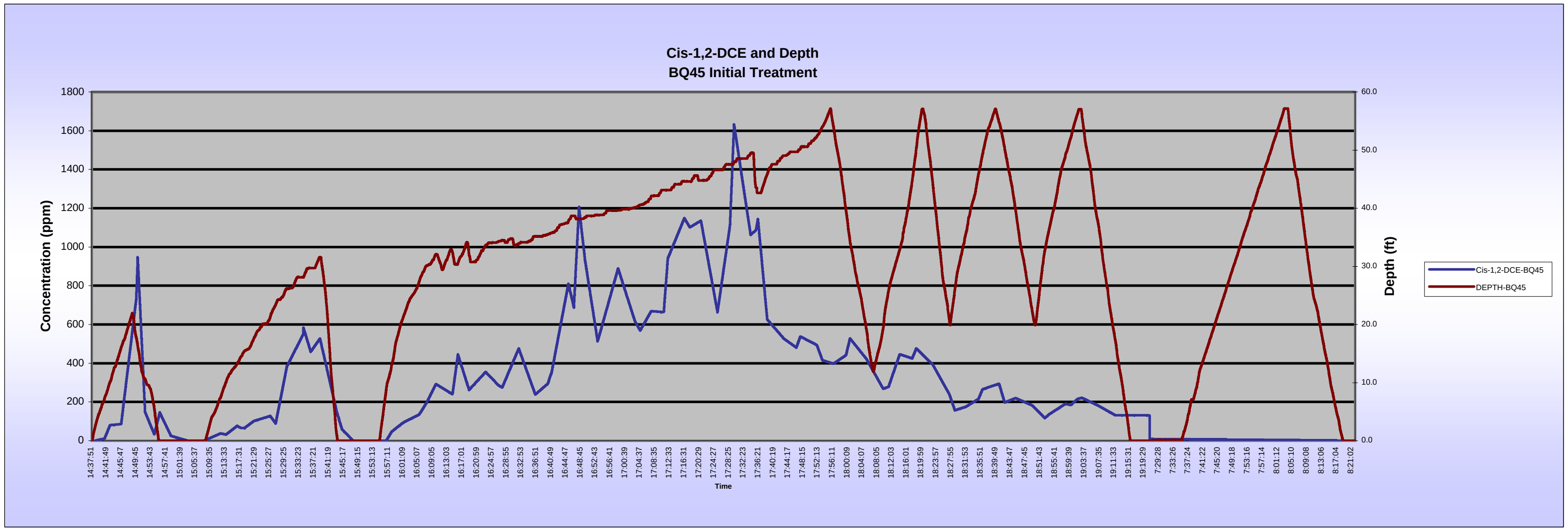


Figure 5-15: TCE Vs. Depth for BQ45 and BQ45 Retreatment



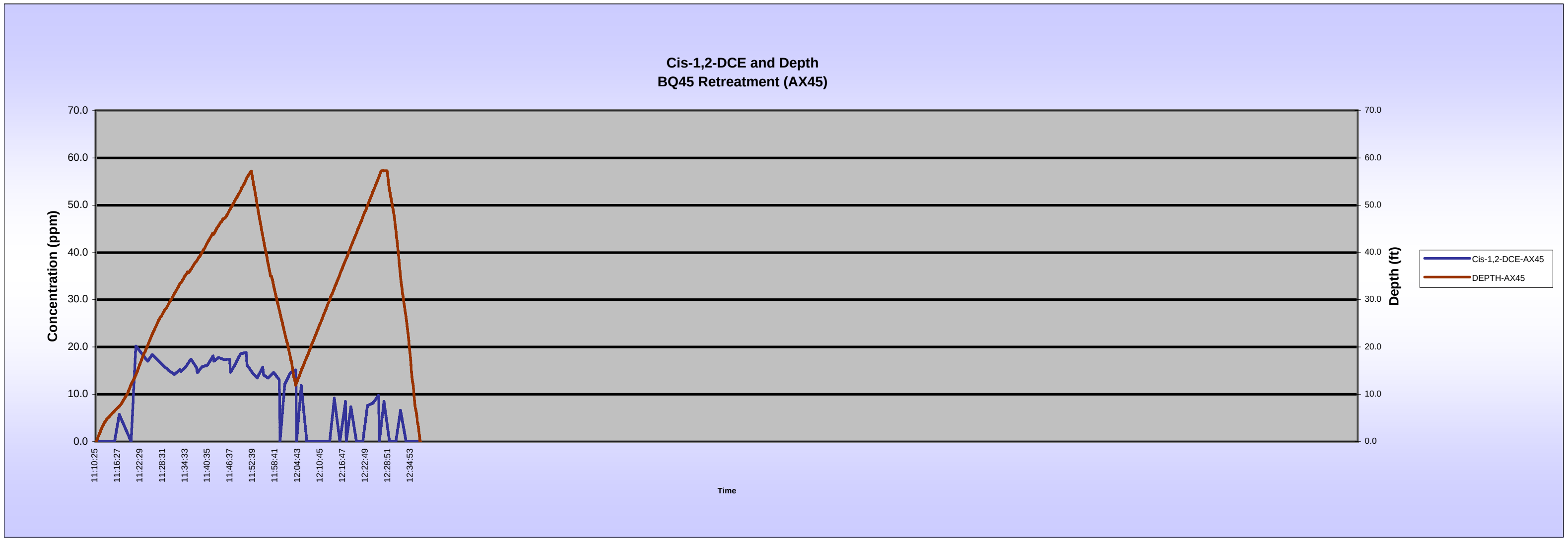
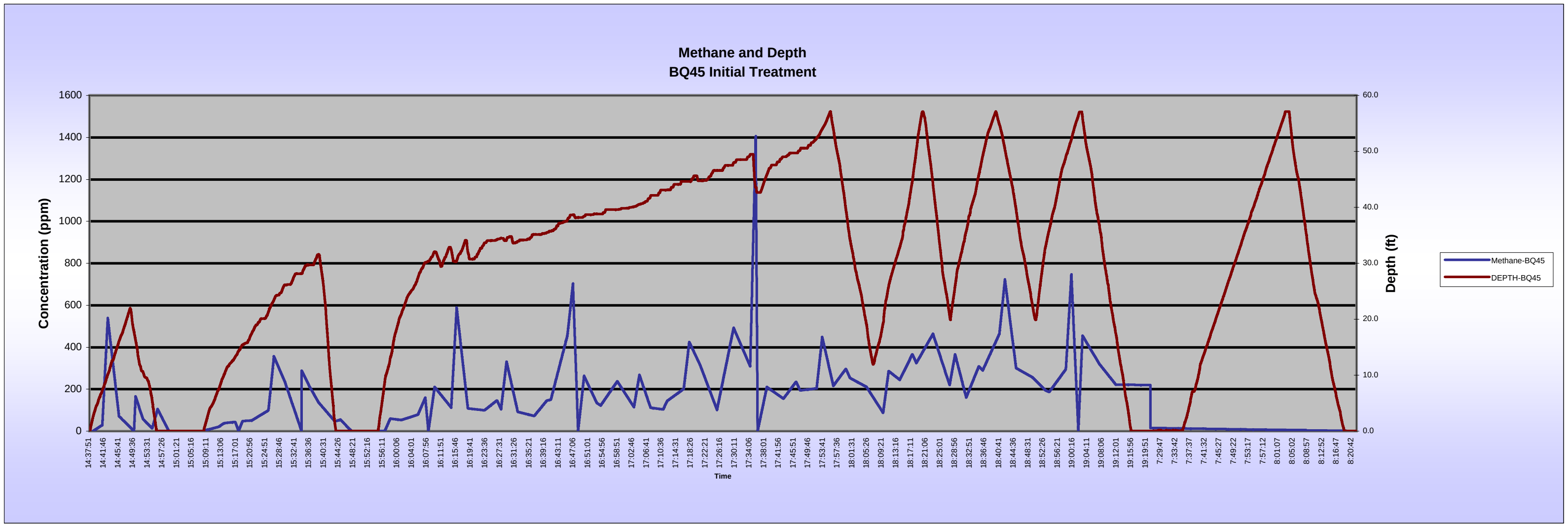


Figure 5-16: Cis-1,2-DCE Vs. Depth for BQ45 and BQ45 Retreatment



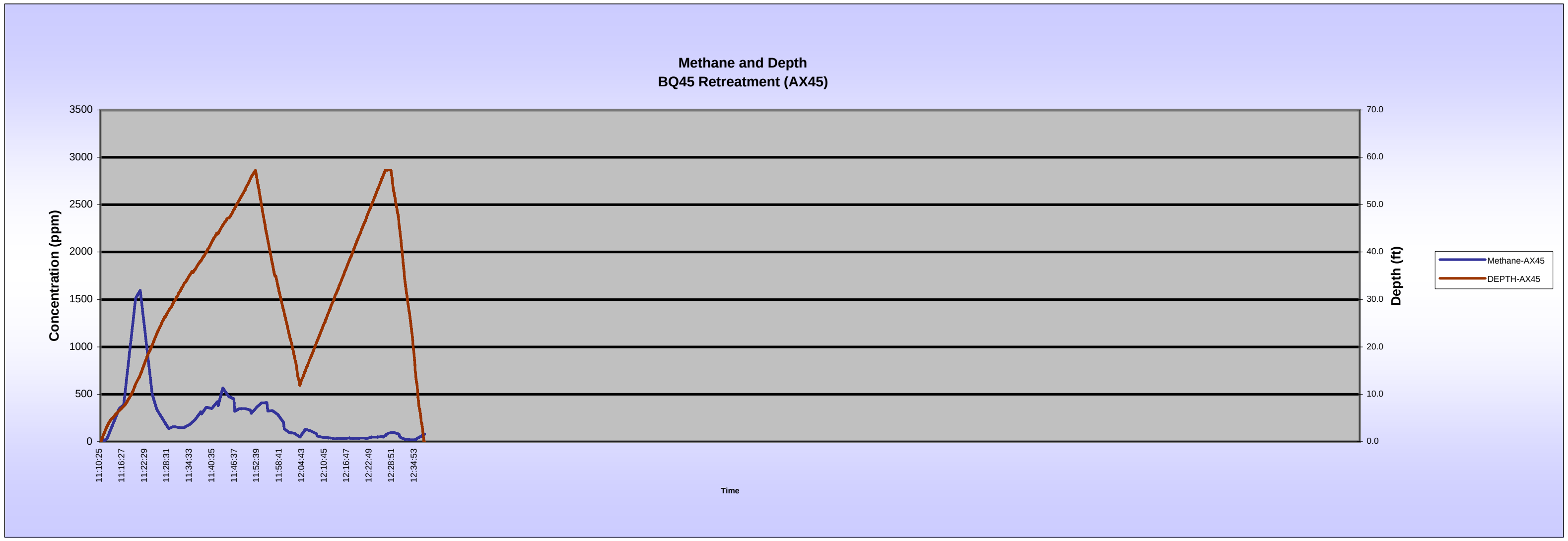


Figure 5-17: Methane Vs. Depth for BQ45 and BQ45 Retreatment

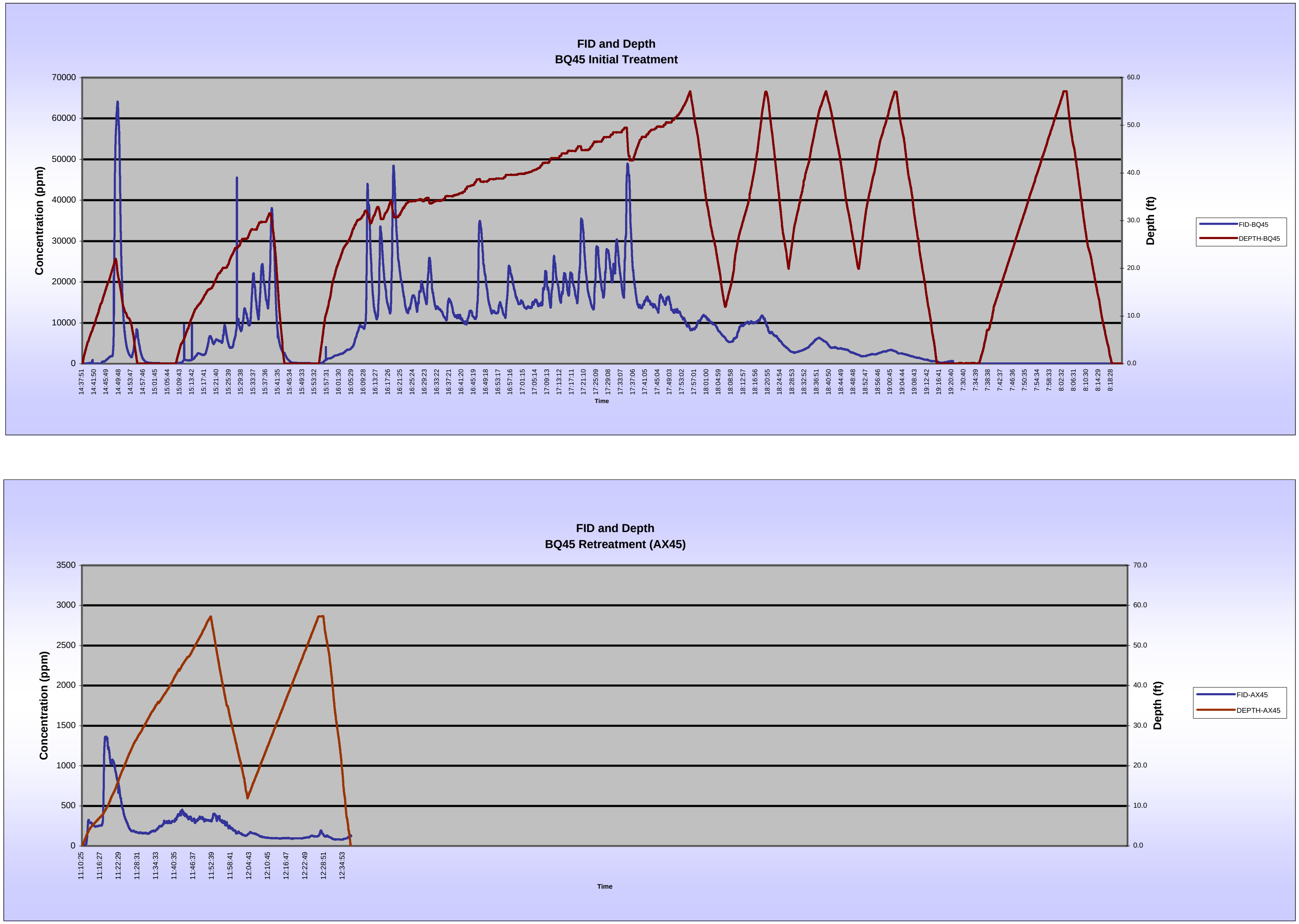


Figure 5-18: FID Vs. Depth for BQ45 and BQ45 Retreatment

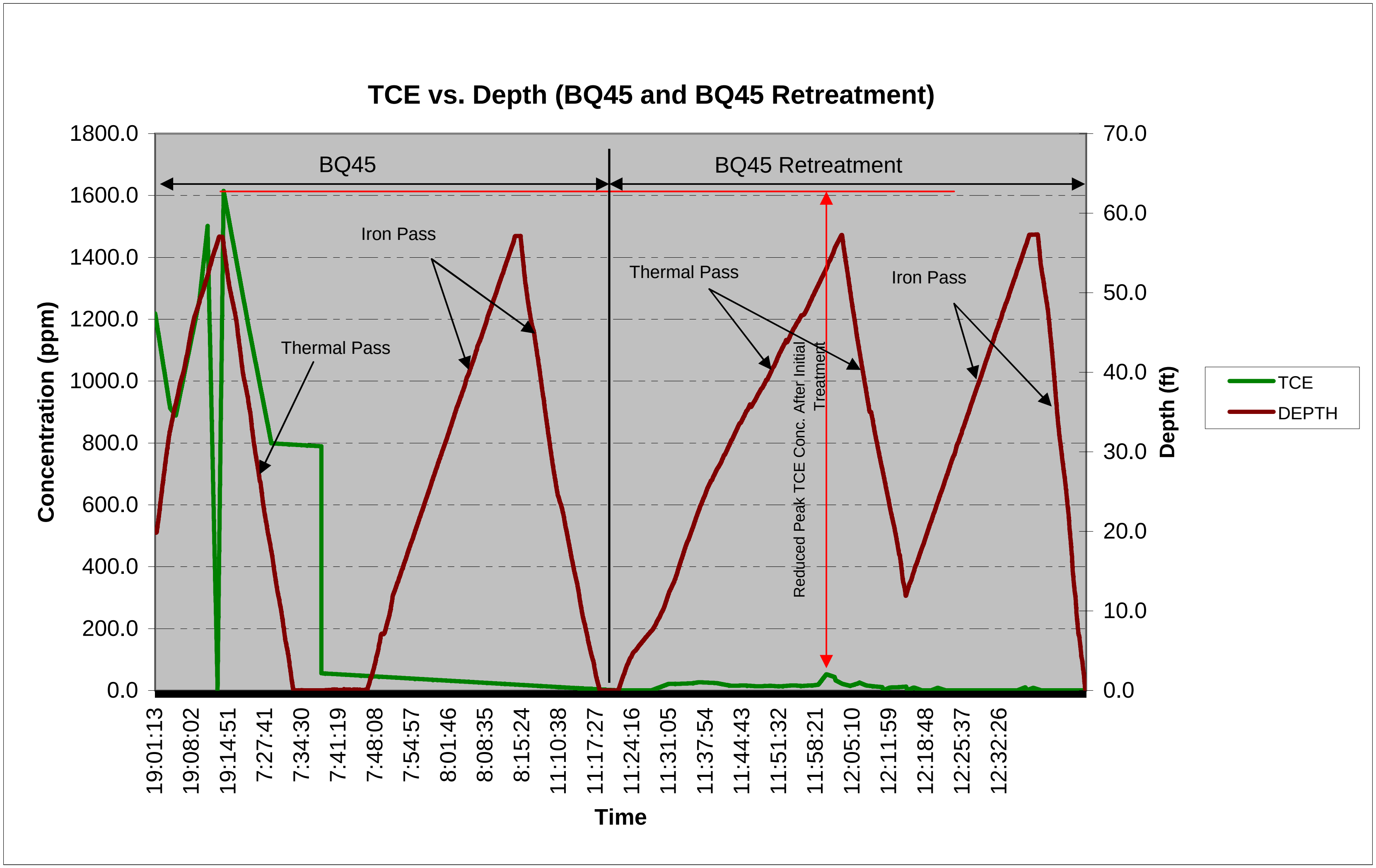


Figure 5-19: TCE Vs. Depth for BQ45 and BQ45 Retreatment Showing Reduction in Peak TCE Concentration Between Treatments

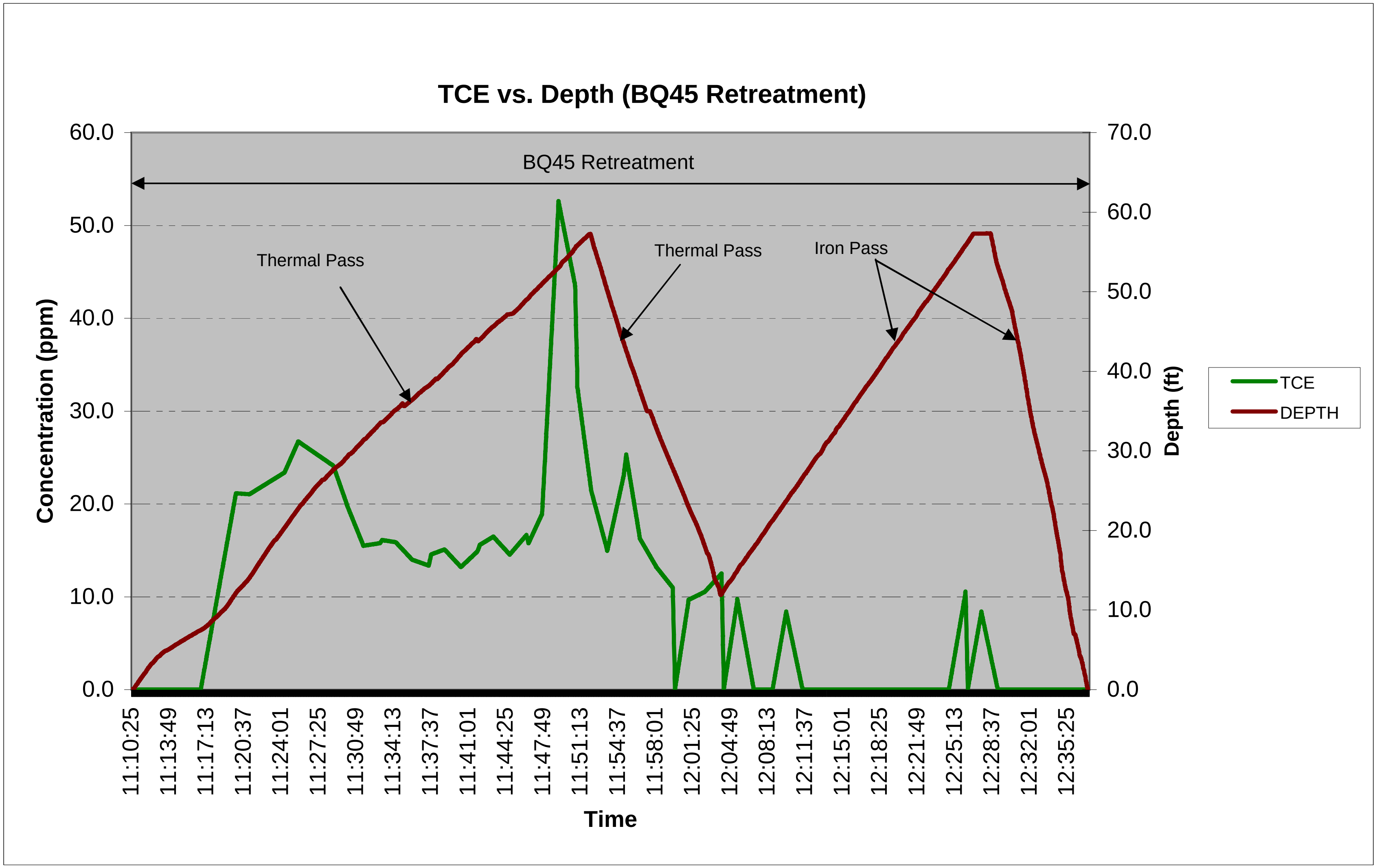


Figure 5-20: TCE Vs. Depth for BQ45 Retreatment

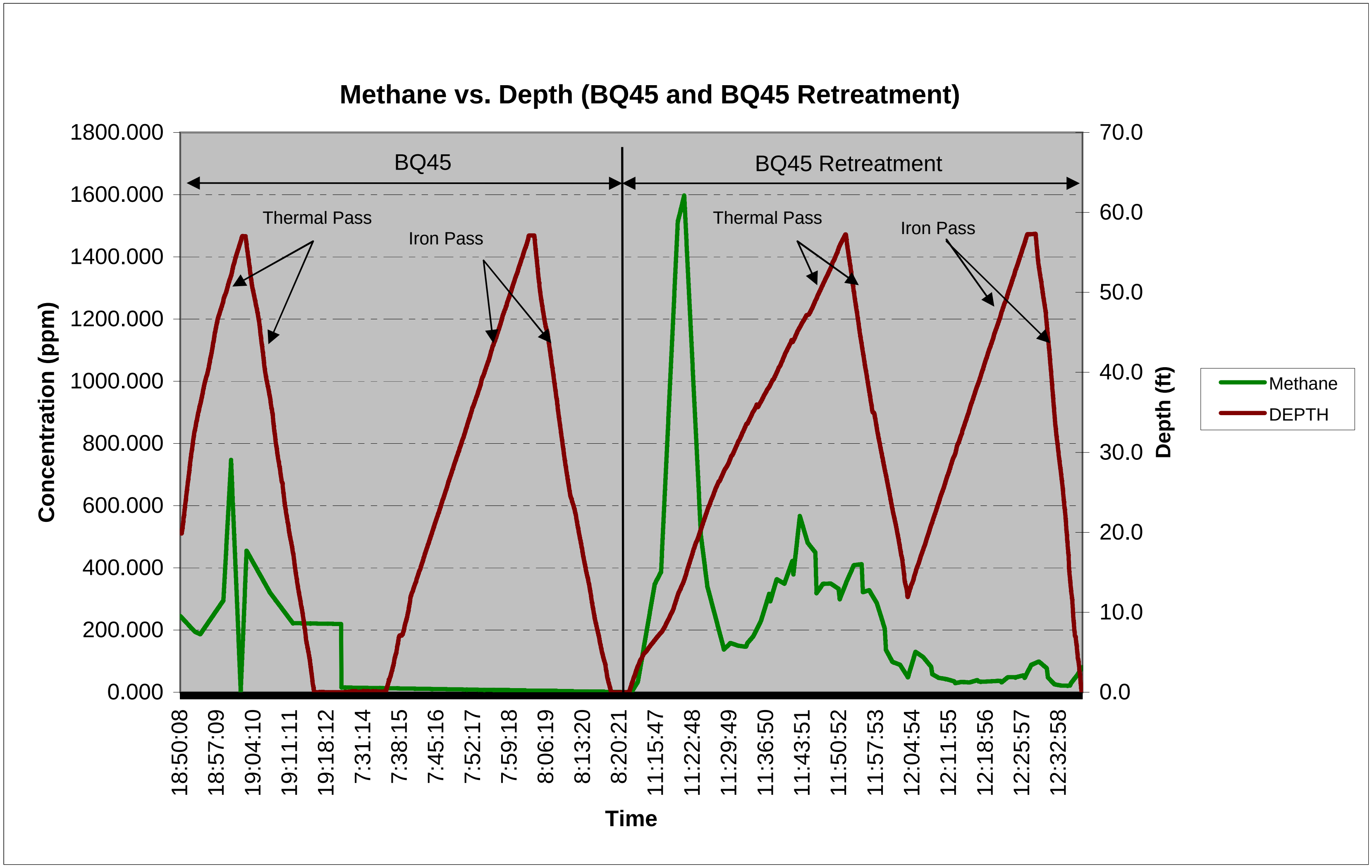


Figure 5-21: Methane Vs. Depth for BQ45 and BQ45 Retreatment Showing Increase in Methane Production After Initial Treatment

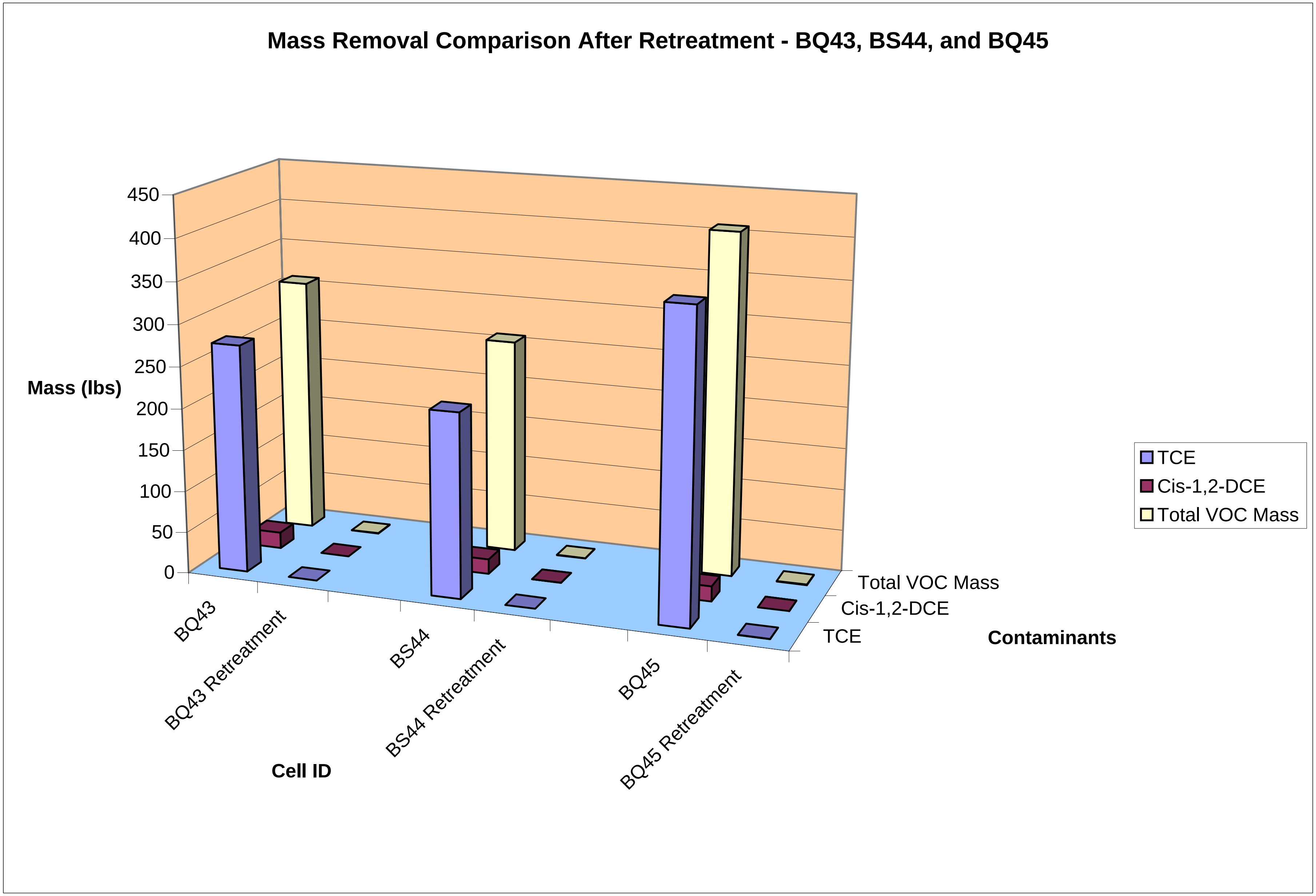


Figure 5-22: Mass Removal Comparison After Retreatment - BQ43, BS44, and BQ45

6.0 REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH), 2006. *Threshold Limit Values for Chemical Substances and Physical Agents Biological Exposure Indices.*

American National Standards Institute (ANSI), 1998. Z358.1.

BEM, 2002. *Corrective Measures Study Report, Facility 1381, Solid Waste Management Unit C021, Cape Canaveral Air Force Station, Florida.* Revision 1.

BEM, 2005. *Corrective Measures Implementation Report- Remediation by In-Situ Steam and Iron Enhanced Soil Mixing, Space Launch Complex 15, Solid Waste Management Unit C030, Cape Canaveral Air Force Station, Florida.* Revision 0.

IRP (Installation Restoration Program), 2005. *Statement of Basis, Facility 1381, Solid Waste Management Unit No. 21, 45th Space Wing, Cape Canaveral Air Force Station, Florida.*

Jacobs (Jacobs Engineering Group, Inc.), June 2005. *Corrective Measures Design, Final (100%) Design Package, Facility 1381-Ordnance Support Facility, Solid Waste Management Unit C021, Cape Canaveral Air Force Station, Florida.* Revision 1.

Kübert, M. and Finkel, M., 2006. *Contaminant Mass Discharge Estimation in Groundwater Based on Multi-level Point Measurements: A Numerical Evaluation of Expected Errors.* Journal of Contaminant Hydrology, Vol. 84, No.1-2, pp. 55-80.

National Institute for Occupational Safety and Health (NIOSH), 1985. *Occupational Safety and Health Guidance Manual for Hazardous Waste Site Activities.*

Occupational Safety and Health Administration (OSHA), *Safety and Health Regulations for General Industry, Title 29 Code of Federal Regulations* (CFR), Part 1910.

OSHA, *Safety and Health Regulations for Construction,* 29 CFR 1926.

Parsons ES, 1993. *Preliminary Assessment #1 Field Sampling Strategy for Facilities at Cape Canaveral Air Station, Patrick Air Force Base, and Malabar.* Revision 2. June 1993.

Parsons ES, 1998. *RCRA Facility Investigation Report for Facility 1381 SWMU 21 (DP-32).* Revision 1. January 1998.

Parsons ES, 2000. *Supplemental CMS Field Investigation Report for Facility 1381, SWMU 21 (DP-32).* Revision 0. June 2000.

Tetra Tech, Inc. September 2005. *Security Police Confidence Course (Facility 18003) and Ordnance Support Facility (Facility 1381), Solid Waste Management Units C091 and C021. Cape Canaveral Air Force Station, Florida, Corrective Measures Implementation Work Plan*.

U.S. Army Corps of Engineers (USACE), 2000. *Safety and Occupational Health Requirements for Hazardous, Toxic, and Radioactive Waste (HTRW) Activities,* ER 385-1-92.

USACE, 2003. Safety and Health Requirements Manual, EM 385-1-1.